Abstract

Adaptive sampling of hotspots in net community production using the VPR, REMUS, and traditional hydrographic methods

Dennis McGillicuddy, Mike Purcell (WHOI) and Rachel Stanley (Wellesley College)

The physical, biological, and geochemical processes that lead to the transfer of carbon from the surface to the deep ocean via the “biological pump” vary on a tremendously wide range of scales. Recent observations from the Video Plankton Recorder (VPR) in the western North Atlantic document intense patches of elevated fluorescence (a proxy for phytoplankton) and strong oxygen signals on horizontal scales of 10km and smaller (Figure 1). These data were collected along transects that allow us to visualize a two-dimensional (alongtrack and vertical) slice of the ocean. The biogeochemical impacts of these features may be quite substantial, and yet have not been assessed because they require three-dimensional surveys of the features. Proposals to undertake such three-dimensional surveys have thus far been unsuccessful, owing to reviewer skepticism that we will be able to effectively track these rapidly evolving features. However, we have conducted Observing System Simulation Experiments (OSSEs) to demonstrate the feasibility of such surveys, and are confident we will be able to execute them. A pilot project demonstrating this capability is precisely what we need to convince the reviewer community that this is possible, thus making the case for a larger more comprehensive study.

We envision a fourteen-day voyage that would allow us to find a hotspot with the VPR, and sample it as it evolves in time. VPR surveys will be complemented by traditional hydrographic sampling of key biogeochemical tracers (triple oxygen isotopes) with the CTD/Rosette. During the CTD surveys, a REMUS 600 will be deployed for fine-scale surveys that will provide unprecedented resolution of the physical and biogeochemical structure of the hotspot. We propose staging the voyage in and out of Miami FL, with a departure date on or after May 17, 2016. A science party of 9 will be needed to allow for 3-person watches in 24/7 operations.

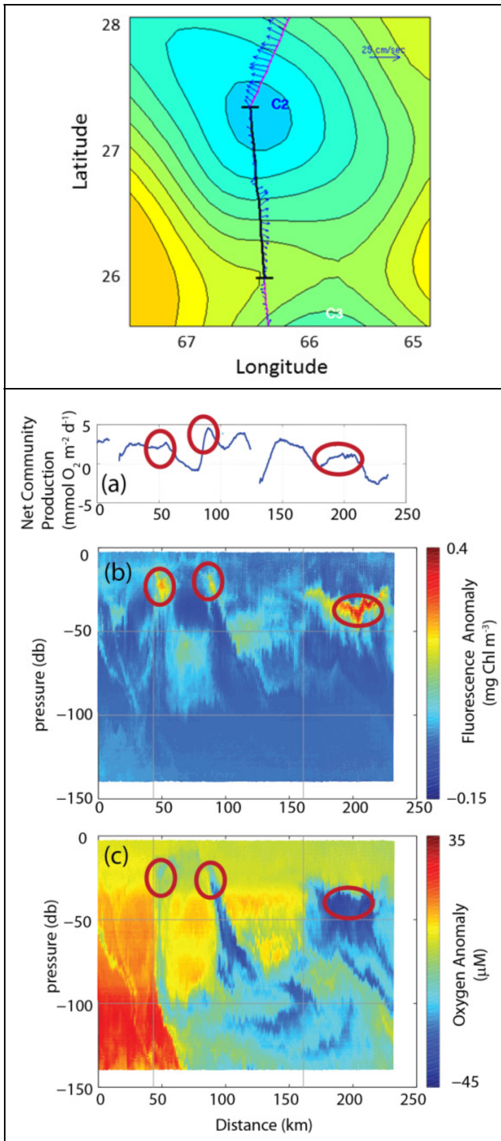

Figure 1. Top: Cruise track overlaid on satellite-based sea level anomaly. Cyclone C2 is a depression in sea level of ca. 20 cm. Blue vectors represent underway ADCP velocity measurements. Panels (a-c) below come from the black portion of the track, with endpoints indicated by hash marks. (a) Net community production rates as determined by O_2/Ar data, in surface water measured underway during a 250 km transect. (b) and (c): fluorescence and O_2 anomalies measured by the VPR on the same transect. Biological hotspots circled in red are shown in all three records.

Introduction

The "biological pump" plays a key role in regulating global climate by exporting roughly 10 Gt of carbon per year out of the euphotic zone [*Falkowski et al.*, 1998]. However, measurements of export production vary by more than an order of magnitude on regional and seasonal scales, and current models poorly capture this variability [*Buesseler and Boyd*, 2009]. Net community production (NCP), defined as the difference between C fixation via photosynthesis and total respiration in the euphotic zone, must balance export production over large spatiotemporal scales (basin wide, annual). However, the processes that control NCP and export production and hence their variability, are likely to occur at smaller submesoscales (SMS)[*Lévy et al.*, 2012]. A key hypothesis that needs to be tested is:

> H_0: *Submesoscale nutrient injections stimulate phytoplankton production, thereby increasing NCP rates.*

In the past, direct observation of submesoscale impacts on NCP has been proved difficult because of the small spatial scales and short temporal scales involved. However, with the addition of an O_2 sensor to the tow-yo'ed Video Plankton Recorder / CTD / sensor system (referred to as the VPR), we now have high-resolution cross-sections of such features (Figure 1). During a recent voyage from Bermuda to Barbados, we saw biological hotspots regularly along our cruise track [*Stanley and McGillicuddy*, submitted]. In order to quantify the change in oxygen in a hotspot, one needs to know the initial oxygen concentration prior to upwelling. Unfortunately, in the recent voyage, we only had information from single transects through three-dimensional fields that were evolving in time. Therefore, we cannot unequivocally determine the source waters for each hotspot. However, we can make a crude attempt to do so by calculating the oxygen concentration of water with the same density, temperature, and salinity as that of the hotspot. When we do so, we find very surprisingly that in two-thirds of the hotspots we analyzed, oxygen appears to be decreasing compared to the likely source water. Only in one-third of the hotspots analyzed was H_0 borne out. Thus – if this crude analysis is correct – there is often actually negative NCP in the hotspots, contrary to our hypothesis H_0. Such negative NCP could occur if photosynthesis were indeed stimulated in the hotspots due to upwelled nutrients, as we hypothesize in H_0, but if respiration was stimulated to a greater extent. To test this, we must determine NCP in hotspots that we follow in space and time, making definitive observations of the source of the upwelled water. Additionally, measurements of gross primary production (which is equal to only the photosynthetic flux) made in the hotspots will allow us to determine if there really is increased photosynthesis in the hotspots, even if the surprising finding of negative NCP is confirmed. Clearly there is great need to further examine hotspots to determine the sign and the magnitude of the change in NCP and gross primary production due to these ubiquitous features.

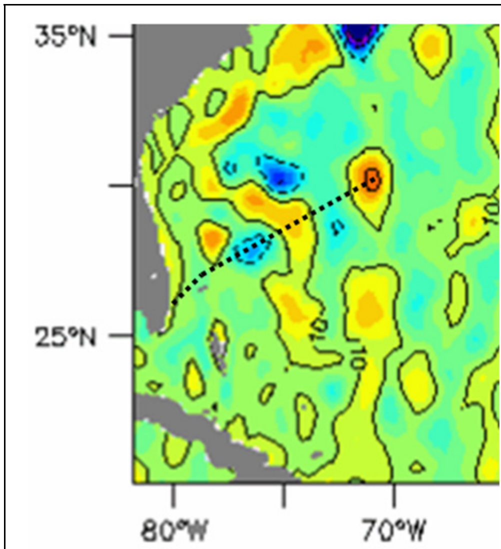

Figure 2. Sea level anomaly for May 1, 2015. Source: http://www.aviso.altimetry.fr

Proposed Research

As we have done in prior work (e.g. Figure 1), real-time satellite observations will be used to target mesoscale features in the NW subtropical Atlantic. An example scenario is illustrated in Figure 2. Departing from Miami, we would target the strong anticyclonic feature located at 30ºN, 70ºW crossing through several other potentially interesting anomalies along the way. At the towing speed of the VPR (10 knots), it will take approximately 3 days to reach the target feature.

To illustrate our proposed sampling strategy, we zoom in on a subdomain of a high-resolution biogeochemical model [*Resplandy et al.*, 2012] containing a hotspot that is representative of the types of features we are interested in (Figure 3). For the purposes of this sampling exercise we assume the spatial structure of the feature is unknown, and that its characteristics are discernible with our towed systems' chlorophyll fluorescence, beam attenuation, and dissolved oxygen sensors. This facilitates construction of an Observing System Simulation Experiment (OSSE), in which we extract simulated observations from the model solution in both space and time. Entering the sampling domain eastbound at 28°N, we encounter the frontal feature oriented NNE-SSW. Upon crossing the feature and seeing conditions return to the background state, we turn 90° to the right, putting us on a southward course. In this transect we pass through the region of highest export, but we do not encounter the absolute peak. We turn 90° to the right, steam 20 km to the west, and then turn 90° to the right again for a northward transect. Again we encounter the heart of the feature, but its magnitude is slightly less than we observed to the east. As soon as we hit background conditions again, we delimit the feature to the west by making a turn to the left, steaming 20 km to the west, and then returning on a southbound transect. Once in background conditions again, we turn eastward and continue until we are 20 km east of the easternmost line and occupy a northbound transect until we hit background conditions again. Because the peak we observe on this transect is lower than the previous peak, we turn westward and then southward to occupy a line half way in between the two lines. This results in a near-direct hit on the peak of the feature, which then becomes the reference point for subsequent process studies. The total cruise track for this three-dimensional survey is 1084 km, requiring 58 hours to complete at a speed of 10 knots.

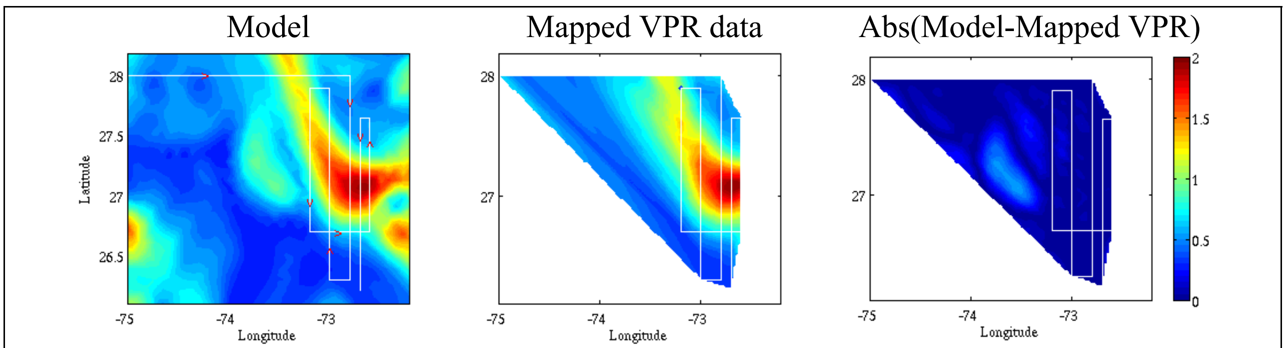

Figure 3. Simulated sampling of a submesoscale hotspot. White line indicates a hypothetical survey, with red arrows indicating the direction of the cruise track. Left: Survey track overlaid on the modeled export field. Middle: mapped version of the simulated observations, which are acquired at 2km horizontal resolution. Right: absolute value of the difference between the "truth" as represented by the model in the left hand panel and the mapped version of the simulated observations. Colorbar at the right pertains to all three fields, in units of mmol N m^{-2} d^{-1}.

We analyze the efficacy of our sampling strategy by mapping the simulated observations (Figure 3, middle) and comparing them with the "truth" as defined by the model output at the central time (Figure 3, left) to quantify the difference between the two (Figure 3, right). From these results it is clear that the survey identifies and delineates the edges of the feature by systematically changing direction whenever local, biogeochemical maxima (as measured by underway and towed sensors) are encountered adjacent to background-level signals. Although the underlying field evolves in space and time during the survey, this strategy is sufficient to provide a synoptic realization of the SMS hotspot. Significant differences between the mapped observations and the "truth" are mostly confined to an area west of the survey tracks, which simply reflects the uncertainty in extrapolation of the mapped field outside the domain of the observations—portions of the map which of course would not be utilized in post-cruise analysis. Of course we recognize that the conclusions from this OSSE are only as valid as the model simulation on which it is based. Even though the resolution of the underlying model is among the finest published to date for such regimes, it does not contain the full range of scales present in the real ocean. Nevertheless, the OSSE gives us confidence we can gather quasi-synoptic snapshots of SMS hotspots, at least insofar as they are represented in a state-of-the-art model.

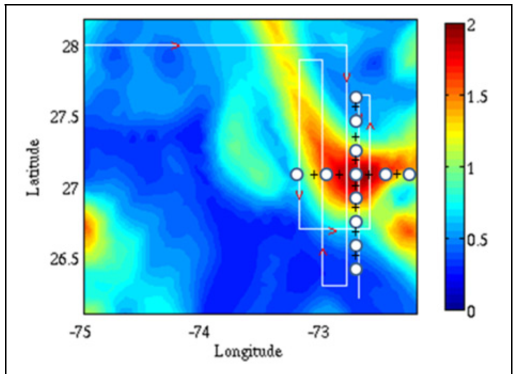

Figure 4. Simulated sampling of hotspot. White line indicates a hypothetical towed survey, with red arrows indicating the direction of the cruise track. Hydrographic stations occupied after the survey are shown as black plus signs (CTD only) and white dots (water samples taken). Colorbar represents export in units of mmol N m^{-2} d^{-1}.

Once we have mapped the target hotspot with the VPR (~2.5 days), the REMUS 600 will be deployed to execute a fine-scale survey of the interior of the hotspot. Onboard sensors will include CTD and ADCP as well as fluorescence and oxygen. We plan for a 1.5 day mission, with the vehicle sampling a regular grid in the upper 150 m of the water column within the inner 10 km of the chosen feature. At a speed of 3.5 knots, the ca. 230 km of trackline available will provide unprecedented resolution of the physical and biogeochemical properties of the hotspot.

While the REMUS survey is taking place, a CTD/Rosette will be deployed from the ship on a sampling grid of ca. 50 km transects across the hotspots with ca. 5 km spacing (Figure 4). Water samples will be drawn in the upper 700 m on half of the casts (12 casts without bottles plus 12 casts x 12 depths; control stations to 1000m) for triple oxygen isotopes, O_2/Ar, nutrients, particle properties, and other sensor-derived parameters (1.5 days to complete). The VPR survey will be repeated to assess temporal evolution of the field since the first snapshot, thereby completing one full observational cycle in 4 days.

We predict the SMS features will remain coherent over scales of weeks based upon our assessment of model output (see below). We will repeat the observational cycle in a quasi-Lagrangian fashion to quantify the evolution of the hotspot. With a 14 day cruise, and allowing for transit time and an initial survey to locate a hotspot, we will be able to execute 2 observational cycles. Given the time scales on which submesoscale features evolve (days to weeks), these observations will provide needed insight into the space-time structure of physical and biogeochemical fields.

We will calculate NCP in the hotspots by measuring the O_2/Ar of discrete bottle samples collected on the CTD casts targeting the hotspots. This method has been used since the late 1980s with great success to constrain rates of NCP [*Craig and Hayward*, 1987]. We also will run a shipboard equilibrator mass spectrometer fed by the underway seawater system in order to continuously quantify NCP in the mixed layer with several km resolution. In our prior observations, the deep hotspots have been expressed in the mixed layer as peaks in NCP.

We will quantify gross primary production in the hotspots by the use of triple oxygen isotopes [*Luz et al.*, 1999]. This is particularly useful since NCP can be negative but gross primary production can still be increasing with time if both photosynthesis and respiration are increasing as the hotspot evolves. The same discrete bottle samples collected in the hotspots for laboratory analysis of O_2/Ar will be analyzed simultaneously for triple oxygen isotopes. These samples will be analyzed in the lab shortly after the cruise.

Broader Context and Significance

The topic of this proposal—to understand the controls on ocean production, export and carbon cycling—has a direct societal benefit in being able to better understand the controls on the current biological pump, which sequesters roughly 10 Gt C yr^{-1} out of the surface ocean. It is not even understood whether this carbon flux will increase or decrease in response to a changing climate, partly because only empirical relationships between production and export exist which do not allow for predictions of future perturbations. Our work will yield insight into the underlying mechanisms on the scales in which these processes operate, thereby providing the basis for parameterization of these effects into climate models.

Relevance to Dalio Explore Fund and Media Objectives

This proposal addresses several of the DEF objectives: (1) there is a strong field component, (2) it is a novel early-stage idea that has been considered high risk by traditional funding agencies (NSF), and (3) the project utilizes promising new technologies and techniques to advance knowledge on an important scientific question. As for a media component, Alucia Productions was contacted, but declined to be involved in this proposal. We will therefore create a cruise blog "Underwater storm-chasers" to convey the essence of our science to the public, drawing analogy between SMS dynamics and atmospheric weather. Video footage will be acquired to document the voyage on WHOI's YouTube channel, including interviews with onboard personnel as well as segments on instrument launch/recovery/operation.

Budget notes: Salary costs for Dr. McGillicuddy will be covered by his Senior Scientist Chair. Dr. Stanley and her student's salary costs are included in a subcontract to Wellesley College where she is now on the faculty; she is listed as a PI in the WHOI budget because she continues to supervise WHOI personnel (Z. Sandwith).

References

Buesseler, K. O., and P. W. Boyd (2009), Shedding light on processes that control particle export and flux attenuation in the twilight zone, *Limnology and Oceanography*, *54*, 1210-1232.

Craig, H., and T. Hayward (1987), Oxygen supersaturation in the ocean: biological versus physical contributions, *Science*, *235*, 199-202.

Falkowski, P. G., et al. (1998), Biogeochemical controls and feedbacks on ocean primary production, *Science*, *281*, 200-206.

Lévy, M., et al. (2012), Bringing physics to life at the submesoscale, *Geophysical Research Letters*, *39*(14), L14602, doi:10.1029/2012gl052756.

Luz, B., et al. (1999), Triple-isotope composition of atmospheric oxygen as a tracer of biosphere productivity, *Nature*, *400*, 547-550.

Resplandy, L., et al. (2012), How does dynamical spatial variability impact 234Th-derived estimates of organic export?, *Deep Sea Research I*, *68*(0), 24-45, doi:10.1016/j.dsr.2012.05.015.

Stanley, R. H. R., and D. J. McGillicuddy (submitted), Submesoscale Hotspots of Productivity and Respiration, *Deep-Sea Research I*.

Adaptive Sampling of Hotspots in Net Community Production Using the VPR, REMUS, and Traditional Hydrographic Methods

DENNIS J MCGILLICUDDY (WHOI Internal Awards)

Oct 12, 2015 to Oct 11, 2017

Summary Budget

Approximate Labor Months

	10/12/15 10/11/17	Total
A. Senior Personnel		
1. DENNIS J. MCGILLICUDDY, Co-PI	0.00	0.00
2. MICHAEL J. PURCELL, Co-PI	1.00	1.00
3. RACHEL H. STANLEY, Co-PI	0.00	0.00
B. Other Personnel		
2. Other Professionals	16.60	16.60
C. Total Direct Labor & Benefits	**$201,724**	**$201,724**
E. Travel		
1. Domestic	11,907	11,907
Total Travel	**11,907**	**11,907**
G. Other Direct Costs		
1. Materials and Supplies	28,175	28,175
5. SubAward	29,836	29,836
6. Other	28,364	28,364
Total Other Direct Costs	**86,375**	**86,375**
H. Total Direct Costs	**$300,006**	**$300,006**
I. Indirect Costs		
1. Lab Costs	105,403	105,403
2. General & Administrative	71,686	71,686
Total Indirect Costs	**177,089**	**177,089**
J. Total Direct and Indirect Costs	**$477,095**	**$477,095**
L. Amount of this Request	**$477,095**	**$477,095**

Adaptive Sampling of Hotspots in Net Community Production Using the VPR, REMUS, and Traditional Hydrographic Methods

DENNIS J MCGILLICUDDY (WHOI Internal Awards)

Oct 12, 2015 to Oct 11, 2017

AOPE Budget

	Approximate Labor Months 10/12/15 10/11/17	Total
A. Senior Personnel		
1 . D. MCGILLICUDDY, Senior Sci	0.00*	0.00
B. Other Personnel		
2. Other Professionals		
P. ALATALO, Res Assoc II	1.05*	1.05
O. KOSNYREV, Sr Res Asst II	7.00	7.00
M. PATRICIAN, Res Assoc III	1.05*	1.05
F. THWAITES, Res Engr	1.05*	1.05
C. Total Direct Labor & Benefits	**$111,372**	**$111,372**
E. Travel (see detail)		
1. Domestic	5,292	5,292
Total Travel	**5,292**	**5,292**
G. Other Direct Costs (see detail)		
1. Materials and Supplies	10,000	10,000
6. Other	20,214	20,214
Total Other Direct Costs	**30,214**	**30,214**
H. Total Direct Costs	**$146,878**	**$146,878**
I. Indirect Costs		
1. Lab Costs	59,918	59,918
2. General & Administrative	40,751	40,751
Total Indirect Costs	**100,669**	**100,669**
J. Total Direct & Indirect Costs	**$247,547**	**$247,547**
L. Amount of this Request	**$247,547**	**$247,547**

* Includes Cruise Participation

Adaptive Sampling of Hotspots in Net Community Production
DENNIS J MCGILLICUDDY (WHOI Internal Awards)
Oct 12, 2015 to Oct 11, 2017
AOPE Budget

Travel Detail

Period 1 10/12/15 - 10/11/17

1. Domestic

Cruise participation (Boston, MA to Miami, FL)

Airfare	Round Trip	4 Tickets		@400	1,600
Ground	General Grnd Transport.	4		@200	800
Lodging	Nightly Rate (inc. Tax)	4 Rooms	3 Nights	@146	1,752
Per Diem	Inside Continental US	4 People	5 Days	@57	1,140
				Trip Total:	5,292

Total Domestic Travel - Period 1 **5,292**

Adaptive Sampling of Hotspots in Net Community Production

DENNIS J MCGILLICUDDY (WHOI Internal Awards)

Oct 12, 2015 to Oct 11, 2017

AOPE Budget

Other Direct Costs - Detail

	10/12/15 10/11/17	Total
G. Other Direct Costs		
1. Materials and Supplies		
a. Supplies	10,000	10,000
Total Materials and Supplies	**10,000**	**10,000**
6. Other		
a. Cruise Shipments	8,550	8,550
b. Nutrient Facility	8,064	8,064
c. Outside Calibration Services	1,000	1,000
d. Shop Services	2,600	2,600
Total Other	**20,214**	**20,214**
Total Other Direct Costs	**30,214**	**30,214**

Adaptive Sampling of Hotspots in Net Community Production Using the VPR, REMUS, and Traditional Hydrographic Methods

DENNIS J MCGILLICUDDY (WHOI Internal Awards)

Oct 12, 2015 to Oct 11, 2017

Chemistry Budget

	Approximate Labor Months 10/12/15 10/11/17	Total
A. Senior Personnel		
3 . R. STANLEY	0.00*	0.00
B. Other Personnel		
2. Other Professionals		
Z. SANDWITH, Res Asst III	3.50*	3.50
C. Total Direct Labor & Benefits	**$26,074**	**$26,074**
E. Travel (see detail)		
1. Domestic	3,969	3,969
Total Travel	**3,969**	**3,969**
G. Other Direct Costs (see detail)		
1. Materials and Supplies	10,075	10,075
5. SubAward	29,836	29,836
6. Other	5,000	5,000
Total Other Direct Costs	**44,911**	**44,911**
H. Total Direct Costs	**$74,954**	**$74,954**
I. Indirect Costs		
1. Lab Costs	13,284	13,284
2. General & Administrative	9,035	9,035
Total Indirect Costs	**22,319**	**22,319**
J. Total Direct & Indirect Costs	**$97,273**	**$97,273**
L. Amount of this Request	**$97,273**	**$97,273**

* Includes Cruise Participation

Adaptive Sampling of Hotspots in Net Community Production
DENNIS J MCGILLICUDDY (WHOI Internal Awards)
Oct 12, 2015 to Oct 11, 2017
Chemistry Budget

Travel Detail

Period 1 10/12/15 - 10/11/17

1. Domestic

Cruise participation (Boston, MA to Miami, FL)

Airfare	Round Trip	3 Tickets		@400	1,200
Ground	General Grnd Transport.	3		@200	600
Lodging	Nightly Rate (inc. Tax)	3 Rooms	3 Nights	@146	1,314
Per Diem	Inside Continental US	3 People	5 Days	@57	855
				Trip Total:	3,969

Total Domestic Travel - Period 1 **3,969**

Adaptive Sampling of Hotspots in Net Community Production

DENNIS J MCGILLICUDDY (WHOI Internal Awards)

Oct 12, 2015 to Oct 11, 2017

Chemistry Budget

Other Direct Costs - Detail

	10/12/15 10/11/17	Total
G. Other Direct Costs		
1. Materials and Supplies		
a. Cruise Supplies		
1. Cartridges	5,000	5,000
2. Tubing	1,000	1,000
3. New pump	1,200	1,200
b. Supplies		
1. Sample Analysis Supplies		
a. Gold gasket	900	900
b. Filament	450	450
c. Liquid n2	600	600
d. Helium	300	300
e. Compressed n2	125	125
f. Misc consumables	500	500
Total Materials and Supplies	**10,075**	**10,075**
5. SubAward		
a. Wellesley College	29,836	29,836
Total SubAward	**29,836**	**29,836**
6. Other		
a. Other Outside Services		
1. Factory Cleaning Mass Spec	2,000	2,000
b. Shipping & Postage	3,000	3,000
Total Other	**5,000**	**5,000**
Total Other Direct Costs	**44,911**	**44,911**

Adaptive Sampling of Hotspots in Net Community Production Using the VPR, REMUS, and Traditional Hydrographic Methods

DENNIS J MCGILLICUDDY (WHOI Internal Awards)

Oct 12, 2015 to Oct 11, 2017

OSL Budget

	Approximate Labor Months 10/12/15 10/11/17	Total
A. Senior Personnel		
2 . M. PURCELL, Prin Engr	1.00	1.00
B. Other Personnel		
2. Other Professionals		
J. DELLIBOVI, Eng Asst III	0.11	0.11
T. HURST, Res Engr	0.11	0.11
R. LITTLEFIELD, Res Engr	0.26	0.26
G. PACKARD, Sr Engr Asst II	0.63*	0.63
R. STOKEY, Prin Engr	0.16	0.16
D. TEBO, Eng Asst III	1.68*	1.68
C. Total Direct Labor & Benefits	**$64,278**	**$64,278**
E. Travel (see detail)		
1. Domestic	2,646	2,646
Total Travel	**2,646**	**2,646**
G. Other Direct Costs (see detail)		
1. Materials and Supplies	8,100	8,100
6. Other	3,150	3,150
Total Other Direct Costs	**11,250**	**11,250**
H. Total Direct Costs	**$78,174**	**$78,174**
I. Indirect Costs		
1. Lab Costs	32,201	32,201
2. General & Administrative	21,900	21,900
Total Indirect Costs	**54,101**	**54,101**
J. Total Direct & Indirect Costs	**$132,275**	**$132,275**
L. Amount of this Request	**$132,275**	**$132,275**

* Includes Cruise Participation

Adaptive Sampling of Hotspots in Net Community Production
DENNIS J MCGILLICUDDY (WHOI Internal Awards)
Oct 12, 2015 to Oct 11, 2017
OSL Budget

Travel Detail

Period 1 10/12/15 - 10/11/17

1. Domestic

Cruise participation (Boston, MA to Miami, FL)

Airfare	Round Trip	2 Tickets		@400	800
Ground	General Grnd Transport.	2		@200	400
Lodging	Nightly Rate (inc. Tax)	2 Rooms	3 Nights	@146	876
Per Diem	Inside Continental US	2 People	5 Days	@57	570
				Trip Total:	2,646

Total Domestic Travel - Period 1 **2,646**

Adaptive Sampling of Hotspots in Net Community Production
DENNIS J MCGILLICUDDY (WHOI Internal Awards)
Oct 12, 2015 to Oct 11, 2017
OSL Budget

Other Direct Costs - Detail

	10/12/15 10/11/17	Total
G. Other Direct Costs		
1. Materials and Supplies		
a. Supplies		
1. Cables	500	500
2. Connectors	600	600
3. Endcap	3,000	3,000
4. Flotation	2,000	2,000
5. Sensor Mounting Frame	2,000	2,000
Total Materials and Supplies	**8,100**	**8,100**
6. Other		
a. Tioga - full day	3,150	3,150
Total Other	**3,150**	**3,150**
Total Other Direct Costs	**11,250**	**11,250**

PI: MCGILLICUDDY, DENNIS
Agency: WHOI Internal Awards
Proposal: 21574 Adaptive Sampling of Hotspots in Net Community Produc
Submission: 00 Adaptive Sampling of Hotspots in Net Community Produc
Version: 01
Period: 01 10/12/2015 - 10/11/2017

I. Total Salaries (All Budgeted Personnel)

a) Regular + At Sea	112,828			
b) Overtime	17,421			
c) Casual	0			
d) GRA Stipend	0			
e) Shore Leave	0			
		Total Salaries & Wages:	130,249	

II. Paid Absences (PA)	**Amount**	**x**	**Rate %**	**= Paid Absences**		
a) Regular	105,740		19.7600	20,895		
				Total Paid Absences:	20,895	
III. Total Salaries, Wages & Paid Absences						**151,144**

IV. Benefit Calculation	**Amount**	**x**	**Rate %**	**= Benefit Cost**		
a) Regular + PA	126,635		35.2700	44,664		
b) Overtime	17,421		31.0600	5,411		
c) Casual	0		6.3900	0		
d) Cruise Leave	5,412		7.1100	385		
e) Sea Duty	1,676		7.1100	120		
				Total Benefits:	50,580	
V. Total Direct Labor and Benefits:						**201,724**

VI. Calculation of the Overhead Base:

Total Salary & Benefits	201,724
Less Premium Pay	(5,807)
Less GRA Stipends	0
Less Shore Leave	0
Overhead Base (non-GRA)	195,916

VII. Lab Overhead Calculation	**Base**	**x**	**Rate %**	**= Lab OH Cost**	
Base (non-GRA)	195,917		53.8000	105,403	
GRA Stipends:	0		26.9000	0	
				Total Lab Overhead:	105,403

VIII. G&A Overhead Calculation	**Base**	**x**	**Rate %**	**= G&A OH Cost**		
Base (non-GRA)	195,916		36.5900	71,686		
GRA Stipends:	0		36.5900	0		
				Total G&A Overhead:	71,686	
IX. Total Indirect Costs						**177,089**
X. Total Salary & Related Costs						**378,813**

Budget Worksheet: 8386.5

Agency:

P.I.

Fringe Benefit Rates:	FY14 Non-Summer Salary rate:	35.80%	For Academic Year Salary, Professional Salaries
	Faculty Summer Salary rate:	17.70%	For Summer Salary ONLY
	Casual/Summer Student Rate:	7.70%	For casual wage and summer students ONLY
F&A Rate [Indirect Costs):	FY14-17 Negotiated Federal IDC Rate:	75.30%	On Salaries and Wages (Excludes Student Payroll and Fringe)

Annual Increases @ 2%

	Yr1	Yr2	Yr3	Yr4	Yr5	Total
Salaries:						
Course Release/Sabbatical	0	0	0	0	0	0
Summer Salary	8,390	4,279	0	0	0	12,669
Other Professional Salary	0	0	0	0	0	0
Casual Wage Salary	0	0	0	0	0	0
Student Salary (Academic Yr)	0	0	0	0	0	0
Student Salary (Summer)	5,000	0	0	0	0	5,000
Subtotal Salaries & Wages:	13,390	4,279	0	0	0	17,669
Fringe:						
Faculty Academic Yr/Professional	0	0	0	0	0	0
Faculty Summer Salary	1,485	757	0	0	0	2,242
Student Summer/Casual Wage	385	0	0	0	0	385
Subtotal Fringe Benefits:	1,870	757	0	0	0	2,627
Total Personnel	15,260	5,036	0	0	0	20,296
Equipment						
Items >$5000/item	0	0	0	0	0	0
	0	0	0	0	0	0
Subtotal Equipment	0	0	0	0	0	0
Travel						
Domestic Travel		0	0	0	0	0
Foreign Travel:	0	0	0	0	0	0
Subtotal Travel	0	0	0	0	0	0
Other Expenses:						
Lab Materials and Supplies	0	0	0	0	0	0
Computing Supplies	0	0	0	0	0	0
Publication Costs	0	0	0	0	0	0
Student Summer Stipends	0	0	0	0	0	0
Consultants	0	0	0	0	0	0
Other Payments	0	0	0	0	0	0
Subtotal Other	0	0	0	0	0	0
Subcontracts						
Direct Costs	0	0	0	0	0	0
Indirect Costs	0	0	0	0	0	0
Total Subcontracts	0	0	0	0	0	0
Total Direct Costs	15,260	5,036	0	0	0	20,296
F&A Costs @ 75.3% x S&W	6,318	3,222	0	0	0	9,540
Total	21,578	8,258	0	0	0	29,836

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Professional Preparation:

1987 B.A., *cum laude*, Engineering Sciences, Harvard College, Cambridge, MA.
1989 M.S., Applied Physics, Harvard University, Cambridge, MA.
1993 Ph.D., Earth and Planetary Sciences, Harvard University, Cambridge, MA.

Appointments:

2007-Present Senior Scientist, Woods Hole Oceanographic Institution.
1999-2007 Associate Scientist (tenure in 2003), Woods Hole Oceanographic Institution.
1995-1999 Assistant Scientist, Woods Hole Oceanographic Institution.
1993-1995 Postdoctoral Scholarship, Woods Hole Oceanographic Institution.
1993-1995 Modeling Fellowship, University Corporation for Atmospheric Research.
1990-1993 Research Assistant, Harvard University.
1989 Visiting Scientist, Institut Für Meereskunde, Kiel, Germany.
1987-1990 Graduate Fellowship, Office of Naval Research.

Products Most Relevant to Proposal:

1. **McGillicuddy, D.J.**, Robinson, A.R., Siegel, D.A., Jannasch, H.W., Johnson, R., Dickey, T.D., McNeil, J., Michaels, A.F., and A.H. Knap, 1998. Influence of mesoscale eddies on new production in the Sargasso Sea. *Nature*, **394**, 263-265.
2. **McGillicuddy, D.J.**, Anderson, L.A., Doney, S.C., and M.E. Maltrud, 2003. Eddy-driven sources and sinks of nutrients in the upper ocean: results from a 0.1 degree resolution model of the North Atlantic. *Global Biogeochemical Cycles*, **17**(2), 1035, doi:10.1029/2002GB001987.
3. Davis, C.S. and **McGillicuddy, D.J.**, 2006. Transatlantic Abundance of the N2-Fixing Colonial Cyanobacterium *Trichodesmium*. *Science*, **312**, 1517-1520.
4. **McGillicuddy, D.J.**, Anderson, L.A., Bates, N.R., Bibby, T., Buesseler, K.O., Carlson, C.A., Davis, C.S., Ewart, C., Falkowski, P.G., Goldthwait, S.A., Hansell, D.A., Jenkins, W.J., Johnson, R., Kosnyrev, V.K., Ledwell, J.R., Li, Q.P., Siegel, D.A. and D.K. Steinberg, 2007. Eddy/Wind Interactions Stimulate Extraordinary Mid-Ocean Plankton Blooms. *Science*, **316**, 1021-1026.
5. **McGillicuddy, D.J.**, 2015. Formation of intra-thermocline lenses by eddy-wind interaction. *Journal of Physical Oceanography*, 45, 606-612, DOI: 10.1175/JPO-D-14-0221.1.

Other Significant Products:

1. **McGillicuddy, D.J.**, Lynch, D.R., Moore, A.M., Gentleman, W.C., Davis, C.S., and C.J. Meise, 1998. An adjoint data assimilation approach to diagnosis of physical and biological controls on *Pseudocalanus* spp. in the Gulf of Maine - Georges Bank region. *Fisheries Oceanography*, **7**(3/4), 205-218.
2. **McGillicuddy, D.J.** and A. Bucklin, 2002. Intermingling of two *Pseudocalanus* species on Georges Bank. *Journal of Marine Research*, **60**, 583-604.
3. **McGillicuddy, D.J.**, Signell, R.P., Stock, C.A., Keafer, B.A., Keller, M.D., Hetland, R.D. and D.M. Anderson, 2003. A mechanism for offshore initiation of harmful algal blooms in the coastal Gulf of Maine. *Journal of Plankton Research*, **25**(9), 1131-1138.

4. **McGillicuddy, D.J.**, Anderson, D.M., Lynch, D.R. and D.W. Townsend, 2005. Mechanisms regulating the large-scale seasonal fluctuations in *Alexandrium fundyense* populations in the Gulf of Maine. *Deep-Sea Research II*, **52**, 2698-2714.
5. **McGillicuddy, D.J.**, 2011. Eddies Masquerade as Planetary Waves. *Science*, **334**, 318-319.

Synergistic Activities

- Development and presentation of a public outreach lecture "Oases in the Oceanic Desert: Turbulent Storms in the Sea and their Impact on Biological Productivity."
- Service on national and international scientific steering committees (U.S. JGOFS, U.S. GLOBEC, GEOHAB).
- Teaching in the MIT/WHOI Joint Program; guest lectures in undergraduate and graduate level courses in ocean science.
- Development of a general computational tool for inversion of the two-dimensional advection-diffusion reaction equation ("Scotia 1.0").

Collaborators & Other Affiliations (within the last 48 months) (Total 69)
A.L. Aretxabaleta (USGS), J. Ballabrera-Poy (CSIC, Spain), P.M. Barrett (UW) , M.J. Behrenfeld (OSU), T.S. Bibby (NOCS), A.L. Bilgili (Istanbul Tech. U), V.M. Bricelj (Rutgers), B. Butman (USGS), D.B. Chelton (OSU), D.A. Couture (Resource Access International), B.G. Crespo (ICM, Spain), P.S. Daylander (USGS), J.R. Deeds (FDA), S.L. Degrasse (FDA), M.S. Dinniman (ODU), K. Fennel (Dalhousie), K.M. Fisher (OSU), P.M. Glibert (UMD), D.A. Greenberg (BIO, Canada), B. Greenan (BIO, Canada), K. Hayashi (UMASS, Dartmouth), R. He (NCSU), J.M. Hickey (Mass DMF), E. Hofmann (ODU), J.W. Lavelle (NOAA), X. Liang (Lamont-Doherty), N. Loomis (Google X Lab), D.R. Lynch (Dartmouth College), S.L. Mack (ODU), M. Maltrud (Los Almos National Lab), J.P. Manning (NOAA/NMFS), S. Maritorena (UCSB), C.M. Marsay (USC), J.L. Martin (DFO Canada), P.J. Milligan (UMASS, Dartmouth), D.G. Mountain (Tuscon, AZ), C. Nash (NOAA), N.B. Nelson (UCSB), K. Norton (California), K. Olli (UTartu, Estonia), E.M. Olson (UBC, Canada), P. Peterson (UCSB), C.M. Petitpas (U. Mass Dartmouth), C. Petrick (NOAA NMFS), C.L. Pilskaln (UMASS, Dartmouth), N.D. Rebuck (NOAA), O. Ross (UEssex, UK), P.N. Sedwick (BIOS), K.G. Sellner (Chesapeake Bay Res. Cons), V.A. Sheremet (URI), C.R. Sherwood (USGS), V. Shue (FDA), D.A. Siegel (UCSB), R.P. Signell (USGS), J.L. Smith (VIMS), W.O. Smith (VIMS), A.H. Song (MIT), R.P. Stumpf (NOAA), P.G. Strutton (UTsamania, Australia), M.A. Thomas (U. Maine), A.M. Thurnherr (Lamont-Doherty), D.W. Townsend (U. Maine), J.T. Turner (UMASS, Dartmouth), E. Vahtera (City of Helsinki Env. Cntr, Finland) L. Velo-Suarez (French Nat. Cntr. Sci. Res), K.D. White (FDA), J. Wilkin (Rutgers), L. Zamudio-Lopez (FSU).

Ph.D. Advisors: Allan R. Robinson and James J. McCarthy, Harvard University (Total 2)
Postdoctoral Advisor: Kenneth H. Brink, Woods Hole Oceanographic Institution (Total 1)

Student & Postdoctoral Fellow Supervision in the Last Five Years (Total 8)
Postdocs: P. Gaube, P. Wallhead, W.G. Zhang, L. Velo-Suarez (all MIT/WHOI)
Students: E. Olson (MIT/WHOI), Y. Li (NCSU); C. Petitpas (U. Mass-D); P. Zhang (Rutgers)

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(a) Professional Preparation:

Florida Atlantic University, Boca Raton, FL	Ocean Engineering	B.S., 1980
Massachusetts Institute of Technology, Cambridge, MA	Ocean Engineering	M.S., 1984

(b) Appointments:

2014-Present Manager, Oceanographic Systems Laboratory, Woods Hole Oceanographic Institution, Woods Hole, MA

2012-Present Principal Engineer, Applied Ocean Physics & Engineering Department, Woods Hole Oceanographic Institution, Woods Hole, MA

2008-Present Manager, REMUS AUV Operations Group, Woods Hole Oceanographic Institution, Woods Hole, MA

2001-2012 Senior Engineer, Applied Ocean Physics & Engineering Department, Woods Hole Oceanographic Institution, Woods Hole, MA

1991-2001 Research Engineer, Applied Ocean Physics & Engineering Department, Woods Hole Oceanographic Institution, Woods Hole, MA

1986-1991 Senior Mechanical Engineer, Lockheed Sanders, Nashua, NH

1984-1986 Mechanical Engineer, Lockheed Sanders, Nashua, NH

1983-1984 Research Assistant, Massachusetts Institute of Technology, Cambridge, MA

1981-1983 Project Engineer, General Dynamics Electric Boat, Groton, CT

(c) Products:

Govindarajan, A., J. Pineda, M. Purcell and J. A. Breier, 2015, Species- and Stage-Specific Barnacle Larval Distribution Obtained from AUV Sampling and Genetic Analysis in Buzzards Bay, Massachusetts, USA. Journal of Experimental Marine Biology and Ecology, 472:158-165

Kilgour, M.J., P.J. Auster, D. Packer, **M. Purcell**, G. Packard, M. Dessner, A. Sherrell, and D. Rissolo, 2014, Use of AUVs to Inform Management of Deep-Sea Corals. Mar. Technol. Soc. J. 48 (1):21-27.

Packard,G., A. Kukulya, T. Austin, M. Dennett, R. Littlefield, G. Packard, **M. Purcell**, G. Skomal, and R. Stokey, 2013, Continuous Autonomous Tracking and Imaging of White Sharks and Basking Sharks Using a REMUS-100 AUV. MTS/IEEE OCEANS 2013 Proceedings, San Diego, CA, 23-26 Sept.

Purcell, M., D. Gallo, G. Packard, M. Dennett, A. Sherrell, M. Rothenbeck, and S. Pascaud, 2011, Use of REMUS 6000 AUVs in the Search for Air France Flight 447. MTS/IEEE OCEANS 2011 Proceedings, Waikoloa, HI, 19-22 Sept., 7.

Moline, M.A**.**, S.M. Blackwell, B. Allen, T. Austin, N. Forrester, R. Goldsborogh, **M. Purcell**, R. Stokey, and C. von Alt, 2005, Remote Environmental Monitoring UnitS: An Autonomous Vehicle for Characterizing Coastal Environments. J. Atmos. Ocean. Tech, 22 (11): 1798–1809.

Stokey, R., A. Roup, C. von Alt, B. Allen, N. Forrester, T. Austin, R. Goldsborough, **M. Purcell**, F. Jaffre, G. Packard, and A. Kukulya, 2005, Development of the REMUS 600 Autonomous Underwater Vehicle. MTS/IEEE OCEANS 2005 Proceedings, Washington, DC, 17-23 Sept., Vol. 2: 1301-1304.

Brown, C., Y. Huot, **M. Purcell**, M. Lewis, and J. Cullen, 2004, Mapping coastal optical and biogeochemical variability using an autonomous underwater vehicle and a new bio-optical inversion algorithm. Limnol. Oceanogr.-Meth. 2(8): 262-281.

Purcell, M., C. von Alt, B. Allen, T. Austin, R. Goldsborough, N. Forrester, and R. Stokey, 2000, New Capabilities of the REMUS Autonomous Underwater Vehicle. MTS/IEEE OCEANS 2000 Proceedings, Providence, RI, 11-14 Sept., Vol. 1: 147-152.

Purcell, M., R. Stokey, R. Goldsborough, T. Austin, N. Forrester, C. von Alt, and B. Allen, 1998, The REMUS AUV Docking System: Overview and Test Results. MTS Ocean Community Conference 1998 Proceedings, Baltimore, MD, 16-19 Nov., Vol. 2: 886-890.

Allen, B., R. Stokey, T. Austin, N. Forrester, R. Goldsborough, **M. Purcell**, and C. von Alt, 1997, REMUS: A Small, Low Cost AUV; System Description, Field Trials and Performance Results. OCEANS 1997 Proceedings, Halifax, Canada, 6-9 Oct. Vol. 2: 994-1000.

(d) Synergistic Activities: N/A

(e) Collaborators (33) & Other Affiliations (0):
Ben Allen (Woods Hole Oceanographic Institution)
Peter Auster (University of Connecticut)
Thomas Austin (Woods Hole Oceanographic Institution)
Andrew Bowen (Woods Hole Oceanographic Institution)
John Collins (Woods Hole Oceanographic Institution)
Mark Dennett (Woods Hole Oceanographic Institution)
Michael Dessner (Waitt Institute)
Norman Farr (Woods Hole Oceanographic Institution)
Olivier Ferrante (Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile, France)
Daniel Fornari (Woods Hole Oceanographic Institution)
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W. Rockwell Geyer (Woods Hole Oceanographic Institution)
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Frederic Jaffre (Woods Hole Oceanographic Institution)
Carl Kaiser (Woods Hole Oceanographic Institution)
Morgan Kilgour (Gulf of Mexico Fishery Management Council)
Amy Kukulya (Woods Hole Oceanographic Institution)
Michael Kutzleb (Phoenix International)
Robin Littlefield (Woods Hole Oceanographic Institution)
Gregory Packard (Woods Hole Oceanographic Institution
Gwyneth Packard (Woods Hole Oceanographic Institution)
David Packer (NOAA, National Marine Fisheries Service, Northeast Fisheries Science Center)
Sylvain Pascaud (LCL Productions, France)
Jesús Pineda (Woods Hole Oceanographic Institution)
Dominique Rissolo (Waitt Institute)
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BIOGRAPHICAL SKETCH

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PROFESSIONAL PREPARATION

Massachusetts Institute of Technology	S.B. Chemistry with minor in Earth Science, June 2000
Southampton Oceanography Centre	Fulbright Fellowship, 2000-2001
MIT/WHOI Joint Program	Ph.D. Chemical Oceanography, August 2007
Princeton University	NOAA Climate and Global Change Postdoctoral Fellow and Hess Postdoctoral Fellow, Department of Geosciences, Aug 2007-July 2009

APPOINTMENTS

January 2015 to present: Assistant Professor, Department of Chemistry, Wellesley College, Wellesley, MA

July 2009 to present: Assistant Scientist, Department of Marine Chemistry and Geochemistry, Woods Hole Oceanographic Institution, Woods Hole, MA (presently on leave)

PRODUCTS

Publications Most Relevant to the Proposed Research

**Denotes student or former postdoctoral associate of Stanley*

Stanley, R. H. R. and D. J. McGillicuddy, Jr., "Submesoscale Hotspots of Productivity and Respiration: Insights from High-Resolution Oxygen and Fluorescence Sections", Submitted to Deep Sea Research, I.

Estapa M. L., D. A. Siegel, K. O. Buesseler, **R. H. R. Stanley**, M. W. Lomas, and N. B. Nelson "Decoupling of net community production and export production at submesoscale fronts in the Sargasso Sea" In press in Biogeochemical Cycles.

Stanley, R. H. R. W. J. Jenkins, S. C. Doney, and D. E. Lott, III "The ^{3}He Flux Gauge in the Sargasso Sea: a Determination of Physical Nutrient Fluxes to the Euphotic Zone at the Bermuda Atlantic Time Series Site." Biogeosciences. 12, 5199-5210. doi: 10.5194/bg-12-5199-2015 (2015)

*Nicholson, D. P., **Stanley, R. H. R.**, and Doney, S. C. "The triple oxygen isotope tracer of primary productivity in a dynamic ocean." (2014) Global Biogeochemical Cycles. 28, 538–552, doi:10.1002/2013GB004704.

Stanley, R. H. R., S. C. Doney, W. J. Jenkins, and D. E. Lott III, "Apparent oxygen utilization rates calculated from tritium and helium-3 profiles at the Bermuda Atlantic Time-series Study site." Biogeosciences, doi:10.5194/bgd-8-9977-2011, 9977-10015 (2012).

Other Significant Publications

Stanley, R. H. R., Z. O. Sandwith, and W. J. Williams. "Rates of summertime biological productivity in the Beaufort Gyre: A comparison between record-low and more typical ice conditions" (2015) Journal of Marine Systems. 147, 29-44.

Goldman, J., S. Kranz, J. Young, P. Tortell, **R. H. R. Stanley,** M. L. Bender, F. Morel. "Gross and net production during the spring bloom along the Western Antarctic Peninsula" (2015) New Phytologist, 205. 182-191.

Stanley, R.H.R. and W. J. Jenkins "Noble gases in seawater as tracers for physical and biogeochemical ocean processes" in The Noble Gases as Geochemical Tracers, Ed. P. Burnard. Springer Verlarg. pp. 55-80. (2013) (Peer-reviewed book chapter)

Stanley, R. H. R., and E. Howard*, "Quantifying rates of benthic microalgal photosynthesis using the triple-isotope composition of dissolved oxygen." Limnology and Oceanography Methods. 11 360-373. (2013).

Nicholson*, D. P., **R. H. R. Stanley**, E. Barkan, D. M. Karl, B. Luz, P. D. Quay, and S. C. Doney, "Evaluating triple oxygen isotope estimates of gross primary production at the Hawaii Ocean Time-series and Bermuda Atlantic Time-series Study sites." J Geophys Res-Oceans 117:C05012 doi:10.1029/2010JC006856. (2012).

SYNERGISTIC ACTIVITIES

- Mentored two graduate students, five undergraduate students, and two high school students while at Woods Hole Oceanographic Institution. Dr. Stanley found it particularly rewarding to mentor a female undergraduate minority student as part of Woods Hole's Partnership in Education Program.
- Mentored undergraduate students at Wellesley College, Princeton University and at MIT (for which effort she was awarded the "Best Undergraduate Advisor of the Year").
- Been a judge at middle school and high school science fairs, where she actively encouraged young girls to consider becoming scientists.
- Taught the "Hot Topics" seminar course for 1st and 2nd year students in the MIT/WHOI Joint Program in Oceanography and currently teaches at Wellesley College numerous courses in chemistry, including inorganic chemistry and aquatic chemistry
- Served as a reviewer for numerous journal articles and for federal proposals.

COLLABORATORS

Eugeni Barkan (Hebrew University)
Bruce Barnett (Duke University)
Burkard Baschek (Helmholtz-Zentrum Geesthact)
Michael Bender (Princeton)
Ken Buesseler (WHOI)
Nicolas Cassar (Duke University)
Scott Doney (WHOI)
Evan Howard (WHOI)
Raffaele Ferrari (MIT)
Bill Jenkins (WHOI)
Dempsey Lott (WHOI)
Boaz Luz (Hebrew University)
Cara Manning (WHOI)
Dennis McGillicuddy (WHOI)
Maria Prokopenko (Panoma College)
Paul Quay (Univ. of Washington)
Zoe Sandwith (WHOI)
Bill Williams (IOS- DFO, Canada)

GRADUATE AND POSTDOCTORAL ADVISORS

Ph.D. Advisor: Dr. Bill Jenkins (WHOI)
Postdoctoral Advisor: Prof. Michael Bender (Princeton)