10.2 REGIONS OF PERSISTENT INTENSE TURBULENCE IN THE RESIDUAL LAYER ARISING FROM AIRCRAFT ENGINE EXHAUST DURING CASES-99

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INTRODUCTION

The CASES-99 campaign in east-central Kansas included numerous measurement techniques for studying the nighttime stable boundary layer region. These techniques included the CIRES Tethered Lifting System (TLS) of the University of Colorado that profiled through the entire nighttime boundary layer (NBL) and well up into the residual layer (Balsley 2002; Frehlich 2002). On at least one occasion, the TLS documented a well-defined narrow region of surprisingly intense turbulence, with observed intensities three orders of magnitude larger than the ambient background level. This layer, which was located well above the top of the NBL in the residual layer between 185m and 195m, was associated with a slightly enhanced (~0.3 C) temperature “step” and contained ~ ± 0.2 m/s wind speed fluctuations.

Examination of the flight path of the University of Wyoming’s King Air showed that the aircraft had flown an east-west track close to the same altitude and approximately one kilometer upwind of the TLS observations, about three minutes earlier than the TLS observation.

The Argonne National Laboratory (ANL) sodar site, which was situated between the TLS and the aircraft track and slightly the east, showed unusually strong returns at the same heights some two minutes following passage of the aircraft. Further study of the sodar returns during the subsequent fifteen minutes, when the King Air had made two additional passes upwind of the ANL site showed two additional strong returns at the approximate heights determined from the aircrafts altimeter, and roughly one minute after the aircraft had passed.

In the upper panel of Figure 1 we have imposed the TLS ascent/descent path (black dotted lines) on a 20-minute range-time-intensity record of the sodar echo returns. Strong echoes in this plot appear as red traces, while the absence of measurable returns appears as a blue background. We have annotated a number of features in the panel for clarity: The regions of strong returns labeled “A/C Noise” correspond to interference when the King Air was at its closest approach to the sodar site. These returns arise from the wide-spectrum sound generated by the aircraft’s engines and received by the sodar. They are not true “echoes” in the sense that they would be present in the absence of a transmitted pulse. The strong returns indicated be the three upward pointing arrows, on the other hand, indicate regions of strong sodar echoes at the heights indicated (190m at 09:01:30, 230m at 09:07:20, and 160m at 09:16). (Note that the time scale in this panel is labeled in decimal hours, while the tick marks are scaled in minutes.)

The first three bottom panels in Figure 1 pertain to the period following the passage of the King Air at 08:59. The first panel show vertical profiles of sodar echo strength obtained over four seven-second intervals encompassing the occurrence of the 09:01:30 echo. The strongest of these profiles shows more then a 10 dB increase in echo strength relative to the background at a height centered on 175m.

The second for the left bottom panel shows a turbulence intensity profile (in this case, we have plotted the energy dissipation rate, ε). The height of maximum turbulence in this profile is 187m, and the width is significantly less than 10m (note that the TLS resolution is less than 1m, while the sodar resolution is approximately 15m). Furthermore, the peak turbulence intensity over background is well over three orders of magnitude (30dB). This is stronger than the turbulence level measured at the surface.

The third from the left panel shows vertical profiles of temperature, wind speed, and two separate turbulence quantities (energy dissipation rate (ε) and the temperature structure constant (C_T^2)). We have expanded the vertical scale to examine only the 40m region surrounding the turbulence maximum. Examination of this panel shows that the temperature structure surrounding the turbulence spike is reasonably smooth, with about a 0.3 C increase. The velocity, on the other hand, appears quite structured, with fluctuations on the order of ~ ± 0.2 m/s. Finally, the turbulence appears somewhat structured, with the more intense signals appearing in ε in contrast to C_T^2.

It is significant that similar detailed structures appear on the two other TLS sensors that passed through the same region a few tens of seconds later. While the general shape of the profile remained unchanged, the character of the fluctuations did not appear to be correlated between sensors.

In the fourth panel from the left, we show a set of profiles similar to those in the first panel, but obtained from the sodar echoes at 09:07:20. In this case, the profiles show a ~10 dB enhancement at roughly 240m at returns a minte or so after the King Air passed upwind of the sodar site at roughly the same altitude. TLS returns, while they show some evidence of an enhanced turbulence, are not as definitive. This is likely due to the fact that the turbulence packages were somewhat lower in altitude a minute after the sodar echo occurred.

Taking into account all of the above results, it appears more than reasonable that the observed enhanced turbulence "event" seen by the sodar at approximately 09:01:36, and the event seen by the TLS approximately one minute later arose from the aircraft engine exhaust being advected horizontally through the region occupied by the sodar and, subsequently, the TLS sensors.

This interpretation is confirmed by the observation of the second event seen by the sodar following the 09:06:30 King Air passage. In addition, although we have yet to analyze the sodar records following the third passage around 09:15, the presence of the enhance (red) returns about one minute following the upwind a/c passage appear comparable the the earlier two events.

We note that the above observations are quite serendipitous as far as the TLS records are concerned. it is reasonable to predict that remotely-sensed returns from a quiescent region such as the residual layer during CASES-99 can be markedly perturbed by advected aircraft exhaust trails drifting through the region. Specifically, enhanced echoes from advected turbulent engine exhausts can be anticipated to contaminate both sodar and FMCW radar records if these instruments are examining the same heights through which the (upwind) aircraft has flown earlier.

The above observations also illustrate the potential for using this type of observation for studying the gradual evolution of a well-confined turbulent region in the free atmosphere. Situating a suite of TLS sensors, sodars, FMCW radars, and possibly Doppler Lidars, at increasing distances downwind of an aircraft exhaust would enable a controlled temporal/spatial analysis of diffusion and transport of the turbulent trail. It would be also possible to monitor the evolution of the turbulent spectrum both within and nearby the trail.

REFERENCES

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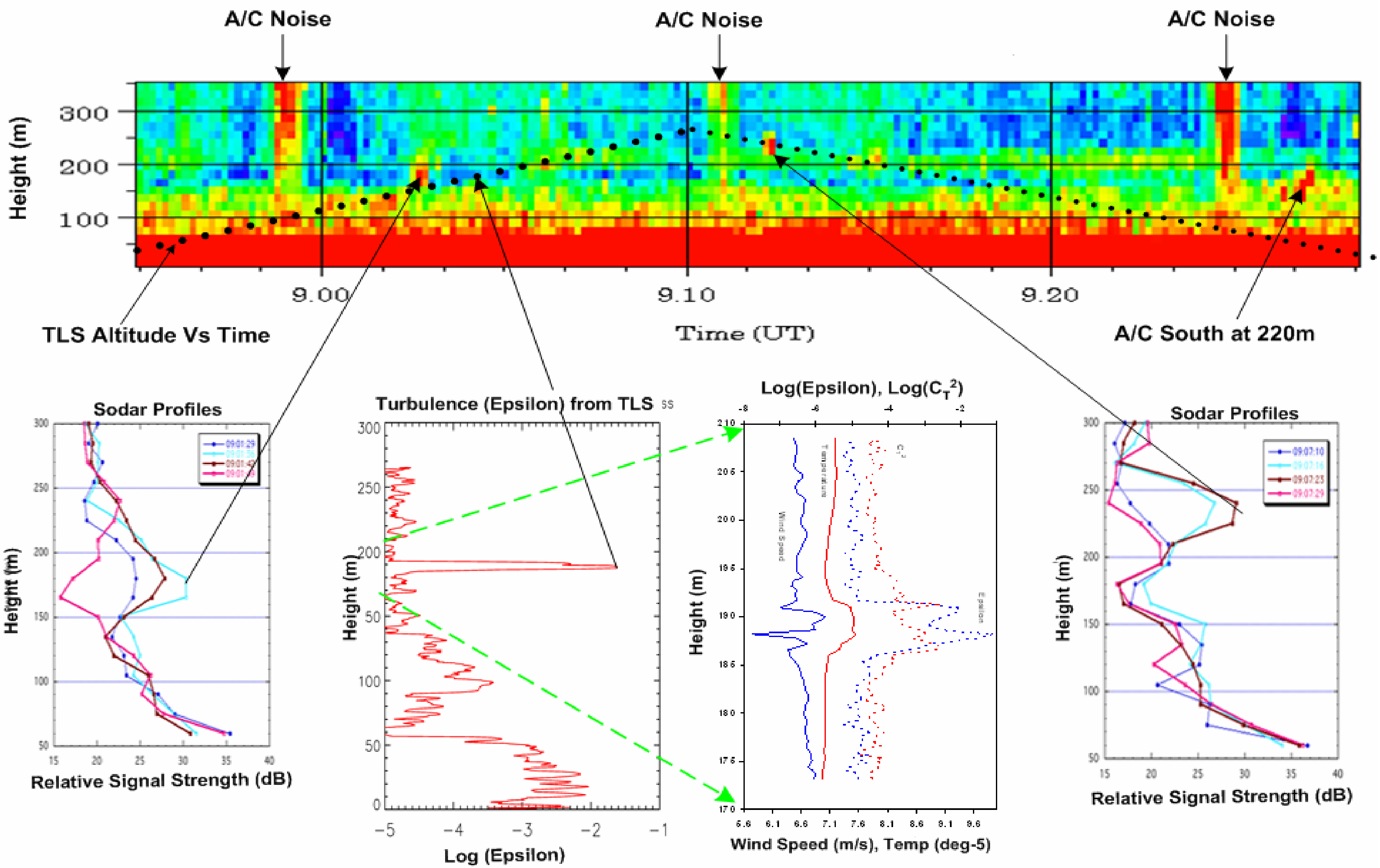

Figure 1. Composite of records from the sodar, TLS, and the height Vs time position of the TLS sensors. The colored panel at the top of the figure is a record of sodar echo intensity as a function of height and time on 20 October 1999, between 08:57 GMT and 09:17 GMT (note that hours are shown as decimal fractions, while the tick marks are plotted in minutes). The dotted line represent the ascent/descent of the TLS. Occurrence times of audible aircraft noise on the sodar record are shown and mark the times when the a/c was at its closest approach downwind of the sodar site. The 1st and last bottom panels show profiles of sodar echo intensity at times indicated by the arrows. The 2nd panel is a TLS profile showing an intense, narrow regions of extremely strong turbulence (energy dissipation rate, ε). The 3rd panel is a blowup of the 2nd panel, also showing wind speed and temperature fluctuations, as well as the enhanced regions of both ε and temperature structure constant (C_T^2).