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STANDARDS FOR MEASURING FOG LIQUID WATER CONTENT

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Abstract: Two laboratory methods of measuring droplet liquid water content (LWC) are proposed as primary measurement standards, because their measurements are fundamental in nature and traceable to other standard measures. These methods, the Chýlek method and the filter method, are compared and found to give LWC values that agree to within 5%. This accuracy is a significant improvement over the accuracy expected in current LWC-measurement technology. It is further proposed that field techniques for measuring droplet LWC are eligible to be named as secondary standards, if their calibration is related to one of the standard methods.

1. INTRODUCTION

The accurate measurement of LWC in fog is important for several reasons, including judging the efficiency of fog water collectors, testing the predictions of fog models, and conducting meaningful research on various aspects of fog behavior. Attaining acceptable accuracy of fog LWC measurements has proved to be a significant and long-lasting problem in cloud physics, because of the inherent difficulty of this measurement, and because there exists no consensus on the standardization of reference methods. Errors in LWC measurements are also hard to quantify; although, errors as large as 50% have been reported [e.g., see Baumgardner, 1996.]

We describe in the following the facilities and instrumentation associated with two laboratory techniques for measuring LWC. The first technique, devised by Chýlek [1978], utilizes the prediction of Mie theory that droplet LWC is directly proportional to infrared light transmission through fog at 11-um wavelength. The second technique consists of drawing fog at a known flow rate into a filter cartridge which is weighed after a given time to measure the accumulated fog water [Mallant, 1988]. Our description stresses features of these laboratory techniques that suggest their suitability as measurement standards.

We further describe LWC measurements made in the CALSPAN Corp., Buffalo, NY cloud chamber using the Chýlek method; and measurements made in the ECN, Petten, The Netherlands cloud chamber using the filter method. These measurements are related to each other by comparing each to the same instrument, a PVM-100 [Gerber, 1991], placed in each of the cloud chambers. The results of this work leads to the proposed use of such cloud chambers as facilities for standard LWC measurements.

2. Filter Method

A schematic of the continuous-flow cloud chamber in Petten is shown in Fig. 1. The features of this chamber include the following; filtered air is blown through a humidification chamber (C) filled with porous ceramic disks that are continuously bathed with water from a heated water reservoir (H), droplets from atomizers or nebulizers are added at G and mixed with the air in D, and the mixture flows throught the test section E where the LWC measurements are made. Temperature measurement in E is fed back to the heater (H) so that the water temperature in the humidifier is regulated to give a stable value of RH near 100% in the chamber. This key feature limits the evaporation or growth of atomized droplets in the chamber as well as in the cartridge filter which is placed in E, and leads to long-term stability of LWC generated in the chamber. Such evaporation or growth of droplets in the filter is thought to be a measurement problem in ambient LWC measurements with the filter method [e.g., see Valente et al., 1989.]

Droplet filters are applied in the Petten chamber in the following manner: filter cartridges contain hydrophobic fibers to prevent absorption into the filter material. filters are pre-conditioned at 100% RH for 2 hrs. prior

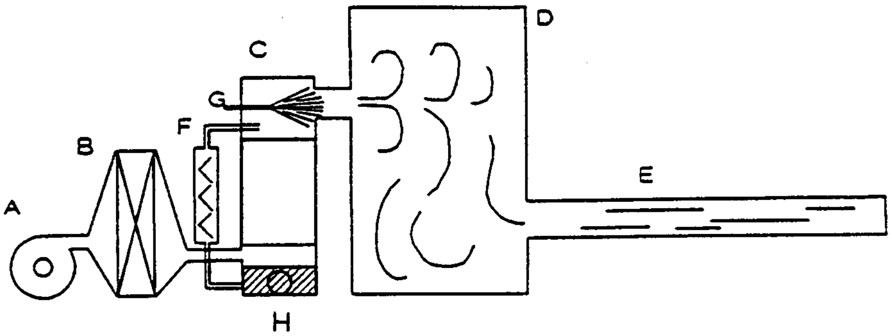

Fig. 1 - Schematic of the fog-wind tunnel at ECN Petten. A (blower), B (filter), C (humidifying chamber), D (mixing chamber), E (test section), F (heater and water reservoir), G (droplet generator), H (water pump); from Mallant [1988.]

to droplet collection to minimize adsorption effects, air is drawn though the filters isokineticaly at 2.15 m/s, the air flow is measured with calibrated flow meters, and identical filter collection systems are installed side-by-side in the chamber test section for quality control. An example of the precise LWC measurements made at the same time with the two filter systems is shown in Fig. 2.

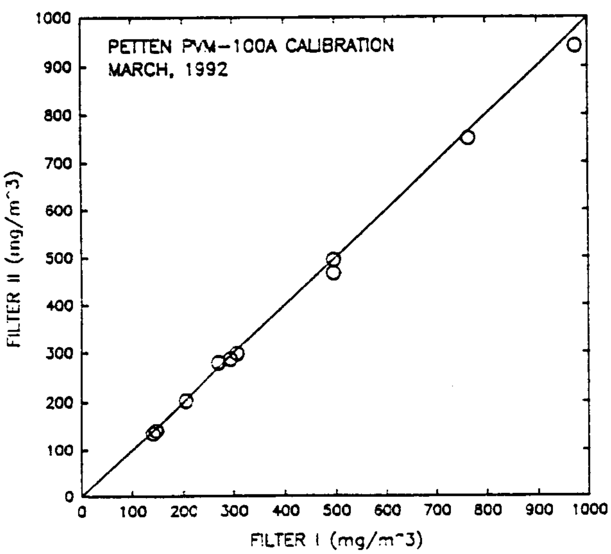

Fig. 2 - Liquid water content (LWC) measurements made simultaneously in the Petten cloud chamber by two filter cartridges for different values of LWC in the chamber.

3. Chýlek Method

Chýlek [1978] noted that the efficiency factor for i.r. extinction at about 11-um-wavelength radiation was approximately linear with the diameter of droplets smaller than about 28 um. Combining this proportionality with the definition of the extinction coefficient (σ) of the radiation, with the definition of the integrated volume of the droplets in the fog, and with Beer's light-transmission law, gave a direct proportionality between the LWC of the fog and the 11-um σ in the fog. Thus measures of σ in the cloud chamber yield measures of LWC. This can be considered a standard LWC measurement method, because of the validity of Mie theory. Such measurements of σ in cloud chambers have the advantage of being done in a relative fashion, because the measurements can be made with and without the droplets in the chamber.

The i.r. transmissometer and cloud chamber at CALSPAN Corp. is shown in the schematic in Fig. 3, and has the following features: an i.r. light beam is

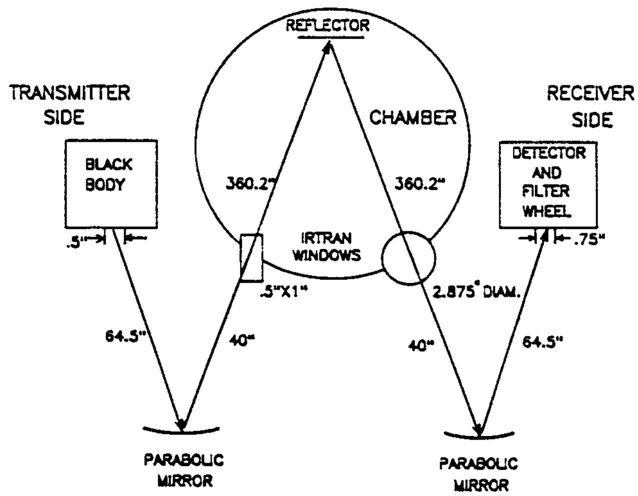

Fig. 3 - Schematic of infrared transmissometer and cloud chamber at CALSPAN Corp., Buffalo, N.Y.

directed through a pressure-tight chamber to yield a path length in the chamber of 18.3 m, the receiver contains a filter wheel capable of selecting a narrow band of the transmitted i.r. light, and fogs can be generated in the chamber by atomizing water as well as by reducing pressure in the chamber pre-humidified to be near RH = 100%. Measurements of i.r. transmission through the chamber are made prior and during fog generation, yielding values of σ and LWC.

An example of PVM-100 LWC measurements compared with the CALSPAN i.r.-transmissometer measurements of LWC is shown in Fig. 4. These measurements [Gerber, 1990] were used to determine the scaling constant (C = 1.71) that converts the output voltage of the PVM-100 to values of LWC, and that gives the best agreement berween the two sets of measurements as shown in Fig. 4. The various runs shown in Fig. 4 correspond to separate and different fog generations in the cloud chamber.

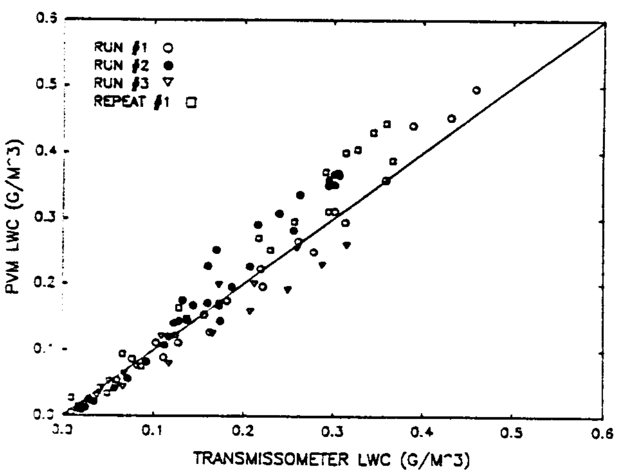

Fig. 4 - Comparison of LWC measured for different droplet fogs (runs) by the PVM-100 and the i.r. transmissometer in the CALSPAN cloud chamber.

4. Comparison of Filter and Chýlek Methods

The PVM-100 served as a means for enabling the comparison between LWC measurements made with the Chýlek method in the CALSPAN cloud chamber and the filter method in the ECN Petten cloud chamber. This was done by placing the PVM-100 into the Petten chamber, and operating it with the scaling constant determined in the CALSPAN chamber. The PVM output is independent of air speed thus permitting this transfer of the scaling constant. This comparison of the PVM with the filter method was done over a 2-year period at the Petten chamber, and is described by Arends et al. [1992] and Gerber et al. [1994]; the results are summarized in Fig. 5. Figure 5 shows a high correlation between the two sets of LWC measurements, and shows a mean difference between the two sets of a factor of K=1.05. This factor is included in the value of the abcissa of the figure, and indicates that on the average the filter method measured LWC values 5% larger than the PVM and the CALSPAN i.r. tramsmissometer LWC values. Figure 5 further shows that this good agreement is independent over a droplet size range given by the two values of the volume median diameter (VMD) of the droplet spectra in the generated fogs.

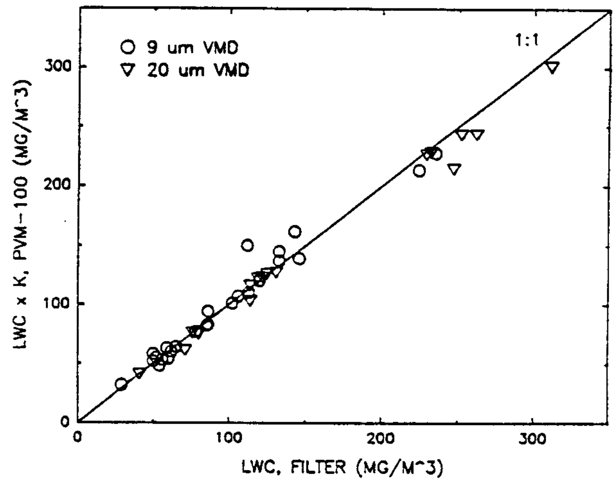

Fig. 5 - Comparison of LWC measured by the filter cartridge and PVM-100 in the ECN, Petten cloud chamber for different values of LWC and volume median diameters (VMD) of the droplet spectra; from Gerber et al. [1994.]

5. Conclusions and Recommendations

a) The comparison of the Chýlek and filter measurements of LWC in the CALSPAN and ECN Petten cloud chambers suggests that these two laboratory methods which are based on fundamental principles, Mie theory for the former and measurements of flow and weight for the latter, measure accurately LWC with an accuracy of about 5%.

b) The Chýlek and filter methods are proposed as primary LWC measurement standards to which other means of measuring LWC in fog are referenced, in order that the accuracy and consistency of field measurements of LWC in fog and cloud are improved. This applies to all principal types of methods for measuring LWC including: droplet size spectrometers [e.g., FSSP-100; Particle Measuring Systems], hot wire probes [J-W and King probes; King et al. (1978)], bulk optical measurements [PVM-100, Gerber et al. (1994); CDS, Lawson and Cormack (1995)], and bulk collection methods [e.g., Valente et al. (1989).] The first two types are primarily used on aircraft, and use high aspiration velocities and non-isokinetic flow for ground-based that cause errors that require better quantification in comparisons with the standard methods. The latter two types can benefit by establishing accurate scaling constants and collection efficiencies in comparisons with the standards.

c) It is also proposed that methods for measuring LWC can qualify as secondary standards, if their calibration is directly traceable to the primary standards, and if these methods can demonstrate acceptable field calibration means and operational stability.

6. Acknowlegments

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7. References

Arends, B.G., G.P.A. Kos, W. Wobrock, D. Schell, K.J. Noone, F. Fuzzi and S. Paul, 1992: Comparison of techniques for measurements of fog liquid water content. *Tellus, 44B*, 604-611.

Baumgardner, D., 1996: Status if in-situ microphysical measurements. *Proc. of ETL/CSU Cloud Modeling and Measurement Workshop.* NOAA/ETL, Boulder, CO, 23-25 Oct. 1995, 67-102.

Chýlek, P., 1978: Extinction and liquid water content of fogs and clouds. *J. Atmos. Sci., 35*, 296-300.

Gerber, H., 1990: Calibratiuon of the PVM (LWC and 3.75 um and 10.59 um infrared extinction) in the CALSPAN environmental chamber. 17-18 August, 1990, Buffalo, N.Y. Report No. GSI-90-03, Gerber Scientific Inc, Reston, VA 20190, pp. 20.

Gerber, H., 1991: Direct measurement of suspended particulate volume concentration and far-infrared extinction coefficient with a laser-diffraction instrument. *Appl. Opt., 30,* 4824-4831.

Gerber, H., B.G. Arends and A.S. Ackerman, 1994: New microphysics sensor for aircraft use. *Atm. Research, 31*, 235-252.

King, W.D., D.A. Parkin and R.J. Handsworth, 1978: Hot-wire water device having fully calcuable response characteristics. *J. Appl. Meteorol., 17*, 1809-1813.

Lawson, R.P and R.H. Cormack, 1995: Theoretical design and preliminary tests of two new particle spectrometers for cloud microphysics research. *Atm. Ressearch, 35,* 315-348.

Mallant, R.K.A.M., 1988: A fog chamber and wind tunnel facility for calibration of cloud water collectors. In: M.H. Unworth and D. Fowler (Eds.), *Acid Deposition at High Elevation Sites.* Kluwer, Dordrecht, 479-490.

Valente. R.H., R.K.A.M. Mallant, S.E. McLaren, R.S. Schemenauer and R.E. Stogner, 1989: Field intercomparison of ground-based cloud physics instruments at Whitetop Mountain, Virginia. *J. Atmos. Oceanic Technol., 6*, 396-406.