GRANTS.GOV

Grant Application Package

Opportunity Title:	Evaluation of Multiple Shallow-water Systems Analysis t
Offering Agency:	Environmental Protection Agency
CFDA Number:	66.466
CFDA Description:	Chesapeake Bay Program
Opportunity Number:	EPA-R3-CBP-14-02
Competition ID:	
Opportunity Open Date:	11/18/2013
Opportunity Close Date:	01/09/2014
Agency Contact:	Tim Roberts roberts.timothy-p@epa.gov

This opportunity is only open to organizations, applicants who are submitting grant applications on behalf of a company, state, local or tribal government, academia, or other type of organization.

Application Filing Name: Zimmerman_14-421

Select Forms to Complete

Mandatory

Application for Federal Assistance (SF-424)

Project Narrative Attachment Form

Budget Information for Non-Construction Programs (SF-424A)

Optional

☐ Other Attachments Form

Instructions

Show Instructions >>

This electronic grants application is intended to be used to apply for the specific Federal funding opportunity referenced here.

If the Federal funding opportunity listed is not the opportunity for which you want to apply, close this application package by clicking on the "Cancel" button at the top of this screen. You will then need to locate the correct Federal funding opportunity, download its application and then apply.

OMB Number: 4040-0004
Expiration Date: 8/31/2016

Application for Federal Assistance SF-424

* 1. Type of Submission:	* 2. Type of Application:	* If Revision, select appropriate letter(s):
☐ Preapplication	☒ New	
☐ Application	☐ Continuation	* Other (Specify):
☒ Changed/Corrected Application	☐ Revision	

* 3. Date Received:	4. Applicant Identifier:
01/09/2014	

5a. Federal Entity Identifier:	5b. Federal Award Identifier:

State Use Only:

6. Date Received by State:		7. State Application Identifier:	

8. APPLICANT INFORMATION:

* a. Legal Name: Old Dominion University Research Foundation

* b. Employer/Taxpayer Identification Number (EIN/TIN):	* c. Organizational DUNS:
546068198	0779459470000

d. Address:

* Street1:	4111 Monarch Way
Street2:	Suite 204
* City:	Norfolk
County/Parish:	
* State:	VA: Virginia
Province:	
* Country:	USA: UNITED STATES
* Zip / Postal Code:	23508-2561

e. Organizational Unit:

Department Name:	Division Name:

f. Name and contact information of person to be contacted on matters involving this application:

Prefix:	Mrs.	* First Name:	Stephanie
Middle Name:			
* Last Name:	Harris		
Suffix:			

Title: Sr. Grant & Contract Administrator

Organizational Affiliation:
Old Dominion University Research Foundation

* Telephone Number:	757-683-4293	Fax Number:	757-683-5290

* Email: sl2harri@odu.edu

Application for Federal Assistance SF-424

*** 9. Type of Applicant 1: Select Applicant Type:**

M: Nonprofit with 501C3 IRS Status (Other than Institution of Higher Education)

Type of Applicant 2: Select Applicant Type:

Type of Applicant 3: Select Applicant Type:

* Other (specify):

*** 10. Name of Federal Agency:**

Environmental Protection Agency

11. Catalog of Federal Domestic Assistance Number:

66.466

CFDA Title:

Chesapeake Bay Program

*** 12. Funding Opportunity Number:**

EPA-R3-CBP-14-02

* Title:

Evaluation of Multiple Shallow-water Systems Analysis to Improve the Assessment of Chesapeake Bay Water Clarity and Submerged Aquatic Vegetation Water Quality Standards

13. Competition Identification Number:

Title:

14. Areas Affected by Project (Cities, Counties, States, etc.):

Add Attachment | Delete Attachment | View Attachment

*** 15. Descriptive Title of Applicant's Project:**

Modeling the impacts of water quality on SAV and other living resources in the tidal Chesapeake Bay

Attach supporting documents as specified in agency instructions.

Add Attachments | Delete Attachments | View Attachments

Application for Federal Assistance SF-424

16. Congressional Districts Of:

* a. Applicant: VA-003
* b. Program/Project: VA-002

Attach an additional list of Program/Project Congressional Districts if needed.

[ ] Add Attachment | Delete Attachment | View Attachment

17. Proposed Project:

* a. Start Date: 03/24/2014
* b. End Date: 03/23/2016

18. Estimated Funding ($):

* a. Federal	73,333.00
* b. Applicant	39,234.00
* c. State	0.00
* d. Local	0.00
* e. Other	0.00
* f. Program Income	0.00
* g. TOTAL	112,567.00

*** 19. Is Application Subject to Review By State Under Executive Order 12372 Process?**

- [ ] a. This application was made available to the State under the Executive Order 12372 Process for review on ______.
- [X] b. Program is subject to E.O. 12372 but has not been selected by the State for review.
- [ ] c. Program is not covered by E.O. 12372.

*** 20. Is the Applicant Delinquent On Any Federal Debt? (If "Yes," provide explanation in attachment.)**

- [ ] Yes
- [X] No

If "Yes", provide explanation and attach

Add Attachment | Delete Attachment | View Attachment

21. *By signing this application, I certify (1) to the statements contained in the list of certifications and (2) that the statements herein are true, complete and accurate to the best of my knowledge. I also provide the required assurances** and agree to comply with any resulting terms if I accept an award. I am aware that any false, fictitious, or fraudulent statements or claims may subject me to criminal, civil, or administrative penalties. (U.S. Code, Title 218, Section 1001)**

- [X] ** I AGREE

** The list of certifications and assurances, or an internet site where you may obtain this list, is contained in the announcement or agency specific instructions.

Authorized Representative:

Prefix:
* First Name: Cynthia
Middle Name: A.
* Last Name: Matney
Suffix:

* Title: Director of Sponsored Programs

* Telephone Number: 757-683-4293
Fax Number: 757-683-5290

* Email: rfawards@odu.edu

* Signature of Authorized Representative: Stephanie Harris
* Date Signed: 01/09/2014

Project Narrative File(s)

*** Mandatory Project Narrative File Filename:** EPA_Water_Clarity_Proposal_REV.pdf

Add Mandatory Project Narrative File | Delete Mandatory Project Narrative File | View Mandatory Project Narrative File

To add more Project Narrative File attachments, please use the attachment buttons below.

Add Optional Project Narrative File | Delete Optional Project Narrative File | View Optional Project Narrative File

BUDGET INFORMATION - Non-Construction Programs

OMB Number: 4040-0006
Expiration Date: 06/30/2014

SECTION A - BUDGET SUMMARY

Grant Program Function or Activity (a)	Catalog of Federal Domestic Assistance Number (b)	Estimated Unobligated Funds: Federal (c)	Estimated Unobligated Funds: Non-Federal (d)	New or Revised Budget: Federal (e)	New or Revised Budget: Non-Federal (f)	New or Revised Budget: Total (g)
1. EPA-R3-CBP-14-02	66.466	$	$	$ 73,333.00	$ 39,234.00	$ 112,567.00
2.						
3.						
4.						
5. Totals		$	$	$ 73,333.00	$ 39,234.00	$ 112,567.00

SECTION B - BUDGET CATEGORIES

6. Object Class Categories	GRANT PROGRAM, FUNCTION OR ACTIVITY				Total
	(1)	(2)	(3)	(4)	(5)
	EPA-R3-CBP-14-02				
a. Personnel	$ 38,778.00	$	$	$	$ 38,778.00
b. Fringe Benefits	16,984.00				16,984.00
c. Travel	2,020.00				2,020.00
d. Equipment					
e. Supplies					
f. Contractual	4,992.00				4,992.00
g. Construction					
h. Other	3,892.00				3,892.00
i. Total Direct Charges (sum of 6a-6h)	66,666.00				$ 66,666.00
j. Indirect Charges	6,667.00				$ 6,667.00
k. TOTALS (sum of 6i and 6j)	$ 73,333.00	$	$	$	$ 73,333.00
7. Program Income	$ 0.00	$	$	$	$

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SECTION C - NON-FEDERAL RESOURCES

(a) Grant Program	(b) Applicant	(c) State	(d) Other Sources	(e)TOTALS
8. ODU Cost share	$ 39,234.00	$	$	$ 39,234.00
9.				
10.				
11.				
12. TOTAL (sum of lines 8-11)	$ 39,234.00	$	$	$ 39,234.00

SECTION D - FORECASTED CASH NEEDS

	Total for 1st Year	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter
13. Federal	$ 35,263.00	$ 8,816.00	$ 8,816.00	$ 8,816.00	$ 8,815.00
14. Non-Federal	$ 19,187.00	4,797.00	4,797.00	4,797.00	4,796.00
15. TOTAL (sum of lines 13 and 14)	$ 54,450.00	$ 13,613.00	$ 13,613.00	$ 13,613.00	$ 13,611.00

SECTION E - BUDGET ESTIMATES OF FEDERAL FUNDS NEEDED FOR BALANCE OF THE PROJECT

(a) Grant Program	FUTURE FUNDING PERIODS (YEARS)			
	(b)First	(c) Second	(d) Third	(e) Fourth
16. EPA-R3-CBP-14-02	$ 9,518.00	$ 9,518.00	$ 9,518.00	$ 9,517.00
17.				
18.				
19.				
20. TOTAL (sum of lines 16 - 19)	$ 9,518.00	$ 9,518.00	$ 9,518.00	$ 9,517.00

SECTION F - OTHER BUDGET INFORMATION

21. Direct Charges:

22. Indirect Charges: 10% of MTDC (base of $66,666) = $6,667

23. Remarks: Our ONR negotiated rate is 53% of the MTDC, per the sponsor's request, the request has been capped at 10% of the MTDC

1. **Applicant: Old Dominion University Research Foundation**

P.O. Box 6369
Norfolk, VA 23508-0369
Phone: (757) 683-4293
Fax: (757) 683-5290
Contact: Stephanie L. Harris (sl2harri@odu.edu)

2. **Background**

i) Project Title: Modeling the impacts of water quality on SAV and other living resources in the tidal Chesapeake Bay.

ii) Old Dominion University is a full-service, non-profit institution of higher learning and scholarly research supported by the Commonwealth of Virginia.

iii) Documentation of non-profit status: Old Dominion University Research Foundation (ODURF) is an independent, not-for-profit, tax-exempt 501(c)(3) organization chartered under the laws of Virginia. ODURF was chartered in 1965 to "promote the educational objectives of the University by encouraging, fostering, and conducting investigation, research, and development in engineering, the physical and life sciences, the humanities, education, and all other branches of learning; and utilizing, publishing, and otherwise making known the results of such investigations, research, and development." ODURF supports and enhances the research mission of Old Dominion University (ODU) by:

- Providing highly valued administrative, fiscal and support services in the most cost-effective and efficient manner
- Fostering a knowledgeable, motivated workforce which provides superior service to its clients

ODURF, in close coordination with ODU, creates and develops opportunities to increase sponsored program activity and to maximize the utilization of research results. Please see attached cost share letter

iv) Brief biographies of applicant leads:

Richard C. Zimmerman Ph.D. Biology University of Southern California, 1983

Professor of Ocean, Earth & Atmospheric Sciences, 2003-present, Old Dominion University

Expertise as related to the proposed research area: Dr. Zimmerman is a recognized expert in the ecological physiology of submerged aquatic vegetation, the physics of radiative transfer in natural waters and ecological modeling of plant eco-physiological processes, including nutrient uptake, light harvesting and response to climate change.

Five relevant publications (of more than 80):

Zimmerman, R.C. 2003. A bio-optical model of irradiance distribution and photosynthesis in seagrass canopies. Limnol. Oceanogr. 48: 568-585.

Zimmerman, R. 2006. Chapter 13. Light and photosynthesis in seagrass meadows. In: A. Larkum, C. Duarte and R. Orth (Editors), Seagrasses: Biology, Ecology and Conservation. Springer, Dordrecht, pp. 303-321.

Zimmerman, R. and Dekker, A., 2006. Chapter 12. Aquatic optics: basic concepts for understanding how light affects seagrasses and makes them measurable from space. In: A. Larkum, R. Orth and C. Duarte (Editors), Seagrasses: Biology, Ecology and Conservation. Springer, Dordrecht, pp. 295-301.

Palacios, S.L. and **R.C. Zimmerman.** 2007. Eelgrass (Zostera marina L.) response to CO2 enrichment: possible impacts of climate change and potential for remediation of coastal habitats. Mar. Ecol. Prog. Ser. 344: 1 – 13. FEATURE ARTICLE

McPherson, M., **V. Hill, R. Zimmerman**, and H. Dierssen. 2011. The optical properties of Greater Florida Bay: implications for seagrass abundance. Estuaries and Coasts 34:1150-1160. FEATURE ARTICLE Coast and Estuarine Science News July 2011 (http://www.erf.org/cesn-list)

Victoria J. Hill, Ph.D. Biological Oceanography, Southampton Institute, U.K., 2002.

Research Asst. Professor, 2006-present, Dept. Ocean, Earth & Atmospheric Sciences, Old Dominion University

Expertise as related to the proposed research area: Dr. Hill is a recognized expert in marine optics, ocean color remote sensing, productivity of marine ecosystems and geospatial analysis.

Five relevant publications (of more than 15):

Hill, V. (2008) The Impacts of Chromophoric Dissolved Organic Material on Surface Ocean Heating in the Chukchi Sea. Journal Geophysical Research (113) doi:10.1029/2007JC004119

Hill, V, and R. Zimmerman. (2010). Estimates of primary production by remote sensing in the Arctic Ocean: Assessment of accuracy with passive and active sensors. Deep Sea Research (57):1243-1254.

V. Hill; P. Matrai; E. Olson; S. Suttle M. Steele; L. Codispoti; **R. Zimmerman** (2013). Synthesis of primary production in the Arctic Ocean: II. In situ and remotely sensed integrated estimates, 1999-2007. Progress in Oceanography (110) 107:125

P. A. Matrai, E. Olson. S. Suttles, **V. Hill**, L. A. Codispoti, B. Light, and M. Steele. (2013). Synthesis of primary production in the Arctic Ocean: I. Surface waters, 1954-2007. Progress in Oceanography (110) 93:106

Hill, V., R. Zimmerman, W. Bissett, H. Dierssen, and D. Kohler. 2014. Evaluating light availability, seagrass biomass and productivity using hyperspectral airborne remote sensing in Saint Joseph's Bay, Florida. Estuaries and Coasts In Press.

John M. Klinck, PhD, Marine Science, North Carolina State University, 1980. Professor, 1996-present, Department of Ocean, Earth and Atmospheric Sciences, Old Dominion University.

Expertise as related to the proposed research area: Dr. Klinck is a recognized expert in modeling of regional scale ocean circulation, primary production and ecosystems; bivalve physiology and genetics; larval physiology and transport in estuaries.

Five relevant publications (of more than 100):

Munroe, D.M**., J.M. Klinck**, E.E. Hofmann and E.N. Powell. 2013. A modeling study of the role of marine protected areas in metapopulation genetic connectivity in Delaware Bay oysters. *Aquatic Cons.*, doi: 10.1002/aqc.2400. online: 20 sept 2013.

Munroe, D.M., E.N. Powell, R. Mann, **J.M. Klinck**, and E.E. Hofmann. 2013. Underestimation of primary productivity on continental shelves: evidence from maximum size of extant surfclam (Spisula solidissima) populations. *Fisheries Oceanography*, 22, 220–233. doi:10.1111/fog.12016.

Soniat, T.M., **J.M. Klinck**, E.N. Powell, and E.E. Hofmann. 2012. Understanding the success and failure of oyster populations: Periodicities of *Perkinsus Marinus*, and oyster recruitment, mortality and size. *J. Shellfish. Res.*,31(3), 635-646.

Powell, E.N., **J.M. Klinck**, X. Guo, E.E. Hofmann, S.E. Ford and D. Bushek. 2012. Can oysters *Crassotrea virginica* develop resistance to dermo disease in the field: the impediment posed by climate cycles. *J. Mar. Res*., 70(2-3), 309-355.

Narvaez, D.A., **J.M. Klinck**, E.N. Powell, E.E. Hofmann, J. Wilkin, and D.B. Haidvogel. 2012. Circulation and behavior controls on dispersal of Easter Oyster (*Crassostrea virginica*) larvae in Delaware Bay. *J. Mar. Res*, 70(2-3), 411-467.

Michael S. Dinniman, M.S. Meteorology, University of Maryland, 1996.
Research Scientist, 1998-present, Center for Coastal Physical Oceanography, Old Dominion University

Expertise as related to the proposed research area: Mr. Dinniman is a recognized expert in coastal ocean circulation modeling and the effects of circulation on marine ecosystems.

Five relevant publications (of more than 22):

Crouch, J.R., Y. Shen, J.A. Austin, and **M.S. Dinniman**. (2008) An educational interactive numerical model of the Chesapeake Bay. Computers and Geosciences, 34, doi:10.1016/j.cageo.2007.03.017.

Dinniman, M.S., J.M. Klinck, and W.O. Smith, Jr. (2011) A model study of Circumpolar Deep Water on the West Antarctic Peninsula and Ross Sea continental shelves. Deep-Sea Research II, 58, 1508-1523, doi:10.1016/j.dsr2.2010.11.013.

Ashford, J., **M. Dinniman,** C. Brooks, A.H. Andrews, E. Hofmann, G. Cailliet, C. Jones, and N. Ramanna. (2012) Does large-scale circulation structure life history connectivity in Antarctic toothfish (*Dissostichus mawsoni*)? Canadian Journal of Fisheries and Aquatic Sciences, 69, 1903-1919, doi:10.1139/f2012-111.

Dinniman, M.S., J.M. Klinck, and E.E. Hofmann. (2012) Sensitivity of Circumpolar Deep Water transport and ice shelf basal melt along the west Antarctic Peninsula to changes in the winds. Journal of Climate, 25, 4799-4816, doi:10.1175/JCLI-D-11-00307.1.

Piñones, A., E.E. Hofmann, K.L. Daly, **M.S. Dinniman, and J.M. Klinck.** (2013) Modeling the remote and local connectivity of Antarctic krill (*Euphausia superba*) populations along the western Antarctic Peninsula. Marine Ecology Progress Series, 481, 69-92, doi:10.3354/meps10256.

Charles L. Gallegos, Ph.D. Environmental Science, University of Virginia, 1979
Microbial Ecologist, 1986-present, Smithsonian Environmental Research Center, Edgewater MD.

Expertise as related to the proposed research area: Dr. Gallegos is an internationally recognized expert in estuarine water quality and the bio-optical modeling of estuaries, photosynthesis of estuarine phytoplankton and the ecology of microbial food webs

Five relevant publications (of more than 60):

Gallegos, C.L., 2005. Optical water quality of a blackwater river estuary: the Lower St. Johns River, Florida, USA. Estuarine, Coastal and Shelf Science 63, 57-72.

Gallegos, C.L., Bergstrom, P.W., 2005. Effects of a Prorocentrum minimum bloom on light availability for and potential impacts on submersed aquatic vegetation in upper Chesapeake Bay. Harmful Algae 4, 553-574.

Gallegos, C. L., R. J. Davies-Colley, and M. Gall. 2008. Optical closure in lakes with contrasting extremes of reflectance. Limnol. Oceanogr. 53: 2021-2034, doi:: 10.4319/lo.2008.53.5.2021.

Biber, P. D., **C. L. Gallegos**, and W. J. Kenworthy. 2008. Calibration of a bio-optical model in the North River, NC: A tool to evaluate water quality impact on seagrasses. Estuaries and Coasts 31: 177-191, doi:10.2007/s12237-007-9023-6.

Kenworthy, W. J., **C. L. Gallegos**, C. Costello, D. Field, and G. Di Carlo. 2013. Dependence of eelgrass (*Zostera marina*) light requirements on sediment organic matter in Massachusetts coastal bays: implications for remediation and restoration Marine Pollution Bulletin in press, doi:10.1016/j.marpolbul.2013.11.006.

v) Funding Requested

Total Costs:	$112,567
Requested from EPA:	$ 73,333
ODU/ODURF Match	$ 39,234

vi) ODURF DUNS Number: 077945947

3. Work Plan

i)

This proposal specifically addresses Activity 1 identified in US EPA RFP EPA-R3-CBP-14-02. We propose to develop a coupled hydrodynamic/biogeochemical/bio-optical model relevant for simulating the concentrations of dissolved O_2, and optically active materials [i.e., Chlorophyll *a* (Chl *a*), total suspended matter (TSM) and colored dissolved organic matter (CDOM)] that attenuate light and control the distribution of submerged aquatic vegetation (SAV) in shallow regions of the Chesapeake Bay. The work proposed here, is stimulated by the fact that the current hydrodynamic model used for managing Chesapeake Bay water quality (CH3D) has reached the limits of its simulation ability (Friedrichs et al. 2012). Although it performs well in the main stem of the Bay, the grid structure of CH3D is too coarse to simulate the dynamics of small embayments and tributaries accurately, particularly in shallow waters (< 2 m depth) where virtually all of the submerged aquatic vegetation (SAV) resources reside. The effort proposed here will develop an appropriately scaled hydrodynamic simulation of shallow water environments based on the Regional Ocean Modeling System (ROMS, Haidvogel et al. 2008) integrated with a mechanistic state-of-the-art bio-optical model of radiative transfer in optically complex waters and SAV canopies to simulate the distribution of water quality, and its impacts on SAV resources in the Chesapeake Bay. A major focus of our effort will involve the determination of relevant spatial and temporal scales necessary to accurately model the shallow water dynamics and bio-optics of 2 to 3 sites identified by the CBP Modeling Workgroup. Results of the scaling analysis will be critical for informing options regarding the development of a baywide strategy to model these shallow water environments, including the linkage of a shallow water "ribbon" model to CH3D and/or the feasibility of developing a single hydrodynamic model that could simulate both the open and shallow waters of Chesapeake Bay.

Hydrodynamic Modeling - The team assembled here is particularly well qualified to perform the proposed model investigations. Dr. Klinck and Mr. Dinniman (both at ODU) have extensive experience simulating the hydrodynamics of coastal environments, at a variety of spatial scales using custom models of their own design, as well as community based, open source models of terrain following ocean circulation such as ROMS (Regional Ocean Modeling System). We have used the ROMS software to set up models of several regions around the Antarctic coast (Ross Sea, west side of the Antarctic Peninsula, Amundsen Sea) as well as a Southern Ocean model. In addition, we have developed a demonstration, interactive model of Chesapeake Bay as a tool for high school students to learn about estuarine circulation (Crouch et al. 2008) that is currently on display at the Virginia Aquarium and Marine Science Center. Finally, we have created a fine scale (10 m grid spacing) model to represent a thermal plume in the Calvert Cliffs area of the Chesapeake Bay in an oscillating tidal flow for use by a group at Virginia Tech to develop search algorithms for drones (Cannell et al. 2006; see also animation at http://www.ccpo.odu.edu/~msd/delta.sst.gif).

For this project, we will develop a demonstration setup using ROMS for a shallow area of Chesapeake Bay having a depth of a few meters (details below). The small model will be forced at the lateral boundaries and surface with conditions provided by the CBP Partnership's Phase 5.3.2 Chesapeake Bay Watershed Model and the 2010 versions of the CH3D Chesapeake Bay Hydrodynamic Model and the Chesapeake Bay Water Quality and Sediment Transport Model. We will also perform model simulations using nutrient and sediment pollutant reduction scenarios provided by the CBP partnership. Based on a small grid spacing to represent the sparse distribution of SAV, we will use a grid with a horizontal spacing of a few ten's of m to look at the effect of water depth and water clarity on the optical character of the water. Due to the shallow water and small grid spacing, the hydrodynamic simulation will require a short time step of a few seconds. Simulations over summer months for limited shallow water areas of the bay will allow us to demonstrate the benefit of this more comprehensive optical model.

The ROMS code allows specification of distributions of variables relevant for SAV (e.g., temperature, salinity, dissolved oxygen, water clarity, chlorophyll *a*, nutrients, total suspended solids, and colored dissolved organic matter) at the specific times and sites selected. These parameters will be provided as input for the existing SAV empirical model and for the more sophisticated bio-optical model of Zimmerman and Gallegos described below.

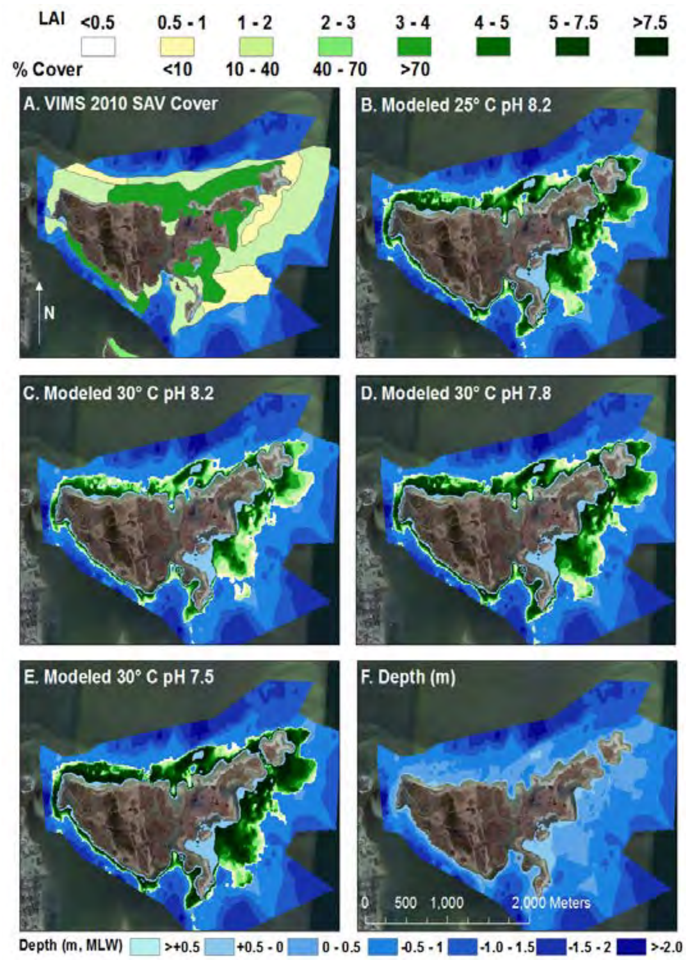

Figure 1. Maps of SAV cover at Goodwin Islands NERR in 2010 provided by the VIMS SAV project (A) and predicted by GL_2.11 for various climate scenarios (B – E). F. DEM based on our acoustic bathymetric survey used for the model calculations.

Bio-optical Modeling - Drs. Zimmerman, Hill and Gallegos have extensive experience modeling radiative transfer processes in optically complex environments relevant to the prediction of SAV abundance in the Chesapeake Bay. Zimmerman and Gallegos are the principal developers of the *GrassLight* software package (current version GL_2.11) that provides a state-of-the art 2-flow solution of the radiative transfer equation for complex submerged environments by integrating the water quality model of (Gallegos 1994, 2001) with the submerged plant canopy model of (Zimmerman 2003b, 2006) to provide mechanistically-based predictors of spectral light attenuation and SAV performance. Dr. Hill has been instrumental in developing innovative visualization schemes of GL_2.11 model results using GIS that illustrate the predicted distribution of SAV abundance across the submarine landscape.

The GL_2.11 software tool is written as a series of linked FORTRAN subroutines, facilitating its integration with the hydrodynamic models described above. GL_2.11 uses standard water quality measures to predict light-limited SAV density and productivity from bio-optical and physiological processes as a function of depth across the submarine landscape in response to water quality (e.g., Chl *a*, TSM, CDOM) and climate (e.g., temperature or ocean acidification). The *GrassLight* model accepts user inputs to simulate a wide variety of benthic substrates (e.g., mud, quartz sand, carbonate sand) and SAV forms, including *Ruppia maritima* (Widgeongrass), *Valsineria americana* (wild celery), *Zostera marina* (eelgrass) relevant to the Chesapeake Bay, as well as tropical species such as *Thalassia testudinum* (turtlegrass), *Halodule wrightii* (shoalgrass) and *Syringodium filiforme* (manatee grass). In addition to promising greater power in predicting SAV responses to the light environment than existing correlative approaches, our bio-optical model, based on the physics of radiative transfer and fundamental plant physiology, provides mechanistic insight into the processes that appear to yield different light requirements for seagrasses growing in different environments. The model accurately predicted the relative contributions of TSM and Chl *a* in regulating the light-limited density and distribution of eelgrass in Dumas Bay WA (Zimmerman 2003a) and tropical seagrasses in Florida Bay (McPherson et al. 2011).

More recently, we used this model to predict the impacts of climate warming and ocean acidification on the stable isotope composition and distribution of eelgrass at the Goodwin Islands NERR, at the mouth of the York River in Chesapeake Bay and in South Bay, a coastal lagoon on the DelMarVa peninsula (Zimmerman, Hill and Gallegos, in prep., McPherson et al. 2014). Visual inspection of the observed distribution of SAV in early summer 2010, before the onset of summertime temperature stress (Fig. 1A) showed good qualitative agreement with modeled eelgrass distribution for average WQ conditions, a cool summer climate (25° C, Fig. 1B), and average epiphyte loads. Both observed and predicted eelgrass densities were highest in the shallow, protected waters close to shore and declined rapidly to a maximum depth of ~1.25 m, although it was not possible to calculate precise levels of agreement between raster-based model predictions of shoot density and field observations limited to hand-drawn polygons of percent cover estimates provided by the VIMS SAV Monitoring Program (http://web.vims.edu/bio/sav/index.html). Modeling the effects of summertime thermal stress (30° C) reduced the simulated eelgrass abundance across the submarine landscape (Fig. 1C vs. Fig. 1B), and reduced the maximum colonization depth to less than 1 m, consistent with patterns of summertime dieback reported in the literature (Moore and Jarvis 2008). Simulating a warm climate with increased CO_2 availability associated with moderate ocean acidification (pH 7.8) predicted for 2050 yielded eelgrass distributions similar to those for populations unstressed by high summertime water temperature (Fig. 1D). Simulation of a warm climate and higher CO_2 concentrations associated with an ocean pH of 7.5 predicted for the year 2100 generated significant expansion of eelgrass density and increased the depth distribution to nearly 1.5 m, despite the warmer climate (Fig 1E). The Digital Elevation Model (DEM) used for mapping eelgrass distributions (Fig. 1F) was generated by interpolation of acoustic soundings taken across the study area, referenced to mean low water (MLW).

Fusion of the hydrodynamic and bio-optical subroutines will be accomplished using standard FORTRAN call statements and should be relatively straightforward. Variable arrays can be defined within the ROMS software to hold the needed parameters and variables. As indicated above, we have already successfully integrated the water column and seagrass canopy bio-optical models to ingest standard water quality data (e.g. turbidity, Chl *a*, CDOM), and can produce reasonably accurate predictions of eelgrass distribution/density across the submarine landscape from user-provided inputs of water quality (Chl *a*, TSM, CDOM), climate (temperature, pH/CO_2), and SAV morphology.

A key objective of the proposed work will be to determine the most reliable spatial and temporal scales for accurate simulation of shallow water hydrodynamics, radiative transfer and the biological responses to light availability in these shallow environments. For example, we currently possess the spatial and bathymetric information to generate a 10 m horizontal grid that should accurately represent the shallow water environment around the Goodwin Islands at the mouth of the York River (Fig 1F). However this grid structure would represent 50,000 to 90,000 horizontal grid points (depending on islands and shoreline). For comparison, the current CH3D model contains approximately 57,000 grid cells. Accurate representation of the hydrodynamics within this 10 m grid scheme will require a computational time step of a few sec. Accurately simulating the biological response to light availability in these turbid shallow environments (up to 2 m depth) will require a vertical resolution on the order of 0.1 m. In contrast, the time steps required to accurately simulate biological processes, particularly for SAV using GL_2.11, may be as long as 1 day if we impose a cloudless marine atmosphere and relatively constant water column optical properties (Gregg and Carder 1990, Gallegos 2001, Zimmerman 2003b). However, the interplay between hydrodynamics and water column optical properties, particularly diffuse attenuation (K_d) resulting from, e.g. tidally-driven fluctuations in sediment load and Chl *a* distribution, will require time steps considerably shorter than 1 day (but probably not 5 sec) to accurately resolve the vertical distribution of irradiance that controls biological production.

The hydrodynamic and bio-optical sub-models will be capable of operating on different time steps, allowing us to separately test the impact of temporal resolution on the physics and biology of these shallow water environments as we degrade the spatial and temporal resolution of our simulations. We will evaluate model performance by evaluating the health of the SAV at certain depths in comparison with presence/absence information about SAV in Chesapeake Bay. The effect of SAV on water quality can also be evaluated to see how these processes compare to observed values.

Site Selection – Although not specifically required by the RFP, we are pleased to suggest two sites as candidates for the shallow water monitoring analysis. The shallow water environment surrounding the Goodwin

Islands National Estuarine Research Reserve (NERR) at the mouth of the York River, represents a brackish water site with sandy sediments influenced by moderate wave exposure to the east. This historically important SAV habitat in the lower Chesapeake Bay has been impacted by eutrophication and summertime thermal stress (Moore et al. 1997, Moore and Jarvis 2008, Moore et al. 2012). Time series observations of SAV cover and water quality are available for this site from the CBNERRS and VIMS SAV websites. Further, we (Zimmerman, Hill & Gallegos) generated a high-resolution (2 m horizontal, 0.1 m vertical) DEM for this site in 2011 and 2012 using funding provided by Virginia Sea Grant and the National Science Foundation (Fig 1F). South Bay, a coastal lagoon on the DelMarVa peninsula represents a saltier, more oligotrophic candidate site. It is the site of a very successful eelgrass revegetation effort headed by R.J. Orth at VIMS (Orth et al. 2006). Water quality time series data relevant to our modeling efforts are available from researchers at VIMS (R.J. Orth & K. Moore, pers. comm.) and from the Virginia Coastal LTER program (A. Schwarzschild, pers. comm). Further, we (Zimmerman, Hill & Gallegos) generated a similar high-resolution DEM (2 m horizontal, 0.1 m vertical) for Hog Island, Spidercrab and South Bay region (not shown) from our Va Sea Grant and NSF-supported research that will be critical for defining shoreline and bathymetry for the modeling effort.

We recognize that bathymetric data with 10 cm vertical resolution is a rarity around Chesapeake Bay, which will not be remedied soon. As an interim measure to facilitate comparisons with other modeling approaches, we note that *GrassLight 2.11* can be used in a standalone mode to estimate the maximum depth of SAV survival at a given location under specified conditions of water quality and incident light. Note, however, that identical water quality does not imply identical light availability, because optical properties of suspended matter differs from place to place. For example, using concentration of Chl*a*=10 mg m^{-3} and TSM=8 g m^{-3}, the water quality optical model predicts that 22.5% of incident irradiance would be available at a depth of 1.7 m in Chincoteague Bay, compared with only 10.6% at the same depth in the Severn River, due to the aforementioned differences in optical properties of TSM. We have particulate inherent optical properties for parameterization of the water quality bio-optical model in the following 28 sites as well as the main stems of the Patuxent and Potomac Rivers (sorted N to S; not all are vegetated):

Gunpowder River	Southeast Creek	Miles River	St. Clement's Creek
Bird River	Magothy River	Tred Avon River	Wicomico River
Back River	Corsica River	Battle Creek	St. Mary's River
Jones Falls Creek	Severn River	St. Leonard's Creek	Manokin River
Gwynns Falls Creek	South River	Mill Creek	Big Annemessex
Curtis Creek	Wye River	Honga River	Chincoteague Bay
Langford Creek	Rhode River	Breton Bay	Goodwin Islands

ii) Budget – See SF424

Budget Justification:

PERSONNEL

Principal Investigator (Zimmerman) - Faculty salary for the Principal Investigator is based on a 9-month performance period. Amounts charged are calculated as follows: salary/9 = rate per month. Rate per month x number of months in semester x percent effort in semester = charge per period. Dr. Zimmerman's salary at the start of this project will be $148,951, and he will devote approximately 0.5 month of academic effort to this project each year as a match by the department of Ocean, Earth and Atmospheric Sciences. A 5% salary increase has been budgeted as of January 1st for each project year.

Co-Principal Investigator (Klinck) - Faculty salary for the Co-Principal Investigator is based on a 12-month performance period. Dr. Klinck's salary at the start of this project will be $122,187, and he will devote approximately 0.5 month of academic effort to this project each year as a match by the department of Ocean, Earth and Atmospheric Sciences. A 5% salary increase has been budgeted as of January 1st for each project year.

Co-Principal Investigators (Hill and Dinniman) – Salary for the Co-Principal Investigators Hill and Dinniman are based on a 12-month performance period. Funding for 1.6 months of effort each year is requested for each of these two Co-PIs. Victoria Hill's salary is budgeted at $62,558 at the start of this project. Michael Dinniman's salary is budgeted at $78,432 at the start of this project. A 5% salary increase is budgeted in the start of year 2.

FRINGE BENEFITS (ONR negotiated rate dated November 1, 2013)

Principal Investigator (Zimmerman) and Co-Principal Investigator (Klinck) - The fringe benefit rate applicable to university faculty academic salaries is 27% of the salary attributable to this project. This rate includes the university's contribution to the Virginia Supplemental Retirement System, FICA, health, life and disability insurance premiums, worker's compensation, unemployment insurance premiums, annual leave, and sick leave. The amount attributable to the in-kind devoted time is provided as a match for this project by the department of Ocean, Earth and Atmospheric Sciences.

Co-Principal Investigators (Hill and Dinniman) - FICA, worker’s compensation, unemployment insurance, health, dental, life and disability insurance premiums, annual and sick leave earnings, tuition reimbursement, and a fringe benefit contribution in lieu of retirement have been budgeted for this position in accordance with current Old Dominion University Research Foundation policies.

TRAVEL - The amount of $1,020 in year 1 and $1,000 in year 2 in domestic travel is requested to attend professional and research conferences to discuss and present results of this research. In addition, the amount of $1,000 in each year in domestic travel is provided as a match by the department of Ocean, Earth and Atmospheric Sciences.

SUPPLIES - Funds in the amount of $1,000 each year are provided as a match for research related materials and supplies by the department of Ocean, Earth and Atmospheric Sciences. This includes computational support and service contracts on servers, the high performance computer cluster maintained by CCPO and software license costs (FORTRAN, MatLab, ArcGIS, etc.).

CONTRACTUAL

Consultant Services – Because of Dr. Gallegos scheduled retirement from SERC, funds to support his participation in the project during Year 2 are requested as a direct contract to him, rather than through his former employer (SERC).

OTHER

Subcontract - We have requested funding in the amount of $3,892 to enter into a contractual agreement with the Smithsonian Environmental Research Center for Dr. Charles Gallegos in Year 1 to assist with integration of the water column component of the bio-optical model with the hydrodynamics.

INDIRECT COSTS - Our ONR negotiated agreement dated April 12, 2011, authorizes an on-campus indirect cost rate of 53% of modified total direct costs effective July 1, 2011, through June 30, 2014. Per the solicitation, only 10% of the MTDC has been requested.

The total cost share amount from Old Dominion University is $39,234, or 34.9% of the $112,568 total project costs.

SUBCONTRACT LETTERS OF COMMITMENT FROM SMITHSONIAN INSTITUTION and C.L. GALLEGOS

Smithsonian Institution

January 08, 2014

Ms. Stephanie Harris
Senior Grant and Contract Administrator - Sponsored Programs
Old Dominion University Research Center
P. O. Box 6369
Norfolk, Virginia 23508

Re: Letter of Intent to Collaborate on EPA Project entitled: "Light Attenuation Modeling for Multiple Shallow-water Systems Analysis for Chesapeake Bay Water Clarity"; SI Principal Investigator: Dr. Charles Gallegos; SI Tax ID # 53-020-6027; DUNS # 08-952-2580; CAGE # 3MXA0

Dear Ms. Harris:

The purpose of this letter is to confirm the intent of Dr. Charles Gallegos Principal Investigator at the Smithsonian Environmental Research Center to collaborate with Old Dominion University Research Foundation in the aforementioned research proposal to the U. S. Environmental Protection Agency (EPA). This collaboration will take the form of a one-year sub-award from the Foundation to the Smithsonian Institution in the total amount of $3,892. A scope of work, budget and budget justification are enclosed. Also attached please find the completed ODURF Sub-recipient checklist/statement and SF-424A budget forms & the Smithsonian current indirect cost rate agreement.

Should EPA decide to fund this proposal, the Smithsonian would expect an agreement with cost principles applicable to a non-profit organization. The Smithsonian will ensure compliance with all pertinent sponsor regulations and policies. Please forward all award documents to one of the following addresses:

For regular mail:
Smithsonian Institution
Office of Sponsored Projects
Attn: J. Scott Robinson
PO Box 37012, MRC 1205
Washington, DC 20013-7012

For FedEx, UPS, or other courier:
Smithsonian Institution
Office of Sponsored Projects
Attn: J. Scott Robinson
2011 Crystal Drive, Suite 352
Arlington, VA 22202

Administrative or business questions should be directed to Violet Jones-Bruce of this office at 202.633.7098 or violet@si.edu. Questions of a programmatic or technical nature may be addressed to Dr. Charles Gallegos at 443.482.2240 or gallegosc@si.edu. We look forward to working with you on this important project.

Sincerely,

[signature] for

J. Scott Robinson, CRA
Director

Enclosures
cc: Dr. Charles Gallegos

Office of Sponsored Projects
PO Box 37012, MRC 1205
Washington, DC 20013-7012
Email.ospmail@si.edu – ph.202/633-7110

Charles L. Gallegos, Ph.D.
2702 Windswept Lane
Annapolis, Maryland 21401

January 7, 2014

Dr. Richard C. Zimmerman
Bio-Optical Research Group
Department of Ocean, Earth and Atmospheric Sciences
4600 Elkhorn Ave.
Old Dominion University
Norfolk, VA 23529

Dear Dr. Zimmerman,

I will be pleased to be involved as an independent consultant in the second year of your project to model light attenuation and submerged aquatic vegetation in shallow water regions of Chesapeake Bay and the Delmarva Coastal Bays.

The period for year 2 will be March 24, 2015 to March 23, 2016. During that time I will:

- Evaluate output of the Regional Ocean Modeling System (ROMS) model related to prediction of the light attenuation spectrum
- Suggest modifications to the ROMS model and parameterization to improve model fidelity with measured data
- Assist with comparison of model output with alternative approaches
- Attend meetings in Annapolis, Maryland, to discuss project plans and progress
- Contribute material to reports related to results from the light attenuation sub-model

During that period, I will devote 64 hours to project tasks, at a rate of $78 per hour.

I look forward to collaborating on this project, and hope your team is successful at the proposal stage.

Sincerely,

Charles L. Gallegos

Charles L. Gallegos, Ph. D.

iii) Environmental Results – Outputs and Outcomes

1) *Output*: The modeling efforts proposed here will demonstrate the utility of coupled hydrodynamic/bio-optical models to predict the dynamics of O_2, water transparency and SAV resources in shallow regions of the Chesapeake Bay. We will identify and quantify critical modeling features, particularly spatial and temporal resolution, necessary to accurately simulate the dynamics of water quality and its impact on SAV resources in shallow regions of the Chesapeake Bay. All model code and simulation results will be provided to the larger CBP partnership in support of Activity 2 defined in this RFP.

2) *Outcome*: Our successful modeling efforts will improve the ability to predict water quality impacts on shallow water environments of the Chesapeake Bay, and lead to more enlightened strategies for managing and monitoring the health of shallow water ecosystems in the Chesapeake Bay. In collaboration with other teams participating in Activities 1 and 2 under this RFP, we will help to provide a robust skill assessment of various modeling approaches, at different scales, that will inform management about the utility of existing models for predicting the behavior of shallow water environments and provide a path toward the development of an integrated modeling effort, including the use of multiple models, to ultimately develop a reliable management tool for the Chesapeake Bay.

iv) Review Criteria

1) **Organizational Capability and Program Description:** The PIs are internationally recognized scientists with particular expertise in the modeling of coastal hydrodynamics (Klinck, Dinniman), and aquatic bio-optics that include both phytoplankton and submerged aquatic macrophytes (Zimmerman, Hill, Gallegos). Co-PIs Zimmerman and Klinck are state-supported tenured faculty at ODU; a portion of their state-supported salaries will be provided in support of the required matching contribution. Co-PIs Hill and Dinniman are soft money research faculty at ODU, and work in close collaboration with Zimmerman and Klinck. Co-PI Gallegos, a full time research scientist at the Smithsonian Environmental Research Center, will be retiring from active federal service in August 2014. Funds to support their contributions to the proposed effort are requested in the budget. All commercial software packages, including FORTRAN compilers, computational and graphical software (e.g. MatLab, Excel, SigmaPlot) and geospatial visualization software (ENVI, ArcGIS) are available in the PI's laboratories. Co-PIs Zimmerman and Gallegos created the *GrassLight* bio-optical model, and provide it to the research community free of charge as an open source package, with all subroutines written in FORTRAN.

2) **Programmatic Capability and Environmental Results Past Performance:**
a &b) Past performance & progress in achieving expected results: All PI's have successfully completed federally and non-federally funded research grants/contracts with numerous agencies, but particularly with NSF, NASA, NOAA (including Virginia Sea Grant) and ONR. The combined team has received more than $15 M in extramural research support and published more than 250 (in total) peer-reviewed articles , book chapters and technical reports during their careers. Co-PIs Zimmerman and Hill are currently supported by the National Science Foundation (OCE 1061823, PLR 1203784) and Virginia Sea Grant. Co-PIs Klinck and Dinniman are currently supported by National Science Foundation (ANT-0944223, CNH-0908939, OCE-0927797, Ant-0944174, AGS-1048989). None of the ODU PIs have received prior support from EPA. Co-PI Gallegos is currently supported by NOAA, and was supported in the past by EPA:

2003-2006: A shallow-water coastal habitat model for regional scale evaluation of management decisions in the Chesapeake region. US Environmental Protection Agency Science to Achieve Results (STAR, RD8308701), $748,749 (Lead PI with D. Weller, T. Jordan, P. Neale, and P. Megonigal)

2001-2005:Development of an optical indicator of habitat suitability for submersed aquatic vegetation for the Atlantic Slope—sub-proposal of the Atlantic Slope Consortium, 'Development, testing, and application of indicators for integrated assessment of ecological and socioeconomic resources of the Atlantic Slope in the Mid-Atlantic States' (with D. Whigham, A. Hines, T. Jordan, P. Marra, and D. Weller). Environmental Protection Agency, Estuary and Great Lakes Environmental Indicators (EAGLes), $3,900,000 (total to SERC).

1998–2002: CISNet Rhode River: Estuarine optical properties as an integrative response to natural and anthropogenic stressors (Lead PI with T. Jordan and P. Neale). Environmental Protection Agency, R826943, $510,181.

All completed projects by all PIs were finished in a timely fashion, all required meetings were attended, all reports and publications and other deliverables, including data, were provided on time. All currently active projects are on schedule.

c) Demonstrated programmatic skill and experience: Co-PIs Klinck and Dinniman have extensive experience modeling the hydrodynamics of coastal environments. We have constructed a number of circulation models for Antarctic coastal areas (Dinniman et al. 2012) and Chesapeake Bay (Crouch et al. 2008) as well as a high resolution (10 km grid) model for a thermal plume in Chesapeake Bay (Cannell et al. 2006). In addition, Klinck has extensive experience with biological processes in circulation models (Narvaez et al. 2012). Co-PI Gallegos was instrumental in developing water quality threshold criteria currently used by the Chesapeake Bay Program, as well as Maryland and Virginia state agencies for establishing water clarity criteria for SAV in the Chesapeake Bay (Gallegos 1994, 2001). Co-PI Zimmerman originally developed the *GrassLight* radiative transfer model for submerged aquatic vegetation (Zimmerman 2003b, 2006), and recently collaborated with Gallegos in merging their models into GL_2.11 (described above), which is capable of directly modeling water quality impacts on radiative transfer and seagrass dynamics from first principles of physics and biology. Co-PI Hill provides critical expertise in the bio-optics of coastal environments and visualization of modeling results using GIS software.

3) **Cost-effectiveness:** The federally-negotiated indirect cost rate for ODURF is currently 53% of Modified Total Direct costs, but the institution has agreed to administer this award at 10%, pursuant to the requirements of the RFP. Further, the contributions of PI salaries and fringe benefit costs (Zimmerman and Klinck) miscellaneous supplies and some travel support in pursuit of these efforts constitute an institutional match of 30.8% of the total project costs, significantly exceeding the 5% match requirement specified in the RFP.
4) **Transferability of Results to Similar Projects and/or Dissemination to the Public:** a - c. All model code and simulation results will be shared directly with the larger CBP partnership. The hydrodynamic models to be employed here are currently in the public domain (e.g. ROMS). Zimmerman and Gallegos own the copyright for *GrassLight* but make the code, as well as compiled versions of the software, freely available at no cost to all interested parties, including members of the larger CBP community. GL_2.11, including all source code, required input files and User Manual is currently available for download on DropBox; access simply requires making the request of Zimmerman and/or Gallegos via e-mail.
5) **Modernization of Methods over Time:** The coupled hydrodynamic/bio-optical model environment created by this team is based on fundamental physical and physiological processes that can be updated through time as information and new algorithms become available, new forcing variables or different levels of spatial resolution or temporal integration are requested or required. The models can simulate a wide variety of conditions at present simply by modifying user-input parameters, but they can also be easily re-configured to automate solution of specific problems or hard-wired to simulate specific environments.
6) **Timely expenditure of Grant Funds:** The PIs are committed to performing the tasks proposed here within the 2-year time frame of the project. The majority of support requested her is for support of the soft-money PIs (Hill, Dinniman and Gallegos) and will be spent in a timely fashion in support of their efforts.

Literature Cited

Cannell, C.J., A.S. Gadre, and D.J. Stilwell. 2006. Boundary tracking and rapid mapping of a thermal plume using an autonomous vehicle. OCEANS 2006, doi:10.1109/OCEANS.2006.306807.

Crouch, J.R., Y. Shen, J.A. Austin, and **M.S. Dinniman.** 2008. An educational interactive numerical model of the Chesapeake Bay. Computers and Geosciences, 34, doi:10.1016/j.cageo.2007.03.017.

Dinniman, M.S., J.M. Klinck, and E.E. Hofmann. 2012. Sensitivity of Circumpolar Deep Water transport and ice shelf basal melt along the west Antarctic Peninsula to changes in the winds. Journal of Climate, 25, 4799-4816, doi:10.1175/JCLI-D-11-00307.1.

Friedrichs, M., K. Sellner, and M. Johnston. 2012. Using multiple models for management in the Chesapeake Bay: A shallow water pilot project., Edgewater MD.

Gallegos, C. 1994. Refining habitat requirements of submersed aquatic vegetation: role of optical models. Estuaries **17**:187-199.

Gallegos, C. 2001. Calculating optical water quality targets to restore and protect submersed aquatic vegetation: overcoming problems in partitioning the diffuse attenuation coefficient for photosynthetically active radiation. Estuaries **24**:381-397.

Gregg, W. and K. Carder. 1990. A simple spectral solar irradiance model for cloudless maritime atmospheres. Limnol. Oceanogr. **35**:1657-1675.

Haidvogel, D.B., Arango, H., Budgell, W.P., Cornuelle, B.D., Curchitser, E., Di Lorenzo, E., Fennel, K., Geyer, W.R., Hermann, A.M., Lanerolle, L., Levin, J., McWilliams, J.C., Miller, A.J., Moore, A.M., Powell, T.M., Shchepetkin, A.F., Sherwood, C.R., Signell, R.P., Warner, J.C., Wilkin, J., 2008. Ocean forecasting in terrain-following coordinates: formulation and skill assessment of the Regional Ocean Modeling System. Journal of Computational Physics, 227, 3595-3624, doi:10.1016/j.jcp.2007.06.016.

McPherson, M., **V. Hill, R. Zimmerman**, and H. Dierssen. 2011. The optical properties of Greater Florida Bay: implications for seagrass abundance. Estuaries and Coasts **34**:1150-1160.

McPherson, M., **R. Zimmerman, and V. Hill**. 2014. Environmental and physiological influences on productivity and carbon isotope discrimination in eelgrass (*Zistera marina* L.). Limnol. Oceanogr. **In Revision**.

Moore, K. and J. Jarvis. 2008. Environmental factors affecting summertime eelgrass diebacks in the lower Chesapeake Bay: implications for long-term persistence J. Coast. Res. **55**:135-147.

Moore, K., E. Shields, D. Parrish, and R. Orth. 2012. Eelgrass survival in two contrasting systems: role of turbidity and summer water temperatures. Mar. Ecol. Prog. Ser. **448**:247-258.

Moore, K. A., R. L. Wetzel, and R. J. Orth. 1997. Seasonal pulses of turbidity and their relations to eelgrass (*Zostera marina* L.) survival in an estuary. J. Exp. Mar. Biol. Ecol. **215**:115-134.

Narvaez, D.A., **J.M. Klinck**, E.N. Powell, E.E. Hofmann, J. Wilkin, and D.B. Haidvogel. 2012. Circulation and behavior controls on dispersal of Easter Oyster (*Crassostrea virginica*) larvae in Delaware Bay. *J. Mar. Res*, 70(2-3), 411-467.

Orth, R., M. Luckenback, S. Marion, K. Moore, and D. Wilcox. 2006. Seagrass recovery in the Delmarva Coastal Bays, USA. Aquat. Bot. **84**:26-36.

Zimmerman, R. 2003a. Appendix M. Final Report. A bio-physical model evaluation of eelgrass distribution and habitat potential in Dumas Bay, WA. In H.D. Berry, A.T. Sewell, S. Wyllie-Echeverria, B.R. Reeves, T.F. Mumford, J.R. Skalski, R.C. Zimmerman, J. Archer. Puget Sound Submerged Vegetation Monitoring Project: 2000 - 2003 Monitoring Report. Nearshore Habitat Program, Washington State Department of Resources, Olympia, WA.

Zimmerman, R. 2003b. A biooptical model of irradiance distribution and photosynthesis in seagrass canopies. Limnol. Oceanogr. **48**:568-585.

Zimmerman, R. 2006. Chapter 13. Light and photosynthesis in seagrass meadows. Pages 303-321 *in* A. Larkum, R. Orth, and C. Duarte, editors. Seagrasses: Biology, Ecology and Conservation. Springer, Dordrecht.