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Global Warming Impacts on Alpine Vegetation Dynamic in Qinghai-Tibet Plateau of China

Yan Qing Zhang[1*], Jeffery M. Welker[2]

[1]Department of Geography, School of Computing Science, Simon Fraser University, Burnaby, Canada
[2]Environment and Natural Resources Institute, University of Alaska Anchorage, Anchorage, USA
Email: *instca@yahoo.com

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Abstract

This study is to illustrate alpine vegetation dynamics in Qinghai-Tibetan Plateau of China from simulated filed experimental climate change, vegetation community dynamic simulation integrated with scenarios of global temperature increase of 1 to 3˚C, and simulated regional alpine vegetation distribution changes in responses to global warming. Our warming treatment increased air temperatures by 5˚C on average and soil temperatures were elevated by 3˚C at 5 cm depth. Aboveground biomass of grasses responded rapidly to the warmer conditions whereby biomass was 25% greater than that of controls after only 5 wk of experimental warming. This increase was accompanied by a simultaneous decrease in forb biomass, resulting in almost no net change in community biomass after 5 wk. Under warmed conditions, peak community bio-mass was extended into October due in part to continued growth of grasses and the postponement of senescence. The Vegetation Dynamic Simulation Model calculates a probability surface for each vegetation type, and then combines all vegetation types into a composite map, determined by the maximum likelihood that each vegetation type should distribute to each raster unit. With scenarios of global temperature increase of 1˚C to 3˚C, the vegetation types such as Dry Kobresia Meadow and Dry Potentilla Shrub that are adapted to warm and dry conditions tend to become more dominant in the study area.

Keywords

Global Warming, Alpine Vegetaion, Qinghai-Tibet Plateau

1. Introduction

Global temperatures are increasing due to the effects of greenhouse gases emission. It is projected that climate changes will have profound biological effects, including the changes in species distributions as well as vegetation patterns (Walther et al., 2002; Klanderud & Birks, 2003; Tape et al., 2006). Many results from observations

[*]Corresponding author.

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and experiments (Sullivan & Welker, 2005), and simulation studies (Zhang, Yang, et al., 1996; Ni, 2000; Song et al., 2005) have depicted shifts in the distribution of vegetation boundary and the mixture of shrubs and grasses.

The Tibetan Plateau covers approximately 2.5 million km^2 with an average altitude of more than 4000 m dominated by alpine tundra (Zheng, 1996). Alpine tundra vegetation is predicted to be one of the most sensitive terrestrial ecosystems to changing climate (Chapin et al., 1992, 2000). This type of ecosystem is composed of slow-glowing plants and are dominated by the soils which can be concentrated with high organic matter near surface soil that undergo frost heave and cryoturbation (Billings, 1987; Xia, 1988). Simultaneously, warmer weather may increase plant growth, and primary production (Wookey et al., 1995) as well as changes in species dominance (Walker et al., 1994; Klein et al., 2007).

Based on 38 years (1959-1996) of climate observations and statistical analysis, the annual mean temperature increased during this period ranged from 0.4˚C to 0.6˚C in the area of Haibei Alpine Tundra Ecosystem Research Station (Li et al., 2004), that is located on northeastern part of Qinghai-Tibetan Plateau (37˚N, 101˚E). In order to study alpine tundra vegetation changes at the regional scale, we model alpine tundra vegetation spatial and temporal dynamics in response to global warming by integrating a raster-based cellular automata and a Geographic Information System (Zhang et al., 2008). Temperature changes across the study area are not only due to elevation, but also to aspect and distance from the nearest stream channel. The liner regression model provided a temperature spatial distribution based on elevation alone, which is the primary step. The normalized temperature surface created by the Multi-Criteria Evaluation (MCE) is highly representative of the potential temperature distribution in a normalized fuzzy format. Assuming each vegetation type in the raster cell unit reacts as homogeneous entity, we conduct a spatial and temporal simulation by combining cellular automata and MCE provided in the IDRISI software (Eastman, 2003).

2. Alpine Tundra above Ground Biomass and Community Responses to Simulated Changes in Climate

2.1. Experimental Treatments and Observations

Our experiment research site is located near Haibei Alpine Meadow Ecosystem Station (37˚N, 101˚E) at an elevation of 3250 m (Xia, 1989). The vegetation of our field site is typical of a *Kobresia humilis* meadow (Zhang & Zhou, 1992). The greenhouse treatment increased mean air temperature by 20% from 12.4˚ to 17.8˚ Cover the course of the growing season. Warmer air temperature subsequently caused higher soil temperatures at 5, 10, and 15 cm under greenhouse (G) as opposed to ambient (C) conditions (Zhang & Welker, 1996).

2.2. Results and Discussion

Total community aboveground biomass in all four treatments was not significantly different in July. The peak aboveground biomass between Greenhouse (G), occurred in September 351.36 g·m^{-2}, and ambient (C) condition, occurred in October 346.19 g·m^{-2}.

Total maximum aboveground biomass at our Tibetan alpine tundra site ranged from 161 to 351 g·m^{-2} under ambient conditions. These ranges in biomass are similar to the peak aboveground biomass at other alpine tundra sites such as on Niwot Ridge, Colorado, U.S.A., where the intercommunity aboveground biomass in different vegetation types ranges from 71 to 309 g·m^{-2} (Walker et al., 1994). Our environmental manipulations simulating climate warming resulted in warmer air and soil temperatures between 1˚C and 5˚C, which is within the ranges of increase reported for higher elevations in Western Europe over the past 15 years (Grabherr et al., 1994) and is within the ranges predicted for tundra habitats under a doubling of CO_2 over the next 50 yr (Maxwell et al., 1992). The season long average increases are also similar to those accomplished in other tundra experimental warming treatments though our lack of nighttime measurements means our averages are slightly higher than those actually experienced by plants and soil in these treatment plots (Chapin & Shaver, 1985; Wookey et al., 1993). However, most importantly, higher temperatures were maintained in our warmed plots into October and may partially explain the extended growing season observed for grasses (Zhang & Welker, 1996).

In conclusion, our findings suggest that Tibetan alpine grasses are predisposed to rapid increases in biomass under simulated climate warming due in part to their inherent life history traits. In addition, the ability of grasses to produce tillers late in the season under warmer conditions extends the period of carbon gain and extends the period in which the community exhibits maximum aboveground biomass. We find that sedges at our site are insensitive in the short term to changes in environmental conditions, while forbs may decrease at the expense of grass biomass. Increases in cloudiness over the Tibetan alpine tundra would likely result in lower aboveground biomass, but if accompanied by higher rainfall the effects may be counter-acting. The extension of peak community biomass into the autumn may in the long term have cascading effects on net ecosystem CO_2 fluxes, nutrient cycling, and forage availability in the alpine ecosystem (Welker et al., 2004).

3. Cellular Automata: Simulating Alpine Tundra Vegetation Dynamics in Response to Global Warming

3.1. Vegetation Dynamic Simulation Model (VDSM)

Spatial modeling processes are available in current Geographic Information System (GIS) software such as IDRISI, which is capable of dealing with a large set of raster data and manipulating the data via operations in a series of discrete time steps, where single raster cells can be influenced by their neighborhood or other data in an overlay. All map layers are imposed on the same grid system. This type of GIS environment provides a sophisticated tool to help us target the real problem in a complex system (Wolfram, 1984; Itami, 1994; Shanmuganathan et al., 2011). In our study, we use GIS analysis, linear regression, MCE, cellular automata (CA), and a raster image calculator to build a unique Vegetation Dynamic Simulation Model (VDSM) (**Figure 1**). Global warming scenarios are interpreted as inputs of the spatial parameters. Large processing tasks are completed by the computer system.

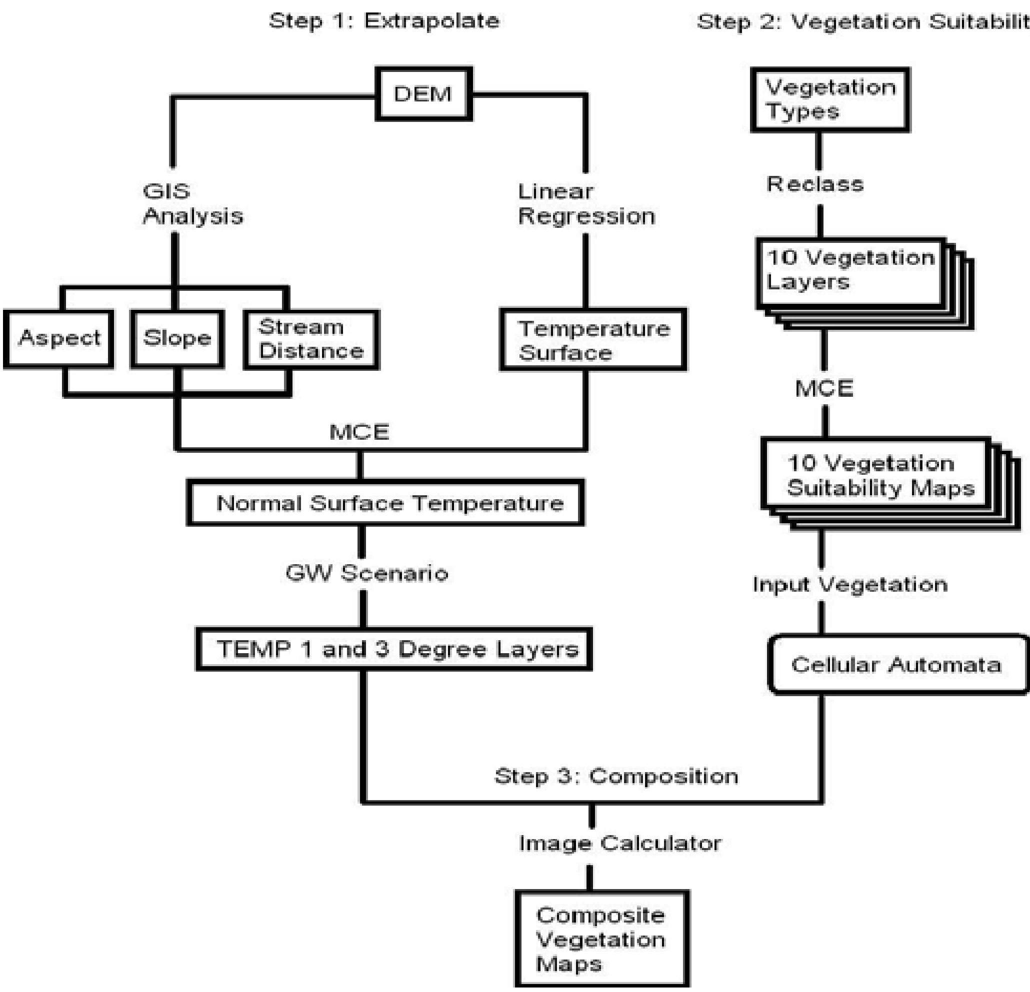

Figure 1. Vegetation Dynamic Simulation Model (VDSM).

The predicted outcome of this study is that individual vegetation types will respond to a global mean temperature increase (GMTI) in 2100 of 1˚C or 3˚C by either expanding or shrinking their range because of plant species' suitability to the warmer and drier climate conditions. This corresponds to 0.1˚C or 0.3˚C per decade, respectively (Leemans, 2004).

3.3. Results and Discussions

Temperature changes across the study area are not only due to elevation, but also due to aspect and distance from the nearest stream channel. The linear regression model provided a temperature spatial distribution based on elevation alone, which is our primary step. Furthermore, the normalized temperature surface created by the MCE is highly representative of the potential temperature distribution in a normalized fuzzy format, showed as Normalized temperature spatial distribution (**Figure 2**). Temperature distribution is correlated with and controlled primarily by elevation. Numerous spatial interpretation methods have been applied to estimate the spatial distribution of temperature (Li, 2005). The interpolation results do not always agree with the actual sample points, including using geo-statistical methods, and spatio-temporal spline. These methods are highly dependent on the distance to the sample points, and the surface equation. In our study, our first step is to create the primary temperature surface based a linear relation with elevation. The objective is to obtain a more accurate temperature map in terms of aspect, suitable temperature, and distance to the stream. We use the Multi-Criteria Evaluation

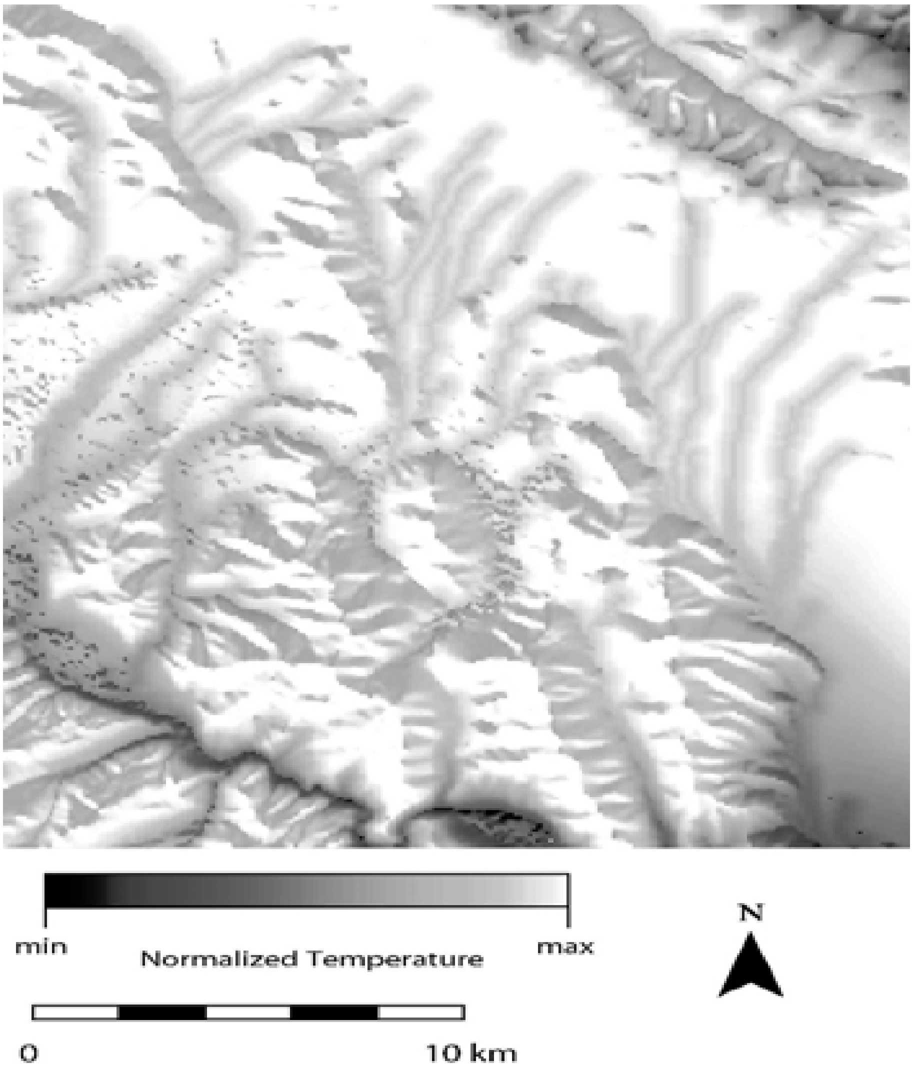

Figure 2. Normalized temperature with values from 0 to 255.

with Weighted Linear Combination (MCE_WLC) to calibrate the spatial temperature distribution. The fuzzy memberships between the temperature and each factor (aspect, suitable temperature, distance to stream) are based on previous research works (Zhang & Zhou, 1992; Zhang & Welker, 1996, Zhang et al., 2008, 2010). The output, the normalized temperature surface is set into fuzzy format (0 - 255). Since the temperature is major factor on determining vegetation composition, structure, and distribution, the normalized temperature surface plays an important role when we simulate vegetation dynamics in spatial and temporal dimensions.

The VDSM integrates the suitability maps created from MCE, Macro-Modeler, CA, and spatial environmental factors. And the temperature-time dimension model is incorporated into the VDSM, which makes the temperature a spatial parameter that affects the vegetation dynamics over a discrete time step. The simulating processes conducted by Macao Modeler generate the temperature increase of 0.1˚C to 0.3˚C per decade, which represents the influences of the different global warming scenarios. The results demonstrate that global temperature increase reduces moisture availability (Zhang & Welker, 1996) such that dry vegetation can invade areas previously occupied by vegetation adapted to moist conditions. The structure of the model is generally applicable to other situations, but the particular factors and constraints used in this model are unique to the Haibei alpine tundra ecosystem.

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