Seasonal Variations in Vegetation Indices derived from *in situ* Type Vegetation Monitoring System at typical landcovers in Japan

- From the Observation Results in PGLIERC and Lake Biwa Project -*

Atsushi Higuchi[1], Kenlo Nishida[2], Akihiko Kondoh[3], Kenji Tanaka[4], Nobuhiro Ebisu[5], Shin-ichi Iida[6], and Eiichi Nakakita[7]

1 Hydrospheric Atmospheric Research Center (HyARC), Nagoya University, Japan

2 Numerical Terradynamic Simulation Group (NTSG)/EOS training Center, School of Forestry, University of Montana, USA/ Institute of Agricultural and Forest Engineering, University of Tsukuba, Japan

3 Center for Environmental Remote Sensing (CEReS), Chiba University, Japan

4 Disaster Prevention Research Institute, Kyoto University, Japan

5 Collage of Agriculture, Ehime University, Japan

6 Doctoral Program in Geoscience, University of Tsukuba, Japan

7 Department of Global Environment Engineering, Graduate School of Engineering, Kyoto University, Japan

ABSTRACT

The activities of the plants affect on not only the global budget of carbon dioxide via photosynthesis processes, but also the water and heat transfer from the vegetated surface into the atmosphere via transpiration processes. Thus, monitoring the seasonal activities of vegetation (phenology) is important. In this purpose, satellite remote sensing, especially optical sensors, is essential to solve above. However, validation sites of remote sensing algorithms for variability of the surface status have been limited. In this article, we proposed that a simple and cheap system to monitor the surface status using several radiometers. In this method, an albedometer and two Photosynthesis Active Radiation (PAR: 400-700 nm) sensors are used. Incoming and outgoing short-wave radiation (approximately 300-4000 nm) can be divided into PAR wavelength and the other wavelengths. We assumed that difference in radiation from the sun and in PAR roughly pretends as near-infrared wave's radiation. From these sets, we can estimates the reflectance of PAR wave (visible) and that of near-infrared and vegetation indices (e.g., Normalized Difference Vegetation Index [NDVI], Simple Ratio [SR]). We install these systems into four typical land cover in Japan. Results from this system can be summarized as follows: 1). This system to monitor the vegetation status generally performed well in each land cover. 2). However, conifer forest was not expressed well the status of vegetation, because of low reflectance in both visible and near-infrared, and 3). Interannual variations in NDVI and SR were found, however sensor's absolute value checks were need to discuss interannual phenomena derived from this system.

Introduction

The activities of the plants affect on not only the global budget of carbon dioxide via photosynthesis processes, but also the water and heat transfer from the vegetated surface into the atmosphere via transpiration processes. Thus, to monitor the activities of vegetation, so-called phenology is important. In this purpose, remote sensing, especially optical sensors, is essential to solve above and to expand the knowledge at patch scale into regional or global. For example, detecting the onset and offset of phenology (corresponding open leaves and fallen leaves, respectively) from multi-temporal or interannual optical remote sensing data were carried out in continental scale (e.g., White *et al.*, 1997) and regional scale (e.g., Hashimoto *et al.*, 2001). Furthermore, several investigators pointed out the relationship between the several vegetation indices which calculated from the combination of surface reflectance of visible and near-infrared (NIR), and the latent heat fluxes (e.g., Sellers, 1985; Verma *et al.*, 1993; Higuchi and Kondoh, 2000; Kondoh and Higuchi, 2001). Several operational satellites (e.g., AVHRR, TM) and new generation sensors (e.g., MODIS, GLI) are and will be in operation, so the increase of operational satellites would make the importance of long-term *in situ* measurement sites for validation of algorithms rise up. However, validation sites for variability of the surface status were limited. Recently, several activities for long-term monitoring the surface fluxes including carbon dioxide have been rise up in continental or regional scale (e.g., Ameri-Flux net, Asian Flux net, GAME-AAN), but it would be looked like that the point of view monitoring the surface status of vegetation was lacked in these activities.

Usually, in situ measurements of spectral characteristics of vegetation are by some spectrometers (e.g., FieldSpec^R) or a video camera which can measure the NIR wavelength (e.g., SILVACAM^R), however, both spectrometer and video camera have to operate manually by researchers. Thus measurement interval is largely depended on the operated researchers and data is non-continuous in time. Validation data for detecting the onset and offset of phenology is better for time-continuous rather than fine spectral resolution dataset with non-continuous in time.

In this article, we proposed a simple and cheap system to monitor the surface status using several radiometers. Our objectives were as follows:

1). Introduce the simple and cheap system monitoring the surface status of vegetation.
2). To apply this system into typical land cover in Japan (grassland, conifer forest [red pine forest], paddy, and broad-leaf forest), we check the performance of this system.
3). To consider interannual performance of this method, we check the availabilities of this sytem for interannual variations of vegetation activities.

System overview and installed sites description

- Simple principle of this system

In this system, an albedometer and two photon quantum sensors for measurements of PAR (Photosynthesis Active Radiation: 400-700 nm) used (see Fig. 1 and Fig. 2). Incoming and outgoing solar radiation (approximately 300-4000 nm) can be divided into PAR wavelength and the other wavelengths. In the other wavelength, solar radiation in the ultraviolet wave (-400 nm) absorb by ozone, longer wavelength side (1200 – nm), energy itself is very small, with several absorption band by water vapor, which compare to near-infrared wave (700-1200 nm). Thus, difference in radiation of solar and of PAR roughly pretends as near-infrared wave's radiation. Equations can be expressed as follows:

$$\rho_{PAR} = PAR\uparrow / PAR\downarrow \quad (1)$$

$$NIR\downarrow \cong Rs\downarrow - PAR\downarrow \quad (2)$$

$$NIR\uparrow \cong Rs\uparrow - PAR\uparrow \quad (3)$$

$$\rho_{NIR} = NIR\uparrow / NIR\downarrow \quad (4)$$

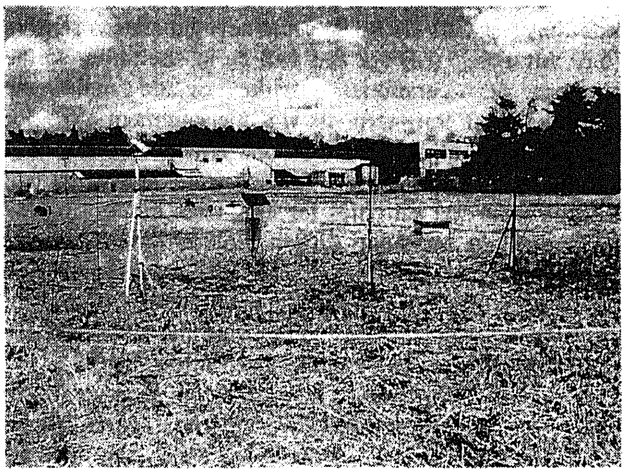

Fig. 1 A snapshot of a simple system for monitoring the surface status at Terrestrial Environmental Research Center, University of Tsukuba, Japan. Right is two PAR sensors, center is an albedometer, left is brightness temperature's radiometer, respectively. A datalogger box can be seen for logging the data.

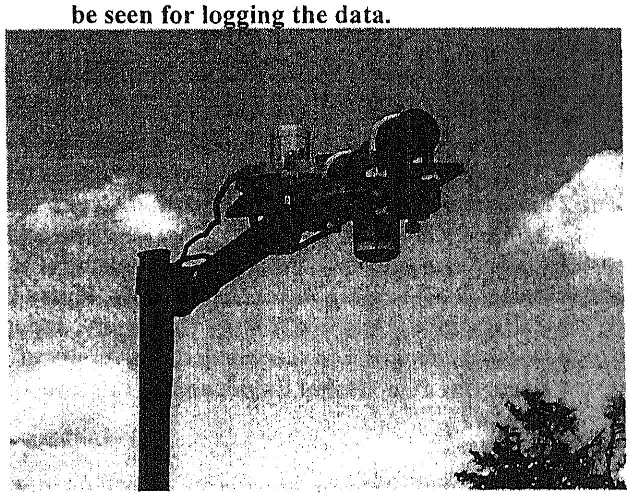

Fig. 2 A snapshot of PAR sensors for this system. To calculate the reflectance of visible and NIR, both downward and upward measured.

Here ρ represents the reflectance of each wavelength (visible, NIR), subscripts indicate the each wavelength, *PAR* and *NIR* are radiation in PAR and NIR wavelength which derived from PAR sensors and an albedometer, respectively (Wm^{-2}), *Rs* shows the short-wave radiation derived from an albedometer (Wm^{-2}), $\downarrow$ and $\uparrow$ indicate downward and upward direction of radiation, respectively. From Eq. (1)-(4), we can estimate each reflectance of visible and NIR. We can also calculate the Vegetation Indices (VIs) such as Normalized Difference Vegetation Index (NDVI), Simple Ratio (SR). In this study, we estimate the Vis as indicators for the surface status of vegetation as follows:

$$NDVI = \frac{\rho_{NIR} - \rho_{PAR}}{\rho_{NIR} + \rho_{PAR}} \quad (5)$$

$$SR = \rho_{NIR} / \rho_{PAR} \quad (6)$$

NDVI ranged from –1 to +1, when vegetation activities are high, NDVI is close to 1, and SR usually ranged 0 to 10, which increased with vegetation activities. Signals from PAR sensors and the albedometer can be stored into multi-purposed datalogger (e.g., CR10 by Campbell Sci., Inc) easily with other micrometeorological components. Thus, it is easy to compare the seasonal march of the surface fluxes and vegetation activities via in situ measurement Vegetation Indices. Advantage of this simple system can be measured the status of vegetation continuously. This system is suitable for monitoring the day to day changing status of vegetation or surface.

Table 1 Site descriptions to install measurement system

Site Name	Lat.	Long.	Land Cover
TERC1	36.1 N	140.1 E	Grassland
TERC2	36.1 N	140.1 E	Red Pine
Biwapro1	35.5 N	136.5 E	Paddy
Biwapro2	35.6 N	136.2 E	Broad-Leaf

	Forest

-Site descriptions for validating this system

Table 1 shows the site of installed the monitoring surface status system.

TERC1 is a grassland which consists of several species of C3 plants and C4 plants grasses. This grassland locates in Terrestrial Environmental Research Center (TERC), University of Tsukuba, Japan. Here is also the water and energy experimental field with more than 30 components of micrometeorological and hydrological instruments that have been measured routinely (Toritani *et al.*, 1989) until 1982. In 1999, Preliminary GLobal Imager experiment at Environ. Res. Center. (PGLIERC) was carried out as an one year's field campaign of remote sensing (Higuchi *et al.*, 2000a). From May in 1999, we started this measurement system at grassland. TERC2 is red pine forest where locates an south side of experimental field (grassland) in TERC. Same system also has been working until August 2000. Biwapro1 is paddy located the north east of Lake Biwa by Lake Biwa Project (Nakakita, 2000). Routine micrometeorological measurement system was started July 1998, and this system added into the routine system in May 2000. Biwapro2 is broad leaf forest where located the north side of Lake Biwa that was also supported by Lake Biwa Project. Routine measurement tower installed in 1998 and added monitoring system in April 2000.

-Determine the surface fluxes at each site

Energy balance equation at the land surface can be xpress as follows:

$$Rn = H + lE + G + {}^{\delta Q}\!/_{\delta t}(S) + A_h + P \qquad (7)$$

where H and lE are sensible and latent heat flux, Rn is net radiation, G is soil heat flux, and $\delta Q / \delta t\ (S)$ is the rate of change of energy storage in some layer (in paddy, some layer is water body for irrigation). Generally, the term of energy advection, Ah, of photosynthesis, P, can be assumed negligible. Value of H was evaluated by an eddy correlation method in TERC1 (grassland) and TERC2 (pine forest) with a sonic anemometer as follows;

$$H = \rho Cp\overline{w'T'} \qquad (8)$$

where ρ is the density of the air, Cp is the specific heat of air, w is vertical wind component, T is air temperature. Over-bar denotes the averaging and prime the deviation from the mean. After estimation of H, lE was determined by Eq. (7) at TERC1 and TERC2.

At Biwapro1 and Biwapro2, the surface fluxes were estimated by energy balance method with Bowen ratio, and in Biwapro1 (paddy), we have to consider the term of S in Eq. (7) as follows:

$$S = \frac{\delta Q}{\delta t} = \frac{D_i + D_{i-1}}{2}(T_{w,i} - T_{w,i-i})Cw \qquad (9)$$

where Di is the depth below the rice plant at the time i, Tw,i is water temperature at the time i, and Cw is the specific heat of water. We recalculated the components of the surface fluxes in 1 hour average at each land cover.

Results and discussion

-Seasonal changes in the spectral reflectance and vegetation indices at each land cover

1). TERC1 (Grassland)

Figure 3 shows the seasonal changes in the surface albedo, spectral reflectance of visible and NIR, vegetation indices, lE and H during daytime, and lE/Qn and H/Qn. Data averaged using 9:00-15:00 JST, and more than Rs downward value is more than 200 W/m^2. Qn is defined as available energy, Qn=Rn-G. Seasonal variations of the surface albedo can do as indicator of the surface status (e.g., Higuchi *et al.*, 2000b), but as these values divided into the signals of visible and NIR from this system, we could see more information about land surface status. From Fig. 3 (b), reflectance of visible decreased rapidly from 90 Day of Year (DOY) to 140 DOY. After this, the reflectance of NIR increased from 120 DOY to 170 DOY.

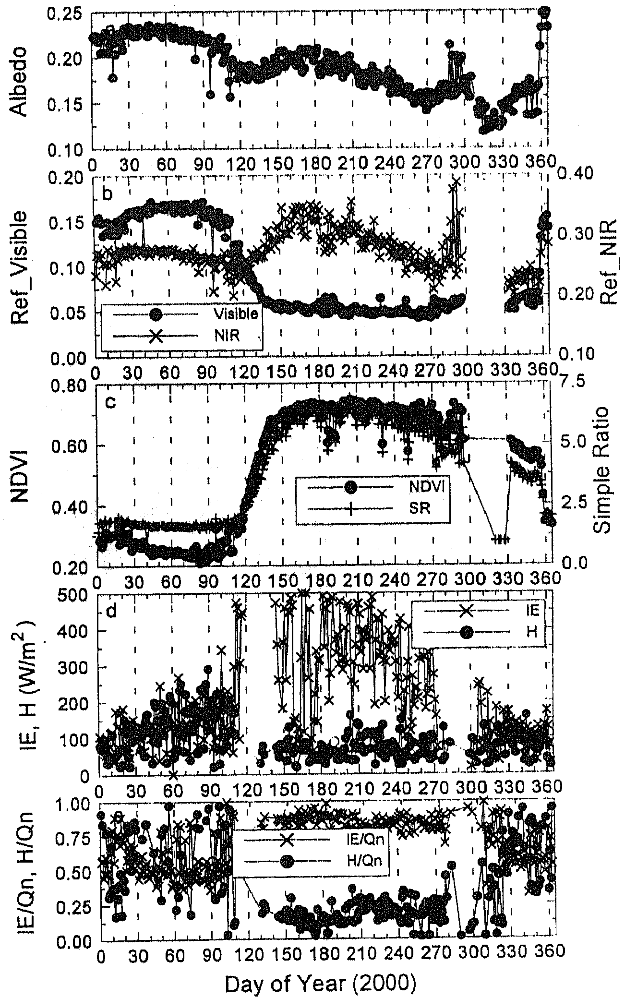

Fig. 3 Seasonal variations of the surface albedo (a), spectral reflectance of visible and NIR (b) by this method, vegetation indices (c) by this method, the sensible (*H*) and latent (*lE*) heat flux (d), and normalized value of the surface fluxes (*lE/Qn*, *H/Qn*) (e) at TERC1 (grassland). Each value is

daytime averaged (9:00-15:00 JST with Rs downward value is more than 200 W/m^2).

We could see the peak of reflectance of NIR in 170 DOY, from this variation of visible and NIR, vegetation indices in NDVI and SR also have seasonal variations. These variations were similar, but in the summer, a little difference was found in the variations in NDVI and SR. Because of routine measurement system problem in TERC1, some measurement lacks were found in Fig.3 (d) and (e). However it could see from Fig.3 that the values of *H* and *lE* were similar in winter (330DOY -90DOY), this period was also the absence of grass, after "onset of phenology (we could define the day from Fig. 3 (b) and (c) as 90 DOY in this year)", *lE* exceeded *H* (see Fig. 3 [d], [e]), because of activities of grass (vegetation) through the process of transpirations.

2). TERC2 (Red Pine Forest [Conifer Forest])

Figure 4 shows the seasonal changes at TERC2 (red pine forest). It should be noted that x axes in Fig. 4 (a) and (b) were different from those of Fig. 3.

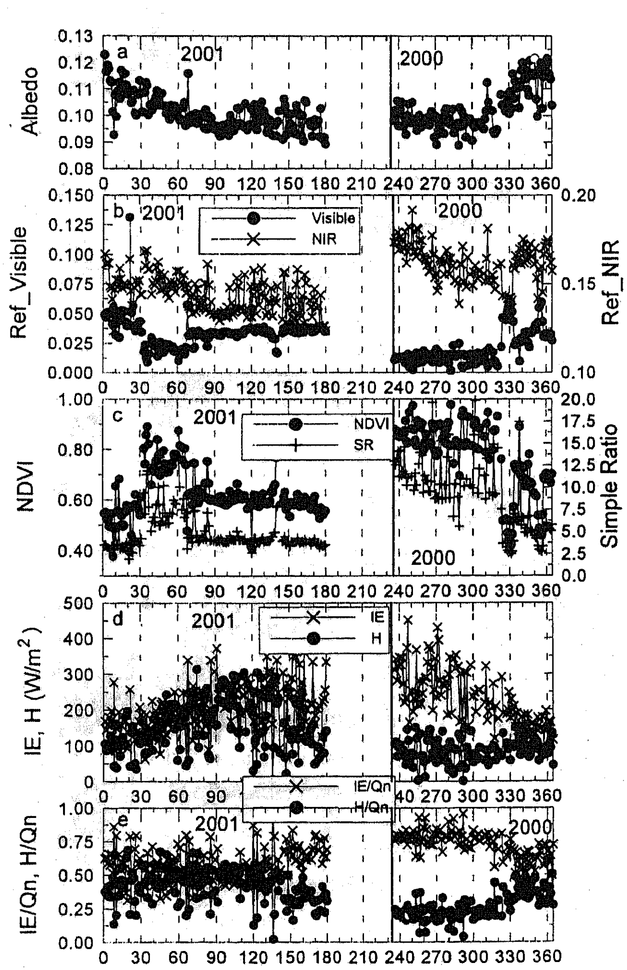

Fig. 4 Seasonal variations of the surface albedo (a), spectral reflectance of visible and NIR (b) by this method, vegetation indices (c) by this method, the sensible (*H*) and latent (*lE*) heat flux (d), and normalized value of the surface fluxes (*lE/Qn*, *H/Qn*) (e) at TERC2 (red pine forest). Each value is daytime averaged with Rs downward value is more than 200 W/m^2.

Seasonal variation in the albedo was found in Fig. 4 (a), but its amplitude was quite small than grassland (Fig. 3 [a]).Generally, conifer forest has small reflectance in both visible and NIR, in this study, it was also found in Fig. 3 (b). Because of small values in reflectance of visible and NIR, NDVI and SR varied widely, but there were not represent the surface status of red pine. As a considerable reason of these phenomena, we installed the PAR radiometers just above the red pine canopy, thus a field of view was too small and it could be considered that this system at red pine forest detected the local effect within a field of view of each sensor. When install this system into conifer forest, it have to get an enough height to see an overview in conifer forest.

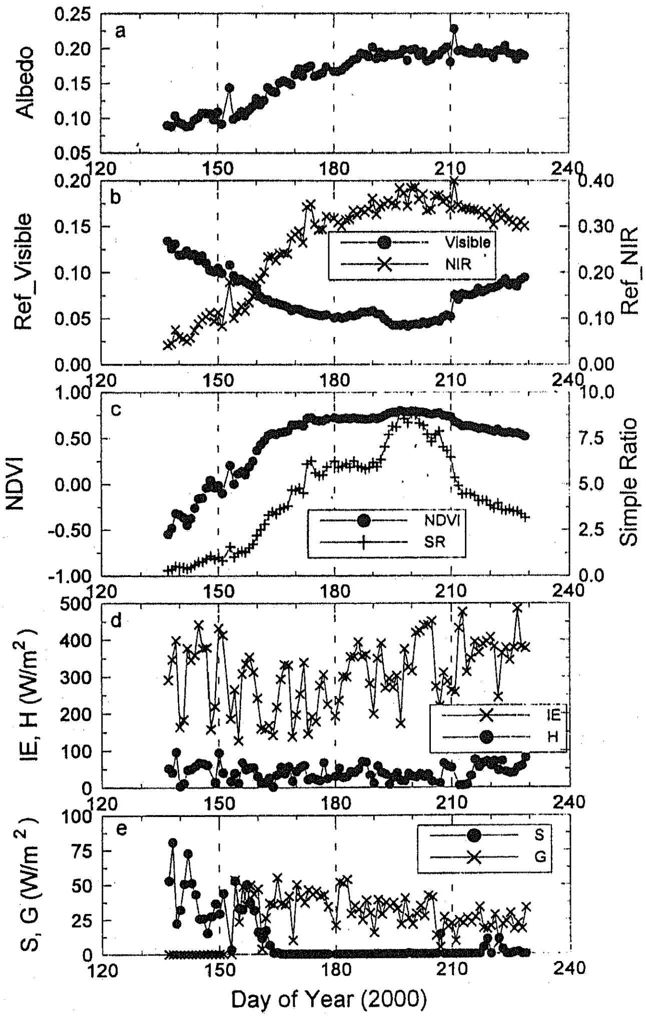

Fig. 5 Seasonal variations of the surface albedo (a), spectral reflectance of visible and NIR (b) by this method, vegetation indices (c) by this method, the sensible (*H*) and latent (*lE*) heat flux (d), and the rate of change of energy storage in irrigated water (*S*) and the soil heat flux (*G*) (e) at Biwaprol (paddy). Each value is daytime averaged (9:00-15:00 JST with Rs

downward value is more than 200 W/m^2).

3). Biwapro1 (Paddy)

Figure 5 shows that seasonal changes at Biwapro1 (paddy). The surface albedo indicates the surface status changes from the water body to rice canopy (Fig.5 [a]), but to see in Fig. 5 (b), more information about the changing status of paddy. Increasing the leaf area density of rice plant, reflectance of visible was decreasing (135-170 DOY), otherwise, in the reflectance of NIR was increasing from the start of this system until 200 DOY. This increase was corresponded to the increase of Leaf Area Index (LAI), and to see carefully in Fig. 5 (b), we could see the increase of reflectance of visible in August (213 – end of this measurement). This period was also corresponded to the change of stage of paddy from growing stage to post-growing (rice plant had come into ear). Only information of albedo (Fig. 5 [a]), such surface condition change could not be detected.

4). Biwapro2 (Broad-Leaf Forest)

Figure 6 shows the seasonal changes at the site of Biwapro2 (Broad-Leaf Forest). From Fig.6 (a), we could see the high albedo values in winter, because of presence of snow, especially from 360 DOY in 2000 to 50 DOY in 2001. Without plotting in Fig. 6 (a), sometimes values of surface albedo were reached 0.6, maybe those days covered by snow. Corresponding to the high values of the surface albedo in winter, reflectance of visible (Fig. 6 [b]) in winter was also high. However, during 60 DOY – 110 DOY in 2001, the surface albedo were decreasing rapidly, this period maybe corresponding to the surface condition changes from snow cover to the absence of snow, from Fig. 6 (b), the reflectance of visible kept high. We expected that this observation result suggested the effect of the shape difference between PAR sensors and albedometer, rather than the actual phenomenon. As shown in Fig. 2, the light detector of PAR sensor is flat, on the other hand, generally, most of albedometer and pyranometer have dome made by glass for protecting the detector part. The dome shape is better to detect the changing solar elevation and its radiation, and it is easy to remove the snow over an dome by itself. On the other hand, the flat shape is difficult to remove the snow and more affective against dirt on the detector. The site of Biwapro2, located on the most of top of mountain, with snow cover in winter, thus, the road to access the observation site was closed in winter season. So, it was impossible to maintain the instruments of this site. To discuss the interannual variation of the surface condition via this system, it should be notice the data quality of short-wave radiation components, especially downward components because of the dirt or shift of direction of each detector.

Seasonal variation in vegetation indices (Fig. 6 [c]) showed a rapid rise up in May 2000 (120-150 DOY), after this rise up, NDVI kept relatively stable vale in summer and autumn. From Fig. 6 (c), in the broad-leaf forest, this method can detect the onset of phenology (open leaves). The seasonal march of the surface fluxes (*H, lE*) can be shown in Fig. 6 (d), (e), these fluxes derived from bowen ratio method, normalized value, *H/Qn*, had minimum peaks in the beginning of August in 2000 (Fig. 6 [e]). This peak is different from the rapid increase in vegetation indices in May (Fig. 6 [c]), and the peak in reflectance of NIR around 150 DOY in 2000 (Fig. 6 [b]).

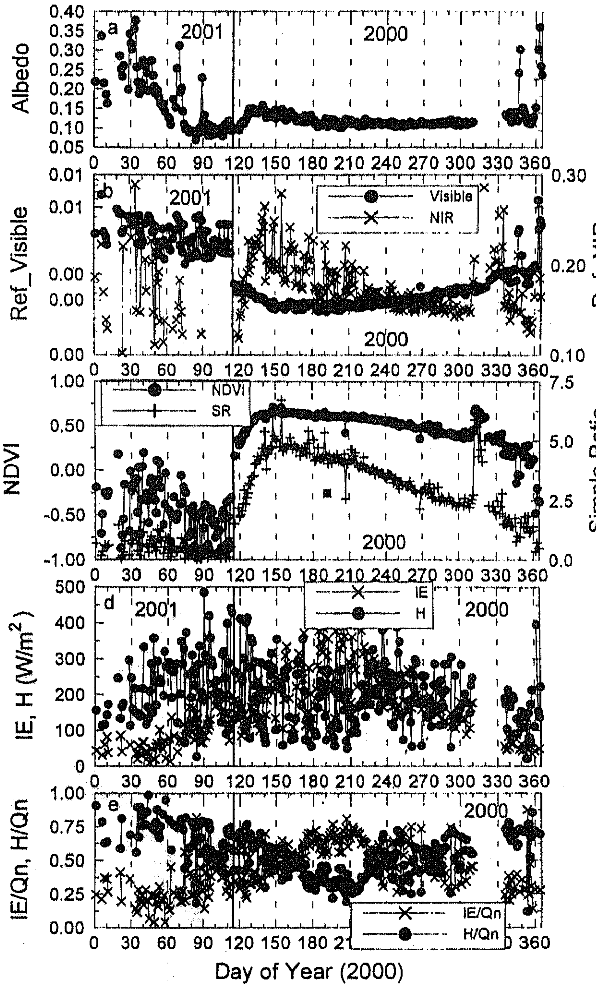

Fig. 6 Seasonal variations of the surface albedo (a), spectral reflectance of visible and NIR (b) by this method, vegetation indices (c) by this method, the sensible (H) and latent (lE) heat flux (d), and normalized value of the surface fluxes (lE/Qn, H/Qn) (e) at TERC2 (red pine forest). Each value is daytime averaged (9:00-15:00 JST with Rs downward value is more than 200 W/m^2). It denotes that x axes in Fig. 6 (b) was scaled by log scale because of high reflectance of visible in winter.

Intercomparisons of seasonal variation in reflectance of visible and NIR, and vegetation indices at each land cover

Figure 7 shows seasonal variations in albedo, reflectance of visible and NIR and NDVI at each land cover. This figure represents well the characteristics of land cover differences in the point of view in vegetation status. From Fig. 7 (a), even if information of the surface albedo, surface status can detect in some level, however, add this system into routine micrometeorological measurement system, more information could be gain. This figure also suggested us that this method is useful in agricultural field, rather than forest. However, both two forests site, we installed the two PAR radiometer just above the canopy of forest. If enough height for installing this system could be available, the results would be changed.

Concluding remarks

We introduced an simple and cheap method for monitoring the surface status using an albedometer and two PAR radiometers. This system's advantage are, firstly, can monitor continuously in time, and relatively it is free of maintain of this system. Routine maintain is clean up the detector of each radiometers. Compare to other in situ optical remote sensors needs more spending time. Secondly, this system can easily added into other micrometeorological measurement system with save the budget. The prices of most of PAR radiometers are cheaper than the other instruments. We hope that this system would become to popular in micrometeorological measurement, and validation sites expanded all over the continents with this systems.

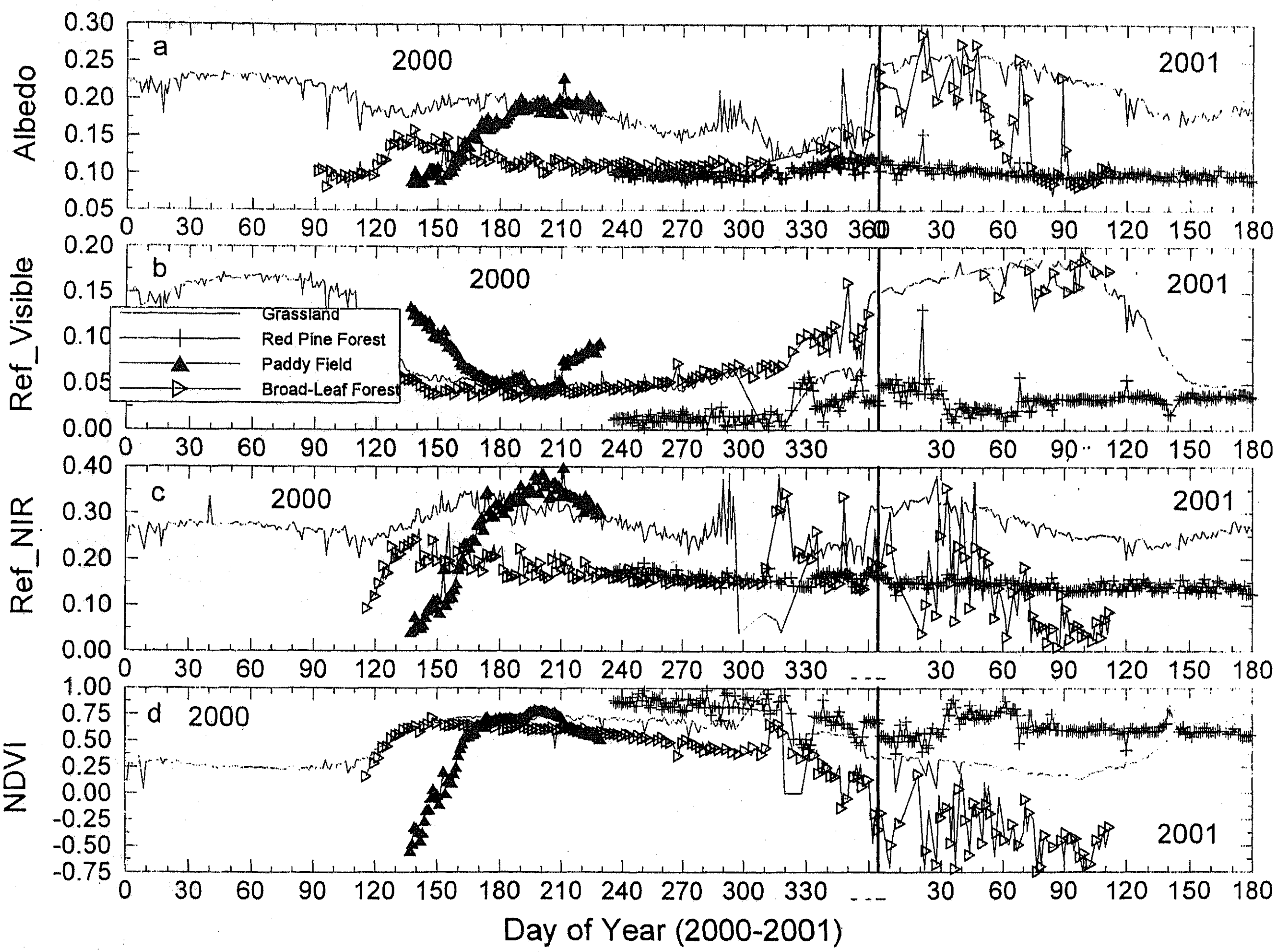

Fig. 7 Inter-seasonal variations of the surface albedo (a), reflectance of visible (b), reflectance of NIR (c), and NDVI (d) at each land cover where this method applied.

References

Kondoh, A., and A. Higuchi, 2001: Relationship between spectral reflectance and evaporation from vegetated surface. *Hydrological Processes*, **15**, 1761-1770.

Hashimoto, H., M. Suzuki, and A. Higuchi, 2001: Analysis of soil surface moisture and phenology in Thailand using NOAA/AVHRR. *J. Japan Soc. Hydrol. & Water Resour.*, **14**, 277-288. (in Japanese with English Abstract)

Higuchi, A., K. Nishida, S. Iida, N. Niimura, and A. Kondoh, 2000a: Preliminary global imager experiment at environmental research center, university of tsukuba (PGLIERC): Its overview. *J. Jananese Asso. Hydrol. Sci.*, **30**, 81-91. (in Japanese with English Abstract)

Higuchi, A., A. Kondoh, S. Ikeda, and H. Kuroko, 2000b: Relationships between the surface fluxes at grassland, paddy field, and at copse, and spectral reflectances in visible and in near-infrared wavelength or vegetation indices derived from satellite remote sensing. I. Seasonal changes in the surface fluxes at each land cover. *J. Japan Soc. Hydrol. & Water Resour.*, **13**, 124-136. (in Japanese with English abstract)

Higuchi, A., and A. Kondoh, 2000: ---, II. Relationship between spectral reflectances in visible and in near-infrared wavelength derived from satellite and the surface fluxes. *J. Japan Soc. Hydrol. & Water Resour.*, **13**, 137-147. (in Japanese with English abstract)

Nakakita, E., 2000: Lake biwa project, *J. Japan Soc. Hydrol. & Water Resour.*, **13**, 429-438. (in Japanese)

Nishida, K., A. Higuchi, 2000: Seasonal change of grassland vegetation found in the preliminary GLI experiment in the Environmental Research Center, *Bull. Terres. Environ. Res. Center, Univ. Tsukuba*, No.1, 1-10. (in Japanese with English Abseract)

Sakai, R.K., D.R. Fizjarrald, and K.E. Moore, 1997: Detecting leaf area and surface resistance during transition seasons, *Agric. For. Meteorol.*, **84**, 273-284.

Sellers, P.J., 1985: Canopy reflectance, photosynthesis and transpiration, *Int. J. Remote Sens.*, **6**, 1335-1372.

Toritani, H., R. Kawamura, J. Shimada, M. Taniguchi, and T. Nishimoto, 1989: On the new system of real time data processor for meteorological and hydrological measurements. *Bull. Environ. Res. Center, Univ. Tsukuba*, No. 13, 147-158. (in Japanese)

Verma, S.B., P.J. Sellers, C.L. Wakthall, F.G. Hall, J. Kim, and S.J. Goetz, 1993: Photosynthesis and stomatal conductance related to reflectance on the canopy scale, *Remote Sens. Environ.*, **44**, 103-116.

White, M.A., P.E. Thornton, and S.W. Running, 1997: A continental phenology model for monitoring vegetation response to international climatic variability. *Glob. Biogeochem. Cycles*, **11**, 217-234.

Key words: in-situ type vegetation monitoring system, vegetation indices, PGLIERC, Lake Biwa Project

(Accepted December 20, 2001)

* This article was reconstructed from the extended abstract in the *Proc. "The Fifth International Study Conference on GEWEX in Asia and GAME"*, 3-5 October, Nagoya, Japan.

地上設置型植生モニタリングシステムを用いた日本での代表的な土地被覆での植生指標の季節変化
—PGLIERC, 琵琶湖プロジェクトの成果から—

樋口篤志[1]・西田顕郎[2]・近藤昭彦[3], 田中賢治[4], 戎信宏[5], 飯田真一[6], 中北英一[7]

1 博（理） 名古屋大学助手 地球水循環研究センター （〒464-8601 名古屋市千種区不老町）
2 博（農） 筑波大学講師 筑波大学農林工学系 （〒305-8572 つくば市天王台 1-1-1）
3 理博 千葉大学助教授 環境リモートセンシング研究センター （〒263-8522 千葉市稲毛区弥生町）
4 工修 京都大学助手 防災研究所水資源研究センター （〒611-0011 京都府宇治市五ヶ庄）
5 農博 愛媛大学助教授 農学部生物資源科 （〒790-8566 愛媛県松島市樽味 3-5-7）
6 理修 筑波大学大学院生 地球科学研究科 （〒305-8577 つくば市天王台 1-1-1 陸域環境研究センター）
7 工博 京都大学助教授 工学研究科環境地球工学専攻 （〒606-8501 京都市左京区吉田本町）

本研究では光学センサー搭載衛星データの検証及び地表面フラックスとの対応関係を調べるために簡易式の地上設置型植生モニタリングシステムを日本を代表する土地被覆上（草地，水田，アカマツ林，落葉広葉樹）に設置し，それぞれの土地被覆から得られる植生指標の季節変化について示した．その結果，以下の知見が得られた；1．草原系（草地・水田）では各植生の季節変化特性を良好にモニターすることが可能である，2．森林系（アカマツ林・落葉広葉樹）ではセンサーとキャノピーの距離が近すぎるため，思うような結果を得ることが出来なかった．3．ただし全般としては各土地被覆特性を示す連続したデータを取得することができ，システムの妥当性を示すことができた．

キーワード：地上設置型植生モニタリングシステム，植生指標，PGLIERC，琵琶湖プロジェクト

（2001 年 12 月 20 日 受理）