The Hawaii Ocean Time-series (HOT): Highlights and perspectives from two decades of ocean observations

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OCB SCOPING WORKSHOP
SEPTEMBER 2010
A Dedicated HOT Team
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
The Hawaii Ocean Time-series (HOT)

- Near monthly cruises to Station ALOHA since October 1988
- Deep ocean (~4800 m) observatory
- Shipboard and remote measurements of ocean biogeochemistry, physics, and plankton ecology
- 4-day cruises, intensive sampling to 1000 m
Time, water, and change

- The value of HOT observations continues to increase with time.
- HOT provides some of the best and only records of biogeochemical and physical variability in the open ocean waters of the Pacific across multiple time scales: episodic, seasonal, interannual, and multi-decadal.
- Knowledge gained from HOT furthers our understanding of global-scale ocean change.
Ongoing projects supported by HOT:

If you build it, they will come...

- **Ocean Carbon System Variability**, NSF; A. Dickson (P.I.), 1988-present
- **WHOI Hawaii Ocean Time Series Station (WHOTS)**, NOAA-NSF; R. Weller (P.I.), 2004-present
- **CFC and SF₆ Water Mass Tracers**, NOAA; J. Bullister (P.I.), 2004-present
- **Microbial Oceanography: Genomes to Biomes – Summer training course**, NSF-Agouron Institute-Gordon and Betty Moore Foundation; D. Karl (P.I.), 2006-present
- **Marine Microbiology Initiative**, Gordon and Betty Moore Foundation; D. Karl (P.I.), 2005-present
- **Center for Microbial Oceanography: Research and Education (C-MORE)**, NSF; D. Karl (P.I.), 2006-present
- **Si Cycling and Dynamics**, NSF; M. Brzezinski (P.I.), 2007-present
- **ALOHA Cabled Observatory**, NSF; B. Howe (P.I.), 2007-present
- **Diazotrophy in a High CO₂ World**, NSF; M. Church (P.I.), 2009-present
- **Profiling Floats for Ocean Biogeochemistry**, NSF-NOPP; K. Johnson, 2007-present
- **Subsurface Moored Profiler**, NSF; M. Alford (P.I.), 2009-present
- **Taxon-specific Variability of Organic Matter Production and Remineralization**, NSF; A. White (P.I.), 2009-present
- **Primary Productivity as a Function of Absorption, Pigment-based Phytoplankton Diversity, and Particle Size Distributions**, NASA; A. White (P.I.), 2009-present
From the Predictable to the Unexpected: Highlights on 3 interlinked themes in ocean biogeochemistry

- Ocean carbon cycling
- Plankton productivity and the importance of community structure
- New production and export
HOT carbon reservoirs and fluxes

- **Carbon reservoirs:**
  - Carbonate system: DIC, total alkalinity, pH, $pCO_2$
    - Coulometry (DIC), potentiometric titration (total alkalinity), spectrophotometric (pH), shipboard (KM) $pCO_2$ equilibrator (SOEST), and moored $pCO_2$ sensor (C. Sabine-PMEL)
  - Total organic carbon (TOC)
    - High temperature combustion
  - Particulate carbon (POC and PIC)
    - High temperature combustion (POC); acidification/ IR detection (PIC)

- **Carbon fluxes:**
  - Biological carbon production (POC and DOC)
    - $^{14}$C-bicarbonate assimilation (primary production), changes in carbon and oxygen
  - Particulate carbon export
    - Sediment trap particle collections
Rising CO$_2$, Falling pH

Dore et al. (2009)
Temporal variability in mixed layer inorganic carbon

Interannual variations in DIC concentrations closely coincident with changes to upper ocean salinity.

Dore et al. (2003)
Interannual variability in inorganic carbon pools

- Annual accumulation (0-150 m) of nDIC ~ 0.1 mol C m\(^{-2}\) yr\(^{-1}\)
- Interannual variations in the E-P balance and mixing important controls on carbon inventories

Winn et al. 1994, Dore et al. 2003, 2009
Processes influencing carbon cycling in the upper ocean at Station ALOHA

Adapted from Keeling et al. (2004)
What is the biological contribution to ocean carbon flux at ALOHA?

Photosynthesis

\[ + \text{O}_2, \quad -\text{CO}_2 \]

Respiration

\[ -\text{O}_2, \quad +\text{CO}_2 \]
The upper ocean habitat

PAR (μmol quanta m^{-2} s^{-1})

MLD

Nitrate + Nitrite (μmol N L^{-1})

Chlorophyll a (μg L^{-1})

^{14}C-PP (μmol C L^{-1} d^{-1})
Light is an important habitat control. Seasonal changes in light appear to drive productivity in both the near surface waters and deep chlorophyll maximum.
HOT observations indicate both chlorophyll and primary production are increasing. Prominent increases occurring below the depth of satellite detection.

Boyce et al. (2010)

Chl a increasing 0.22 mg m\(^{-2}\) yr\(^{-1}\)

\(^{14}\)C-PP increasing 0.33 mmol C m\(^{-2}\) yr\(^{-1}\)

Corno et al. (2007), Saba et al. (2010), Luo et al.
Material transfer through the food web

Zooplankton dry weight (0-150 m) increasing at 37 mg m$^{-2}$ per year

Measurements and models of primary production at Station ALOHA

- **Carbon production**
  - $^{14}$C-bicarbonate assimilation (daylight incubation period ~12 hours)
  - DIC, TOC, and PC variability

- **Oxygen production**
  - In vitro O$_2$ bottle incubations
  - In situ O$_2$ dynamics: gliders, floats, moorings, and ships
  - $^{18}$O$_2$ production from H$_2$$^{18}$O
  - $^{16}$O, $^{17}$O, $^{18}$O Triple O$_2$ isotopes

- **Bio-optics and satellites**
  - Bio-optical approaches
  - Satellite remote sensing
**In vitro O₂ dynamics at Station ALOHA**

- **Net Community Production:** -4.2 to -7.4 mol C m⁻² yr⁻¹
- **Gross Primary Production:** 11.9-14.0 mol C m⁻² yr⁻¹
- **Respiration:** 17-21 mol C m⁻² yr⁻¹
- **Conclusion:** Net heterotrophy due to incubation conditions and/or under sampling

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**Figure Description:**

- **Top Graph:** GPP, NCP, and R (μmol O₂ L⁻¹ d⁻¹) vs. Depth (m)
  - GPP: **●**
  - R: **▲**
  - NCP: **▼**

- **Bottom Graph:** GPP, R, NCP (mmol O₂ m⁻² d⁻¹) vs. Day of year
  - GPP: **●**
  - R: **▲**
  - NCP: **▼**

- **Legend:**
  - GPP: **●**
  - R: **▲**
  - NCP: **▼**

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*e.g. Williams et al. (2004)*
Mixed layer $O_2$ is in equilibrium with the atmosphere.

Rate of subsurface $O_2$ accumulation provides information on NCP.
In situ $O_2$ dynamics at Station ALOHA

- >6+ years of in situ measurements (2003-05, 2008-present)
- Net Community Production: 1.1-1.7 mol C m$^{-2}$ yr$^{-1}$

Riser and Johnson (2008)
<table>
<thead>
<tr>
<th>Method</th>
<th>Rate</th>
<th>Period of measurements</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixed Layer O$_2$ + Ar budgets</td>
<td>1.4 - 3.7 (± 1.0)</td>
<td>1992–2008</td>
<td>Emerson et al. (1997); Hamme and Emerson (2006); Juanek and Quay (2005); Quay et al. (2010)</td>
</tr>
<tr>
<td>DIC + DI$^{13}$C budgets</td>
<td>2.7 - 2.8 (± 1.4)</td>
<td>1988–2002</td>
<td>Quay and Stutsman (2003); Keeling et al. (2004)</td>
</tr>
<tr>
<td>Mooring O$_2$</td>
<td>4.1 (± 1.8)</td>
<td>2005</td>
<td>Emerson et al. (2008)</td>
</tr>
<tr>
<td>Sub-mixed layer float profiles</td>
<td>1.1 - 1.7 (±0.2)</td>
<td>2003-2010</td>
<td>Riser and Johnson (2008)</td>
</tr>
<tr>
<td>Sub-mixed layer glider surveys</td>
<td>0.9 (± 0.1)</td>
<td>2005</td>
<td>Nicholson et al. (2008)</td>
</tr>
<tr>
<td>Sediment traps</td>
<td>0.9 (± 0.3)</td>
<td>1989–2009</td>
<td>HOT core data</td>
</tr>
</tbody>
</table>

NCP appears constrained to ~2-fold variability
GPP estimated ~20-fold greater than NCP
What controls variability in nutrient supply supporting net community production?
Plankton community structure plays a key role in carbon flux to the deep sea
Controls on nitrogen supply to the upper ocean

- **Physical:**
  - Mixing, upwelling, diffusion, advection
    - NO$_3^-$ supported new production

- **Biological:**
  - N$_2$ fixation (N$_2$ $\rightarrow$ NH$_3$)
    - N$_2$ supported new production
Physical supply of nutrients: Mixing

Winter mixing “increases” upper ocean nitrate concentrations
Mesoscale variability at Station ALOHA

Real-Time Mesoscale Altimetry - Aug 19, 2010

Sea Surface Height Anomaly (cm)

Nitrate [μM]

Depth [m]

Temperature (°C)

SSHa (cm)

Depth (m)

24.6 kg m⁻³

Y = 2.2 + 136, R² = 0.47
Biological supply of nutrients: N$_2$ fixation

Rates of N$_2$ fixation are variable, but generally increase in the spring and summer.
July 19-26, 2005
July 2005

April 2005

January 2005

Fong et al. (2007)
Time series measurements of near-surface ocean $N_2$ fixation at Station ALOHA

Episodic increases in $N_2$ fixation by diazotrophs $>10 \mu$m appear associated with mesoscale (anticyclonic) eddies.

Church et al. (2009)
Both appear to support new production, but for different reasons.
HOT insights

- Biological and physical processes interact to control time-variability in ocean carbon inventories and fluxes.

- The complexity of ocean ecosystem change demands interdisciplinary studies.

- HOT measurements indicate we need to study carbon cycle processes at a range of scales, from decadal to seasonal to episodic.

- The value of HOT continues to increase with time.
Facing Future

- The complexity of ecosystem dynamics, even in this “stable” ecosystem, demands sustained observations.

- The shipboard time series program continues to enrich our understanding of the NPSG, and help direct application of remote and autonomous sensing technologies.

- These multi-decadal time series programs are some of our best (and only) barometers of ocean ecosystem change.