Joint Retrieval of Vegetation Structure and Photosynthetic Activity from MISR

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Abstract—

This paper describes the implementation of a physical and mathematical approach to design a simple 2-dimensional algorithm dedicated to the interpretation of data collected by MISR. One dimension of information fully exploits the spectral information in the blue, red and near-infrared bands while the other dimension capitalizes on the multiangular capability of MISR to assess the anisotropic behaviour of terrestrial surfaces with respect to solar radiation. This approach delivers an estimate of the Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) that relates to the vegetation photosynthetic activity. The anisotropy shape is strongly related to the architecture of the vegetation and, under some favourable conditions, it permits revealing some type of surface heterogeneity. The proposed VEGetation Activity and Structure (VEGAS) algorithm for MISR therefore delivers two axes of information representing the FAPAR and the vegetation structure at the MISR subpixel full spatial resolution.

I. Introduction

Operational applications aiming to provide relevant and accurate information on the state of terrestrial surfaces must rely on computationally fast and efficient approaches. This objective is fulfilled by implementing optimization procedures which take into account the technical specificities of each sensors, *e.g.*, the spectral band numbers, locations, responses and widths as well as the viewing geometries. This strategy has been applied to design FAPAR retrieval algorithm for a series of single-angle multispectral sensors including SeaWiFS, MERIS, GLI and VEGETATION (see for instance [1]) . These algorithms are all equivalent in the sense that they share similar mathematical constraints and are all optimized to estimate the FAPAR. This generic methodology can be adapted to any single-angle sensor collecting BRF measurements in the blue, red and near-infrared domains, as well as to advanced sensors capable of documenting the angular field of upward radiances in these spectral domains. In the case of single-angle sensors, however, and due to the lack of instantaneous directional sampling of the BRF spectral fields, average angular effects are approximated, once for all, on the basis of the simulated training scenarios. This approximation recognizes the anisotropic behaviour of the BRF fields and implements a mean spectral anisotropic pattern assumed to be appropriate for any and all geophysical situations at global scale . Thanks to their ability to sample the spectral BRF fields at various viewing geometries, multiangle sensors permit the estimation of these anisotropic patterns on a per pixel basis. Accordingly, this specific measuring capability translates into an improved accuracy at various stages of the data analysis whenever the quality of the derived products can benefit from a reliable assessement of the angular effects.

The MISR instrument on board the Terra platform offers the capability of acquiring reflectance data on any Earth target in four spectral bands, from up to nine different directions, in at most seven minutes, at a spatial resolution of 275 m (local mode) and 1.1 km (global mode) (see [2]). It is noteworthy that the global mode acquisition also delivers, at 275 m, *i.e.*, the full spatial resolution of MISR, the nadir measurements in the four spectral bands and the nine angle measurements in the red band only. The design of a simple FAPAR algorithm for MISR can therefore take advantage of the added angular information fully available at both 275 m and 1.1 km resolution. This can easily be based on a refinement of the generic methodology summarized previously in order to release the assumption concerning the anisotropic patterns of the spectral BRF fields. Furthermore, as discussed in [3], the anisotropic pattern observed at the red wavelength can be interpreted in its own right and the parameter k_{red} of the RPV model [4] can further be used to expose the surface heterogeneity at the subpixel scale. These two axes of information about surface structure and FAPAR can then be jointly analyzed to provide enhanced information on the state of the terrestrial surfaces. For all practical purposes, both axes of information, namely FAPAR and structure, have to be retrieved optimally from each data strings collected by the instrument for every pixel and at the Top Of the Atmosphere (TOA).

The present contribution thus elaborates on the approach originally developed for single-angle observation sensor and take advantage of the MISR design to develop an advanced algorithm, the VEGetation Activity and Structure (VEGAS) algorithm for MISR.

II. The VEGetation Activity and Structure (VEGAS) algorithm

The VEGAS algorithm is designed and implemented with a series of constraints including the requirements (1) to

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compute the desired information on the basis of data from a single pass, (2) to exploit both the global and the local data acquisition modes, (3) to minimize the amount of required pre-processing by exploiting the L1B2 data (*e.g.*, fast cloud screening, no atmospheric corrections, etc ...) and (4) to minimize the computational load.

A. The FAPAR axis

The assessment of FAPAR capitalizes on the approach originally developed for single-angle observation sensors (*e.g.*, SeaWIFS, MERIS, GLI, VEGETATION) fully described in [5], [1] and [6]. As such, it exploits the multi-spectral measurements provided by MISR and implements a series of three polynomial formulae (the two first polynomial are needed to derive the so-called rectified red and near-infrared band values which are used as inputs into a third polynomial delivering the FAPAR values) which coefficients are optimized specifically for the MISR sensor. The derivation of the formulae as well as the optimization steps are based on a wide range of geophysical scenarios we generated using various radiation transfer models for the coupled surface-atmospheric medium (see [1]). The optimization is achieved using an ensemble of cost functions specifically established specifically to account for the MISR multi-spectral and multi-angular characteristics (see [7]). The unique multi-angle capability of the MISR sensor allows the estimate of the angular fields of BRFs which, in turn, translates into an improved estimate of FAPAR as compared to those derived from single-angle sensors. In both global mode acquisition at 1.1 km and in local mode at 275 m spatial resolution, the anisotropy of the BRF fields are dynamically estimated from the actual MISR measurements. In global mode acquisition at 275 m spatial resolution only, this anisotropy is approximated from model simulations at the appropriate MISR spectral bands, as done for any single-angle sensor.

B. The Structure axis

The vegetation structure is characterized using the red spectral band only through the parameter k_{red} entering the modified Minnaert function of the RPV model. The estimate of this parameter value at the surface level, namely k_{red}^{TOC} at the Top Of Canopy (TOC), from TOA measurements is achieved with a rectification procedure applied to the parameter k_{red}^{TOA}. The latter recognizes and exploits the fact that the asymmetry parameter of the RPV model, namely Θ_{red}^{TOA}, provides a signature of atmospheric turbidity. As implemented for the FAPAR axis, the appropriate polynomial formulae used to estimate the surface structure information are established with model generated geophysical scenarios and a set of cost functions accounting for the MISR technical characteristics. The parameter k_{red}^{TOC} is sensitive to the surface structure and vegetation architecture. As argued in [3] and [8], this parameter value is directly linked to the vegetation architecture and, under some favourable circumstances, its value can be used to determine the degree of surface heterogeneity at the MISR sub-pixel spatial resolution. Since the assessement of the structure axis relies only on the BRF fields measured in the red spectral band, this information is available in both global and local mode at 275 m spatial resolution.

III. VEGAS WITH AIRMISR DATA

The AirMISR instrument, extensively described in [9], was flown by the NASA ER-2 aircraft at an altitude close to 20 km, under almost cloud-free conditions, over the Konza prairie site in Kansas on July 13, 1999 around noon. This dataset permits us to test the robustness of our approach with respect to the atmospheric effects. Indeed, a surface BRF dataset was derived on the basis of the measured TOA BRF spectral fields using dedicated atmospheric correction and image matching procedures. Therefore, both BRF datasets, that is at TOA and surface levels, could be used as inputs to the series of polynomial functions we optimized to generate the estimated FAPAR axis. A perfect resistance of the FAPAR estimation with respect to atmospheric effects would thus translate into the production of quite similar FAPAR maps over the Konza prairie from these two very different datasets. Indeed, no systematic bias between these two estimates is found and a limited scatter of the distributions is observed (see [7]). This experiment illustrates and confirms that the FAPAR axis is resistant to clear sky atmospheric effects.

This AirMISR dataset was further analyzed with the help of the RPV model in order to estimate, at the pixel spatial resolution, the values of the parameter k_{red}^{TOC}. The derived map (see [3]) identifies a number of well-defined patterns which are directly related to the organization of the landscapes, *i.e.*, some of the agricultural, pasture and other lands can be easily identified on the basis of the values depicted by the k_{red}^{TOC} parameter. Some of these fields can be classified with respect to their bowl (k lower than 1.0) or bell-shape (k larger than 1.0) anisotropy pattern. A ground inspection of a number of these fields was conducted just about a year after the AirMISR data acquisition. It confirmed that the fields characterized by a bell-shaped anisotropy pattern exhibited some significant degree of heterogeneity at the scale of a few tens of meters. By contrast, a bowl-shape type of anisotropy was associated with those fields which do not exhibit strong vertical structures or large

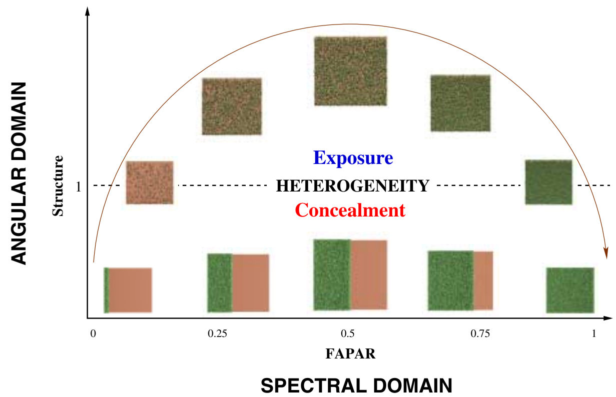

Fig. 1. Conceptual representation of the FAPAR-Structure Algorithm for MISR. The horizontal axis relates to the photosynthetic activity of the vegetation through an estimate of the FAPAR exploiting the multispectral MISR capabilities. The vertical axis represents the angular shape of the BRF measured in the red MISR band. The domains where subpixel heterogeneity is either exposed or concealed are also indicated together with a sample of panels vizualing some typical type of surface conditions.

enough spectral constrast between the vertical structure and the background at the scale of the AirMISR measurements.

IV. Concluding remarks

This study illustrates the two main advantages arising from the joint multi-angular and multi-spectral sampling: The potential to assess uniquely information about the surface structure at the subpixel resolution and the improved accuracy for the estimate of the corresponding FAPAR pixel values. The angular and spectrally derived information can be easily combined on a two-dimensional graph as illustrated in figure 1.

The various tests performed on the basis of AirMISR datasets were essential in assessing the quality of the VEGAS algorithm which is currently applied on MISR data at the Space Applications Institute of the Joint Research Centre (Italy).

The proposed FAPAR-Structure algorithm for MISR can be applied both in local mode data at full spatial resolution, *i.e.*, 275 m as well as in global mode both at full and reduced (1.1 km) spatial resolutions. The VEGAS algorithm implements a generic rectification procedure applied to data collected in the red and near-infrared MISR bands. This procedure delivers parameter values which then enter the final estimate of the two VEGAS axes, namely the surface angular signature and the FAPAR. It allows a computationally efficient estimate of the corresponding quantities and capitalizes on the MISR conceptual innovations. Its application should improve the present knowledge of vegetation characteristics at regional and global scales.

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