THE APPLICATION OF RADIOSONDES TO METEOROLOGY

By O. M. Ashford, B.Sc.

A paper by R. Schulze, entitled "Zum Einsatz der Radiosonde in der Meteorologie und Ballistik. Aufgaben und Forderungen, Typisierung", formed the subject of a Meteorological Office Discussion which was held at the Science Museum on February 23, 1948. As the original paper has not been published and as the discussion covered a field likely to be of general interest to meteorologists, it was decided to present an account in the form of a general article rather than as a brief report on the discussion. The part of Schulze's paper which deals with the classification of radiosondes is omitted and in view of the recent articles on wind measurement by Harrison (*Met. Mag.*, October 1947) and Scrase (to be published shortly in *Weather*) this aspect is only dealt with very briefly. No attempt has been made to follow Schulze's arguments in detail and a great deal has been included from other sources.

ACCURACY

The application of radiosondes has developed so rapidly in recent years that it is easy to forget that they are still relatively new tools for the meteorologist, and that we ought continually to be reviewing the questions: "What accuracy is required from radiosondes?" and "What accuracy do we obtain from radiosondes?" Before we can answer these questions, however, we must answer another: "What do we mean by accuracy?" Petterssen and Sheppard, in a paper submitted to the recent I.M.O. meeting in Toronto, suggest that the most satisfactory method of expressing the standard of performance for meteorological purposes is a 90 per cent error (hereafter called the "allowable" error), which is the error not exceeded in 90 per cent of the observations. If the distribution is normal, this allowable error is 2·43 times the probable (or 50 per cent) error.

TABLE 1. Accuracy requirements for radiosonde observations (after Schulze).

	Temperature		Relative humidity		Pressure		Wind	
	acceptable	desirable	acceptable	desirable	acceptable	desirable	above 10 m./s.	below 10 m./s.
Meteorology	±0·5° C.	±0·4° C.	±5%	±3%	±5 mb.	±100 m.	±2m./s.	±1m./s.
Ballistics	±0·5° C.	±0·4° C.	±5%	±3%	±4 mb.	±100 m.	±1m./s.	±1m.s/.

NOTES: The "desirable" pressure accuracies are given in terms of the corresponding height intervals.
Only "acceptable" values are given for wind.

We must also distinguish between random and systematic errors. For many purposes a fairly large systematic error is permissible, e.g. in computing lapse rates no error is incurred in the result if all the temperature readings are in error by an equal amount. Some systematic errors are characteristic of a particular type of radiosonde and are, therefore, only of secondary importance for synoptic work provided that all the other stations in the network are using the same type of instrument.

Schulze estimates values for two classes of accuracy, the "acceptable" accuracy and the "desirable" accuracy. He does not define these in any strict mathematical sense, but it seems reasonable to assume that his "desirable" figures are comparable with the allowable error defined above. His "acceptable" accuracy is the minimum that would be tolerated for present-day use in Germany. A summary of his estimates is given in Table 1.

Petterssen and Sheppard estimate the allowable error both in the measured wind and in the evaluated geostrophic wind as 2·5 m./s. The geostrophic wind error may be stated alternatively as an allowable error of 0·6° C. in the mean temperature of the air column between 1,000 and 750 mb. when the observing stations are 300 km. apart. The corresponding errors for the 1,000–500 mb. and the 1,000–300 mb. columns are 0·3° C. and 0·2° C. respectively. Petterssen and Sheppard also state that the allowable error in the evaluated lapse rate is 0·4° C. over a height of 300 m.

Turning to the question of what accuracy is obtainable from current types of radiosondes, it must be remembered that in the absence of any absolute standard of comparison it is very difficult to do more than estimate the random errors of one particular type of instrument and the systematic differences between different types. There is an obvious need for an "absolute" radiosonde to be used as a yardstick for measuring the absolute errors of all routine types.

Dymond (*Proc. Phys. Soc.*, Vol. 59, 1947, pp. 645–666) estimates the random probable error of the Kew pattern radiosonde as ±5 mb., ±0·4° C. and ±10 per cent in pressure, temperature and relative humidity, respectively. The humidity figures only apply to temperatures above –20° C., below which the hygrometer element becomes unreliable. The chief systematic errors in temperature are those due to lag and radiation. The thermometer takes 4·5 seconds to indicate 50 per cent of a sudden change of temperature in an air stream of 5 m./s. at normal density. The resulting error in temperature when the lapse rate is 6° C. per km. and the radiosonde is rising at the normal rate of ascent is +0·2° C. at low levels, increasing to +0·45° C. at 200 mb. The radiation error is difficult to assess, but Dymond considers that it does not exceed +0·5° C. at heights up to 15 km. It is difficult to compare Dymond's figures with Petterssen and Sheppard's stated requirements because of the different method of presentation, but it is fairly obvious that there is still considerable room for improvement in the performance of radiosondes.

Before considering improvements in the design of the instruments, it is worth while examining briefly the desirability of applying corrections for lag and radiation errors. The lag errors must be very uniform for a given type of radiosonde, and can be safely neglected for many purposes. Where upper air analyses are based on observations from several different types of radiosonde and for ballistic applications, it would, however, be worth while applying a correction. Before doing so, the lag would have to be measured very carefully at different rates of ascent and different air densities. Experimental verification of the significance of the corrections could be obtained by making some special radiosonde ascents to a limited height of, say, 10 km. and comparing the ascent with the descent—if the instrument is carried to greater heights, the gradual failure of the battery introduces complications.

Schulze assumes that radiosonde observations are corrected for radiation error by the Väisälä method (*Mitt. des Met. Inst. der Universitaet Helsinki*, No. 47, 1941). This method is based on the assumption that there is no true diurnal variation of air temperature in the stratosphere, but recent work has thrown suspicion on the validity of this assumption. As the radiation error of the Kew radiosonde is so small, it is probably safer with this instrument not to apply any corrections until more is known about diurnal temperature variations in the stratosphere.

An accuracy of ±5 mb. and ±0·5° C. in pressure and temperature, respectively, corresponds to an accuracy of ±0·5 per cent of the overall range to be covered by a radiosonde. It is interesting to note that British Standard Specification 89, 1937, which deals with the accuracy of electrical measuring instruments, calls for a range percentage accuracy of between 0·2 and 0·6 per cent in the case of substandard instruments and between 0·75 and 3·5 per cent for first grade instruments. These figures do not include errors due to external causes, such as voltage variation and ambient temperature. Further, if recording is called for, the B.S. Specification relaxes the accuracy for first grade instruments to between 2 and 4 pe1 cent. Clearly, we are expecting a lot from a radiosonde if it has to be of comparable accuracy to a sub-standard instrument and yet be capable of being roughly handled at the launch, of providing a telemetering link between the balloon and the ground station, and possibly of including a recorder, quite apart from expecting it to be very cheap and simple to use. The cost of instruments increases rapidly as the required accuracy increases, and the final design of any normal radiosonde must be a compromise between accuracy and cost. It is therefore very impcrtant that the user should not demand a greater accuracy than what is really needed.

IMPROVEMENTS IN RADIOSONDE DESIGN

The "absolute" radiosonde mentioned above will only be used in relatively small numbers, and the question of cost is, therefore, of lesser importance for this type of instrument. One obvious way of attempting to improve the accuracy would be to use two or more elements to cover the required range. For example, we might have one aneroid box to cover the range 1,000–500 mb., a second 500–100 mb. and a third 100–20 mb.

Schulze mentions the possibility of using a hypsometer for measuring the pressure, as suggested by Von Schröder in 1936. A possible design is illustrated in Figure 1, the main feature being a device to ensure that the water boils continuously with no possibility of superheating. This is achieved by having a pocket of air below the water and separated from it by a filter which allows the air to pass through to the water as the external pressure decreases.

When used in a radiosonde, if the water is boiling at the beginning of th ascent, it will continue to boil throughout the ascent, provided that heat losse by conduction are small. The chief advantage of the hypsometer is that i

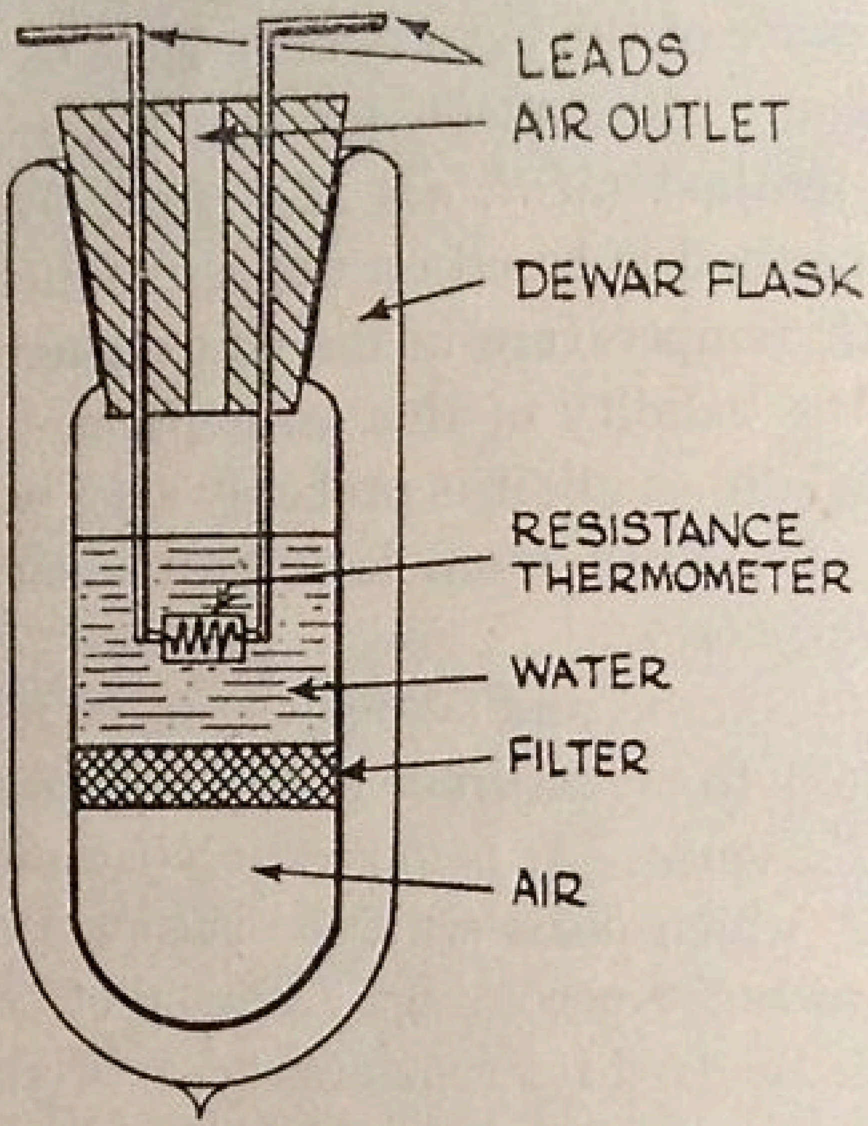

Fig. 1. Proposed design for hypsometer for use in radiosondes.

sensitivity increases rapidly as the pressure decreases, as shown in Table 2. The height interval corresponding to the pressure error in the last column o the table is approximately 30 m. throughout.

Table 2. Variation of boiling point of water with atmospheric pressure.

Pressure (p)	Boiling point of water (t)	Δp for $\Delta t = 0{\cdot}1°$ C.
10 mb.	6·9° C.	0·07 mb.
50 mb.	32·8° C.	0·28 mb.
100 mb.	45·8° C.	0·51 mb.
300 mb.	69·1° C.	1·3 mb.
750 mb.	91·8° C.	2·8 mb.
1,000 mb.	99·7° C.	3·7 mb.

Air temperature might be measured in the absolute sonde by a son velocimeter (an instrument for measuring the velocity of sound). The velocit of sound in air is proportional to the temperature, decreasing about 60 cm. se per degree Centigrade fall of temperature. The advantages over th conventional thermometer are that the lag would be negligible, and wit careful design it should be possible to make the instrument practically fre from radiation errors.

In view of the current use in upper air analysis of the depths betwe standard pressure levels, Sheppard has suggested, as an alternative to th conventional radiosonde, a system in which the height of a radiosonde wou be measured by radar precisely when it passed the various standard press levels. For this system, the pressure device would have to be much mo accurate than the usual aneroid box.

It should also be possible to construct a radiosonde to give a direct measure of the lapse rate. The lag error of a thermometer is proportional to the lapse rate, and the difference in the temperature of two thermometers of different lags would therefore indicate the lapse rate. This type of instrument is probably of little practical value, because it would not respond quickly enough to changes in the lapse rate. Another possibility is to measure the air density directly with an interferometer, but there are considerable technical difficulties. Readings of density would be very useful for providing a check on the pressure and temperature observations ; alternatively, if combined with a measurement of height by radar, they would enable one to deduce the pressure and temperature as required.

Undoubtedly one of the most difficult problems is to design a better radiosonde hygrometer element. In hair and goldbeaters' skin hygrometers, the lag increases so rapidly at low temperatures that the readings are of very limited value below —20° C. Hygrometers using a wet-bulb thermometer are equally unsatisfactory, because the wet-bulb depression becomes very small at low temperatures, e.g. at —20° C. a depression of only 1° C. corresponds to a relative humidity of 40 per cent. The primary cause of these difficulties is that the quantity of water vapour in the air at low temperatures is minute, even under saturated conditions. Schulze is not optimistic about being able to improve very much on existing instruments. Unless some hygrometer is invented which works on a new principle, it is difficult to see any alternative to development of the Dobson-Brewer frost-point hygrometer (*Proc. Phys. Soc.*, January 1948). There is no fundamental reason why this type of hygrometer should not be designed as part of a radiosonde, but the cost will almost certainly be so great as to limit its application to research work and use as an absolute radiosonde.

There are many other interesting lines of development for radiosondes, e.g. the use of rockets instead of balloons, the designing of thermometers insensitive to radiation, and the measurement of other atmospheric properties such as ozone content or electrical potential gradient. The greatest benefit to all concerned will only be achieved if there is a continual interchange of knowledge between the upper air expert and the instrument designer.

FROST

ARTIST, LAPIDARY, ARTIFICER

You take for canvas every window-pane
And thereon grave all darkly in the night,
Needing no pencil, brush or etcher's tool.
Such rich designs of 'canthus foliage,
No Grecian sculptor ever limned or cut
Upon his temple's capital and frieze.

You deal in onyx, opals, diamonds,
And form of some poor rag, forlornly left
To flutter coldly in the wintry wind,
Pectoral and plate more richly dight than that
Which Aaron wore, and string on garden ropes
Gems that outshine a monarch's diadem.

So silently you work, and yet how well!
No hammer's clang or anvil's ring is heard,
Nor boastful engine, neither noise of crane
While now you coat the lake with deck of ice,
Strong as ships' steel, and make of every eave
An armoury of rapiers and of spears.

L. G. H. LEE