Study of EM Signals Propagation through Marine Atmospheric Boundary Layer And Static Pressure Measurements in Marine Atmospheric Boundary Layer During CBLAST

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LONG-TERM GOALS

The long-term goal of this project is to acquire physical understanding of the mechanisms controlling the coupling between the ocean and the atmosphere. Through the last decades extensive experimental efforts have been devoted to phenomenological description of air-sea interaction. The goal of such approach is to present air-sea exchange in terms of transfer coefficients, thus encapsulating the complex physics, and parameterizing these coefficients trough one (or small number) of variables. In particular, these efforts included work on determining the ocean surface's drag coefficient, essential in calculating air-sea momentum exchange. The experimental estimates of the drag coefficent have persistently produced scatter that has not been reduced by improving the qualty of measurements or by accumulating more statistics. Such situation suggests that the phenomenological desciption of air-sea interaction possibly reaches its limits and our understanding can only be advanced by a more deatiled look into the physics of air-sea exchange. The analysis of pressure measurements from RED and the ongoing CBLAST experiments is aimed at that. My work also continues to be focused on electomagnetic propagation over the ocean with the goal to reduce discrepancies between model predictions and experiments.

OBJECTIVES

The recent review of Taylor (2000) determines that poor understanding of the interfacial fluxes is a major source of uncertainty in the current models ocean circulation and climate. Information of the pressure field in the boundary layer over the ocean is essential to understanding the mechanical coupling at the air-sea interface. Previous measurements (Shemdin and Hsu (1967), Kendall (1970), Dobson (1971), Elliott (1972) , Snyder (1974)) have produced inconsistent results and have been primarily concerned with the air pressure distribution on the water surface. Although that distribution controls the surface wave generation and waves growth rate, pressure measurements in atmospheric suface layer offer some advantages. First, positioning the pressure probe on the surface requires it to be protected form the water, which leads to less-than-perfect instrument designs and introduces measurement distortions (Dobson (1971)). Second, the pressure distribution on the surface cannot uniquely determine the air flow structure and therefore an agreement with a particular wind-wave ineraction theory on the surface is insufficient to validate a wind-wave interaction mechanism (or

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theory). In this context, our objective is to study experimentally the spatio-temporal structure of the pressure field in the atmospheric surface layer over the ocean and compare that structure with theoretical or modeling results.

My work is also focused on finding practical, yet valid alternatives to the model of Miller-Brown (Miller et al. (1984)), shown to be incorrect in its assumptions regarding the statistics of the surface waves (Hristov and Friehe (2003)). The Miller-Brown model has been adopted for describing electromagnetic wave scattering from ocean surface and has propagated through the literature as supperior to other models (Hitney (1999), Levy (2001)). The considered alternatives build on the small slope approximation (Voronovich (1998), Fuks *et al.* (1999)). Such approach is free of the deficiencies of the two-scale model, which combines the Kirchhoff and small perturbation methods.

APPROACH

To validate a theory from measurements requires us to select physically meaningful quantities that both the theory and experiment can produce for comparison. Predictions of numerical models on wind-wave interaction, especially nonlinear ones, can be difficult to generalize to a form suitable for comparison with measurements. In particular, their results may to a large extent be dependent on the specific wave spectrum chosen for modeling, while that specific spectrum is unlikely to be reproduced especially in a field experiment. A linear theory for wind-wave interaction, on the other hand, is free of such disadvantages as its predicitions are invariant with respect to the observed wave-spectrum. Limiting our consideration to a linear wind-wave interaction theory allows direct comparison of theory and experiment in terms of transfer functions of the wave-induced fields. With that in mind, the basis of our approach to studying the air pressure strucuture over the waves is to obtain the pressure's linear response to wave forcing from the field data of RED and CBLAST experiments and compare it with numerical results from the critical layer theory of Miles (1957). Consistent with our goal, we rely on a linear filtering to separate turbulent and wave-induced components in the measured signals (Hristov *et al.* (1998)). In this effort I am collaborating with Kenn Anderson and the members of the RED project team and Jim Edson of WHOI.

WORK COMPLETED

Participation in the CBLAST experiment, done in close collaboration with WHOI's Dr. Jim Edson, was a considerable part of my work trough the year. Two Met3A barometers and two 202BG differential pressure transducers with pneumatic filters were deployed at the WHOI's Air-Sea Interaction Tower and since early summer generate continuous data (Figure 1).

The work on the RED experiment data analysis included the task of correcting the measured signals for the motion of the instrument platform. Data collected from the Boeing CMIGITS II unit, the Systron Donner MotionPak as well as FLIP's gyroscope were used to solve the inertial navigation problem in order to account for the changing position and orientation of FLIP. Then we could proceed with the dynamic characterization of the atmospheric surface layer in terms of fluxes of momentum and heat as well as profiles of refractivity, wind speed, temperature and humidity. These results have been used as an input for modeling radar signals propagation in ducting conditions. However, the model's weak response to varying refractive index suggests the need to study the model's sensitivity.

The structure of the wave-induced velocities and pressure was of primary interest in our analysis.

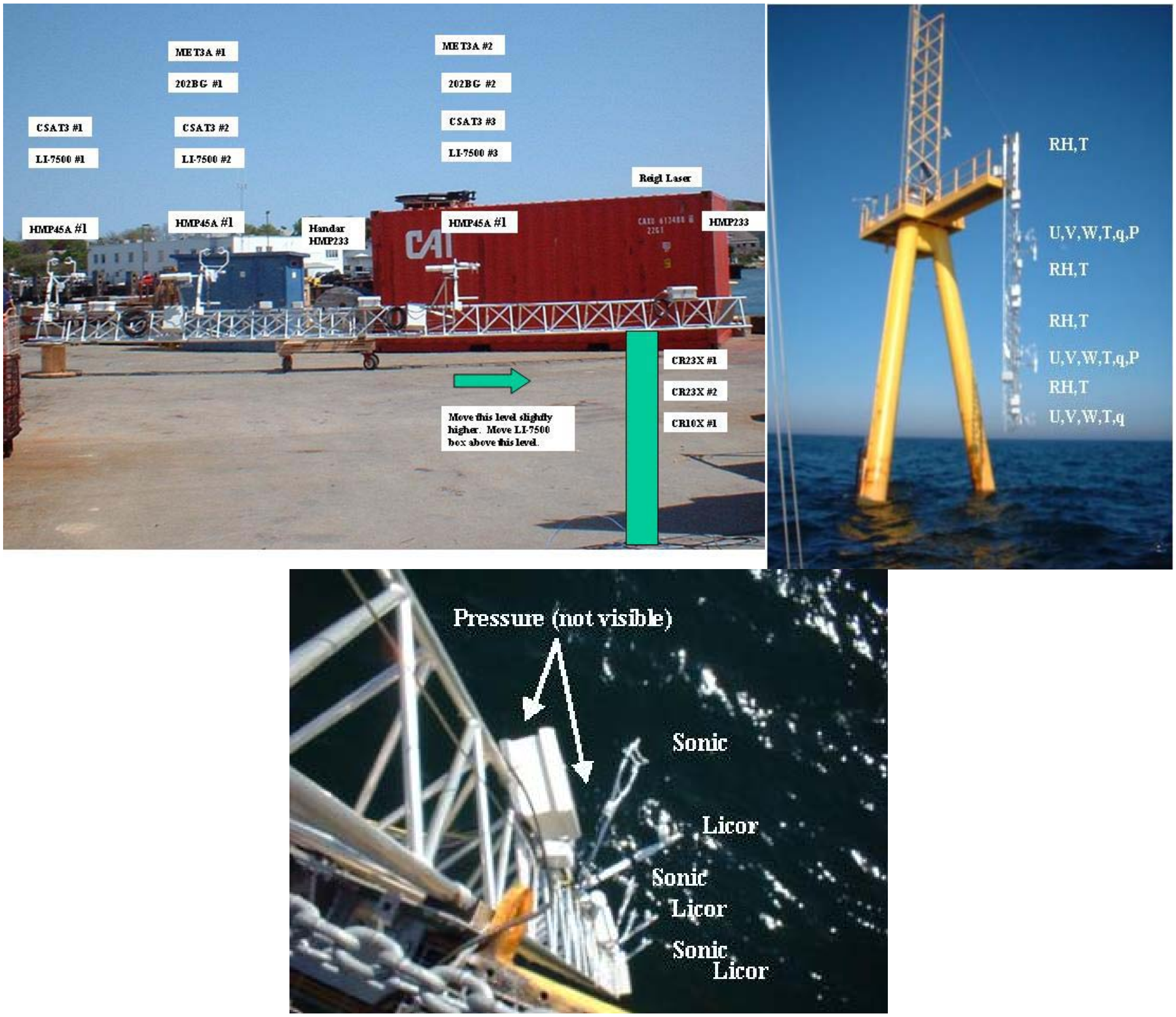

Figure 1. The CBLAST instrument mast partially assembled with four pressure sensors at the Woods Hole Oceanographic Institution (upper left photo) and the mast installed at WHOI's Air-Sea Interaction Tower (upper right and lower photo). Photographs courtesy of Dr. Jim Edson.

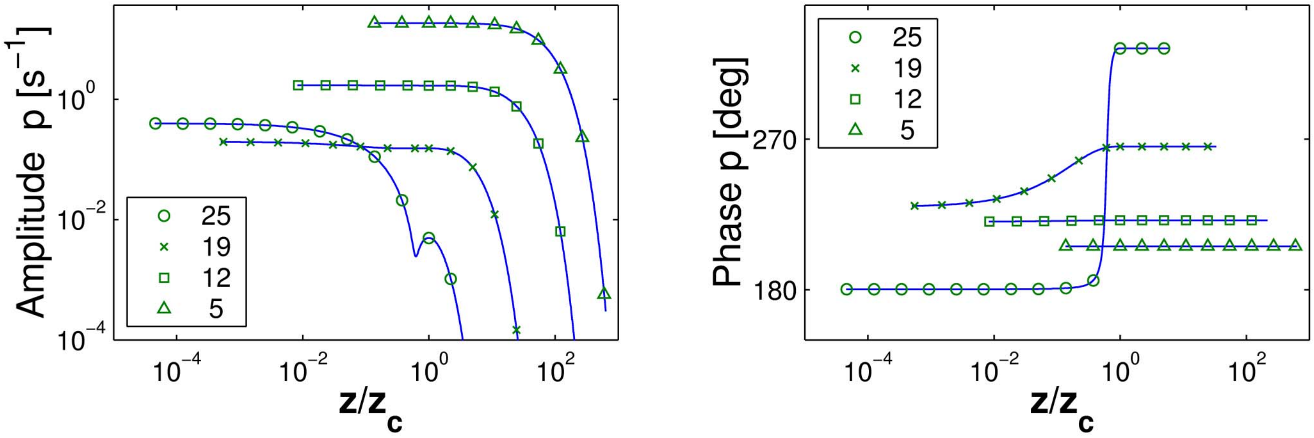

Figure 2. The amplitude (left) and phase (right) vertical profiles of wave-coherent pressure, obtained as numerical solutions from the critical layer theory (Miles (1957)). Different curves correspond to different values of the wave age parameter C/u_****, as indicated by the legend. Unlike the wave-induced velocities, the pressure, may exhibit no distinct features at the critical height*** $z = z_c$***. Both the amplitude and phase may remain flat at*** $z = z_c$

RESULTS

Both vertical and along-wind velocity fluctuations clearly exhibited the distinct critical layer pattern, while the pressure followed the predictions of the critical layer theory (the pressure field may not show any distinct features at the critical height, Figure 2). Figure 3 shows the complex-valued transfer function of the wave-induced pressure as predicted by the critical layer theory (Miles (1957)), consistent with experimental estimates. The agreement is therefore better at wave scales where the wave spetrum is well populated an poorer at slower (shorter) waves range. The surface wave spectra commonly show wave energy concentrated at longer wavelengths as a result of nonlinear wave-wave interactions. As a result, shorter wavelenghts are left with relatively little energy and the fluctuations in the air they induce have smaller amplitudes. Consequently, the signal-to noise ratio at higher frequencies is large thus leading to greater uncertainty in experimental estimates of amplitudes and phases of the wave-induced fields.

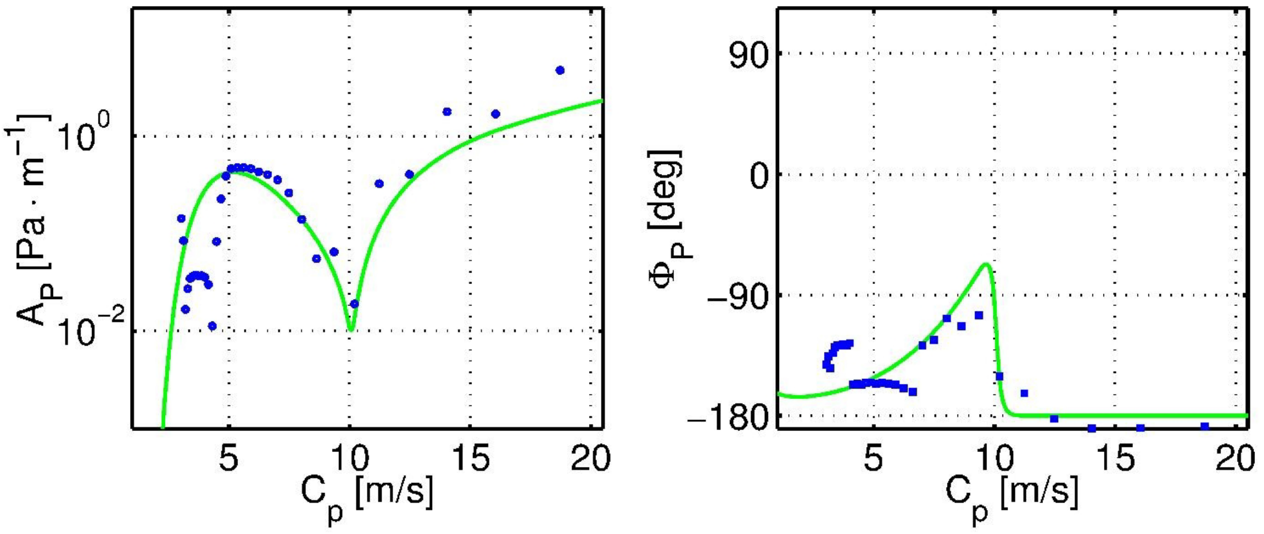

Figure 3. Amplitude (left) and phase (right) of the wave-coherent pressure vs. the wave phase speed C_p. The continuous line shows numerical results from the critical layer theory (Miles (1957)) and dots are experimental estimates.

IMPACT/APPLICATIONS

Insight into the physical mechanisms of wave generation, as given by the results in Figure 3, is important for advancing our understanding of air-sea interaction and complementary to the phenomenological description of interfacial exchange processes.

Previous experiments have concluded that the critical layer theory (Miles (1957)) under-predicts the observed wave growth rate. Although discrepancy between that theory and the measurements may have broader causes, possible inconsistencies in the measurements analysis may have contributed to such conclusions. Wave-induced pressure fluctuations have been considered to decay exponentially with the distance from the water surface with no change in phase (Snyder *et al.* (1981)) and that has been accepted as an established fact in later works. Such assumption allowed measurements in the air to be extrapolated down to the surface and used to recover the pressure distribution on the air-water interface as well as to estimate the waves growth rate. The consistency we observe here between the critical layer theory and our measurements in the air suggests that the profiles in Figure 2 may be an appropriate extrapolation to the surface and that compared with these profiles the exponential extrapolation would clearly overestimate the surface pressure. In turn, this clearly leads to experimental overestimates of the waves growth rate and at least partially explains some observed discrepancies between measurements and theory.

TRANSITIONS

Clearly, the quantitative information on the wave-induced pressure brings better understanding of the air-sea momentum and kinetic energy exchange, a substantial source of uncertainty in modeling and forecasting (Taylor (2000)).

The marine boundary layer dynamics, as inferred from these measurements, is useful in design and simulation studies of man-made objects flying low above the surface waves (Nielsen Engineering and Research, Inc., http://www.nearinc.com).

SUMMARY

The year's work summarized here includes measurements within the CBLAST experiment, intended to describe the structure and dynamics of the atmospheric surface layer over the ocean. The analysis of pressure signals from the RED experiment revealed the pressure response to surface waves forcing and showed it to be consistent with predictions of the critical layer theory. An error was identified in a widely adopted Miller-Brown model for electromagnetic waves scattering from the ocean surface and my ongoing work is focussed on finding practical, yet valid alternatives to that model.

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