P3.6

OBSERVATIONS OF TURBULENCE DURING BAMEX MISSIONS

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1. Introduction

The occurrence of large mesoscale convective systems (MCSs) during the warm season over much of the central United States presents a hazard to aviation that has not as yet been thoroughly assessed. In addition to lightning and hail, the extensive mid- to upper-level anvil clouds that form in these systems can cause severe turbulence. Although avoidance of these areas by passenger aircraft and general aviation is usually possible, it is advantageous to know the risk of turbulence in regions within and close to the anvil clouds, during late stages of development when anvil features are not as clearly delineated.

Unfortunately, avoidance also means that observations within MCSs are few. During the Bow Echo and Mesoscale Convective Vortex Experiment (BAMEX; Davis *et al.*, 2002) held in the central United States in summer 2003, however, several research flights in midtroposphere (10 000 to 16 000 ft) observed state and aircraft flight variables within and near the edges of large mesoscale anvils. A dropsonde aircraft (Learjet) flying at high levels was coordinated with two P-3 research aircraft below. During at least two of these flights (June 10 and June 23), the mission scientist and the lead cloud physics scientist on board the NOAA P-3 described in their logs several periods of moderate to heavy turbulence. These two and perhaps ten other BAMEX missions offer the opportunity to diagnose turbulence episodes with dropsonde launches and *in situ* aircraft measurements at midlevels in anvil regions where the intensity and frequency of turbulence is still relatively unknown.

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We present here an early study of BAMEX observations intended to identify MCS anvil flights with significant turbulence reports. On the basis of preliminary examination, flights on June 10 will be emphasized, although a more general examination of flight data from the entire experiment may reveal other potential cases. Results are primarily observational and exploratory in nature, but it is hoped that subsequent analyses will allow an assessment of the turbulence threat to general aviation and passenger airlines in the vicinity of anvil regions during mature and late stages of MCS development. These analyses should also help to focus research on particular MCS-related phenomena with apparent relationships to turbulence.

2. The 10 June MCS Flights

The BAMEX aircraft missions on 10 June (IOP7A) observed a bow echo that initially developed in eastern Nebraska (Davis *et al*. 2004). Three aircraft (the NOAA and NRL P-3's and the dropsonde Learjet) sampled the system from its early stages around 0100 UTC until 1100 UTC, when the anvil of the MCS was several hours past its greatest extent but still large. The radar patterns of Fig. 1 (at 0540 UTC) reveal a bowed line of very intense echoes in extreme northwest Missouri and southwest Iowa. As Fig. 2 (bottom panel) illustrates, aircraft at this time were carefully avoiding the airspace occupied by the MCS. By 0809 UTC, an extensive anvil had formed behind and northeast of the convective line (Fig. 3). Some intrepid aircraft were now traversing the upper regions of the anvil volume (Fig. 2, top panel).

2.1 Turbulence Reports and Flight Data

Since scheduled aircraft avoid MCS regions, there are likely not enough PIREP (pilot report) observations of turbulence for this case or for any such system to provide useful confirmation (it should also be noted that the nocturnal nature of large MCSs minimizes anvil encounters). On the 10 June research flights, good confirmation for turbulence is provided by aircraft observations (*e.g.*, the NOAA P-3 accelerometer data on Fig. 4) and by onboard scientist logs (for the NOAA P-3 mission, these logs were provided by Dave Jorgenson and Brian Jewett and are available at the BAMEX Field Catalog internet website http://www.ofps.ucar.edu/bamex/catalog/). Both noted several periods of moderate to severe turbulence.

To quantitatively identify and analyze turbulent structures, intercomparisons of the aircraft accelerometer records, scientist logs, and nearby Learjet dropsonde observations will be necessary. The flight plan for the 10 June case called for dropsondes coordinated as closely as possible with the P-3. In practice, however, the logistics of coordinating several aircraft with different flight speeds, etc., made these attempts difficult. During the mission, there were ~8 instances ("approaches") when Learjet drops were made within 60 km of the NOAA P-3. Several of these approaches occurred early in the mission between 0400 and 0530 in a region just behind the bowed convective line (Fig. 1). Scientist logs reported some turbulence on the NOAA P-3 at about 16,000 ft MSL during this early period, but far more substantial turbulence was reported later between 0700 and 0900 UTC. The accelerometer record (Fig. 4) confirms these reports, particularly for the period beginning about 0700. Thus, the drops made during two approaches at 0848 and 0904 should provide good turbulent episodes for further research.

2.2 Physical Mechanisms

Much of the turbulence experienced by research aircraft during IOP7A was undoubtedly of convective origin. This would be particularly likely during the close approaches to the convective line (*cf*. Fig. 1). However, within the anvil at a distance from the leading convective line other turbulence-generating mechanisms might also be present. One possibility is shear-generated turbulence above and below the rear inflow jet. The dropsonde observation at 0526 UTC (Fig. 5) shows a distinct signature of the jet close behind the leading convective edge, and may be a preferred location for the development of turbulence.

Another related mechanism is suggested by the Slater, Iowa, wind profiler time section in Fig. 6. For several hours starting about 0500 UTC, when the Slater profile was within the northern margins of the anvil, there is a marked turning and acceleration of the upper-tropospheric (anvil top) winds. Development of jet streaks such as these is commonly noted in the environment of large MCSs (Maddox 1983) and is likely the result of MCS-synoptic scale interaction. In these regions during mature to late stages of MCS development, there could be instances of shear-generated turbulence above or below these jet streaks and either within or to the north of the dissipating anvil cloud. Another example of the use of wind profiler data to detect strong outflow regions above MCSs and rear inflow jets is provided by Ralph *et al.* (1995).

Other mechanisms to be investigated include turbulence associated with gravity waves, as reported in Koch *et al*. (2004), and instability mechanisms near the anvil top and the freezing level. The wave intrinsic frequency and the sense of vertical energy propagation can both be determined using the "wave hodograph method" from individual dropsonde profiles. The retrieved wave source location can then be related to other mesoscale phenomena, such as the rear inflow jet.

3. Future Plans

We also plan to investigate the flight data for June 23, which logs indicate to be a good additional source for observations related to turbulence (dropsondes are only available in front of this system, unfortunately). We will also investigate other cases that a preliminary examination of mission logs and reports have identified as potential candidates. In the SCATCAT case study reported by Koch *et al*. (2004), numerical simulations of turbulence encounters during the experiment in the central Pacific were made to determine physical mechanisms and assess the performance of turbulence algorithms. It may be possible to attempt similar simulations for these BAMEX cases, although the physical structures in this case are clearly mesoscale or smaller in origin. These efforts will be directed toward enhancing our understanding of the causes of observed turbulence, which in turn should lead to development of new and improved turbulence diagnostics.

4. Acknowledgments

We thank the aircraft crews and scientists aboard the P-3s and Learjet and on the ground for their efforts during this mission. Thanks also to all the BAMEX personnel who made the field experiment a reality. Several of the figures in this paper were accessed or adapted from the UCAR JOSS website at http://www.ofps.ucar.edu/bamex/catalog/index.html. We thank them for their efforts to make these data available in a convenient and timely fashion. We are indebted to Paula McCaslin and Nita Fullerton for their reviews of this paper.

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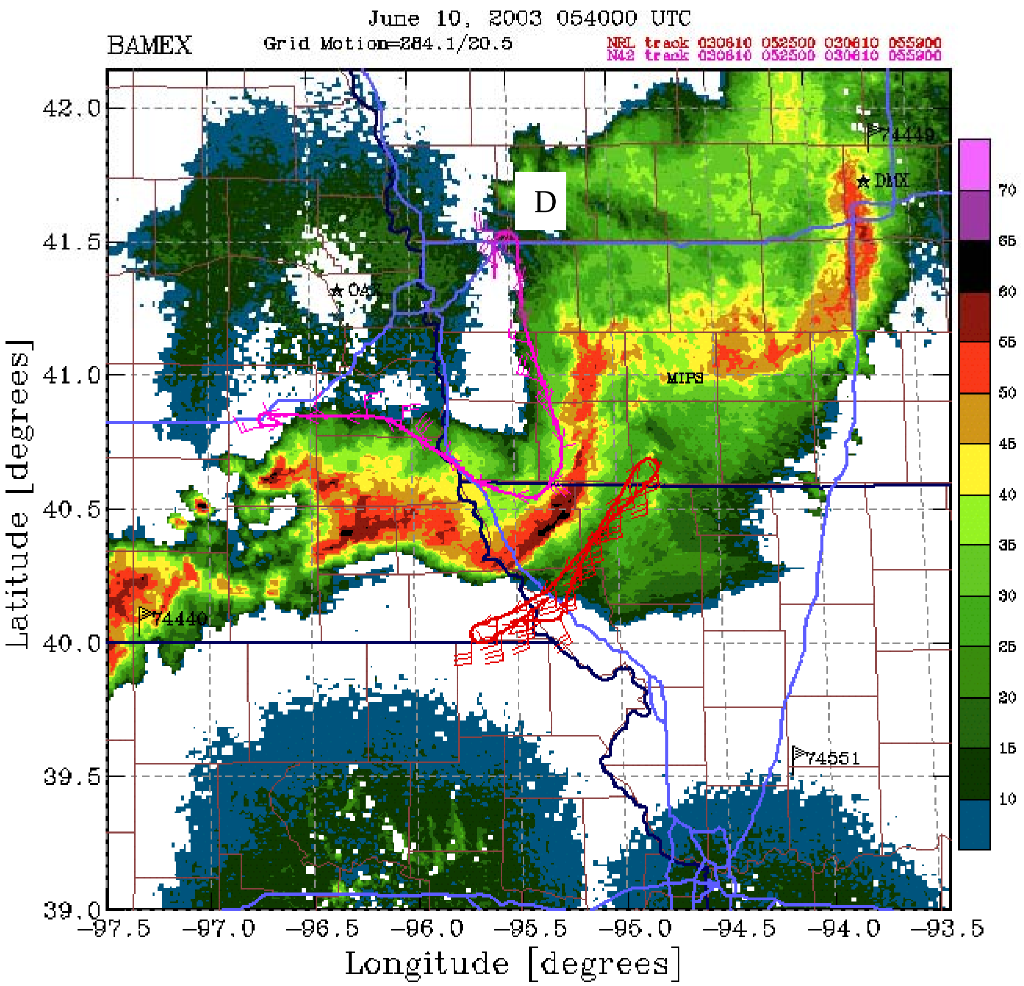

Fig. 1. NEXRAD radar observations at 0540 UTC 10 June 2003. Simultaneous flight track segments for two P-3 aircraft are also shown; pink denotes the NOAA P-3 and red the NRL P-3. The location of the dropsonde launch at 0526 UTC is denoted as "D". Adapted from image available at http://www.ofps.ucar.edu/bamex/catalog/index.html

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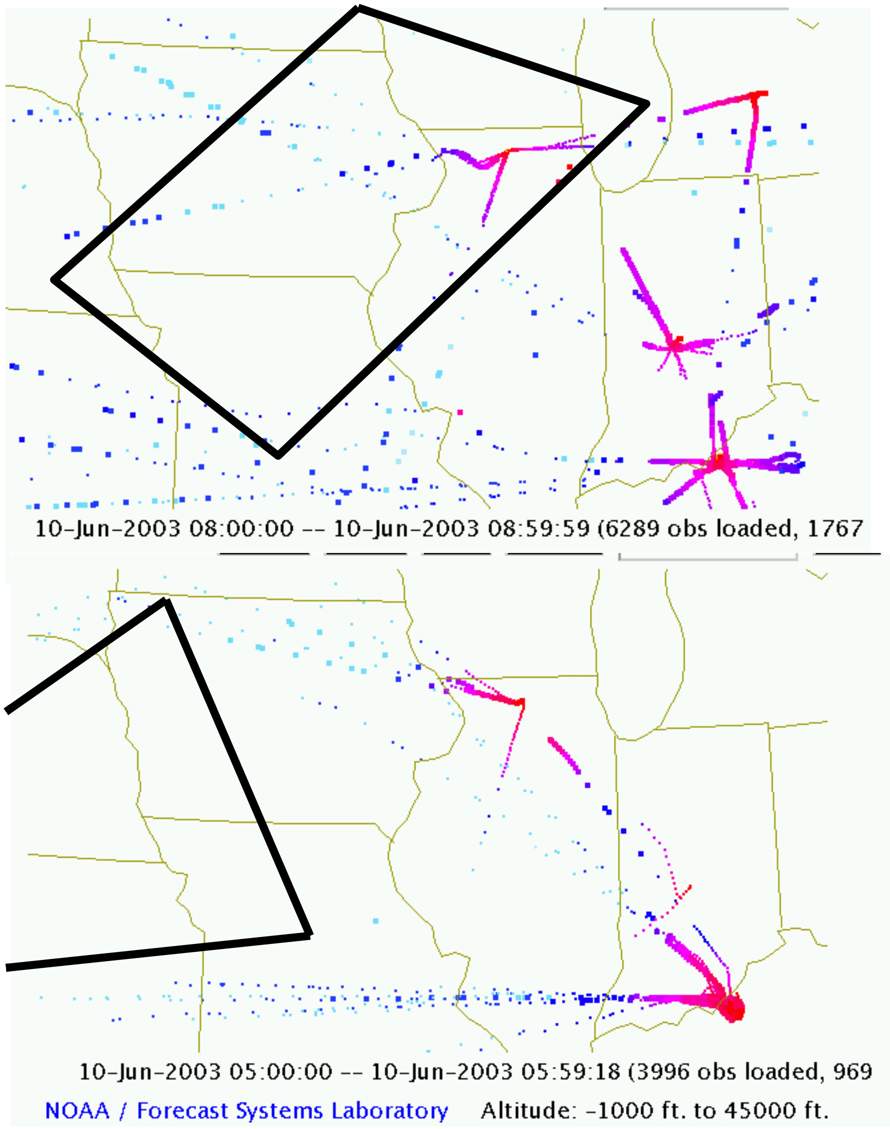

Fig. 2. Scheduled aircraft flight data reports (ACARS) for 1-h periods on 10 June 2003 starting at 0800 UTC (top panel) and 0500 UTC (bottom panel). Light and dark blue reports are at altitudes that would intersect the anvil clouds. See Figs. 3 and 1, respectively for location and extent of convective and anvil regions at these times; schematic cloud shields (denoted by heavy black lines) roughly delineate these areas. ACARS reports were accessed from the FSL ACARS website (http://acweb.fsl.noaa.gov/).

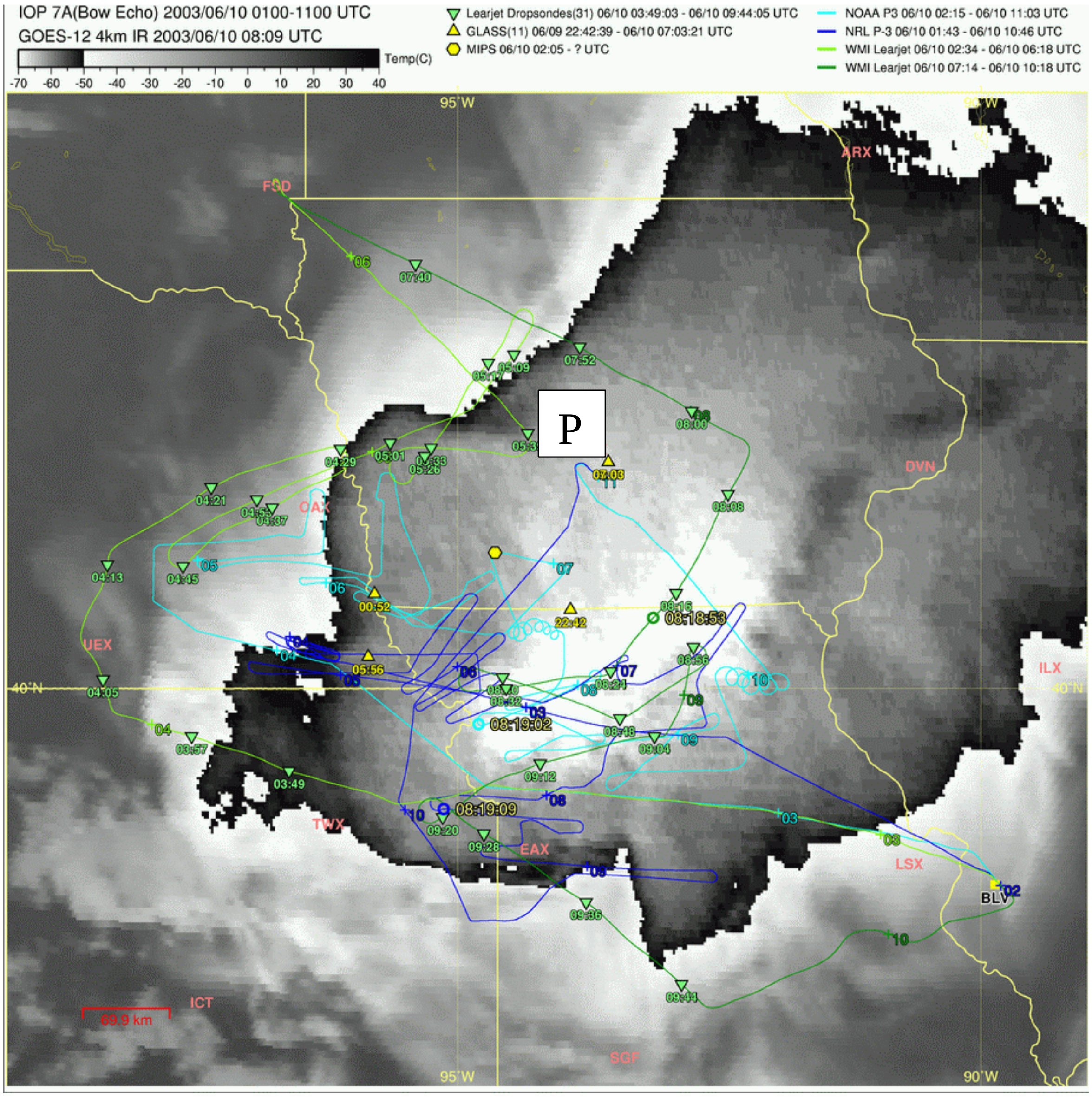

Fig. 3. Infrared satellite imagery at 0809 UTC 10 June 2003. The locations of aircraft tracks and dropsonde observations are superposed (note that tracks span the entire mission duration). “P” indicates the location of the Slater, Iowa, profiler (see text). Available from the UCAR JOSS BAMEX website at http://www.ofps.ucar.edu/bamex/catalog/index.html.

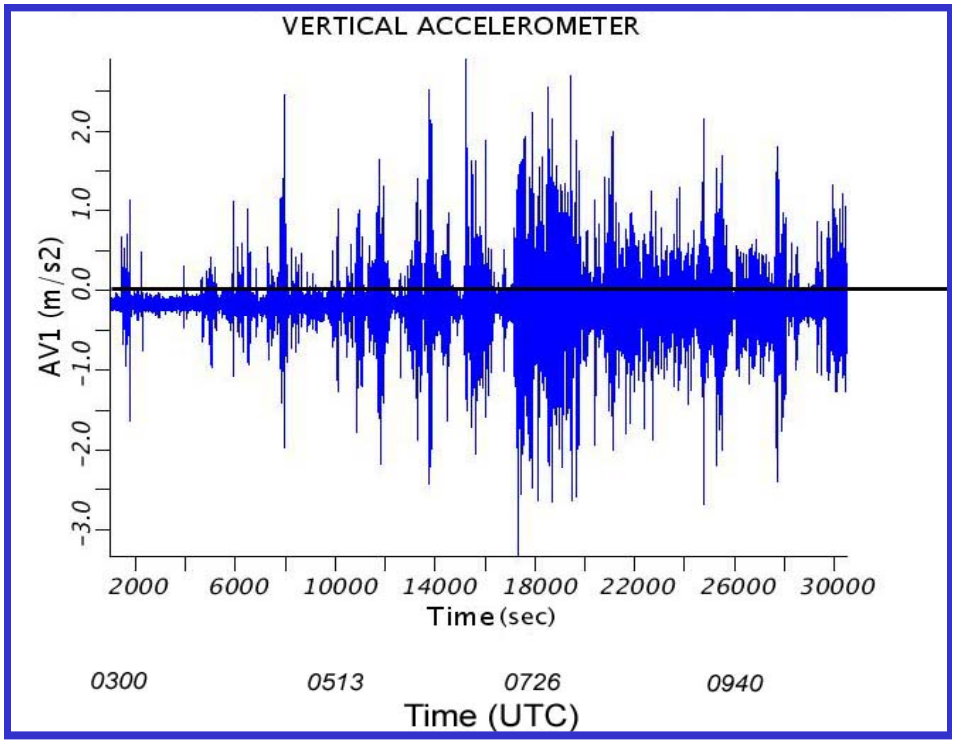

Fig. 4. NOAA P-3 accelerometer observations during the 10 June mission.

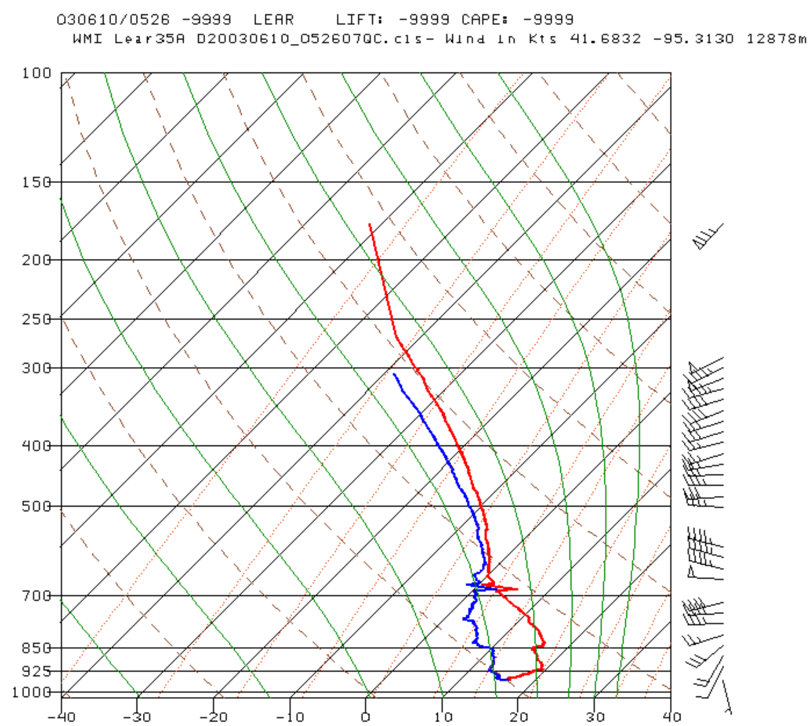

Fig. 5. Temperature and wind observations from Learjet dropsonde at 0526 UTC 10 June 2003. The location of this drop is shown on Fig. 1. From http://www.ofps.ucar.edu/bamex/catalog/index.html.

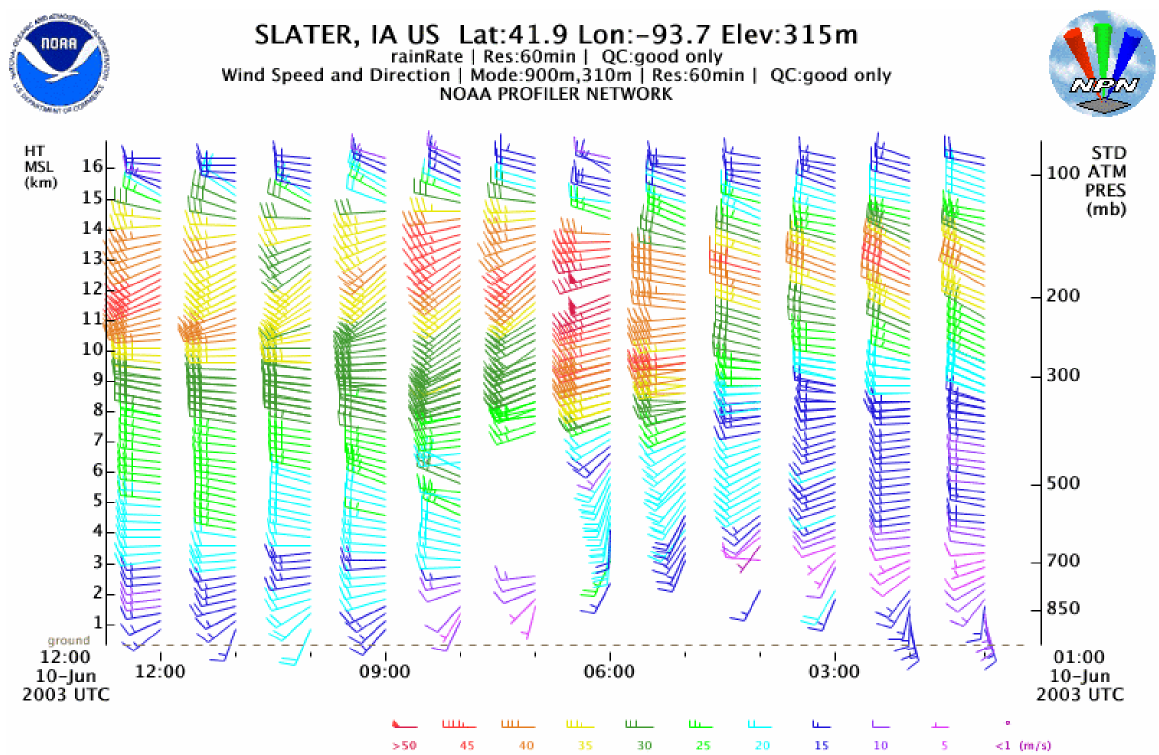

Fig. 6. Wind profiler observations at Slater, Iowa, wind profiler site. See Fig. 3 for location. Profiler data is avilable at the website http://www.profiler.noaa.gov/jsp/profiler.jsp