Reflectance of invariant targets: Validation of in-flight HyMAP and DAIS measurements with in-situ data

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INTRODUCTION

Quoting Justice *et al*. [1]: “Validation is the process of assessing by independent means the accuracy of the data products derived from the system outputs, and must be distinguished from calibration which is the process of quantitatively defining the system response to known controlled signal inputs”.

Several international efforts are being done at present to establish the uncertainty of derived products such as LAI and fAPAR from coarse resolution satellites comparing them with the in-situ data, which is assumed to be the target value. The approach of these efforts is to develop a standard methodology for validation.

On the other hand, reflectance can be considered as the primary product in the optical spectral region since the retrieval of the derived products in this domain is mainly based on both the combination of spectral bands and the inversion of the reflectance models. Therefore, and prior to the validation of the derived products, a validation of the reflectance data provided by the satellites is required. This validation is done by using airborne platforms so as to test the quality of the sensor data, calibration and atmospheric correction methods.

The spectral reflectance of natural surfaces presents a spatial, temporal and angular dependence, which causes a natural variability in the reflectance. Therefore, factors such as spatial heterogeneity, temporal variation in moisture status, plant physiology, atmospheric conditions or the anisotropic behaviour of the natural surfaces can increase the differences between the in-situ and the in-flight measurements more than the errors associated with the airborne data.

Consequently, it is necessary to develop an optimised methodology for the validation of airborne reflectance data. This methodology should be based on minimising the natural sources of variability in the reflectance to assure the comparability between the in-situ and the in-flight data. In this way, the ideal surface for validation purposes is the invariant target.

Assuming that the dependence of the spectral reflectance is spatial, temporal and angular, we can express this as follows:

(1)

An invariant target must verify that the spectral reflectance does not change when the spatial, temporal or angular co-ordinates do. Mathematically it is expressed as follows:

(2)

From this equation we deduce three conditions that should be verified for validation:

i) Homogeneity, ii) Simultaneity and iii) Isotropy.

Homogeneity affects the election of the validation surface. We should refuse heterogeneous samples since the in-situ measurements cannot be representative enough of the up-scaling airborne data. The effect is larger in vegetation crops than in soils, although extensive sampling throughout the field increases the spatial significance of the measurement.

Simultaneity is really difficult to achieve, especially because of the existing differences in the time scale between the in-situ sampling and the in-flight data obtained over an experimental area. Within short time periods, the atmospheric changes can introduce errors in the reflectance of around 5%, [2]. If the time lap increases, the sun zenith angle influence becomes relevant and, then, for time periods of more than one or two hours, the moisture status or the plant physiology is an added factor and the reflectance is not comparable anymore. To reduce this source of error, the measurements must be taken, as far as possible, at the time of the flight. The coordination between the airborne and the field radiometry teams should be good and the measurements should be taken within small time intervals.

Isotropy shows the higher source of error in common validations. By removing the sun zenith angle influence, which in this work has been considered as temporal error source, the angular dependence of the reflectance could be characterised by the view zenith angle and the relative actral reflectance measurement. Particularly, the wide-FOV of both HyMap (60º) and DAIS (50º) provide a wide view zenith angle range, which produces a different influence on reflectance depending on the acquisition plane.

In order to reduce all these sources of reflectance variability, we have made a previous study of the in-situ characterisation of the validation targets and the acquisition geometry of the in-flight data.

Our main contribution to the DAISEX campaigns has been to take the in-situ reflectance measurements of several selected targets or "units" for the validation from the *in-flight* optical sensor data. Our activities involve DAISEX 1998, DAISEX 1999 and DAISEX 1999 Extension.

In an effort to reach an optimised validation methodology, we briefly present in this work the methodology developed to ensure the comparability between the in-situ and the in-flight data and the spectral validation of DAIS (all three campaigns) and the HyMap (only the 1999 campaign) instruments.

Finally, the spectral reflectance of DAIS and HyMap sensors has been calculated by means of the selected *in-situ* measurements. In this validation, we have emphasised the spectral reflectance quality of the data. Other problems of the *in-flight* data such as geometric corrections, saturation or noisy bands are analysed in another communication, [3], of this workshop.

METHODOLOGY

a) Description of the selected units

During the three campaigns we have taken measurements from different natural surfaces (soils and vegetation) and from two artificial targets (fabric and asphalt).

The selection of the targets was made so that the surfaces would display spectral contrast, homogeneity and isotropy. Vegetation samples were included in order to study the response of the sensor to drastic changes in the reflectance.

Due to the fact that some of the units are located out of 'Las Tiesas' perimeter or correspond to threshing floor or road junctions, not all of them have been labelled following the Daisex protocol. Therefore, we are going to use a specific terminology for the validation surfaces.

A more detailed description of the units as well as their location and the instrumentation used for the acquisition of field radiometry data has been presented in another paper [4] of this workshop. The following table shows the main characteristics of the units for validation.

Table 1. Description of the units for each campaign

DAISEX 1998		
Unit 1	Alfalfa	Field 4
Unit 2	Corn	Field 5
Unit 3	Red clay soil	S3

DAISEX 1999		
Unit 1	Compacted marly soil	-
Unit 2	Rough red clay soil	S2
Unit 3	Fabric	-
Unit 4	Smooth red clay soil	S10

DAISEX 1999 Extension		
Unit 1	Asphalt	-
Unit 2	Limestone soil	-
Unit 3	Smooth red clay soil	S5
Unit 4	Corn	V1

We find the fabric, which covers an area of 150 m2 (Unit 3 of DAISEX 1999), a target of special interest. This material was selected because of its specific spectral signature. The spectrum in the visible and NIR regions is like a Heaveside step function at 700 nm and similar to the vegetation response in this region. This type of spectral signature is very useful when estimating the instrument response to drastic transitions in the radiance. Furthermore, this material displays very marked absorption features at 1600 nm and three other peaks appear beyond 2000 nm (as it can clearly be seen in figure 2-b)

All the measurements were carried out simultaneously at the time of the flights at intervals of less than 40', except the vegetation measurements from DAISEX 1998 that were carried out 1h before the flight. On the other hand, additional measurements were taken in order to evaluate the diurnal variability of the units.

b) Previous analysis

In order to improve the physical meaning of this validation, we have made a previous analysis focused on minimising natural reflectance variability.

In order to minimise the heterogeneity of the samples and, consequently, the up-scaling effect over the radiometric response of the surface, a great number of smooth soils have been used. The standard deviation of both the in-situ and in-flight measurements is a good indicator of the heterogeneity of the samples. In the graphs showing spectral signatures we can observe the average reflectance and the confidence interval, which is very small due to the homogeneity of the selected samples.

As previously mentioned, the non-simultaneity of the measurement could introduce important differences in the reflectance, mainly due to the variation in the sun zenith angle and the influence of this variation on the reflectance of surfaces. This influence is related to the anisotropy of the surfaces, which is introduced in soils mainly by its roughness.

In order to evaluate this difference, we have calculated the ANIFi [5], an anisotropy factor defined as follows:

$$ANIFi\left(\lambda,\theta_i,\varphi_i,\theta_i',\varphi_i'\right)=\frac{R_0\left(\lambda,\theta_i,\varphi_i\right)}{R_0\left(\lambda,\theta_i',\varphi_i'\right)} \qquad (3)$$

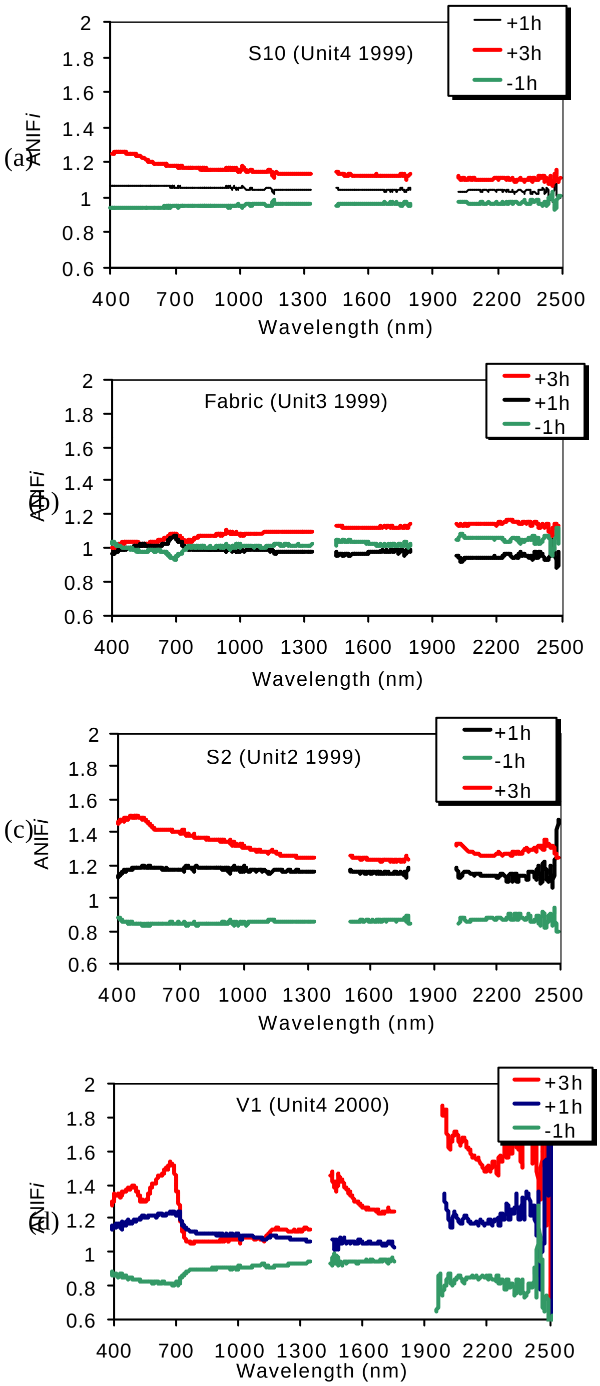


Fig.1. Anisotropy factor introduced by the non-simultaneity in the measures for a different target. Legend indicates the temporal interval where positive corresponds to a decreasing sun zenith angle.

Where R_0 is the reflectance obtained from nadir, θ is the zenith angle, φ the azimuth angle, and the sub-index *'i'* indicates the in-coming flux direction.

We have evaluated this anisotropy at one and three hour intervals respectively for the units used in the 1999 and year 2000 campaigns, and some of the results can be observed in fig.1.

Figure 1 shows two very suitable targets and two rejected ones. On the left side, we present the smooth red clay soil and the fabric cover (figure 1-a and 1-b) measured in 1999. Both show differences of less than 10% in reflectance for a one-hour interval. In addition, these units show no wavelength variations. The red line shows the relative variation in the reflectance introduced by the change in the sun zenith angle in a three-hour interval. On the right side, two rejected surfaces can be seen (figure 1-c and 1-d). The rougher red clay soil displays differences of 20% in one hour (figure 1-c). On the other hand, the heterogeneous vegetation presents similar differences to the ones observed in the rough soil but it also reveals some spectral dependence, which is clearly shown in the three-hour interval line. The wavelength dependence of the vegetation canopies is explained with detail in another paper, [6] of this issue.

Therefore, the non-simultaneity of the measurement could introduce differences of about 10% in the reflectance between the in-situ and the in-flight measurements at one-hour intervals.

In order to evaluate the anisotropic reflectance influence we have made a complete analysis of the anisotropic reflectance, [6]. The results clearly indicate that the orthogonal plane is the most adequate for reducing anisotropic effects, and that both soils and dense vegetation canopies exhibit a very isotropic behaviour in this plane, while sparse vegetation is more influenced by the view zenith angle. The anisotropic behaviour of the reflectance presents a wavelength dependence that should be taken into account due to the fact that those regions where single scattering governs are more affected by anisotropy than those where multiple scattering occurs. In general, soils have a higher anisotropy and are not dependent of wavelength, whereas vegetation shows important variations in the anisotropy between the VIS and the NIR regions.

Based on this study, we have finally selected the following flights:

Table 2. Flights selected for the validation. SLT (Solar Local Time)

HyMap			
Name	**Date**	**SLT**	**Plane**
Bar1_12	99/06/03	11:52	Orthogonal
Bar2_08	99/06/04	8:16	Orthogonal

Bar2_15	99/06/04	15:11	Orthogonal
DAIS			
Name	**Date**	**SLT**	**Plane**
Bar_1	98/08/11	12:10	Orthogonal
Bar1_12	99/06/03	11:52	Orthogonal
Bar_1	00/06/29	12:12	Principal

As we can see in table 2, only in the year 2000 campaign, the images correspond to the principal plane acquisition, due to the fact that both flights were carried out in east-west direction at noon.

HyMap has provided the images of the three different flight times carried out in the DAISEX 1999 campaign, whilst for DAIS we have used one image for each campaign.

RESULTS

a) HyMAP

The graphs show the comparison of the spectral signature measured in-situ (black) with the one measured in-flight (grey) for the three selected units (2 bare soils and fabric) at the Daisex '99 campaign.

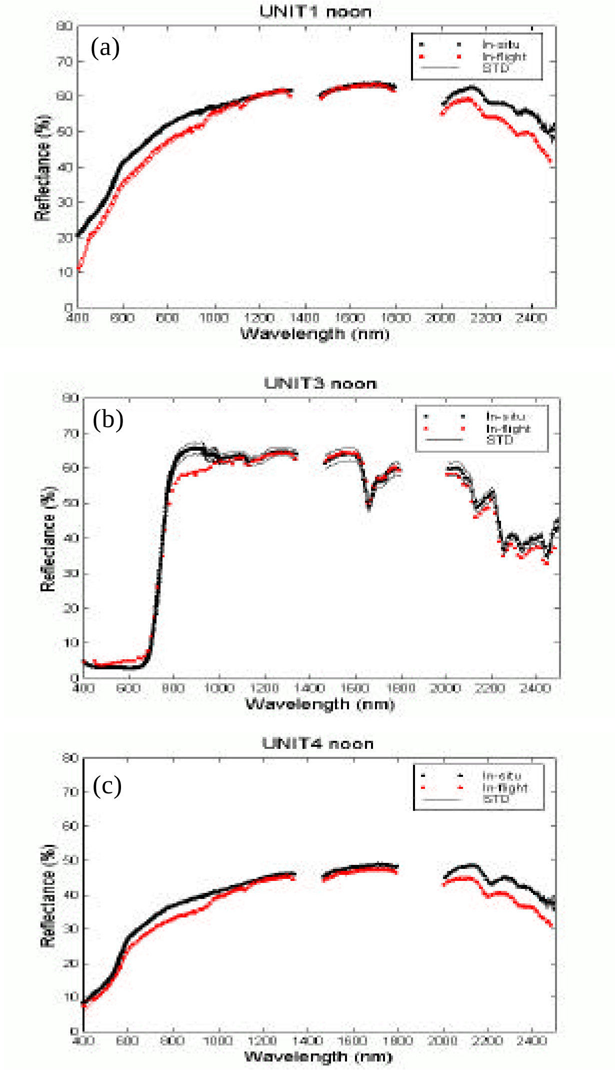


Figure 2. Spectral signatures of the validation units obtained in-situ and in-flight at noon flight time.

A visual inspection reveals that the major differences are shown at values below 1000 nm and beyond 2000 nm, an interval where HyMap data underestimates the reflectance *in-situ*. Yet, the affinity between these values is very good.

HyMap data reproduces very well the shape of the in-situ spectral signature for soils (figures 2-a and 2-c), except at around 900 nm where the in-flight data falls away slightly. It should be pointed out that there is a change in the spectral module of the HyMap instrument at 900 nm.

For the fabric signature (fig 2-b), the HyMap data reproduces perfectly the drastic change in the NIR region and all the absorption features illustrating the quality of the HyMap instrument. The small variations around 900 nm, where the in-flight data does not reach the maximum value, are perfectly normal and are caused by the influence of the neighbour pixels.

The following graphs correspond to the afternoon flight time.

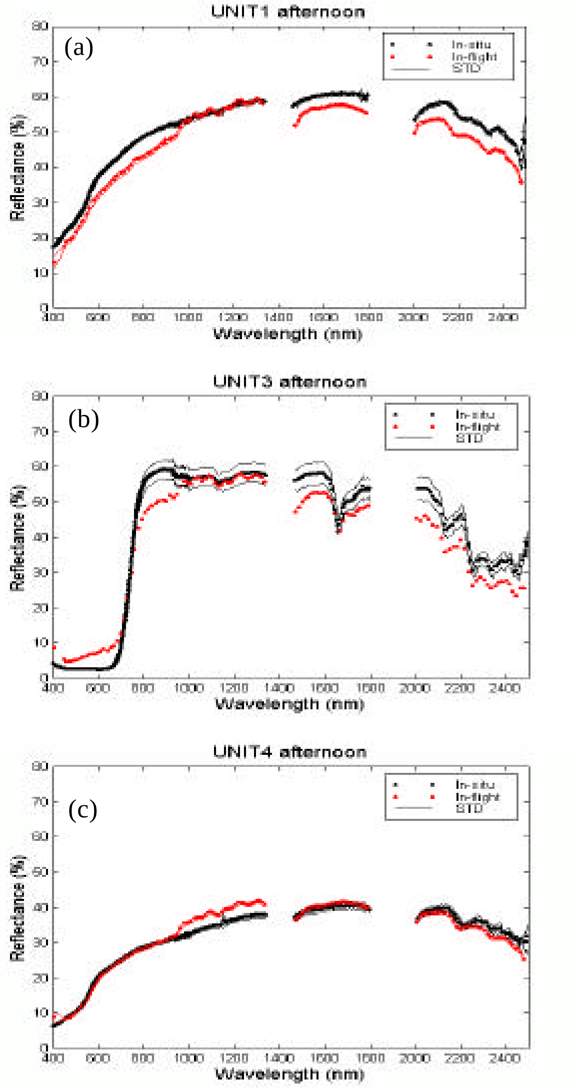
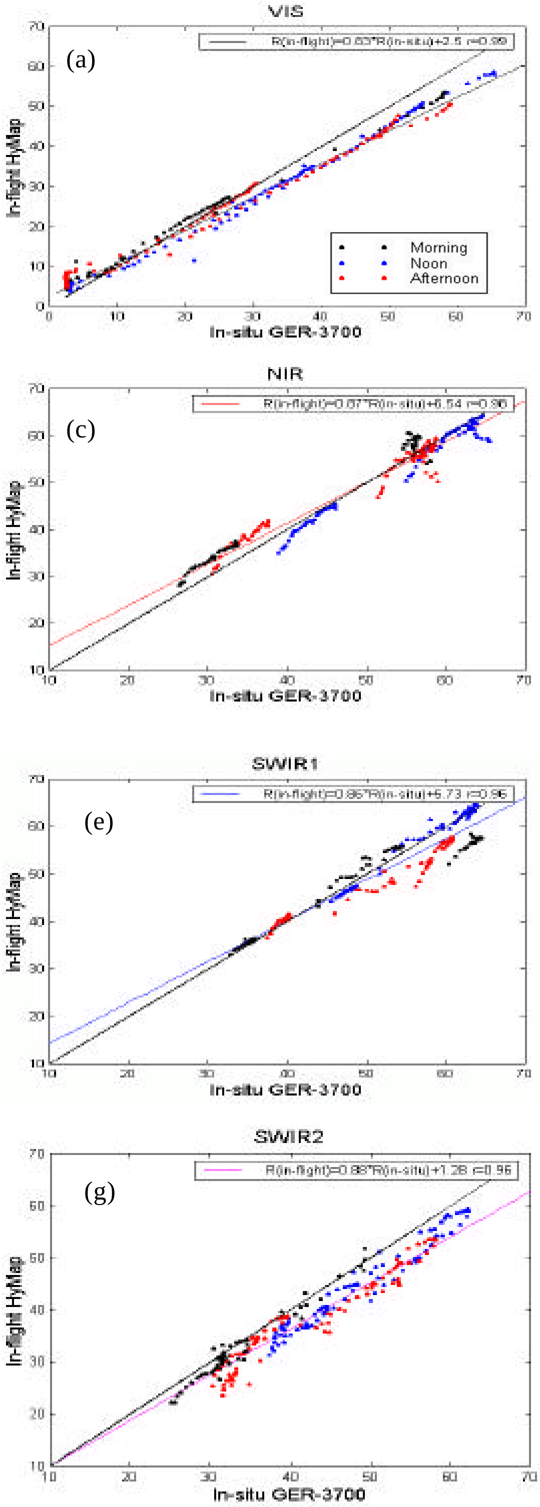


Figure 3. Spectral signatures of the validation units obtained in-situ and in-flight at afternoon flight time.

These graphs show the same general tendency as the one observed at noon flight time, although the SWIR1 region in Unit 1 and Unit 3 indicates an increased difference. However, an abnormal effect in the form of several peaks can be identified in the HyMap spectral signatures. This effect, clearly manifested in Unit 4, appears also in the principal plane images and in the morning flights for the selected units and has been associated to the water vapour correction in the image. These peaks have been analysed in the whole of the image and the results can be looked up in [3].



The results corresponding to the morning flight do not introduce any new elements in the discussion.

In order to find out if the origin of any error is associated with the in-situ or the in-flight measurements, we have made a series of scatter-graphs. On the left side of figure 4, the different colours represent the morning (black), the noon (blue) and the afternoon (red) flights. On the right side, the colours represent Unit 1 (black), Unit 3 (blue) and Unit 4 (red).

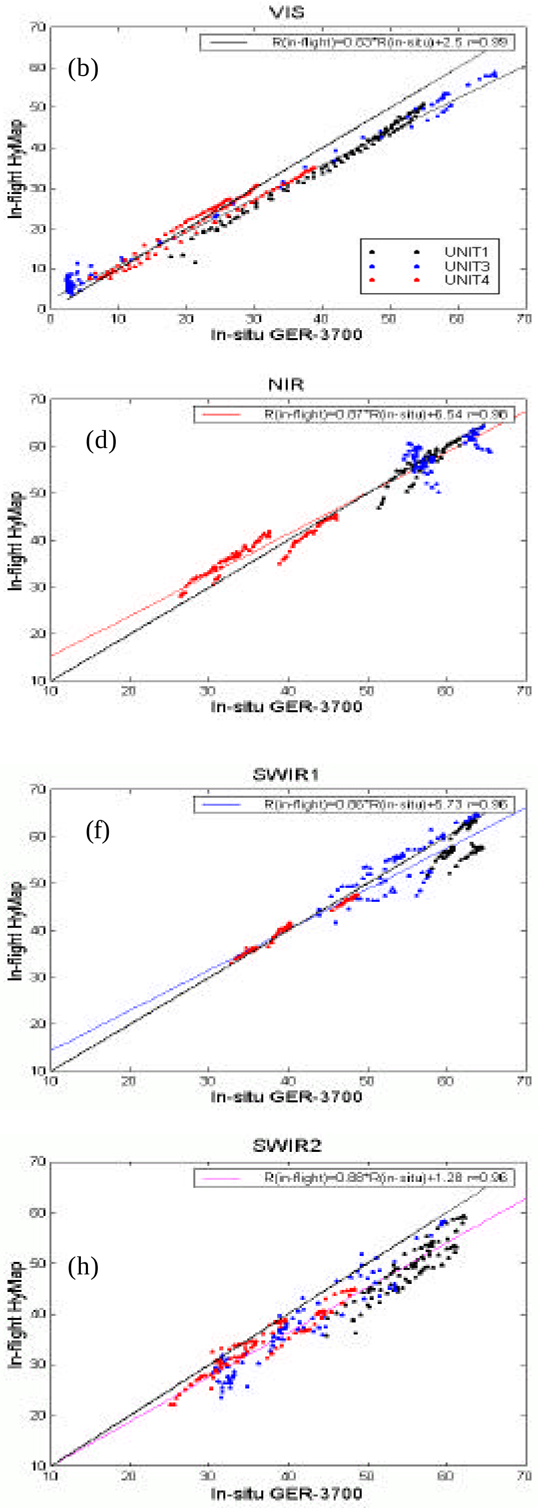


Figure 4. Scatter-graphs between in-flight HyMap and in-situ data. On the left, colours display the different flights, and on the right colours display the different validation units.

The graph 4-a) corresponding to the visible region (400- 800 nm) shows that the in-flight data underestimates the in-situ data regardless of the flight time, whilst graph 4-b) shows the better adjustment of the Unit 4 in the visible region. These results indicate that Unit 4, the smooth and large red clay soil S10, is the best validation surface and that Unit 1, the compacted marl soil, and Unit 3, the fabric, have less satisfactory in-situ characterisation. It is important to point out the following aspects: first, Units 1 and 3 are smaller than Unit 4 so they should be more affected by the adjacent pixel contribution to the radiance of the in-flight data. Second, Unit 4 is seen approximately from nadir in all flights whereas Unit 1 and Unit 3 are seen at morning and afternoon flight times at a view zenith angle of approximately 25º.

The NIR regions present clearly defined differences for Unit 4 which are associated with the flight time and therefore with the in-flight data. As we can observe in graph 4-c), the concordance between the in-flight and the in-situ data is very good at the noon flight. However, the morning and afternoon flights overestimate reflectance and the abnormal effect in the form of peaks can again be seen. Moreover, the abnormal correlation in this region can also be observed in the Unit 1 and Unit 3 (graph 4-d).

The SWIR1 region shows a good adjustment at noon flight in Unit 1 and Unit 3. However, the morning and afternoon flights differ from the 1:1 line in the NIR data. This could be associated with the influence of both the high view and sun zenith angle together with the atmospheric effect due to the fact that Unit 4 is seen near nadir for all flights and shows a perfect adjustment to the 1:1 line for all 3 flight times.

As we can see in the plots 4-g) and 4-h), the results are very satisfactory in the SWIR 2 regions.

b) DAIS

DAISEX 1998

We are going to introduce the results corresponding to DAISEX 1998 where two vegetation covers (alfalfa and corn) were measured and a transect on a smooth red clay soil (S3) was undertaken. The vegetation measurements were carried out 1 hour before the flight and the ANIF*i* informed us that due to the increased solar zenith angle, the in-flight data had to be approximately 10% higher than the in-situ characterisation. The results can be seen in figure 5.

Figures 5-a) and 5-b) show that for vegetation covers exist important differences between in-situ characterisation and in-flight data in the Red and NIR regions. Several factors, including an effect caused by the design of the instrument, are definitely involved in these variations.

On the other hand, the smooth tendency in the spectral signature of the soils and the adequate characterisation in-situ show a very good concordance with the DAIS data, as it can be appreciated in figure 5-c). We have obtained the scatter-graph (figure 6) for this target, and the results have been very satisfactory except in the SWIR2 region where the DAIS data are noisy and generate a less satisfactory affinity between the results.

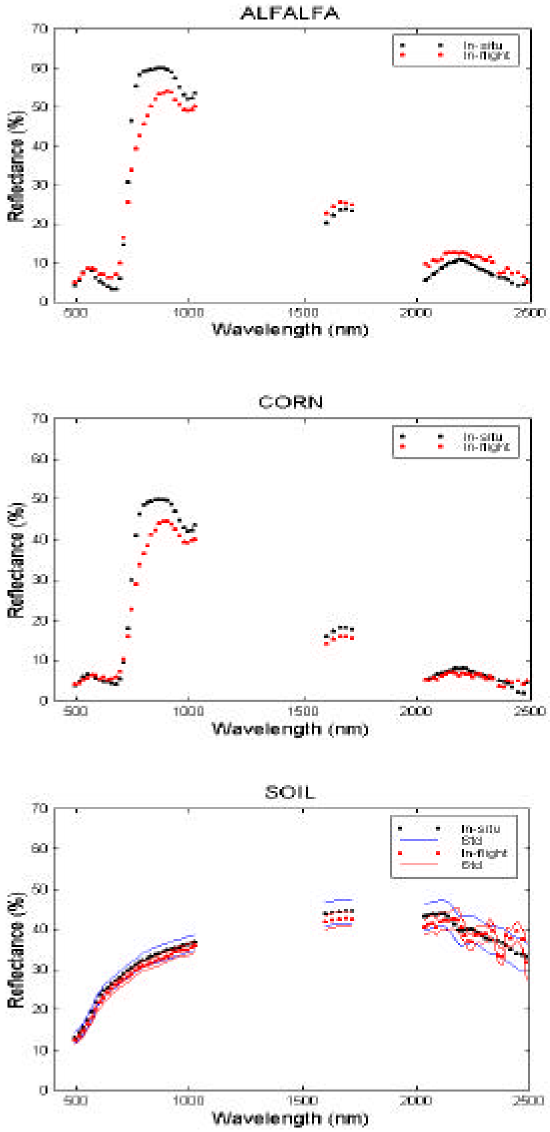


Figure 5. Spectral signatures of the validation units obtained in-situ and in-flight at afternoon flight time.

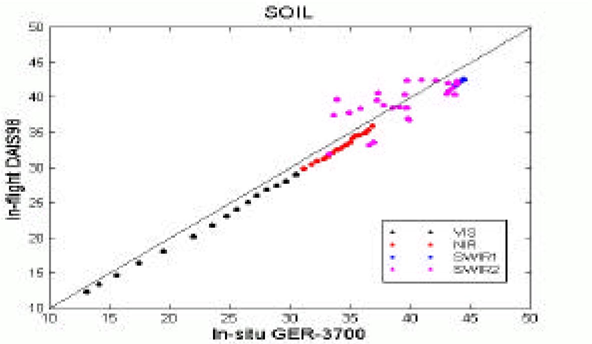


Figure 6. Scatter-graph between the in-flight DAIS data and in situ measurements for the soil, S3. Colours represent the different spectral regions.

DAISEX 99

The DAISEX 1999 was a better-prepared campaign and more surfaces were measured simultaneously. Only the noon flight corresponding to the orthogonal plane has been analysed for DAIS. There are several factors that should be highlighted in the results (figure 7) obtained during this campaign.

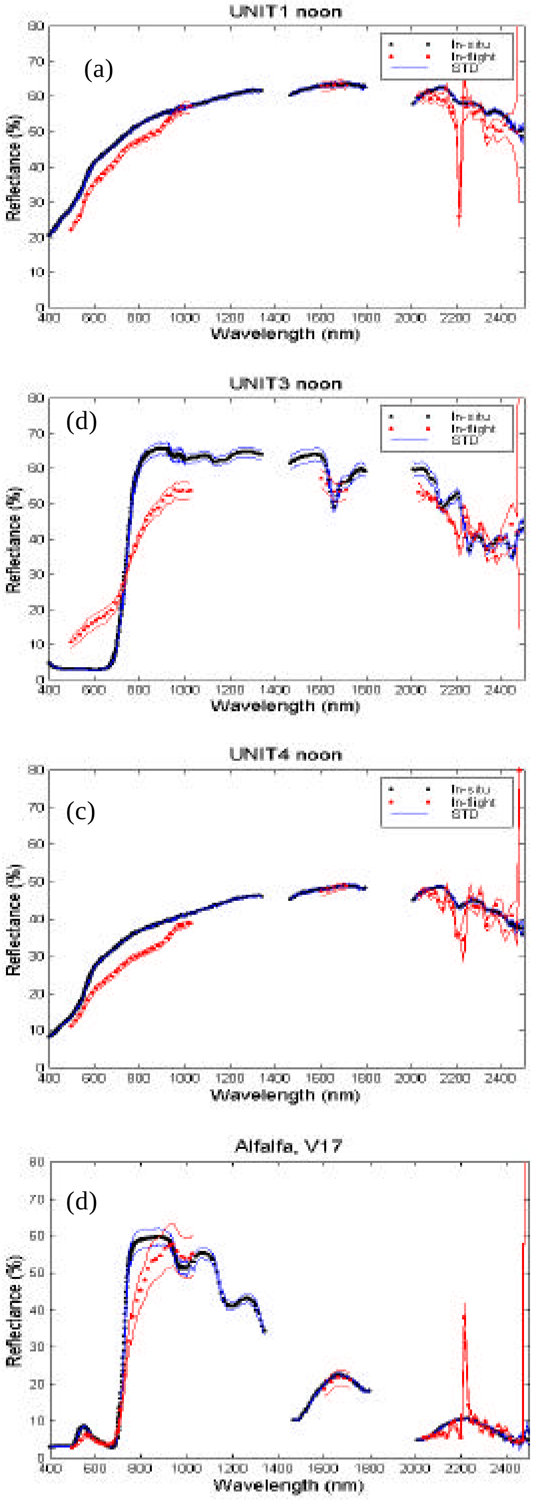


Figure 7. Spectral signatures of the validation units obtained in-situ and in-flight at noon flight and d) additional alfalfa cover.

On the one hand, the soils in-flight signatures suffer a slight drop at 900 nm in Unit 1 and Unit 4, same as with the Hymap. On the other hand, a very good affinity can be observed in the SWIR1 region, but the SWIR2 region has turned out to be very noisy.

For the first of the artificial targets, fabric, the results are unsatisfactory. This is shown in figure7-b) and we have rejected this unit in the subsequent analysis. The 150 m2 of fabric cover gives 3 similar pixels in the DAIS image so we would expect better and similar results to the HyMap ones. There is a certain amount of uncertainty in this unit that affects the DAIS measurements, including the possibility of not having any pure pixels of fabric in the image.

In order to avoid the possibility of not having any pure pixels of fabric surface as well as to study the response of DAIS to strong changes in reflectance, we have included a very homogeneous alfalfa cover in the analysis (figure 7-d). We can see that DAIS data fall down again in the NIR region and that the in-flight data do not reach th

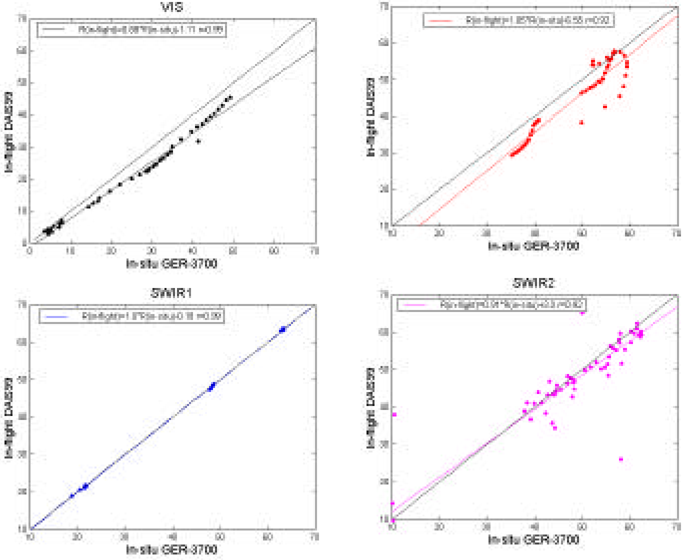


Figure 8. Scatter-graphs corresponding to Unit 1, Unit 4 and the alfalfa cover for spectral regions.

We can clearly appreciate a good correlation in the visible band and an excellent concordance in the SWIR1 region.

However, there is again a lack of agreement in the vegetation cover in the NIR: a sharp increase in the vegetation implies a failure in the DAIS in-flight data.

In the SWIR2 region, the DAIS data has plotted various points which are very far from 1:1 line and which correspond to very noisy DAIS bands.

DAISEX 1999 Extension

Lastly, we would like to examine the year 2000 campaign, where only flights in the principal plane were undertaken. Thereby, we must consider the anisotropy of the reflectance as a result of the different view zenith angles. The four units selected for this campaign are seen by the sensor in the forward, backward and nadir regions. Figure 9 shows the comparison between the in-situ and the in-flight spectral signatures.

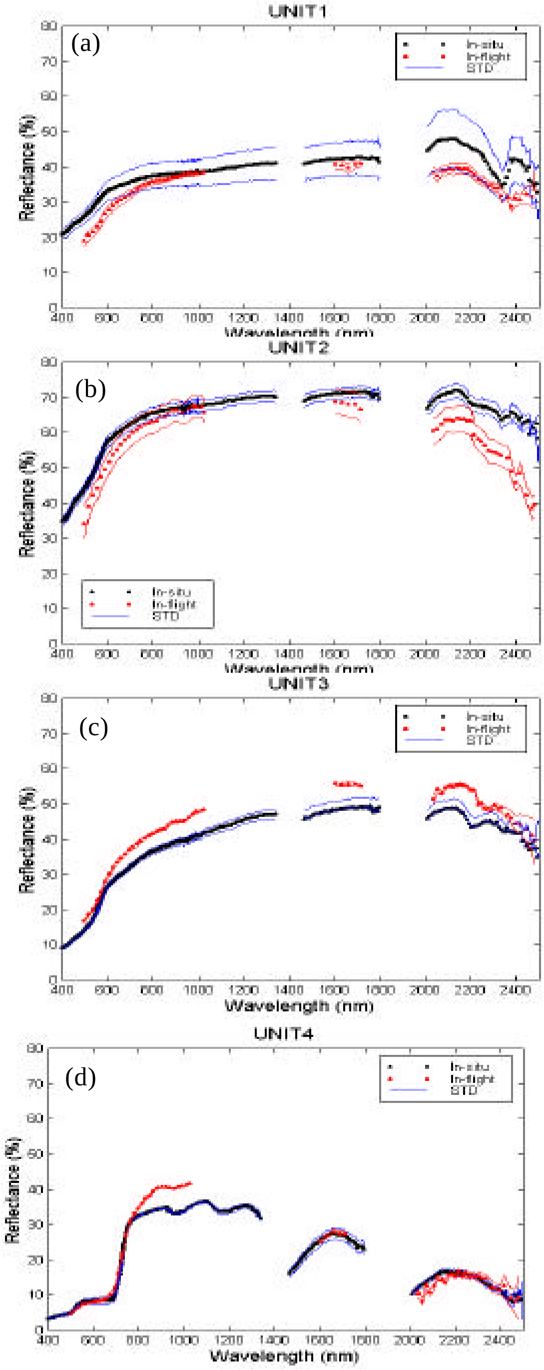


Figure 9. Spectral signatures of the validation units obtained in-situ and in-flight in Daisex-99 extension. This year the images were acquired in the principal plane.

As we can see in figure 9-a), Unit 1, or asphalt, has been slightly underestimated by DAIS. Since Unit 1 is seen in the forward region, this result is an expected one. Nevertheless, the shape of the in-flight spectral signature respects the in-situ spectral signature. In Unit 3, the DAIS data overestimate the in-situ data due to the proximity of these data to the hot spot. The shape of the in-situ spectral signatures is then reproduced once more.

On the other hand, Unit 2 and Unit 4 are seen near the nadir view and therefore the in-flight data show less influence of the anisotropy. Consequently, the concordance is good except for the soil in the SWIR2 region and NIR for the vegetation.

The major problems in Unit 2 are associated with the in-situ characterisation. They are caused by the target surface, which matches a junction in a very bright limestone road. This unit shows colour variations due to the presence of darker soils in this road and it also shows a small area very influenced by the surrounding areas. Nevertheless, the worst results are in the SWIR2 region, which is common for all the units.

The disagreement in the NIR in Unit 4 is mainly induced by the heterogeneity of the target and a poor in-situ characterisation. The use of a crane to obtain the measurements prevents us from doing extensive sampling throughout the field.

However, we can observe in the in-flight reflectance that in the NIR region the reflectance begins to fall away and does not reach its maximum value, as in the other vegetation signatures retrieved from DAIS. Furthermore, in the red region the absorption features are not present. Both effects must be attributed mainly to a problem in the design of the instrument used, which shows difficulties to record quickly strong changes in the radiance.

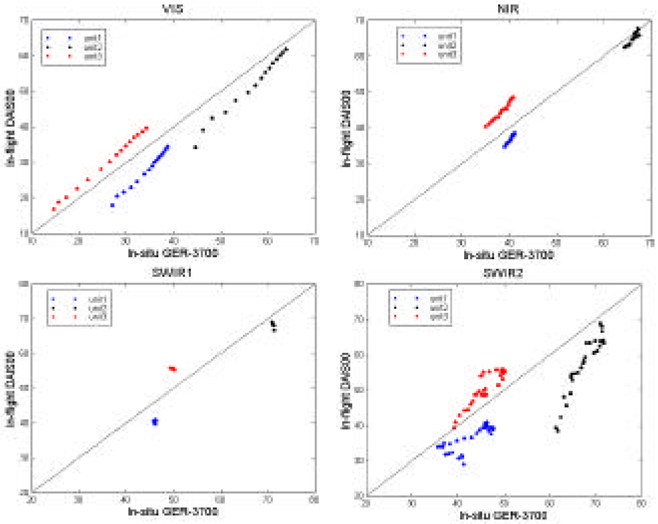


Figure 10. Scatter-graphs corresponding to Unit 1, Unit 2 and Unit 3 for spectral regions.

Figure 10 shows the scatter-graphs of the Daisex 2000 campaign and we can clearly observe the effect of the view zenith angle in the principal plane. The values from Unit 3 are represented in red and depicted as seen from a close position to the hot spot. Thereby, in all these graphs the DAIS data overestimate the in-situ reflectance acquired from nadir. Unit 1 is represented in blue and depicted as seen from the forward scattering region. The inverse takes place now: the DAIS data underestimates the in-situ reflectance. Unit 2 is represented in black and depicted as seen near nadir. It shows the best affinity with the in-situ data since it is seen from the same view angle.

For spectral regions we can observe that also in this campaign the SWIR2 region shows the poorest results of the DAIS data.

4.CONCLUSION

In this work we have done a validation of the in-flight optical sensors data DAIS and HyMap. Prior to the validation, we have developed a strategy to optimise the validation of the in-flight reflectance data. This operational methodology is based on the following points:

- The selection of surfaces that verify high degree of homogeneity and isotropy. The artificial targets have been used in order to achieve major homogeneity and isotropy.
- In-situ characterisation should be done 'simultaneously' to the flights.
- Validation surfaces should display spectral contrast in order to analyse the in-flight response in the major range of reflectance.
- Surfaces with strong transition in the reflectance as in vegetation spectral signatures and, alternatively, targets with well-known absorption features should be considered.
- Surfaces should be large enough so as to reduce the effect of the surrounding areas in the in-flight data. This has been the main problem of the selected units.
- We should reduce the viewing geometry influence in the airborne imagery. That is why we have selected images obtained in the orthogonal plane. Alternatively, we can normalise the image of the BRDF effects.

For the HyMap data corresponding to DAISEX '99 campaign the main aspects are listed below:

- In general, the HyMap instrument has shown as much quality in the spectral calibration as in the response to the strong transition in the radiance.
- For spectral regions, the validation in the NIR region reveals some problems associated with the in-flight data; for the other spectral regions, the concordance is very good and the in-flight data shows low noise.
- As a result of the errors associated to the viewing geometry and the atmospheric corrections, the results for the validation of the noon flight are better than the ones of the morning and afternoon flights.

The data validation results are less satisfactory for the DAIS, and we have found the following problems:

- DAIS data have problems to reproduce the spectral signature of vegetation in the transition between the Red and NIR region. DAIS data smooth the spectral signature, underestimating the maximum values and overestimating the minimum values.
- DAIS data show very noisy values in the SWIR2 region.
- In the SWIR1 region, DAIS data show an excellent concordance with the in-situ characterisation. In the visible region, DAIS data also show a good correlation with the in-situ data. In the NIR region, DAIS data are only satisfactory for smooth spectral signatures.

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