residual errors of the VIZ radiosonde hygristor as deduced from observations of sub-cloud layer structure

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1. Introduction

The second Venezuelan International Meteorological and Hydrological Experiment (VIMHEX II) used the VIZ 1290 series standard radiosonde. This had been modified with a redesigned humidity duct (Friedman, 1972) following the discovery that the humidity sensor was far from thermal equilibrium with the atmosphere in sunlight (Morrissey and Brousaides, 1970; Teweles, 1970; Ostapoff *et al.*, 1970). Riehl and Betts (1972) presented preliminary results from VIMHEX II with the new sonde, showing no systematic change in the specific humidity between night and day soundings. In contrast, Sanders *et al.* (1973) have reported daytime relative humidities were as much as 25% too low during the Barbados Oceanographic and Meteorological Experiment with an earlier model sonde.

It is the intent of this paper to estimate the residual errors of the hygristor element from sub-cloud layer measurements.

2. Observationally based technique

An additional field observation of measuring the ascent time of radiosonde balloons from release to cloud base permitted an estimation of the hygristor error. Those observations, a total of 14 ascents, were selected where the balloon entered the base of a non-precipitating cloud. The vertical separation of the instrument package (10 m below the balloon), and the variable time taken for the balloon to disappear into the cloud lead to an uncertainty in cloud-base pressure of perhaps 1–2 mb. From the ascent time, the level of cloud-base could be accurately located on the radiosonde strip chart, giving the pressure $p(b)$, temperature $T(b)$ and observed relative humidity RH(b) at cloud base. From these, the potential temperature $\theta(b)$ and saturation mixing ratio $r_s(b)$ at cloud base were computed. The air entering cloud base was assumed to be saturated and $r_s(b)$ was compared with the mixing ratio values observed below cloud base. At and just below cloud base, the observed

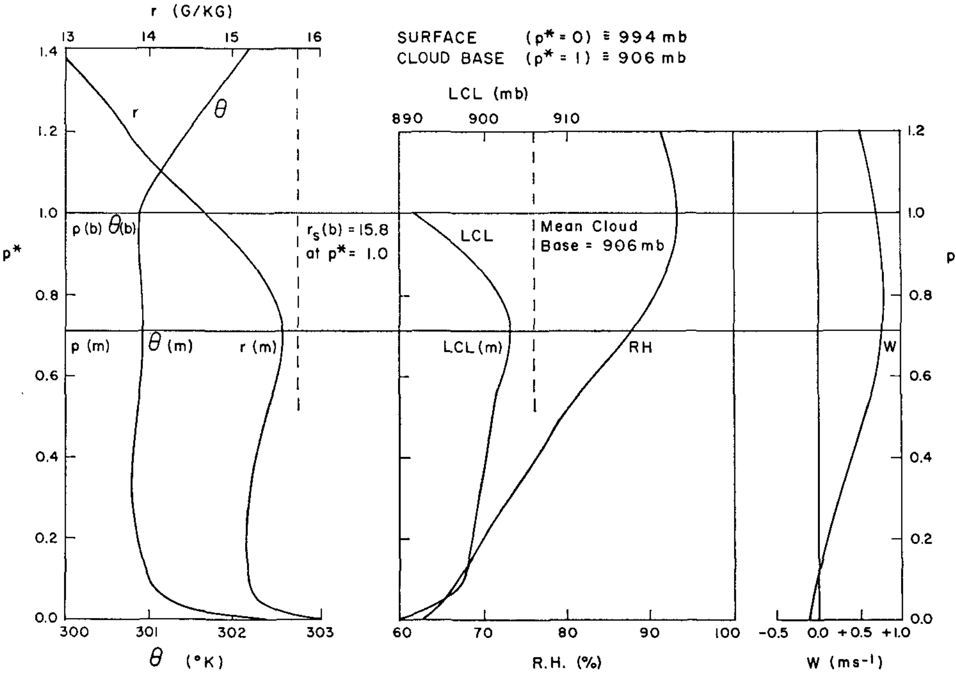

FIG. 1. Mean profile for 14 radiosonde ascents through cloud-base of potential temperature (θ), mixing ratio (r), lifting condensation level (LCL), relative humidity (RH), perturbation vertical velocity (w).

mixing ratio was always below $r_s(b)$, indicating an error of the hygristor at relative humidities near 100%, but all soundings showed a local maximum in mixing ratio and pressure of the lifting condensation level (LCL) at a level $p(m)$ about one-third of the depth of the sub-cloud layer below cloud base $p(b)$.

3. Mean profile

For each ascent, the depth of the sub-cloud layer was used as a scaling factor to define new pressure levels

$$p^*(I) = \frac{p(s) - p(I)}{p(s) - p(b)}$$

where $p(s)$ is the surface pressure, and I indicates a data level. In these coordinates, the surface becomes $p^* = 0$ and cloud base $p^* = 1.0$. After this scaling, the data levels were interpolated (to intervals of p^* of 0.05), and the 14 soundings averaged to give a mean sub-cloud profile (Fig. 1). This mean profile is well representative of the individual ones.

Figure 1 shows the mean profile of θ, r, the LCL of air at a level, RH, and w, which is the deviation of the balloon ascent rate from a mean value (4.7 m sec^{-1}) for all ascents during the experiment. The real vertical resolution for the thermodynamic parameters is about 10 mb ($\Delta p^* \sim 0.1$), but for w it is much less ($\Delta p^* \sim 0.4$).

Figure 1 shows that the hygristor does not respond well above 90% relative humidity; on entering non-precipitating clouds, the sensor did not generally reach 100%. Despite the poor vertical resolution in w, it is also clear that the balloons entered updrafts rising into cloud with vertical speeds $\sim$0.7 m sec^{-1} in the upper half of the sub-cloud layer. Also, around $p^* = 0.6$, the sonde entered warmer, moister air with properties (θ, r) nearly corresponding to saturation at the measured mean cloud base. The local maximum in mixing ratio $r(m)$ and pressure of the LCL (LCL(m)) visible at $p^* = 0.7$ was taken as an indication of cloud-roots extending below cloud-base to this level, along the line sensed by the rawinsondes. (The fall in r, LCL above $p^* = 0.8$ is related to the poor response of the hygristor above 90% RH.) Figure 2 indicates a likely circulation relative to a cloud in the sheared flow below cloud-base. The mean wind field is basically easterly, and it has been assumed that the cloud moves with a steering level around 900 mb. Whatever the actual circulation, it is clear that the air rising through cloud base does not have the properties of surface air, but probably originated above the surface superadiabatic layer, in the nearly well mixed layer.

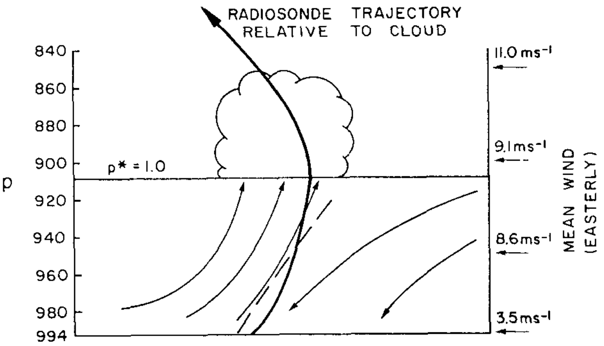

FIG. 2. Suggested circulation relative to a cloud in the sub-cloud layer, indicating how an ascending radiosonde can enter rising moister air in the upper part of the sub-cloud layer.

TABLE 1.

Ascent Number	$p(b)$	$p(m)$	$r_s(b)$	Δr
49	915	951	16.0	0.0
51	912	952	17.1	−0.5
63	921	949	15.4	−0.1
79	909	932	15.9	−0.1
85	906	956	15.8	−0.5
109	886	919	15.1	−0.1
112	914	937	15.8	−0.4
114	868	890	14.0	0.3
115	850	866	14.6	−0.3
141	924	955	16.0	−0.4
156	924	938	16.5	−0.3
172	917	930	16.0	−0.1
198	919	930	16.2	−0.7
254	916	950	16.8	−0.1
Mean Values	(906)	(933)	15.80	−0.24

4. Results

In general, as in Fig. 1, the maximum values $r(m)$, LCL(m) at $p(m)$ were below the cloud-base saturation mixing ratio $r_s(b)$ and pressure $p(b)$. The true value of the mixing ratio at $p(m)$ was assumed to be $r_s(b)$ and the difference $\Delta r = r(m) - r_s(b)$ was calculated (Table 1). Δr is, in general, negative, indicating that the highest mixing ratio recorded in the upper part of the sub-cloud layer is a little below the saturation mixing ratio at cloud-base.

The mean value was $\overline{\Delta r} = -0.24$ g kg^{-1} with a standard deviation of 0.26 g kg^{-1}, corresponding to a systematic error of relative humidity at $p(m)$ of −1.5% and a similar random error. Some of the variance is likely to be due to the uncertainty in cloud-base pressure and some to baseline errors. This value of $\overline{\Delta r}$ would correspond to a temperature difference between hygristor and thermistor of 0.3C (Morrissey and Bousaides, 1970).

In general, carbon humidity element errors are complex functions of ambient temperature, the magnitude of the relative humidity, and the direction in which the relative humidity is changing. For the specific temperatures and humidities encountered during these measurements this temperature difference could be due to residual solar heating of the carbon-strip hygristor (all ascents were in daytime, mostly at 1000 local time), or to the greater thermal lag of the hygristor as the sonde rises through the dry adiabatic layer. If $\overline{\Delta r}$ is attributed solely to thermal lag of the hygristor, it corresponds to a thermal response distance in the vertical of 3 mb.

This hygristor error $\overline{\Delta r}$ is an order of magnitude less than the errors observed at low levels in the tropics with the earlier VIZ sonde (Sanders *et al.*, 1973; Betts, 1973a). However, since the sample represents ascents into cloud, the possibility exists that the instrument was partially shielded from solar radiation. Indeed, it is possible (but unlikely) that the increase in r from $p^* = 0.3$ to 0.7 in Fig. 1 is partly due to the sondes rising into the shadow of the clouds. If this were so, a further error of about -2% in the humidity due to solar radiation is indicated, still much less than with the earlier sonde.

As an indirect check on the magnitude of the humidity error associated with the thermal lag of the hygristor, 25 soundings were selected that showed a marked transition layer at the top of the sub-cloud layer. These were first scaled in pressure so that the base of the transition layer was at $p^* = 1$ and then averaged. The mean profile of θ and r and r_c, corrected for a 3-mb thermal lag in the hygristor (Sanders *et al.*, 1973) is shown in Fig. 3. The shallow transition layer is isothermal and the sub-cloud layer nearly dry adiabatic, so that at $p^* = 1$, the ascending sonde enters a region of constant temperature, from a region where the lapse of temperature is about $-9\mathrm{C}\ \mathrm{km}^{-1}$. The sonde emerges at $p^* = 1.15$ into the cumulus layer where $\partial T/\partial z = -5\mathrm{K}\ \mathrm{km}^{-1}$. A transition like this will show up humidity errors due to thermal lag (Bunker, 1953). Figure 3 shows a slight decrease in the fall of r with height in the transition layer which is removed by the lag correction. This adds confidence to the deduction that the hygristor thermal lag is not large.

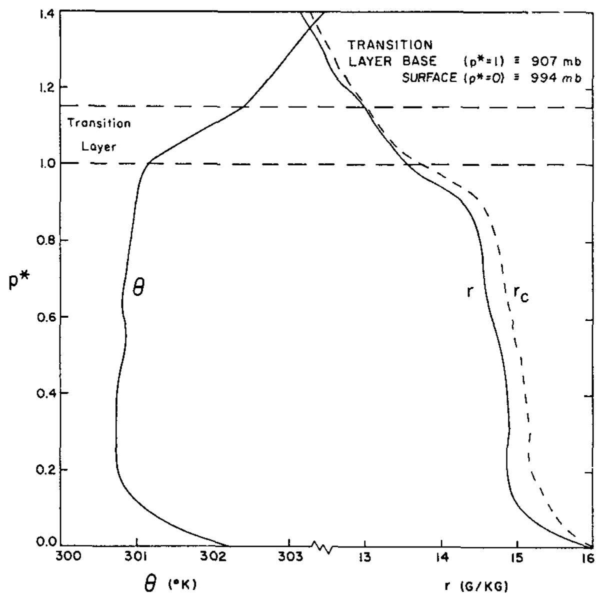

FIG. 3. Average of 25 radiosonde ascents which showed a marked transition layer, showing profiles of θ, r and r_c (mixing ratio corrected for 3-mb thermal lag of the hygristor).

5. Conclusion

The careful observation and timing of the disappearance of a radiosonde balloon through cloud-base is an important measurement, both for the study of the structure of the atmosphere below cloud, and for the assessment of the accuracy of radiosonde humidity measurements. This study showed humidity observations from the VIZ 1290 series radiosonde were about 2% too low in the sub-cloud layer. If attributed to thermal lag of the hygristor, this corresponds to a lag of 3 mb in the vertical.

It is also clear that shallow, tropical cumulus over land have roots in the sub-cloud layer. Furthermore, the air rising through cloud-base has properties (θ, r), which are closer to those of the nearly well mixed sub-cloud layer air than to the air near the surface, thus confirming one assumption of the sub-cloud layer model proposed in Betts (1973b).

Acknowledgments. The VIMHEX II experiment was supported by the Office of Naval Research under Contract No. N00014-68A-0493-002, the Atmospheric Sciences Section of the National Science Foundation under Grant GA-33182, the Meteorological Service of the Venezuelan Air Force, and the Facilities Laboratory of the National Center for Atmospheric Research.

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