13.1 IMPROVEMENT OF THE BULK FORMULA IN WEAK-WIND CONDITIONS

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1. INTRODUCTION

One of the goals of the CBLAST Weak-Wind Experiment was to examine sea-surface fluxes in weak winds. The number of cases of fluxes for weak-wind conditions was reduced by frequent fog development shortly after the onset of weak winds. Fog leads to condensation on the transducers of the sonic anemometers and unreliable or flagged data. None the less, enough data was captured to identify basic characteristics of the turbulent flow for weak wind conditions.

The weak-wind case is of considerable practical interest because it leads to poor dispersion and maintenance of high concentrations of contaminants in coastal zones. Weak winds can also lead to formation of dense fog over large areas, particularly with flow of warm air over cooler water. Weak-wind conditions over the sea often produce anomalous stress values due to interaction between the wind and wave field (e.g., Grachev et al., 2003). This paper concentrates on the influence of the nonstationarity of the wind field in weak-wind conditions. With weak large-scale flow, "background" mesoscale motions emerge as a dominant influence, leading to meandering of the wind vector and invalidation of the usual flux parameterizations.

The background mesoscale motions may be due to inertial gravity waves or collapse of turbulence to two-dimensional modes followed by vortex merging (upscale energy transfer). Other mechanisms include convection waves (e.g., Kuettner et al., 1987), solitons (Sun et al., 2004), inactive eddies (Högström et al., 1999), longitudinal vorticies aligned with the wind direction, or, simple waves in the horizontal wind field (Oettl et al., 2005). However, most of our time series reveal structures much more complex than expected from the above mechanisms, perhaps due to superposition of different modes. We also find that the mesoscale motions in the boundary layer are characterized by highly variable spectra (Vickers and Mahrt, 2007), not amenable to practical spectral similarity theory.

In this study, we analyze turbulence data from the Air-Sea Interaction Tower (ASIT) collected during the CBLAST experiment in late summer of 2003, previously analyzed Edson et al. (2004). The offshore tower is located 3 km south of Martha's Vineyard in 15 m of water. 20-hz turbulence measurements were collected by a CSAT3 sonic anemometer (Campbell Scientific, Inc.).

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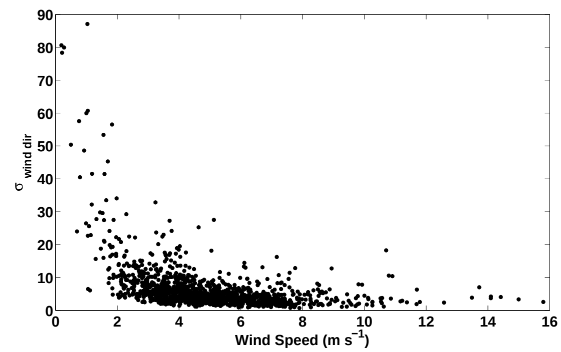

Figure 1: The dependence of the one-hour standard deviation of the 1-minute wind direction on the speed of the one-hour vector averaged wind.

The ASIT data indicate mesoscale activity comparable in strength to that over relatively flat homogeneous land surfaces. The strength of the mesoscale motions shows no dependence on wind direction. This general independence of wind direction suggests that the mesoscale motions are not due to proximity of the continent, although some mesoscale motions can propagate from land to sea regardless of the actual wind direction.

The within-record mesoscale variation of velocity vector is quantified by defining the mesoscale flow as the variation on time scales between the largest turbulence scales and the record length, here one hour

$$\tilde{u} \equiv \overline{u} - [u]; \;\; \tilde{v} = \overline{v} - [v]; \qquad (1)$$

where the overbar signifies averaging over the subrecord of length τ. The component $\tilde{u}$ is the nonturbulent deviation from the record average $[u]$ and so forth.

A meso-velocity scale for the mesoscale flow is defined as

$$V_{meso} \equiv [(\tilde{u}^2 + \tilde{v}^2)^{1/2}] \qquad (2)$$

This velocity scale can be derived in terms of the augmentation of the wind by the mesoscale flow (Mahrt, 2007). V_{meso} is closely related, but not equal to, the

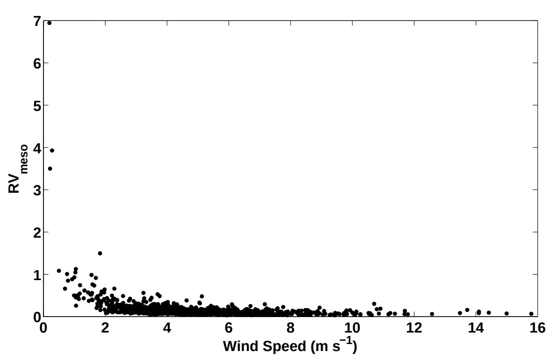

Figure 2: The relative meso-velocity scale as a function of wind speed .

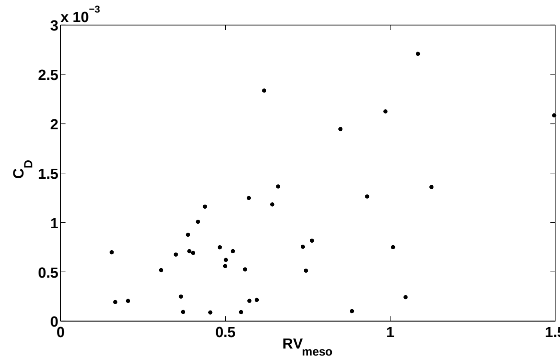

Figure 3: The drag coefficient as a function of the relative meso-velocity scale for winds less than 1.5 ms^{-1}. Five points are offscale.

square root of the kinetic energy of the mesoscale flow. Although, we use a variable averaging width to define the turbulence (Vickers and Mahrt, 2006), the mesoscale motion here is defined as all motions on scales between 1 minute and one hour. The fixed range of time scales avoids between-record differences in the range of mesoscale motions, but leads to an inconsistency in terms of simple Reynolds averaging. The meso-velocity scale for the ASIT data averages about 0.5 ms^{-1}, similar to averaged values that we have computed over relatively flat land surfaces.

As found in Anfossi et al. (2005), the strength of the mesoscale flow shows no obvious dependence on wind speed. As a result, the mesoscale motions become important when the speed of the large-scale flow becomes sufficiently small, $< 1.5ms^{-1}$ in Anfossi et al. (2005). Similar behavior is observed here. As a consequence, the subrecord standard deviation of the wind direction increases with decreasing wind speed and becomes large as the speed of the large scale flow decreases below about $1.5ms^{-1}$ (Figure 1).

The importance of the subrecord mesoscale motion can be assessed by scaling V_{meso} by the speed of the one-hour record-averaged wind, to define the relative meso-velocity scale

$$RV_{meso} \equiv \frac{V_{meso}}{[u]} \quad (3)$$

Since the meso-velocity scale is relatively independent of wind speed, the relative meso-velocity scale increases rapidly for very weak winds ($< 1.5ms^{-1}$) and becomes as large as 7 for very weak winds, less than $< 0.5ms^{-1}$ (Figure 2).

For weak winds ($1.5 < ms^{-1}$), the drag coefficient appears to increases with increasing relative meso-velocity scale (Figure 3), although the large scatter prevents conclusions. The mesoscale flow not only enhances the shear-generation of turbulence, but the mesoscale variation of the wind field prevents complete adjustment of the wave field to the wind field. The high-frequency part of the wave field is constantly adjusting analogous to fetch limited flows in the spatial domain. The large scatter in Figure 3 could be due such wave effects and large flux errors for cases of weak turbulence. Further investigation is required with additional data sets.

2. FUTURE

We are currently modifying the bulk formula to include the impact of unresolved mesoscale motions on the surface fluxes for weak-wind conditions, mathematically similar to generalization of the bulk formula for vanishing wind speed in Beljaars (1995), Fairall et al. (1996) and Williams (2001). Here, the generalization of the bulk formula must include the influence of a wide variety of mesoscale motions that are prevalent in stable conditions. Incorporation of information on wave activity is required for meaningful development.

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