A new bioclimatic index: Associating temperature sum with thermal seasonality

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[Abstract]

Thermal variation plays a main driver for governing the type and distribution of vegetation, especially in the humid region. This paper aims to provide a modified thermal index, effective warmth index (EWI) which associate temperature sum with thermal seasonality, compared with commonly used other indices for classifying and predicting of vegetation zones through a case study of Taiwan. With these different thermal indices calculated and mapped at a 100-m spatial resolution, the corresponding climate-vegetation classification schemes are applied to predict the vegetation zones. The accuracy of spatial prediction is evaluated with Kappa coefficient, referring to 651 vegetation plots. The prediction of potential natural vegetation zones using EWI is the best one (Kappa=0.759), compared with other indices. This result suggests that thermal seasonality is effective for improving the prediction of warmth index in explaining the altitudinal zonation and distribution of vegetation in Taiwan, and potentially in humid East Asia.

Keywords: thermal seasonality, effective warmth index, climatic-vegetation classification, Taiwan

1. Introduction

The existing bioclimatic indices developed from continental and global scales and related to the latitudinal variation may not be suitable for describing the climate and vegetation at a regional scale along with a prominent altitudinal gradient (Lydolph, 1985), such as in Taiwan. Moreover, the thermal seasonality, or annual temperature range, may work simultaneously with the average or accumulated temperature on the distribution of vegetation (Fang et al., 1996; Guo and Werger, 2010; Meurk, 1984; Wolfe, 1979). Thus, this paper aims: (1) to calculate and evaluate the commonly used bioclimatic indices in Taiwan; (1) to test the effectiveness of thermal seasonality on the differentiation and altitudinal distribution of vegetation in Taiwan, with a new thermal bioclimatic index, explicitly taking the temperature seasonality into account.

2. Thermal indices

Table 1 listed the thermal indices and their formulas and references used in this paper, including mean annual biotemperature (ABT; Holdridge's (1967)), warmth index (WI; Kira (1991)), biological warmth index (BWI; Ni (1997)), and effective warmth index (EWI; a novel index proposed by this study).

In this paper, we propose a new thermal index, effective warmth index (EWI), which combines the two crucial thermal indices, temperature sun (i.e. WI) and thermal seasonality (i.e. annual temperature range (ATR)). The coefficient 0.5 of ATR is empirical and refers to Wolfe's (1975, 1995) studies. It is the ratio of mean annual temperature divided by ATR. The reason of negative value is that the effectiveness of ATR for plant growth is almost contrary to that of mean annual temperature and WI (Wolfe, 1995, p. 128). The idea of EWI resulted from the distinguishability of plant-available temperature sun and thermal seasonality at different latitudes. Fig. 1 gives a comparative example between two different latitudinal stations with equivalent WI but different ATR.

The bioclimatic indices used in this paper, including ABT, WI, BWI, ATR, and EWI, could be calculated and drawn from 12 layers of MT and their formulas through GIS.

3. Results

The layers of thermal indices used in this paper were represented in Fig. 2. According to different climate-vegetation classification schemes and their bioclimatic indices, the spatial patterns of predicted vegetation zones could be mapped. As illustrated in Fig. 3, Taiwan possesses five to seven vegetation zones from alpine to lowland. Fig. 4 is the comparison of predicted vegetation zones based on different schemes. Table 2 revealed Kappa coefficient and strength of agreement among predicted vegetation zones according to different climate-vegetation schemes by comparison with 651 vegetation survey plots.

4. Discussion

EWI is a synthetic bioclimatic index which associates temperature sum (or namely as total energy amount or accumulated temperature; i.e., WI) with thermal seasonality (i.e., ATR). Both WI and ATR were critical for plant and vegetation (Fang et al., 1996; Ohsawa, 1990; Tuhkanen, 1980; Wolfe, 1979; 1995). On the one hand, WI has been demonstrated to be an idea reflection of effective cumulative energy supply, on the other hand, ATR, which is also used as an index of climatic continentality (Meurk, 1984), can reflect the limitation of low temperature to the distribution of certain plant functional types (Fang et al., 1996; Flantua et al., 2007; Wolfe, 1979; 1995). This modification can be especially useful for description or prediction of monsoon climate with strong seasonality.

The extent of ATR is between 5.9 and 14.0°C in Taiwan (Fig. 2d), indicating that Taiwan has a relatively mild oceanic climate throughout the year. Although it acts only as a minor modification to WI (ranges 7.1 ~ 239.7°C), the Kappa value for EWI is larger than that for WI. This suggests that seasonality has obvious effect on vegetation distribution in Taiwan, and the effect can be stronger when the distribution of a specific species is concerned. The influence of thermal seasonality should be more significant in high latitude

(Fig. 1b).

Although many bioclimatic indices once proposed and applied, a novel thermal index that integrate temperature sum and thermal seasonality is still lacking. EWI can fill this gap by setting up a more concise link between thermal index and vegetation distribution, this might be especially helpful for application in a region with a larger scale and a climate of stronger seasonality than Taiwan.

5. Conclusions

EWI combining temperature sum with thermal seasonality is more suitable to predict vegetation zones than average or cumulative temperature. The synthetic concept of EWI is a new idea, thus further modeling and validation are obviously required, especially in other regions.

Table 1 Simple thermal indices and their formulas used in this paper.

Thermal index	Formula	Reference
ABT (mean annual biotemperature)	*ABT=1/12*ΣMT* *(in °C, for 12 months 0<MT<30)*	Holdridge (1967)
WI (warmth index)	*WI=Σ(MT-5)* *(in °C, for 12 months MT>5)*	Kira (1991)
BWI (biological warmth index)	*BWI=Σ(MT-10)* *(in °C, for 12 months MT>10)*	Ni (1997)
EWI (effective warmth index)	*EWI=WI-0.5*ATR* *(in °C, for 12 months MT>5)* *ATR (annual temperature range) = (MT of the warmest month) - (MT of the coldest month)*	This study

MT: monthly mean temperature (°C)

Table 2 Kappa coefficient and strength of agreement for predicted vegetation zones.

Predicted vegetation zones with different indices and classification regimes	Kappa	Agreement[a]
WI (Su, 1984b) (Fig. 2a)	0.698	good
WI (Kira, 1991) (Fig. 2b)	0.187	poor
BWI (Ni, 1997) (Fig. 2c)	0.017	poor
WI (Song, 1999) (Fig. 2d)	0.247	poor
WI (Fang, 2001) (Fig. 2e)	0.255	poor
EWI (Chiu et al., 2008) (Fig. 2f)	0.759	very good

[a] Strength of agreement suggested by Monserud and Leemans (1992): Kappa values < 0.4 poor, 0.4 ~ 0.55 fair, 0.55 ~ 0.7 good, 0.7 ~ 0.85 very good, and > 0.85 excellent.

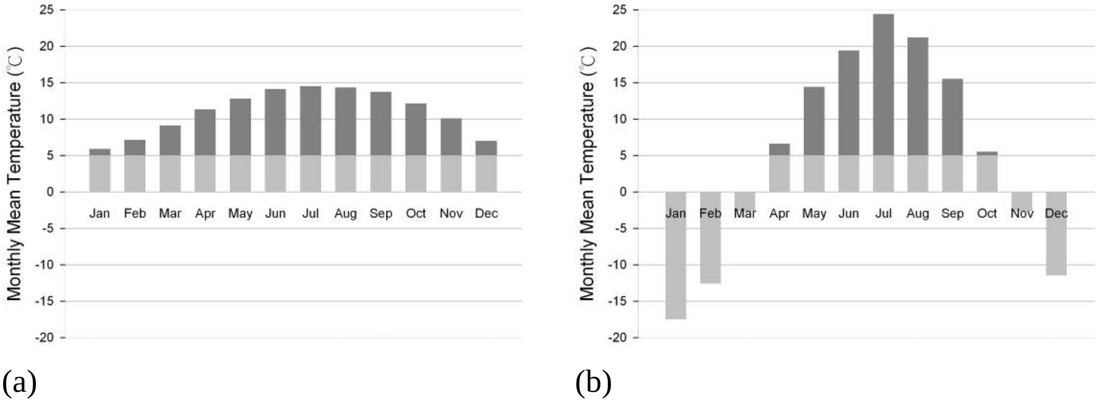

Fig. 1. The illustration of idea and concept of effective warmth index (EWI) associating temperature sum (warmth index, WI; i.e. area sum of dark grey) with thermal seasonality (annual temperature range, ATR). A comparative example of two different latitudinal stations: (a) Alishan, Taiwan (23.28°N, 120.52°E, 2450 m a.s.l.) where WI=72.0, ATR=8.6, and EWI=67.70; (b) Jilin, China (43.52°N, 126.35°E, 180 m a.s.l.) where WI=72.0, ATR=41.9, and EWI=51.05. The two stations, with equal WI (72) but separate ATR (8.6 versus 41.9), have different thermal conditions for plant growth that could be revealed by the synthetic index EWI (67.70 versus 51.05).

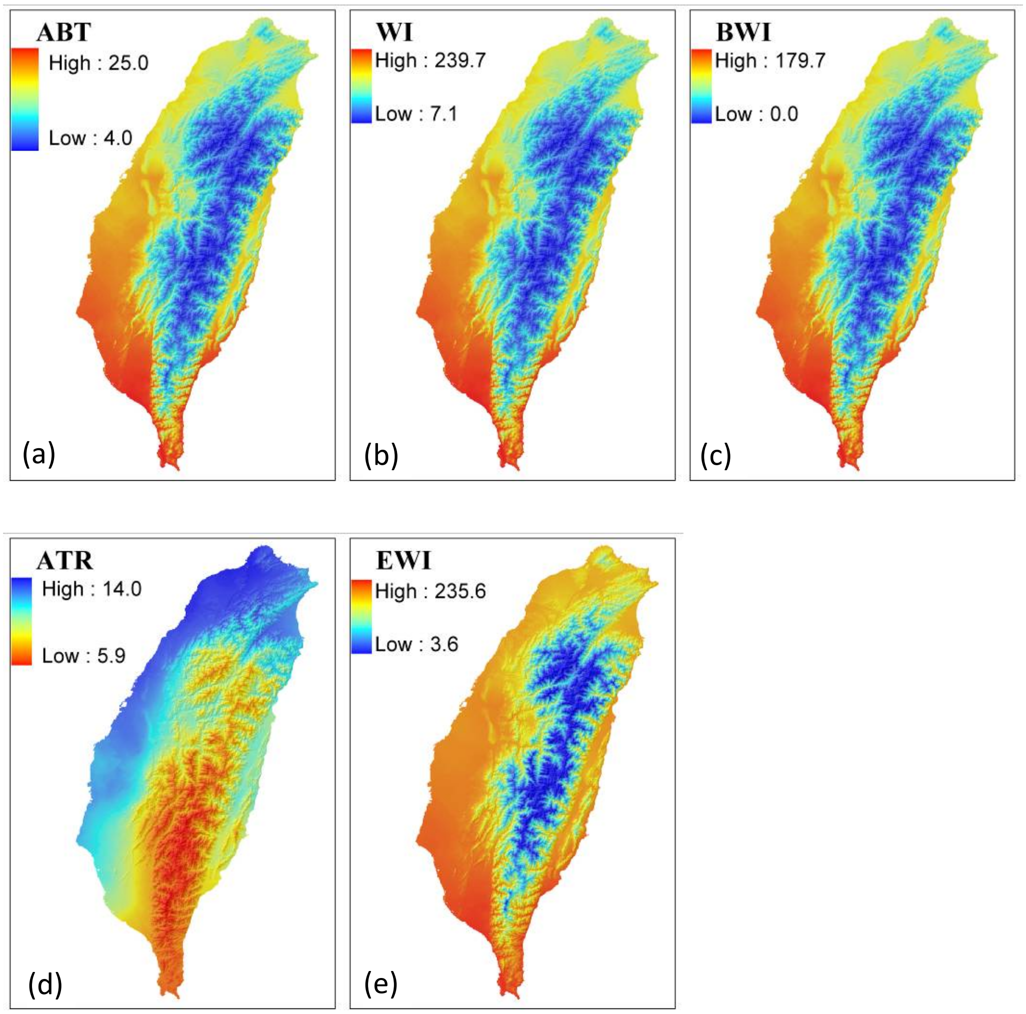

Fig. 2. Spatial patterns of the five bioclimatic indices: (a) annual biotemperature (ABT); (b) warmth index (WI); (c) biological warmth index (BWI); (d) annual temperature range (ATR); (e) effective warmth index (EWI). Except for ATR, the other four indices varied mainly with topography.

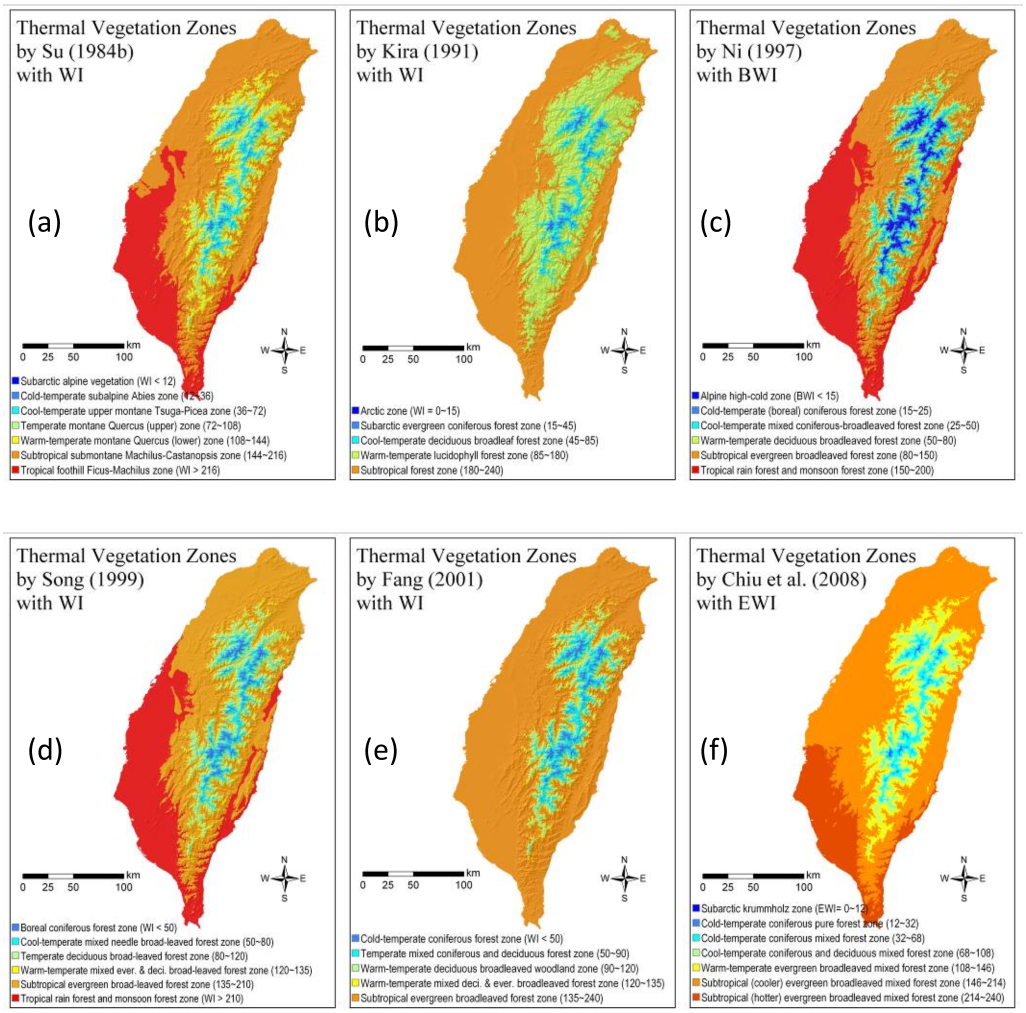

Fig. 3. Predictive vegetation maps based on different authors' climate-vegetation classification schemes with their thermal indices: (a) 7 zones predicted by Su (1984b) with WI; (b) 5 zones predicted by Kira (1991) with WI; (c) 6 zones predicted by Ni (1997) with BWI; (d) 6 zones predicted by Song (1999) with WI; (e) 5 zones predicted by Fang (2001) with WI; (f) 7 zones predicted by Chiu et al. (2008) with EWI.

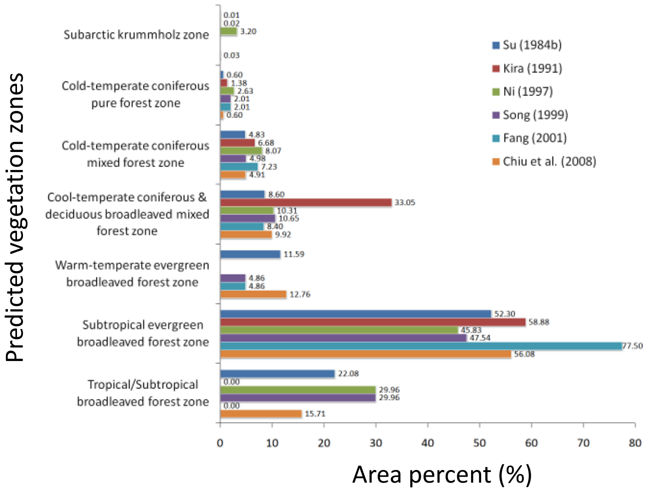

Fig. 4. The comparison of predicted vegetation zones based on different climate-vegetation classification scheme.