A SPECTRAL FITTING MODEL FOR CHLOROPHYLL FLUORESCENCE RETRIEVAL AT GLOBAL SCALE

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1. INTRODUCTION

Chlorophyll sun-induced red and far-red fluorescence retrieval from space was recently proposed as a possible candidate for monitoring the vegetation status at global scale. However, vegetation fluorescence detection is very difficult. Due to the very weak fluorescence emission signal in comparison to the reflected signal, detection is only possible by performing radiance measurements in some of the atmospheric absorption bands (O_2A and O_2B). Here solar radiation is strongly attenuated while passively induced fluorescence is minimally influenced by the energy loss in these spectral regions.

To obtain an accurate retrieval of any information in these regions it is necessary to use high spectral resolution forward modeling and fitting. A general study of the algorithm was first performed at the maximum spectral resolution of MODTRAN5 , i.e. 0.1 cm^{-1} [1]. All the efforts were then focused to determine the possibility of a still accurate fluorescence retrieval at the VIS-NIR fluorescence Imaging Spectrometer (FIS) resolution (2 cm^{-1}) of the ESA FLEX mission [2].

For fluorescence simulation we used the output file of a program (FluorSAIL) [3] which utilizes a leaf-canopy model to produce the vegetation signal.

To fit the two red and far-red fluorescence bands, two spectroscopic functions were searched that could fit simulated fluorescence with a minimum number of parameters. To properly decouple the reflected signal from fluorescence, reflectance was fitted along with fluorescence. The fitting procedure assumes a smooth reflectance spectrum which represents the unique external information available, and simulates the retrieved spectra by means of an ancillary instrument monitoring vegetation from space along with the FIS instrument. The same fluorescence and reflectance mathematical models were used to fit the simulations performed by locating the sensor at the top of atmosphere (TOA) and on ground. It is important that in both cases retrieval could be made with the same algorithm. The measurements performed on ground are useful for validation and instrument calibration.

2. FLUORESCENCE AND REFLECTANCE MATHEMATICAL MODELS

The two O_2B and O_2A spectral observation windows of FIS instrument are 20 nm wide and are nearby the red peak of the chlorophyll fluorescence band and the shoulder of the far-red one, respectively. The radiance data collected in these two separate spectral windows can be examined together if one spectral mathematical model is used for fluorescence. In fact, for monitoring at global scale, a faithful reproduction of fluorescence in the two spectral windows is required but also other information like the peak ratio between the two major emission bands would be desirable. We found that by fitting the two fluorescence bands by means of two Voigt functions (8 parameters), it is possible to reach these goals. For example, polynomials are not suitable to give this joined information, but can be used to fit fluorescence and reflectance in less extended spectral regions (e. g. 5 nm) [4].

The robustness of this choice was tested by adding a Gaussian multiplicative noise to the simulated radiance. We considered a noise with a standard deviation proportional to the signal or to its root mean square, whose value was comparable to the maximum fluorescence value. In this procedure the reflectance was fitted by means of cubic spline functions with a minimum number of 3 knots in the O_2A spectral window, and 4 knots in the O_2B, respectively, for the different reflectance variability as a function of wavelength in these two regions.

3. RETRIEVAL ALGORITHM

We first examined the case of a Lambertian surface. The sensor radiance at TOA is due to the contribution of reflected radiance and fluorescence plus the contributions of scattered radiation. A detailed description of all these contributions can be found in [5] and references there in. According to MODTRAN5, the at sensor radiance in the absence of fluorescence: TOTAL_RAD is the sum of the total diffuse radiation SOL_SCAT and the radiance coming from the reflected radiation by the target: GRND_RFL. Two runs of MODTRAN5 were used, one for each O_2 absorption band: 677nm – 697nm and 750nm – 770nm, with sensor nadir viewing and situated at 500 km above ground. Sun was at zenith angle of 30°; the aerosol were rural type, the visibility was 20 km, mid-latitude typical summer atmosphere. The outputs were obtained for the maximum MODTRAN5 resolution, i.e. $0.1cm^{-1}$. Radiance was expressed in W/cm^2-ster-cm^{-1}. For sensor at TOA, the radiance reaching the ground S that contributes to GROUND_RFL is not a direct output of MODTRAN5. Hence, the radiance reaching the ground was deduced from the two available outputs, i.e. GROUND_RFL and transmittance T as :

$$S = GROUND\_RFL / (T*R) \qquad (1)$$

where R is the reflectance of the Lambertian surface. The total radiance on the ground GROUND_RAD was then expressed by the sum of the diffusively reflected radiance plus fluorescence F as:

$$GROUND\_RAD = S*R + F \qquad (2)$$

The measured sensor radiance at TOA (SENSOR_RAD) was obtained from the convolution of the TOA radiance with the Instrumental Line Shape (ILS) of the detection instrument as:

$$SENSOR\_RAD = [GROUND\_RAD*T + SOL\_SCAT]\otimes ILS = [(S*R + F)*T + SOL\_SCAT]\otimes ILS \qquad (4)$$

A multiplicative noise is also added to SENSOR_RAD to model the behavior of the electronics. For the retrieval we used:

$$SENSOR\_RAD_m = [(S*R_m + F_m)*T + SOL\_SCAT]\otimes ILS_m \qquad (5)$$

where R_m, F_m, ILS_m are the mathematical functions used to represent the unknowns. LSQCURVEFIT is a Least Square Program of MATLAB7 that uses SENSOR_RAD and (5) to find the set of parameter values for F_m, R_m, and ILS_m by means of a best fit procedure depending on the mathematical model adopted. In the absence of measurements, F, R are the simulated files and ILS is a Gaussian function with a standard deviation of 2 cm^{-1}. For on ground measurements the direct outputs of MODTRAN5 were used. The Relative Root Mean Square Error with respect to the magnitude of the observed value and residuals were used for the evaluation of the results. The cases of non-Lambertian surfaces were also addressed by using a coupled soil-leaf-canopy and atmosphere radiative transfer modeling [5].

4. REFERENCES

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