Wetness or Warmth, Which is the Dominant Factor for Vegetation?

Rikie Suzuki, Jianqing Xu, and Ken Motoya
Frontier Research System for Global Change
3173-25 Showamachi, Kanazawa-ku Yokohama, Kanagawa 236-0001, Japan
rikie@jamstec.go.jp (R. Suzuki), jxu@jamstec.go.jp (J. Xu), kmoto@jamstec.go.jp (K. Motoya)

Abstract: The wetness, a function of precipitation and temperature etc, and the warmth, a function of temperature, are the dominant factor for global vegetation distribution. This paper employs the normalized difference vegetation index (NDVI), warmth index (WAI), and wetness index (WEI), and focuses on an essential climate-vegetation relationship at global scale. The NDVI was acquired from 'Twenty-year global 4-minute AVHRR NDVI dataset.' The WEI is defined as the fraction of the precipitation to the potential evaporation. The WAI was calculated by accumulating the monthly mean temperature of the portion exceeded 5°C throughout the year. Meteorological data for the WEI and WAI calculation were obtained from the ISLSCP CD-ROM. All analyses were conducted for 1 × 1 degree grid box on the terrestrial area of the Earth, and on annual value basis averaged in 1987 and 1988. The result of analyses demonstrated that there are two regimes in their relations, that is, a regime in which NDVIs vary depending on the WEI, and a regime in which NDVIs vary depending on the WAI. These two regimes appeared to correspond to the wetness dominant and warmth dominant vegetation, respectively. The geographical distributions of two regimes were mapped. Most of the world vegetation is categorized into wetness dominant, while warmth dominant vegetation is seen in the high-latitude area mainly to the north of 60°N in the Northern Hemisphere and high-altitude areas.
Keywords: NDVI, NOAA/AVHRR, ISLSCP, Potential evaporation, Warmth index, Aridity

1. Introduction

The vegetation geographical distribution in terrestrial area in the world is strongly controlled by the climate [6, 7, 8]. Especially, the wetness and warmth are the most essential factors that define the limitation of the vegetation distribution. It is well known that vegetation in the desert and tundra is not active due to scarcity of wetness and warmth, respectively. We considers that almost all the vegetation in the world is stressed more or less by the dryness or low-temperature and it is possible to divide the world vegetation into wetness dominant and warmth dominant. A previous paper investigated the relationship among the net primary production, the radiative dryness, and the net radiation in the world, and exhibited a concept regarding the vegetation and climate distribution [4]. However, the number of data sampled for that analysis was not enough for the discussion in terms of wetness versus warmth dominancy.

This study uses remotely-sensed global vegetation index data of the NOAA/AVHRR, and makes an attempt to divide the vegetation into two regimes, wetness dominant and warmth dominant, and demonstrate their distribution. The Wetness Index (WEI) and the Warmth Index (WAI) are calculated and their relation to the vegetation index is examined. The result will bring a better understanding on the climate and vegetation relationship. It will be a basic knowledge to predict the vegetation change due to climate change.

2. Data and Method

All analyses were conducted for 1 × 1 degree grid box on the terrestrial area of the Earth, and on annual value basis averaged in 1987 and 1988.

1) NDVI

This study employs the monthly Normalized Difference Vegetation Index (NDVI) acquired from 'Twenty-year global 4-minute AVHRR NDVI dataset' produced by Chiba University [1] that is a transformed version of the Pathfinder global 10-day composite 8 km AVHRR NDVI data. One of the transformation is the map projection change from Interrupted Goode Homolosine projection to Plate Carree projection for easier usage of the data. The other transformation is Temporal Window Operation (TWO) method which makes smooth natural NDVI temporal change patterns. The mean NDVI from March to September in the Northern Hemisphere, and September to March in the Southern Hemisphere in 1987 and 1988 was calculated for each 1 × 1 degree grid box over the global terrestrial area.

2) Wetness Index (WEI) and Warmth Index (WAI)

The wetness index is defined as the fraction of the precipitation to the potential evaporation (*Ep*). *Ep* is defined in the present study as the evaporation expected from a continuously saturated surface [2, 9]. Here, surface roughness is assumed as 0.005 m, albedo ref = 0.06

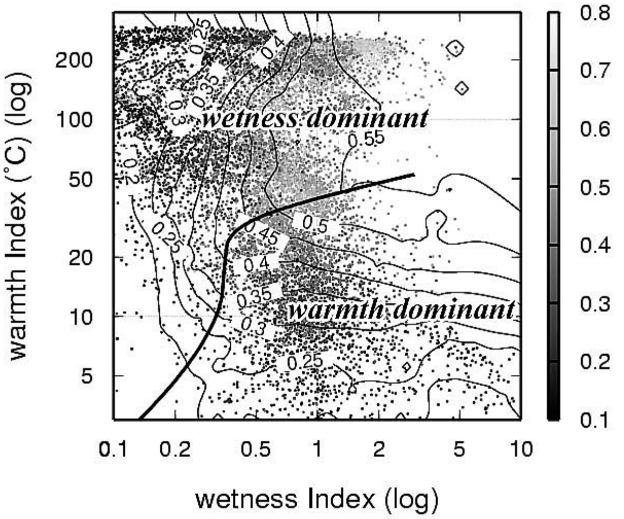

Figure 1. The relationship among the NDVI, WEI, and WAI. The NDVI value (gray scale) at each grid box is plotted in the WEI-WAI orthogonal coordinate. The NDVI contours are drawn according to the NDVI distribution. The boundary line between two regimes, wetness dominant and warmth dominant, is indicated by a bold line.

(water surface), surface emissivity $\varepsilon = 0.98$, evaporation efficiency $\beta = 1.0$. The ground heat flux G is neglected. According to the definition,

$$R^{\downarrow} = \varepsilon\sigma T_{SE}{}^{4} + H + \iota Ep \,,$$
$$H \;= c_p\rho C_H U\,(T_{SE} - T_{AM}) \,,$$
$$\iota E = \iota\rho\beta^{*}\, C_H U\,(h\, q_{SAT}(T_{SE}) - q_{AM})$$

where,

$$R^{\downarrow} = (1 - \mathrm{ref}\,)\, S^{\downarrow} + \varepsilon L^{\downarrow} \,.$$

Here, $R^{\downarrow}$ is the input radiation at the ground surface. σ the Stefan-Boltzmann constant ($5.670\times10^{-8}\,\mathrm{Wm^{-2}K^{-4}}$), T_{SE} is the calculated surface temperature which satisfied the heat balance equations. Sensible heat flux H and latent heat flux ιE are computed for the same time, c_p represents the specific heat of air, ρ the density of air. T_{AM} is the air temperature, ι the latent heat of vaporization, h the relative humidity (%), $q_{SAT}(T_{SE})$ the specific humidity at saturation of T_{SE}, q_{AM} the specific humidity of air. The evaporation rate E under these conditions is defined as the potential evaporation Ep. $C_H U$ is the exchange speed, $C_H U = \mathrm{Max}(a + b \times 0.7U, c \times (T_{SE} - T_{AM})^{1/3})$, with $a = 0.0027\ \mathrm{ms^{-1}}$, $b = 0.0031$, $c = 0.0036\ \mathrm{ms^{-1}K^{-3}}$. The ratio P_a/Ep_a was defined as the wetness index WEI, where Ep_a is annual total Ep, P_a the annual precipitation.

The WAI was calculated as an annual cumulative temperature of the monthly mean temperature exceeding a threshold of 5°C.

For the calculation of the WEI and WAI, a dataset produced by International Satellite Land Surface Climatology Project (ISLSCP) [3, 5] was used. The dataset includes a meteorological forcing, such as air temperature, dew point temperature, wind, surface pressure, radiation, and precipitation. Air temperature, dew point temperature, wind speed, and surface pressure for every 6 hours were taken directly from the operational 4DDA (4-Dimensional Data Assimilation) data of the European Centre for Medium-Range Weather Forecasts (ECMWF). Surface radiation was determined by combining the satellite-based monthly mean surface shortwave downward radiation of the NASA/Langley Research Center (LaRC) with the surface shortwave radiation of the ECMWF model. The variation in the shortwave radiation for 6-hour intervals generated by the 4DDA model at ECMWF was normalized so that its monthly mean equaled the observed NASA/LaRC value.

Precipitation was proportional to the value obtained every 6 hours in the National Centers for Environmental Prediction (NCEP) re-analysis, and the value of precipitation was adjusted so that the monthly total corresponded to the monthly precipitation determined from precipitation gauge observations by the Global Precipitation Climatology Centre (GPCC). Moreover, we tried to compensate systematic errors in measuring precipitation originated in the wind-induced undercatchment of the rain gauges based on a similar method of WMO's empirical formulas.

3. Result

1) Relation among the NDVI, WEI, and WAI

The relationship among the three indices (NDVI, WEI, WAI) at each 1 × 1 degree grid box over the terrestrial area of the world was examined, and demonstrated in Fig.1. High NDVIs distribute in the area with high WEI and WAI. If the WEI is low, the NDVI shows low value that corresponds to the vegetation in arid region such as steppe and savanna. If the WAI is low, the NDVI also show low value that corresponds to the vegetation in low temperature areas such as tundra.

Note that the contour lines of the NDVI in Fig. 1 have a bending point. Those points are indicated by connecting them with a bold line in Fig. 1. Over this bold line, NDVI contours are drawn vertically, while under the line they are drawn horizontally. This means that the NDVI changes depending mainly on the WEI over the line, while mainly on the WAI under the line. These two regions in Fig. 1 appear to be attributed to the wetness dominant regime and warmth dominant regime of the vegetation, respectively.

2) Geographical Distribution of Wetness Dominant and Warmth Dominant Vegetation

Figure 2 displays the geographical distribution of grid boxes in the two regimes that were divided in Fig. 1.

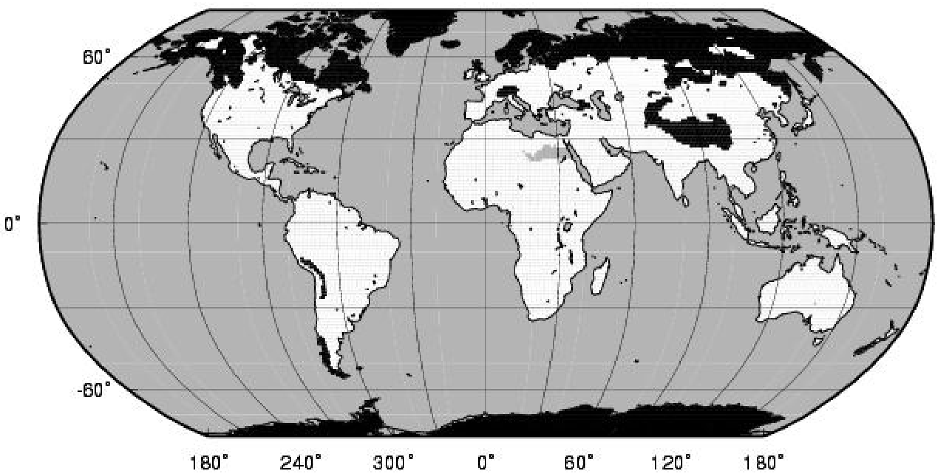

Figure 2. The global distribution of the wetness dominant vegetation (white area) and warmth dominant vegetation (black area) in each 1 × 1 grid box. Gray color indicates the area with no data.

It is obvious that two regimes are mapped in clearly separated areas. Most of the world vegetation is categorized into wetness dominant, while warmth dominant vegetation is seen in the high-latitude area in the Northern Hemisphere and high-altitude areas in addition to Antarctic continent. A boundary between them is formed along about 60ºN line in the Eurasia which roughly corresponds to the boundary between taiga forest and other forests. The Tibetan plateau is also categorized as a warmth dominant vegetation.

4. Discussion and Conclusion

Suzuki *et al.* [6] argued by a detail analysis of the NDVI in Siberia that the precipitation is the dominant factor for the NDVI south-north variation in arid-taiga transect, while temperature is the dominant for that in taiga-tundra transect. Moreover, Suzuki *et al.* [7] demonstrated that the NDVI in the zone around 60ºN in northern Asia shows the maximum value in annual mean basis. The boundary of the wetness dominant and warmth dominant vegetation obtained by this study is quite close to the zone discussed in Suzuki *et al.* [7]. These results suggest us that the vegetation around 60ºN line in Siberia has the most favorable climatic condition for vegetation in Siberia in terms of wetness and warmth, and consequently shows highest NDVI. As going to far from the zone, the vegetation diminishes due to aridity and low-temperature.

The analysis of the relationship among the NDVI, WEI, and WAI clearly demonstrated that there are two regimes of the vegetation: wetness dominant and warmth dominant vegetation. The result brings a better understanding on the essential climate and vegetation relationship at a global scale. Moreover, it helps us to understand and predict the vegetation change due to climate change. Analyses on the relation to the vegetation type are the next step in the future.

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