Surface Flux Formulations in the Coastal Zone

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LONG-TERM GOAL

Derive a new drag law and roughness length relationship for the coastal zone.

OBJECTIVES

Our primary objective is to isolate the influences of wave age and/or fetch on the drag coefficient and surface roughness length. This includes examination of the influence of internal boundary layer development on heat and momentum fluxes in the coastal zone, that can lead to large deviations from existing similarity theory. The second main objective is to replace the wave age with more specific wave properties. The final objective is to provide the data sets to other modeling groups.

APPROACH

Our initial objectives were realized by first quality-controlling the RASEX data and intercomparing fluxes between different levels. Different estimates of the "observed" roughness length using the profile method and eddy correlation were compared. Using the observed values of the drag coefficient and roughness height, different existing relationships were tested and new formulations for the transfer coefficients for heat and momentum were developed. The analysis has been extended to a much larger RASEX data set outside the intensive period, which includes a large sample of offshore internal boundary layer cases. The analysis has been applied to the FLIP data set.

WORK COMPLETED

During the past year, the dependence of the nondimensional shear on stability (z/L) was studied in detail from the RASEX data in order to focus more directly on the validity of Monin-Obukhov similarity. Monin-Obukhov similarity theory has been examined by other investigators with RASEX data for higher moment equations. However the nondimensional shear is the most crucial aspect of the similarity theory in that it leads to the stability functions in the bulk aerodynamic application used in virtually all numerical models. The results of this work are described in the next section.

We have finished analysis of the LongEZ Flip data and have determined that either flux measurement errors are substantial or the behavior of the momentum flux is severely complicated by swell with large directional differences from the wind vector. We have decided to concentrate on completing the analysis of RASEX data before returning to the LongEZ Flip data.

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RESULTS

We find that the largest scale turbulent eddies are suppressed in shallow convective internal boundary layers, leading to larger non-dimensional shear compared to the Monin-Obukhov (MO) prediction. Cospectra of the wind stress from the 6-m and 32-m levels support this theory in that lower frequency (large eddy) transport is indeed suppressed by shallow IBL depth (Figure 1). These data suggest that for the convective case, the nondimensional shear is less than predicted by traditional MO similarity but increases with increasing z/h, where h is the depth of the boundary layer.
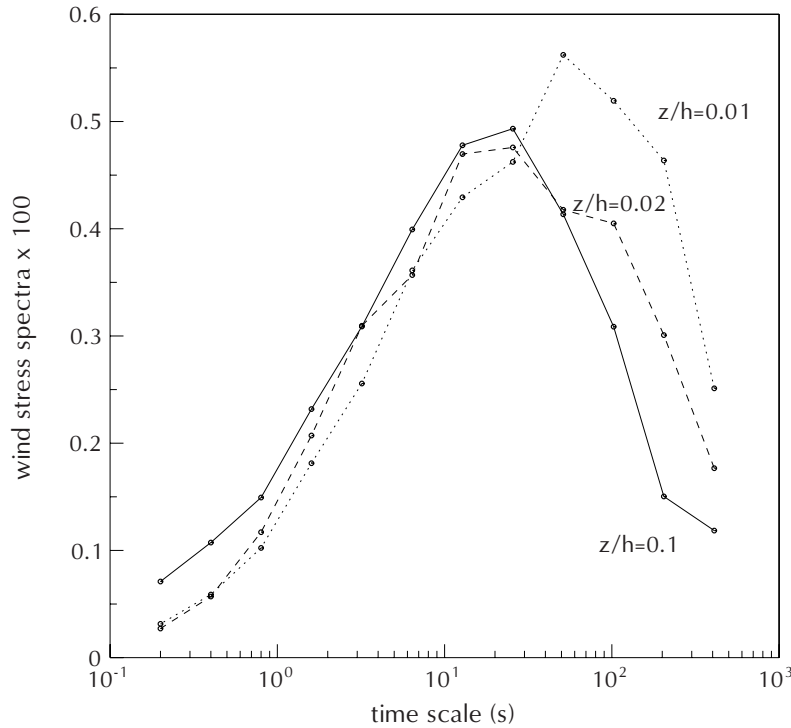

Figure 1. Average multi-resolution spectra of the 1 hour average kinematic wind stress (m^2/s^2) at the 6 m level for unstable conditions for z/h= 0.1 (solid), z/h= 0.02 (dashed) and z/h= 0.01 (dotted) where h is the parameterized internal boundary layer depth. The time scale axis represents the time scale of the stress.

In shallow stable boundary layers, elevated generation of turbulence associated with entrainment leads to smaller non-dimensional shear compared to the traditional prediction. We attribute this to the top-down nature of the turbulence in the presence of shallow stable IBLs in advective conditions where the stress decreases with height more slowly than the mean shear, or may even increase with height. This is apparently due to suppression of turbulence near the surface by the stratification in concert with shear-generation of turbulence aloft. However, advection of stress may also be important.

In stable stratification, smaller non-dimensional shear is clearly observed over young growing waves compared to older waves. We conclude that with the long adjustment time scale and weaker turbulence associated with stable stratification, the mean shear in the coastal zone does not completely adjust to the wind-wave coupling influence on the stress. The possible dependence of nondimensional shear on wave

age contradicts the assumption of MO similarity theory that the local flux-gradient relationship in the surface layer is independent of surface conditions. In this data set, the observation heights are well above the estimated wave boundary layer height so that dependence of nondimensional shear on wave state is not expected based on traditional MO similarity theory. More investigation is needed.

We have derived a sequence of models which describe the dependence of the nondimensional shear on stability, wave state, and the depth of the boundary layer. The combined influence of young waves and shallow stable IBL depth leads non-dimensional shear, which is substantially smaller (greater mixing) than predicted by Monin-Obukhov similarity theory. In this situation, the stress is large relative to the shear due to the wind-wave coupling influence and elevated generation of turbulence. This contrasts with the unstable case where shallow internal boundary layer depth suppressed mixing, leading to nondimensional shear which was greater than that predicted by Monin-Obukhov similarity theory.

IMPACT/APPLICATION

The above results seriously undermine the overall validity of Monin-Obukhov similarity theory in the coastal zone. From another point of view, the assumptions required by Monin-Obukhov similarity theory are not met. At the same time, the generalization of Monin-Obukhov similarity theory offered above cannot be considered as general. The data represents only one location, and the influences of wave state, stability and internal boundary layers have not been conclusively isolated. Our next strategy is to incorporate data from the Duck Shoaling Experiment and incorporate data from other existing data sets in order to evaluate the generality of the above results.

We are also converting the above results to new stability functions and parameterization of the roughness length for numerical models applied to the coastal zone. The initial philosophy is to employ traditional stability functions and modify the surface roughness length formulation to statistically accommodate the role of wave state and advection (internal boundary layers) in the coastal zone. We have formed a modelling group with investigators from NCAR, University of Oklahoma, NRL and Oregon State University, which will test the new formulations when we release them.

RELATED PROJECTS

Work on an ONR grant entitled "Spatial Variations of the Wave, Stress and Wind Fields in the Shoaling Zone" (N00014-97-1-0279) will conduct an additional field program at Duck, North Carolina in March of 1999. This program will concentrate on spatial variations in the coastal zone with offshore flow of warm air over cool water using the LongEZ aircraft.

PUBLICATIONS

Vickers, Dean and L. Mahrt, 1999: Monin-Obukhov similarity theory in the coastal zone. Submitted to the *Quart. J. of the Roy. Met. Soc.*

Vickers, Dean and L. Mahrt, 1999: Monin-Obukhov similarity theory in the coastal zone. 13th Conference on Boundary Layers and Turbulence. Amer. Met. Soc.