OBSERVATION OF FOREST ENVIRONMENT CHANGES IN SIBERIA

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Commission VIII, WG VIII/7

KEY WORDS: Forest environment, Siberia, Time-series model, NOAA

ABSTRACT:

Basic forest information of Siberia in global scale has been corrected as GIS datasets from the IIASA, IGBP and other organizations as well as satellite image and field survey data. Thermal data as well as vegetation index is considered useful to evaluate environmental conditions taking into account the impact of global warming in Siberia. The NOAA Pathfinder data from 1981 to 2001 were used and the large fluctuations originated from noises have been removed by either method of LMF and LMF-KF. As the land surface temperature (LST) data, the Channel 4 data of NOAA-AVHRR were used. By applying the LMF-KF to NOAA Pathfinder data, we could get cloud-free and noise-free images with 10 days interval for both NDVI and LST. The LST shows higher than station temperature in summer time and the relation becomes inverted in winter time. The LST data is useful for understanding environmental condition of the terrain. One of such examples is the satellite warm index (the summation of temperature when it is higher than 5 degree C), which is considered useful for zoning the eco-region. The images of various indices of the world were created. The maximum NDVI of each year, for example, is a good indicator for annual changes of vegetation condition as each NDVI shows the seasonal condition of vegetation coverage. The trend of annual maximum LST for 20 years shows the average temperature changes of the surface, which are related to the impact of global environmental changes to the ground. The NPP in Russia in late 1990s was estimated as 7.8 million tC. The NPP in the whole Russia was increasing but it was decreasing in European Russia because of deforestation.

1. INTRODUCTION

1.1 Phenological Changes

Phenological changes of ecosystem are greatly related to the changes of natural environment, such as water, temperature, soil and solar radiation. Growth condition of vegetation and soundness of ecosystem can be evaluated, if the seasonal changes of the photosynthesis are continuously monitored. Based on this idea, we have studied to get historical information about environmental changes of the world.

Many researches utilize frequent observation satellite such as NOAA/AVHRR and SPOT/Vegetation for global environment study (Ricotta et al., 1999). In such researches, the 10-day composite images, which are created by choosing the best data in 10 days for each pixel, are often used to monitor seasonal changes of terrain conditions. The monthly composite data are not appropriate for monitoring phenological aspects because most of the seasonal changes of vegetation occur within a few weeks (Viovy et al., 1992). However, the influences of cloud, haze and system noises still remain in the 10-day composite data and that makes difficult to monitor phenology on the ground with 10 days interval.

NOAA satellite has a long history of their observation of the Earth and there are data sets of 20 years of the globe. However, only the NDVI data are used in many studies and land surface temperature (LST) data were seldom processed, although temperature is well known as one of the most important environmental parameters.

There are two difficulties for using these data in a long-term analysis. One is the differences of the radiometric sensitivities of sensors on different NOAA satellites. The other difficulty comes from the algorithm to minimize both the atmospheric and systematic noises in satellite data to observe the ground condition.

1.2 Siberian Forest

Russia has about 800 million ha of forest land, which is about 20 % of the world forest land, and not a few simulation studies show that the global environment change might affect them. However, there is not enough ground information which covers the whole vegetated area with the same accuracy. Satellite remote sensing is considered effective to monitor the large forest area. NOAA and SPOT-VGT as well as MODIS are considered effective to monitor the environmental conditions because of their frequent observation capabilities.

Basic forest information of Siberia in global scale has been published by various institutions and we have corrected the GIS datasets of the IIASA, IGBP and other organizations as well as satellite image and field survey data. However, it was not so clear to understand the trends of environmental conditions of whole Siberia. Therefore, we tried to develop methodologies to monitor environmental conditions of Siberian forest to know

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the impact of long-term environmental changes to Siberian forest.

1.3 Carbon flow in Siberian Forest

The carbon flow in Siberian forest is illustrated as Fig. 1, indicating that the ration of carbon storage in soil is quite big. It means that the soil carbon should be considered as a source of CO2 emission as well as the above ground biomass when deforestation occurs in this region.

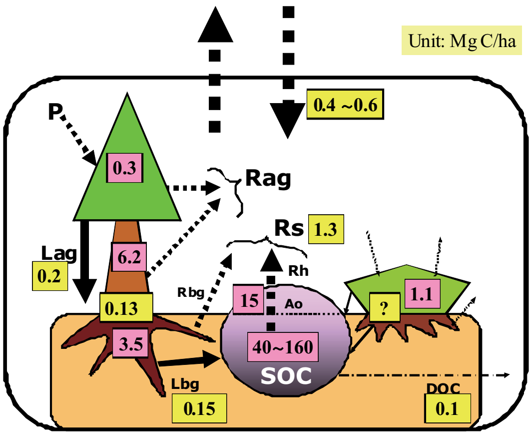

Figure 1. Carbon flux in Siberia (Y. Matsuura)

1.4 Trend of temperature increase

Temperature of last 50 years recorded at weather stations in Siberia shows that the maximum temperature is rather stable but the minimum temperature is increasing by 0.4 degree C in every 10 years (Fig.2). This trend is not clear in northern latitude area (>70 degree) but is significant in southern latitude area in Russia. However, there is not enough stations to monitor these trends and satellite remote sensing data is considered useful to cover the whole Siberia with the same sensor at the same local time.

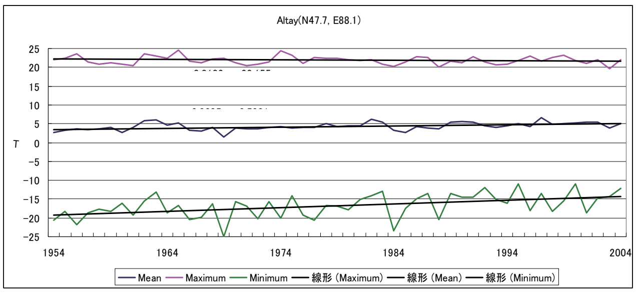

Figure 2 Temperature of last 50 years in Siberia (example: weather station at Altay; N47.7, E99.1)

2. PROCESSSING METHODOLOGIES

2.1 Satellite Data

Siberia has large area of its extent (Longitude: E30 – E180) and satellite remote sensing data with global observation capability is necessary to monitor its forest conditions. Thermal data as well as vegetation index is considered useful to evaluate environmental conditions taking into account the impact of global warming. The forest growth in Siberia is rather slow and a long term observation is needed to estimate the trend of forest growth. Then, we introduced the data set of NDVI and LST data of NOAA for 20 years. **B**ecause the length of growing season changed only about ten days in last 20 years, at least the 10 day composite data is required for detecting the seasonal changes in last 20 years in Siberia.

Although the 10 day composite data are created by selecting the best data of each pixel in every 10 days, there are many pixels which are affected by cloud and haze. We introduced the LMF Processing and LMF-KF Processing to overcome these problems

2.2 LMF Processing

It is assumed that the seasonal change for each pixel is modelled by the sum of cyclic functions. It is also considered that model parameters are determined by the 10 day composite satellite data. Subsequently, the technique was developed to produce a new noise-free image using the models derived for each pixel with time-series data. We call this processing the LMF model processing. The LMF model processing is composed of three steps as follows:

1) Revision of data by setting the adjacent maximum value;
2) Fitting of the time series model by a combination of cyclic functions;
3) Automatic decision to determine the optimum combination of the cyclic functions for the model of each pixel.

$$d'_t = Min\begin{bmatrix} Max\left(d_{t-w+1}, d_{t-w+2}, \cdots, d_t\right), \\ Max\left(d_t, d_{t+1}, \cdots, d_{t+w-1}\right) \end{bmatrix} \qquad (1)$$

where d_t = the observed variable at the time t
w = the window size
d'_t = the modified variable at time t.

$$f_t = c_0 + c_1 t + \sum_{l=1}^{N}\left\{c_{2l}\sin\left(\frac{2\pi k_l t}{M}\right) + c_{2l+1}\cos\left(\frac{2\pi k_l t}{M}\right)\right\} \qquad (2)$$

where c_i = a coefficient
t = time (the interval unit)
N = the pair number of the cyclic function
M = the data number in a period (in case of NOAA 10 day composite products: M = 36)
kl = the periodicity of each cyclic function in a period (in case of M = 36 , kl = 1, 2, 3, 4, 6 and 12, meaning one year, a half year, 4 months, 3 months, 2 months and 1 month periods, respectively).

$$AIC = D\{\log(2\pi\sigma) + 1\} + 2(j+1) \qquad (3)$$

where D =s the number of data,
j = number of functions used
σ = the standard deviation of the residual

2.3 LM-KF Model

In the LMF model processing, it is assumed that the seasonal changes can be expressed by a combination of linear and trigonometric functions like Eq. 2. Nishiyama (1991) reported that the discrete time variant NMR (Nuclear Magnetic Resonance) spectrum can be estimated when the frequency components of a signal are known. We applied his algorithm to the LMF model processing. When considering the set of coefficients {c0, c1,...,c2N+1} of Eq. 2 as the state vector of a state space model, their values can be estimated (state estimation) with a Kalman filter. The new methodology, LMF-KF model (Eq. 4), was built in order to identify not only seasonal changes but also year-by-year fluctuations by considering the time dependency of each coefficient (Sawada et al. 2005).

$$f_t = c_0(t) + \sum_{l=1}^{N} \left\{ c_{2l}(t) \cdot \sin\left(\frac{2\pi k_l t}{M}\right) + c_{2l+1}(t) \cdot \cos\left(\frac{2\pi k_l t}{M}\right) \right\} \quad (4)$$

3. SATELLITE DATA PROCESSING

3.1 Result of LMF-KF Processing

The NOAA Pathfinder data from 1981 to 2001 were processed. On the NDVI data, the large fluctuations originated from noises have been removed by either method of LMF and LMF-KF. The LMF-KF model processing reveals the annual changes. As the LST data, we introduced the Channel 4 data of NOAA-AVHRR. The result of the LMF-KF model was well correspond to the meteorological data derived from AMeDAS in Japan.

After the LMF-KF processing to NOAA Pathfinder data for 20 years (1981-2001), we could get "clear" (cloud-free and noise-free) images with 10 days interval for both NDVI and LST. Because both the NDVI and LST are obtained from the LMF-KF processing, many possibilities to monitor environmental conditions in vegetated area were developed.

3.2 Characteristics of LST Data

The radiometric resolution of the channel 4 of NOAA-AVHRR, used as the LST, is high enough to monitor ground surface temperature. The relationship between LST and the temperature measured at the meteorological station shows that there are some seasonality. The LST shows higher than station temperature in summer time and the relation becomes inverted in winter time. These differences are depending on the location and land cover (Fig. 3).

3.3 Various Informative Data

The LST data is useful for understanding environmental condition of the terrain. One of the examples, is the satellite warm index (the summation of temperature when it is higher than 5 degree C), which is considered useful for zoning the eco-region. LST makes us possible to monitor the condition of the annual changes of satellite warm index in Russia.

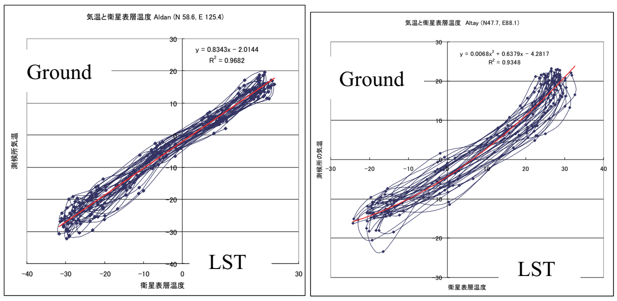

Figure 3. Relations between LST and ground temperature

The LMF-KF processed images brought us the possibilities to develop further indices by the combination of NDVI and LST (Table 1), which could be useful for monitoring various phenological conditions of vegetated area.

Table 1. Indices derived from NDVI and LST

(Index)	(Meaning)
NMXV, NMXD	Maximum NDVI, the day
NMNV, NMND	Minimum NDVI, the day
TMXV, TMXD	Maximum LST, the day
TMNV, TMND	Minimum LST, the day
T5S, T5D	Warm index, duration: LST > 5 C deg.
T00S, T00D	Freezing index, days: LST < 0 C deg.
NST5	ΣNDVI : LST >5 C dg.
MNV1	Minimum NDVI : LST>1C deg.
MXV1	Maximum NDVI: LST>1C deg.
NOND	Onset day : MNV1 to MAV1
NOFD	Offset day: MAV1 to MNV1
NOOD	Duration of growing season
NOOS	ΣNDVI during the NOOD

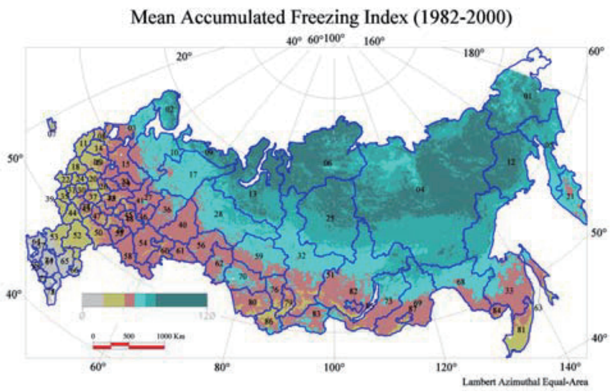

Figure 4. Mean annually accumulated freezing index map

4. ANALYSIS AND RESULTS

The reliability of the LMF-KF processing methodology was checked by the simulation data. It could reveal the surface condition by minimizing the affects of clouds and the system noises. The 3-color composite images derived from NDVI and LST of every 10 days for 20 years with 8km resolution (more than 720 scenes in total) clearly show the global dynamics of surface conditions of the world, including Siberian forest.

4.1 NDVI and Thermal Data

The images of various indices of the world, shown in Table 1, were created. The maximum NDVI of each year is considered as a good indicator for annual changes of vegetation condition as each NDVI shows the seasonal condition of vegetation coverage. The trend of annual maximum LST for 20 years is considered the average temperature changes of the surface, which must be related to the effect of global environmental and changes of ground coverage.

The onset day and offset day of vegetation growth of each pixel were defined from the maximum and minimum NDVI when the LST has greater than 1 degree C. The accumulation value of the NDVI between onset and offset is the NOOS index (Table 1). The NOOS has the highest relation with the forest distribution map which was reported by the International Institute for Applied Systems Analysis (IIASA). It seemed that the NOOS could be used as a good indicator for forest area.

The annually accumulated Freezing Index image of each year was also created from the LST data. The Mean Accumulated Freezing Index over 20 years (Fig.2) was compared to the permafrost extent map which had been created by IIASA. They have similar pattern and satellite maps have an advantage over the map at its frequent monitoring capability.

4.2 Seasonal Changes

The seasonal changes are well observed on the NDVI and LST images individually. However, the combination of NDVI and LST shows clearly the growing season and the trend of vegetation condition of each pixel. We assumed that the LST greater than 5 degree C or 1 degree C is the growing season and the accumulation of the NDVI during the period is related to the vegetation growth uptaking the CO2.

4.3 Annual changes of Net Primary Product (NPP)

The NDVI and LST processed by our LMF-KF methodology were introduced to estimate NPP of the world. The NPP in Russia in late 1990s was estimated as 7.8 million tC. The NPP in the whole Russia was increasing (Fig5.) but it was decreasing in the European Russia because of deforestation.

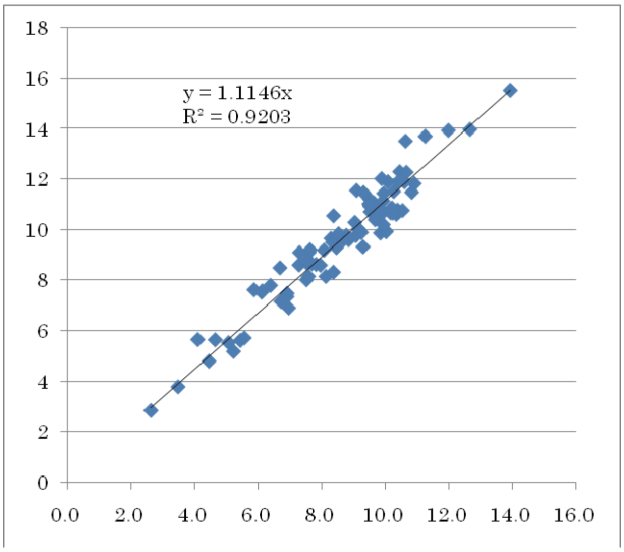

Figure 5. Comparison of NPP between Satellite and ground (tC)

4.4 Annual changes of LAI

Both seasonal changes and annual changes of LAI were analysed from the MODIS data in 2000 to 2006. The LMF-KF was applied to the MODIS LAI data of the world. The LAI in Siberia shows maximum value of a year in middle July. The maximum LAI of each year decreased dramatically in 2002 but the impact to the carbon uptake was not clearly estimated.

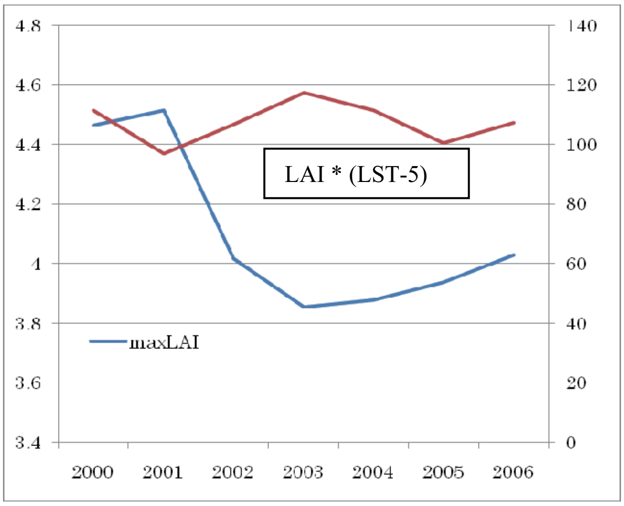

Figure 6 Maximum LAI of the year and the annual summation value of the LAI * (LST-5)

5. DISCUSSION

The LMF-KL processing could successfully create cloud and noise free images of NDVI and LST with 10 day interval for 20 years from the NOAA Pathfinder data. The combination of NDVI and LST is a unique and effective methodology for studying forest conditions in this region. These data can be used for further studies on carbon fixation and release.

ACKNOWLEDGEMENT

This report is a result of the Study on Estimation of Carbon Storage and Fixation in the Boreal Forest funded by the Global Environment Research Fund of Ministry of the Environment, Japan. The current NPP calculation methodology comes from Dr. Yoshio Awaya, Gifu University.

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