

SPECTRAL CHARACTERISTICS OF THE MARINE SURFACE LAYER

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LONG TERM GOALS

The goal of this research is to gain a better understanding of the flow characteristics of the marine surface layers, including the coupling at the air-sea interface. Specifically, the research focuses on the influence of ocean waves on turbulent processes, especially those involved in stress-wave interactions. The long range goal of this research is to develop new and/or revise old theoretical descriptions of turbulence, such that they are universally applicable to both over land and over sea boundary layers. This is to be accomplished by focusing on the physical processes unique to the marine boundary layers through a combination of scale analysis and numerical modeling.

OBJECTIVES

The PI's first objective is to improve our understanding of flux profile relationships over the ocean using our profile measurements in the kinetic energy, momentum, and scalar variance budget equations. This involves an investigation of the applicability of Monin-Obukhov (MO) similarity theory to over-ocean measurement in order to determine these functions and their proportionality factors (e.g., the von Karman and Kolmogorov constants). That is, the goal is to determine these functions over the open ocean where a difference with land derived functions is possible due to the fluid ocean surface. The PI's second objective in this research is to investigate how the wave induced flow affects the turbulent processes in the marine surface layer. In these studies the PI will focus on the role that stress/wave interaction plays in modifying the magnitude and direction of the momentum flux within the wave boundary layer (WBL).

APPROACH

The Marine Boundary Layers (MBL) Accelerated Research Initiative centers around two field programs designed to examine the 3-D structure of the marine boundary layers: the Risø Air-Sea Experiments (RASEX) conducted in shallow water off the coast of Denmark, and the MBL Main Experiments conducted in deep water off the California coast. In these experiments we deployed fast response and mean sensors to investigate the vertical structure of the atmospheric surface layer (lowest 10% of the marine boundary layer). The overall structure of the atmospheric boundary layer is being investigated by coupling these measurements with remotely sensed variables (e.g., lidar, wind profiler, and sodar) and rawinsonde launches. Horizontal variability is being investigated by combining all of the above with data taken from research vessels, microwave radars, and a research aircraft. The oceanic boundary layer is being investigated with a similar set of instrumentation, including sonars, drifting buoys, current meters,

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towed instruments and vertical profilers. These two boundary layers are then coupled together using simultaneous measurements of the wave field. This involved the deployment of wave-wire arrays and remote sensing instrumentation on both sides of the interface.

Our approach has involved the decomposition the measured signals into mean, wave-induced, and turbulent components. The techniques we are using to decompose the signal involves traditional phase averaging as well as more sophisticated approaches involving Hilbert transforms and a new similarity theory involving wave-pressure and wave-velocity correlations. The separation of the flow into wave-induced and turbulent components simplifies the interpretation of the data by allowing us to study the processes separately.

WORK COMPLETED

The collaborative work between the PI and Jeff Hare (NOAA/ETL), Jim Wilczak (NOAA/ETL), and Tetsu Hara was published in the *Journal of Physical Oceanography* in an article entitled “A similarity analysis of the structure of air flow over surface waves”. A comparison of the flux measurements computed aboard the R/V Wecoma and R/P FLIP was included in the *Journal of Atmospheric and Oceanic Technology*’s article entitled “Direct covariance flux estimates from mobile platforms at sea”, which is now in press. Additionally, our initial investigations on the influence of ocean waves on marine surface layer flows were summarized in 10 extended abstracts presented at the Conference on Wind-Over-Wave Couplings: Perspectives and Prospects, and at the 12th Symposium on Boundary Layers and Turbulence.

RESULTS

Our investigation of MO similarity demonstrated that the theory is valid in the marine surface layer as long as it is applied to turbulence statistics taken above the wave boundary layer (Edson and Fairall, 1997). This study found that the TKE budget is well described by a balance between production and dissipation except for slightly unstable conditions where production exceeds dissipation by as much as 17%. We have argued that this is due to a local imbalance between the pressure and energy transport. Additionally, we have argued that the good agreement between our results and the overland results of Vogel and Frenzen (1992) and Thiermann and Grassl (1992) suggest that our measurements are generally taken above the WBL. However, over developing surface waves, part of the energy flux entering the surface layer is not dissipated into thermal energy, but rather is transported to the surface to generate and sustain waves and currents. This energy flux is expected to result in a “dissipation deficit” in the volume-averaged dissipation rate that would result in local production exceeding dissipation. Therefore, part of this deficit may be a function of sea-state, which is not expected to obey traditional MO similarity theory.

We would expect the dissipation deficit to be greatest over the youngest seas where the energy flux is largest. Evidence for this effect is given by Edson et al. (1997), which showed that the younger the seas the greater the deficit. The challenge is how to determine parameterizations that account for the flux of kinetic energy into the ocean as a function of sea state. We are currently working on the hypothesis that observed dissipation deficit is due to a pressure transport term that is sea-state dependent. This proposition seems reasonable since the pressure flux evaluated at the surface, $\overline{wp_o}$, represents the energy flux into the waves. A simple model of this terms has been shown to account for most of the observed deficit. We are now trying to compute this term directly from the FLIP pressure sensor measurements.

IMPACT

These results have had a profound impact on the modeling community. As a result, we have been asked to give briefings and seminars on these results at the Naval Research Laboratory in Monterey and at the National Center for Atmospheric Research in Boulder. The results are also impacting the way that researcher interpret the measurements taken from ocean observing system. For example, it has been long known that flux estimates from indirect methods require additional parameterizations to account for wave-induced effects. Our MBL investigations are now providing a clearer picture of the physical processes in the wave boundary layer responsible for effects.

RELATED PROJECTS

The work involved in the MBL ARI nicely complements the research objectives of our involvement in the NSF's Coastal Ocean Processes Study. Our component of this progress is investigating the role of surface waves and atmospheric forcing in air-sea gas exchange. Sean McKenna, a WHOI/MIT Joint Program student, is using an AASERT to investigate the role of surfactants in air-sea interaction. This investigation is also expected to met some of the objectives of our ONR sponsored remote sensing research. Since the radar systems sense this forcing through the effect of the winds stress and atmospheric stability on the wave field, the knowledge gained from the MBL and CoOP programs concerning stress/wave interaction will also assist us in our remote sensing research. Finally, the MBL program is also providing important information to the Coastal Mixing and Optics ARI. The FLIP measurements will greatly assist the PI in interpreting the data he collects from a sonic anemometer mounted on the central mooring of the CMO array. In particular, the FLIP analysis will allow the PI to adjust his inertial-dissipation estimates of the momentum flux to take into account some of the influences of the wave-induced flow. The results from the two programs are being combined by Michiko Martin, a naval student in the WHOI/MIT Joint Program.

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