An Experimental study of the wind vector, the temperature structure and the stability class of the Marine Atmospheric Boundary Layer using an Acoustic Sounder

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Abstract: - In the frame of the CBLAST-Low project the main characteristics of the vertical structure of the Marine Atmospheric Boundary Layer (MABL) up to the height of 600m was examined using both remote and in situ sensing instrumentation at the southern coast of the Nantucket Island, MA, USA, during the summer of 2003. During the experimental campaign, observations of the vertical structure of the MABL indicated the development, very frequently, of a Low-Level Jet (LLJ) at low heights, associated with very stable atmospheric conditions, characterized the first 150m followed by slight stable to neutral conditions at higher levels. Characteristics of the LLJ related to the echo strength (analogue to the temperature structure parameter C_T^2), the stability class and the wind vector calculated by the Acoustic Sounder (SODAR) are presented.

Key-Words: Acoustic Sounder, Marine Atmospheric Boundary Layer, Mean Structure

1 Introduction

In the recent years, the study of the Marine Atmospheric Boundary Layer (MABL) has been the topic of main interest for atmospheric physics. In this frame, the CBLAST-Low project aims at understanding of the air-sea interaction and the coupled atmospheric and oceanic boundary layer dynamics at low wind speeds, where the dynamic processes are driven and/or strongly modulated by thermal forcing [1]. As part of the CBLAST-Low experiment, we made extensive ground-based measurements on Nantucket Island, MA, USA, during summer 2003. The main objectives of the measurements were to study the turbulent vertical structure of the MABL, to characterize atmospheric boundary layers in a variety of meteorological conditions, and to evaluate mesoscale models (COAMPS^{TM}). Our measurement site was on the western side of the island, at a distance of 90m from the waterfront where the land surface was relatively flat [2].

The ability of SODARS to measure the mean and the turbulent components of the wind speed as well as the temperature structure parameter C_T^2 is well known [3], [4]. Also using SODAR measurements of the profiles of mean wind speed and variances of the wind components, the estimation of Turbulent kinetic energy (TKE) and momentum flux profiles is possible, under near neutral conditions [5], [6].

During the experimental campaign a SODAR system, a laser ceilometer, a 20m meteorological mast equipped with slow and fast sensors at three levels and radiosondes launched every four to six hours per day were used. The SODAR (a Remtech PA2 Acoustic Radar system) was measuring the vertical profiles of the horizontal wind speed and direction, the vertical (w), the standard deviations of the three wind components and the atmospheric stability class. More details regarding SODAR system and it parameters can be found at [7]. In this work data from the SODAR were used to study the vertical structure of the LLJ observed during the 3rd of August, 2003.

2 Results and discussion

In order to study the vertical structure of the MABL under the development of LLJ, initial results using data from the SODAR (up to 600m height) for the 3rd of August, 2003 are presented. The 3rd of August is characterized during midnight with intense south-westerly flow (marine sector), which is persisting for the whole day.

Figures 1 and 2 give the atmospheric stability class derived from the Sodar during this day. Stability classes 1, 2, 3, and 4 correspond to stable, slightly stable, neutral, and slightly unstable thermal stratification respectively. Very stable atmospheric conditions characterize the first 150m followed by slight stable to neutral conditions at higher levels.

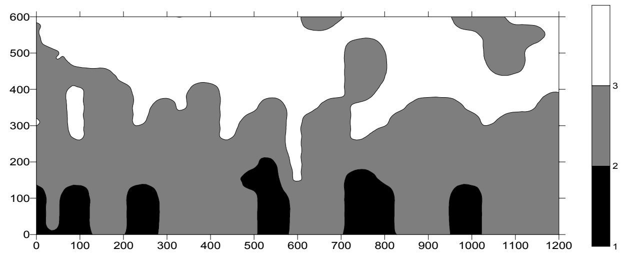

Fig. 1: Time-height cross-section of the atmospheric stability during 3/8/2003 00:00 – 12:00. Stability classes are given in the text. Time is UTC.

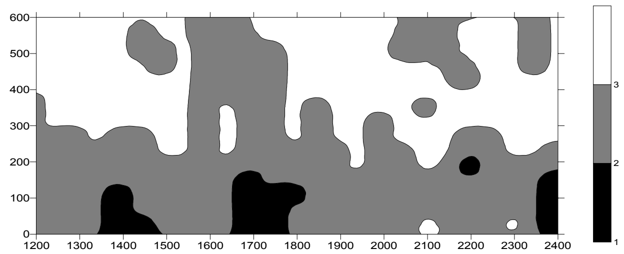

Fig. 2: Time-height cross-section of the atmospheric stability during 3/8/2003 12:00 – 24:00 UTC.

Figures 3 and 4 give the time height cross section of the wind vectors for the same period. It is evident from this figure that the wind during the period between 00:30 UTC to 8:00 UTC with south-westerly flow characterized by low to moderate wind is changing to an intense south-westerly flow covering a height of 600m. Conversion from UTC to LST requires a subtraction of 4 hours (LST = UTC - 4hr).

The time - height cross section of the wind speed for the 3rd of August is given in Figures 5 and 6. During the period from 04:30 UTC to 12:00 UTC a LLJ is developed at heights between 200-250m while after 17:00 UTC two LLJs are developed at 150 and 400m respectively. These two LLJs gradually descend to the height of 100 and 250m correspondingly, while their strength is increasing.

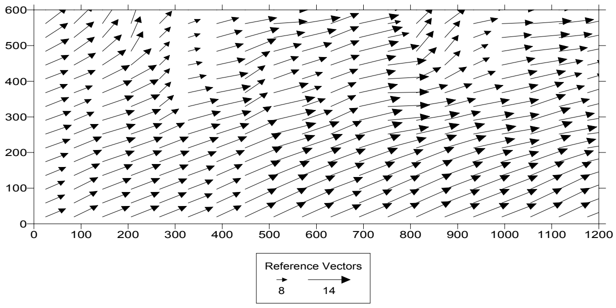

Fig. 3: Time-height cross-section of the wind vectors during 3/8/2003.

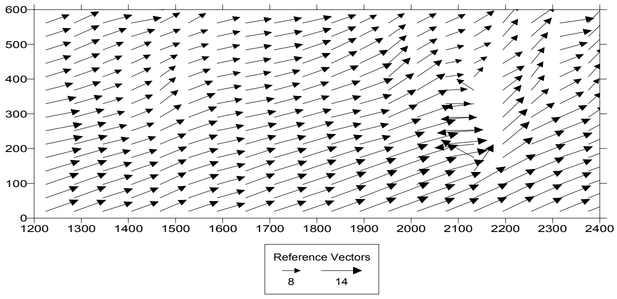

Fig. 4: Time-height cross section of the wind vectors (m/sec) during 3/8/2003 12:00 – 24:00 UTC.

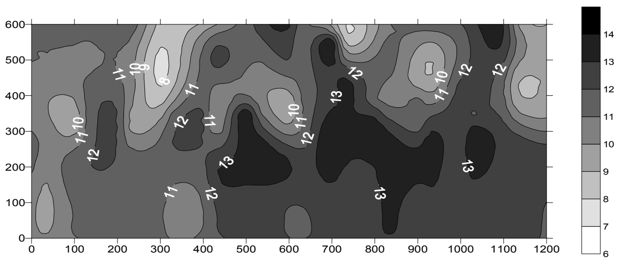

Fig. 5: Time-height cross-section of the wind speed during 3/8/2003 00:00 – 12:00 UTC.

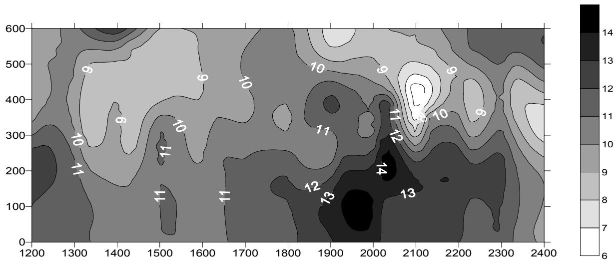

Fig. 6: Time-height cross-section of the wind speed during 3/8/2003 12:00 – 24:00 UTC.

The development and characteristics of the marine LLJ have been observed and studied under various conditions. It was found, according to the literature, that a large scale horizontal temperature contrast causing baroclinicity in the ABL [8] or an inertial oscillation due to frictional decoupling over the sea [9], are possible causes of the LLJ. In our case, where very stable stratification is characterized the lower part of the ABL, the main mechanism is likely to be the frictional decoupling and the subsequent inertial oscillation, although horizontal temperature gradients were no doubt present.

At Figures 7 and 8 the time-height plot of the echo strength (analogue to the temperature structure parameter C_T^2) calculated by the SODAR for the same period is presented. A strong echo maximum (corresponding to the base of an inversion) is established at 350 – 400m height for the whole period while a secondary maximum is evident at a height of 150m most of the time. This is in accordance with the above mentioned mechanism, that LLJ should be located at the top of a strong ground based inversion.

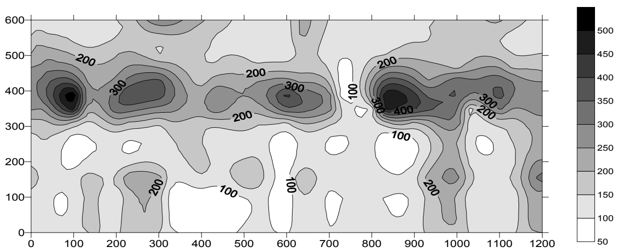

Fig. 7: Time-height cross section of the echo strength during 3/8/2003 00:00 – 12:00 UTC.

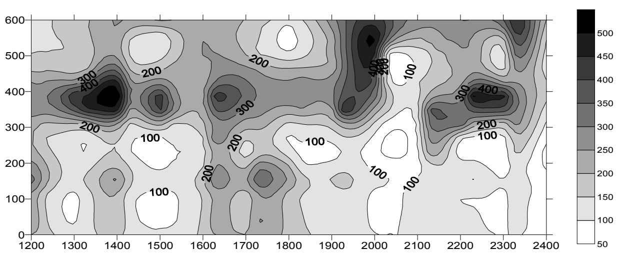

Fig. 8: Time-height cross section of the echo strength during 3/8/2003 12:00 – 24:00 UTC.

At Figures 9 and 10 the time height plot of the vertical wind component (w) calculated by the SODAR for the same period is presented. Upward motion is observed below and close to the LLJ core layer, while downward motion characterizes the surface layer. Above the LLJ layer a succession of upward and downward air mass motions is evident.

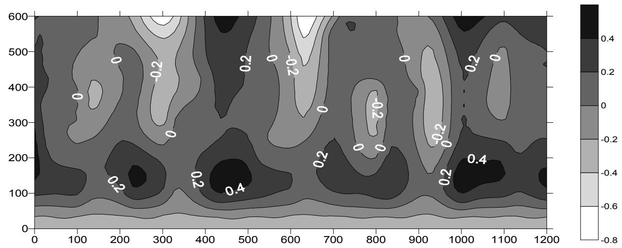

Fig. 9: Time-height cross section of the vertical wind component (w) during 3/8/2003 00:00 – 12:00 UTC.

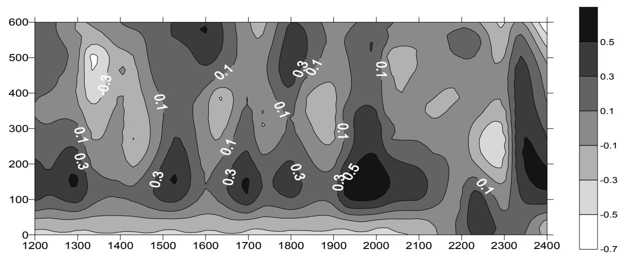

Fig. 10: Time-height cross section of the vertical wind component (w) during 3/8/2003 12:00 – 24:00 UTC.

3 Concluding Remarks

The analysis of the measurements revealed the following characteristics of the vertical structure of the MABL near the coast of an island:

- The MABL is characterized by strong to moderate stability at low levels while less stable and neutral atmospheric conditions appeared at higher levels.

- The LLJ observed at the first 500m above the strong surface based temperature inversion is developed probably due to the frictional decoupling and the subsequent inertial oscillation.

- The air flow just below and close to the LLJ core layer is characterized by upward motion, while downward motions are observed close to the surface. Above the LLJ layer and up to 600m height, a succession of intense positive and negative values is observed.

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