CALIBRATION AND VALIDATION OF ENVISAT MERIS
PART 1: VICARIOUS CALIBRATION AT RAIL ROAD VALLEY PLAYA (NV)

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ABSTRACT

On August 22, 2002, a vicarious calibration (VC) experiment of MERIS, a pushbroom imaging spectrometer on ESA's ENVISAT, was performed. The purpose of this experiment was the acquisition of in-situ measurements of surface and atmospheric conditions over a bright, uniform target. These data were then used to compute top-of-atmosphere (TOA) radiances, which were correlated with the MERIS TOA radiances (Level 1b product), to determine the in-flight radiometric response of the on-orbit sensor. The Rail Road Valley Playa, NV, was the primary target chosen by the Optical Sciences Center, University of Arizona, and the Remote Sensing Laboratories, University of Zürich, for this experiment. The in-situ estimations of top-of-atmosphere radiances lie within less than 6% of the MERIS measurements, except for band 11 (760 nm) and band 15 (900 nm). The absolute uncertainty of the vicarious calibration experiment is estimated to be less than 3.36%. Based on the uncertainties of the vicarious calibration method and the calibration accuracies of MERIS, no recommendation to update the MERIS calibration may be given.

1 INTRODUCTION

The Medium Resolution Imaging Spectrometer MERIS) [1] is one of ten instruments on board ESA's ENVISAT platform. MERIS is a 68.5° field-of-view pushbroom imaging spectrometer that measures the solar radiation reflected by the Earth, at a ground spatial resolution of 300 m (full resolution) and 1200 m (reduced resolution), in 15 spectral bands in the visible and near infra-red. MERIS allows global coverage of the Earth in 3 days.

1.1 Vicarious Calibration

Vicarious calibration is an independent pathway for monitoring instrument radiometric performance, including error assessment with reflectance standards, field instruments and atmospheric radiation measurements. In general, the experiment follows a reflectance-based approach with ground measurements of the atmospheric optical depth and surface reflectance over a bright natural target [2].

In this experiment, two approaches of calculating TOA radiance are performed:

- Assumption of a typical Rail Road Valley Playa aerosol model and horizontal visibility (first iteration approach, case "A").
- Determination of an aerosol model and horizontal visibility from radiative transfer code (RTC) inversion, based on in-situ sun photometer data (analytical approach, case "B").

Subsequently, MODTRAN-4 [3][4], a radiative transfer code (RTC) is used, constrained by field data, to calculate the top-of-atmosphere radiance at the sensor. Input parameters include the ground measurements of the surface reflectance, sun-target-sensor geometries and the atmospheric properties (aerosol model, horizontal visibility).

2 DATA ACQUISITION BASELINE

2.1 MERIS

On August 22, 2002 MERIS flew over Rail Road Valley Playa (38,54° latitude, -115.72° longitude, 1350 m asl) in relative orbit 442. In this orbit, MERIS acquired data of the Rail Road Valley Playa test site under 12.23° off-nadir to the west, at 18:02 UTC, 11:02 Pacific Daylight Time. The sun was at a zenith of 35.16° and azimuth of 131.36°, relative to local north. Data was acquired in full resolution (FR) mode (MER_FR_1PNIPA20020822 _180221_000000872008_00442_02500_0031.N1). Rail Road Valley is a desert site with no vegetation. Desert playas are preferred for vicarious calibration of moderate spatial resolution sensors due to their optical properties, predictably sunny conditions and low atmospheric aerosol loading [5].

2.2 In-Situ Field Measurements

The following ground field instruments were operated during the Rail Road Valley vicarious calibration experiment:

- An Analytical Spectral Devices, Inc. (ASD) Portable Spectrometer to measure the surface spectral hemispherical directional reflectance factor (HDRF) (only in the nadir view direction) as a function of wavelength in the spectral range between 350 nm and 2700 nm. The variability in the spectral measurements, due to target inhomogeneity and instrument calibration uncertainties is around ±3% over the 350-1200 nm range.
- A CIMEL sun photometer to measure the total atmospheric optical depth / /. Langley analysis is used to retrieve the aerosol optical depth from these measurements in seven spectral channels in the 400-900 nm range.

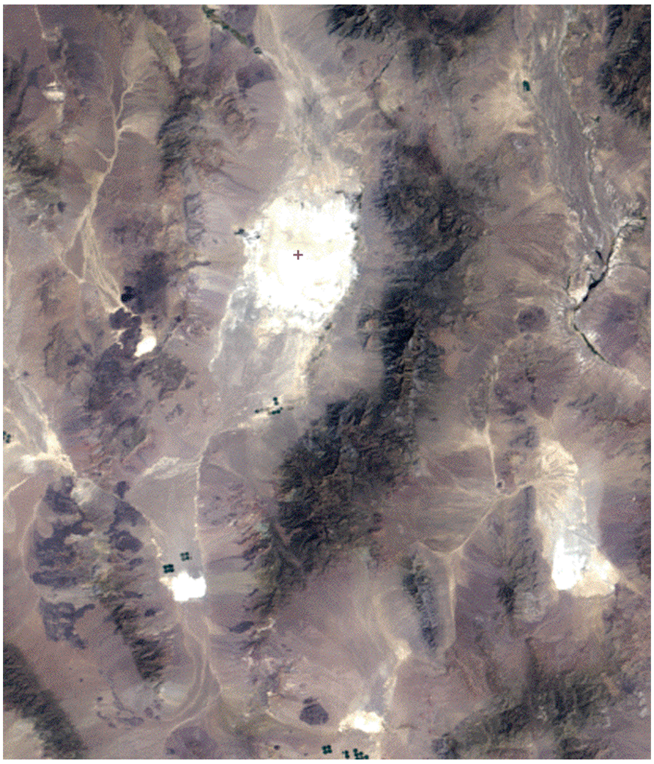

Fig.1: Rail Road Valley Playa target, Nevada, as acquired by MERIS on August 22, 2002. The symbol identifies the VC testsite.

3 ANALYSIS AND RESULTS

1.1 Radiative Transfer Calculation of TOA Radiance

In a first step, the definition of an appropriate atmosphere, as it was present at the time of data take must be addressed. As mentioned in Section 1.1., two approaches of atmosphere description were performed: the assumption of a typical Rail Road Valley Playa atmosphere situation (case "A"), and the derivation of atmospheric key parameters from in-situ sun photometer data and radiative transfer code inversion (case "B").

Fig.2 shows the input data to the atmosphere simulations as performed using MODTRAN-4. The first iteration approach (A) assumes a horizontal visibility of 80±5 km and an urban aerosol model, which takes into account the unusually high concentration of black carbon [6] assumed to be present in the atmosphere due to California and Oregon wildfires.

The analytical approach (B) results in an urban aerosol model and a horizontal visibility of 40±5 km at a 90% confidence level as best fit. Fig.2 shows the wavelength-dependent transmittances of a number of modelled atmospheres, the transmittances derived from the in-situ measured sun photometer data and the best fitting atmosphere (B). It can be seen clearly that the unusual aerosol concentration in the 380-670 nm range at the time of data take can not be modelled properly using standard aerosol models. A higher amount of small aerosols should be present in an optimal aerosol model. Mixing of aerosol models could improve the result.

The reference solar irradiance of Thuillier [7], as adopted for ENVISAT by ESA, is used for the atmospheric modelling. The use of MODTRAN standard irradiance data would result in a mean deviation of 4.66% for the radiance calculation over the 400-900 nm wavelength range (Fig.3).

Test site location, data acquisition time and date, as well as the sun-target-sensor geometries are optimized for the ground truth area (9 pixels) in the MERIS data set.

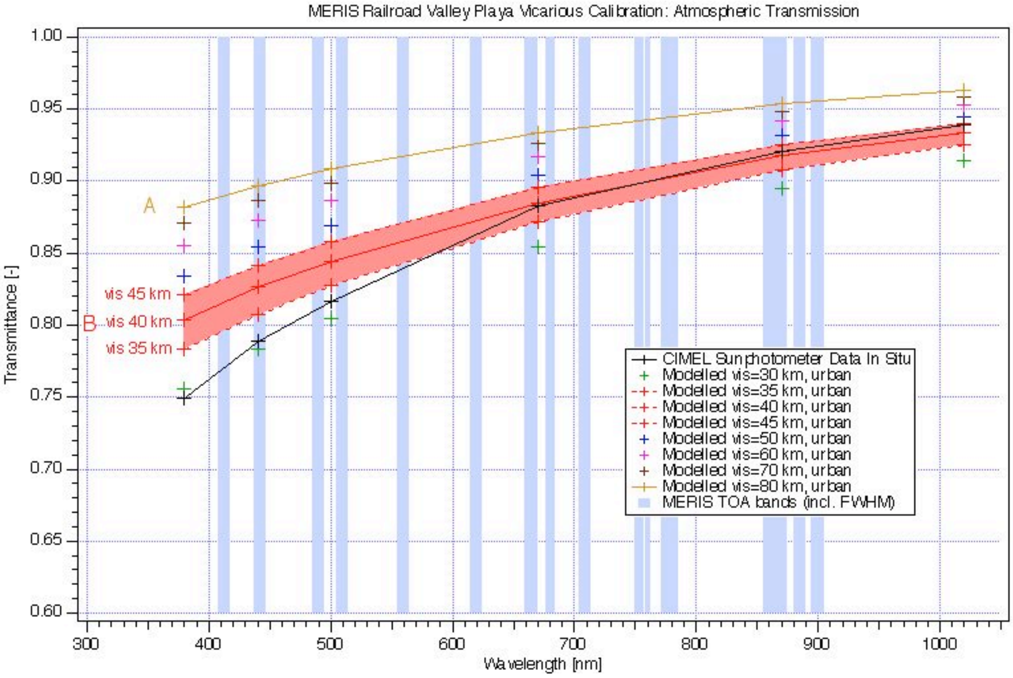

Fig.2: Wavelength-dependent transmittances of a number of modelled atmospheres, the in-situ sun photometer data and the best fitting atmosphere (urban aerosol model, vis = 40±5 km) for the Rail Road Valley Playa VC test site.

	First Iteration (A)	Analytical Approach (B)
Solar Irradiance Data	Thuillier 2002	
Aerosol Model	Urban (unusually high concentration of black carbon assumed to be present due to California and Oregon wildfires)	
Horizontal Visibility	80±5 km	40±5 km (90% confidence level)
Test Site Location **Data Acquisition Time, Date** **Sensor View Geometry**	Optimized for specific ground truth pixels in MERIS data set sensor zenith: 167.77° (nadir: 180°), sensor path azimuth: 278.55°	

Tab.1: MODTRAN-4 Input Data.

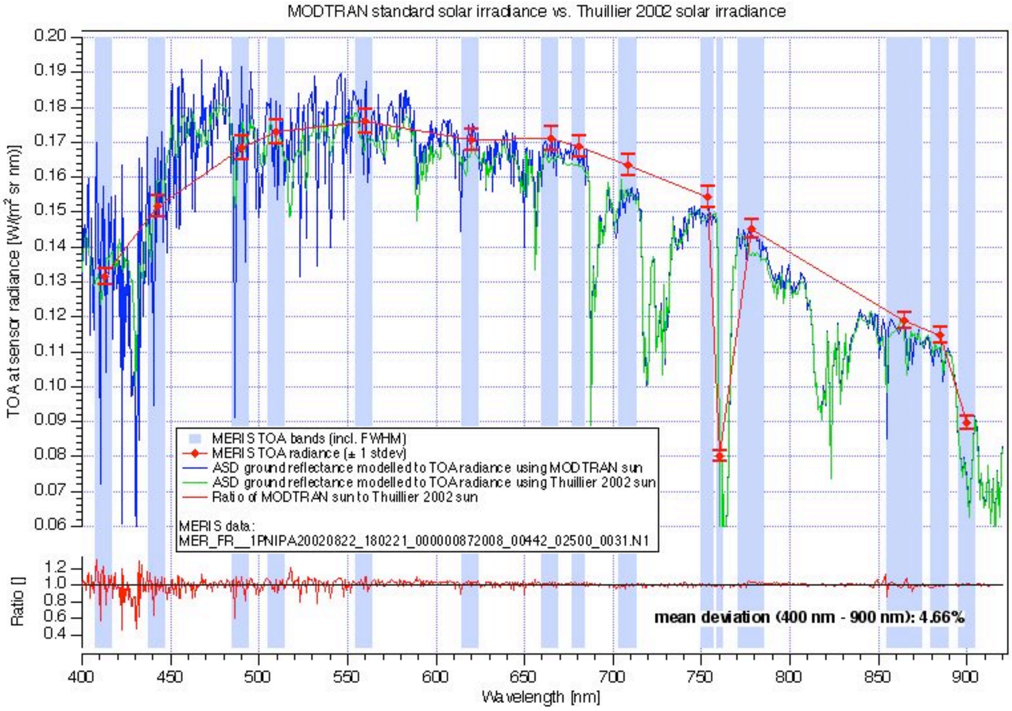

Fig.3: Comparison between the solar irradiance of Thuillier and the MODTRAN standard solar irradiance data.

3.2 Comparison of Ground Measurements to MERIS Observations

Fig.4 and Fig.5 show the results of the MODTRAN modelled top-of-atmosphere radiances from the spectral ground truth data for the first iteration approach (Fig.4) and the analytical approach (Fig.5), together with the MERIS measured radiances in the corresponding MERIS bands. The shapes of the modelled curves and the MERIS measured TOA-radiances do not fully match in both cases, indicating the beforementioned difficulties in finding an appropriate aerosol model for the untypical atmospheric conditions during data take.

Nevertheless, the differences between MERIS-measured and radiative transfer-modelled TOA radiances from VC are less than 6% for all MERIS bands, except for band 11 (oxygen band at 760 nm) and band 15 (water vapour absorption region at 900 nm), as can be seen from Tab.2. These two bands need more precise ground truth data (e.g., meteorological data) for vicarious calibration. Excluding these two bands from a quality assessment leads to a mean difference between MERIS-measured radiances and modelled TOA radiances of 2.140% for the first iteration approach (A) and 3.147% for the analytical approach (B) for the remaining MERIS bands.

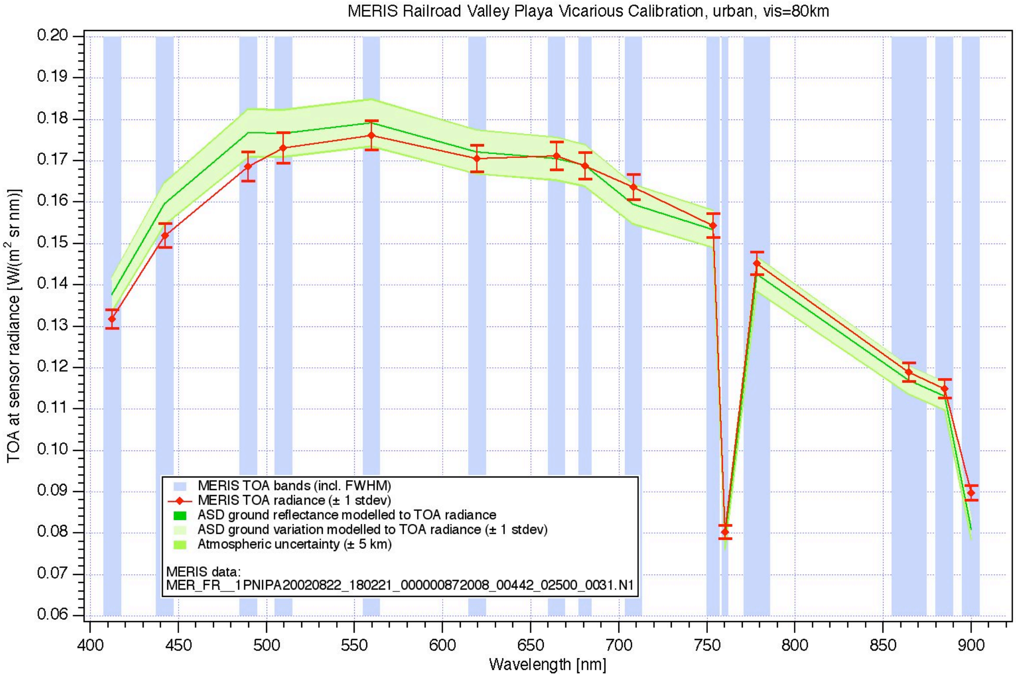

Fig.4: MERIS measured and MODTRAN modelled top-of-atmosphere radiance for the first iteration approach (A).

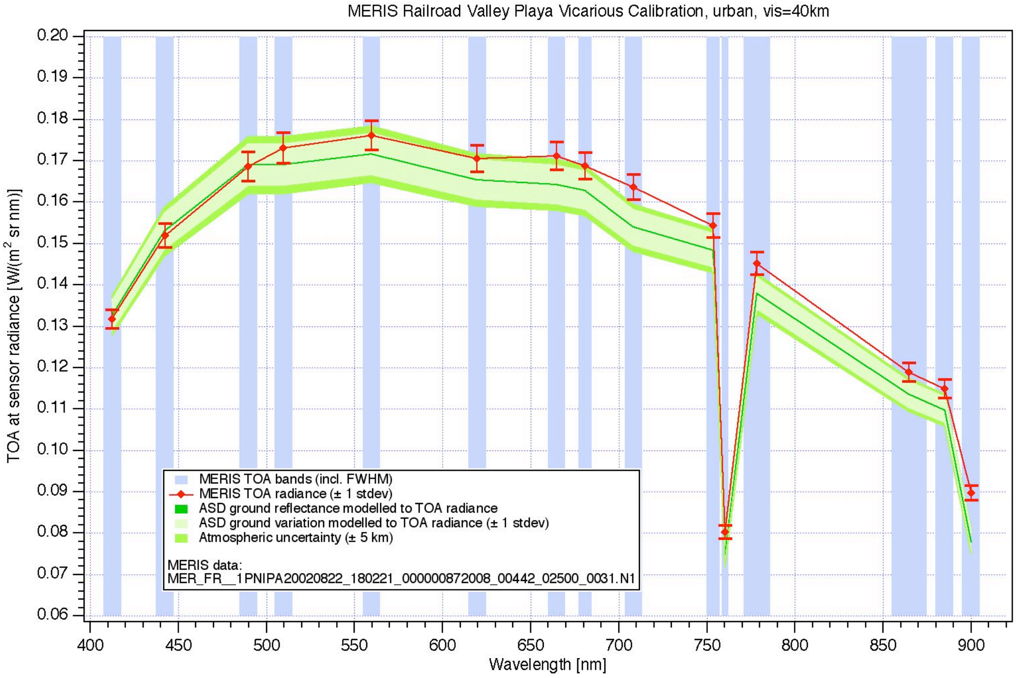

Fig.5: MERIS measured and MODTRAN modelled top-of-atmosphere radiance for the analytical approach (B).

MERIS channel	**Center Wavelength (nm)**	**Differences between MERIS and TOA radiances from VC (%)**	
		Urban, vis=40±5 km	Urban, vis=80±5 km
1	412.545	-0.604	-4.481
2	442.401	-0.844	-5.193
3	489.744	-0.335	-4.861
4	509.700	2.356	-2.037
5	559.634	2.543	-1.727
6	616.620	3.035	-0.881
7	664.640	4.028	0.398
8	680.902	3.442	-0.123
9	708.426	5.884	2.480
10	753.472	3.856	0.573
11	**760.354**	**6.999**	**2.571**
12	778.498	5.011	1.820
13	864.833	4.512	1.622
14	899.849	4.465	1.619
15	**899.860**	**13.230**	**9.895**
Mean Difference (%), **Excl. channel 11 and 15**		2.685 **2.140**	4.076 **3.147**

Tab.2: MERIS and VC top-of-atmosphere radiances differences.

A summary of the uncertainties for the VC computed radiances is provided in Tab.3. The absolute uncertainty is estimated to be lower than 3.36%. Surface reflectance errors including errors in geolocation, in-situ sampling, test site inhomogeneity and instrument absolute calibration are not included in this error budget, because they are assumed to be represented by the ±3% variability of the spectral measurements (±1 stdev from the mean), as indicated in Chapter 2. The VC calibration error part of the atmospheric uncertainty, listed in Tab.4 for each MERIS band, is based on the ±5 km horizontal visibility range assumed for the selected mean visibilities (80 km, 40 km).

Error Source	**Absolute Uncertainty (%)**
Solar Irradiance Knowledge	2
Spectralon Reflectance Knowledge	1.5
Relative Surface BRF Knowledge	1
Atmospheric Characterization[*]	< 2
Cosine of Solar Zenith	< 0.1
Root-sum-square	**< 3.36**

Tab.3: Vicarious calibration error budget.

Vis (km)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**mean**
80±5	0.47	0.52	0.55	0.55	0.53	0.49	0.46	0.45	0.45	0.41	0.59	0.41	0.37	0.36	0.48	**0.47**
40±5	1.90	2.13	2.24	2.25	2.20	2.04	1.91	1.87	1.83	1.74	2.34	1.70	1.54	1.51	1.91	**1.94**

Tab.4: Bandwise atmospheric uncertainty (%).

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[*] Bandwise atmospheric uncertainty in Tab.4

4 CONCLUSIONS

Reflectance-based vicarious calibration methods generally have absolute uncertainties of 3-5% [8]. The absolute uncertainty of this study's VC activities is estimated around 3.36%. All bandwise VC results lie within less than 6% of MERIS-measured TOA radiances, except for channel 11 (oxygen band at 760 nm) and channel 15 (water vapour absorption region at 900 nm). They need more precise atmospheric characterization for VC. The mean difference between MERIS- and VC- mean TOA radiances are around 2% for the first iteration approach (case A), and around 3% for the analytical approach (case B), excluding channels 11 and 15. An incorrect assumption about aerosol absorption can strongly affect the VC accuracies of the shorter wavelength bands. During data acquisition, North American wildfires strongly altered the type of atmosphere generally present at the test site. Radiative transfer model inversion including non-standard aerosol models (e.g., the influence of black carbon particles) could further improve VC results.

At present, the uncertainties of the VC method and the absolute calibration accuracies of MERIS do not allow to formulate a need to update the MERIS calibration. Surface HDRF measurements using a goniometer could improve the VC of large field-of-view sensors, since an off-nadir geometry could be modelled more precisely when using directional reflectance data other than from nadir.

Based on the findings of this study, a new VC experiment in a very large and spectrally homogeneous area (eg., Erg Murzuk (CNES site Libya), Algerian Sahara (DLR site), Dasht-e Kevir (Iran), Chott el Cherid (Tunisia)) is proposed. The supposed uniform test site should preferably fill the complete field-of-view of the five MERIS cameras, in order to satisfactorly address the individual camera behaviours and directional effects. Similar results could also be obtained from multitemporal observations of a potential test site in varying orbits.

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