DAIS SYSTEM PERFORMANCE, FIRST RESULTS FROM THE 1995 EVALUATION CAMPAIGNS*

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ABSTRACT

Since early 1995 DLR's Institute for Optoelectronics is operating the DAIS-7915. This new imaging spectrometer covers the electromagnetic spectrum from the visible to the thermal infrared wavelength region. The sensor has been calibrated in the laboratory and was flown on board DLR's Do-228 aircraft. Between May 1995 and November 1995 almost 100 airborne scenes were acquired. The data collected during these campaigns were intended to prove the validity of laboratory calibration, to support the improvement of the instrument and of the data processing and evaluation facility and to show the application potential of imaging spectroscopy with the DAIS. This paper will present first results describing the laboratory calibration and inflight validation in the 0.4-2.5 µm wavelength region as well as some data quality aspects.

1. INTRODUCTION

The 79-channel Digital Airborne Imaging Spectrometer (DAIS-7915or DAIS), was built by GER Corp. (Chang *et al.*, 1993) and funded by the European Union and DLR. The sensor covers the electromagnetic spectrum from the visible to the thermal wavelength region with 4 spectrometers. This paper will discuss the reflective bands of the first three spectrometers. An evaluation example of the thermal bands can be found at Richter (1996). The spatial resolution varies from 2.5 to 25 m, depending on the flight altitude of the aircraft. The first spectrometer in the range of 0.4 - 1.1 µm can be operated in three different wavelength configurations (Lehmann *et al.*, 1996). This paper will focus on data acquired in configuration 1, as on these most of the work has been carried out.

Between May 1995 and November 1995 the DAIS 7915 went through a series of on ground and airborne tests. The spectral response functions of all bands were measured several times and reported by Fries (1995). From the response curves acquired in January 1996 the center wavelength and bandwidth for every band were derived and are given in Figure1. The accuracy of the spectral calibration was estimated to be about 4 nm.

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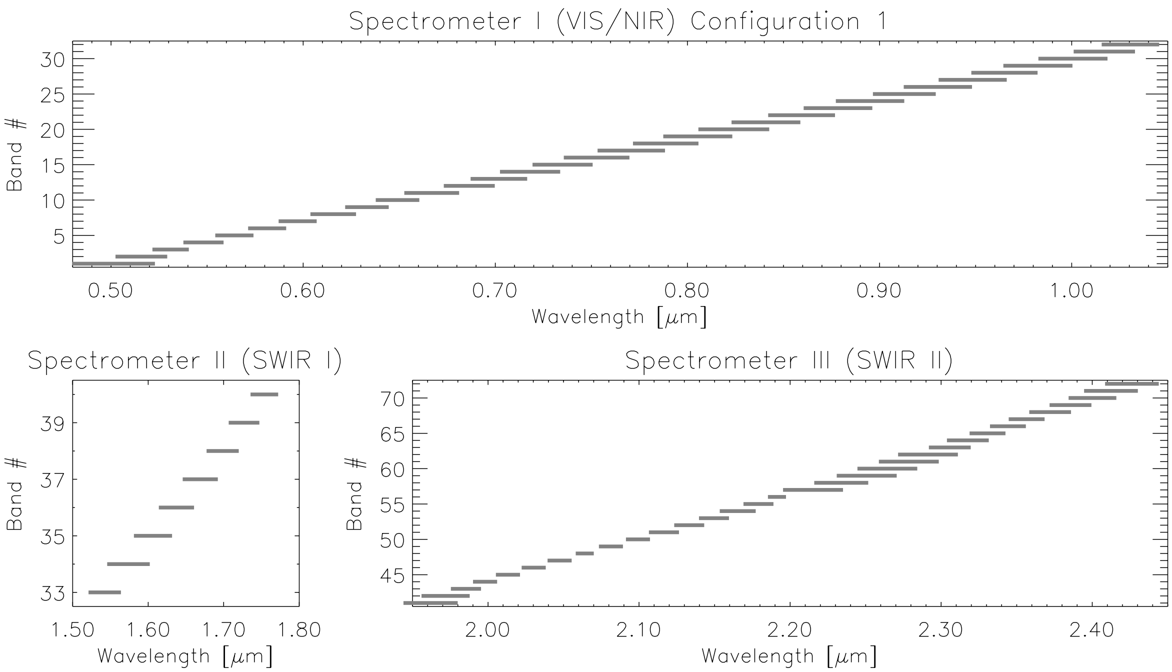

Figure 1. Bandposition and bandwidth in the first three spectrometers of the DAIS 7915

Almost 100 airborne scenes spread all over Germany were acquired during the flight season. The average length of a scene is about 2000 scan lines. The data volume per scene including the housekeeping channel is about 170 MB. Thus, almost 20 GB of airborne raw data are available. The test site evaluated in this paper is located near DLR's research facility west of Munich and contains a spectrally well known target, previously used for sensor inflight calibration. It comprises small lakes, forests, agricultural sites, urban and industrial areas. Besides that, data takes were obtained to launch different pilot studies. One example covers the monitoring of mining dumps in former East Germany (Müller *et al.*, 1996). Another one was carried out to investigate forest damages in south western Germany. Richter (1996) has developed an atmospheric correction for airborne DAIS data and describes the derivation of heat fluxes using the thermal channles.

2. LABORATORY CALIBRATION

Three laboratory calibration cycles in April, July and November 1995 were completed. For calibration, the DAIS scanning unit is mounted on top of an integrating sphere which is part of DLR's Multipurpose Calibration Facility (MCF) (Oertel, 1994). The steps of laboratory calibration of the DAIS were first reported by Müller (1995) and slightly modified since. Some approaches were adapted from the AVIRIS calibration procedure described by Chrien *et al.* (1990).

A number of scenes is acquired at different illumination levels. The integrating sphere can be lightened by 18 quartz lamps mounted inside the sphere to form a circle around the opening. In the original setup each lamp had a power of 200 W. To achieve uniform illumination conditions inside the sphere at least two lamps have to be switched on. This results in a radiance level which is already higher than the average at sensor radiance observed during inflight operation. Depending on the position of the lamps used, radiance variations in the FOV of the sensor in the range of 5 % are possible if less than 4 lamps are switched on. In case more than 4 lamps are turned on, some channels reach their saturation level. Thus, if 200 W lamps are used only three brightness levels are available for calibrating the DAIS sensor. This was the case in the first two calibration cycles.

Shortly after the first calibration cycle was finished, a change in the hardware had to be performed. As a result the position of the nadir pixel was altered so that the data can not be used for calibration of data acquired at a later point in time. The evaluation of the second calibration run showed that calibration at lower radiance levels and with higher radiance homogeneity is desireable. Operating the integrating sphere with 2*200, 3*200W and 4*200W lamps resulted in unsatisfactory homogeneity at low radiances and did not allow to prove the sensors linearity at relevant radiance levels. Before the third cycle was carried out, a number of the original 200W lamps of the integrating sphere were replaced by 100 W lamps. This extends the dynamic range of the calibration down to radiances similar to those observed during regular flight conditions. The number of brightness levels available for calibration is doubled. The additional mounting of 45 W lamps is intended, but could not yet been realized due to problems with the stabilized power supply.

During the last calibration in November it turned out that the presence of the scanner above the opening of the integrating sphere alters the radiance inside the sphere significantly. Until then, radiance measurements of the integrating sphere were taken without the sensor mounted on top. The differences showed to be as high as 8 % for certain wavelength regions. For this reason all radiance measurements for the third calibration cycle were conducted simultaneously to the data acquisition with the DAIS sensor. The spectroradiometer used for this purpose is an ASD Field Spec FR which covers the wavelength region from 0.4 to 2.5 µm. The ASD instrument is calibrated using measurements of a stabilized source with known radiance. The resulting ASD radiance spectra

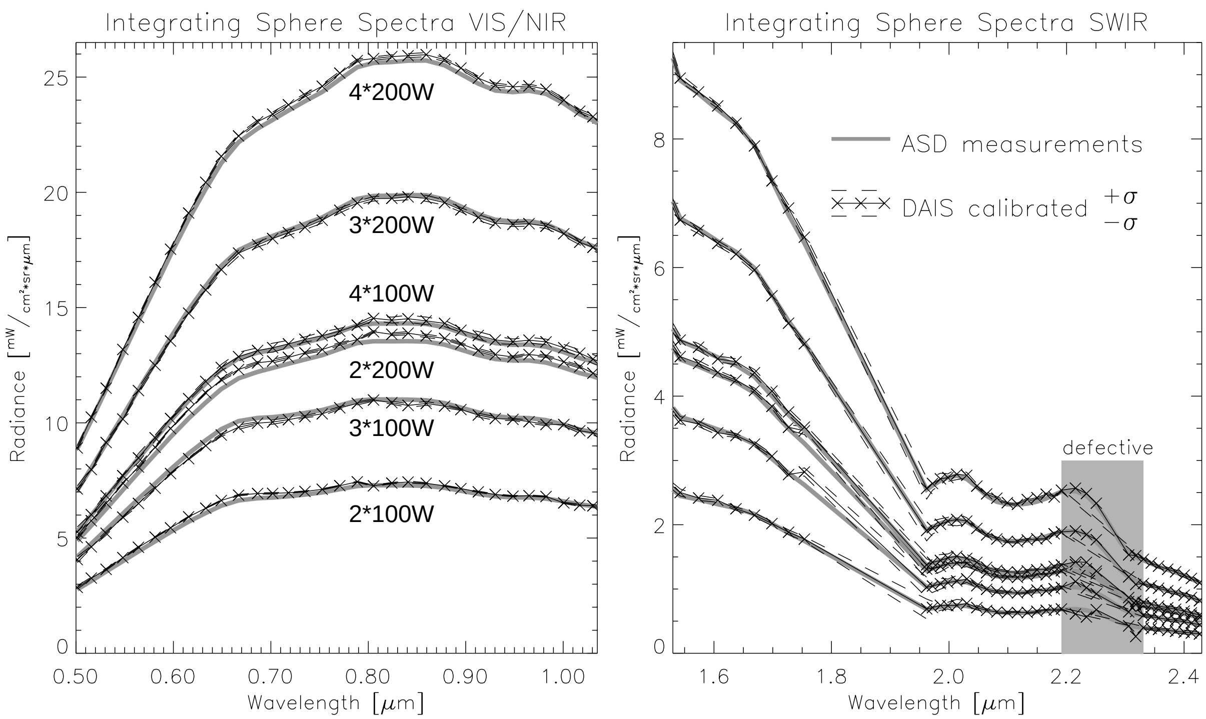

Figure 2. Measured radiance spectra and DAIS calibrated data acquired on the integrating sphere

were resampled to the DAIS bands using a convolution algorithm and the DAIS response curves obtained by the spectral calibration part (SCP) (Oertel, 1994). These resampled radiance spectra serve as the reference for the DAIS calibration, they are given in Figure 2.

The DAIS laboratory calibration data went through the system correction procedures. The channels of the first spectrometer (1-32) with DC coupled electronics were dark current corrected. To the channels 32-72 of the two SWIR spectrometers the AC coupling correction was applied. The preprocessing is described in more detail by Strobl *et al.* (1996). Eight bands in the third spectrometer were malfunctioning due to electronic problems. They may not be evaluated for calibration purposes.

The Kennedy type scan mechanism requires separate calibration of each of the four possible scan mirror facet combinations involved in a scan line. For every brightness level about 400 scan lines are recorded. To eliminate random system noise about 80 scan lines for each of the facet combinations are averaged. This average values are used to perform a linear regression with the measured radiances to compute the calibration coefficents for each facet combination and for all 512 pixels in the scan swath.

The derived calibration coefficents are applied to the laboratory data to validate their accuracy. The mean and standard deviation for each of the scenes is presented in Figure 2. The overall calibration accuracy is found to be better than 3 % in most cases. The only exception to this is the measurement taken at the 2*200W lamp illumination, where deviations up to 5 % are found. This is attributed to the inhomogeneity of radiance inside the integrating sphere. In fact, the deviations for the 4*100W and 4*200W combinations are less than 1.5 %.

The mean and the standard deviation of the laboratory data takes are used to determine the signal to noise ratio at different radiance levels under laboratory conditions. The minimum and maximum SNR ratios retrieved are displayed in Figure 3. When looking at these SNR's one has to keep in mind that they are not calculated using a small box of 3x3 or 5x5 pixels, but are representing several thousands of single measurements. These SNR values do not only include variations within an entire scan line but as well variations across more than 50 lines. They might be influenced by spatial and temporal inhomogeneities of the radiance inside the integrating sphere or small scan frequency fluctuations. They give the worst case for the laboratory. Nevertheless, these SNR values are comparable to those achieved under flight conditions. The SNR's for a 5x5 pixel window in laboratory data is found to be a factor of 2 to 5 higher than the ones listed here.

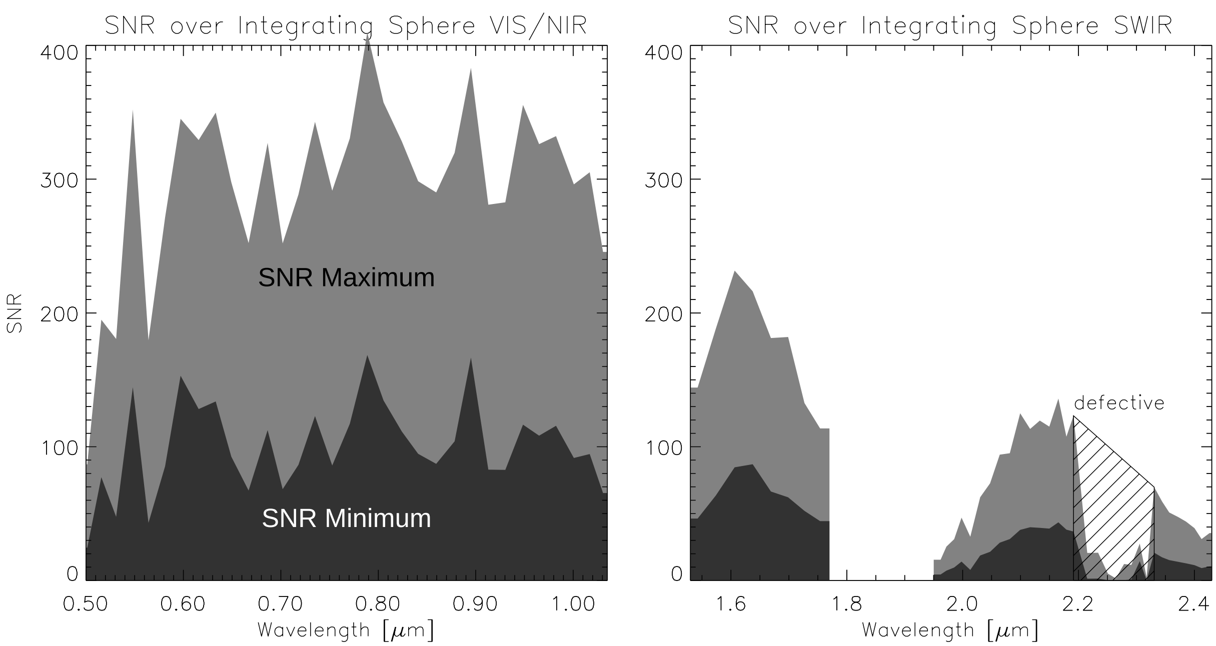

Figure 3. Signal to Noise Ratios calculated from entire scenes acquired on the integrating sphere

The comparison of the November calibration with the one conducted in July indicated that the sensor sensitivity slowly degraded with time. This degradation was estimated from laboratory and airborne measurements and taken into account when calibrating inflight data. To calibrate the eight bands in the third spectrometer which were defective in November, calibration data of July were used.

3. INFLIGHT VALIDATION

The method used here to estimate the calibration accuracy of a hyperspectral sensor was repeatetly applied for AVIRIS calibration and reported by Green *et al.* (1990, 1994). Four scenes from the 1995 campaigns were chosen to validate the system performance and calibration accuracy. They were acquired over a period of 6 month. Table 1 lists the acquisition parameters of this data takes.

Table 1. Acquisition parameters of airborne datatakes used for inflight validation

DATE [1995]	TIME [Local]	ALTITUDE [m AGL]	HEADING [deg] 90°=East	SOLAR AZIMUTH [deg]	SOLAR ZENITH [deg]	CONFIG VIS/NIR	SCAN FREQUENCY
May 04	10:50	2250	354	125.7	43.4	1	12 Hz
June 20	10:50	2650	352	116.8	38.3	1	12 Hz
July 13	10:25	2100	350	110.9	43.8	1	12 Hz
Oct. 24	12:45	3000	355	193.5	60.7	1	12 Hz

At three of this dates ground truth data are avaiable. The test site investigated here is a concrete covered area of about 80 by 50 meters, the apron of the airfield at DLR's research facility in Oberpfaffenhofen.

In each of the scenes between 30 and 80 pixels covering the concrete field are identified. Figures 4a-d show a subset of band 6 {580 nm} of the image data on which the pixels selected for averaging are marked. Unfortunately the geometric quality of the image acquired in October is very poor. The scene is distorted due to heavy aircraft manoeuvering.

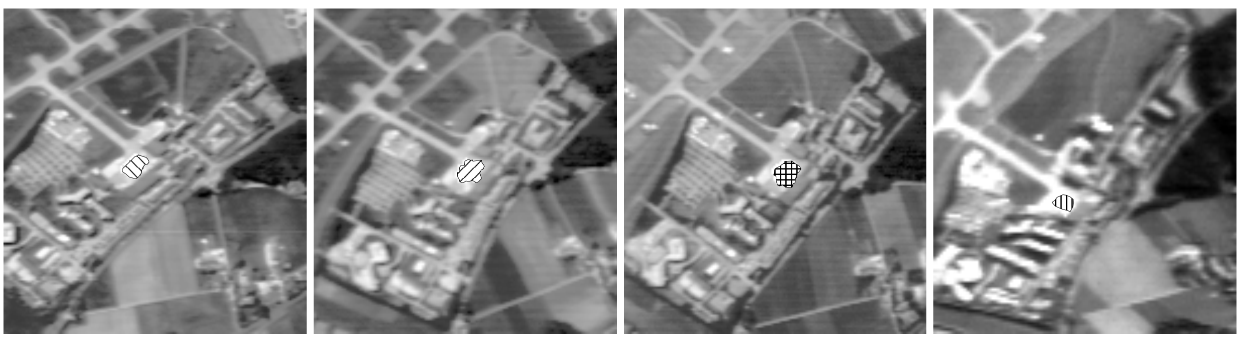

Fig. 4a. May 4th 1995 Fig. 4b. June 20th Fig. 4c. July 13th Fig. 4d. October 24th

Selecting the optimal pixels for representing the mean radiance response of the concrete surface is difficult. The apron is not perfectly homogeneous and might be obstructed by parked aircraft at its sides. For this reason it is intended to put an artifical well calibrated test area in place for 1996 inflight calibration and validation. However, in 1995 the apron was the most suitable calibration target.

The obtained average spectra are compared to predicted at sensor radiances. At sensor radiance is estimated by using ground reflectance spectra measured with a GER IRIS MARK V spectroradiometer and the radiative transfer code MODTRAN (Berk *et al.*, 1989). The input parameters for MODTRAN like visibility, air pressure, temperature and humidity are taken from radiosonde data collected at a nearby meteorological station.

The MODTRAN predicted radiance spectra are resampled to the DAIS band positions and bandwidths. The resulting radiance values can be directly compared to the ones obtained from the calibrated DAIS scenes. Figure 5 shows the MODTRAN predicted at sensor radiances and the DAIS measured and calibrated data for all four acquisition dates.

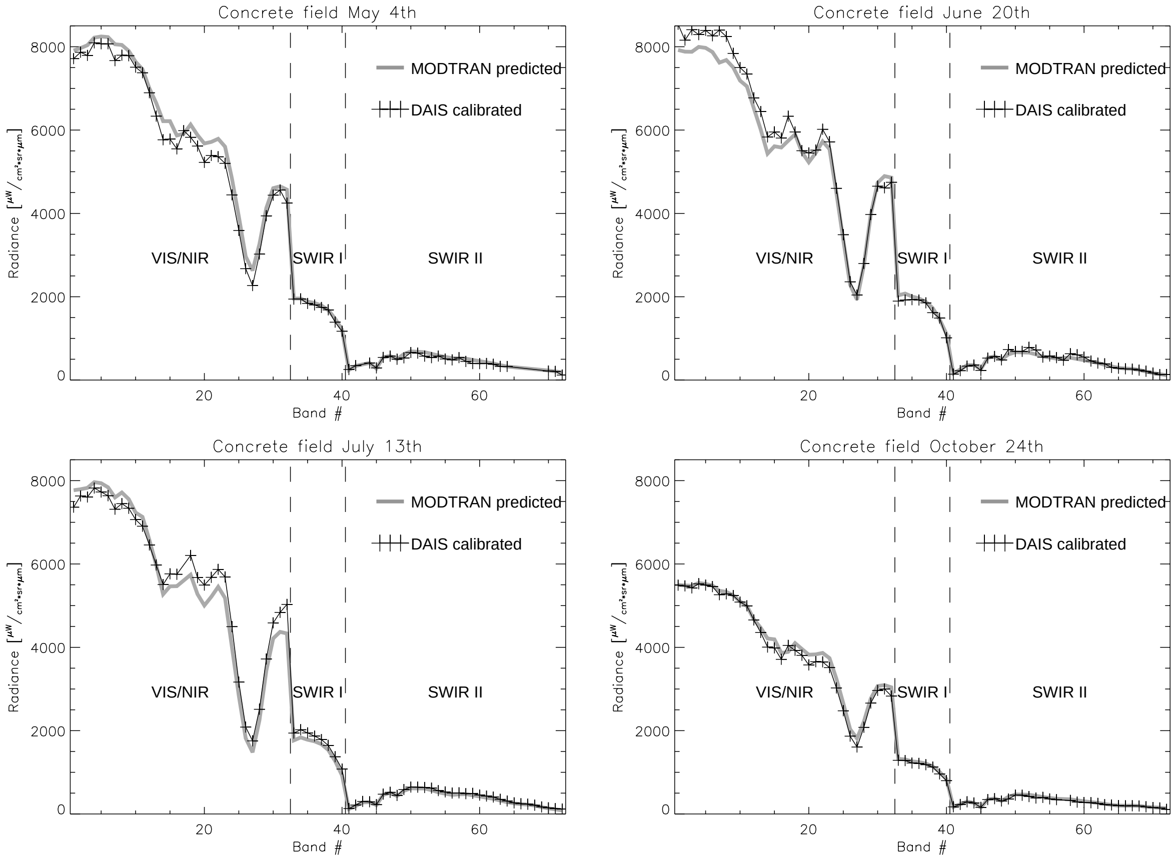

Figure 5. DAIS measured and MODTRAN predicted at sensor radiance for the inflight validation dates.

Some DAIS bands were defective at some dates like the band 65 to 68 in the May scene and thus excluded from the analysis. They are also not plotted in Figure 5. The calibration accuracy is estimated in two ways. Averaging the absolute values of relative deviation for each band gives a per band accuracy over the entire time span of observations. The mean absolute value of relative deviation over all bands at a given date is a measure for the correspondance of the MODTRAN and DAIS spectra for each observation day. Both parameters are given in Figure 6.

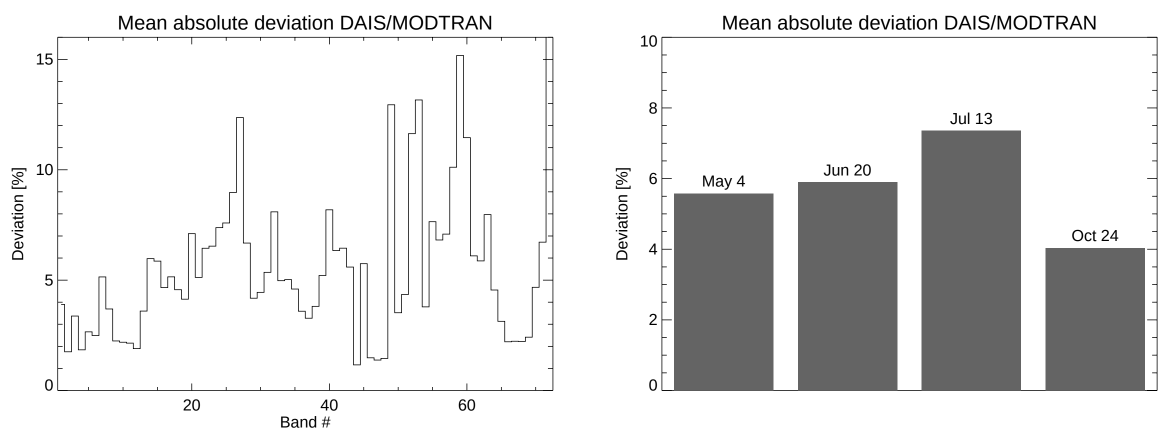

Figure 6. Mean deviations of DAIS measurements from MODTRAN predicted radiances

The per band accuracy varies beetween 5 and 15 % in most bands and thus meets the expectations based on the results of the laboratory calibration. The overall accuracy at the different acquisition dates is about 6-8 %. The high deviations in the first 10-15 bands of the June overflight might be caused by cleaning the scan mirrors before that data take.

At the current stage it is still difficult to estimate error bars for these parameters. Several sources of uncertainty have been spotted so far. As mentioned above the apron is not an ideal calibration target. Spatial and temporal variations of up to 20 % in some wavelength ranges of the reflectance measurements were observed. Secondly Oberpfaffenhofen is surrounded by several lakes. The humidity and visibility may change rapidly and often differs significantly from the location at which the radiosonde data for MODTRAN input are acquired. As reported by Green *et al.* (1994) the MODTRAN calculation itself and errors in the solar irradiance spectrum may add to this.

4. DATA QUALITY IMPROVEMENT

Constant efforts are made to improve the system performance of the DAIS scanner since its first tests at DLR in late 1994. One of the major problems encountered was caused by vibrations originating from the turbo prop engines of the DO-228 aircraft. These vibrations were picked up especially by the third spectrometer and lead to a strong striping in the SWIR II imagery.

An image example showing this artifact is shown in Figure 7. The displayed band 65 {2.33 µm} was acquired on July 13th. It is heavily disturbed by striping but otherwise shows satisfying image quality and SNR.

The stripes were present in all 32 bands of the spectrometer but with variing intensity. Channels with low signal levels were degraded even further and information otherwise exploitable was lost.

Figure 7. DAIS Bd. 65, July 13th

To identify the striping, separate it from the image information and remove it, a method suggested by Nielsen *et al.* (1994) was used. The Maximum Noise Fraction transformation first introduced by Green *et al.* (1988) is the first step during which the image information is isolated from the noise. Another well suited method for separating signal from noise in an image is the Minimum/Maximum Autocorrelation Factors transformation (MAF) described by Switzer and Green (1984). Both transformations make use not only of the spectral redundancy but as well take into account the spatial characteristics of the imagery. It is possible to optimize the signal/noise isolation by altering the noise model or the dilatation in the autocorrelation computation.

Here, the MNF method and a simple noise model were used. The noise was estimated to be the difference between the original and a 3x3 median filtered image. Due to its special covariance properties which differs from the ones of the image information and the random noise the striping components sum up in one of the first MNF bands.

Fig. 8a. SWIR II, MNF 1, July

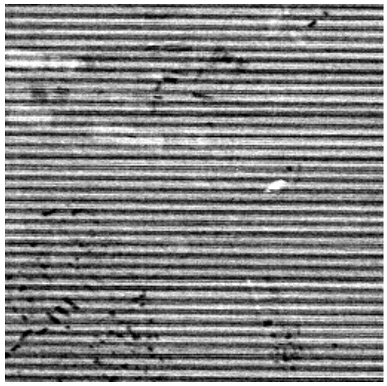

Fig. 8b. SWIR II, MNF 2, July

Figure 8a,b display the first two bands output by the MNF transformation of the July 13th scene. Only the SWIR II channels were used in the transformation as the presence of bands from other spectrometers which show no or different striping only would disturb the covariance matrix.

As pointed out by Nielsen *et al.* (1994) a very effective way to reduce the striping in all bands of the spectrometer is to filter only the affected MNF's and then perform a back transformation. This has the advantage that the different noise patterns in the MNF's can be removed with different methods separated from each other. In this case we would remove the striping using a fourier algorithm, while for the suppresion of salt and pepper noise a median filter is more appropriate.

The use of the MAF and MNF transformation not only eases the filtering of multiband imagery. They may as well be used to detect and separate noise patterns otherwise obscured or mixed. In our case we evaluated the effectiveness of new shock mounts which replaced the old ones in order to help the striping problem in the SWIR II bands.

Figure 9 shows again band 65 from the third spectrometer (SWIR II) as it appeares in the October datatake. The overall data quality and SNR is not as good as it was in the July scene. This is mainly due to the low sun zenith angle at which, compared to the July level only about two third of the energy reaches the detector. Taking this into account the improved performance of the new shock mounts is visible.

Figure 9. DAIS Bd. 65, Oct. 24th

This was verified by carrying out a MNF transformation for all SWIR II bands in the same manner as described above for the July scene. The first two bands of the MNF transformed data are presented in Figure 10.

Fig. 10a. SWIR II, MNF 1, Oct.

Fig. 10b. SWIR II, MNF 2, Oct.

The striping again showed up in the second MNF band but it is obviously of much less significance compared to MNF band 2 of the July data.

This examples illustrates the usefullness of noise isolation not only for the improvement of image quality but also for assessing the performance of certain hardware constituents.

5. CONCLUSIONS

The first year of DAIS operation at DLR was dedicated to prepare the instrument and the processing and evaluation facility for operational performance in 1996.

Three laboratory calibration cycles were performed. Only the third fulfilled the requirements in terms of homogeneity of the integrating sphere at the desired radiance levels. It was possible to derive accurate calibration coefficents and validate the linearity of the instrument over most of the relevant radiance range. Further improvements of the facility towards calibration at even lower radiances are planned and will be in place before the first 1996 campaign.

The laboratory calibration was validated with four inflight scenes acquired between May and October 1995. Although the uncertainties of some involved parameters are not known, the calibration accuracy can be estimated to be between 5-15 % depending on the band. Through a well defined calibration target and more frequent overflights the calibration accuracy of inflight data should be enhanced in 1996.

Advanced statistical techniques like MNF and MAF transformations are used to investigate the noise pattern in the data and support filtering. The results from the noise analysis help to allocate noise sources and allow to control the improvements achieved by modifications to the instrument hardware.

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Information about the DAIS and some data examples can be found in the WWW at the DAIS home page:
“http://www.op.dlr.de/ne-oe/fo/dais/dais.html”