Final performance report: Connecting global HYCOM to FLEAT

Award Number: N00014-17-1-2958

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MAJOR GOALS

The objectives of this research are to better integrate global simulations of the HYbrid Coordinate Ocean Model (HYCOM) with another Office of Naval Research (ONR)-funded effort, the FLow Encountering Abrupt Topography (FLEAT) Directed Research Initiative (DRI). The PI, Brian Arbic, proposed to achieve this integration in three ways:

First, the funding requested here allowed Arbic to attend FLEAT project meetings and collaborate with FLEAT project scientists. Arbic leveraged FLEAT-relevant HYCOM simulations that had already been performed by Arbic's former postdoc, Dr. David Trossman (now a scientist at The University of Texas at Austin). Trossman's HYCOM simulations were performed without tides, and were done with an inline insertion of parameterized internal lee wave drag. These HYCOM simulations are therefore relevant to the FLEAT project goal of understanding the impact of topography upon the low-frequency oceanic general circulation.

Second, the supplemental funding requested here allowed Arbic's (now former) graduate student, Conrad Luecke, to participate in the FLEAT project. Luecke's first five years as a PhD student were primarily supported by previous ONR grants, and he wrote his PhD, which he defended in September 2017, primarily on our HYCOM tidal simulations. However, Luecke had a significant interest in observational physical oceanography, and was therefore a perfect student to participate in FLEAT. Luecke went on one of the 2017 FLEAT cruises, and based himself at Scripps during the 2017-2018 academic year, his last as a PhD student., while Arbic was on a sabbatical in France. While at Scripps, Leucke was supported by FLEAT funding and worked on a paper analyzing FLEAT data to complete his PhD work dissertation. Luecke began a postdoc at NRLSSC in April 2019, working on the MISO-BOB project with Hemantha Wijesekera.

Third, together with other FLEAT-funded colleagues, Arbic led a paper on connecting global models such as HYCOM with process models of topographic wave drag. This paper appeared in a special issue of *Oceanography* magazine on the FLEAT project. Arbic helped with, and was a co-author on, the Johnston et al. (2019) summary article in the *Oceanography* FLEAT special issue.

OBJECTIVES

The objectives of this project were to (1) present global HYCOM simulations at FLEAT meetings, as a way of reminding everyone that the flow-topography interactions under study in FLEAT are important for global models, (2) integrate Conrad Luecke into the FLEAT project so that he could write a paper on analysis of FLEAT data as part of his PhD thesis, and (3) prepare articles for the FLEAT special issue of *Oceanography* magazine.

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
17-06-2020	Final Technical Report	9/1/2017-1/31/2020

4. TITLE AND SUBTITLE	
Connecting global HYCOM to FLEAT	**5a. CONTRACT NUMBER**
	5b. GRANT NUMBER N00014-17-1-2958
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Arbic, Brian K.	**5d. PROJECT NUMBER**
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	**8. PERFORMING ORGANIZATION REPORT NUMBER**
REGENTS OF THE UNIVERSITY OF MICHIG UNIVERSITY OF MICHIGAN 503 THOMPSON ST ANN ARBOR MI 48109-1340	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	**10. SPONSOR/MONITOR'S ACRONYM(S)**
ONR REG OFFICE CHICAGO 230 SOUTH DEARBORN CHICAGO, IL 60604-1595	ONR
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for Public Release; Distribution is Unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
This project allowed us to attend FLEAT meetings and present our Navy HYCOM simulations with parameterized topographic wave drag, which demonstrate that the flow-topography interactions of interest in the FLEAT DRI are of direct relevance to US Navy operational modeling. Funds from this grant also supported the last year of Conrad Luecke's PhD work. Luecke is currently writing up a paper on analysis of some FLEAT data, while he works as a postdoc at the US Naval Research Laboratory. Finally, Arbic wrote an article for the FLEAT special issue of Oceanography (Arbic et al. 2019), on the importance of wave drag in models, and helped with the Johnston et al. (2019) FLEAT summary article.

15. SUBJECT TERMS
Ocean modelling
Topography

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			Brian K. Arbic
Unclassified	Unclassified	Unclassifie d	SAR		**19b. TELEPHONE NUMBER** *(Include area code)* 734-763-2087

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

APPROACH

Global HYCOM simulations without tides but with a parameterized internal lee wave drag acting on mesoscale eddy flows were performed by Trossman et al. (2013, 2016, 2017). Trossman showed that the wave drag impacts the model energy budget to first order—i.e., that the wave drag dissipates a substantial fraction of the wind-energy input to the low-frequency eddying general circulation. Because Trossman's simulations used an inline wave drag, he was able to examine the impacts of the wave drag on the modeled oceanic flows. This is in contrast to some previous studies (Nikurashin and Ferrari 2011, Scott et al. 2011) performed with an offline analysis using output from a model that did not contain wave drag as it ran. Trossman showed that the wave drag impacts the modeled stratification in the abyss, the near-bottom kinetic energy. Less profound, but still measurable, effects were found on sea surface height variance and surface kinetic energy. Along with several FLEAT-supported colleagues, Arbic wrote an article for the FLEAT special issue of *Oceanography* (Arbic et al. 2019), on the importance of wave drag in models and on continuing efforts (by the co-authors) to improve understanding of flows over topography through process studies which can feed into improved parameterizations used in global models such as HYCOM. Arbic also helped with, and was a co-author on, the summary article of the special issue (Johnston et al. 2019).

In a separate thread, graduate student Conrad Luecke analyzed FLEAT thermistor data, under the supervision of Professors Matthew Alford and Jennifer MacKinnon of Scripps Institution of Oceanography, and Professor Jonathan Nash of Oregon State University.

The individuals involved in this research at the University of Michigan are given below.

--Brian K. Arbic was the PI of this grant. Arbic was the supervisor of David Trossman, who wrote the papers Trossman et al. (2013, 2016, 2017) described above, and of Conrad Luecke.

--Conrad Luecke was a graduate student whose final year of dissertation research was supported by this grant. Luecke spent the final year of his PhD studies at Scripps Institution of Oceanography (University of California San Diego), working on analysis of FLEAT thermistor data. Conrad completed his PhD in September 2018, and is now a postdoc at NRLSSC.

WORK COMPLETED

The Trossman et al. (2013, 2016, 2017) papers were published before this grant started.

The grant supported the final year of Luecke's PhD. Luecke acknowledged this grant in his second thesis paper, Luecke et al. (2020a), on the comparison of high-resolution global simulations of HYCOM and Massachusetts Institute of Technology general circulation model (MITgcm) with historical moored temperature and velocity records. Luecke was supported primarily by this grant as he started to write up a third thesis paper (Luecke et al. 2020b) on analysis of FLEAT thermistor data. He will submit this paper shortly, as he works as a postdoc at NRL Stennis.

ACCOMPLISHMENTS (RESULTS)

Table 1, from Trossman et al. (2016), shows that both wave drag and bottom drag substantially impact the energy budgets in 1/12° and 1/25° HYCOM. Figure 1 (Figure 2 of Trossman et al. 2016) displays the wave drag energy dissipation in the model in four field campaign regions. The FLEAT region, shown in the upper left, is a region of significant wave drag dissipation. Table 2, from Trossman et al. (2016), shows that sea surface height variance and surface kinetic energy are reduced measurably with the introduction of wave drag, but not by as much as the near-bottom kinetic energy is. Table 3, taken from Trossman et al. (2017), demonstrates that introduction of wave drag yields an eddy baroclinicity, as measured by the ratio of eddy kinetic energy in the upper 100 meters and eddy kinetic energy in the bottom 500 meters, that is nearly equal to the baroclinicity induced by increasing the quadratic bottom drag coefficient by a factor of 100.

Figure 2 displays the frequency spectra of chi_T, the destruction of thermal variance, as a function of depth, computed from FLEAT thermistor data for a paper in preparation by Conrad Luecke (Luecke et al. 2020b). Most of the variance lies between the Coriolis frequency f and the buoyancy frequency N, as expected from the linear theory of internal gravity waves, whose breaking is hypothesized to underlie the dissipation seen in the figure.

Table 1

The globally integrated energy dissipation rate [TW = 10^{12}W] due to quadratic bottom boundary layer drag (BD) and parameterized topographic internal lee wave drag (WD) from the final year of climatologically forced HYCOM simulations. The simulations are run with and without wave drag at both 1/12° and 1/25° resolutions.

Wave Drag?	Resolution	Year	BD	WD
No	1/12°	14	0.31	N/A
Yes	1/12°	20	0.14	0.40
No	1/25°	13	0.34	N/A
Yes	1/25°	17	0.17	0.42

Table 2

The area-averaged values without wave drag (no WD) and with wave drag (WD) as well as the percent differences [in brackets] with the addition of wave drag for several diagnostics: sea surface height variance (SSH var.), geostrophic surface kinetic energy (SKE), and kinetic energy in the bottom 500 m (KE_{bot500}). At each resolution, the percent difference is computed as the area-averaged diagnostic with wave drag minus that without wave drag and divided by the area-averaged diagnostic without wave drag. Negative values imply a decrease in the diagnostic, on global average, upon insertion of wave drag.

diagnostic	units	1/12° (no WD, WD) [percent]	1/25° (no WD, WD) [percent]
SSH var.	m^2	(0.0077, 0.0059) (−23.4%)	(0.0083, 0.0068) (−18.1%)
SKE	$m^2 s^{-2}$	(0.0067, 0.0057) (−14.9%)	(0.0075, 0.0063) (−16.0%)
KE_{bot500}	$m^2 s^{-2}$	(0.0094, 0.0076) (−19.1%)	(0.019, 0.0077) (−59.1%)

TABLE 3. The ratio of the total KE in the top 100 m (KE_{top100}) to total KE in the bottom 500 m (KE_{bot500}) from the regional 1/12° HYCOM and global 1/25° HYCOM simulations. Grid points within 30 indices of the coasts were excluded from this calculation due to the occurrence of infinitesimal layer thicknesses. The asterisk (*) indicates that KE_{top100} was not saved; instead, the geostrophic SKE is used.

Global/regional	Wave drag?	C_d	KE_{top100}/KE_{bot500}
Regional	No	2.5×10^{-3}	18.5
Regional	No	5.0×10^{-4}	3.51
Global	No	2.5×10^{-3}	16.1
Global	No	2.5×10^{-1}	41.8
Global	Yes	2.5×10^{-3}	51.1*

D.S. Trossman et al./ Ocean Modelling 97 (2016) 109–128 113

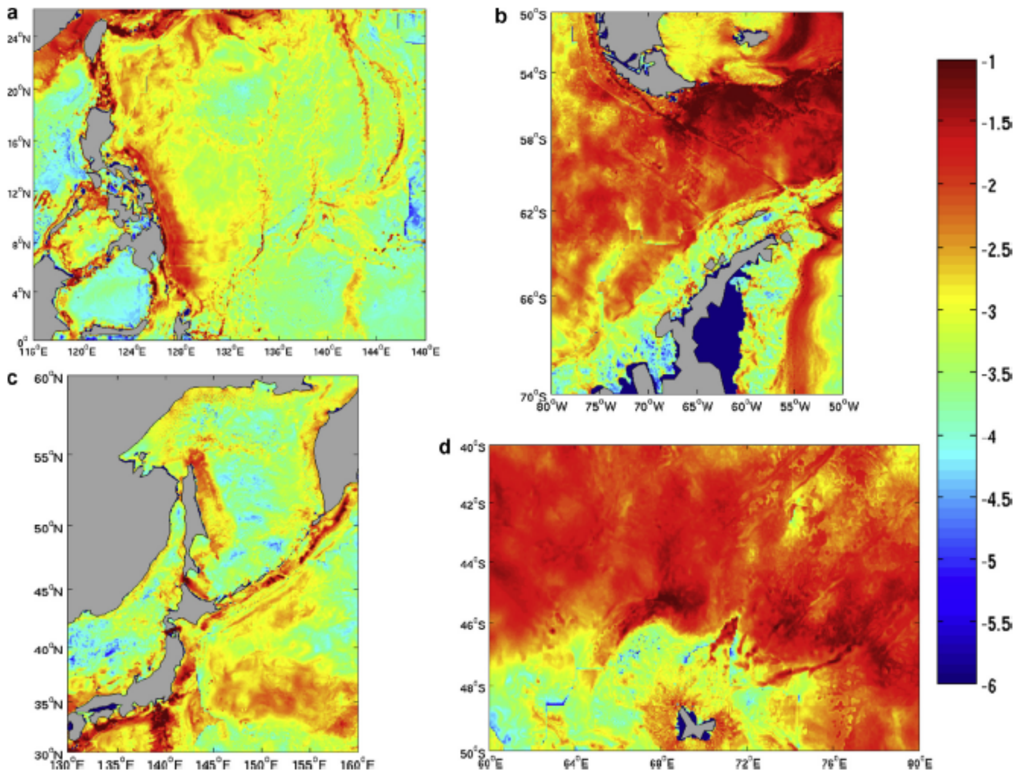

Fig. 2. The base 10 logarithm of the energy dissipation (units in W m^{-2}) associated with wave drag in the (a) FLEAT (FLow Encountering Abrupt Topography), (b) DIMES (Diapycnal and Isopycnal Mixing Experiment in the Southern Ocean), (c) KESS (Kuroshio Extension Study System), and (d) SOFine (Southern Ocean Finestructure) observational campaign regions in the 1/25° HYCOM simulation. An average over the final year of the model simulations has been performed. Seams visible in some regions separate abyssal hill regions, where the abyssal hill power spectrum of Goff and Jordan (1988), Goff (2010), and Goff and Arbic (2010) was used, from non-abyssal hill regions where a machine learning algorithm was used-see Trossman et al. (2013) for details.

Figure 1. Wave drag dissipation in four field campaign regions, in HYCOM simulations with wave drag. From Trossman et al. (2016). FLEAT region is shown in upper left.

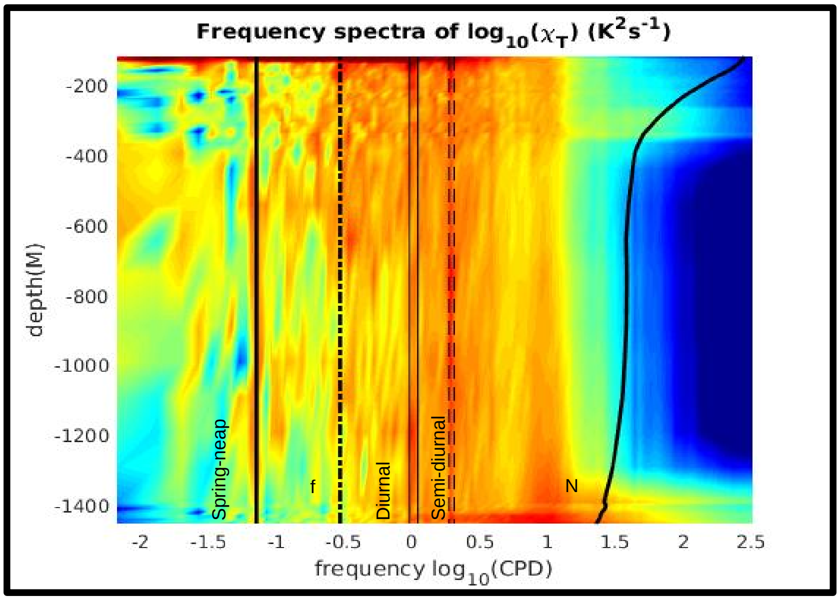

Figure 2. Frequency spectra of temperature variance destruction, chi_T, computed from FLEAT thermistor data, as a function of depth. From a paper in preparation by Conrad Luecke (Luecke et al. 2020b).

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TRAINING
Graduate student Conrad Luecke went on a research cruise, and completed the final year of his PhD, with the support of this award.

DISSEMINATION
The results presented here were published in scientific journals and communicated in project meetings and scientific conferences.

PLANS
Luecke plans to submit Luecke et al. (2020b), the final chapter of his dissertation, shortly.

HONORS
None.

TECHNOLOGY TRANSFER
None.

IMPACT/APPLICATIONS

Trossman's results show that parameterizations of flow-topography interactions impact global simulations of the HYbrid Coordinate Ocean Model that is being used as the dynamical core of the US Navy ocean forecasting system.

RELATED PROJECTS

Arbic has worked with the global HYCOM team for many years on HYCOM simulations with embedded tides.

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