Validation of ATSR-2 land surface reflectance data

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ABSTRACT: To test and validate atmospheric and surface algorithms in the reflected solar bands, field measurements were made simultaneous with ATSR-2 data acquisitions in representative sites and seasons. Campaigns were conducted on La Crau (France), Uardry and Amburla (Australia), with dates chosen to give a range of phase angles, including values near the hot spot. Field data included full BRDF measurements of surface, solar direct and diffuse irradiance, and optical depth. The Mackay atmospheric retrieval model defines a shape factor R as the ratio of forward to nadir reflectance and predicts that R is semi-independent of wavelength. The retrieval procedure adjusts the parameters of the 5S atmospheric model until R matches at two selected wavelengths. The field data indicate generally high precision of the 5S model and the Mackay inversion scheme. Measured shape factors at the ground matched well except at Amburla. Mackay's retrieval gave reflectance values within 3% on La Crau, but did not converge at the small phase angles encountered in Australia. Direct application of the 5S model with measured optical depth also gave retrieved values within 3% of measurements. The models require some improvement to deal with small phase angles, red soils and atypical aerosols, but the database is not model-specific and can be used to test other retrieval procedures.

Introduction

The **A**long **T**rack **S**canning **R**adiometer (-version **2**) was launched by ESA on the ERS-2 satellite in April 1995. In addition to three bands designed to measure thermal emissions, it measures four bands of reflected solar radiation, at 0.555, 0.66, 0.86 and 1.6• m (channels V1, V2, V3 and 1b) with a pixel size at nadir of 1.1 km. The key instrumental innovation is that ATSR-2 produces a near-simultaneous pair of images at two viewing angles of about 0° and 55°, offering the possibility of an autonomous correction for atmospheric effects without the need for surface observations. Work by Mackay *et al*., (1998) established a theoretical procedure to determine atmospheric turbidity by matching retrieved surface reflectance to values predicted over a range of turbidities. The aim of this research was to validate such procedures in the field to ensure that the algorithms are robust under operational conditions.

Validation

Validation is a key requirement for the geophysical interpretation of earth observation data. The signal recorded at the satellite is the result of a series of physical interactions between electromagnetic radiation and the earth's surface, the atmosphere and the instrument optical system. Inversion of the signal to determine surface characteristics requires algorithms to calibrate the signal and to correct for attenuation and scattering in the atmosphere. Calibrations degrade, while atmospheric correction algorithms tend to assume idealised atmospheres and are subject to consequent uncertainties. Validation of these algorithms establishes the magnitude of these uncertainties and allows calibration coefficients to be updated. While some aspects of these processes can be modelled and validated on synthetic data, only a full operational validation can address the observing system as a whole. The field validation approach applied here is necessarily limited in the range of conditions that can be considered, but is essential to establish confidence in the information derived from the satellite.

The objectives of the project were as follows:

To conduct campaigns of field measurement over a representative set of sites and seasons with atmospheric attenuation and scattering measured coincident with the acquisition of ATSR-2 data.

To establish a database from the field measurements capable of use for testing and validating a range of atmospheric and surface algorithms, both for ATSR-2 and other satellite radiometers.

To validate and test under operational conditions the specific atmospheric correction procedure developed by Mackay *et al*., (1998)

Programme of Research

The ATSR-2 instrument produces a pair of images, one near-nadir and the other in the forward view at about 55°. On the day side of the earth, the forward view is always south looking, giving rise to a geographical asymmetry, with observations at large phase angles (sun – surface – satellite) in the northern hemisphere and relatively small phase angles in the southern hemisphere. The phase angle is fundamental to the determination of atmospheric corrections as well as being a primary parameter in the description of the bidirectional reflectance distribution function of the surface. As well as differing between the forward and nadir views, the phase angle depends on latitude and season and varies across the width of the instrument scan. The field campaigns and measurement protocol were designed to exploit these variations to sample across the range of phase angles encountered in ATSR-2 data.

Field campaigns

Four field measurement campaigns were conducted: a summer and a winter campaign at a northern hemisphere site (France) and an autumn campaign at two southern hemisphere sites (Australia). Concurrent satellite and field data were collected on the *La Crau* site in southern France (43°33’N, 4°51’E) during a summer campaign, (Crau I) 4-22 July 1995 and during a winter campaign, (Crau 2) 9-16 January 1997. *La Crau* is a prehistoric river delta with a surface of pebbles and sparse low vegetation. *La Crau* is a well-established site for remote sensing studies and a section of 400 metres square is routinely used for calibration-validation of the SPOT HRV sensors.

Table 1: Dates and sites of ATSR-2 image acquisitions

La Crau	*Amburla*	*Uardry*
19 July 1995	21 April 1997	9 May 1997
22 July 1995	24 April 1997	12 May 1997
13 January 1997	27 April 1997	

Although the extent of the site (*ca*. 15x10 km) is relatively small, the use of a well-characterised and accessible site within Europe was a considerable operational advantage.

A comprehensive survey conducted as part of this research showed that the site meets the criteria of spatial uniformity and low variability in bidirectional reflectance over its full extent and is suitable as a regular validation site for use with kilometre resolution instruments such as ATSR-2 (Rondeaux *et al*., 1997; 1998).

Campaigns on a further two sites in Australia were conducted with the collaboration of CSIRO. The campaign on the *Amburla* site (23º23'S, 133º07'E) near Alice Springs took place from 21-27 April 1997. The area is used for grazing cattle and camels and comprises a red soil with a sparse covering of dry Mitchell grass (Prata and Cechet, 1999). The campaign at *Uardry* (34º23'S, 145º18'E) near Hay NSW, took place from 9-15 May 1997. The site is used for sheep and by CSIRO for continuous monitoring of the surface energy budget at a measurement scale of about 1 km (Prata *et al*., 1998). The surface here was found to be almost ideal for validation. The area is flat with sparse, low vegetation under an atmosphere with few aerosols and low water vapour.

The field campaigns were each planned to coincide with a minimum of three satellite overpasses to minimise the risk of poor weather and (subject to good weather) to broaden the range of phase angles recorded. The 1995 campaign on Crau I was also timed to coincide with independent measurement campaigns conducted by INRA (*Institut National de la Recherche Agronomique*) with the participation of *Université des Sciences et Techniques de Lille* and the UK Meteorological Research Flight (Rondeaux *et al*., 1997). ATSR-2 data were collected throughout each of the field campaigns: good quality cloud-free data were found on the dates shown in Table 1:

Field measurements

On each campaign, series of measurements were made of the bidirectional reflectance distribution function of the surface. The GER 3700 SIRIS instrument from the NERC EPFS (Equipment Pool for Field Spectroscopy) was used for Crau I, while the other campaigns used the ASD Fieldspec FR radiometer. Details of these instruments are given by Milton *et al*., (1997) and NERC (1999). These instruments provide high spectral resolution and good precision across the full solar spectrum with calibration traceable to NPL standards. Measurements were made under clear sky conditions over several days on

Table 2: Nadir reflectance data for the study sites
Means of ≥100 spectra; cv = mean coefficient of variation

	V1	V2	V3	1b	cv
Crau 1	0.16	0.22	0.31	0.39	13%
Crau 2	0.12	0.13	0.28	0.29	34%
Amburla	0.12	0.23	0.31	0.37	16%
Uardry	0.13	0.18	0.26	0.43	19%

each campaign, with different sites selected within the study area on successive days. The measurement procedure on Crau I was for a sequence of measurements at 0° (nadir), ±30° and ±55° inclinations at azimuths of 0°, ±45° and 90° relative to the sun. Reference measurements on a calibrated panel were made at regular intervals and the orientations of the measurement planes were adjusted to follow the movement of the sun during the sequence of measurements over about one hour. Minor variations in procedure were made on the other campaigns. To avoid making measurements on trampled ground, the BRDF in the Australian campaigns was measured on only one side of the solar plane (assuming symmetry). And on Crau 2, the strong *Mistral* wind made it impossible to mount the radiometer head safely on a tripod, so hand-held measurements were made at approximate angles. A total of 36 BRDF data sets were collected on Crau I, 38 on Amburla and 69 on Uardry. On Crau 2, three full BRDF sequences were measured plus an additional 15 sets of selected directional scans. In addition to the BRDF data, global and diffuse spectral irradiance (400-1100nm) were measured with a Licor LI 1800 spectroradiometer. Optical depth was also measured. At the time of each ATSR-2 overpass, a set of directional reflectance data at specific angles representative of the ATSR-2 view was also recorded. In total, over 3000 individual spectra were collected on the four sites.

Representative data from the field campaigns are given in Table 2. The values showed no significant variation across the sites or with time of day, allowing the surface measurements to be scaled up for comparison with ATSR-2 data. A significant seasonal variation is observed on *La Crau.*

Data Analysis

The atmospheric correction procedure

The atmospheric correction procedure developed by Mackay *et al*., (1998) is based on iterating the 5S model (Tanré *et al*., 1990) until an invariance criterion is satisfied. In Mackay's study, the characteristics of surfaces were modelled with a combination of the SAIL, SOILSPECT, PROSPECT and KUUSK models (Verhoef, 1984; Jacquemoud *et al*., 1992; Jacquemoud and Baret, 1990 and Kuusk, 1991). The modelled results indicate that the

ratio of reflectances at the two viewing angles • (55°)/• (0°), termed the shape factor R(•), is relatively independent of wavelength for a wide range of natural surfaces. The invariance criterion is R(V1) = R(V2) for non-vegetated surfaces, as in this study, and R(V1) = R(1b) for vegetated surfaces. The inversion procedure works by varying the assumed aerosol optical depth • $_{550}$ to retrieve surface reflectance values until the shape factors match. The data obtained in the field campaigns allow separate validations of shape factor invariance and of the 5S model as well
a full test of the retrieval procedure.

Shape factors

Figure 1 shows the shape factor measured in the Crau I campaign, plotted from the BRDF data for the full range of azimuths. The figure indicates that while the shape factor varies considerably with azimuth, the values in bands V1 and V2 match closely. For the specific direction viewed by ATSR-2, the values are 0.86 and 0.85 respectively. Analysis of Crau 2 data showed slightly higher values of 1.05 and 0.98 and while individual values of the ATSR-2 view shape factor varied somewhat from site to site, the values for the two bands moved in parallel. On Amburla and Uardry, the pattern was similar to figure 1, but the values and discrepancies between bands were somewhat larger. However, the relative azimuth for the Australian sites is close to 180° (by design), where the shape factor reaches its peak. On Uardry, the match is still close (1.80 and 1.76 for V1 and V2 respectively), but serious differences occur at Amburla (1.71 and 1.51) indicating a soil shape factor that does not conform to the model.

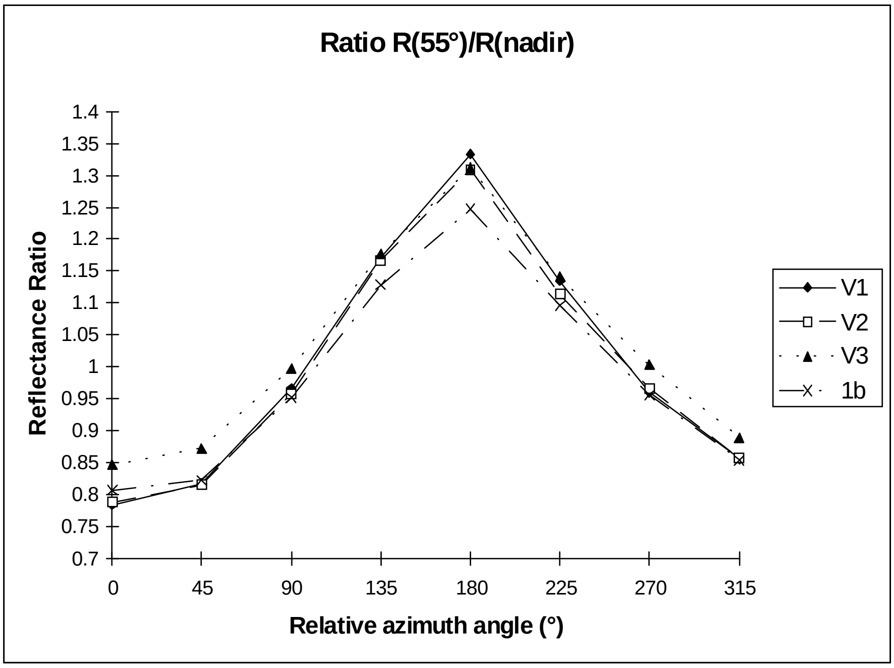

Figure 1: Shape factor as a function of relative solar azimuth in Crau 1

Retrieval of optical depth and surface reflectance

The 5S model requires as input an aerosol optical depth at 550nm, • $_{550}$. Spectrophotometer measurements on La Crau on 19 July 1995 found a value of 0.326 (Devaux, 1995). The measured phase function indicates a characteristic quite close to the 5S urban model at small scattering angles, but with strong absorption at larger

angles (Rondeaux *et al*., 1997).
The shape matching retrieval procedure generated the results shown in figure 2. The urban model gave the best retrievals, within 3% of measured values, with a slightly higher • 550 and R(•) matching at a value of 0.80.

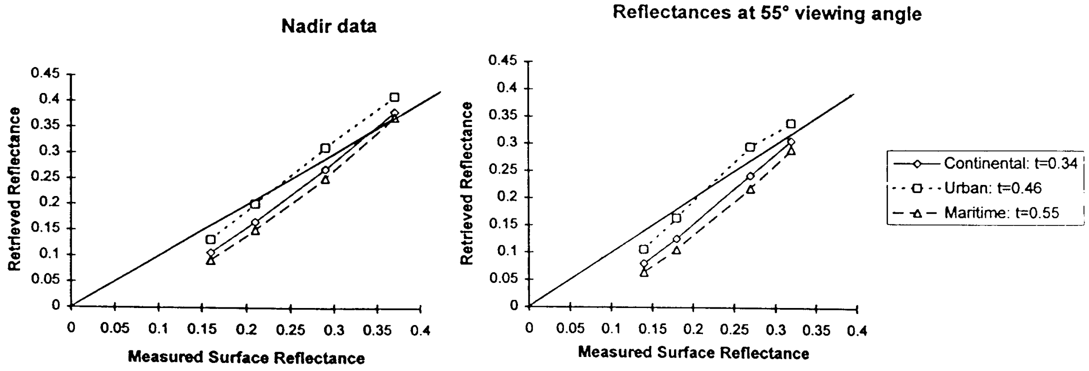

Figure 2: Retrieval of surface reflectance, La Crau, 19 July 1995

On Crau 2, • 550 was estimated with an uncalibrated Cimel sunphotometer by performing Langley plots of solar beam attenuation at three wavelengths with airmass. The derived value was 0.06, compared with 0.03 estimated by shape matching assuming a continental aerosol. Retrieved reflectances in both cases were within 3% (slightly better with shape matching) except at 1.6• m where there was some uncertainty in the calibration.

On the Australian campaigns, aerosol optical depths measured with the CSIRO rotating shadowband radiometer were very low (• 550< 0.03), except at Amburla on 24 April 1997, (0.05-0.1). Retrievals with these values give results that are again within 3% of measured data, but it was found that the Mackay iteration procedure was unable to generate a match in shape factors.

Surface BRDF models
The surface data have also been applied to test BRDF models. The model of Roujean *et al*. (1992) is shown to fit the Australian data to a high degree of precision (fig. 3). BRDF models allow shape factors to be generalised more easily, providing the basis, in principle, for more robust inversion algorithms.

Conclusions
High quality data were collected in four field campaigns and have been used under operational conditions to validate ATSR-2 measurements and test the 5S model and the Mackay inversion scheme. Retrieval of surface reflectance to 3% precision is found at all sites and for both low and high turbidity.

The retrieval scheme developed by Mackay *et al*., (1998) worked well on *La Crau* both in summer and winter, but failed to achieve convergence on the Australian data. This was not unexpected, as the shape factor is largest near the "hot-spot" and the convergence criteria are theoretically weaker in the solar plane. It also appears that the spectral modelling on which the scheme is based is inappropriate for the red Amburla soil. A weakness was also found in the

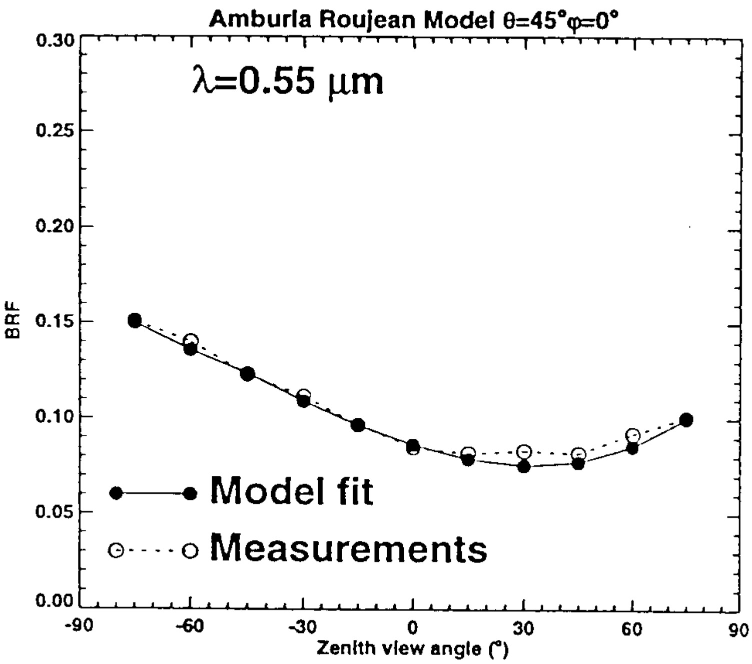

Figure 3: Fit of the Roujean BRDF model to field data at Amburla

limited palette of aerosol models in 5S, though this was more apparent in Crau 1 where • 550 was large.

The results show that surface reflectance can be retrieved to a high degree of accuracy from ATSR-2 data and demonstrate the importance of validation in establishing confidence in earth observation data. The database is not model-specific and can be used to test other models and procedures, such as estimation of albedo. Further work is required to develop more general retrieval models with the required robustness and to test retrieval procedures over a wider range of terrain, including vegetated surfaces.

Acknowledgements

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