Report of Preliminary Analysis of Data from Dew-Point Hygrometer Profiles During the
ARM 1996 WVIOP

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Abstract

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Unique commercial light-weight chilled-mirror dew-point sensors were flown on tethered balloons during the Water Vapor Intensive Operation Period (WVIOP) in September 1996. Comparisons were made between *in situ* and remote sensing instruments that detect water vapor. We obtained a special waiver to fly the sensors up to 1 km both day and night from the FAA. Preliminary comparisons with tower mounted, surface-based temperature/relative humidity probes, rawinsonde, air-borne chilled-mirror dew point, and Raman lidar profiles are included. Profiles during nocturnal boundary layer wind jet occurrences are presented as special cases along with balloon-borne nephelometer light scattering profile comparisons.

Experiment Overview

The participation of our group at LANL in the 1996 Atmospheric Radiation Measurements (ARM) Water Vapor IOP was focused on vertical profiles of water vapor mixing ratios using a chilled-mirror dew-point hygrometer. The chilled-mirror systems are commercial instruments purchased from Meteor AGTM (Switzerland) and flown on a tethered balloon with the tethersonde[®] meteorological profiling system from AIR Inc. (United States). The chilled-mirror systems are designed to fly on tethered balloons (Richner et al. 1991). The tethersonde[®] system has been used to study complex terrain airflows (Clements et al. 1989; Porch et al. 1991), urban boundary layers (Porch et al., 1992), and marine boundary layers (Porch et al. 1995). The experiment took place 9-30 Sept. 1996 at the Southern Great Plains (SGP) Clouds and Radiation Testbed (CART) central facility near Billings, OK. In order to accomplish this experiment, each of the following steps were completed:

1. FAA clearance requiring two waivers was obtained to fly the balloon package to 1 km altitude (both day and night) and with no deflation device should the balloon break free.
2. Conditioning electronics needed to be constructed to make the output signals from the chilled-mirror hygrometer compatible with signal levels that can be transmitted on the three spare channels of the tethersonde[®] (0-1 Volt).
3. Our tethersonde[®] packages were sent to AIR for calibration.
4. The chilled-mirror systems were delivered to Oklahoma University for comparisons with Oklahoma Mesonet humidity sensors and the dew-point hygrometer system flown on the Twin Otter escort plane for the ARM Unmanned

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Aeronautical Vehicle (UAV). Unfortunately, instrument problems caused by an inadvertent over voltage allowed only 15 minutes of comparison. This comparison showed that the intercomparison would have to be redesigned so that the entire sensor would be exposed to uniformly humid air rather than drawing air through a tube (this is because of back flow of ambient air into the chilled-mirror sensor). The instruments are presently at the University of Wisconsin for post-calibration comparisons.

5. Measurements began 9 Sept. 1996 using a chilled-mirror sensor borrowed from Hal Cole at NCAR that was used with their calibration reference rawinsonde system. This system (which is identical to the two chilled-mirror Meteor AG™ that were damaged) was used along with the repaired chilled-mirror systems when they were returned 19 Sept. 1996. These measurements included vertical profiles as well as surface-based comparisons with the Vaisala™ temperature and relative humidity probe at the Balloon-Borne Sounding System (BBSS). Also, the combined voltage gains and offsets from the voltage conditioning and tethersonde® signal processing were determined using a calibrated voltage source provided by Tom Stoffel of NREL.
6. At the end of the experiment (30 Sept. 1996) the chilled-mirror systems, conditioning electronics and tethersonde® system were sent to the University of Wisconsin for post-calibration.

Occasional problems occurred on some of the profiles obtained during the experiment. These were usually associated with weak batteries even though an effort was made to replace the batteries at each launch. Also, some problems occurred that might have been associated with radio interference. Two tethersonde® systems were used at two different frequencies (403.5 and 404.7 MHz). The possible interference related problems only occurred with the 404.7 MHz system. This frequency is close to the 404.5 MHz Lamont Profiling System frequency. The above problems affected less than half the profiles, and then usually only resulted in high noise on the chilled-mirror reference temperature measurement. This signal should change slowly with altitude and it may be possible to recover affected profiles by low-pass filtering of the reference temperature signal. Also, occasional wind and rain conditions precluded several days of operation (we attempted to take advantage of these periods for surface comparisons and calibration).

Despite the occasional problems mentioned above, the experiment was successful in the following aspects:

1. Meteorological variability allowed profiles during a wide variety of humidity conditions (about a factor of three; 5-15 g kg⁻¹ mixing ratios).
2. The near continuous operation of the two Raman Lidar, AERI, Microwave Radiometer, and *in situ* humidity sensor systems allowed comparisons on almost every successful profile of the chilled-mirror dew-point hygrometer sensors.
3. Weather conditions cooperated to allow comparison of the dew-point sensors on the balloon and chilled-mirror dew point and frost point hygrometers on the Twin Otter aircraft on the three days the system was flown in September.

Instrument Platforms and FAA Aspects

The chilled-mirror and tethersonde® systems were flown on two platforms:

1. A 7.5 m³ helium balloon with an A/C powered winch with 2 km of line flown to a maximum altitude of 1 km (Fig. 1).
2. A large kite system provided by Ben Balsley from the University of Colorado with a winch which was integrated with a capstan on the rear wheel of an automobile (also flown to a maximum altitude of 1 km) [Fig. 2].

The kite platform was used with the chilled-mirror system on 21 and 22 Sept. 1996. The maximum wind on the 22nd exceeded maximum winds under which the balloon-borne system should operate ($\approx 10 \text{ m s}^{-1}$) so profiles could not have been obtained otherwise. The winds this day were close to exceeding the maximum winds recommended for the kite system brought to the SGP ($\approx 15 \text{ m s}^{-1}$).

These systems were operated both during the day and at night (usually 15:00 to 01:30 LDT). FAA regulations required banners every 50 m on the tethered-balloon system during the day and strobe lighting on the balloon at night.

Instrumentation

The chilled-mirror dew-point hygrometer was especially designed as a light-weight low power consumption system that is ideal for balloon-borne operation. The manufacturer's specifications of the system are described in Fig. 3. The chilled-mirror system was operated in tandem with the AIR tethersonde® system. The voltage outputs from the chilled-mirror system (chilled-mirror, air, and reference temperature thermistor voltages)

were transmitted on three spare channels of the tethersonde® transmitting electronics. The tethersonde® also transmits the relative humidity and air temperature from a wet-bulb/dry-bulb sensor as well as wind speed and direction, and pressure for altitude determination. The manufacturer's specifications for the tethersonde® system are shown in Fig. 4.

On two occasions, a balloon-borne nephelometer was flown. This instrument measures the integrated aerosol light scattering coefficient (from close to 0 degrees forward scatter to close to 180 degrees backscatter) for comparison with aerosol backscattering profile measurements from the Raman and Micropulse Lidar systems, and surface aerosol light scattering measurements made at the SGP Aerosol Facility. The light scattering signal was also sent on the spare channels of the tethersonde® system. The instrument was calibrated using the established light scattering coefficient of Freon-22 and filtered air.

Preliminary Instrument Comparison Results

Table 1 lists all the files taken during the experiment based on date and local daylight time when the file began. These files contain both profiles and surface comparisons. The files marked .XLS are EXCEL® processed files with plots. Files marked .RAW (raw data), EDT (edited files to remove extraneous headers), and .TST (test files) without corresponding .XLS files indicate files with problems or little utility. Figures 5 and 6 show examples of surface comparisons with a Vaisala™ temperature/relative humidity probe at the BBSS that participated in the initial intercomparison. The comparison on 13 Sept. (Fig. 5) was during a relatively warm dry period and the comparison is relatively close in mixing ratio. However, the comparison on 16 Sept. (Fig. 6) showed an offset with the Vaisala™ sensor value elevated by about 0.5 g kg^{-1} . This period followed a rain and it is possible that the Vaisala™ sensor was reading a little high. At times during wet periods the Vaisala™ sensor read over 100% relative humidity.

An example of temperature comparisons between a tethersonde® dry-bulb sensor and the Vaisala™ probe temperature are shown in Fig. 7. The tethersonde® temperatures were used (after correcting for the $\approx 0.5 \text{ }^{\circ}\text{C}$ offset in Fig. 7 by increasing the reported temperature from the tethersonde®) to derive relative humidities from the chilled-mirror sensor because of problems with the temperature sensor in the NCAR chilled-mirror sensor. It is important to remember that water vapor mixing ratio is directly determined from the dew-point temperature and pressure without the need to know the air temperature.

$$w = 621.97 * P_{\text{sat}}(T_d) / (P - P_{\text{sat}}(T_d))$$

where w is the mixing ratio in g kg^{-1} , $P_{\text{sat}}(T_d)$ is the saturation vapor pressure at the dew-point temperature (T_d), and P is the pressure in kPascals.

The purpose of flying the chilled-mirror sensors was to provide comparison profiles for the Vaisala™ rawinsondes, the humidity measurements on the 60 m tower, and remote sensing instruments like the Raman lidar, Microwave Radiometer, and the AERI. Figure 8 shows an example of a very preliminary (none of the final calibrations have been applied) comparison between mixing ratio profiles determined by the chilled-mirror balloon-borne, rawinsonde, and Raman lidar. Though each profile has a similar shape, the offsets (at least in these unprocessed data) are considerable.

The chilled-mirror dew-point sensors have the potential to be the standard for comparisons of water vapor mixing ratio between instruments. Dew point sensors are usually the standard instruments in humidity calibration. Post-experiment calibration under way now at the University of Wisconsin is critical. However, environmental differences shown in Fig. 9 through 12 will need to be explained. Figure 9 shows a comparison of mixing ratio determined from two chilled-mirror sensors (NCAR and Swiss1) flown with two separate tethersonde® systems (at 403.5 MHz and 404.7 MHz) on the same tethered balloon on the way up. Figure 10 shows the same comparison on the way down. Figures 11 and 12 show the same comparison for a later flight for NCAR and Swiss2 sensors. We need to understand why these sensor values appear to diverge with height.

Comparison of the measured air temperatures from the two tethersonde® sensors on the dual package flights described above (Figs 13 and 14) helps explain some of the differences. Figure 13 shows the air temperature from the two tethersonde® systems with height for the first comparison ascent. These temperatures also show a similar divergence with height. This implies that either a real environmental difference existed between the two sensors (separated by about 1 m) or an environmental or interference effect existed on the transmitting electronics. It is also possible that environmental response differences in the conditioning electronics may be causing a small effect because the overlap of temperatures close to the surface appears closer than the derived mixing ratio comparison,.

Dew point sensor comparisons were also made between the chilled-mirror sensor on the tethered balloon and the chilled-mirror dew-point sensor on the Twin Otter aircraft. Figures

15-16 show a preliminary (again final calibration factors have not been applied) comparison between the chilled-mirror dew-point temperatures on the tethered balloon (Tether), the SGP Vaisala™ rawinsonde profile (BBSS), and the chilled-mirror dew point from the Twin Otter (TO) on 20 and 21 Sept., respectively. The comparison between the two dew-point sensors is encouraging, especially when one considers the fact that the aircraft was not allowed closer than 4 km to the tethered balloon for safety reasons. The lower altitude dew points determined by the aircraft sensor were obtained from ascent from the airport over 40 km distant from the SGP ARM site.

Profile Results

Though the purpose for the tethered-balloon chilled-mirror dew-point profiles was comparison with other water vapor systems, many of the profiles are scientifically interesting in themselves. Figure 17 illustrates a nighttime humidity profile on 10 September. The relative humidity decreases up to the nocturnal inversion height of about 150 m (970 kPascals). This might be expected as this is the region with the highest temperature. Figure 18 compares the water vapor mixing ratio and wind profiles for the same profile in Fig. 17. This comparison shows that the nocturnal boundary layer jet is drier than air above and below. This is a little surprising as the mid-west synoptic nocturnal jet is usually thought of as a mechanism for transporting water vapor northward over Oklahoma (e.g. Arritt et al. 1996). It is tempting to speculate that the wind jet associated with the inversion frictional decoupling with the ground pulls dry air down from above. However, since the air is relatively more moist above as well as below, a three dimension effect seems likely. Advection of relatively dry air from the southwest seems possible, but at least at the SGP site for 11 and 24 Sept. the jet was almost directly from the south (Figs. 19 and 20, respectively). Both these profiles also show a decrease in water vapor at the jet. Figure 21 shows a wind feature from the west with little or no change in water vapor mixing ratio.

Another profile comparison of interest comes from the nephelometer carried on the balloon on 22 and 24 Sept. The night of 22 Sept. was very hazy compared to most of the nights during the experiment as judged by the Moon's halo. The night of 24 Sept. was also relatively hazy but less than on 22 Sept. The prominent multiple-value feature on the profile on 22 Sept. (Fig. 22) is the result of the high turbulence and rough ride of the nephelometer on the kite and probably the result of impact of the nephelometer with the kite tether line

and shaking loose of surface-deposited aerosol on internal surfaces of the nephelometer. The profile on 24 Sept. agrees very well in shape with Raman lidar backscattering signals.

Recommendations

The tethered balloon-borne chilled-mirror dew-point combination has the potential for improving the accuracy of water vapor comparisons. Some of the improvements to consider in future water vapor IOPs include the following:

1. Improved mechanisms for calibration comparisons, hopefully on site at the SGP minimizing possible aging and transportation related sensitivity changes.
2. Improved conditioning electronics for the chilled-mirror outputs to match tethersonde® requirements.
3. Improved real-time analysis software needs to be developed so that the spare channel data are plotted along with the tethersonde® channels (this would improve response to low power, connection and interference problems).
4. More dual package profiles need to be taken to better understand the origin and statistics of differences between chilled-mirror sensors.
5. More work needs to be done to separate signal and noise on the chilled-mirror sensors, especially the reference temperature signal.
6. The nighttime lighting of the tethersonde® needs to be improved (especially for aircraft coordinated experiments). Perhaps a search light could be used to illuminate the balloon and at least qualitatively show light scattering profile differences from night to night.

The above list of recommended improvements should not detract from the positive success of the tethered-balloon chilled-mirror dew-point hygrometer part of the 1996 WVIOP.

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WVIOP910

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09101323.EDT	13K	Microsoft Word do...	—	Sun, Sep 15, 1996, 7:34 PM
09101543	13K	document	—	Tue, Sep 10, 1996, 4:10 PM
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09101654.XLS	182K	Microsoft Excel do...	—	Fri, Sep 27, 1996, 7:53 PM
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WVIOP911

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Table 1 Data files taken during the 1996 WVIOP named by month (09) day and Local Daylight Time the file began.

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WVIOP913

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WVIOP915

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WVIOP917

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WVIOP921

Name	Size	Kind	Label	Last Modified
09210927	39K	document	—	Sat, Sep 21, 1996, 10:59 AM
09210927.EDT	52K	Microsoft Word do...	—	Sat, Sep 28, 1996, 6:30 PM
09211029	39K	document	—	Sat, Sep 21, 1996, 12:01 PM
09211029.EDT	52K	Microsoft Word do...	—	Sat, Sep 21, 1996, 2:43 PM
09211232	26K	document	—	Sat, Sep 21, 1996, 1:43 PM
09211232.XLS	351K	Microsoft Excel do...	—	Sat, Sep 28, 1996, 12:50 AM
09211558	26K	document	—	Sat, Sep 21, 1996, 5:53 PM
09211558.XLS	260K	Microsoft Excel do...	—	Sat, Sep 28, 1996, 1:02 AM
09211652	13K	document	—	Sat, Sep 21, 1996, 5:03 PM
09211652.RAW	13K	document	—	Sat, Sep 21, 1996, 5:03 PM
09211726	13K	document	—	Sat, Sep 21, 1996, 5:44 PM
09211726.RAW	13K	document	—	Sat, Sep 21, 1996, 5:42 PM
09211744	26K	document	—	Sat, Sep 21, 1996, 6:53 PM
09211744.RAW	39K	document	—	Sat, Sep 21, 1996, 6:47 PM
09211823	26K	document	—	Sat, Sep 21, 1996, 7:52 PM
09211823.XLS	338K	Microsoft Excel do...	—	Sat, Sep 28, 1996, 1:21 AM
09211959	26K	document	—	Sat, Sep 21, 1996, 9:06 PM
09211959.XLS	260K	Microsoft Excel do...	—	Fri, Oct 4, 1996, 11:54 AM
09212106	26K	document	—	Sat, Sep 21, 1996, 9:48 PM
09212106.XLS	234K	Microsoft Excel do...	—	Sat, Sep 28, 1996, 1:46 AM

WVIOP922

Name	Size	Kind	Label	Last Modified
09221828	13K	document	—	Sun, Sep 22, 1996, 6:46 PM
09221828.RAW	13K	document	—	Sun, Sep 22, 1996, 6:29 PM
09221846	26K	document	—	Sun, Sep 22, 1996, 7:50 PM
09221846.XLS	221K	Microsoft Excel do...	—	Fri, Oct 4, 1996, 12:02 PM
09222001	13K	document	—	Sun, Sep 22, 1996, 8:24 PM
09222001.NEF	13K	Microsoft Word do...	—	Sun, Sep 22, 1996, 8:50 PM
09222001.XLS	52K	Microsoft Excel do...	—	Sat, Sep 28, 1996, 6:54 PM

WVIOP923

Name	Size	Kind	Label	Last Modified
09231106	13K	document	—	Mon, Sep 23, 1996, 11:11 AM
09231106.RAW	13K	document	—	Mon, Sep 23, 1996, 11:09 AM
09231137	13K	document	—	Mon, Sep 23, 1996, 1:15 PM
09231137.RAW	26K	document	—	Mon, Sep 23, 1996, 12:07 PM
09231439	26K	document	—	Mon, Sep 23, 1996, 3:28 PM
09231439.XLS	156K	Microsoft Excel do...	—	Tue, Oct 15, 1996, 5:43 PM
09231528	13K	document	—	Mon, Sep 23, 1996, 4:02 PM
09231528.XLS	117K	Microsoft Excel do...	—	Tue, Oct 15, 1996, 5:46 PM
09231606	13K	document	—	Mon, Sep 23, 1996, 4:30 PM
09231606.XLS	117K	Microsoft Excel do...	—	Tue, Oct 15, 1996, 5:49 PM
PROFIL23b.XLS	182K	Microsoft Excel do...	—	Tue, Oct 15, 1996, 5:39 PM

WVIOP924

Name	Size	Kind	Label	Last Modified
09241318	26K	document	—	Tue, Sep 24, 1996, 2:31 PM
09241318.XLS	273K	Microsoft Excel do...	—	Sat, Sep 28, 1996, 7:04 PM
09241431	39K	document	—	Tue, Sep 24, 1996, 4:03 PM
09241431.XLS	312K	Microsoft Excel do...	—	Thu, Oct 17, 1996, 11:10 AM
09241533	39K	document	—	Tue, Sep 24, 1996, 5:04 PM
09241533.EDT	39K	Microsoft Word do...	—	Tue, Sep 24, 1996, 8:43 PM
09241533.XLS	351K	Microsoft Excel do...	—	Wed, Oct 16, 1996, 2:50 PM
09241603	26K	document	—	Tue, Sep 24, 1996, 4:59 PM
09241603.XLS	247K	Microsoft Excel do...	—	Thu, Oct 17, 1996, 11:17 AM
09241704	26K	document	—	Tue, Sep 24, 1996, 6:01 PM
09241704.XLS	247K	Microsoft Excel do...	—	Wed, Oct 16, 1996, 3:39 PM
09241722	26K	document	—	Tue, Sep 24, 1996, 7:24 PM
09241722.XLS	273K	Microsoft Excel do...	—	Fri, Sep 27, 1996, 12:28 PM
09241824	26K	document	—	Tue, Sep 24, 1996, 7:47 PM
09241824.XLS	273K	Microsoft Excel do...	—	Fri, Sep 27, 1996, 12:23 PM
09241947	26K	document	—	Tue, Sep 24, 1996, 8:24 PM
09241947.NEF	26K	Microsoft Word do...	—	Tue, Sep 24, 1996, 8:51 PM
09241947.XLS	65K	Microsoft Excel do...	—	Thu, Sep 26, 1996, 4:04 PM
09242120	13K	document	—	Tue, Sep 24, 1996, 9:53 PM
09242120.XLS	156K	Microsoft Excel do...	—	Fri, Sep 27, 1996, 12:50 PM

WVIOP927

Name	Size	Kind	Label	Last Modified
09271356	13K	document	—	Fri, Sep 27, 1996, 2:41 PM
09271356.XLS	143K	Microsoft Excel do...	—	Sat, Sep 28, 1996, 11:42 AM
09271442	26K	document	—	Fri, Sep 27, 1996, 3:45 PM
09271442.XLS	299K	Microsoft Excel do...	—	Sat, Sep 28, 1996, 11:59 AM
09271545	26K	document	—	Fri, Sep 27, 1996, 5:10 PM
09271545.XLS	312K	Microsoft Excel do...	—	Sat, Sep 28, 1996, 12:16 PM
09271710	39K	document	—	Fri, Sep 27, 1996, 6:32 PM
09271710.XLS	312K	Microsoft Excel do...	—	Sat, Sep 28, 1996, 12:28 PM
09271832	13K	document	—	Fri, Sep 27, 1996, 7:01 PM
09271832.XLS	156K	Microsoft Excel do...	—	Sat, Sep 28, 1996, 12:39 PM
09271906	26K	document	—	Fri, Sep 27, 1996, 7:49 PM
09271906.XLS	234K	Microsoft Excel do...	—	Sat, Sep 28, 1996, 1:01 PM
09272008	39K	document	—	Fri, Sep 27, 1996, 9:33 PM
09272008.XLS	312K	Microsoft Excel do...	—	Sat, Sep 28, 1996, 1:14 PM

WVIOP928

Name	Size	Kind	Label	Last Modified
09281221	39K	document	—	Sat, Sep 28, 1996, 1:44 PM
09281221.XLS	312K	Microsoft Excel do...	—	Sun, Sep 29, 1996, 8:07 AM
09281344	26K	document	—	Sat, Sep 28, 1996, 2:54 PM
09281344.XLS	325K	Microsoft Excel do...	—	Sun, Sep 29, 1996, 8:09 AM
09281454	39K	document	—	Sat, Sep 28, 1996, 4:18 PM
09281454b.XLS	390K	Microsoft Excel do...	—	Sun, Sep 29, 1996, 8:32 AM
09281618	26K	document	—	Sat, Sep 28, 1996, 5:21 PM
09281618b.XLS	273K	Microsoft Excel do...	—	Sun, Sep 29, 1996, 8:25 AM
09281721	26K	document	—	Sat, Sep 28, 1996, 6:23 PM
09281721b.XLS	260K	Microsoft Excel do...	—	Sun, Sep 29, 1996, 8:38 AM
09281823	26K	document	—	Sat, Sep 28, 1996, 7:20 PM
09281823b.XLS	286K	Microsoft Excel do...	—	Sun, Sep 29, 1996, 8:44 AM
09281920	26K	document	—	Sat, Sep 28, 1996, 8:26 PM
09281920.XLS	260K	Microsoft Excel do...	—	Sun, Sep 29, 1996, 11:33 AM
09282026	26K	document	—	Sat, Sep 28, 1996, 9:16 PM
09282026.XLS	234K	Microsoft Excel do...	—	Sun, Sep 29, 1996, 11:40 AM

Name	Size	Kind	Label	Last Modified
09291332	26K	document	—	Sun, Sep 29, 1996, 2:08 PM
09291332.XLS	208K	Microsoft Excel do...	—	Sun, Sep 29, 1996, 10:59 PM
09291409	26K	document	—	Sun, Sep 29, 1996, 3:00 PM
09291409.XLS	260K	Microsoft Excel do...	—	Sun, Sep 29, 1996, 11:09 PM
09291502	13K	document	—	Sun, Sep 29, 1996, 3:14 PM
09291502.EDT	13K	Microsoft Word do...	—	Sun, Sep 29, 1996, 10:15 PM
09291519	26K	document	—	Sun, Sep 29, 1996, 4:08 PM
09291519.XLS	247K	Microsoft Excel do...	—	Sun, Sep 29, 1996, 11:20 PM
09291612	26K	document	—	Sun, Sep 29, 1996, 4:48 PM
09291612.XLS	195K	Microsoft Excel do...	—	Sun, Sep 29, 1996, 11:30 PM
09291648	13K	document	—	Sun, Sep 29, 1996, 5:21 PM
09291648.XLS	195K	Microsoft Excel do...	—	Sun, Sep 29, 1996, 11:39 PM
09291722	13K	document	—	Sun, Sep 29, 1996, 5:33 PM
09291722.XLS	78K	Microsoft Excel do...	—	Sun, Sep 29, 1996, 11:49 PM

Figure Captions

Fig. 1. A 7.5 m³ helium balloon with a chilled-mirror dew-point hygrometer during the 1996 WVIOP.

Fig. 2. A large kite system provided by Ben Balsley from the University of Colorado.

Fig. 3. The manufacturer's specifications of the Meteor AGTM chilled-mirror dew-point hygrometer system.

Fig. 4. The manufacturer's specifications for the tethersonde® system.

Fig. 5. A comparison on 13 Sept. of water vapor mixing ratios from the chilled-mirror hygrometer and VaisalaTM temperature/relative humidity probe at the BBSS that participated in the initial intercomparison.

Fig. 6. A comparison on 16 Sept. of water vapor mixing ratios from the chilled-mirror hygrometer and VaisalaTM temperature/relative humidity probe at the BBSS that participated in the initial intercomparison showing an offset with the VaisalaTM sensor value elevated by about 0.5 g kg⁻¹.

Fig. 7. A comparison of temperature between a tethersonde® dry-bulb sensor (TairTS), the air temperature from the NCAR chilled-mirror sensor (Tair), the chilled mirror reference temperature (Tref), and the VaisalaTM probe temperature.

Fig. 8. An example of a preliminary (none of the final calibrations have been applied) comparison between mixing ratio profiles determined by the chilled-mirror balloon-borne (tether), rawinsonde (Vaisala), and the scanning Raman lidar on 25 Sept.

Fig. 9. A comparison of mixing ratio on 24 Sept. determined from two chilled-mirror sensors (NCAR CM and Swiss1) flown with two separate tethersonde® systems (at 403.5 MHz and 404.7 MHz) on the same tethered balloon on the way up.

Fig. 10. The same comparison as Fig. 9 on the way down.

Fig. 11. The same comparison as Fig. 9 for a later flight for NCAR CM and Swiss2 sensors on the way up.

Fig. 12. The same comparison as Fig. 9 for a later flight for NCAR CM and Swiss2 sensors on the way down.

Fig. 13. The air temperature from the two tethersonde® systems (Tdry and Tdry2) with height for the first comparison ascent (Fig. 9).

Fig. 14. The air temperature from the two tethersonde® systems (Tdry and Tdry2) with height for the second comparison ascent (Fig. 11).

Fig. 15. A preliminary (final calibration factors have not been applied) comparison between the chilled-mirror dew-point temperatures on the tethered balloon (Tether), the SGP VaisalaTM rawinsonde profile (BBSS), and the chilled-mirror dewpoint from the Twin Otter (TO) on 20 September.

Fig. 16. Same as Fig. 15 on 21 September.

Fig. 17 A nighttime relative humidity profiles from the chilled-mirror (CM) and tethersonde® wet-bulb/dry-bulb (WD) on 10 Sept. when a wind jet was observed above the nocturnal inversion.

Fig. 18. The water vapor mixing ratio (NCAR CM) comparison and wind profiles (wind speed WSpeed and south wind component WSpeed S Comp) for the same profile in Fig. 17.

Fig. 19. An analogous profile to that shown in Fig. 18 for the next night 11 Sept.

Fig. 20. An analogous profile to that shown in Fig. 18 for the night of 24 Sept.

Fig. 21. An analogous profile to that shown in Fig. 18 for the night of 27 Sept.

Fig. 22. Kite-borne nephelometer light scattering profile on 22 Sept. (Bscat 9/22) and balloon-borne profile on 24 Sept. (Bscat 9/24).

Fig. 1

Fig 2

TP3-ST

Fig. 4. The manufacturer's specifications for the tethersonde® system.

High stability, narrow band transmission. The TetherSonde telemeters its data to the AIR Atmospheric Data Acquisition System (ADAS), an automatic, digital output ground station. A crystal controlled FM transmitter produces high stability, narrow band transmissions which allow communication at distances up to 20 km with only 10 mw of power.

Crystal control eliminates RF tuning problems and insures reliable noise-free data. It also permits a number of TetherSondes to operate in close proximity without interference.

GENERAL DESCRIPTION

Construction:	Body molded of expanded polystyrene. A single printed circuit card contains all electronics.
Power:	Sealed 9V alkaline transistor radio battery
Operating time:	6-8 hours
Size:	Fits into 30cm x 30cm x 10cm volume
Weight:	225 grams (8 oz.)

ORDERING INFORMATION

Specify transmission frequency if other than 403.5 Mhz.	
Model TS-3A-SP	Dry bulb and wet bulb humidity measurement
Model TS-3A-SPH	Dry bulb and carbon hygistor humidity measurement

TETHERSONDE SPECIFICATIONS MODEL TS-3A-SP and TS-3A-SPH

The following are performance specifications when used with an AIR ground station in a field environment including all sources of error for digital, non-baselined data.

SENSORS

Temperature (Wet and Dry Bulb)

Range:	+50°C to -70°C
Precision:	0.5°C for +40°C to -40°C 1.0°C for +50°C to -70°C
Thermistor Match:	0.1°C for +35°C to -20°C
Resolution:	0.01°C
RMS Noise Equivalent:	0.04°C
Response Time:	Dry bulb: 3 sec., Wet bulb: 12 sec.

Humidity (TS-3A-SP, from psychrometric equation)

Range:	3% to 100%
Precision:	3% for 0°C to 50°C 5% for -10°C to 0°C 10% for -25°C to -10°C
Resolution:	0.1% RH

Humidity (TS-3A-SPH, using carbon hygistor)

Range:	20% to 100% RH
Precision:	5% RH, +40°C to -40°C
Resolution:	0.1% RH

Pressure (Absolute Barometric)

Range:	1050 to 600 mb
Accuracy:	5 mb
Precision:	1 mb
Resolution:	0.1 mb
Temperature Compensation:	Computed by AIR ground station

Wind Speed

Range:	0-20 m/s
Precision:	0.25 m/s
Resolution:	0.1 m/s

Wind Direction

Range:	2-358 (4 deadband)
Precision:	5
Resolution:	1

Spare Inputs (4 each)

Range:	0 - 100%
Precision:	1%
Resolution:	0.1%

TRANSMITTER

Carrier Frequency:	403.5 Mhz (std), 400-410 Mhz (optional)
Modulation:	FM, narrow band
Audio Modulation:	1.5 KHz to 3.5 KHz
Transmitter Type:	Crystal VCXO with 9x multiplication
Stability:	0.02% (+50°C to -70°C)
Deviation:	±5 KHz

Tuning:	± 20 KHz
Sidebands:	35 dB down
Transmitter Power:	10 milliwatts
Telemetry Range (nominal):	20 km
Antenna:	¼ wave vertical monopole
RF Polarization:	linear, vertical

ATMOSPHERIC INSTRUMENTATION RESEARCH,

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Albuquerque, NM 87123
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FAX: (505) 275-9978

Mixing Ratio Comparison Tsonde #1907 9/13/96 Before Rain

Fig. 5

Mixing Ratio Comparison Tsonde #1214 9/16/96 After Rain

Fig. 6

Comparison of Vaisala Temperature Tsonde #1907 9/13/96

Fig. 7

water vapor comparison
wv0925j1.101 profile 4
Sept. 25, 1996

Fig. 8

Mixing Ratio Profile
9/24/96 17:04 LDT

Fig. 9

Fig. 10

Mixing Ratio Profile
9/24/96 15:33 LDT

Fig. 11

Fig. 12

Tethersonde, 9/24/96, 15:33 LDT, ARM WVIOP Tsonde #1214 and sensor Swiss2

Fig.13

Tethersonde, 9/24/96, 17:04 LDT, ARM WVIOP Tsonde #1214 and Swiss1

Fig. 14

Tethersonde Chilled Mirror with Twin Otter Overpass
9/20/96, 19.2-20.5 UTC ARM WVIOP

Fig. 15

Tethersonde Chilled Mirror with Twin Otter Overpass
9/21/96, 18.1-18.6 UTC Down, ARM WVIOP

Fig. 16

Tethersonde, 9/10/96, 21:25 LDT, ARM WVIOP Tsonde #1907 and NCAR DP Sensor

Fig. 17

Mixing Ratio 9/10/96, 21:25 LDT, ARM WVIOP

Mixing Ratio or Wind Speed

Fig. 18

Profiles 09/11/96 23:45 LDT

Mixing Ratio or Wind Speed

Fig. 19

Profiles 9/24/96 21:20 LDT

Mixing Ratio or Wind Speed m/s

Fig. 20

Fig. 21

Fig. 22