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The potential of Pléiades imagery for vegetation mapping: an example of grasslands and pastoral 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 5, RapidEye). En témoigne le programme national CarHAB, initié en 2011 par le Ministère de l'Écologie, qui s'appuie notamment sur la télédétection pour assister les 11 Conservatoires Botaniques Nationaux dans leurs travaux de cartographie de la végétation à l'échelle nationale. L'angle physiognomique de la végétation, qui traduit la structure intrinsèque des végétations et de manière variable les pratiques agricoles auxquelles elles sont soumises, a été retenu. Afin d'affiner la précision sémantique et géométrique des types de végétation, l'usage d'une imagerie issue d'un capteur infra-métrique, tel que Pléiades, dont les potentialités visuelles et géométriques se rapprochent de celles de la photographie aérienne, apparaît prometteur. Les travaux abordés dans cette recherche s'intéressent à la cartographie physiognomique de la végétation des milieux ouverts prairiaux et pastoraux dans le département de l'Isère. Les potentialités de Pléiades sont démontrées au travers de l'analyse de la séparabilité par analyse texturale des faciès ligneux, herbacés et de la végétation associée aux éboulis.

Mots-clés : Cartographie de la végétation, physiognomie de la végétation, variables texturales, imagerie THRS 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). In France, the government launched an ambitious project to map all terrestrial habitats of the national territory. – Thus, CarHAB project uses remote sensing technology to support field work and ground observations for vegetation mapping in support to the 11 National Botanical Conservatories working on the whole of French territory. For this purpose, a physiognomic typology has been produced. This typology captures the intrinsic structure of vegetation and potentially its land use. In order to improve semantic and geometric accuracy of the vegetation cover, the use of infra-metric imagery, such as the ones provided by Pléiades constellation offer valuable insights. This imagery offers visual and geometric potentialities closed to aerial photos but with the advantage of better spectral information. Results presented in this research focus on physiognomic mapping of natural and semi-natural vegetation of pasture, grasslands and farmland areas in Isère Department in France. The potentialities of Pléiades imagery are demonstrated by evaluating

separability capabilities of textural analysis of woody and herbaceous habitats and vegetation associated to screes.

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

1. Introduction

This study is part of the national level CarHAB project on habitat mapping in France aiming at mapping natural and semi-natural vegetation of the French territory at a scale of 1:25 000. CarHAB project 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 basemap learning about the physiognomic and environmental characteristics of vegetation. This basemap aims to provide support for the extrapolation of phytosociological surveys conducted on the field before the completion of the final vegetation map. Phytosociological surveys are realized by National Botanical Conservatories working in each region.

In Isère territory, inventory and mapping of natural and semi-natural habitats by the National Alpine Botanical Conservatory (NABC) relies on specific methods based on geographic information systems (GIS) combined with vegetation surveys. This mapping approach is mainly based on the specifications for inventory and mapping of habitats and species under the Natura 2000 network initiative. The overall methodology consists of two phases:

1. A vector-stored mapping at a scale of 1:5000 based on most recent colour infrared aerial photography to carry out a preliminary map of the main types of environments (i.e. physiognomical-ecological delimitation).
2. Field work that includes visiting a maximum number of photo-interpreted polygons in order to achieve phytosociological relevés necessary to identify, inventory and characterize natural and semi-natural habitats.

The physiognomical-ecological delineation consists in identifying homogeneous colour, textural and ecological regions. In addition, a first phyto-ecological typology is built up as a prototype, based on phytosociological related bibliography and previous expert knowledge of the area. Field survey provides new geo-located vegetation points listing each species where cover-abundance values and discriminant environmental variables are recorded. This method allows improving

the pre-determined typologies based on the syntaxonomical checklist and habitat classification systems while refining habitats delineation. These syntaxa are then linked to national and European systems (i.e. CORINE Biotopes, Natura 2000 EUR 27, EUNIS).

The crucial mapping phase of CarHAB project (i.e. physiognomical-ecological delineation well-known as time consuming) can greatly benefit from Earth observation-based physiognomic maps based on automatic classification and wide-field sampling strategies (Langanke et al., 2007). The use of remote sensing for vegetation mapping has become the object of many successful studies in the last years (e.g. Bock, 2003; Bock et al., 2005; Díaz Varela et al., 2008; Estes et al., 2010; Förster et al., 2008; Franke et al., 2012; Jelaska et al., 2005; 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 species or communities, they offer nowadays accurate means for pattern recognition of broad habitat categories (Turner et al., 2003). Indeed, many species are restricted to discrete habitats such as woodland, heathland or grassland. In this sense, physiognomy (i.e. recovery rate of vegetation, biomass, variability in phenological response and morphology) seems to be the most discriminant parameter, using remote sensing data, that can clearly support the identification of different types of habitats present in relatively large, spatially contiguous, units. This exploratory research is based on the assumption that vegetation physiognomy mapping can be supported by an ontology characterized by a rule-based classification using texture features extracted from Pléiades imagery. After presenting the general framework of the study, the most pertinent results of texture features potentialities are analysed and discussed through vegetation mapping related issues.

2. Material and methods

2.1. Existing materials

Remote sensing methods for complex vegetation mapping are classically based on supervised classification trained with known spectral profiles (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 for this national effort of CarHAB project that can be replicated to a national level and extrapolated to other habitat mapping efforts in Europe, based on the design of a standard rule-based model of classification that seems more appropriate (Rapinel, 2012). Using this approach, the image analyst progressively (hierarchically) classifies the image and iteratively adjusts the rules (boolean and/or fuzzy) (Lucas et al., 2011). As a result, the classification scheme closely reflects the predetermined ontology and becomes replicable to other areas. Moreover, the object-based classification appears to be very well-adapted to the design of consistent rule-based models. As described by Kim et al. (2009) as well as Benz et al. (2004) or Lang (2008), object-based image analysis stimulates the human interpreters' ability to conceptualize while produces a classification ontology. In addition, spectral heterogeneity of VHRS images, due to submetric spatial resolution, limits the relevance of pixel-based classification (Kim et al., 2009; Lang,

2008; Mesner and Oštir, 2014; Wang et al., 2010). But this fine 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). 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 by using Gray Level Co-occurrence Matrix (GLCM) to measure texture information (Haralick, 1979). Within the framework of CarHAB project, there is an ontology model of vegetation physiognomies that has been designed for open environments. This conceptual model is based on thematic layers, multitemporal series and VHRS images. Only features derived from VHRS images are analysed (i.e. mainly texture features) within this study. Given the potentialities of VHRS texture features and first visual inspections of the imagery, the capabilities of Pléiades imagery is demonstrated through three different broad physiognomic types. We found advantages in the detection of certain vegetation characteristics such as mineral grading (Type I), hydromorphy and trophic gradients (Type II), or shrubby cover (Type III).

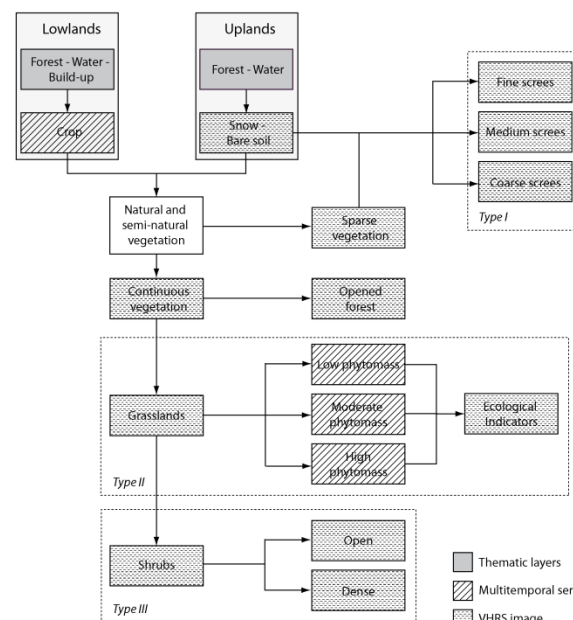


Figure 1: Ontology model of vegetation physiognomies for open environments, CarHAB Project.

The closed forests, water bodies and build-up areas (top of Figure 1), are extracted from BD Forêt V. 2® IGN and BD TOPO® IGN. Depending on the kind of open environment (lowlands and uplands), the natural and semi-natural vegetation is extracted by removing crops using a multitemporal analysis (i.e. detection of bare soil at least once a year), while snow and bare soil are classified using spectral thresholding. The vegetation is then divided into two types: continuous vegetation and sparse vegetation (< 50% of vegetation cover). Sparse vegetation and bare soil are both divided into three levels of grading (Type I). Opened forest category is extracted, in order to analyse continuous vegetation.

Once grasslands and shrubs are discriminated, grasslands are differentiated into three levels of biomass on which we investigate ecological indicators such as heterogeneity cover, hydromorphic gradient and agricultural impacts (i.e. mowing and grazing) (Type II). Finally, the opening degree of woody habitats is evaluated (i.e. open or close) (Type III). In order to proof the feasibility of a rule-based classification for the discrimination of vegetation physiognomy we used separability measurements of texture features for each type (i.e. Type I, II and III). In addition to GLCM texture features, most often referenced in the literature, Structural Feature Set textures (SFS), originally dedicated to urban features recognition (Huang *et al.*, 2007) have been computed. A visual interpretation has indeed allowed establishing promising outcomes.

2.2. Study areas and Pléiades imagery

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

- The most northern window (Fig. 2.1) covers about 30 km². This area called "Bas-Dauphiné" is dominated by grasslands and cultures in the fertile lower valleys while interfluvies 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 cultures. 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).

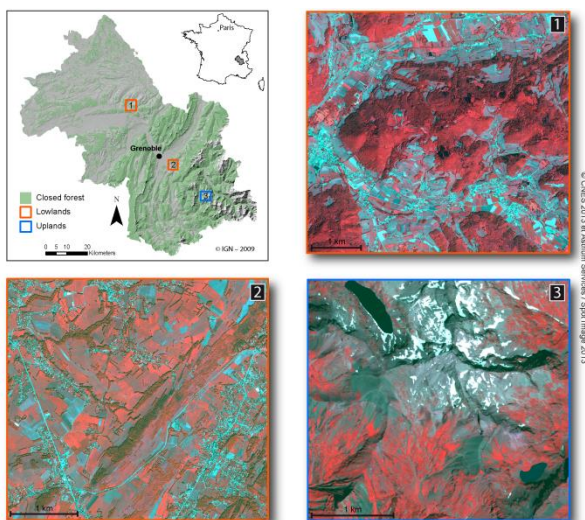


Figure 2: Location of study areas of open environments in Isère department (France) (orange boxes: lowlands; blue box: montane zone).

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 2.7 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). Fig. 2 shows three false colour composites using 2 m near-infrared, red and green bands. Images of each window were segmented and classified with eCognition Developer 8.9 software.

2.3. Texture features extraction

At the object level, mean and standard deviation of texture features were extracted from the Pléiades panchromatic band based on texture analysis methods: i) Haralick (Haralick, 1979) and ii) structural feature set (SFS) (Huang *et al.*, 2007). 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 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.

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 neighboring 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.

2.4. Separability analysis

The ability of texture features to discriminate physiognomic classes was 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 optimum 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 training objects 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.

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

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 classes. This threshold is calculated using a Bayesian statistical approach solving the equation (3); this threshold can be used for the decision rule base value.

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

3. Results

Figure 3 shows a radar chart illustrating “Jeffries – Matusita” distances for separability assessment of 3 broad types of vegetation (i.e. Type I, II and III) divided into 2 pairs of physiognomies (more ecological-oriented characteristics), second pairs refer to closer physiognomies:

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

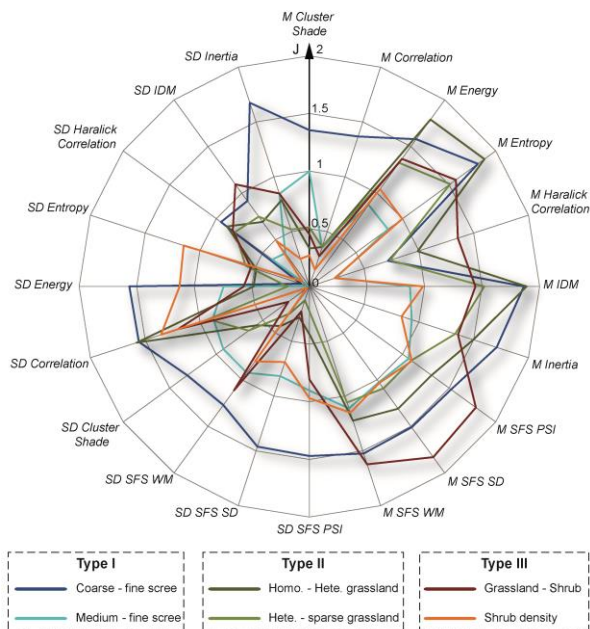


Figure 3: “Jeffries-Matusita” distance for separability assessment for 3 physiognomic types (Types I to III) (M...: mean value; SD...: standard deviation).

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 a 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.

3.1. 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 allow 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.

3.2. 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).

3.3. 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.

4. Discussion

Perhaps 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. We can distinguish their physiognomic homogeneity or heterogeneity (exclusive herbaceous cover, association of herbaceous and woody vegetation or scree grading). Plot heterogeneity perception depends on the geometry of objects extracted by segmentation. Then object-based approaches can be used to better extract heterogeneous vegetation that corresponds to habitat perception. Subsequently, it becomes possible to distinguish vegetation cover gradients in discontinuous habitats; in order to better discriminate herbaceous-ligneous mosaics and to assess the rates of each homogeneous physiognomy.

Concerning our results within this exploratory research, 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 to better assess habitat composition of forest edges comprising shelterbelts, shrub belts and herbaceous fringes. In the same way, the separation 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 to improve the discrimination of hayfields and pastures and indirectly to deepen herbaceous vegetation recognition. 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. Some of ecological indicators (e.g. trophic and hydromorphic ones), tackled in this research, can potentially be extracted from digital elevation models (DEM), depending on the position on the slope. However, a 25 m DEM resolution, as delivered in France by IGN, generates inaccuracies as compared to those extracted from Pléiades image textures.

5. 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). In this sense, this work helped to identify the best texture features for every specific type of vegetation. One interesting point is that texture features are likely enable the offset of spectral resolution shortcomings. Small landscape elements (e.g. tree, boulder, etc.) can indeed be captured by Pléiades sensor, while habitat mapping seems to be better handled by an object-based approach. 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.

In addition, the very high spatial resolution presents some operational advantages for vegetation mapping. 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 outputs, increasing the interest and acceptance of remote sensing applications by botanists and ecologists. In conclusion, the detection of small but ecologically significant habitats is generally improved (e.g. small altitudinal wet grassland habitats).

Finally, as suggested by the ontological model (Fig. 1), classification of vegetation types can be improved considering vegetative cycles and agricultural practices that vary according to the type of vegetation, both spatially and temporally. Thus, this requires the use of time series in addition to a very high spatial resolution images (i.e. Pléiades imagery), recorded at key times of the vegetative cycle in conjunction to the agricultural calendar, such as future products from the Sentinel constellation piloted by ESA.

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