RADIOMETRIC INTERCALIBRATION OF MOMS AND SPOT BY VICARIOUS METHOD

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ABSTRACT

The homogeneous test site of La Crau (South of France) was used for radiometric calibration of the MOMS-camera onboard the Russian MIR-Station and of the HRV/HRVIR cameras on the SPOT-01 and SPOT-04 satellites. The test site has an extention of approx. 400 m x 400 m and is composed of bare soil and pebbles. For the spectral characterisation of the test site reflectance measurements with field spectrometers as well as multispectral images with airborne instruments from low flight altitude were obtained.
To determine atmospheric optical parameters the ground irradiance of the sun was measured during the time the space cameras passed over the test site.
With the measured reflectances and atmospheric parameters the 6S-radiation transfer model was used to calculate the spectral radiance reaching the space cameras. The paper describes the measuring techniques and discusses the calibration results.

1. INTRODUCTION

ONERA and DLR have agreed to cooperate in the field of optical remote sensing systems calibration. In this framework a joint field campaign by teams of ONERA / CNRS-LISE and DLR was carried out in 1998 at La Crau test site for vicarious calibration of MOMS-2P and SPOT. Two days were used for measurements: 29 June 1999 with a SPOT-04 overflight and 2 July 1999 with overflights of SPOT-01 and MOMS-2P.

2. THE LA CRAU TEST SITE AND ON GROUND INSTRUMENTATION

The La Crau test site is located in southeastern France at 4.87°E longitude and 43.50°N latitude about 50 km northwest of Marseille. It is a flat area of about 60 km^2. The ground is uniformly covered by pebbles and dry grass-like vegetation (Fig. 1). From a certain distance the ground looks like a homogeneous flat surface of a yellowish, brownish colour tone.
The climate in this region is dry and sunny and the optical properties of the ground vary little during the year. For the calibration a section of 400 x 400 m^2 in the center of the test site was used (Fig 1). This center section is called the calibration area [7].

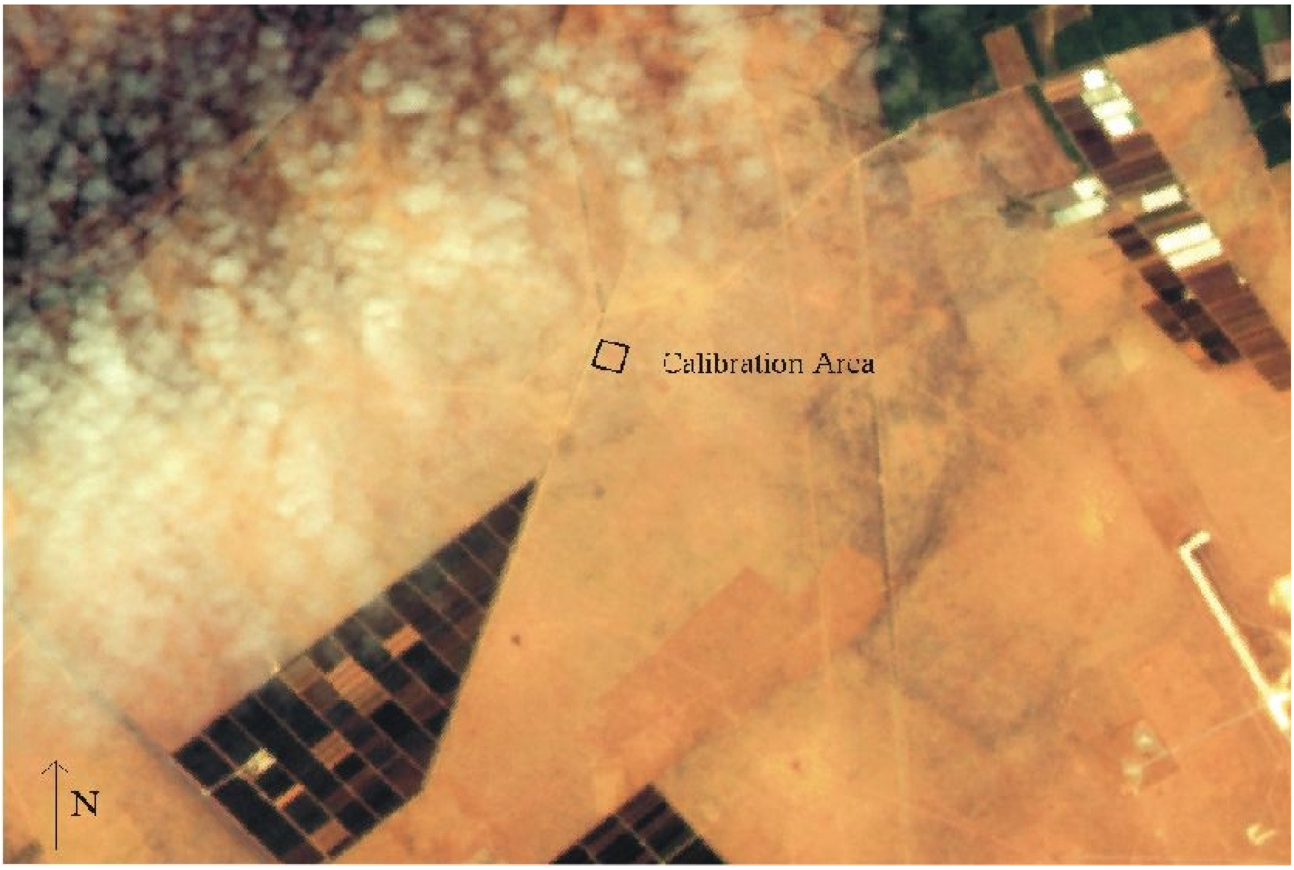

Fig. 1: Enlarged MOMS-2P-scene (2 July 1998) with 400 x 400 sqm calibration area.

The La Crau test site is used on routine basis for SPOT calibration. Therefore it is equipped with a CIMEL automatic radiometer operated by the CNRS LISE French laboratory originally developed for SPOT absolute calibration [1]. The instrument is a sunphotometer mounted on a 10 meter high mast and consists of two collimators, one for IR channels (Germanium detector) and one for visible bands (Silicon detector). The instrument delivers data in nine spectral bands 10 nm wide. The central wavelengths are 380 nm for molecular scattering, 440 nm, 550 nm, 670 nm, 870 nm and 1600 nm for aerosols in the SPOT and VEGETATION spectral bands, 936 nm for the water vapour, 1020 nm to complete the aerosols knowledge. The radiance at 870 nm is acquired both with the IR and the visible collimators in order to intercalibrate them. The automatic operating procedure includes 3 sequential modes repeated all the day long for optical airmasses up to 5. In the first mode, the sun collimator points at the sun and measures direct solar irradiance in order to retrieve the water vapour abundance, aerosol optical depths and the Angström coefficient. The second mode consists in sky radiances measurements in the almucantar and principal plane and is used for phase function retrieval. In the last mode, the collimator scans the ground both in azimuthal and zenital directions and measures the surface BRDF. This instrumentation enables autonomous self-sufficient measurements for SPOT calibration. As the instrument had power unit and data transmission troubles on the 7/2/98, it has been replaced by the previous operational instruments, formerly used on the test site for vicarious calibration. First a classical automatic CIMEL sunphotometer with the commonly used six filters centered at 440 nm, 670 nm, 870 nm, 1020 nm for the aerosols characterisation, and 937 nm (10 nm wide) and 940 nm (50 nm wide) for the water vapour was operated instead. As a redundancy, a portable CIMEL 318 sunphotometer equipped with the same bands was operated simultaneously in manual mode [8]. These instruments are not fully equipped for all the Spot spectral channels and can only be used for the atmospheric characterization.
Therefore, a ground radiometer, based on a standard photodiode equipped with 3 bands centered at 550, 650, 850 nm provides the ground reflectance in the 3 SPOT multispectral channels. For MOMS bands, shifted with regards to SPOT, the spectrometer ZEISS-MCS[2] was used to measure the ground reflectance, the total and diffuse downwelling irradiance. The last two parameters lead to the atmospheric direct transmittance from which the aerosol optical properties will be derived. This method although indirect, offers the advantage to give spectral information and thus to separate the contribution of most important gazeous constituents and aerosols. This technique was assessed for the first time during this campaign, and the proven method based on the

sunphotometer and ground radiometer, already operational for SPOT calibration, will be used here as a validation principle.

3. SPECTRAL REFLECTANCE OF THE TEST SITE

3.1 Ground reflectance measurements

Reflectance measurements were made with the Zeiss … MCS … Spectrometer [2] in the spectral range 360 … 950 nm with a spectral resolution of 3 … 4 nm; the spectral sampling interval was 0.8 nm. The field of view on the ground was about 40 x 40 cm^2. As white reference a Ba SO_4 … coated panel with calibrated reflectance was used.The reflectance measurements were made inside the so called measuring box (Fig .2) of approx. 50m x 50m.

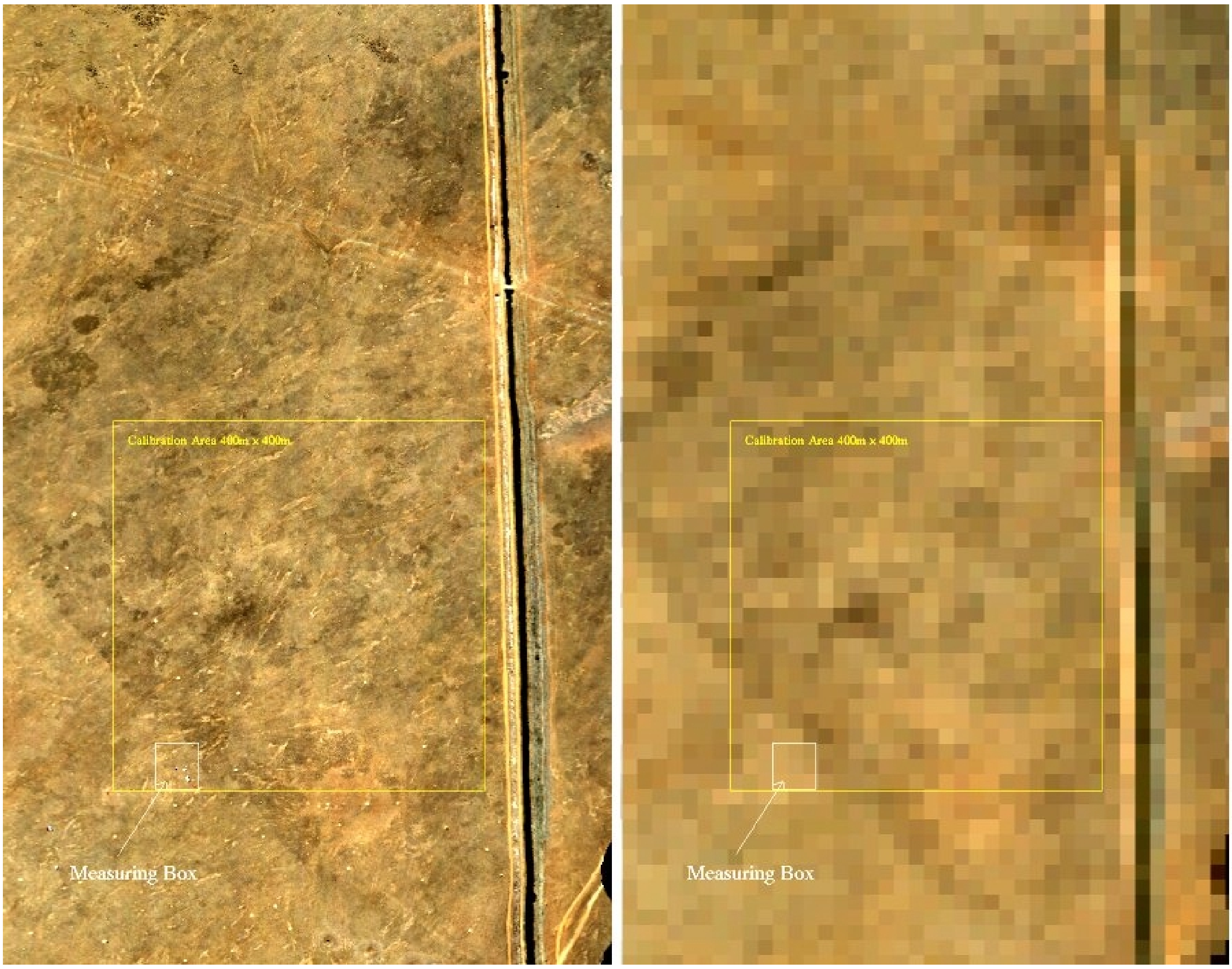

Fig. 2: Daedalus image of test site from 300m altitude with calibration area and Measuring Box , left: 0.8m x 0.8m ground pixel size, right: resampled to 18m x 18m ground pixel size.

During 10:52 and 11:45 GMT on 2 July 1998 250 reflectance measurements were made. The average reflectance curve derived from these measurements and its standard deviation is shown in Fig 3. Ground reflectance measurements on 29 June 1998 lead to the same results.

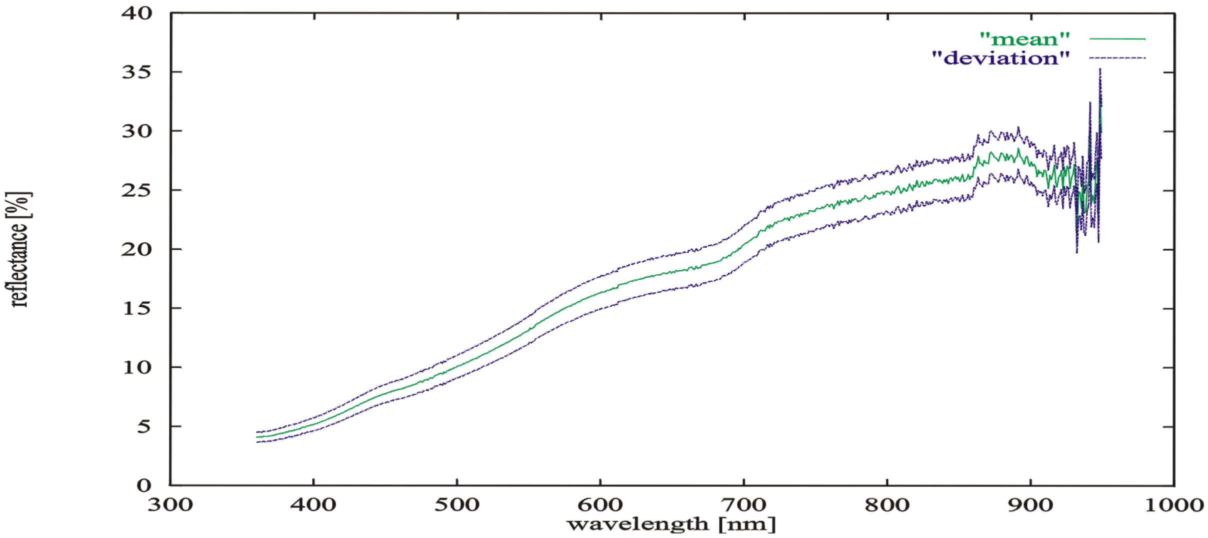

Fig. 3: Ground reflectance (r) and standard deviation measured 2 July 1998.

3.2 Spatial extrapolation of reflectance by means of airborne multispectral images

The test site was recorded from 300 m altitude with the 11-channel multispectral scanner Daedalus AADS 1268 (.Table 1) with a ground pixel size of approx. 0,8 x 0,8 m. The overflight took place at 11:30 GMT on 2 July 1998; at the same time the ground irradiance was measured

The full resolution Daedalus image is shown in Fig. 2 (left). To eliminate scan angle effects due to path radiance and atmospheric transmittance the radiance values of each pixel along the scan line were relatively adjusted to those in the position of the measuring box (Fig. 2).

Dividing the radiances measured in the channels of the Daedalus Scanner by the respective ground irradiances give reflectances (r_{300}) as seen from 300 m altitude (Table 1). The scanner and the ground radiometer were calibrated with the same standard calibration source. To determine the reflectance for Daedalus-channel 9 (1.57-1.78 µm the incoming irradiance was computed with the 6S-program (see chapter 5).
The reflectance values r_{300} are compared in table 1 with ground reflectances r of Fig. 3.

Channel	λ_{eff} [µm]	Band Edges [µm]	r_{300} [%]	r [%]
1	0.439	0.424 … 0.450	5.40	7.25
2	0.494	0.465 … 0.520	9.46	9.72
3	0.564	0.522 … 0.600	13.51	14.24
4	0.615	0.594 - 0.634	16.86	17.06
5	0.660	0.626 … 0.690	18.38	18.23
6	0.728	0.692 … 0.759	20.14	22.47
7	0.835	0.756 … 0.906	25.11	25.90
8	0.960	0.897 … 1.022	*not used*	*not used*
9	1.677	1.571 … 1.780	30.50	30.50

Table 1: First nine spectral channels of Daedalus AADS 1268 airborne scanner, measured reflectances from 300m altitude (r_{300}) as well as ground measured reflectances (r).

Due to atmospheric influences both reflectance measurements are not identical.

From Table 1 a correction function can be obtained with which the r_{300} … values for each pixel can be converted to equivalent ground reflectances r [7].
The corrected average reflectance from all pixels of 0.8 x 0.8 m^2 in the 400 x 400 m^2 test site and its standard deviation can be obtained from the Daedalus image.

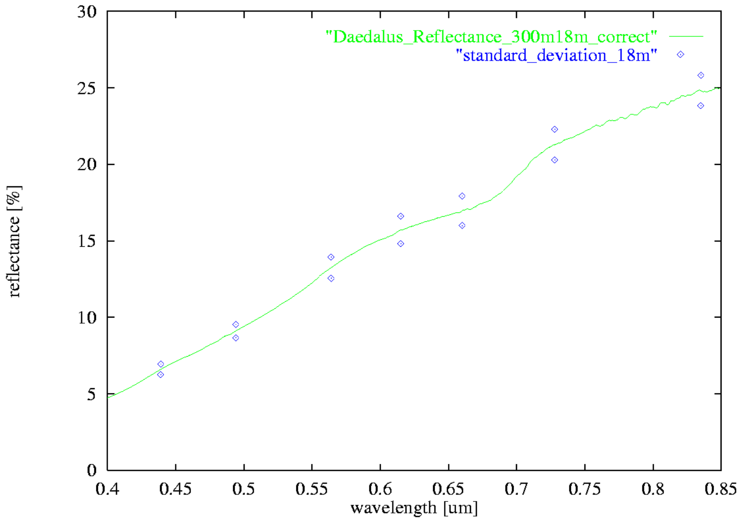

Fig.4: Average reflectance and standard deviation of the 400m x 400m calıbratıon site of La Crau for 18m x 18m ground pixel size.

MOMS and SPOT ground pixels have a square size of 18 m respectively 20 m. A Daedalus image processed to 18 m ground resolution as seen by SPOT and MOMS is shown in Fig. 2 (right). The reflectance standard deviation of this 18 m … pixel image (Fig. 4) is reduced by a factor of 2 in comparison to the 0.8 m … pixel image and is in the order of 4,4 %. This is a measure of the spatial homogeneity of the test site as seen from SPOT and MOMS. It is assumed that the reflectance curve derived for 2nd July is also valid for 29th June.

3.3 Comparison of reflectance data sets

The CIMEL ground radiometer was used the 29th June before and after SPOT overpass. It was hand held and scanned the whole area and acquired a sequence of several hundred values, with an instantaneous foot print of approx. 10 by 10 cm². A measurement of a BaSO4 white reference was used to convert the data into directional hemispherical reflectance. The mean value allow a comparison at three wavelengths with the spectral reflectance curve obtained with corrected Daedalus data. The results are in good agreement (Fig. 5). The standard deviation of the CIMEL measurements shows the variability of the site at the measurement scale.

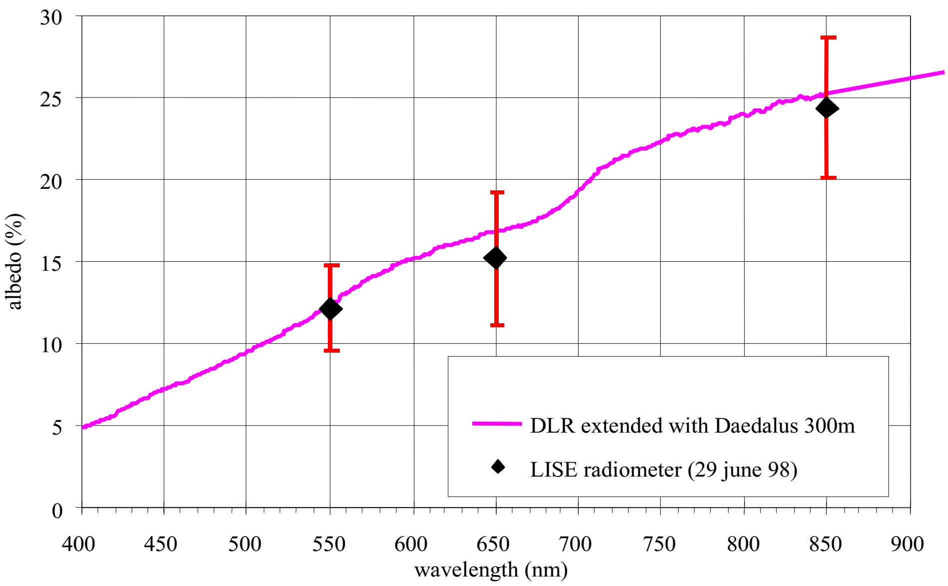

Fig. 5: Ground reflectance of La Crau test site. (The reason that the reflectance measured with the ZEISS radiometer (see Fig.3) is higher than the average reflectance obtained from the corrected Daedalus data is due to the fact that the ZEISS measurements were made in the Measuring Box only, which has a lighter tone than the average Calibration Area .)

4. OPTICAL PARAMETERS OF THE ATMOSPHERE

4.1 Ground irradiance

To determine the optical parameters of the atmosphere the downwelling total irradiance and the skylight irradiance was measured with the Zeiss MCS-Spektrometer. For measuring the skylight the direct sun light was covered by a little plate of appr. 5 cm diameter [7].

The total irradiance is given by the following formula:

$$E_t = E_s \cdot \cos\vartheta + E_{sky} \qquad (1)$$

E_t : Total irradiance
E_s : Direct sun irradiance on a surface vertical to the radiation direction
E_{sky} : Skylight irradiance
ϑ: Sun zenith angle; can be determined from geographical coordinates and time
E_t and E_{sky} were measured nearly simultaneously [Fig. 6].

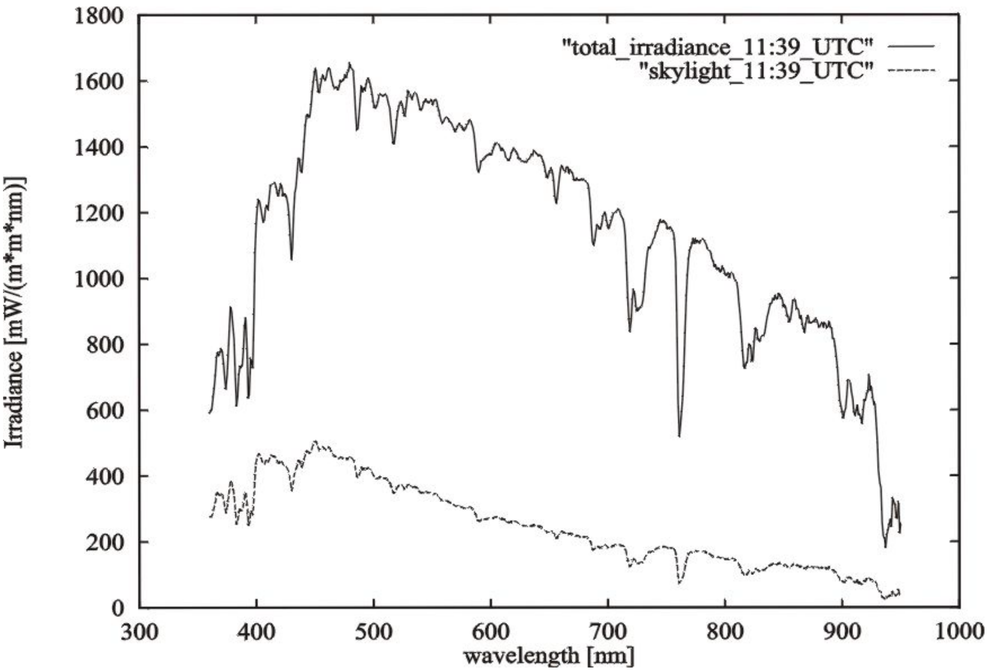

Fig 6: Measurement of total irradiance E_t and skylight irradiance E_{sky} at 11:39 GMT, 2 July1998 (sun zentith angle= 20.56°)

4.2 Atmospheric transmittance

The direct sun irradiance can also be written as:

$$E_s = E_o \cdot T^{1/\cos\vartheta} \qquad (2)$$

T : Atmospheric Transmittance
E_o : Extraterrestrial irradiance
Combining (1) and (2) gives the atmospheric transmittance:

$$T = \left(\frac{E_t - E_{sky}}{E_o \cdot \cos\vartheta} \right)^{\cos\vartheta} \qquad (3)$$

For the extraterrestrial sun irradiance E_o data compiled by Neckel and Labs [3] can be used. Due to the changing distance between sun and earth during the year the Neckel and Labs data have to be corrected with the factor $\left(1 + 0.016\cos\left(\frac{2\Pi(D-3)}{365}\right)\right)$, where D is the day of the year.

Transmittance spectra for 10:56 and 11:39 GMT for 2 July 1998 derived by means of equation (3) are shown in Fig. 7.

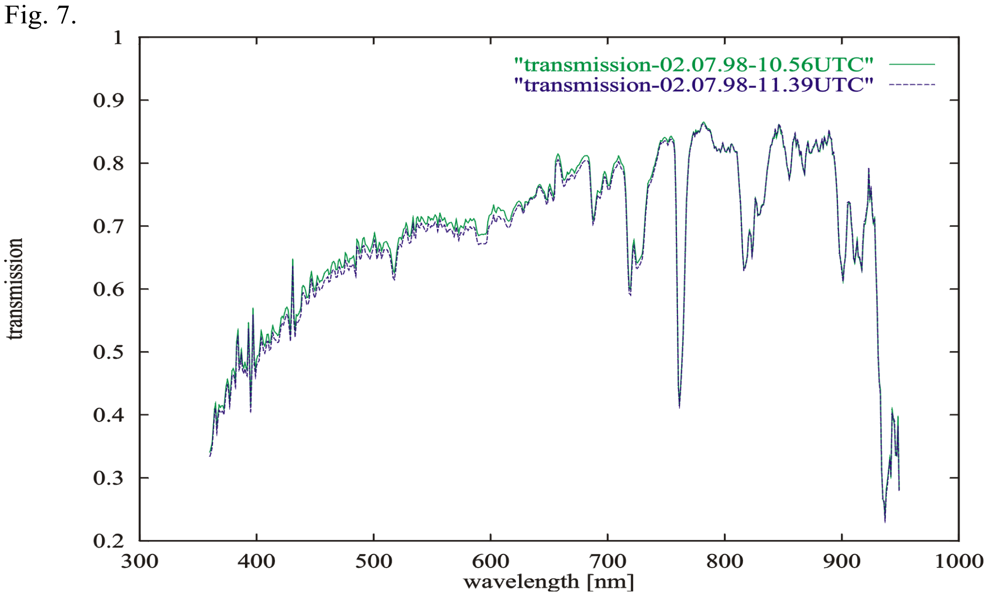

Fig. 7 Atmospheric transmittance for 10:56 and 11:39 GMT, 2 July 1998

From these curves it can be found that the optical thickness of the atmosphere for this day (τ = -ln T at λ=0.55µm) is as follows:

$\tau =$ 0.34 at 10:56 GMT (SPOT-01)

$\tau =$ 0.35 at 11:39 GMT (MOMS-2P)

From the CIMEL measurements and from modelling with the 6S program (see chapter 5) the optical thickness was determined to be between 0.33 and 0.34 [8], which is in good agreement with the above measurements.
For 29th of June the optical thickness was found to be $\tau =$ 0.40.
These optical thickness values are used in the 6S … atmospheric radiation transfer model (s. next chapter).

5. UPWELLING RADIANCE

To compute the upwelling radiance the 6S-atmospheric radiation transfer model developed by the university of Lille [4] was used. The input parameters for this program are the geometrical conditions, which can be obtained from the location and time, the atmospheric model i.e. the optical thickness at 0.55 µm and the aerosol type and the ground reflectance.

The ground reflectance can be taken from Fig. 4. The optical thickness was determined by means of equation (3) To find the appropriate aerosol type the downwelling total irradiance was computed with the 6S-program for different aerosol types and compared with the actual measured irradiance spectra. For 29 June 1998 the best fit of the computed to the measured data was obtained for a continental aerosol type (Fig.8). The mean deviation over the spectrum from 360 to 900 nm is less than 2.5%. This figure can be regarded as an accuracy figure for the atmospheric model.
For 2nd July it was found that a best fitting for both data sets (at 10:56 and 11:39) could be obtained for maritime aerosols (Fig. 9). The mean deviation over the spectrum from 360 to 900 nm is not more than 3%.
The explanation that maritime aerosols are the right choice for 2 July 1998 is probably that during the measurements Cirrocumulus developed from the seaside to the northwest of the test site.
From the CIMEL measurements also the Ångstroem coefficient was determined; its value was found to be …1.1. This value is more an indication for a continental aerosol type, but a slight mixture with maritime aerosols may

have occured [8]. In spite of this indication for continental aerosols the maritime aerosol type was used for the 6S-modelling.

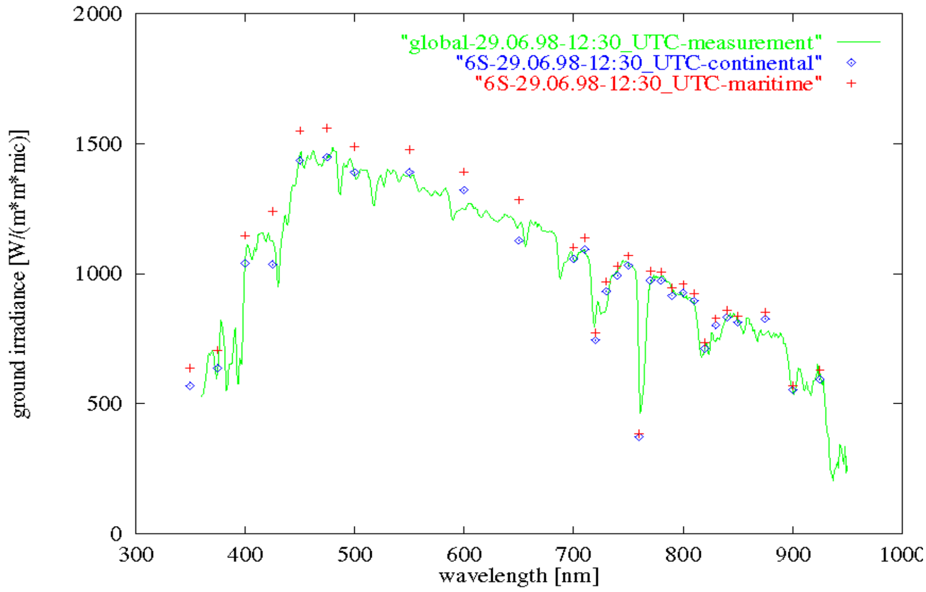

Fig.8: Comparison of measured irradiance (solid line -) at 12:30 GMT with optical thickness τ=0.4 and computed irradiances with continental (◊) and maritime (+) aerosol type.

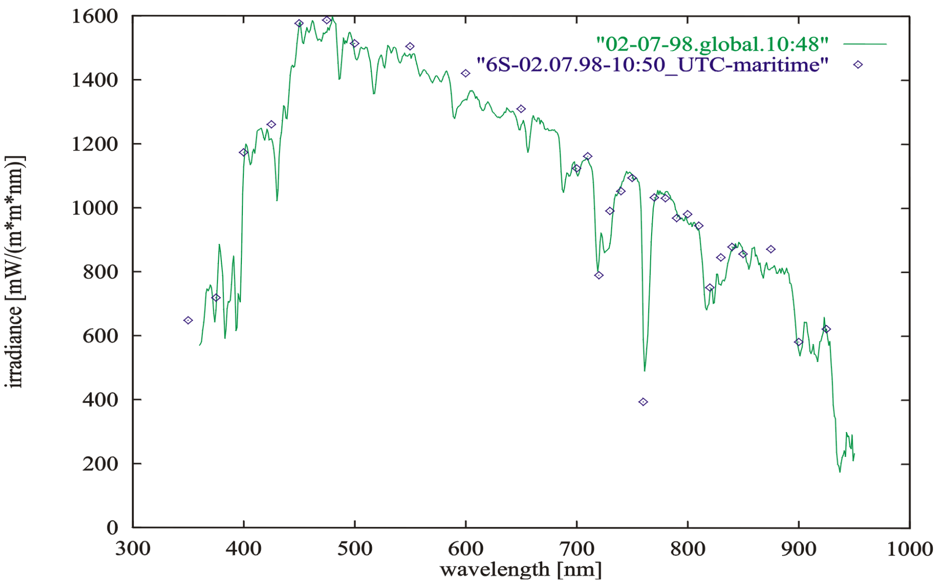

Fig. 9: Comparison of computed (◊) and measured irradiance (solid line -)at 10:48 GMT with optical thickness τ= 0.34

The upwelling radiance L was computed for each spectral channel of SPOT-1 and of MOMS-2P for the time the satellite cameras recorded the test site (Table. 2):

$$L = \frac{\int L_\lambda \cdot R_\lambda \cdot d\lambda}{\int R_\lambda d\lambda} \tag{4}$$

L_λ: spectral upwelling radiance
R_λ: spectral sensitivity of the channel

6. CALIBRATION

Under the assumption that a linear relation between input (radiance L) and output (Digital Number DN) exists the absolute calibration factor A can be determined from:

$$DN = A \cdot L \qquad (5)$$

The absolute calibration factor is the product of the absolute colibration coefficient A\` and a gain factor G_m:

$$A = A' \cdot G_m \qquad (6)$$

$Gm = 1.3^{(m-3)}$ m=1,2,3, ,8 for SPOT-1
$Gm = \sqrt{2}^{\,(m)}$ m=0,1,2, ,7 for MOMS-2P
$Gm = 1.5^{(m-2)}$ m=1,2,3, ,8 for SPOT-4

The calibration factor for each spectral channel was derived from the computed upwelling radiances and the corresponding average Digital Number of the Calibration Area in the SPOT and MOMS-2P images. Table 2 shows the values for MOMS-2P, SPOT-01 and SPOT-04 images.

Time	Sensor	Gain	Channel *µm*	Upwelling Radiance L *mW/(sr m² nm)*	DN	Calibration factor *(sr m² nm)/mW* A	A\`
29 June 1998 10:51 GMT Sun Zenith: 23.15°	SPOT 4 HRVIR-2	3	0.50-0.59	74.2	82.79	1.116	0.744
		3	0.61-0.68	73.0	102.29	1.401	0.934
		2	0.78-0.89	65.9	66.26	1.005	1.005
		3	1.58-1.75	20.1	172.48	8.581	5.721
02 July 1998 10:50 GMT Sun Zenith: 23.40°	SPOT 1 HRV-1	8	0.50-0.59	80.0	120.38	1.505	0.405
		8	0.61-0.68	82.4	88.38	1.073	0.289
		7	0.78-0.89	72.2	104.73	1.451	0.508
02 July 1998 11:47 GMT Sun Zenith: 20.60°	MOMS-2P	2	0.449-0.511	89.1	116.02	1.302	0.651
		2	0.532-0.571	84.4	116.67	1.382	0.691
		5	0.645-0.677	83.5	179.86	2.154	0.381
		1	0.772-0.815	82.3	125.20	1.521	1.076

Table 2: Calibration factors for MOMS-2P, SPOT-01 and SPOT-04 derived from upwelling radiance computed with the 6S-program and corresponding average Digital Number (DN) of the calibration area.

7. DISCUSSION

For SPOT-01 calibration besides La Crau other test sites, e.g. White Sands, and also other methods (lamp calibration) are used. From all these measurements a ´best estimate´ for the calibration factor is derived.
The obtained calibration factors for SPOT-01 (Table 2) differ only slightly from the published best estimate : 4.73% (XS 1), 0.31% (XS 2) and 2.34% (XS 3). For SPOT-04 the agreement with official published calibration factors is in all channels better than 5%. The calibration accuracy of SPOT by various methods is estimated by A. Meygret et al. [6] to 4-8%.
The good agreement between the actual and the previous calibration measurements for SPOT-01 shows that the applied methods are reasonable. As the measurements for MOMS-2P and SPOT-4 were carried out under the same environmental conditions as for SPOT-01 and with the same methods it can concluded that they also lead to reasonable results.
With respect to MOMS-2P two remarks have to be made:

- The weather situation for vicarious calibration was not optimal on 2 July 1998 because some clouds developed near the test site between SPOT-01 and MOMS-2P overflight. This may have affected the calibration of MOMS-2P at 11:47 GMT.

- The calibration values for MOMS-2P (Table 2) are for all channels by 25-39% lower than those obtained 16 months earlier with inflight sun calibration [5]. A clear reasonable explanation for this change can not be given. There may be two assumptions:
  (1) a real loss in sensitivity occurred which is in line with the operational experience that the gains have to be set one value higher than before to get high quality images or
  (2) the inflight sun calibration was incorrect probably to an incorrect reflectance figure of the diffuser plate used in the calibration procedure.

8. CONCLUSIONS

The following conclusion can be drawn from the presented investigations:

- Vicarious calibration delivers reliable and repeatable result
- Atmospheric radiation transfer programs with sufficient accuracy exist for vicarious calibration
- Good calibrated space sensors as SPOT can be used for intercalibration of new sensors
- The increased number of satellites and the different data types make intercalibration an essential task

9. ACKNOWLEDGEMENTS

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