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Satellite Ecology, an Attempt to Link Remote Sensing with Ecology for River Basin Studies

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Abstract

The Satellite Ecology Program has been launched since 2004 at Gifu University. The goal of this Program is to find the links between remote sensing, ecosystem ecology and micrometeorology for studying ecosystem structures and functions in the mountainous landscape of central Japan. It aims at making "Satellite Ecology" into a comprehensive yet practical science by making regional carbon and water monitoring via satellite remote sensing technology which has advanced drastically. It enrolls the Ecological Process Research Group, the Remote Sensing Analysis Group, and the Meteorological Observation and Modeling Group. The characteristics of this Program are, meso-scale regional study, carried out on mountainous landscapes consisting of a complex of various ecosystems, and interdisciplinary collaboration. In this review paper, we introduce the background, concepts, and some findings by the Remote Sensing Group. Our group contributed for the evaluation of horizontal accuracy of high resolution images, the creation of multi-stage landcover classification maps, the development of ground validation methods using digital imagery, and forest phenology analysis using seasonal MODIS/NDVI.

1. Background

Moving into the 21st century, the surrounding environment of remote sensing has changed drastically. First and foremost, sensors onboard earth observation satellites have improved in spatial, spectral and temporal resolutions (Akiyama et al., 2004). That is, super high resolution satellites like QuickBird and IKONOS possess 2.4 or 4 m of spatial resolution, Terra/MODIS and EO-1/Hyperion can take hyperspectral images, and Terra and Aqua/MODIS acquire daily data with 250 m of resolution. In addition, user friendly software and programs have prevailed for image analysis, and the Geographic Information System (GIS) became widespread as a necessary and reliable tool. The Global Positioning System (GPS) with high precision accuracy has also become an imperative tool for field survey and ground truth. Table 1 shows noteworthy progressions of satellite sensors between 1990's and 2000's.

Frequent observation with low spatial resolution satellites such as NOAA/AVHRR, and Terra and Aqua/MODIS has clarified various global environmental issues (eg. Myneni, 1997). However, there are few methods to verify the accuracy of actual events happening on the ground. Because of the remarkable progress of remote sensing technology, it has become possible to validate ground-based ecological processes using finer resolution satellites at a regional scale. Figure 1 shows overlapping of scale in a process ecology experiment and satellite remote sensing analysis in the spatial and temporal domains (Akiyama, 2006).

2. The Satellite Ecology Program

In the 21st Century the COE (Center Of Excellence) Program of the Japan Society for the Promotion of Science, "Satellite Ecology" has been launched in 2004 at Gifu University. The goal of this Program is to find the linkage between remote sensing, ecosystem ecology and micrometeorology for studying ecosystem structure and function in the mountainous landscape of central Japan. Figure 2 shows schematic roles of three research groups including the Ecological Process Research Group, the Remote Sensing Analysis Group, and the Meteorological Observation and Modeling Group (Koizumi and Muraoka, 2005). It has been carried out with 9 permanent researchers and 4 degree recipients. This Program aims at making "Satellite Ecology" into a comprehensive yet practical science by making regional carbon and water monitoring via satellite remote sensing technology which has advanced drastically.

Specific themes for the Remote Sensing Group include forest and landcover type classification at multiple scales, the creation of a distribution map of biomass and carbon storage, and spatio-temporal changes of leaf area in the study area. These will be combined with CO_2, water and heat flux of the forest, and soil respiration and photosynthesis measurement by the Ecological Process Research Group and the Meteorological Observation and Modeling Group. The framework of the ecology- meteorology model (by the name of SATECO model) was established in 2006 with a 1km mesh, which was improved to a 100m mesh in 2008 (Yoshino et al., 2008, Tamagawa et al., 2008).

The characteristics of this Program are, meso-scale regional study, carried on mountainous landscapes consisting of a complex of various ecosystems, and interdisciplinary collaboration.

This Program also aims at the creation of a worldwide research post in this new scientific field. For this reason, we are expanding the wave of research exchanges between Asian and European Institutes. The cultivation of young scientists is also an important issue here.

Out of these Programs, the authors will try to introduce research activities done by the Remote Sensing Group in Section 4.

Table 1. Improvement of spatial, spectral and temporal resolutions of satellite sensor between 1990's and 2000's

Resolution	1990's	2000's
Spatial	20m (SPOT/HRV)	2.4m, 4m (QuickBird, IKONOS)
Spectral	7bands (Landsat/ETM+)	36bands, 220bands (MODIS, Hyperion)
Temporal	Daily (NOAA/AVHRR)	2times/day (AM/PM) (Terra/Aqua MODIS)

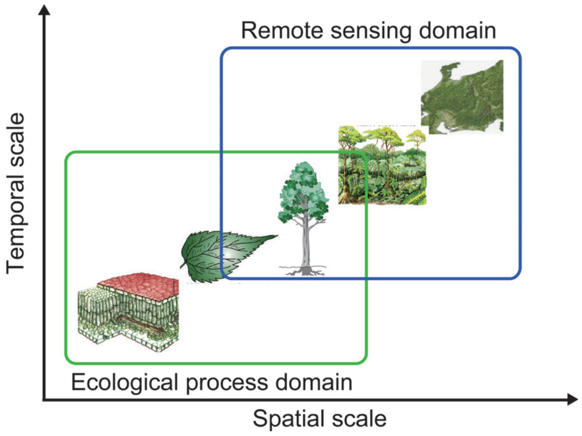

Fig. 1. Overlapping of Remote sensing analysis domain and Ecological process research domain on spatio-temporal scales.

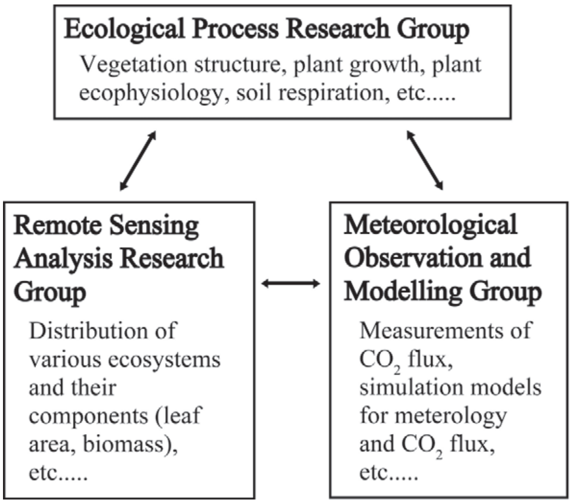

Fig 2. Configuration of supporting research groups for Satellite Ecology Program and its roles

3. *Study area and super site*

3.1. Study area

The study area, the Daihachiga River basin, is located in the northern part of the Gifu Prefecture, in central Japan (Figure 3). It covers 60 km^2 of catchment area, 1000 m of altitude gap between headstream (1,595m above sea level, asl) and confluence point to Miya River (600 m asl). The study area is dominated by rigid forest land including vast deciduous broadleaved (DB) forests and evergreen coniferous (EC) forests, a small area for agricultural land, and some residential and commercial areas near the central Takayama city.

We investigated 28 forest plots inside the study area in 2005 and estimated aboveground biomass from allometry formula using Diameter at Breast Height (DBH) reported by Komiyama et al. (2002).

For agriculture lands, seasonal biomass and leaf area index (LAI) changes were examined for 3 years in rice paddy fields, corn fields, pastures, and abandoned crop fields.

Data of air temperature is being collected at 10 sites distributing portable microclimate recorders (HOBO, USA) from 600 m to 1,570 m asl. at 20 minute intervals since January in 2006.

3.2. Super site

The super site was established in the early 1990's in the cool-temperate DB forest at around 1,400 m asl. This site is located in the upper stream zone inside the study area (Figure 3), and occupies 1 hectare (100m by 100m) of land. The original vegetation was Japanese beech (*Fagus crenata*), but it is now covered by

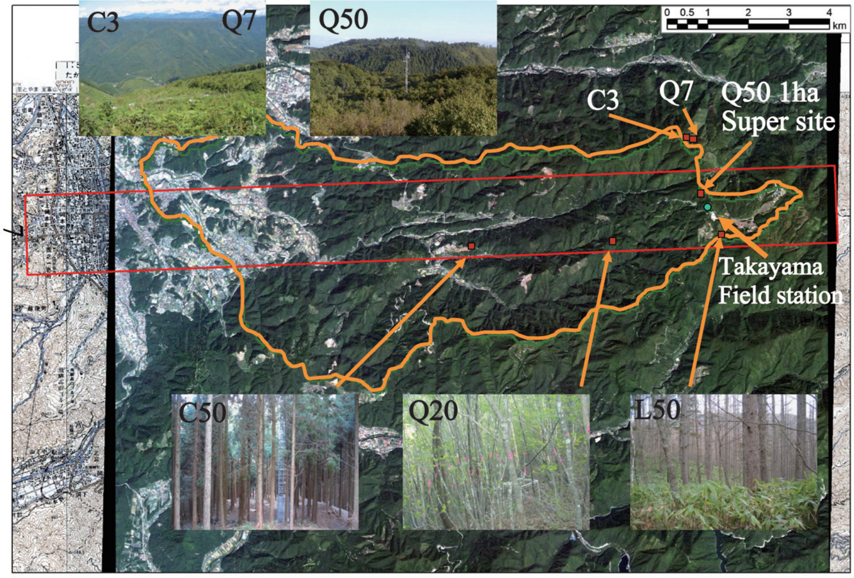

Fig. 3. Satellite image of the study area (Daihachiga river basin, inside yellow line) and photographs showing several forest sites with different species and ages
One hectare super site is appearing on the right end of the study area.
C:Cider forest, Q:Quercus dominant DB forest, L:Larch forest. Numbers following alphabet mean forest age.

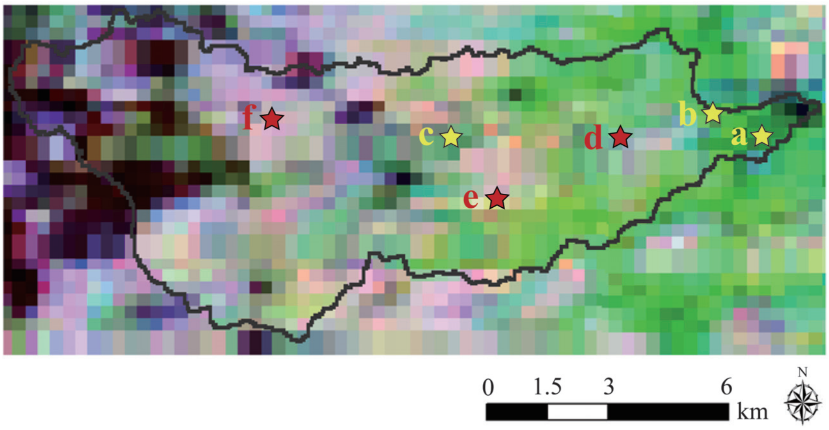

Fig. 4. Forest type classification using MODIS/NDVI acquired in different seasons a, b and c (greenish color) are deciduous forest, d, e, and f (whitish color) are evergreen forest. Dark color on the left side shows construction in Takayama city. Assigned March on red, July on green, and November on blue.

Table 2. Concept of multi-stage classification of forest class according to the spatial resolution of satellite Low resolution corresponds to Terra and Aqua MODIS, Middle resolution for Landsat/ETM+, SPOT/HRV and Terra/ASTER, High resolution for ALOS/AVNIR-2, IKONOS and QuickBird, respectively.

Class	Low Resolution 250 - 500 m	Middle Resolution 15 - 30 m	High Resolution 2 - 10 m
Forest	Deciduous (D)	D Broadleaved (DB)	DB with Sasa (DBs)
			DB without Sasa (DB-)
		D Coniferous (DC)	DC with Sasa (DCs)
			DC without Sasa (DC-)
	Evergreen (E)	E C (EC)	EC of Cedar (ECe)
			EC of Cypress (ECy)
			EC of Pine (ECp)
	Mixed (M)	B C (MM)	Mixed, DB dominant, B>50% (MMb)
			Mixed, EC and DC dominant, C>50% (MMc)
	Fallen (F)	Fallen (FF)	Fallen, old (FFo)
			Fallen, young (FFy)

a secondary DB forest including *Quercus crispula, Betura ermanii, Betura platyphylla* var. *japonica*. The forest floor is covered by a dense dwarf bamboo, *Sasa sinanensis* (Sakai et al., 2001). Tree census has been carried out every year since 1999, and has found 44 tree species, 1,907 stem numbers higher than 1.3m. Net primary production (NPP) of this site using stem growth by yearly tree census was 2.38 Mg ha^{-1} (Ohtsuka et al., 2005). Jia and Akiyama (2005) estimated 440.6 tC ha^{-1} of total carbon is stored in this ecosystem, 107.0 tC ha^{-1} of it is in vegetation, and 333.6 tC ha^{-1} in soil.

Two carbon flux towers were set up in the study area. One was built by the National Institute of Advanced Industrial Science and Technology (AIST) at 1400 m asl. in the super site, and it measures carbon dynamics between atmospheric and terrestrial layers in the DB forest. CO_2 flux at the DB forest has been measured since 1993, now it was certified as one of the AsiaFlux forest sites. The results of CO_2 flux measurement clarified that atmospheric CO_2 concentration increased 1.8% per year during these 10 years. The annual NEP (net ecosystem production) values for 1999, 2000 and 2001 were estimated to be 198, 309 and 290 gC m^{-2} year^{-1} (Saigusa et al., 2005). A second tower was built in 2005 by Gifu University in a Japanese cedar (*Cryptomeria japonica*) forest which was artificially planted in the 1960's at the mid-stream of the study area (800 m asl.).

An ecological observation tower was built in 2002 in the DB forest at 1,430 m asl. The corridors were set at 18 m, 10 m and 4 m of height. Here we can directly measure several physiological phenomena of the canopy. Muraoka and Koizumi (2005) reported photosynthesis and structural characteristics of the canopy using this tower.

4. Some findings by the Remote Sensing Group

4.1.The evaluation of horizontal accuracy of high resolution image

One of the fundamental and specific problems of high resolution satellite imag to apply on mountainous rigid landform area is accurate registration and geometric correction. Kojima et al. (2007) described the quantitative evaluation of the horizontal accuracy of ortho-QuickBird images using DEM (Digital Elevation Model), DSM (Digital Surface Model) and the control points over the top of the tree canopy. Tree height also affected the horizontal errors as well as topographical elevation. They estimated the accuracy of several images of high resolution satellite.

4.2. Multi-stage landcover classification

Multi-scale and multi-stage landcover classification was carried out using various remote sensors such as aerial hyperspectral imagery by CASI, satellite images by QuickBird, ALOS/AVNIR-2, Terra/ASTER, Landsat/ETM+, and Terra/MODIS. Table 2 shows the concept of multi-stage classification for part of the forest class. Coarse resolution satellite imagery like MODIS can identify 3 or 4 forest classes, but images from mid- and fine-resolution can detect 5 to 11 classes according to the spatial resolution.

Wahid and Akiyama (2007) analyzed the ALOS/AVNIR-2 which was launched January 2006 with 10m spatial resolution. They could identify 13 classes including 10 vegetation classes (6 forest and 4 crop and grassland classes), 2 construction classes, and 1 water class. Kojima et al. (2008) analyzed the data from several satellites for comparison, and concluded that one-meter to several tens of meters of spatial resolutions, and daily to weekly temporal resolutions, are suitable to understand the structures and functions of a basin ecosystem. Maki et al. (2008) mapped the potential distribution of dwarf bamboo under the DB forest using DEM and the differences in ASTER/NDVI between pre- and post-leaf fall period. As the result, the logistic regression model indicated an overall accuracy of 86.11%. Isolation of a DB forest and an EC forest can be done using MODIS/NDVI images acquired on 3 different seasons. Figure 4 shows an NDVI composite image with the March, July and November data assigned to R/G/B, respectively. Here, a, b, c (greenish color) are the DB forests, and d, e, f (whitish color) are the EC forests (Maki, unpublished).

4.3. Ground validation methods using digital image

The development of a proper method for ground validation is important for knowing the actual situation of plant phenology happening on the ground.

Kawamura et al.(2001) examined spatial and temporal variations of light regime and leaf phenology of the DB forest in the super site, by taking photographs and using the shoot sampling method for 9 representative tree species from the leaf development stage in spring to leaf fall in autumn. As a result, development and falling of leaves in *Betula ermanii* and *Betula platphylla* var. *japonica* were several days earlier than those of *Quercus crispula*.

Tsuchida et al. (2005) developed the PEN (Phonological Eyes Network) system for phenology monitoring. One of them was applied at the Takayama super site of DB forest beneath the ecological observation tower. It consisted of an automatic-capturing digital fisheye camera (ADFC) and a hemispherical spectroradiometer (HSSR) system. They reported that when PEN observation is combined with flux or ecosystem research, the validation study of ecosystem remote sensing will be enhanced. This kind of stationary measurement can take accurate data, but it gives a limited spot of information.

Ishihara et al. (2008) proposed a ground observation method to acquire data on detailed phenology changes of various vegetation types. They took digital images using a digital camera and movie camera between spring and autumn from around 600m asl. to 1,340m asl. points along the mountain road. It was confirmed that changing patterns of calculated Normalized Channel DN (Maeda et al., 2005) reflected the forest phenology change. Especially, the pattern of Normalized Green coincided with the leaf development stage and the yellowing stage, and the change of Normalized Red fit to the defoliation stage (Figure 5).

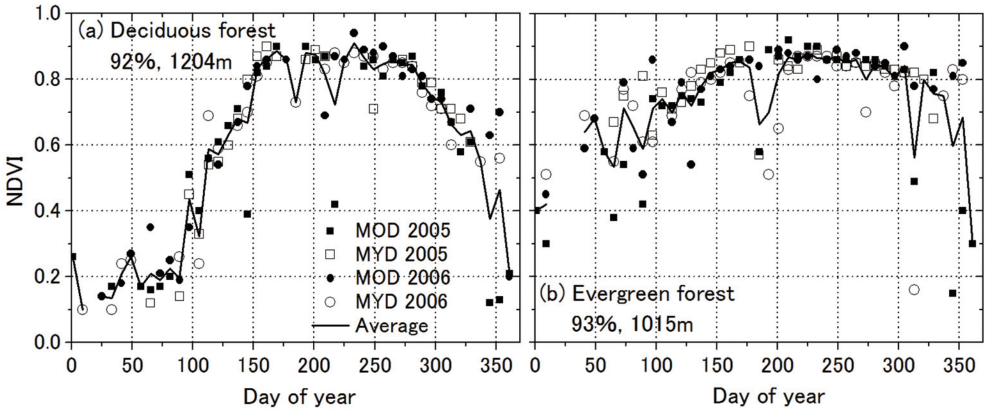

Fig. 5. Seasonal variation patterns of MODIS/NDVI by Terra (MOD) and Aqua (MID) in 2005 and 2006
(a) Deciduous dominant (92%) forest at 1204m asl. (b) Evergreen dominant forest (93%) forest at 1015m asl.

Akiyama et al. (2007) tried to use walnut (*Juglans mandshurica* Maxim) as an indicator plant of DB species. They selected 13 walnut trees growing at different altitudes along a mountain road in the study area, and visually recorded 6 phenological events from bud start-up to complete defoliation. They also measured chlorophyll concentration in leafs using a SPAD meter. According to the results, it was found that walnut phenology was affected by air temperature in spring. But it did not synchronize with MODIS/NDVI changes. Existence of floor vegetation and snow-melting might be the main causes for the inconsistency.

4.4.Forest phenology analysis using seasonal MODIS/NDVI

A forest fluctuates its photosynthetic capacity according to the seasonal changes of leaf amounts and leaf assimilation rates (Sakai et al., 2006). Especially in DB forest, status of leaf changes from development, maturing, yellowing, and shedding in a yearly cycle. Nagai et al. (2008) estimated the dates of budburst (BB) and leaf defoliation (LD) from 2004 to 2006 in the super site using the PEN (Tsuchida et al., 2005) system, which observes by a spectroradiometer situated above the DB forest canopy, and the satellite-based NDVI, which was obtained by the MODIS sensors onboard Terra and Aqua satellites. The ground- and the satellite-based NDVIs increased in the BB and decreased in the LD periods. However, when they estimated the dates of BB and LD by using the threshold value, which was the midpoint between the annual maximum NDVI and the annual minimum NDVI, the estimated date of BB was 20 days earlier than the ground observation and the estimated date of LD was 32 days later than the ground observation.

Spatial resolution and temporal resolution is a setoff relation under the present satellite systems. Frequent observing sensor is inevitable for the forest phenology monitoring, but it has a coarse spatial resolution (250m, in the case of MODIS). Therefore, we must consider about mixel in the mountainous area.

Ishihara et al. (2008) calculated the vegetation ratio (DB and EC) in 250m grid by using detailed landcover map derived from QuickBird image to verify the characteristics of MODIS/NDVI seasonal variation. As the result, EC kept longer peak season of NDVI compared with DB forests in the study area. In addition, the seasonal variation pattern of NDVI changed according to the mixing ratio of DB and EC forest.

5. Conclusions

Recent progress in remote sensing allows analysis of ecosystem function and structure using satellite imaging. Several scales of landcover maps from precise to brief were created in response to the purposes. Moreover, if remote sensing technology is combined with several methods like flux measurement, PEN observation for ecosystem research, validation study of ecosystem will be enhanced.

As spatial resolution and temporal resolution is a setoff relation under the present satellite systems, the Remote Sensing Group applied several satellite data possessing different resolutions to fill any gaps. Development of a scaling method is still important.

Leaf phenology is one of the key parameters for the estimation of carbon budget in the forest. But we could not find the best fitting method from high temporal satellite imagery because of course, of spatial resolutions. New technology for the mixel analysis is needed.

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