A preliminary note on the measurement of water-vapor content in the middle stratosphere

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The determination of the distribution of water vapor in the higher troposphere and stratosphere, which is particularly essential to a thorough understanding of the general circulation of the atmosphere, has been an unusually difficult problem because of the extremely low concentrations in these regions. We are therefore pleased to announce that as a culmination of several years of laboratory research we obtained on 1 July 1949 a detailed balloon sounding of the atmosphere to a height of over 30 km, of which continuous measurement of the dew-point temperature was the outstanding feature. This sounding represents an increase of nearly two and one-half times in the maximum altitude at which water-vapor determinations have been made.

This sounding was made possible by the development in our laboratory of an automatic, continuously operating electronic dew-point hygrometer. Since the necessary brevity of this correspondence does not permit an extended discussion of the details of the instrument, only the major points may be mentioned at this time; a complete description will appear in a later publication.

The complete sounding instrument consists of the electronic dew-point hygrometer, air temperature thermocouple designed to minimize lag and radiation error, hypsometer for pressure measurement, thermocouple voltage amplifier, reference ice bath, standard cell for calibration, sequence switch, radio telemetering unit, and battery power supply. The special plastic balloon used for the ascent, as well as the launching and tracking facilities, were provided by General Mills, Inc., Aeronautical Research Division, and the U. S. Navy, at Camp Ripley, Minnesota.

The balloon was launched at 0633 CST on 1 July 1949 at Camp Ripley about 14 hours after the passage of a weak cold front followed by an extremely dry modified mP air mass. Examination of fig. 1, which presents the sounding from the surface to 405 mb, shows the very dry character of the lower layers. The shallowness of the surface moist layer is clearly indicated. The character of the ground inversion is not definitely known since the telemetering system does not accommodate temperatures greater than 17C. This indefinite region is shown as a dashed curve in fig. 1. The extreme dryness of the air near the 400-mb level is of particular interest.

Fig. 2, the remainder of the sounding, shows more points of interest. The dew point remains about constant on the average, with several sharp excursions, while the temperature decreases. At the 300-mb level the dew point and temperature begin to decrease in a more or less parallel manner until, at about 210 mb, the dew point begins to rise and approach saturation. A small saturated isothermal layer is found at 188 mb, with temperature and dew point both decreasing until the tropopause is reached at 157 mb. Shortly after passing the tropopause, the lowest dew point of the sounding (−77C) is observed at 152 mb. At higher elevations the dew point rises irregularly, as does the temperature. At 106 mb a region of slight supersaturation appears, followed thereafter by sharp drying, and for the remainder of the ascent the air is characterized by low relative humidity.

If one focusses attention on that part of the sounding up to and including the tropopause, one finds a strong similarity to soundings made by Dobson[2] with a dew-point hygrometer installed in a high-altitude aircraft. These soundings showed a tendency for saturated or nearly saturated layers to appear just below the tropo-

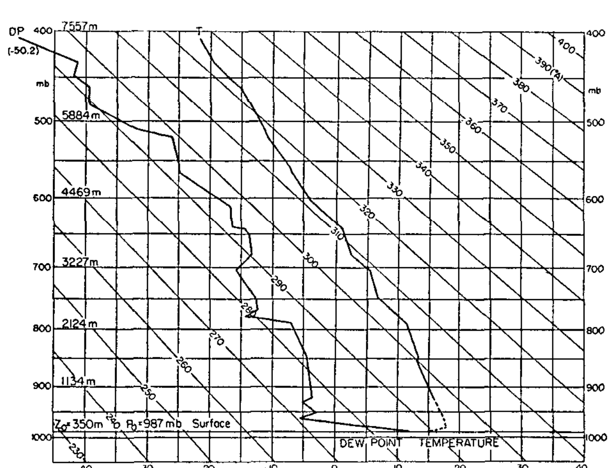

Figure 1.

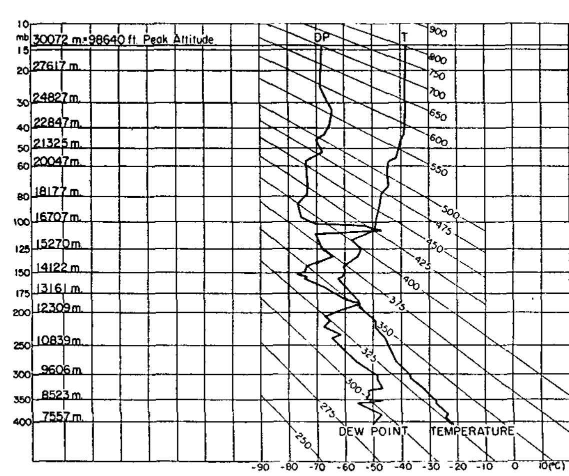

Figure 2.

pause with extremely dry regions just above. The extension of moisture measurement to 30 km provided by the present sounding also tends to corroborate a prediction made by Dobson that the dew point in the region above the tropopause should remain roughly constant in the range 190K to 205K (−83C to −68C). The only unexpected feature of this sounding is the appearance of the second region of saturation near 16 km. It might be thought that this indication is due to a temporary malfunction of the instrument; however certain signals which are included in the telemetered data to check on such malfunctions showed everything to be in order during this part of the sounding. We must therefore conclude that the phenomenon is a real one.

The fact that saturated layers can exist in the upper atmosphere without producing visible cloudiness has also been discussed by Dobson. His conclusion (with which the writers agree) is that either (*1*) the absence of numerous nuclei for condensation in the clean air of high altitudes inhibits sublimation until pronounced supersaturation is reached, or (*2*) due to the exceedingly small mass of water per unit volume of air, the crystals which form at saturation are too small or too sparsely scattered to be detectable optically. It is probable that (*2*) is the better explanation since some cloud-chamber experiments conducted by Dobson using well-filtered air showed that very little supersaturation is required to produce condensation at low temperatures.

Perhaps the most striking feature of this sounding is the amount of stratification of both temperature and moisture which is observable. Due to unusually low lags of the sensing elements as compared to those of radiosondes, the microstructure of the atmosphere is brought more sharply into prominence. A quite strong correlation between the positions of changes in the temperature and dew-point lapse rates is clearly evident upon inspection of the charts. Significance must also be attached to the fact that none of the layers with lapse rates at or near the dry adiabatic possesses the dew-point lapse rate corresponding to a constant mixing ratio. Consideration of the above observations leads to the conclusion that, at least for the air mass in which this sounding was made, the vertical mixing plays only a very minor part in establishing the distribution of water vapor and that one must look to advective and/or lateral mixing processes to account for the distribution.

Extended discussion of the absolute accuracy of the data obtained from the sounding will be included in the later publication. Laboratory data indicate that the maximum error in any temperature or dew point is not greater than 1.5C and that the dew point depression at a given level is accurate to 0.25C. The good agreement between the peak altitude calculated from the sounding by the hydrostatic equation and that given by double theodolite tracking (36-mile baseline) shows that no systematic error exists in the temperature measurements.

It would be quite presumptuous at this point to attempt to account for the observed temperature and moisture distributions on theoretical grounds with only one isolated sounding at our disposal. We feel, however, that a systematic sounding program using instruments of the type described in this note would make possible a deeper understanding of the processes which bring about the distribution of moisture and heat in the atmosphere.

We gratefully acknowledge the contributions of Mr. Verner E. Suomi, Department of Meteorology, University of Wisconsin, under whose direction this work was begun. We are also grateful to the U. S. Navy and General Mills, Inc., and to personnel at Camp Ripley for providing the balloon and other flight facilities and for their personal cooperation.

[1] Work performed under contract N6-ori20, Task Order 1, with the Office of Naval Research, U. S. Navy.

[2] G. M. B. Dobson, A. W. Brewer, and B. M. Cwilong, "Meteorology of the lower stratosphere," *Proc. roy. Soc. London* (*A*), **185**, 144–175, 1946.