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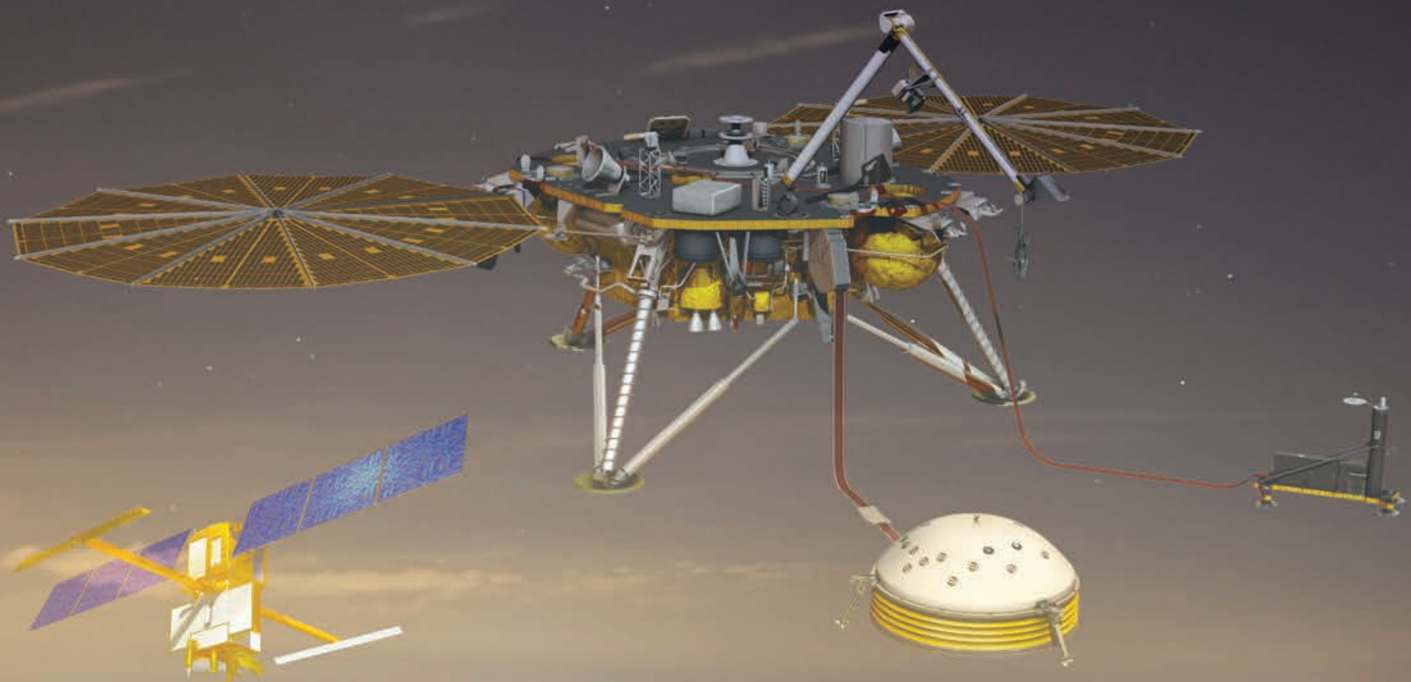

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Romain Dziegielinski

ICONOGRAPHY
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Orianne Arnould (CNES Diffusion)

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AUTHOR
A. Bégué[1], B. Bellon[1], R. Gaetano[1], V. Lebourgeois[1]
1 TETIS (Land, Environment, Remote Sensing and Spatial Information), CNRS UMR 9000, CIRAD, Maison de la télédection, 500 rue Jean-François Breton, 34093 Montpellier, Cedex 5, France

Mapping agricultural systems using satellite images

Agricultural systems are the key to understand land use in relation to sustainability, and thus, in view of the global challenges, there is an urgent need to better characterise these systems at both the regional and global scales. We present recent methodology developments for multi-scalar agricultural systems' mapping - from the cropping system to the agricultural land use system - such as multi-sensor data combination, expert knowledge-driven methods and land units stratification.

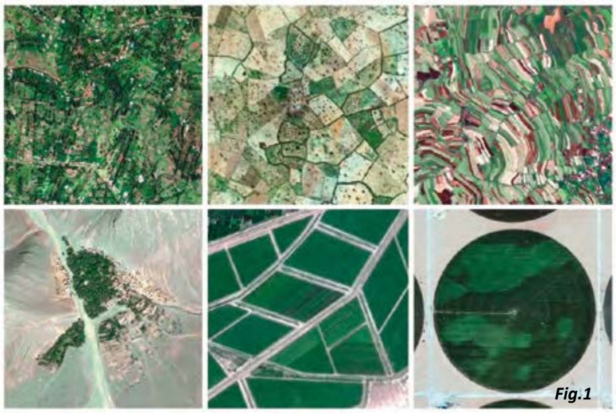
Fig.1

The necessary increase of the world's agricultural production, in response to population growth, will have to cope with climate change, increased competition for land and increasing environmental pressures. The production increase will mainly come from higher yield, but also from higher cropping intensities such as multiple cropping and/or shortening of fallow periods. The agricultural systems are the key to understand land management sustainability, and thus there is an urgent need to better characterise these systems at the regional and global scales, with a particular emphasis on the various pathways toward agricultural intensification. Earth observation data already provide insight into the direction and magnitude of the changes in area under cultivation. However, land cover mapping, with limited consideration of land management, is insufficient to draw a complete picture of coupled human-environment systems, and research must evolve from traditional land cover mapping to land use system mapping [1]. We propose here to illustrate some new methodological advances concerning multi-scalar agricultural systems' mapping, from the field (cropping system) to the agro-landscape unit (agricultural land use system).

CROPPING SYSTEM MAPPING

A cropping system refers to the crop type, sequence, and arrangement, and to the management techniques used on a given field over the years. The first descriptor of an agricultural system is thus the crop type or group. Classifications of crops at the field scale are essentially based on time series of optical or radar images, but their quality depends on the spatial and temporal resolution of the satellite data and on the type of agricultural system in place. To be able to answer to the constraints of the different agricultures of the world (illustrated in Fig. 1), multi-sensor, but also multisource approaches (e.g. satellite, environmental and socio-economic data) are needed.

In France, the national programme THEIA has led to significant advances in the processing of time series of high frequency decametric images for mapping land cover, such as the iota2 chain that produces a land cover map for France on a yearly basis, or the Random Forest classifier/object-based approach applied to multisource spatial data (e.g. decametric resolution image time series, metric resolution image, Digital Elevation Model) that produces land use maps of smallholder agricultural zones at different nomenclature levels. For example, in Madagascar where the small agricultural systems are characterised by high intra- and inter-field variability and where satellite observations are disturbed by cloudy conditions, Lebourgeois *et al.* (2017) [2] showed that classification results were improved by a hierarchical approach (cropland masking prior to classification of more detailed nomenclature levels). The spectral indices derived from the high-resolution time series were shown to be the most discriminating variable, and the very high spatial resolution image was found to be

essential for the segmentation of the area into objects, but its spectral and textural indices did not improve the classification accuracies.

Regarding cropping practices, Bégué *et al.* (2018) [3] reviewed remote sensing studies on crop succession (crop rotation and fallowing), cropping pattern (tree crop planting pattern, sequential cropping, and intercropping/agroforestry), and cropping techniques (irrigation, soil tillage, harvest and post-harvest practices, crop varieties, and agro-ecological infrastructures). They observed that most of the studies carried out exploratory research on a local scale with a high dependence on ground data, and used only one type of remote sensing sensor. Furthermore, most of the methods relied heavily on expert knowledge about local management practices and environment.

AGRICULTURAL LAND USE SYSTEM MAPPING

In response to the need for generic remote sensing tools to support large-scale agricultural monitoring, Bellon *et al.* (2017) [4] presented a new approach for regional-scale mapping of agricultural land use systems based on object-based NDVI time series analysis. The approach first obtains relatively homogeneous land units in terms of phenological patterns, by performing a principal component analysis on an annual MODIS NDVI time series, and automatically segmenting the resulting high-order principal component images. The resulting land units are then classified into cropland or rangeland based on their land-cover characteristics. Finally, the cropland units are further classified into cropping systems based on the correspondence of their NDVI temporal profiles with the phenological patterns of the cropping systems of the study area. With this approach, a map of the main agricultural land-use systems of the Brazilian state of Tocantins was produced for the 2013-2014 growing season (Fig. 2). This map shows the potential of remote sensing to provide valuable baseline spatial information for supporting large-scale land-use systems analysis.

The current spatial technologies, and particularly the SENTINEL constellation, are expected to significantly improve the monitoring of cropping practices in the challenging context of food security and better management of agro-environmental issues. However, the methods will have to cope with the variety of the agricultural systems of the world, through land stratification, multi-sensor data combination, and expert knowledge-driven methods.

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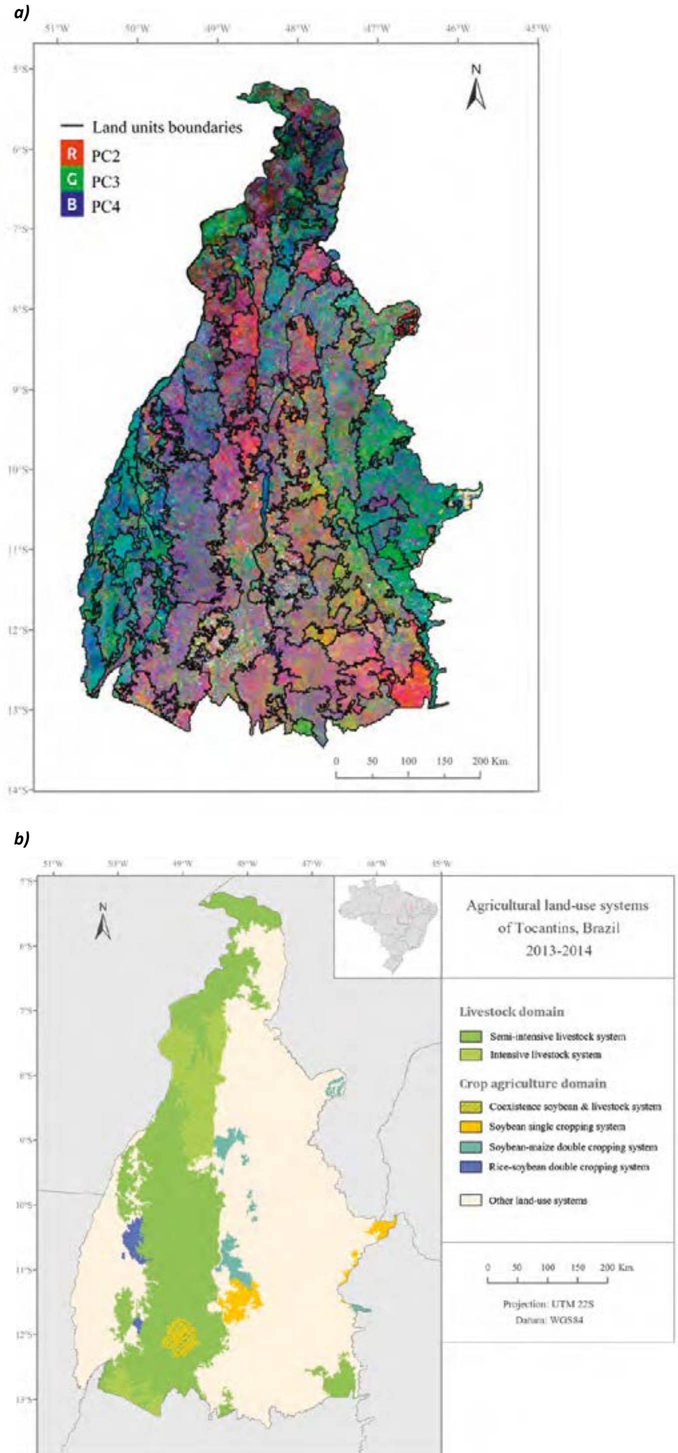

Fig.2

Fig. 1: 1 km² of agricultural land from above (Google Earth images): Top line, from left to right: agroforestry (Tanzania), rainfed annual crop (Senegal), highland rice (Madagascar); Bottom line, from left to right: oasis (Tunisia), sugarcane (Senegal), centre-pivot irrigated crop (Egypt). © *CIRAD/TETIS.*

Fig. 2: Tocantins state (Brazil) in the 2013-2014 growing season: a) land units' boundaries over a colour composition of 3 principal component (PC) images (RGB PC2, PC3, PC4) used as the segmentation variables, b) main agricultural land-use systems, established using MODIS-NDVI time series. © *After [4].*