11.1 ON THE VERTICAL TURBULENT STRUCTURE OF THE MARINE ATMOSPHERIC BOUNDARY LAYER

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1. INTRODUCTION

Acoustic Sounding has been proved a valuable tool for probing the Atmospheric Boundary Layer (ABL). With high temporal and spatial resolution, it is sometimes more desirable compared to single-level turbulence measurements in certain research areas of the ABL (Kallistratova and Coulter, 2004). The ability of Acoustic Sounders (SODARS) to measure variances of the wind speed components and turbulent fluxes and to determine turbulence characteristics and scaling parameters is of great interest for ABL numerical modeling and ABL parameterizations, under different meteorological conditions (Coulter and Kallistratova, 2004). An attempt to use SODAR for measurements of momentum flux and turbulence kinetic energy (TKE) profiles was made by Kramar and Kallistratova (1998) and Kramar and Kouznetskov (2002) using the semi empirical theory of turbulence together with measurements of profiles of mean wind speed and variances of wind components. Kouznetsov et al (2004) suggested the possible use of SODAR measurements of σ^2_w to derive turbulence parameter profiles (TKE and momentum flux), using a simple parameterization for the estimation of TKE and momentum flux profiles, based on SODAR measurements, under near neutral conditions.

It is the purpose of this work to give information on the vertical turbulent structure of the Marine Atmospheric Boundary Layer (MABL) using mainly SODAR data obtained at Nantucket Island during summer 2003 in the frame of the CBLAST-Low project.

2. EXPERIMENTAL AREA AND INSTRUMENTATION

In the frame of the Coupled Boundary Layers and Air Sea Transfer Program (CBLAST)-Low, the vertical structure of the MABL was studied using both in situ (a 20-m mast equipped with slow and fast wind, temperature and humidity sensors) and remote sensing instrumentation (SODAR). The experimental campaign was carried out during summer 2003 (31st of July to 27th of August) at the Nantucket Island, MA, USA. The experimental instrumentation was installed at a location 90m from the southern coastline of the Nantucket Island, on a quite flat terrain with no rubs or other obstacles. A commercial (Remtech PA2) SODAR system was in operation using phase array transducers in order to support 3 - beam operation mode (Figure 1). In order to protect the antenna of the SODAR from the ambient acoustic noise (mainly from breaking sea waves) and to protect the nearby area from the emitted acoustic pulses, the SODAR was placed into a deep hole (2mX2mX1m) and shielded around with trusses of hay and wooden sheets. The orientation of the SODAR antenna was such that the system provides information on the vertical (w) and the two horizontal wind components, u (the northeastward component at 35^{O}) and v (the northwestward component at 305^{O}). The SODAR measurements yielded at 30 minute interval, the horizontal wind speed and direction, the vertical component of the wind w, the standard deviations of the three wind components, the momentum fluxes of the wind components ($\overline{u'w'}$ and $\overline{v'w'}$) and the atmospheric static stability up to the height of 800m. The total vertical momentum flux, the turbulent kinetic energy (TKE) and the turbulence intensity for the three wind components were also calculated.

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Information on the in-situ instrumentation is given by Wang et al (2004) presentation at the same Symposium. In this work initial results regarding the MABL structure using data from the SODAR (up to 400m height) and from the sonic anemometer (at 20m height) for the 15th of August are presented. The sonic anemometer was measuring the three components of the wind, the sonic temperature and related quantities.

Figure1: The antenna of the SODAR system

3. RESULTS AND DISCUSSION

The 15th of August was characterized by low winds (3 to 4 m/s) up to 400m height blowing from south– westerly direction. Figure 2 gives the time height cross-section of the wind vectors for the time period 15:00 – 23:30 GMT. The wind vectors were calculated by the SODAR every thirty minutes.

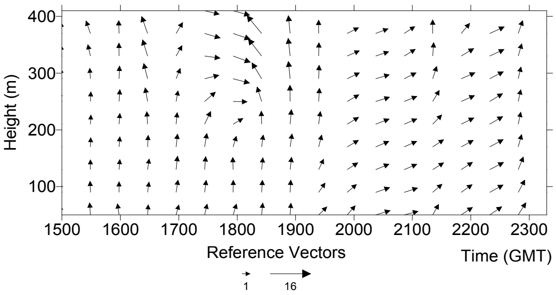

Figure 2: Time –height cross section of the wind vectors during 8/15/2003

According to this figure during midday hours the wind blows from the southern direction with low speeds up to the height of 400m. After 18:00 GMT a shift of the wind direction to the south - westerly sector with an increase in magnitude is evident.

The time height cross section of the wind speed is presented in Figure 3. An intense wind shear can be observed at higher levels during the transient period (17:00 – 19:00 GMT) when the shift of the wind direction was realized.

Figure 4 gives the time height cross-section of the stability class derived by the SODAR for the 15th of August. It should be mentioned that stability class 1 corresponds to stable atmospheric conditions, class 2 to slightly stable, class 3 to neutral and class 4 to slightly unstable conditions. According to this figure, during the period of the day characterized by southerly flow with low wind speed values, the atmospheric conditions are stable up to higher levels. Later on, during the transient period and the period that is characterized by southwesterly flow, the stable conditions are maintained at lower levels while neutral conditions are observed at higher levels associated with higher wind speed.

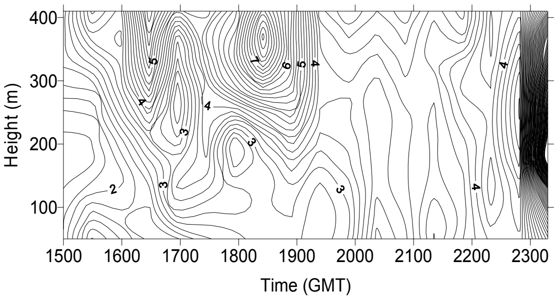

Figure 3: Time –height cross section of the wind speed during 8/15/2003

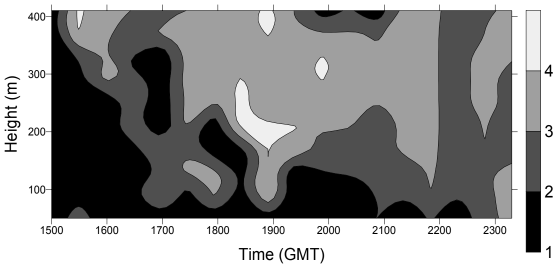

Figure 4: Time height cross-section of the stability class during 8/15/2003. Stability classes are given in the text

The time height cross-section of the variance σ^2_w of the vertical component of the wind speed is presented in Figure 5. According to Kouznetsov et al (2004) the fluctuations of the vertical wind component give an alternative method to derive TKE under neutral stratification. This TKE can be derived from σ^2_w using the relation $TKE \cong 3.4\,\sigma_w^2$ in the SODAR-covered part of the ABL, while under non-neutral conditions the coefficient of the relation should be a function of M-O stability parameter z/L. High level of turbulence is evident during the transient period and after 21:00 GMT when an increase of the wind speed is observed.

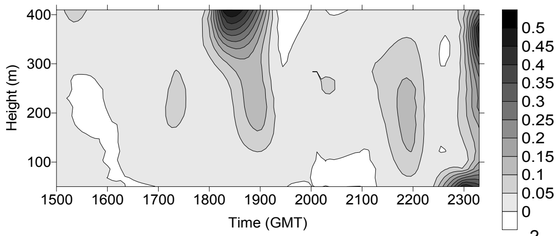

Figure 5: Time height cross-section of the σ^2_w during 8/15/2003.

The same characteristics are observed at Figure 6 that gives the sum of the momentum fluxes $\left[\left(\overline{u'w'}\right)^2+\left(\overline{v'w'}\right)^2\right]^{1/2}$ where intense momentum fluxes are evident at the same periods of time.

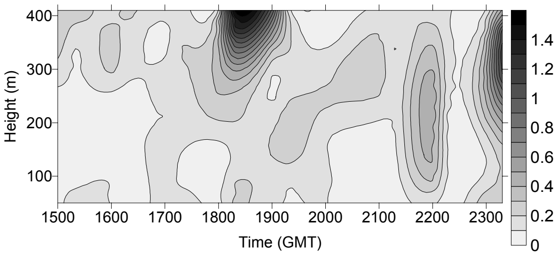

Figure 6: Time height cross-section of the sum of momentum fluxes during 8/15/2003.

Figure 7 gives an example of the development of a weak Low Level Jet (LLJ), which is observed often for cases with south-westerly flows. The LLJ is more intense under high wind conditions, leading to high values of positive momentum fluxes at higher levels (Helmis et al 2004). In this case at the 15th of August for the time period 20:00-21:00 (GMT) the wind flow is characterized by south-westerly direction with low wind speed (3-4m/s). In Figure 7 where the wind speed is normalized to the wind speed at 400m height (background flow) and the 20m measurement is calculated from the mast data, a wind maximum is evident at 50m height.

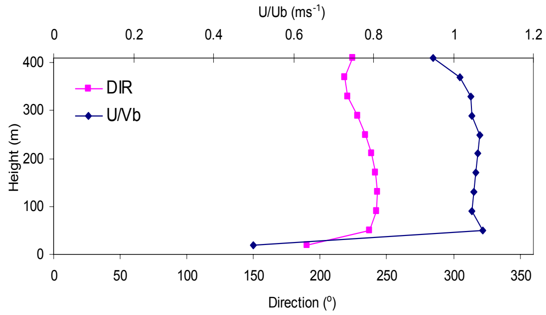

Figure 7: The normalized wind speed and direction at 8/15/2003 20:00-21:00 (GMT)

At Figure 8 the vertical profiles of the two components of the momentum fluxes $\overline{u'w'}$ and $\overline{v'w'}$ along with the turbulent variance σ^2_w of the vertical velocity normalized to the background flow V^2_b are given. The values of the momentum fluxes estimated by the sonic at 20 m are also incorporated in the figure. Negative values close to the ground are observed while large values of fluxes with positive and negative values for $\overline{u'w'}$ and $\overline{v'w'}$ respectively, as well as large values of turbulence are evident at higher levels (150 - 300m), probably associated with the wind maximum observed at 50m. It should be mentioned that Deardroff (1973) has shown that when the surface stress is relatively small, a wind profile such as the one observed in Figure 7 can generate large stresses with enhanced positive values for $\overline{u'w'}$ and opposite sign values for $\overline{v'w'}$ through

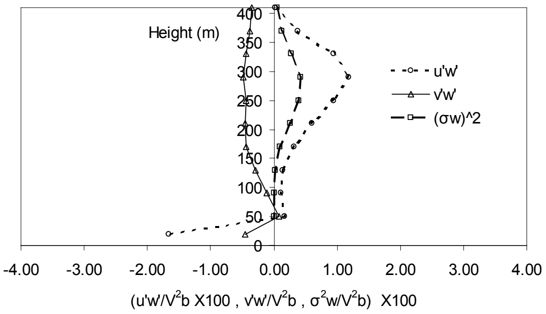

Figure 8: The normalized two components of the momentum fluxes and the variance of the vertical component of the wind speed at 8/15/2003 20:00-21:00 (GMT)

entrainment of momentum from above. Kaimal et al (1976) observed momentum flux profiles with increasing values in magnitude with height, reaching a maximum value near $0.5 z_i$ and decreasing above that height. Possible causes for this behavior that were suggested, are baroclinicity, entrainment of momentum from above or the influence of the averaging periods that they used. Li et al (1983) studying the structure of stable layers in the nocturnal lower atmosphere, observed upward vertical fluxes of longitudinal momentum, with its maximum values above the jet core. Smedman et al (1995) observed the presence of a pronounced LLJ at very low height (30 – 150m above the surface of the sea) that was characterized a marine stable boundary layer over coastal waters at the Baltic Sea. Finally it should be mentioned that these results are in agreement with Sullivan et al (2004) work where the influence of the swell on the development of LLJ and the turbulent structure of the MABL were studied using an LES model. In our case more data analysis for the influence of the wind speed and stability is needed, in order to determine the relative importance of the previously mentioned factors.

4. CONCLUDING REMARKS

We analyzed the measurements of mean wind and turbulence variances and fluxes from an acoustic radar (SODAR) to study the vertical structure of the atmospheric boundary layer near the coast of an island. The measurements revealed the variation of boundary layer stability and turbulence characteristics in response to background flow. The SODAR measurements also indicated large magnitude of momentum flux at higher levels, presumably associated with the shear forcing near the developed wind maximum. Thus the SODAR measurements proved to be valuable in understanding the boundary layer turbulence structure. Further study is underway to understand the momentum transport and the TKE balance of the jet-related boundary layer under different meteorological conditions, using more SODAR observations and other relevant measurements from this experiment.

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