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Methods for modelling of temporal and spatial distribution of air temperature at landscape scale in the southern Qilian mountains, China

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Abstract

Understanding temporal and spatial distribution of surface air temperature (SAT) at the landscape scale is essential in assessing the potential ecological conditions for ecological restoration and in making decisions for regional management in the Qilian mountains, northwest China. Based on the measurement of air temperature, this study developed a linear regression relationship between the monthly mean SAT and elevation and locational/topographic factors. On average over the year, the model had a higher accuracy to predict SAT in the southern Qilian mountainous terrain of the Heihe River Basin. The study also compared the built linear regression model with geostatistical methods (i.e., ordinary kriging, splines and inverse distance weight), generally, the predictions errors obtained by the geostatistical methods were larger than that by regression method. The worst results were produced by spline. It was noteworthy that for several months (i.e. growing seasons) ordinary kriging yielded smaller prediction errors than the linear regression of temperature against elevation and locational/topographic factors did. We selected the OK method to estimate the SAT in the growing seasons, because accurately estimating surface air temperature during the ecologically meaningful time period was very important to model future ecological processes. Modeled SAT increased from northeast to southwest with highest value occurring in the Yinglou gorge, the outlet of Heihe River in the study area. Temporally, highest SAT value, ranging from 9.2 to 18.7 °C, appeared in the July, and the lowest SAT value, from 3.3 to 13.3 °C, was seen in May.

Keywords: Surface air temperature; Linear regression; Geostatistical methods; Qilian mountains; Landscape scale

1. Introduction

Over the recent decades, the area covered by forest has declined steeply due to human activities such as timber extraction, fuelwood gathering, extensifica-

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tion of grassland for grazing and intensive cultivation (Daily, 1995). As a result, erosion, mud-rock flow, flood and soil fertility decrease have been widely reported in literature to have a great influence on the agricultural potentials. There is now evidence that many forest systems have become highly stressed and dysfunctional (Vitousek et al., 1997). The services provided by these ecosystems such as maintenance of ground and surface water supplies, balance of atmospheric gasses and reduction soil erosion and so on are extremely important to human welfare, but they are losing step by step. So restoration of the ecosystems has never been more critical than at the present time. Predicting vegetation spatial patterns (static probabilistic maps) in landscape scale is a major task for planning restoration and for implementing sustainable management, since changes in vegetation spatial patterns due to human influence could be estimated by comparing current patterns with landscape scale predictions of natural species distribution (Guisan and Zimmermann, 2000; Franklin, 1995; Davis and Goetz, 1990; Iverson et al., 1997) and restoration sites could be identified by the predictions.

Effects to describe vegetation patterns in montane systems historically have relied on elevation as ecological "proxy" variable to represent complex environmental gradients (Austin, 2002; Whittaker, 1978). While elevation is reasonably correlated with distributions of species, this indirect correlation is unsatisfying. It has been understood that variability in temperature is major determinant of plant distribution (Stephenson, 1990). Temperature not only affects the rates of most biotic processes, including phenology, growth, carbon fixation, and respiration, plant moisture requirements and plant water relations (Kramer, 1983; Waring and Schlesinger, 1985; Aber and Melillo, 1991), but also interacts with terrain, soils, and insolation, and these interactions cumulatively impact tree growth, species composition and susceptibility to disturbance (Turner and Gardner, 1991). Therefore, these effects above have driven the development of models that predict temperature at landscape scales (Pielke and Mehring, 1977; Running et al., 1987). A number of landscape temperature prediction methods, for example, the vertical lapse method, regional regression and geostatistical techniques, have been developed for the various ecosystems and conditions over the last a few decades (Leffler, 1981; Boyer, 1984; Russo et al., 1993; Régnière and Bolstad, 1994; Régnière, 1996; Bolstad et al., 1997). However these methods by themselves do not incorporate other terrain-related factors, such as slope gradient and slope orientation. Working in the southern Appalachian mountains, Bolstad et al. (1998) suggested that spatially extrapolated estimates of temperature from a few low elevation weather stations are consistently biased due to the inability to account for local topographic effects which are governed largely by the relationship of slope orientation to solar radiation. In the middle latitudes of the Northern Hemisphere, the north-facing slopes are a few degree celsius colder at the same elevation than the south-facing slopes. The reason is the different annual amount of sun radiation falling on a unit area of the surface. McCutchan and Fox (1986) showed that aspect differences could be even more important than elevation in controlling temperature. Bolstad et al. (1998) suggested that temperature maxima, in particular, are sensitive to topographic exposure. Although importance of topographic effects on solar radiation and then on temperature has long been recognized, incorporation of these effects in the irradiance and temperature models is either neglected or simplified (Brock, 1981; Vardavas, 1987; Bonan, 1989; Nikolov and Zeller, 1992), due to the complexity of formulation and the lack of suitable modeling tools. A few years ago advances of the raster modeling in a frame of geographic information systems (GIS) together with analysis of remotely sensed data made it possible to include topographic effects in the solar radiation models at fine spatial scales over arbitrary periods of time (Dubayah, 1994; Dubayah and Rich, 1995). The spatial distribution of surface air temperature as a function of slope angle and slope orientation in regional scale also become realization (Šafanda, 1999; Liu, 2002; Zhao, 2003).

The Heihe River Basin, the second largest inland river basin in the arid region of northwest China, consists of three major geomorphological units—the southern Qilian Mountains, the middle Hexi Corridor and the northern Alxa Highland. The southern Qilian Mountains is hydrologically and ecologically the most important unit because it functions as the water source to support the irrigating agriculture in the Hexi Corridor and also to maintain the ecological viability in the northern Alxa Highland. Because of deforestation and extensification of grassland for grazing, the lower altitudinal boundary of a forest-covered area is shrinking toward the top of the mountains. That has