RICE MONITORING IN ASIA USING SAR DATA

Thuy Le Toan
Centre d'Etudes Spatiales de la Biosphère
18 Avenue Edouard Belin, 31400 Toulouse, France
Tel : +33 5 61 55 66 71, Fax : +33 5 61 55 85 00
Thuy.Letoan@cesbio.cnes.fr

ABSTRACT

Rice is the staple food for more than half of humanity. Global rice production has increased continuously in the last half-century, since the Green Revolution. In the same period, the use of chemical inputs, the introduction of modern high-yielding varieties with short growing cycles, and the increased access to machinery and irrigation systems have led to a linear growth of the crop yields (+0.05ton/ha/year) according to the FAO (Food and Agriculture Organization of the United Nations 2009) as well as to an increase of the number of crops per year. This higher cropping intensity (from single to double or triple crop) together with the conversion of non arable land to arable land have resulted in a drastic increase of rice harvested areas in the 60s and 70s (+1.4Mha/year) which slowed down in the 80s and 90s (+0.46Mha/year) and has tended to stabilize over the last ten years as a result of approaching the limits of land use and of cropping intensity, however with a large inter-annual variability due to climatic conditions and socio-economic factors. As both the increase in yield and in planted areas will be facing limitations in the next decades, it is unlikely that rice production can keep increasing at the same rate. Meanwhile, world population, and therefore demand for food, has increased linearly over the last fifty years (+80M/year), and is projected to keep growing until around 2050 up to 9 billion inhabitants (United Nations Department of Economic and Social Affairs, Population Division 2004). This conjuncture is prone to create tensions in food markets that could lead to world food price crises - as in April 2008 when the price of rice has more than doubled in only seven months - and eventually to famines. In this context of price instability and threatened food security, tools to monitor rice production in real-time are highly needed by governments, traders and decision makers.
Accurate information is needed on the spatial distribution of rice fields, water resource management, risk occurrence and annual production projections. However, most agricultural surveys rely mainly on statistics based on limited ground samplings at which data are extrapolated on a national scale. Although the census can provide statistical estimates, the slow and unsystematic collection of data can act as a limitation for timely decision-making.
Moreover, rice agriculture is strongly involved in various environmental aspects, from water management to climate change. For this reason, a longer term inter-annual monitoring is also required in order to study the impact of the changes in rice areas and in cultural practices that are likely to occur in the next years to face the economic and environmental context.

Satellite remote sensing data offer a unique possibility to provide frequent and regional to global-scale observations of the Earth over a long period (the lifespan of a satellite is around 10 years, and satellites are launched regularly to provide continuity in the data).
Optical sensors are seriously limited by frequent cloud cover in tropical and sub-tropical areas where rice is grown in majority. A study combining agricultural census data and a large

dataset of Landsat TM imagery allowed producing maps of the distribution of rice agriculture in China at a 0.5° spatial resolution (Frolking et al. 2002). However, to achieve the coverage of such a large area with high-resolution (30m) optical images, a consequent amount of data (520 scenes) had to be collected over a period of two years, which makes the method unsuitable for the production of timely statistics or yearly results. Because of the need of a high temporal observation frequency to get enough cloud-free images, a frequent global coverage can be ensured only through the use of medium resolution (around 250m-1km) sensors, such as the MODerate resolution Imaging Spectrometer (MODIS), SPOT Vegetation, or the MEdium Resolution Imaging Spectroradiometer (MERIS). These methods have produced very valuable outputs on the spatial distribution of rice agriculture at large scale (e.g. in China and in South-East Asia using Vegetation and MODIS, cf. Xiao et al. 2002, Xiao et al. 2005, Sakamoto et al., 2006, Xiao et al. 2006). These results can be used in conjunction with information from other sensor types, in particular radar data.

Radar imaging systems, contrarily to optical sensors, have an all-weather capacity. The radar data are also well adapted to distinguish rice from other land cover types because of the specific response of the radar backscattering of inundated vegetation. The interaction between a radar electromagnetic wave and vegetation involves mainly three mechanisms: the volume scattering, the scattering from the ground attenuated by the vegetation canopy, and the multiple scattering between the volume and the ground. The last term brings a negligible contribution compared to the two others in the usual case of vegetation growing over non-flooded soils. However, in the case of flooded fields such as rice paddies, this term becomes dominant when the plants develop because of the double-bounce between the plant stems (which are the dominant scatterers in the volume) and the water surface. This has been demonstrated by theoretical models for the case of C-band co-polarized (HH or VV) backscatter at 23° incidence angle (Le Toan et al. 1997; Wang et al. 2005). This volume-ground interaction (double-bounce) is responsible for the first of the two main properties of the rice backscatter: the backscattering intensity at polarizations HH and VV show a significant increase during the vegetative phase, right after the low values of the flooding stage, and then decrease slightly during the reproductive phase until harvest. This backscatter increase in rice fields was generally observed from ERS, RADARSAT-1 or ASAR to be superior to 8 dB, and sometimes much more (Chakraborty et al. 2005; Chen et al. 2007; Kurosu et al. 1995; Shao et al. 2001). Ground-based scatterometer measurements on an experimental paddy field in Japan have shown that this high backscatter increase is observed not only at C-band but also at X-band and L-band (Inoue et al. 2002). For L-band however, other studies demonstrated that in the case of mechanically planted fields, this increase is smaller (3-4 dB) except in specific configurations of the plant rows (orientation and spacing) where resonant scattering leads to extreme backscatter increases of more than 20 dB (Rosenqvist 1999). This dependence on the plant row configuration limits the usefulness of L-band data for operational applications at wide scale.

The vertical structure of the rice plants is responsible for the second property of the rice backscatter: the vertically polarized wave is more attenuated than the horizontally polarized wave, and for that reason the ratio of the HH and VV backscatter intensities is higher than that of most other land cover classes, reaching values around 6-7dB according to a joint analysis of ERS and RADARSAT-1 data (Le Toan et al. 1997; Ribbes and Le Toan 1999) and to the modelling of C-band HH and VV (Le Toan et al. 1997; Wang et al. 2005). The same is observed at X-band (Le Toan et al. 1989).

The rice fields mapping methods based on SAR data that have been developed so far mainly rely on these two properties of rice fields. The first property (high backscatter increase during rice growing season) has been exploited in classification algorithms using the temporal change of co polarized backscatter as a classification feature, mostly at C-band, in various

Asian countries (Chen and McNairn 2006; Le Toan et al. 1997; Liew et al. 1998; Ribbes and Le Toan 1999). The second property (high HH/VV polarization ratio) has led to the development of methods using this polarization ratio as a classification feature, at C-band in Vietnam (Bouvet et al. 2009) and at X-band in Spain (Lopez-Sanchez et al. 2010). All these rice mapping schemes have proven effective but have been applied only at local scales, with high resolution (less than 50 m) data. The use of these methods and data to map rice on larger areas (regional to continental scales) would require the acquisition and processing of a dissuasive amount of high resolution data. The existence of wide-swath sensors in recent and current (ASAR, RADARSAT-2, PALSAR, RISAT-1) or forthcoming (Sentinel-1, ALOS-2) systems opens the way to the adaptation of these methods to medium-resolution (50-100m) data for the mapping of rice areas at large scale (Bouvet and Le Toan, 2011) .

In this presentation, examples of rice mapping and monitoring using radar data at different rice grown regions in Asia, such as China, Japan, Vietnam, Thailand, Indonesia will be given. The presentation will discuss on the need to adapt remote sensing methods to new cultural practices, such as direct seeding instead of transplantation (Lam Dao et al.,2009), and mid season drainage instead of continuous flooding.
We will also outline the joint use of optical and radar remote sensing data and will discuss on the need for systematic satellite data acquisition for a rice monitoring programme.

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