9.4 FINE SCALE TURBULENCES MEASUREMENTS IN CASES99 USING TRIPLE-HOT-FILM ANEMOMETERS

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1.0 INTRODUCTION

The basic ground-based turbulence and flux sensors used in the Cooperative Atmospheric Surface Exchange Study (CASES-99) were three-dimensional sonic anemometers (CSAT3, Campbell Scientific Inc.). Sonic anemometers are likely to have limited high frequency response when the turbulence scale is too small to be resolved by their 10 cm path length (Kaimal and Finnigan, 1994). Therefore, their use near the ground and in very stable conditions is in question. In these cases, a very small, fast response sensor is needed to resolve eddies responsible for transport. Hot- wire and hot-film anemometers are the only sensors currently available that meet these size and speed requirements.

Basic problems using hot-film technology in open air can be grouped as follows. (1) Those problems that are associated with voltage drift due to changing environmental temperatures. (2) Those problems that are associated with acceptable mean wind approach angles. Multi-film probes must be pointing into the wind. When the wind approach angle is large (>± 54.7^o from parallel to the probe axis for the probes used herein), flow interference by probe supports and adjacent -films makes the data unusable. Even at mean approach angles near parallel to the probe axis, fluctuating wind vector directions outside the acceptance cone in turbulent flows cause significant errors due to non-unique solutions to heat transfer equations. (3) Those problems that are associated with sensor calibration due to sensor response deviation from true cosine law, from film aging, from non-ideal probe geometry due to inherent construction error, and from difficult alignment in the field of the small size films.

2.0 METHODS

2.1 Measurements

Two levels of instruments were mounted on the 5.5 m tower measuring wind components and air temperature. At each level, 1.5 m and 5 m, a Campbell Scientific, Inc. (model CSAT3) 3-D sonic anemometer, a TSI, Inc. (model 1294-20) triple-hot-film anemometer, and a TSI, Inc. (model 1210) single cold film temperature sensor were mounted 5 cm apart on a common boom (Figure 1).

Triple-hot-film sensors consisted of three orthogonal films with a sensing length of approximately 1.5mm. The hot-film sensors were end flow types with cylindrical configuration.

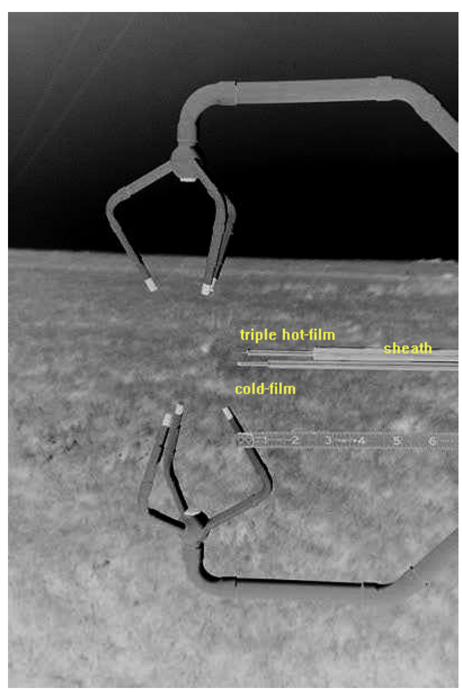
All probes were mounted on the East side of the tower and were leveled and checked regularly. The instruments at 1.5 m were lowered to 0.5 m on 19 October 1999 and remained at that level through 29 October. The sonic anemometer data were recorded at 20 Hz and the hot-film data at 200 Hz.

2.2 Rectification

In general, the voltage drift problem was handled in CASES-99 using an automated, continuous, zero-wind calibration system together with careful calibration in the University of Connecticut wind nozzle. Fluctuating wind vector directions were accommodated using corrections from co-located sonic anemometers Horizontal and vertical coordinate rotations outlined by Kaimal and Finnigan (1994) rotations were used to quantify mounting alignment errors.

2.3 Hot-film zero drift correction

The hot-film anemometers were retrofitted with an automated pneumatic wind shield system to periodically measure the zero wind speed output voltage (E_{0i}). The system was designed, built and first used in CASES99. Data in each 59-minute period were assigned an E_{0i} by averaging the E_{0i} voltage values proceeding and following the time period.



2. 4 Hot-film calibration

A free jet wind nozzle and pitot tube, described by Miller et al. (1989) were used to produce effective calibration velocities, V_{ei} for the hot-film sensors. A fourth-order polynomial equation was fit to the calibration data to provide the conversion from voltage to wind speed. Calibrations were performed before and after the experiment and were found to change very little.

2.5 Probe orientation error and rotation

Use of the collocated sensor for correction requires the hot-film and sonic probes be oriented exactly in the same planes. The field orientations of the collocated sonic and hot-film anemometer were not exactly coincident in three-dimensional space. Horizontal orientation of the two instruments was defined by the angle of the mean wind vector, computed by the sonic anemometer during an isolated event, when the wind vector was parallel to the probe axis. The two non-vertical hot-film sensors on the probe measure the same effective velocity, $V_{e2} \approx V_{e3}$, when the probe is oriented in the u_1–u_3 plane. In this situation, the wind approaches the two non-vertical sensors at the same incident yaw angle ($\phi_2 \approx \phi_3$). The time of an event when $V_{e2} \approx V_{e3}$ was isolated and the horizontal wind vector direction incident to the sonic anemometer axis was computed giving the correction angle.

2.6 Mean wind direction acceptance angles

Data were considered acceptable only when the mean wind approached the hot-film probe axis in its acceptance cone. The outer limit of the acceptance cone is defined by the angle where the mean wind vector approaches the probe axis < 54.74 degrees.

When the wind fluctuates outside the acceptance cone, the films do not change sign as the direction velocity vector passes normal to the individual films. In this situation, velocity vector magnitudes cannot be allocated correctly among the three components due to the lack of a negative sign in the velocity vector magnitude, V. Therefore, the sign of the individual effective cooling velocity vectors can not be determined directly by the instrument. In this study we resolved this problem by the use of the collocated sonic anemometer to provide a yaw angle correction for the individual films on the triple-film probe. The wind component resolution equations from Lakshminarayana (1982) and our corrections to them using the co-located sonic anemometer are detailed in Skelly et al. 2002.

3.0 HOT-FILM FLUX MEASUREMENTS

Comparison of turbulent kinetic energy (TKE) from the two sensors showed the hot-film measured values were about 15 to 20% higher than those from the sonics. Here in the TKE measurements there is a slight difference between day and night where the sonic to hot-film ratios are generally smaller at night. When the measurements are high enough above the ground that the local roughness does not have an effect (z = 5 m and z = 1.5 m) the differences are minimized during stable conditions. Near the ground (z = 0.5 m) in the roughness sublayer, the sonic to hot-film ratio increases significantly at night.

Friction velocities (u_*) from the sonic and hot-film were consistent during daytime convective boundary layers with the hot-film measurements higher than the sonics. This ratio changed from .85 at z = 5 m to .98 at z = 0.5 m demonstrating that the sonic and hot-film sensors reacted differently as the surface was approached and the scale of turbulence became smaller and more isotropic. We believe the sonic underestimated u* nearer the ground during the convective boundary conditions.

The two measurement systems demonstrated the most difference in heat flux measurements (H). At z = 5m, hot-film measured flux is higher than the sonic by about 30% in the day and 44% at night. We believe the major reason for this is our lack of "accurate" calibrations for the cold-film heat sensors. The effects of general stability and proximity to the ground on the $H_{sonic}/H_{hot\text{-}film}$ ratio indicated they were sensing different scales of turbulent fluctuations closer to the ground. Sometimes at night, during stable conditions, the hot-film measured heat flux actually changed sign very close to the surface whereas the sonic did not. This upward heat flux at night, very near the ground, was unexpected and we initially suspected the cold-film sensor but could find no malfunctions. We noted a frequent, very thin, cold air drainage layer just above the roughness sublayer, which could explain a divergence of sensible heat and the change in flux direction.

Literature Cited

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