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TEXAQS-II RADAR WIND PROFILER, RADIO ACOUSTIC SOUNDING SYSTEM, SODAR, AND LIDAR DATA QUALITY CONTROL AND MIXING HEIGHT DERIVATION

Final Report
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INTRODUCTION

The Texas Air Quality Study II (TexAQS-II) was designed to provide support for State Implementation Plan (SIP) revisions. The SIP revisions outline strategies for improving air quality to meet the new federal 8-hr ozone standard and regional haze requirements. As part of TexAQS-II, a field study was conducted to collect air quality and meteorological data throughout eastern Texas for the period from May 1, 2005, through October 15, 2006. As part of the field study, various organizations made upper-air meteorological measurements at several locations. These measurements were collected by twelve 915-MHz radar wind profilers (RWPs), three 404 MHz RWPs, nine Radio Acoustic Sounding Systems (RASS), two sodars, and one lidar. These instruments provide vertically, horizontally, and temporally resolved wind, virtual temperature (T_v), and mixing height information. These data will be used by the Texas Commission on Environmental Quality (TCEQ) and other study participants to explain the physical processes that influence air quality and to support modeling and air quality forecasting in eastern Texas. However, before these data can be used, they must first undergo quality control (QC) to remove bad data. In addition, because these instruments do not provide direct measurements of mixing heights, the mixing height data must be derived and quality-controlled subsequent to data collection.

This report summarizes the subjective QC of all available data collected by the RWPs, RASS, sodars, and lidar during the study and the derivation of mixing heights for sites with 915-MHz RWPs and sodars. In addition, this report discusses the availability of data collected by these instruments and describes the data files that are compiled on the compact disk (CD) that accompanies this report. All data on the CD have been validated to Level 2, which means that they are ready for use in modeling and data analysis.

MEASUREMENTS OVERVIEW

Table 1 lists the measurement sites from which RWP, RASS, sodar, and lidar data are available for the study period (May 1, 2005 - October 15, 2006) and their respective locations. **Figure 1** shows the site locations.

Table 2 summarizes the measurements. To optimize data recovery and resolution, the RWPs were configured to cycle in “low” and “high” operational modes. In “low” operational mode, the 915-MHz RWPs measured winds from about 100 m above ground level (agl) up to about 1,000 m agl and had a vertical resolution of about 60 m. In “high” mode, they had greater altitude coverage, from about 200 m agl to about 4,000 m agl, and a coarser vertical resolution of about 100 m. Wind data from both modes were merged to create a single profile with 60-m resolution data below 800 m agl and 100-m resolution data from 800 m agl to about 5,000 m agl. In addition, hourly daytime mixing heights were derived from the 915-MHz RWP signal-to-noise ratio, vertical velocity, and spectral width data. The mixing heights range from about 100 m to about 4000 m agl.

Table 1. Summary of measurements sites.

Site	Site ID	RWP	RASS	Sodar	Lidar	Operator	Latitude (°N)	Longitude (°W)	Elevation (m)	Start Date	End Date
Arcola	ACL	915 MHz	X			NOAA PSD[a]	29.51	95.48	21	7/14/06	10/17/06
Beeville	BVL	915 MHz	X			NOAA PSD[a]	28.37	97.79	75	6/03/05	10/18/06
Brazos A19	BRZ	915 MHz	X	Mini-4900 Hz		STI[b]	28.17	95.58	24	9/13/05	11/9/06
Brenham	BHM	915 MHz	X			NOAA PSD[a]	30.22	96.37	94	7/13/06	9/26/06
Calaveras Lake	CAL			Remtech		TCEQ[c]	29.27	98.31	134	6/01/05	10/15/06
Cleburne	CLE	915 MHz				TCEQ[c]	32.35	97.43	250	5/19/05	10/17/06
Huntsville	HVE	915 MHz	X			NOAA PSD[a]	30.72	95.64	101	6/16/05	10/17/06
Jayton	JTN	404 MHz				NOAA NPN[d]	33.01	100.98	707	6/27/05	10/17/06
Jefferson County	JFC	915 MHz				TCEQ[c]	29.94	94.10	5	6/22/05	10/17/06
LaPorte	LPT	915 MHz				TCEQ[c]	29.66	95.06	8	5/19/05	10/17/06
Ledbetter	LDB	404 MHz				NOAA NPN[d]	30.09	96.78	122	6/27/05	10/17/06
Longview	LVW	915 MHz	X			NOAA PSD[a]	32.38	94.71	106	6/15/05	10/15/06
Moody	MDY	915 MHz	X			NOAA CSD[e]	31.34	97.37	248	11/12/05	10/15/06
New Braunfels	NBF	915 MHz	X			STI[b]	29.70	98.02	195	6/29/05	10/17/06
Palestine	PAT	404 MHz				NOAA NPN[d]	31.77	95.71	119	6/27/05	10/27/06
Ron Brown[f]	RHB				200 Hz	NOAA/CIRES[g]	various		5	7/26/06	9/11/06
Sonora	SNR	915 MHz	X			NOAA PSD[a]	30.26	100.57	697	6/01/05	7/11/06

[a] National Oceanic and Atmospheric Administration Physical Science Division
[b] Sonoma Technology, Inc.
[c] Texas Commission on Environmental Quality
[d] National Oceanic and Atmospheric Administration National Profiler Network
[e] National Oceanic and Atmospheric Administration Chemical Science Division
[f] Instrument on board a ship in the Gulf of Mexico and Galveston Bay.
[g] National Oceanic and Atmospheric Administration and the Cooperative Institute for Research in Environmental Sciences

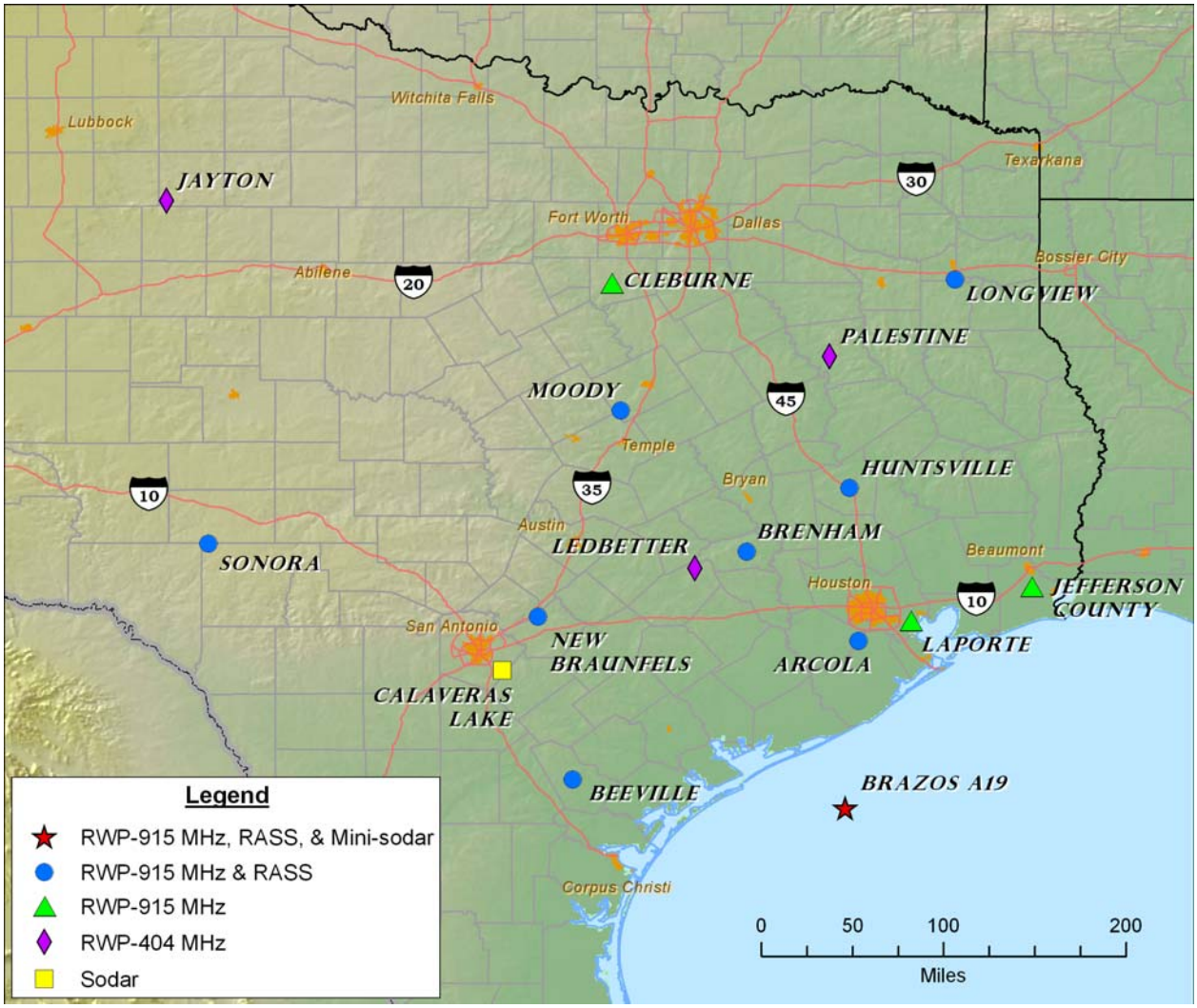

Figure 1. Site map showing location of instruments.

Table 2. Summary of measurements.

Instrument	Parameter	Time Resolution	Vertical Resolution (m agl))	Typical Height Coverage (m apl)
RWP 915 MHz	Winds	Hourly or twice hourly	~60 in lowest 800 and ~100 above 800	~100 up to 4000
RWP 915 MHz	Mixing Heights	Hourly	~60 in lowest 800 and ~120 above 800	~100 up to 4000
RWP 404 MHz	Winds	Hourly	250	~500 up to 16,000
RASS	Virtual Temperature	Hourly	~60	~140 up to 1,000
Mini-sodar	Winds	10-minute	5	~15 up to 150
Remtech sodar	Winds	Twice hourly	15	~50 up to 635
Lidar	Winds	15-minute	10 to 30	~2 up to 3000

In “low” operational mode, the 404-MHz profilers measured winds from about 500 m above ground level (agl) up to about 9,000 m agl and had a vertical resolution of 250 m. In “high” mode they had greater altitude coverage up to 16,000 m agl and a vertical resolution of 250 m. Wind data from both modes were merged at 7,500 m agl to create a single profile with 250-m resolution data up to about 16,000 m agl.

The RASS measured virtual temperature (T_v) for the first five minutes of each hour. The T_v is the temperature that a dry parcel of air would have if its pressure and density were equal to that of a moist parcel of air. Virtual temperatures were measured from about 120 m agl up to about 1,600 m agl, with a 60-m vertical resolution.

The mini-sodar at Brazos A19 (the offshore platform) was configured to measure 10-minute averaged profiles of wind speed and wind direction. Winds were measured from 15 m above platform level (apl) up to 150 m apl, with a 5-m vertical resolution. The sodar at Calaveras Lake was configured to measure 30-minute averaged profiles of wind speed and wind direction. Winds were measured from 50 m agl up to 635 m agl, with a 15 m vertical resolution. Sodar data from the Water Works and the University of Houston campus sites were not available.

The lidar on the Ron Brown measured winds every 15 minutes from about 2 to 3000 m above the ship deck with a vertical resolution ranging from 10 to 30 m. The ship deck is 5 m msl.

Figures 2 through 6 show examples of wind, T_v, and mixing height data. Figure 2 shows a time-height cross-section of wind data from the RWP on July 28, 2005, at New Braunfels. The winds are plotted as wind barbs, with the color and barbs indicating the speed. Each short barb represents 2.5 m/s, and each long barb represents 5 m/s. The values of the barbs are combined to show speed. For example, a single long barb and a short barb denote 7.5 m/s (5 m/s + 2.5 m/s = 7.5 m/s). Pennants represent 25 m/s. Barbs and pennants are drawn to the left of the direction of air movement.

In Figure 2, the passage of a cold front can be seen by the sudden shift in wind direction and speed near the surface at about 0200 Central Standard Time (CST). According to surface weather charts (not shown), a cold front was observed to have passed through New Braunfels at that time. The depth of this cold front can be inferred from Figure 2 by observing where the winds suddenly change direction. For example, at 0800 CST, the wind changes direction from northeasterly at 10 m/s at 400 m agl to southwesterly at 5 m/s at 600 m agl.

Figure 3 shows profiles of T_v measured by the RWP/RASS at New Braunfels from 0200 CST through 0700 CST on July 28, 2005. In this example, the passage of the shallow cold front observed in Figure 2 can be followed by noting the decrease in T_v between 0200 CST and 0700 CST. The presence of a small inversion can be observed at about 400 m agl at 0700 CST. This inversion represents the approximate depth of the cold front observed in Figure 2, although a smaller amount of cooling is evident above this level.

Figure 4 shows profiles of T_v measured by the RWP/RASS at New Braunfels from 1500 to 1600 CST on July 29, 2005. In this example, a temperature inversion during the

afternoon hours is apparent up to about 350 m agl. Temperature inversions are important because they trap pollutants near the surface, which can lead to poor air quality.

Figure 5 shows a time-height cross-section of reflectivity data measured by the RWP/RASS at New Braunfels and mixing heights derived from the reflectivity data for May 4, 2006. In this example, the mixing height is about 200 m agl at 0800 CST (14:00 UTC) and grows to a height of about 2,000 m agl by 1400 CST (20:00 UTC). A slow-growing mixing height is an indicator that pollutants released into the air will remain trapped within the boundary layer for a longer period of time, leading to poor air quality.

Figure 6 shows a plot of the mini-sodar data at Brazos A-19 on December 19, 2005. The mini-sodar reported winds from 15 m apl to about 100 m apl on this day. However, data recovery was poor on many days because of noise on the platform.

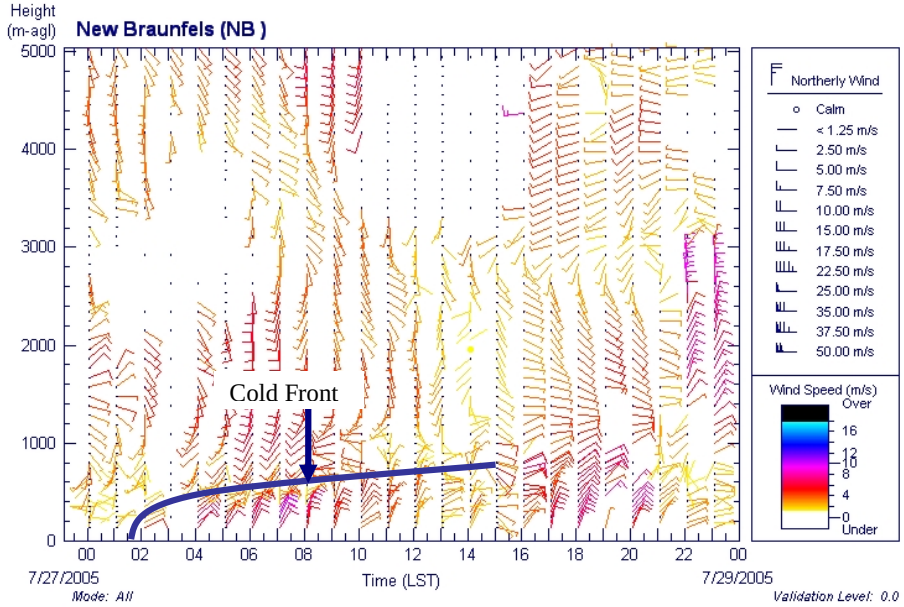

Figure 2. RWP wind data from New Braunfels, Texas, on July 28, 2005, showing passage of a shallow cold front at about 0200 CST.

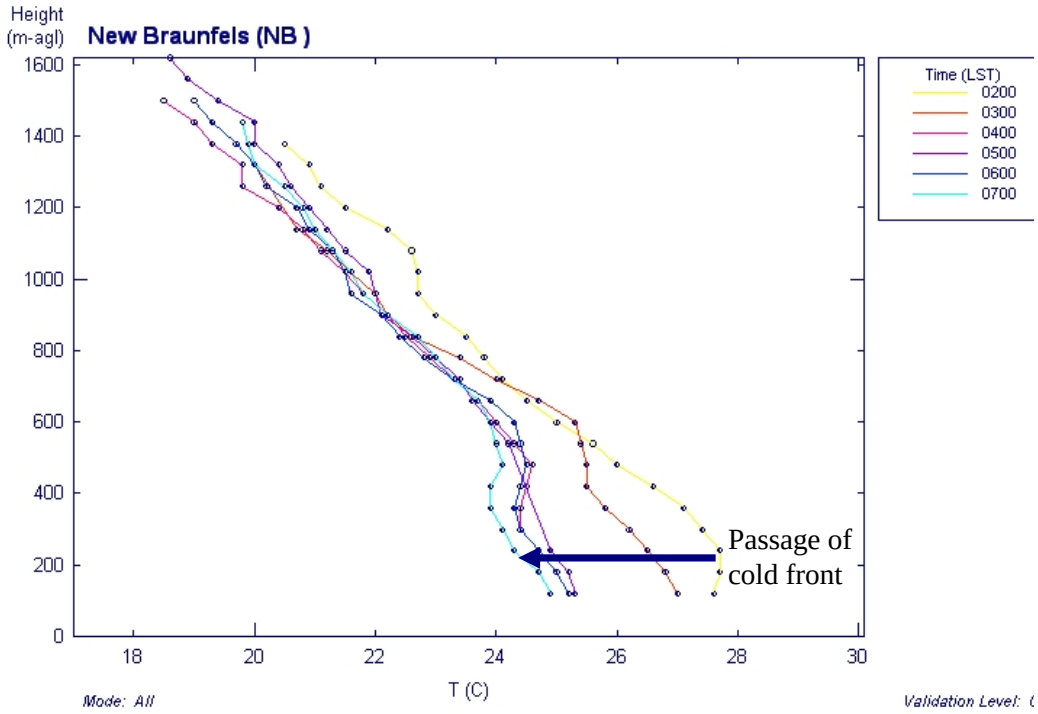

Figure 3. RWP T_v data from New Braunfels, Texas, on July 28, 2005, showing passage of a shallow cold front at about 0200 CST.

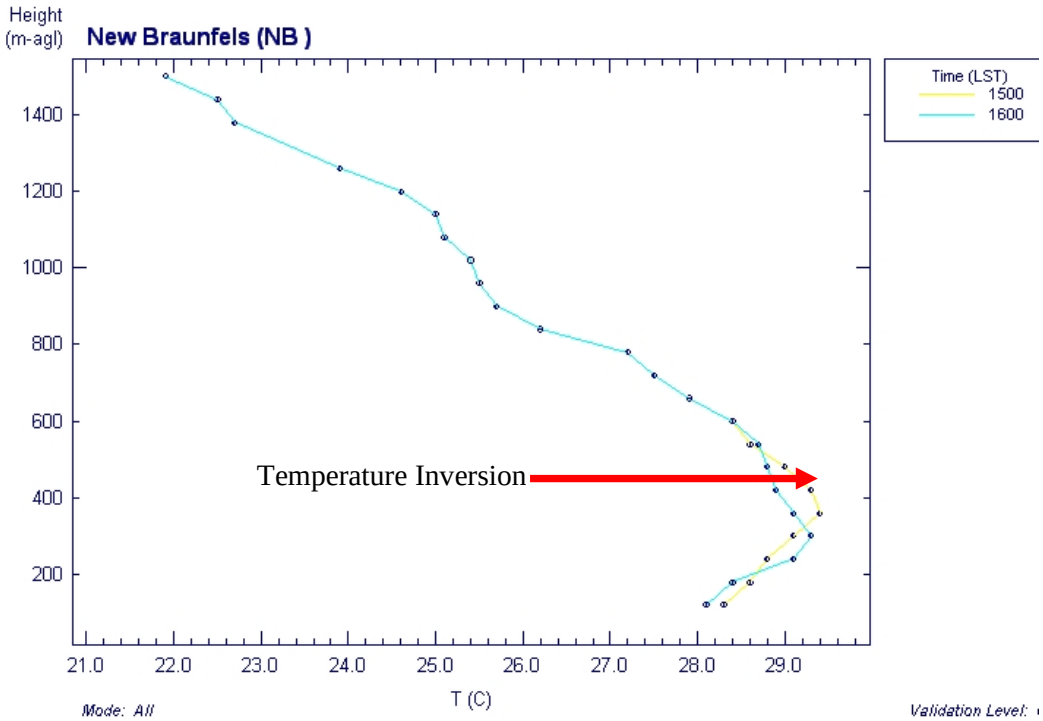

Figure 4. RWP T_v data from New Braunfels, Texas, on July 29, 2005, from 1500 to 1600 CST showing a temperature inversion at approximately 350 m agl.

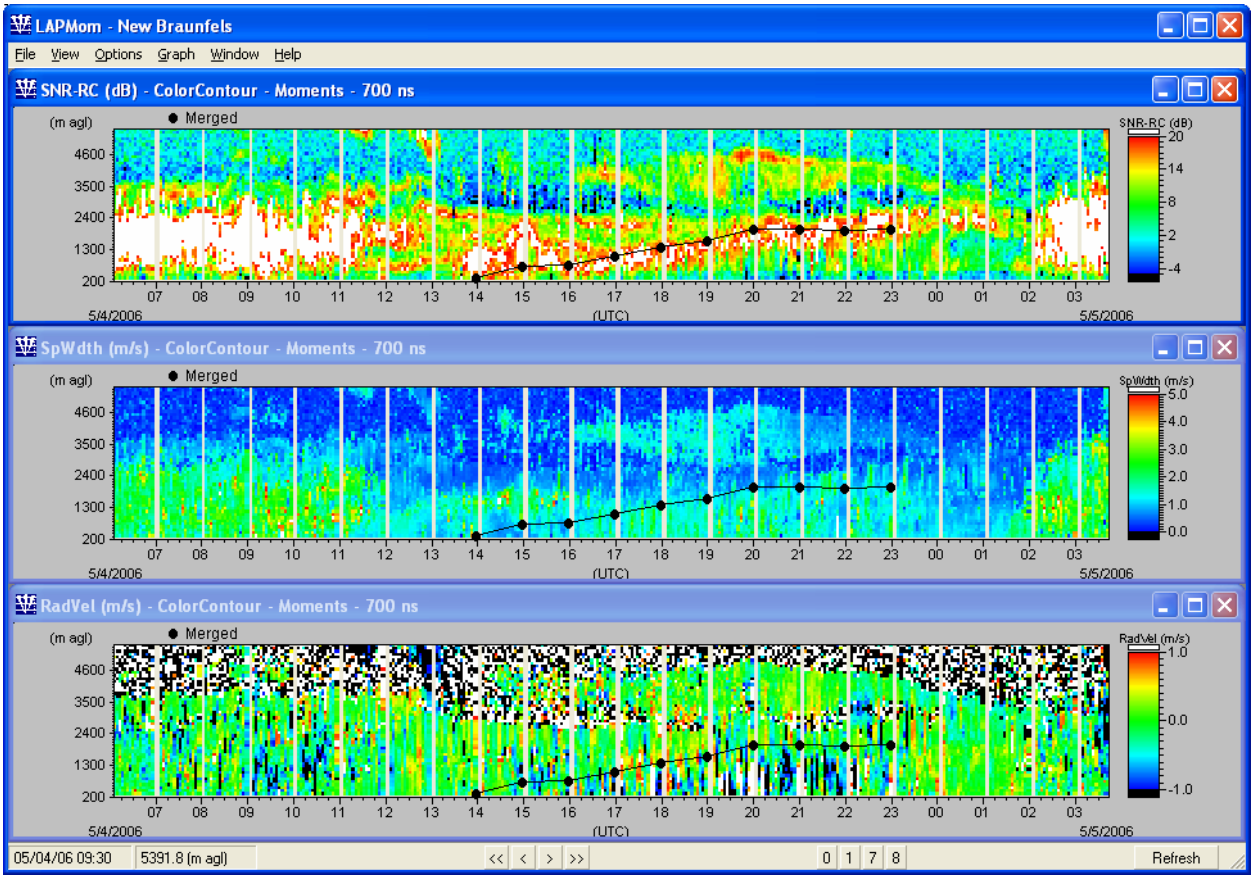

Figure 5. RWP reflectivity and mixing height data from New Braunfels, Texas, on May 4, 2006.

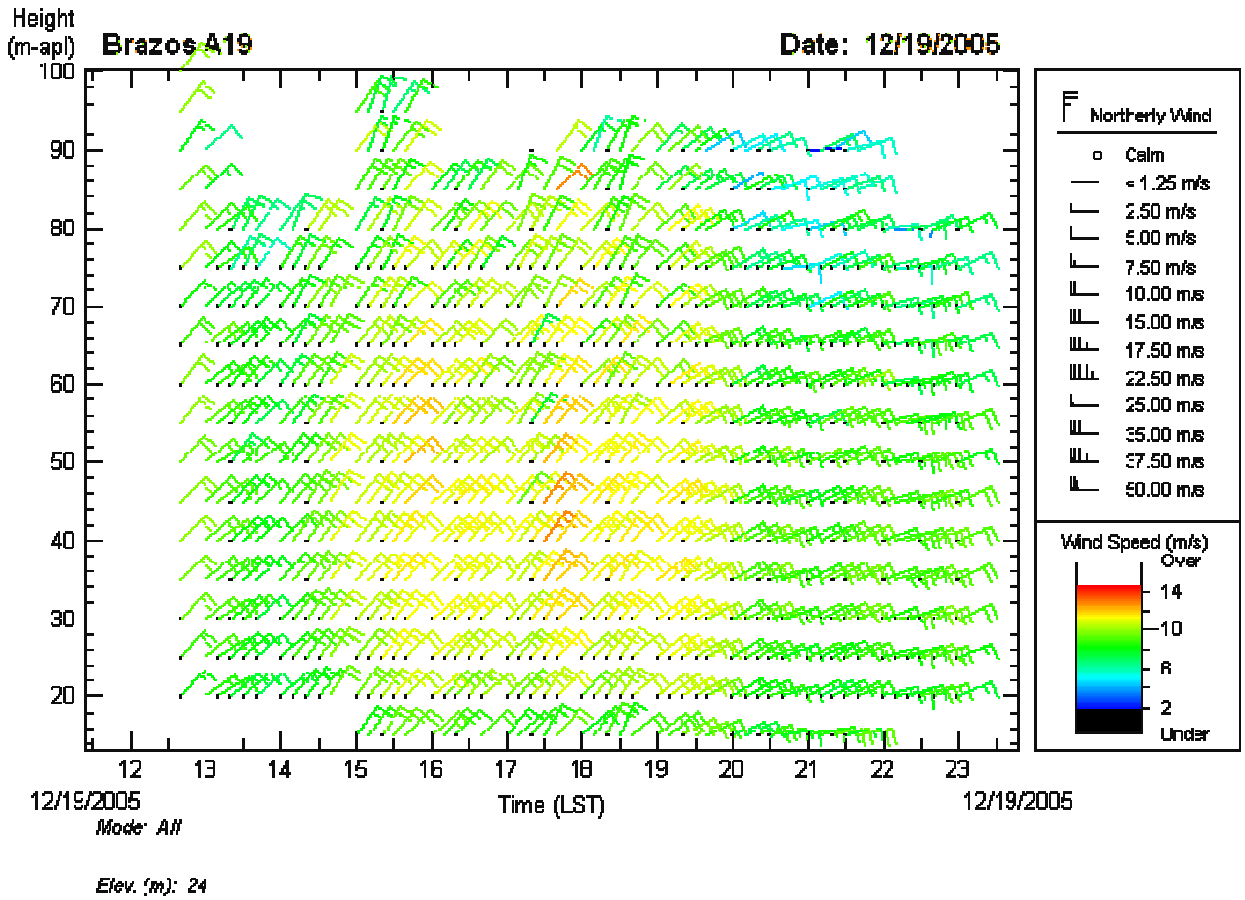

Figure 6. Example plot of wind profiles measured by the mini-sodar on December 19, 2005, at Brazos A19 in the Gulf of Mexico. Winds are plotted in the conventional wind barb plot format, where the orientation of the shaft indicates wind direction and the number and length of bars indicates wind speed.

DATA AVAILABILITY

Figures 7 through 9 show the periods when data are available for each site and parameter during the study period. Periods when data are unavailable are primarily the result of instruments not operating; however, some periods of data are not available because data were invalidated during the subjective quality control effort. The latter reason is especially common in the sodar data.

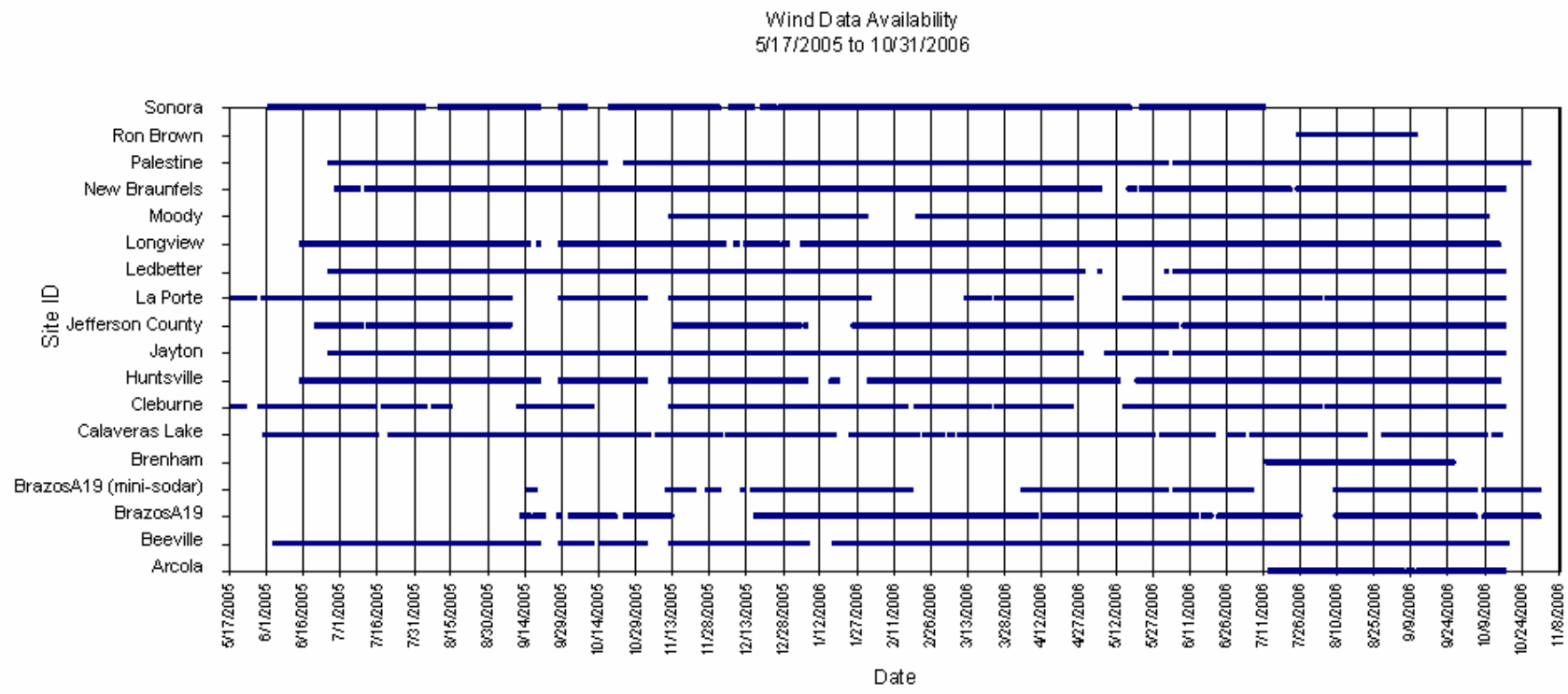

Figure 7. Wind data availability.

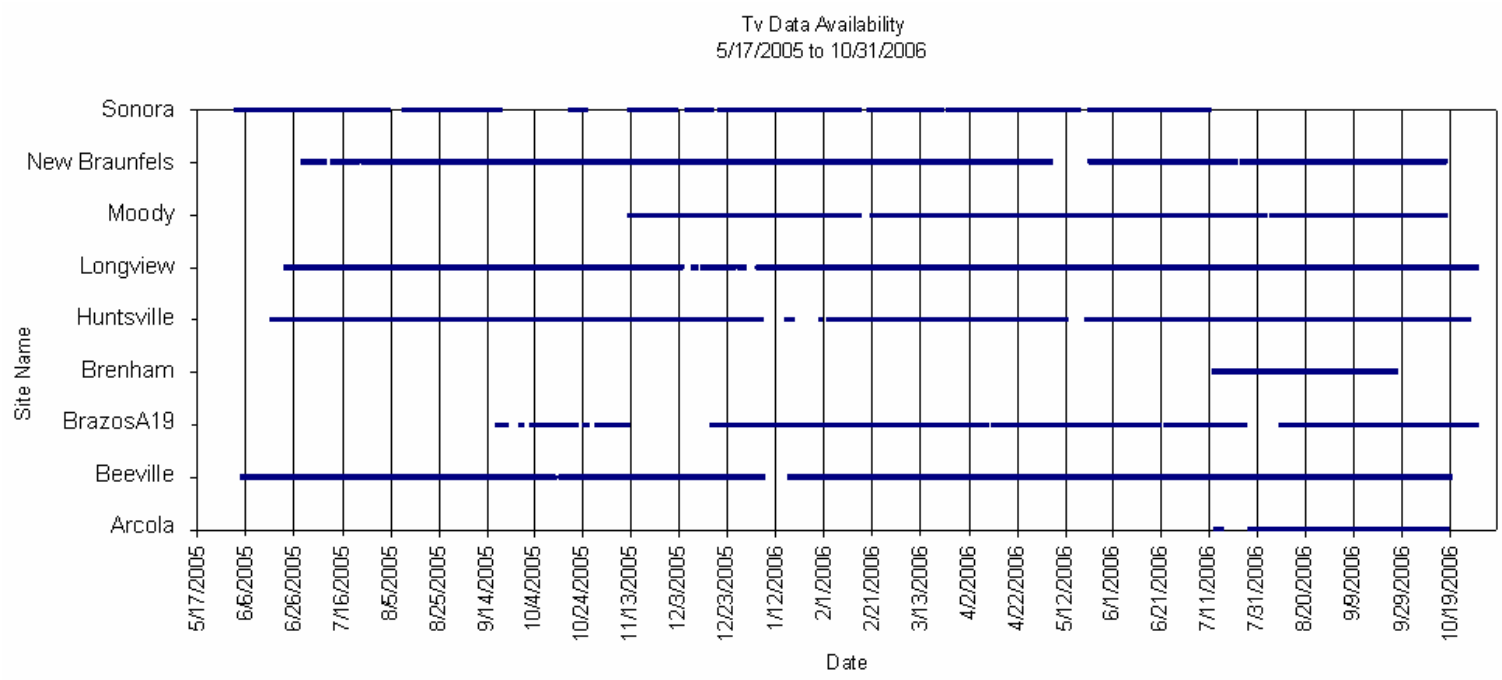

Figure 8. T_v data availability.

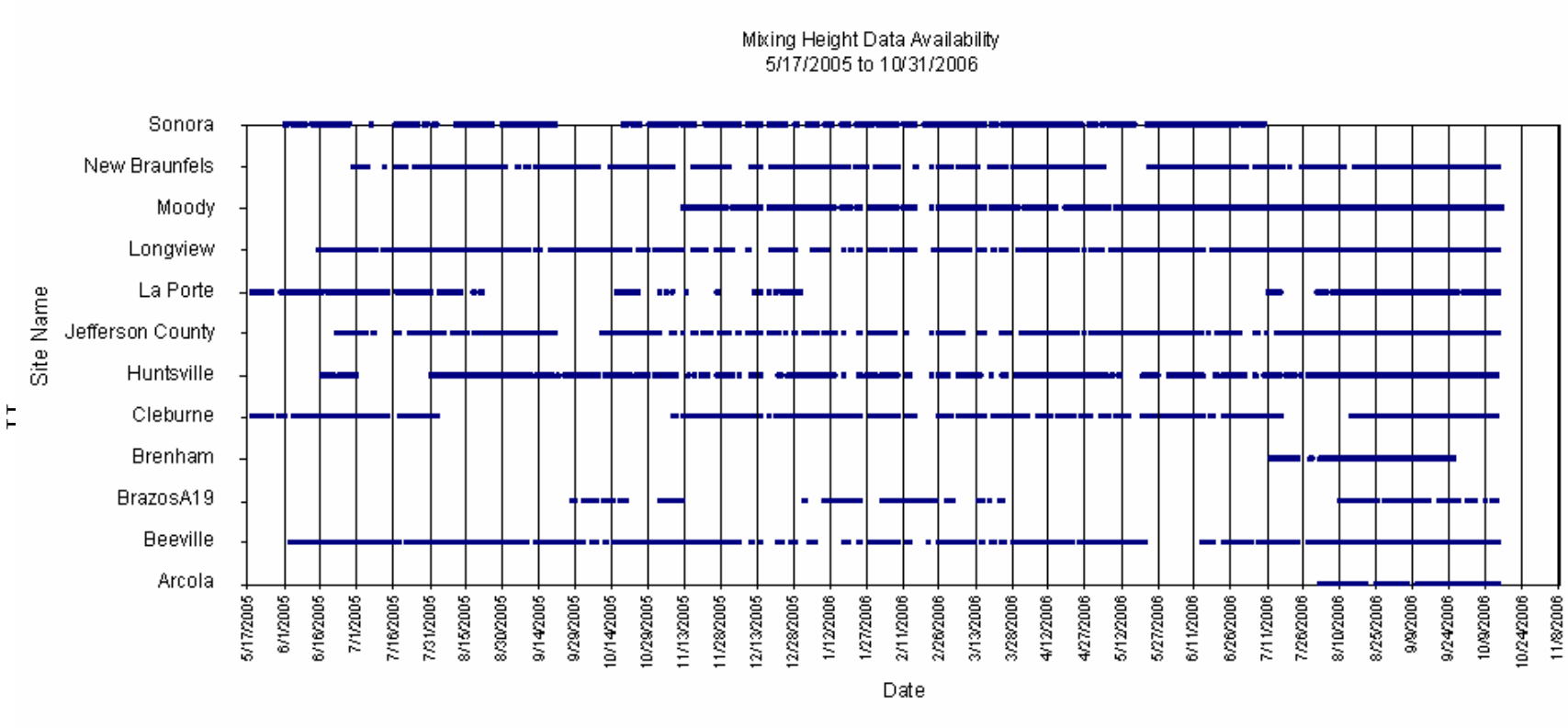

Figure 9. Mixing height data availability.

QUALITY CONTROL

The data on the CD accompanying this report have been reviewed and validated by a meteorologist and are ready for immediate use by analysts and modelers. This section describes the steps that were followed to process and perform the data validation screening and QC of the upper-air data.

The data validation process involved identifying inconsistent observations (outliers) and assigning QC codes to each data point to indicate its validity. Several stages, or "Levels", in the data validation process were included:

Level 0.0. Raw data, not quality-controlled.

Level 0.5. Data that were subjected to automatic QC screening by software (e.g., Weber and Wuertz, 1991[1] for the radar).

Level 1.0. Data that were subjected to quantitative and qualitative reviews for accuracy, completeness, and internal consistency. Staff who understand the measurement systems and the meteorological processes expected to be reflected in the data performed the qualitative reviews.

Level 2.0. Data that were compared with prior hour data, model output to evaluate directional consistency with synoptic patterns, and data from other nearby instruments (profilers, rawinsondes, or upper-air maps).

The following steps were used to validate data to Level 2.0 validation.

1. The Level 0.0 data were obtained from the various site operators.
2. Manual review of the data was performed by an experienced meteorologist. The reviewers carefully examined plots of the data, identified outliers, and evaluated the reasonableness of the data. The reviewers flagged the resulting data as "valid", "invalid", or "missing", using the appropriate QC codes.

The following QC codes were used (note: we recommend using only data with a QC code ≤ 2):

0 = Valid
1 = Valid, no vertical correction
2 = Valid, calibration applied
8 = Invalid with a data value of:
- -940 = failed auto QC
- -950 = unable to create consensus average
- -960 = radial velocities too high/low
- -980 = invalidated by reviewer

9 = Missing with a data value of –999

[1] Weber B.L. and Wuertz D.B. (1991) Quality control algorithms for profiler measurements of wind and temperatures. Technical memorandum by NOAA Environmental Research Laboratories, Boulder, CO, ERL WPL-212.

3. Reviewers used internal and external sources of data to determine the validity of the observations. **Table 3** lists internal data sources that were commonly used and briefly explains their use. Internal data sources included other parameters that were measured by the same instrument, collocated data sources, and other internally generated data (e.g., instrument performance logs and site operator logs). For example, when checking for precipitation contamination in the RWP or RASS data, reviewers often relied on the RWP's vertical velocity measurements, which record the fall velocity of rain during precipitation events.

Table 3. Internal data sources used during data validation.

Internal Data Sources	Usage
RWP vertical velocity data	Check for vertical velocity biasing in the RASS data. Check for precipitation contamination of upper-air winds.
RWP signal-to-noise ratio (SNR) data	Check for precipitation contamination, bird contamination, and ground clutter.
Surface meteorological wind data	Check for consistency in the RWP's lower-level wind data.

Table 4 lists external data sources and brief explanations of their use. Examples of external data sources include NOAA buoy data, National Weather Service (NWS) upper-air and surface weather charts, satellite images, radiosondes, and other profilers.

Table 4. External data sources used during data validation.

External Data Sources	Explanation of Usage
NWS upper-air meteorological charts	Perform reasonableness checks to evaluate the spatial consistency of the upper-level winds based on geopotential height gradients depicted on 700-mb and 850-mb charts.
NWS surface meteorological charts	Track synoptic-scale weather features (e.g., frontal positions and thunderstorms) that may affect instrument performance or data quality.
Radiosondes, profilers, and NOAA buoys	Check temporal and spatial consistency in the wind speed and wind direction data.

An example of wind data that were invalidated is shown in **Figure 10**. In this example, a persistent area of data indicating northerly winds can be seen at around midnight between 2000 m agl and 4000 m agl. However, the reported northerly winds were actually caused by the radar measuring the motion of birds migrating to the south. Birds act as large radar "targets," so that signals from birds overwhelm the weaker atmospheric signals. These bird-contaminated data were invalidated and removed from the data set during quality control. Additional information about bird contamination of RWP data can be found in Wilczak et al., 1995.[2] All 915-MHz sites, except Brazos A19, experienced contamination due to birds from about 10:00 pm to 2:00 am CST at altitudes of between about 800 m agl and about 2000 m agl during early fall 2005 and 2006.

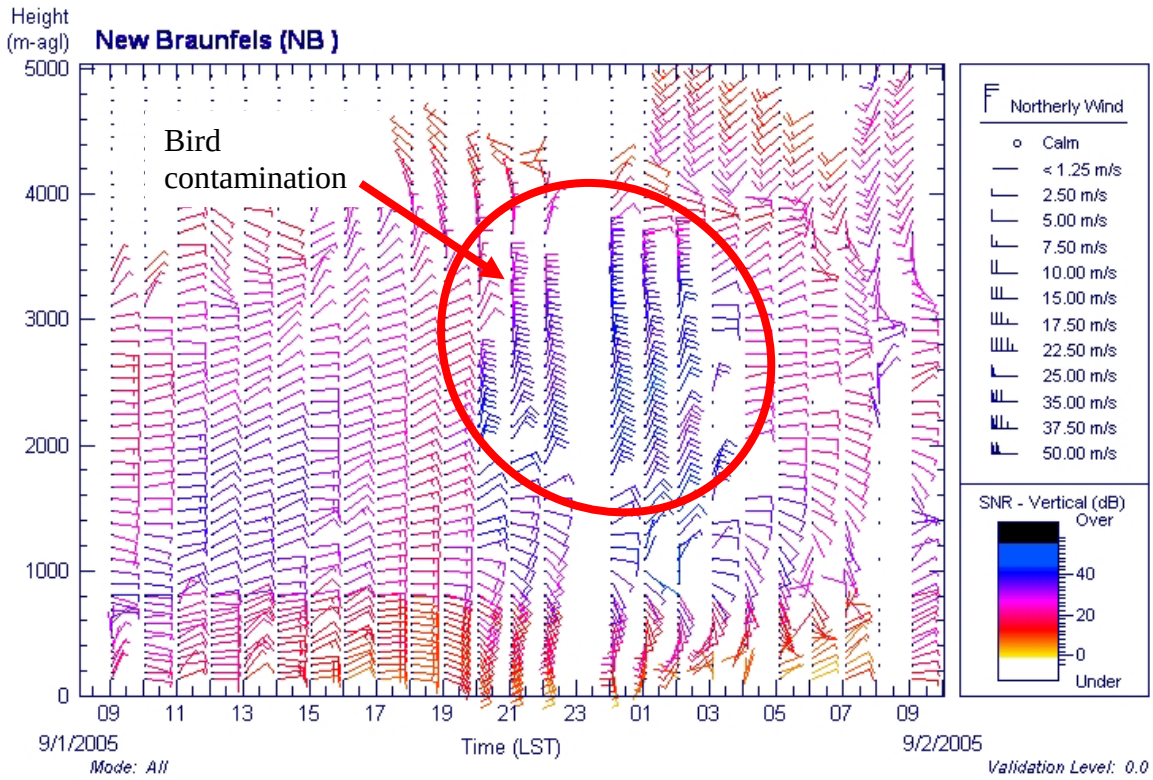

Figure 10. Invalidated RWP wind data collected at New Braunfels, Texas, on September 1 and 2, 2005

[2] Wilczak J.M., Strauch R.G., Weber B.L., Merritt D.A., Ralph F.M., Jordan J.R., Wolfe D.E., Lewis L.K., Wuertz D.B., Gaynor J.E., McLaughlin S., Rogers R., Riddle A., and Dye T. (1995) Contamination of wind profiler data by migrating birds: characteristics of corrupted data and potential solutions. *J. Atmos. Ocean. Technol.* **12** (3), 449-467.

MIXING HEIGHT DERIVATION

The hourly daytime mixing height data on the CD accompanying this report have been created, reviewed, and validated by a meteorologist and are ready for immediate use by analysts and modelers. This section describes the methods used to derive the mixing heights.

RWP reflectivity data from the 915-MHz RWPs (or signal-to-noise ratio [SNR] data) were used to estimate the height of the daytime surface-based mixed layer, the marine boundary layer (MBL), and the convective boundary layer (CBL). This data can be used to detect the mixing height because the data values are strongly influenced by the refractive index of the atmosphere. Turbulence produces variations in atmospheric temperature, humidity, and pressure, which in turn cause variations in the radar refractive index. In the PBL, humidity fluctuations contribute most to the variations in the radar refractive index. The greatest humidity variations tend to occur at the top of the aforementioned boundary layers. For example, Wyngaard and Lemone (1980)[3] showed that the radar refractive index peaked at the inversion located at the top of the CBL because of warm, dry, aloft air entraining into cooler, moister air below the inversion.

Figure 11 shows an example of time-height SNR data obtained from the RWP from which mixing heights were derived. Blue and green in the cross-section show weak signal returns, and orange and red show strong returns, i.e., large values of SNR. The black line during daylight hours indicates the mixing height analyzed from the SNR. At times, the peak SNR may not always define the surface-based mixed layer and may depict some other aloft layer such as a subsidence inversion. Therefore, we also viewed SNR plots in conjunction with vertical velocity, spectral width, and RASS T_v plots to ensure that peak SNR properly characterized the surface-based mixing height.

In addition to using RWP data to derive mixing heights, we also reviewed available sodar backscatter and wind data to derive mixing heights. However, because of data quality and the limited height coverage of the sodar measurements, we were unable to derive mixing heights using this data.

[3] Wyngaard J.C. and LeMone M.A. (1980) Behavior of the refractive index structure parameter in the entraining convective boundary layer. *J. Atmos. Sci.* **37**, 1573-1585.

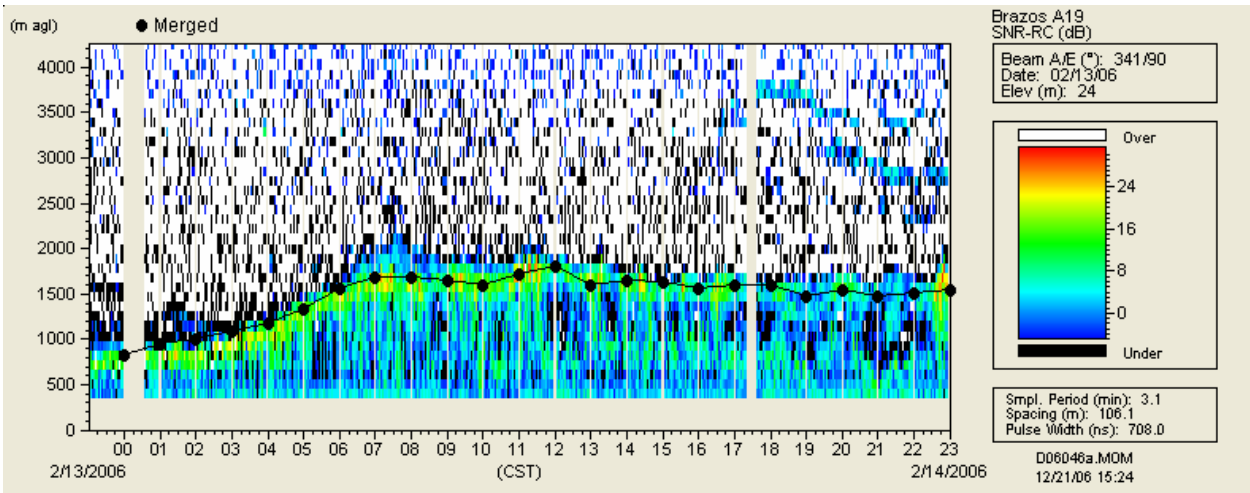

Figure 11. Time-height cross-section of RWP SNR data at Brazos A-19 on February 13, 2006. The top of the MBL is shown as the black solid line.

DATA FILE INFORMATION

The enclosed CD contains upper-air data files and mixing heights stored in Microsoft Excel. The time standard for the data is begin hour Coordinated Universal Time (UTC). This section describes the file formats.

Upper-Air Data Files

The upper-air data files are provided in the FSL (Forecast Systems Laboratory) RAOB (RAdiosonde OBservation) format. The file naming convention for the FSL RAOB wind data files is SSS _RWP.txt, the file naming convention for the FSL RAOB RASS data files is SSS_RASS.txt, and the file naming convention for the FSL RAOB sodar data files is SSS_SODAR.txt.

where: SSS = three letter site ID

For example, the file CAL__SODAR.txt contains the sodar wind data from the Calaveras Lakes site for the entire study.

The lidar data are provided in NASA Ames data format. A full description of the lidar file format can be found at <http://www-air.larc.nasa.gov/missions/etc/IcarttDataFormat.htm#5b>.

The FSL RAOB data format (**Figure 12**) is similar to the format used by the National Severe Storms Forecast Center (NSSFC). The first four lines of the sounding are identification and information lines. All additional lines are data lines. An entry of 32767 (original format) or 99999 (new format) indicates that the information is either missing, not reported, or not applicable. **Table 5** describes the FSL RAOB file format

```
                    ---COLUMN NUMBER---

   1       2       3       4       5       6       7       8       9
LINTYP
                    header lines
 PROF      HOUR      DAY    MONTH      YEAR    (blank)    (blank)    MIN       RES
   1     WBAN#      WMO#      LAT       LON     ELEV      (blank)
   2     (blank)    (blank)  (blank)    (blank)   (blank)    (blank)
   3     (blank)     STAID   (blank)    (blank)  (blank)    WSUNITS

                    data lines
   9   PRESSURE     HEIGHT      TEMP    DEWPT   WIND DIR    WIND SPD
   4
   4
   4
   4
   4
    .
    .
    .
```

Figure 12. Example of FSL RAOB file format.

Table 5. Legend describing the FSL RAOB file format.

Parameter Name	Parameter Description
LINTYP: PROF 1 3 4 9	Type of identification line = Profiler sounding Date Information line = station identification line = station identifier and other indicators line = mandatory level = surface level
HOUR:	Begin Hour of Day in UTC
DAY:	Day of Month (1 - 31)
MONTH:	Month of Year (1 - 12)
YEAR:	Year (1900 - 2999)
MIN:	Minute timestamp of data
RES:	Resolution of the data
LAT:	Latitude in degrees and hundredths
LON:	Longitude in degrees and hundredths
ELEV:	Elevation from station history in meters
WSUNITS:	Wind speed units in tenths of a meter/second
STAID:	Radar Station Name
PRESSURE:	In tenths of millibars. These are all standard pressure heights except for line type 9, it could be a measurement.
HEIGHT:	Height in meters (m) (MSL)
TEMP:	Virtual Temperature in tenths of degrees Celsius
DEWPT:	Dew point temperature in tenths of a degree Celsius
WIND DIR:	Wind direction in degrees
WIND SPD:	Wind speed in knots or meters/second

Mixing Height Data File

The file naming convention for the mixing height data files is SSS_Mixing.xls

where: SSS = Site ID

For example, the file NBF_Mixing.xls contains the mixing height data from the New Braunfels site for the entire study period.

The mixing height data are stored in worksheets, by month, in a Microsoft Excel Spreadsheet. The first 31 lines contain header information defining each of the data fields found in lines 32 through the end of the file. The datetime field is in CST and UTC, begin time. The mixing height is in meters agl. QC codes are in the last field in the file.