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Can the global modeling technique be used for crop classification?

S. Mangiarotti[a,*], A.K. Sharma[a,b,c], S. Corgne[b], L. Hubert-Moy[b], L. Ruiz[d,e], M. Sekhar[c,d], Y. Kerr[a]

[a] Centre d'Études Spatiales de la Biosphère (CESBIO), UMR CNRS-UPS-CNES-IRD, Observatoire Midi-Pyrénées, 18 avenue Édouard Belin, Toulouse 31401, France
[b] UMR 6554 LETG, Université de Rennes 2-CNRS, Place du Recteur H. Le Moal, Rennes Cedex, France
[c] Department of Civil Engineering, Indian Institute of Science, Bangalore, India
[d] Indo-French Cell for Water Sciences (LMI CEFIRSE), IRD, Indian Institute of Science, Bangalore, India
[e] UMR SAS, INRA, AGROCAMPUS OUEST, Rennes 35000, France

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A B S T R A C T

Crop detection from remote sensed images is of major interest for land use and land cover mapping. Classification techniques often require multi-temporal images. However, most of these techniques assume that the cultural cycle occurs at the same dates across plots or for a given crop and do not take into account the sensitivity to initial conditions of the dynamical behaviors. Such hypotheses are not well adapted when a wide diversity of practices is observed for the same crops from one crop field to another, which is often the case in tropical context. To cope with these difficulties, a new classification technique based on the global modeling technique is introduced in this paper. It is first applied to a case study based on chaotic oscillators. It is then tested on crop classification observed from satellite data.

The Berambadi watershed (South India) is taken as a case study to test this new classification approach. Crop classification is a difficult problem in Southern India where optical satellite images are scarce during the monsoon season due to cloud cover, and where crop land is divided in parcels (i.e. crop fields) of very small sizes with diversified crops. The Landsat-8 images were used to monitor an ensemble of 104 parcels of ten different crops (irrigated and non-irrigated). Using global modeling, a bank of crop models was first obtained for the ten crops considered in the study. A metric is introduced to compare the observed signal to the obtained crop-models used as reference for each crop dynamic. Based on this metric, the possibility to use global models as references for distinguishing crops is investigated. The results provide a good proof-of-concept and show promising potential for crop classification.

1. Introduction

The estimation of crop area extents is required for numerous applications: early estimates of agricultural production, anticipating importation needs or markets reactions, mapping areas affected by climatic disasters, providing information about past and present agricultural practices, investigating future agricultural policies, etc. Satellite remote sensing can provide time series of spatially distributed information that can be used for crop classification. Most of the earliest techniques developed to classify the land surface have been based on the differences in radiometric properties of land surface and/or canopy at a given date, and were therefore limited to very contrasted classes such as forest, grassland, crops, snow, surface water, bare soils etc. (e.g. [1]).

During the last twenty years, satellite spatial resolution and time repeatability have considerably improved, up to sub-metric resolution and daily sampling. To expand upon the spectral information obtained from the sensor, new classes of techniques based on temporal signal have been introduced [2–6]. Among the numerous developments to take advantages of the temporal information for classification, a few studies have investigated the interest of the signal derivatives [7–9]. Similarly, a few works have tried to develop classification techniques that do not require knowing the detection period beforehand [10,11].

Model-based classification is another class of approach [12–14] which essential interest is to take the dynamical behavior into account in the detection process. Despite this interest, model-based approaches remain too costly in time processing to be applied to large ensembles because it requires producing a large number of models or simulations.

* Corresponding author.
E-mail addresses: sylvain.mangiarotti@ird.fr, sylvain.mangiarotti@cesbio.cnes.fr (S. Mangiarotti).

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One common problem of using time series for classification is data scarcity and data noise. To tackle these two problems, it is sometimes preferred to substitute the measured time series by a fitted analytical function such as the double sigmoid function that allows obtaining time series free of noise which simplifies the problem. This technique can be quite useful in practice, by enabling to get outputs systematically [15–19]. However, by focusing on very specific approximations of the original signal (sigmoidal form), such predefined shape also necessarily limits the differentiation between crops and may thus lessen their distinction.

Another problem of using time series for crop classification arises because, in the same region, growth and vegetative development phase of a given crop can vary both spatially and across years, due to differences in agricultural practices (sowing dates, fertilization, irrigation, etc.) soil properties or meteorological conditions (rainfall heterogeneity, floods, droughts, etc.). In most of the recent developments, the relation between the measured signal and the dynamics underlying the observed system is not taken into account in the classification process [1–11,15–19]. Moreover, most of the algorithms used for classification are based on the stochastic paradigm (e.g. [20–22]) which means that the deterministic behavior is not taken into account in the classification process, and that the variability is considered as a noise. Though, the crop dynamics can be dominantly deterministic as it was proven recently by approximating the crop dynamics by a chaotic model (that is, by deterministic equations presenting a high sensitivity to the initial conditions) which can give rise to cycles with a large range of amplitudes, and unpredictable at long time scales [23].

In the present paper, the problem of signal classification is introduced in a general way by expressing the formal link between the studied dynamical system and the measured signal itself. Considering this link, a new classification approach based on global modeling is introduced for the crop classification from single observable time series.

A statement of problem is first provided in the next Section 2 in order to clarify the objectives and the contribution of the study. The context of this paper is then presented in Section 3, with a special focus on the field and satellite data and on the ten crops considered in the study. The methodology is described in Section 4: the modeling problem is explained, the global modeling is presented; the metric used to estimate the model-observation matching is defined; and the classification technique is introduced. Results and discussions are presented in Section 5, the dynamical behaviors of the ten crops considered in the study are analyzed, the obtained crop models are presented as well as their application for crop classification; their sensitivity to noise is tested and their potential for crop classification is analysed. Complementary analyses based on chaotic oscillators were also performed to investigate the potential of the approach under fully controlled conditions; these are provided as supplementary material. Conclusions are drawn in the last Section 6.

2. Statement of problem

The main target of the present study is to introduce a new classification approach – a model-based classification independent of the initial conditions – based on the global modeling technique, and to provide a proof of concept for it. Originally, the global modeling technique was not defined for classification and a specific methodology has to be developed for this target.

The global modeling technique offers a specific interest for crop classification because it is well adapted to model non periodic dynamical systems and weakly predictable behaviors, which is the case of vegetation and crop cycles in semi-arid areas [23–26].

The interest of model-based classification techniques compared to other techniques is to take the dynamical behavior into account in the detection process. However, in practice, model-based techniques may be very time consuming, either by requiring numerous model identifications when the detection is based on model parameters comparisons, or numerous model simulations when based on the forecast error. Because crop classification problems are generally of large scales, huge amounts of data generally have to be processed. Therefore, it is necessary to develop approaches that can be light in computation.

To make this objective possible, an alternative model-based formulation is here proposed. The idea is to obtain a single model for each studied crop that should provide an optimal description of the original crop dynamic. These crop models will then be used as a reference of the crops dynamics. In order to minimize the computation time, no simulation will be performed for the detection: a metric will be introduced in order to estimate the distance directly between a given signal and the crop-models taken as a reference. The use of this metric will avoid systematic model identification and model forecasts (that is for each signal to analyze).

One reference model being necessary for each studied crop, a model search will first be applied as follows:

- An ensemble of representative cycles will be chosen in order to model the crop dynamic. These cycles should provide a good representativeness of the crop dynamic and of its variability.
- The global modeling technique will be applied to this data set in order to obtain a model for each studied crop (its algebraic formulation and its precise parameterization). Note that, to be selected, the model should be numerically integrable on a sufficiently long time, and, as far as possible, should enable the production of a large range of trajectories in order to enable the detection of all the situations that may be encountered by the same crop.

Once one reference crop model will be available for each studied crop, a metric will be required for the detection. This metric is defined as follows: each crop model is assumed to provide an optimal representation of the crop dynamics so that it can be used as a reference for the crop. To detect a crop, the distance between the observed signal and the crop reference has to be estimated. The information of the observed time series (with unknown crops) will thus be injected into the reference crop model and the residual signal will be used to estimate the distance between the observed signal and the crop (as represented by the reference crop model). This way, neither extra model identifications, nor model simulations will be necessary. Such a distance should be estimated on a time window in coherence with the crop cycle length. Based on such a metric, this distance will be very quick to estimate, and could be applied iteratively along running windows, even if a very large ensemble of time series is concerned.

To optimize the classification, the characteristic time used for each crop will be first calibrated manually (the crop cycles used to obtain the reference crop models can be used for this purpose). Once the characteristic window length is fixed for each crop, the classification can be applied to other time series (the ones corresponding to unknown crops). To do it, the distance between the observed signal and the reference crop-models has to be estimated for each crop. For a given signal, the detected crop will be the crop for which the minimum distance will be obtained.

Several assumptions are required to apply this classification technique. The first one relates to observability. The global modeling technique takes its background from the theory of nonlinear dynamical systems (or chaos theory). One important interest of this theory is to enable the reconstruction of the phase space of a dynamical system from one single observational time series [27,28]. To guaranty the full reconstruction of the phase space, the dimension m of the reconstructed dynamics has to be such as $m \geq 2D_H + 1$ with D_H the dimension of the original dynamics.