

Typhoon Impacts and Student Support

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Award Numbers: N00014-08-1-0577, N00014-10-1-0313

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LONG-TERM GOALS

I seek to understand the interactions between the ocean and tropical cyclones including typhoons and hurricanes.

OBJECTIVES

These grants support efforts in the TC10/ITOP (Tropical Cyclone 2010 / Impacts of Typhoons on the Ocean in the Pacific) program. This program, joint between ONR and Taiwanese investigators, studied the ocean response to typhoons in the western Pacific Ocean in 2010. ITOP focused on the following scientific questions:

- *How does the cold wake of a typhoon form and dissipate?*

Typhoons produce a complex three-dimensional response of the underlying ocean including strong surface currents, upwelling of the thermocline, intense mixing across the thermocline, the radiation of near-inertial internal waves and the formation of a cold wake behind the storm. The cold wake persists for at least several weeks after the typhoon passage, with a combination of solar heating, lateral mesoscale stirring, lateral mixing by baroclinic instability and continued vertical mixing determining the rate and character of wake dissipation. The wake is also expected to modify the atmospheric boundary layer and the biology and chemistry of the upper ocean, particularly pCO₂. ITOP seeks to measure the ocean response in detail, with particular emphasis on the mechanisms of cold wake formation and dissipation, and to compare these measurements with model results.

- *What are the air-sea fluxes for winds greater than 30 m/s ?*

Tropical cyclones draw their energy from the underlying warm ocean. Their intensity depends on the exchanges with the ocean; a greater flux of heat and moisture to the storm leads to a stronger storm, but a larger drag on the ocean leads to a weaker storm. These exchanges are poorly parameterized in existing typhoon forecast models leading to errors in the ability of these models to predict typhoon intensity. The first reliable estimates of the exchange coefficients at these high wind speeds, made during the last decade, have shown a dramatic decrease in drag coefficient relative to previous parameterizations. ITOP seeks to make additional measurements, at higher wind speeds and under a larger variety of conditions.

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE 30 SEP 2013		2. REPORT TYPE		3. DATES COVERED 00-00-2013 to 00-00-2013	
4. TITLE AND SUBTITLE Typhoon Impacts and Student Support				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) University of Washington, Applied Physics Laboratory, 1013 NE 40th St, Seattle, WA, 98105				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 5	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

- *How do ocean eddies affect typhoons and the response to typhoons?*

Ocean mesoscale eddies are expected to modulate the ocean response to typhoons by varying the depth of the pycnocline and thus the intensity and location of the cold wake. This, in turn, will change the air-sea fluxes and thus the intensity of the typhoon. Thus warm eddies act as typhoon boosters, by limiting the amount of cooling in the wake and cold eddies act as typhoon dampers. ITOP seeks to study these interactions in detail.

- *What is the surface wave field under typhoons ?*

The air-sea exchange depends critically on the state of the ocean surface, most importantly characterized by the surface waves. The wave fields beneath typhoons are complex, with multiple dominant wave directions varying and interacting across the different storm quadrants. Modern coupled air-sea models of tropical cyclones include explicit models of the wave fields from which the air-sea exchange rates are computed. More practically, the enormous surface waves produced by typhoons are of great interest in themselves. ITOP seeks to measure the surface wave field underneath typhoons, to compare these measurements with models and to assess their impact on air-sea exchange and remote sensing signatures.

- *How is typhoon genesis related to environmental factors?*

Over the tropical western North Pacific, the monsoon environment contains favorable large-scale conditions related to tropical cyclone formation and intensification. The monsoon and tropical cyclone activity vary in response to multiple synoptic-scale and intraseasonal phenomena such as waves in the monsoon trough and the Madden-Julian Oscillation. ITOP seeks to examine how these large-scale environmental factors affect the formation and intensification of tropical cyclones.

- *Typhoon forecasting*

Although the primary aim of ITOP is typhoon research, much of the data gathered by ITOP will be immediately useful for operational forecasting of typhoons. ITOP seeks to make such data available to all regional forecasting organizations and, as much as possible, work with them to improve typhoon forecasting during the experimental period.

APPROACH

ITOP was a large international program. Details of the program operations are included in my 2011 annual report. This grant supports my role as Chief Scientist in ITOP, the analysis of my own measurements during this project, supervision of Rosalinda Mrvaljevic, a graduate student supported under the Early Student Support grant and co-supervision of Andy Hsu, a graduate student with Ren Chieh Lien. Andy's work is reported in Ren Chieh Lien's annual report.

During ITOP, Lagrangian floats were deployed by Air Force C130's: 3 in Typhoon Fanapi and 3 in Typhoon Megi. The Lagrangian floats are designed to accurately follow the three-dimensional motion of water parcels within the ocean mixed layer while measuring their temperature and salinity. This is accomplished by matching the density of the floats to that of the water surrounding them, as measured by onboard CTDs, so that the net buoyancy of the floats is less than 1g, and by a large vertical drag provided by a folding cloth drogue with approximately 1 m² area. The floats are deployed in specialized air-deployment packages which protect the floats during handling and deployment from the C130, release the parachute upon water impact and then release the float from the package 20-40 minutes after water entry.

The floats measured pressure, temperature and salinity, thus allowing vertical velocity, vertical kinetic energy and vertical heat and salt fluxes to be estimated. The floats also measured ambient sound (30 Hz – 50 kHz) from which wave breaking rates could be estimated and the difference in pressure between their top and middle, from which surface wave height could be estimated. Some of the floats carried oxygen sensors (supported by a separate NSF grant) from which oxygen flux could be computed. They thus could relate atmospheric forcing, surface wave properties and ocean boundary layer turbulence under extreme wind and test ocean boundary layer turbulence models.

WORK COMPLETED

With I-I Lin, I organized a tropical cyclone session at the 2012 AGU meeting at which 15 ITOP talks and posters were presented.

The ambient noise data has been cleaned and analyzed in cooperation with Dr. Zhongxiang Zhao and a manuscript “The Sound of Tropical Cyclones” written.

An algorithm to compute surface wave spectra from pressure differences measured on the ITOP floats has been developed and verified against WaveRider data at OWS-P. With L-C Lien, surface wave spectra have been computed for the ITOP float data.

Depth and time distribution of vertical kinetic energy has been computed for all of the ITOP floats.

RESULTS

Rosalinda Mrvaljevic completed her Masters’ and, despite good progress, decided to abandon a science career and get a degree in family therapy. Her Masters’ work has been published in GRL. A compendium of all 30,000 ITOP temperature profiles near Typhoon Fanapi used in Rosalinda’s work has been compiled into a uniform data set and distributed to ITOP investigators.

A paper, led by I-I Lin, but with considerable input and encouragement from me, has been published in GRL.

A synthesis of various measures of upper ocean turbulence and air-sea fluxes now show a clear dependence of these on surface waves rather than on wind speed alone. Fig. 1 shows the drag coefficient computed from EM-APEX floats in the ITOP typhoons as part of ESS student Y.Hsu’s work. Details are described in R-C Lien’s annual report. Typhoon Megi shows extremely high drag as the wind is rising with the approaching storm. Fig. 2 compares these and oxygen fluxes, with wind and wave estimates at the same locations. All of the turbulence and flux quantities peak before the wind, but at a time close to the peak of the wave height and wave breaking rate as measured by ambient sound. This is strong evidence that upper ocean turbulence and resulting air-sea fluxes can probably not be parameterized in terms of wind speed alone; surface wave quantities will also have to be included.

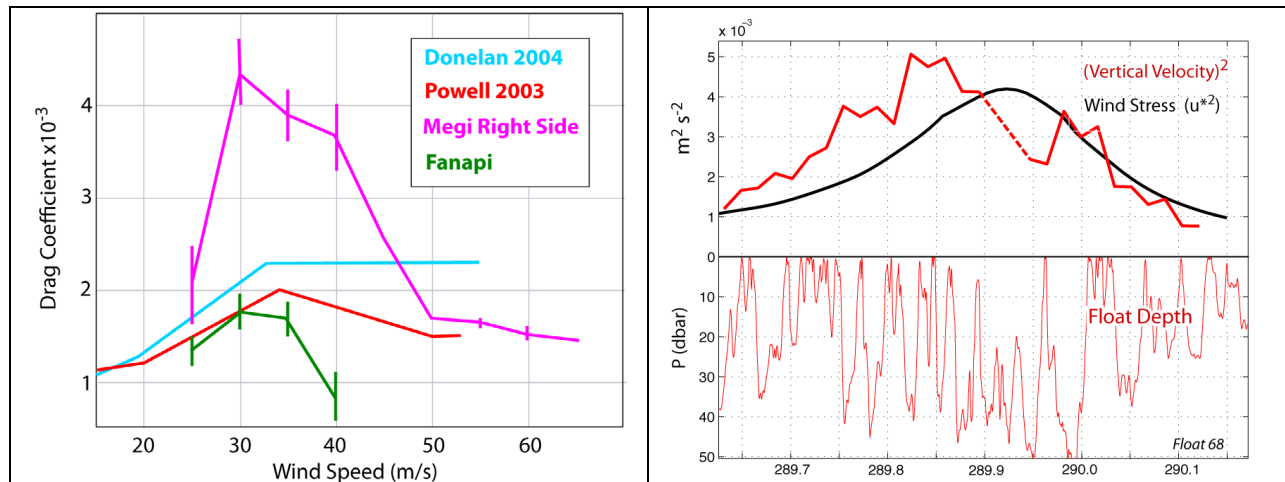


Figure 1. Left) Drag coefficient computed from upper ocean momentum budget using data from EM-APEX floats deployed in T. Fanapi (green) and T. Megi (magenta) compared to laboratory (cyan) and dropsonde (red) estimates. Megi shows very large drag at 30-40 m/s. Right) Vertical kinetic energy (top) computed from Lagrangian float data (bottom) from T. Megi leads wind stress computed from aircraft wind speed (black) by several hours.

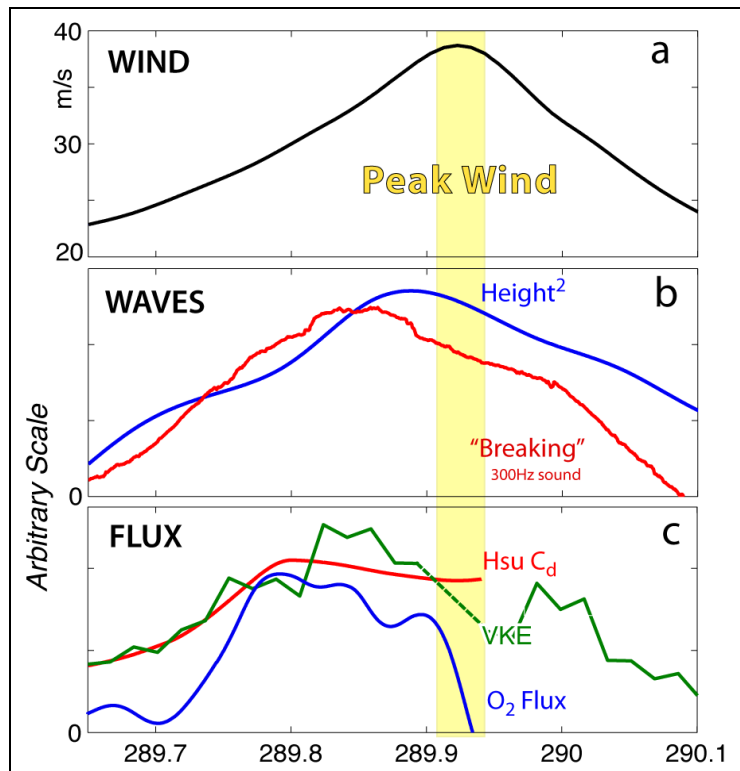


Figure 2. Evolution of turbulence and flux quantities in Typhoon Megi. a) Wind speed from mapped aircraft winds. Yellow bar shows time of peak wind. b) Wave height (blue) computed from Lagrangian float pressures and intensity of wave breaking (red) computed from 300 Hz sound measured on the float. Both lead the wind speed. c) Air-sea oxygen flux (blue), vertical kinetic energy (green) and drag (red) computed from Lagrangian and EM-APEX floats. All three lead the wind speed by several hours and therefore follow the waves and wave breaking better than the wind speed. This indicates that waves, not just wind, are controlling these quantities

IMPACT/APPLICATIONS

Tropical cyclone forecasts have shown little improvement in storm intensity over the last 20 years. The newest generation of predictive models, including the Navy's COAMPS system, couple atmospheric, oceanic and surface wave components in an attempt to properly model the storm, ocean and air-sea physics which govern storm intensity. ITOP has gathered a comprehensive data including all three of these components, which is thus suitable for testing these new models.

RELATED PROJECTS

PUBLICATIONS

Lin, I-I, P. Black, J. F. Price, C.-Y. Yang, S. S. Chen, C.-C. Lien, P. Harr, N.-H. Chi, C.-C. Wu and E. A. D'Asaro, An ocean coupling potential intensity index for tropical cyclones, *Geophysical Research Letters*. Vol. 40, Issue 9, p. 1878-1882, doi: 10.1002/grl.50091

Mrvaljevic, Rosalinda K., Peter G. Black, Luca R. Centurioni, Ya-Ting Chang, Eric A. D'Asaro, Steven R. Jayne, Craig M. Lee, Ren-Chieh Lien, I-I Lin, Jan Morzel, Pearn P. Niiler, Luc Rainville, Thomas B. Sanford, Observations of the cold wake of Typhoon Fanapi (2010), 2013, *Geophysical Research Letters*. 40, 1–6, doi:10.1029/2012GL054282, 2013

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