SIMILARITY IN THE MARINE ATMOSPHERIC SURFACE LAYER: THE ROLE OF INTERMITTENCY AND BOUNDARY-LAYER STRUCTURES

C. W. Fairall and R. J. Hill
R/E/ET7
NOAA Environmental Technology Laboratory
325 Broadway
Boulder, CO 80303
Tel:303-497-3253
Fax: 303-497-6978
email: cfairall@etl.noaa.gov

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LONG-TERM GOALS

Improved understanding of fundamental processes of turbulence and air-sea interactions.

OBJECTIVES

The standard model for dealing with turbulence and air-sea interactions has three components:

(1) The ocean surface can be characterized by its temperature and aerodynamic roughness.

(2) Given (1) we can use the wind speed and air temperature/humidity to determine the air sea fluxes. All relevant properties of the profiles of the mean and turbulent fields in the surface layer can them be computed with scaling parameters derived from these fluxes using Monin Obukhov Similarity (MOS) theory.

(3) The small-scale properties of the turbulence (structure functions and inertial subrange spectra) can be described solely in terms of the wavenumber/spatial separation and the dissipation rates. This is the so-called Kolmogorov hypothesis.

Our objective is to investigate various physical processes that lead to violations of the standard model and to develop new models that more thoroughly describe turbulent processes in the marine surface layer. For example, (1) is violated by sea spray, oceanic near-surface mixing processes, and interactions of the wind/stress vectors with the 2-dimensional ocean surface wave spectrum; (2) is violated by intermittent processes associated with larger scale boundary layer dynamics and coherent structures; violations of (3) are characterized by the "revised" Kolmogorov hypothesis that at least one large scale variable introduces intermittency that influences small scale dynamics and that this influence increases with the order of the processes examined.

APPROACH

We have taken a combined theoretical, analytical, and experimental approach to studying these problems. The theoretical work (primarily the bailiwick of R. J. Hill) has been a rigorous examination

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of various aspects of the fundamentals of correlation functions, structure functions, and spectra in locally isotropic, incompressible turbulence. The work has included certain aspects of processing data, various assumptions used by previous investigators to simplify the theory, and fundamental relationships between higher order velocity statistics and the pressure structure function. The experimental and analytical work (primarily the bailiwick of C. W. Fairall and J. E. Hare) involves analysis of data from the standard model point of view to improve the various dimensionless MOS functions for application over the ocean, evaluation of these data using nonlinear (chaos) techniques, and investigation of coupling effects to BL-scale structures and surface waves. The data used has come from existing data from previous field programs plus the MBL-sponsored RASEX field program in Denmark and the FLIP/Wecoma field program off the coast of California. For the MBL field program, we combined with the ETL lidar group to obtain measurements of boundary-layer turbulence profiles and coherent structures to complement the near-surface turbulence and wave measurements.

WORK COMPLETED and RESULTS

The theoretical work has been very productive. In the last year a paper has been published describing acceleration correlations for small scale turbulence (Hill and Thoroddsen 1997). This paper has direct application in aerosol and cloud droplet coagulation theory and models. A paper has also been published summarizing the state-of-the-art in scintillation methods to estimate surface fluxes (Hill 1997a). A paper has been submitted on fourth-order velocity statistics (Hill and Wilczak 1997) and a technical report written on velocity-velocity and pressure-gradient structure functions (Hill 1997b). Finally, a paper was submitted deriving an updated version of the dynamic equation for homogeneous turbulence (Hill 1997c).

The standard MOS analysis of existing databases is nearing completion. Papers have been written on MOS similarity over the ocean, oceanic roughness relationships, and air-sea flux parameterizations. An algorithm is described that produces accurate fluxes from bulk measurements for the zero to 10 m/s wind speed range (Fairall et al. 1996a; Clayson et al. 1996). A paper was submitted summarizing the analysis of two of our existing datasets to obtain all terms of the TKE and scalar variance budget equations over the ocean (Edson and Fairall 1997); no significant differences were found between over land and over ocean functions. All terms were found to obey the theoretical MOS convective limit. A paper published on a new theoretical derivation of the convective limit for the marine atmospheric boundary layer where we show that gustiness associated with PBL-scale intermittency limits the instability of the surface layer and prevents scalar fluxes from approaching zero values as the vector wind approaches zero (Grachev et al. 1997). Also, a new method was developed for estimating the surface layer stability from bulk measurements that does not require iteration (Grachev and Fairall 1997). Two papers have appeared on air-sea interaction measurement and analysis techniques (Fairall et al. 1997; Edson et al. 1997).

Work also continues on non-standard processes. A paper has been published on the cool skin and the warm layer in the upper meter of the ocean; their influence on air-sea fluxes is on the order of 10 Wm^{-2} (Fairall et al. 1996b). A model was developed that allows bulk water temperature data to be corrected for warm layer and cool skin effects. A paper describing a nonlinear analysis for correlation and embedding dimensions of turbulence and radar ocean surface scattering time series for velocity-stress retrievals from radar data has been submitted (Palmer et al. 1997). In an analysis of RASEX data, J. Hare developed a similarity model for analysis of wind-wave and pressure-wave coupling. It was found that the assumed exponential decay of this coupling with height is a good approximation for covariance statistics but not for quadrature statistics (Hare et al. 1997).

IMPACT

The theoretical work on pressure and higher-order velocity turbulence statistics is the first significant advance in this area since the 50's. It is directly relevant to the key features of the MBL program: higher-order moments, structure functions, non-traditional analyses. The bulk flux routine incorporates many innovations (gustiness, cool skin and warm layer effects, proper convective functions, rain heat and momentum flux, Webb effect, and a critical Richardson number in unstable conventions); it is expected to become a community standard and should be incorporated into operational weather forecast models (e.g., the Navy's). The work done on structure functions and dissipation rates will improve understanding of the TKE budget over the ocean vs over the land; it will also lead to better inertial-dissipation flux estimates. We also expect future analyses to add greatly to knowledge of wind, wave, and flux relationships. Working jointly with Jim Edson, experimental techniques to measure fluxes from ships were advanced considerably over the last 4 years. The systems developed will greatly improve air-sea flux information in future field programs.

TRANSITIONS

As discussed above, the new bulk algorithm and bulk Richardson number parameterization could be adopted in Navy operational forecast models.

RELATED PROJECTS

This work is related to several other research projects in the ETL air-sea interaction group.

"Air-sea flux studies during TOGA-COARE", NOAA Climate and Global Change Program. This is an investigation of fluxes and flux parameterization methods in the tropical western Pacific. The emphasis is on short-term climate variability.

"Shipboard measurements of cloud-radiative properties in the tropical western Pacific", Department of Energy ARM program, (DE-AI02-92ER61366). This is a study of cloud forcing of the oceanic surface energy budget.

"Environmental sensing", DoD Advance Sensor Application Program (P.ETL.2090). Investigation of air-sea interaction aspects of remote sensing of the sea surface.

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