

VARIATIONS IN CROPLAND PHENOLOGY IN CHINA FROM 1983 TO 2002

Wenbin Wu^{a,*}, Ryosuke Shibasaki^a, Peng Yang^b, Qingbo Zhou^b, Huajun Tang^b

^a Center for Spatial Information Science, University of Tokyo, Tokyo 153-8505, Japan - wwbyn@iis.u-tokyo.ac.jp, shiba@csis.u-tokyo.ac.jp

^b Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences, Beijing 100081, China - (yangpeng, zhouqb, hjtang@mail.caas.net.cn)

KEY WORDS: Cropland phenology, Starting date of growing season (SGS), NDVI, Variation, China

ABSTRACT:

In this study, we used the NDVI time-series datasets to investigate variations in the starting dates of growing season (SGS) in China's cropland from 1983 to 2002. To do so, a smoothing algorithm based on an asymmetric Gaussian function was first performed on the NDVI dataset to minimize the effects of anomalous values caused by atmospheric haze and cloud contamination. The SGS of cropland was estimated based on the smoothed NDVI time-series datasets for 1983, 1992 and 2002, respectively. The resulting three datasets were then overlaid together to calculate the changes in SGS during the period of 1983-1992 and 1992-2002. The results showed that the average date of SGS in China's cropland over the past 20 years becomes progressively later as moving toward to the north from the south of China, corresponding well with the temperature and precipitation gradients in China. The variations of the SGS varied considerably with location and investigation period, and its general trend was characterized by a significant advance during these two periods. This study supported the conclusion by previous studies that the SGS has advanced over the past two decades at the middle and high latitudes in the northern hemisphere. Several factors can profoundly influence phenological status for cropland, such as climate change, soils and human activities. How to discriminate the impacts of biophysical forces and anthropogenic drivers on phenological events of cultivation remains a great challenge for further studies.

1. INTRODUCTION

Phenology is the chronology of periodic phases of development of living species. Interannual and interseasonal variations in phenological events have broad impacts on terrestrial ecosystems and human societies by altering global carbon, water and nitrogen cycles, crop production, duration of pollination season and distribution of diseases (Penuelas and Filella, 2001; Soudani et al., 2008). Therefore, phenology has emerged recently as an important focus for ecological and climatic research (Menzel et al., 2001; Cleland et al., 2007).

In situ observations, bioclimatic models and remote sensing constitute the three possible ways for monitoring the variations of vegetation phenological events (Schaber and Badeck, 2003; Fisher et al., 2007; Soudani et al., 2008). Field-based approaches are nearly impossible to extend to large areas as observations of vegetation phenology across large areas are expensive, time consuming and subject to uncertainty due to operator bias. Bioclimatic models are often specie-specific and calibrated at local scales. Their applications at larger scales may not be accurate and depend on availability of vegetation maps and complete and consistent climate records used as forcing variables. Remote sensing has the advantages of being the only way of sampling at low-cost with good temporal repeatability over large and inaccessible regions.

Numerous studies have been implemented to detect and estimate vegetation phenology analogues such as the starting date of growing season (SGS), ending date of growing season (EGS), and length of growing season (LGS) at continental or regional levels. These studies, mainly using time-series of NDVI datasets derived from NOAA/AVHRR, TERRA/MODIS

and SPOT/VEGETATION, focused in either developing methods for reconstructing a high-quality time-series datasets (Viovy et al., 1992; Roerink and Menenti, 2000; Jönsson and Eklundh, 2002; Zhang et al., 2003; Chen et al., 2004; Bradley et al., 2007) or exploring and evaluating the use of satellite-derived phenological metrics for studying terrestrial ecosystems dynamics at different spatial and temporal scales (Myneni et al., 1997; Zhou et al., 2001; Lee et al., 2002; Yu et al., 2004; Zhang et al., 2004; Beck et al., 2006 and 2007; Heumann et al., 2007; Maignan et al., 2008). Unfortunately, most these studies were conducted in North America, Europe, Sahel and Sudan regions, and Central Asia, little study has been undertaken to examine possible changes in phenology on the scale of China. Furthermore, these previous studies mainly focused on phenology of natural vegetation such as forests, shrub lands, and grassland, rather than cropland phenology. The objective of this study is to investigate variations in phenology of China's cropland from 1983 to 2002 by using NDVI time-series datasets.

2. MATERIALS AND METHODOLOGY

2.1 MATERIALS

In this study, NDVI time-series datasets at a spatial resolution of 8 km and 15-day interval were acquired from the NASA Global Inventory Modeling and Mapping studies (GIMMS) group derived from the NOAA/AVHRR series satellites (NOAA 7, 9, 11, and 14) for the period of January 1983 to December 2002. The GIMMS NDVI datasets have been corrected to remove some non-vegetation effects caused by sensor degradation, clouds and stratospheric aerosol loadings from volcanic eruptions. Detailed information on the processing

* Corresponding author.

and quality issues of the GIMMS dataset can be found in Slayback et al. (2003) and Tucker et al. (2005). Although relatively coarse resolution, the GIMMS NDVI dataset is the only publicly available global dataset to extend from 1981 to present and was thus widely used for near real-time global vegetation monitoring (Zhou et al., 2001; Brown et al., 2004; Tarnavsky et al., 2008). China's cropland distribution data was obtained from the National Land Cover Dataset 2000 (NLCD-2000), produced by the Chinese Academy of Sciences through visual interpretation and digitization of satellite images (Landsat TM/ETM+) at a scale of 1:100,000 (Liu et al., 2005). The digital version of the China Administration Map from the Chinese National Survey Agency, which represents China's national, regional, and provincial administrative boundaries of 1995/1996, was used to obtain subsets of the global NDVI datasets for China.

2.2 METHODOLOGY

2.2.1 Data preparation: The initial step involved clipping the global NDVI datasets to the coverage of the official boundary of China according to the China administration map. The NLCD-2000 at the 1: 100,000 scale was converted into a gridded database with the same cell size of global NDVI datasets at an 8 km spatial resolution. To cope with differing spatial resolutions, we used the majority-rule approach to aggregate the NLCD-2000 raster to the coarser spatial resolution. This approach searches for the land cover type with the highest frequency within the new coarser grid cell.

2.2.2 Creating smooth NDVI time-series data: The GIMMS NDVI dataset was developed by the Maximum Value Composite (MVC) technique. Although it is widely accepted that composite NDVI images can greatly reduce cloud and other atmospheric noise while retaining dynamic vegetation information, residual atmospherically related noise, as well as some noise due to other factors, e.g., surface anisotropy, still remain in the NDVI datasets. These problems tend to create data drop-outs or data gaps and make it difficult to identify phenological transition dates with a high accuracy. In order to reduce the impact of bare soils and sparsely vegetated grids on the NDVI trends, grid cells with annual mean NDVI smaller than 0.1 were excluded for analysis, as done in Zhou et al. (2001) and Piao et al. (2006).

Furthermore, asymmetric Gaussian function fitting was used to minimize the perturbations and reduce contamination in the NDVI time-series data. Asymmetric Gaussian function fitting is a semi-local curve-fitting method (Jönsson and Eklundh, 2002 and 2004). First, simple local nonlinear model functions were fitted to sets of data points. The adopted local model functions have the general form

$$f(t) \equiv f(t; c_1, c_2, a_1, \dots, a_5) \equiv c_1 + c_2 g(t; a_1, \dots, a_5) \quad (1)$$

$$g(t; a_1, \dots, a_5) = \begin{cases} \exp\left[-\left(\frac{t-a_1}{a_2}\right)^{a_3}\right], & t > a_1 \\ \exp\left[-\left(\frac{a_1-t}{a_4}\right)^{a_5}\right], & t < a_1 \end{cases} \quad (2)$$

where $g(t; a_1, \dots, a_5)$ is a Gaussian-type function, the linear parameters c_1 and c_2 determine the base level and the amplitude, a_1 determines the position of the maximum or minimum with respect to the independent time variable t , a_2 and a_3 determine

the width and flatness of the right function half, a_4 and a_5 determine the width and flatness of the left half.

The local functions were then used to build global functions that correctly describe the NDVI variations in the full vegetation season. As shown in Figure 1, if we denote the local functions describing the NDVI variation in intervals around the left minima, the central maxima, and the right minima by $f_L(t)$, $f_C(t)$ and $f_R(t)$, the global function $F(t)$ that correctly models the NDVI variation in full interval $[t_L, t_R]$ is

$$F(t) = \begin{cases} \alpha(t)f_L(t) + [1 - \alpha(t)]f_C(t), & t_L < t < t_C \\ \beta(t)f_C(t) + [1 - \beta(t)]f_R(t), & t_C < t < t_R \end{cases} \quad (3)$$

where $\alpha(t)$ and $\beta(t)$ are cut-off functions that in small intervals around $(t_L + t_C)/2$ and $(t_C + t_R)/2$, respectively, smoothly drop from 1 to 0. The merging of local functions to a global function is a key feature of the method. It increases the flexibility and allows the fitted function to follow a complex behaviour of the time-series. Subsequent extraction of phenological parameters was based on the smooth NDVI time-series dataset generated from global model function.

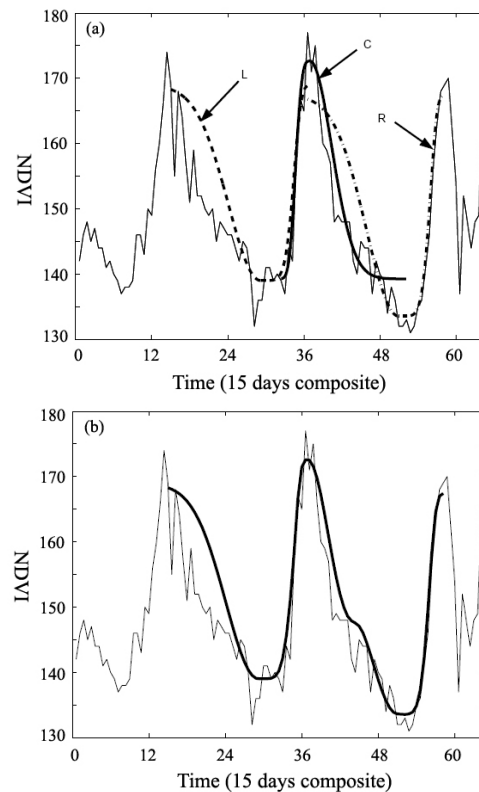


Figure 1. (a) Left (L), Central (C) and Right (R) local Gaussian functions. (b) Merged global function.

2.2.3 Extracting phenological parameters: Several phenological parameters such as the SGS, EGS and LGS can be extracted from the smoothed NDVI time-series data. However, it should be noted that harvesting two or more crops from the same field in one year (multiple cropping) is very common in many regions of China. Changes in multiple cropping patterns over the past few decades could take place and caused some variations in cropland phenology. For this reason, this study focused only on the SGS of cropland and analyzed their variations during the period of 1983-2002.

In general, there are two approaches for determining the SGS from the seasonal variation in NDVI. The first method uses a

NDVI threshold to identify the beginning of photosynthetic activity in the spring. The second one identifies the period of larger increase in NDVI as the beginning of growing season. A limitation associated with the “threshold” approach is that various land cover types require the use of different thresholds. Since most land cover types are a mixture of plant types, determining the optimal threshold value for whole China can be difficult. Changing solar zenith and azimuth viewing angles can influence the NDVI values, also complicating the use of the threshold approach. Thus, the second approach was used in this study. The SGS were estimated as the time point at which the value of the fitted function has first exceeds 20% of the distance between minimum and maximum at the rising limb. During calibration, it was found that estimates of SGS using values less than 20% had increased error due to noise effects. The SGS was extracted for the year 1983, 1992 and 2002, respectively, and these three phenological data were then overlaid together to calculate changes in phenology for the period of 1983-1992 and 1992-2002. The China administrative boundary map was used to aggregate the statistics of phenological changes at provincial levels for analysis.

3. RESULTS AND DISCUSSION

3.1 General pattern of SGS in China’s cropland

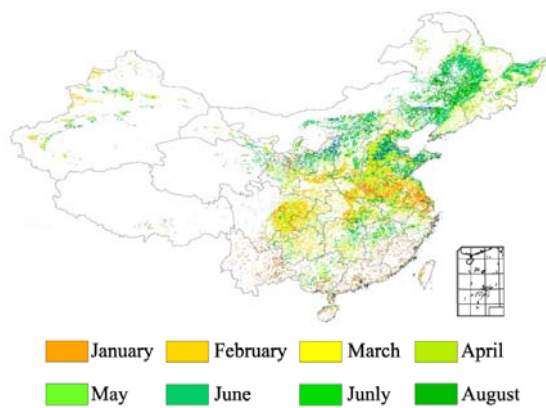


Figure 2. Average SGS in China’s cropland from 1983 to 2002.

The distribution of average SGS in China’s cropland is shown in Figure 2. The average date of SGS in cropland varies considerably across China, and in general becomes progressively later as moving toward to the north from the south of China. This variation in SGS corresponds well with the temperature and precipitation gradients in China. The cropland in the southern part of China has the earliest dates of SGS, usually in late January to late February. Most major agricultural production regions in China, such as the North China plain, the Sichuan basin in the south-west and the plain of the middle delta of the Yangtze River in central China, experience the SGS in early March to late April, while in some regions of North China, the SGS arrives in early May. The date of SGS for the North-east China normally occurs in early May to late June, yet, some regions have the relatively earlier SGS, which arrives in April.

3.2 Spatial variations of SGS in China’s cropland

The variations of SGS dates in China’s cropland for the period of 1983-1992 and 1992-2002 are shown in Figure 3. It can be

seen that the variations of SGS in both periods are characterized by a combination of advanced patterns in some regions and delayed patterns in other regions. For the first period of 1983-1992, the regions with a significantly advanced SGS covered much of the north-east and North China plain, as well as some parts of regions along the Great Wall of Inner Mongolia, and the middle and lower reaches of the Yangtze River. The regions that experienced a later date of SGS can be observed in croplands of the Loess plateau, south-west and south of China (Figure 3a). In the second period of 1992-2002, the variations in SGS showed some difference when compared with those of the first period. A constant advance in SGS occurred in the North China plain and the middle and lower reaches of the Yangtze River. Loess plateau and Sichuan basin also showed an earlier trend of SGS. However, most croplands of the north-east, regions along the Great Wall of Inner Mongolia, north-west and south of China presented a later SGS pattern (Figure 3b).

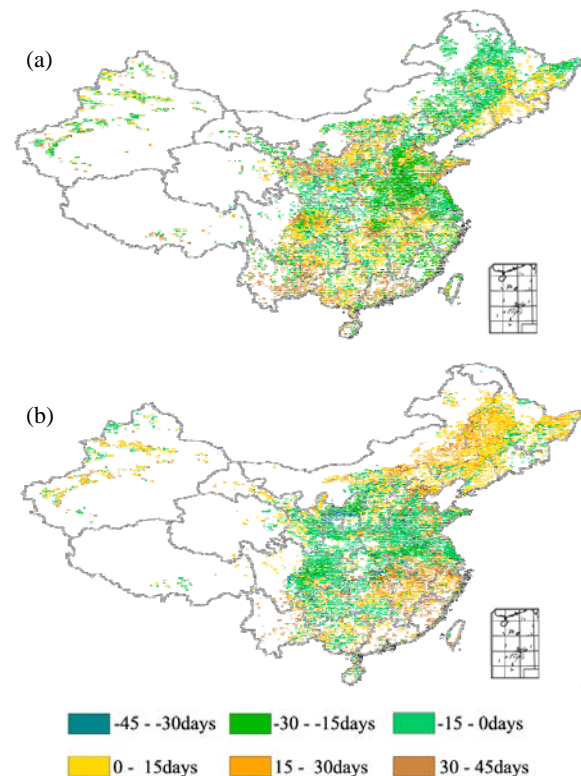


Figure 3. Variations of SGS in China’s cropland during the period of (a) 1983-1992 and (b) 1992-2002.

When looking at provincial level, Henan, Anhui, Hubei, Shanghai, Taiwan, Shandong and Jiangsu provinces showed a significant advance in cropland SGS during both two periods, resulting in about -15 – -30 days in total over the past 20 years. Yunnan, Guangdong, Sichuan, Hebei, Fujian and Guangxi provinces also experienced an early SGS trend of -15 days, but with a significant fluctuation over two periods. On the contrary, the SGS of croplands in Hainan, Tianjin, Ningxia and Zhejiang provinces was relatively delayed by 30 days from 1983 to 2002. Changes in SGS for other regions generally fluctuated over time and they showed little change or non-change during the study period (Figure 4).

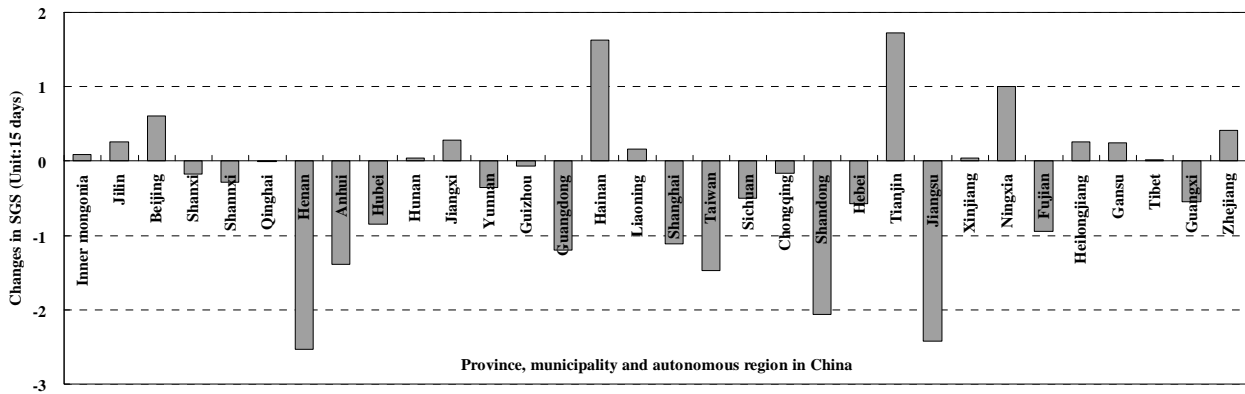


Figure 4. Variations of phenology in different provinces in China from 1983 to 2002.

3.3 Phenology change and driving forces

Several factors can profoundly influence cropland phenological status. Among these factors, climate change, particularly the global warming induced by increasing atmospheric greenhouse gases, has been suggested to be the major cause of the advance and extension of the growing season. Zheng et al. (2002) used phenology data from 26 stations of the Chinese Phenology Observation Networks of the Chinese Academy of Sciences and the Climatic data to study the impacts of climate warming on plant phenophases in China for the last 40 years. They concluded that in general there are three kinds of changes in spring phenophase: advance, constant variation and delay, which correspond to the increase, unobvious change, and decrease in the spring temperature, respectively. Ge et al. (2003) made the similar study and found that there was a relative high correlation between changes in spring phenology and changes in growing season temperature, and no significant relationship between spring phenology and precipitation in the same period. The study by Xiao et al. (2004) reconfirmed the result that temperature variations in China have a considerably larger impact on vegetation phenology than precipitation variations; in particular, the warming in spring strongly influences the spring vegetation activities. Several studies have suggested a time lag between vegetation growth and climate variability. Piao et al. (2006) analyzed the relationships between the onset date and pre-season climatic variables in temperate zone of China. The highest negative correlation between the onset date of vegetation green-up and pre-season temperature was found in the preceding 2-3 months, suggesting that the mean temperature at that time could have the greatest influence in triggering the green-up of the vegetation.

However, it should be noted that phenological events for cultivation are not only controlled by climate change, but also severely affected by anthropogenic activities, such as crop type, planting, irrigation, fertilization, use of pesticides, and harvest (Zhang et al., 2004). These field management measures could also lead to variations in phenology for China's cropland. However, little research has been performed for the relative contribution of these anthropogenic factors, because of the complex interaction of these mechanisms. How to separate the impact of human activities and climatic changes on phenological events of cropland remains a great challenge for further studies (Piao et al., 2006).

4. CONCLUSIONS

Based on the GIMMS NDVI biweekly time-series data, we investigated the variations in the SGS in China's cropland over the past 20 years. This study interpreted that the variations of SGS varied considerably with location and investigation period, and its general trend was characterized by a significant advance during these two periods. Many studies by using observed atmospheric CO₂ concentration, *in situ* phenological networks, remote sensing data and phenological modeling have revealed that the SGS has advanced and growing season duration has significantly lengthened over the past two decades at the middle and high latitudes in the northern hemisphere. This study supports the conclusions of previous studies to some extent. In addition, phenological variations for cultivation are not only controlled by climate change, but also severely affected by anthropogenic activities, such as crop type, planting, irrigation, fertilization, use of pesticides, and harvest. The effects of anthropogenic driver on phenological events of cultivation should be given more attention in future phenological studies.

REFERENCES

- Beck, P.S.A., Atzberger, C., Hogda, K.A., et al., 2006. Improved monitoring of vegetation dynamics at very high latitudes: a new method using MODIS NDVI. *Remote Sensing of Environment*, 100, pp, 321–334.
- Beck, P.S.A., Jönsson, P., Hogda, K.A., et al., 2007. A ground-validated NDVI dataset for monitoring vegetation dynamics and mapping phenology in Fennoscandia and the Kola peninsula. *International Journal of Remote Sensing*, 28, pp, 4311–4330.
- Bradley, B.A., Jacob, R.W., Hermance, J.F., et al., 2007. A curve fitting procedure to derive inter-annual phenologies from time series of noisy satellite NDVI data. *Remote Sensing of Environment*, 106, pp, 137–145.
- Brown, M.E., Pinzon, J.E., Tucker, C.J., 2004. New vegetation index dataset available to monitor global change. *EOS Transactions*, 85, pp, 565–569.
- Chen, J., Jönsson, P., Tamura, M., et al., 2004. A simple method for reconstructing a high-quality NDVI Time-series data set based on the Savitzky-Golay Filter. *Remote sensing of Environment*, 91, pp, 332–344.

- Cleland, E.E., Chuine, I., Menzel, A., et al., 2007. Shifting plant phenology in response to global change. *Trends in Ecology and Evolution*, 22, pp, 357–365.
- Fisher, J.I., Richardson, A.D., Mustard, J. F., 2007. Phenology model from surface meteorology does not capture satellite-based greenup estimations. *Global Change Biology*, 13, pp, 707–721.
- Ge, Q., Zheng, J., Zhang, X., et al., 2003. Climate change and phenology variations in China over the past 40 years. *Progress in Natural Science*, 13, pp, 1048–1053.
- Heumann, B.W., Seaquist, J.W., Eklundh, L., et al., 2007. AVHRR derived phenological change in the Sahel and Soudan, Africa, 1982–2005. *Remote Sensing of Environment*, 108, pp, 385–392.
- Jönsson, P., Eklundh, L., 2002. Seasonality extraction by function fitting to time-series of satellite sensor data. *IEEE Transactions on Geoscience and Remote Sensing*, 40, pp, 1824–1832.
- Jönsson, P., Eklundh, L., 2004. TIMESAT—a program for analyzing time-series of satellite sensor data. *Computers & Geosciences*, 30, pp, 833–845.
- Lee, R., Yu, F., Price, K.P., et al., 2002. Evaluating vegetation phenological patterns in Inner Mongolia using NDVI time-series analysis. *International Journal of Remote Sensing*, 23, pp, 2505–2512.
- Liu, J., Liu, M., Tian, H., et al., 2005. Spatial and temporal patterns of China's cropland during 1990–2000: An analysis based on Landsat TM data. *Remote Sensing of Environment*, 98, pp, 442–456.
- Maignan, F., Bréon, F.M., Bacour, C., et al., 2008. Interannual vegetation phenology estimates from global AVHRR measurements: Comparison with in situ data and applications. *Remote Sensing of Environment*, 112, pp, 496–505.
- Menzel, A., Estrella, N., Fabian, P., 2001. Spatial and temporal variability of the phenological seasons in Germany from 1951 to 1996. *Global Change Biology*, 7, pp, 657–666.
- Myneni, R.B., Keeling, C.D., Tucker, C.J., et al., 1997. Increased plant growth in the northern high latitudes from 1981 to 1991. *Nature*, 386, pp, 698–702.
- Penuelas, J., Filella, I., 2001. Responses to a warming world. *Science*, 294, pp, 793–794.
- Piao, S., Fang, J., Zhou, L., et al., 2006. Variations in satellite-derived phenology in China's temperate vegetation. *Global Change Biology*, 12, pp, 672–685.
- Roerink, G.J., Menenti, M., 2000. Reconstructing cloudfree NDVI composites using Fourier analysis of time series. *International Journal of Remote Sensing*, 21, pp, 1911–1917.
- Schaber, J., Badeck, F.W., 2003. Physiology based phenology models for forest tree species in Germany. *International Journal of Biometeorology*, 47, pp, 193–201.
- Slayback, D., Pinzon, J., Los, S.O., et al., 2003. Northern hemisphere photosynthetic trends 1982–1999. *Global Change Biology*, 9, pp, 1–15.
- Soudani, K., Maire, G., Dufrêne, E., et al., 2008. Evaluation of the onset of green-up in temperate deciduous broadleaf forests derived from Moderate Resolution Imaging Spectroradiometer (MODIS) data. *Remote Sensing of Environment*, doi:10.1016/j.rse.2007.12.004.
- Tarnavsky, E., Garrigues, S., Brown, M.E., 2008. Multiscale geostatistical analysis of AVHRR, SPOT-VGT, and MODIS global NDVI products. *Remote Sensing of Environment*, 112, pp, 535–549.
- Tucker, C.J., Pinzon, J.E., Brown, M.E., et al., 2005. An extended AVHRR 8-km NDVI data set compatible with MODIS and SPOT Vegetation NDVI data. *International Journal of Remote Sensing*, 26, pp, 4485–4498.
- Viovy, N., Arino, O., Belward, A.S., 1992. The best index slope extraction(BISE): A method for reducing noise in NVDI time-series. *International Journal of Remote Sensing*, 13, pp, 1585–1590.
- Xiao, J., Moody, A., 2004. Trends in vegetation activity and their climatic correlates : China 1982 to 1998. *International Journal of Remote Sensing*, 25, pp, 5669–5689.
- Yu, F., Price, K.P., Ellis, J., et al., 2004. Satellite Observations of the seasonal vegetation growth in central Asia: 1982–1990. *Photogrammetric Engineering & Remote Sensing*, 70, pp, 461–469.
- Zhang, X., Friedl, M.A., Schaaf, C., et al., 2003. Monitoring vegetation phenology using MODIS. *Remote Sensing of Environment*, 84, pp, 471–475.
- Zhang, X., Friedl, M.A., Schaaf, C.B., et al., 2004. Climate controls on vegetation phenological patterns in northern mid- and high latitudes inferred from MODIS data. *Global Change Biology*, 10, pp, 1133–1145.
- Zheng, J., Ge, Q., Hao, Z., 2002. Impacts of climate warming on plants phenophases in China for the last 40 years. *Chinese Science Bulletin*, 47, pp, 1826–1831.
- Zhou, L., Tucker, C.J., Kaufmann, R., et al., 2001. Variations in northern vegetation activity inferred from satellite data of vegetation index during 1981 to 1999. *Journal of Geophysical Research–Atmosphere*, 106, pp, 20069–20083.

ACKNOWLEDGEMENTS

This study was supported and financed by the Ministry of Education, Culture, Sports, Science and Technology of Japan under its DIAS (Data Integration and Analysis System) project, and by the Foundation for National Non-Profit Scientific Institution, Ministry of Finance of China (IARRP-2008). All persons and institutes who kindly made their data available for this analysis are acknowledged.

