# FluorMODgui: A Graphic User Interface for the Spectral Simulation of Leaf and Canopy Fluorescence Effects

P.J. Zarco-Tejada[1], J.R. Miller[2], R. Pedrós[3], W. Verhoef[4], and M. Berger[5]

[1] *National Research Council (IAS-CSIC), Córdoba, Spain – pzarco@ias.csic.es*
[2] *Dept. of Earth and Space Science and Eng., York University, Toronto, Canada*
[3] *Laboratoire Environnement et Développement, Universite Paris 7, Paris, France*
[4] *National Aerospace Laboratory NLR, Emmeloord, The Netherlands*
[5] *European Space Agency, ESA–ESTEC, Noordwijk zh, The Netherlands*

## Abstract

This paper reports on the status of the FluorMODgui, a Graphic User Interface (GUI) software package developed within the frame of the FluorMOD project *"Development of a Vegetation Fluorescence Canopy Model"*. The study was launched in 2002 by the European Space Agency to advance the science of vegetation fluorescence simulation through the development and integration of leaf and canopy fluorescence models based on physical methods. The FluorMODgui enables simulation of leaf and canopy reflectance with the effects of chlorophyll fluorescence, running the leaf and canopy models (dubbed FluorMODleaf and FluorSAIL) independently, as well as through a coupling scheme. Inputs for the FluoMODleaf layer are N (number of leaf layers, as in PROSPECT), $C_{ab}$ (chlorophyll a+b content), $C_w$ (water equivalent thickness), $C_m$ (dry matter content), $F_i$ (fluorescence quantum efficiency), T (temperature), S (species type), and Sto (stoichiometry). Inputs for the FluorSAIL canopy layer are: a MODTRAN4 6-parameter spectra, a soil reflectance spectra, leaf reflectance & transmittance spectra, a excitation-fluorescence response matrix (back & forward), 2 PAR-dependent coefficients for the fluorescence response to light level, solar zenith angle, viewing zenith & relative azimuth angles, canopy LAI and LIDF parameters, and a hot spot parameter. Outputs for the linked leaf-canopy fluorescence model are the leaf spectral reflectance, transmittance, and canopy reflectance with and without the fluorescence signal. Current software developments also accommodate multiple runs to simulate diurnal effects under different viewing geometries.

**Keywords:** *leaf fluorescence; canopy fluorescence; graphic user interface; reflectance*

## 1. Introduction

The FluorMOD project *"Development of a Vegetation Fluorescence Canopy Model"* was launched in 2002 by the European Space Agency (ESA) to advance the science of vegetation fluorescence simulation. The main objective of the project was the development and integration of leaf and canopy fluorescence models based on physical methods. The development of a linked leaf-canopy model to simulate the effects of natural solar-induced fluorescence on canopy-level fluorescence signal which would enable the assessment of fluorescence detection potential using near-contact, airborne and satellite-level remote sensing sensors. As a result of these efforts, the FluorMOD project (Miller, this issue) is making progress on the development of a leaf model that simulates the effects of fluorescence, FluoMODleaf (Pedrós *et al*., this issue), and a canopy level model, FluorSAIL (Verhoef, this issue), which incorporates an excitation-

fluorescence matrix computed externally by means of the leaf-level fluorescence model. The FluorMODgui Graphic User Interface (GUI) is under development as part of this project, to provide a seamless link between inputs and outputs required for running both FluoMODleaf and FluorSAIL models, to facilitate uniform user interaction, and to enable the setup of multiple runs to simulate diurnal effects under different viewing geometries. This paper provides a description of the graphic interface that will be used as a tool for leaf and canopy model validation through the use of existing and future field datasets in the context of this ESA project and the interested scientific community.

## 2. The FluorMOD Graphic User Interface

The FluorMOD Graphic User Interface is developed in Visual Studio .net framework with Visual Basic code (Microsoft, Redmond, WA, USA) compiled into an executable file to run under Microsoft Windows XP operating system. A general view of the GUI can be seen in Figure 1, showing four main parts: i) a menu area where the leaf model and canopy model can be executed, a tool for simulating leaf and canopy models in a *Diurnal and Iteration* setting; and other tools for the user such as opening the working directory where all input and output files are stored, and help buttons for the leaf and canopy models and for the GUI can be obtained; ii) a common area for the atmospheric file data input, with a text window for the name of the MEP format file, with plotting capabilities. This MEP atmospheric file is common for both the leaf and the canopy-level simulation; iii) an area for running the FluoMODleaf model, with inputs and graphic outputs; and iv) an area for running the FluorSAIL model, with inputs and outputs, enabling the user to plot the text-generated output from the canopy model runs. The FluorMODgui provides a convenient link between the leaf and canopy models,

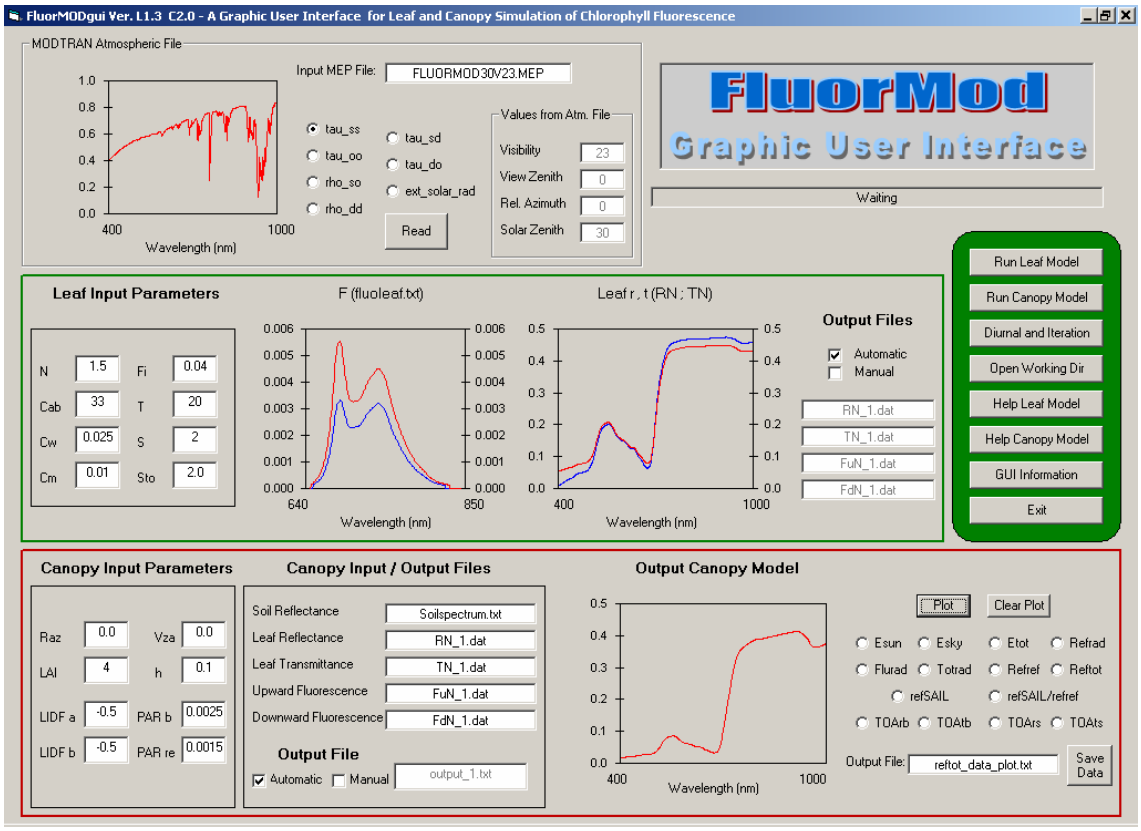

Figure 1. General view of the FluorMOD Graphic User Interface.

with proper input/output file naming and data structure. Some of the capabilities incorporated are: error handling on file opening; automatic and manual output naming system; help files provided in text form for both the leaf and canopy models; a direct link with the working directory to access output files; a *status screen* showing when the leaf or canopy model is running; disabled execution buttons when leaf or canopy models are running to prevent triggering a new run before completion; top of atmosphere (ToA) options for plotting the output results from the canopy model; diurnal simulation and multiple iteration tool allowing simulation of a diurnal setting, with different Modtran MEP files as input and selected leaf and canopy variables allowed to change. The multiple iteration tool permits the selection of a variable and generates the loop for the completion of several iterations; graphs with multiple plot capability are enabled for comparison purposes; data from multiple plots can be saved in a text file for easy comparison between different model runs; finally, a pop-up window with contact information for the leaf, canopy model and GUI authors is available.

The Atmospheric File input area (Figure 2) shows a text input window for the text file in MEP format that will be used in the simulations, enabling the graphic view of the MEP input file data. The beginning of each MEP file is a copy of the associated "so-called" .tp5 file used as input for MODTRAN4, containing the effective atmospheric parameters for visibility, and solar zenith, view zenith and relative azimuth angles.

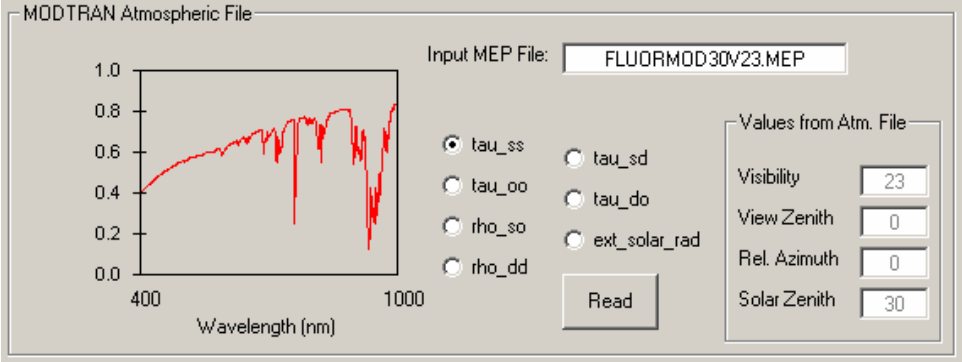


Figure 2. View of the Atmospheric File input area of the FluorMOD Graphic User Interface.

The leaf model execution (Figure 3) requires the following leaf parameters: N as the number of layers in PROSPECT; $C_{ab}$ as chlorophyll a+b content in $\mu g/cm^2$; $C_w$ as water equivalent thickness in cm; $C_m$ as dry matter content in $\mu g$; Fi as fluorescence quantum efficiency; T as temperature in degrees Celsius in the range [0, 26]; S as species temperature dependence (after Agati, 1998), with 1=broad bean; 2=bean; 3=ficus; 4=tomato; and 5=pea; Sto as stoichiometry of PSII to PSI reaction centers, which depends on species and on light conditions, with high light Sto~2 and low light Sto~1.1.

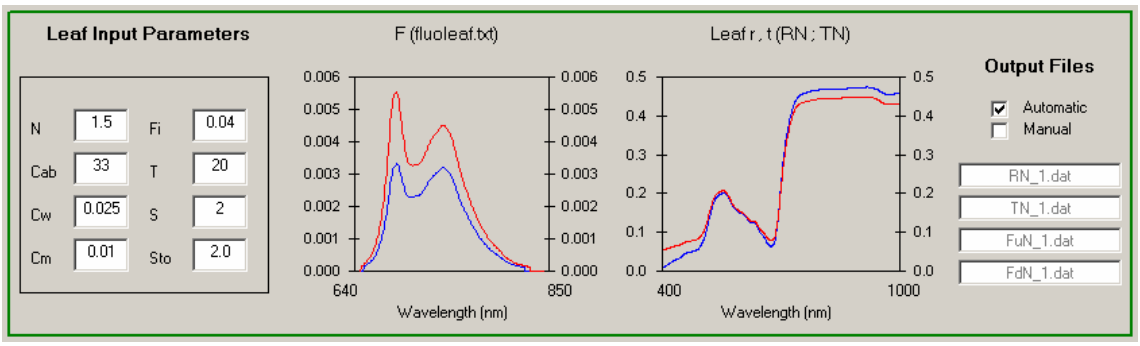


Figure 3. View of the Leaf Model area of the FluorMOD Graphic User Interface.

The outputs for the leaf model execution are text files: RN.dat, containing the leaf reflectance in the [400, 1000] nm range (601 rows); TN.dat, containing the leaf transmittance in the [400, 1000] nm range (601 rows); and two matrices, FuN.dat and FdN.dat, containing the upward and downward fluorescence matrix with dimensions 351 x 211, corresponding to excitation wavelengths in the 400-750 nm range (351 rows) and fluorescence emission in the 640-850 nm range (211 columns). Such output files are plotted in the leaf model area of the GUI, enabling an automatic or manual naming for the leaf files generated.

The canopy-level model execution area (Figure 4) requires the viewing zenith angle; the solar zenith angle, taken from the MEP file; the viewing azimuth angle; the canopy leaf area index; the leaf inclination distribution function (LIDF) parameters, *a* and *b*; the hot spot parameter; and the PAR-dependence parameters *bP* and *re*. Input files required are the atmospheric MODTRAN4 MEP file; the soil spectrum file; and the four output files from the leaf model which are automatic inputs for the canopy model, such as: the leaf reflectance file; leaf transmittance file; and the upward and downward fluorescence matrices mentioned previously. An output file name with the simulation results is automatically created to enable multiple runs creating different output names, or manually named by the user. The output simulation file contains the solar irradiance in $Wm^{-2}\mu m^{-1}$ (Esun); sky irradiance in $Wm^{-2}\mu m^{-1}$ (Esky); total irradiance in $Wm^{-2}\mu m^{-1}$ (Etot); reference (= without fluorescence) radiance in $Wm^{-2}\mu m^{-1}sr^{-1}$ (refrad); fluorescence radiance in $Wm^{-2}\mu m^{-1}sr^{-1}$ (flurad); total radiance in $Wm^{-2}\mu m^{-1}sr^{-1}$ (totrad); reference reflectance factor (refref); total reflectance factor (including fluorescence) (reftot); reference reflectance factor according to SAIL model (Verhoef, 1984) (refSAIL); ratio SAIL/FluorSAIL for reference reflectance factor (refSAIL/refref); reference top-of-atmosphere radiance for bare soil surroundings in $Wm^{-2}\mu m^{-1}sr^{-1}$ (TOAref_bare); total top-of-atmosphere radiance for bare soil surroundings in $Wm^{-2}\mu m^{-1}sr^{-1}$ (TOAtot_bare); reference top-of-atmosphere radiance for surroundings same as target in $Wm^{-2}\mu m^{-1}sr^{-1}$ (TOAref_same); and total top-of-atmosphere radiance for surroundings same as target in $Wm^{-2}\mu^{-1}sr^{-1}$ (TOAtot_same).

The canopy model area of the Graphic User Interface enables plotting any of these output simulation results, enabling the overlay of several model runs into the same canopy output chart. The data from a single or multiple run for any selected output variable can be saved into a text file that can easily be loaded into spreadsheet software for further data analysis. The output canopy simulation chart plot can be cleared at any time to start a new series of runs, also clearing the output text file created with the simulation results.

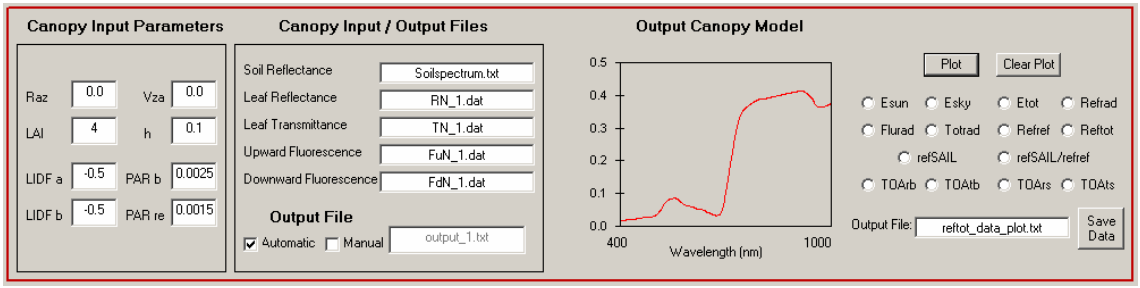

Figure 4. View of the Canopy Model area of the FluorMOD Graphic User Interface.

## 3. Diurnal and Multiple Iteration Tool

Two objectives adopted by the team for validation functionality with the FluorMOD Graphic User Interface were: i) to facilitate a diurnal simulation by automatically changing the input parameters at both leaf and canopy levels; and ii) to accommodate the execution of multiple runs for an input variable at specified steps. These two objectives are facilitated by the *Diurnal and Multiple Iteration Tool* built as a pop-up window that the user can execute from the main menu (Figure 5). The inputs that the user can modify in the diurnal setup are the atmospheric MEP file; leaf-level model variables such as Temperature (T) and the fluorescence quantum efficiency (Fi); canopy-level variables such as relative azimuth and view zenith angles; and the PAR dependence parameters *b* and *re*. Any of these input variables can be set to a fixed value, or ramped up or down as function of a diurnal variation.

The multiple iteration tool enables the selection of a leaf or canopy variable and set the start, end and step increment for the multiple simulation. The multiple run and diurnal execution are started by first clearing the output plot, or overlaying new output simulation data to the plot. The multiple simulation tool provides the user with information regarding the number of runs to complete as function of the start, end and step increments for the given variable, showing the runs left to complete the series of simulations during execution time. The execution process for both the diurnal and multiple iteration can be cancelled at any time by the user.

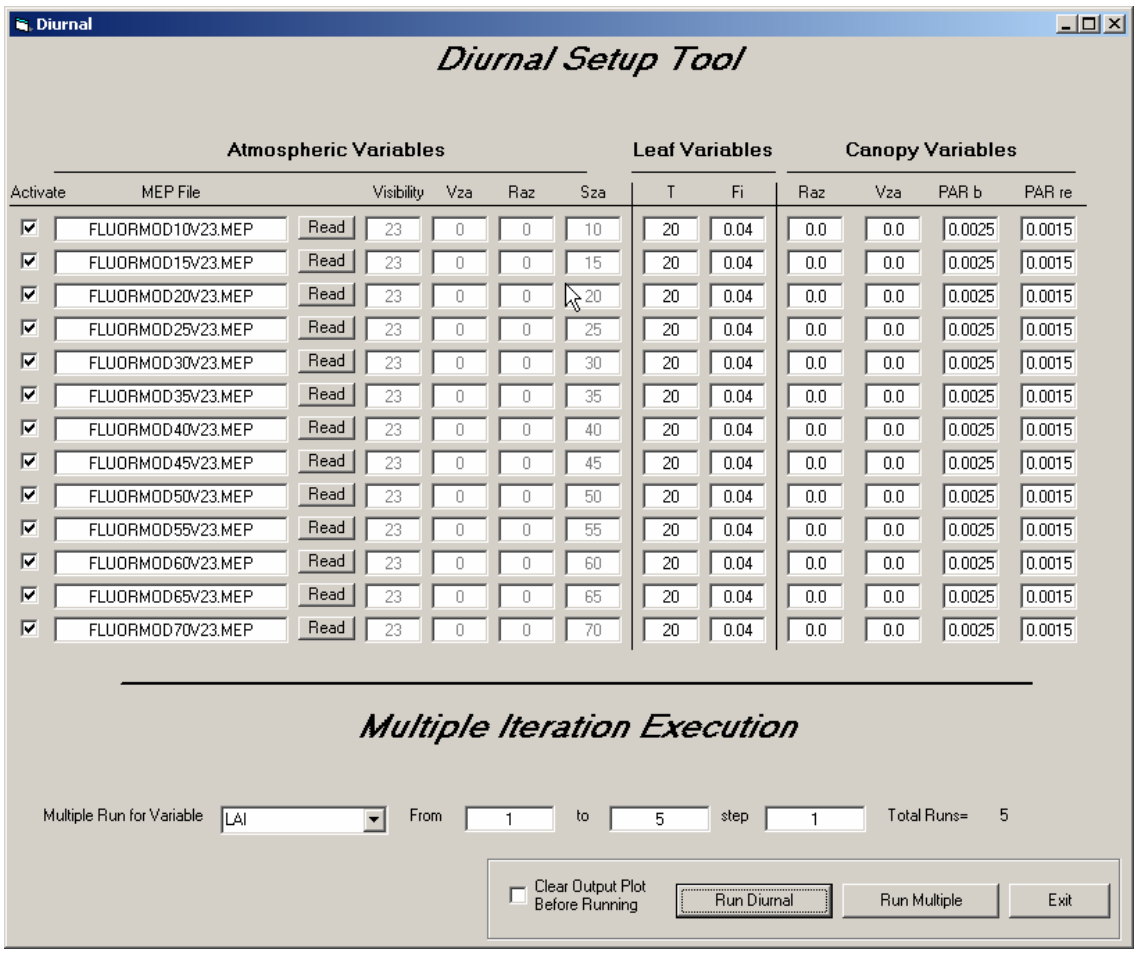

Figure 5. View of the Diurnal Setup and Multiple Iteration Execution Tools of FluorMODgui.

## 4. Simulation Results

Different examples of the FluorMOD Graphic User Interface are shown in this section. Figure 6 shows the simulation results at the leaf level for the fluorescence emission spectra for two levels of $C_{ab}$ (20 and 60 µg/cm$^2$) and quantum fluorescence efficency extreme values Fi=0.04 and Fi=0.5. The simulated leaf emission spectra are then used as input to the canopy model. Figure 7 shows the canopy reflectance simulation results for $C_{ab}$ ranging from 20 to 70 µg/cm$^2$ and Fi ranging between 0.04 and 0.9 as modelled by FluoMODleaf linked to FluorSAIL using the FluorMODgui. Spectral differences in the canopy reflectance can be detected in the red edge due to the fluorescence effects as function of a varying fluorescence quantum efficiency. An emission peak at 761 nm can be detected due to the fluorescence *in-filling* at the oxygen band.

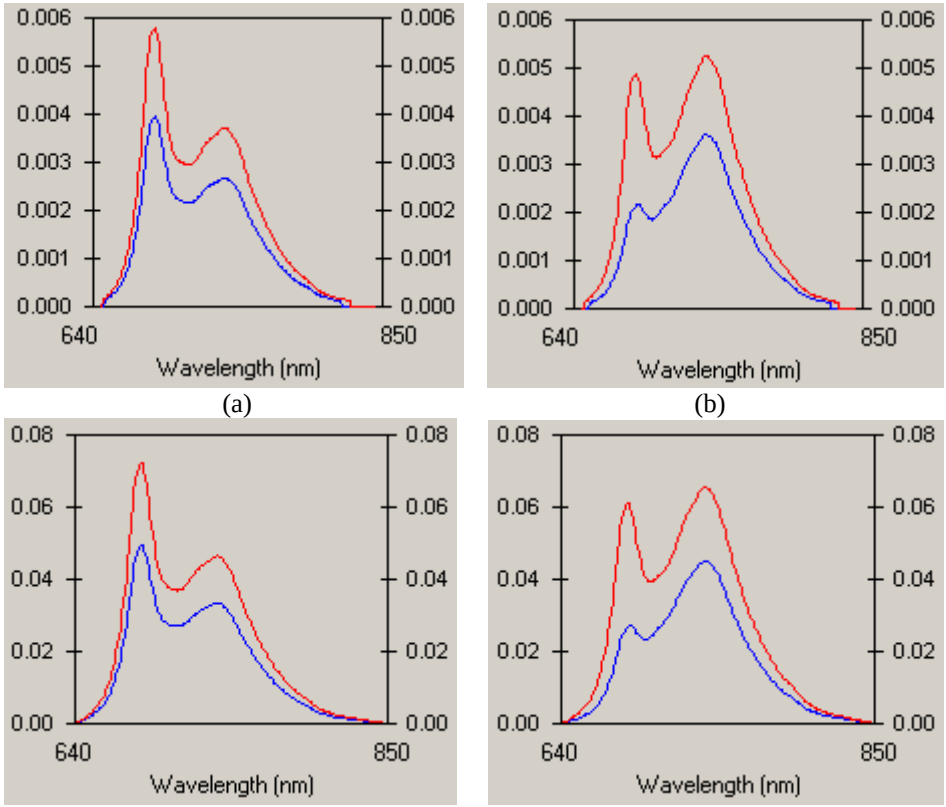


Figure 6. Simulation results for the fluorescence emission spectra for $C_{ab}$=20µg/cm$^2$ (a, c) and $C_{ab}$=60µg/cm$^2$ (b, d) for Fi=0.04 (a,b) and Fi=0.5 (c,d) using FluorMODgui.

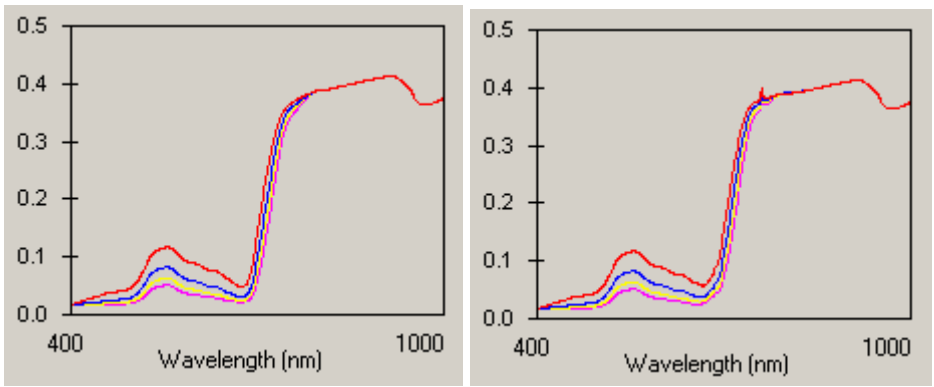


Figure 7. Canopy reflectance simulation results for $C_{ab}$ ranging from 20 to 70 µg/cm$^2$ and Fi=0.04 (left) and Fi=0.9 (right) using FluorMODgui.

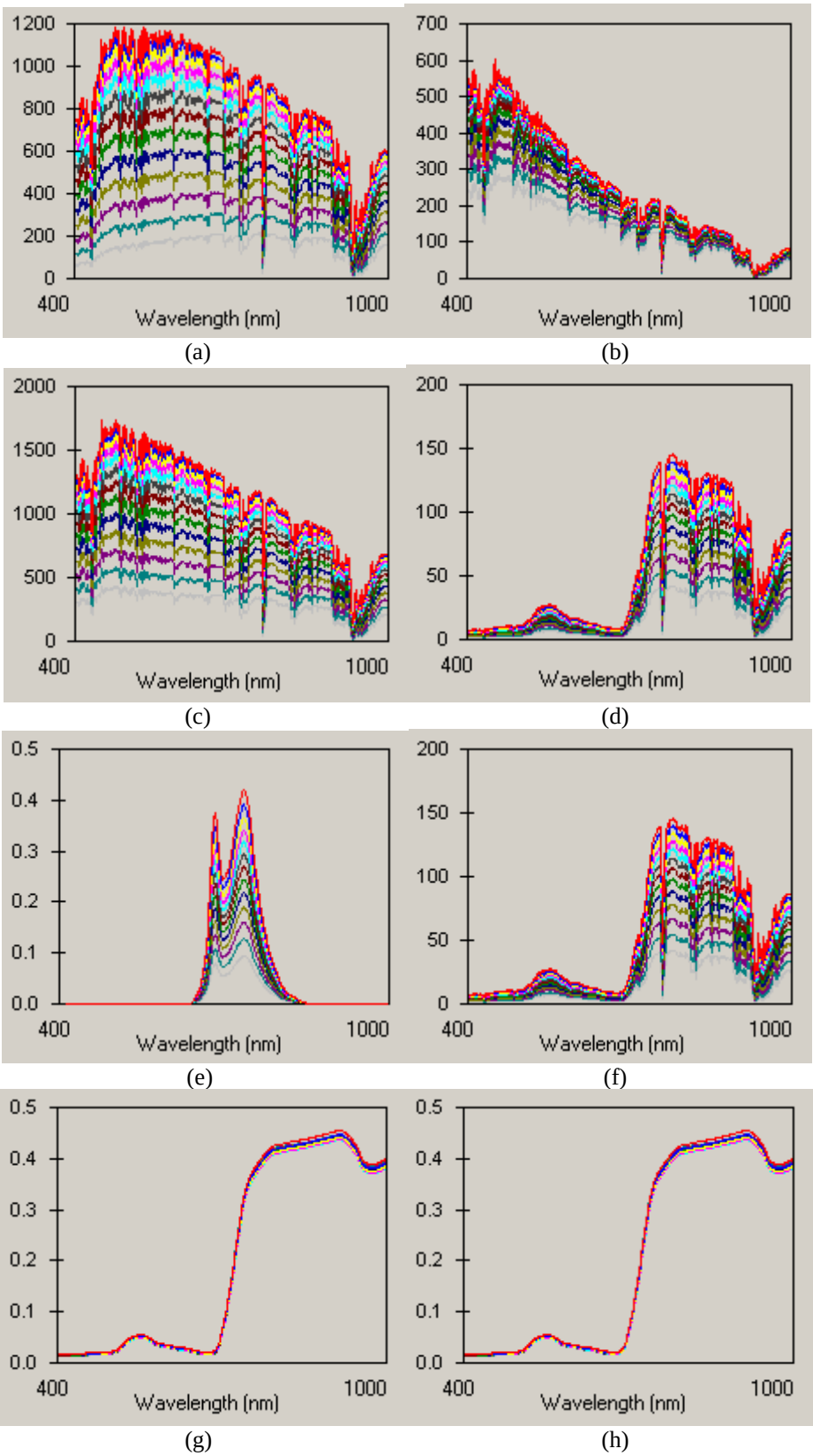


Figure 8. Diurnal simulation for a solar zenith angle ranging from 10º to 70º using FluorMODgui for solar irradiance (a); sky irradiance (b); total irradiance (c); radiance without fluorescence (d); fluorescence radiance (e); total radiance (f); reference reflectance (g); and total reflectance including fluorescence (h).

An example of the diurnal simulation using the FluorMOD diurnal simulation tool can be seen in Figure 8. The diurnal simulation was setup for a solar zenith angle ranging from 10º to 70º, showing the simulation for solar irradiance (a); sky irradiance (b); total irradiance (c); radiance without fluorescence (d); fluorescence radiance (e); total radiance (f); reference reflectance (g); and total reflectance including fluorescence (h).

## 5. Conclusions

A Graphic User Interface developed within the frame of the FluorMOD project *"Development of a Vegetation Fluorescence Canopy Model"* funded by the European Space Agency was presented. The FluorMODgui enables simulation of leaf and canopy reflectance with the effects of chlorophyll fluorescence, running the leaf and canopy models FluorMODleaf and FluorSAIL independently and through a coupling scheme. The Graphic User Interface facilitates multiple runs with varying leaf and canopy variables, generating the model results in plots and enabling the output data to be saved in text files for further analysis. A diurnal and multiple iteration tool is presented which facilitates the user's simulation of the diurnal effects of fluorescence as function of variables that change in a diurnal setting. It is expected that the FluorMODgui interface will be used as a tool for leaf and canopy model validation through the use of existing and future field datasets under the frame of this ESA project and for the interested scientific community.

**Acknowledgements**

The development of the FluorMODgui interface has been carried out in the frame of the ESA-project *Development of a Vegetation Fluorescence Canopy Model*, ESTEC contract no. 16365/02/NL/FF. Within the same project, the leaf and canopy fluorescence models FluorMODleaf and FluorSAIL were developed and provided by R. Pedrós and S. Jacquemoud of LED, University of Paris, I. Moya, Y. Goulas and J. Louis of LURE, University of Paris-South, and Wout Verhoef, National Aerospace Laboratory NLR.

## References

Agati G. (1998), Response of the in vivo chlorophyll fluorescence spectrum to environmental factors and laser excitation wavelength, Pure Appl. Opt. 7, 797-807.

Miller, J., Overview of FluorMOD: A Project to Develop an Integrated Leaf-Canopy Fluorescence Simulation Model, 2nd International Workshop on Remote Sensing of Vegetation Fluorescence, 17-19 Nov. 2004, Montreal, Canada.

Pedrós, R., S. Jacquemoud, Y. Goulas, J. Louis, I. Moya, A new leaf fluorescence model, 2nd International Workshop on Remote Sensing of Vegetation Fluorescence, 17-19 Nov. 2004, Montreal, Canada.

Verhoef, W. (1984), Light scattering by leaf layers with application to canopy reflectance modeling: The SAIL model. *Remote Sensing of the Environment* 16: 125-141.

Verhoef, W., Extension of SAIL to model solar-induced canopy fluorescence spectra, 2nd International Workshop on Remote Sensing of Vegetation Fluorescence, 17-19 Nov. 2004, Montreal, Canada.