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A comparative real-time trial between the UK Met. Office and Oceanroutes to predict road surface temperatures

John E. Thornes, Birmingham Climate and Atmospheric Research Centre, School of Geography, The University of Birmingham, Birmingham B15 2TT, UK

A comparative trial between the Met. Office and Oceanroutes to predict road surface temperatures for a motorway site in Cumbria was held in the spring of 1994. Hourly data for 26 nights when the minimum road surface temperature was equal to or less than 5 °C have been analysed and the results show no significant difference between the accuracy of the forecast for the two organisations. An end-user specification for road weather forecast providers is also presented.

1. Introduction

The National Ice Prediction Network (NIPN) set up by the Department of Transport in the United Kingdom (Thornes 1991, 1993) now has more than 550 outstations of which 262 (48%) were ‘forecast sites’ during the winter of 1993/94. Only Sweden, also with 550 outstations, has a comparable national network, as shown in Table 1.

Table 1. State of play of road weather information systems around the world as of 1 September 1994

<table>
<thead>
<tr>
<th>County</th>
<th>Thermal mapping (km)</th>
<th>Road weather outstations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Europe</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Austria</td>
<td>0</td>
<td>280</td>
</tr>
<tr>
<td>Belgium</td>
<td>5000</td>
<td>0</td>
</tr>
<tr>
<td>Denmark</td>
<td>500</td>
<td>160</td>
</tr>
<tr>
<td>Finland</td>
<td>500</td>
<td>150</td>
</tr>
<tr>
<td>France</td>
<td>750</td>
<td>200</td>
</tr>
<tr>
<td>Germany</td>
<td>0</td>
<td>200</td>
</tr>
<tr>
<td>Holland</td>
<td>1800</td>
<td>300</td>
</tr>
<tr>
<td>Italy</td>
<td>0</td>
<td>40</td>
</tr>
<tr>
<td>Luxembourg</td>
<td>200</td>
<td>20</td>
</tr>
<tr>
<td>Norway</td>
<td>3500</td>
<td>20</td>
</tr>
<tr>
<td>Spain</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Sweden</td>
<td>15000</td>
<td>550</td>
</tr>
<tr>
<td>Switzerland</td>
<td>1000</td>
<td>440</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>60000</td>
<td>550</td>
</tr>
<tr>
<td>North America</td>
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<tr>
<td>USA</td>
<td>1000</td>
<td>350</td>
</tr>
<tr>
<td>Canada</td>
<td>400</td>
<td>10</td>
</tr>
<tr>
<td>Others</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Japan</td>
<td>300</td>
<td>4</td>
</tr>
<tr>
<td>Totals</td>
<td>88250</td>
<td>3121</td>
</tr>
</tbody>
</table>

Until recently, the Met. Office was the only supplier of road weather forecasts via the Open Road service (Open Road is a registered trademark of the UK Met. Office); however, since the winter of 1989/90 Oceanroutes have also offered a comparable service and many Highway Authorities are now going out to tender for a forecast provider. For the winter of 1993/94, of the 262 forecast sites, the Met. Office provided for 237 (90.5%) and Oceanroutes 25 (9.5%) with a total turnover between them of approximately £1.5 million. In order to provide quantitative evidence as to the accuracy of the two services the Vaisala TMI (representing authorities with Vaisala Road Weather Systems) User Group organised a ‘head-to-head’ trial between the Met. Office and Oceanroutes for a site in Cumbria. Previous trials in 1990 and 1992 (unpublished) have shown that the Met. Office was significantly more accurate than Oceanroutes. For example, in the Welsh Office trial (1992) for 82 nights, in predicting the minimum road surface temperature the Met. Office had a bias of −0.47 °C with a root mean square error of 1.55 °C, compared with Oceanroutes’ bias of −1.4 °C and a root mean square error of 2.26 °C.

2. Data collection

From the 23 February 1994 until the end of March 1994 the Met. Office (Newcastle Weather Centre) and Oceanroutes (based in Aberdeen) both provided hourly forecast road surface temperatures for the Catterlen site on the M6 motorway near Penrith (Figure 1). This site was not previously a forecast site and therefore both parties had no previous experience of forecasting for this site, although the Met. Office Weather Centre at Newcastle has provided the Open Road service for Cumbria for many years. Catterlen is a typical motorway site, well exposed and at a height of approximately 200 m.
Data for 34 nights in the period considered were available for analysis, of which on 26 nights the minimum road surface temperature fell to 5°C or below and on 6 nights to 0°C or below (Table 2).

The Met. Office and Oceanroutes were able to obtain the actual road surface and atmospheric conditions by dialling-in to the Cumbria Instation (which stores data from all the Cumbria sensors) based in Carlisle. Normally, 24-hour forecasts are issued at about 1300 using an energy balance model (the Met. Office use their own model, Rayor (1987), and Oceanroutes use an American Model developed by Surface Systems in St Louis) that is initialised at noon. Oceanroutes did not choose to use the observed noon road surface temperature to initialise their model but chose instead whatever they thought would be the most appropriate road surface temperature. The Met. Office, on the other hand, always used the observed noon road surface temperature and therefore no analysis of the noon road surface temperature accuracy has been made. The mean time of issue of the Met. Office forecast for the 34 nights considered was 1322 and for Oceanroutes was 1314.

3. Performance accuracy and error analysis

There are a number of ways in which the accuracy of a weather forecast can be assessed. For the purposes of this trial the hourly forecasts of road surface temperature at Catterlen and the predicted minimum road surface temperature issued by the Met. Office and Oceanroutes have been compared with the observed road surface temperatures at the site. The road sensor is a Vaisala DRS12 located in the fast lane of the south-bound carriageway and the data were stored on the Cumbria Instation. The Met. Office forecast was also stored on the Cumbria Instation, whereas the Oceanroutes forecast was faxed on a daily basis. The Met. Office and Oceanroutes were asked at the end of the trial period to provide the hourly forecast data on disk and these data were then checked against the original issued forecasts.

Complete data sets for 34 nights have been analysed to give the mean hourly bias and root mean square error. For the 26 nights when the minimum road surface temperature fell to 5°C or below: Type 1 (no frost forecast but frost occurs: potential accidents) and Type 2 (frost forecast but no frost occurs: potential wasted salt) errors have been identified and a percentage accuracy figure calculated. The threshold level of 5°C or below is taken from the Department of Transport end-user minimum specification for road weather forecasts as shown in the Appendix. The threshold of 5°C was chosen by the Department of Transport for the calculation of end-of-season statistics in consultation with the Met. Office and Oceanroutes. Highway engineers are only interested in nights when salting might have been considered and 5°C is considered a reasonable cut-off threshold. Note that for the purpose of the trial 0°C is considered to be a frost and that a frost is therefore defined as when the road surface temperature falls to 0°C or below irrespective of the road surface condition. Note that a Type 1 error that can lead to accidents is much more serious than a Type 2 error which can mean wasted salt. Also, in economic terms a Type 1 error is potentially more expensive in that a fatal accident is valued at nearly £1 million whereas to salt unnecessarily a county may cost of the order of £20,000.
Comparison between predictions of road surface temperatures

4. Accuracy of minimum road surface temperature forecasts

Table 2 shows the minimum road surface temperature forecasts and actual minimum road surface temperature for the 34 nights for both Oceanroutes and the Met. Office. Both forecasts exhibit a negative bias; the mean bias for all 34 nights is identical at −0.48 °C for both the Met. Office and Oceanroutes. The root mean square error is 1.52 °C for Oceanroutes and 1.48 °C for the Met. Office. These results show that the Met. Office accuracy has changed little since the 1992 Welsh Office trial whereas the Oceanroutes accuracy has improved significantly.

Figure 2 shows the forecast minimum road surface temperature and actual minimum road surface temperature for the 26 nights when the minimum road surface temperature was ≤5 °C. For these nights the Oceanroutes bias is reduced to −0.14 °C with a root mean square error of 1.2 °C compared with a reduced Met. Office bias of −0.38 °C with a root mean square error of 1.5 °C. This shows that Oceanroutes produced more accurate minimum road surface temperature forecasts than the Met. Office for the critical nights when the minimum road surface temperature was ≤5 °C.

5. Mean hourly bias and mean hourly root mean square error

Figure 3 shows the mean hourly bias for Met. Office and Oceanroutes for the 34 nights considered. It can

Table 2. The actual and forecast minimum road surface temperatures at the Catterlen site for the 34 nights considered in 1994

<table>
<thead>
<tr>
<th>Date</th>
<th>Actual</th>
<th>Forecast</th>
<th>Category</th>
<th>Error</th>
<th>Date</th>
<th>Actual</th>
<th>Forecast</th>
<th>Category</th>
<th>Error</th>
<th>Date</th>
<th>Actual</th>
<th>Forecast</th>
<th>Category</th>
<th>Error</th>
<th>Date</th>
<th>Actual</th>
<th>Forecast</th>
<th>Category</th>
<th>Error</th>
<th>Date</th>
<th>Actual</th>
<th>Forecast</th>
<th>Category</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>23/24 Feb.</td>
<td>1</td>
<td>−2.0</td>
<td>−1.1</td>
<td>F/F</td>
<td>2</td>
<td>−3.0</td>
<td>−3.9</td>
<td>F/F</td>
<td>−0.9</td>
<td>3</td>
<td>−1.6</td>
<td>0.0</td>
<td>F/F</td>
<td>−1.0</td>
<td>4</td>
<td>2.9</td>
<td>3.9</td>
<td>−0.2</td>
<td>1.0</td>
<td>5</td>
<td>4.1</td>
<td>3.9</td>
<td>−0.1</td>
<td>1.4</td>
</tr>
<tr>
<td>26/27 Feb.</td>
<td>6</td>
<td>2.3</td>
<td>2.2</td>
<td>F/F</td>
<td>7</td>
<td>0.3</td>
<td>1.7</td>
<td>Type 1</td>
<td>0.4</td>
<td>8</td>
<td>3.1</td>
<td>2.2</td>
<td>−0.9</td>
<td>0.6</td>
<td>9</td>
<td>1.7</td>
<td>1.1</td>
<td>−0.9</td>
<td>0.6</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>01/02 Mar.</td>
<td>10</td>
<td>6.2</td>
<td>6.7</td>
<td>−0.9</td>
<td>11</td>
<td>3.1</td>
<td>2.2</td>
<td>−0.9</td>
<td>0.5</td>
<td>12</td>
<td>6.4</td>
<td>2.0</td>
<td>−4.4</td>
<td>0.6</td>
<td>13</td>
<td>8.3</td>
<td>8.9</td>
<td>−2.0</td>
<td>0.6</td>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>06/07 Mar.</td>
<td>14</td>
<td>4.8</td>
<td>2.8</td>
<td>−2.0</td>
<td>15</td>
<td>3.1</td>
<td>1.1</td>
<td>−2.0</td>
<td>0.6</td>
<td>16</td>
<td>5.5</td>
<td>3.9</td>
<td>−1.6</td>
<td>0.3</td>
<td>17</td>
<td>0.6</td>
<td>0.0</td>
<td>Type 2</td>
<td>−0.6</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>12/13 Mar.</td>
<td>18</td>
<td>3.7</td>
<td>4.4</td>
<td>−0.7</td>
<td>19</td>
<td>4.9</td>
<td>3.7</td>
<td>−1.2</td>
<td>0.9</td>
<td>20</td>
<td>3.5</td>
<td>2.8</td>
<td>−0.7</td>
<td>0.0</td>
<td>21</td>
<td>1.7</td>
<td>1.5</td>
<td>−0.2</td>
<td>0.2</td>
<td></td>
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</tr>
<tr>
<td>16/17 Mar.</td>
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<td>23</td>
<td>1.2</td>
<td>−0.4</td>
<td>Type 2</td>
<td>−1.6</td>
<td>24</td>
<td>−0.7</td>
<td>0.6</td>
<td>Type 1</td>
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<td></td>
</tr>
<tr>
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<td>26</td>
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<td>−1.1</td>
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<td>2.8</td>
<td>−2.4</td>
<td></td>
<td>28</td>
<td>8.2</td>
<td>7.2</td>
<td>−1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21/22 Mar.</td>
<td>29</td>
<td>3.1</td>
<td>5.7</td>
<td>2.6</td>
<td>30</td>
<td>5.8</td>
<td>2.8</td>
<td>−3.0</td>
<td></td>
<td>31</td>
<td>−0.2</td>
<td>0.0</td>
<td>F/F</td>
<td>0.2</td>
<td>32</td>
<td>No Oceanroutes forecast issued</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>26/27 Mar.</td>
<td>33</td>
<td>3.3</td>
<td>3.1</td>
<td>−0.2</td>
<td>34</td>
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<td>2.2</td>
<td>−2.0</td>
<td></td>
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<td>5.3</td>
<td>3.9</td>
<td>−1.4</td>
<td></td>
<td>36</td>
<td>3.4</td>
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</tr>
<tr>
<td>01/02 Mar.</td>
<td></td>
<td>F/F</td>
<td></td>
<td></td>
<td>0.1</td>
<td></td>
<td>0.0</td>
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</tr>
<tr>
<td>06/07 Mar.</td>
<td></td>
<td>0.5</td>
<td></td>
<td></td>
<td>0.6</td>
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<td></td>
<td></td>
<td>0.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.4</td>
<td></td>
<td></td>
<td>−0.9</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>12/13 Mar.</td>
<td></td>
<td>−0.7</td>
<td></td>
<td></td>
<td>0.6</td>
<td></td>
<td>0.0</td>
<td></td>
<td></td>
<td>−0.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.5</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>16/17 Mar.</td>
<td></td>
<td>1.7</td>
<td></td>
<td></td>
<td>0.7</td>
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<td>0.0</td>
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<td>5.0</td>
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<td>5.0</td>
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<tr>
<td>21/22 Mar.</td>
<td></td>
<td>1.6</td>
<td></td>
<td></td>
<td>0.8</td>
<td></td>
<td>0.0</td>
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<td></td>
<td>5.4</td>
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<td></td>
<td>5.4</td>
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<td>0.1</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>26/27 Mar.</td>
<td></td>
<td>2.5</td>
<td></td>
<td></td>
<td>1.0</td>
<td></td>
<td>0.0</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>2.92</td>
<td>−0.48</td>
<td></td>
<td></td>
<td>F/NF=frost forecast/no frost occurred (Type 2 error).</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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</tbody>
</table>

F/F=frost forecast/frost occurred.
NF/NF=no frost forecast/no frost occurred.
be seen that Oceanroutes forecast the afternoon (maximum) temperatures more accurately than the Met. Office, and the minimum temperatures around dawn, but that the Met. Office forecast the evening temperatures more accurately than Oceanroutes. The overall mean negative bias of both the Met. Office and Oceanroutes is evident. For the 23 hours considered, the average bias for the Met. Office is $-0.15 \, ^\circ C$ and for Oceanroutes $-0.45 \, ^\circ C$. The afternoon forecast is important because this is when Highway Engineers will be deciding whether or not road salting action is likely for the coming night. For instance, just after 1500 the Engineer can display a graph of the forecast road surface temperature with the actual road surface temperatures for 1200, 1300, 1400 and 1500 plotted on it. Their confidence in the forecast will be reduced if the actuals are some way off the forecast.

Figure 4 shows the mean hourly root mean square error (RMSE) which shows similar results to Figure 3. Oceanroutes did slightly better in the afternoon and early morning whereas the Met. Office did considerably better than Oceanroutes in the evening. The mean hourly root mean square error for the 23 hours for Oceanroutes was $1.73 \, ^\circ C$ and for the Met. Office was $1.61 \, ^\circ C$. Figure 4 confirms that the small afternoon bias in the Oceanroutes forecasts shown in Figure 3 was unlikely to be due to large errors either side of
zero error cancelling out. It is interesting to note that the RMSEs for the 0800 forecast, which is nearly 20 hours after issue, are less than the RMSEs in the afternoon just hours after issue. Weather forecast accuracy does not always decline linearly with time.

6. Type 1 and Type 2 errors

Figure 5 shows plots of forecast minimum road surface temperature against actual minimum road surface temperature for the Met. Office and Oceanroutes. Both plots are similar but Table 3 shows that whereas Oceanroutes had two Type 1 and two Type 2 errors, the Met. Office did slightly better with only one Type 1 error and two Type 2 errors. Table 4 shows the forecast minimum road surface temperature errors for the six nights when the minimum road surface temperature fell below 0 °C, and also the same information for those nights when a Type 1 or Type 2 error occurred. There were three nights in a row (16/17, 17/18, 18/19 March) when Oceanroutes were the wrong side of 0 °C and picked up their two Type 1 errors as also shown in Table 4.

On the two occasions that Oceanroutes made a Type 1 error their minimum road surface temperature forecast was 1.1 °C and 1.3 °C in error. This shows how difficult such forecasts are when such a critical threshold as 0 °C exists.
Table 3. Percentage accuracy of forecasts for nights when the minimum road surface temperature is less than 5 °C

<table>
<thead>
<tr>
<th></th>
<th>Oceanroutes</th>
<th>Met. Office</th>
<th>Climatology</th>
<th>Persistence</th>
</tr>
</thead>
<tbody>
<tr>
<td>NF/F (Type 1)</td>
<td>2</td>
<td>1</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>F/NF (Type 2)</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>F/F</td>
<td>4</td>
<td>5</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>NF/NF</td>
<td>18</td>
<td>18</td>
<td>20</td>
<td>16</td>
</tr>
<tr>
<td>85%</td>
<td>88%</td>
<td>77%</td>
<td>73%</td>
<td></td>
</tr>
</tbody>
</table>

F/F=forecast/frost occurred.  
NF/NF=frost forecast/no frost occurred.  

Table 4. Nights when the minimum road surface temperature (MRST) fell to ≤0 °C and/or a Type 1 or Type 2 error occurred

<table>
<thead>
<tr>
<th>Date</th>
<th>Oceanroutes MRST* forecast</th>
<th>Actual</th>
<th>Met. Office MRST* forecast</th>
</tr>
</thead>
<tbody>
<tr>
<td>23/24 February</td>
<td>-1.1</td>
<td>-2.0</td>
<td>-2.0</td>
</tr>
<tr>
<td>24/25 February</td>
<td>-3.9</td>
<td>-3.0</td>
<td>-2.7</td>
</tr>
<tr>
<td>25/26 February</td>
<td>0.0</td>
<td>-1.6</td>
<td>0.3 (Type 1)</td>
</tr>
<tr>
<td>11/12 March</td>
<td>0.0 (Type 2)</td>
<td>0.6</td>
<td>2.0</td>
</tr>
<tr>
<td>14/15 March</td>
<td>2.8</td>
<td>3.5</td>
<td>0.0 (Type 2)</td>
</tr>
<tr>
<td>16/17 March</td>
<td>0.6 (Type 1)</td>
<td>-0.5</td>
<td>-2.0</td>
</tr>
<tr>
<td>17/18 March</td>
<td>-0.4 (Type 2)</td>
<td>1.2</td>
<td>-1.4</td>
</tr>
<tr>
<td>18/19 March</td>
<td>0.6 (Type 1)</td>
<td>-0.7</td>
<td>-0.1</td>
</tr>
<tr>
<td>25/26 March</td>
<td>0.0</td>
<td>-0.2</td>
<td></td>
</tr>
</tbody>
</table>

Table 5 shows the timing and duration of road surface temperatures below or equal to 0 °C degrees celsius for the six nights identified in Table 4. For the five relevant nights that the Met. Office predicted a frost the timing and duration were very good, and only on the night of 16/17 March was the predicted time of zero late and only by 1 hour. Oceanroutes also did well on the four relevant nights, although on the 25/26 February their forecast was 3 hours late as to when the road surface temperature would fall to 0 °C.

Figure 6 shows the percentage accuracy for the 26 nights when the minimum road surface temperature fell to ≤ 5 °C. The Met. Office had an accuracy of 88% whereas Oceanroutes achieved 85%. For comparison the Met. Office achieved an average accuracy of 84% at Troutbeck – the nearest standard forecast site – over the last three winters.

Another way of looking at the accuracy of the forecast data is to consider what is called the 'Hit Rate' and the 'False Alarm Rate' for each forecast provider (Stanski et al., 1989). The 'Hit Rate' is the number of frosty correctly forecast – for the Met. Office this is five out of six (83%) and for Oceanroutes it is four out of six (67%). The 'False Alarm Rate' is the number of frost forecasts that were incorrect, for the Met. Office this was two out of seven (29%) and for Oceanroutes was two out of six (33%).

The mean minimum road surface temperature for the 34 nights was 2.9 °C. If the minimum road surface temperature had been predicted to be 2.9 °C every night (Climatology) then the forecast accuracy would have been 77%, as shown in Table 3. If the previous day's minimum road surface temperature had been used each day to predict the minimum road surface temperature (Persistence) then the accuracy would have been 73%, as shown also in Table 3. Climatology had a 'Hit Rate' of zero and a 'False Alarm Rate' of zero, whereas Persistence had a 'Hit Rate' of 50% and a 'False Alarm Rate' of 57%. Both forecast providers...
did significantly better than both Climatology and Persistence. Obviously ‘Climatology’ is of no use to highway engineers with a ‘Hit Rate’ of zero!

7. Conclusion

Ideally, a trial for a whole winter would have been preferable as there were only six nights when the road surface temperature fell below zero in the study period. However, the trial was sufficient to show that both the Met. Office and Oceanroutes are capable of providing an excellent service with accuracies of 88% and 85% respectively for the critical nights when the minimum road surface temperature was 5 °C or below.

Overall, there is little to choose between the Met. Office and Oceanroutes services. The Met. Office perform better on percentage accuracy and ‘Hit Rate’, but Oceanroutes perform slightly better on maximum and minimum road surface temperature prediction.

An end-user minimum specification for road weather forecasts has been drawn up for the Department of Transport by the author and a copy of the relevant section is shown in the Appendix. This specification suggests a minimum accuracy of 86% for nights when the minimum road surface temperature is 5 °C or below, including updates that are made before midnight. Some Highway Authorities are introducing penalty clauses if the accuracy falls below 86%, but are also offering incentives of extra payments if the accuracy is greater than 86%.

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I would like to thank the Vaisala-TMI user group who sponsored this research and also I would like to thank Sue Lane for helping with the data analysis, David Sheard and Doug Coyle of Cumbria County Council, Antony Astbury of the Met. Office and Ian Davy of Oceanroutes for their full cooperation. Also, I would like to acknowledge the interesting and useful comments of the referees.

Appendix. Level of accuracy

For the purpose of this specification a ‘frost’ is defined as when the road surface temperature falls to 0 °C or below.

The accuracy of road weather forecasts should be no less than 86%. Calculation shall be on the basis of the percentage of predictions in the (no frost/no frost + frost/frost) categories for the winter nights considered when the observed minimum road surface temperature at a forecast site in the authority was 5 °C or below. If an update has been issued before midnight it should be used in the analysis even if it is less accurate than the original forecast. In the case of a dispute the Department of Transport shall act as arbitrator (Thornes, 1993).

References