THE POTENTIAL OF PLÉIADES IMAGERY FOR VEGETATION MAPPING: A CASE STUDY OF PLAIN AND MOUNTAINOUS OPEN ENVIRONMENTS

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Résumé

L'usage de la télédétection pour la cartographie de la végétation sur de vastes territoires tend à se généraliser avec des capteurs offrant un double compromis fauchée large - résolution métrique (Spot, RapidEye). La résolution infra-métrique de l'imagerie du capteur Pléiades ouvre de nouvelles opportunités en apportant des informations sur la structure des couverts végétaux. Dans le cadre du projet national de cartographie de la végétation de France (CarHAB), cette recherche explore les potentialités de cette imagerie et de l'analyse texturale (Haralick et SFS) pour améliorer la discrimination des habitats ligneux, herbacés et rocheux, en plaine et montagne (département de l'Isère). Des résultats prometteurs montrent le pouvoir de discrimination de variables texturales dérivées de l'imagerie Pléiades pour l'analyse de la structure de la végétation. Ils ouvrent la voie à des méthodes reproductibles de classification expertisée pour la cartographie de la végétation des milieux ouverts.

Mots-clés : *Cartographie de la végétation, physionomie de la végétation, variables texturales, imagerie THR Pléiades.*

Abstract

Nowadays the use of remote sensing for vegetation mapping over large areas is becoming progressively common, with the increase of satellites providing a good trade-off between metric spatial resolution and large swath (e.g. Spot 5, RapidEye). Infra-metric imagery of Pléiades constellation offer valuable insights on vegetation structure. In the framework of the French national project CarHAB, this research aims at exploring the potential of this imagery and associated texture features (Haralick et SFS) in order to improve the discrimination of woody and herbaceous habitats and vegetation associated to screes. The work was tested in both, plain and mountainous environments in the French Alps (Isere Department). Promising results suggested that texture features derived from Pléiades imagery have a great potential discriminating vegetation structure. In all, the approach developed opens innovative ways towards a replicable rule-based classification scheme for vegetation mapping over open environments.

Keywords: *vegetation mapping, vegetation physiognomy, texture features, VHR Pléiades imagery.*

1. Introduction

One of the most crucial phases of vegetation mapping concerns the physiognomic-ecological characterization. This time consuming identification of homogenous regions, can greatly benefit from Earth observation-based maps based on automatic classification techniques (Langanke et al., 2007; Wang et al., 2010). The use of remote sensing for vegetation mapping has becoming the object of many successful studies in the last years (e.g. Bock et al., 2005; Díaz Varela et al., 2008; Estes et al., 2010; Förster and Kleinschmit, 2008; Franke et al., 2012; Hatunen et al., 2008; Lucas et al., 2011; Nagendra and Rocchini, 2008; Spanhove et al., 2012). Even if Earth observation techniques do not allow to directly detect plant communities, they offer nowadays accurate means for pattern recognition of broad habitat categories (Turner et al., 2003). In particular, physiognomy (i.e. recovery rate of vegetation, biomass and morphology) seems to be the most discriminant parameter, using remote sensing data, to identify different types of habitats present in relatively large, spatially contiguous, units.. The resulting maps have the capacity to locate broad physiognomic types, but still well-known confusions will persist between woody, herbaceous and shrubby habitats for a same biomass level. Hence, the assessment of vegetation structure at the community level (few square meters) seems to be a significant improvement. Consequently, the sub-metric spatial resolution, as the one, provided by Pléiades, represents a promising potential for a more accurate vegetation mapping.

According to that reasoning, the assumption of this exploratory research is that vegetation mapping can be enhanced by texture analysis derived from Pléiades. Further, the originality of this research, as compared to classical supervised classification, stems from the use of a classification scheme based on an ontology implemented through replicable logical rules. Moreover, the study of many texture features provides an opportunity to identify the most relevant ones for each vegetation type.

Usually, remote sensing methods for complex vegetation mapping are indeed based on supervised classification (Bock et al., 2005; Laliberte et al., 2006; MacAlister and Mahaxay, 2009). Yet, replication capability of this type of classification is rather low. Accordingly, we support a more operational strategy that can be replicated, based on the design of a standard rule-based model of classification that closely reflects the predetermined ontology (Lucas et al., 2011). This object-based classification appears to be very well-adapted to the design of consistent rule-based models that can be implemented through a set of binary thresholds. . As described by several authors (Kim et al. 2009; Benz et al. 2004; Lang, 2008), object-based image analysis stimulates the human interpreters' ability to conceptualize vegetation classes while producing classification ontology. In addition, spectral heterogeneity of VHSR images, due to submetric spatial resolution, allows generating discriminant texture features recognition for vegetation mosaics. Texture feature refers to the tonal variation in an image (Ge et al., 2006; Ota et al., 2011; Murray et al., 2010) and may be a good proxy for vegetation structure (Wood et al., 2012). Finally, the improvement of classification accuracy by adding texture analysis has been demonstrated by numerous authors (Coburn and Roberts, 2004; Franklin et al., 2001). Kim et al. (2009; 2011) and Ota et al. (2011) have respectively demonstrated this assumption on IKONOS-2 and Quickbird imageries.

In this context, this work argues that texture features based on Pléiades imagery have a high discriminative potential. It opens new perspectives for the operationalization of detailed vegetation mapping incorporating a replicable rule-based classification approach. After presenting the operational context of this research and its general framework, the most pertinent results of texture features potentialities are analysed and discussed through perspectives of vegetation mapping.

2. Operational context

In order to illustrate how texture features can improve vegetation mapping through rule-set based classification, this research builds upon a national level initiative in France. CarHAB project aims at mapping natural and semi-natural vegetation of the French territory at a scale of 1:25 000. It addresses three major challenges based on stakeholders needs: i) provide a comprehensive inventory of vegetation and habitats, ii) assess their conservation status and iii) provide the baselines for related planning and conservation projects. Vegetation mapping relies on achieving base map learning about the physiognomic and environmental characteristics of vegetation. This base map is aiming at providing support for the extrapolation of phytosociological surveys conducted on the field before the completion of the final vegetation maps.

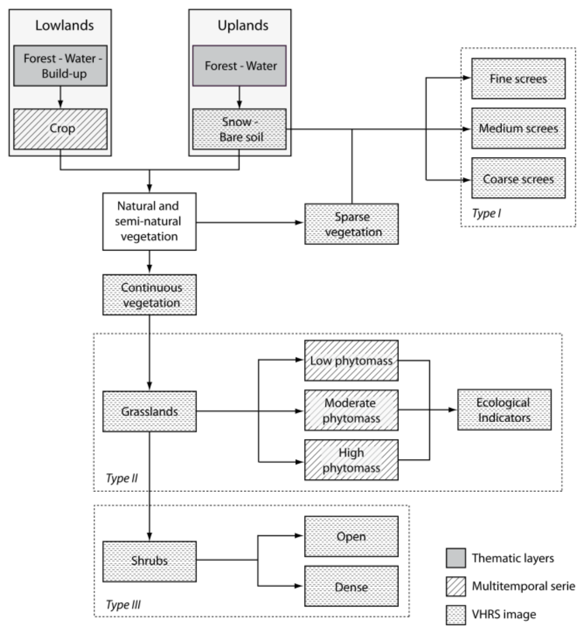

Figure 1: Ontology model of vegetation physiognomies for open environments, CarHab Project.

Classically, National Botanical Conservatories carry out the base maps of the main physiognomical-ecological types by photo-interpretation at a scale of 1:5 000 based on most recent colour infrared aerial photography (Thierion et al., under review). As mentioned hereinbefore, the creation of the base map can drastically be improved and speed up by implementing remote sensing approaches. Within the framework of CarHAB project, there is thus an ontology model of vegetation physiognomies of open environments which has been translated into a classification tree (Fig. 1). This hierarchical approach is based on the analysis of thematic layers, multitemporal series and VHRS images. The method is implemented in an object-oriented image analysis framework.

The hierarchical classification approach can be regarded as follows. Firstly, the closed forests, water bodies and buid-up areas (top of Fig. 1), are extracted from BD Forêt V.2® IGN and BD TOPO® IGN. Secondly, in open lowlands the natural and semi-natural vegetation is extracted by removing annual crops using a multitemporal analysis (i.e. detection of bare soil at least once a year) on the basis of National Alpine Botanical Conservatory (CBNA) database. At the same time, in open uplands, snow and bare soil are classified using spectral threshold. The vegetation is then divided into two types: continuous vegetation and sparse vegetation (< 50% of vegetation cover).

Given the potentialities of VHSR texture features, the capabilities of Pléiades imagery is demonstrated from that step. Three different broad physiognomic types are split into more accurate subtypes, these are usually very difficult to detect with lower spatial resolution imagery. Though Pléiades image, we found advantages in the detection of vegetation characteristics such as mineral grading (Type I), hydromorphy and trophic gradients of herbaceous cover (Type II), or shrubby cover (Type III). Sparse vegetation and bare soil were both divided into three levels of grading (Type I). Once grasslands and shrubs were discriminated, we investigated ecological indicators of grasslands cover, such as heterogeneity cover, hydromorphic gradient and agricultural impacts (i.e. mowing and grazing) (Type II). Finally, the opening degree of woody habitats was evaluated (i.e. open or close) (Type III).

In order to proof the feasibility of a rule-based classification for the discrimination of vegetation structure, we used separability measurements of texture features for each type (i.e. Type I, II and III).

3. Material and methods

3.1. Study areas and Pléiades imagery

The study sites are based on three windows located in the Isere Department nearby Grenoble (Fig. 2). Two of them correspond to lowlands while the third one is located in mountainous zone:

- The most northern window (Fig. 2.1) covers about 30 km². This area called "Bas-Dauphiné" is dominated by grasslands and cultivated lands in the fertile lower valleys while interfluves are mainly forested. The area ranges in altitude from 433 to 875 m asl.
- The middle window (Fig. 2.2) covers about 24 km². This area called "Vizille" is made up essentially of temporary grasslands and to a lesser extent

cultivated lands. The southern steep slopes are dominated by xerothermic calcareous grasslands with dynamics of forest regrowth. The area ranges in altitude from 287 to 1214 m asl.

- The most southern window (Fig. 2.3) covers about 10 km². This area called "Lac du Vallon" is a mountainous area whose altitude ranges from 1764 to 3003 m asl. It is characterised by high-diversity vegetation with communities specific to subalpine and alpine areas. The vegetation is thus dominated by alpine grasslands, moors and mineral habitats (screes).

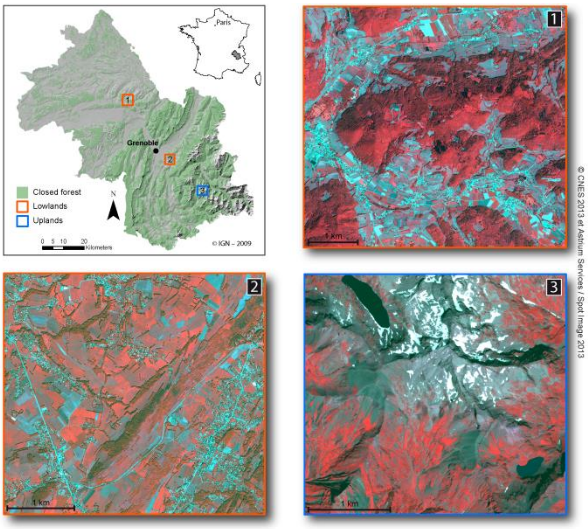

Figure 2: Location of study area windows representing open environments in Isère department (France) (orange boxes: lowlands; blue box: mountainous area).

In this study, Pléiades multispectral and panchromatic images were acquired on 12 August 2013 to be used for rule-based classification. Images provide 16-bit data and contain four multispectral bands with 2.8 m pixels (2 m after resampling) (blue: 430 - 550 nm, green: 490 - 610 nm, red: 600 - 720 nm and infrared: 750 - 950 nm), along with one panchromatic band with 0.7 m pixels (0.5 m after resampling) (480 - 830 nm). Multispectral and panchromatic imagery was geometrically corrected using ground control points extracted from BD ORTHO® IGN and the Digital Elevation Model BD Alti® IGN. The residual RMS error for the GCPs identified on the panchromatic image is around 1 pixel (0.7 m). Fig. 2 shows three false colour composites using 2 m near-infrared, red and green bands. Panchromatic Image of each window was segmented with eCognition Developer 8.9 software in order to extract texture features.

3.2. Texture features extraction

At the object level of the segmentation, mean and standard deviation of texture features were extracted based on texture analysis methods: i) Haralick (Haralick, 1979), most often referenced in the literature and ii) structural feature set (SFS) (Huang et al., 2007), originally dedicated to urban features recognition but whose visual interpretation has promising outcomes. Features were processed using the Orfeo Toolbox library (Grizonnet and Inglada, 2010). Seven local Haralick textures features were processed: Cluster Shade, Correlation, Energy, Entropy, Haralick Correlation, Inverse Difference Moment (IDM) and Inertia. These indices were calculated from grey-level co-occurrence matrix (GLCM) matrices (windows) of co-occurrences that identified pairs of pixels in an image having the same pair of gray levels according to direction and distance. The parameters used for calculation of Haralick texture features are a window size of 3 x 3 pixels for the processing neighborhood and offset distances for the co-occurrence computation of 1. These parameters have been determined by visual examination of each texture and on the basis of size of the objects to be detected (boulder, shrub, furrow, etc.).

The SFS approach consists on new statistical measures, that are efficient to extract structural features of direction lines, such as weighted mean (WM), and standard deviation (SD) which complete the previous algorithm PSI (pixel shape index). Direction lines can be defined as a series of predetermined numbers of equally spaced lines through the central pixel. The extension of direction lines is based on the neighbouring gray level similarity and the lines radiating from the central pixel in different directions. In one direction, the spectral difference is measured between a pixel and its central pixel in order to decide whether this pixel lies in the homogeneous area. For this study, the spectral and spatial thresholds have been respectively set to 50 and 100.

3.3. Sampling plots and typology

This exploratory research is not oriented to mapping particular vegetation types, but rather to assess the ability of texture features to discriminate them. The assessment of its performance is based on a set of samples for each physiognomic type.

Three broad types of vegetation (i.e. Type I, II and III) are divided into 2 pairs of physiognomic types (more structural characteristics); second pairs always refer to closer physiognomies:

- i) Type I for vegetated screes:
  - Coarse scree - Fine scree
  - Medium scree– Fine scree
- ii) Type II for grasslands:
  - Heterogeneous grassland - Homogeneous grassland
  - Sparse grassland – Heterogeneous grassland
- iii) Type III for shrubby habitats:
  - Grassland - Shrub
  - Open shrub - dense shrub

Objects issued from the segmentation of Pléiades image served as a geometric reference for sample acquisition. Mean and standard deviation of each texture feature are thus extracted for each object using eCognition. From that geographic layer, we have manually selected samples of each physiognomic type through photo-interpretation and from CBNA database. Samples of each physiognomic type are distributed over the whole of each area. As not to influence results, the number of sampling plots is equal between each physiognomic type of each pair (i.e. 35 samples for Type I and 20 samples for Types II and III). The mean area of samples is 0.28 ha.

3.4. Separability analysis

The assessment is tested using the Seath method (Separability and Threshold) developed by Nussbaum et al. (2006). For each pair of classes, this method calculates the degree of separability and the optimal binary threshold value that should be used. This method is applicable to rules' determination for object-based classification. Two physiognomic classes are compared, through a set of samples, in terms of separability according to the "Bhattacharyya distance" B (1). For better comparability, the B value is converted into "Jeffries-Matusita" distance, called J (2) which has the advantage of varying between 0 and 2. The higher the value of J (i.e. close to 2), the better the separability between the two classes is.

$$B = \frac{1}{8}(m_1 - m_2)^2 \frac{2}{\sigma_1^2+\sigma_2^2} + \frac{1}{2}\ln[\frac{\sigma_1^2+\sigma_2^2}{2\sigma_1\sigma_2}] \quad (1)$$

where m_i and σ_i are respectively the mean and standard deviation for the distribution of the variable for the two classes considered.

$$J = 2(1 - e^{-B}) \quad (2)$$

If the value of J is close to 2, then it is possible to estimate the optimal threshold that provides the best discrimination capability between the two types. This threshold is calculated using a Bayesian statistical approach solving the equation (3).

$$p(x) = p(x \backslash C_1)p(C_1) + p(x \backslash C_2)p(C_2) \quad (3)$$

This binary threshold is then used for implementing the rule of the discrimination between the two types of the pair.

4. Results

Figure 3 shows a radar chart illustrating "Jeffries – Matusita" distances for separability assessment of texture features for the 6 pairs of physiognomic types. The mean and standard deviation of texture features are respectively located on the right and on the left of the chart while SFS and Haralick features are respectively on the lower part. Globally, 60% of texture features showed very good separability (i.e. J value higher than 1.5) for at least one of the pairs. As observed in the chart, mean texture features presented a better performance than the standard deviation whilst SFS texture features outperformed Haralick values. Considering the pairs, the discrimination of coarse and fine screes had the higher number of features with very high separability - half of the features resulted on J values higher than 1.5). Following with a very good separability performance we found, "Grassland – Shrub" and "Heterogeneous grassland - Homogeneous grassland" pairs with respectively 5 and 4 features. Yet, we found more problems to discriminate closer physiognomies. Nevertheless, the pair "Open shrub - dense shrub" could be separated by 7 features with a good separability performance (i.e. between 1.0 and 1.5). The more difficult discriminations concerned, "Sparse – Heterogeneous grassland" and "Medium – Fine scree" pairs (showed few discriminant features). Each Type is separately analysed hereafter.

4.1. Type I : Screes separability

At the end, we obtained mixed results regarding scree separability performance. Whilst coarse and fine scree showed very good discrimination; few texture features allowed the discrimination of fine and medium ones. 50% texture features presented indeed a J value higher than 1.5 for the former (e.g. means of IDM or Entropy have a J value greater than 1.8), while for the latter only means of SFS features passed the threshold of 1.0 (i.e. good separability). Concerning the coarse – fine pair, mean-based features of Haralick were the most efficient and SFS textures showed a quite constant score slightly lower than 1.5. We can then argue that SFS textures are likely to better support the discrimination of fine tone details.

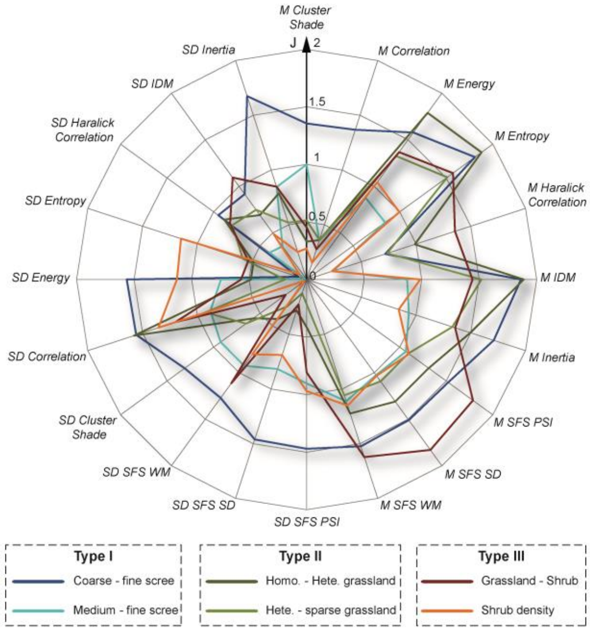

Figure 3: "Jeffries-Matusita" distance for separability assessment for 3 physiognomic types (Types I to III) (M...: mean value; SD...: standard deviation).

4.2. Type II : Grassland separability

The partition of three kind of grasslands: sparse grassland (with soil outcrops), homogenous grassland and heterogeneous grassland (with wet spots) confirms the best scores (J > 1.5) of mean texture features (M Energy, M Entropy, M IDM). As expected, J values were higher in the distinction of homogeneous and heterogeneous textures classes than in the distinction of two heterogeneous textures classes. Contrary to scree discrimination, Haralick features provided better results than SFS for the two pairs of grasslands types. On the contrary, SFS texture features presented, the same range of J values than the pair of "fine and medium scree" (i.e. J value around 1.0).

4.3. Type III : Shrub separability

Conversely, SFS texture features appear to be the best for the discrimination between grasslands and shrubs (e.g. SFS-SD, SFS PSI and SFS WM have a J value higher than 1.7). In addition, Haralick texture can also contribute providing a very good discrimination potential between these two classes (M Entropy, M IDM, M Energy). Concerning shrub density discrimination, as expected, the performance was proven to be weaker. Altogether, despite showing some problems for certain classes, Haralick texture values can provide a good contribution, for the discrimination between open and closed shrubs with a J distance > 1.35. In addition, results also showed that mean features were well adapted to discriminate between shrubby and herbaceous vegetation while standard deviation was better adapted to capture the level of variability of shrub cover.

5. Discussion

One of the most important contributions of Pléiades sensor is in the sensitivity to capture intra-plot organization of open environments thanks to its high spatial resolution. It thus becomes possible to distinguish vegetation gradients in discontinuous habitats. This better discriminates herbaceous-ligneous mosaics and helps to assess the rates of each homogeneous physiognomic type as compared to coarser spatial resolution products. Concerning our exploratory results, detection of trees and groves of trees in herbaceous formations can be used to monitor woody recolonization within a context of lower agricultural pressures. As a consequence, it allows better assessing habitat composition of forest edges comprising shelterbelts, shrub belts and herbaceous fringes. In the same way, the separability potential of grassland physiognomies contributes to better identify their nature. Xeric grasslands, located on steep slopes, are recognizable with sparse herbaceous cover while mesophilic grasslands and wet vegetations, located on flat areas and thalwegs, have a homogeneous herbaceous cover. Thus, the herbaceous cover texture gives crucial information on the topographic and trophic gradients, which greatly impact species composition. In addition, human practices, as mowing or grazing, are perceptible on Pléiades imagery thanks to specific textures (alignments, cover heterogeneities). Their detection allows improving discrimination of hayfields and pastures. Thus, we can distinguish low wet vegetation, mowed in august (acquisition date of Pleiades imagery), from high wet vegetation, unfarmed and vegetated. Finally, in the same vein, scree grading, provides consistent information on the size of stones and indirectly on the scree stability. It thus allows determining a gradient of soil depth directly correlated to the presence of various sparse vegetated habitats.

The quality of the obtained results represents a significant base for further experimentations. The robustness of statistical analyses on larger areas appears as the most critical issue to consider. The mapping of these physiognomic types on the whole of a given territory constitutes key important issues, as well as an independent statistical validation. Moreover, radiometric and topographic corrections, especially for mountainous areas, might be applied in order to better guarantee replication of the method. Still limitations exist due to the differences on spatial resolution between available digital elevation model and Pléiades imagery (25 m vs. 0.7 m). Some topographical rules (i.e. considering aspect and slope in addition to spectral thresholds) might prevent topographic correction.

Finally, this research is based on a mono-date approach while considered types vary along the growing season. The replication capability of the method, as suggested by the ontological model (Fig. 1), can also consider vegetative cycles and agricultural practices that vary according to the type of vegetation, both spatially and temporally. Thus, in addition to texture analysis, this requires the use of time series recorded at key times of the vegetative cycle in conjunction to the agricultural calendar. Future products from the Sentinel constellation piloted by ESA open possibilities for innovative applications with better capabilities as the one tested within the framework of this work.

6. Conclusion

These results suggest that texture features extracted from Pléiades imagery, particularly from the very high spatial resolution of the panchromatic band (i.e. 0.5 m), can drastically improve the recognition of some complex physiognomies, that are highly correlated to ecological indicators (i.e. trophic, hydromorphic, soil depth gradients). This research is oriented to improve the identification of best texture features for every specific type of vegetation. One interesting point is that texture features likely enable the offset of spectral resolution shortcomings. Small landscape elements (e.g. tree, boulder, etc.) can indeed be captured by Pléiades sensor. The high number of consistent "Jeffries –Matusita" distances for each pair of vegetation types, provides promising opportunities for rule-based classification and thus replicable methods as expected by CarHAB project.

Finally, the very high spatial resolution presents some operational advantages. The delineation of vegetation in key habitats is accurate as expected by users; in particular botanical conservatories. This clearly represents an exciting progress as compared to lower resolution (even 5 m) remote sensing efforts, increasing the interest and acceptance of remote sensing applications by botanists and ecologists.

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