

Meteorological and Wave Measurements from a Stable Research Platform at Sea

Tihomir Hristov

Department of Mechanical Engineering

Johns Hopkins University

Department of Mechanical Engineering

Johns Hopkins University

3400 North Charles Street

Baltimore, MD 21218

Telephone: (410) 516-4397 fax: (410) 516-7254 email: Tihomir.Hristov@jhu.edu

Award Number: N00014-07-10203

LONG-TERM GOALS

The approach that describes air-sea exchange as interaction between a flow and a rough surface, now considered traditional, dates back to the 1950s (Charnock, 1956). Within that approach, the complex exchange processes are condensed down to exchange coefficients, thus delivering computational efficiency in large-scale numerical modeling of air-sea meteorology. However, inability to distinguish between momentum and kinetic energy transferred to waves from those transferred to currents, as well as considerable variance in the experimental estimates of the drag coefficients, show some of the applicability limits for this traditional approach. Clearly, a short-term phase-resolved wave forecasting, a goal of the High-Resolution Wave-Air-Sea Interaction project, requires a more detailed mechanistic description of the marine boundary layer dynamics with a special focus on the elements distinctly introduced by the compliant interface and the sea surface waves. While wave dynamics on the water side has already been reduced to a computationally-intensive numerical problem (Friehe et al., 2007, section III.B), the complexity of which is determined by the number of nonlinearly interacting wave modes, the wind driving of the waves on the other hand, is less understood. Current challenges include gaps in theoretical knowledge and in techniques for numerical modeling. In particular, the observational validation for most of the wind-wave interaction mechanisms proposed so far in theoretical works is lacking. The purpose of this work is to advance our understanding on these open issues.

OBJECTIVES

This project's objective is to produce a consistent-with-observations description for the structure and dynamics of the marine atmospheric boundary layer that will be suitable to incorporate in models for short-term wave prediction. We will seek to identify the significant physical processes active in the marine boundary layer and quantify their contributions to the wind-wave growth, using Hasselmann's (1965) hierarchy of mechanisms as a framework of our studies. Two of the lower order mechanisms in that framework have been addressed experimentally, while eleven of them have never been approached observationally. Some non-expandable mechanisms, such as flow separation, have received renewed interest in light of the work of P. Sullivan, NCAR. Detection of such mechanisms in measurements will be among our important objectives.

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 2009		2. REPORT TYPE		3. DATES COVERED 00-00-2009 to 00-00-2009	
4. TITLE AND SUBTITLE Meteorological and Wave Measurements from a Stable Research Platform at Sea				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) Johns Hopkins University, Department of Mechanical Engineering, 3400 North Charles Street, Baltimore, MD, 21218				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 6	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

Ensuring the practicality of wave forecasts requires that we explore both the dynamical and numerical causes of uncertainty and the propagation of that uncertainty from the radar observations of the surface, through the models and mechanisms employed, to the wave prediction results. The horizon is the natural spatial limitation for the radar, establishing a limitation for the time to produce a forecast. Understanding the uncertainty causes and propagation will let establishing the limits (horizon) of predictability and will allow formulating a criterion for an optimal compromise between dynamic completeness and computational efficiency of the forecasting models, so that the forecasts are produced within the imposed time limits.

APPROACH

Observational data collected by the field experiment will deliver information on the boundary layer dynamics and will be used to calibrate numerical models. The atmospheric pressure measurements will serve for estimating the direct energy input to the waves occurring through form drag. The wind velocity measurements will be analyzed to identify wave-turbulence interaction and its contribution to the wave growth. Recent numerical results reported by P. Sullivan have predicted instances of air flow separation in cases of extreme wave slope and surface roughness. We will seek to recognize signs of such phenomena in the data and estimate their influence on the wave field evolution.

The PI closely collaborates with other members of the project's team. The experimental component is carried out with Carl Friehe (UCI). The work on data assimilation, surface and boundary layer air flow modeling will be done with Eric Terril (UCSD) and Peter Sullivan (NCAR).

WORK COMPLETED

The trial cruise of this project was carried out in order to work out the essential experimental steps, validate the software and test the performance of the instruments. It was conducted between July 6th and July 13th, 2009 from the R/P FLIP, drifting and changing its heading freely over about 30 nautical miles. Two days for towing, one day of deploying the booms, two days for instrumenting the mast and one day for bringing the instruments back in, reduced the week at sea down to two days for collecting data. The platform's path is shown in Figure 1, where the data gap corresponds to the period of connecting the instruments' cables to the data collection system and testing the signals. Figure 2 shows the instrumented mast and the deployed instruments are listed in Table 1. Total of 28 instruments were tested and the number of variables sampled continuously was 105.

Table 1. List of instruments deployed during the trial experiment.

Instruments	Quantity measured	Height/Location
5 Cups	Wind speed	2 at 6.9m, 2 at 7.9m
2 Vanes	Wind direction	6.9m, 13.30m
RMY Propeller	Wind speed & direction	6.9m
EG&G Dew point	Dew point temperature	15.35m
Krypton Hygrometer	Atm. humidity	13.30m
Infrared SST	Sea surface temperature	_____
2 Sonic Anemometers	Wind velocity, Air temperature	3.7m, 13.30m
Motion at Sonic 2	Accelerations & Ang. rates	13.30m
FLIP's Gyroscope	Heading	_____
4 Pressure Pairs	Atmospheric pressure	2.06m, 3.70m, 8.78m
GPS Unit	GPS location and timing	_____
2 Thermistors	Air temperature	15.35m
Inertial Nav. Unit	GPS position, Motion	Tower

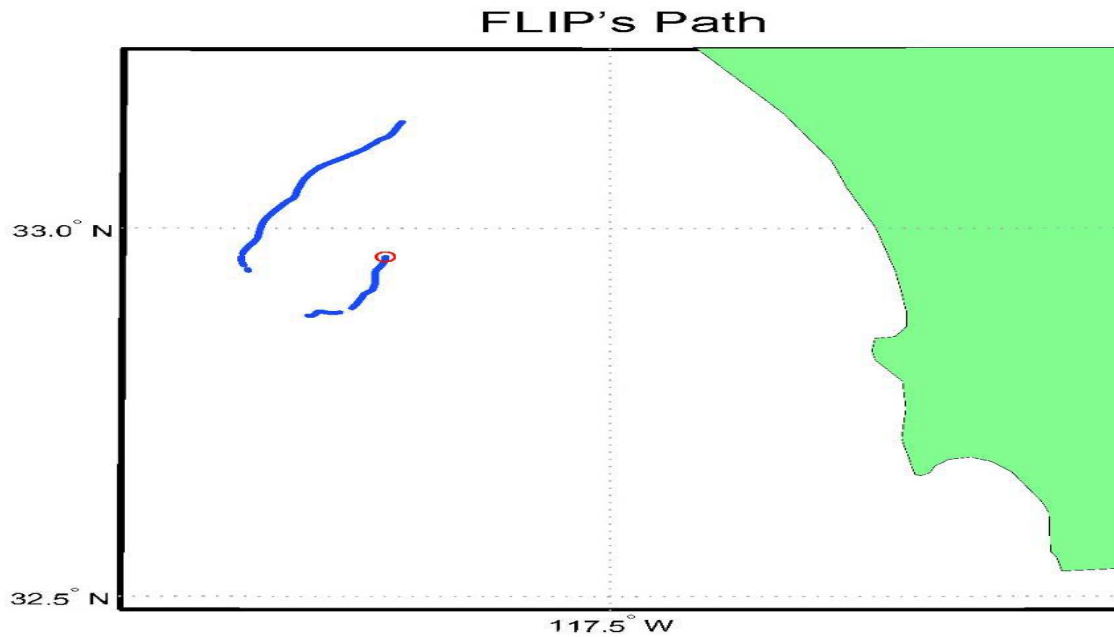


Figure 1. A The path of the drifting R/P FLIP during the trial experiment, as registered by an onboard GPS tracking device.

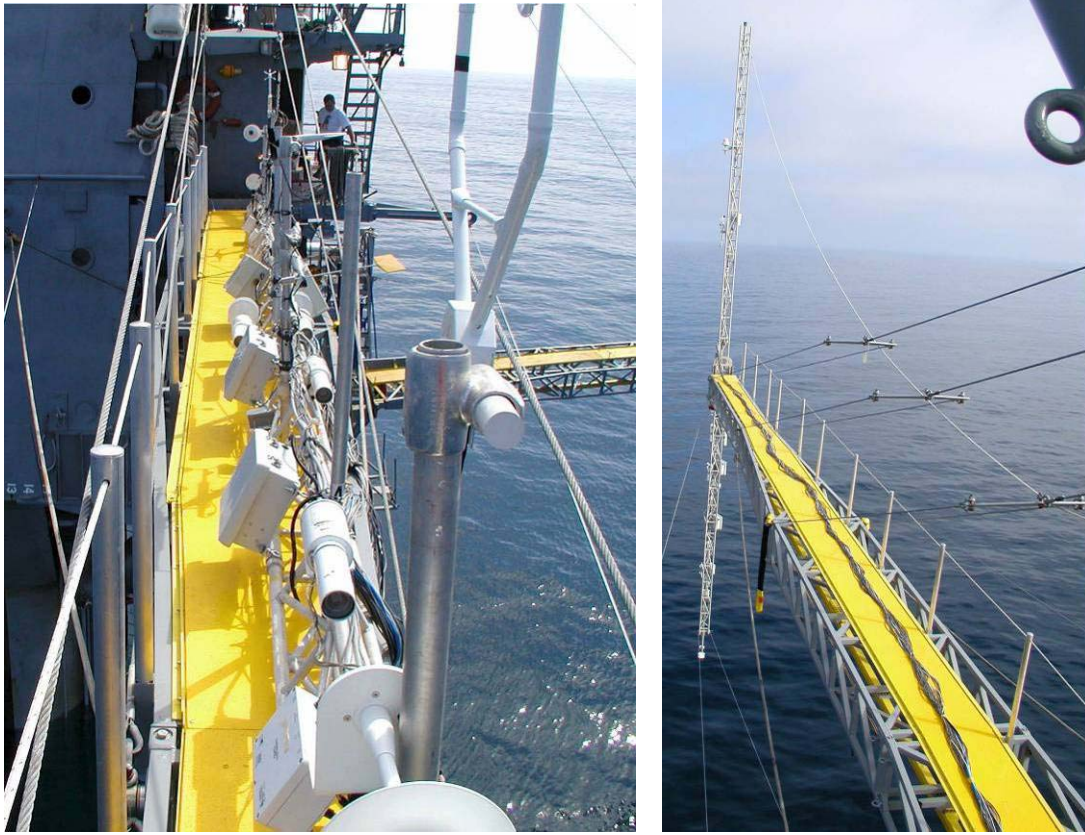


Figure 2. *The instrumented mast on the port boom (left) and deployed vertically (right).*

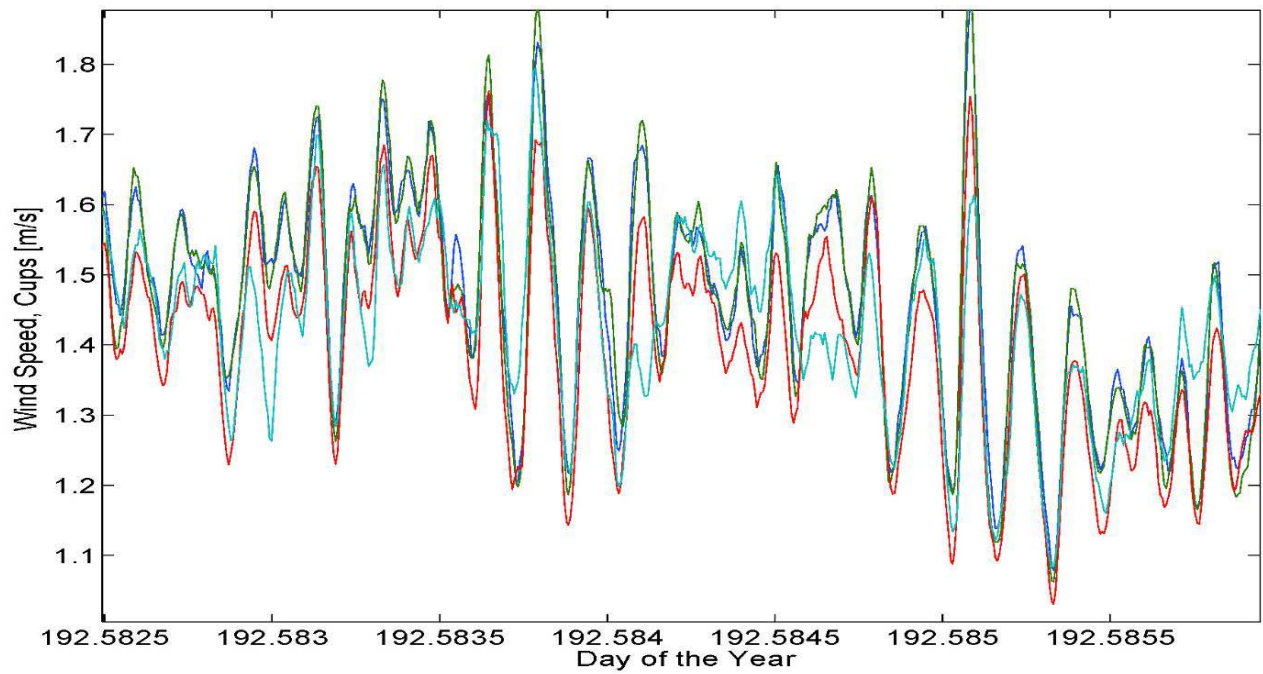


Figure 3. *Wave-induced fluctuations of the wind speed, as registered by four of the cup anemometers. This wave signature is directly observable in the wind velocity signals in light winds. With increase of the wind speed the turbulence blurs the wave effects and a separation*

RESULTS

Among the essential components of the meteorological array were the instruments measuring airflow velocity (sonic anemometers, cups, vanes), pressure sensors, and the units for GPS tracking and inertial navigation.

Both the sonic anemometers and the cups have clearly registered the wave modulation of the wind velocity, responsible for the wave generation, Figure 3. Instances of that modulation are directly observable in the signals in light winds. At higher winds, although the wave-induced fields still exist and are the key flow component that carries the wind-wave interaction, they are blurred by the more intense turbulence, and their identification requires wind velocity filtering (Hristov *et al.*, 2003).

Figure 4 shows measurements of atmospheric pressure, with wave signature clearly present. The signals demonstrate virtually no vertical decay of the wave effects in pressure, a distinct feature of the pressure field predicted by both analytic and numerical modeling (Hristov *et al.*, 2003). Such a feature is inconsistent with the traditional assumption of exponential decay of the wave-induced pressure with height, incorrectly used to extrapolate atmospheric pressure measurements down to the surface. Almost no turbulence is observable in the pressure signals, indicating low efficiency of the random force mechanism for wave generation (Phillips, (1957)). According to expectations, the two pressure instruments at level 5 track consistently. Temperature measurements from the pressure units were found to depend on the radiative solar heating. To reduce such dependence the units are upgraded to ensure more aspiration.

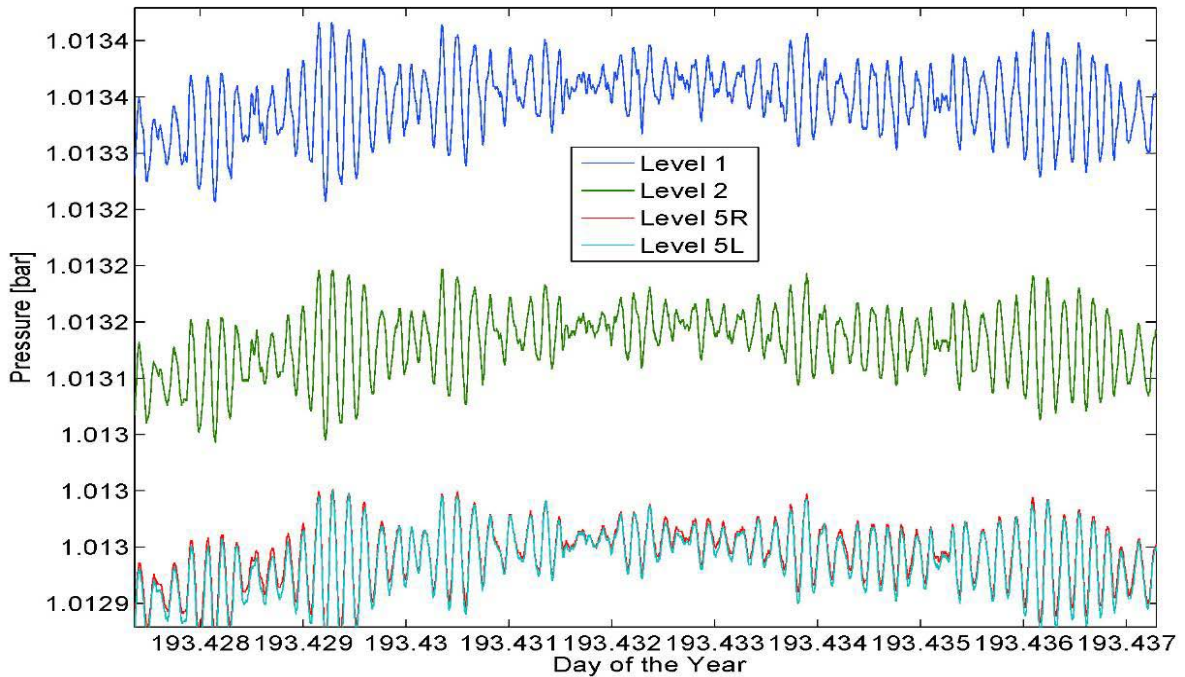


Figure 4. Wave-induced fluctuations from four pressure sensors, with height from the surface distinguished by the color; blue corresponds to the instrument closest to the surface, green being the next in height, and red and cyan are at the same level, highest from the surface.

The platform heading was recorded simultaneously from the FLIP's gyroscope and the inertial navigation unit. Although the two track consistently for 40 hours, there is an instance of failure of the inertial navigation unit. We currently conduct extensive testing to determine the cause of failure and ensure uninterrupted operation.

IMPACT/APPLICATIONS

The results of this research are expected to advance the basic science of the air-sea interaction and will be applied to operational models for short-term wave modeling and forecasting. The information on the structure and dynamics of the marine atmospheric boundary layer (MABL) and the statistics of the ocean surface will advance the description and modeling of signal propagation over the ocean. The profound physical similarities between propagation of radar signals over the ocean and acoustic signals in the water will extend possible applications to the acoustic domain. Since the MABL structure and dynamics is also essential in designing and modeling the performance of flying objects operating close to the ocean surface, such engineering applications of this project results are foreseeable as well.

RELATED PROJECTS

The PI is unaware of any related projects.

REFERENCES

- H. Charnock, "Statistics and Aerodynamics of the Sea Surface", *Nature*, v. 177, pp. 62--63, 1956.
- C. Friehe, K. Melville, and D. Yue (steering committee), High Resolution Air-Sea Interaction DRI Science Plan, 2007.
- T. Hristov, S. Miller, C. Friehe, "Dynamical coupling of wind and ocean waves through wave-induced air flow", *Nature*, v. 422, pp. 55--58, 2003.
- K. Hasselmann, "Weak-Interaction Theory of Ocean Waves", in *Basic Developments in Fluid Dynamics*, v.2, Academic Press, New York, pp. 117--182, 1965.
- O. M. Phillips, On the generation of waves by turbulent wind. *J. Fluid Mech.* v. 2, pp. 417--445, 1957.