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Transitional responses of vegetation activities to temperature variations: Insights obtained from a forested catchment in Korea

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SUMMARY

Vegetation activities sensitively response to topological conditions and a changing climate. To better understand vegetation dynamics under varying environmental conditions, we analyze observations of vegetation indices, Land Surface Temperature (LST), air temperature, and precipitation of a Korean forest over an 11 year period from year 2000 to 2010. While a positive relationship between EVI (Enhanced Vegetation Index) and LST is established for all seasons, independent of elevation, the EVI–LST relationship exhibits a threshold above which the rate of EVI increase over LST increase changes significantly. This transitional point is associated with the condition that the air temperature triggers the start of the growing season. The EVI–LST relationship above the threshold exhibits a hysteresis loop, i.e., rising limb differs from falling limb. We identify two types of hysteresis patterns, i.e., a single loop and a twisted loop. The variation in loop width between the ascending and descending paths contains a signature in annual precipitation of concurrent year. In our analysis, annual precipitation above 1600 mm is associated with LST difference more than 5 °C in the loop width.

1. Introduction

The distribution and health of vegetation assemblages vary through altitudinal variability or geographical location because of their sensitive response to environmental conditions (von Humboldt, 1807; Wahlenberg, 1811; Grisebach, 1838; Schimper et al., 1903; Woodward, 1987; Bridge and Johnson, 2000). An improved understanding of how vegetation growth is affected by topographic settings and climatic variables will provide greater insight into environmental systems dynamics. Earlier studies have tended to focus on the role of elevation, rainfall, and temperature (Bian and Walsh, 1993; Goetz, 1997; Goward et al., 2002; White et al., 2005). However, the mechanisms which control vegetative response to climatic conditions across various topographic settings are not well understood.

Among studies that investigated the role of temperature using data obtained from satellites, Goetz (1997) found a negative relationship between Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature (LST) in grassland sites in Kansas, USA, where high NDVI is related to low LST in dense vegetation while low NDVI is associated with high LST in sparsely vegetated areas. Tateishi and Ebata (2004) found that the direction (positive or negative) in the correlation between NDVI and LST varies with land cover type. In the precipitation-dependent woody savannah and savannah, the correlation is negative, whereas for other land cover types including deciduous broadleaf forest, the correlation is positive. Karnieli et al. (2010) suggested that the correlation between NDVI and LST is seasonal and dependent on latitude; and that the correlation is generally positive when energy is the limiting factor (for example, at the beginning of the growing season). However, during the middle of growing season, the correlation is mostly negative since energy is not a limiting factor.

While these earlier studies have provided knowledge on the general response of vegetation activities to temperature, the detailed behavior of vegetation response to changing temperature could be more complex. The rate of photosynthesis is generally modulated by various factors such as solar radiation, CO_2 concentration, soil temperature, and soil moisture content (Kozlowski and Pallardy, 1996). When rainfall is absent in the previous season, growing biomass may deplete soil moisture during the growing period (Troch et al., 2009) that increases soil temperature. In return, leaf transpiration through stomata reduces sensible heat flux in the canopy leaf. If sufficient rain falls during the period of greenness, soil moisture can be replenished. Wet soil may decrease the soil surface temperature by more than 10 °C (Small and Kurc, 2003).

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Therefore, the relationship between vegetation activities and temperature is not necessarily simple and the actual relationship between these two varies temporally due to association with other sources such as moisture (Goetz, 1997), and the relationship may be highly nonlinear. The primary purpose of this study is to acquire a better knowledge on this seemingly complex fundamental relationship between vegetation activities and temperature across altitudinal variations with a consideration of soil moisture through precipitation.

To achieve this goal, we investigate the role of temperature on the vegetation growth over a particular region, i.e., a small catchment with undisturbed broadleaf deciduous forest that is in pristine condition in the temperate climate zone. Using this tractable approach, we aim to obtain a better understanding of how vegetation dynamics are affected by different environmental conditions. We are particularly interested in quantifying a specific feedback relationship between the temperature and the vegetation growth, using satellite remote sensing data obtained over different seasons. We aim to address whether temperature provides a positive feedback in vegetation growth and whether such response varies with season and elevation.

2. Study area and data processing

The study area is in Korea with a humid temperate and East Asia monsoon climate. A small pristine catchment of 18.6 km^2 is selected, and is referred to as the Sancheong catchment, in the southern part of the Korean Peninsula, at 127.71° East and 35.36° North (Fig. 1). The catchment is located in mountainous rugged terrain with maximum and minimum elevation of 1878 m and 414 m, respectively. The small catchment is composed of deciduous broadleaf forest as shown in land cover map from Oak Ridge National Laboratory Distributed Active Archive Center (ORNL DAAC) (2009) and data from Korea Forest Service (2012).

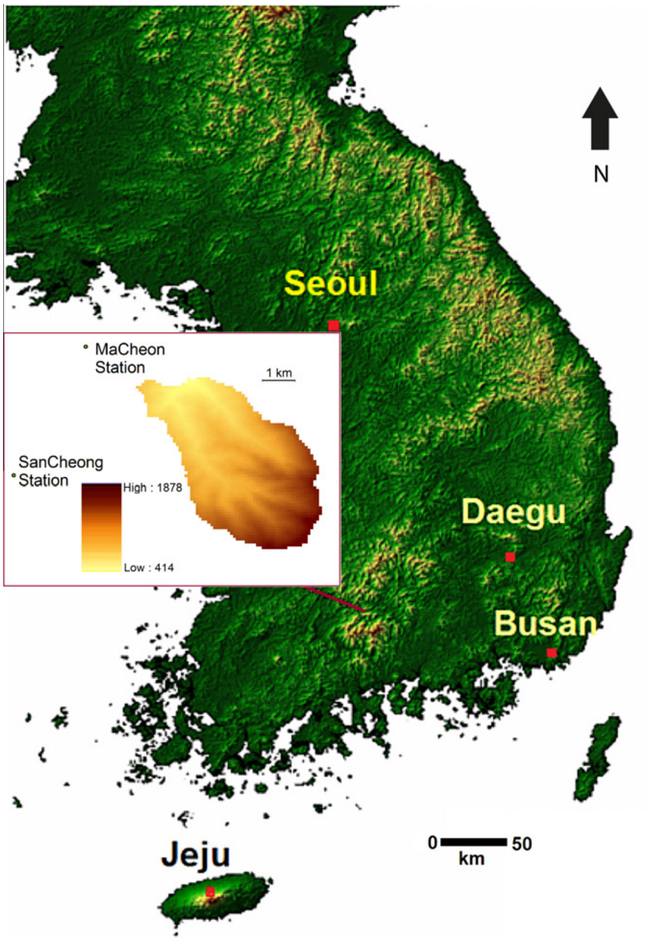

Fig. 1. Study area in South Korea; inset: Sancheong catchment showing Macheon gauging station.

Various kinds of data are used for this study. We use Normalized Difference Vegetation Index (NDVI) (Tucker, 1979) and Enhanced Vegetation Index (EVI) (Huete et al., 1997) to assess vegetation health, Land Surface Temperature (LST), ground-measured air temperature, Digital Elevation Model (DEM) for elevation, and precipitation. We use spatially distributed data for all these except the air temperature and the precipitation. Daily precipitation data from year 2000 to 2009 is obtained from a single station, named the Macheon station (Fig. 1) at an elevation of 300 m above sea level (a.s.l). This station is selected as it is closest to the catchment among available stations operated by Korean government agencies.

Vegetation Indices (VIs), i.e., NDVI and EVI are provided by USGS (United States Geological Survey). Their values are calculated based on reflectance measurements originally acquired from Moderate Resolution Imaging Spectroradiometer (MODIS) instrument with two platforms, i.e., TERRA (starting from year 2000) and AQUA (starting from year 2002). NDVI is the ratio of the difference between reflectance of near infrared and red bands as:

$$\mathrm{NDVI} = \frac{\rho_{\mathrm{NIR}} - \rho_{\mathrm{Red}}}{\rho_{\mathrm{NIR}} + \rho_{\mathrm{Red}}} \tag{1}$$

while EVI is calculated as:

$$\mathrm{EVI} = \frac{G(\rho_{\mathrm{NIR}} - \rho_{\mathrm{Red}})}{\rho_{\mathrm{NIR}} + C_1\rho_{\mathrm{Red}} - C_2\rho_{\mathrm{Blue}} + L} \tag{2}$$

where ρ_{Blue}, ρ_{Red}, and ρ_{NIR} are surface reflectances in the blue, red, and near infrared bands, respectively. In this equation, G is the gain factor, L is for the canopy background adjustment. C_1 and C_2 are coefficients for correcting aerosol influences in the red band by using the blue band. MODIS EVI use these coefficient values as follows: $G = 2.5$, $L = 1$, $C_1 = 6$, and $C_2 = 7.5$. These values are suggested as the optimum values to separate green canopy from background noise and atmospheric disturbances such as aerosol (Huete et al., 1994, 1997).

Both NDVI and EVI range from -1 to 1. The greater the value is, the greater the vegetation activities where the value of 1 indicates maximum greenness, a small-positive value (usually less than 0.1) represents bare soil, and a negative value represents a non-terrestrial surface such as ocean. NDVI is one of the most extensively used vegetation indices in the study of vegetation dynamics. NDVI has a long record with more than 20 years of data from the Advanced Very High Resolution Radiometer, which has been extended by the MODIS program; while MODIS Terra EVI commenced in 2000 the same year as MODIS NDVI.

NDVI is more responsive to chlorophyll variations, whereas EVI is more receptive to canopy dynamics (Gao et al., 2000). Unlike NDVI, EVI signals are less affected by atmospheric disturbance by the inclusion of the blue band, which is absent in NDVI. EVI is more sensitive in vegetation with a dense canopy (Huete et al., 2002; Fensholt et al., 2006) and its value is usually lower than NDVI. EVI shows more resistance to variations in canopy background (Gao et al., 2000) while the use of NDVI may be problematic when detecting VIs on partially closed canopies (Rocha and Shaver, 2009; Huete et al., 2002). EVI is more sensitive to seasonal vegetation dynamics (Ferreira et al., 2003), which was demonstrated in the finding of a “green-up” in the Amazon during the dry season (Huete et al., 2006) and the detection of forest destruction due to severe ice and snow storms in China (Chen and Sun, 2010).