W O R L D   M E T E O R O L O G I C A L   O R G A N I Z A T I O N

INSTRUMENTS AND OBSERVING METHODS

REPORT No. 10

HUMIDITY MEASUREMENT

RADIATION EFFECTS ON THE WMO REFERENCE PSYCHROMETER IN THE FIELD

by

R.G. Wylie & T. Lalas
CSIRO, Australia

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$$(\delta T)_{B,A} = (\varepsilon_{B,S} - \varepsilon_{A,S})(\Delta T)_S + (\varepsilon_{B,T} - \varepsilon_{A,T})(\Delta T)_T \quad \ldots.(2)$$

or, numerically,

$$(\delta T)_{B,A} = 0.84(\Delta T)_S + 0.95(\Delta T)_T. \quad \ldots.(3)$$

Analogously,

$$(\delta T)_{L,A} = 0.05(\Delta T)_S + 0.95(\Delta T)_T. \quad \ldots.(4)$$

Solving (3) and (4), we obtain

$$(\Delta T)_S = 1.27[(\delta T)_{B,A} - (\delta T)_{L,A}] \quad \ldots.(5)$$

and

$$(\Delta T)_T = 1.12(\delta T)_{L,A} - 0.07(\delta T)_{B,A} \quad \ldots.(6)$$

Equations (5) and (6) allow $(\Delta T)_S$ and $(\Delta T)_T$ to be calculated from the experimental results for any particular set of conditions.

As the normal dry element of the reference psychrometer has the same surface as element A, then, for the same particular set of conditions, the extraneous radiation would raise its temperature by the amount given by (1), or, numerically, by

$$(\Delta T)_A = 0.14(\Delta T)_S + 0.03(\Delta T)_T \quad \ldots.(7)$$

This can be evaluated using the values of $(\Delta T)_S$ and $(\Delta T)_T$ given by (5) and (6).

If the normal wet cotton-sleeve covered element were in the psychrometer for the particular set of conditions, the extraneous radiation would raise its temperature by an amount which is a little more difficult to calculate, because h and h_W differ considerably. It was shown by Wylie in Annex IV of the 1969 Final Report that, because of the effect of the evaporation process, the effective total heat-transfer coefficient h_W is j times the value which would occur if evaporation did not take place, j being given by

$$j = \frac{Ap + \beta}{Ap}, \quad \ldots.(8)$$

where A is the psychrometer coefficient, p is atmospheric pressure, and β is the rate of change of the saturation vapour pressure of water with temperature at the wet-element temperature. (It should be noted that j depends on the wet-element temperature, and hence on the temperature and humidity.) We therefore have

$$(\Delta T)_W = \frac{1}{j}\,[\varepsilon_{W,S}(\Delta T)_S + \varepsilon_{W,T}(\Delta T)_T] \qquad \ldots.(9)$$

or numerically,

$$(\Delta T)_W = \frac{1}{j}\,[0.59(\Delta T)_S + 0.98(\Delta T)_T] \qquad \ldots.(10)$$

The values of $(\Delta T)_A$ and $(\Delta T)_W$ calculated from (7) and (10) are the radiation errors in the observed dry- and wet-element temperatures respectively. The corresponding error in the derived relative humidity can be calculated using the psychrometer equation. It can be calculated for the air temperature and humidity which actually accompanied the particular radiation conditions, or for any other temperature and humidity hypothetically regarded as accompanying those conditions. (In the latter case, j must be evaluated for the hypothetical temperature and humidity.)

5. MEASUREMENTS

Experiments were carried out between 9.00 a.m. and 3.00 p.m. on a number of days in approximately mid-winter and mid-summer. Conditions involving a clear sky, a hazy sky or sky dotted with isolated clouds, and complete cloud cover, were included for each season. Each experiment involved the continuous recording of $(\delta T)_{B,A}$ and $(\delta T)_{L,A}$ in consecutive runs until representative values could be read from the records. (It would, of course, have been better to have recorded the two quantities simultaneously, but only one instrument was available.) The actual temperature differences were thereby obtained well within ±0.01°C. Each experiment further involved doing this for three orientations of the instrument, in which

(a) the elements viewed only the sky (elevation 45°),

(b) the instrument was horizontal, and

(c) the elements viewed only the ground (elevation -35°).

The azimuth of the direction of the instrument was more or less opposite to that of the sun. There were 33 experiments in all.

Although the air temperature was about 30°C in summer, as compared with about 15°C in winter, there is no significant difference between the values of $(\Delta T)_S$ and $(\Delta T)_T$ for the two seasons. Accordingly, the results for the two seasons have been lumped together for purposes of their analysis. They relate to ventilation at the standard airspeed of 4.5 m/s.

6. RESULTING VALUES OF $(\Delta T)_S$ AND $(\Delta T)_T$

(a) Instrument directed skywards. Both for clear-sky conditions and conditions of a hazy sky or sky dotted with isolated clouds, $(\Delta T)_S$ and also $(\Delta T)_T$ varied from about -0.3°C to +0.3°C. It would appear that the scattering ability of an apparently clear sky varies over a considerable range. With complete cloud cover, only positive values of $(\Delta T)_S$ were encountered, again ranging up to about 0.3°C, while values of $(\Delta T)_T$ ranged from about -0.07°C to +0.2°C. However, as cloud temperature varies considerably with cloud height, $(\Delta T)_T$ might be expected sometimes to attain considerably larger negative values.

(b) Instrument directed groundwards. In this case, a few very small negative values of $(\Delta T)_T$ were encountered, but otherwise the values of $(\Delta T)_S$ and $(\Delta T)_T$ were positive. Also, the values for total cloud cover were generally smaller than those for the other conditions. The values of $(\Delta T)_S$ for all sky conditions ranged up to about 0.3°C and those of $(\Delta T)_T$ up to about 0.2°C.

(c) Instrument horizontal. The results were intermediate between those for the skywards and groundwards orientations, as is to be expected.

7. CORRESPONDING ERRORS IN THE RELATIVE HUMIDITY AND TEMPERATURE

The individual values of $(\Delta T)_S$ and $(\Delta T)_T$ obtained from each experiment, which are naturally correlated, have been used to calculate the corresponding radiation errors that would occur in the relative humidity and air temperature given by the normally constituted reference psychrometer. This has been done for a temperature of 20°C and relative humidities of respectively 20, 50 and 80%. The resulting values take into account the correlation between $(\Delta T)_S$ and $(\Delta T)_T$.

The relative-humidity errors, averaged over all sky conditions, are given in Table I. The table also gives the standard deviations of the values averaged. The errors for the three separate sky conditions are given in Table II.

A comparison of Table I with Table II shows that the small average error values in the first table for direction of the instrument towards the sky do not represent a consistently low error but a favourable average over sky conditions. For this reason, the standard deviation is more a measure of variation than a guide to the probabilities of values.

The values in Table II show that relatively large radiation errors can occur not only when the instrument is directed towards the sky, but also when it is directed towards the ground. However, regardless of the sky condition, the error for the horizontal position is intermediate between those for the other positions. Further, it is considerably smaller in magnitude than the larger of those for the other positions, and is associated with the smallest standard deviation. Therefore, as the effect of the sky condition is to be ignored in using the instrument, the horizontal position is distinctly preferable for relative humidity measurement.

Because the smallness of the radiation error in the relative humidity when the instrument is horizontal obviously depends on the dry and especially the wet element being able to 'see' both the sky and the ground, a conclusion as to the magnitude of the error likely in practice must be drawn in a conservative manner. Looking at the last

RADIATION ERROR IN THE RELATIVE HUMIDITY (IN % r.h.)

TABLE I

INSTRUMENT DIRECTED TO	NUMBER OF EXPERIMENTS	20% r.h.		50% r.h.		80% r.h.	
		MEAN ERROR	STANDARD DEVIATION	MEAN ERROR	STANDARD DEVIATION	MEAN ERROR	STANDARD DEVIATION
SKY	33	+0.09	0.41	+0.05	0.37	+0.01	0.34
GROUND	32	+0.31	0.20	+0.27	0.18	+0.23	0.17
HORIZON	27	+0.20	0.14	+0.15	0.12	+0.10	0.11

TABLE II

	CLEAR SKY				HAZE OR CLOUD				TOTAL CLOUD COVER			
		MEAN ERROR				MEAN ERROR				MEAN ERROR		
INSTRUMENT DIRECTED TO	NUMBER OF EXPERIMENTS	20% r.h.	50% r.h.	80% r.h.	NUMBER OF EXPERIMENTS	20% r.h.	50% r.h.	80% r.h.	NUMBER OF EXPERIMENTS	20% r.h.	50% r.h.	80% r.h.
SKY	10	-0.16	-0.16	-0.16	15	+0.09	+0.04	-0.02	8	+0.36	+0.30	+0.23
GROUND	10	+0.45	+0.40	+0.36	14	+0.35	+0.30	+0.24	8	+0.12	+0.10	+0.08
HORIZON	9	+0.17	+0.13	+0.09	14	+0.22	+0.16	+0.10	4	+0.24	+0.19	+0.14

line in Table II, we see that the values do not vary much from one sky condition to another. Here we will first adopt the largest values given in Table I for the horizontal orientation, namely 0.20% relative humidity for the average radiation error, and 0.14% relative humidity for the associated standard deviation, which occur for the lowest relative humidity.

Taking the uncertainty at the 95% confidence level to be twice the standard deviation, its value is 0.28% relative humidity. We may combine this uncertainty statistically with that which arises from the uncertainties in the wet- and dry-element temperatures and the value adopted for A, which amounts to 0.30% relative humidity, and so obtain a value of 0.41% relative humidity. Then, on the basis that no correction will be applied for the average radiation error, we may conservatively obtain an effective uncertainty simply by adding the magnitude of this error to the uncertainty of 0.41% relative humidity, to obtain a value of 0.61% relative humidity. However, while the value that would be obtained for higher temperatures (higher than 20°C) is less than this, the value that would be obtained for the allowed lower temperatures is slightly greater. Consequently, to obtain a general result, we round the value to 1% relative humidity.

This uncertainty is only about a third of the minimum required uncertainty for routine surface measurements of humidity, as estimated by Hawson (WMO-No.267.TP.151), and so is satisfactory for a reference standard instrument.

The results for the radiation error in the observed air temperature are more straightforward to interpret, and need no tabulation. Averaging over the different sky conditions, the mean value is about 0.025°C for each direction of the instrument. The standard deviation for direction towards the sky is 0.026°C, while that for each of the other directions is only about half this value. (There were approximately 30 experimental values for each case.) Thus, the horizontal direction, which has been seen above to be superior for relative humidity measurement, is as good as, or better than, either of the other directions as regards air-temperature measurement.

For the horizontal instrument, the average radiation error in the observed air temperature is found to be 0.026°C and the associated uncertainty to be 0.024°C. Combining the latter statistically with the uncertainty of 0.03°C contributed by the thermometry, we get a value of 0.038°C. Finally, on the basis that no correction will be applied for the average radiation error, and by analogy with the procedure followed for the uncertainty in the humidity, we conservatively add the average radiation error to this value to obtain an effective uncertainty of 0.64°C, and round this to 0.07°C. Unlike the corresponding uncertainty in the humidity, this value is approximately valid regardless of the temperature and humidity.

The uncertainty is less than half the minimum required uncertainty for routine surface measurements, as estimated by Hawson (*loc. cit.*), and so the reference psychrometer could serve as the reference standard for air-temperature measurement as well as for relative humidity measurement.

It should be noted that, above a snow covered surface, high values of $(\Delta T)_S$ could almost certainly give rise to larger errors in the relative humidity and air temperature than found for a grassed surface. Over a bare sand surface, high values of both $(\Delta T)_S$ and $(\Delta T)_T$ could probably give rise to larger errors.

8. CONCLUSIONS

When the reference psychrometer is operated above a level area covered with short grass, the axis of the psychrometer should be approximately horizontal.

The uncertainties contributed by extraneous radiation to the relative humidity and air temperature given by the reference psychrometer are comparable in magnitude with those which arise collectively from the effects of the uncertainties in the wet- and dry-element temperatures and the value adopted for the psychrometer coefficient, the latter uncertainties having the maximum values consistent with the specification for the psychrometer.

On the basis that no corrections will be applied for the average radiation errors, so that any estimates of uncertainties must include an allowance for the average errors as well as for the uncertainties in the errors, effective overall uncertainties have been estimated conservatively for the relative humidity and the air temperature. These estimates do not exceed respectively one third of the minimum required uncertainty in the relative humidity and one half of the minimum required uncertainty in the air temperature, as given for surface meteorological measurements by Hawson (WMO-No.267.TP.151).

The reference psychrometer could therefore serve as the reference standard for surface meteorological measurements of air temperature as well as of humidity.