Comparison of special characteristics of drought-stressed vegetation observed by In-Situ measurements and satellite remote sensing

Comparison of Spectral Characteristics of Drought-Stressed Vegetation Observed by *In-Situ* Measurements and Satellite Remote Sensing

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Abstract

Monitoring of canopy drought condition can be crucial not only for predicting vulnerability to forest fire and diseases but also for estimating forest productivity as a result of climate changes. In recent years, the frequency and magnitude of forest fires have increased during the spring drought season in the Korean peninsular. Although there have been several studies on the spectral characteristics of different moisture content of leaf, it is still not quite clear whether the spectral property of leaf can be extended to the canopy-level, which is observed from satellite remote sensing.

In this study, we attempt to compare the spectral characteristics of water stressed vegetation by using the laboratory measurement on leaf and the canopy reflectance spectra extracted from satellite hyperspectral image data. Laboratory reflectance spectra were measured using a portable spectro-radiometer. Canopy reflectance spectra of the sample forest stands were extracted from EO-1 Hyperion imaging spectrometer data obtained during the drought season in 2001 and then compared with the ones obtained in 2002 when the precipitation was in normal. The preliminary results showed that the leaf-level spectral characteristics of water-stressed samples did not quite correspond with the canopy reflectance spectra. Although moisture content of vegetation can be an influential factor to the amount of radiant flux reflected from leaf-level, it may not be a direct parameter to change the spectral characteristics of canopy-level. Canopy reflectance spectra are much more complex than leaf spectra and can be varied by several structural variables (such as LAI, percent coverage, and biomass) other than canopy moisture content.

1. Introduction

Symptom of canopy water stress can be varied by the length and magnitude of the drought. Lack of water content in vegetation can be major limitation to primary productivity and, further can cause environmental problems such as wild-land fire (Marod, 2004). In general, the drought condition in temperate forest is very seasonal and lasts only a few months, which may not cause any noticeable change on canopy.

Whether remote sensing can detect such drought stress depends on the spectral characteristics of leaf and canopy levels. Spectral characteristics of vegetation water deficiency have been an interesting topic in remote sensing community. It has been well known that the leaf reflectance increases as the moisture content of leaf decreases, in particular at the wavelength of water absorption bands of shortwave infrared (SWIR) spectrum. Several studies found that plant water stress affects spectral reflectance in near infrared (NIR) and SWIR regions (Harris, 2005; Ustin, 1998). Recent development of hyperspectral sensor data has provided the capability to detect minute variation of vegetation spectra. However, most studies using hyperspectral data are still concentrated on leaf-level moisture content and there have been few studies that deal with canopy-level spectral characteristics, in particular for forests having high crown closure (Bowyer, 2004; Asner et al., 2004). In close canopy situation, the spectral resolution of multispectral data may not be sensitive enough to the canopy water content. Hyperspectral sensing may be an alternative to overcome such limitations by providing very narrow spectral bands that may allow us to observe particular spectral features resulted from drought stress. In this study, we are trying to compare the spectral characteristics of water stressed vegetation, which are obtained from the *in-situ* spectral measurement and the hyperspectral satellite image data.

2. Methods

2.1 Spectral measurements of leaf samples

To measure leaf-level reflectance spectra at different moisture levels, we collected sample leaves from pitch pine (*Pinus rigida*) and oak (*Quercus mongolica*) trees in nearby suburban forests. The sample leaves were stored in moist plastic zipper bag and were brought to the laboratory. Reflectance spectra were continuously measured on the same sample leaves that were getting dry under the two 500-W halogen lamps illuminated at 50cm over the sample.

Reflectance spectra were measured using a portable spectro-radiometer (GER 2600), which can measure spectral reflectance over the wavelength region between 350nm and 2,500nm. Reflectance spectra were measured at 1m above the sample with a 10 degrees FOV lens. At each measurement, the spectroradiometer actually provides percent reflectance value for 612 continuous bands over the wavelength from 350nm and 2,500nm. Reflectance measurements were performed every 10-20 minute during the first 2 hours and continued until the sample leaves began to show noticeable symptoms, such as rolling and senescence. We also measured weight of the sample leaves at the time of spectral measurement. Relative leaf water content is calculated by dividing it by the weight of the first weight.

2.2 Canopy spectra extraction from EO-1 Hyperion data

Unlike the leaf-level reflectance, it is not easy to obtain the reflectance spectra of plant canopy, in particular for the drought stressed forest canopy. We have chosen satellite hyperspectral image data to extract reflectance spectra at canopy-level. EO-1 Hyperion satellite data provide about 240 narrow and continuous bands ranging from 400 to 2,500nm wavelength range, which enable us to obtain reflectance spectrum for every pixel.

For the study, two Hyperion images were acquired on early June in both 2001 and 2002. Study area located in western part of South Korea has experienced relatively severe drought during the spring of 2001, in which the accumulated precipitation is 150mm less than the normal year at the time of satellite data acquisition (Figure 1). The forest in this area has diverse group of species composition and stand ages between 20 to 50 years old. To compare with the laboratory measurements, the sample ground plots are mainly plantation pine stands (*Pinus rigida)* and mixed deciduous species with oak dominant. The study areas also include large areas of irrigated rice fields, non-irrigated cropland, and pasture.

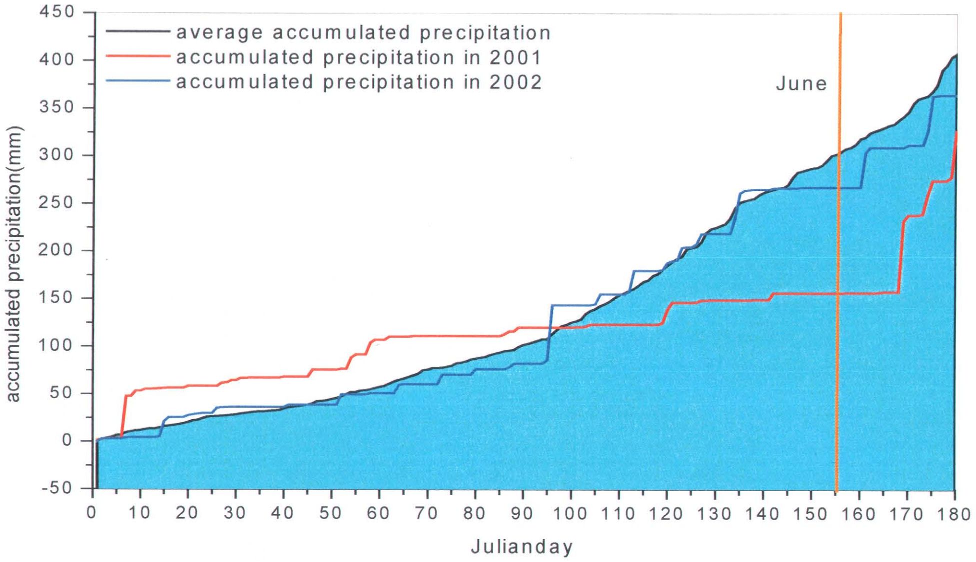

Figure 1. The accumulated precipitation of the spring drought in 2001 as compared to the normal precipitation year (2002) and the average.

Initially, we try to compare the spectral characteristics of sample ground plots between 2001 (drought year) and 2002 (normal year). Although it would be ideal to have two temporal scenes cover the same area, such datasets were not available. Since EO-1 satellite was launched as an experimental satellite, the image acquisition capability is rather limited. Instead, the area covered by each scene was 100km apart. We believe that the geographical discrepancy does not affect any serious problem since the sample ground plots used to extract canopy spectra are carefully surveyed and represent about the same surface coverage and canopy structure.

Since the ground truth data collection was not available at the time of data capture, we used forest stand maps, land cover maps, and aerial photographs to select sample plots. Further ground survey was conducted to verify forest stand characteristics, such as species composition, canopy density, and tree age. To compare the canopy drought stress between forest and non-forest vegetation, additional sample plots were also selected from irrigated rice fields and non-irrigated grassland. During the ground survey, exact plot locations were determined using a differential global positioning system (DGPS).

Before extracting reflectance spectra of known sample stands, the Hyperion data were atmospherically corrected and geo-registered to a plane rectangular coordinate systems using a set of ground control points. Among 242 spectral bands, those bands having high sensor noises and heavy atmospheric water absorptions near 1,400nm and 1,900nm were removed and only 208 bands are finally used. About 10 pairs of sample plots (including seven forest stands, a rice field, a cropland, and a pasture) were located from each of two atmospherically corrected Hyperion data. For each sample ground plot, canopy reflectance spectra were obtained by averaging the reflectance values that were extracted from four pixels surrounding the sample plot.

A number of studies have used spectral indices for analyzing vegetation water content. The water index is a simple mathematical transformation to enhance spectral characteristics of water absorption features. Water index (WI) is a simple ratio of two spectral bands in NIR region, in which one of them is strong water-absorption band and the other is not (Harris, 2005). In general, the wavelength regions used for water absorption bands are 950-970, 1150-1260, and 1520-1540nm. The other reference bands used for the water index are usually 860nm, 900nm, and 1240nm (Penuelas, 1997; Gao, 1996). We have also tested a general purpose normalized difference vegetation index (NDVI) whether they are sensitive to the canopy drought stress condition.

3. Results and Discussions

The moisture content change within the detached leaves is different between two species (Figure 2). While the pine needles show gradual decrease in relative moisture content, the oak leaves show rather rapid decline within a few hours. Oak leaves lost about 50% of water content within 4 hours while pine needles lost only about 30% within 14 hours. Pine needles do not show any noticeable symptoms of color change nor rolling until up to 10 hours. However, oak leaves begin to show rolling and yellowish after about 160 minutes. Although we are not sure the exact physiological limit of leaf moisture content that may separate between 'damage' and 'stress' of these two tree species, we may say that trees are in damage when the leaf begins to roll and its color turns to yellow. From the Figure 2, we may say that pine tree may be more resistant to water deficiency as compared to oak trees during the drought season.

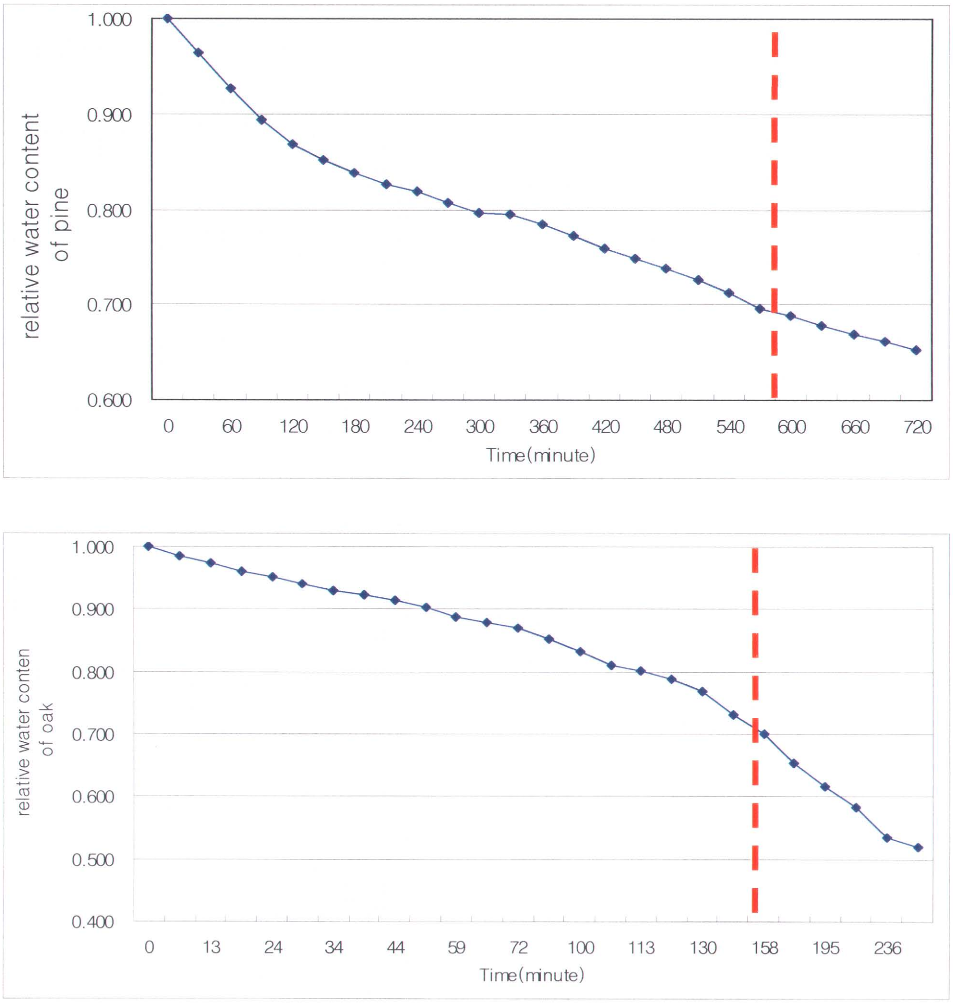

Figure 2. Change of relative moisture content of sample leaves of pine and oak during the laboratory measurement. Red dashed line indicates rolling and yellowish of leaf.

Figure 3 shows laboratory measured reflectance spectra of pine needles and oak leaves as the moisture content is decreasing by time elapsed. In general, reflectance increases as moisture content of leaf decreases in all wavelengths. In our experiments, the results are not quite the same as the general pattern except for the wavelengths longer than 1,100nm. Leaf reflectance show very minimal changes in visible wavelength. As mentioned earlier, both pine needles and oak leaves did not show any evident color change until the last measurement.

It is very curious to see the reflectance of oak leaves at NIR region (700 to 1,100nm). Although the moisture content at this time is reduced by 50% after 15 hours, they are still showing the lowest reflectance in this wavelength region. In natural condition when the leaf water level drops to half, the tree might not be survived and the leaf color turned to yellow. Only possible explanations on this strange pattern may be found from the morphological change of oak leaf. Oak leaves begin to show rolling about 1 hour after the first measurement. After 15 hours, they were completely rolled over, which might affect the viewing surface (such as shadow) of leaves within the field of view (FOV) of the spectro-radiometer. The reflectance spectra of pine needles show gradual increase as the relative moisture content drops. Detached pine needles did not show any morphological changes until 10 hours after the first measurement.

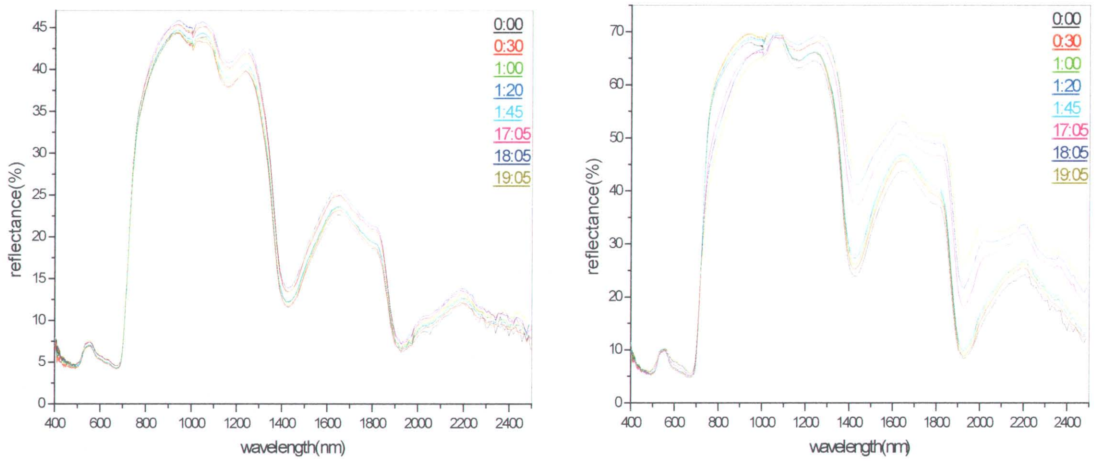

Figure 3. Leaf reflectance spectra obtained by laboratory measurements using spectro-radiometer: pine needles (left) and oak leaves (right).

Comparison of canopy spectra between drought season (2001) and normal season (2002), which were extracted from pine and mixed deciduous forests, shows very different pattern as compared to the laboratory measured leaf spectra. The inverse relationship between reflectance and leaf-level moisture content cannot found at the canopy level observed in this study. Forest canopy spectra extracted from the drought year vary by wavelength and forest types (Figure 4).

In visible wavelength, canopy reflectance of drought year is higher than normal year, which seems to follow the general leaf-level reflectance. Reflectance pattern in NIR wavelength can be divided at 940nm, which is known as one of several water absorption features. In plantation pine, canopy reflectance of drought year is higher in this region, while the mixed hardwood canopy show slightly lower reflectance. The slightly higher NIR reflectance of the pine stand under the severe drought condition may be explained by several factors. As seen in Figure 3, the reflectance spectra of pine needles do not change much by the moisture level. The 50 days long spring drought may not affect the physiology and morphology of the pine tree canopy. Instead, the higher NIR reflectance may come from background soil or understory vegetation.

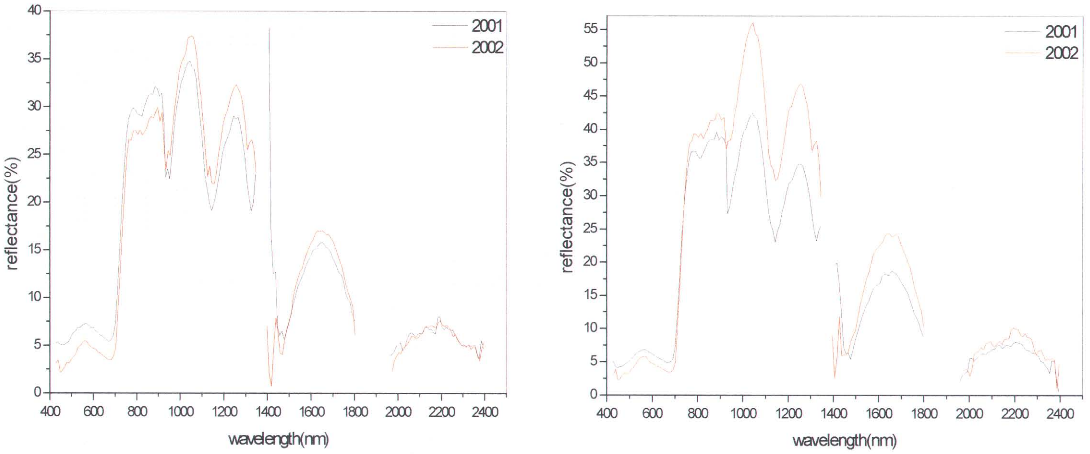

Figure 4. Canopy spectra obtained from Hyperion image of drought year (2001) and normal condition (2002), which were extracted from pine (top) and mixed deciduous (bottom) forests.

Beyond 940nm, reflectance spectra of the drought year are lower than normal year in both plantation pine and mixed hardwood forests, which is opposite to the leaf level reflectance. The lack of precipitation during the early growing season definitely result influences the leaf growth and, consequently, the canopy coverage and leaf area index. Several hardwood species including oaks in temperate mixed forests in Korea begin their growing season from March. Leaf growth onsets in April and reaches the maximum stage in July and August. Almost no precipitation from early March in 2001 would surely affect the leaf growth and the foliage mass in mixed deciduous canopy. The less amount of green foliage in mixed deciduous forest contributes the lower reflectance in NIR and SWIR region.

While the leaf-level reflectance is determined by biochemical properties of leaf (such as pigmentation, cell structure, and moisture content), the canopy-level reflectance is affected by more several factors including leaf, crown morphology, green biomass, and canopy structure. In this preliminary analysis, we do not include the analysis on the effects of canopy structure and the amount of actual amount of foliage mass. Excluding the effects of such factors can provide us a better insight on the spectral characteristics of canopy drought stress.

Although several spectral indices that are designed to be sensitive to vegetation water contents, they are mostly based on the spectral absorption features that can be observed in the leaf-level reflectance spectra. When we applied a simple water index (WI) to the spectral reflectance values obtained from the two Hyperion data, the results are not very informative (Figure 5). The WI should be lower during the drought season when the moisture level is low. Figure 5 shows the opposite results of high WI in the drought year. This is because the water absorption features observed at the leaf spectra and the canopy spectra were different.

The differences in NDVI between the drought and normal years are more clear at the non-irrigated agricultural crops and pasture, which is not very surprising because of the leaf development status at the time of data acquisition (early June) between the drought year and the normal year. The lack of precipitation during the early growing season definitely influences the less leaf growth and, consequently, the low canopy coverage and leaf area index. This explanation can be further applied to the NDVI difference observed in two hardwood forest stands. Several hardwood species in temperate mixed forests in Korea begin their growing season from March. Leaf growth onsets in April and reaches the maximum stage in August. Almost no precipitation from early March in 2001 would surely affect the leaf growth and the foliage mass in hardwood canopy. Compared to other sample plots, two plantation pine stands show minimal difference in the NDVI between the drought and normal year. Like in hardwood stands, pine forests might be also suffered foliage loss during the drought season. However, the NDVI is not very sensitive in very dense and close canopy forests. The very dense canopy closure and relatively high LAI of the plantation pine stands are probably the small change in NDVI. Better spectral indices may be necessary to be more sensitive to canopy moisture content regardless of other parameters, such as species, canopy structure, and amount of foliage biomass (Penuelas et al., 1997; Hunt and Rock, 1989).

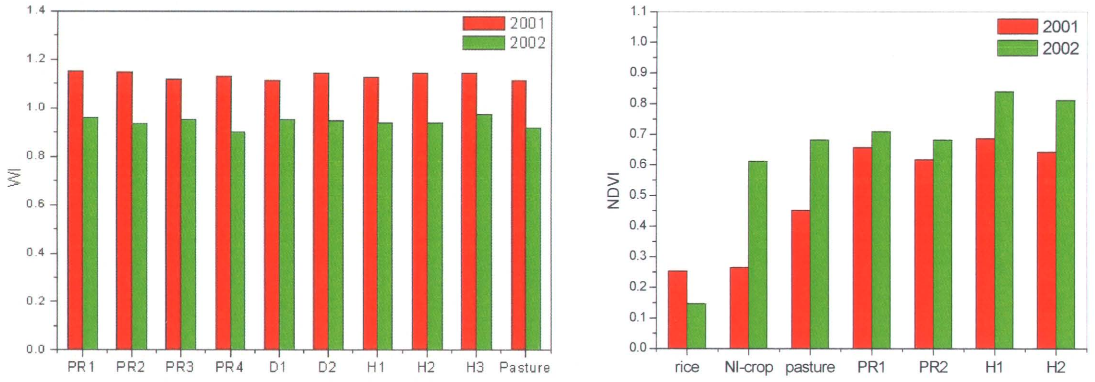

Figure 5. Spectral indices obtained from the Hyperion reflectance over the sample ground plots: WI (left) and NDVI (right).

4. Conclusions

Detection of canopy drought stress can be very important for several applications ranging from forest fire hazard monitoring and assessment of forest productivity. This preliminary comparison of reflectance spectra between the leaf-level measurements and the canopy-level observation from the satellite hyperspectral image data shows no consistent results between the leaf-level and canopy-level. Reflectance spectra from laboratory measurements may not be directly applied to canopy level for analyzing drought stress in forest. Canopy spectra under the drought stress, extracted from the atmospherically corrected Hyperion satellite data, do not correspond to the leaf-level by wavelength and forest types.

Although several spectral water related indices (such as WI) are developed to monitor drought stress, they are based on the leaf-level reflectance spectra and do not work very well with the canopy-level reflectance. Considering the potential of hyperspectral data for obtaining complete spectral characteristics at canopy-level, other spectral indices that are more sensitive to canopy moisture stress can be developed in the near future.

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