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ON THE SOLAR RADIATION ERROR OF THE DIFFERENT RADIOSONDES

by

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Abstract

A short statistical investigation has been made about the radiation error of different radiosondes according to the first international comparison of six various types of radiosonde. The Finnish sonde has the greatest radiation error. The error of French sonde is c. 1/2 of the error of Fi sonde and that of the American sonde is c. 1/3 of the error of Fi sonde. Those of the Swiss and German sondes appear above the 100-mb level. The radiation error of the English sonde appears below 200 mb and seems to be nearly constant above the 100-mb level.

1. *Introduction*

An international comparison of the various types of radiosonde was made at Payerne in May 1950. Observational results [3, 4, 5] were obtained in daylight (abt. 1500 GCT) and in darkness (abt. 2100 GCT). From these the radiation error of the thermometers of the different radiosondes may be investigated. As observations were carried out with 6 different radiosondes: Finnish (Fi), French (Fr), Swiss (S), English (UK), American (US) and German (US_z), the data obtained are most valuable. A radiation error correction system, based on research work, has been developed for the Finnish (Fi) and the American (US) radiosondes.

2. On the radiation error

The radiation from the sun, the diffuse and reflected radiation that originates either directly or is reflected from the instrument to the thermometer, is the primary cause of the radiation error. The radiation, however, also affects the radiation shields, heating them and warming the ventilating air. Thus, to a small amount the radiation error is affected also by radiation from the shields [7]. It is obvious that the radiation warms up the whole instrument, producing heat which is conducted to the thermometer. Moreover, as the various radiosondes differ in design, the different components of the radiation error may differ in detail in each type of radiosonde. Besides, the warming of the radiosonde may also affect the working of the instrument and the results obtained.

In stead of the proper radiation error of the radiosonde thermometer VÄISÄLÄ [9] uses as a practical measure of it the difference between day and night soundings made in the stratosphere. This general and practical definition contains all components of the radiation error. Because of the rather small diurnal variation of temperature in the stratosphere (see the other article of ROSSI in this issue of GEOPHYSICA, p. 218) this definition gives very closely the proper radiation error.

3. Radiation error of the Finnish radiosonde

The determination of the radiation error of the Finnish radiosonde is based on VÄISÄLÄ's [9, 6] definition. Thus the radiation correction on the thermometer of the Finnish radiosonde reduces the temperature measured at day time to the night value. The radiation error ($\triangle T$) is calculated from the formula [6]:

$$(1) \qquad \triangle T = S(h)\ I\ (h,p)\ \sqrt{\frac{300}{v}} \cdot \left(\frac{100}{p}\right)^{0.852}$$

$S(h)$ is a function depending on the elevation angle (h) of the sun, determined experimentally by day-night observations and during the solar eclipse of 1945. $S(h)$ is different in different sondes, depending on differences in the insolation of the thermometer. $I(h,p)$ indicates the relationship between the intensity of incoming solar radiation, the elevat-

ion angle of the sun and the air pressure [10]. In the formula (1), v is the rate of ascent in m/sec., and p the pressure at which the radiation error is calculated. When the rate of ascent remains nearly constant and the value of $I(h,p)$ increases in ascent, the value of the radiation error $\triangle T$ increases with height as $\left(\frac{100}{p}\right)^{0.852}$. This constitutes the most characteristic feature of the radiation error of the radiosonde thermometer.

In calculating the radiation error in connection with sounding, a diagram is plotted in a co-ordinate system based on formula (1) on the reverse side of the calibration curve sheet [6]. The value of $\triangle T$ is given as a function of the elevation angle of the sun, h, and of the logarithm of the air pressure (200—10 mb). In the diagram the effect of the rate of ascent may easily be considered. In routine work when calculating the radiation error below the 200-mb level, the measurement is supposed to be free from radiation error at a pressure of 500 mb. At a pressure of 200 mb the value of the radiation error is taken from the diagram and between 500—200 mb interpolated linearly. From the height of 200 mb upwards, a curve is drawn on the diagram, using the elevation angle of the sun, the pressure and rate of ascent, to indicate the value of $\triangle T$. If, however, $\triangle T$ is computed from formula (1) for the 500-mb height, with the elevation angle of the sun $h > 14°$, $\triangle T$ becomes $> 0.5°$ C and

Table 1. Radiation error of the Fi radiosonde thermometer at different pressure levels at Payerne in May 1950.

Dat.	mb / Gg	950	500	200	100	50	25
11.5.50	14.53	0.4	1.0	2.2	4.2	7.6	13.8
12.5.	14.57	0.4	1.1	2.3	4.2	7.6	
13.5.	15.48	0.4	0.9	2.0	3.8	(7.0)	
15.5.	15.12	0.4	1.0	1.7			
17.5.	14.49	0.5	1.0	2.3	4.5	8.4	16.5
18.5.	15.29	0.4	1.0	1.9	4.2	7.8	
19.5.	14.49	0.4	1.0	1.7	3.9	7.7	14.6
20.5.	15.03	0.4	1.0	2.0	4.1	7.7	(14.5)
22.5.	15.11	0.4	1.0	2.2	4.1	7.7	(12.8)
24.5.	16.11	0.3	0.8	1.6	3.1	5.3	9.9
Mean	$\triangle T_{FI}$	0.4	1.0	2.0	4.0	7.4	13.7

with $h>40°$, $\triangle T>1.0°$ C, and correspondingly for a 1000 mb pressure with $h>9°$, $\triangle T>0.1°$ C, and with $h>30°$, $\triangle T>0.3°$ C. In practice the radiation error is in troposphere uncertain when the clouds change radiation conditions. But the radiation correction according to formula (1) gives a general view for radiation error in lower layers.

For soundings at Payerne in May 1950, the formula (1) was applied when calculating the radiation error of the Fi radiosonde below 200 mb, and above this layer the calculation was made from the diagram based on formula (1). The value of the radiation error at different pressures is given in Table 1. According to these values the thermometer of the Fi radiosonde shows too high temperature, the average of the error being 0.4°C near the earth's surface. The radiation error increases with height, and at a pressure of 25 mb it is about 14 °C.

4. Radiation error of the American (US) radiosonde

Also the radiation error correction of the US radiosonde reduces the observed temperature to the night value [8]. Observations at Payerne were made with two US radiosonde types, AF 403 mc/s and AF 1680 mc/s. Only a few observations were made, however, with the last-mentioned sonde, consequently attention will be paid only to the radiation errors of the first-mentioned. The diagram A2 (U.S. WB) 1 Mars. 1950 shows the radiation error of AF 403 mc/s. When calculating a radiation error at 400 mb, the error is supposed to be 0. The radiation error at 200 mb is taken from the diagram and the layers 400—200 mb are interpolated linearly. Above 200 mb, the value of the radiation error is taken from the diagram.

For the purpose of the observations at Payerne, the value of the radiation error above 200 mb was obtained from the diagram. As I consider it questionable that the radiation error of the thermometer at 400 mb pressure is 0. I estimate the radiation error below 200 mb as proportional to the radiation error of the Fi radiosonde. The value of the radiation error is seen in Table 2. The values in the table show that the radiation error of the US radiosonde thermometer is 0.1°C near the earth's surface, and 0,3° C at 500 mb. The radiation error increases with height, which is also the case with the Fi radiosonde. The value of the radiation error is about 30 per cent of the value of the Fi sonde.

Table 2. Radiation error of the US radiosonde thermometer at different pressure levels at Payerne in May 1950.

Dat.	mb / Gg	950	500	200	100	50	25
11.5.50	15.28	0.2	0.4	0.8	1.2		
12.5.	15.34	0.1	0.4	0.8	1.7	2.9	6.1
15.5.	15.56	0.1	0.3	0.7	1.2		
17.5.	15.12	0.1	0.3	0.7	1.1	2.2	4.9
18.5.	15.14	0.1	0.3	0.8	1.6	3.9	
19.5.	15.29	0.1	0.3	0.6	1.0	2.2	5.9
22.5.	15.01	0.1	0.4	0.8			
24.5.	16.11	0.1	0.3	0.6			
Mean	$\triangle T_{US}$	0.1	0.3	0.7	1.3	2.8	5.6

5. *Radiation errors of the Fr, S, UK and US_z radiosondes*

When using the available data any attempt to get an idea of the radiation error of the other participating radiosondes must, according to VÄISÄLÄ, be based on the difference between the day and night observations, chiefly in the stratosphere. It is true that the time interval between the observations is rather long, about 6 hours, and that, consequently, the temperature variation, due to changes of weather, may unfavourably influence the results, especially as the available material is rather small. For all radiosondes in use at Payerne, calculations were based on observations of day and night temperature differences ($\triangle T_1$) for different pressures. The average differences and the number of pairs of observations are shown in Table 3.

When checking the results it has to be observed that at the beginning of the ascent the elevation angle of the sun was about 40° and at the end about 35°. As the accuracy of the thermometer is not perfect (about $\pm$ 1.5° C) it affects the values in Table 3. I believe, however, that the values will give at least a qualitative description of the radiation error of the different radiosondes. The radiation error of the Fi sonde is greatest. It is in Table 3 greater than the value calculated according to formula (1). This may be due to the above-mentioned factors. The average temperature difference of the Fr sonde is somewhat smaller than that of the Fi sonde. The difference increases with height, as is also the

Table 3. Average day-night temperature difference at different pressure levels by different types of radiosonde according to observations made at Payerne, May 1950.

	mb	200	150	125	100	90	80	70	60
Fi	$\triangle T_1$	3.2	4.6	4.6	6.0	5.6	—	—	—
	n	4	4	3	3	2	1	1	1
Fr	$\triangle T_1$	1.0	2.0	1.8	3.6	4.8	4.5	4.2	4.5
	n	7	7	7	5	4	4	4	4
S	$\triangle T_1$	0.4	—1.0	—0.1	—1.6				
	n	5	5	5	2				
UK	$\triangle T_1$	1.1	1.5	1.5	2.4	1.6	0.9	1.0	2.0
	n	6	6	6	5	3	2	2	2
US	$\triangle T_1$	0.5	0.9	1.3	1.5	1.3	2.6	3.2	2.5
	n	4	4	4	3	3	3	3	2
USz	$\triangle T_1$	0.7	0.2	0.8	1.4	1.7	1.9	2.5	1.3
	n	5	5	5	4	4	4	4	3

case with the Fi sonde. The value of the radiation error of the Fr radiosonde is about 60 per cent of the error of the Fi sonde. Comparatively few observations have been made with S sondes, but it seems that no radiation error appears below the 100-mb level. The values obtained by the UK sondes seem to be nearly constant at different pressures.[1]) Although the above-mentioned factors may influence the results, it seems obvious that the UK sonde differs from the Fi, Fr, and US sondes, where the radiation error increases distinctly in ascending. Observations made with US radiosondes show that the average value of the day-night temperature difference is about the same as the radiation error derived from the diagram. The data obtained with US_z radiosondes show that the value of the radiation error is smaller in lower than in higher levels. The average value indicates that the radiation error of US_z sondes, below the 100-mb level, is very small [2]. In higher levels it is smaller than the radiation error of the US radiosonde.

In simultaneously made temperature observations, the corrected temperature of the Fi or US sondes was used as basis and the difference

[1]) According to daily soundings in Crawley ($\varphi = 51° 05'$ N, $\lambda = 00° 13'$ W) from May 20 to July 20 1953 the difference between day and night observations increases with height from 200 mb (1,7° C) to 80 mb (4,5° C) and above the 80-mb level is nearly constant 4,5° C [1].

of the other sondes against this basis was calculated. The average values of these differences ($\triangle T_2$) and the number of observations are given in Table 4.

Table 4. Average temperature difference of Fr, S, UK and US_z sondes against corrected temperatures of Fi and US sondes.

	mb	200	150	125	100	90	80	70	60	50	40	30
Fr	$\triangle T_2$	1.0	—0.1	0.5	1.6	2.9	2.6	2.3	3.3	4.2	4.6	6.1
	n	5	5	5	5	5	5	4	4	4	4	3
S	$\triangle T_2$	—0.0	—0.6	—0.0	—0.4	2.3	1.8	1.7	2.4	3.2	3.9	—
	n	6	6	6	5	3	3	2	2	2	2	1
UK	$\triangle T_2$	1.8	1.6	2.3	3.0	2.9	2.1	1.6	2.6	3.0		
	n	4	4	4	2	1	1	1	1	1		
US_z	$\triangle T_2$	—0.9	—0.2	0.6	0.6	1.9	1.2	1.3	1.5	2.0	—	—
	n	2	2	2	2	2	2	2	2	2	1	1

The values in Table 4 indicate somewhat different results than the difference calculated from the day-night observations. None-the-less, they essentially complete the above-mentioned results, even if they largely have to be considered as qualitative. The radiation error of the Fr sonde increases in ascending, the value being hardly 50 per cent of the radiation error of the Fi sonde. Below 100 mb the S sonde thermometer seems to be almost free from radiation error, but above this layer an increase occurs with height. Unfortunately the data obtained with the UK sonde are rather scant, however, the values of an observation above 100 mb seem to confirm the impression that the radiation error remains nearly constant. Below 100-mb level the radiation error of the US_z sonde is relatively small.

As an almost constant radiation error does not seem to be natural ($\triangle T$) dependence on pressure in formula (1)) there must be organs in the UK radiosonde which are influenced by the radiation, compensating the radiation error of the thermometer. In connection with this qualitative study it is not possible to investigate these factors. It is, however, to be hoped that the question will be studied nearly.

6. *Conclusion*

1). According to data available, the 6 radiosondes participating in the comparison may be placed, as far as radiation error goes, in groups:

a) the radiation error increases in ascent: Fi, Fr, S, US and US_z.

b) the radiation error is comparatively constant: UK.

2). The radiation error of the Fi sonde is greatest. The radiation error of the Fr sonde is 40—60 per cent of the Fi sonde. That of the S and US_z sondes appears above the 100-mb level. The radiation error of the US sonde is about 30 per cent of the Fi sonde. That of the UK sonde already appears below the 200-mb level and is nearly constant above the 100-mb level.

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