Observations of Shear-Induced Turbulence using HARLIE

David O. Miller
Science and Engineering Services, Inc., Greenbelt, Maryland 20771

Geary K. Schwemmer
Laboratory for Atmospheres, NASA Goddard Space Flight Center, Greenbelt, Maryland 20771

Thomas D. Wilkerson, Jason Sanders
Utah State University, Logan, Utah

David Guerra
Saint Anselm College, Manchester, New Hampshire

Steven Moody
Orca Photonics, Inc., Seattle, Washington

ABSTRACT

Measurements of atmospheric aerosol structure were made using HARLIE (Holographic Airborne Rotating Lidar Instrument Experiment) during the HOLO-1 field campaign. The scanning ability of HARLIE affords a unique opportunity to view various atmospheric phenomena including several instances of shear-induced turbulence. Using the data collected using HARLIE and upper-air wind profiles the nature of the instabilities is discussed

1. Introduction

Shear-induced instabilities are a common occurrence in the atmosphere. Occurring between two stably-stratified layers, these instabilities amplify at the expense of the kinetic energy of the mean flow and dissipate their energy into small-scale turbulence. In the absence of continued forcing, this diffusion reduces the shear between the layers. However, if the forcing is lasting, these instabilities can continue for hours. Often referred to as clear-air turbulence, these instabilities have made themselves known to many commercial airline passengers.

During the HOLO-1 field campaign several instances of shear-induced instabilities were observed using HARLIE (Holographic Airborne Rotating Lidar Instrument Experiment). These observations are discussed by means of the data collected using HARLIE and the meteorological data for the period.

2. Instrument Description

HARLIE was constructed to test the feasibility of using holographic scanning receivers in lidar systems (Schwemmer, 1998). It uses a 40 cm diameter transmission holographic optical element (HOE, Figure 1b) as the collecting and focusing aperture. The HOE has a 45-degree diffraction angle and is rotated during operation resulting in a conical scan of the atmosphere. Figure 1a shows the transceiver assembly and electronics rack. Operating at the 1064 nm Nd:YAG wavelength, HARLIE is sensitive to atmospheric aerosols.

3. Experiment Environment

The principal objectives of the HOLO-1 campaign were to evaluate the performance of HARLIE and to aid in the development new applications for conical scanning aerosol lidars. One possible application is the derivation of wind profiles in the vertical by tracking the motions of aerosol structures.

The data presented here were collected on March 10, 1999, during the HOLO-1 field campaign held at the Space Dynamics Lab (SDL) in Logan, UT. Logan is located in Cache Valley approximately 100 km north of Salt Lake City, UT. The town sits an elevation of ~1400 m above sea level (ASL) at the foot of the Wasatch Mountain Range with nearby peaks reaching ~2700 m ASL. About 15 km to the west of Logan is the Wellsville Mountain Range with peaks reaching ~2850 m ASL. These mountain ranges play an important role in the atmospheric dynamics of Cache Valley.

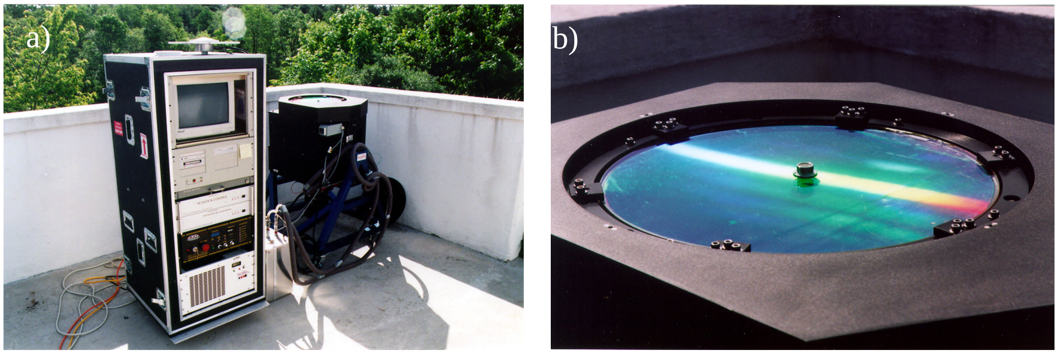

Figure 1: HARLIE electronics rack and transceiver (a) and HOE (b).

In-situ measurements of atmospheric parameters (e.g., temperature, humidity, and winds) were not taken during HOLO-1. Meteorological data from the nearest National Weather Service observing site, located in Salt Lake City, is used in this discussion.

4. Observations

Referring to the 1200 UTC upper-air soundings, there was strong wind shear in the vertical between 500 mb (~5.6 km ASL) and 300 mb (~9.2 km ASL). The hodograph from Salt Lake City (Figure 2a) shows the wind direction and velocity in knots plotted beside each level.

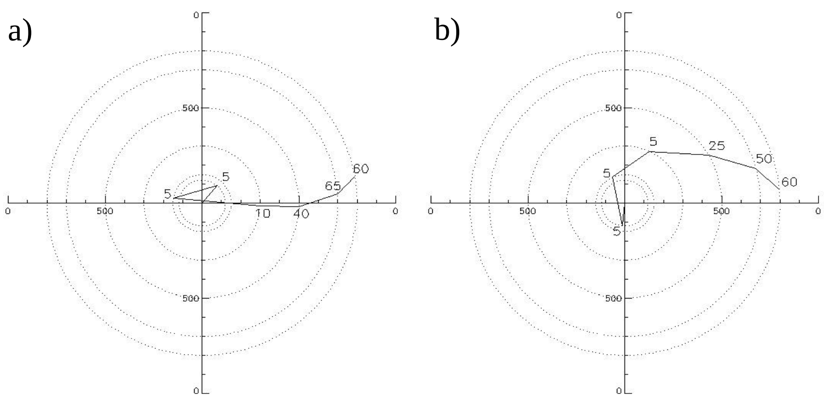

Figure 2: Hodograph from 310/99 at 1200 UTC (a) and 3/11/99 at 0000 UTC (b) for Salt Lake City, UT. The wind velocity (knots) is indicated adjacent to the directional points.

Strong vertical wind shear frequently produces shear instabilities between stably-stratified layers ($\delta\rho/\delta z < 0$). The instabilities begin as undulations in the interface between the layers, and, if the forcing continues, the instabilities at the interface amplify. Occasionally, the instabilities will roll up into billows often referred to as Kelvin-Helmholtz (K-H) waves. A striking example of this is shown in Figure 3 at 9 km ASL.

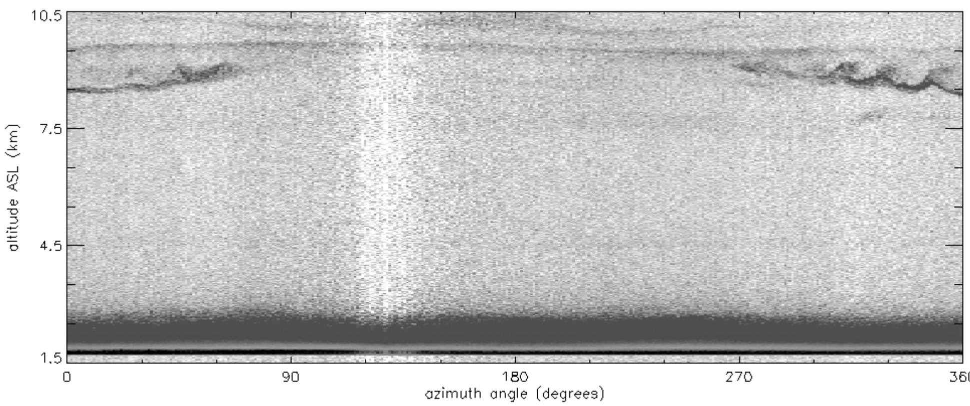

Figure 3: Atmospheric scan showing Kelvin-Helmholtz waves between 8.5 and 9.5 km ASL.

The waves grow at the expense of the kinetic energy of the mean flow and eventual break down into small-scale turbulence. The waves illustrated in Figure 3 occurred at a typical cruising altitude of commercial aircraft. However, the turbulence felt on airplanes in flight is due to the small-scale turbulence not the large billows (Wallace and Hobbs, 1977).

Another example of shear-induced turbulence occurred later in the day, between 2300-0100 UTC. There was both velocity and directional vertical shear present as seen in Figure 2b between 700 (~3 km ASL) and 500 (~5.6 km ASL) mb. As the afternoon progressed, the bottom interface of the layer begins to undulate (Figure 4). Figure 5 shows the eventual breakdown of the bottom interface into turbulence. The general wavelike appearance of the layer is caused by the southeasterly flow (at 850mb) over the Wasatch Mountains.

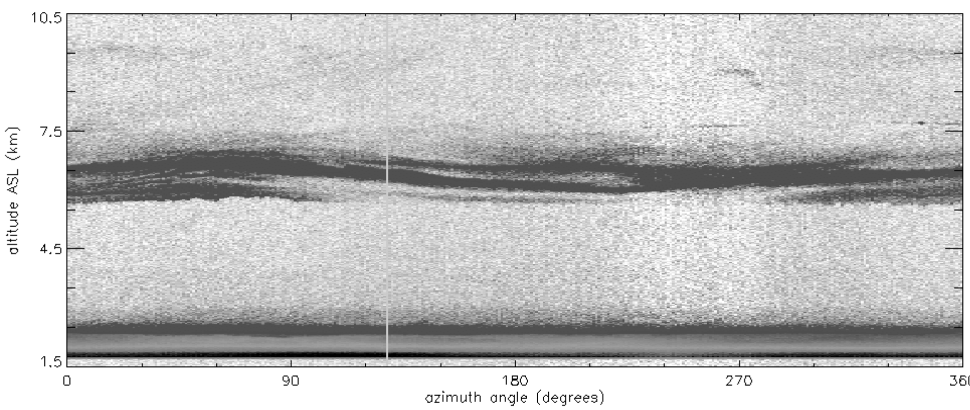

Figure 4: Atmospheric scan showing shear-induced undulation at the bottom interface of the layer at 6 km ASL.

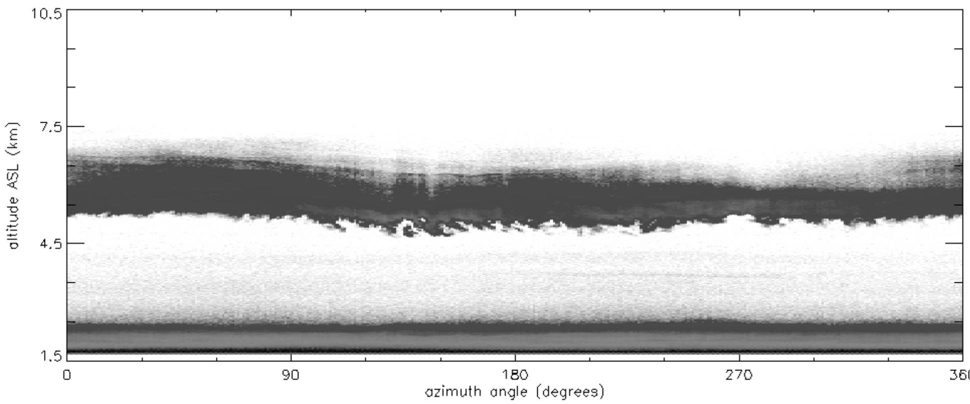

Figure 5: Atmospheric scan showing the breakdown of the bottom interface of the layer into turbulence.

5. Conclusions

Shear-induced instabilities play an important role in the transfer of momentum in the atmosphere. Several cases of instabilities were observed via HARLIE, a scanning-lidar system based on a holographic optical element. These cases were discussed in the context of the meteorological environment of when they were observed. Future work includes using data collected via HARLIE and more frequent local-weather observations to perform a more quantitative treatment of these types of events.

6. Acknowledgments

The authors wish to thank the NASA Cross-Cutting Technology and SBIR programs for supporting this effort. We also appreciate the effort of all those involved with the field campaign and data analysis.

References

Schwemmer, G. K.: 1998, 'Holographic Airborne Rotating Lidar Instrument Experiment (HARLIE)', *Nineteenth International Laser Radar Conference, Proc.*, 6-10 July 1998, Annapolis MD, NASA/CP-1998-207671/PT2, 623-626.

Stull, R. B.: 1994, '*An Introduction to Boundary Layer Meteorology*', Kluwer Academic Publishers, Netherlands, 666 pp.

Wallace, J. M., and P. V. Hobbs: 1977, '*Atmospheric Science: an Introductory Survey*', Academic Press, San Diego, 467 pp.