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Use of ENVISAT/ASAR wide-swath data for timely rice fields mapping in the Mekong River Delta

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ABSTRACT

Because of the importance of rice for the global food security and because of the role of inundated paddy fields in greenhouse gases emissions, monitoring the rice production world-wide has become a challenging issue for the coming years. Local rice mapping methods have been developed previously in many studies by using the temporal change of the backscatter from C-band synthetic aperture radar (SAR) co-polarized data. The studies indicated in particular the need of a high observation frequency. In the past, the operational use of these methods has been limited by the small coverage and the poor acquisition frequency of the available data (ERS-1/2, Radarsat-1). In this paper, the method is adapted for the first time to map rice at large scale, by using wide-swath images of the Advanced SAR (ASAR) instrument onboard ENVISAT. To increase the observation frequency, data from different satellite tracks are combined. The detection of rice fields is achieved by exploiting the high backscatter increase at the beginning of the growing cycle, which allows the production of rice maps early in the season (in the first 50 days). The method is tested in the Mekong delta in Vietnam. The mapping results are compared to existing rice maps in the An Giang province, with a good agreement (higher than 81%). The rice planted areas are retrieved from the maps and successfully validated with the official statistics available at each province ($R^2=0.92$). These results show that the method is useful for large scale early mapping of rice areas, using current and future C band wide-swath SAR data.

1. Introduction

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 (+0.05 ton/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 (+1.4 Mha/year) which slowed down in the 80s and 90s (+0.46 Mha/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 (+80 M/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.

Moreover, rice agriculture is strongly involved in various environmental aspects, from water management to climate change due to the high emissions of methane. 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.,

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2002). However, to achieve the coverage of such a large area with high-resolution (30 m) 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 250 m–1 km) sensors, such as the MODerate resolution Imaging Spectrometer (MODIS), VEGETATION, or the MEdium Resolution Imaging Spectroradiometer (MERIS). The joint analysis of time-series of vegetation and water indices derived from these sensors, such as the Normalized Difference Vegetation Index (NDVI), the Enhanced Vegetation Index (EVI), or the Normalized Difference Water Index (NDWI), also known as the Land Surface Water Index (LSWI), exhibits a specific temporal behaviour during flooding of rice paddies and transplanting of rice plants. This feature has been exploited to map the spatial distribution of rice agriculture at large scales in China using VEGETATION (Xiao et al., 2002a,b) and MODIS (Xiao et al., 2005), and in South and South-East Asia using MODIS (Xiao et al., 2006). Although these methods have produced very valuable outputs, none of them allows the retrieval of planted areas without the use of ancillary data. Indeed, because of the large number of mixed pixels at such spatial resolutions, the fractional cover of rice in each pixel classified as rice had to be estimated through the use of high-resolution Landsat TM imagery (Xiao et al., 2002b, 2005). Also, in (Xiao et al., 2006), the cropping intensity had to be derived from national agricultural statistics datasets, and the rice distribution in the Mekong River Delta was not properly reported according to the authors, probably because the flood pattern misleads the rice detection algorithm. The spatio-temporal distribution of rice phenology in the Mekong River Delta has been accurately estimated by a harmonic analysis of EVI time profiles from MODIS (Sakamoto, Nguyen, Ohno, Ishitsuka, & Yokozawa, 2006). However, this method is not able to discriminate rice from other crops or vegetation types, and a prior identification of rice fields – e.g. by existing databases – is therefore needed.

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, Manjunath, Panigrahy, Kundu, & Parihar, 2005; Chen, Lin, & Pei, 2007; Kurosu, Fujita, & Chiba, 1995; Shao et al., 2001). 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 6–7 dB according to a joint analysis of ERS and RADARSAT-1 data (Le Toan et al., 1997; Ribbes & 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, Laur, Mougin, & Lopes, 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 & McNairn, 2006; Le Toan et al., 1997; Liew et al., 1998; Ribbes & 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, Le Toan, & Lam Dao, 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 current (ASAR, RADARSAT-2, PALSAR) or future (Sentinel-1, RISAT-1) systems opens the way to the adaptation of these methods to medium-resolution (50–100 m) data for the mapping of rice areas at large scale. However, no satellite wide-swath data with dual-polarization HH and VV capability is available so far, so only the methods based on backscatter temporal change can be considered.

The present study aims at developing an operational method for the early assessment of rice planted areas using medium-resolution wide-swath single-polarization SAR imagery, by exploiting the outstanding temporal behaviour of rice backscattering. Because of the limitations of L-band in mechanically planted fields and because of the absence of wide-swath sensors operating at X-band, we choose to use C-band data. Section 2 describes the test site and the data used in the study. The mapping method is developed in Section 3. Section 4 presents the mapping results and their validation.

2. Site and data

2.1. Site description

The study site is the Mekong Delta, the major rice-producing area in Vietnam. It produces more than half of the rice in Vietnam, thus accounting for around 3% of the world production.

The Mekong Delta is a region constituted by 13 provinces in the southern tip of the country, covering around 40,000 km² (275 km from North to South, 260 km from West to East), where the Mekong River approaches and empties into the South China sea through a network of nine main distributaries. The topography is very flat, with most of the land below 5 m. Fig. 1 presents the locations and names of the 13 provinces and the topography of the area from the Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM). The climate is tropical (8.5°N–11°N in latitude), with the wet season starting in May and lasting until October–November, and the dry season from December to April. Seasonal floods occur in a large part of the area, starting in August in the upper Delta, then spreading to the lower Delta, peaking in September–October and lasting until the