

REPORT DOCUMENTATION PAGE

Form Approved
OMB NO. 0704-0188

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1. AGENCY USE ONLY (Leave Blank)		2. REPORT DATE Nov 4, 2002	3. REPORT TYPE AND DATES COVERED Final: 9/21/98 - 6/30/02	
4. TITLE AND SUBTITLE High-Resolution S-band Profiling of the Atmospheric Boundary Layer			5. FUNDING NUMBERS DAAG55-98-1-0513	
6. AUTHOR(S) Stephen J. Frasier (PI)				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Elec. & Comp. Engr., U. Massachusetts, Amherst, MA 01003			8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) U. S. Army Research Office P.O. Box 12211 Research Triangle Park, NC 27709-2211			10. SPONSORING / MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision, unless so designated by other documentation.				
12 a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution unlimited.			12 b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) An S-Band FMCW atmospheric radar was constructed, tested, and operated during the 1999 Cooperative Atmosphere Surface Exchange Study nocturnal boundary layer experiment (CASES-99). There the radar system provided real-time guidance to research aircraft and other sensors in locating gradients and turbulent layers. We participated in three subsequent CASES workshops and submitted a journal paper describing the instrument and initial CASES results. Finally, we have performed coordinated observations with the TEP radar at Amherst during 2001 and 2002.				
14. SUBJECT TERMS FMCW, Radar, Atmospheric Boundary Layer			15. NUMBER OF PAGES 12 (inclusive)	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OR REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION ON THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT UL	

NSN 7540-01-280-5500

Standard Form 298 (Rev.2-89)
Prescribed by ANSI Std. 239-18
298-102

Enclosure 1

**FINAL REPORT:
ARO Grant DAAG-55-98-1-0513: “High Resolution S-Band Profiling of the
Atmospheric Boundary Layer”**

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Submitted to

Army Research Office

November 4, 2002

Abstract

An S-Band FMCW atmospheric radar was constructed, tested, and operated during the 1999 Cooperative Atmosphere Surface Exchange Study nocturnal boundary layer experiment (CASES-99). There the radar system provided real-time guidance to research aircraft and other sensors in locating gradients and turbulent layers. We participated in three subsequent CASES workshops and submitted a journal paper describing the instrument and initial CASES results. Finally, we have performed coordinated observations with the TEP radar at Amherst during 2001 and 2002.

Contents

1	List of Manuscripts	3
2	Scientific Personnel	3
3	Report of Inventions	3
4	Scientific Progress and Accomplishments	4
4.1	Scientific Objectives	4
4.2	Approach	4
4.3	Tasks Completed	4
4.4	Scientific Results	5
5	Technology Transfer	6

List of Figures

- 1 Evening transition observed on October 19, 1999. Local time is UTC - 5 hours. . . . 6
- 2 Top: Kelvin-Helmholtz billows observed in the residual layer in the evening of October 26, 1999. Bottom: Shear-induced turbulence driven by a low-level jet (confirmed by radiosonde) that developed above 200 m later in the evening. 7
- 3 Adaptive median filter separation of boundary layer radar echo into Bragg-dominated (top) and Rayleigh-dominated (bottom) components. 8
- 4 TOP: View of the Tilson Farm field site at UMass. Visible are a 20' tower with a 3D sonic anemometer, a Doppler sodar (on right), FMCW radar, and TEP array (behind FMCW). BOTTOM: Closeup of the FMCW radar antennas. 9
- 5 Top: FMCW time-height cross section of 20 minutes of early afternoon boundary layer on Oct 4, 2001. The lower portion of the images shows a heavily insect-laden mixed layer developing towards a capping inversion. Bottom: Corresponding TEP image shows same clear-air structure though with coarser resolution. Note reduced sensitivity to insects. 10
- 6 Top: 3-hour FMCW time-height cross section of late morning and early afternoon CBL development on Oct 4, 2001. (The FMCW image of the previous figure corresponds to the tail-end of this segment) Bottom: Late evening to early morning October 4-5, 2001 shows intermittent elevated layers. The bright band from 100-200 m is due to ground clutter from surrounding trees. 11

1 List of Manuscripts

1. Ince, T., S.J. Frasier, A. Muschinski, A.L. Pazmany (2002 submitted), “An S-band FMCW Boundary Layer Profiler: Description and Initial Results”, submitted to *Radio Sci*, June 2002.
2. Sun, J., D.H. Lenschow, S.P. Burns, R. Banta, R. Coulter, S. Frasier, T. Ince, C. Nappo, B. Balsley, M. Jensen, D. Miller, B. Skelly, J. Cuxart, W. Blumen, X. Lee, X-Z Hu (2002), “Intermittent Turbulence in Stable Boundary Layers and its Relationship to Density Current”, to appear in *Boundary Layer Meteorology*, Oct 2000.
3. Ince, T., A.L. Pazmany, S.J. Frasier, “High resolution Profiling of the Atmospheric Boundary Layer”, *2000 International Geoscience and Remote Sensing Symposium (IGARSS'2000)*, Honolulu, Hawaii, July, 2000, IEEE.
4. Ince, T., J. Li, F.J. Lopez-Dekker, A.L. Pazmany, S.J. Frasier, “Radar Observations of the Stable Boundary Layer During CASES'99”, 14th Symposium on Boundary Layers and Turbulence”, Snowmass, CO, Aug 2000, American Meteorological Society, pp. 355-357.
5. Ince, T., A.L. Pazmany, S.J. Frasier, R.E. McIntosh, 1998: A high resolution FMCW S-band radar for boundary layer profiling and cloud applications, *Proceedings of the Battlespace Atmospheric and Cloud Impacts on Military Operations Conference*, P. Tattleman, Ed., Air Force Research Laboratory, AFRL-VS-HA-TR-98-0103, Environmental Research Papers, No. 1217.

2 Scientific Personnel

1. Stephen J. Frasier, Principal Investigator
2. Andrew L. Pazmany, Research Assoc. Professor
3. Turker Ince (PhD Sept. 2001, “Clear-Air Radar Observations of the Atmospheric Boundary Layer”, U. Massachusetts, Amherst)
4. Apoorva Bajaj (MS student)

3 Report of Inventions

None.

4 Scientific Progress and Accomplishments

4.1 Scientific Objectives

The overall objective of our research program is to obtain a better understanding of the fine-scale structure of the ABL through the use of high-resolution radar techniques.

4.2 Approach

Our approach has been to (1) build, test, and evaluate the operation of an S-band FMCW radar for high-resolution profiling of the ABL, (2) participate in a joint field experiment with the Turbulent Eddy Profiler (TEP) radar and other research instrumentation, and (3) compare S-band measurements with simultaneous UHF measurements and interpret results with respect to grid-scale vs. subgrid-scale turbulence and intermittency.

4.3 Tasks Completed

During 1998 we focused on construction of the S-band FMCW radar's RF electronics and data acquisition systems. PC-based control software and real-time DSP software was written and tested. Testing of the complete radar system commenced in the spring of 1999.

In September 1999, we transported the system to Leon, KS to participate in the CASES'99 experiment during the month of October. There, the radar operated during 11 Intensive Observation Periods (IOPs) and produced real-time imagery of a variety daytime and nocturnal boundary layer features including Kelvin-Helmholtz instabilities, gravity waves, and convection. Real-time images were used to guide research aircraft to sample these features with on-board instrumentation. The FMCW radar was colocated with the TEP radar to allow intercomparison of UHF and S-band observations at different spatial scales. Summary observations of the S-band radar were transmitted to the JOSS CASES'99 website.

Collected data were processed to 5 second averaged profiles. Both radar images (GIFs) and data (NetCDF format) were provided to the NCAR JOSS data archive in May 2000. Since then, we have been working with other CASES investigators in studying particular events in various IOPs. Preliminary results were reported in two conferences, IGARSS 2000 and the 2000 AMS Boundary Layers and Turbulence Symposium.

During 2001 we have continued in analysis of CASES observations with the FMCW through participation in two CASES workshops. A manuscript was completed. We have also used the

summer/fall of 2001 to obtain coordinated measurements with the FMCW radar and the TEP radar at our Amherst field site.

Two observation periods were conducted: One during August and one during October 2001. During the August test, collaborators from NOAA/ETL and from U. Nebraska-Lincoln were present. During these periods, we obtained combined measurements with the FM-CW radar, TEP, an X-band radar, a sodar (which malfunctioned), and sonic anemometers on loan from PSU. Sample observations are shown in the following section, and many more are posted on our boundary layer web site <http://abyss.ecs.umass.edu/tep/>.

We have also put effort into radar system improvements. Through a DURIP and university matching funds, we have purchased a flatbed truck and are refurbishing an elevation-over-azimuth positioner to permit arbitrary pointing of the FMCW antennas.

4.4 Scientific Results

Figure 1 shows the decaying convective boundary layer and evening transition observed on October 19, 1999. The residual layer and two elevated layers are easily observable. The texture of the CBL scattering is indicative of strong insect scatter embedded within Bragg scattering from refractive index fluctuations. After dusk ($T \approx 150$ min) insect activity recurs, enhancing the scattering from the residual layer.

Figure 2 shows activity observed in the nocturnal boundary layer during the evening of October 26-27, 1999. The upper panel shows a K-H billow that formed in the residual layer at approximately 8:30 pm. The lower panel shows the onset of ground-based turbulence driven by a low-level jet that formed at approximately 2 am. Both images also show discrete echoes from insects.

We have spent some effort on the classification of radar echoes to assess the impact of insect scatter on clear-air returns. In particular, we have applied an adaptive median filter technique to radar images to separate Bragg- and Rayleigh-type echoes. The performance of the filter is demonstrated in figure 3.

During Summer and Fall 2001, TEP and the FMCW were deployed at a local field site in Amherst, MA (Figure 4). Figure 5 shows time-height cross sections of FMCW and TEP data collected in Amherst, MA on Oct 4, 2001. Besides the difference in range resolutions (2.5 m for FMCW, 30 m for TEP), the notable difference between the two radar images is the sensitivity to Rayleigh scatter from insects. The radars differ in frequency by a factor of 3.2, yielding a 20 dB difference in sensitivity to small particles. It is clear, however, that they observe common clear-air signals.

Figure 6 shows 3-hour time-height cross sections of typical daytime and nighttime behavior

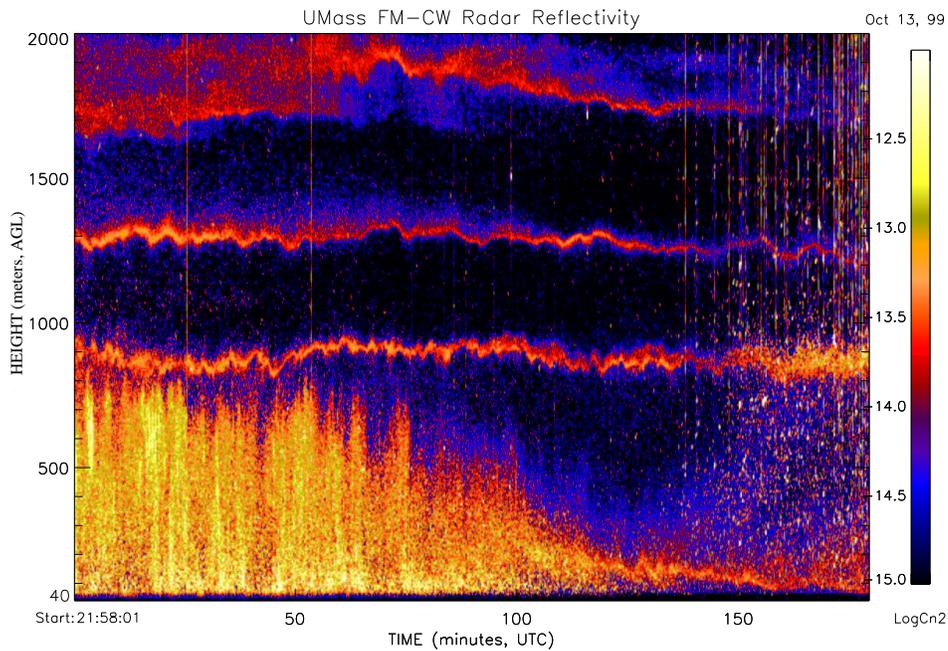


Figure 1: Evening transition observed on October 19, 1999. Local time is UTC - 5 hours.

observed during the October measurement period. We are using these imagery to aid in analysis of TEP data collected during the same period.

5 Technology Transfer

None.

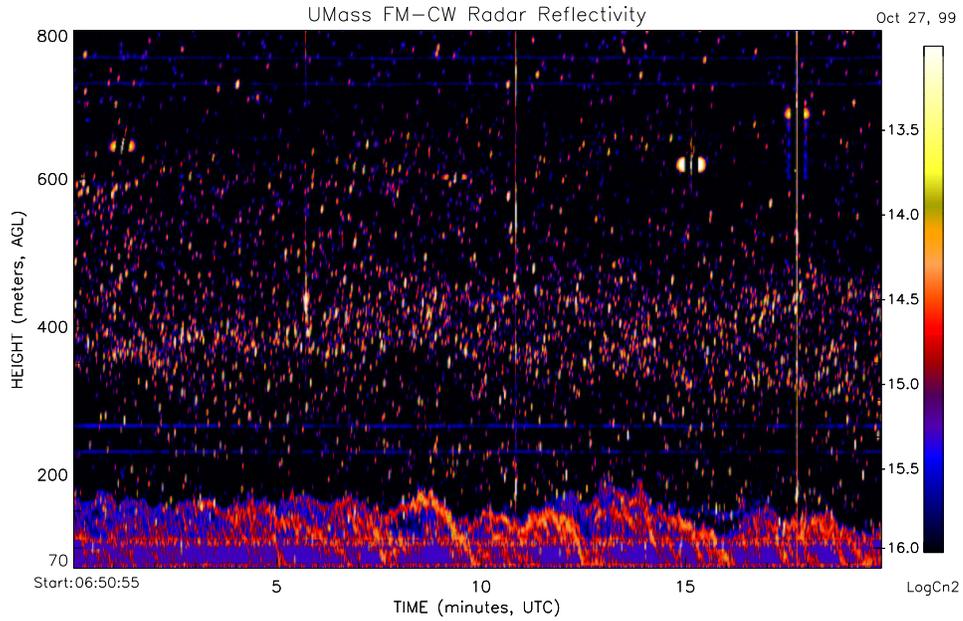
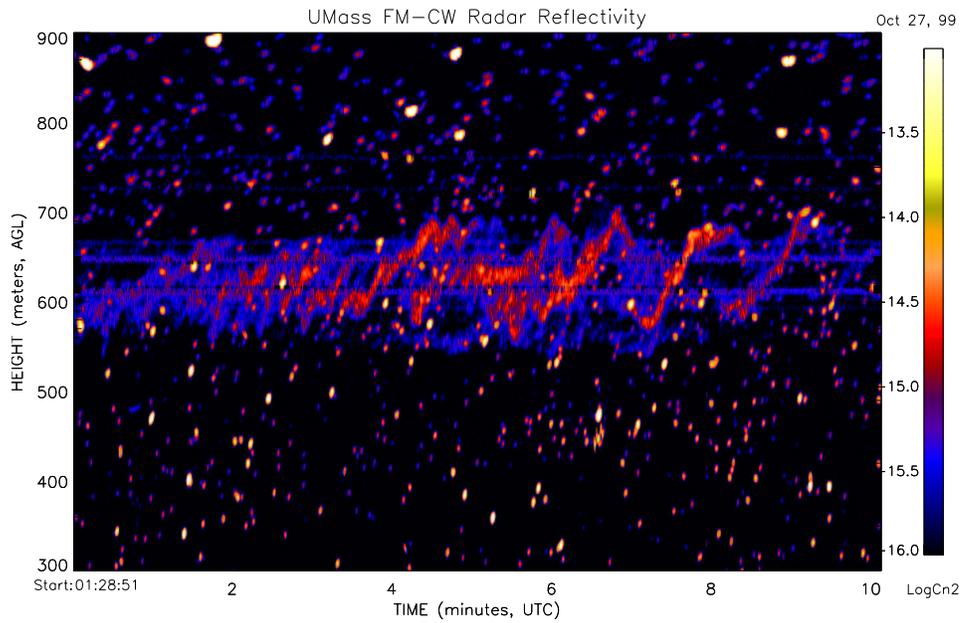


Figure 2: Top: Kelvin-Helmholtz billows observed in the residual layer in the evening of October 26, 1999. Bottom: Shear-induced turbulence driven by a low-level jet (confirmed by radiosonde) that developed above 200 m later in the evening.

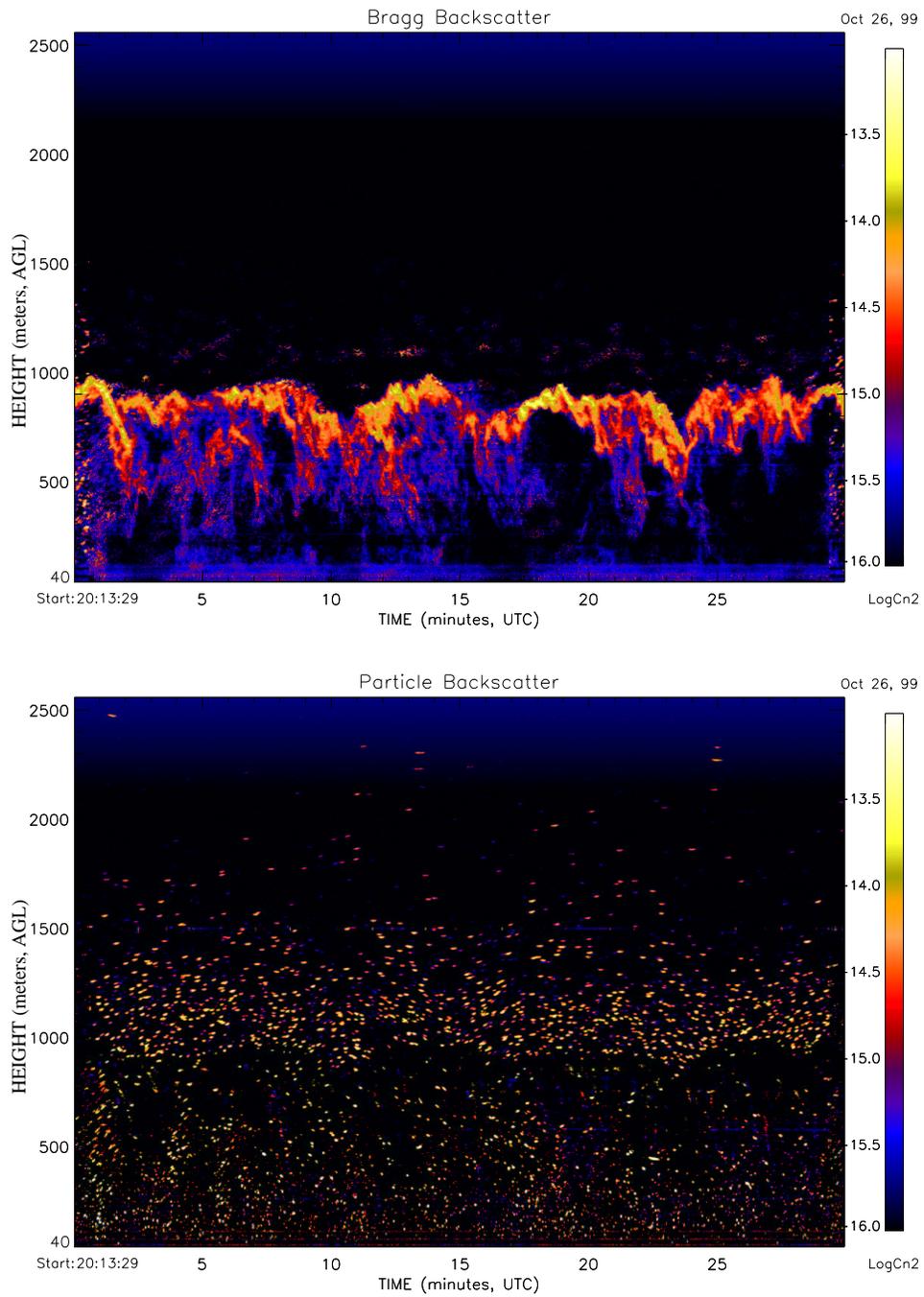


Figure 3: Adaptive median filter separation of boundary layer radar echo into Bragg-dominated (top) and Rayleigh-dominated (bottom) components.



Figure 4: TOP: View of the Tilson Farm field site at UMass. Visible are a 20' tower with a 3D sonic anemometer, a Doppler sodar (on right), FMCW radar, and TEP array (behind FMCW). BOTTOM: Closeup of the FMCW radar antennas.

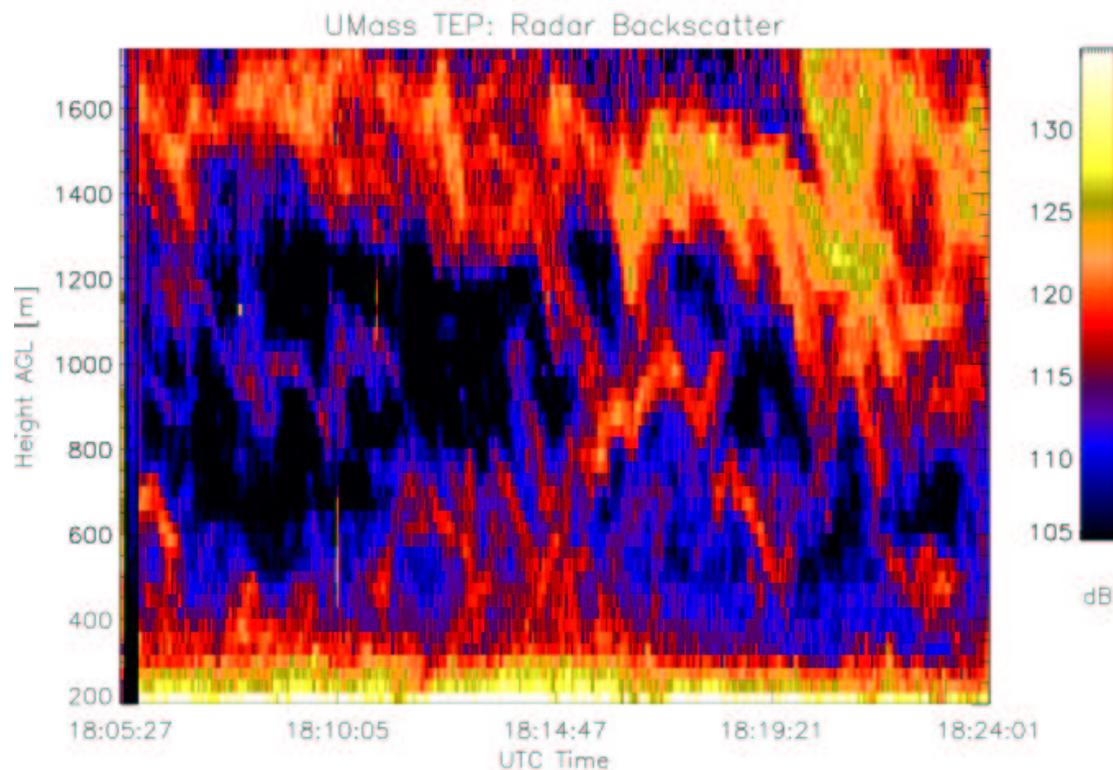
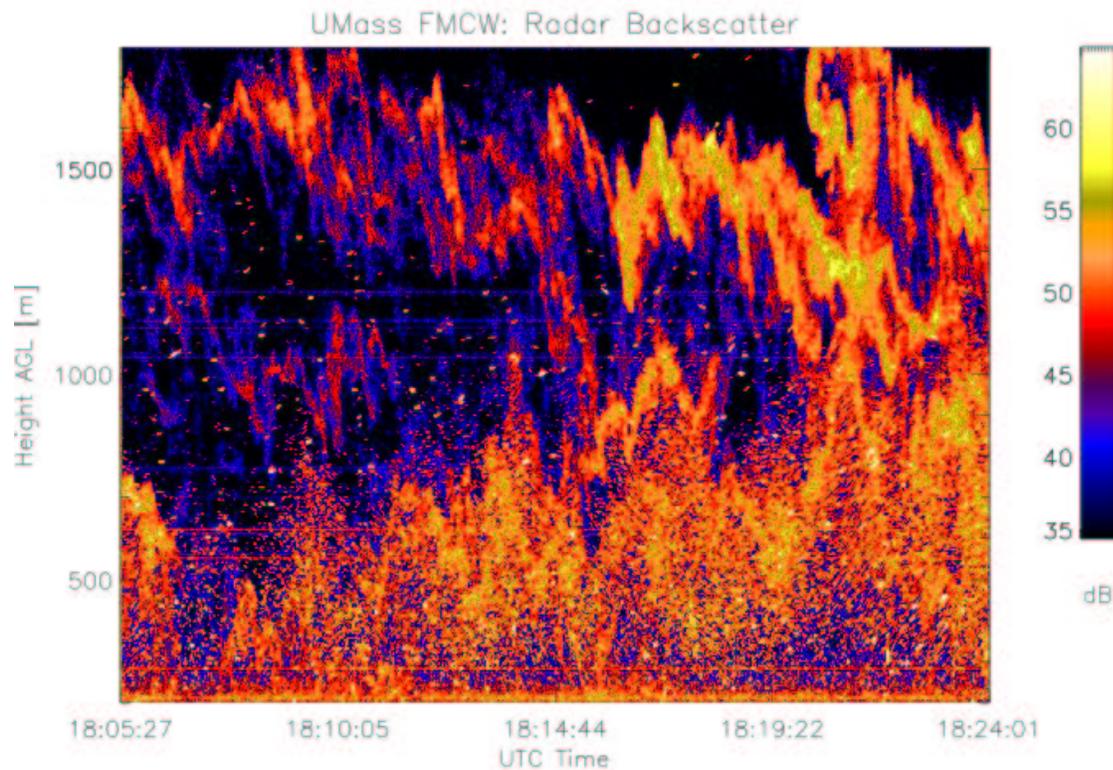


Figure 5: Top: FMCW time-height cross section of 20 minutes of early afternoon boundary layer on Oct 4, 2001. The lower portion of the images shows a heavily insect-laden mixed layer developing towards a capping inversion. Bottom: Corresponding TEP image shows same clear-air structure though with coarser resolution. Note reduced sensitivity to insects.

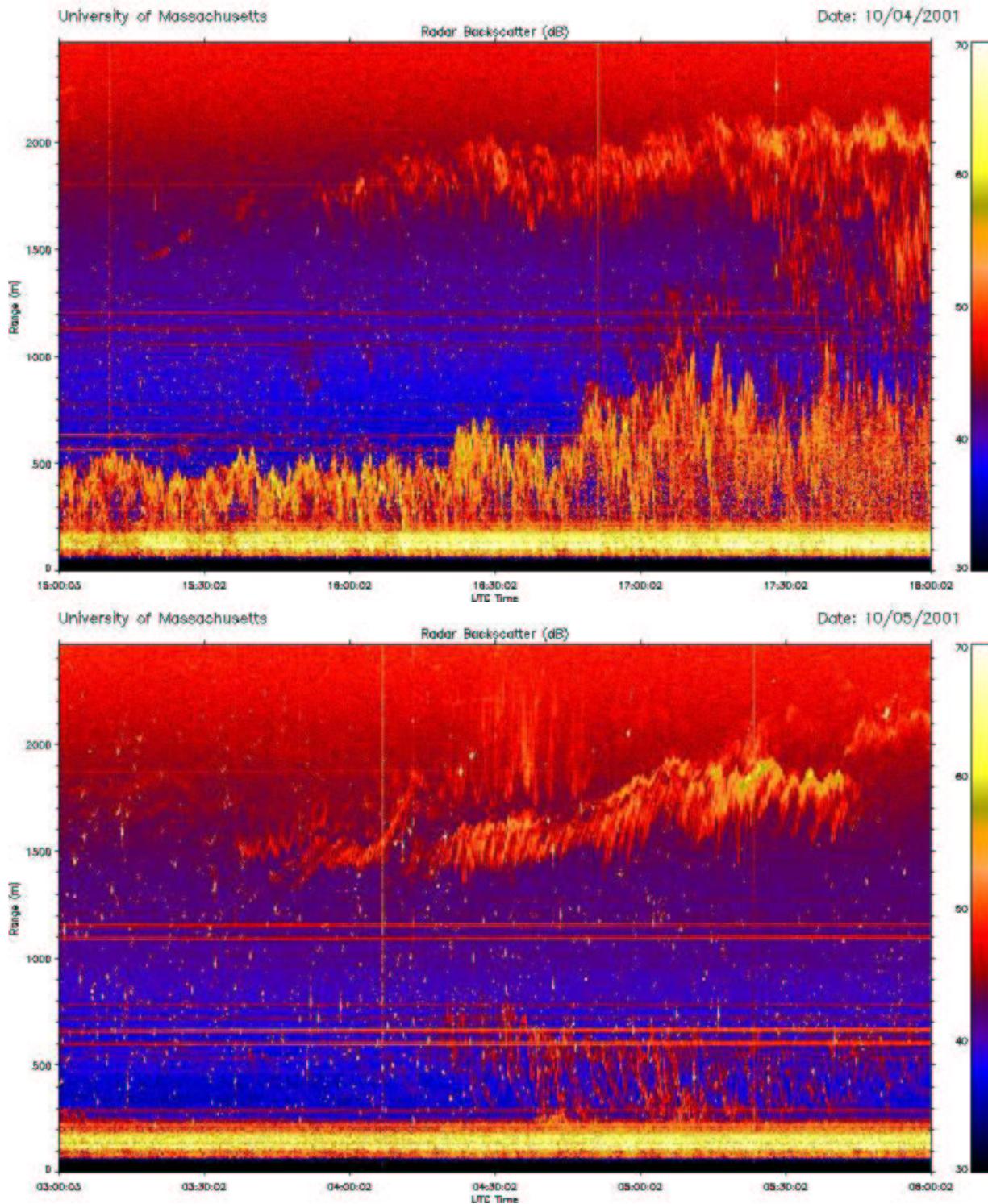


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