Absolute accuracy of water vapor measurements from six operational radiosonde types launched during AWEX-G and implications for AIRS validation

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Received 14 April 2005; revised 2 August 2005; accepted 20 October 2005; published 7 April 2006.

[1] A detailed assessment of radiosonde water vapor measurement accuracy throughout the tropospheric column is needed for assessing the impact of observational error on applications that use the radiosonde data as input, such as forecast modeling, radiative transfer calculations, remote sensor retrieval validation, climate trend studies, and development of climatologies and cloud and radiation parameterizations. Six operational radiosonde types were flown together in various combinations with a reference-quality hygrometer during the Atmospheric Infrared Sounder (AIRS) Water Vapor Experiment-Ground (AWEX-G), while simultaneous measurements were acquired from Raman lidar and microwave radiometers. This study determines the mean accuracy and variability of the radiosonde water vapor measurements relative to simultaneous measurements from the University of Colorado (CU) Cryogenic Frostpoint Hygrometer (CFH), a reference-quality standard of known absolute accuracy. The accuracy and performance characteristics of the following radiosonde types are evaluated: Vaisala RS80-H, RS90, and RS92; Sippican Mark IIa; Modem GL98; and the Meteolabor Snow White hygrometer. A validated correction for sensor time lag error is found to improve the accuracy and reduce the variability of upper tropospheric water vapor measurements from the Vaisala radiosondes. The AWEX data set is also used to derive and validate a new empirical correction that improves the mean calibration accuracy of Vaisala measurements by an amount that depends on the temperature, relative humidity, and sensor type. Fully corrected Vaisala radiosonde measurements are found to be suitably accurate for AIRS validation throughout the troposphere, whereas the other radiosonde types are suitably accurate under only a subset of tropospheric conditions. Although this study focuses on the accuracy of nighttime radiosonde measurements, comparison of Vaisala RS90 measurements to water vapor retrievals from a microwave radiometer reveals a 6–8% dry bias in daytime RS90 measurements that is caused by solar heating of the sensor. An AWEX-like data set of daytime measurements is highly desirable to complete the accuracy assessment, ideally from a tropical location where the full range of tropospheric temperatures can be sampled.

Citation: Miloshevich, L. M., H. Vömel, D. N. Whiteman, B. M. Lesht, F. J. Schmidlin, and F. Russo (2006), Absolute accuracy of water vapor measurements from six operational radiosonde types launched during AWEX-G and implications for AIRS validation, *J. Geophys. Res.*, *111*, D09S10, doi:10.1029/2005JD006083.

1. Introduction

[2] A great variety of atmospheric research is influenced, either directly or indirectly, by water vapor measurements from radiosondes. Radiosonde data from operational programs such as the U.S. National Weather Service (NWS) and similar programs worldwide are commonly assimilated into forecast models. Because of their high vertical resolution, radiosonde data are increasingly used to evaluate (validate) water vapor retrievals from ground-based and satellite remote sensors [e.g., *Soden et al.*, 2004; *Soden and Lanzante*, 1996]. Radiosonde water vapor measurements are also used in climate-related research, including studies of trends in upper troposphere (UT) water vapor, stratospheric dehydration and troposphere-stratosphere exchange processes, and initiation and maintenance of cirrus clouds, although it is questionable whether most radiosonde data are really accurate enough for these purposes. Since

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0148-0227/06/2005JD006083$09.00

water vapor concentrations decrease by several orders of magnitude between the surface and the lower stratosphere (LS), it is particularly challenging to accurately measure relative humidity (RH) throughout the tropospheric column, especially with a low-cost operational radiosonde. It is important to realistically establish the accuracy of radiosonde water vapor measurements in order to evaluate the contribution of observational uncertainty to the uncertainty in forecast model results, remote sensor validations, radiative transfer calculations, cloud parameterizations, and other applications that use radiosonde data as input. An indication of radiosonde measurement accuracy is provided by radiosonde intercomparison experiments such as those conducted by the World Meteorological Organization [e.g., *Sapucci et al.*, 2005; *Yagi et al.*, 1996; *Schmidlin*, 1998; *Ivanov et al.*, 1991]; however, these studies compare operational radiosondes only to each other, which is not sufficient for estimating the absolute accuracy of the measurements. This study will quantify in detail the operational accuracy of radiosonde water vapor measurements throughout the troposphere, by comparing in situ radiosonde measurements to simultaneous measurements from a reference-quality research instrument of known absolute accuracy.

7. Summary and Conclusions

[65] This study has yielded detailed estimates of radiosonde water vapor measurement accuracy for six operational radiosonde types launched during AWEX: Vaisala RS80-H, RS90, and RS92; Modem GL98; Sippican Mark IIa; and the Snow White chilled mirror hygrometer. The accuracy estimates (mean and variability) were derived by comparing in situ radiosonde measurements with simultaneous measurements on the same balloon by a reference-quality sensor of known absolute accuracy, the CU CFH. This study also evaluated the impact of a correction for sensor time lag error on Vaisala radiosonde measurements, then the corrected data were used to derive and validate a new empirical correction for uncertainty in the Vaisala calibration. Although most radiosondes are calibrated in terms of RH rather than an absolute water vapor quantity such as mixing ratio, this study reports radiosonde accuracy in absolute terms as a percentage of the measured RH value, because it is the uncertainty in absolute water vapor amount that is the most relevant quantity for assessing observational error in most atmospheric applications. Radiosonde measurements are inherently less accurate in an absolute sense for dry conditions than for moist conditions (e.g., a 2% RH bias error is increasingly significant in an absolute sense as the RH decreases).

[66] A basic conclusion from this study is that there is no simple answer to the question "how accurate are water vapor measurements from a given radiosonde type?" Radiosonde accuracy varies substantially as a function of RH and T, and different radiosonde types have different strengths and weaknesses in different realms of RH and T space. Furthermore, the accuracy of RS80-H, Modem, and SW radiosondes may be substantially degraded by clouds, particularly thick ice clouds. Reliable use of data from these radiosonde types requires quality control to identify cloud influences. Only the Vaisala RS90 and RS92 radiosondes make reliable measurements within and above thick ice clouds, because of their alternately heated dual sensor design. Several other general characteristics of radiosonde performance were observed in this and previous studies: The SW is incapable of measuring very dry conditions (<6% RH), and substantial errors in the lower troposphere are possible if the proper phase of condensate on the mirror cannot be determined; the Sippican radiosonde cannot reliably measure dry conditions (RH < 20%), and the Sippican sensor becomes unresponsive at a temperature level that varies between −20 and −50°C; and the RS80-H and Modem radiosondes have substantial time lag error in the UT (although the RS80-H time lag error can be corrected).

[67] This study quantified the mean accuracy and variability of radiosonde water vapor measurements relative to the CFH as a function of RH and T (Figures 4, 5, 8, and 9 and Table 3), and then investigated the impact of the time lag and AWEX empirical calibration corrections on the accuracy and variability of Vaisala measurements. The absolute accuracy of the CFH reference sensor was shown from both observational and instrumental considerations to be about 3% in the LT and about 6% in the UT. Overall, the most accurate operational radiosonde tested is the Vaisala RS92 (and RS90), whose mean percentage accuracy relative to the CFH is <5% for most conditions in the LT, and <10% in the MT and UT. The corrections improve the RS92 mean accuracy relative to the CFH to <1% in the LT, <2% in the MT, and <3% in the UT, and the time lag correction substantially reduces the variability in the UT. Only the RS92 and RS90 are sufficiently accurate for AIRS validation throughout the troposphere, especially if the corrections are applied. The corrections also substantially improve the RS80-H accuracy, such that corrected RS80-H data are marginally suitable for AIRS validation if the data are screened for the sensor-icing effect of clouds. The broad community would benefit from the operational application of the corrections to NWS RS80-H data. In contrast, the Sippican and Modem radiosondes are only reasonably accurate under relatively warm and moist conditions, and measurements from these radiosondes are generally not suitable for research purposes under cold or dry conditions.

[68] The quantitative accuracy assessment given in this paper applies only to nighttime radiosonde measurements, when solar radiation error is not an issue. The impact of solar radiation error on AIRS RS90 validation measurements was investigated by comparing to simultaneous retrievals of PWV from an ARM microwave radiometer, with the result that solar radiation produces a dry bias of 6–8% in RS90 measurements in the LT (probably more in the UT). Further investigation of the MWR-scaling technique as a means of correcting the solar radiation dry bias is warranted, particularly with regard to the dependence of solar radiation error on RH and T. Correction of the nonsolar component of RS90 measurement error (the time lag and AWEX empirical calibration corrections) leads to a moistening of the AIRS RS90 validation profiles in the UT by a mean of ~15% at TWP and ~10% at SGP, and ~1–3% drying in the LT. Both corrections are sensitive to the individual profiles measured, which leads to considerable variability in the magnitude of the corrections between profiles, and the mean correction magnitudes give only a rough indication of the impact of the corrections on individual profiles.