Sino-Japanese collaborations benefit China's crop monitoring system

Wu Wenbin[1], Zhou Qingbo[1], Yang Peng[1], Liu Jia[1], Chen Youqi[1], Zou Jinqiu[1], Shi Zhongchao[2]

[1] Key Laboratory of Agricultural Remote Sensing, Ministry of Agriculture and Rural Affairs / Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences, China
[2] Department of Restoration Ecology and Built Environment, Faculty of Environmental Studies, Tokyo City University, Japan

Abstract

Remotely sensed data has played an important role in agricultural monitoring across space and time. This paper reviews ten years of collaboration studies in agricultural remote sensing between IARRP and JIRCAS. This successful collaboration has made great contributions to the development of China Agricultural Remote Sensing Monitoring System (CHARMS) with the support of the Chinese Ministry of Agriculture. The monitoring system has been in operation and running since 2002. To date, CHARMS has been applied for mapping of crop planting areas, monitoring of crop growth, estimation of crop yields, monitoring of natural disasters, supporting of precision and facility agriculture. However, the CHARMS system is still confronted with great challenges. Advancing algorithms of agronomic parameters and soil quality for satellite data are favored in future research, especially to improve the performance of remote sensing monitoring in the fragmented landscapes. In addition, the thematic series of products in terms of land cover, crop allocation, crop growth and production are required to be addressed in association with other data sources at multiple spatial scales.

1 Overview of IARRP-JIRCAS collaborations in agricultural remote sensing

Information on crop acreage, spatial distribution, and growth conditions is critical for governments at multiple levels to make decisions so as to ensure national food security, particularly for countries like China with a large population and limited land resources (Shi *et al.* 2014). Since 1972, when the first Landsat satellite launched, remote sensing has been developing rapidly and has been widely used to collect agriculture and agronomy information over time and space. Based on this information, stakeholders can spatially identify the areas with large variations in production and productivity and make appropriate decisions in response to these changes (Atzberger 2013; Tang *et al.* 2015).

The application of remote sensing technology in China started in the field of geology with very obvious social and economic benefits, which subsequently drove its application to other fields. In the late 1980s, due to the urgent demand from the agricultural sector and the advancement of remote sensing technology, satellite images were used by some agricultural scientists for resource surveys, production estimation and disaster monitoring. At that time, technology innovation, model construction and system development largely lagged behind the application needs. It was critical to develop the monitoring methodology as well to improve the research capacity through joint research and talents training. With this goal, the Institute of Agricultural Resources and Regional Planning (IARRP), Chinese Academy of Agricultural Sciences, and Japan International Research Center for Agricultural Sciences initiated their collaborative research in 1999. The ten-year long collaboration comprised two stages: 1999–2003 and 2004–2008. The aim of the first collaboration period was to develop a method for monitoring major crops in China using remote sensing and geographic information system (GIS) technology. The second period built on the research of the first stage and expanded to develop the method for agro-environmental assessment. In both stages, there was frequent staff exchange between IARRP and JIACAS. Several symposiums were also co-organized. This close collaboration has generated several books, proceedings and journal articles. There was no doubt that the IARRP-JIRCAS collaboration in agricultural remote sensing would definitely contribute to the development of the agricultural monitoring system and provide strong spatial data support for the agriculture sector.

2 Development of crop monitoring system and its application

Crops in China are grown in complex and diverse landscapes and commonly mixed with other vegetation. Based on IARRP-JIRCAS collaboration achievements, the IARRP established the China Agricultural Remote Sensing Monitoring System (CHARMS) in 1998 with the support of the Agriculture Remote Sensing Application Center of the Ministry of Agriculture to effectively and efficiently monitor crop conditions at a regional level by combining remote sensors, in situ observation stations, and wireless sensor networks (Tang *et al*. 2010). Using data generated by this system, discriminative crop diagnostic techniques incorporating complex quantitative inversion algorithms were developed and deployed nationwide to gather data on major crop and agro-environmental variables for assessment and analysis. The system has been in operation since 2002, providing rapid and reliable agricultural information to support important decisions regarding the management of crops throughout China. However, foreign satellite data has been the main source for CHARMS since its establishment, resulting in huge costs for the long-term domestic application. The launch of the China GF series satellite in 2013 enabled the substitution of foreign satellite data with Chinese satellite data for CHARMS. GF satellite data gradually became the essential data source owing to its superb spatial resolution, scanning width and revisit period in agricultural remote sensing monitoring.

1) Crop distribution mapping

Monitoring of crop distribution and planting areas is the basic task in CHARMS (Hu *et al*. 2015). Three different levels of requirements exist for the monitoring of crop planting areas using high-resolution data: crop inventory survey for the entire country, monitoring of the dynamic changes in the crop area in the entire country, and early identification of the crop area for crop growth monitoring. The time and accuracy required for monitoring of these three aspects are different. The crop inventory survey requires the satellite data to spatially cover the entire crop cultivation area or at least the main crop production area. In terms of the time requirement, there needs to be at least one-time phase in the crop growing season during which the target crop can be identified. The current minimum mapping unit is approximately 10 m × 10 m, which cannot meet the requirements when satellite data are used to monitor the area in South China where plots are fragmented (Liu *et al.* 2014). The highest requirement for dynamic monitoring of the crop area in the entire country is full coverage, which cannot be satisfied in most cases. The frame of spatial sampling is used to randomly select the satellite images for the targeted region, and then the extrapolation method is performed to obtain information on the target crop in entire monitoring areas. Regardless of the method used, it is necessary to obtain images of the same coverage area in two periods – the current year and the previous year – so as to calculate the dynamic changes in the area (whether the area increases or decreases). The minimum mapping unit for this aspect is also approximately 10 m × 10 m. This likewise cannot meet the requirements when satellite data are used to monitor areas in China with a complex planting structure (e.g., areas where crops are sown with drills, different types of crops are sown together, and plots are fragmented). Monitoring the crop growth conditions requires early identification of the crop area; the information related to the crop spatial distribution should generally be obtained within one month of sprouting. The current minimum mapping unit is approximately 250 m × 250 m (Peng *et al.* 2011; Zhang *et al.* 2015).

The 2 m/8 m resolution data collected by the GF-1 satellite can be used to perform crop inventory survey and dynamic monitoring of crop acreage in the entire country. If a revisit cycle of 42 days and the duration of the growth period of early rice (100 days, the shortest among the crops) are used for the calculation, 2.5 relevant periods of data can be collected. After removing the invalid data due to cloud coverage and the early and late periods of the crop, at least one period of data collection within the growth period of early rice can be acquired. If the duration of the growth period of winter wheat (240 days, the longest among the crops) is used for the calculation, six periods of data collection can be acquired. After removing the invalid data (e.g., cloud cover data and the data collected during the early (the sowing period), middle (the wintering period), and late periods, during which it is difficult to distinguish winter wheat from other crops), at least two periods of data collection can be acquired. Furthermore, the 16 m resolution data collected by the GF-1 satellite can be used to perform early identification of the crop area (Wang *et al.* 2015). The 16 m resolution data have a revisit cycle of 5 days. If this revisit cycle is used for the calculation, nine periods of early-period data collection of the crop can be acquired. After removing the invalid data (e.g., the data collected during the period after sowing and before sprouting, during which the crop cannot be identified, as well as the cloud cover data, etc.), two to three periods of early-period data collection of the crop can be acquired. These data are expected to be able to meet the requirements for monitoring the crop growth conditions and for performing early identification of the crop area.

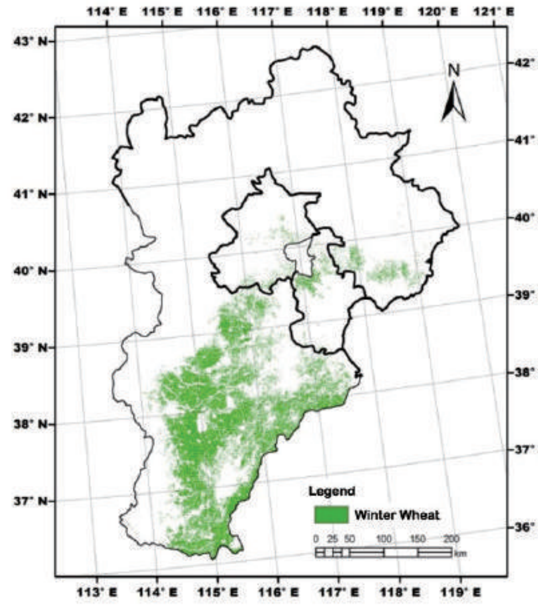

Fig. 1 Extraction of plating areas of winter wheat in Jing-Jin-Ji region in 2014 using GF-1 16 m data

2) Crop growth monitoring

Currently, the Moderate Resolution Imaging Spectroradiometer (MODIS) data are used as the data source for monitoring crop growth conditions in CHARMS (Zhou *et al*. 2005). Acquisition is conducted once every 14 days for all of China, with the spatial resolution of 250 m. A total of nine crops are routinely monitored, including winter wheat, spring wheat, summer maize, spring maize, early rice, late rice, one-season rice, soybeans, and cotton. The main shortcoming is that the monitoring period is relatively long. The correlation between the growth condition index and crop yield needs to be improved, the number of economic and sugar crops that are monitored needs to be increased, and a higher accuracy of the early crop identification needs to be achieved (Huang *et al*. 2010). It is expected that these gaps may be eliminated or mitigated when the EOS/MODIS data are replaced by the 16 m GF-1 data for crop growth monitoring. The monitoring temporal frequency can be shortened from 14 days to 10 days and the accuracy of the early identification of crops can reach 16 m, which is an obvious improvement in comparison with existing resolution of 250 m. In addition, the observation capability of growth sensitivity of different crops also increases. Consequently, the accuracy of the growth condition index and the correlation between crop growth and crop yield can be increased. With improvement of the spatial resolution and spectral sensitivity, the capacity to identify economic crops (e.g., peanuts, rapeseed, etc.,) and sugar crops (e.g., sugar cane, etc.,) is also improved, which in turn makes it possible to monitor the growth conditions of these crops.

3) Natural disasters monitoring

Several types of natural disasters including droughts, floods, accumulated snow, diseases and pests frequently occur in China's agricultural sector. Currently, the routine operational monitoring of droughts, floods and accumulated snow are in effect, but the real-time emergency monitoring services are not being conducted. The monitoring of plant diseases, pests and freezing is still in the research stage and has not been put into operation. The GF satellite can be used to partially solve the issues with disaster monitoring. The increase in spatial resolution of GF-1 visible bands is significantly useful for improving the accuracy of drought index and water bodies identification, such that the accuracy of monitoring droughts and floods can be improved. Moreover, the 16 m resolution data also helps deliver an early accurate identification of crop areas, which makes it consequently possible to perform a precise evaluation on the affected area and production loss caused by droughts and floods in small regions. For snow disasters, however, due to the lack of a 1.63 – 1.65 μm snow-sensitive channel, the snow monitoring capacity of the GF-1 satellite will not be significantly improved. It can be used to evaluate the snow-affected area over a small region. Similar to the snow disaster case, the monitoring capacity of the GF-1 satellite for plant diseases, pests, and freezing will not be significantly improved due to the lack of an accumulation of multi-year data and sensitive bands, although it will be possible to use these data to evaluate the affected area in a small region based on information on the level of impact of the disaster.

4) Crop yield estimation

Remote-sensing based crop yield estimation in CHARMS is normally conducted with two different methods: a statistical model based on vegetation indexes such as NDVI and EVI, and a mechanism model based on the photosynthetic efficiency of crops (Yang *et al*. 2008). The former method can be completely replaced by the GF-1 data, which can facilitate to obtain a good yield index that is consistent with the crop growth conditions. Nevertheless, the vegetation index-based model has a relatively poor stability and applicability when it is used to monitor crop yields in different areas at different growth times. Therefore, it is necessary to modify the model based on the time and location at which it is used to monitor the crop yield. The mechanism model based on photosynthetic efficiency needs to use remote sensing data to calculate numerous parameters such as the photosynthetically active radiation (PAR), net primary productivity (NPP), fraction of PAR (fPAR), and ratio of the dry weight of the yield to the dry weight of the crop. Although this model can best illustrate the effects of crop growth conditions on yields at different growth stages, it is only used to monitor the crop yield in some provinces and regions due to its relatively large number of parameters (Huang *et al*. 2015). As the GF-1 satellite cannot provide data for calculating the PAR due to its current spectral band settings, other satellite data has to be included. Therefore, the GF-1 satellite data can only be partially used in this crop yield model.

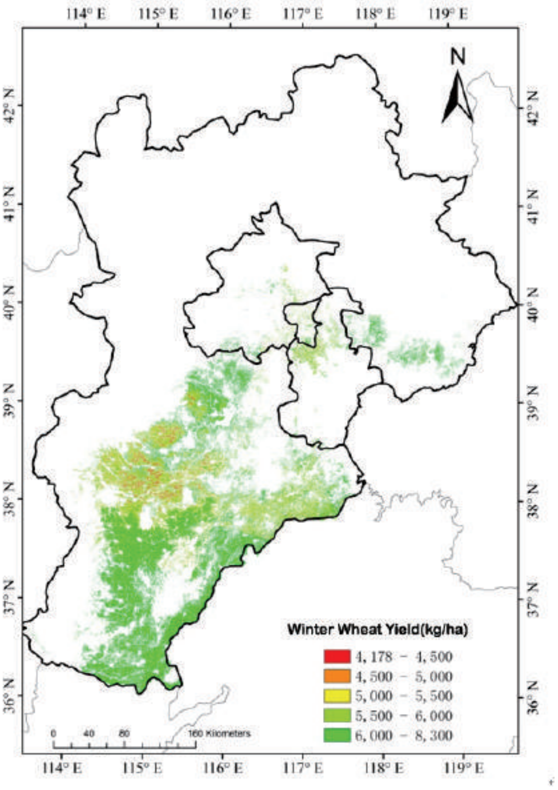

Fig. 2 Estimation of winter wheat yields in Jing-Jin-Ji region in 2014 using GF-1 16 m data

3 Conclusion

Requirements for objective information will largely increase in the future due to expected changes in the agricultural sector. Agricultural remote sensing monitoring systems should thus be able to provide timely information on crop production, growth status and yield over large areas and at low costs. Such information needs to be provided as early as possible during the growing season and updated periodically throughout the season until harvest. However, some great challenges remain to be addressed in crop monitoring by using remote sensing at regional levels. For instance, crop area extraction is the main application field of remote sensing agriculture monitoring, yet the classification methods are still to be fully investigated (Qiu *et al.* 2015; Waldner *et al.* 2015). The algorithms of agronomic parameters related to crop growth conditions and soil moisture content are still lacking, which is the research focus of the future application of remote sensing in agriculture (Potgieter *et al.* 2013). The remote sensing data, when combined with ground measurement data, can used to monitor the nutrients (nitrogen, phosphorus, potassium, etc.) in farmland soil as well as the spatial variation of crop growth conditions, which can support the management of precision agricultural production. Moreover, with the increase in spatial resolution, accurate estimation of crop yields in small areas will become an important application of remote sensing data. Remote sensing can help analyze yield gaps and monitor related agricultural practices. However, simple vegetation index (VI) -based approaches are often not sufficient as they can be used only for a specific area, and the crop growth model also contains some uncertainty in parameterization and calibration. The integration of individual models seems to be the future development trend as well as a great challenge in crop yield estimation using remote sensing data (Huang *et al*. 2015). All of these features require more in-depth and innovative studies so as to build a consolidated base for the operational monitoring systems for diverse decision making.

References

1 Atzberger C. (2013) Advances in remote sensing of agriculture: context description, existing operational monitoring systems and major information needs. *Remote Sensing*, 5,949-981.

2 Huang J, Ma H, Su W, Zhang X, Huang Y, Fan J, Wu W. (2015) Jointly Assimilating MODIS LAI and ET Products Into the SWAP Model for Winter Wheat Yield Estimation. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 8, 4060-4071.

3 Huang J, Tian L, Liang S, Ma H, Becker-Reshef I, Huang Y, Su W, Zhang X, Zhu D, Wu W. (2015) Improving winter wheat yield estimation by assimilation of the leafarea index from Landsat TM and MODIS data into the WOFOST model. *Agricultural and Forest Meteorology*, 204, 106-121.

4 Huang Q, Tang H, Zhou Q, Wu W, Wang L, Zhang L. (2010) Remote-sensing based monitoring of planting structure and growth condition of major crops in Northeast China. *Transactions of the Chinese Society of Agricultural Engineering*, 26, 218-223 (in Chinese).

5 Hu Q, Wu W, Song Q, Yu Q, Yang P, Tang H. (2015) Recent progresses in research of crop patterns mapping by using remote sensing. *Scientia Agricultura Sinica*, 48, 1900-1914 (in Chinese).

6 Liu K, Liu S, Lu Z, Song Q, Liu Y, Zhang D, Wu W. (2014) Extraction on cropping structure based high spatial resolution remote sensing data. *Chinese Journal of Agricultural Resources and Regional Planning*, 35, 21-26 (in Chinese).

7 Peng D, Huete A, Huang J, Wang F, Sun H. (2011) Detection and estimation of mixed paddy rice cropping patterns with MODIS data. *International Journal of Applied Earth Observation and Geoinformation*, 13, 13-23.

8 Potgieter A.B, Lawson K, Huete A.R. (2013) Determining crop acreage estimates for specific winter crops using shape attributes from sequential MODIS imagery. *International Journal of Applied Earth Observation and Geoinformation*, 23, 254-263.

9 Qiu B, Li W, Tang Z, Chen C, Qi W. (2015) Mapping paddy rice areas based on vegetation phenology and surfacemoisture conditions. *Ecological Indicators*, 56, 79-86.

10 Shi Y, Ji S, Shao X, Tang H, Wu W, Yang P, Zhang Y, Shibasaki R. (2014) Framework of SAGI agriculture remote sensing and its perspectives in supporting national food security. *Journal of Integrative Agriculture*, 13, 1443-1450.

11 Tang H, Wu W, Yang P, Zhou Q, Chen Z. (2010) Recent progresses in monitoring crop spatial

patterns by using remote sensing technologies. *Scientia Agricultura Sinica*, 43, 2879-2888 (in Chinese).

12 Tang H, Wu W, Yu Q, Xia T, Yang P, Li Z. (2015) Key research priorities for agricultural land system studies. *Scientia Agricultura Sinica*, 48, 900-910 (in Chinese).

13 Waldner F, Sepulcre Canto G, Defourny P. (2015) Automated annual cropland mapping using knowledge-based temporal features. *ISPRS Journal of Photogrammetry and Remote Sensing*, 110, 1-13.

14 Wang L, Liu J, Yang F, Fu C, Teng F, Gao J. (2015) Early recognition of winter wheat area based on GF-1 satellite. *Transactions of the Chinese Society of Agricultural Engineering*, 31, 194-201 (in Chinese).

15 Yang P, Wu W, Zhou Q, Zha Y. (2008) Research progress in crop yield estimation model based on spectral reflectance data. *Transactions of the Chinese Society of Agricultural Engineering*, 24, 262-268 (in Chinese).

16 Zhang G, Xiao X, Dong J, Kou W, Jin C, Qin Y, Zhou Y, Wang J, Angelo Menarguez M, Biradar C. (2015) Mapping paddy rice planting areas through time series analysis of MODIS land surface temperature and vegetation index data. *ISPRS Journal of Photogrammetry and Remote Sensing*, 106, 157-171.

17 Zhou Q, Liu J, Wang L, Deng H. (2005) Current situation and prospect analysis of the application of EOS-MODIS satellite data in Agriculture. *Journal of Library and Information Sciences in Agriculture*, 17, 202-205 (in Chinese).