Export fluxes, net and new production in West Antarctica
H. Ducklow & M. Stukel, LDEO
OCB-2013
Outline:
Overview of study region, climate warming, diatom bloom-dominated ecosystem (but changing)

Export production (sediment traps, Thorium-234)

Gross Oxygen Production ($^{17}\Delta$-GOP) and Net Community Production ($O_2$-Ar)

New Production ($^{15}$NO$_3$ uptake; NO$_3$ drawdown, Iodide production)
Acknowledgements

**Traps:** Anton Post, Matt Erickson *(MBL)*

**Thorium-234:** Ken Buesseler, Stephanie Owens *(WHOI)*, Mike Stukel *(LDEO)*.

$^{17}\Delta$-GOP, $O_2$-Ar: Kuan Huang, Mike Bender *(Princeton)*, Nicolas Cassar, Rachel Eveleth, Bruce Barnett *(Duke)*

$^{15}$NO$_3$ uptake: Keith Weston *(UEA & BAS)* et al. DSR1 75:52-66

Nitrate drawdown: Marco Pedulli *(UMass)*

Iodide production: Tim Jickells, Rosie Chance, Alex Baker *(UEA)*
Palmer LTER Study Region along the WAP: 300 x 700 km: Process Studies Embedded in a Long-Term Observational Context

- **Rothera Base (UK)**
- **Avian Island**
- **Charcot Island**
- **Palmer Station (US)**

**Satellite remote sensing**
- ocean color (chlorophyll)
- surface temperature
- sea ice, 1978-present

**Process Studies**
- 3 Hotspots on annual cruise:
  - Palmer
  - Avian Island
  - Charcot Island
  - RaTS (BAS)
  - Year-round weekly sampling

**Regional Survey**
- Process Studies
- 3 Hotspots on annual cruise: Palmer

**Sediment Trap**
- Palmer LTER
- 2X-weekly sampling, October to April

**Annual Hydrographic Survey**
- (CTD-Rosette, Net Tows)

**Thermistor Moorings**

**Canyons & Deeps**

**BAS RaTS Local Time Series**
- Weekly, year-round

**Regional Survey Local Time Series**
- Semi-weekly, October - April

**Antarctic Peninsula**
Palmer Station Antarctica (1968-present)
home of:
Palmer, Antarctica Long Term Ecological Research (LTER) Project, 1990-2014

open year-round, 45 people, reached almost only by sea
Local-scale science near Palmer Station
Daily-weekly sampling Oct to April

Water column hydrography and plankton ecology

Seabird ecology and demography

Bill Fraser and Gentoo Penguins
Regional-scale oceanography along the Peninsula every January

ARSV Laurence M GOULD
230 feet  3400 tons
50 officers + crew + scientists
75 day endurance
NASA GISS temperature anomalies June-July-August 2002-12

Degree C anomaly relative to JJA 1950-1980
Sea ice duration: -100 days since 1978

+7°C since 1950

-1.8°C seawater freezes
69 South, 100 km from Charcot Island in Jan 2012: summer sea ice!
2 km inside ice edge: the original characteristic of polar ocean ecosystems before warming

Montes-Hugo et al Science 2009
Palmer region penguin populations, 1975-2012

Adélie penguins: 80% decline  (native, ice-obligate species)
Chinstrap & Gentoo penguins: new immigrants, now >50% of total
LTER Survey Grid Climatologies, January 1995-2013

P: Palmer Station, R: Rothera Base, △ Sed Trap
Palmer LTER Station E, 3 km offshore, Oct 2012 – March 2013

PAL LTER Data, figure courtesy Philippe Tortell
Sea Ice and Phytoplankton Blooms

Palmer Station

Per cent Ice Cover

Chlorophyll

Jan 94      96       98      00       02      04       06      08      10       12

Rothera Base

Per cent Ice Cover

Chlorophyll
Surface NO3 depletion (< 5 μM) in 8 of 19 seasons. 5 longest and 5 shortest ice duration years: No clear relationship with drawdown. NO3 depleted in 4/5 shortest ice years.

depletion years – high chl diatoms? non-depletion yrs – iron limited? cryptophytes?
Potential New Production (PNP) from NO3 drawdown

mean NO3 drawdown 13 mmol N m$^{-2}$ d$^{-1}$

mean potential new production (January) 1257 mgC m$^{-2}$ d$^{-1}$
LTER and RaTS Moored Sediment Trap deployments:

LTER: 1992-2013
170 m, 350 m deep

RaTS: 2005-2007
200 m, 520 m deep

All using McLane Mark IV conical traps
Amundsen Sea
Polynya
International Research Expedition
Technicap Cylindrical Trap,
350 m
500 m deep
McLane Mark IV 21 samples/yr

Technicap PPS 4/3 24 samples/year

Krill fecal pellets

LTER Sed Traps

ASPIRE Sed Trap

Jan Jan Feb
Mar Apr May Jun Jul Aug Sep Oct Nov Nov Nov Nov Nov Dec Dec Dec
LTER Export flux and % Sea Ice Cover

Export (mgC/m²/day)

Per cent ice cover

Mar-92 to Mar-12

Dave Karl Era

Duck Era

Trap Failed to rotate

Recovery Failed
ASPIRE: $\delta^{13}C = -30 \, \text{o/oo}$

Export

$\text{mgC/m}^2/\text{day}$

1-Jan-10  1-Mar-10  1-May-10  1-Jul-10  1-Sep-10  1-Nov-10  1-Jan-11  1-Mar-11  1-May-11  1-Jul-11  1-Sep-11  1-Nov-11  1-Jan-12  1-Mar-12  1-May-12  1-Jul-12  1-Sep-12  1-Nov-12

Per cent ice cover

0  25  50  75  100

Trap IN

1-Jan-10  1-Mar-10  1-May-10  1-Jul-10  1-Sep-10  1-Nov-10  1-Jan-11  1-Mar-11  1-May-11  1-Jul-11  1-Sep-11  1-Nov-11  1-Jan-12  1-Mar-12  1-May-12  1-Jul-12  1-Sep-12  1-Nov-12

Trap OUT

LTER

$\text{mgC/m}^2/\text{day}$

1-Jan-10  1-Mar-10  1-May-10  1-Jul-10  1-Sep-10  1-Nov-10  1-Jan-11  1-Mar-11  1-May-11  1-Jul-11  1-Sep-11  1-Nov-11  1-Jan-12  1-Mar-12  1-May-12  1-Jul-12  1-Sep-12  1-Nov-12

Per cent ice cover

0  25  50  75  100
ASPIRE Export Flux
Extrapolated from 350 to 150 meters using Martin coefficient
### Export Production

What fraction of the annual primary production is exported to depth?

<table>
<thead>
<tr>
<th>Region</th>
<th>PP gC m(^{-2}) y(^{-1})</th>
<th>Annual Flux gC m(^{-2}) y(^{-1})</th>
<th>e-ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>WAP</td>
<td>180</td>
<td>2.5</td>
<td>0.01</td>
</tr>
<tr>
<td>ASPIRE</td>
<td>88</td>
<td>7.1</td>
<td>0.08</td>
</tr>
<tr>
<td>Bermuda</td>
<td>180</td>
<td>9.4</td>
<td>0.05</td>
</tr>
</tbody>
</table>
Particle fluxes, January 2009: Comparison of estimates from traps and Thorium-234 disequilibrium (index of particle removal)

The Moored Trap may be undertrapping by a factor of 10-30 (comparison based on 4 samples in Dec-Jan 2008-09)

Buesseler, McDonnell, Schofield, Steinberg & Ducklow GRL 37 (2010)
WAP Export Production?

What fraction of the annual primary production is exported to depth?

<table>
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<th>Region</th>
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<th>e-ratio</th>
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<tbody>
<tr>
<td>WAP (Trap)</td>
<td>180</td>
<td>2.5</td>
<td>0.01</td>
</tr>
<tr>
<td>WAP (Th-234)</td>
<td>180</td>
<td>50</td>
<td>0.28</td>
</tr>
<tr>
<td>ASPIRE</td>
<td>??</td>
<td>??</td>
<td>??</td>
</tr>
</tbody>
</table>
Moored trap fluxes, 2008-13 (mmol C m\(^{-2}\) d\(^{-1}\))

<table>
<thead>
<tr>
<th>Month</th>
<th>2008-09</th>
<th>09-10</th>
<th>10-11</th>
<th>11-12</th>
<th>12-13</th>
<th>Avg</th>
</tr>
</thead>
<tbody>
<tr>
<td>December</td>
<td>0.3</td>
<td>--</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>0.5</td>
<td>0.2</td>
</tr>
<tr>
<td>January</td>
<td>0.2</td>
<td>--</td>
<td>1.1</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>0.3</td>
</tr>
<tr>
<td>February</td>
<td>--</td>
<td>--</td>
<td>2.3</td>
<td>1.3</td>
<td>&lt;0.1</td>
<td>1.2</td>
</tr>
<tr>
<td>Mean</td>
<td>0.2</td>
<td>--</td>
<td>1.1</td>
<td>0.5</td>
<td>0.2</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Compare to Th-234: 4.5 (2009), 10 (2010)
Weston et al. DSR 2013:

Marguerite Bay trap 2005-07

Exportable production:
NO3 drawdown: 13 Mol C m⁻² y⁻¹
15NO3 new production = 16 Mol C m⁻² y⁻¹
Trap carbon flux 0.2 Mol C m⁻² y⁻¹

F-ratio from ¹⁵N = 0.8
E-ratio: 0.01

“…high recycling, low export system…”
Thorium-234 derived export flux (100 meters) mmol C m$^{-2}$ d$^{-1}$ – Mean 10 (Jan), 4.5 (March)*

* Moored trap fluxes are 0.1 – 2.5

Depth distribution of Thorium 234 export

Export horizon – 40m

mmol C m$^{-2}$ d$^{-1}$

Mike Stukel, LDEO, 2013
Discrete surface water samples (i.e., ML) from CTD casts
Have data for 2008-2013

Kuan Huang, GBC 26 (2012)
Biological oxygen supersaturation, underway, 2013

Continuous equilibration inlet mass spectroscopy (EIMS)
Will have data for 2012-2014

Rachel Eveleth, Nicolas Cassar, 2013
## LTER Gross, Net and Export Production (January 2010)

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross Primary Production (ML)</td>
<td>84.9 +/- 28.5</td>
<td>(24 to 150)</td>
</tr>
<tr>
<td></td>
<td>mmol C m(^{-2}) d(^{-1})</td>
<td></td>
</tr>
<tr>
<td>Net Community Production (ML)</td>
<td>26 +/- 16</td>
<td>(5 to 63)</td>
</tr>
<tr>
<td>NOP:GOP (O(_2))</td>
<td>0.19</td>
<td>(0.03 to 0.54)</td>
</tr>
<tr>
<td>NCP:GPP (C)</td>
<td>“F” = 0.38</td>
<td></td>
</tr>
<tr>
<td>Th(_{234}) C Export (EZ)</td>
<td>8.7 +/- 2.4</td>
<td>(3 to 12)</td>
</tr>
<tr>
<td>Trap Flux (170 m)</td>
<td>0.5 +/- 0.7</td>
<td>(0.02 to 2.3, Dec-Feb)</td>
</tr>
<tr>
<td>C(_{14})-PP (EZ)</td>
<td>542 +/- 503</td>
<td>(66 to 2372)</td>
</tr>
</tbody>
</table>

*NCP and GPP courtesy K Huang & M Bender, Princeton Univ
Th\(_{234}\) courtesy S Owens & K Buesseler, WHOI*
Iodide accumulation as an indicator of seasonal new (or maybe total?) production (Chance, Jickells, Baker et al 2010)

Theory of Iodide as a productivity indicator
Campos et al 1996

IO₃⁻ → I⁻ Biological linked to primary production

I⁻ → IO₃⁻ very slow (months)

Hence Iodide (I⁻) production potentially contains a record of productivity

\[ y = 90.317x + 811643 \]
\[ R^2 = 0.9559 \]
Seasonal Production Estimates

\[ y = -0.2851x + 35.205 \]
\[ R^2 = 0.4916 \]

I/C assimilation ratio:

1.6 x 10^{-4}

Seasonal Iodide accumulation

20-150 nmol / liter

22 – 35 Mol C m^{-2}

(NO3 drawdown: 8)

Chance, Jickells, Baker
2012 LTER Samples.
Summary

1. Time series don’t begin at BATS and end at HOT
2. Moored sediment traps have uncertain accuracy but most probably undertrap by order of magnitude
3. But they yield one of our only year-round carbon flux records; only source of physical samples for biological, chemical analyses
4. Most of the flux is in the ice-free (or nearly ice-free) period
5. But there was significant flux in winter too (ASPIRE)
6. Overall, Amundsen Sea fluxes were higher than at LTER site (even not accounting for depth difference)
Summary, cont’d

6. Trap contents appear to be dominated by phytodetritus in Amundsen, krill fecal pellets in LTER traps.

7. New technologies offer better resolution in space & time, improved estimates of production available for export.

8. GPP > NCP > Th234 Export > Trap catch; NCP:GPP = 0.2 (apparent e/f ratio = 0.4, consistent with preconceived ideas about Antarctic foodweb & biogeochemical dynamics.

9. NCP>Th234 implies horizontal export or DOC export.

10. How much do the traps undertrap? How much remineralization between 100 & 300 meters?
Thanks very much for your interest
Acknowledgements

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US Antarctic Program & Support Contractors

Many colleagues & collaborators
Questions?