Boundary-Layer Structure Obtained with a Tethered Balloon System and Large-Scale Observations of the Arctic Basin Obtained with a Satellite Data Acquisition System at the SHEBA Ice Camp

R. Storvold, H. A. Eide, P. Utley, K. Stamnes, and G. Adalsgeirsdottir
University of Alaska Fairbanks
Fairbanks, Alaska

D. Lubin
Scripps Institution of Oceanography
University of California, San Diego
LaJolla, California

B. D. Zak
Sandia National Laboratories
Albuquerque, New Mexico

P. Lawson
SPEC, Inc.
Stratton Park Engineering Company, Inc.
Boulder, Colorado

T. Svendby
University of Oslo
Oslo, Norway

R. Moritz
University of Washington
Seattle, Washington

J. A. Moore
National Center for Atmospheric Research
Boulder, Colorado

Abstract

Temperature, wind, and water vapor profiles through the atmospheric boundary layer are important for the study of the energy balance in the Arctic. Tethered balloon systems (TBSs) have several advantages to the normal weather balloons and ground-based remote sensing instruments. In the Arctic winter, we have periods of very strong inversions and high atmospheric stability. This leads to an extreme stratification and large vertical gradients. Because of the low temperatures in the Arctic and the long response time of normal weather balloon sondes, they do a poor job under such conditions due to the rapid ascent. The tethered balloon allows us to adjust the ascent speed to the conditions and it also gives higher vertical resolution than the remote sensing systems and the weather balloon sondes can give. The sensors are easy to calibrate and are of higher quality than the weather balloon sondes, which have to be disposable. We also gather time series at different altitudes using multiple sensors to study the change in the boundary layer during changing cloud conditions, and during the formation and break-up of the surface inversion layer in connection with sunset and sunrise or changes in cloud conditions.

Introduction

A tethered tower system has been deployed on Surface HEat Budget of the Arctic Ocean (SHEBA) since December 4, 1997. This system allows us to take high-resolution profiles of temperature, humidity, wind speed, and wind direction through the atmospheric boundary layer. We also archive advanced very high-resolution radiometer (AVHRR) satellite data at the ice camp obtained from a TeraScan system operated onboard the SHEBA ship. The data contain very useful information concerning cloud and ice cover of the entire Arctic basin. These data will be used to 1) test existing algorithms for remote sensing of surface and cloud properties, 2) develop improved algorithms to characterize cloud and surface properties, and 3) estimate atmosphere-surface radiative energy budgets. This data set allows us to estimate cloud and surface properties as well as radiative energy budgets for the entire Arctic Basin.

The data collection is done by the Atmospheric Radiation Measurement (ARM)/SHEBA data Quality Assurance personnel at the SHEBA ice camp, and the work presented here focuses on the tethered balloon and remote sensing operations. We will present typical samples of data that we have obtained from these systems so far.

System Description

The TBS is an "off-the-shelf system" available from Atmospheric Instrumentation Research, Inc. (A.I.R.) consisting of a radio receiver, a laptop PC, an electric winch with a 2-km line, 5 m^3 helium balloons, and 6 sensor packages each consisting of a barometer, anemometer, electronic compass, humidity probe (capacitance polymer), and a radio transmitter.

The satellite receiving station from SeaSpace, Inc. consists of a Sun SPARC 5 workstation with TeraScan software, a TeraScan High-Resolution Picture Transmission (HRPT) receiving station and antenna, a Global Positioning System (GPS), and a gyro interface to the ship's gyro.

Operations

Profiles of temperature, humidity, and wind can be obtained from ground-based as well as satellite-based remote sensing instruments and in situ measurements. The greatest advantage of the TBS system is that it is inexpensive (U.S. $30 thousand) to acquire and easy to operate. It provides high-accuracy, high-resolution data that remote sensing instruments at the current time are incapable of providing. The sensors are easy to calibrate and no post-processing of the data is required. The ascent speed can be adjusted to provide good in situ measurements of humidity during cold conditions. This is important because in situ humidity sensors with a long response time would be unable to measure the steep vertical gradients in humidity that exist in the Arctic if the ascent takes place too rapidly.

The TBS system has certain operational limitations that make it a good supplement to remote sensing instruments, although it does not replace the need for this kind of instrumentation. The most important limitation is a vertical operational range of about 1 km. The system can only be launched in low to moderate wind conditions with up to 5 m/s surface wind and 15 m/s to 20 m/s upper air wind. Due to material limitations, it should only be operated at temperatures above -40° C. Battery lifetime is 1 hour to 6 hours depending on air temperature and external heat applied. Vertical resolution or time resolution has to be sacrificed when time series of vertical profiles are gathered, either by measuring at fixed heights or by scanning vertically up and down continuously. The system can operate unattended while at constant altitude.

Measurements

We have picked 3 days of very different sky conditions during the Arctic night to study the effects of clouds on the boundary-layer structure in the Arctic. We also show time series during formation of an inversion layer during sunset in mid-March (Figures 1-9).

Case 1. December 13, Arctic Stratus Clouds

A low layer of liquid arctic stratus clouds is located between 1 km and 2 km (see Figure 2). The temperature profile under the cloud up to 500 m is close to adiabatic. At about 500 m, there is a strong wind shear and a temperature inversion (see Figures 1 and 2). Arctic stratus clouds show up dark on the satellite image because they are warmer than the ice surface at this time of the year (see Figure 7).

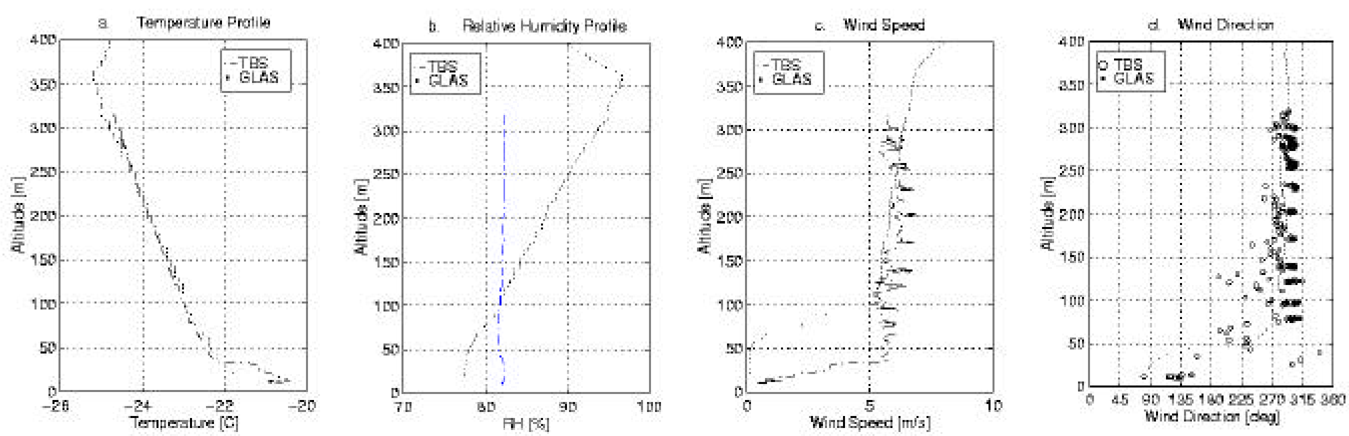

Figure 1. Case 1: December 13, arctic stratus clouds; tethered balloon (TBS) and weather balloon [GPS Lorang Atmospheric Soundings (GLAS)]. (For a color version of this figure, please see *http://www.arm.gov/docs/documents/technical/conf_9803/storvold-98.pdf*.)

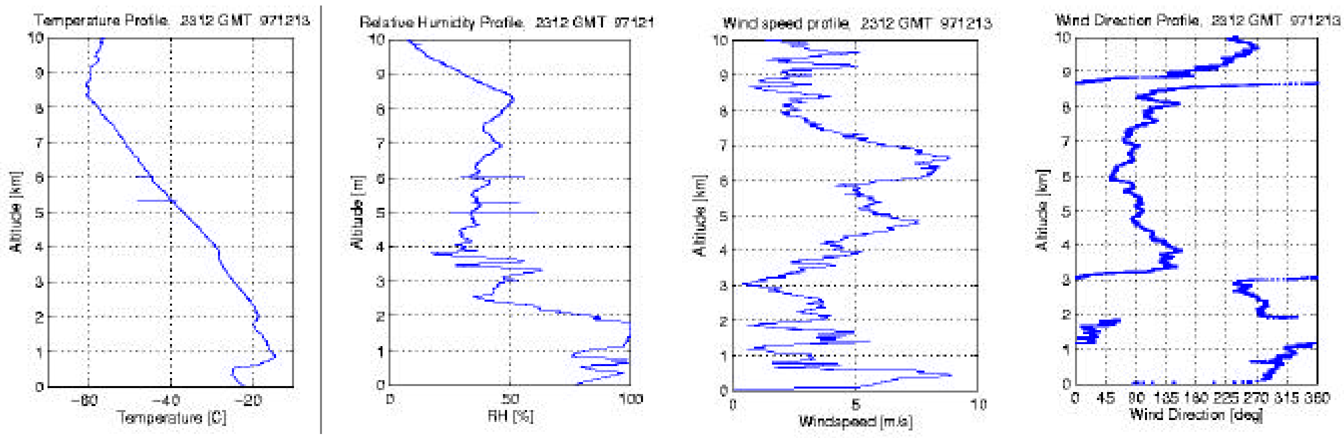

Figure 2. Case 1: December 13, arctic stratus clouds. Weather balloon (GLAS) up to 10 km. (For a color version of this figure, please see *http://www.arm.gov/docs/documents/technical/conf_9803/storvold-98.pdf*.)

Case 2. December 15, Cirrus Clouds

A layer of cirrus ice clouds is located between 3 km and 5 km aloft (see Figures 3 and 4). These clouds are optically very thin (low Lidar backscatter ratio). There is a strong inversion from the surface up to 1 km and a moderate inversion up to 3 km with very stable atmosphere, which admits large vertical gradients in humidity. The temperature profile does not differ much from the clear-sky case (case 3). But the clouds can be located using relative humidity (RH) measurements or cloud lidar measurements. In the thermal AVHRR channel 5 (4.5 µm), the clouds appear bright white because these clouds usually are colder than the surface ice (see Figure 7). Cirrus clouds are often very thin and can be difficult to see in the AVHRR image but can then more easily be detected with a cloud radar or a cloud lidar.

Case 3. December 25, Clear Sky

In this case, we have a strong surface inversion (see Figures 5 and 6) and a stable air column, which leads to strong stratification and large vertical gradients in RH. Because AVHRR has a resolution of 1.1 km, only larger leads are visible in the images (see Figure 7).

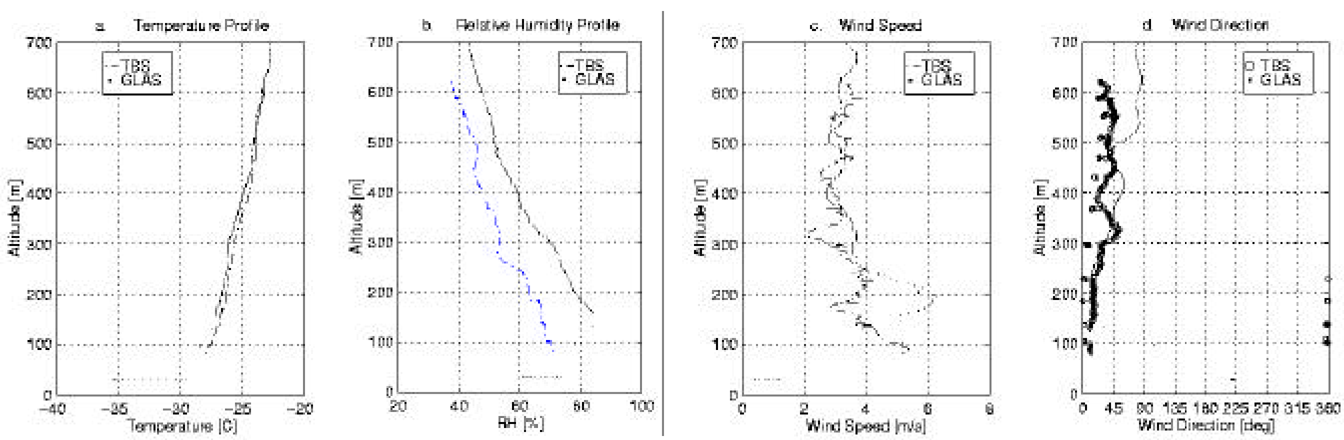

Figure 3. Case 2: December 15, cirrus clouds; weather balloon (GLAS) up to 10 km.

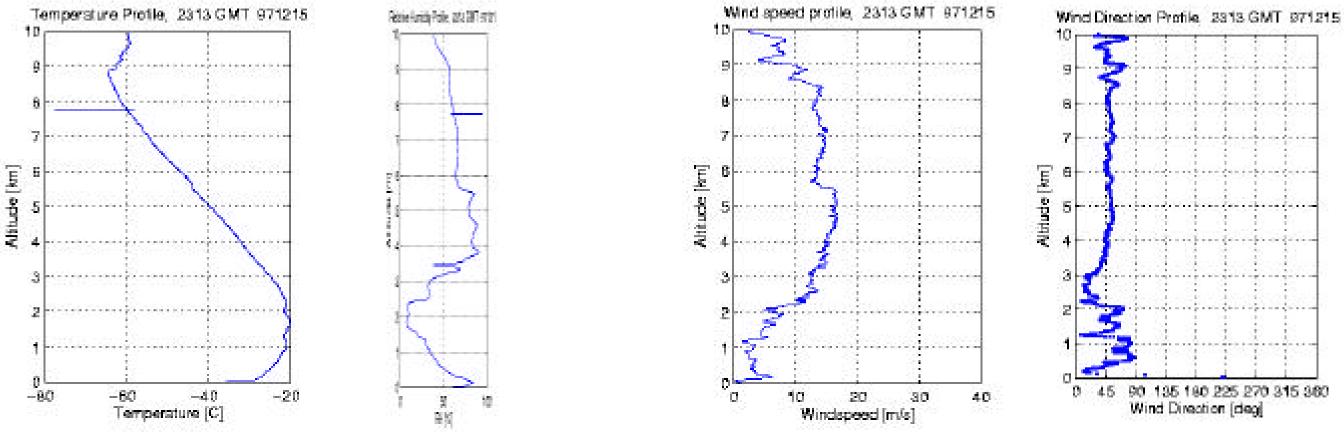

Figure 4. Case 2: December 15, cirrus clouds; tethered balloon (TBS) and weather balloon (GLAS). (For a color version of this figure, please see *http://www.arm.gov/docs/documents/technical/conf_9803/storvold-98.pdf*.)

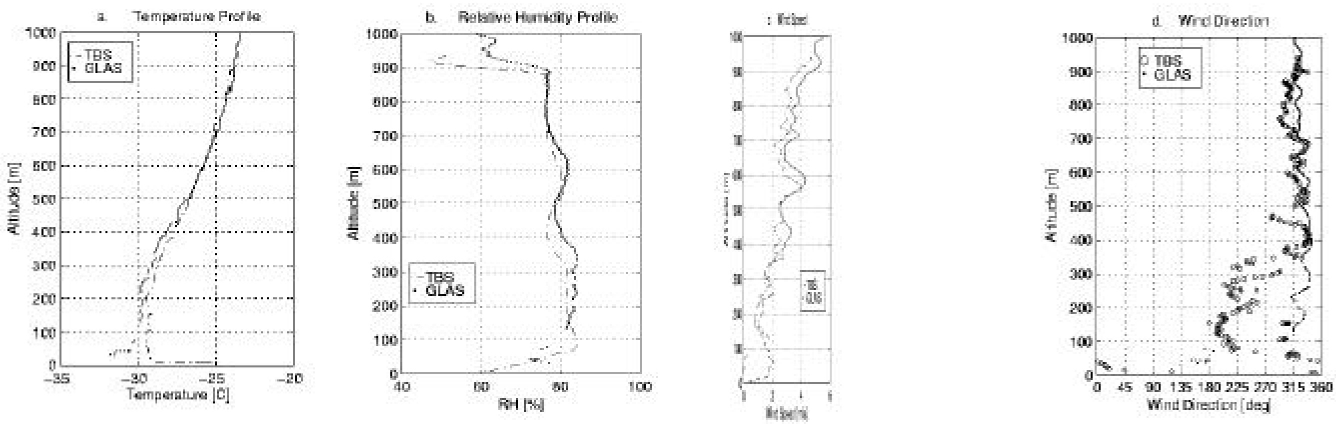

Figure 5. Case 3: December 25, clear sky; tethered balloon (TBS) and weather balloon (GLAS).

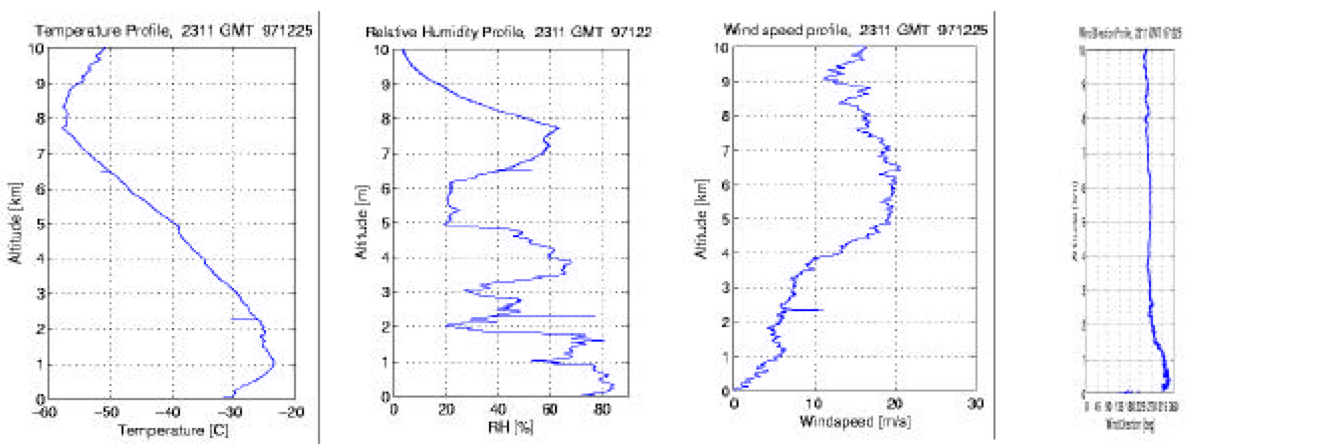

Figure 6. Case 3: December 25, clear sky; weather balloon (GLAS) up to 10 km. (For a color version of this figure, please see *http://www.arm.gov/docs/documents/technical/conf_9803/storvold-98.pdf*.)

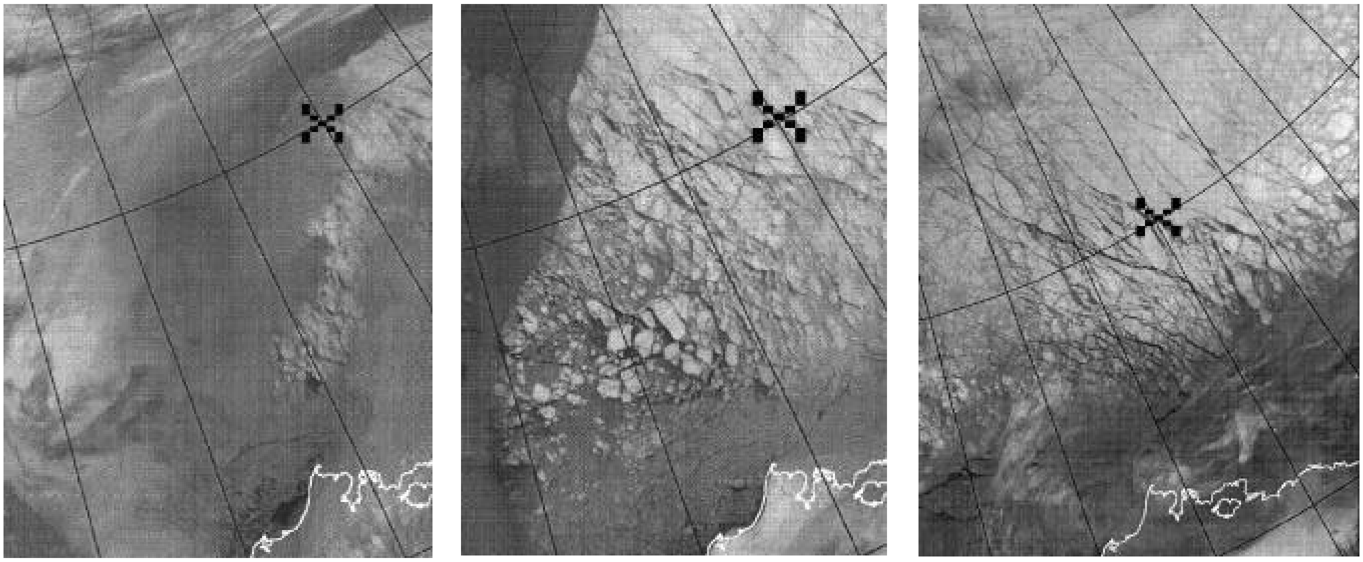

Figure 7. AVHRR Channel 5 (4.5 µm) for December 13, 15, and 25. SHEBA's approximate position (150W, 75N) is marked with an "x." On December 13, we had a low stratus cloud (dark bands); on December 15, we had thin cirrus clouds (white streaks); and on December 25, we had a clear sky.

Case 4. March 23, Time Series of Boundary Layer Profile During Sunset

During a 2-hour flight, we got two high-resolution profiles from the ground to 300 m (see Figure 8) and a time series with sensors at 40 m (TBS 6), 100 m (TBS 5), 150 m (TBS 4), 200 m (TBS 3), and 300 m (TBS 1) altitude (Figure 9). From the high-resolution profile, we can observe the onset of the formation of a ground inversion layer as the sun sets. From the time series, we can observe a thin layer of strong temperature and RH gradient between 200 m and 300 m, which is "sinking" with time with a warmer air mass above as part of a larger inversion layer that extends up to 1 km as seen in the weather balloon soundings (right panels Figure 9). Boundary-layer wave activity is clearly seen from TBS 3 (200 m) (Figure 9) as it is located at the boundary of the surface inversion with a period of 12 minutes to 15 minutes.

Conclusions

The Tethered Tower System has unique features that makes it a valuable supplement to other remote sensing instruments and in situ instruments designed to investigate the atmospheric boundary layer. It allows us in a simple manner to collect high-resolution, high-accuracy wind, temperature, and humidity data through the boundary layer. These data are valuable as input to single-column models as well as by providing a baseline for remote sensing instruments. Low cost and high mobility make this system ideal for campaign-based operations.

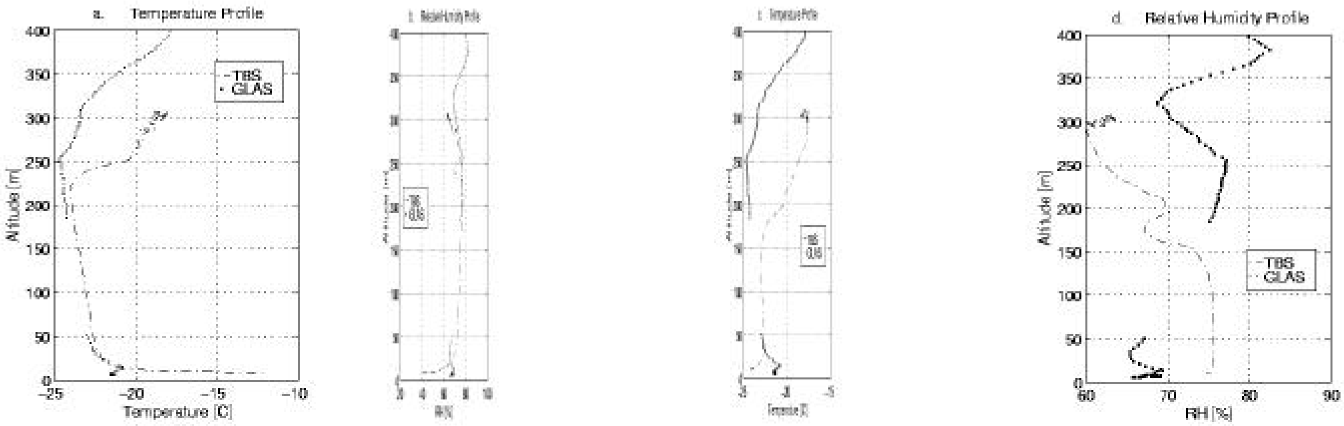

Figure 8. Case 4: March 23, high-resolution boundary layer profile before and after sunset.

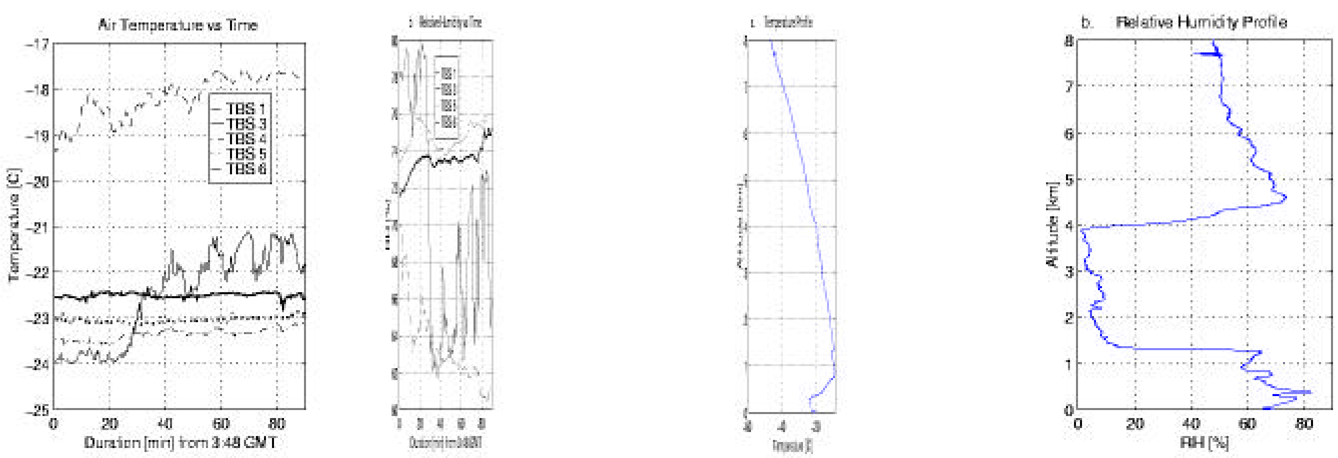

Figure 9. Case 4: March 23. Left panels: Time series of boundary layer profile during sunset, taken with a tethered tower. Right panels: Weather balloon sounding at 00 GMT (about 4 hours prior to sunset). (For a color version of this figure, please see *http://www.arm.gov/docs/documents/technical/conf_9803/storvold-98.pdf*.)