Observations of Significant Variations

in Radiosonde Ascent Rates Above 20 km.

A Preliminary Report

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1. Introduction:

Commonly known measurements obtained from radiosonde observations are pressure, temperature, relative humidity (PTU), dewpoint, heights and winds. Yet, another measurement of significant value, obtained from high resolution data, is the radiosonde ascent rate. As the balloon carrying the radiosonde ascends, its' rise rate can vary significantly owing to vertical motions in the atmosphere. Studies on deriving vertical air motions and other information from radiosonde ascent rate data date from the 1950s (Corby, 1957) to more recent work done by Wang, et al. (2009). The causes for the vertical motions are often from atmospheric gravity waves that are induced by such phenomena as deep convection in thunderstorms (Lane, et al. 2003), jet streams, and wind flow over mountain ranges.

Since April, 1995, the National Weather Service (NWS) has archived radiosonde data from the MIcroART upper air system at six second intervals for nearly all stations in the NWS 92 station upper air network. With the network deployment of the Radiosonde Replacement System (RRS) beginning in August, 2005, the resolution of the data archived increased to 1 second intervals and also includes the GPS radiosonde height data. From these data, balloon ascent rate can be derived by noting the rate of change in height for a period of time

The purpose of this study is to present observations of significant variations of radiosonde balloon ascent rates above 20 km in the stratosphere taken close to (less than 150 km away) and near the time of severe and non-severe thunderstorms. Also included are observations taken during weather events where no thunderstorms were present.

2. Calculation of Balloon Ascent Rate

Balloon ascent rates in m/s were calculated and plotted from the difference in derived PTU height (geopotential) from one second to the next. To reduce noise from the pressure sensor, these 1 second data were smoothed over a moving 60 second interval. Smoothed one second ascent rates were also obtained from the GPS heights. They were also smoothed over a 60 second interval to help remove the pendulum motion of the ascending radiosonde and other noise. Heights derived from the PTU data are independent of those derived from the GPS data and the two measurements can be used to verify that the ascent rates measured are accurate.

3. Balloons Used

NWS upper air stations use a balloon weighing about 600 gms. The balloons are typically inflated with 1.7 to 2.0 cubic meters (65 to 70 cubic feet) of either hydrogen or helium gas. When inflation is completed, the balloon is mostly spherical in shape and has a diameter of about 1.5 meters. The balloons typically have an ascent rate between 250 to 350 meters/minute and the average burst height is about 30 km. At that altitude the balloon has expanded to nearly 7 meters in diameter. The shape of balloon as it rises is not always a perfect sphere. Some balloons will ascend with a somewhat flattened top, slowing the ascent speed, while others will rise faster because they have a more rounded top. The dimensions of the balloon can also change as the balloon rises and expands owing to uneven thickness of the balloon membrane.

4. Case Studies

Balloon ascent data from a variety of weather events, some historic and dating back to the late 1990s, were investigated. Some notable severe storms, such as the May, 1999, Oklahoma City F5 tornado and the May, 2010, EF-5 tornado that struck El Reno, OK, are not presented. In these cases there were missed observations near the time of the severe weather or there were soundings that did not go much higher than 20 km.

All the radiosonde ascent rate plots show ascent rate in m/s in the x-axis and height in meters in the y-axis (on the left side). Altitudes in feet are also shown and along with the wind profile.

Case Study 1: The Joplin, MO, Tornado

An EF-5 tornado struck Joplin, Missouri on May 22, 2011, shortly before 23:00 UTC. More information on the storm is provided here:

http://www.spc.noaa.gov/exper/archive/events/110522/index.html

There is a NWS weather office in Springfield about 100 km away to the east of Joplin that takes routine radiosonde observations. On May 22, the office also took a 19:00 UTC sounding. Figures 1a through 1d shows balloon ascent rate plots from soundings taken from 12:00 May 22 to 12:00 May 23. Balloon ascent rates in m/s as derived from the PTU (red) and GPS (black) data are shown. Note that for the 12:00 and 19:00 UTC observations the ascent rates do not show significant variations throughout the observation. However, the 00:00 UTC sounding (Figure 1c) released at 23:35 UTC, shows significant changes in ascent rate that persist to above 30 km. About 12 hours later, when the 12Z May 23 sounding was taken, (figure 1e) the strong variations in ascent rate were no longer seen.

The radiosonde for 00Z May 23 radosonde was not ingested into a thunderstorm at any time during the sounding. Figure 2 shows the radar imagery at the time of the balloon release. The severe thunderstorm that struck Joplin had moved east, but was not at the Springfield NWS office at the release time

In Figure 1d note the rapid change in ascent rate near 31,000 meters. The high and low ascent rates are marked with an orange dot. A review of the 1 second radiosonde data (Figure 1d) showed that the minimum unsmoothed PTU derived ascent rate was at -0.6 m/s at an altitude of 30,801 meters. At 31,526 meters the unsmoothed 1 second ascent rate had increased to 11.4 m/s. This translates to a 12 m/s ascent rate change in a layer 725 meters thick. From the 1 second latitude and longitude data the radiosonde traveled 0.4 km in this layer when it was about 46.5 km away to the northeast of the launch site. Figure 3 shows the radar imagery for the time (01:05 UTC) when the radiosonde was in this layer. Figures 4 and 5 show the visible satellite imagery for 00:15 and 00:45 UTC, respectively. Note waves in the thunderstorm top over south-central Missouri in Figure 4 (inside red circle).

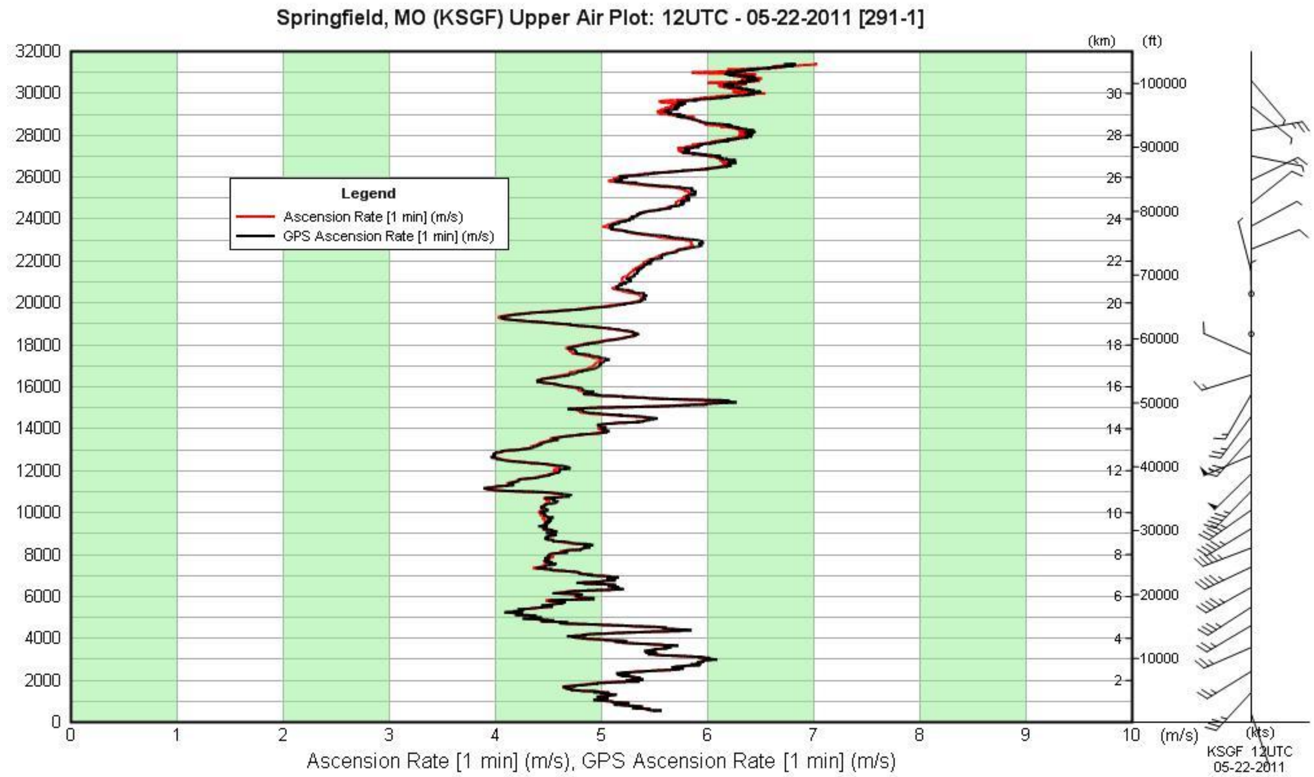


Figure 1a

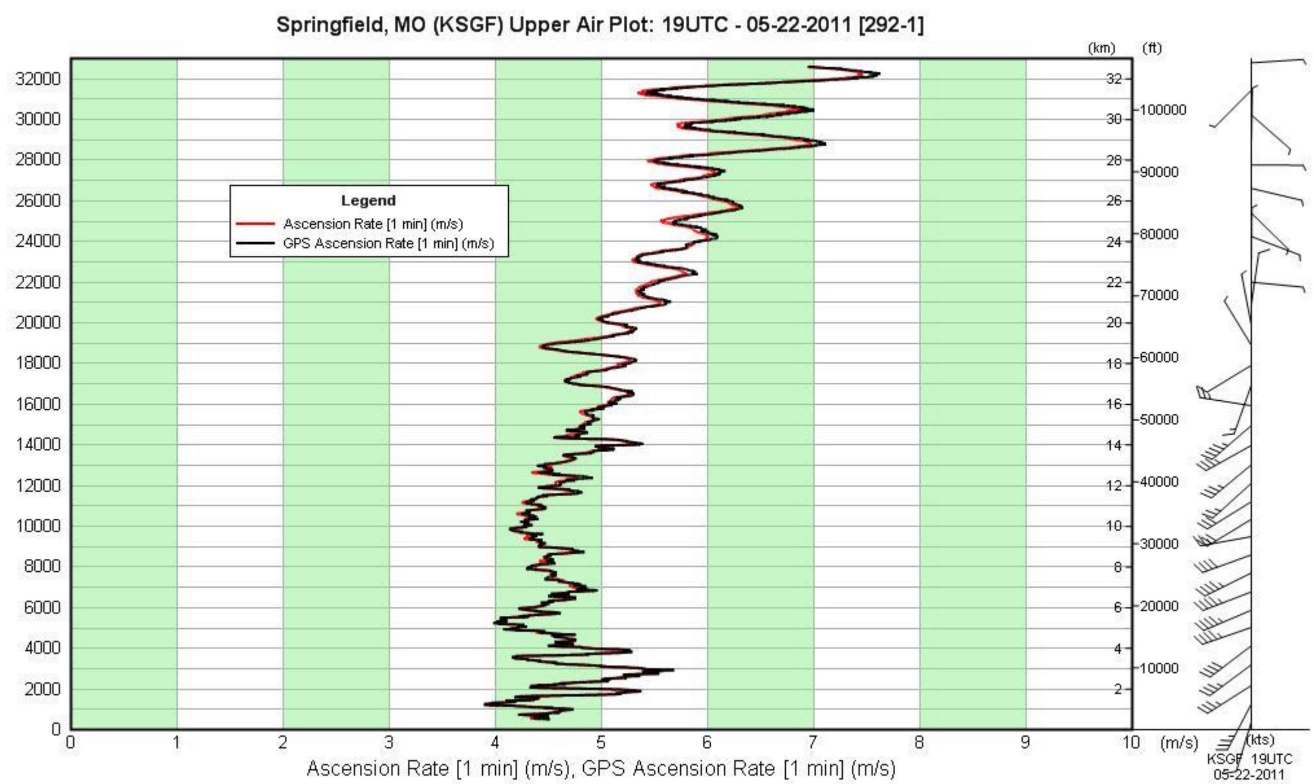


Figure 1b

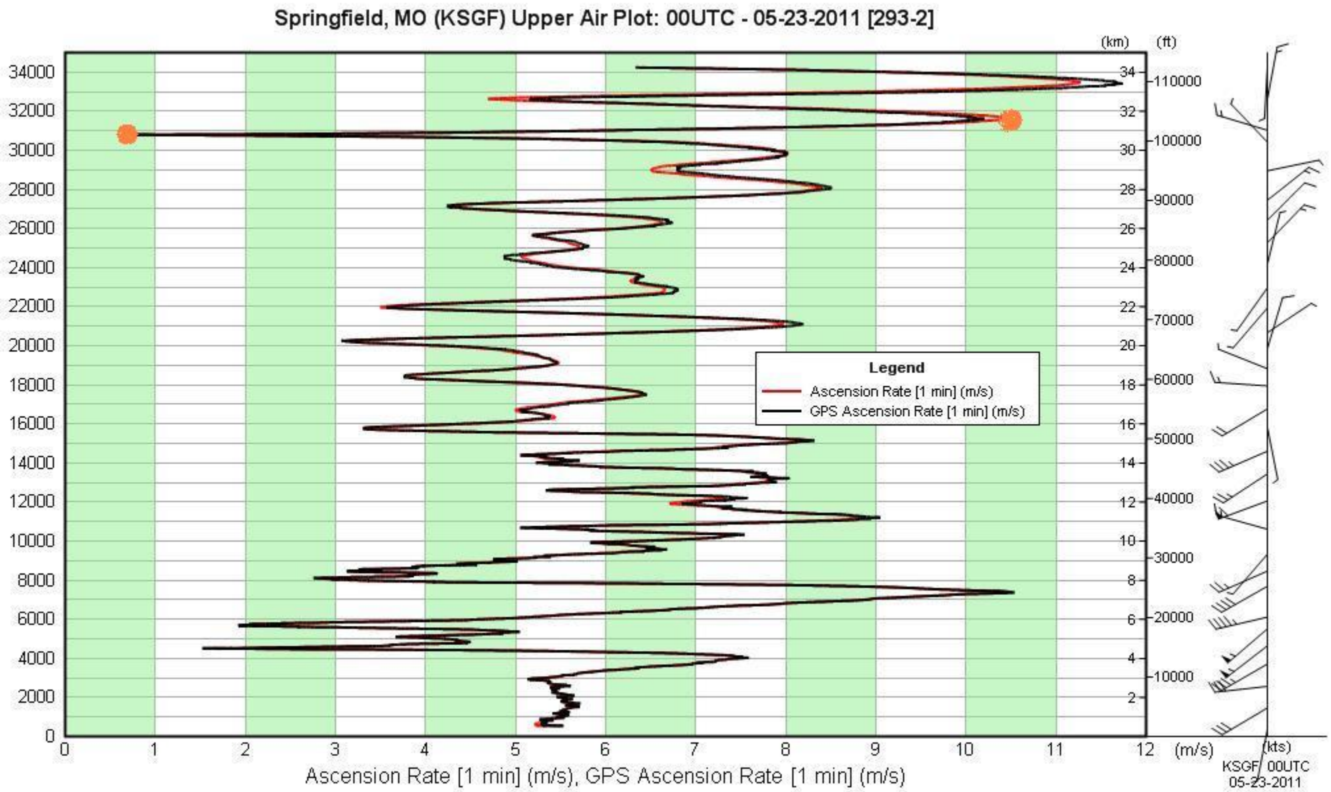

Springfield, MO (KSGF) Upper Air Plot: 00UTC - 05-23-2011 [293-2]
Legend
Ascension Rate [1 min] (m/s)
GPS Ascension Rate [1 min] (m/s)
Ascension Rate [1 min] (m/s), GPS Ascension Rate [1 min] (m/s)
(km)
(ft)
(m/s)
(kts)
KSGF 00UTC 05-23-2011

Figure 1c

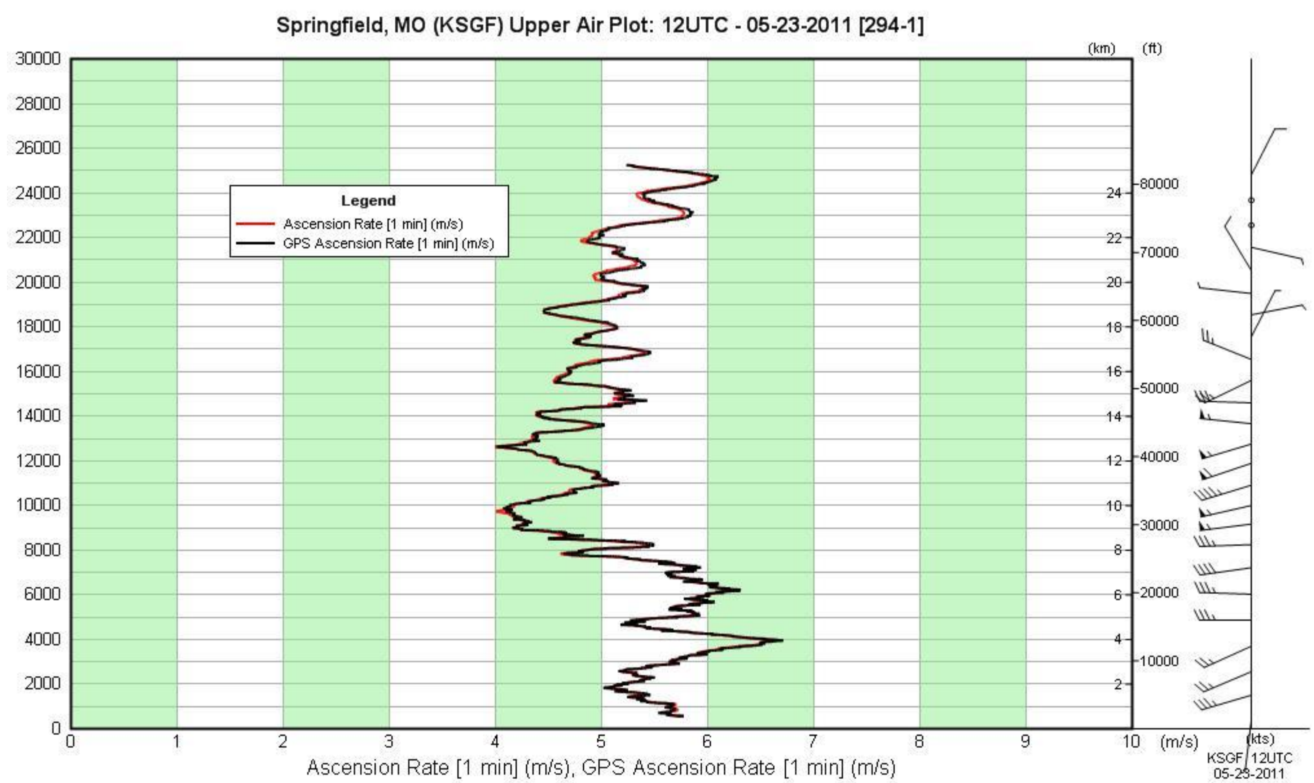

Springfield, MO (KSGF) Upper Air Plot: 12UTC - 05-23-2011 [294-1]
Legend
Ascension Rate [1 min] (m/s)
GPS Ascension Rate [1 min] (m/s)
Ascension Rate [1 min] (m/s), GPS Ascension Rate [1 min] (m/s)
(km)
(ft)
(m/s)
(kts)
KSGF 12UTC 05-23-2011

Figure 1d

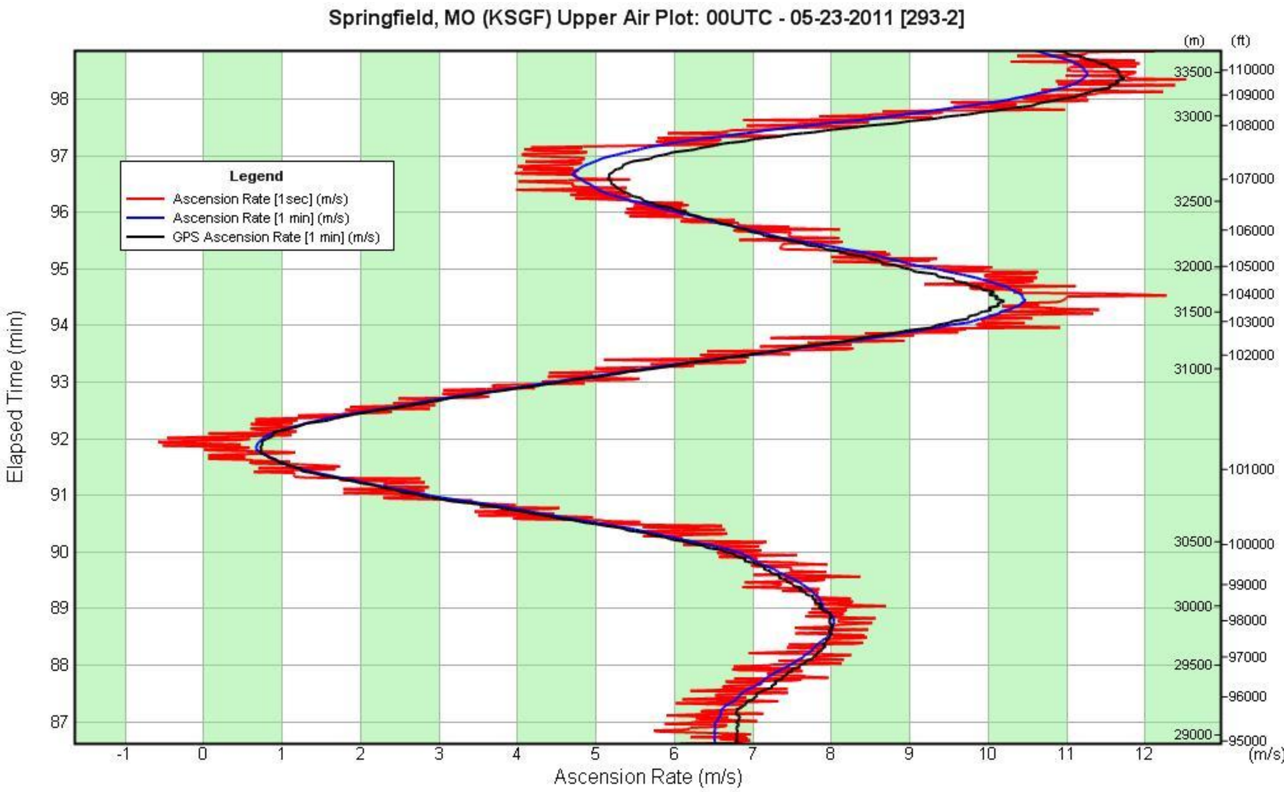


Figure 1e

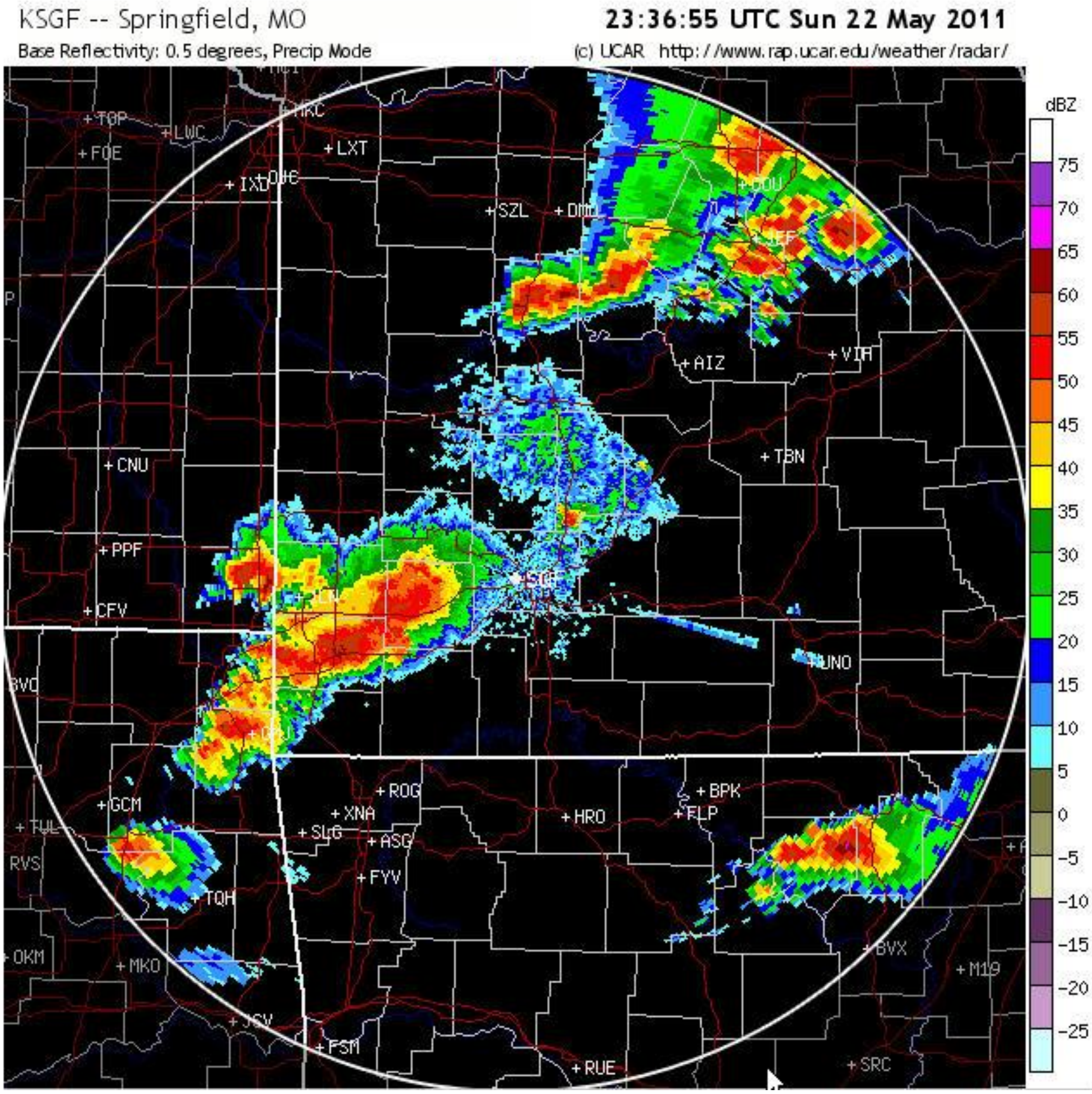


Figure 2 (Courtesy of UCAR)

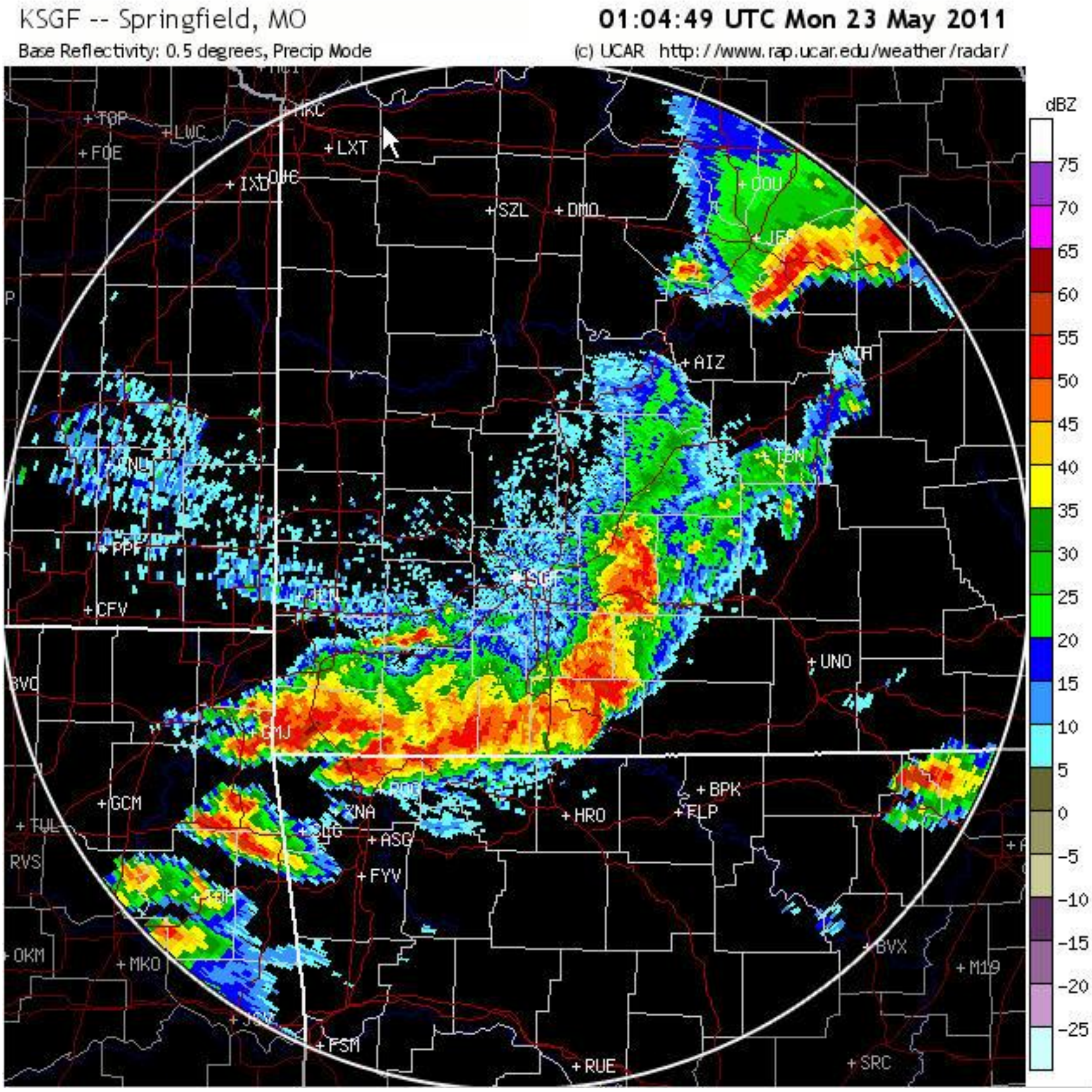


Figure 3 (Courtesy of UCAR)

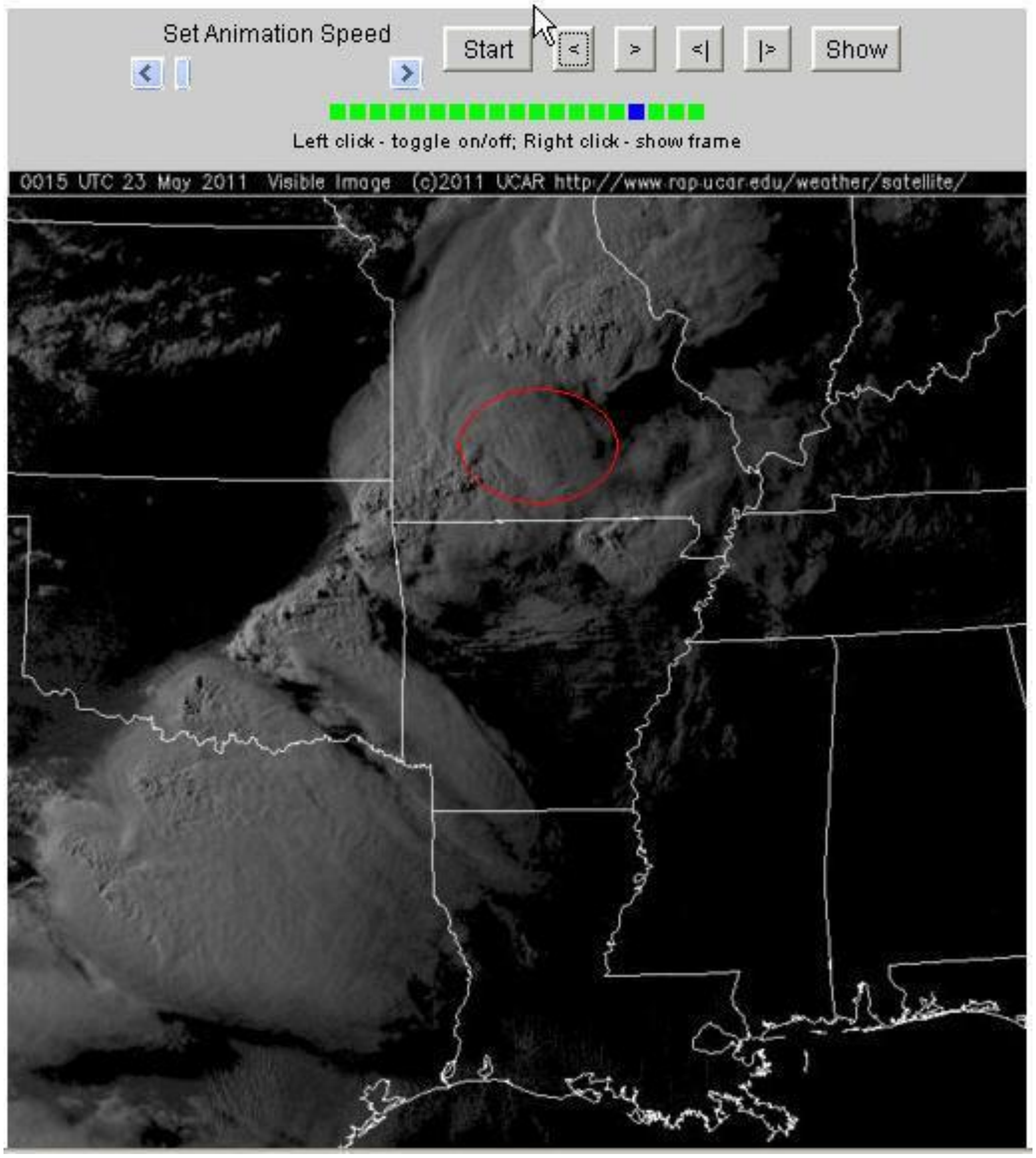


Figure 4 (Courtesy of UCAR)

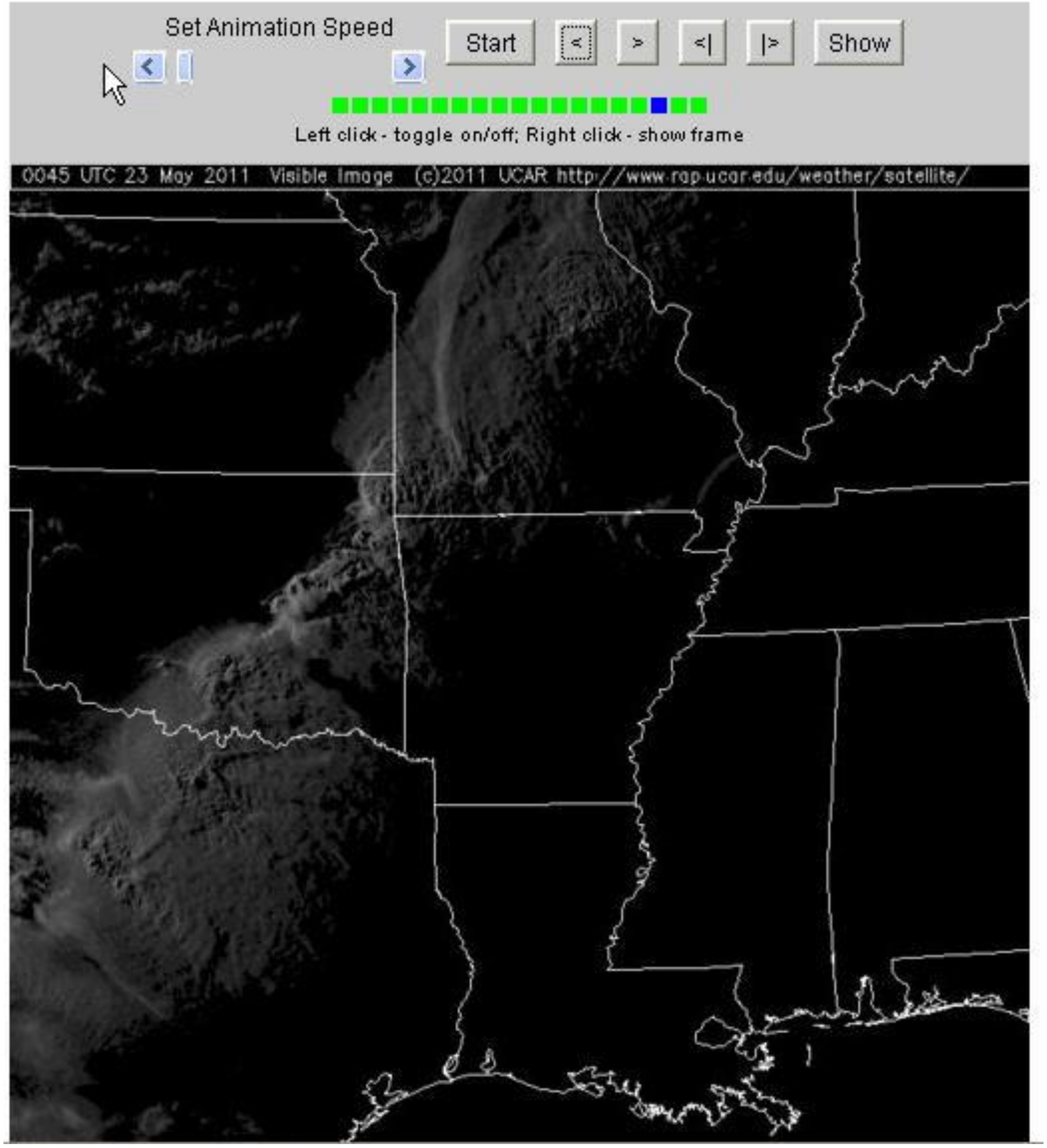


Figure 5 (Courtesy of UCAR)

Case Study 2: Waves Caused by Non-severe Weather

From November 23 to 26, 2010, soundings from the NWS office in Valley, Nebraska, (near Omaha) showed significant changes in balloon ascent rates in the stratosphere above 20 km. Figures 5, 6 and 7 show balloon ascent rates examples during this time period. No severe weather was occurring during these soundings and high pressure was over the area as shown in the surface weather maps (Figures 8 and 9). A jet stream (see Figure 10) possibly combined with other weather features likely caused these waves.

Note: The balloon ascent rate data from the soundings were derived from the NCDC archive product, which is in BUFR format. While the ascent rate data from the PTU data is available in the archive, the data plotting software was only able to retrieve the GPS data. Only ascent rates from the GPS data are shown in the figures.

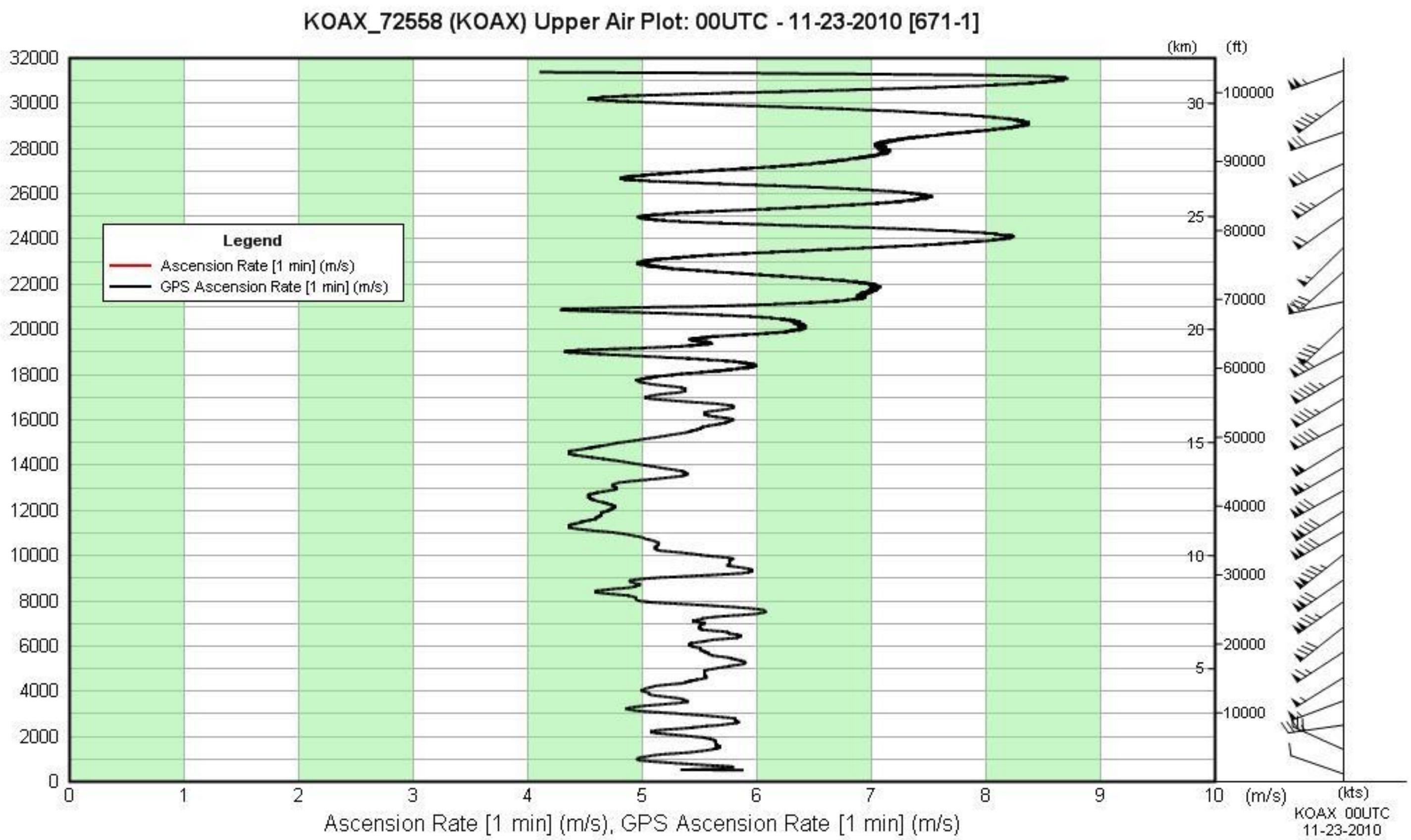


Figure 5

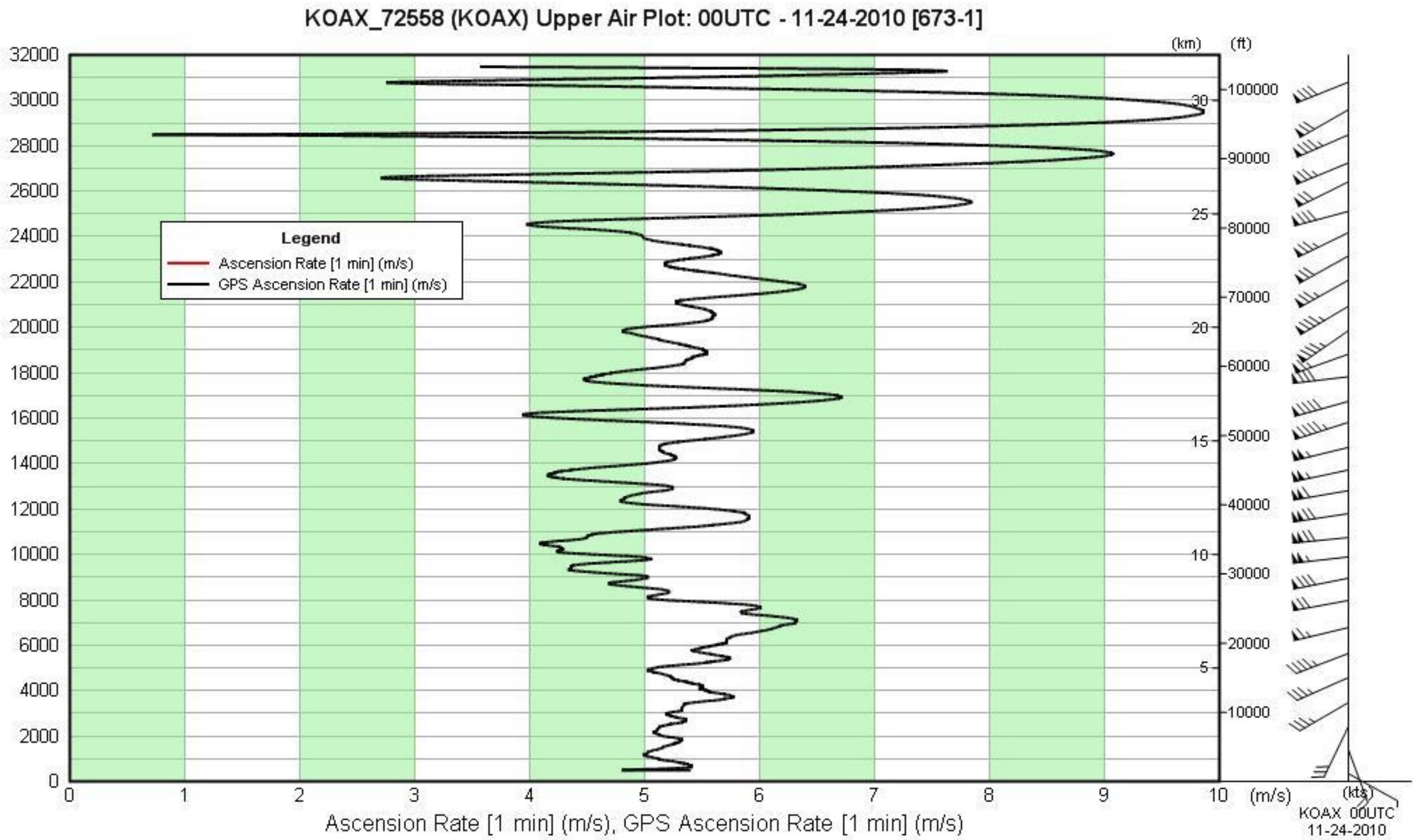


Figure 6

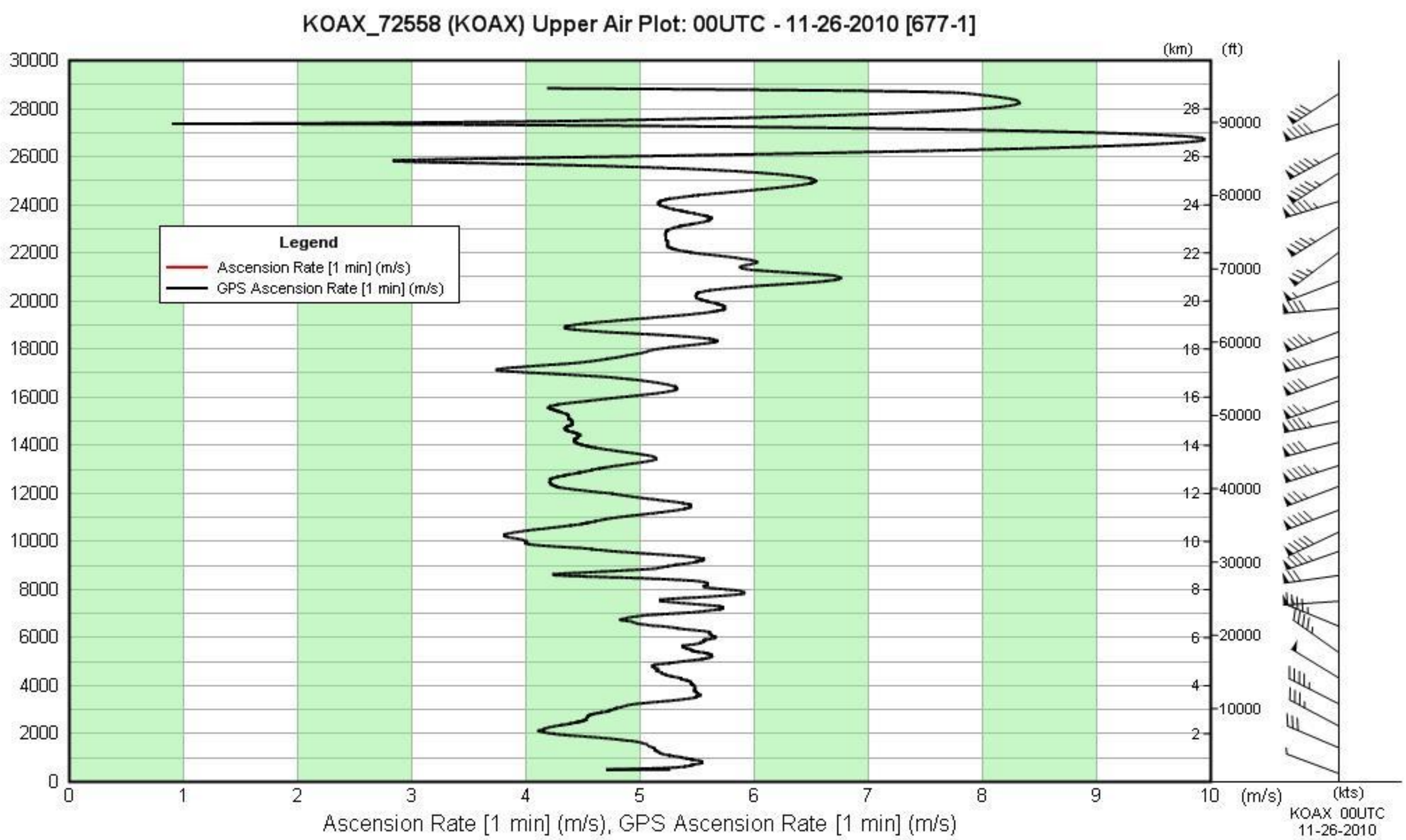
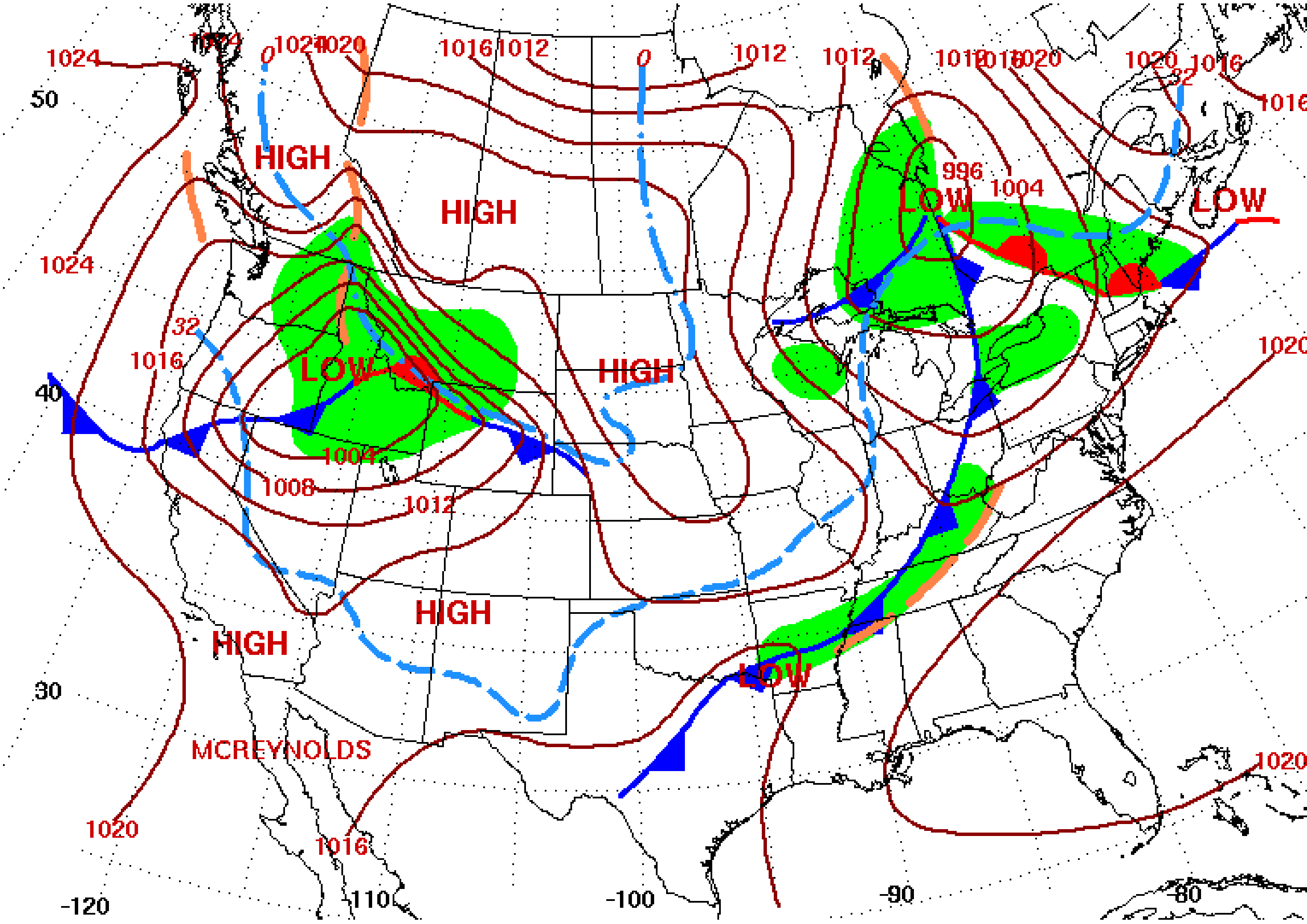


Figure 7



Surface Weather Map at 7:00 A.M. E.S.T.

Figure 8 (surface weather map Nov 23, 2010)

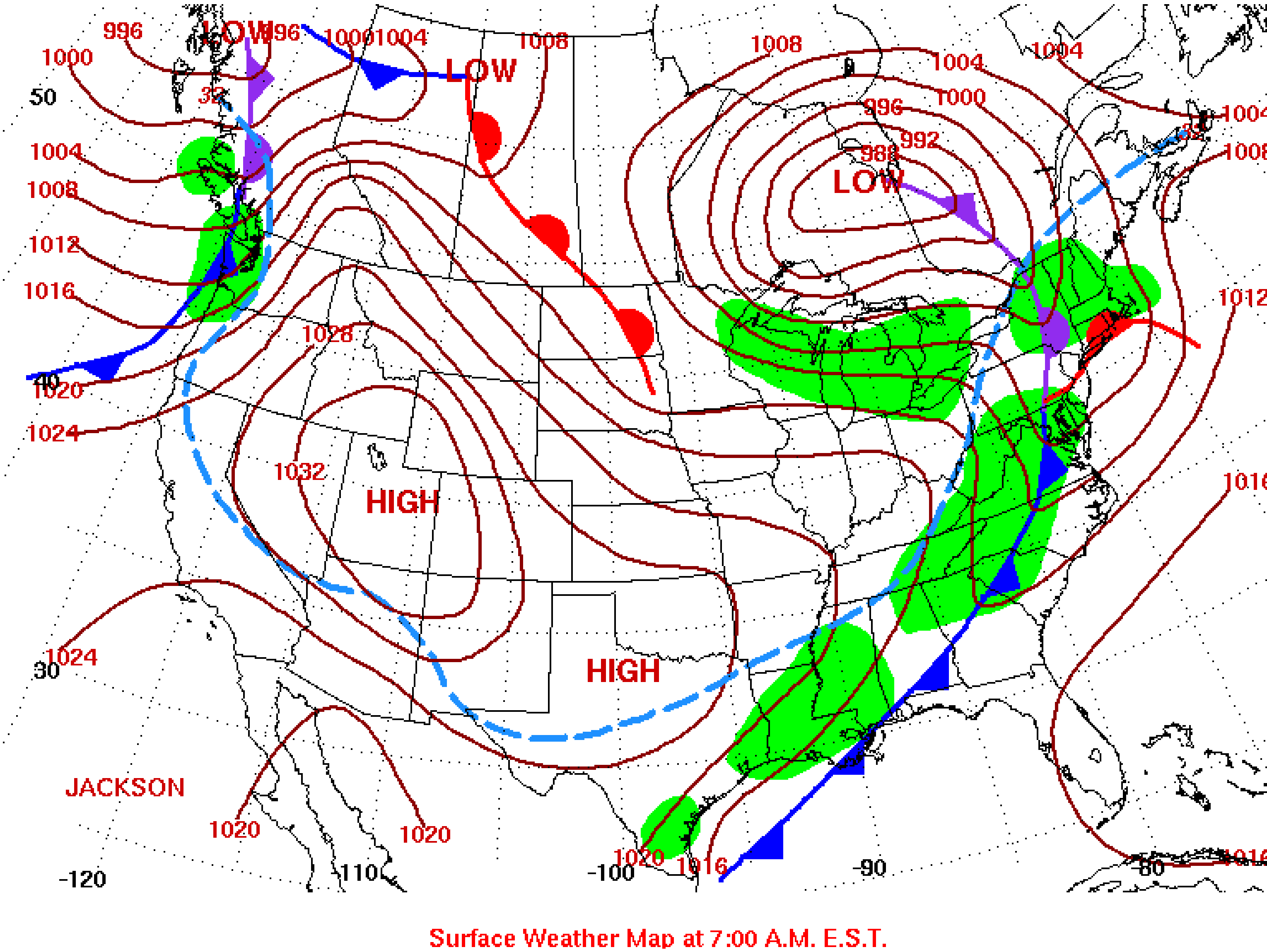


Figure 9 (surface weather map November 26, 2011)

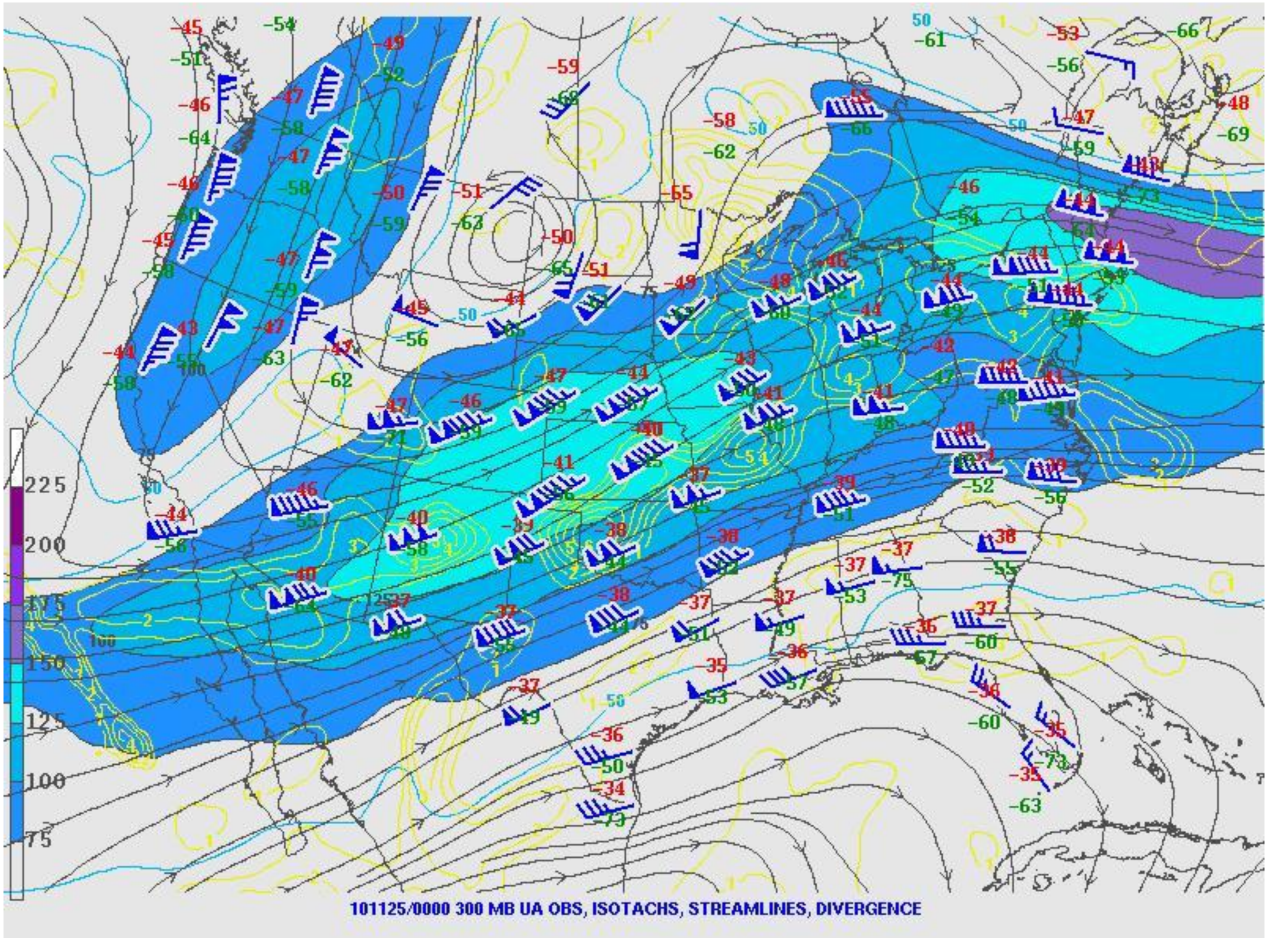


Figure 10: 300 mb analysis 00:00 UTC Nov 25, 2010 (courtesy of NCEP/SPC)

Case Study 3: Severe Thundestorms over the TX Panhandle and Eastern OK

From the evening of April 22, 2010, to the early morning hours of April 23, severe thunderstorms occurred over the Texas panhandle and eastern Oklahoma. Figure 10 shows visible satellite imagery for 00:45 UTC, April 23. More information on the storms is available at these websites:

http://www.spc.noaa.gov/exper/archive/events/100422/index.html

http://www.srh.noaa.gov/ama/?n=april_22_2010

http://www.srh.weather.gov/lub/?n=events-2010-20100422

http://www.mesonet.ttu.edu/cases/SevereWX_042210/20100422.html

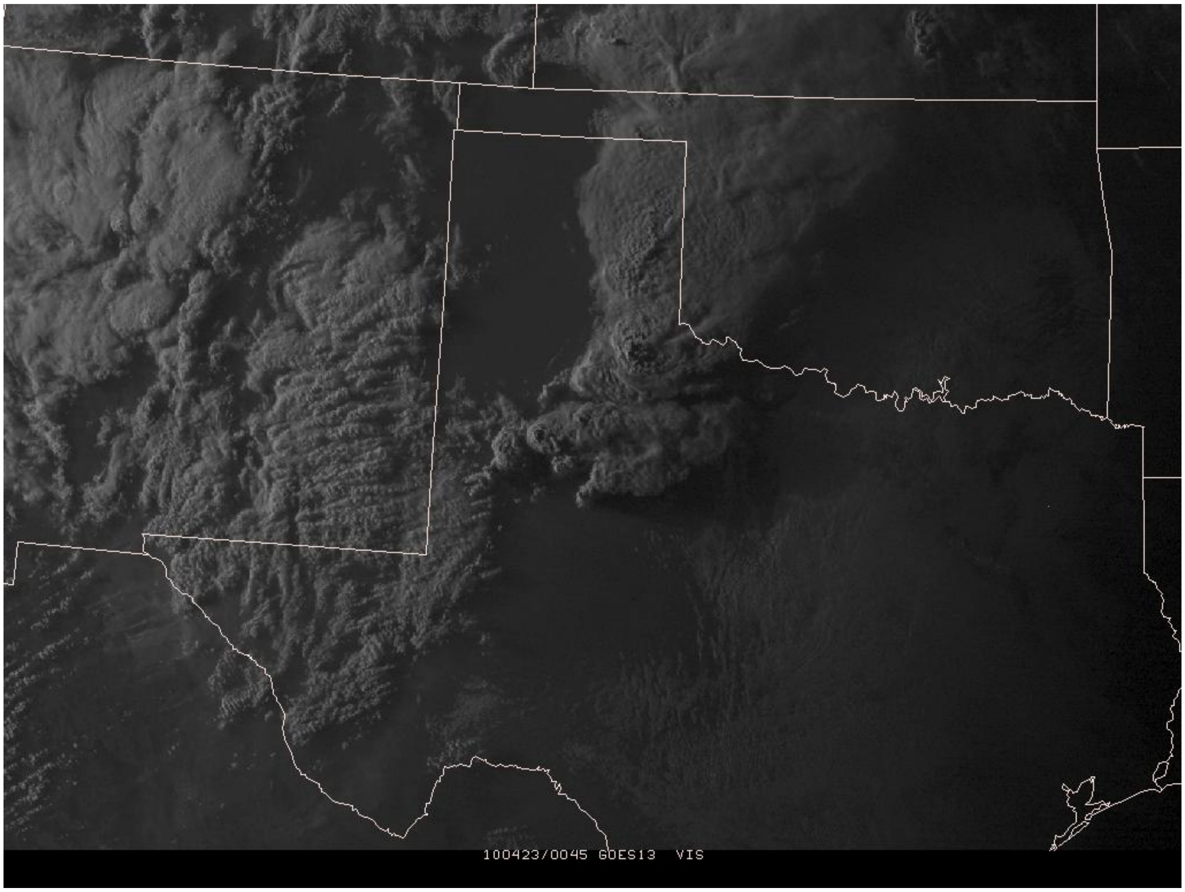


Figure 10: Visible satellite photo 00:45 UTC April 23, 2010 (courtesy of the West Texas Mesonet)

NWS operates an upper air station at Amarillo, TX, and Norman, OK, and balloon ascent rate plots are shown in Figures 11 through 18 for each site before and after the severe storms occurred. None of the soundings were ingested into the thunderstorms.

Note that the significant changes in ascent rate above 20 km can be seen in the 00:00 UTC Amarillo sounding (Figure 13) and about 12 hours later (12:00 UTC April 23) at the Norman sounding (Figure 17). In Figure 11 notice that the GPS ascent rates and the ascension rate derived from the PTU data don't agree well. This is likely from a small leak in the pressure sensor or another defect of some kind in the sensor.

In Figure 17, orange dots were placed on the ascent rates at about 26 km and 27.5 km. At this location, the radiosonde was about 100km ENE from the radiosonde launch site in Norman In this layer, the radiosonde appears to have traveled along a complete atmospheric wave (trough to trough). The ascent rates rose as high as about 8 m/s and slowed to about 3 m/s. The distance covered was about 4.5 km.

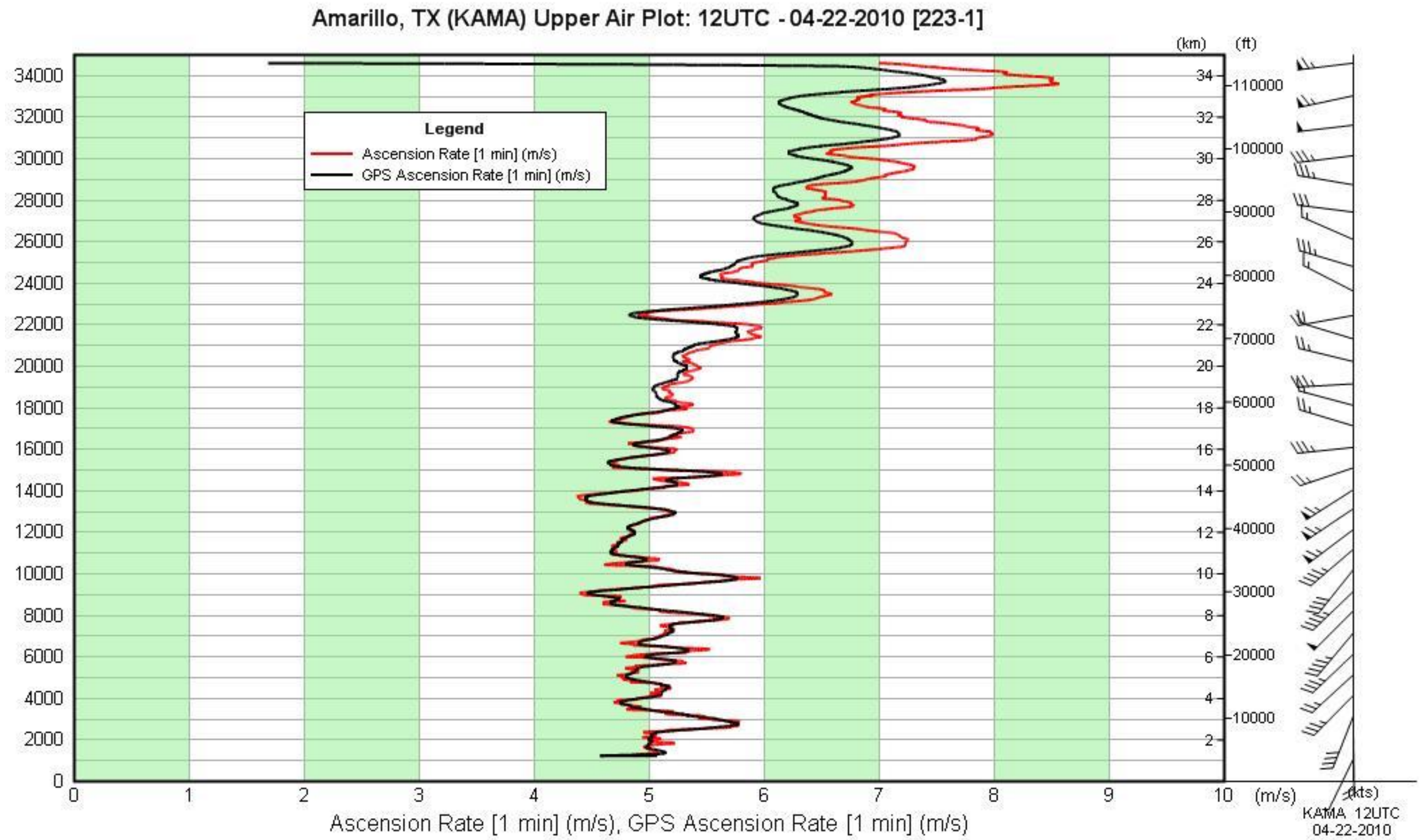


Figure 11

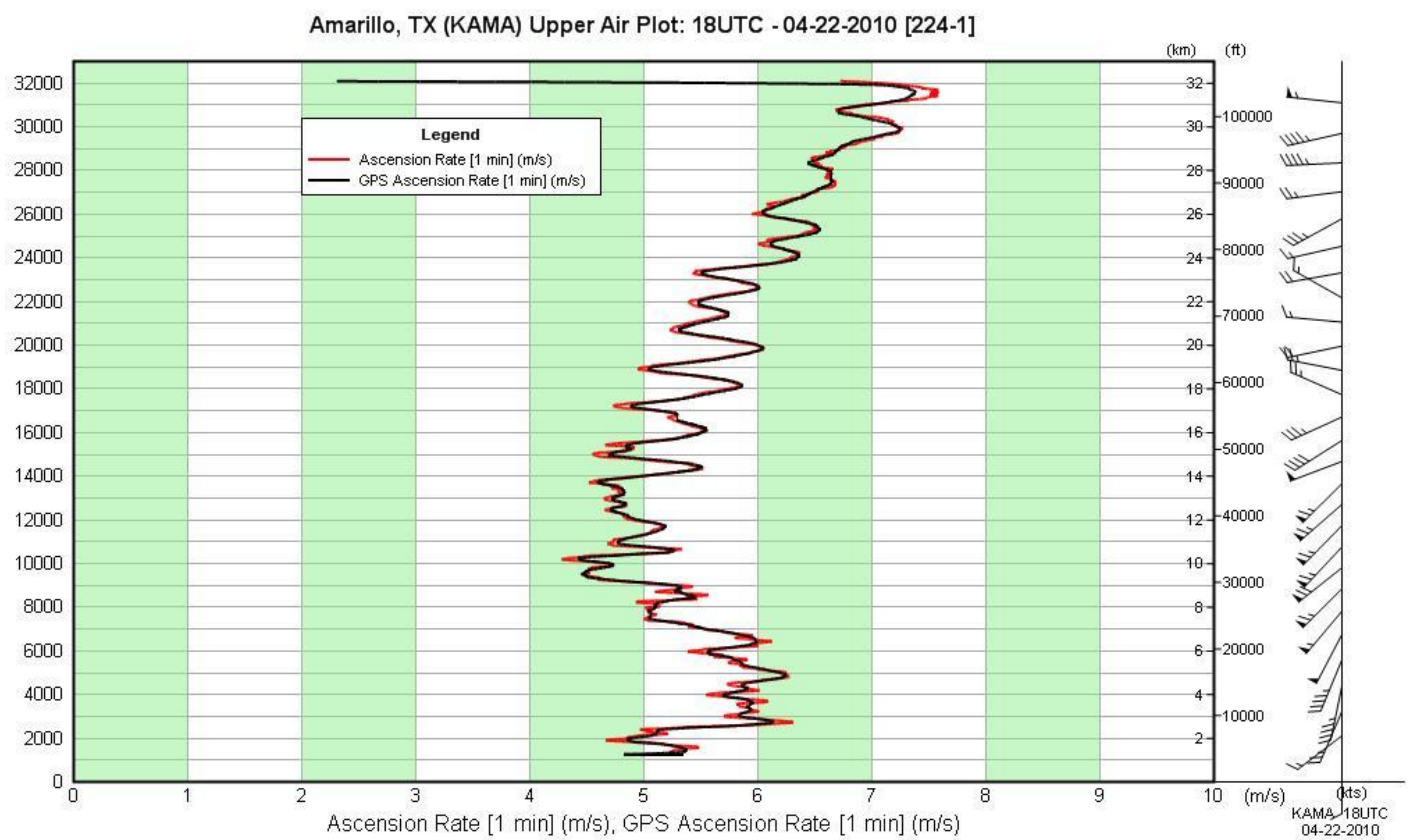


Figure 12

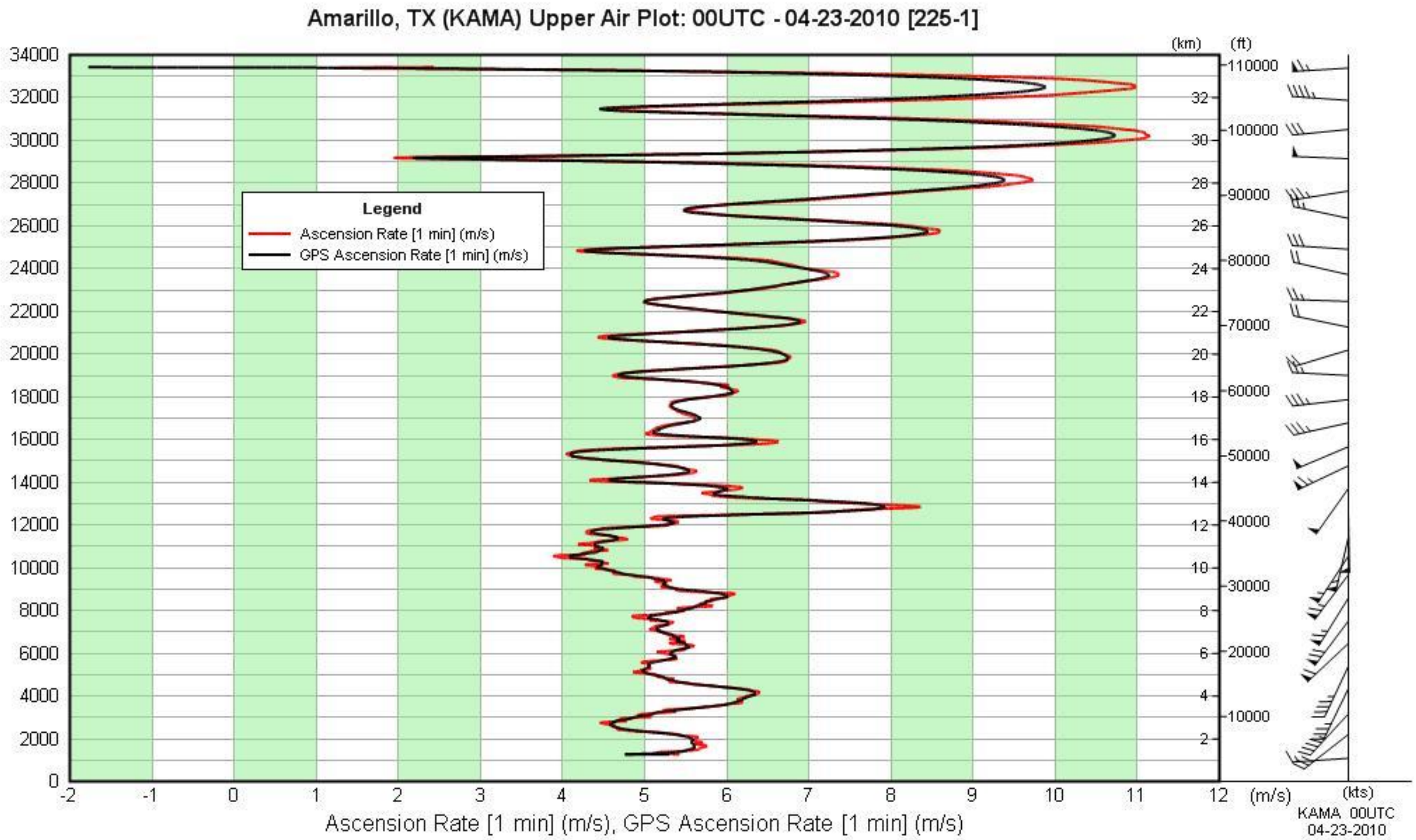


Figure13

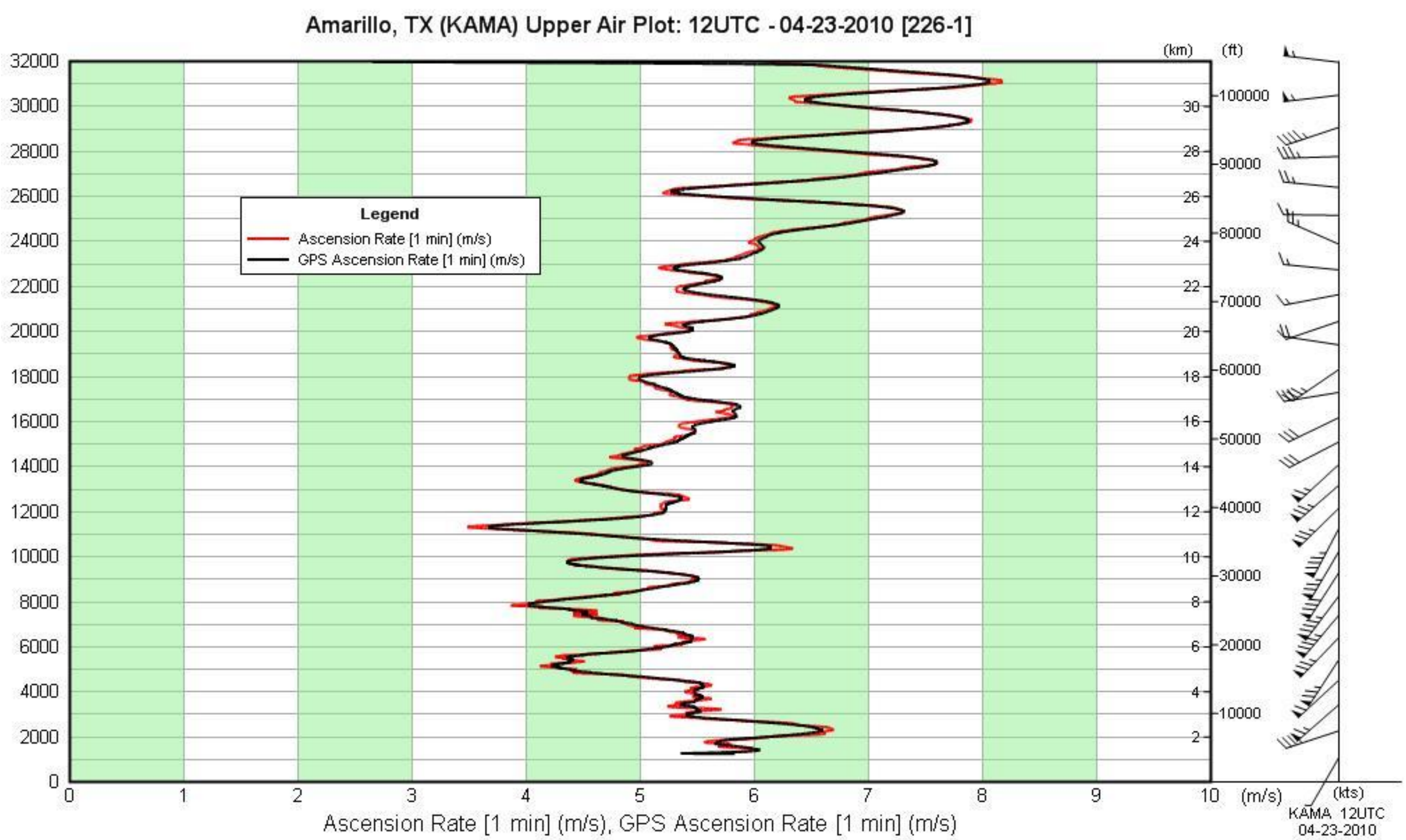
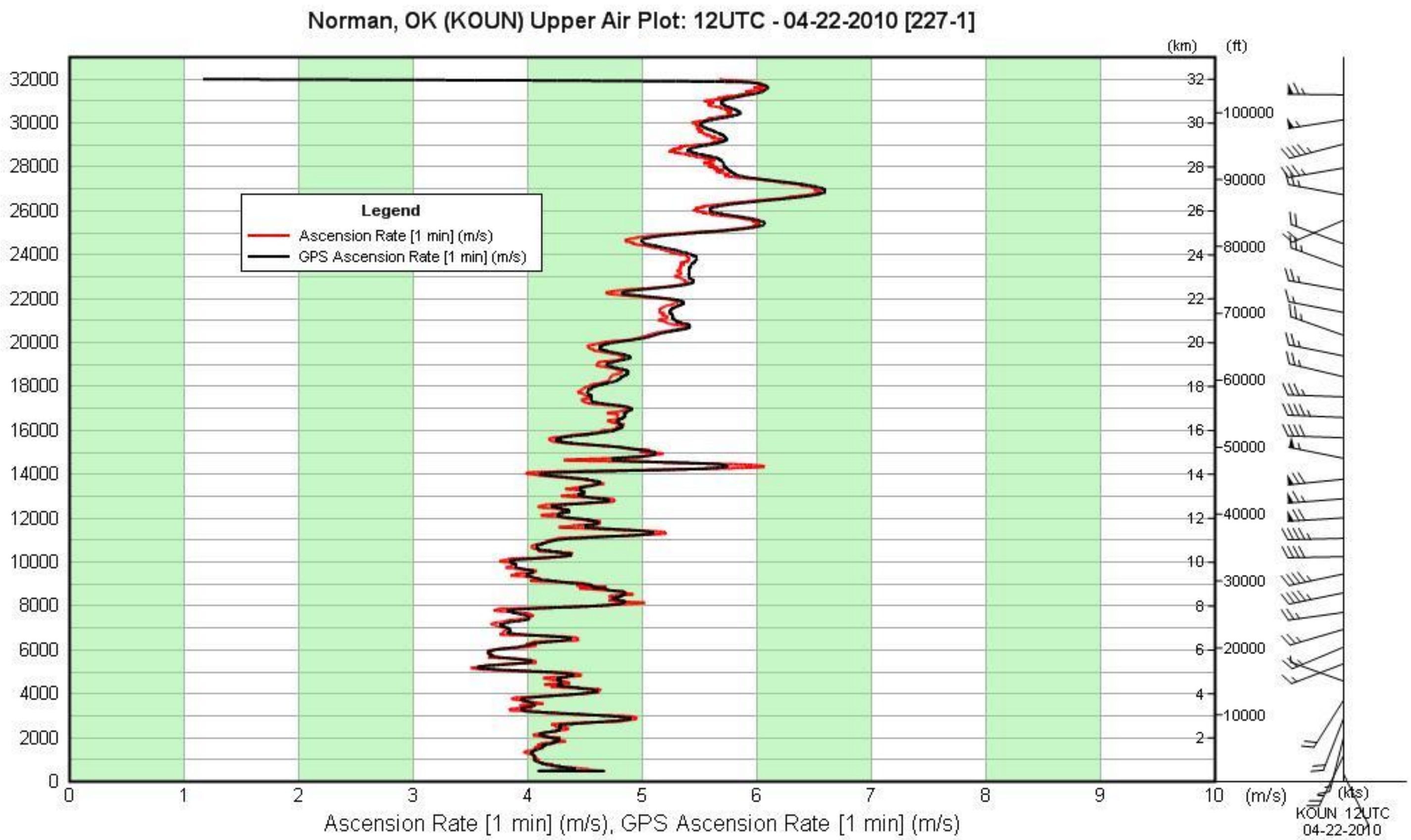
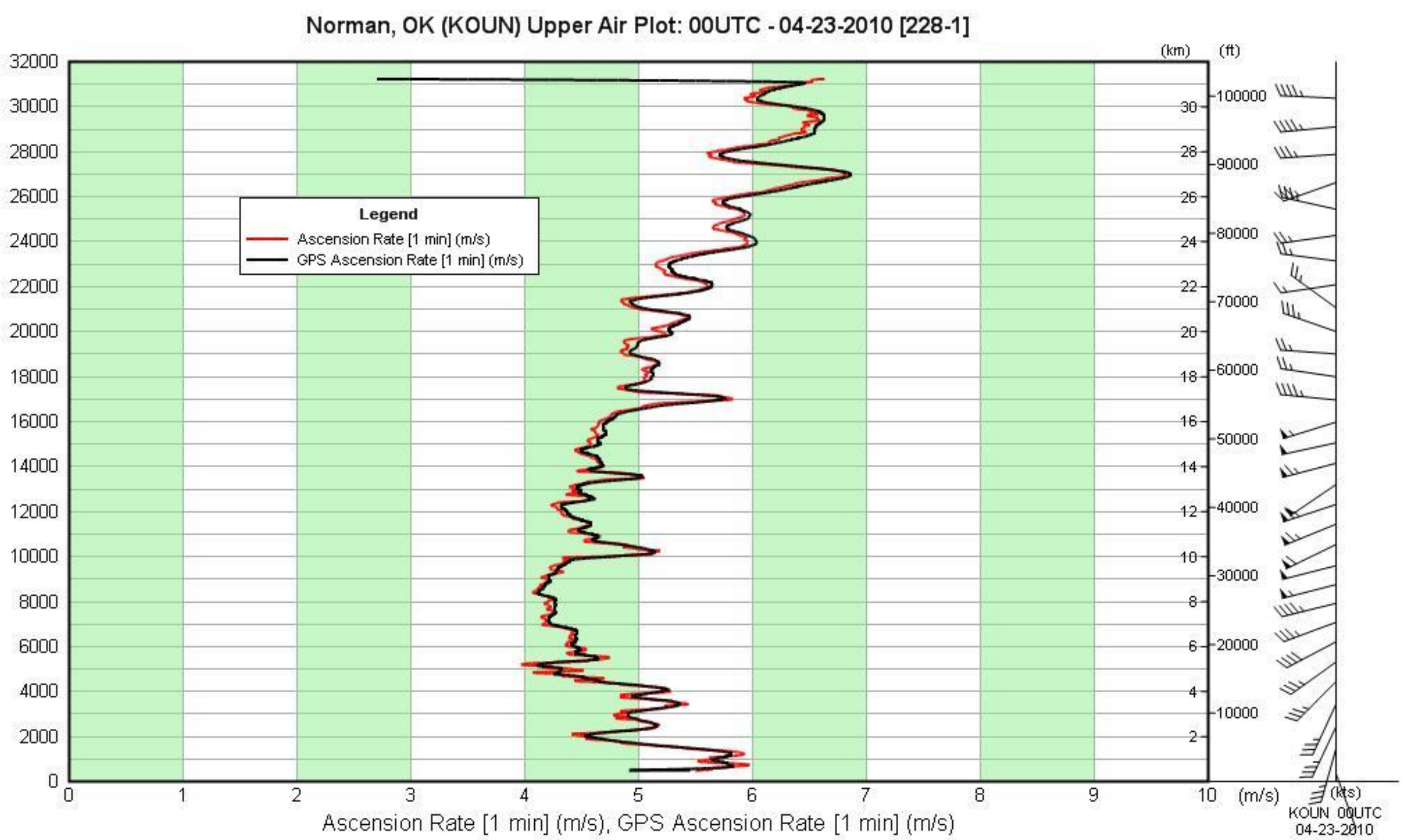


Figure 14



Norman, OK (KOUN) Upper Air Plot: 12UTC - 04-22-2010 [227-1]
Legend
Ascension Rate [1 min] (m/s)
GPS Ascension Rate [1 min] (m/s)
Ascension Rate [1 min] (m/s), GPS Ascension Rate [1 min] (m/s)
(km)
(ft)
(m/s)
(kts)
KOUN 12UTC
04-22-2010

Figure 15



Norman, OK (KOUN) Upper Air Plot: 00UTC - 04-23-2010 [228-1]
Legend
Ascension Rate [1 min] (m/s)
GPS Ascension Rate [1 min] (m/s)
Ascension Rate [1 min] (m/s), GPS Ascension Rate [1 min] (m/s)
(km)
(ft)
(m/s)
(kts)
KOUN 00UTC
04-23-2010

Figure 16

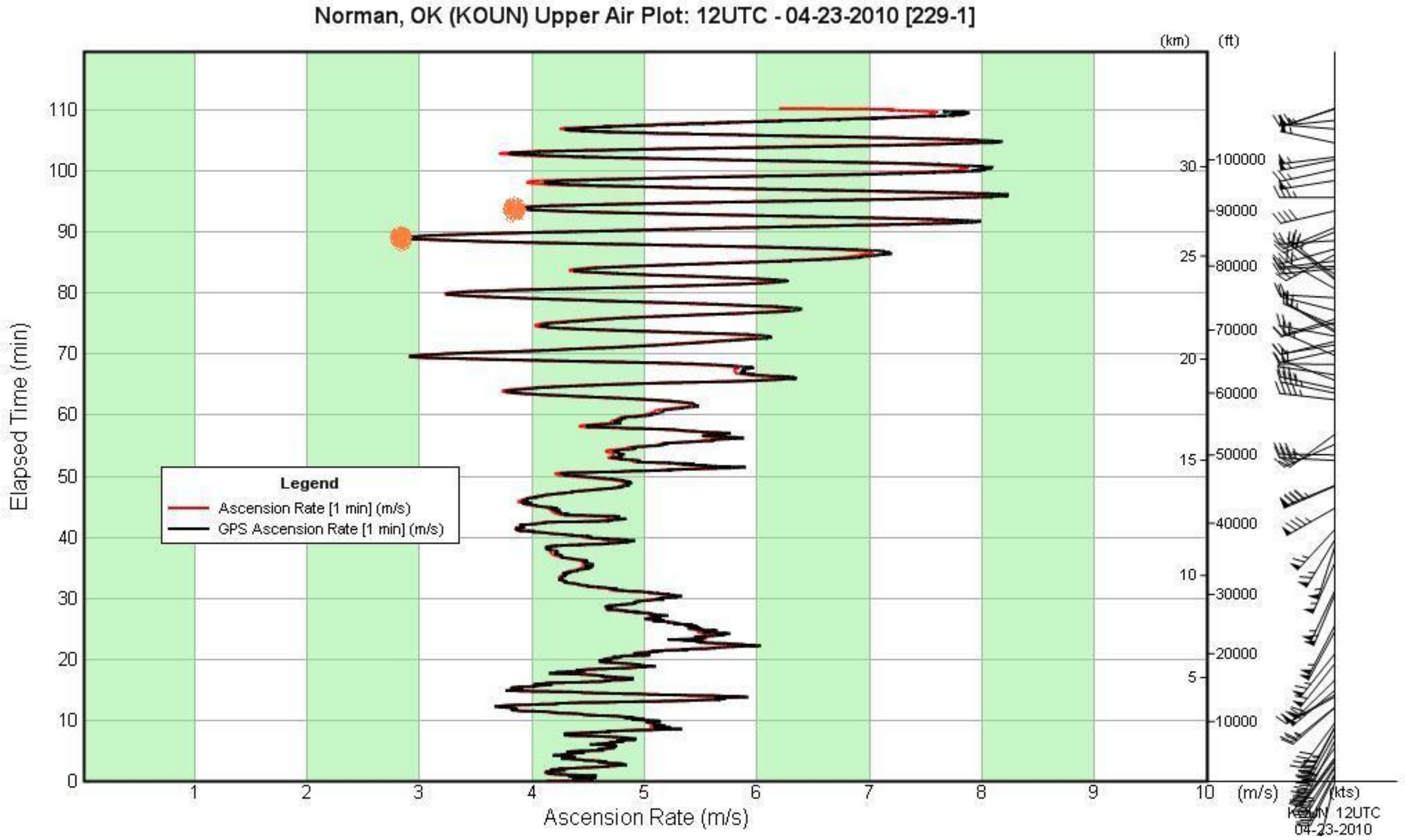


Figure 17

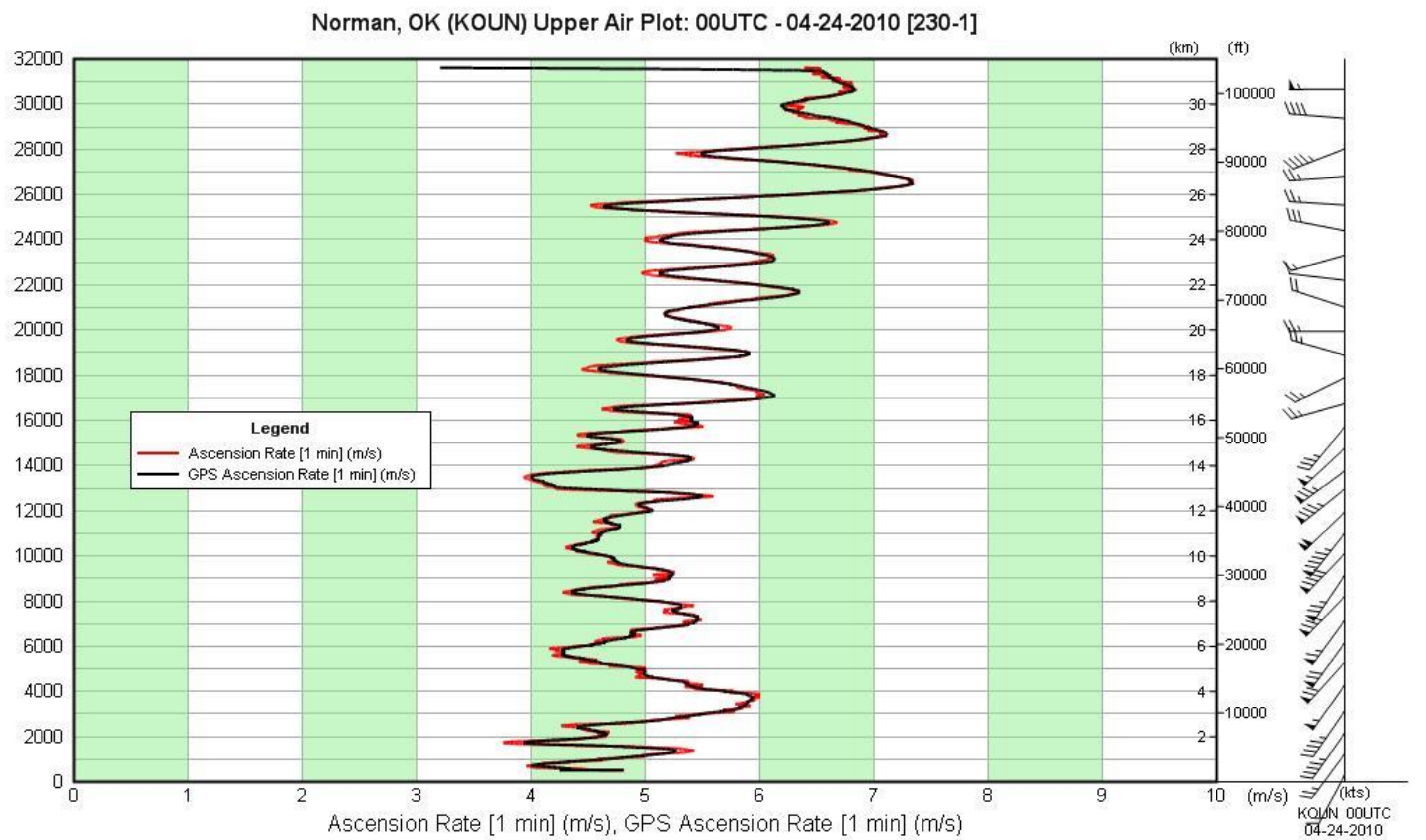


Figure 18

Case Study 4: Non Severe Thunderstorm

On May 19, 2010, rain and non-severe thunderstorms covered most of Kansas and Missouri owing to low pressure system that moved along the Oklahoma and Kansas border. More than 150 km away, in Oklahoma and Arkansas, severe weather (hail and tornadoes) occurred during the day. Balloon ascent rate plots from the upper air station in Springfield are shown in Figure 19, 20, and 21. In this case, non-severe thunderstorms occurred at Springfield. Note that the plots do not show the significant swings in ascent rates as seen during severe weather events shown in other cases in this study.

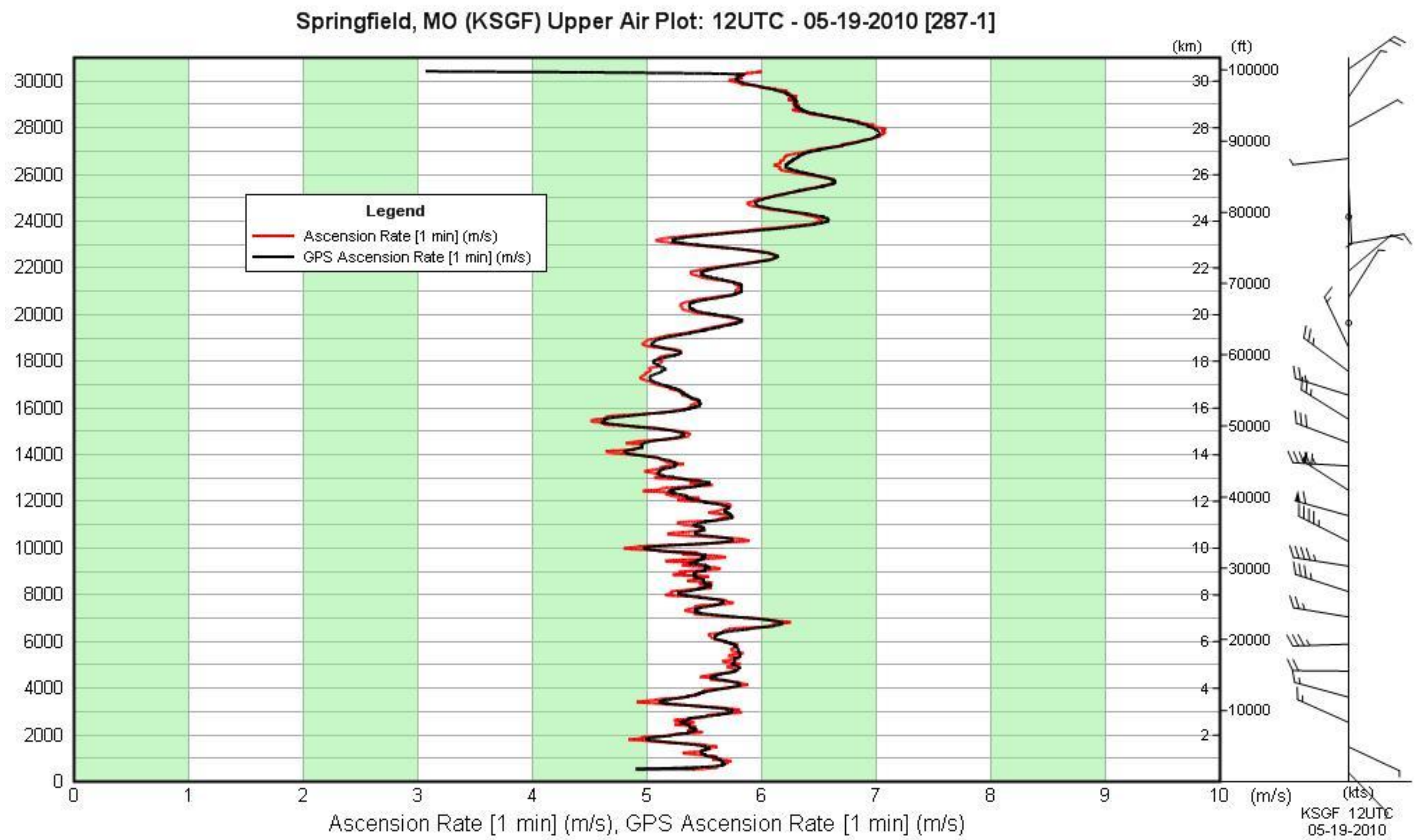


Figure 19

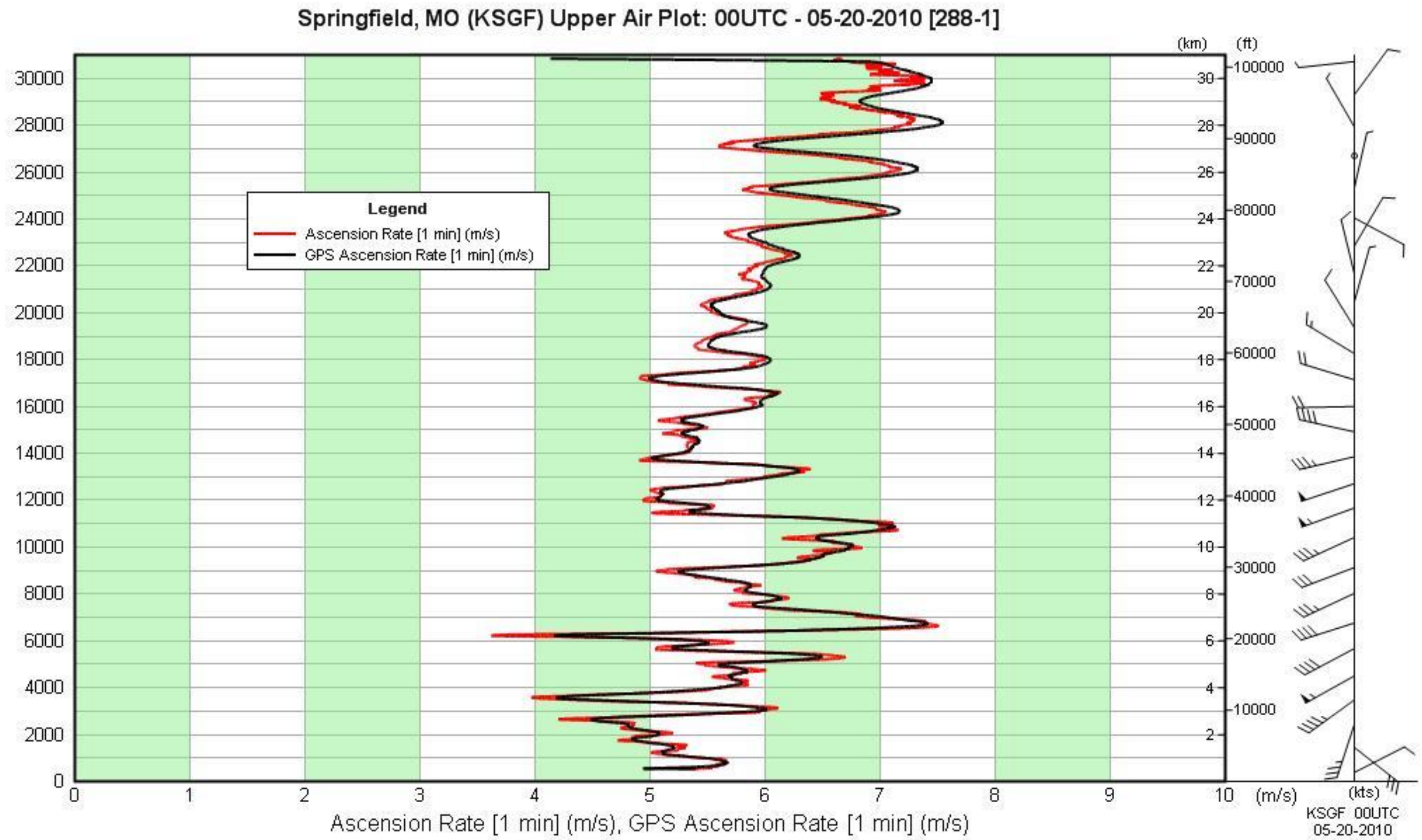


Figure 20

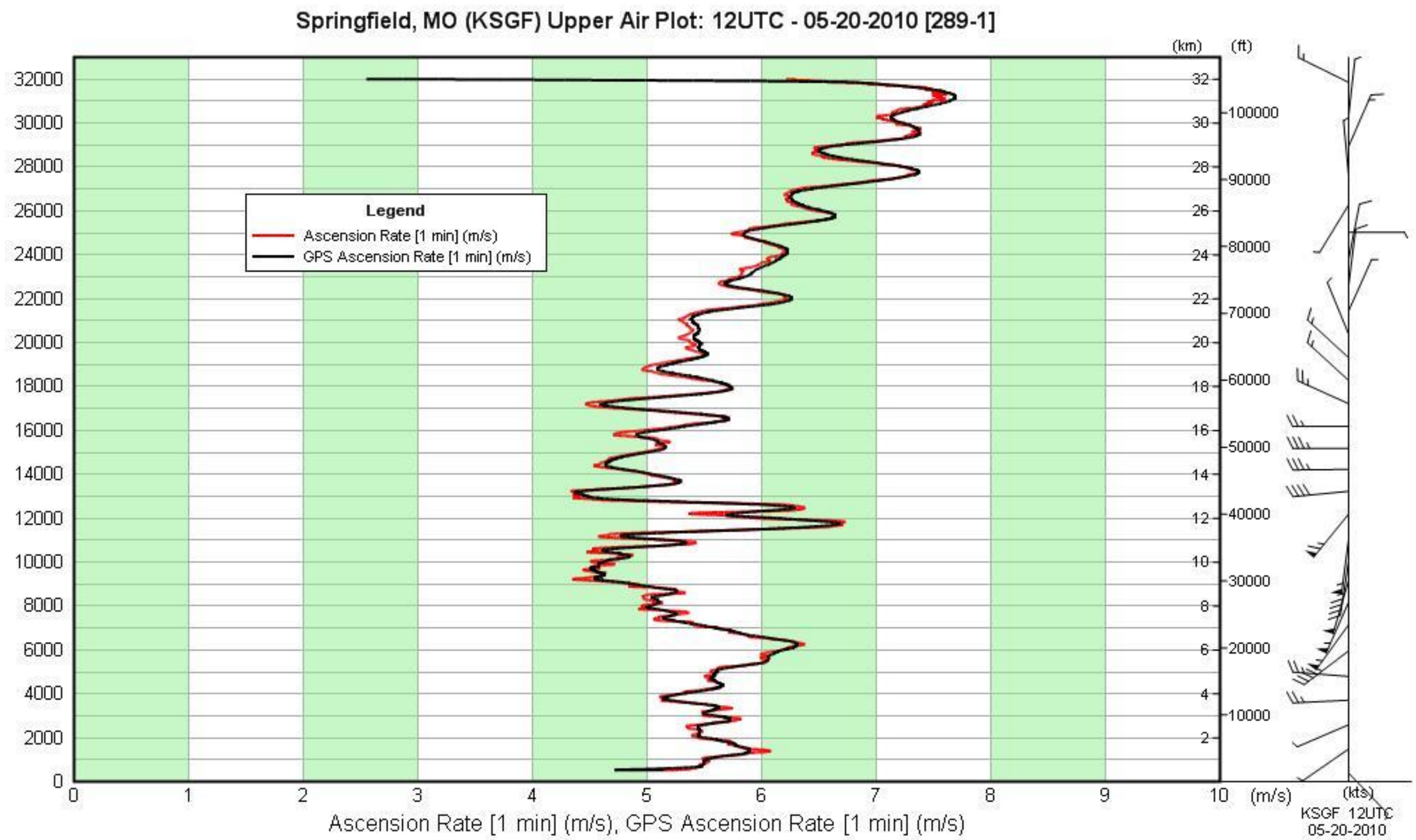


Figure 21

Case Study 5: The Springfield, MA, Tornado

A line of severe thunderstorms passed through New England on June 1, 2010, and an EF-3 tornado struck Springfield, MA, during the late afternoon. Hail 3.25 inches in diameter was reported in Shaftsbury, VT. More information on the storm is available here:

http://www.spc.noaa.gov/exper/archive/events/110601/index.html

Figures 22 through 28 show the radiosonde ascent rate plots from the NWS offices in Albany and Upton, NY (on Long Island), before and after (beginning 00:00 UTC, June 2) the tornado event. The June 2, 12:00 UTC, Albany sounding terminated below 20 km.

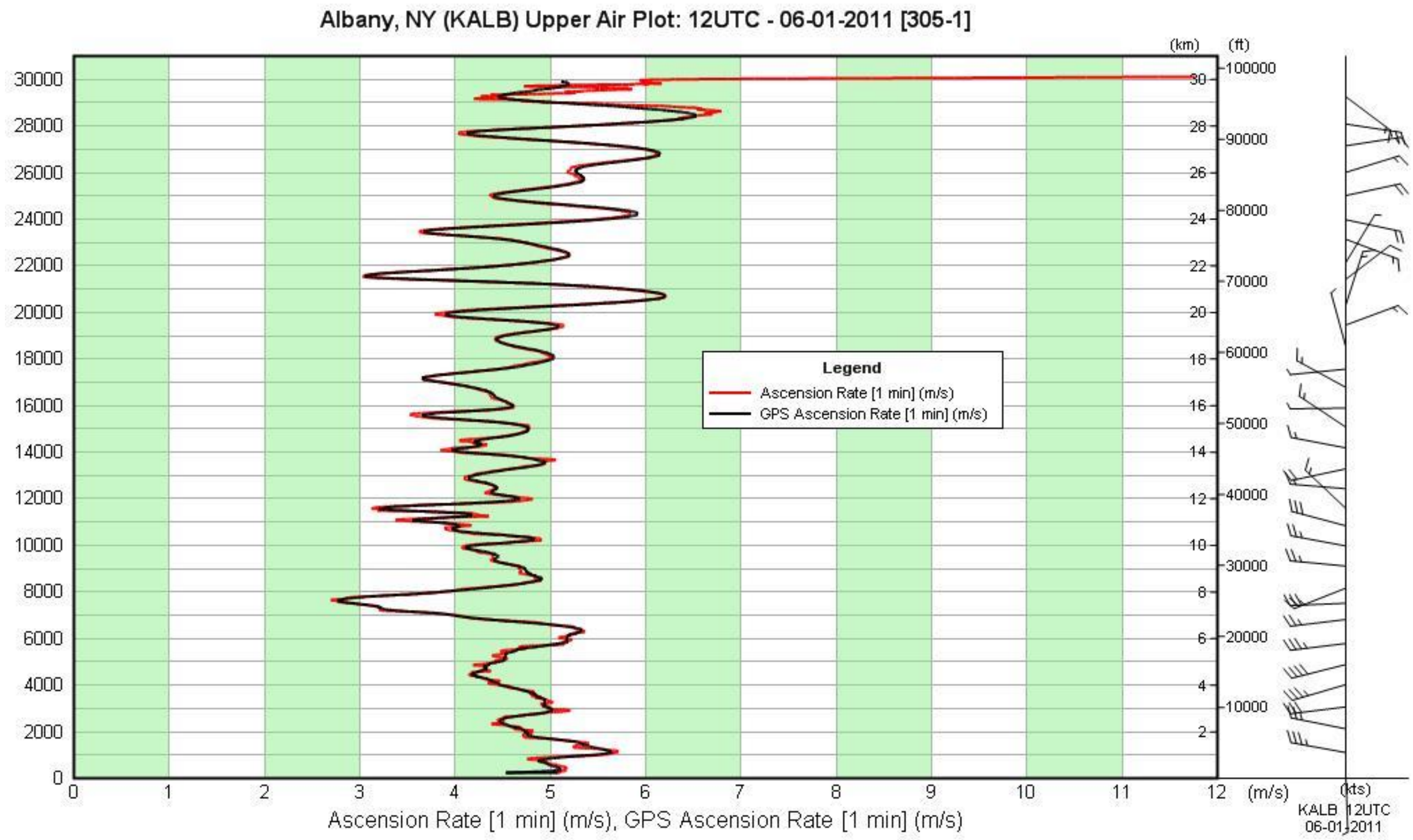


Figure 22

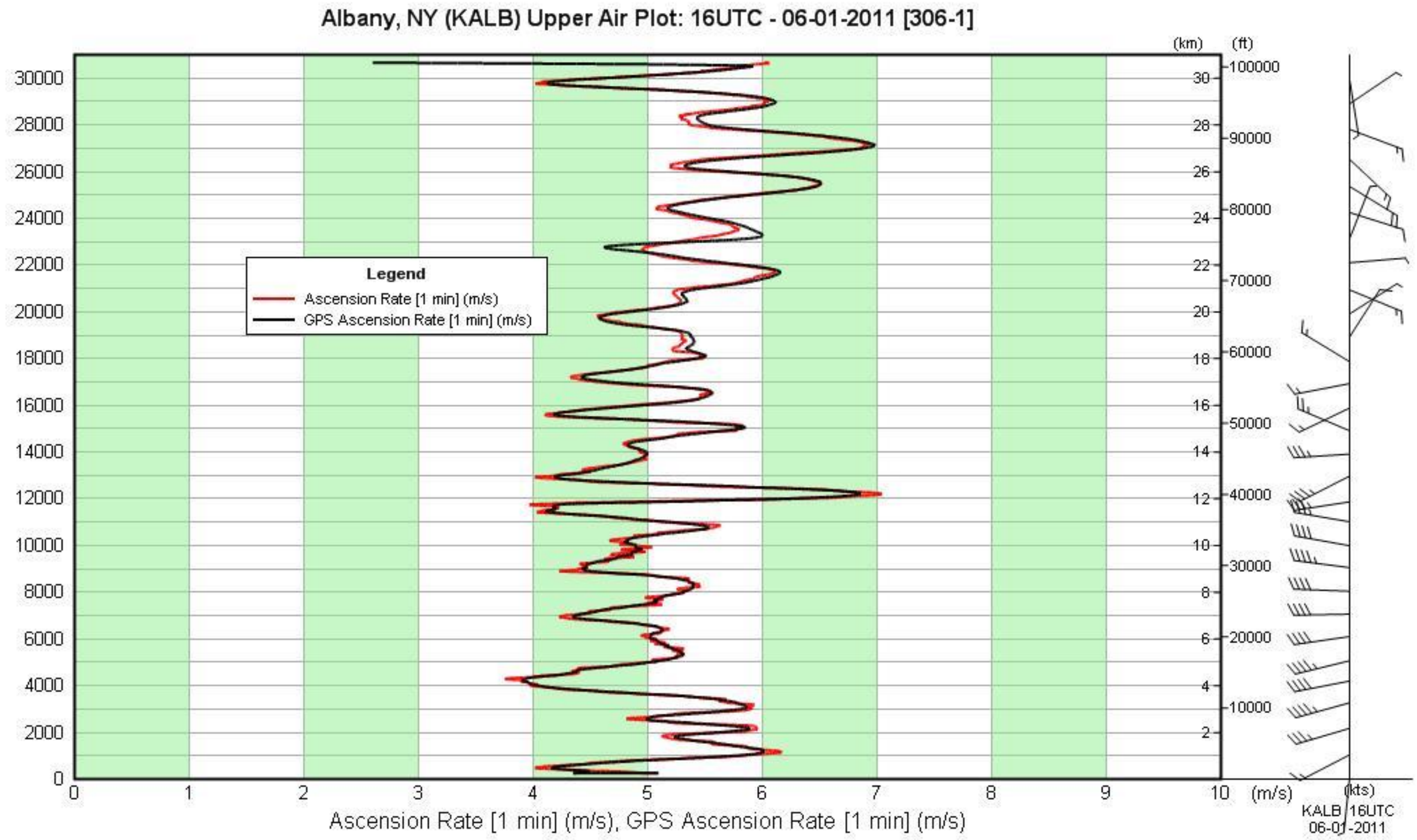


Figure 23

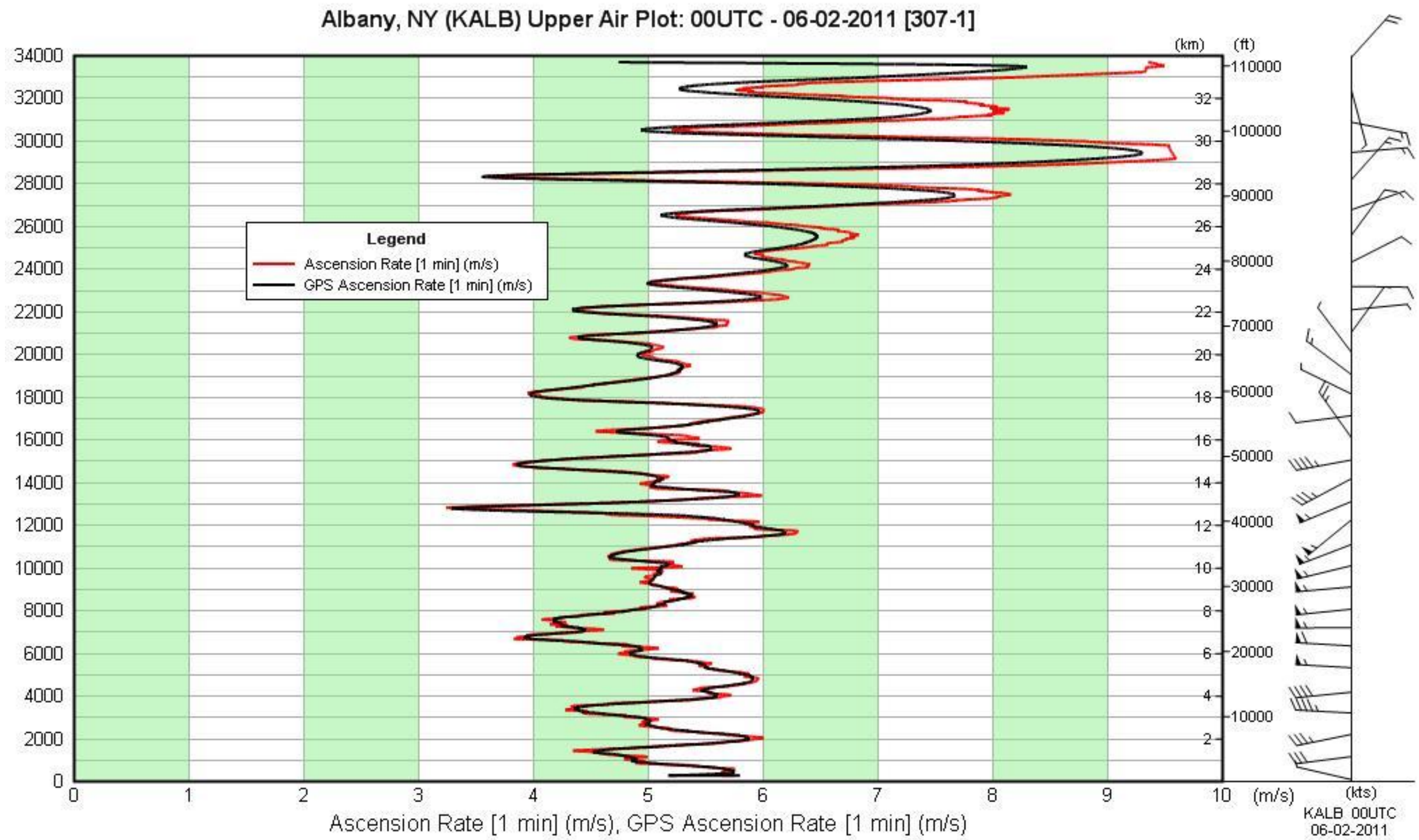


Figure 24

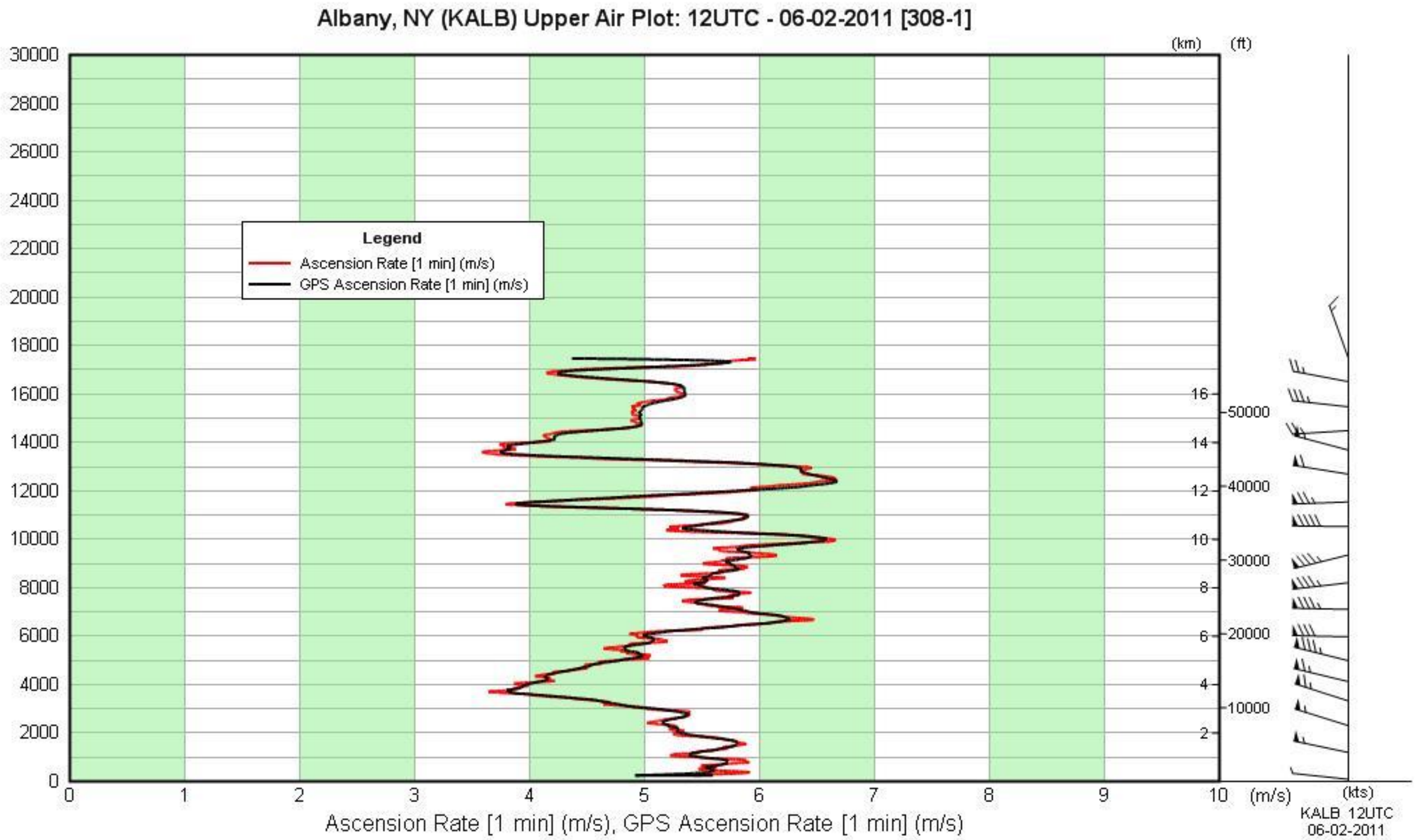


Figure 25

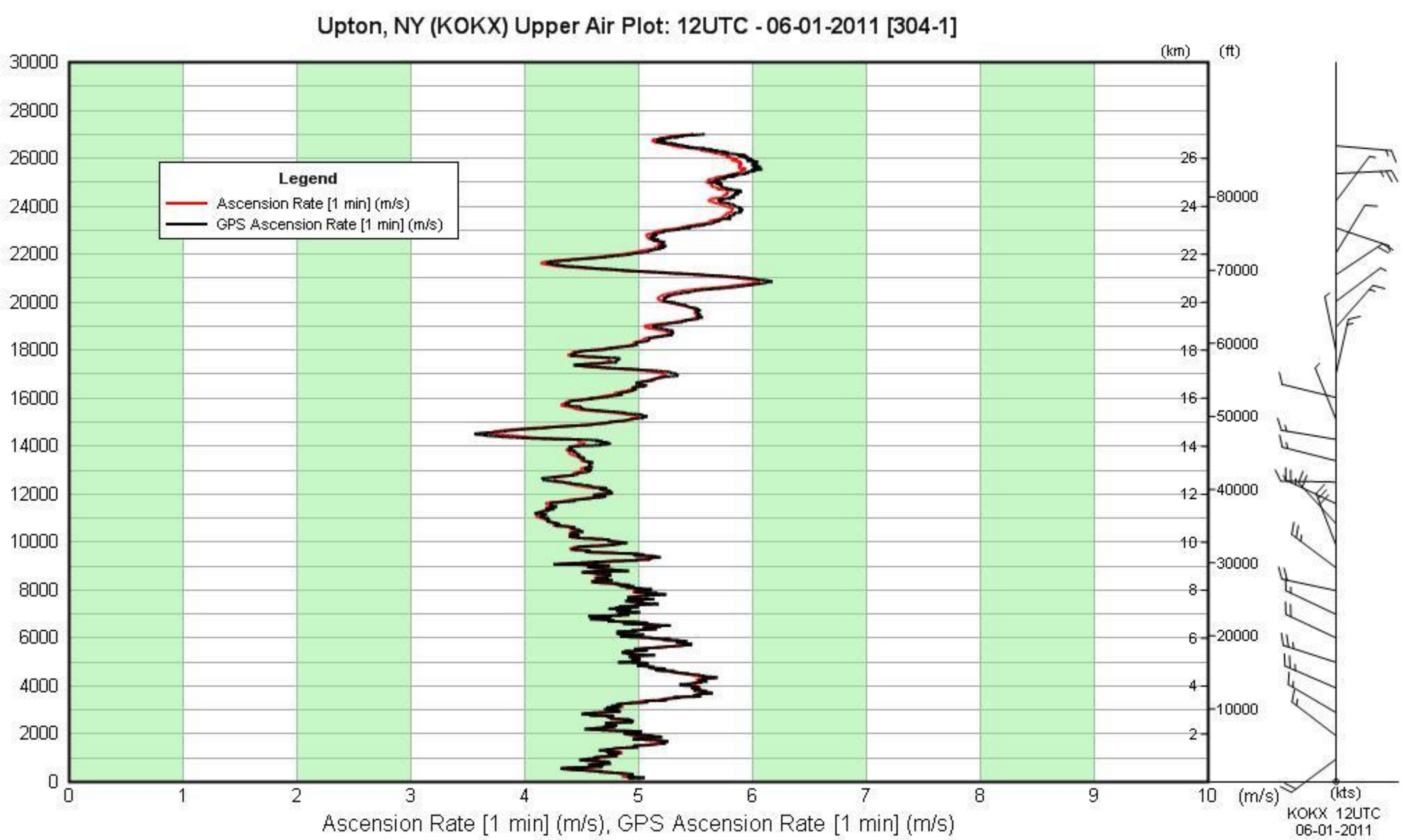


Figure 26

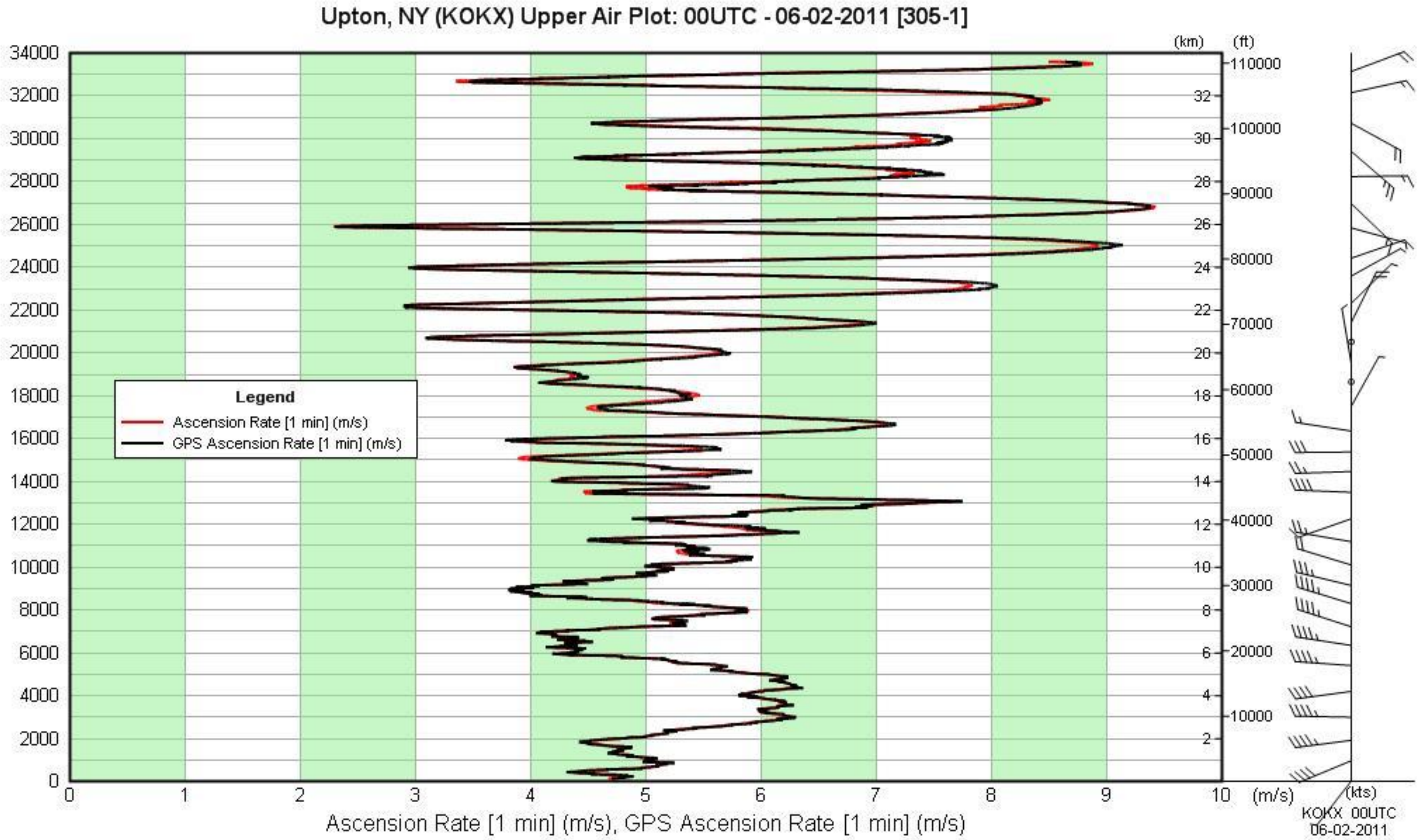


Figure 27

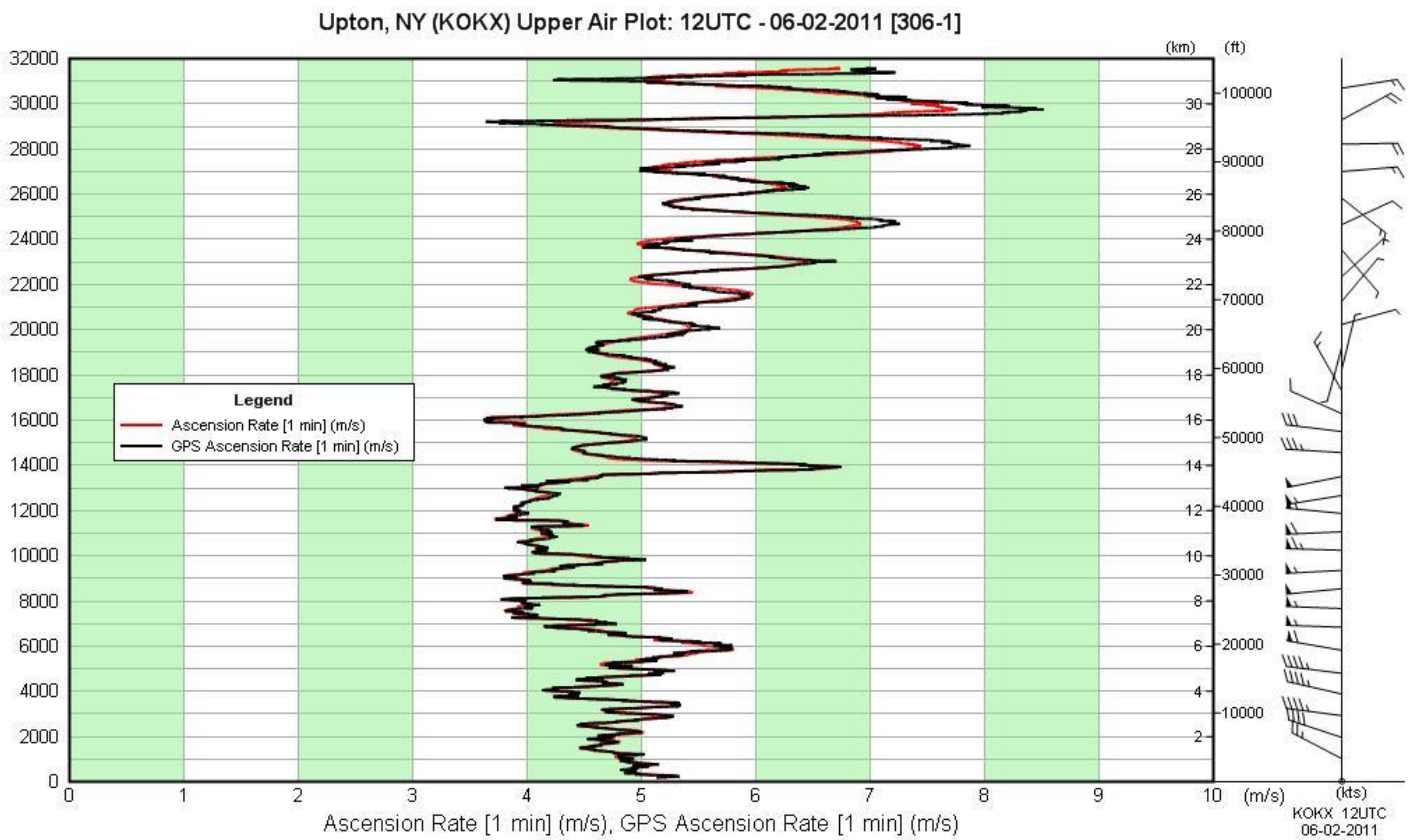


Figure 28

Case Study 6: Greensburg, KS, Tornado

From May 4 to 6, 2007, central Kansas experienced severe weather with large hail and tornadoes. An EF-5 tornado struck Greensburg Kansas at about 02:00 UTC on May 5, 2007. More information on the severe weather that occurred on May 4 is provided here:

http://www.spc.noaa.gov/exper/archive/events/070504/index.html

The nearest NWS upper air station to Greenburg is Dodge City, KS, about 65 km away to the west-northwest. Figures 29 to 38 show radiosonde ascent rates from Dodge City, KS from 00:00 UTC May 5 through 12:00 UTC May 7. The 12:00 UTC May 6 sounding is missing. The office was using MicroART at the time and only ascent rates derived from the PTU data are available. Note that the plots show more abrupt or "saw-toothing" of the data. This is a result of six second data being used and that MicroART archives the pressure with a resolution of only 0.1 mb (RRS archives the pressure to 0.01 mb resolution). The 18:00 UTC sounding taken May 6 (Figure 35) may have been ingested into a convective cloud as the radiosonde ascent rate shows an abrupt shift upwards near 4,000 meters.

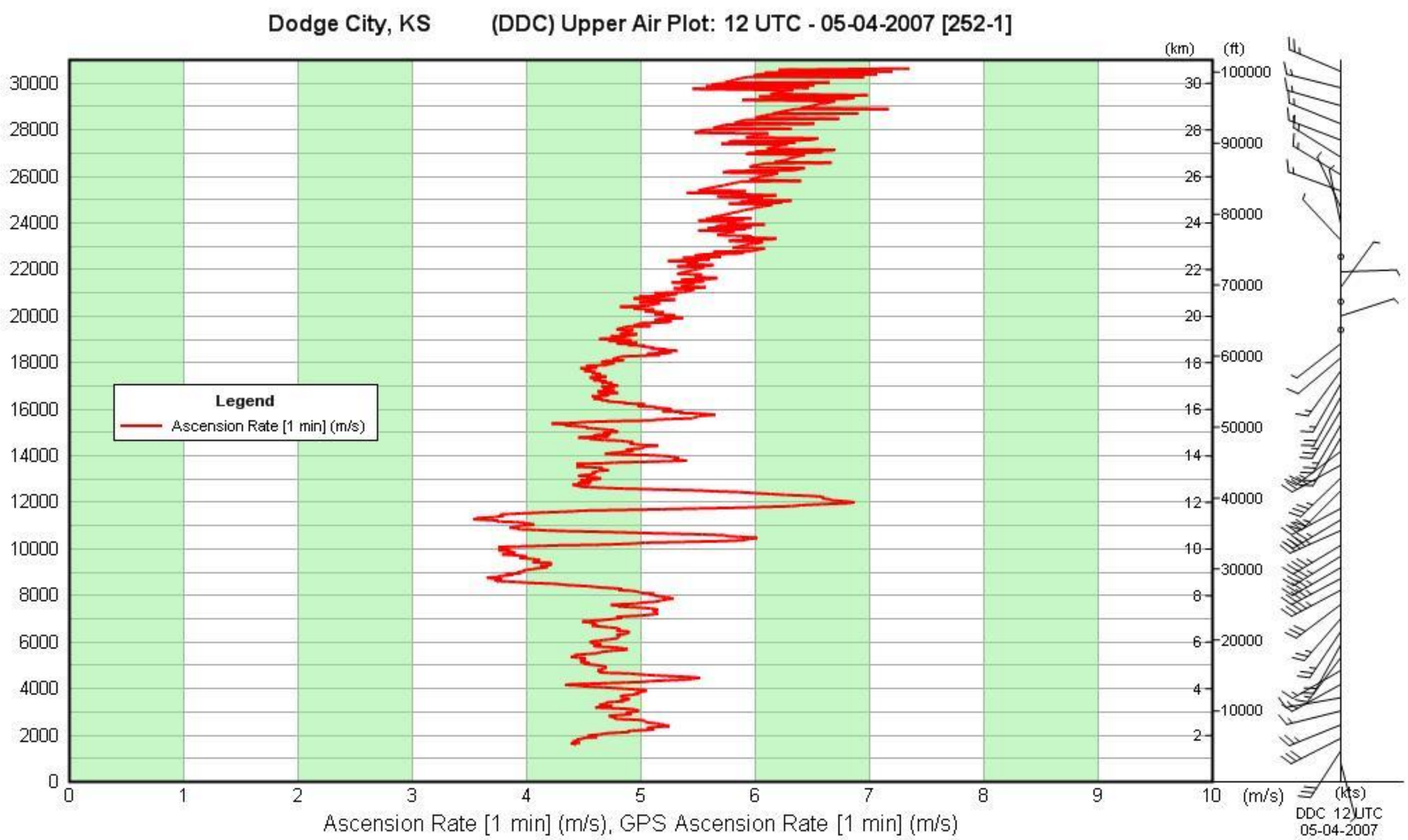


Figure 29

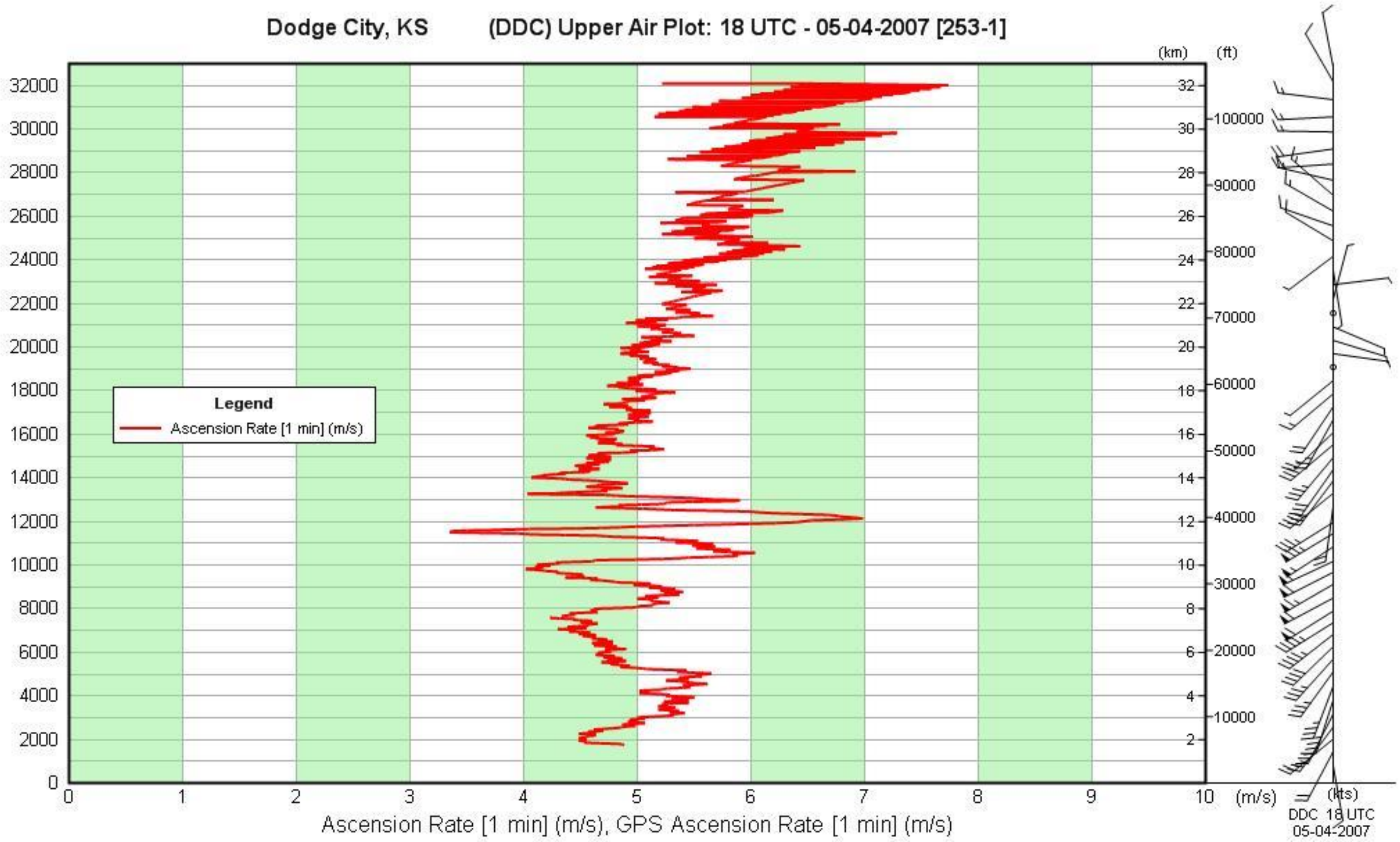


Figure 30

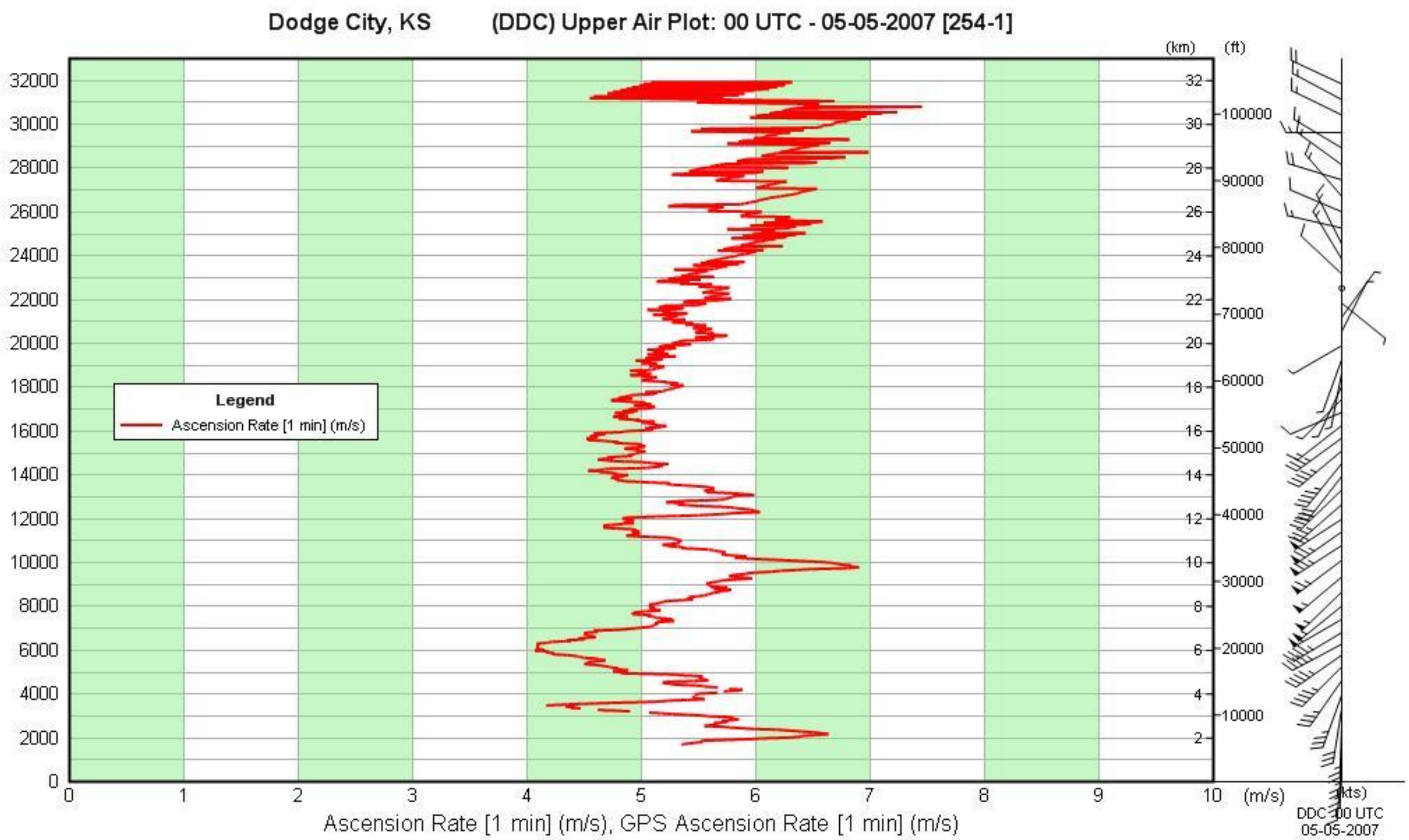


Figure 31

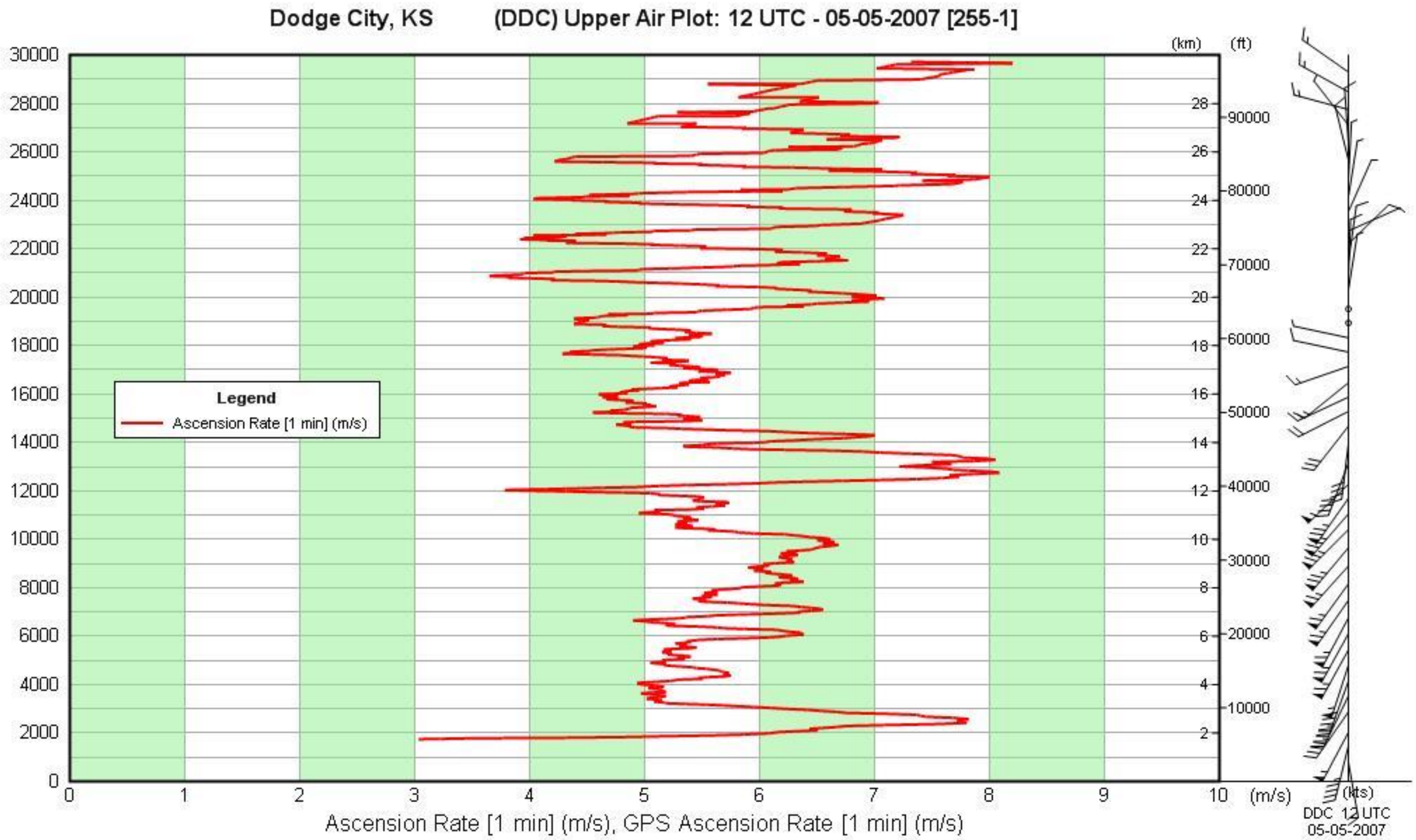


Figure 32

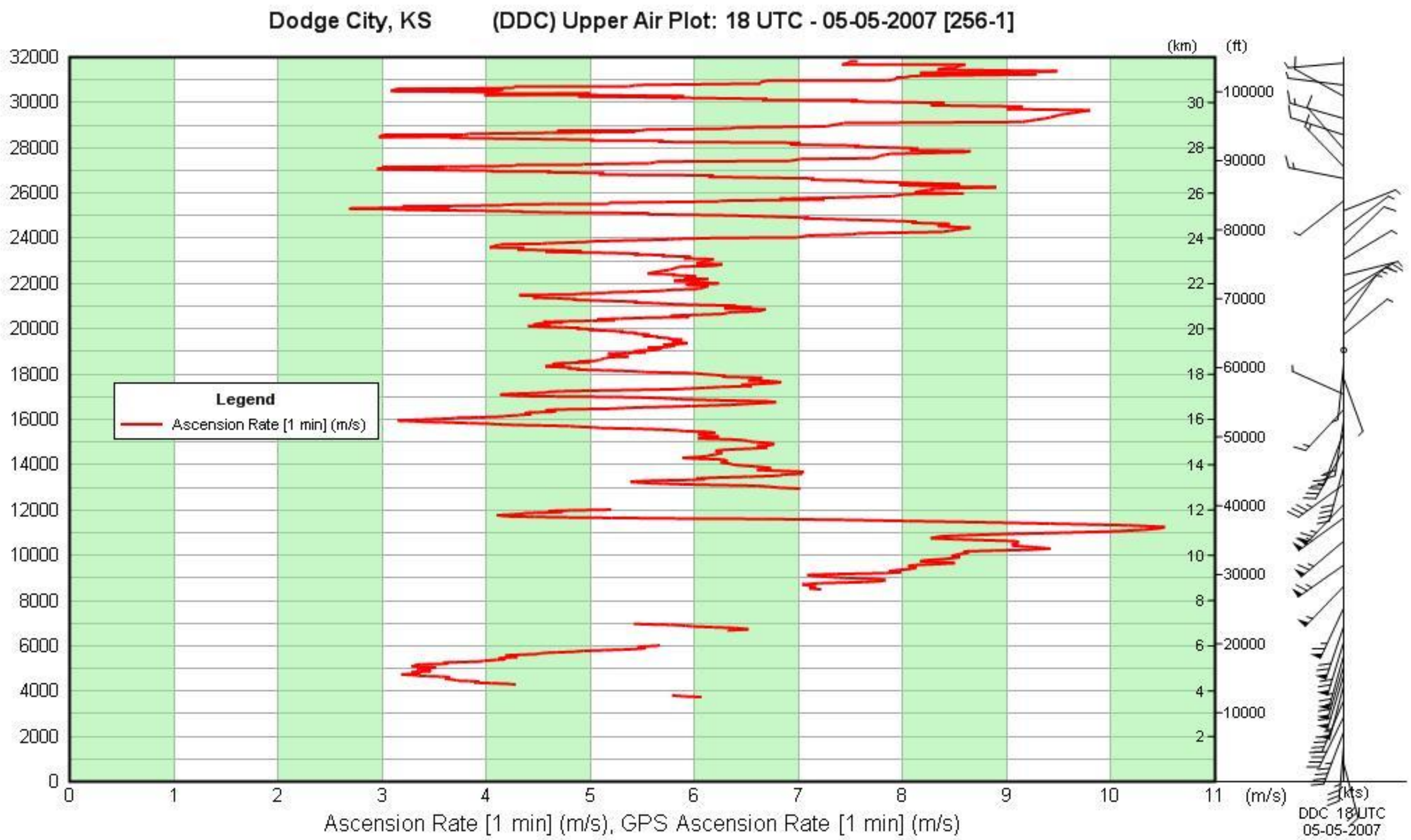


Figure 33

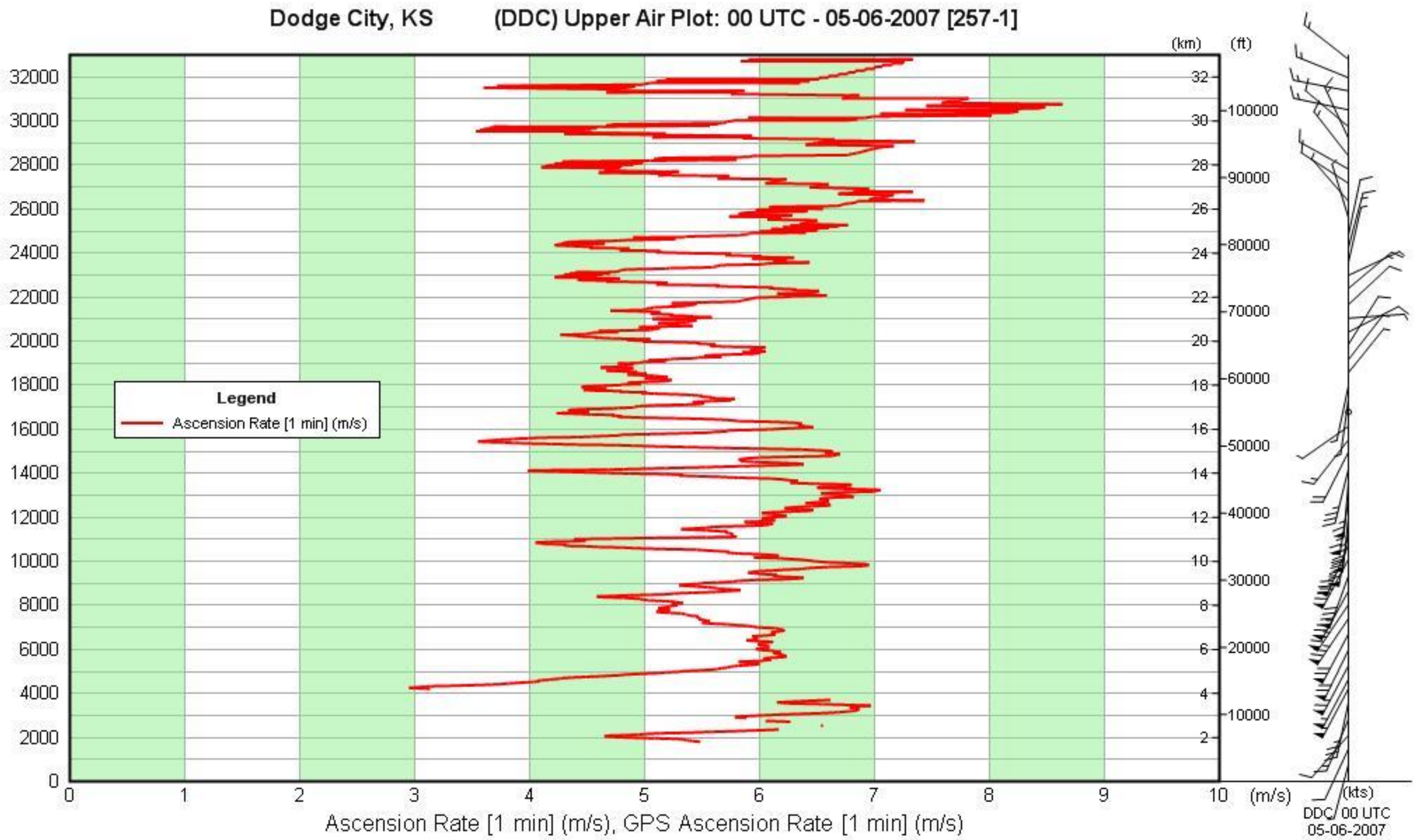


Figure 34

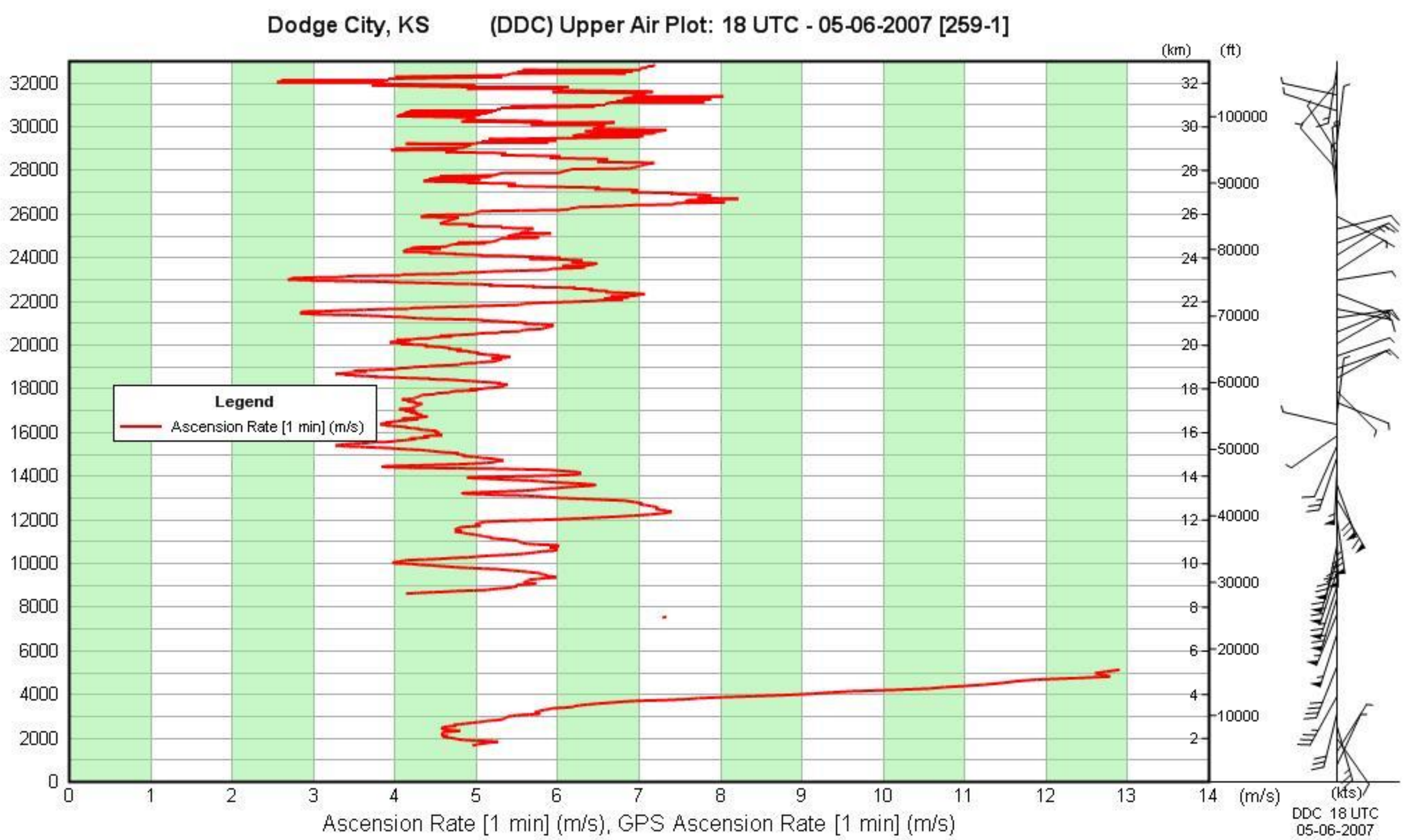


Figure 35

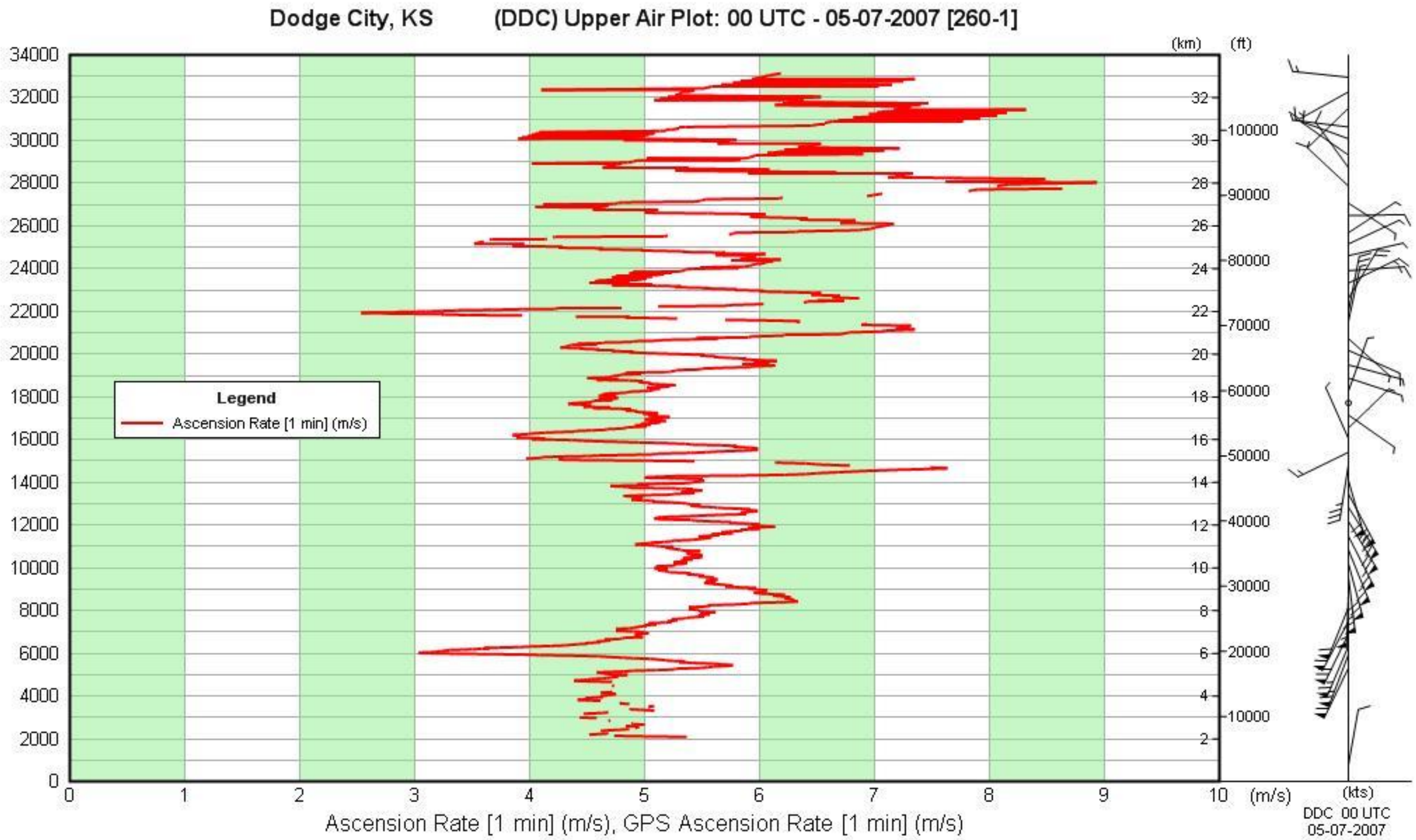


Figure 36

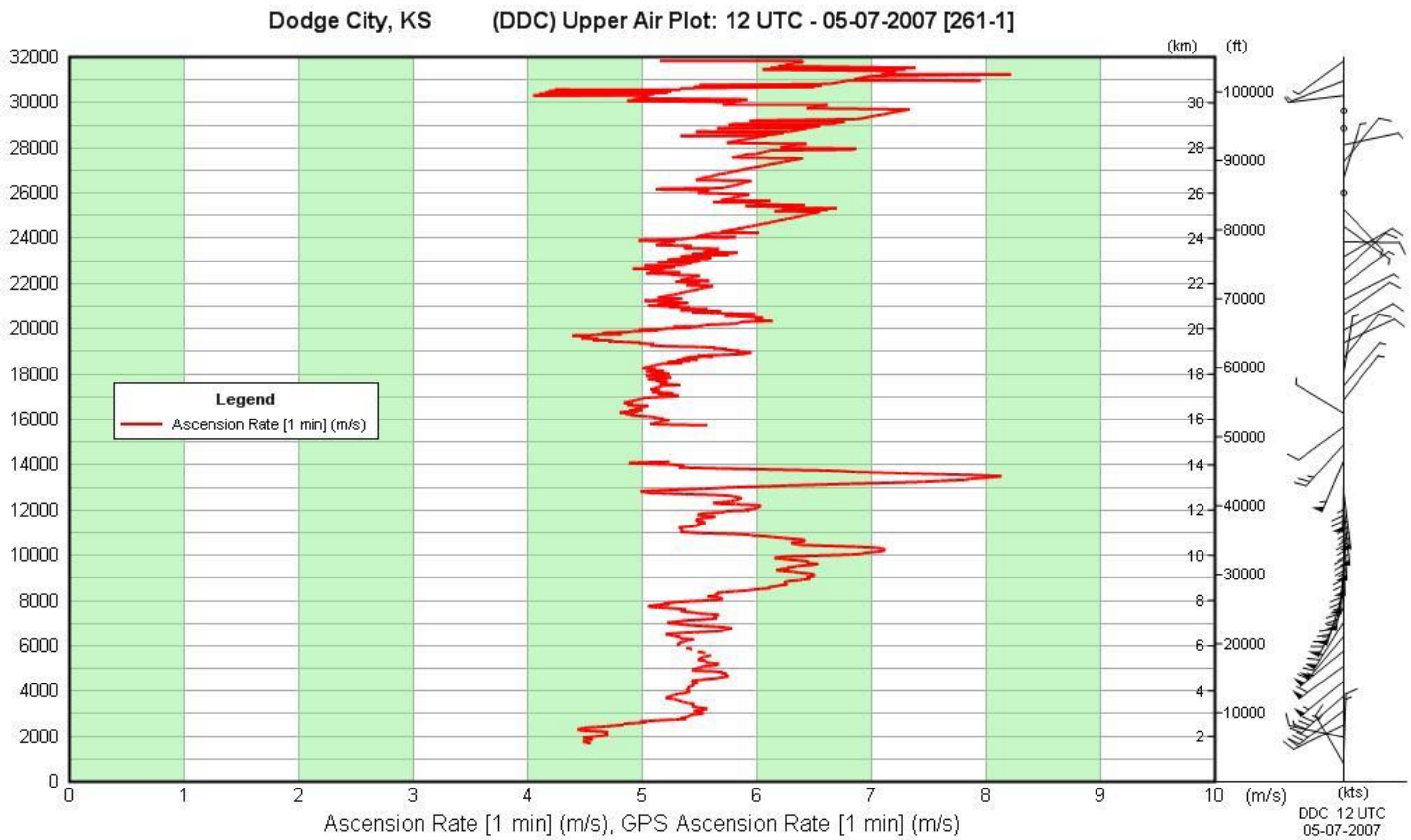


Figure 37

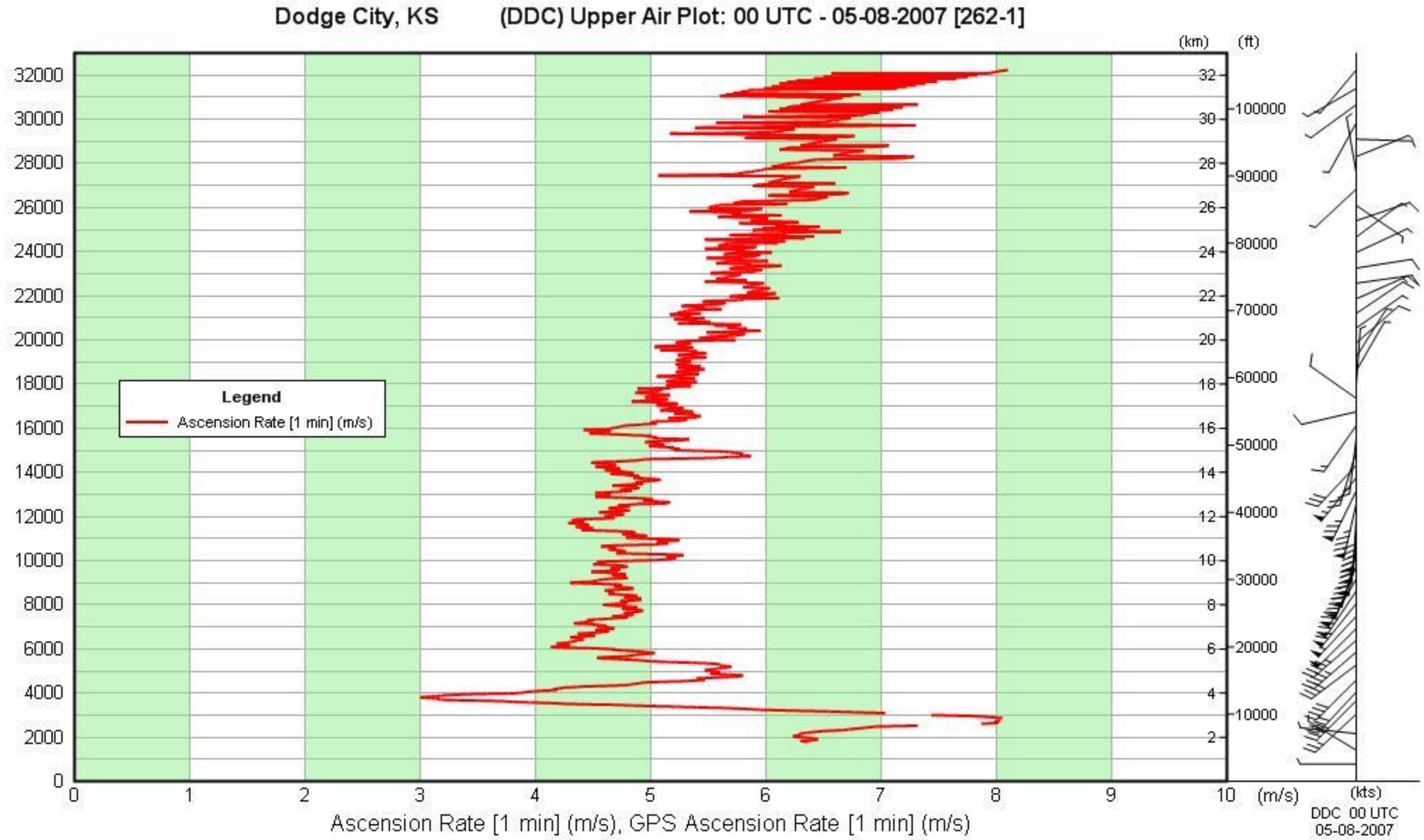


Figure 38

<u>Case Study 7: The Hallam, NE, Tornado</u>

At about 01:30 UTC on May 23, 2004, Halem, NE, was struck by a EF-4 tornado. More information on the storm is provided here.

http://www.spc.noaa.gov/exper/archive/events/040522/index.html

http://www.crh.noaa.gov/oax/archive/hallam/hallam.php

The nearest NWS upper air station to Hallam is located at Valley, NE, about 100 km away to the northeast. At the time of the storm, the office was using MicroART. Shown in Figures 39 through 41 are radiosonde ascent rates from Valley before and after the storm occurred. The 12:00 UTC, May 22, sounding was missing.

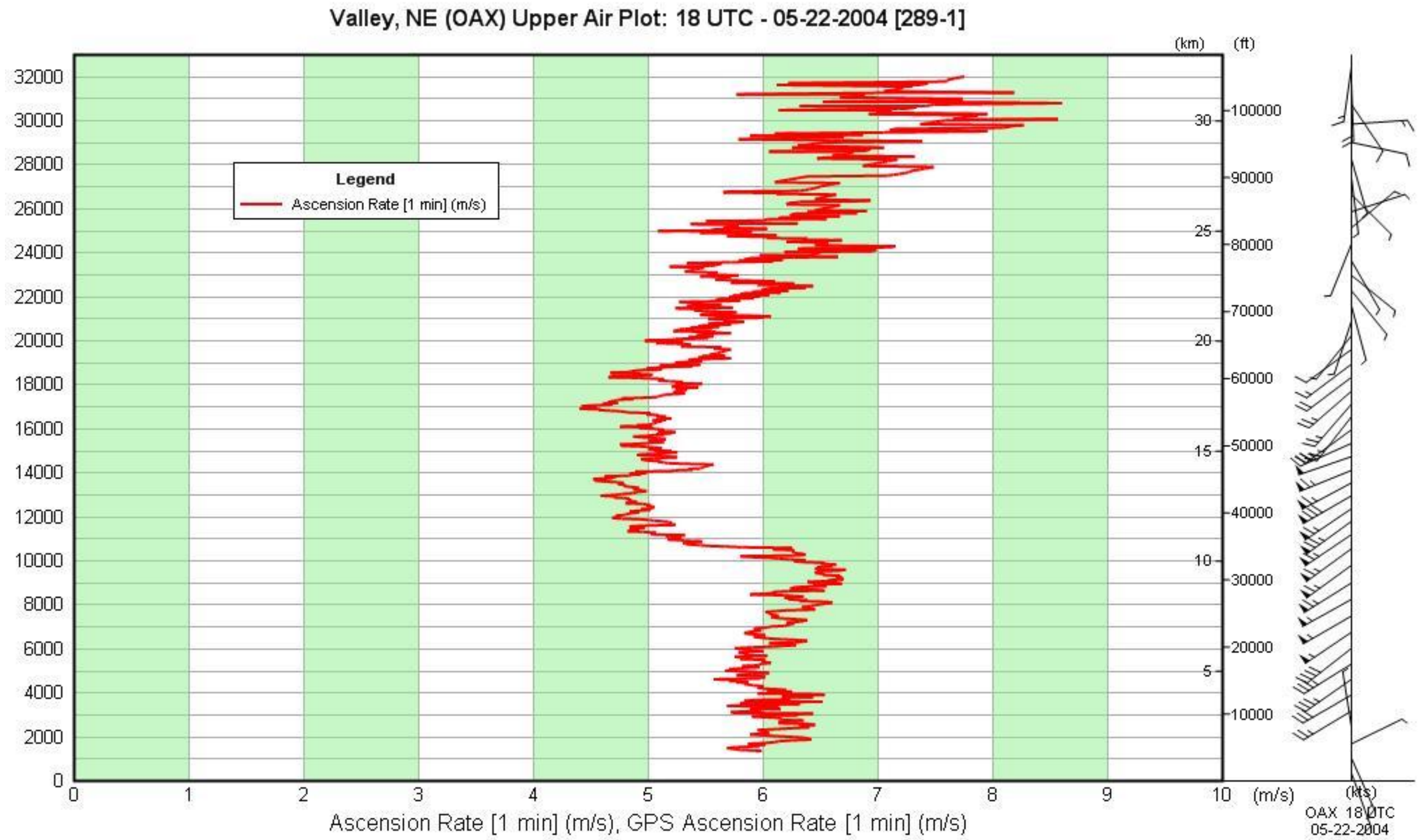


Figure 39

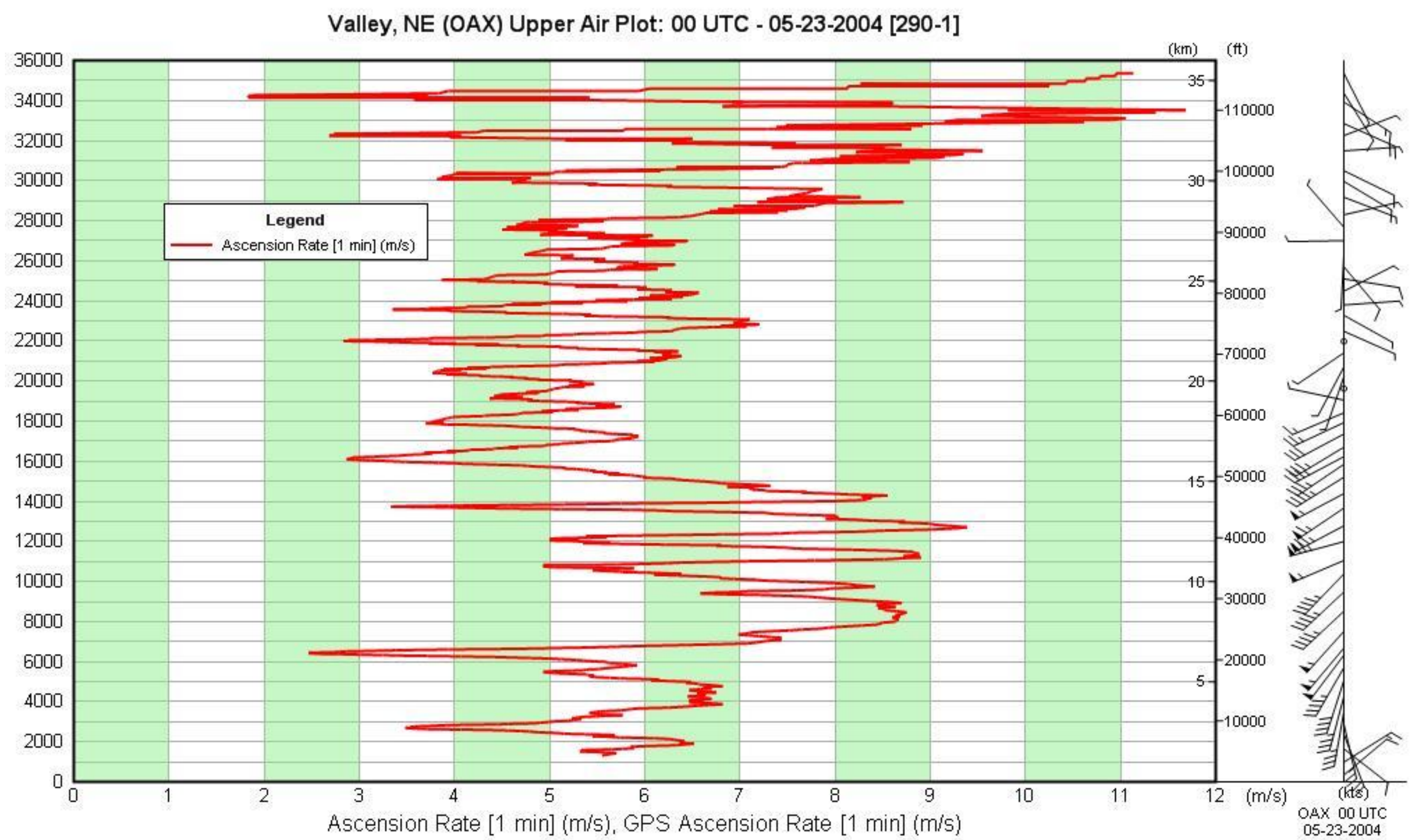


Figure 40

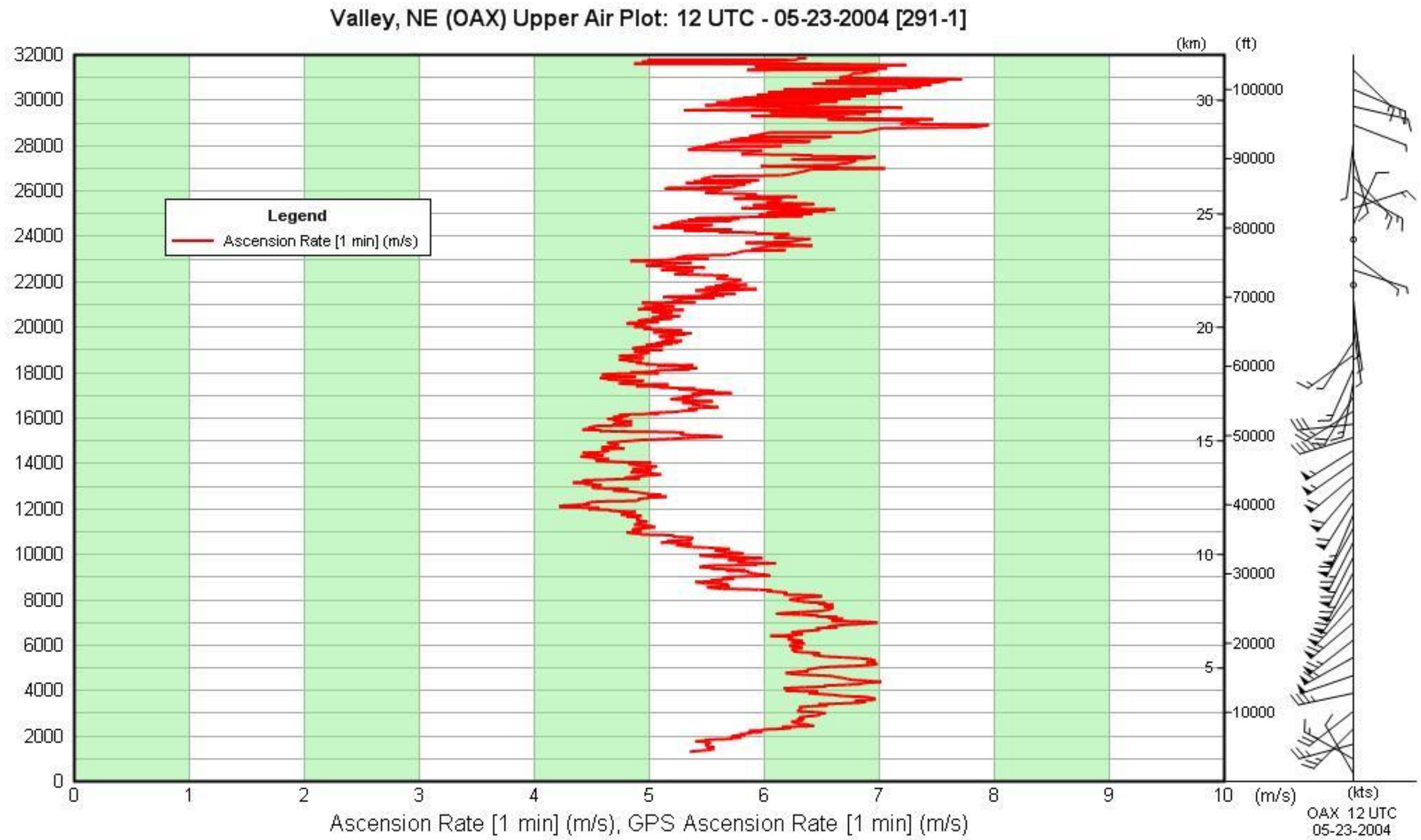


Figure 41

<u>Case Study 8: Non Severe Thunderstorm</u>

Non severe thunderstorms, caused by a stationary front, moved across Long Island, NY, from June 11 through early June 12, 2011. These storms passed near the NWS upper air station located at Upton, NY. Figure 42 shows radar imagery for 21:03 UTC on June 11 and Figure 43 shows radar imagery for 07:55 UTC on June 12. Figures 44 through 47 show the radiosonde ascent rate plots for the soundings taken before and after this weather event. Note that no significant changes in ascent rates (i.e., gravity waves) are seen above 20 km in the stratosphere.

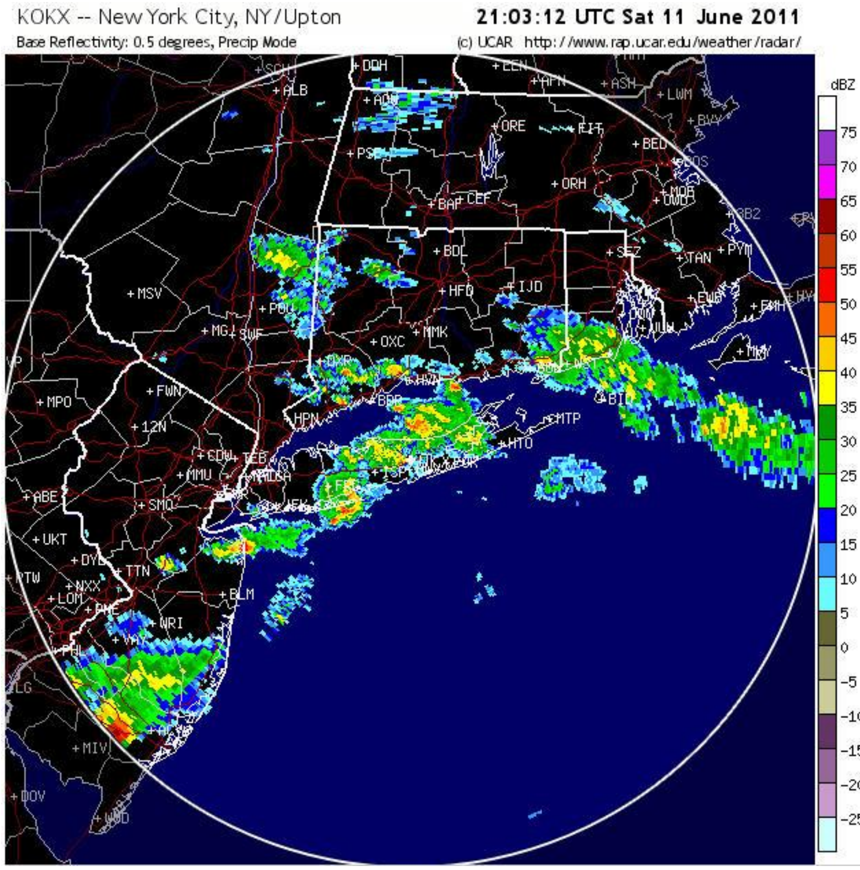


Figure 42 (Courtesy of UCAR)

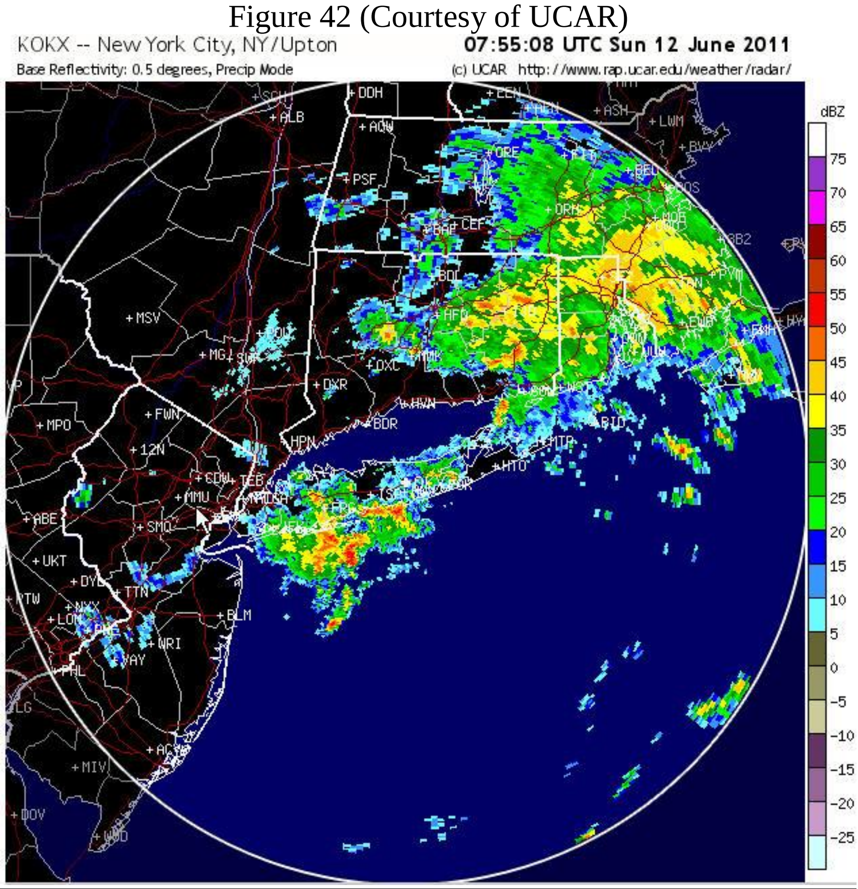


Figure 43 (Courtesy of UCAR)

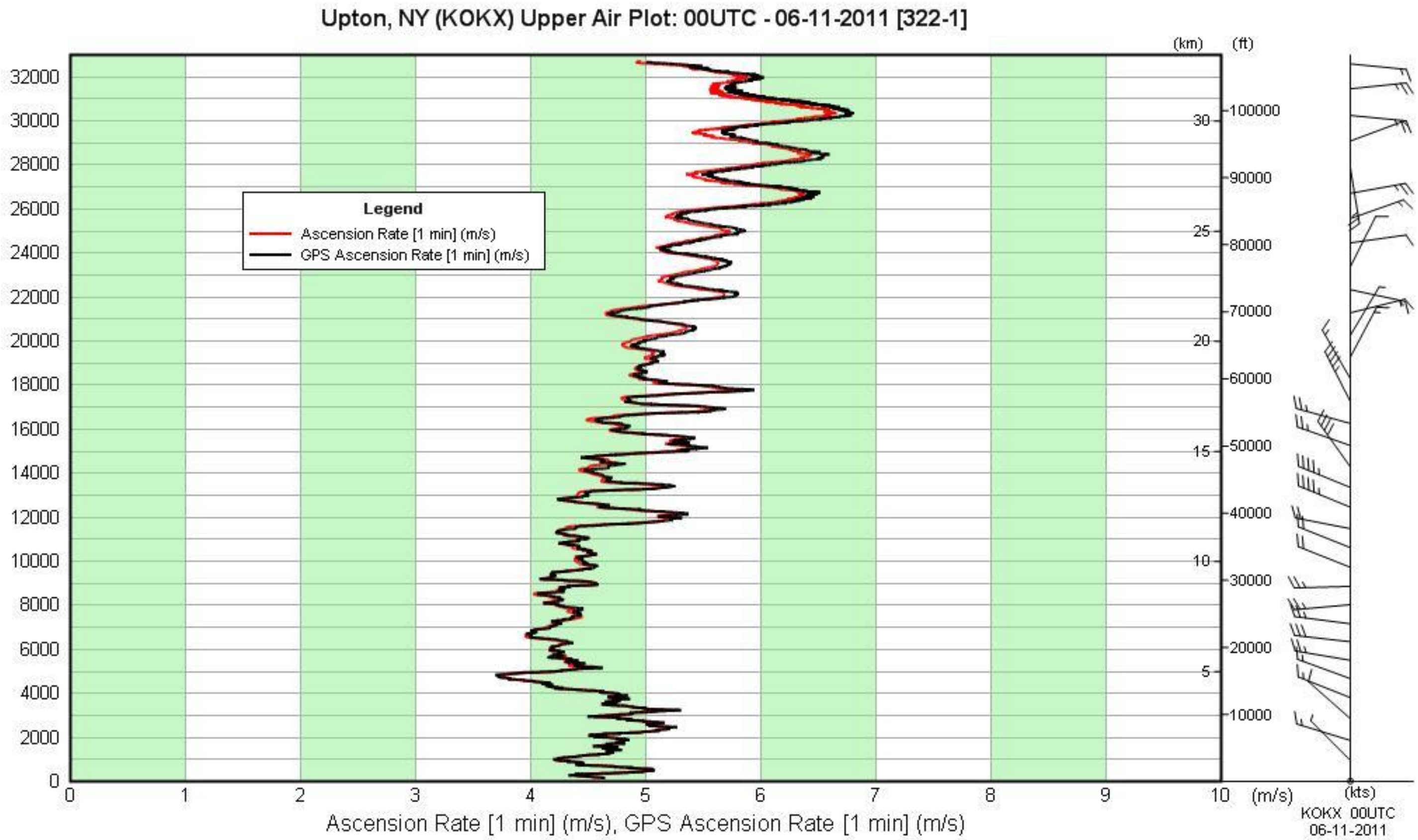


Figure 44

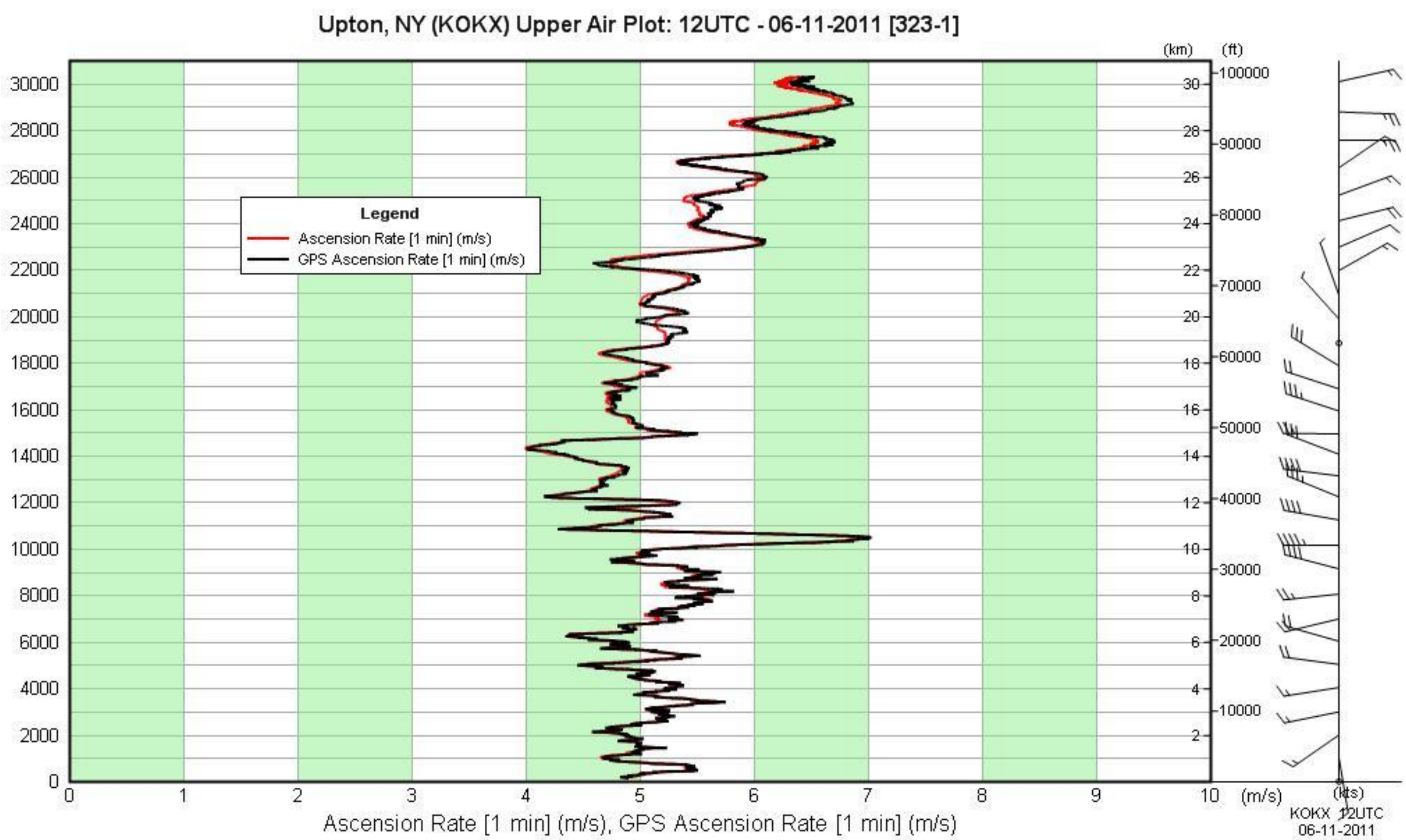


Figure 45

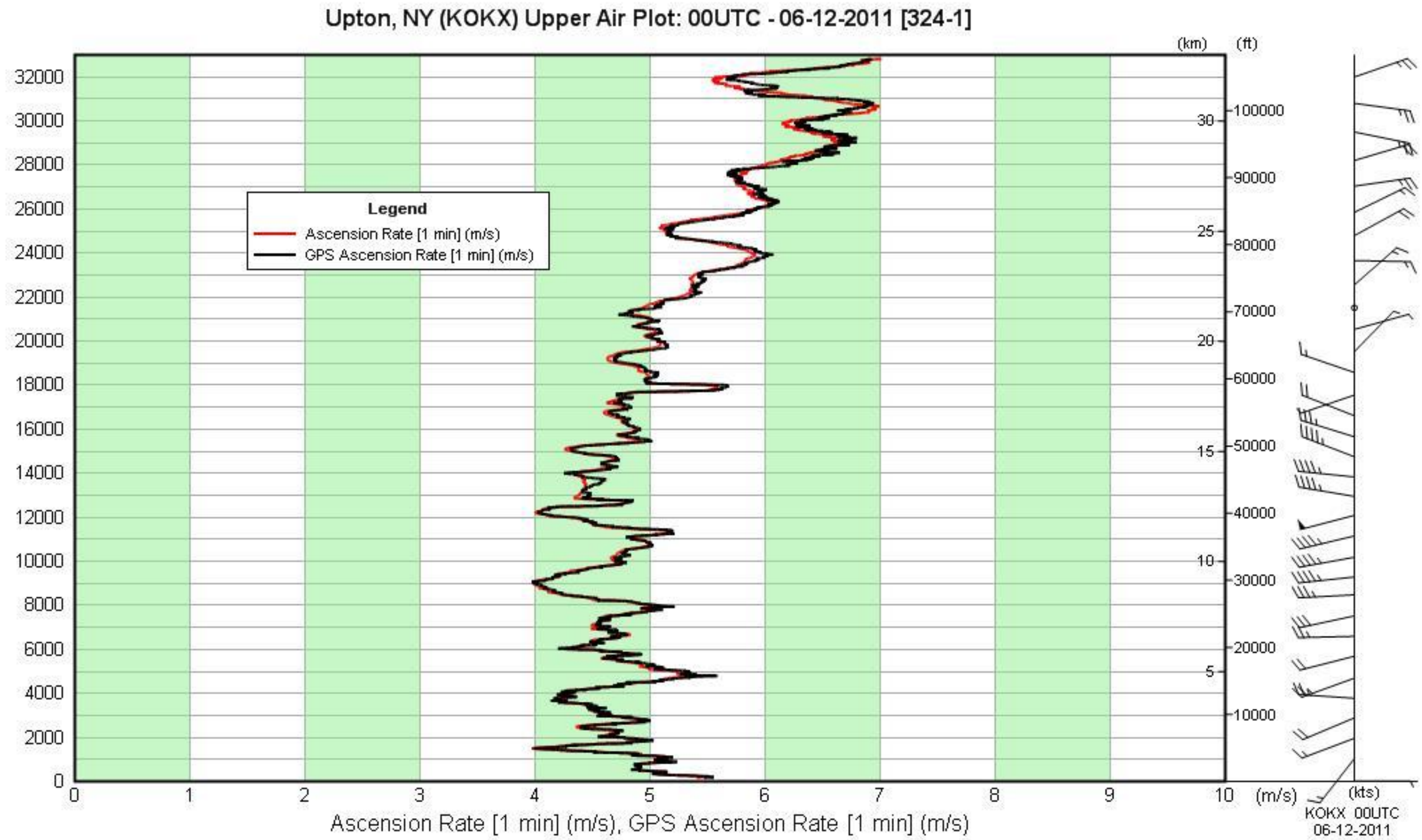


Figure 46

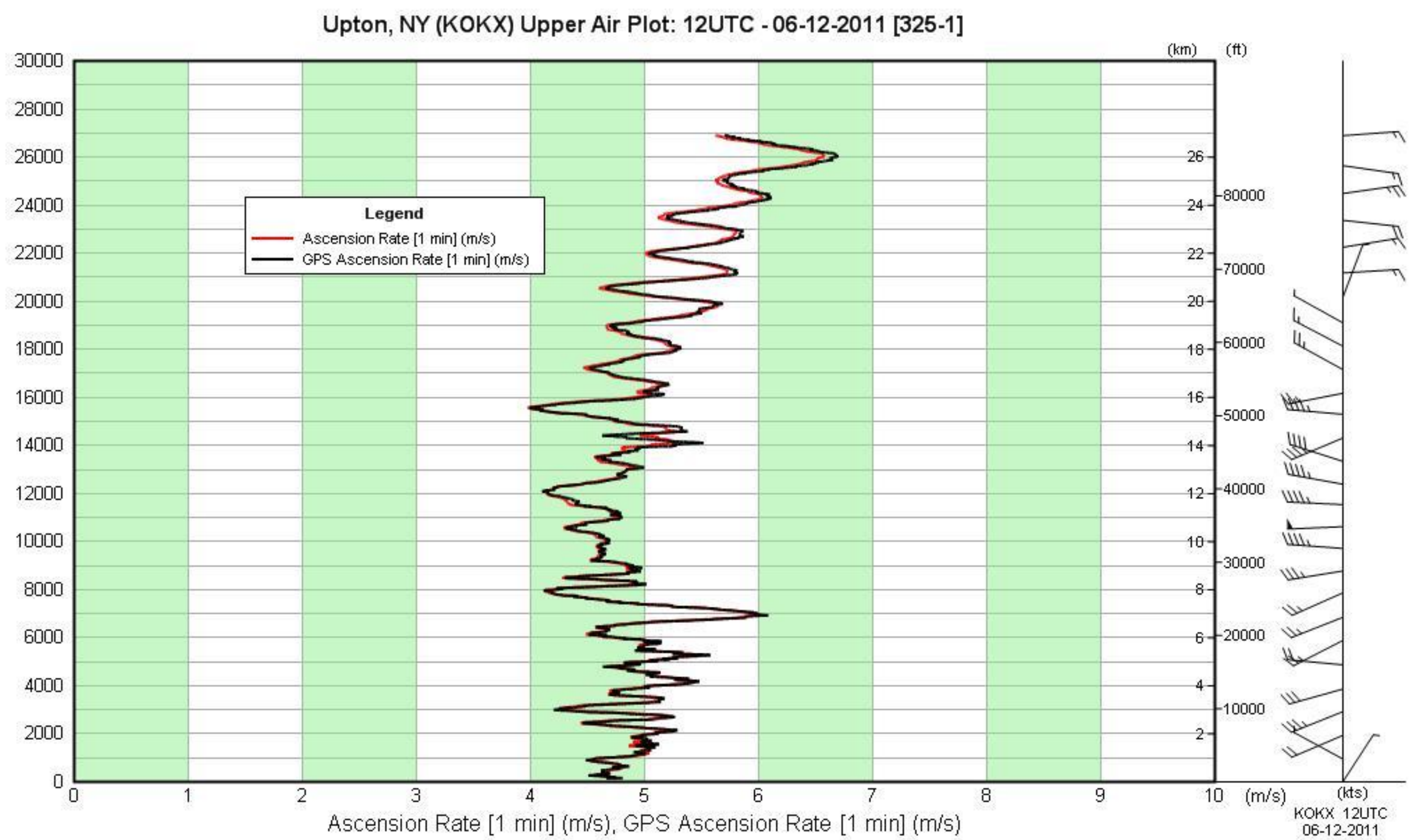


Figure 47

Case Study 9: Severe Thunderstorms with 1.75 inch hail and strong winds

During the afternoon of May 27, 2011, thunderstorms formed along a stationary front that stretched from New England to the panhandle of Florida. During the afternoon, severe thunderstorms formed east of the front. southern Georgia and northern Florida had storms with strong winds (toppled trees) and hail as large as 1.75 inches in diameter. The NWS office and upper air station in Jacksonville, FL, reported 1.75 inch hail at 20:17 UTC. No tornadoes were reported from these storms. More information on this weather event can be found here:

http://www.spc.noaa.gov/exper/archive/events/110527/index.html

Figures 48 through 50 show the radiosonde ascent rates before and after the storms. Note in that in the May 28, 00:00 UTC sounding, gravity waves above 20 km can be seen, but they are not as pronounced as those observed in other cases where severe storms with tornadoes occurred.

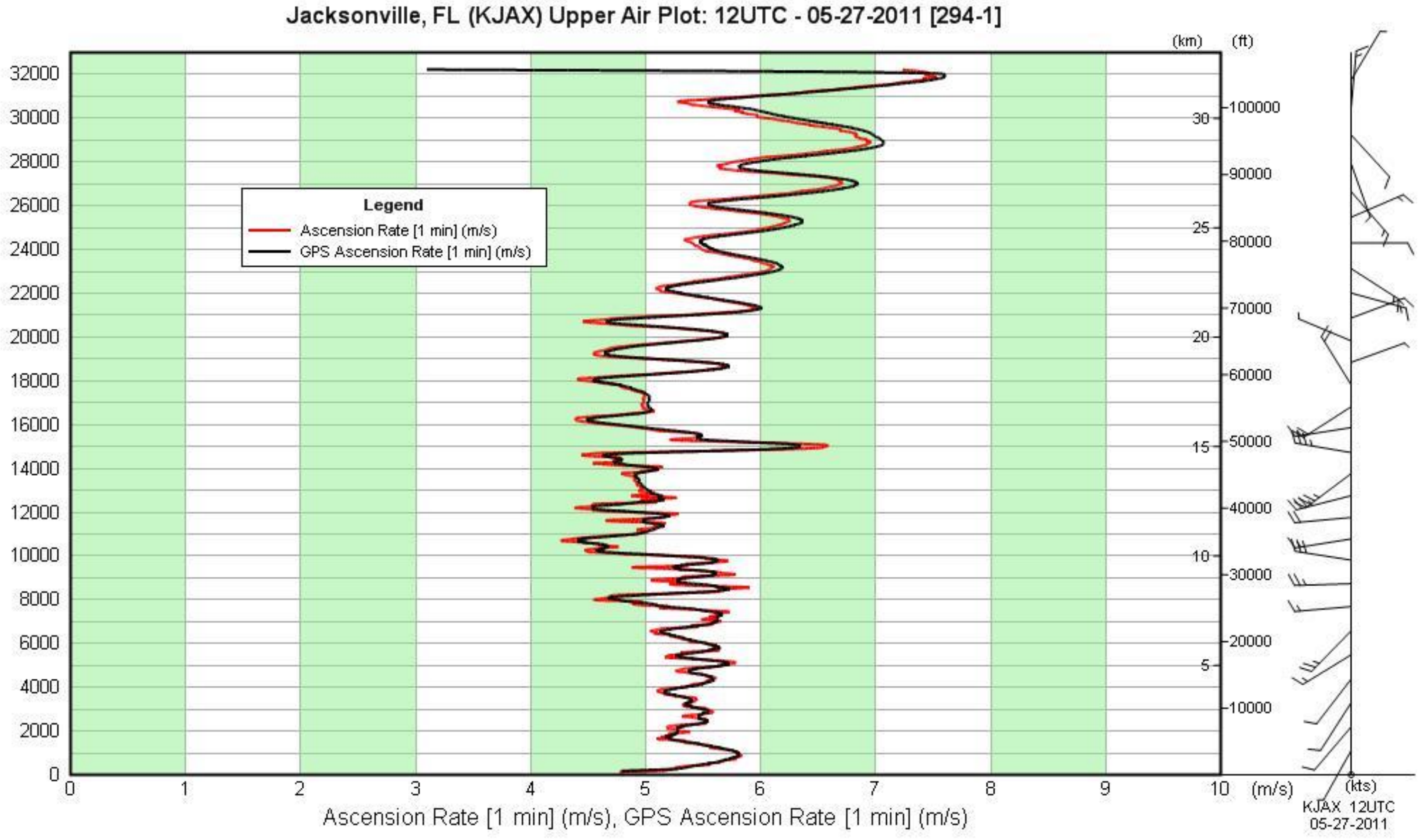
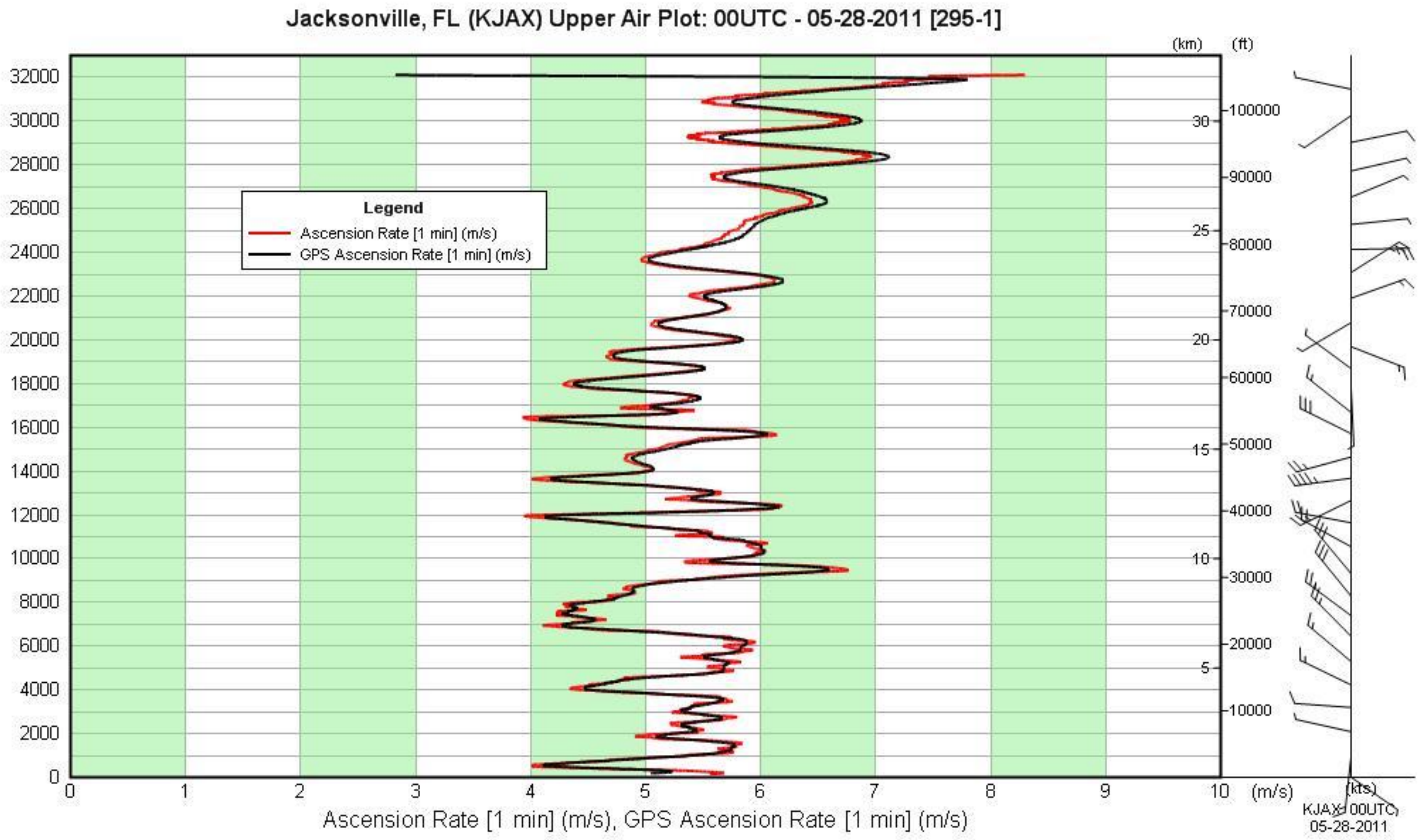


Figure 48


Jacksonville, FL (KJAX) Upper Air Plot: 00UTC - 05-28-2011 [295-1]
Legend
Ascension Rate [1 min] (m/s)
GPS Ascension Rate [1 min] (m/s)
Ascension Rate [1 min] (m/s), GPS Ascension Rate [1 min] (m/s)
(km)
(ft)
(m/s)
(kts)
KJAX 00UTC
05-28-2011

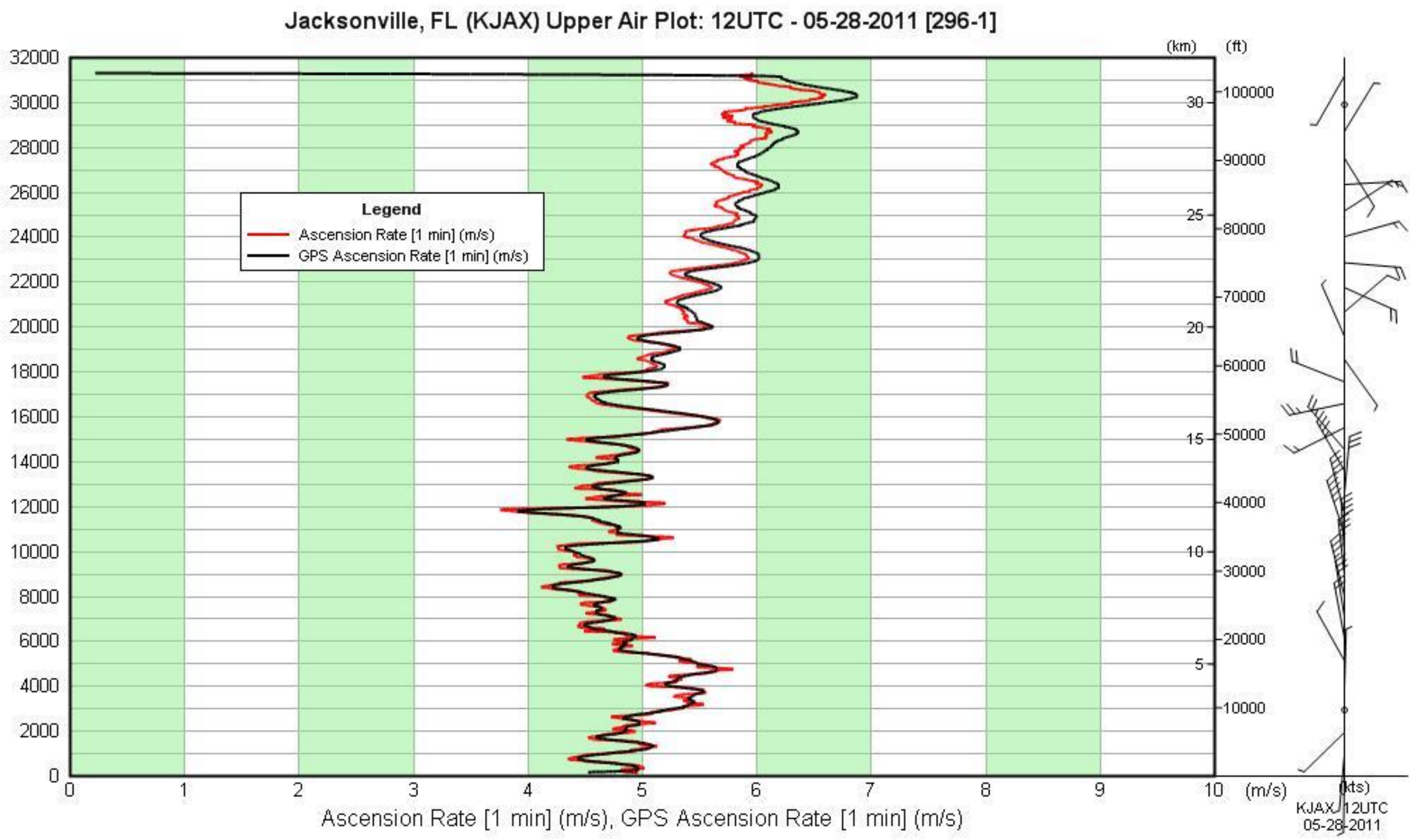

Jacksonville, FL (KJAX) Upper Air Plot: 12UTC - 05-28-2011 [296-1]
Legend
Ascension Rate [1 min] (m/s)
GPS Ascension Rate [1 min] (m/s)
Ascension Rate [1 min] (m/s), GPS Ascension Rate [1 min] (m/s)
(km)
(ft)
(m/s)
(kts)
KJAX 12UTC
05-28-2011

Figure 50

__Case Study 10: EF-0/EF-2 Tornadoes and 4 inch hail near Dallas-Fort Worth, TX__

During the afternoon and evening of May 24, 2011, severe thunderstorms occurred around Dallas-Forth Worth, TX, producing hail up to 4 inches in diameter and mostly EF-0 tornadoes. There was one report of an EF-2 tornado. Tornadoes touched down in the area between 22:46 and 03:50 UTC and the 4 inch hail was reported at 00:42 UTC. The NWS upper air station at Fort Worth launched the 00:00 UTC observation at 23:29 UTC. So in this case the sounding took place while severe weather was occurring around the station. More information on the storm is provided here.

http://www.spc.noaa.gov/exper/archive/events/110524/index.html

A report on the tornadoes from these storms is available here:

http://www.srh.noaa.gov/fwd/?n=stormdamage052411

Figures 51 through 55 show the radiosonde ascent rates before and after the severe weather event. Only ascent rates from the GPS are available. A Special sounding taken at 18:00 UTC is shown in Figure 53. Note the significant waves above 20 km in the 00:00 UTC sounding (Figure 54). Twelve hours later (Figure 55) the waves are no longer seen.

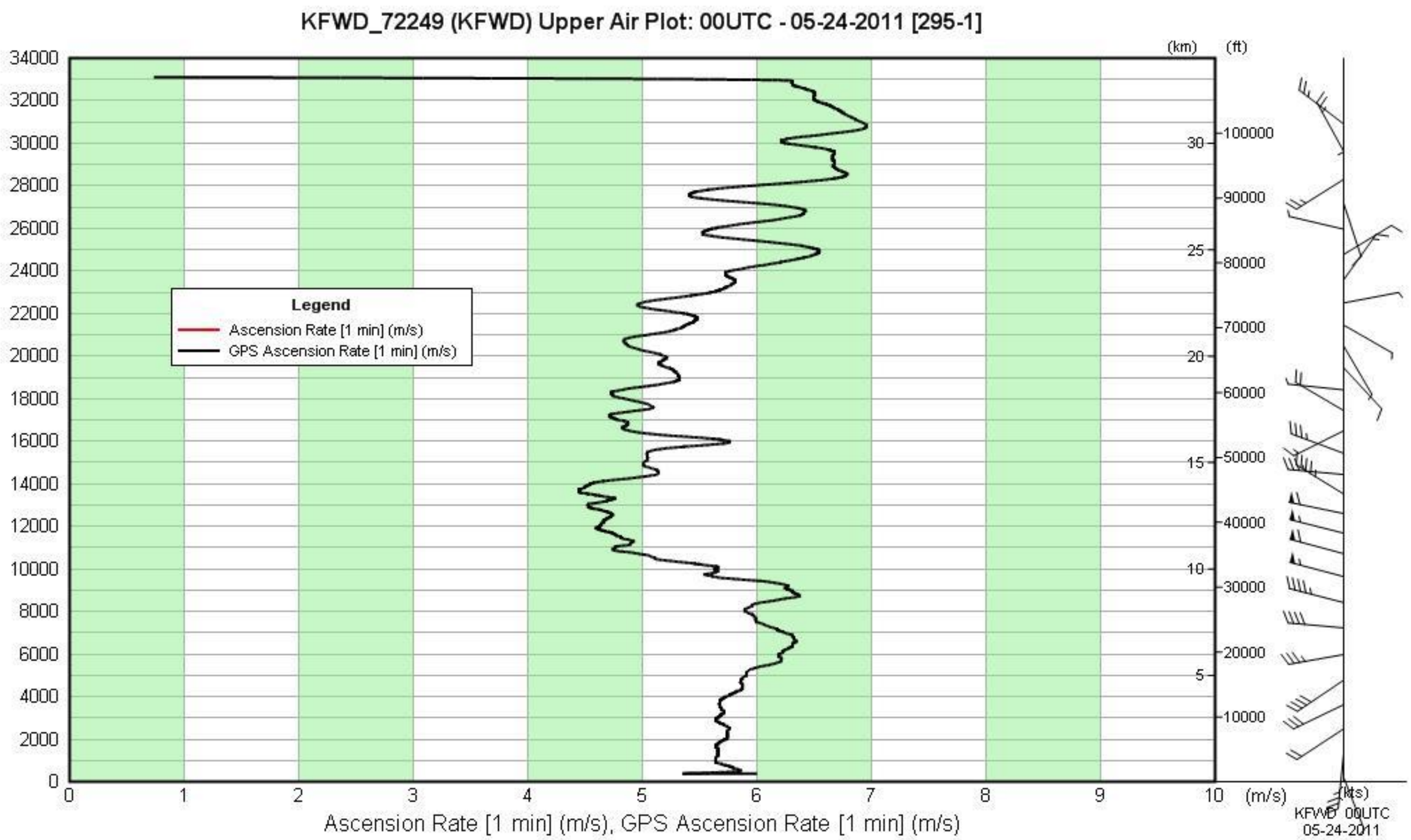


Figure 51

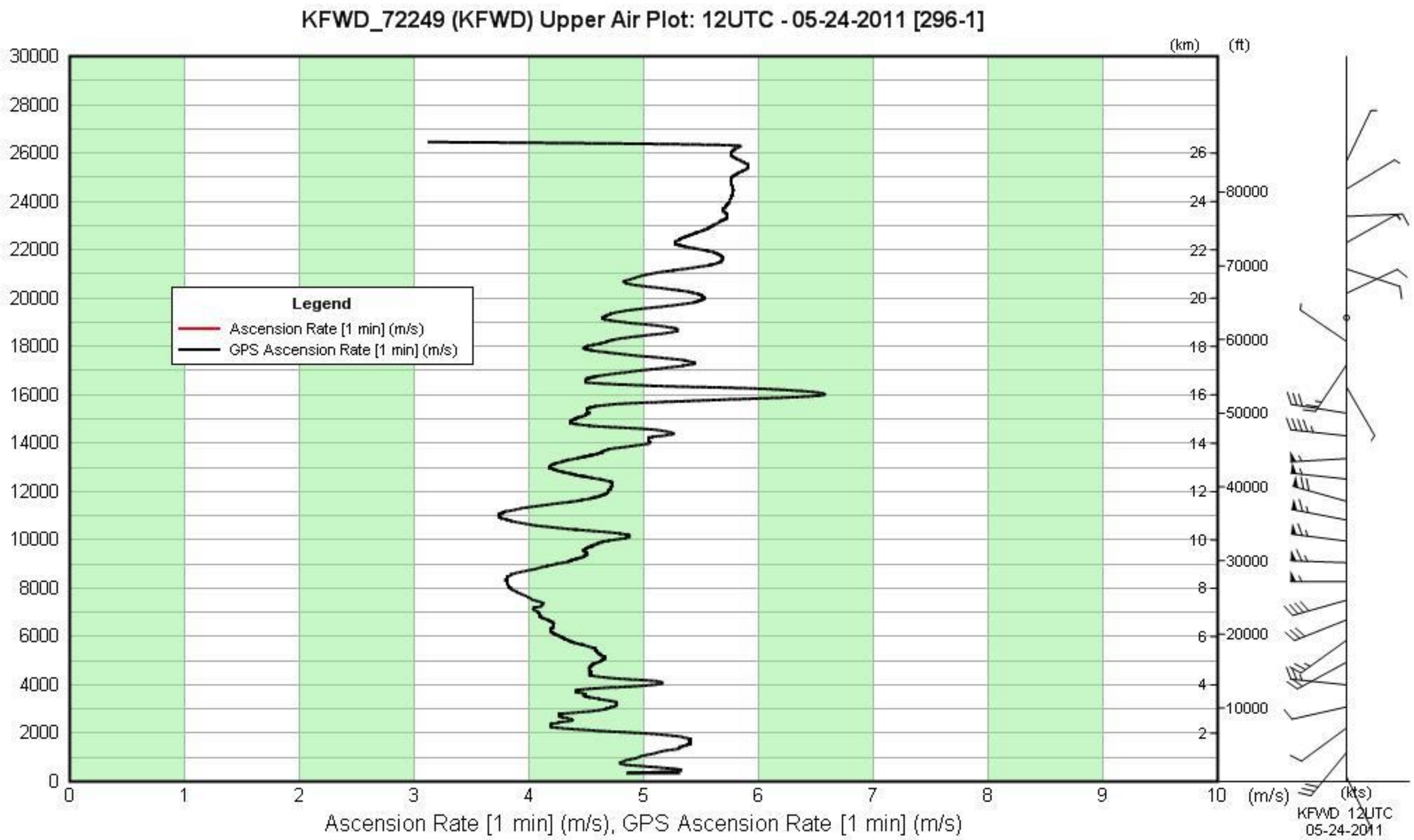


Figure 52

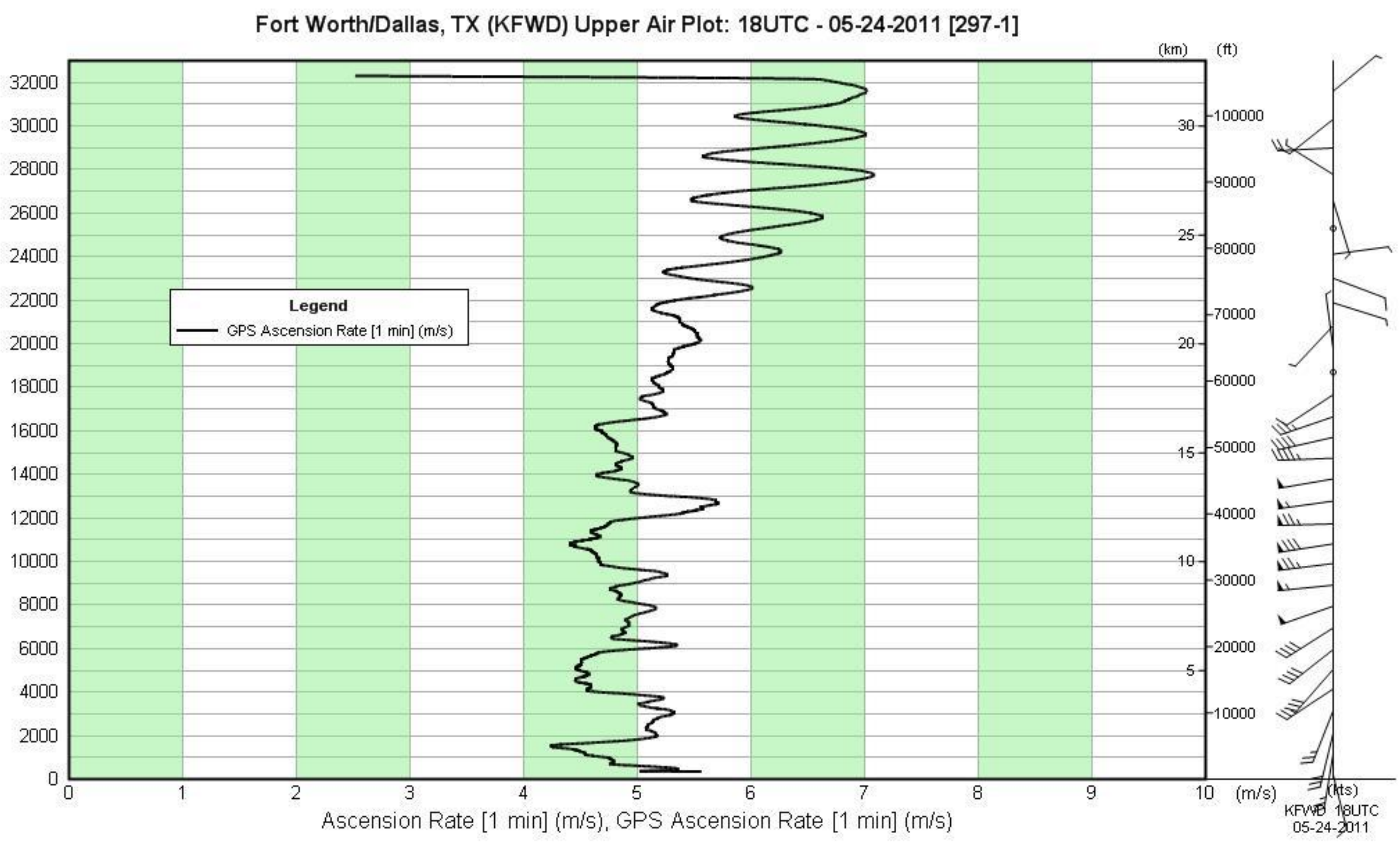


Figure 53

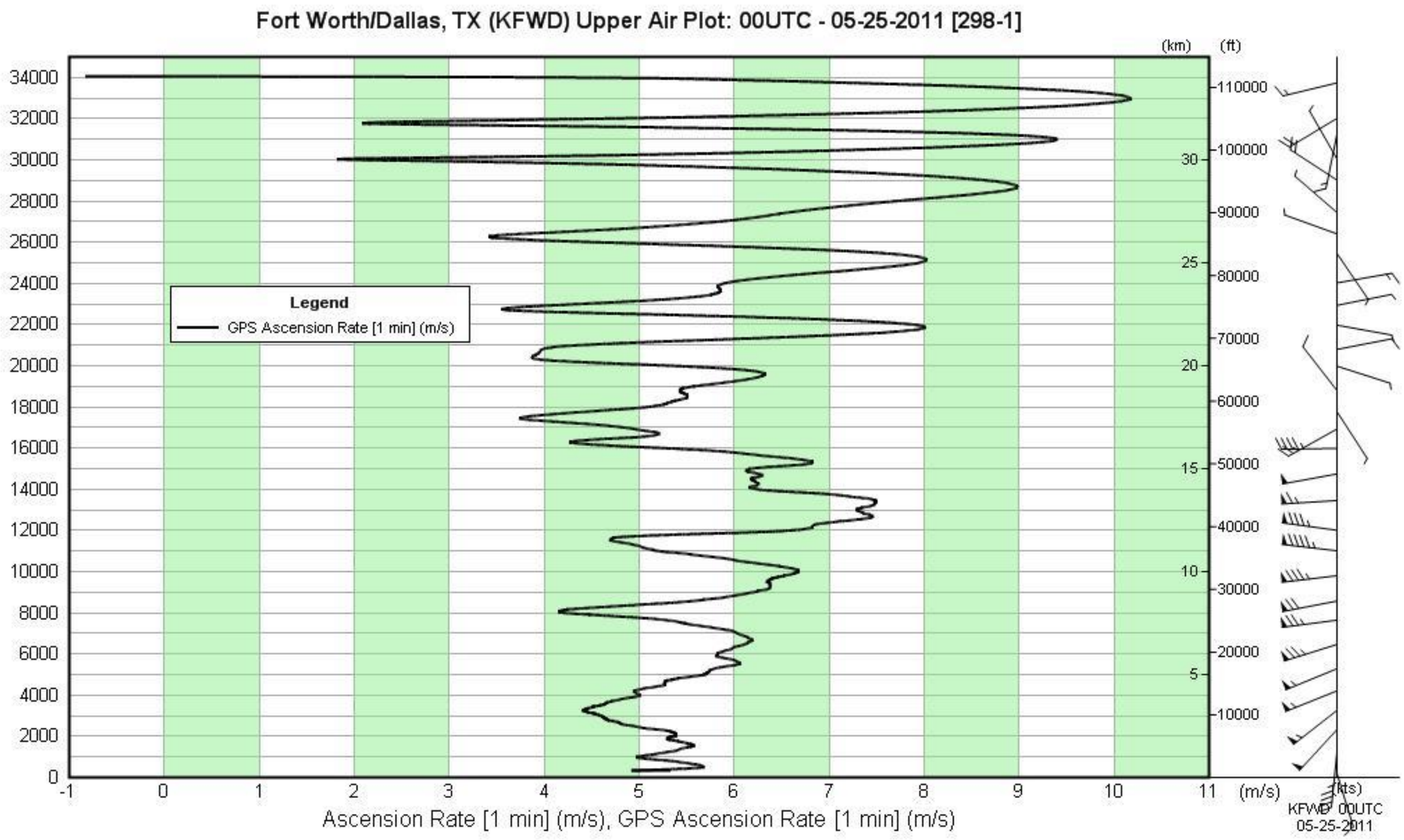


Figure 54

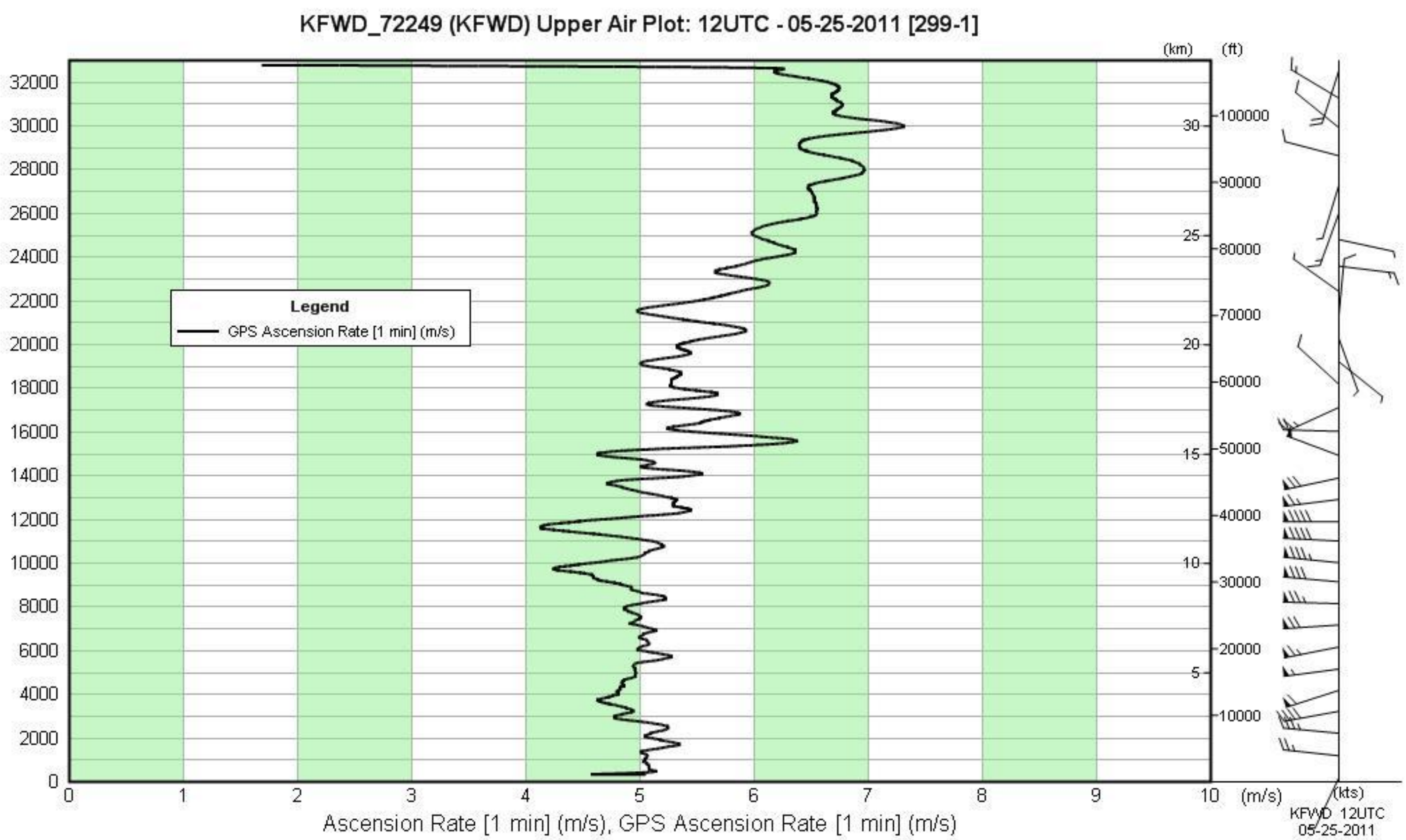


Figure 55

Case Study 11: Derecho passes over Davenport, IA

On the morning of July 11, 2011, a Derecho with severe weather passed over the NWS upper air station at Davenport, IA. Information on the storm is presented here:

http://www.crh.noaa.gov/dmx/?n=july2011derecho

http://cimss.ssec.wisc.edu/goes/blog/archives/date/2011/07/11

The NWS upper air station at Davenport, IA, delayed the early morning July 11 radiosonde release until 13:13 UTC. Figures 56 through 59 show the radiosonde ascent rates from 00:00 UTC, July 11, through 12:00 UTC, July 12. Only GPS ascension rates are shown. Note the significant changes in ascent rates in the 13Z, July 11, sounding. The radiosonde was located over the storm when it entered the stratosphere.

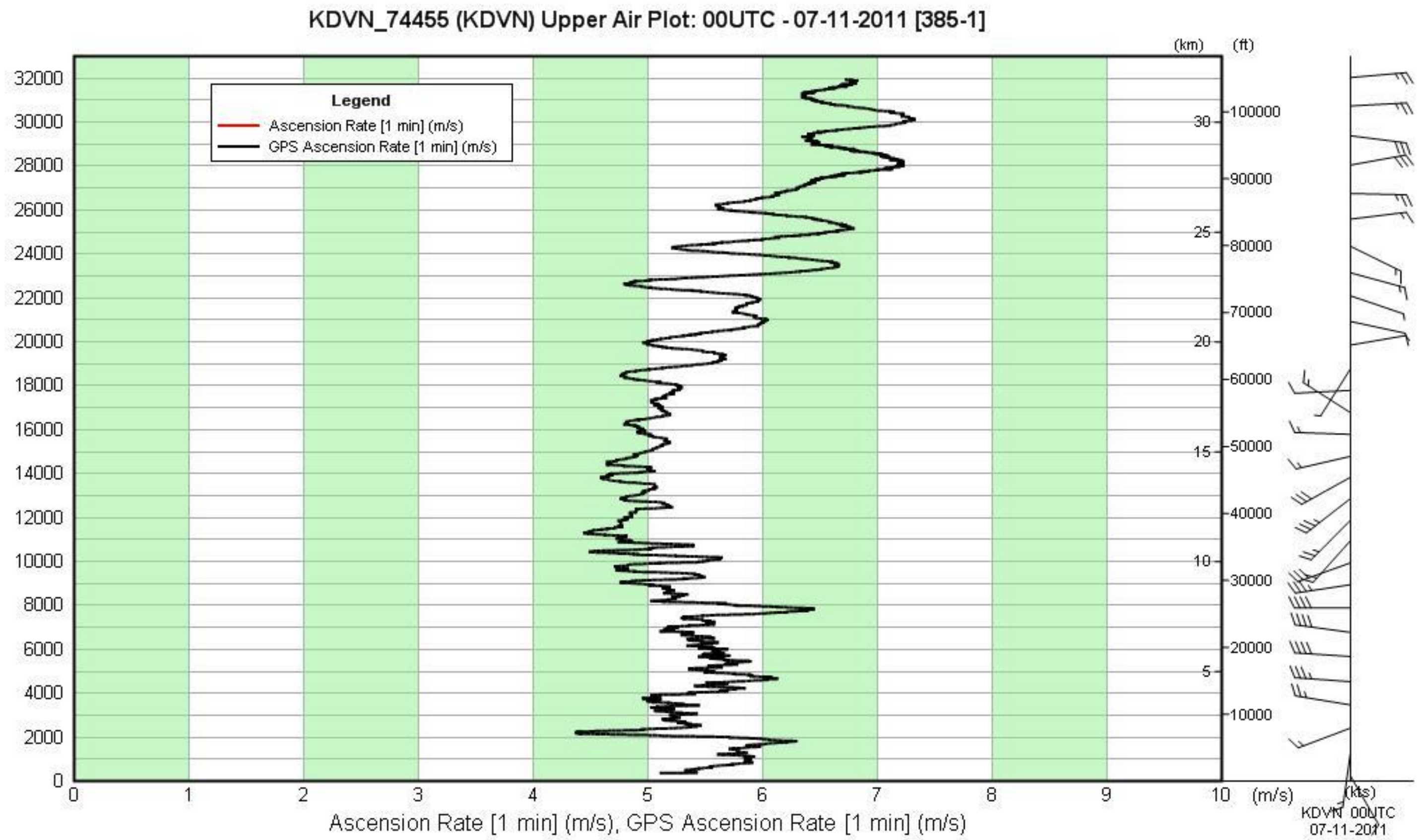


Figure 56

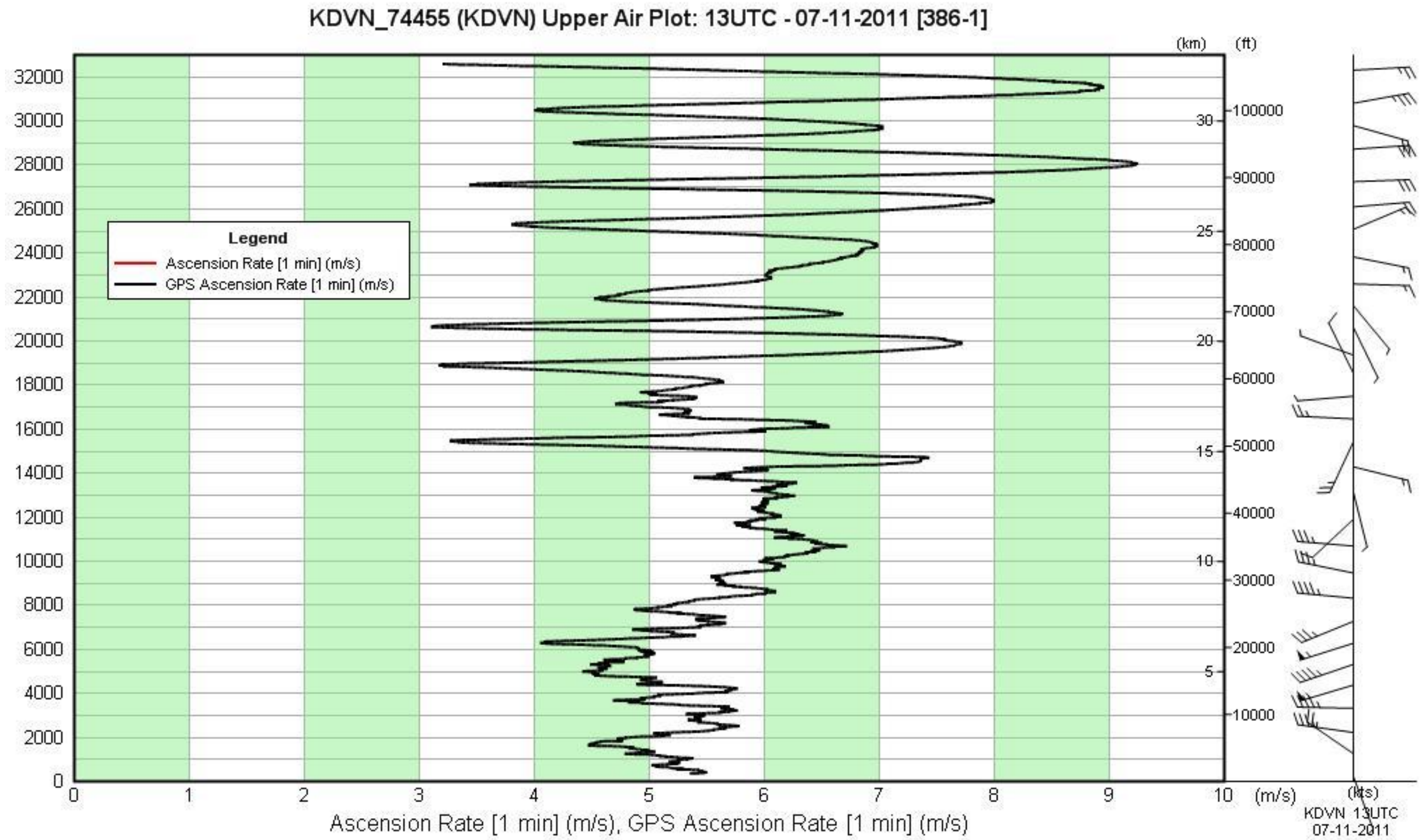


Figure 57

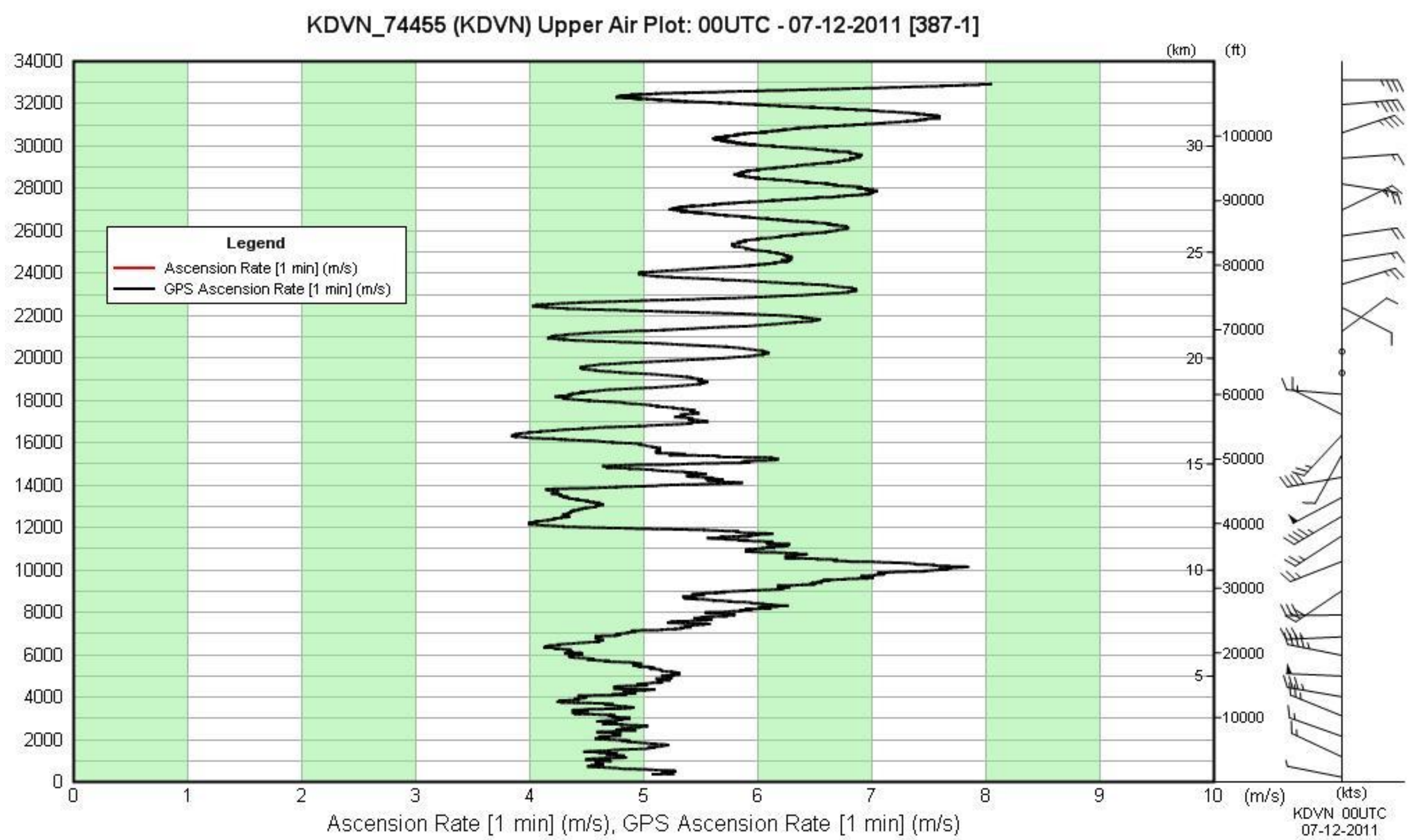


Figure 58

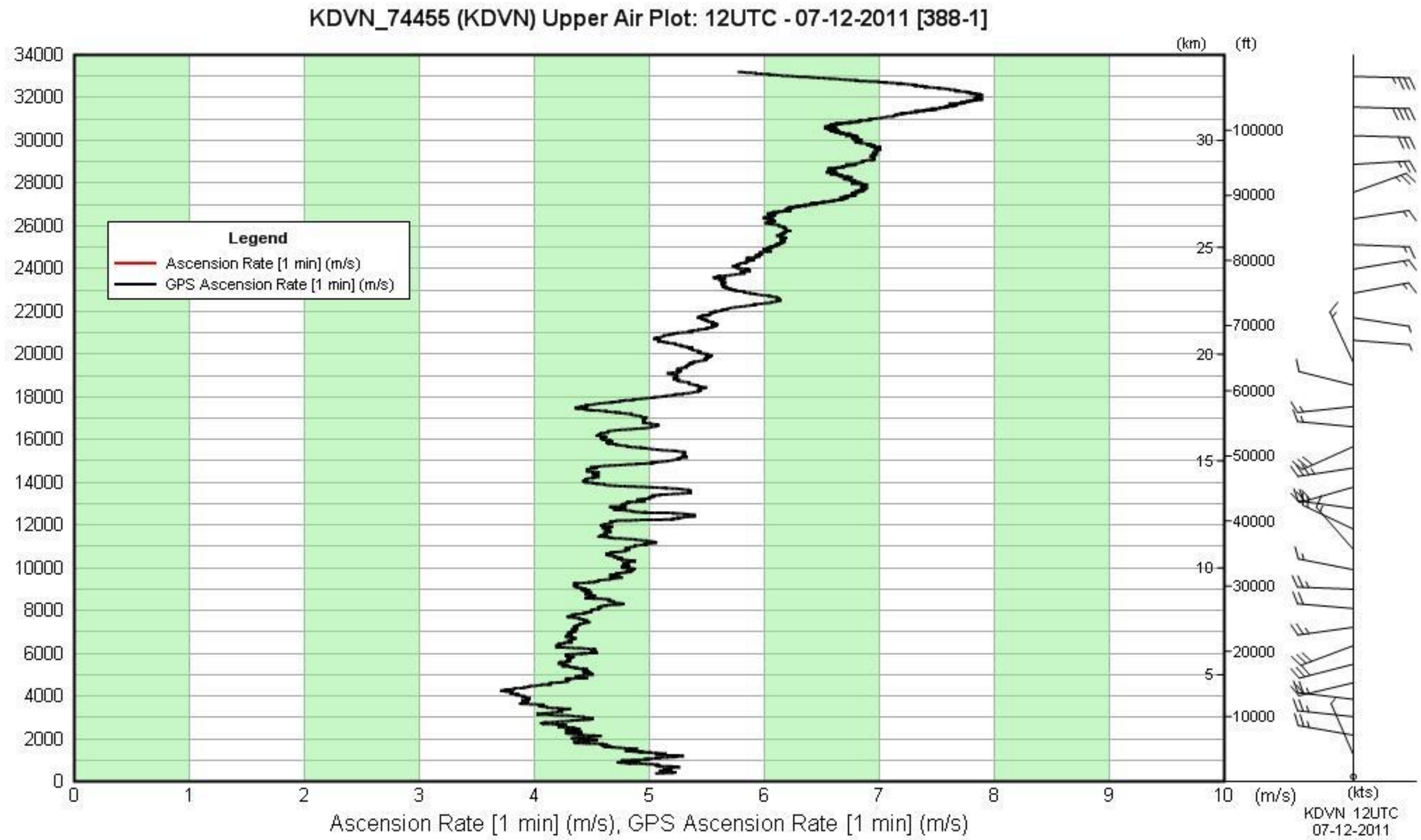


Figure 59

Case Study 12: Hurricane Irene passes over eastern NC.

Hurricane Irene passed over eastern North Carolina as a Category 1 storm during the morning of August 27, 2011. The NWS operates an upper air station at Morehead City, NC, and the eye of the hurricane was about 20 km away when the radiosonde was released at 11:02 UTC that morning. Figures 60 through 64 show the radiosonde ascent rates as the hurricane approached and passed to the north later in the day on August 27. The 00:00 UTC August 27 sounding terminated early. Note that no significant changes in ascent rate above 20 km are seen in the plots, but note the strong spike in the ascent rate in the 11 to 14 km layer that appears in 00:00, August 27, sounding and increases in magnitude in the 12:00 UTC sounding. The sounding taken the next morning does not show the spike.

Figures 65 through 67 show the radiosonde ascent rates taken at the NWS upper air station in Charleston, SC, as the hurricance passed by out at sea. Note the extreme spikes in the ascent rate between 13 and 14 km in Figure 67.

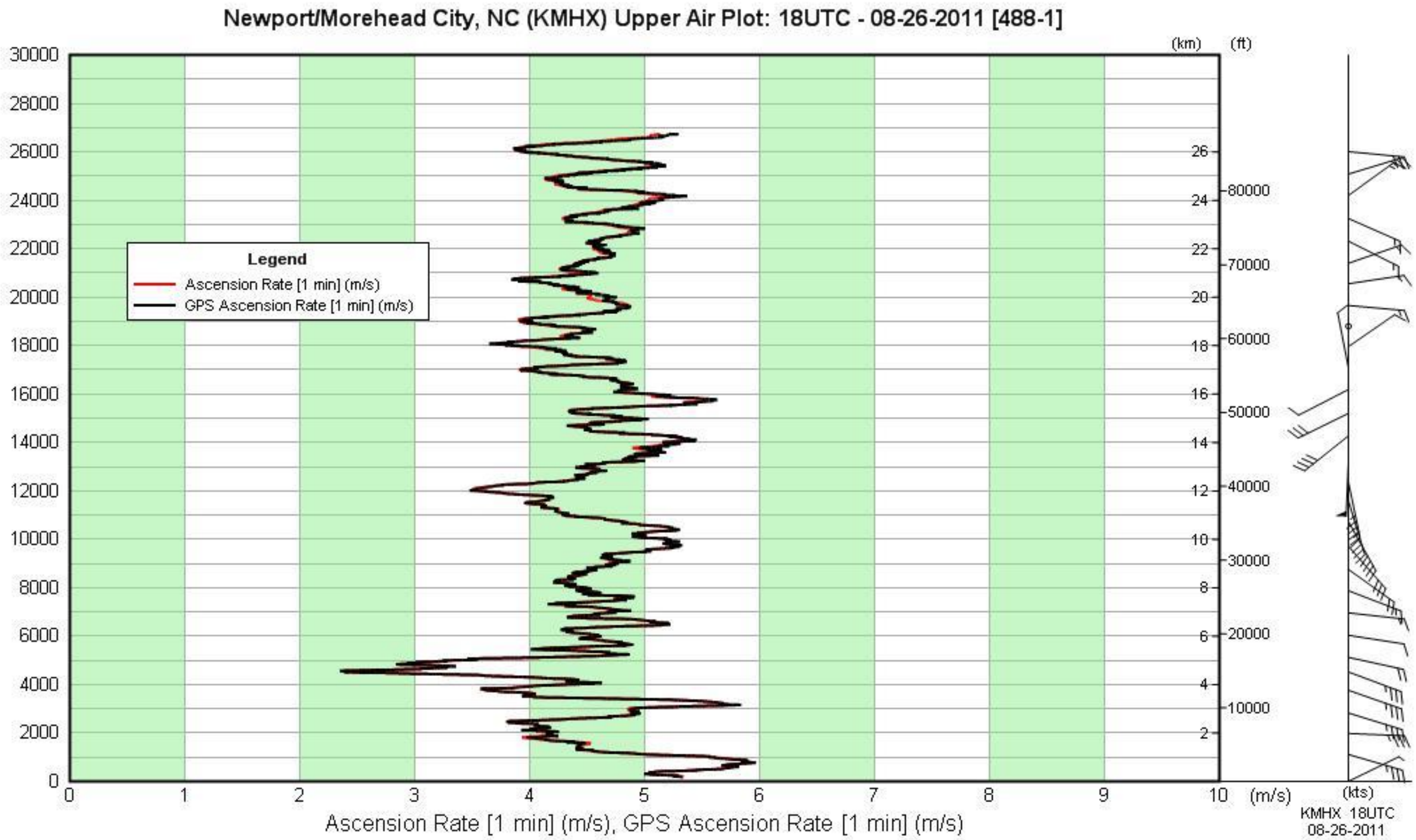


Figure 60

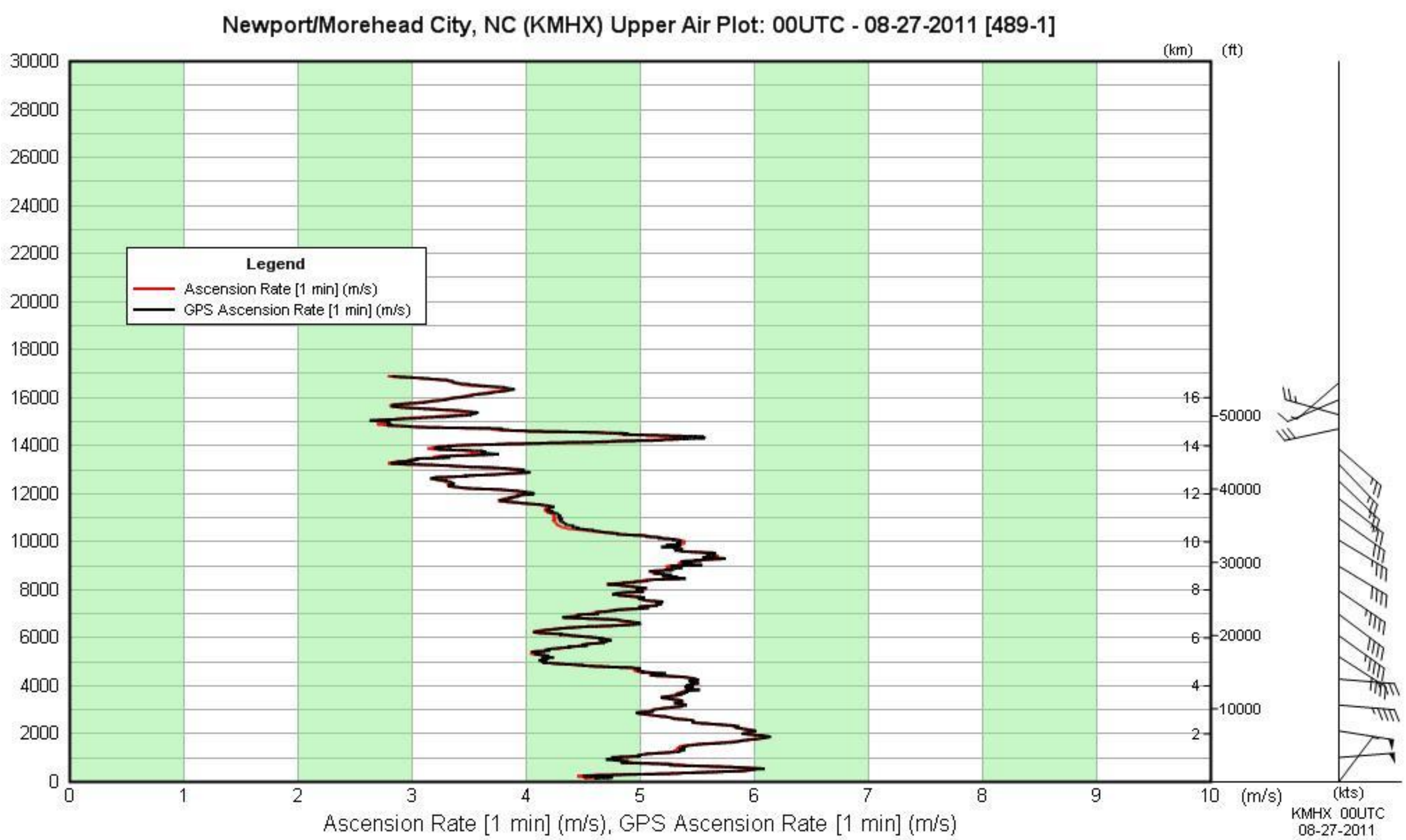


Figure 61

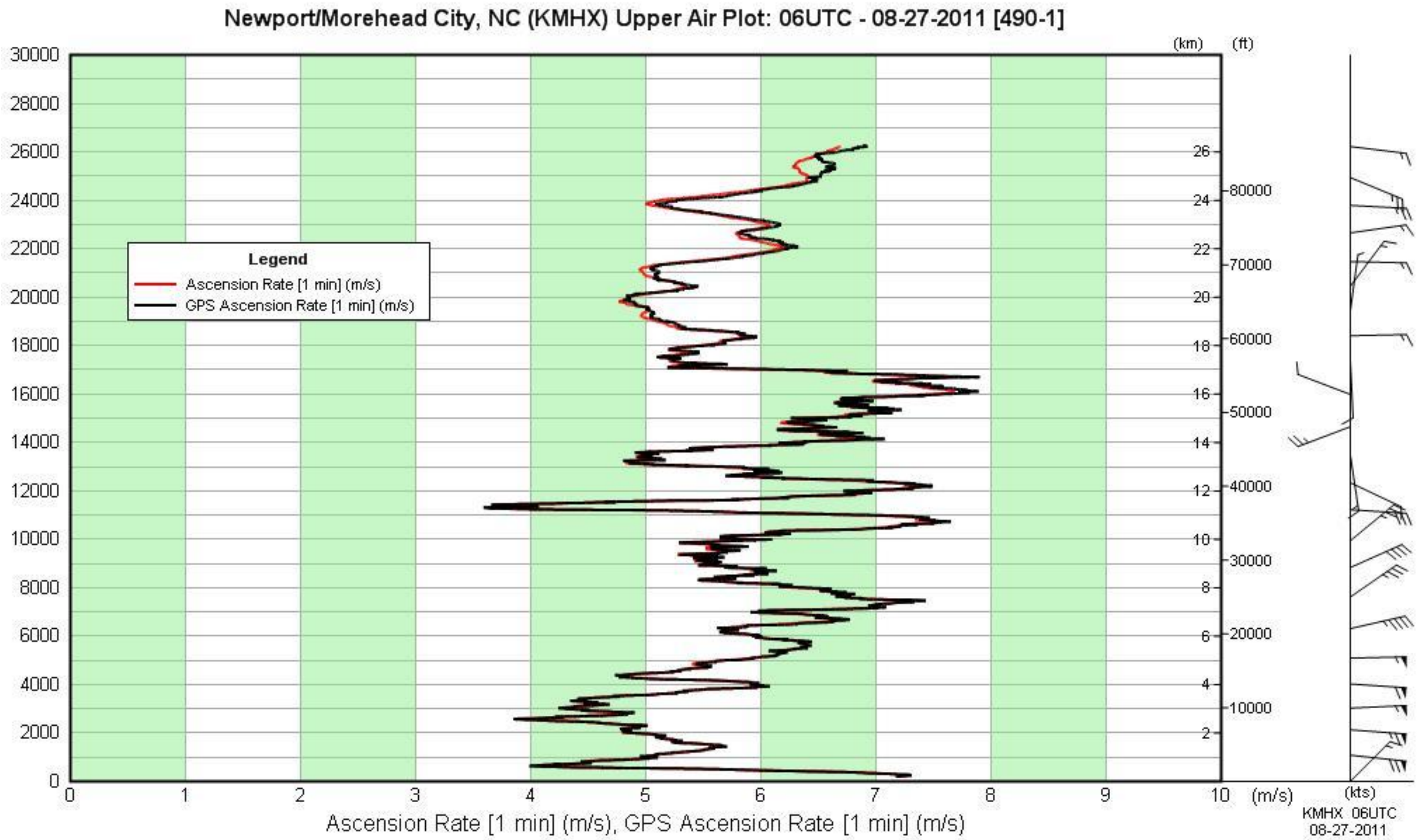


Figure 62

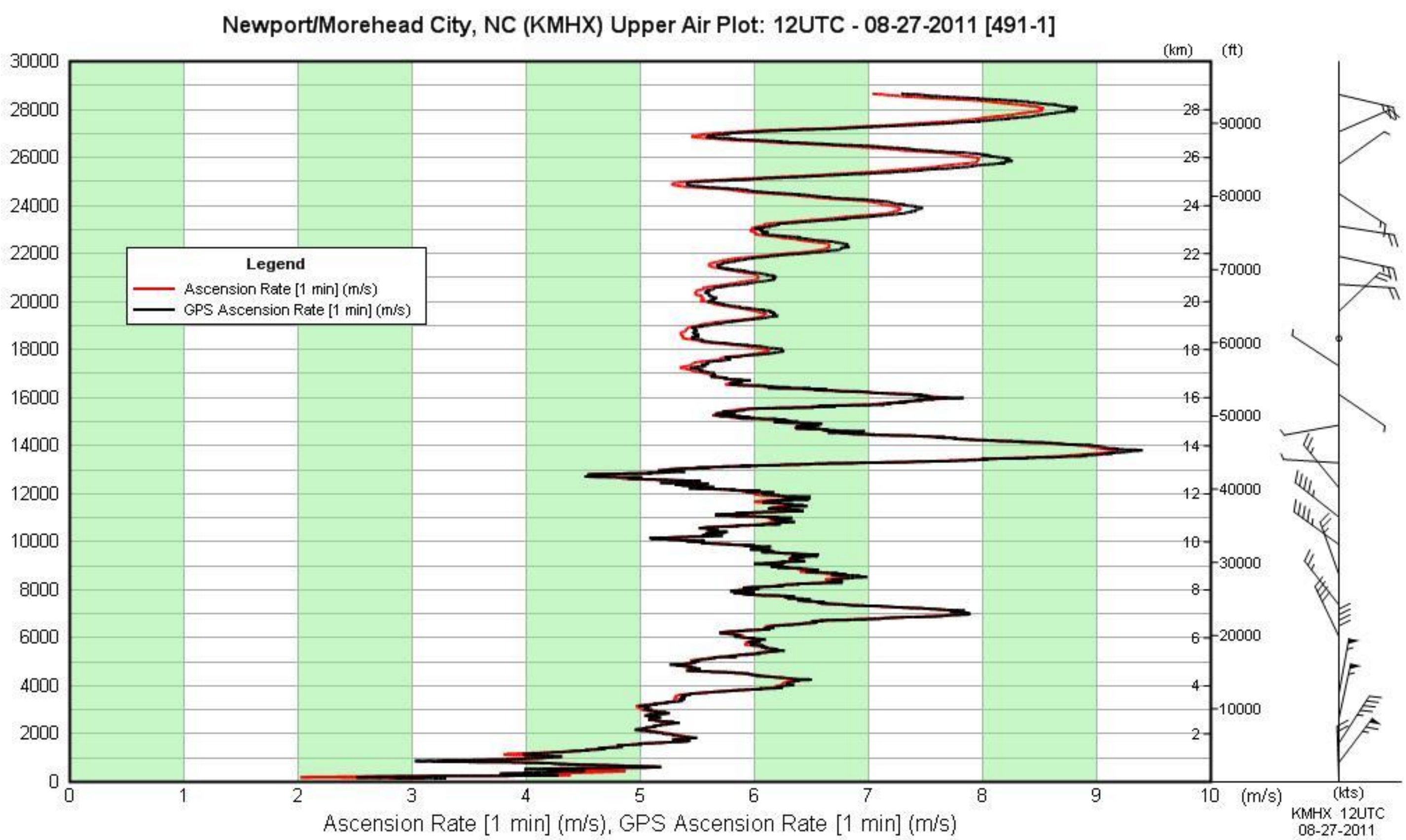


Figure 63 (Hurricane Irene is about 20 km away at the time of balloon release)

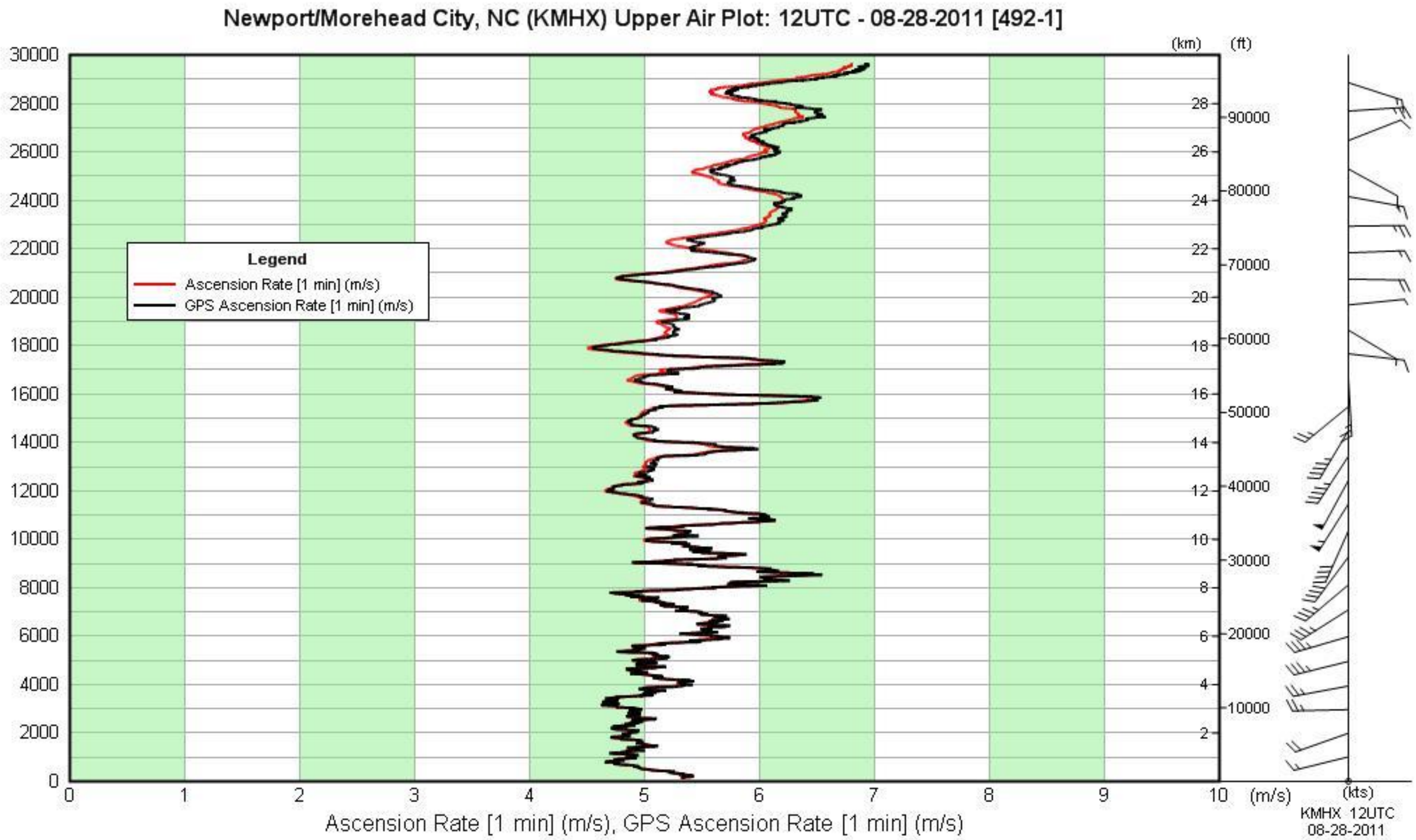


Figure 64

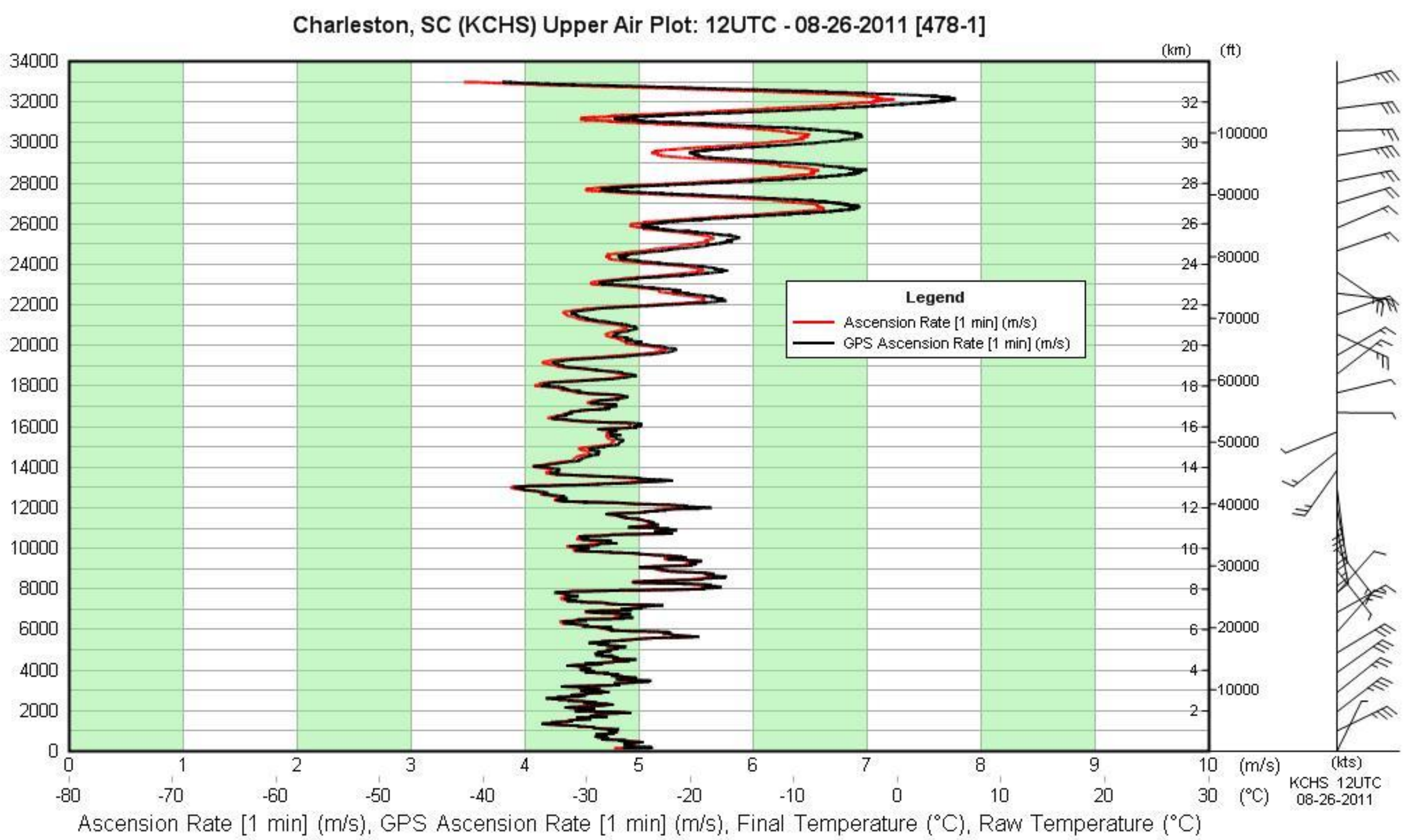


Figure 65

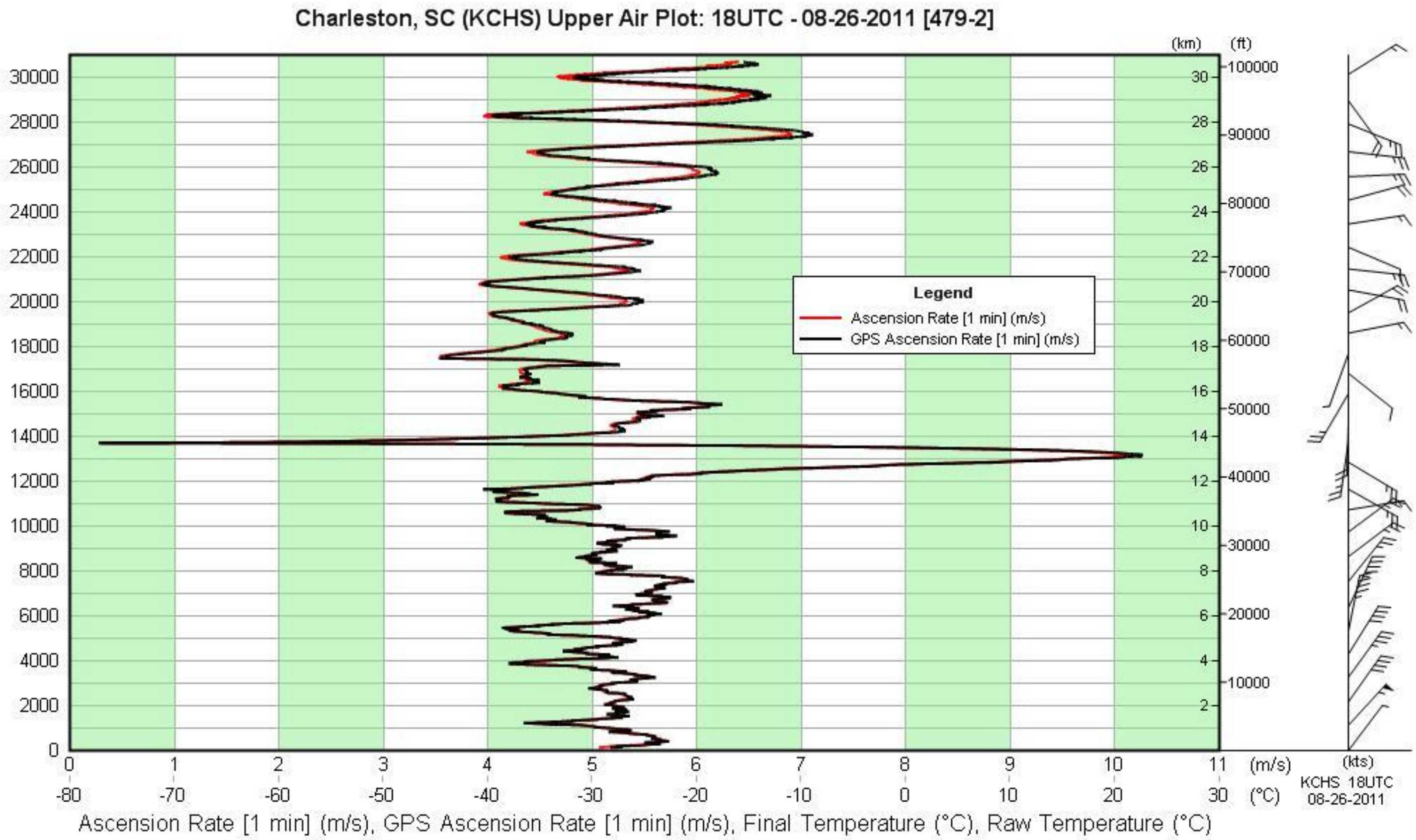


Figure 66

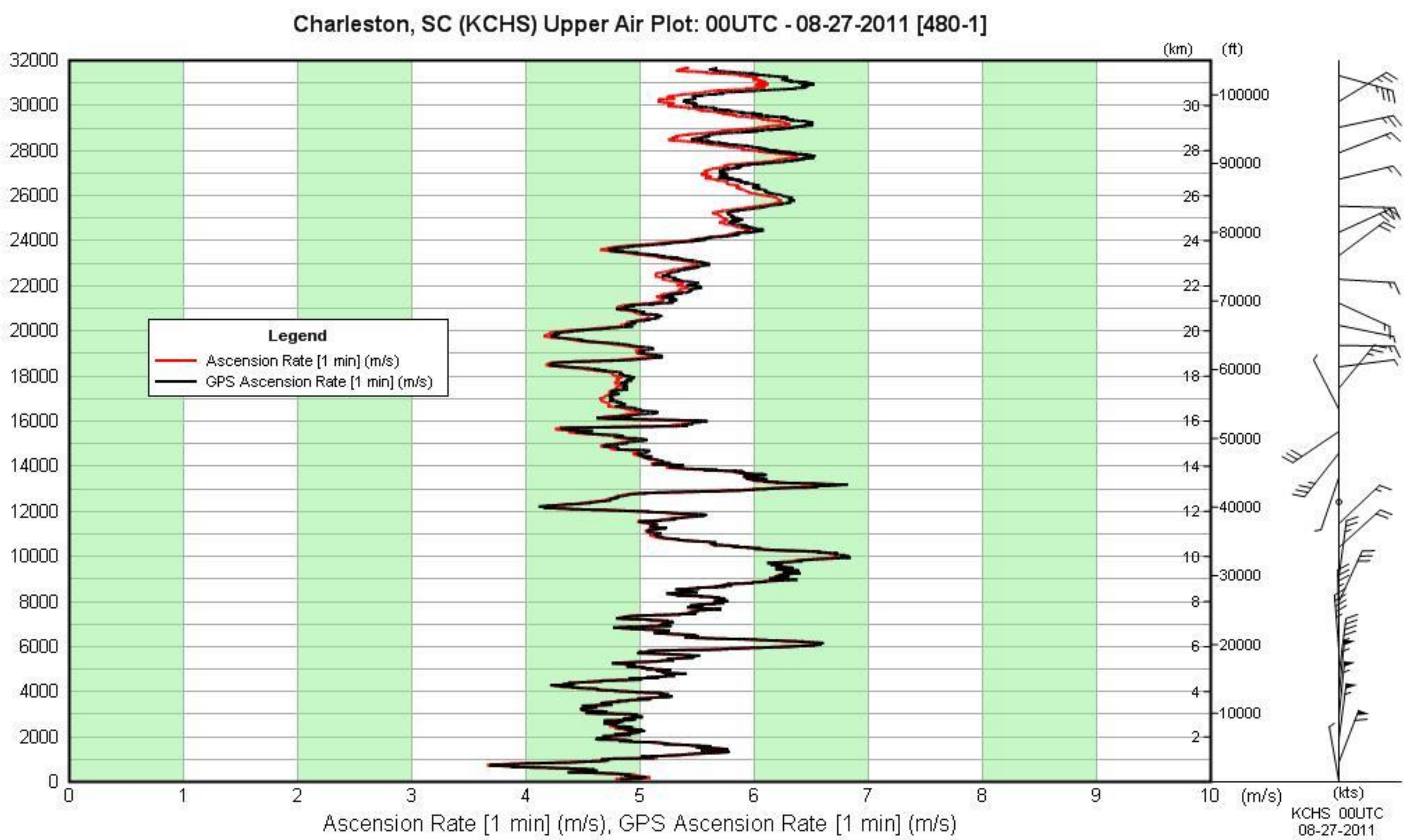


Figure 67

Case Study 13: Bearing Sea Super Storm

A very strong, hurricane-like winter storm hit northwest Alaska in November, 2011. More information on the storm is provided here:

http://earthobservatory.nasa.gov/IOTD/view.php?id=76382

Figure 68 through 71 show radiosonde ascension rates from the NWS upper air station in Saint Paul Island, AK, from November 12 and 13, 2011. This office is located in the Bering Sea. Figure 70 shows the most pronounced waves above 20 km and they occurred several days after the storm had passed. Figures 72 through 75 show a sample of radiosonde ascent rates from the NWS upper air station in Nome AK, from November 8 to 12Z Nov 11. The 00Z, November 11 sounding had the most significant changes in Ascent rate during this period.

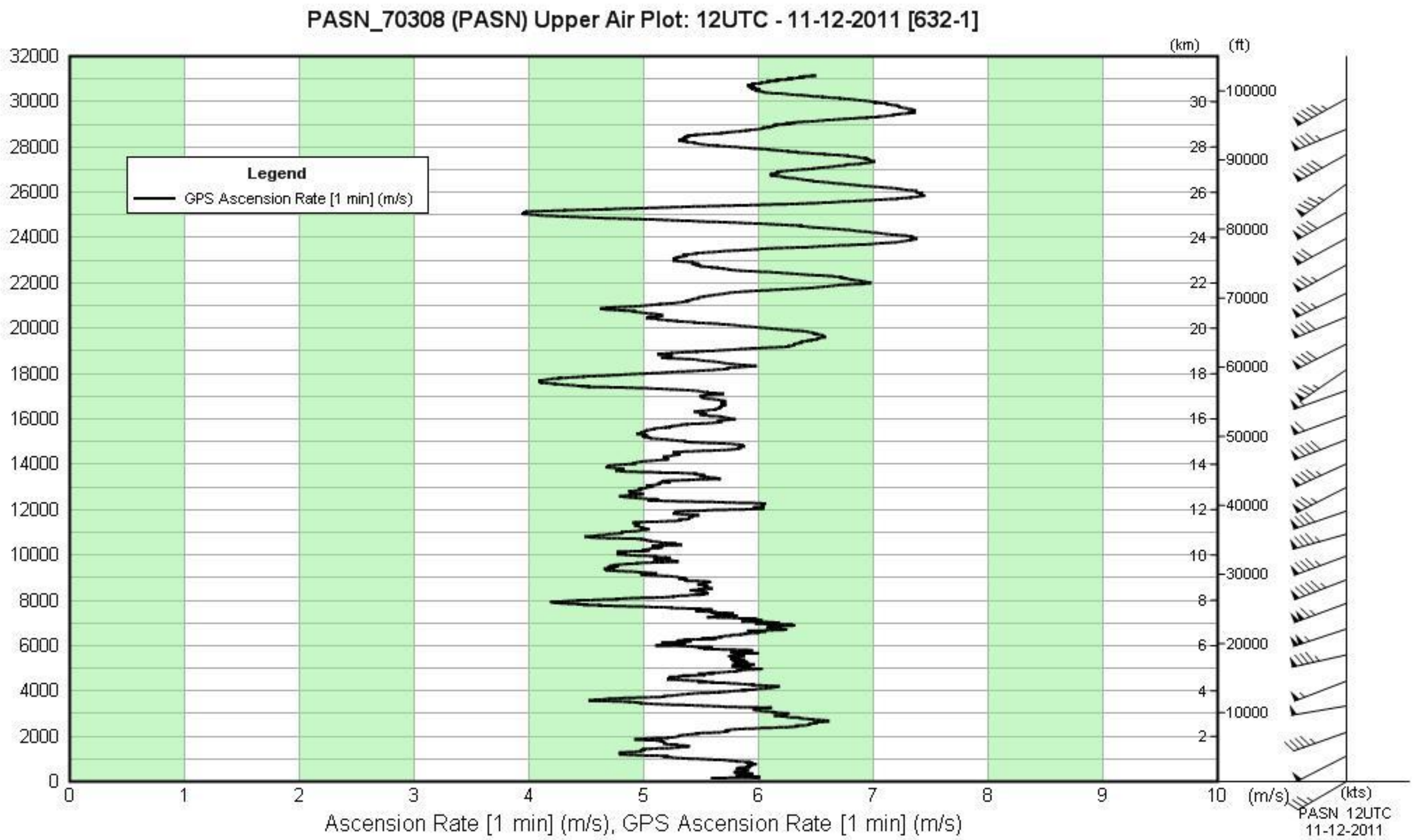


Figure 68

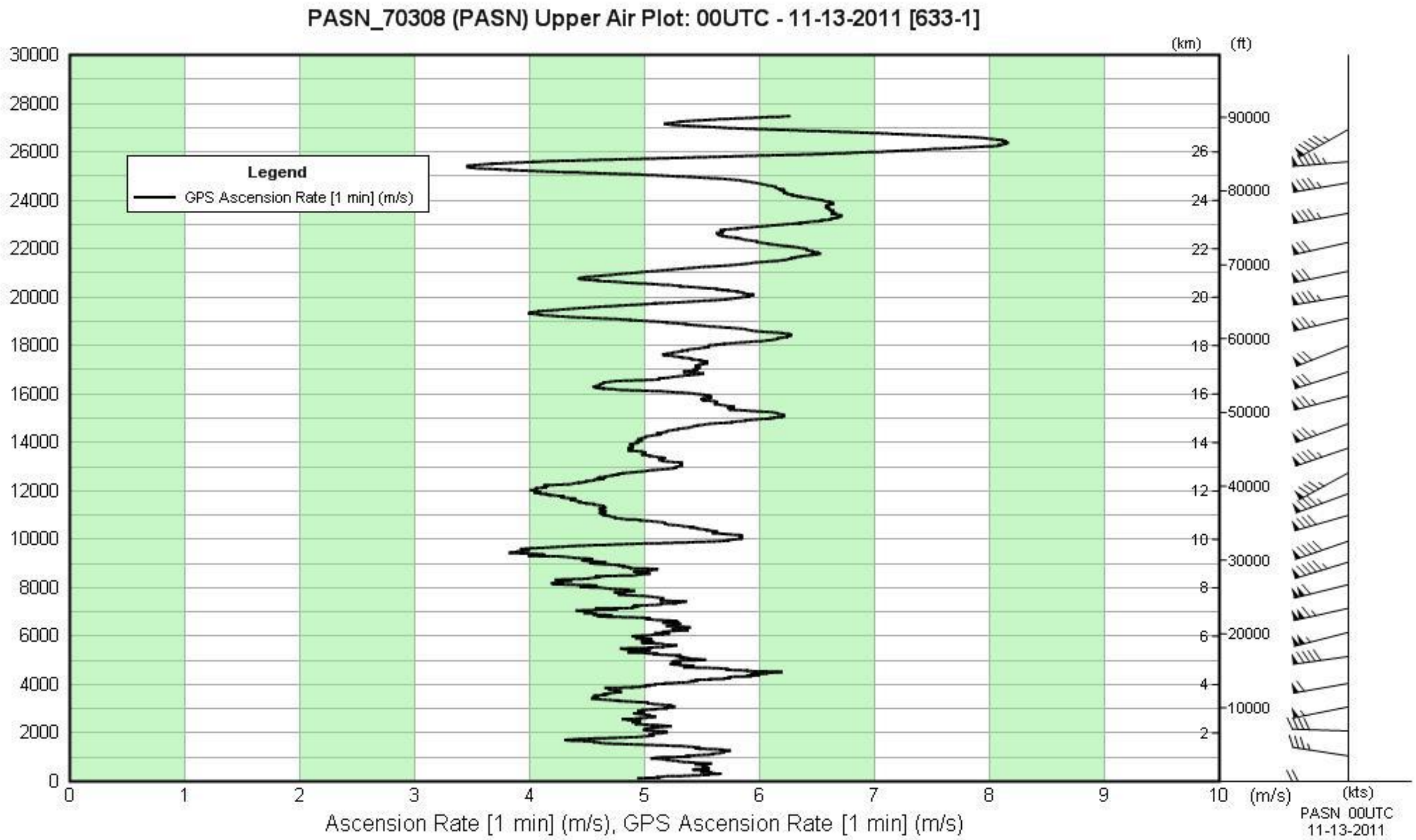


Figure 69

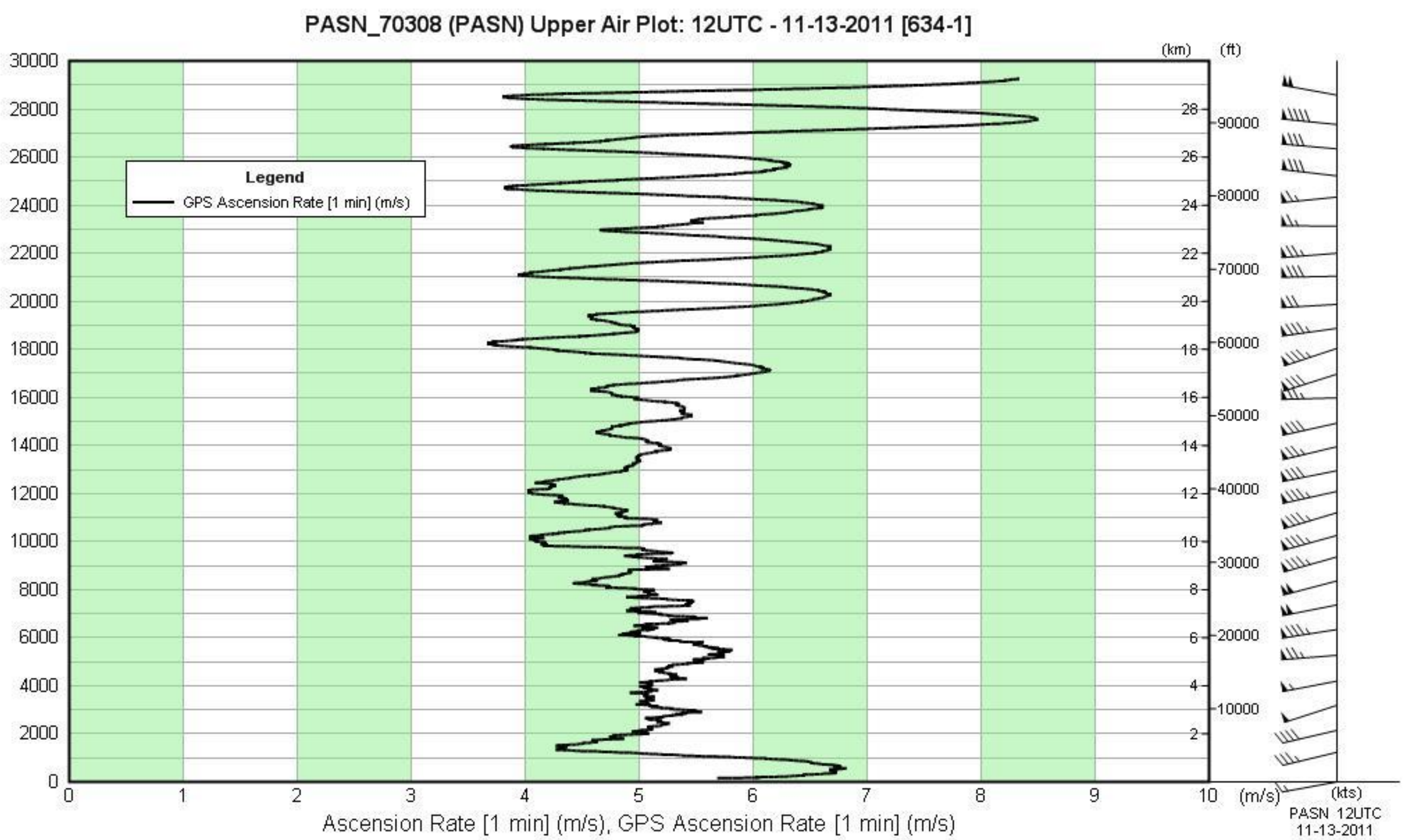


Figure 70

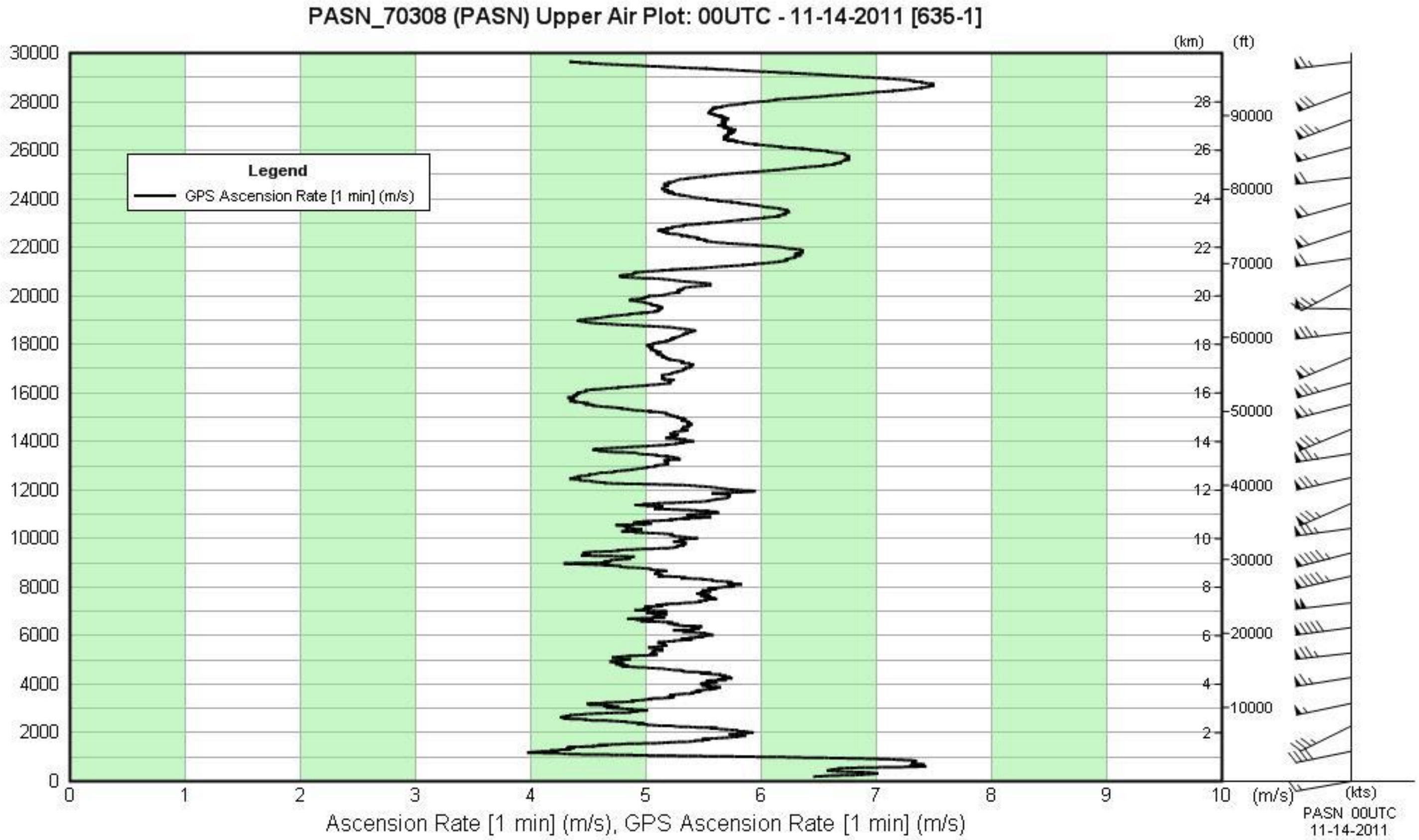


Figure 71

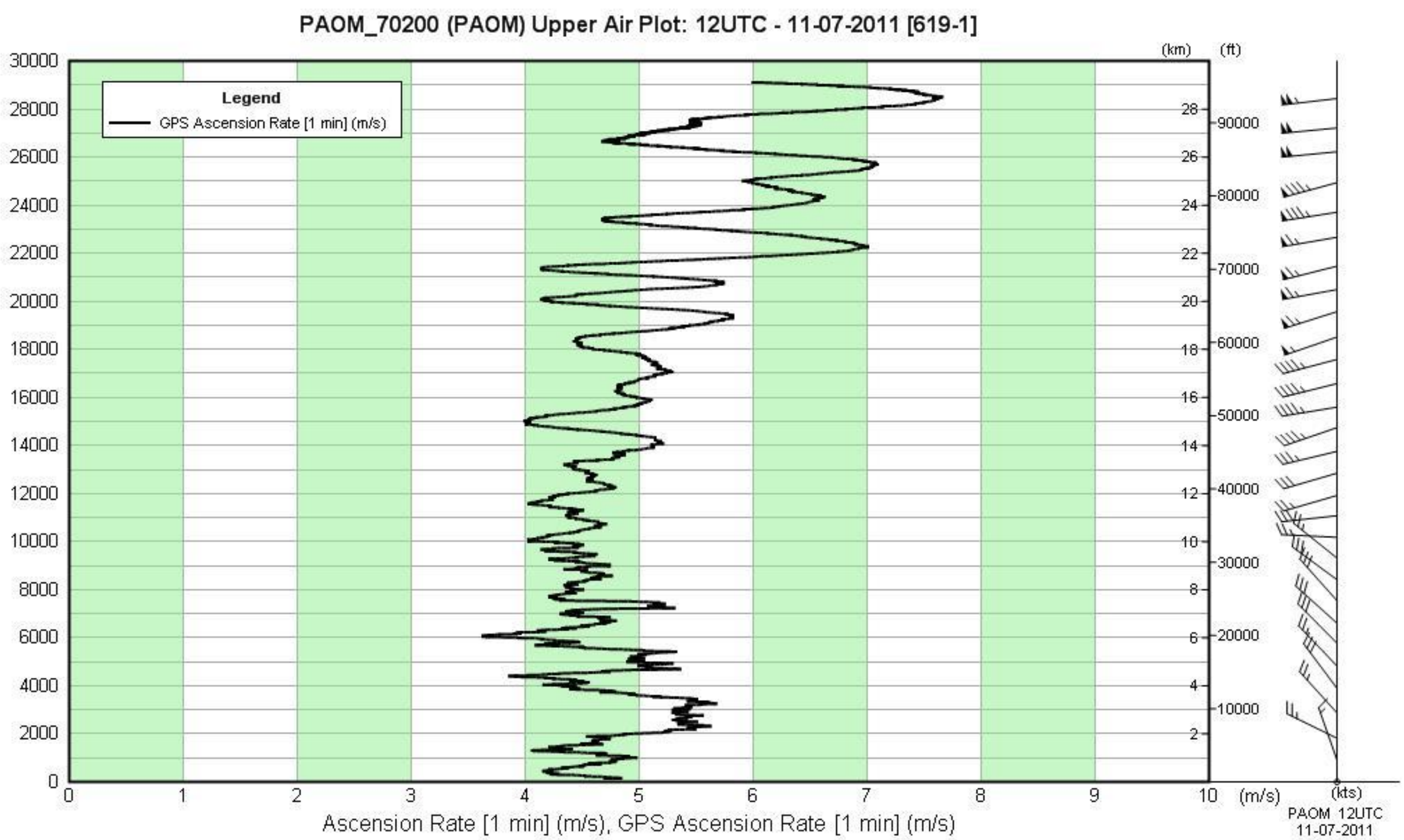


Figure 72

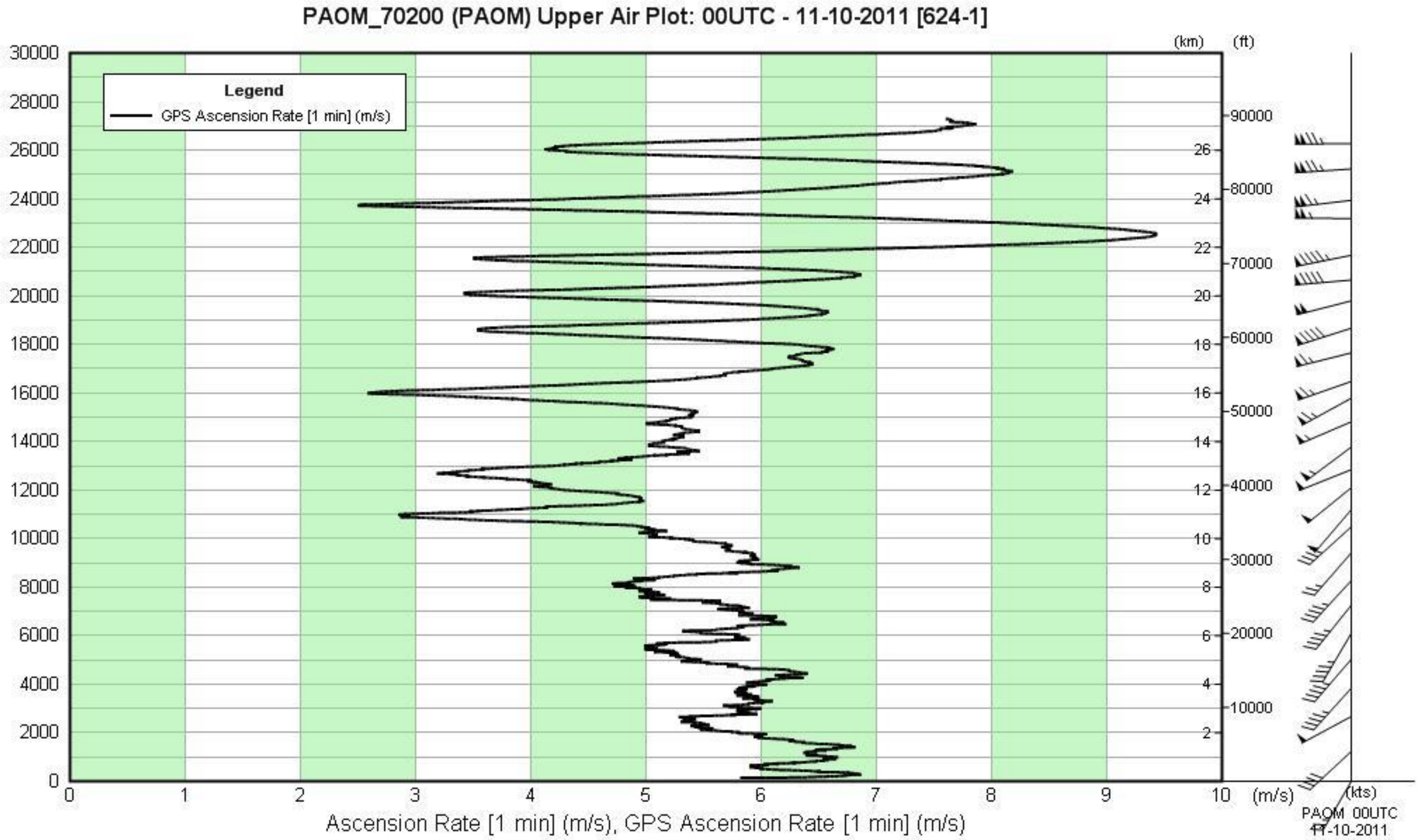


Figure 73

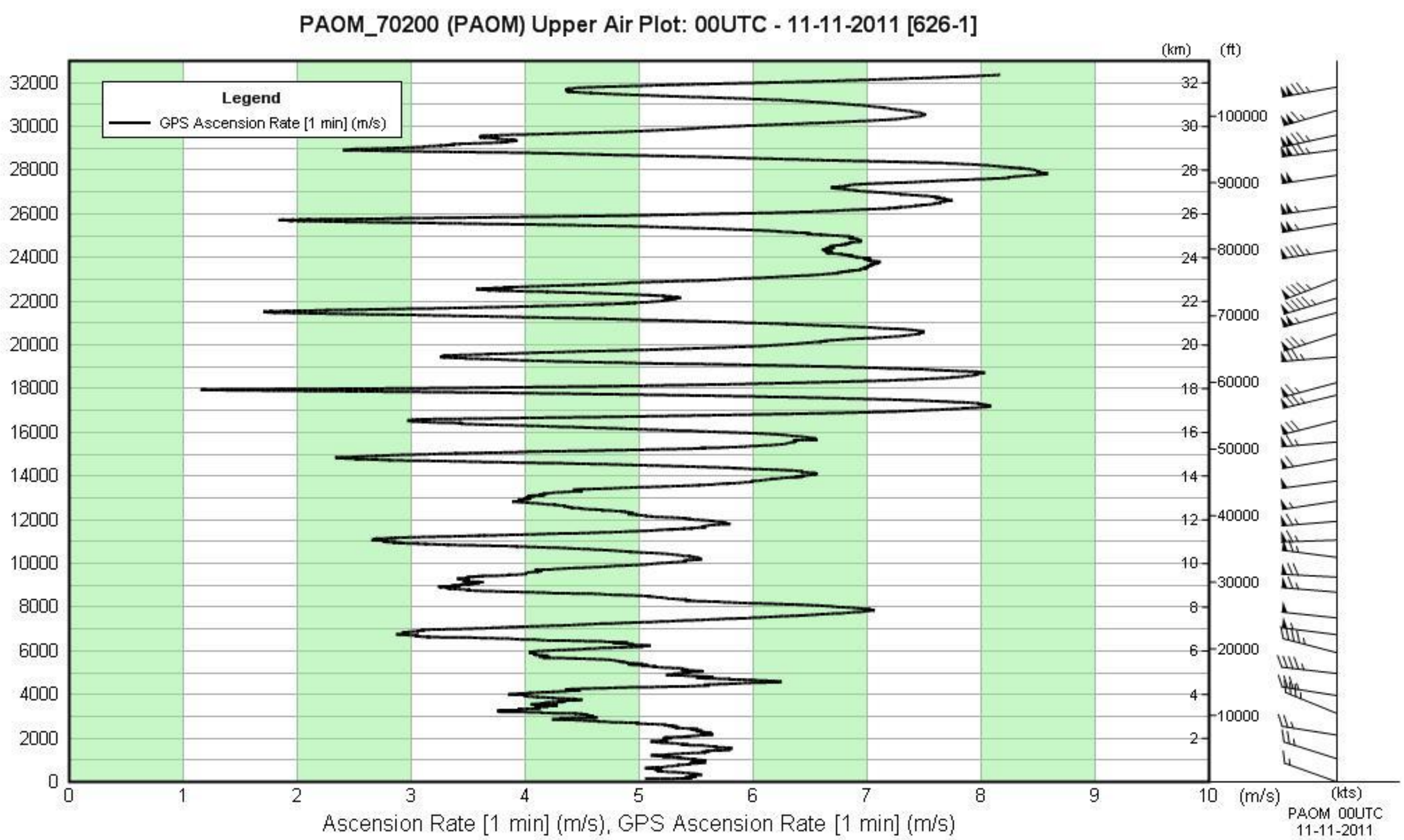


Figure 74

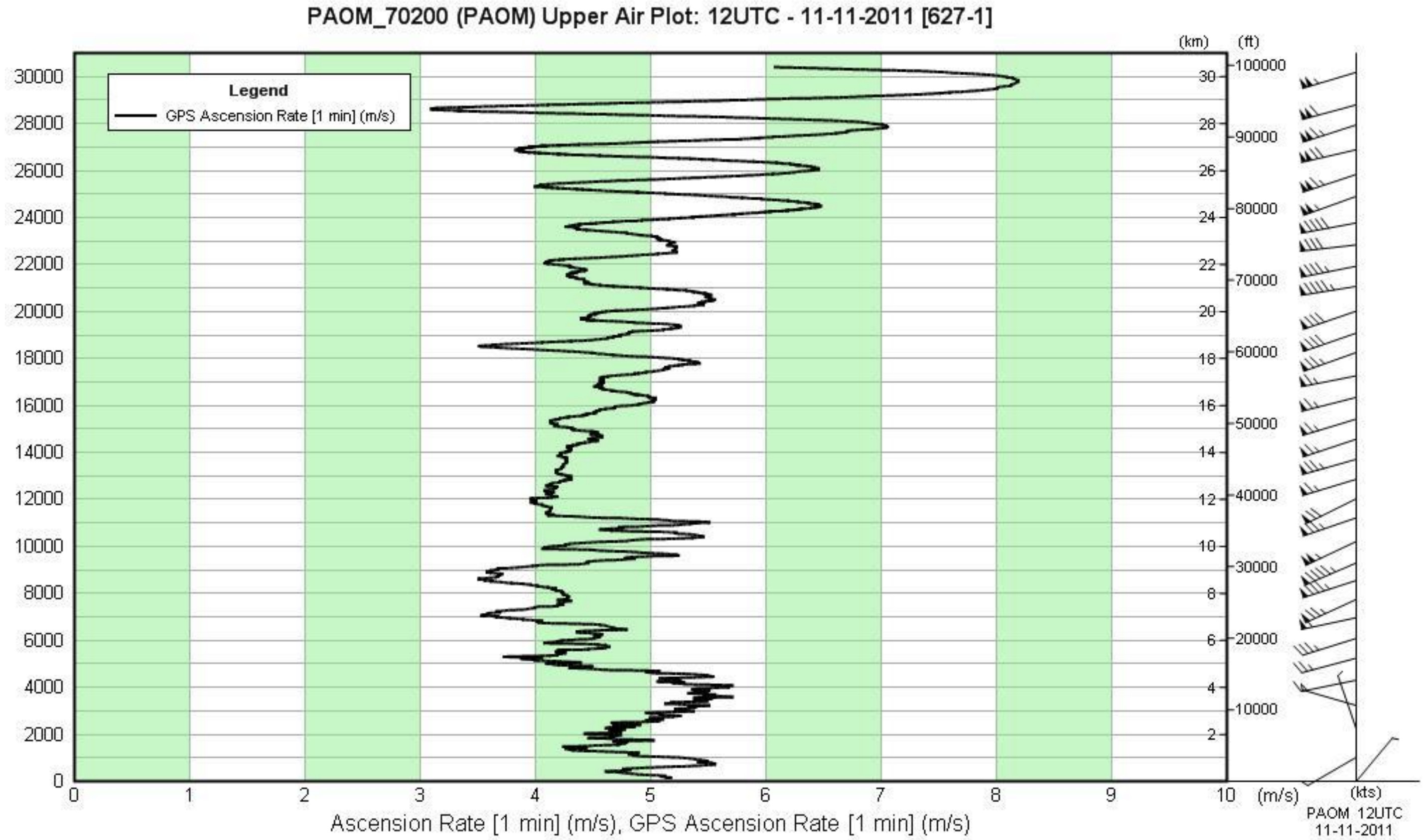


Figure 75

5. Discussion and Conclusions

Studying changes in radiosonde ascent rates provide interesting data on vertical motions in the atmosphere. In this study, they were observed from Alaska to the southern United States. From the case studies presented here, severe thunderstorms (large hail and/or tornadoes) appear to be a cause of significant gravity waves above 20 km in the stratosphere. Changes in radiosonde ascent speed were seen to vary by more than 10 m/s in a layer less than 1 km thick. It's not certain how far away from the storm the large waves above 20 km can be detected from the radiosonde data, but it could be more than 100 km.

Further investigations will be done to determine if there is a link between the severity of the storm and the magnitude of the stratospheric gravity waves they generated above 20 km. Yet, it should be noted than non-severe atmospheric phenomena such as Jet Streams can also cause significant gravity waves above 20 km and this would need to be taken into account.

Another area of study will be to determine whether or not strong hurricanes (category 3 to 5) produce strong stratospheric gravity waves (Kuester et al., 2008) above 20km. Soundings near hurricane Irene (category 1) were examined and showed some interesting ascent rate changes between 11 and 14 km. Yet, they did not show strong waves above 20 km.

NWS radiosonde data prior to about 1985 was recorded on paper rolls and archived. If these paper data or derived digital archive products have sufficient resolution, one could possibly derive usable radiosonde ascent data and subsequent vertical air motion data as far back as the 1940s. Interesting research on atmospheric vertical motions related to historic severe weather events (e.g., the massive tornado outbreak in April, 1974) could be done. And if there is a link between the magnitude of the gravity waves and the severity of the

thunderstorm that caused them, one could possibly detect severe thunderstorms near radiosonde stations from historic data collected during the 1940s and 1950s. During those years there were no routine radar or satellite observations to help detect severe storms and in some areas there were fewer storm spotter reports.
Above about 10 km significant corrections are typically applied to the temperature data owing to the effects of solar/infrared radiation. It would be of interest to determine what impact significant changes in ascent rate have on the temperature error and corrections that need to be applied.

Efforts are underway by the NWS to provide high resolution, 1 second RRS radiosonde data in real-time to data users. Each data point would contain the raw and smoothed PTU and heights (derived from the PTU and GPS data) data, as well as the latitude and longitude of the radiosonde.

As more case studies are completed they will be added to this report.

Corresponding Author Email Address: W.H. Blackmore, upperair@noaa.gov

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