

Develop and Test Coupled Physical Parameterizations and Tripolar Wave Model Grid: NAVGEM / WaveWatch III / HYCOM

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LONG-TERM GOALS

An efficient global atmosphere-ocean-wave coupled modeling system which utilizes the best, current knowledge of physics, particularly for fluxes at the sea surface.

OBJECTIVES

The specific objectives are to implement and test the following:

1. Wave forcing from WAVEWATCH III in HYCOM
2. NAVGEM- WAVEWATCH III -HYCOM coupling
3. Global tri-pole grid in WAVEWATCH III

KEY PERSONNEL

In addition to the PIs given above, the following persons contributed to this project during FY13:

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APPROACH

1. Implementation and testing of wave forcing from WW3 (WAVEWATCH III[®], Tolman 1991, Tolman et al. 2002, Tolman 2009) in HYCOM (Hybrid Coordinate Ocean Model, Bleck 2002).

Task 1a. Under the 6.2 project “Coupled Air-Ocean-Wave Prediction System”, wave forcing was added to NCOM (Navy Coastal Ocean Model, Martin 2000). Using NCOM as a guide, wave forcing is implemented in HYCOM in this project. In particular, this involves the following tasks. (a) Add the capability to read in to HYCOM from disk the following wave input fields: Stokes drift current (SDC), wave-to-ocean momentum flux (WOMF), bottom orbital wave current (OWC). (b) Add SDC terms to the model equations. (c) Apply WOMF as an additional surface stress. (d) Enhance shallow water bottom drag using OWC. (e) Extend the ESMF (Earth System Modeling Framework) layer in HYCOM to import SDC, WOMF and OWC fields and export SSC (surface current) and SSH (surface height) fields. (f) Setup and run regional and global test cases demonstrating these new capabilities. Testing may be performed on a regional model.

Task 1b. During FY13-16, the surface wave radiation stress gradients (WRSG) method of representing the excess wave-to-ocean momentum flux (WOMF) in COAMPS (Coupled Ocean/Atmosphere Mesoscale Prediction System, Hodur 1997) will be replaced by a physically consistent alternative method, constructed in term of momentum budgets (MB) of the wave, atmosphere and ocean models. The R&D components of this effort will be supported by 6.2 NRL Core during FY14-16. Technical tasking associated with the new method will be conducted in FY13 via this ESPC (Earth System Prediction Capability) 6.4 component, such that the coupling methodology for WW3-to-HYCOM interactions is consistent with the new MB method, allowing 6.2 development to progress directly into the experimental global system during FY14-16. During FY13, a low-order implementation of the new method will be demonstrated using SWAN (Simulating Waves Nearshore, Booij et al. 1999) - NCOM coupling, and subsequently WW3-HYCOM coupling. In addition to streamlining the 6.2 to 6.4 pathways, by taking this approach we also avoid unnecessary testing of WW3-HYCOM coupling using the obsolescent WRSG method. The demonstration will be done by file transfer in FY13 and via coupler in FY14.

2. Implementation and testing of NAVGEM-WW3-HYCOM coupling.

Though it is understood that engineering shortcuts are sometimes required (e.g. the existing one-way coupling of NOGAPS/WW3 and NOGAPS/HYCOM), the starting point for ESPC coupling will be a consistent accounting of momentum fluxes between models. To this end, we will implement in NAVGEM (Navy Global Environmental Model, Pauley et al. 2013) the option to use a revised surface drag calculation which is forced to be (in the mean) consistent with the empirical drag estimates presently used for surface forcing of WW3 and HYCOM. Simultaneously, WW3 and HYCOM will be operated such that surface stresses are directly ingested, with these stresses being consistent with NAVGEM and the new WOMF approach. This will be tested and recommendations will be made

regarding whether to utilize this more physically consistent approach in the ESPC coupled system. This will be done via file transfer by Q2 FY14 and via coupler by Q2 FY15.

3. Implement global tri-pole grid in WAVEWATCH III

A global tri-pole grid will be implemented in WAVEWATCH III (WW3). Current WW3 supports curvilinear grids and a global grid with the usual periodicity along the i-index. In addition to the i-index periodicity, the global tri-pole grid includes an “arctic seam”, that is, a wrapping of the grid in the j-index in the arctic region. Implementation of a global tri-pole grid in WW3 involves accounting for this “arctic seam” in the spatial propagation of wave energy. Setup and run a lower horizontal resolution global test case demonstrating this new capability.

Scaling of WW3 will be poor for any global grid with resolution much higher than 0.5° , since this creates a severe imbalance between the number of sea points vs. the number of spectral bins. NCEP has proposed a working solution to this issue, called “hyper-scaling” (H. Tolman, poster presentation at Waves In Shallow Environments conference, April 2013). This approach utilized the multi-grid feature of WW3 (Tolman 2008), splitting the global grid into a mosaic of grids, but unlike the original intent of the multi-grid feature, here all grids have roughly equal resolution. Unfortunately, this requires communication between equal rank irregular grids, which is not yet functioning in WW3. We will adapt the code to address this during FY14, but since this task was not included in our original planning, it may result in some delays in downstream tasking.

Two-way coupled WW3 will be implemented into operational Global Ocean Forecasting System (GOFS) 3.5, thus making it the coupled HYCOM / CICE / WW3 component of ESPC. In addition to the wave-ocean coupling, ice coverage will be imported to WW3 from CICE (Community Ice Code, Hunke and Lipscomb 2008), via the GOFS driver/coupler. Since WW3 currently supports input of ice coverage this requires no additional changes to WW3 model. The WW3 model will be implemented into the ESPC system along with modifications to the real-time scripts. Software and scripts to generate wave-related output products will also be developed and implemented. This will be an extension of the developments under a separate 6.4 project for WW3 transitions. In addition to the wave-ocean coupling, the top-level driver/coupler will be extended to include a data atmosphere component. This component will process atmospheric input for the system. The required atmospheric forcing fields will be imported to each model via the coupling interface, rather than via native input files.

WORK COMPLETED

Task 1a. The goal is to read in Stokes Drift from files and to include Stokes drift terms in HYCOM's equations. Stokes Drift is often represented as a vertical profile sampled at fixed depths. In HYCOM the vertical consists of the average quantity across finite volume layers that change in thickness with time. So, fixed points in the vertical are not a good fit to HYCOM. Our initial approach was to instead read in surface Stokes drift for each wave frequency at the same time interval as atmospheric forcing (e.g. hourly or 3-hourly) and these are linearly interpolated in time inside HYCOM every time step (typically a few minutes long) and converted to the finite volume profile across HYCOM's actual layers. We use the vortex force approach to Stokes drift of Ardhuin et al. (2008), but simplify by retaining only the wave-induced mass transport in both the continuity and momentum equations. In addition we added the effects of Langmuir turbulence to HYCOM's KPP mixed layer model following Smyth et al. (2002).

Task 1b. Seven new surface stress output variables have been added to the COAMPS wave model component (SWAN), consisting of five vectors for wave-to-ocean momentum flux, one for wave-to-atmosphere momentum flux, and one for atmosphere-to-wave momentum flux. All are calculated from the wave model physical source functions. A control/experiment pair of COAMPS simulations was conducted for the Indian Ocean. In the control simulation, the tradition methods of WRSF wave-to-ocean momentum flux, τ_{rs} , is used. The surface stress received by the ocean model therefore, is the sum of the atmospheric stress (where 100% of the wind stress from the atmospheric model is directly applied) and τ_{rs} . In the experimental simulation, the ocean model (NCOM) surface forcing is modified using the MB method, with methods and software developed via this project. The direct momentum flux from atmosphere to ocean is based on best knowledge of relevant physics. This flux is the tangential stress supported by viscosity in the atmospheric boundary layer. It is estimated from the 10 m wind speed of the atmospheric model using the new software based on Banner and Peirson (1998), and is significantly less than the total atmospheric stress (e.g. less than 50% of the total for $U_{10} > 8$ m/s and less than 20% for $U_{10} > 15$ m/s). The remainder of the stress applied to the ocean model is from wave dissipation, being the sum of the five vectors for wave-to-ocean momentum flux. The wave model physics are treated in a consistent way: the tangential stress, since it goes directly to the mean flow, is not available to the wave model, but the remainder—known as the normal stress or wave-supported wind stress—is the only stress used in the wave model source function. The wave-to-atmosphere and atmosphere-to-wave fluxes are calculated and exported from the wave model, but are not used in these experiments; new methods of two-way coupling between waves and atmosphere will be addressed later, within a separate 6.2 project (w/ COAMPS, discussed below) and this EPSC component (w/NAVGEN, discussed above).

RESULTS

Task 1a. Calculating the Stokes drift vertical profile every time step from the surface Stokes drift for each wave frequency proved to be too computationally expensive to use in practice. So we now instead do this calculation off-line, converting to a single profile across a set of fixed horizontal layers chosen to be optimal for HYCOM vertical configuration. The layer averages (not single point samples) are read into HYCOM at the same time interval as atmospheric forcing and these are linearly interpolated in time inside HYCOM every time step and converted from the input fixed depth profile to HYCOM's instantaneous profile using a finite volume remapping (interpolation) routine that is already built into HYCOM. Since Stokes drift profiles are well behaved, interpolation from fixed layers to actual layers produces almost identical results to calculating the layer averages exactly from the surface Stokes drift for each frequency. Since KPP requires the surface Stokes drift, the input starts with the total surface drift (i.e. with a surface layer of zero thickness) and then the layer averages below the surface.

In a test at Ocean Station Papa for 2003 using NOGAPS forcing, adding Stokes drift to the dynamics had no noticeable effect on the 1-D (infinite f-plane) solution but adding Langmuir turbulence to KPP deepened the mixed layer leading to generally cooler SSTs, as shown in Figure 1.

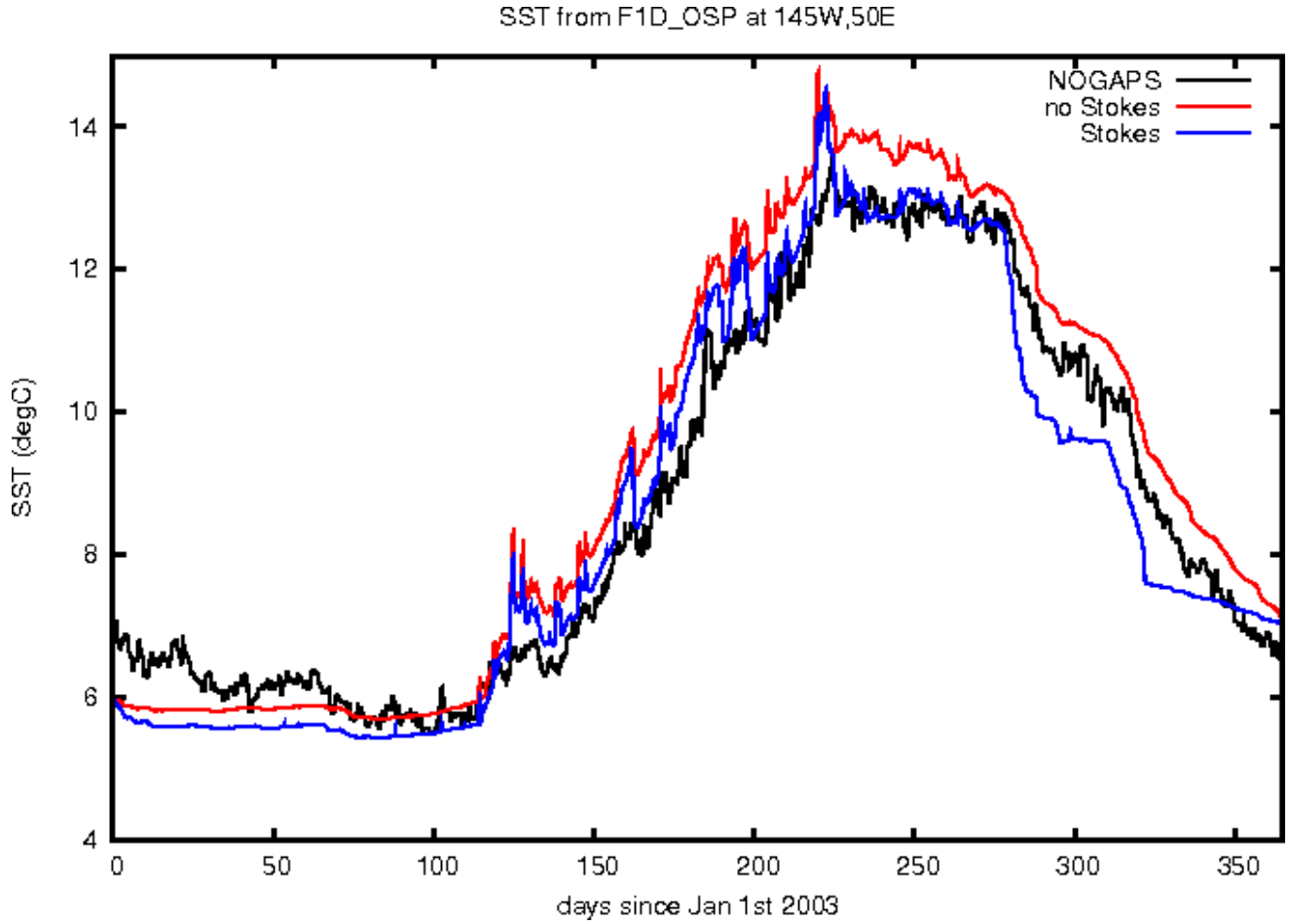


Figure 1 SST from 1-D HYCOM using KPP at Ocean Station Papa with NOGAPS atmospheric forcing, with and without Langmuir turbulence effects in KPP.

Task 1b. Results from the twin simulations for the Indian Ocean are shown in Figure 2. Panel (a) shows the direct momentum flux from atmosphere to ocean in the new method (experimental simulation). Panel (b) shows the total flux from wave to ocean (experimental simulation). Panel (c) shows the total flux to the ocean (experimental simulation). Panel (d) shows wave-supported atmospheric stress (normal stress, experimental simulation). Panel (e) shows the total stress to the ocean (control simulation, compare with (c)). Finally, panel (f) shows the impact of the new method (experimental minus control).

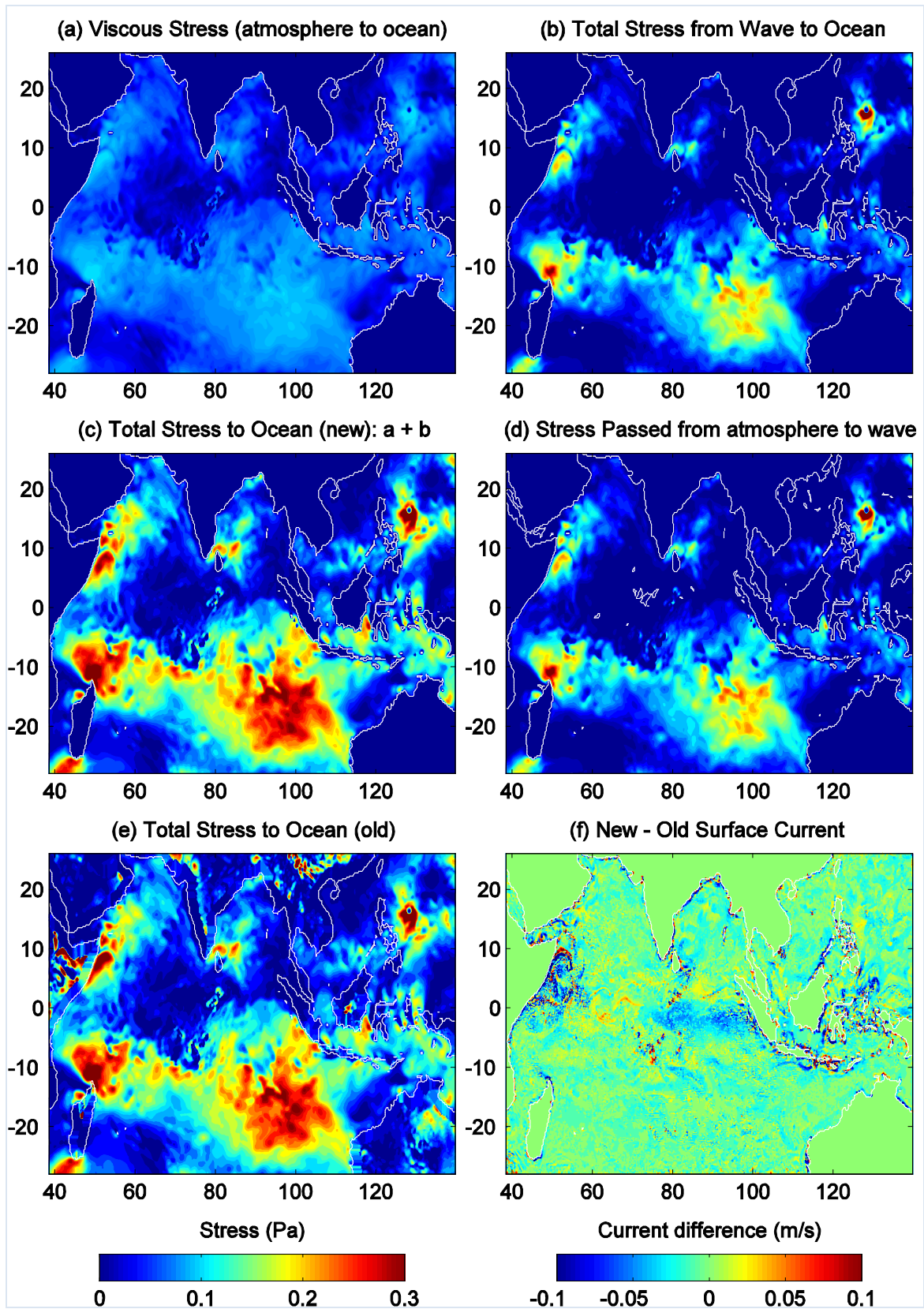


Figure 2. Results from COAMPS test simulations of the Indian Ocean 1200 UTC 23 Aug 2011. See text for explanation.

IMPACT/APPLICATIONS

The methods developed here will be used in the next generation of regional coupled modeling (COAMPS) and the first generation of global atmosphere-wave-ocean coupled modeling (ESPC).

TRANSITIONS

Metric testing of the coupled HYCOM / CICE / WaveWatch-III component of ESPC and complete VTR with acceptance by VTP. The VTR will document ocean model improvement associated with wave interactions and wave model improvement associated with ocean interactions. Specific metrics are still being determined.

RELATED PROJECTS

This project will benefit from methodology and code development conducted within the FY14 NRL Core 6.2 New Start, “Momentum Conservation Between Ocean, Wave, and Atmosphere.” (Jay Veeramony).

Work in this project is coordinated with 6.4 projects concerned with model coupling inside the COAMPS framework, such as the project, “Coupled Air-Ocean-Wave Prediction System Verification and Validation” (Rick Allard).

Of course, this ESPC component will benefit from progress in related ESPC components, such as “Coupling Infrastructure” (Tim Campbell).

REFERENCES

- Ardhuin, F., N. Raschle, K.A. Belibassakis 2008: Explicit wave-averaged primitive equations using a generalized Lagrangian mean. *Ocean Modeling*, **20**, 35-60.
- Banner, M.L. and W.L. Peirson, 1998: Tangential stress beneath wind-driven air-water interfaces. *J. Fluid Mech.* **364**, 115-145.
- Bleck, R. 2002. An ocean general circulation model framed in hybrid isopycnic-Cartesian coordinates. *Ocean Modelling* **4**, 55–88.
- Booij, N., Ris, R.C., and L.H. Holthuijsen, 1999. A third-generation wave model for coastal regions, Part 1: Model description and validation. *J. Geophys. Res.* **104** (C4), 7649-7666.
- Hodur, R. M., 1997: The Naval Research Laboratory’s Coupled Ocean/Atmospheric Mesoscale Prediction System (COAMPS). *Mon. Wea. Rev.*, **125**, 1414-1430.
- Hunke, E. C. and W. H. Lipscomb, 2008: *CICE: The Los Alamos Sea Ice Model. Documentation and Software User's Manual. Version 4.0*. T-3 Fluid Dynamics Group, Los Alamos National Laboratory, Tech. Rep. LA-CC-06-012.
- Martin, P.J., 2000: *A Description of the Navy Coastal Ocean Model Version 1.0*. NRL Technical Report NRL/FR/7322-00-9962, 42 pp.

- Pauley, R., J. Nachamkin, W. Clune, T. Duffy, and L. Lyjak, 2013: Operational Test Report for Navy Global Environmental Model (NAVGEN) System. (DoD Distribution only, not approved for public release).
- Smyth, W.D., E.D. Skillingstad, G.B. Crawford, H. Wijesekera 2002: Nonlocal fluxes and Stokes drift in the K-profile parameterization. *Ocean Dynamics*, **52**, 104-115.
- Tolman, H.L., 1991: A Third generation model for wind-waves on slowly varying, unsteady, and inhomogeneous depths and currents. *J. Phys. Oceanogr.* **21(6)**, 782-797.
- Tolman, H.L. 2008: A mosaic approach to wind wave modeling. *Ocean Modelling*, **25**, 35-47.
- Tolman, H.L., 2009: User Manual and System Documentation of WAVEWATCH IIITM Version 3.14, Tech. Note, NOAA/NWS/NCEP/MMAB, 220 pp.
- Tolman, H.L., B. Balasubramanian, L.D. Burroughs, D.V. Chalikov, Y.Y. Chao, H.S. Chen, and V.M. Gerald, 2002: Development and implementation of wind-generated ocean surface wave models at NCEP. *Weather and Forecasting (NCEP Notes)*, **17**, 311-333.

RELEVANT PUBLICATIONS

- R. A. Allard, T. A. Smith, T. G. Jensen, P. Y. Chu, E. Rogers, T. J. Campbell, U. M. Gravois, S. N. Carroll and K. Watson, 2012: Validation Test Report for the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS) Version 5.0: Ocean/Wave Component Validation *NRL Report* NRL/MR/7320--12-9423. [published]
- P. J. Martin, E. Rogers, R. A. Allard, P. J. Hogan and J. G. Richman, 2012: Results from Tests of Direct Wave Mixing in the Ocean's Surface Mixed Layer *NRL Report* NRL/FR/7320--12-10216. [published]
- T. A. Smith, S. Chen, T. Campbell, P. Martin, W. E. Rogers, S. Gabersek, D. Wang, S. Carroll and R. Allard, 2013: Ocean-wave coupled modeling in COAMPS-TC: A study of Hurricane Ivan (2004) *Ocean Modelling* vol 69 doi:10.1016/J.ocemod.2013.06.003. [published, refereed]