The Enea Lidar Fluorosensor: Results on Vegetation Health

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ABSTRACT

The ENEA excimer laser based lidar fluorosensor operating from a mobile station has been used to detect spectral and time resolved LIF signals from vegetation. Some results obtained during joint LASFLEUR field campaigns are presented.

1. INTRODUCTION

The ENEA group, who built at Frascati a lidar fluorosensor for land and sea surveying [1], joined by November 1990 the EUREKA/LASFLEUR Project, which is aimed at investigating the feasibilitity of remotely monitoring the vegetation (forests, cultivations, etc.) health by fluorescence lidar techniques, with the final goal of designing an airborne system for field surveillance. The ENEA participation has been addressed mainly to check the lidar field performances, taking advantage of its spectral and time resolved capabilities to analyze the laser induced fluorescence (LIF) from vegetation.

Laboratory activities at ENEA have been carried out [2] to test the lidar fluorosensor capabilities of remotely sensing LIF emission by plants at distances of a few hundred m. Joint measurement campaigns with other European groups have been held (Viterbo (I), 1991 [3] and Oberpfaffenhofen (D), 1992 [4]) with the main goal of establishing relationships between LIF remotely sensed data and plant physiology. In this paper, we present some of the results obtained by our group during these campaigns.

Lidar echoes have been acquired under a variety of weather conditions from plants with different degrees of stress. Chemical analysis by plant physiologists on some of the investigated samples have been carried out to seek for correlations between LIF data and pigments contents and activities.

The maximum useful range of our lidar fluorosensor, when remotely measuring LIF spectra from vegetation, has been found to lie around 100 m.

2. EXPERIMENTAL ARRANGEMENT AND DATA REDUCTION

The ENEA lidar fluorosensor [1-3] has been designed to measure both LIF spectra and decay times in selected spectral regions from the investigated targets. Prior to the 1992 campaign [4], the system (Fig. 1) has been upgraded to become more suitable to remote sensing of vegetation, by acting mainly upon the laser transmitter and the detection configuration.

An optional Raman shifter has been added to the transmitter line, which provides a few mJ pulses at various emission wavelenghts in the "eye-safe" blue-green region. The Raman shifted emission, usually the second Stokes generated in CH_4 or D_2, is first wavelenght selected by a Pellin-Broca prism and then recollimated by means of a beam expander. Although some data have been gathered on field at Raman shifted frequencies, we will limit here to report on measurements with 308 nm, 100 mJ, 20 ns, 2 Hz repetition rate exciting excimer laser pulses.

A biaxial transmitter-receiver geometry has been adopted for field measurements. The excimer laser divergence (full angles: hor.=0.8 mrad; Vert.=0.4 mrad) ensures the produced LIF radiation to fall within the field of view of the receiving Newtonian telescope, which focusses it onto a glass fiber optic bundle (2 m long, 3.2 mm dia. at entrance) after passing suitable optical filters. By bifurcating in two halves, the bundle contemporarily routes the collected radiation both to the Optical Multichannel Analyzer (EG&G-OMA III, 1024 channels), and to the Streak Camera (Hamamatsu, 512 channels). Each half-bundle (1.1 mm radius at exit) is terminated by a proper focal length spherical lens to match the F# of the corresponding detection system. Streak camera results will be reported elsewhere.

In the process of data reduction, instrumental checks and appropriate corrections have been carried out, as listed below:

- The OMA has been calibrated throughout the wavelength region 300 nm to 800 nm.
- All the measured OMA spectra have been corrected for

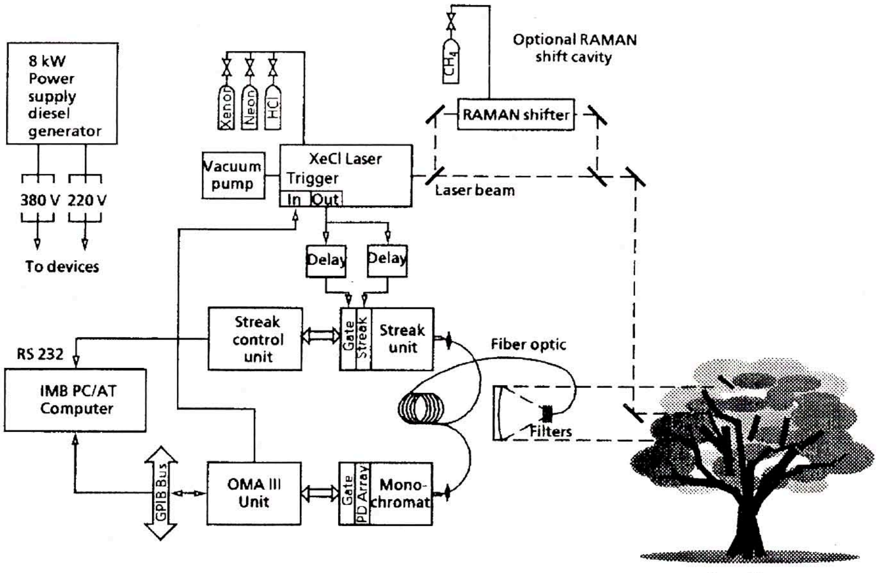

Fig. 1 - Sketch of the send-receive sub-systems of the ENEA lidar fluorosensor used in field experiments upon vegetation.

the detector spectral sensitivity through the whole near UV - visible region.

- With the OMA gate time set at the chosen value (200 ns), electronic noise "spectra" have been first measured throughout all the 1024 channels, and then subtracted from all the subsequent LIF measurements.
- Before data normalization (to 100 pulses), the accumulated signal intensity on OMA spectra has been checked to be exactly proportional to the number of pulses.
- The (negligible) background spectrum detected by the OMA during the short gating time is automatically subtracted by the instrument itself from raw data.
- LIF spectra at 308 nm excitation require special corrections for those species, like conifers, emitting a broad blue-green fluorescence whose tail overlaps the weak chlorophyll red bands. This tail has been estimated by extrapolating beyond 660 nm the data taken in the range 550 to 650 nm and then subtracted from the red portion of the spectra.

In this data analysis, we agreed to follow for uniformity the currently adopted procedure by the LASFLEUR Community to piecewise integrate the corrected LIF spectra with a 20 nm bandwidth around five characteristic wavelength channels: the near UV (UV-385 nm), the Blue (B-450 nm), the Green (G-530 nm), the first Red (R1-690 nm) and the second Red (R2-735 nm) channel. While it is well established that the red channels are related with chlorophyll-a emission [7], other visible fluorescence, ranging from the near-UV to the green, appear to be a multi-origin process associated to different pigments and sites of emission [8]. Spectral ratios can then be formed between various channels contents to be tentatively correlated with "in-situ" chemically measured plant physiological parameters and for vegetation recognition [9].

3. RESULTS AND DISCUSSION

Typical LIF spectra from **Spruce** (picea omorica), **Maple** (acer platanoides), **Maize** (zea mais), **Cornel** (cornus mas) and **Elm** (ulmus), as investigated by our lidar fluorosensor during the 1992 campaign [4], are presented in fig. 2. Those spectra, measured in identical conditions (distance, pulse energy, number of pulses, etc.) contain embedded information upon the vegetation species, photosynthetic activity and corresponding stress status.

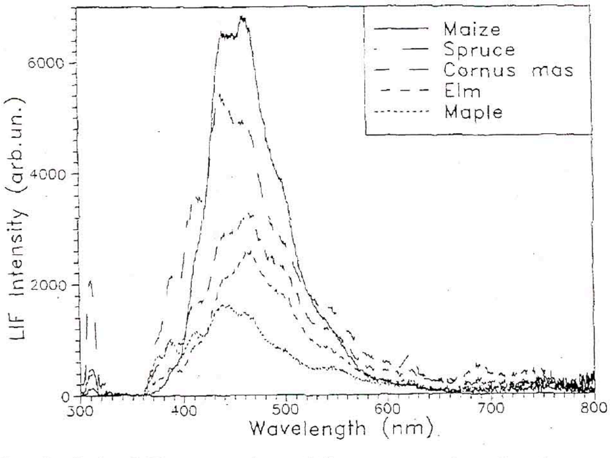

Fig. 2 - Lidar LIF spectra from different trees placed at the same distance (20-30 m).

3.1 Remote recognition

Assessing the vegetation health from remotely sensed LIF data requires a previous unambiguous species identification, based upon the same population of data, since different plants exhibit different spectral signatures due to their peculiar pigments types and concentrations. From a purely heuristic point of view, we statistically manipulated our spectral data with the goal of identifying a reliable procedure for remote vegetation recognition. A very promising method turns out to be the one sketched in Fig. 3.a, where the 2-D hystogram in the (UV/B, G/B) plane, counted over the entire population of available data, does allow for discriminating among Elm, Maize, Maple and Spruce+Cornel. The latter two, in turn, become separated in the (UV/B, R1/B) plane of fig. 3b.

In airborne field surveys, recognizing a large number of different tree species in a forest may require to use a larger set of ratios, covering the whole spectral range. In this case, if **n** is the minimum number of spectral ratios Rsj (j=1,n) required for identifying the species s, laboratory measured averages <Rsj> must be made available to form a reference database of Species Specific Ratios (SSR), extended to vegetation of some forestal and agricultural importance.

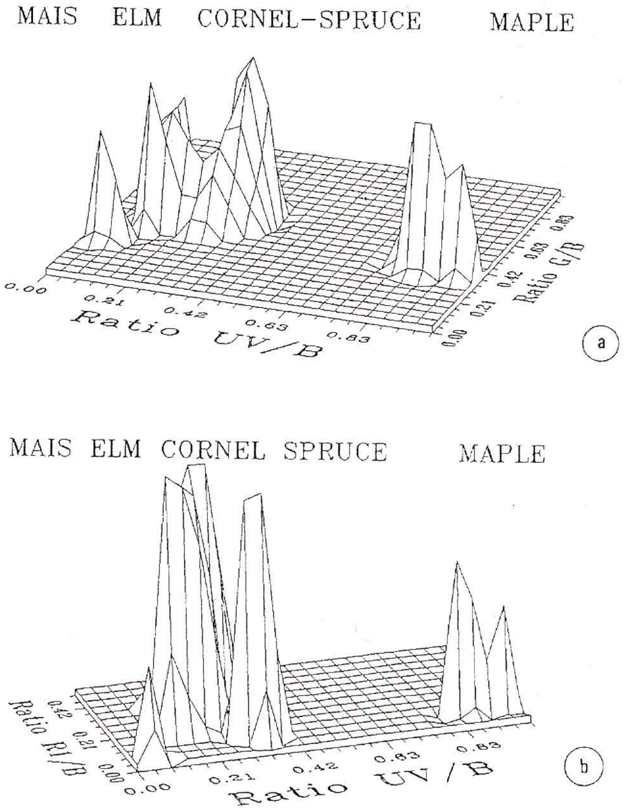

Fig. 3 - Vegetation recognition: a) (UV/B, G/B) plane; b) (UV/B, R1/B) plane.

Airborne collected spectral ratios Rij (i=1,N; j=1,n), where N is the total number of measurements taken over the same area and n is the number of spectral ratios considered, can then be mapped to the database SSR's to disentangle each species s. As a first raw indicator, we suggest using the average distance Δ in the n-dimensional space of spectral ratios, i.e.

$$\Delta = 1/N \sum_{i}^{N} \sum^{n}_{j} (Rij - < Rsj >)^2$$

which should exhibit a minimum just for one vegetation species, thus identifying its presence in the field data population. The confidence level for recognition can furtherly be estimated by evaluating the typical variances of the SSR's <Rsj>.

3.2 Daily Cycles (Maize)

In the 1992 campaign [4] four sets of Maize plants at different stages of growth and nutritional stresses were available. Families P (Maize 1) and S (Maize 2) were healthy plants from Karlsruhe, grown with nutrient on peat and sand, respectively. Families A (Maize 3) and B (Maize 4) were stressed plants from Munich, grown in sand on a small pot with and without nutrient, respectively.
An example of daily cycle LIF measurements upon the healthy maize sample (Maize 2: S3) is reported in Fig. 4, where diurnal trends of the R1/R2 and B/R1 ratios are compared to changes in atmospheric parameters. Spectral ratios are seen to be mainly influenced by average changes in the sun radiance, being the observed anticorrelation more remarkable for B/R1 than for R1/R2.

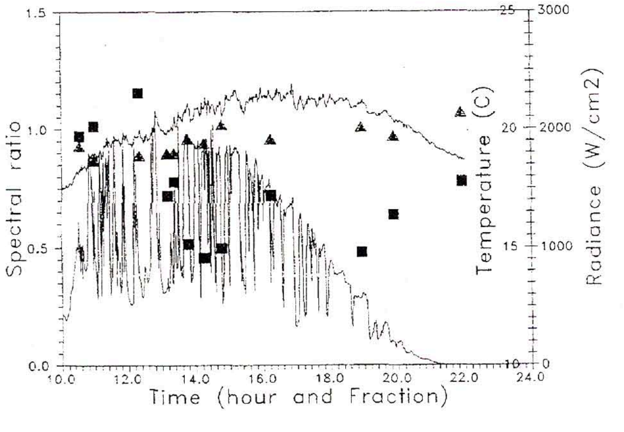

Fig. 4 - Daily cycles measured on maize by 8-Jul-92 and compared to available atmospherical data. (▲ R1/R2 ratio; (■ B/R1 ratio; upper curve: temperature; lower curve: sun radiance).

3.3 Chlorophyll contents and stresses (Maize, Elm)

As shown in fig. 5, a very weak correlation emerges between remotely sensed LIF R1/R2 ratios and total chlorophyll content as locally measured in maize leaves of different families. A similar behaviour is confirmed by the laboratory data of Ref. [8] for chlorophyll contents above 15-20 $\mu g/cm^2$. With our data, however, just the extreme cases of very healthy (S) and very stressed (B) plants appear to be distinguishable within the experimental uncertainties in average values of several determinations under fairly constant atmospheric and daylight conditions. As a matter of fact, stresses in maize turn out to be more easily recognized by other spectral ratios, as in the (G/B, B/R1) plane representation of fig. 6, where healthy and nutritionally stressed samples cluster in well separated peaks. Similar consideration apply to the healthy-water stressed data from elm trees plotted in fig. 7, which refer to campaign [4], but have also been observed in campaign [3].

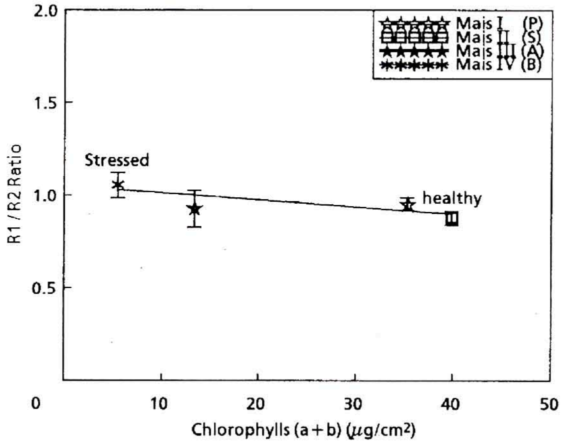

Fig. 5 - Correlation between the R1/R2 ratio and the chlorophyll content in different maize plants.

3.4 Other pigments contents (Maize, Maple)

Suitable combinations of spectral ratios can also help to drop out to some extent atmospheric parameters contributions from the collected data. In the example of fig. 8, a rather linear relationship is found between the (B/R1)/(R1/R2) ratio of ratios, averaged over many lidar determinations, and the (X+C)/(a+b) total carotenoid to total chlorophyll content ratio, as measured in different maize plants.
Specific spectral ratios can provide information upon different pigment contents. As an example, UV/B and G/B ratios taken during the central part of the day (roughly at constant solar radiance) from different maple leaves and plotted in fig. 9, are clearly correlated to the corresponding locally measured carotenoid content.

CONCLUSIONS AND PERSPECTIVES

In the course of the present data analysis, we learnt that many opportunities are hidden in remotely sensed LIF spectra to go back to specific features of the investigated vegetation. Species and stresses can be statistically classified by using a number of spectral ratios, although a deeper investigation by vegetal physiology specialists is recommended (and welcomed) in view of reliably connecting such experimental findings to the current knowledge upon plants components and behaviour. A more justified choice of optimum (species, stress) indicators from remote LIF measurements will follow accordingly.

From the instrumental point of view, our lidar fluorosensor performances gained benefit both from field experience and from comparisons with other similar apparata. We expect the reliability of collected information to be enhanced when time resolved data will be merged with LIF spectra.

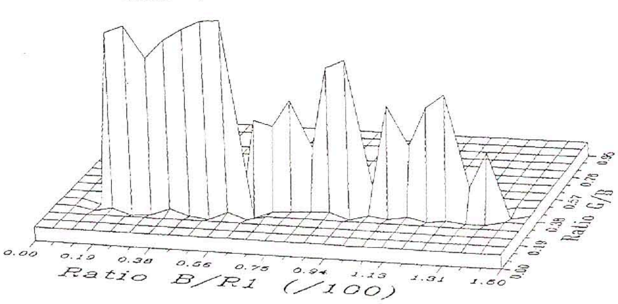

Fig. 6 - Distribution of maize 2 and maize 4 populations in the (G/B, B/R1) plane to ascertain nutritional stresses.

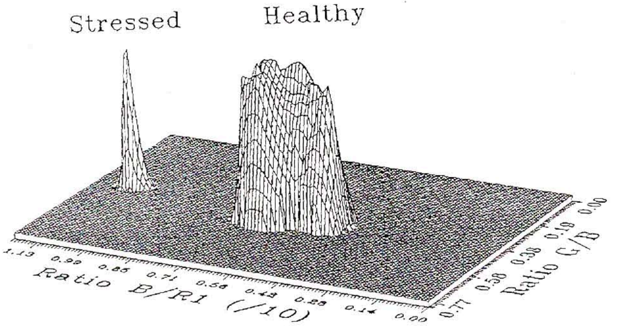

Fig. 7 - Distribution of healthy and water stressed Elm branches in the (G/B,B/R1) plane.

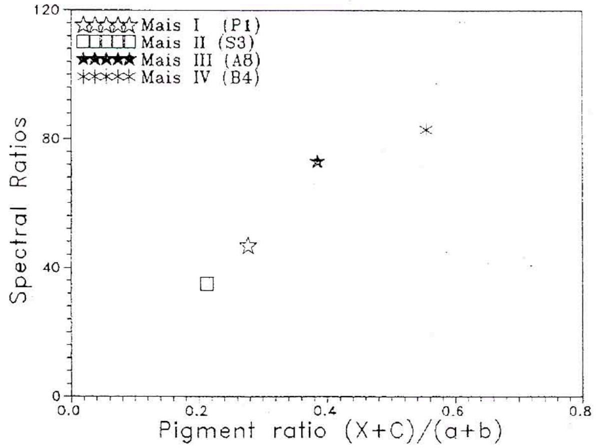

Fig. 8 - Correlation between the (B/R1)/(R1/R2) quantity and the pigment ratio in different maize plants.

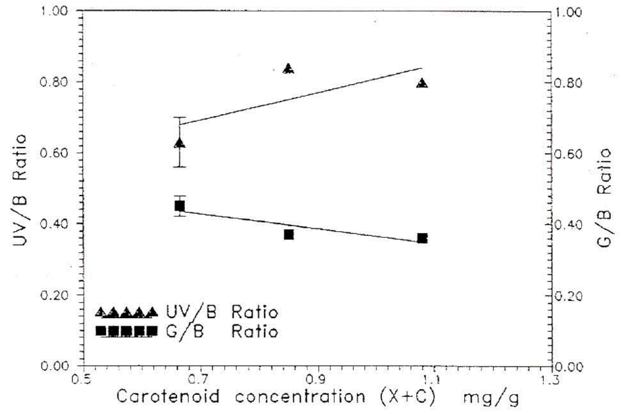

Fig. 9 - Correlation of UV/B and G/B ratios with the carotenoid content in maple leaves.

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