Clear sky radiation measurements at Lerwick

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SUMMARY

Measurements of direct solar radiation in clear sky conditions at Lerwick showed that aerosol absorbs about 3 per cent of the incident radiation per unit air mass, with no appreciable diurnal variation. Systematic variations were found in the sensitivity of a Kipp solarimeter.

1. INTRODUCTION

In an analysis of global and diffuse solar radiation measurements in cloudless conditions made in a number of places, Robinson (1962) deduced that at Lerwick and Malta, where the atmosphere might be expected to be clean, the absorption attributed to aerosol at noon exceeded 10 per cent and decreased irregularly as the solar elevation decreased. Further observations were made at Lerwick in June 1963 in very clear conditions, and Hamilton and Collingbourne (1967) confirmed Robinson’s findings and concluded that either the sensitivity of the solarimeter varies systematically, or that there is an unknown gaseous absorber with a very pronounced noon maximum.

2. MEASUREMENTS IN 1968

Measurements were made at Lerwick in June 1968 of the normal incident radiation, $I$, by an Angström pyrheliometer (No. 24). This was compared with the Kew Angström pyrheliometer (recently calibrated at Stockholm) beforehand and afterwards: in both cases the agreement was better than 1 per cent. Though there was at times some light cirrus cloud good observations were made in a very clear atmosphere in the mornings of 5 and 6 June and in the afternoon of 17 June. The values of the diffuse radiation $D$ as measured by the operational diffuse solarimeter are plotted against sin $h$, where $h$ is the solar elevation, in Fig. 1 (a). Observations on other days when cirrus cloud was visible showed that this had a marked effect on $I$ and $D$ and on these chosen days observations have been rejected if the value of $D$ exceeded the value of the mean curve in Fig. 1 (a) by 1 mW cm$^{-2}$—it being assumed that cirrus too close to the sun to be visible was diffusing the direct radiation. Thus measurements of diffuse radiation have been used to select the observations when it may be confidently accepted that the sky was clear of all but the thinnest invisible cloud.

3. AEROSOL ATTENUATION

The individual values of $I$, measured by the Angström pyrheliometer in 1968 are plotted as circles in Fig. 1 (b), the mean of two readings taken within a period of ten minutes is plotted as a cross. The mean curve may be taken as representing the normal value of $I$ for a clear day in early June in Lerwick. From this curve the values of $I$ for selected values of sin $h$ have been entered in Table 1. Robinson’s (1962) tables have been used in estimating $\Delta I$, the loss in radiation due to Rayleigh scattering, and absorption by ozone and water vapour. The attenuation due to aerosol is obtained by subtracting this accountable radiation, $I + \Delta I$, from the radiation incident on the atmosphere which has been taken to be 134 mW cm$^{-2}$ (solar constant 1.38 mW cm$^{-2}$, radius vector 1.014). It should be noted that this calculated difference is very sensitive to errors in this assumed value of the solar constant, the estimates of attenuation due to Rayleigh scattering, and of absorption by water vapour and ozone, and to experimental errors. The aerosol attenuation values might be as much as 3 mW cm$^{-2}$ in error. However, it can be seen that these attenuation values vary almost linearly with $m$, while the 1963 Lerwick measurements, in the form given by Paltridge (1969) showed no variation of attenuation with air mass.

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Figure 1 (a) and (b). Variation of diffuse and normal incident radiation with solar elevation under clear sky conditions.

**TABLE 1. MEASURED AND COMPUTED RADIATION COMPONENTS**

<table>
<thead>
<tr>
<th></th>
<th>sin h</th>
<th>Air mass, m</th>
<th>Direct radiation, I</th>
<th>Estimated attenuation, ΔI</th>
<th>I + ΔI</th>
<th>Aerosol attenuation</th>
<th>Diffuse radiation D</th>
<th>Model diffuse radiation, ( D_0 )</th>
<th>(( D - D_0 )) cosec ( h )</th>
<th>Down/up scattering ( f )</th>
<th>Aerosol scattering</th>
<th>Aerosol absorption</th>
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<tbody>
<tr>
<td></td>
<td>0.3</td>
<td>3.30</td>
<td>60.0</td>
<td>47.0</td>
<td>107.0</td>
<td>27.0</td>
<td>7.0</td>
<td>3.8</td>
<td>10.7</td>
<td>2.0</td>
<td>16.0</td>
<td>11.0</td>
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<tr>
<td></td>
<td>0.4</td>
<td>2.49</td>
<td>70.5</td>
<td>4.0</td>
<td>110.5</td>
<td>23.5</td>
<td>8.0</td>
<td>4.3</td>
<td>9.2</td>
<td>2.5</td>
<td>12.9</td>
<td>10.6</td>
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<tr>
<td></td>
<td>0.5</td>
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<td>78.5</td>
<td>35.8</td>
<td>114.3</td>
<td>19.7</td>
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<tr>
<td></td>
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<td>1.67</td>
<td>85.0</td>
<td>32.6</td>
<td>117.6</td>
<td>16.4</td>
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<td>28.2</td>
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<td>11.5</td>
<td>5.9</td>
<td>7.0</td>
<td>8.0</td>
<td>7.9</td>
<td>4.4</td>
</tr>
</tbody>
</table>

Water vapour content 1.5 cm; ozone 0.375 cm. Unit: mW cm⁻¹
This attenuation consists of scattering and absorption, and the amount due to scattering could be calculated from the measured values of diffuse radiation if we knew accurately the ratio, \( f \), of downward to upward scattering; the aerosol scattering from the incident radiation is equal to \((1 + 1/f) (D - D_0) \cos \theta \), where \( D_0 \) is the model diffuse radiation due to Rayleigh scattering. Robinson (1962) and Hamilton and Collingbourne (1967) used values of \( f \) which increased from 2 to 8 as \( \sin h \) increased from 0·3 to 0·8, and the use of these values leads to the values of aerosol scattering and aerosol absorption shown in Table 1. It can be seen that within the rather large limits of error both the aerosol scattering and the aerosol absorption increase approximately linearly with the air mass.

This reasonable experimental result, obtained from measurements by an absolute radiation instrument, suggests that the apparent anomalous results obtained by Robinson (1962) and Hamilton and Collingbourne (1967) were caused by systematic variations in the sensitivity of the solarimeters. Accordingly the opportunity was taken to calibrate the solarimeter in use against the Ångström pyrheliometer.

4. Calibration of Solarimeter under Operational Conditions

Firstly a comparison was made of \( D^1 \), the value of diffuse radiation obtained from using the standard shade ring correction appropriate to the solar declination, and of \( D \), the value of the diffuse radiation when the solarimeter was shaded by a disk which subtended the same solid angle as the aperture of the Ångström pyrheliometer. It was found that \( D = 1·06 D^1 \) when \( \sin h = 0·8 \), a value agreeing well with Drummond (1956), decreasing with solar elevation to 1·01 when \( \sin h = 0·4 \).

From the simultaneous measurements of \( I \) and \( D^1 \), from which \( D \) is calculated, and from the voltage output, \( V \), measured by a recording potentiometer, of the Kipp solarimeter No. 2389 (and on 17 June an additional solarimeter No. 1670) the sensitivity, \( S \), of the solarimeter was calculated at the time of each clear sky pyrheliometer observation from the equation \( S = V/(I \sin h + D) \). The results are shown in Fig. 2. It can be seen that the sensitivity increases as \( \sin h \) decreases, the increase from \( \sin h = 0·8 \) to \( \sin h = 0·3 \) being about 8·5 per cent. This variation is much larger than that obtained from the sum of the corrections for (a) cosine response, (b) non-linearity and (c) temperature derived from the laboratory work described by Hamilton and Collingbourne (1967). Further laboratory work is being undertaken to settle this difference.

A constant sensitivity was used in computing the 1963 Lerwick solarimeter measurements: when these are corrected using a sensitivity similar to that measured in 1968 values of aerosol attenuation are obtained which vary almost linearly with air mass.

It remains to evaluate the effect of circumsolar radiation if the shading disk of the solarimeter did not perfectly match the aperture of the pyrheliometer. Ångström and Rodhe (1966) have given values of circumsolar radiation as a function of \( m \beta \), where \( m \) is the air mass, \( \beta \) is the coefficient of turbidity defined by

\[
e = \beta \lambda^{-\alpha}
\]

where \( \alpha \) is 1·5 to 2, \( \lambda \) is the wavelength in microns, and \( e \) is the aerosol extinction coefficient given by \( me = \text{aerosol attenuation}/134 \). From Table 1 it is seen that \( e = 0·08 \), \( \lambda^{-\alpha} \) is about

![Figure 2. Variation with solar elevation of apparent sensitivity of two solarimeter under clear sky conditions.](image-url)
3-0 so $\beta$ is about 0·03. For $m\beta = 0·10$ the circumsolar radiation is only 2·5 per cent of the direct solar radiation, so an error of ten per cent in the matching would give rise to only a very small error in the measurement of sensitivity even at the lowest solar elevation.

5. CONCLUSION

Measurements of normal incident solar radiation on a clear day at Lerwick show that the attenuation attributed to aerosol varies almost linearly with the air mass and amounts to 8 per cent per unit air mass, of which about 5 per cent is due to aerosol scattering and about 3 per cent to aerosol absorption. The measurements also showed that the sensitivity of a Kipp solarimeter varied with the solar elevation and azimuth. This variation, and other calibration errors are sufficient to account for the 'anomalous absorption' discussed in previous papers.

ACKNOWLEDGMENT

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REFERENCES

Angström, A. and Rodhe, B. 1966 'Pyheliometric measurements with special regard to the circumsolar sky radiation,' Tellus, 18, pp. 25-33.


