P1.35 SITE-SPECIFIC FROST WARNING IN MOUNTAINOUS REGIONS BY ESTIMATING GEOGRAPHIC POTENTIAL FOR COLD-AIR ACCUMULATION

U. Chung* and J. I. Yun
Department of Ecosystem Engineering, Kyung Hee University, Suwon, Korea

1. INTRODUCTION

Most spatial interpolation models incorporate a lapse rate correction to accommodate the elevation difference for daily minimum temperature estimation in large areas (Dodson and Marks, 1997; Nalder and Wein, 1998). Cold - air drainage on slopes and cold - air pools in the lower basin are among the other factors which may affect the lapse rate (Lindkvist et al., 2000). We present a means of adding a cold air accumulation concept to conventional spatial interpolation models for estimating the site-specific daily minimum temperature in complex terrain under radiative cooling conditions.

2. METHODS AND MATERIALS

2.1 *Model Description*

An equation to estimate daily minimum temperature T at a given site by an inverse distance weighted (IDW) interpolation of measured data at surrounding stations can be written as

$$T = \frac{\sum \frac{T_i}{d_i^2}}{\sum \frac{1}{d_i^2}} + \left(z - \frac{\sum \frac{z}{d_i^2}}{\sum \frac{1}{d_i^2}} \right) \Gamma + \varepsilon \qquad \text{--------------------- (1)}$$

where T_i is observed minimum temperature at station 'i', d_i is distance from the site to station 'i', z is site elevation, zi is station elevation, Γ is temperature change per unit change in elevation and ε is the unknown error. ε can be caused by many physical processes but is assumed in this study to be caused by cold - air accumulation and the so-called thermal belt formation under radiative cooling conditions.

To analyze the components of the unknown error, hypothetical profiles of daily minimum temperature during a typical radiative cooling night are given in Fig. 1. The profile depicted by "A" is that of the standard atmosphere, formed by an adiabatic lapse rate. Daily minimum temperature observed at a surface synoptic station is often lower than the temperature predicted from the lapse rate because of in situ air cooling by radiation. Consequently, the temperature profile will usually bend towards the land surface, forming curved line "B". Most synoptic stations are free from cold air inflow from the surroundings, preventing enhanced cooling associated with cold air accumulation. Since the synoptic station observations are used in spatial interpolation, the conventional elevation-effect correction using equation (1) should follow profile "C". However, sites in topographically complex regions usually have cold-air inflow from or outflow to the surrounding area in addition to the cooling of in situ air. The combined cooling effect may resemble the observed minimum temperature profile "D". When we estimate the daily minimum temperature at these locations by the conventional method using profile "B", errors may arise from two parts divided by the altitude Z1. The so-called thermal belt is assumed to start from Z1 and to end at Z2 (inversion cap). From the valley bottom to Z1, the spatially interpolated temperatures could be overestimated by E1, while those from Z1 to Z2 are underestimated by E2. From the hypothetical drawings and the subsequent field experiments, the size of E2 is assumed to be an exponential function of elevation and E1 a logarithmic function of cold air inflow.

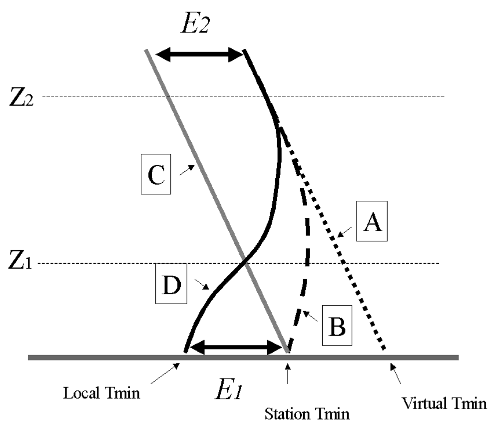

Fig. 1. Hypothetical profiles of minimum temperatures caused by the nocturnal radiative cooling.

The E2 function can be approximated by observing temperature profiles of the nocturnal boundary-layer for the given area. If we assume a ground surface consisting of regular grid cells, the cooled, descending air on a given grid cell should flow into one of the surrounding 8 grid cells. The flow direction can be determined by finding the direction of steepest descent from each cell, which is calculated from a digital elevation model (DEM). The accumulated flow is based upon the number of cells flowing into each cell. Output cells with a flow accumulation of 0 are local topographic highs and indicate ridges. Each grid cell now has a cold - air accumulation value as an attribute, which is expected to explain the unknown error at the cell location in estimating minimum temperature during radiative cooling nights. For the E1 function, we need to obtain a quantitative relationship between the estimation error and the flow accumulation expressed as the number of cells.

2.2 *Derivation of Model Parameters*

A 2.1 by 2.1-km area located on the southwestern slope of Mt. Jiri in Korea was selected for the study. A sampling network of 14 portable temperature micro-loggers (HOBO H8 Pro, Onset Computer Corporation, USA) was deployed in March 2001. The 8 sites were used to derive the model parameters describing the relationship between the cold air accumulation and the temperature estimation error in the study area. Remaining 6 sites were intended for subsequent model validation purposes (Fig. 2).

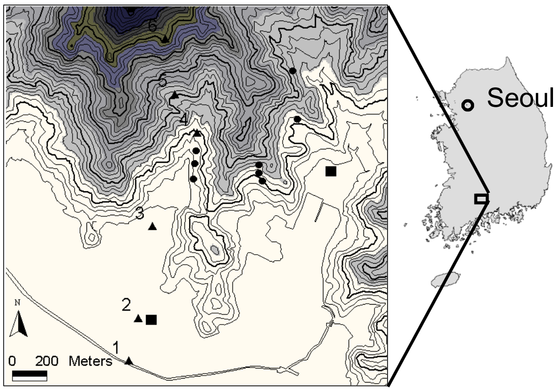

Fig. 2. Locator map for the study area with locations of 8 micro-loggers for model development (circle) and 6 micro-loggers for the model validation (triangle).

We first calculated daily minimum temperature at the 8 HOBO sites by spatially interpolating from the 6 synoptic station observations based on the conventional model. Differences between the calculated and the observed temperatures at the 8 sites are the error term ε in equation (1). Flow accumulation (the number of inflow cells) of each HOBO site was calculated from the 10m DEM by using the coordinate data and the flow direction grid. In order to determine the surrounding areas most accurately representing the cold air effects, zonally averaged flow accumulations were calculated by successively increasing the cell radius from 1 to 10. Temperature estimation errors at the 8 HOBO sites were regressed to the common logarithm of 11 flow accumulation values, respectively.

To measure the temperature profiles and accurately define the so-called thermal belt position within the study area, a tethered balloon inflated with helium gas was launched with 6 temperature sensor transmitters attached at 50m height intervals. Temperature data from these transmitters were received by a dedicated transceiver (Model TMT-5A, Vaisala, Finland) on the ground, where data were recorded.

3. RESULTS AND DISCUSSION

3.1 *Model Parameters*

When the temperature estimation errors were regressed to a common logarithm of the smoothed averages of cold air accumulation, the highest coefficient of determination (r^2 = 0.78) was found at the cell radius of 5. If the original flow accumulation is used, only 14% of the estimation error could be explained. The coefficient of determination increases as the smoothing radius expands up to 5 cell, but a plateau or even decreasing trend appears after the 5 cell radius. The area bounded by 5-cell radius corresponds to approximately 1 ha.

A ground inversion began to develop as early as 2000 LST and deepened to form a so-called thermal belt with the warmest zone at 300 - 400m above the valley floor. From this result we derived an exponential function simulating the inversion strength.

The final form of our model which was applied to the validation was

$$T = \frac{\Sigma \frac{T_i}{d_i^2}}{\Sigma \frac{1}{d_i^2}} + \left(z - \frac{\Sigma \frac{z}{d_i^2}}{\Sigma \frac{1}{d_i^2}} \right) \Gamma - \varepsilon 1 + \varepsilon 2$$

with

$$\varepsilon 1 = \left(\frac{R}{R_{\max}} \right) \cdot \log_{10} \left(FA_5 \right)$$

and

$$\varepsilon 2 = \left(\frac{R}{R_{\max}} \right) \cdot I_{\max} \left[1 - \exp\left\{ - 0.03 \left(Z - Z1 \right) \right\} \right]$$

where FA5 is the 5-cell average flow accumulation expressed as the number of grid cells flowing into the site. R is the daily temperature range and Rmax is the maximum value of daily temperature range, found in the historical climate record. Imax is the maximum inversion strength estimated at the nearest synoptic station.

3.2 *Model Performance*

Fig. 3 shows the cold air accumulation pattern over the study area which is calculated from a 10m DEM with 5-cell radius smoothing. The spots with higher accumulation are evident in the low-lying areas and valleys, while much less accumulation occurred over the slopes and the ridges. The amount of cold air accumulation at each grid cell should be regarded as a flow potential expected under the strongest radiative cooling conditions. Since there is a day-to-day variation in the strength of radiative cooling, the actual flow accumulation will be variable. We assume a fixed pattern of the flow accumulation regardless of the intensity, but a variable flow amount is adjustable using the R/Rmax ratio.

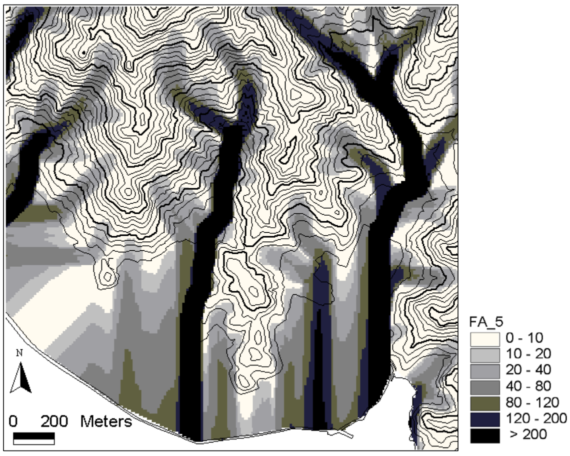

Fig. 3. A cold-air accumulation pattern over the study area represented by the flow direction and accumulation calculated from a 10m digital elevation model with 5 cell-radius smoothing.

When the model is coupled with the flow accumulation pattern and applied to selected radiative cooling dates in April 2001-2003, there is general agreement between the estimated and measured daily minimum temperatures at the 6 sites, showing 0.74 for the coefficient of determination (Fig. 4). Considering that frost warning or site selection in fruit cultivation is the most important role of the minimum temperature estimation, the relatively good performance of the model at the low temperature region of the figure is very promising. The model can predict observed subfreezing temperatures at higher flow accumulation sites on dates when synoptic station temperatures were above freezing. The conventional method using the lapse rate corrected IDW did not predict temperatures below freezing on these dates (Fig. 4).

Our method can be used to produce a gridded map of daily minimum temperature and it will be useful not only for avoiding the frost-sensitive spots if it is produced from historical climate data, but also for the forecast of imminent frost hazards with enough lead time to prepare countermeasures if it is made from real-time forecasts or observations.

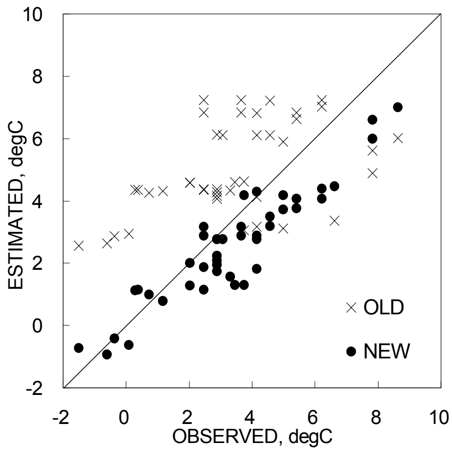

Fig. 4. Plots of the estimated versus the observed minimum temperatures on frost days in April 2001-2003 (NEW). Results from a conventional method (inverse distance weighting with lapse rate correction) are also shown for the comparison (OLD).

ACKNOWLEDGEMENTS

This work was supported by grant No. R01-1999-000-00175-0 from the Basic Research Program of the Korea Science & Engineering Foundation and by a grant from Rural Development Administration.

REFERENCES

Dodson, R., and D. Marks, 1997: Daily temperature interpolated at high spatial resolution over a large mountainous region. *Climate Research* **8**, 1-20.

Lindkvist, L., T. Gustavsson, and J. Bogren, 2000: A frost assessment method for mountainous areas. *Agricultural and Forest Meteorology* **102**, 51-67.

Nalder, I. A., and R. W. Wein, 1998: Spatial interpolation of climatic normals: test of a new method in the Canadian boreal forest. *Agricultural and Forest Meteorology* **92**, 211-225.