New techniques for route-based forecasting

Andrew Brown[1], Simon Jackson, Peter Murkin, Peter Sheridan, Alasdair Skea, Samantha Smith, Anthony Veal and Simon Vosper

Met Office, Exeter, U.K,
[1] Email: andy.brown@metoffice.gov.uk

ABSTRACT

Progress with the development of a new route-based forecasting system is presented. It uses a new high resolution Numerical Weather Prediction model to provide the best possible meteorological input. The development of new techniques to represent the important effects of hills and valleys which are still on too small scale to be seen by the NWP model is described. Finally, it is shown that the shading and sky-view parameters required for the energy balance model used to predict road surface temperature and state can be accurately predicted.

Keywords: Downscaling Orography Shading Sky view.

1. INTRODUCTION

Many road forecasting systems follow the basic strategy of taking meteorological input from a Numerical Weather Prediction (NWP) model, attempting to post-process to some extent to correct for features not captured by the model (e.g. valleys and coastal effects), and then running a separate road model to predict the evolution of road surface temperature and state. Forecaster or statistical post-processing may also be applied (before or after the road model) in order to attempt to correct for model errors.

The most accurate road forecast is likely to result from taking the optimum approach at each step in this chain. In particular the quality of the basic NWP meteorological forecast is key, and any detailed along-route modelling is likely to be in error if that basic forecast is in error. Encouragingly though, as detailed in the companion paper in these proceedings [1], the performance of NWP models has been steadily improving over the years. The move to much higher resolution models offers much promise - both because of more accurate forecasts in a regional sense, and also because they can directly represent more of the variability that is important for route-based forecasting. For these reasons the Met Office route-based forecasting system is driven by the new 4km resolution NWP model of the United Kingdom.

As NWP issues are discussed in [1], in this paper we focus on the development and validation of new techniques for post-processing the NWP output to allow for the effects of unresolved orography (hills and valleys). We also show that the shading and sky-view parameters required by the energy balance model can be accurately obtained.

2. METHODOLOGY

A number of different complementary techniques have been used in the development and validation of the new methods. They are detailed below. We believe that the bringing together of these different techniques is key to maximizing the rate of progress in improving models of along-route variations.

2.1 Instrumented car surveys

Car surveys have been performed on a number of different routes around the United Kingdom. These provide high spatial resolution (20m) measurements of air and road temperature [5]. The availability of both is found to be very useful as it makes it easier to decouple orographic effects (which typically affect both) from shading, sky view and road construction effects (which have little effect on the air temperature). The car surveys provide data both to aid in the development of particular aspects of the route-based forecasting system, and also provide verification data to evaluate the complete system.

A large number of surveys have been carried out on different nights on some routes in order to get information on the repeatability of the results (as in [9]). Additionally repeated legs through a number of nights have also been performed in order to examination the development of along-route temperature variations (as in [6]).

To illustrate the range of cases studied on one route, Fig. 1 shows a scatter plot of 18UTC-00UTC averaged downwelling long wave radiation measured at Exeter versus modelled geostrophic wind for each night from January 1 – April 10 2007. The filled squares indicate the nights on which surveys were carried out on the nearby A361. This route was chosen as it is relatively exposed but has significant height variations and so provides good data for investigating orographic effects. As can be seen the surveys tended to be carried out on nights with light winds and low downwelling radiation (i.e. clear skies), because of a deliberate focus on the most stable nights. However, some of the cases (e.g. nights 30 and 92) were sufficiently cloudy and or windy that essentially damped conditions were also sampled.

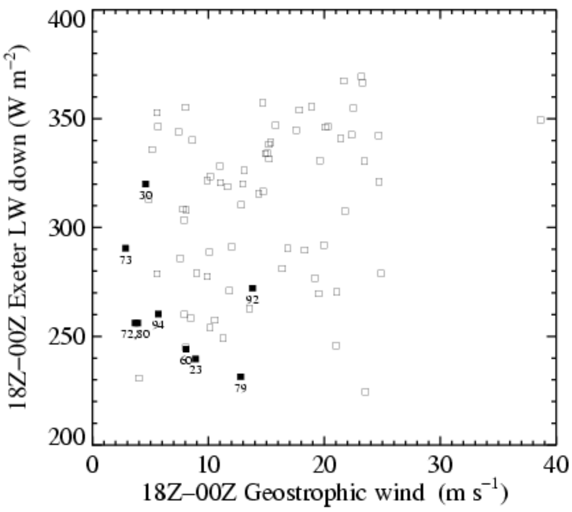

Fig. 1. Scatter plot of 18UTC-00UTC averaged downwelling long wave radiation measured at Exeter versus modelled geostrophic wind for each night from January 1 – April 10 2007. The filled symbols indicate the nights on which surveys were carried out (with the number showing Julian day).

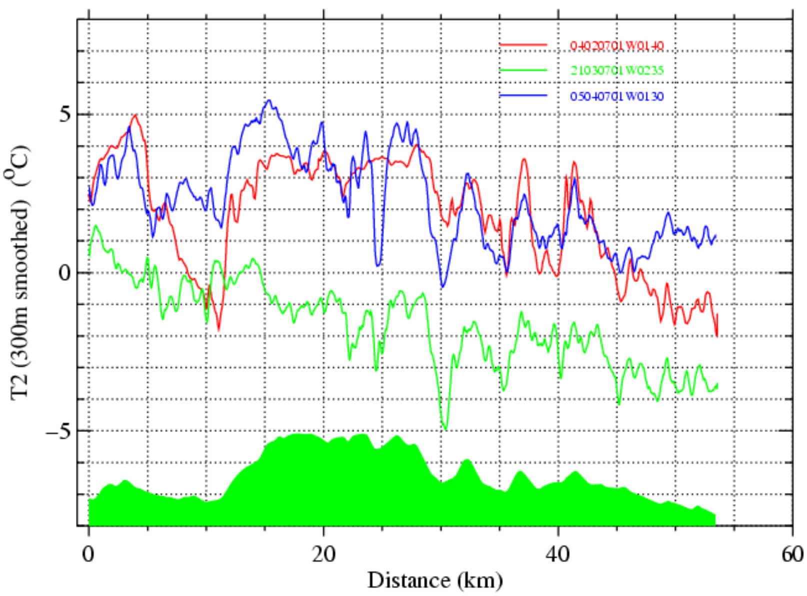

Fig. 2. Air temperature from early morning runs on three of the most stable cases. The green shading indicates the altitude (maximum to minimum height is around 200m).

Fig. 2 shows some example data, showing the air temperature measurements (T2) from early morning runs on three of the most stable cases. Considerable variability of T2 can be seen within each of the 3 runs. There are qualitative similarities between them (consistent with [9]) and an obvious tie to orography. For example, it tended to be cold in Exe valley at 10 km, in various dips between 20 and 25 km and in the three valleys between 30 and 40 km. However, there are important differences in the details. For example, the first case (red) showed the biggest cooling into the Exe valley, but relatively little cooling in the dips between 20 and 25km (with no signal at all apparent at 25 km where the other two cases (green and blue) showed significant cooling). The road temperature measurements (not shown) also indicated cooling in valleys, although with smaller variations – valleys typically around 1 degree colder than their surroundings. This suggests that an accurate representation of the effects of pooling in small dips and valleys on road surface temperature is important. However, other rather larger-scale sources of variability appeared to be at least as important (and varied from night to night), emphasing the key role that the quality of the meteorological forecast has on that of a road forecast.

2.2 Use of fixed sensor data

Although car surveys provide high spatial resolution data there are obviously limitations in terms of time resolution and the number of separate cases that can realistically be studied. Accordingly, fixed sensor data provides a value complementary resource – much poorer spatial but much better time resolution. An example of its use is given in Section 3.2.

2.3 Idealized modelling studies

Both car and fixed sensor data give valuable information on how conditions vary along a route. It is also possible to infer some information on why conditions vary as they do. For example, rapid formation after sunset of a cold pool in a valley probably indicates that local sheltering (rather than drainage) is the dominant mechanism [6]. However, in order to supplement the observations it is extremely useful to perform idealized modelling studies. This approach has been widely and successfully used in the development of new schemes to improve NWP models [2, 11], and is now being applied to the road problem. The big advantage of this approach is that it provides a clean environment to test various hypotheses. For example, Section 3.3 shows some examples from a study [10] where valley depth, wind speed and cloud cover were independently varied in order to investigate the factors controlling valley pooling.

3. OROGRAPHIC DOWNSCALING

Fig. 3 shows the orography as seen by the 4km model (left) and the real orography (right) for a part of south west England. At this resolution at least the main features are reasonably captured – unlike at 12km resolution when the high areas of Dartmoor in the south west of the plot and Exmoor in the north effectively merge into one area of high land. However, there is still clearly a considerable amount of local variability not explicitly captured by the model, and the role of the orographic downscaling scheme is to predict the effects of these variations not seen by the model. Its role is particularly crucial for route-based forecasting, as at locations without fixed sensors there is no possibility of using statistical correction based on model to observation differences.

3.1 Altitude-based correction

The first step in the orographic downscaling correction is based on the discrepancy in height between the real and the modelled point. Fig. 4 shows results from fixed site sensors in Devon and shows that, unsurprisingly, temperature tends to decrease with height on a cloudy, windy night, but increase with height on a clear, calm night. The key problem is obviously to predict the lapse rate. Three methods have been used:

1) Prediction as a function of external parameters (geostrophic wind and cloud cover)
2) Estimation from the modelled temperature profile at the point of interest
3) Estimation from the relationship between modelled temperature and height in the area surrounding the point of interest

Method 3 has been found to be the most reliable (in comparison with fixed site data) when using data from the 4km NWP model. However, it is worth noting that with such a high resolution NWP model the choice is not particularly critical. With a coarser resolution model, the required corrections will be both larger and harder to estimate accurately (as for example, the model may not resolve sufficient variability of height for method 3 to be viable).

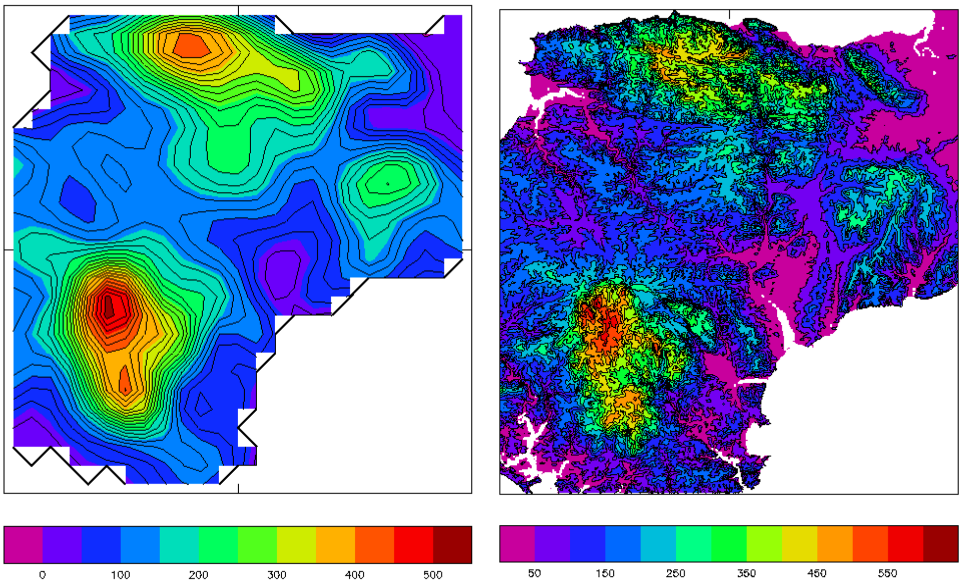

Fig. 3. 4km resolution NWP model orography (left) and real orography (right) for an area of SW England.

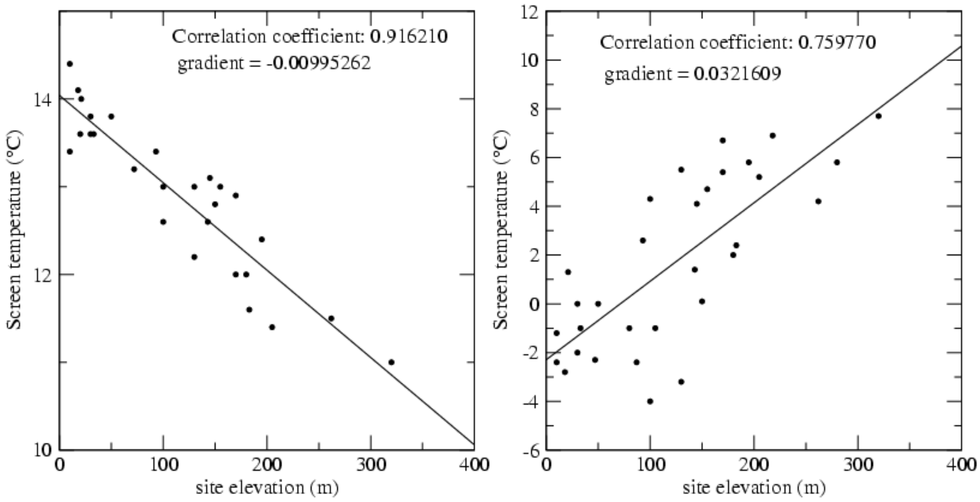

Fig. 4. Screen temperature as a function of site elevation from RWIS in Devon, SW England for a cloudy windy night (left) and a clear calm night (right).

3.2 Valley parametrization

A further correction is required to reflect the fact that a point in a valley will on a stable night often be colder than another point which is at the same height but not in valley. To investigate this effect, a detailed study has been carried out with the Met Office BLASIUS research model [10]. Fig. 5 shows example wind fields at and potential temperature contours at 04UTC from four simulations with varying wind and cloud cover. As expected, pooling of cold air in the valley is greatest in cloud-free conditions with light winds, and decreases as either the cloud cover or wind speed increases.

Close examination of the flow fields in these simulations reveals that the reduction in temperature within the valley is clearly not a result of drainage flows down the valley sides, but instead occurs *in situ*, at the bottom of the valley. The sheltering which occurs in the valley is sufficient to reduce the turbulent mixing of warm air from aloft, therefore allowing rapid cooling of the air adjacent to the ground. This mechanism enables the cold pools to become set up relatively early in the night (Fig. 6), and is consistent with earlier experimental work [6] and with the results found in the car trials.

A wide range of simulations has been carried out to map out the variation of valley cooling as a function of wind speed, stability and valley dimensions and hence produce a tool for representing the effects of valleys unresolved in the NWP model. They indicate that the critical non-dimensional controlling parameter is a Froude number (combining wind, stability and valley depth information), as previously suggested from field experiments [7, 8]. Note the interesting result (Fig. 7) that for given cloud cover and wind speed, the amount of additional cooling in the valley increases up to a certain threshold valley depth, but then does not increase any further. The explanation is that once the valley is deep enough for turbulence to cut-off entirely, further increases in valley depth have no effect.

The new parametrization has been found to be largely successful in reproducing the temperature variations caused by the valleys on the A361 route – correctly predicting cooling on the stable nights and having little impact on the cloudy nights. The main exceptions are the cases where the meteorological model itself incorrectly predicted the cloud – again highlighting that route-based detail is unlikely to be accurate if the basic meteorology is incorrect.

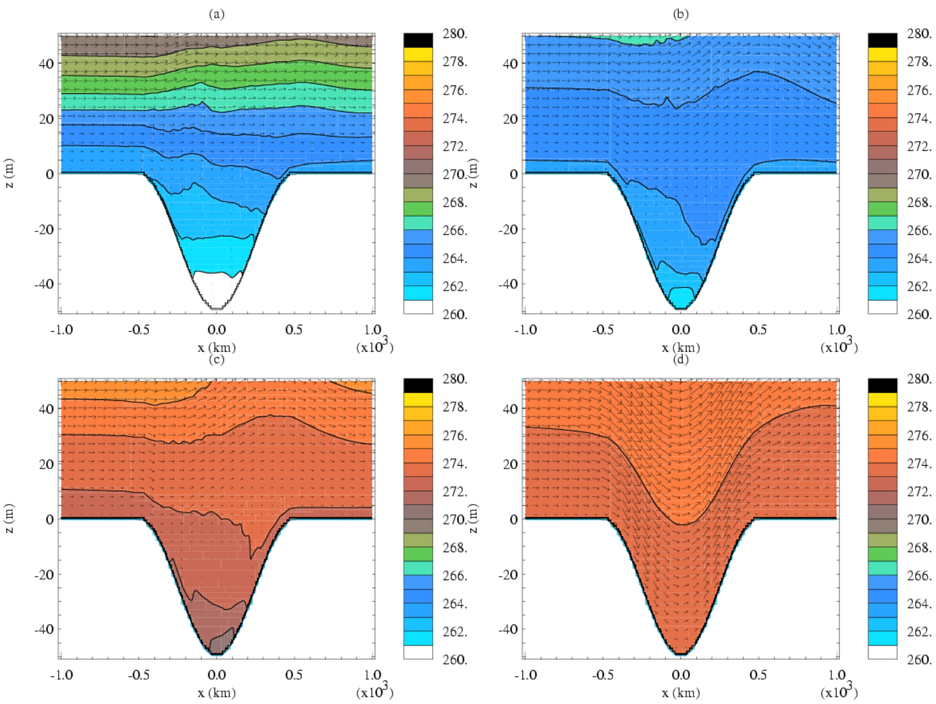

Fig. 5. Modelled potential temperature and flow fields in a valley. Wind increases from left to right and cloud increases from top to bottom.

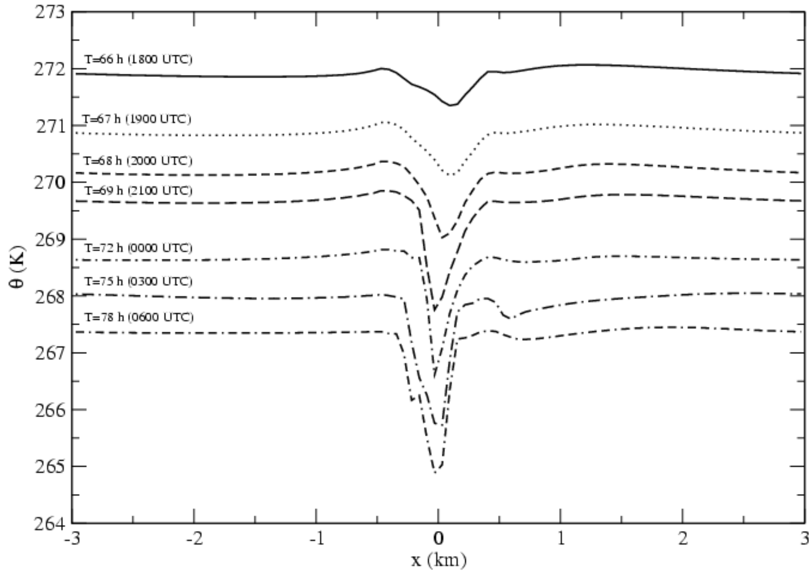

Fig. 6. Time evolution of modelled near surface potential temperature from a stable case. The valley is centred at x=0.

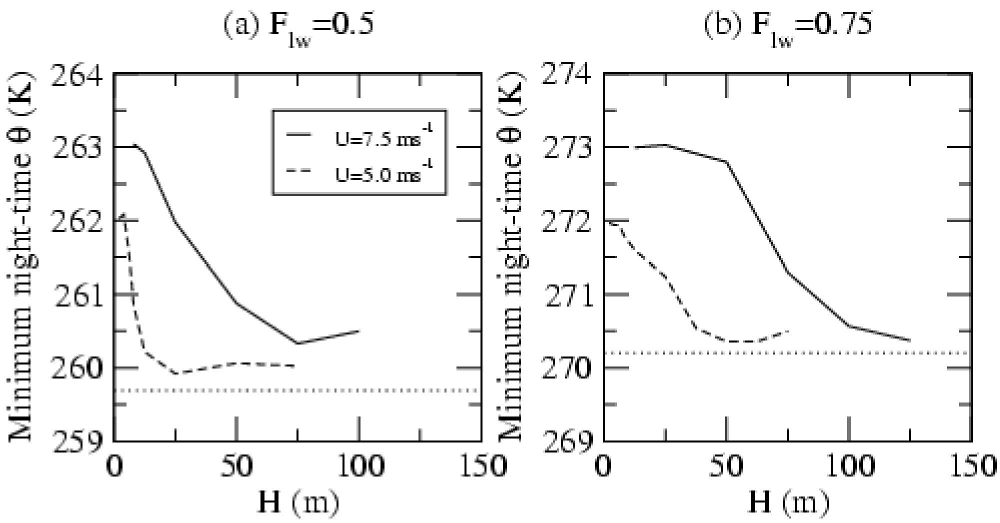

Fig. 7. Variation of simulated minimum potential temperature in the valley as a function of valley depth (H) and geostrophic wind speed (U). Left: clear conditions; Right: partially cloudy conditions.

4. SHADING and SKY VIEW

Shading (obstruction of incoming sunlight) will tend to decrease the temperature of the road surface, while restricted sky view (reducing net outgoing radiation) will tend to increase it (e.g. [3]). These effects can be well represented in an energy balance model provided that sufficiently accurate geographical data is available [4]. Fig. 8 shows an example of car survey measurements of road surface temperature at 17UTC on a clear day (coloured circles), superimposed on the predicted number of hours of shading since noon (grey shades). It can be seen that there is an excellent correlation between the two, with depressed temperatures occurring each time shading is predicted. Hence we are confident that these effects can be accurately represented.

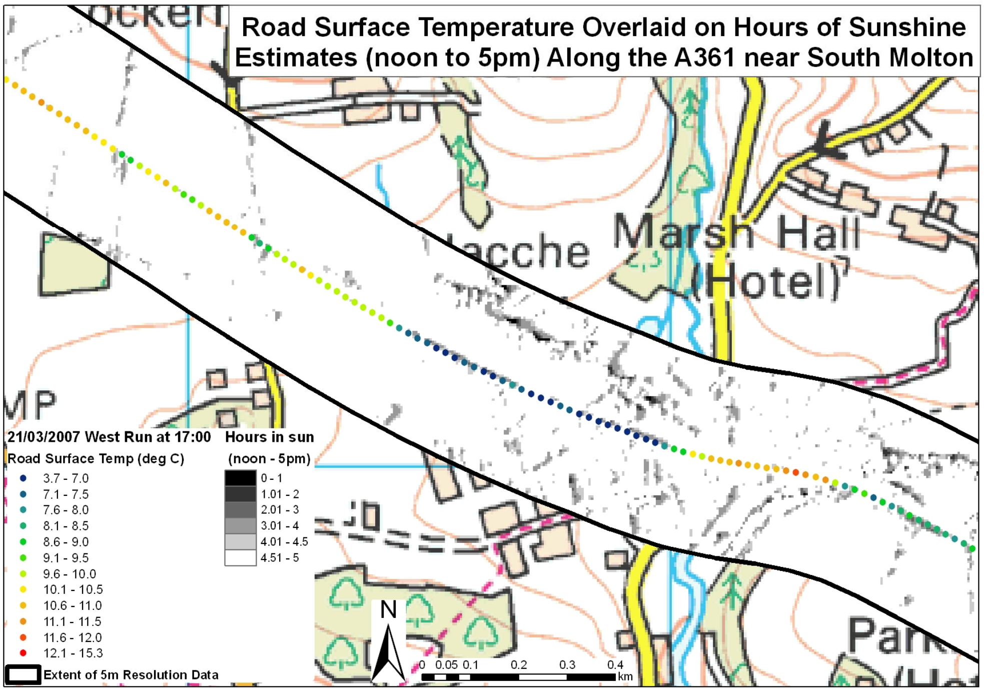

Fig. 8. Afternoon measurements of road surface temperature and predicted number of hours of shading since noon.

5. CONCLUSIONS

New techniques have been developed to represent some of the important processes affecting along-route variations. Particular attention has been paid to the orographic problem, taking advantage of the opportunities presented by the use of high resolution NWP. The next stage of the work will be to further verify and tune the methods using the large amount of survey data now available from a variety of different routes. Some of these are relatively flat, while others (e.g. in Scotland) pass through very significant mountains, and hence they provide a range of different tests for the methods.

On some nights, small-scale variations along a route will be crucial in determining whether a road needs treatment or not. However, as noted in the introduction, any road forecast will be crucially dependent on the quality of the meteorological forecast (e.g. is the presence or absence of cloud correctly predicted?). Hence as well as focusing on optimization of the techniques to predict detailed variations in road temperature and state, ongoing efforts to evaluate the complete end-to-end system will also be crucial.

5. REFERENCES

[1] Brown, A.R., Jackson, S., Murkin, P., Sheridan, P., Skea, A., Smith, S. and Veal, A. 2008. *Weather prediction for the road industry*. SIRWEC proceedings (ID:16).

[2] Brown, A.R. and Wood, N. 2003. *Properties and parametrization of the stable boundary layer over moderate topography*. J. Atmos. Sci. 60: 2797-2808.

[3] Chapman, L., Thornes, J.E. and Bradley, A.V. 2001. *Modelling of road surface temperature from a geographical parameter database. Part I: Statistical*. Meteorol. Appl. 8: 409-419.

[4] Chapman, L., Thornes, J.E. and Bradley, A.V. 2001. *Modelling of road surface temperature from a geographical parameter database. Part II: Numerical*. Meteorol. Appl. 8: 421-436.

[5] Gustavsson, T. 1999. *Thermal mapping – a technique for road climatological studies*. Meteorol. Appl. 6: 385-394.

[6] Gustavsson, T., Karlsson, M., Bogren, J. and Lindqvist, S. 1998. *Development of temperature patterns during clear nights*. J. Appl. Meteorol. 37: 559-571.

[7] Holden, J.J., Derbyshire, S.H. and Belcher, S.E. 2000. *Tethered balloon observations of the nocturnal stable boundary layer in a valley*. Boundary-Layer Meteorol. 97: 1-24.

[8] Mason, P.J. 1987. *Diurnal variations in flow over a succession of ridges and valleys*. Quart. J. Roy. Meteorol. Soc. 113: 1117-1140.

[9] Shao, J., Lister, P.J., Hart, G.D. and Pearson, H.B. 1996. *Thermal mapping: reliability and repeatability.* Meteorol. Appl 3: 325-330.
[10] Vosper, S.B. and Brown, A.R. 2008. *Numerical simulations of sheltering in valleys: the formation of nighttime cold-air pools*. Accepted for publication in Boundary-Layer Meteorol.
[11] Wood, N. and Mason, P.J. 1993. *The pressure force induced by neutral, turbulent flow over hills*. Quart. J. Roy. Meteorol. Soc. 119: 1233-1267.

ACKNOWLEDGEMENT
Thanks to Jörgen Bogren and Torbjörn Gustavsson of Klimator AB for their assistance with the setting up of the car surveys.