Balloon borne soundings for the validation of upper tropospheric humidity and temperature

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1. Objectives

There is a great deal of interest in measurements of upper tropospheric humidity. This interest is generated by the important role water vapor plays in the radiation budget of the atmosphere as well as its role in atmospheric chemistry, in particular heterogeneous chemistry. There is a great need for global measurements of upper tropospheric water vapor, both from remote sensing platforms as well as from in situ platforms, due to the large variability of water vapor over short spatial scales.

The AIRS instrument onboard the Aqua satellite is currently the most advanced infrared spectrometer instrument for upper tropospheric humidity and temperature. The objective of this project is to provide in situ validation measurements of relative humidity and temperature for AIRS using the NOAA/CMDL frost-point hygrometer at various locations and climatic conditions.

A minor objective is to test and validate the new Snow White frost-point hygrometer, which is commercially produced by Meteolabor in Switzerland. This instrument is flown with most NOAA/CMDL hygrometers and is used in a number of ARS validation efforts.

Ozone is an important tracer for upper tropospheric and lower stratospheric dynamics and is of great interest in the studies of processes affecting water vapor in the upper troposphere, lower stratosphere. Simultaneous ozone profiles are provided as part of the validation measurements.

2. Accomplishments

Most dedicated humidity soundings carry three humidity sensors, namely the NOAA/CMDL frost-point hygrometer, the Snow White hygrometer and the Vaisala RS80-H humicap sensor. These soundings also carry ECC ozone sondes. The NOAA/CMDL frost-point is considered a reference instrument for the middle and upper troposphere and used to validate the other two. In addition, the Snow White and Vaisala sensors provide relative humidity (RH) measurements in the lower troposphere, thus creating a continuous profile between the surface and the middle stratosphere around 25 km.

An overview of the soundings obtained up to present is given in table 1.

Location	Instruments	# soundings
San Cristóbal, Galapagos	FP/O3/SW/PTU	2
San Cristóbal, Galapagos	PTU	29
San Cristóbal, Galapagos*	O3/PTU	4
Hilo, HI	FP/O3/SW/PTU	7
Huntsville, AL**	FP/O3/SW/PTU	2
Boulder, CO	FP/O3/SW/PTU	1
Sodankylä, Finland***	FP/O3/SW/PTU	2

Table 1. Dedicated AIRS validation soundings up to present. The instruments used are: FP = NOAA/CMDL frost-point hygrometer, O3 = ECC ozone sonde, SW = Snow White sonde, PTU = Vaisala RS80-H radiosonde.
*) The ozone soundings at San Cristóbal are dedicated SHADOZ soundings, which are matched with AIRS overpasses. **) Simultaneous BBAERI observations exist for the frost-point soundings at Huntsville. ***) The soundings at Sodankylä are dedicated SAGE III validation measurements, which also match AIRS overpasses.

A sample profile is given in figure 1, which shows relative humidity for the NOAA/CMDL hygrometer, the Snow White hygrometer, and the Vaisala humicap H, as well as the ozone mixing ratio profile. Shown in this graph is only the ascent profile, however, most data files also contain the part of the descent profile, where the sensors can be considered reliable.

Snow White intercomparison

The comparisons between the Snow White and the NOAA/CMDL hygrometer have shown a general agreement between the two sensors for the lower and middle troposphere, with two important limitations in the upper troposphere and under very dry conditions. In the upper troposphere the Snow White begins to deviate from the NOAA/CMDL measurements at frost-point temperatures below -75°C (figure 2). In mid latitudes, this level lies close to the tropopause, whereas in tropical latitudes, this level lies approximately 2 km below the tropopause. The second important limitation of the Snow White sensor is its cooling capacity, which leads to a lower limit of 5-8% relative humidity. In layers with RH values below this threshold, the Snow White sensor looses the frost coverage on the mirror and the reported data are not valid frost-point measurements. This condition remains until frost coverage on the mirror is restored. An example of this limitation is shown in figure 3. In no circumstance can observations of the Snow White sensor in the stratosphere be considered reliable observations.

This work has been submitted for publication to the Journal of Atmospheric and Oceanic Technology under the title "The behavior of the Snow White chilled-mirror hygrometer in extremely dry conditions". A copy of this article has been enclosed.

Sounding campaigns at the validation sites

San Cristóbal, Galapagos

The first field campaign at San Cristóbal took place at the end of August of 2002. While the launches were very successful, their value was somewhat limited, since during this period AIRS encountered unexpected problems and had shut down for most of the observation period.
The project supports regular radiosonde launches at San Cristóbal, Galapagos. Most sondes are timed to daytime overpasses, which occur approximately every 2-3 days in equatorial regions and are launched by local personnel. During my visit at San Cristóbal the data transmission via the GTS satellite link was restored, which allows real time transmission of routine radio soundings. AIRS dedicated soundings are transmitted by e-mail.

Huntsville, Al

This field campaign had been planned to take place at the ARM/CART site in Oklahoma in cooperation with ozone sonde launches by Dr. Mike Newchurch and BBAERI observations by Dr. Wallace McMillan. Due to the problems in obtaining access to the ARM/CART site for foreign nationals, in particular for Mohammed Ayoub, working for Mike Newchurch, this campaign was relocated to Huntsville, AL. Two soundings were launched at the new balloon facility of the University of Alabama at Huntsville. BBAERI observations at UAH were conducted by Kurt Lighter. A third planned launch was cancelled due to poor weather conditions. This balloon was later launched at Boulder. During this campaign the use of a new telemetry system including code correlated GPS positioning, was successfully implemented.

Hilo, Hawaii

The initial campaign at Hawaii took place as validation/calibration effort for the new Raman lidar operated by Dr. John Barnes at MLO. These soundings were launched at MLO and provided an excellent verification for the lidar system. Dedicated AIRS validation observations have been launched monthly since September 2002. We decided not to continue Snow White observations as part of the NOAA/CMDL hygrometer payload at Hilo, since the low humidity limit of the Snow White sensor would impact between 60-80% of all soundings, affecting an altitude range upward of 1 km. In this geographic region, the Snow White is not a useful sensor for validation observations, covering the entire troposphere.

3. Data management and archival strategy

The data of all soundings are quality checked after the completion of each field campaign. In addition to the data of each sensor an additional data field is created, which combines the best humidity measurements in each altitude region to a continuous profile between the surface and about 25 km. These data are transferred to an anonymous JPL ftp server and a notification that new data are available is sent out to Eric Fetzer and Stephen Leroy. Some of the data are also posted on a web site, which is accessible to the collaborators of this project. The dedicated AIRS radiosonde data are sent to Boulder by e-mail and included in the normal data processing, quality check and archival at JPL.

4. Issues

One mayor issue that still needs to be resolved is the access of foreign nationals to JPL computers. As a German citizen I am not able to push data directly into the validation data archive, nor can I access data from other groups directly. A temporary anonymous ftp site was set up to allow me to transfer data to JPL. A notification that data have arrived there is necessary and the data have to be removed from there and placed into the proper locations. Corrections to the data, which became necessary in one case, are tedious with a considerable risk that incorrect data remain in the archive.

The difficulties to get foreign national clearance for the ARM/CART site prompted Dr. Newchurch and me to relocate a combined ozone and water vapor campaign from the ARM/CART site to Huntsville. Due to the importance of the ARM/CART site this was a considerable drawback. However, we were able to invite the BBAERI instrument of Dr. McMillan to Huntsville, which provided simultaneous surface remote observations during the balloon soundings. The planned ARM/CART campaign for this year will most likely take place as intended, since I expect to get clearance for myself.

Logistical issues in the cooperation with INAMHI have prevented the launch of frost-point hygrometers during the past three months. With the new director of INAMHI who was put in charge in the middle of February, we expect that some of these logistical issues will be solved.

5. Interactions with other team members

We have good working relationships with several other validation teams. In particular with John Barnes at Hilo, who is directly involved in the frost-point launches at Hilo and with Dr. Mike Newchurch at UAH and Dr. Wallace McMillan, who we cooperated with during the last Huntsville campaign. There are occasional contacts with other members of the validation and science team and we provide them with data as soon as they become available. The exchange of information through regular phone conferences and occasional net meetings, which are coordinated by the validation team leader, is excellent. The feedback on the data that we have collected so far, in particular the feedback by Dr. Laraby Strowe, has been very encouraging.

6. Future work

1. We are planning to conduct the campaign at the ARM/CART site in cooperation with Dr. Larry Miloshevich at NCAR, who will provide extended calibrated radiosonde observations during this period. Furthermore we plan to coordinate this campaign in cooperation with the ARM/CART Raman Lidar. The frost-point soundings launched during this campaign will have full GPS, which provide better positioning of the data.
2. As part of the continuing observations at Hilo, HI, several frost-point soundings will be launched at MLO rather than at Hilo in an effort to validate the Raman Lidar observations at MLO.
3. Two campaigns are planned at San Cristóbal, Galapagos. One of these will take place between November and January, i.e. during the cloud free season. Regular radiosonde launches will continue to be launched in coordination with AIRS overpasses.
4. Other soundings, not funded through this project will be coordinated with AIRS overpasses on an opportunity basis.

7. Figures

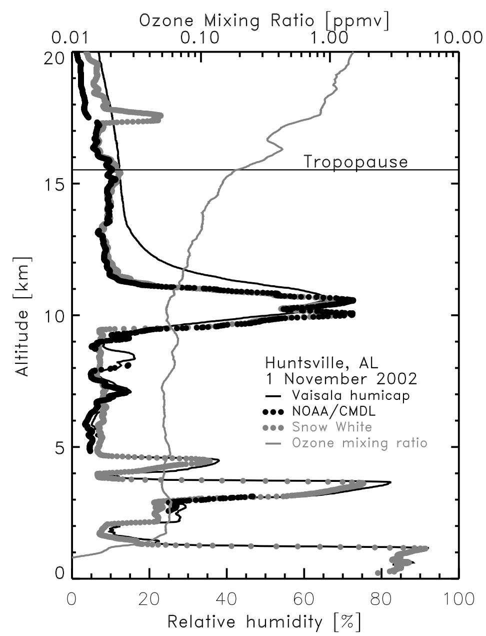

Figure 1. Sounding profile at the balloon launch facility of the University of Alabama at Huntsville.

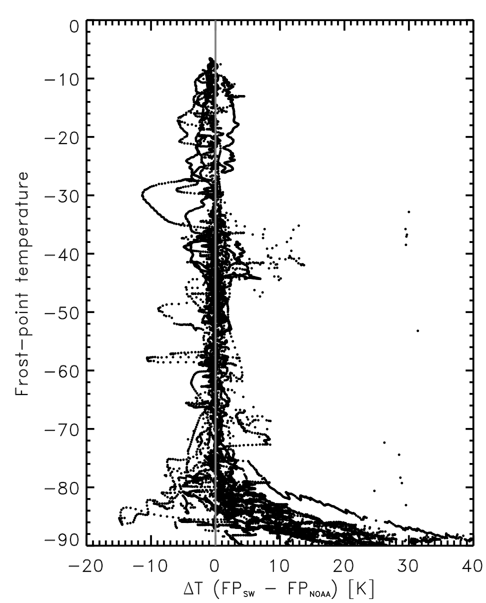

Figure 2. Difference between Snow White and NOAA hygrometer frost-point temperatures in the troposphere.

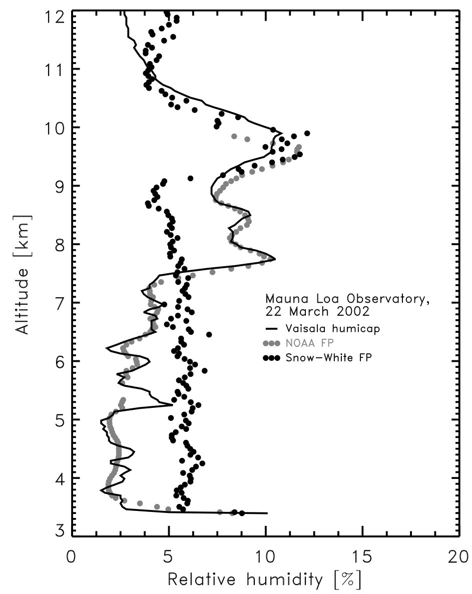

Figure 3. Profile showing the dry humidity limit of the Snow White sensor between 3.5 and 9 km.