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Contribution of multispectral and multitemporal information from MODIS images to land cover classification

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Abstract

The goal of this study is to evaluate the relative usefulness of high spectral and temporal resolutions of MODIS imagery data for land cover classification. In particular, we highlight the individual and combinatorial influence of spectral and temporal components of MODIS reflectance data in land cover classification. Our study relies on an annual time series of twelve MODIS 8-days composited images (MOD09A1) monthly acquired during the year 2000, at a 500 m nominal resolution. As our aim is not to propose an operational classifier directed at thematic mapping based on the most efficient combination of reflectance inputs — which will probably change across geographical regions and with different land cover nomenclatures — we intentionally restrict our experimental framework to continental Portugal. Because our observation data stream contains highly correlated components, we need to rank the temporal and the spectral features according not only to their individual ability at separating the land cover classes, but also to their differential contribution to the existing information. To proceed, we resort to the median Mahalanobis distance as a statistical separability criterion. Once achieved this arrangement, we strive to evaluate, in a classification perspective, the gain obtained when the dimensionality of the input feature space grows. We then successively embedded the prior ranked measures into the multitemporal and multispectral training data set of a Support Vector Machines (SVM) classifier. In this way, we show that, only the inclusion of the approximately first three dates substantially increases the classification accuracy. Moreover, this multitemporal factor has a significant effect when coupled with combinations of few spectral bands, but it turns negligible as soon as the full spectral information is exploited. Regarding the multispectral factor, its beneficence on classification accuracy remains more constant, regardless of the number of dates being used.

Keywords: Statistical separability analysis; MODIS intra-annual composite data; Land cover classification; Support Vector Machines

1. Introduction

Multitemporal satellite images composites are now of standard use in land cover classification of large areas at regional and global scales (Cihlar, 2000). Considering in the one hand, that single date images may fail at discerning different land cover types that temporarily share similar spectral reflectance characteristics (Liu et al., 2003; Vieira et al., 2001); and recalling on the other hand, that most of the worldwide landmass is covered by vegetation with distinct phenologies, it is not senseless to believe that non-stationarities of images time series are valuable sources of information to get more accurate land cover maps (Knight et al., 2006). Data sets from the Advanced Very High Resolution Radiometer (AVHRR) have been used to map land cover types through monthly composites describing seasonal variations in photosynthetic activity of vegetation (DeFries & Belward, 2000). However, mainly two of the five broad spectral bands sensed by AVHRR instrument are valuable for land observation, thus being insufficient to distinguish subtle differences in vegetation types with similar annual phenologies (Borak & Strahler, 1999). Even so, land-sensing instruments that collect data at higher spectral resolutions, such as Landsat Thematic Mapper (TM), were generally not used to derive comparable regional products due to

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incomplete spatial coverage, infrequent temporal coverage with inevitable cloud contamination and the associated large data volumes not practicable in an automatic land cover classification context at such geographical scale (DeFries & Belward, 2000).

Recently launched Earth Observation (EO) sensors exhibit enhanced spectral and radiometric resolutions, wide geographical coverage and improved atmospheric corrections, while preserving a temporal resolution comparable to that of AVHRR. This is precisely the case for the Moderate Resolution Imaging Spectroradiometer (MODIS) which is at the core of our study. Regarding spectral coverage, MODIS spans a broad spectrum with a large number of narrow bandwidth channels that constitute an advantage for a large scope of tasks and circumstances (Landgrebe, 2005). In this direction, recent literature has shown that narrow bands can outperform broad bands in quantifying biophysical vegetation characteristics (Thenkabail et al., 2000). In addition, MODIS has on-board automatic positional calibrations that reduce the inherent AVHRR susceptibility to problems of misregistration in multitemporal analyses. All these new potentialities should help addressing the challenges of automatic land cover classification of wide geographical areas (Carrão et al., 2007), recalling that MODIS data already proved successful in a host of regional applications requiring fine scale cover information: mapping of irrigated areas in the Ganges and Indus river basins (Thenkabail et al., 2005), production of a landform map of North Africa (Ballantine et al., 2005), regional land cover mapping to monitor biological conservation in the Great Yellowstone Ecosystem (Wessels et al., 2004), land cover classification over the Yellow River basin, China (Matsuoka et al., 2004), to cite but a few.

However, increasing the number of spectral channels and lengthening the data time series does not necessarily mean that the quantity of effective information for land cover classification is increasing proportionally. The information gain depends on the mutual independence of the co-occurring measures, and often all the necessary structure to discriminate between land cover classes lies in a low dimensional feature space (Landgrebe, 2005). On the other hand, data sets with oversized dimension directly penalize the performances of most supervised classifiers. As the dimensionality increases with the number of spectral channels, the number of training samples for training a specific classier should be increased exponentially as well. This effect can significantly increase the classifier's sensitivity to class boundaries' precision (also referred to as "Hughes phenomenon") when the size of the training sample set can not handle the input space dimension (Ho & Basu, 2002; Jackson & Landgrebe, 2001). The consequence is that the classification accuracy first grows and then declines as the number of spectral channels increases while training samples are kept the same. Increasing the number of training sampling units, when it is possible, can overcome the "Hughes phenomenon", but then it incurs another risk which is that of over-fitting. More practically also, the computational cost of classification is generally a non-linearly increasing function of the feature space dimension. All these reasons highlight the necessity for a better organization of the information initially diluted in the original high dimensional input space, and several extraction/selection techniques, such as discriminant analysis, have been commonly used to perform a particular type of feature extraction (Landgrebe, 2005).

In this study we evaluate the relative usefulness of high spectral and temporal resolutions of MODIS imagery data for land cover classification. Our work is a methodological study to answer the fundamental question raised by the proliferation of hyperspectral and multitemporal satellite imagery: Regarding land cover classification, what is the informational content inherent to reflectance measured in different wavelengths and at different times? We also address the corollary question: Within the same context and based on our particular data set, how to combine in a certain effective way, spectral channels with acquisition dates?, where "effective way" is meant for optimizing the trade-off between land cover differentiation and feature space dimension. In the course, we were naturally led to evaluate the beneficence expected from inserting temporal diversity in a multispectral based classification framework.

To tackle these issues and to answer these questions, we followed a rigorous process in two main steps: 1) temporal and spectral data prioritization; and 2) use of land cover classification performances to assess the informational increment conveyed by additional temporal or spectral measures. We resort to a statistical separability analysis based on the Mahalanobis median distance to rank temporal and spectral features according to their individual and joint ability at separating land cover classes. Specific use of Mahalanobis distance was not crucial, and we could have defined the input features' prioritization based on classification results directly. However, as we wanted to keep the organization procedure as independent as possible from the classifier choice, simple arithmetic and geometric arguments led us to choose the median Mahalanobis distance as our ordering criterion.

To measure the capacity of each retained features combination at differentiating land cover classes, we used overall classification accuracy as an index to evaluate the relative information gained from each spectral or temporal dimension adjunction. As we deal with a finite data set, it is essential to minimize the influence of the searching space dimension onto the classifier performance, so that results only depend on the amount of added information. In other words, the benefits resulting from adding a new dimension to the feature space must not be annihilated by the classifier performance decrease due to dimension increase. Structurally, Support Vector Machines (SVM) (Vapnik, 1998) are kernel based supervised classifiers whose performances are quite unaffected by oversized dimensions of input feature spaces (Gonçalves et al., 2006; Huang et al., 2002; Marçal et al., 2005; Mercier & Lennon, 2003; Pal & Mather, 2005; Watanachaturaporn et al., 2004, 2005; Zhu & Blumberg, 2002). Inherent computational cost notwithstanding, this is the unique reason that motivated our choice of SVM for the classification task. Like this, we claim that the best classification performance should naturally be obtained with the full rank data set, and we will quote experimental results that show that indeed, the misclassification rate is constantly decreasing with the input feature space dimension.