Appendix X – Frostpoint Hygrometers

Of all techniques available to measure atmospheric water vapor only balloon-borne, cryogenically cooled frostpoint hygrometers are capable of high-quality profile measurements from the wet surface layer to the very dry middle stratosphere with high vertical resolution and excellent long-term stability. These instruments have a long history, dating back to the 1940s (Brewer et al., 1948; Barrett et al., 1949). Intensive campaigns have taken place since the 1960s (Mastenbrook, 1968; Mastenbrook, 1971) and routine observations have been made between 1964 and 1978 at Washington, DC (Mastenbrook and Oltmans, 1984), and since 1980 at Boulder, CO (Oltmans and Hofmann, 1995; Scherer et al., 2008; Hurst, et al., 2011). Currently two cryogenically cooled frostpoint hygrometers exist: the Cryogenic Frostpoint Hygrometer (CFH) and the NOAA Frostpoint Hygrometer (FPH). Both instruments rely on the same measurement principle, share a common origin and are considered largely equivalent. The CFH is commercially available, while the FPH is fabricated in-house by NOAA. Intercomparisons of stratospheric water vapor measurements by these two instruments have shown no significant difference (Vömel et al., 2007a; Rollins et al., 2014). Longstanding differences do exist between the measurements of stratospheric water vapor by several aircraft-based instruments and the balloon-borne frostpoint hygrometers (Rollins et al., 2014), but there is little doubt about the long-term stability of the frostpoint technology. Frostpoint measurements are fundamentally temperature measurements that are relatively easy to calibrate and maintain calibration stability over decades. Thus, the technique does not require further justification to be accepted as an NDACC instrumental method for stable long-term measurements of stratospheric and tropospheric water vapor.

Using these instruments, stratospheric water vapor can be measured with an uncertainty better than 10 % (Vömel et al., 1995; Vömel et al; 2007a). In addition, the CFH allows tropospheric water vapor measurements with uncertainties better than 3% (Vömel et al; 2007a). Comparisons of stratospheric water vapor measurements with Aura Microwave Limb Sounder (MLS) retrievals show differences of less than 3% (Vömel et al., 2007b; Hurst et al., 2014).

Quality Criteria for the Evaluation of a New Frostpoint Sounding Station
Presently, 7 sites perform routine frostpoint soundings (Ny-Ålesund, Sodankylä, Lindenberg, Boulder, Hilo, San José (Costa Rica), and Lauder). These sites launch frostpoint hygrometers as part of the GCOS Reference Upper Air Network (GRUAN) or within the framework of the NOAA long-term monitoring activities. Some additional sites conduct campaign-based observations, which may contribute to NDACC as well.

Like other small sounding instruments, frostpoint hygrometers are often flown only once and are lost after measurement. Manufacturing stability and the adherence to standard operating procedures (SOPs) are therefore essential in their use for long-term measurement programs. Although manufacturers work hard to provide the best possible instrumentation, it is important to monitor the

calibration of each instrument on-site, just prior to launch. Stations should perform a simple one-point ground check to establish a long-term record of calibration stability. This record can be used to monitor potential drifts caused by manufacturing variability or by changes in pre-flight instrument preparations.

The manufacturers of cryogenic frostpoint hygrometers produce a consistent product with well-established characteristics. Therefore, the evaluation of candidate frostpoint sounding sites for acceptance into the NDACC network will be primarily based on their adherence to the recommended SOPs for instrument preparation and ground check and data analysis. Such SOPs will soon become available within the context of GRUAN sounding operations. These guidelines assure that the sonde performance is not negatively impacted by deviations in instrument preparation and will help the user obtain the best possible results. The current operations have been well monitored and guarantee a high level of fidelity for these observations.

In cases, where a station wishes to deviate from the SOPs for either practical or scientific reasons, NDACC will support such deviations provided the station PI(s) discuss the proposed changes with the Sonde Instrument Working Group (IWG) representatives, document them in the data base, and provide results showing the consequences of the changes from standard frostpoint operations as defined in the SOPs.

References

Barrett, E. W., L. R. Herndon Jr., and H. J. Carter (1949), A preliminary note on the measurement of water vapor content in the middle stratosphere, J. Meteorol., 6, 367-368.

Brewer, A. W., B. Cwilong, and G. M. B. Dobson (1948), Measurement of absolute humidity in extremely dry air, Proc. Phys. Soc., 60, 52-70.

Hurst, D. F., S. J. Oltmans, H. Vömel, K. H. Rosenlof, S. M. Davis, E. A. Ray, E. G. Hall, and A. F. Jordan (2011), Stratospheric water vapor trends over Boulder, Colorado: Analysis of the 30 year Boulder record, J. Geophys. Res., 116, D02306, doi:10.1029/2010JD015065.

Hurst, D. F., A. Lambert, W. G. Read, S. M. Davis, K. H. Rosenlof, E. G. Hall, A. F. Jordan, and S. J. Oltmans (2014), Validation of Aura Microwave Limb Sounder stratospheric water vapor measurements by the NOAA frost point hygrometer, *J. Geophys. Res*. *Atmos*., *119*, doi:10.1002/2013JD020757.

Mastenbrook, H. J. (1968), Water vapor distribution in the stratosphere and high troposphere, J. Atmos. Sci., 25, 299–311.

Mastenbrook, H. J. (1971), The variability of water vapor in the stratosphere, J. Atmos. Sci., 28, 1495–1501.

Mastenbrook, H. J., and S. J. Oltmans (1983), stratospheric water vapor variability for Washington, DC/Boulder, CO: 1964–82, J. Atmos. Sci., 40, 2157–2165.

Oltmans, S. J. and D. J. Hofmann (1995), Increase in lower-stratospheric water vapour at a mid-latitude Northern Hemisphere site from 1981 to 1994, Nature 374, 146-149; doi:10.1038/374146a0.

Rollins, A. W., et al. (2014), Evaluation of UT/LS hygrometer accuracy by intercomparison during the NASA MACPEX mission, J. Geophys. Res. Atmos., 119, 1915–1935, doi:10.1002/2013JD020817.

Scherer, M., Vömel, H., Fueglistaler, S., Oltmans, S. J., and Staehelin, J. (2008), Trends and variability of midlatitude stratospheric water vapour deduced from the re-evaluated Boulder balloon series and HALOE, Atmos. Chem. Phys., 8, 1391-1402, doi:10.5194/acp-8-1391-2008,.

Vömel, H., Oltmans, S. J., Hofmann, D. J., Deshler, T., and Rosen, J. M. (1995), The evolution of the dehydration in the Antarctic stratospheric vortex, J. Geophys. Res., 100, 13 919–13 926, doi:10.1029/95JD01000.

Vömel, H., D. E. David, and K. Smith (2007a), Accuracy of tropospheric and stratospheric water vapor measurements by the cryogenic frost point hygrometer: Instrumental details and observations, J. Geophys. Res., 112, D08305, doi:10.1029/2006JD007224.

Vömel, H., et al. (2007b), Validation of Aura Microwave Limb Sounder water vapor by balloon-borne Cryogenic Frost point Hygrometer measurements, J. Geophys. Res., 112, D24S37, doi:10.1029/2007JD008698.

Version: March 13, 2017