Signal of vegetation variability found in regional-scale evapotranspiration as revealed by NDVI and assimilated atmospheric data in Asia

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Abstract: This study focused the relationship between the Normalized Difference Vegetation Index (NDVI) and the evapotranspiration (ET) temporal changes. Especially, the interannual change of the NDVI and ET from 1982 to 2000 at regional to continental scales was highlighted mainly over Asia. Monthly global NDVI data were acquired from Pathfinder AVHRR Land (PAL) data (1 × 1 degree resolution). The monthly ET was estimated from assimilated atmospheric data provided from National Centers for Environmental Prediction (NCEP) (2.5 × 2.5 degree resolution), and gridded global precipitation data of CPC Merged Analysis of Precipitation (CMAP) (2.5 × 2.5 degree resolution). Significant positive correlations were found between the NDVI and ET interannual changes in May and June over western Siberia. Moreover, it was revealed that the most of area in Asia has positive correlation coefficient in May and June. These results delineate that the vegetation activity significantly contributes to the ET interannual change over extensive areas.

***Keywords:** climate change, CMAP, NCEP-2, PAL*

1. Introduction

The vegetation distribution and its temporal variability are strongly dominated by the climate as many literatures have described (Walter 1973, Woodward 1987). Inversely, the vegetation activity influences the climate system. For example, the seasonal change of vegetation canopy largely modifies the albedo and aerodynamic roughness of the land surface. Especially, the transpiration from the vegetation of an extensive forest should play an important role in the water and energy cycle in the climate system. Therefore, it is considered that the interannual ("long-term" in other word) change of the vegetation have a great possibility to change the climate system.

The relationship between the vegetation and evapotranspiration (ET) has been surveyed by some previous studies (e.g. Kondoh, 1995; Suzuki et al., 1998). However the long-term relationship of them over large-scale areas has not been studied so far. The objective of this study is to investigate the temporal change relationship between the vegetation and ET over regional to continental scale areas mainly over Asia. 19 years from 1982 to 2000 was targeted.

The ET practically contains a component of evaporation, which does not directly relate to vegetation, in addition to the transpiration. However we consider that it is possible to seize a signal, which is originated in the vegetation change, in the ET variation.

2. Data and analyses

2.1. NDVI

For analyses of the vegetation at an extensive scale, the Normalized Difference Vegetation Index (NDVI), which is computed from the measurement of the sensor "Advanced Very High Resolution Radiometer" (AVHRR) of the NOAA satellite, is useful data. The NDVI is computed by following equation:

$$NDVI = (Ch2 - Ch1)/(Ch2 + Ch1),$$

where $Ch1$ and $Ch2$ are measurements from AVHRR channels 1 (visible) and 2 (near-infrared), respectively.

Monthly global NDVIs from 1982 to 2000 are obtained from the Pathfinder AVHRR Land (PAL) data set, that has 1 × 1 degree spatial resolution (NASA, 1999). The raw AVHRR data would contain unfavorable temporal fluctuations due to non-vegetational factors such as the drift of the satellite orbit and sensor degradation. The PAL data were corrected for these fluctuations and allows us to investigate the reliable interannual change of the vegetation.

2.2. Evapotranspiration (ET)

The ET from the surface can be estimated from the water budget in the atmosphere which was discussed in Peixoto and Oort (1983, 1992). The ET from the bottom (i.e. ground surface) of an air column, which vertically extends from the ground surface to the top of the atmosphere, can be expressed by the following atmospheric water budget equation,

$$ET = P + \frac{\partial W}{\partial t} + \nabla_H \cdot \vec{Q},$$

where t is the time; P, the precipitation at the bottom; W, the precipitable water in the air column; and $\nabla_H \cdot \vec{Q}$, the horizontal flux divergence of water vapor integrated from the surface to the top of atmosphere (so called "aerial runoff").

This study assumed air columns above 2.5 × 2.5 degree (longitude and latitude) grid cells over the region, and computed the ET for each grid cell. For the monthly precipitation P, the "CPC Merged Analysis of Precipitation (CMAP)" (2.5 × 2.5 degree spatial resolution) dataset was used (CPC/NOAA). This global precipitation product was a composite of several kinds of data sources such as gauge observation, satellite estimates, and numerical model outputs. Gauge measurements are used to estimate precipitation over the land.

It is possible to compute the terms $\partial W / \partial t$ and $\nabla_H \cdot \vec{Q}$ from the specific humidity and wind data. In the present study, gridded atmospheric data provided by National Centers for Environmental Prediction (NCEP) are used to calculate $\partial W / \partial t$ and $\nabla_H \cdot \vec{Q}$. This data set is known as so-called NCEP-2 (Kanamitsu et al., 2000).

The monthly $\nabla_H \cdot \vec{Q}$ for each 2.5 × 2.5 degree

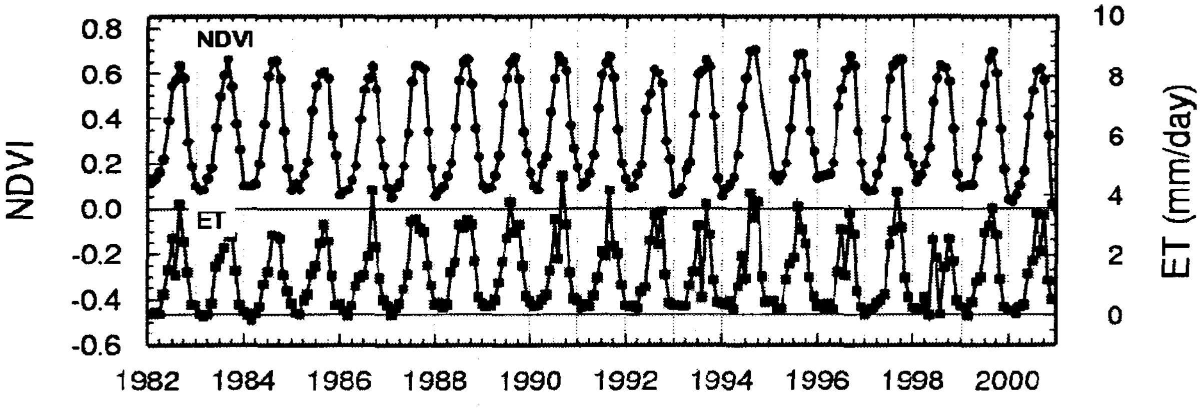

Figure 1 Temporal changes of the NDVI and ET over Northeast China from 1982 to 2000.

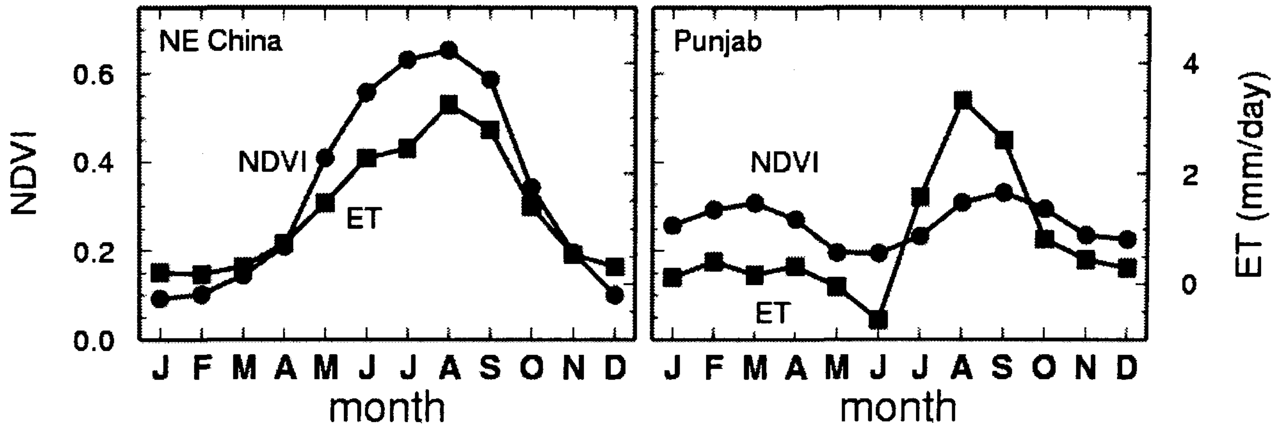

Figure 2 Mean seasonal changes of the NDVI and ET for the 19 years over two example areas: Northeast China (left) and Punjab (right).

grid cell from 1982 to 2000 was estimated by integrating the flux divergence from the ground to 0 hPa. The monthly $\partial W / \partial t$ was calculated from precipitable water difference between the beginning and end of each month. A discussion on the estimation accuracy of $\nabla_H \cdot \vec{Q}$ can be found in Oki et al. (1995).

3. Result

3.1. Seasonal change of the NDVI and ET

Figure 1 indicates an example of the monthly change of the NDVI and ET that are averaged over Northeast China (120E - 130E, 40N - 50N) from 1982 to 2000. The NDVI shows noticeable seasonal cycle. The value in winter is around 0.1, while that in summer exceeds 0.6. These NDVI seasonal cycles demonstrate the phenological characteristic of the actual vegetation there, that is, the active phase in summer and the dormancy phase in winter. Similarly, the ET indicates seasonal cycle; the ET in winter is around 0 mm/day, while that in summer is 3 – 4 mm/day.

Figure 2 clearly exhibits the relationship between the monthly NDVI and ET seasonal cycles which are averaged for the 19 years over two sample areas. Over Northeast China, both of ET and NDVI show quite similar uni-modal seasonal evolution i.e. minimum in winter and maximum in summer. Fig. 2 also indicates the seasonal change of them over Punjab area (70E – 77.5E, 30N – 32.5N) as another example. The NDVI seasonal cycle has two apparent peaks in March and September. Malingreau (1986) reported that this bi-modal seasonal change of the NDVI is related to the bi-seasonal cultivation, wheat in spring and rice in summer. Note that the ET seasonal cycle has similar seasonal cycle, that is, two maximums in February – April and August, and the annual minimum in June can be seen. As Suzuki et al. (1998) pointed out, these facts probably delineate that the vegetation activity is detected in the estimated ET in these areas.

3.2. Interannual change of the NDVI and ET

To analyze the interannual change of the NDVI and ET, their monthly anomalies from monthly mean for the 19 years (1982 – 2000) were calculated for each 2.5 × 2.5 degree grid cell. Figure 3 demonstrates the interannual change of the NDVI and ET which are the mean in May and June, averaged over western Siberia (60E - 90E, 55N - 65N).

Quite similar interannual changes can be seen for these 19 years (r = 0.75). Both the NDVI and ET show small values in 1983, 1993, and 1996, and large values in 1991, 1997, and 2000. Moreover, increasing trend can be seen both in the NDVI and ET.

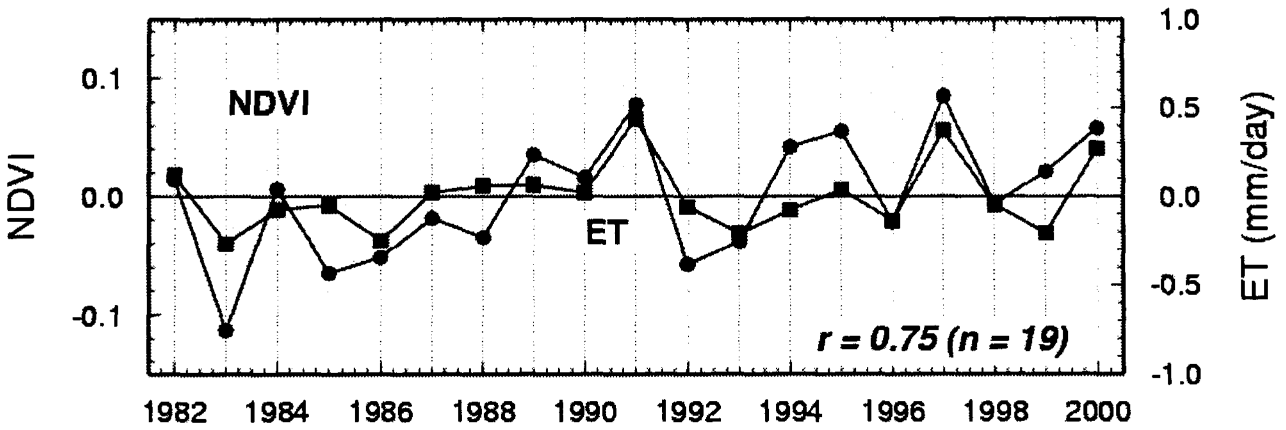

Figure 3 Interannual changes of the NDVI (circle) and ET (square) anomalies over western Siberia.

The increasing trend of the NDVI seem to be consistent with Myneni et al. (1997, 1998). Although the estimate ET contains some components of the evaporation from the ground surface in addition to the transpiration component, this result suggests that the ET interannual change is dominated by the interannual change of the vegetation at regional scale.

The correlation coefficient of them in May and June are the highest among all 12 months, and that was why the mean temporal change in May and June is indicated in Fig 3. Since May and June are the season in which the vegetation is most active, the highest correlation in May and June may be an evidence that the transipiration activity considerably contributes the ET interannual change.

Figure 4 shows the distribution of the correlation coefficient between the monthly anomalies of the NDVI and ET interannual changes (mean of May and

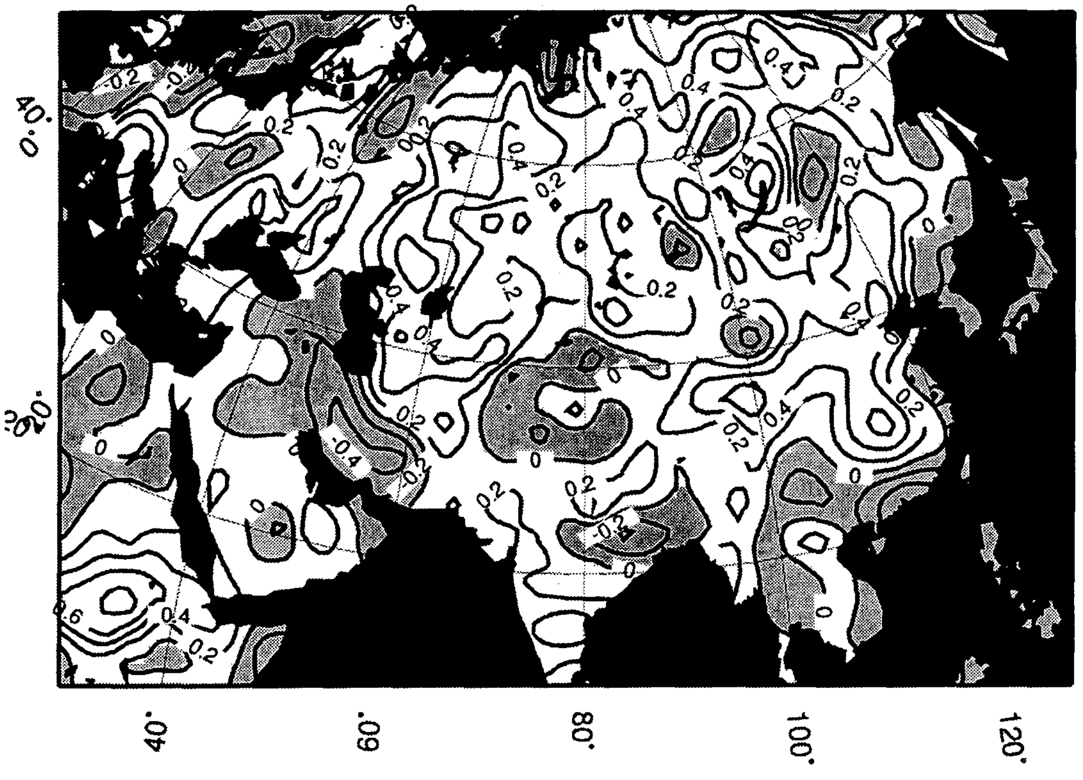

Figure 4 Distribution of the correlation coefficient between the NDVI and ET anomalies (mean of May and June) from 1982 to 2000. The area with negative coefficient is hatched.

June) at each 2.5 × 2.5 degree grid cell over Asia. The correlation coefficient over the most of regions shows positive value, and that suggests the ET interannual change may contain a signal of vegetation change over the most of areas in Asia. Negative coefficients can be seen in some areas. In arid areas and high altitude areas, it appears that the very low NDVI in such areas may result an instable and negative correlation coefficient. Negative coefficients can be found over a large area in northeastern Siberia and eastern India etc, however their exact reason is unknown.

4. Summary

The monthly time series of the NDVI, which is a satellite-derived vegetation information, and the ET, which was estimated from the gridded atmospheric data, was examined at regional and continental scales from 1982 to 2000. Significant positive correlation was found between the NDVI and ET interannual changes in May and June over western Siberia, suggesting a great contribution of the vegetation to the ET interannual variability. Moreover, it was revealed that the most of area in Asia has positive correlation coefficient in May and June.

These results delineate that the vegetation activity has significant contribution to the ET over extensive areas. When we predict forthcoming climate change, it should be necessary to take into account the vegetation as a forcing factor of the atmosphere.

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