DEVELOPMENT OF NEW VEGETATION INDEXES, SHADOW INDEX (SI) AND WATER STRESS TREND (WST)

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ABSTRACT:

For the analysis of vegetation areas using satellites, a variety of vegetation indexes such as NDVI and EVI have been developed. However, most indexes have weak response to grasping the type and quality (the growth state and situation) of vegetation. To grasp these vegetation characteristics, we have developed new vegetation indexes, i.e. shadow index (SI) and water stress trend (WST). We estimate SI from damping factor of radiation caused by shadow and apply it for analysis of vegetation type and structure. And we also estimate WST from variation of vegetation temperature which corresponds to vegetation moisture content, and apply it to detect the damage from water stress. We report preliminary results applied these indexes to satellite data. Two indexes are useful for vegetation analysis, such as the grasp of vegetation type, canopy structure, and drought state.

1. INTRODUCTION

Global warming has become a serious problem in the world. The Forth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) predicted that the global warming is already in progress and it should be caused from the increase of greenhouse gases with the extension of human activities (Climate Change, 2007). These global changes will give a serious influence for human society and various ecosystems. A major element of greenhouse gases is carbon which is generally released in the form of CO_2. Carbon reservoirs are included in the atmosphere, forests, soils, fossil fuels, and oceans. In one carbon cycle, plants absorb CO_2 and release O_2 to the atmosphere by photosynthesis. In other words, vegetation over land surface accumulates carbons which are released to the atmosphere as CO_2. Therefore, global monitoring of vegetation is quite important to predict future movement of global climate.

In order to analyze vegetation areas using satellite data, a variety of vegetation indexes have been developed. The most commonly applied index is normalized difference vegetation index (NDVI). NDVI is very useful for deriving two-dimensional vegetation parameters, such as the fraction of absorbed photosynthetically active radiation (fAPAR) and percentage of green cover (Asrar, 1989; Calson et al., 1997; Tucker, 1979). Moreover, EVI (the enhanced vegetation index), which is developed as improvement version of NDVI, is strongly correlated with structural parameters of canopy, such as leaf area index (LAI) (Huete et al., 2002). However, these indexes have weak response to grasping the quality (the growth state and situation) of vegetation and vegetation (tree) type. Therefore, it is required to develop new vegetation indexes that are possible to grasp the vegetation characteristics mentioned above. Then, we devised new vegetation indexes, which are named shadow index (SI) and water stress trend (WST). Here, we introduce these new indexes, and show the preliminary results applied them to satellite data.

2. DEVELOPMENT OF NEW VEGETATION INDEX

2.1 Shadow Index (SI)

Radiance drops significantly when the object is shaded. In a scene observed by satellite, there are regions shaded by clouds, mountains and fabrics. And microscopically, for example, leaves of trees in the shade are also observed in the most of forests and generate texture pattern. Thus, shadow effect is inevitable for satellite data, but its correction is very difficult. However, in other viewpoint, it is available to classification of land-cover and vegetation type by estimating the amount of shady parts. Damping factor caused by shadow effect varies with land coverage. In vegetation regions, mixing ratio of observing shady regions varies widely with vegetation type, plant growth, season, and so on, because the structure and roughness of vegetation are different each other.

We have developed the normalization technique for satellite spectra to suppress topographic and atmospheric effects (Ono et al., 2002). From the results of conventional analysis, we found that the normalization method with arithmetic mean of applied bands can suppress the shadow effect as well as the topographic and atmospheric effects. In other words, this method can recognize shady regions and evaluate the shadow effect. The ratio of observed radiance to its normalization value corresponds to the damping factor of radiation, and we define this ratio as shadow index (SI).

SI varies with the mixing rate and damping factor of shady objects. The distribution of shady objects plays an important role to the high-quality estimation of vegetation biomass and the high-quality land-cover classification. And it is useful to monitor the change of canopy gap and the boundary between grass and forest. Therefore, SI would be very important index for vegetation analysis.

2.2 Water Stress Trend (WST)

Recently, various areas were suffering heavily from drought. The drought ruins the crops which are indispensable for the animal life as well as water. The shortage of water is serious for maintenance of their life, but area lacking water is spreading out by the influence of global warming.

A lot of indexes have been developed to detect the water stress from the spectral radiometer data (Gao, 1996; McFeeters, 1996; Xu, 2006). However, signs of withering appeared in the most of these indexes are too late. To detect the damage from water stress at an early stage by monitoring plant growth in a land, we proposed a new vegetation index named water stress trend (WST) (Ono et al., 2010).

To duration of water stress, plants have a tolerance and keep the vegetation moisture content for some days. Thus, this content indicates the viability of plants. Water is hard both to warm up and to cool down. This means that variation of vegetation temperature depends on vegetation moisture content. Based on this characteristic of water, we took temperature variation throughout the day, or during the daytime as WST.

3. ANALYSIS RESULT

We have applied SI and WST to ground measurement data and radio-control helicopter data, and obtained reasonable results (Ono et al., 2007; Ono et al., 2010). In this study, we applied these indexes to satellite data, and examined their applicability and generality. Used are 0.05 degree global data of NOAA/AVHRR (1981-1999) and Terra/MODIS (2000-2009). The results are shown in the following paragraphs.

3.1 Shadow Index (SI)

We applied SI to the global satellite data. Annual and monthly means of SI values in 2009 are shown in Figures 1(a) and (b), respectively. As seen from Figure 1(b), the value and distribution of SI varied according to the season. In a vegetation area, SI varies with the type of covering plants, and we have coniferous forest, broadleaf forest and grassland in descending order of SI values as expected from the results obtained from ground measurement data. SI also varies with the structure of canopy, such as evergreen or deciduous broadleaf, and closed or open. Thus, SI is useful for the detailed vegetation analysis, such as classification of vegetation type, and grasp of vegetation growth situation.

To investigate the results in more detail, we estimated the seasonal variations of SI in the total areas of Japan and Mongolia. Obtained results are shown in Figure 2. In Japan, about two parts in three by the area are covered with forests. In Mongolia, on the other hand, grassland extends over the country.

The observed pattern of seasonal variation of SI in Japan is very similar to the result of our ground measurement for the forest of Larix kaempferi at Yatsugatake observation site. Structure of vegetation, especially amount of leaves is reflected on the SI. In spring, many of the trees begin to sprout new leaves, and increase number of leaves and their volume. Then, observing regions of ground surface decrease and SI keeps decreasing for two months. Since leaves become overlapped each other in summer, observing shady leaves increase and SI increases. In

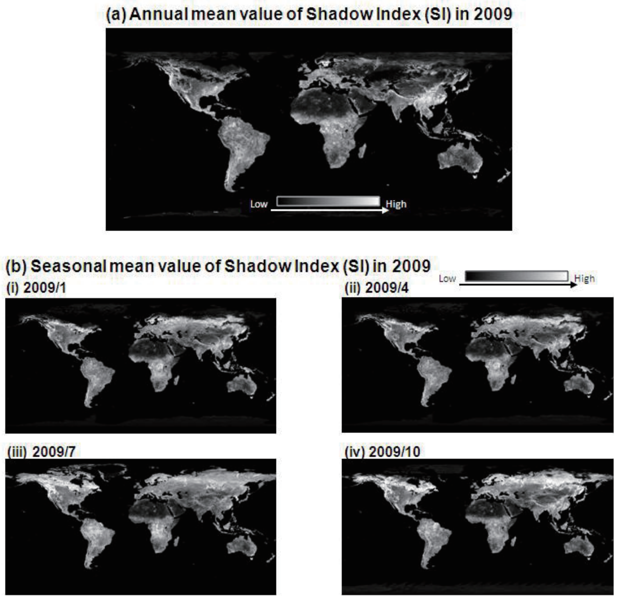

Figure 1. The global images are (a) annual mean value and (b) seasonal mean value of Shadow Index (SI). Used data were observed by Terra/MODIS in 2009.

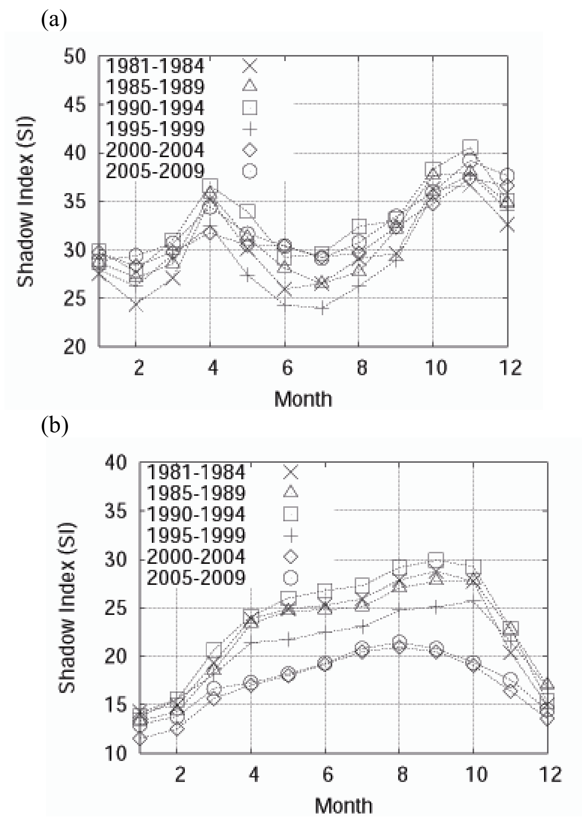

Figure 2. The seasonal change of Shadow Index (SI) in (a) Japan and (b) Mongolia. Used SI values are mean value of five years data, which were observed by NOAA/AVHRR and Terra/MODIS from 1981 to 2009.

autumn, SI decreases again by defoliation. Then, SI repeats an increase and a decrease with the passage of season in Japan (in forest). On the other hand, seasonal variation of SI in Mongolia is simple. SI becomes high as the grass grows up, and low as the grass dies. In a word, this variation of SI expresses the variation of leaf amount and vegetation biomass well.

3.2 Water Stress Trend (WST)

We applied WST to global satellite data. Obtained annual and monthly means of WST in 2009 are shown in Figures 3(a) and (b), respectively. The higher vegetation coverage is, the smaller WST become. Then, WST is high in a desert, and low in a vegetation region in order of forest and grassland. The obtained distribution of WST is corresponding to "World Atlas of Desertification" of the UNEP (United Nations Environment Programme) report (UNEP, 1997).

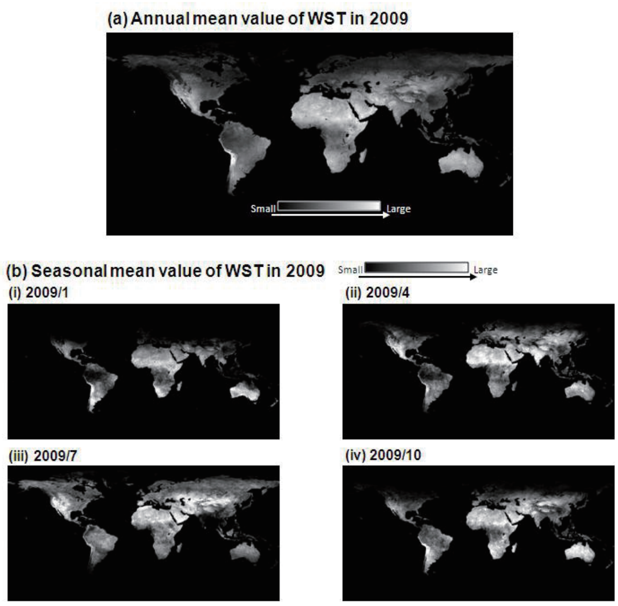

Figure 3. The global images are (a) annual mean value and (b) seasonal mean value of Water Stress Trend (WST). Used data were observed by Terra/MODIS in 2009.

WST is expected to detect a sign of damage from a drought. We estimated the annual variation of WST from 2000 to 2009 in 4 countries where the crops were badly damaged on account of the unseasonable weather in recent years. The results are shown in Figure 4. Australia suffered great damage of drought in 2002 and 2006, Argentina in 2008, and Kenya in 2009, and Japan was damaged by hot weather in 2007. Precipitation varies every day and every month, but as seen from Figure 4, WST varied slowly under normal conditions and became high behind the beginning of unseasonable weather.

The annual variation of WST corresponds to that of precipitation well. That is, the rain causes the content of vegetation (soil) moisture to increase, and WST to decrease. Using the spectral radiometer data, we estimated the annual variation of NDVI and NDWI (Normalized Difference Water Index) in the same countries. Obtained results are also shown in Figure 5. As seen from the figure, WST has high values during a certain period in the year of drought damage, but neither NDVI nor NDWI are necessarily low. The response of NDVI and NDWI to the water stress is very slow, and plants do not back to life at the point of the time NDVI or NDWI begins to decrease. Thus, WST is useful for early diagnosis of water stress and for detection of insufficiency of precipitation or damage of drought at an early stage.

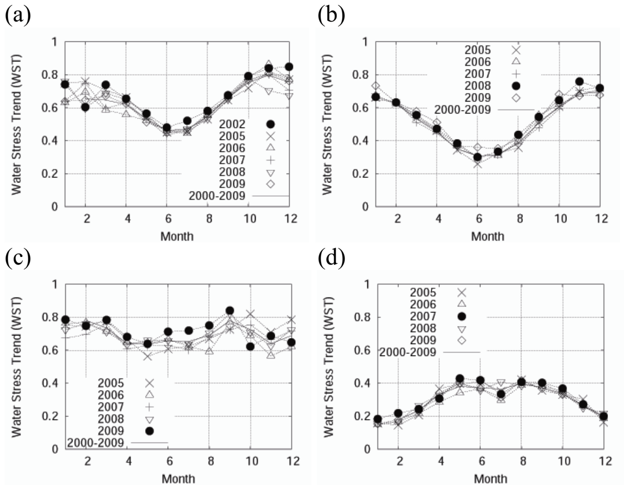

Figure 4. The seasonal change of Water Stress Trend (WST) in (a) Australia, (b) Argentina, (c) Kenya, and (d) Japan. Used data were observed by Terra/MODIS from 2000 to 2009.

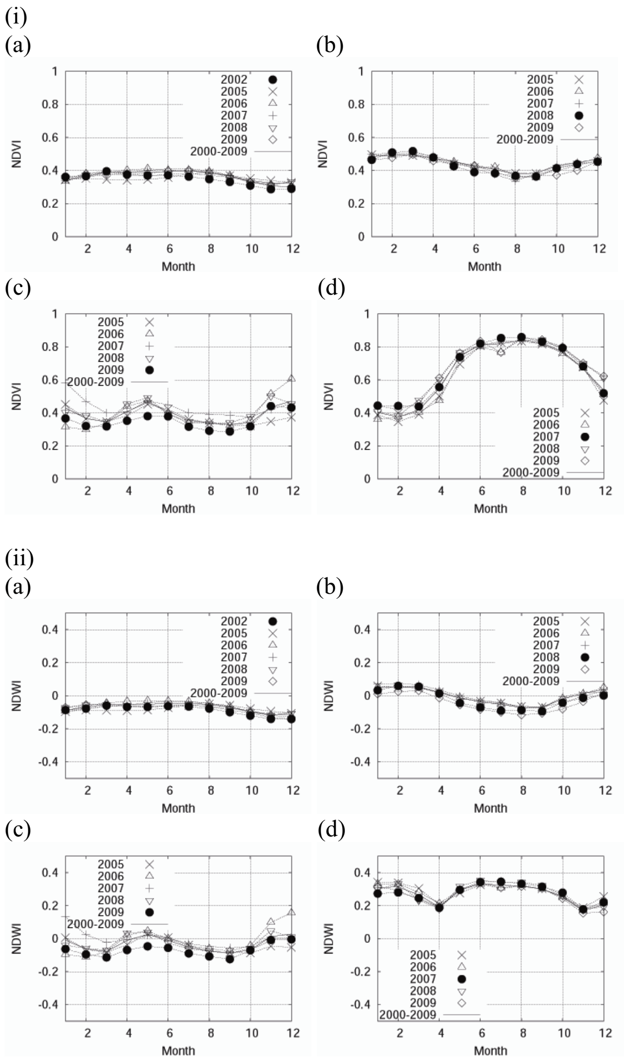

Figure 5. The seasonal change of (i) NDVI (Normalized Difference Vegetation Index), and (ii) NDWI (Normalized Difference Water Index) in (a) Australia, (b) Argentina, (c) Kenya, and (d) Japan. Used data were observed by Terra/MODIS from 2000 to 2009.

Crop (food) products suffer large-scale damage from drought. Because food is indispensable for animal life, the detection of damage areas of drought at an early stage is very important. Therefore, it is expected that WST becomes an important index for vegetation analysis.

4. SUMMARY

Most of conventional vegetation indexes are useful for grasping vegetation coverage, but have small effect to the analysis relative to the vegetation quality (the vegetation growth state and situation), vegetation (tree) type, and vegetation structure. Therefore, new vegetation indexes are required to analyze them.

On the analysis of vegetation area, we noticed shady regions observed by the sensor. Damping factor of the radiation varies with the mixing ratio of shady parts which depends on vegetation (tree) type, plant growth, season and so on. Then, utilizing this damping effect, we developed a new vegetation index, SI (Shadow Index).

Applying SI to satellite data, it is found that SI is useful for vegetation analysis, such as classification of vegetation type, grasp of vegetation situation and canopy structure. By using SI, we could monitor gaps of canopy and boundaries between grass and forest.

In addition, we developed another vegetation index, which is named Water Stress Trend (WST). WST is an index which corresponds to vegetation moisture content in plants, and can apply to detect the damage of drought at the early stage. Though normal vegetation indexes are estimated from spectral radiometer data, WST is estimated from the thermal data utilizing the characteristic of specific heat of water. In comparison with the variation of radiation spectra, daily variation of plant temperature is more sensitive to detect the sign of damage by drought. WST can grasp the drought damage at early stage, and is useful to understand the distribution of precipitation. Moreover, WST is expected to contribute to the forecast of the food (crop) production.

The Japan Aerospace Exploration Agency (JAXA; former NASDA) has made a new plan of Global Change Observation Mission (GCOM) for monitoring of global environmental change and understanding the mechanism of global environmental change, including global warming (Honda et al., 2007). Data obtained from GCOM are necessary for the monitoring of global climate change and the improvement of climate model, and it should be useful for contribution to social benefits. The GCOM mission will consist of two series of medium-sized satellites: GCOM-C (Climate) and GCOM-W (Water). GCOM is designed to establish a long-term observation for monitoring global environment changes, improving knowledge of climate system, developing climate forecast models, and distributing the environmental data.

As mentioned above, we have developed Shadow Index (SI) and Water Stress Trend (WST), and these two indexes are included in the land products of GCOM-C. SGLI (Second Generation GLI) onboard GCOM-C satellite is one of GCOM mission, and provides optical sensors from Near-UV to MTIR. Characteristic specifications of SGLI are as follows:

1) Ultra Violet (380 nm),
2) Three direction polarization observation (red and NIR),
3) 250 m resolution (from Near-UV to SWIR),
4) 500 m resolution (MTIR).

These are new and unique characteristics, and GCOM-C/SGLI data would be useful for understanding the global circulation of carbon, estimating radiation budget, monitoring environmental changes, and also our comprehension of primary marine production.

Land products of SGLI are 14 (standard products are 9, and research products are 5). Most of physical parameters in the products are estimated quantitatively by utilizing SGLI spectral characteristics obtained from new and unique sensors. In addition to NDVI, SI and WST are included in the GCOM-C/SGLI land products as vegetation indexes. SI plays a role in the grasp of vegetation type and structure, and WST in the grasp of the drought state. By the combination of these vegetation indexes, we could monitor the land-cover and the growth quantity of plants which are very important to understanding Earth's environment change. Thus, GCOM-C/SGLI land products bring useful information on many fields of human benefit. Hereafter, the further development of two indexes is required.

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