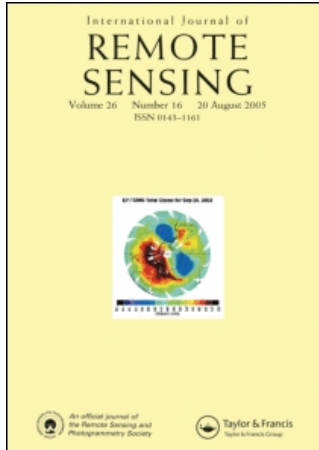


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La Crau: a European test site for remote sensing validation

G. RONDEAUX†, M. D. STEVEN†, J. A. CLARK‡
and G. MACKAY§

†Department of Geography, University of Nottingham, Nottingham, NG7 2RD, England, UK

‡Department of Physiology and Environmental Science, University of Nottingham, School of Agriculture, Sutton Bonington, Loughborough, LE12 5RD, England, UK.

§Department of Geography, University of Leicester, Leicester, LE1 7RH, England, UK.

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Abstract. Well characterized reference sites are of major importance for the calibration of remote sensors and the validation of retrieval algorithms. A 0.4 km square zone of 'La Crau', an arid area in the South of France, is well established for the calibration of SPOT HRV sensors, and has been regularly used for a variety of remote sensing campaigns. This study reports an investigation of the potential use of a more extended area of La Crau as a validation site for lower spatial resolution satellite sensors. Sample Bidirectional Reflectance Distribution Function (BRDF) measurements were acquired over a large part of the area of La Crau during a 3-week period in July 1995. The data were analysed to provide a detailed spectral characterization of the surface of La Crau and its temporal, directional and spatial variability. The results were used to simulate the three optical channels and the 1.6 μm channel of the ATSR-2 sensor and compared with ATSR-2 image data from the site.

1. Introduction

Confidence in the retrieval of surface physical properties from remotely sensed satellite data requires accurate calibration of the satellite sensors and validation of the retrieval algorithms. Both calibration and validation procedures can be performed efficiently, at least in the visible and near-infrared domains, by ground-based measurements on a well defined test site concurrent with satellite overpass. For the purpose of calibration (Slater *et al.* 1987), the radiance at the satellite level can be estimated from atmospheric parameters and the measured Bidirectional Reflectance Distribution Function (BRDF) of the ground surface. Absolute calibration coefficients are then determined by comparing the estimated top-of-atmosphere (TOA) radiance to the mean digital signal for the calibration site on the satellite image (Gu *et al.* 1992). Conversely, validation studies aim to compare pre-calibrated satellite radiance measurements with the radiance estimated from ground BRDFs of known surfaces and atmospheric parameters.

Both procedures require precise knowledge of the physical characteristics of the surface and of the state of the atmosphere at the time of satellite observation. Reference sites must be flat surfaces that can be regarded as uniform over an extended area of several pixels in all directions. The residual variability of such sites must be well characterized by appropriate sampling procedures. The accuracy of BRDF

measurements is critical to the understanding of the radiative exchanges which determine the radiance reading at the satellite.

A well established study site, which has been used regularly for remote sensing experiments for some years, especially for the calibration of SPOT HRV sensors, is 'La Crau sèche' (43°33' N, 4°51' E) between Arles and Marseille in the South of France (figure 1). La Crau is a flat area roughly 15 km × 10 km in extent, covered with large pebbles and sparse low vegetation. A square area of 400 m × 400 m in the middle of La Crau has been carefully chosen for the absolute calibration of the SPOT HRV instrument (Gu *et al.* 1990). SPOT calibration using this area is now a reliable and routine procedure. The aim of this study was to investigate the suitability of the remaining area of La Crau sèche for use as a calibration and validation site for lower spatial resolution satellite sensors.

A field campaign was conducted in July 1995, to coincide with a SPOT calibration campaign, to test La Crau as a validation site for ATSR-2 land surface data products. This paper reports measurements of the BRDF of La Crau in the four ATSR-2 channels, and attempts to quantify the spatial variability of the wider site in relation to the established SPOT site.

2. La Crau

'La Crau sèche' (The dry Crau) is a 60 km² flat area in the south-east of France, on the eastern bank of the river Rhône, about 50 km north-west of Marseille (Gu *et al.* 1990). This area has a dry and sunny Mediterranean climate, which is hot and dry in summer but can be cool and wet in winter. However the precipitation on La Crau is only about 610 mm *per annum*, so that the natural ecology approximates to a semi-desert. In July the remaining vegetation is typically dry and dead, after several months without rain. There is a seasonal flush of green vegetation in late winter and spring when the soil is wet, but for much of the year La Crau presents an essentially constant surface. Another non-negligible advantage for remote sensing studies comes from the 'Mistral', which often blows strongly down the Rhône valley, leaving the area cloud free for extended periods.

The surface of La Crau is composed of a reddish sandy clay soil, pebbles and a sparse cover of vegetation. The most arresting visual features are the irregularly spaced pebble cairns built by prisoners of war in World War Two to prevent airborne landings. The cairns dominate the otherwise featureless landscape, but occupy a trivial area and will have a negligible effect on the radiative properties, except for a few minutes at sunrise and sunset. In the winter and spring La Crau is grazed by large flocks of sheep. In the heat of summer the sheep are moved to alpine pastures, leaving La Crau the domain of grasshoppers and the occasional itinerant bird-watcher or scientist. A handful of large rectangular sheepfolds are distributed over La Crau. Irrigation canals also cross the area.

Concerns were expressed about 10 years ago when the unique landscape of La Crau sèche started to experience new encroachment for cultivation. Three large orchards were established on the south-west side of La Crau, one of which extends to within 0.5 km of the existing SPOT site. On the north side, past attempts at ploughing are still visible. However, La Crau sèche is now a zone of 'special protection', and was acquired in December 1996 by the 'Conseil général des Bouches du Rhône', making it a valuable reserve for both science and wildlife.

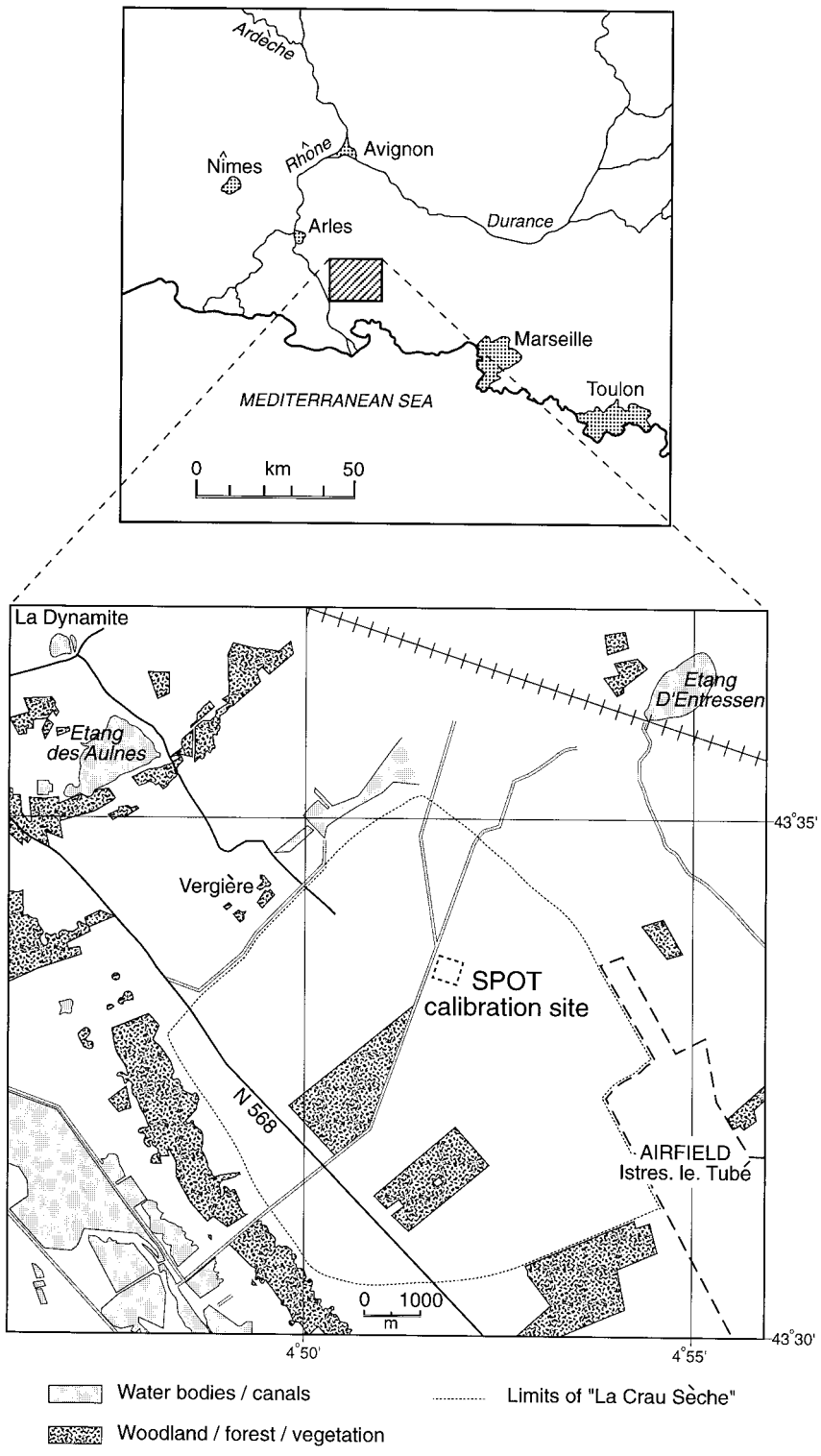


Figure 1. Location map of La Crau 'sèche' in the south of France.

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3. Materials and methods

3.1. ATSR-2

The ATSR-2 instrument, launched on the ERS-2 satellite in April 1995, is a development of the Along Track Scanning Radiometer (ATSR) on ERS-1. ATSR-1 is primarily a thermal scanning instrument and the main modification is that ATSR-2 carries three additional channels in the visible and near-infrared, complementing the existing ATSR-1 1b channel ($1.61 \mu\text{m}$) operating in the reflected solar spectrum. The spatial resolution of ATSR-2 is similar to the Advanced Very High Resolution Radiometer (AVHRR), with a pixel size at nadir of about 1 km, but the ATSR-2 spectral bands are narrower. The four ATSR-2 bands considered here are:

$$V1 = 0.545\text{--}0.565 \mu\text{m}$$

$$V2 = 0.649\text{--}0.669 \mu\text{m}$$

$$V3 = 0.855\text{--}0.875 \mu\text{m}$$

$$1b = 1.58\text{--}1.64 \mu\text{m}$$

The particular feature of the ATSR is that the conical scan geometry of the sensor system provides views of the surface at two angles—at nadir and a forward view at about 55° (Prata *et al.* 1990). Consequently, radiances measured in the along track view are available, in addition to near-simultaneous nadir view radiances of the same targets.

3.2. Surface measurements

Bidirectional surface reflectance measurements were performed with a Geophysical Environmental Research Inc. Single Field-Of-View IRIS (SIRIS) high spectral resolution radiometer on loan from the NERC-EPFS (UK Natural Environment Research Council Equipment Pool for Field Spectroscopy). The SIRIS is a high-performance field spectroradiometer operating from $0.35 \mu\text{m}$ to $2.5 \mu\text{m}$, comprising two units: an optical head and a portable PC control (figure 2). The instrument has an angular field-of-view of $13^\circ \times 5^\circ$, corresponding to an area on the ground of approximately $34 \text{ cm} \times 13 \text{ cm}$ when viewing at nadir from a working height of 1.5 m. The SIRIS was fixed on a mounting plate on a tripod to enable measurements in different inclinations and orientation. A white halon panel was used as a reflectance reference.

To obtain a good representation of the site, data were acquired at a set of sample areas randomized around La Crau, assessing a different area each day. Within each area, the SIRIS (on the tripod) was positioned successively at different sampling points. From each point, data were taken in the solar plane, the perpendicular plane and the two 45° planes, at five inclination angles: -55° , -30° , 0° , 30° and 55° , with the orientation of the planes following the sun while performing the measurements. Reference measurements with the halon panel were taken at regular intervals. Thus, each BRDF data set includes 21 spectra, taken in the following order: reference panel, nadir view, 30° view for azimuths of 0° (toward the sun), 45° , 90° , 135° , 180° , 225° , 270° and 315° , a second reference panel measurement, a repeat of the eight azimuths with the 55° viewing angle, and a final nadir and reference panel measurement. The full sequence lasted about 1 h.

A total of 36 full BRDF datasets were acquired under clear sky conditions over a period of 3 weeks in July 1995. The dates of the measurements were 4, 6–9, 11–13,



Figure 2. The set-up of the GER-SIRIS spectroradiometer for BRDF measurement of La Crau.

16, 17, 19, 21 and 22 July. Complementary spectra were also taken in key view directions recorded by ATSR-2 at the time of overpass on the overpass days. These corresponded to the centre and cross track limits of the ATSR-2 forward and nadir scans. ATSR-2 filter functions were applied to all spectra to determine ground reflectances in the four ATSR-2 bands.

4. Data analysis

4.1. Spatial variability and satellite data

Previous measurements of the spatial variability of the reflectance of 'La Crau sèche' were reported by Gu *et al.* (1990). These measurements were made in the SPOT bands at different scales (from 0.5 m to 20 m pixels) and were used to select the location of the SPOT calibration site as well as to estimate the mean vertical reflectance of this site. The study of Gu *et al.* showed that La Crau offered a relatively homogeneous surface, and that the variability in the reflectance was mainly due to the contrast between soil and vegetation. It also showed that when the dimension of the pixels was increased from 0.5 m to 20 m, the coefficient of variation decreased, but this reduction was relatively small because surface heterogeneities are distributed rather uniformly at these different scales, as a consequence of variations in the proportions of pebbles and vegetation cover. For pixel sizes larger than 10 m, the coefficients of variation were stable at around 4% in the SPOT bands.

The spatial resolution of ATSR-2 nadir pixels is approximately 1 km, larger than the dimensions of the SPOT calibration site. Table 1 gives the ATSR-2 TOA reflectances and their coefficients of variation of the site of La Crau acquired on two dates during the 1995 campaign. These values are taken from raw data without any

Table 1. Top-of-atmosphere (TOA) reflectances (%) for the La Crau terrain and their coefficients of variation (in italic), estimated from raw ATSR-2 data (approximately 20 pixels).

TOA reflectance (%) and <i>coefficient of variation (%)</i> of ATSR-2 data of La Crau		V1 (0.56 μm)	V2 (0.66 μm)	V3 (0.87 μm)	1b (1.6 μm)
19 July 1995	Nadir view	13.09 <i>4.09</i>	16.44 <i>4.75</i>	25.74 <i>4.43</i>	35.29 <i>2.44</i>
	Forward view	12.19 <i>5.60</i>	13.61 <i>6.74</i>	23.02 <i>3.02</i>	27.90 <i>4.53</i>
22 July 1995	Nadir view	13.04 <i>2.92</i>	16.31 <i>4.37</i>	24.14 <i>4.58</i>	33.64 <i>1.7</i>
	Forward view	12.95 <i>2.85</i>	14.87 <i>3.41</i>	23.78 <i>2.27</i>	28.07 <i>2.18</i>

atmospheric correction, for an area of about 20 pixels which appears quasi-uniform on the images. Despite the coarser spatial resolution and the larger area of the site, the coefficients of variation are similar to the 20 m scale coefficients of variation found by Gu *et al.* (1990, 1992) for the SPOT reference subsite.

4.2. Mean reflectance

A typical ground reflectance spectrum for La Crau measured on site can be seen in figure 3. This spectrum is similar to that of bare soil, with reflectance increasing steadily from the visible to the near-infrared. The influence of the scarce natural vegetation is therefore limited at this time of the year. Absorption features in the infrared are evident around 1430–1450 nm and more strongly around 1820–1900 nm, but are not relevant to our analysis which concentrates on the ATSR-2 bands.

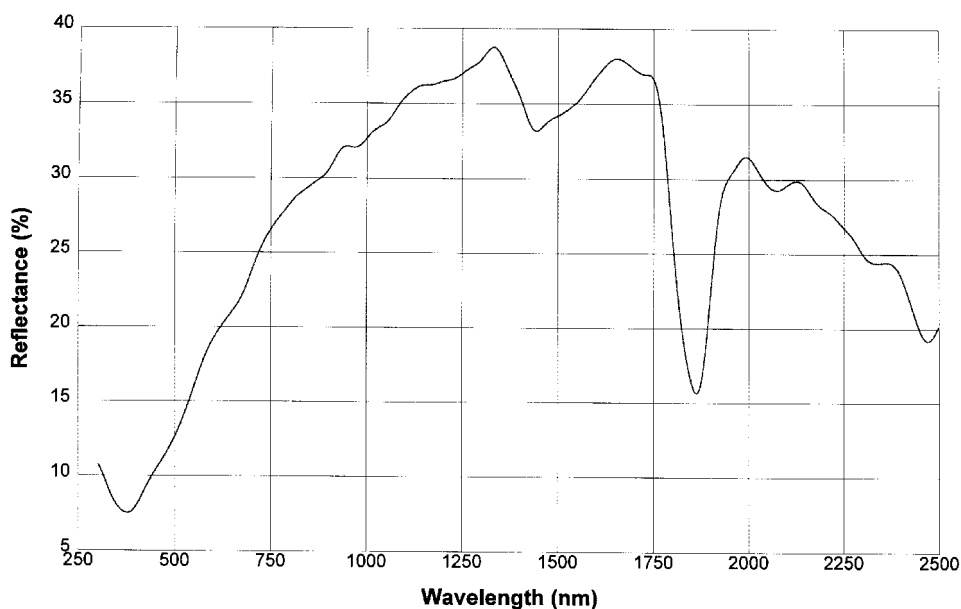


Figure 3. Average surface reflectance spectrum of La Crau.

The nadir reflectance measurements taken across the whole site during the 3-week period, totalling 100 spectra, are summarized in table 2. The standard deviations about the means are between 2 and 4%, much lower than the mean reflectances, indicating the relative homogeneity of the site. Mean values in the three first bands are consistent with those obtained in the previous study of La Crau (Gu *et al.* 1990). Standard deviations of absolute reflectance and the corresponding coefficients of variation are slightly higher than the 1 to 2% standard deviation and 5 to 10% coefficient of variation recorded by Gu *et al.* (1990). The difference can be explained by the fact that our data cover a larger part of La Crau, whereas the previous study characterized the variability of the SPOT calibration site only.

4.3. The landscape components

The surface of La Crau is covered with pebbles and a sparse low, dry vegetation. Separate spectra for a bed of stones, a vegetation patch (as seen in figure 2) and a patch of bare soil were acquired independently of the other measurements in order to estimate the relative contributions of each of these components to the reflectance signal. The stone and vegetation spectra were taken as near as possible to the hot-spot geometry to avoid any shadow effects. The bare soil data were measured at nadir.

These spectra are plotted in figure 4. All the curves follow a general similar pattern. As the vegetation was dry, its spectrum does not show the typical reflectance spectrum of green vegetation in the visible and near-infrared. Differences from the other spectra appear mainly in stronger absorption features in the infrared wavelengths. The pebbles covering the ground are highly reflective over most of the spectrum. The contrast between pebbles, soil and vegetation is only about 5% in the near-infrared (800–1300 nm), increasing to about 10% in the visible and the middle-infrared bands. Reflectance values in the ATSR-2 bands corresponding to these spectra are shown in table 3.

The total reflectance of La Crau could be described as a combination of the responses of these three main components. However, an estimate of the typical proportions of pebble, soil and vegetation would be needed and adjusted for shadow effects associated with the pebble pavement and vegetation architecture. Some seasonal variation of the reflectance of La Crau would be expected, especially when the vegetation is greener. However the relative homogeneity of the site is expected to stay constant enough for validation purposes. Gu *et al.* (1990) studied the evolution of the coefficient of variation of the mean radiance of the SPOT calibration site, in the SPOT channels, over time. They found very little change in the coefficient of

Table 2. Summary statistics of the ground reflectance measurements at nadir taken on La Crau for the ATSR-2 bands during July 1995 (100 spectra). The data cover a range of solar zenith angles from 21° to 70°.

	V1 (0.56 µm)	V2 (0.66 µm)	V3 (0.87 µm)	1b (1.6 µm)
Mean reflectance (%)	16.30	21.79	30.99	38.59
Maximum	24.65	33.13	39.95	46.68
Minimum	10.68	14.52	20.94	26.06
Standard deviation (%)	2.47	3.18	3.36	4.02
Coefficient of variation (%)	15.14	14.60	10.85	10.42

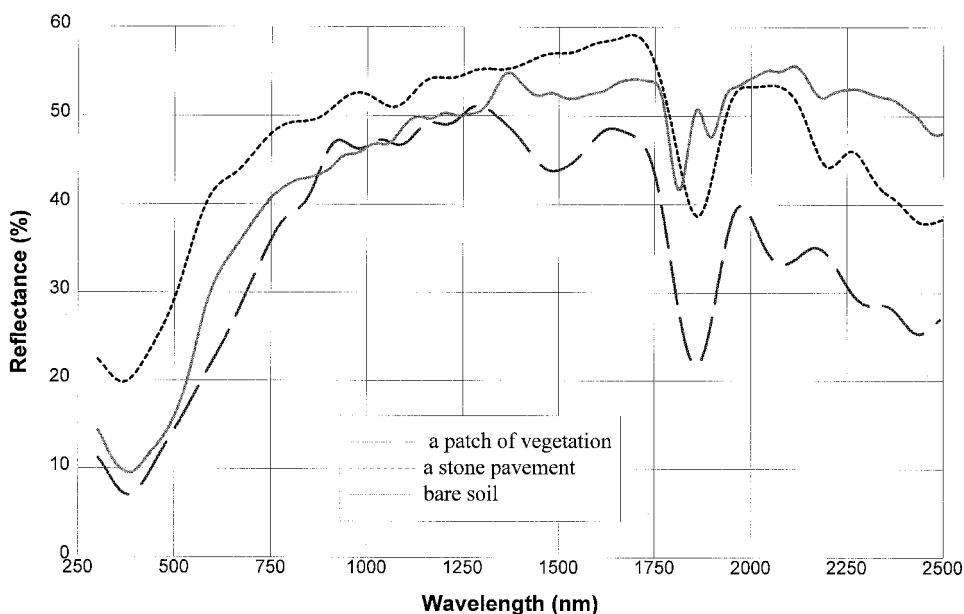


Figure 4. Reflectance spectra of the landscape components of La Crau: pebbles (— —), vegetation (— —) and bare soil (— —).

Table 3. Reflectance values of the main components of the surface of La Crau.

Reflectance (%)	V1 (0.56 μm)	V2 (0.66 μm)	V3 (0.87 μm)	1b (1.6 μm)
Vegetation patch	18.7	26.8	40.8	48.1
Pebble bed	37.4	43.4	49.3	58.3
Bare soil	23.7	35.2	43.3	52.7

variation, demonstrating its good temporal stability, although these results were from raw SPOT data without any atmospheric correction.

4.4. Diurnal variability

The effect of the range of sun angles on the data was evaluated by analysing the variation in all the nadir data acquired during the campaign as a function of the corresponding solar zenith angle at the time of measurement. No significant trend appeared in any of the ATSR-2 bands. The increase in mean reflectance was about 3% only when the solar zenith angle changed from 20° to 70°, demonstrating the independence of the nadir reflectance of angle of illumination over this range.

4.5. Bidirectional reflectance

Very few natural surfaces meet the specifications of a Lambertian surface. In general the spectral BRDF depends on the nature of the surface and much of its behaviour can be described in terms of the phase angle (sun–surface–sensor) which depends on latitude, season, time of day and sensor orientation. For a given solar zenith angle, the shape of the BRDF is usually a smoothly varying function, with

the following two nodal points. (i) As the phase angle approaches zero, a marked increase is observed in bidirectional reflectance due to the disappearance of shadows as the viewing position converges on the solar direction, a phenomenon known as the 'hot-spot'. (ii) A component of specular reflection may also be observed over smooth surfaces (although these are not common on land) when the view direction is towards the sub-solar point.

An ideal BRDF would consist of data viewing the same target from different directions at the same instant. In our study, to minimize problems of equipment alignment, each BRDF was constructed by viewing the surroundings from a central point, rotating the radiometer head about the support axis to complete a set of measurements in the shortest possible time. However, as long as the surface conditions are sufficiently uniform, such measurements can be treated as representative of a true BRDF. Alternatively, each point on the BRDF represents a different sample of the landscape subarea.

Figure 5 shows the overall variation of the bidirectional reflectance factor of La Crau normalized against the corresponding mean nadir reflectance. The data were averaged for each viewing angle. The highest ratios (up to 1.35) were obtained in the backscattering (downsun) direction (180° relative azimuth), close to the hot-spot. Particularly high values were found in the $1.6\ \mu\text{m}$ channel, where up to 69% reflectance at a 55° viewing angle was recorded. Reflectance in the plane normal to the sun (azimuths of 90° and 270°) was within 2% of the values at nadir. The lowest values were obtained when looking toward the sun (azimuth of 0°) despite noticeable specular reflection from some of the stones. The range of variation was greatest in the near-infrared (V3) and infrared (1b) channels. In contrast, Gu *et al.* (1992) found that the hot-spot was least marked in the SPOT-XS3 band because of the sparse vegetation.

During the field campaign reported here, surface measurements were taken from a different sampling area each day. Within each sampling area, two to four BRDFs were acquired. Sampling areas were typically about 1–2 km apart and within an area, sampling points of BRDF measurement were about 10–50 m apart, avoiding the cairns. Visually, the surface conditions in a particular area were quite uniform, but slight differences were sometimes noticeable from one sampling area to the next in the relative proportions of pebbles, bare soil and vegetation cover. Despite such visual differences, the standard deviations of reflectances for off-nadir viewing angles were less than 4%, except for bands V3 and 1b at a 55° viewing angle and close to the hot-spot (up to 8%).

4.6. Analysis of variance

The two main factors affecting the response of the surface are the phase angle of the measurement and the condition of the surface. A two-way analysis of variance (ANOVA) was performed on all data in each ATSR-2 band in order to estimate the impact of these factors (table 4). Phase angles were divided in 11 classes of 10° intervals (from 0° to 110°). The sampling areas were classified according to the day of the BRDF measurements (11 classes).

The phase angle, as expected, is associated with a large contribution in the variation of the BRDF, particularly in the $1.6\ \mu\text{m}$ channel. However, the phase angle only explains 40–45% of the variation, implying relatively low bidirectional effects, as seen in figure 5, and indicating that La Crau is a good reference surface. The

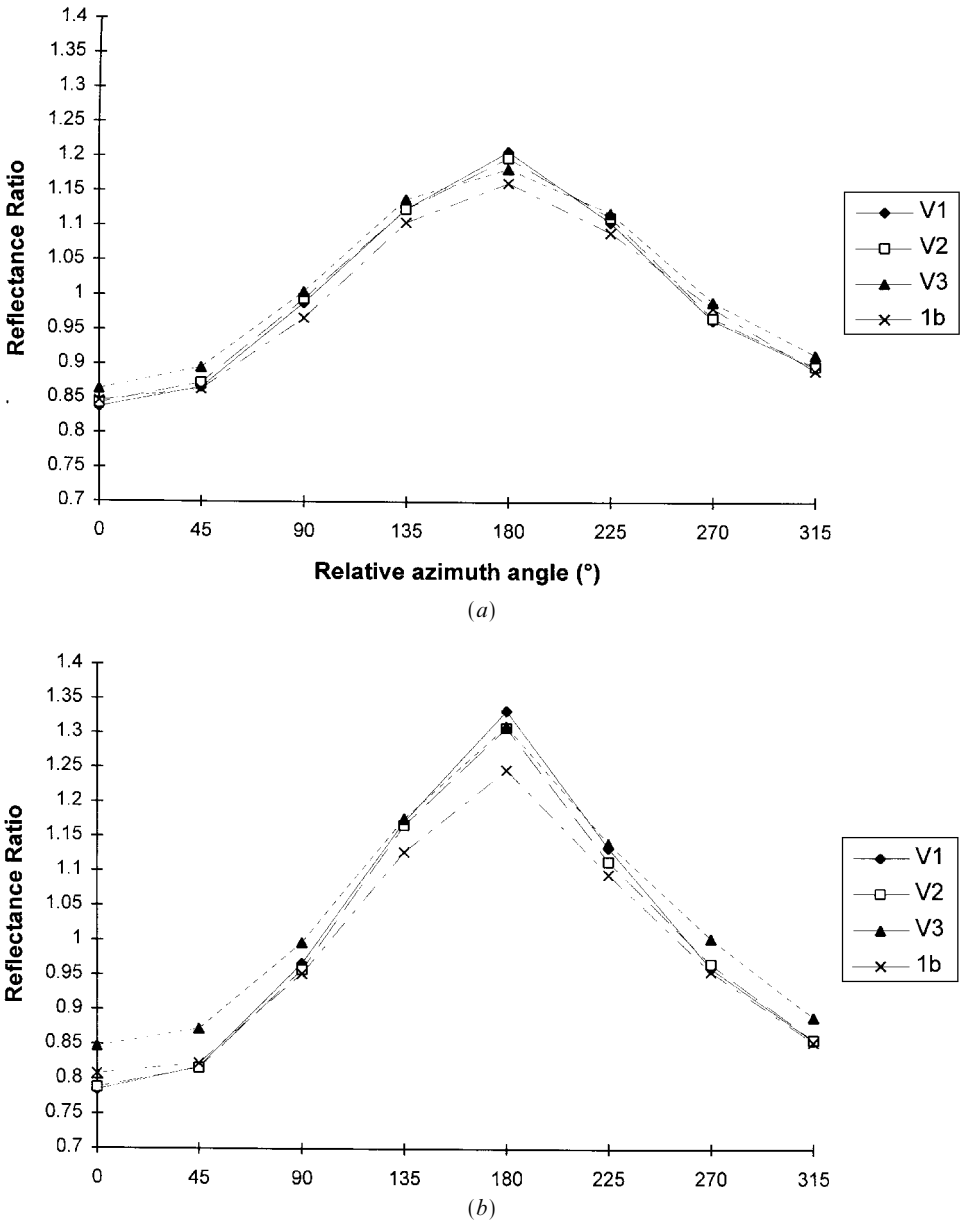


Figure 5. Variations in the shape of the BRDF measured over La Crau in the four ATSR-2 bands as a function of relative azimuth. Upper plot, the ratio of 30° to nadir reflectance; lower plot, the ratio of 55° to nadir reflectance.

importance of the sampling area (on the day of measurement) is even less (15% in the 1.6 μm channel, up to 20% in the 0.87 μm channel). The residual variance is relatively important in all channels, indicating that the variability within each sampling area is greater than the variability between these areas. However, such variation would not be detectable at the 1 km scale.

Table 4. Analysis of variance (ANOVA) for each channel.

Source of variation	V1 (0.56 μm)	V2 (0.66 μm)	V3 (0.87 μm)	1b (1.6 μm)
Phase angle	40.09	37.41	38.83	44.81
Main effects:				
Sampling area (%)	18.42	17.95	20.18	15.78
Angle/area interactions (%)	7.74	7.32	5.89	5.27
Explained (%)	60.99	57.95	60.32	60.72
Residual (%)	39.01	42.05	39.68	39.32

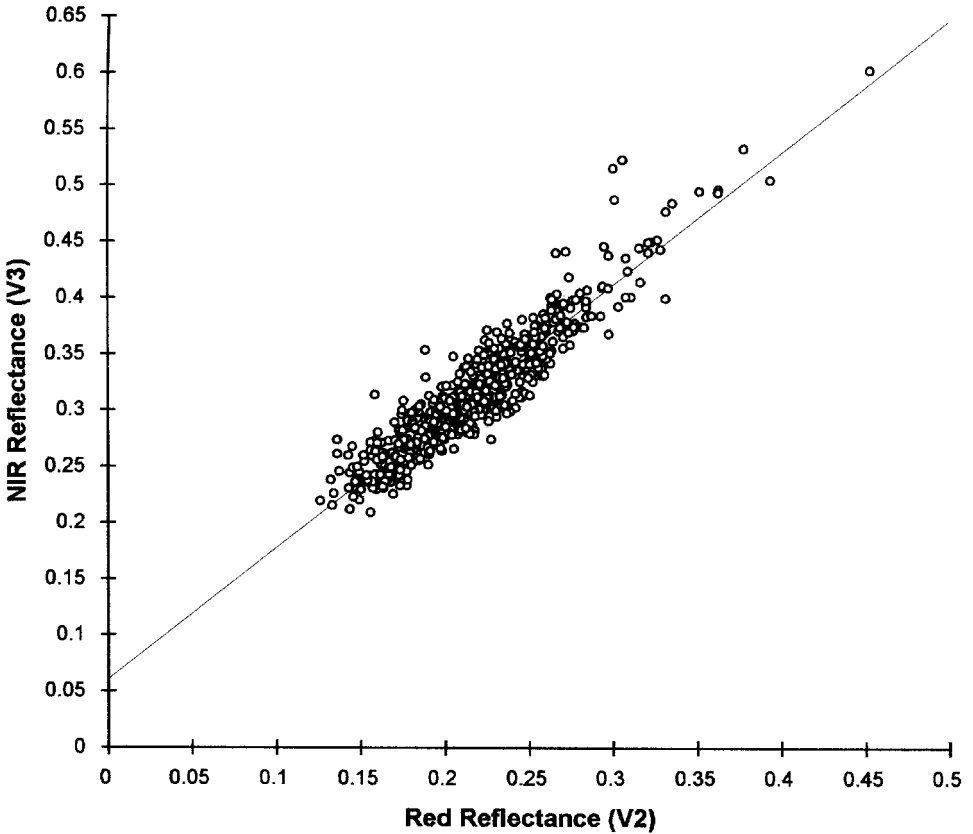


Figure 6. The relationship between near-infrared (V3) and red (V2) ATSR-2 band reflectances for all surface measurements: the regression line has the equation $V3 = 1.17 V2 + 0.06$, with a coefficient of determination $r^2 = 0.87$.

4.7. The soil line

The low impact of the variability due to vegetation cover is shown on the red–near-infrared scatterogram (figure 6), plotted for all ground data (all dates and viewing angles) in the ATSR-2 V2 and V3 bands. The data are relatively tightly grouped around a single soil line, with a coefficient of determination $R^2 = 0.87$. The two points on the graph that depart furthest from the fitted line were noted as having

a relatively large green thistle in the centre of the target! At this site, as at others, spectral variability results in significant uncertainty in ground truth.

5. Validation of the ATSR-2 data

For comparison with the ATSR-2 data, table 5 gives the reflectances measured at the ground on 19 July 1995 at the time of the overpass, in the same viewing geometry as the ATSR. However, these measurements characterized a particular point of the landscape and might not represent the full site. Therefore, measurements in the ATSR geometries taken regularly each day at different sampling points, along with the complete BRDF measurements, are also shown in table 5.

The ATSR-2 data were corrected for atmospheric effects by the 5S model (Tanré *et al.* 1987), used here in the inverse mode to retrieve surface reflectance from the satellite data. The retrieved reflectances are then compared with the values measured on the ground under the same geometric conditions.

The 5S model requires knowledge of the aerosol optical depth at 550 nm, as well as the type of aerosol present in the atmosphere. Atmospheric measurements were made during the campaign, throughout the day while surface measurements were being taken, and especially at the time of the overpasses. Spectrophotometer measurements acquired on the site by the LOA (Laboratoire d'Optique Atmosphérique, Université des Sciences et Techniques de Lille, France), on 19 July 1995 show that the aerosol optical depth τ at 550 nm at the time of the overpass was 0.326 (C. Devaux, personal communication), and that the aerosol phase function was of an urban type, although with stronger absorption at large scattering angles (Rondeaux *et al.* 1997). Accounting for these conditions under a mid-latitude summer atmospheric model (pre-installed in the 5S code), the retrieved surface reflectances are

Table 5. Sample instant reflectances (%) of La Crau recorded on 19 July 1995 at the time and view directions of the ATSR-2 overpass, with mean reflectances (%) and their corresponding standard deviations (%) (in *italic*) recorded at ATSR-2 views and directions for all measurement dates in July 1995.

Reflectance (%) of La Crau in the ATSR-2 viewing geometry		V1 (0.56 μm)	V2 (0.66 μm)	V3 (0.87 μm)	1b (1.6 μm)
19 July 1995	Nadir view	16.2	20.6	29.0	35.4
	Forward view	14.0	18.1	27.2	31.8
All July dates	Nadir view mean	15.9	20.9	29.6	37.1
	<i>Standard deviation</i>	2.5	3.2	3.1	3.7
	Forward view mean	13.6	17.8	26.7	31.7
	<i>Standard deviation</i>	1.9	2.1	2.6	2.8

Table 6. Retrieved surface reflectances from the ATSR-2 data, using the 5S code with a mid-latitude summer atmospheric model, an urban aerosol phase function and an aerosol optical depth $\tau=0.326$ at 550 nm.

Surface reflectance (%) of La Crau retrieved from ATSR-2 data		V1 (0.56 μm)	V2 (0.66 μm)	V3 (0.87 μm)	1b (1.6 μm)
19 July 1995	Nadir view	12.7	19.1	29.4	39.5
	Forward view	11.0	15.7	27.5	32.4

shown in table 6, both for the nadir and forward viewing angles. Comparison with table 5 indicates that satisfactory agreement was found for each viewing geometry, with a maximum deviation of 3% of reflectance. Aerosol optical depth was not available for the 22 July overpass, but the satellite measured radiances are very similar (table 1).

6. Conclusion

Analysis of the measurements of the surface BRDF of the site at La Crau surrounding the established SPOT site has shown that the relatively good homogeneity and stability of the reflectance data are also evident over most of La Crau sèche. These properties are key requirements for a remote sensing calibration and validation site. The main characteristics of La Crau which made it a good reference site for validation of 1 km resolution sensors are:

- (1) the site is uniform over an appropriate large area;
- (2) the coefficients of variation of the surface reflectance are less than 15%;
- (3) nadir reflectance varies minimally within the practical range of sun angles; also no strong bidirectional effect was recorded;
- (4) variations over time are expected to be small.

Finally, the site has the advantage of good communication links and is within Europe, making access easy and convenient. Therefore La Crau offers a valuable resource which is probably unique in Europe for its combination of uniformity, accessibility, relatively clear skies, and its protected status.

ATSR-2 data of La Crau also present a low spatial variability, with a quasi-uniform area of about 20 pixels around the SPOT site. For validation purpose, TOA reflectances have been atmospherically corrected to retrieve the ground reflectances. The good agreement with values measured at the surface offers considerable potential for the use of bi-angular ATSR-2 land surface data.

Acknowledgments

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References

- GU X., GUYOT G., and VERBRUGGHE M., 1990, Analyse de la variabilité spatiale d'un site-test: exemple de La Crau (France). Analysis of the spatial variability of a test-site: the example of the Crau (France). *Photo-Interprétation*, **1**(5), 39–52.
- GU X., GUYOT G., and VERBRUGGHE M., 1992, Evaluation of measurement errors in ground surface reflectance for satellite calibration. *International Journal of Remote Sensing* **13**, 2531–2546.
- PRATA A. J. F., CECHEZ R. P., BARTON I. J., and LLEWELLYN-JONES D. T., 1990, The along track scanning radiometer for ERS-1 scan geometry and data simulation. *IEEE Transactions Geoscience and Remote Sensing*, **28**, 3–13.
- RONDEAUX G., STEVEN M. D., and CLARK J., 1997, An example of coupling ground, airborne and satellite data: ATSR-2 validation campaign, La Crau 1995. *Seventh International Colloquium 'Physical Measurements and Signatures in Remote Sensing'*, Courchevel, France, 7–11 April 1997 (Rotterdam: Balkema), pp. 341–347.

- SLATER P. N., BIGGAR S. F., HOLM R. G., JACKSON R. D., MAO Y., MORAN M. S., PALMER J. M., and YUAN B., 1987, Reflectance and radiance based methods for the in-flight absolute calibration of multispectral sensors. *Remote Sensing of Environment*, **22**, 11–37.
- TANRÉ D., DEROO C., DUHAUT P., HERMAN M., MORCETTE J. J., PERBOS J., and DESCHAMPS P. Y., 1987, Simulation of the satellite signal in the solar spectrum (5S). Laboratoire d'Optique Atmosphérique, Université des Sciences et Techniques de Lille, 59655 Villeneuve d'Ascq Cédex, France.