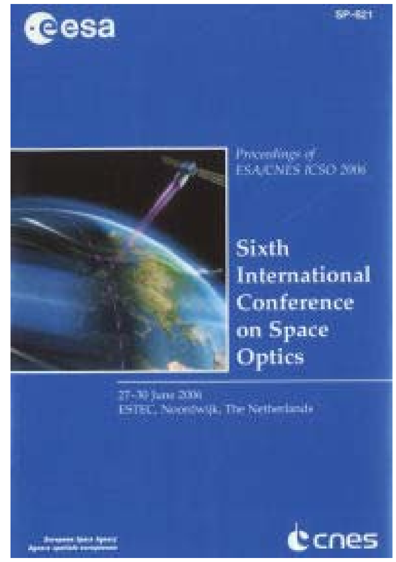
International Conference on Space Optics—ICSO 2006

Noordwijk, Netherlands

27–30 June 2006

Edited by Errico Armandillo, Josiane Costeraste, and Nikos Karafolas



Enhancement of diffusers BRDF accuracy

Gerard Otter, Gregory Bazalgette Courrèges-Lacoste, Hedser van Brug, Jos Groote Schaarsberg, et al.

International Conference on Space Optics — ICSO 2006, edited by Errico Armandillo, Josiane Costeraste,
Nikos Karafolas, Proc. of SPIE Vol. 10567, 1056740 · © 2006 ESA and CNES
CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2308087

ENHANCEMENT OF DIFFUSERS BRDF ACCURACY

Gerard Otter[1], Grégory Bazalgette Courrèges-Lacoste[1], Hedser van Brug[1], Jos Groote Schaarsberg[1], Steven Delwart[2] and Umberto del Bello[2]

[1]TNO Science and Industry, Stieltjesweg 1, 2628 CK Delft, the Netherlands
[2]ESA ESTEC, Noordwijk, the Netherlands

ABSTRACT

This paper reports the result of an ESA study conducted at TNO to investigate properties of various diffusers. Diffusers are widely used in space instruments as part of the on-board absolute calibration. Knowledge of the behaviour of the diffuser is therefore most important.

From measurements of launched instruments in-orbit it has been discovered that when a diffuser is used in the vacuum of space the BRDF can change with respect to the one in ambient conditions. This is called the air/vacuum effect and has been simulated in this study by measuring the BRDF in a laboratory in ambient as well as vacuum conditions.

Another studied effect is related to the design parameters of the optical system and the scattering properties of the diffuser. The effect is called Spectral Features and is a noise like structure superimposed on the diffuser BRDF. Modern space spectrometers, which have high spectral resolution and/or a small field of view (high spatial resolution) are suffering from this effect. The choice of diffuser can be very critical with respect to the required absolute radiometric calibration of an instrument. Even if the Spectral Features are small it can influence the error budget of the retrieval algorithms for the level 2 products.

In this presentation diffuser trade-off results are presented and the Spectral Features model applied to the optical configuration of the MERIS instrument is compared to in-flight measurements of MERIS.

1. INTRODUCTION

Diffusers are widely used for the in-orbit absolute radiometric calibration of earth observation instruments. Like the earth the diffuser is illuminated by the sun giving a radiance signal, which is then measured by the instrument. With a known BRDF of the diffuser the irradiance of the sun can be determined. This irradiance is then used to determine the earth albedo from the earth radiance.

Proc. '6th Internat. Conf. on Space Optics', ESTEC, Noordwijk, The Netherlands, 27-30 June 2006 (ESA SP-621, June 2006)

Several different type of diffusers are developed and used in space. On ENVISAT the MERIS instrument used a number of Spectralon diffusers and the SCIAMACHY instrument uses two aluminium diffusers. The BRDF of these diffusers are both determined on ground under ambient conditions. Once in-orbit it was found that the BRDF was changed with respect to the on-ground calibration. This is called the air/vacuum effect.

Another effect of the diffuser was discovered during the on-ground instrument calibration of the SCIAMACHY instrument. When calibrating the sun port it was found that small noise like features appeared on the measured irradiance spectrum. These features however where not noise but where introduced by the diffuser. These features are since then known as spectral features and are caused by speckle behaviour.

To increase the knowledge on diffuser behaviour ESA ESTEC has conducted a study carried out by TNO to investigate the different properties of various diffusers. This paper is a summary of the findings of this study.

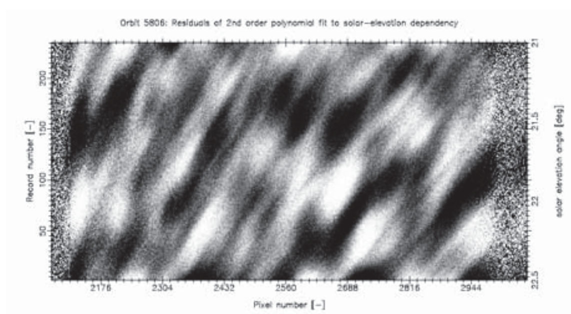


Fig. 1. Spectral Features visualization in the in-flight SCIAMACHY sun-over-diffuser measurement. Wavelength is horizontal, solar elevation angle is vertical [1]

2. DIFFUSERS

Within the study two diffuser properties where studied. The air/vacuum effect was studied on a Spectralon diffuser as used in the MERIS instrument. The spectral features on several diffuser types of different manufactures.

The choice to measure the air/vacuum effect only on one diffuser was manly practical. The measurements concerned with this effect are long and expensive. The choice for the Spectralon is made because of the knowledge of this material from the MERIS project and the fact that Spectralon is a purpose material, which means more likely to have contamination in air and therefore a bigger air/vacuum effect.

The spectral features where determined for five different diffusers:

1. An Aluminium diffuser, manufactured in-house by TNO. This type of diffuser is used in instruments like OMI, SCIAMACHY and GOME.
2. A Quasi Volume Diffuser (QVD, main material Quartz), manufactured in-house by TNO. This type of diffuser is used in instruments like OMI and GOME-2.
3. A Spectralon diffuser (main material PTFE), manufactured by Labsphere. This type of diffuser is used in the MERIS instrument.
4. A Fluorion diffuser (main material PTFE), manufactured by Altran technology. This type of diffuser has no space heritage.
5. A White tile diffuser (de-polished white ceramic), manufactured by NPL. This type of diffuser has no space heritage.

3. AIR/VACUUM EFFECT

The air/vacuum of the Spectralon diffuser was determined by measuring the BRDF for different angular configuration in both air and vacuum. For this a special vacuum chamber was developed to enable radiance and irradiance measurements within vacuum. Due to the nature of the chamber radiance could only be measured at fixed angles. The sum of the angle of incidence and the observed scattering angle is always 90 degrees.

A set of incidence and detection angles where measured under both ambient and vacuum conditions. The ratio between the ambient and the vacuum BRDF was used to determine any effect. In the figure below the results can be found. Note that the configuration 65 incidence/ 25 detection is measured twice. This configuration is measured as first and last of the series. Since the vacuum was fully established in the beginning the measurement are marked as vacuum 1 and 2.

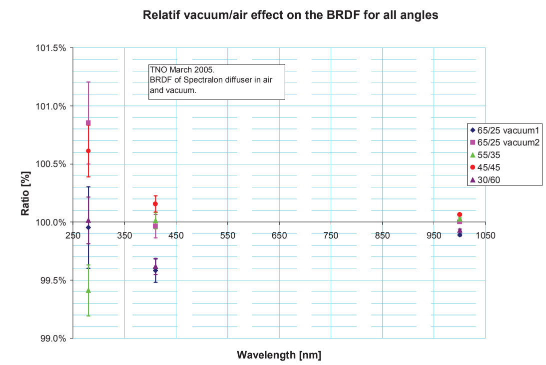


Fig. 2. Ratio of the BSDF measurements in vacuum and air for all angles vs wavelengths.

From figure 2 it can be seen that there is no clear air vacuum behaviour, although the ratios are significantly different from 1. The change of BRDF seems to be rather random. When the results are plotted against the pressure a more consistent picture can be seen. In figure 3 the results for 280 nm are given showing an air vacuum effect depending on the vacuum pressure. Only the point at 55/35 is off from the general trend. This is an unknown measurement artefact. For 410 nm and 1000 nm similar results are found only with smaller ratios (and no artefact at 55/35).

From the results the following was concluded:

- An air vacuum effect was observed for the Spectralon diffuser.
- The effect increases with decreasing wavelength, at 280 nm an effect of 1 % was observed.

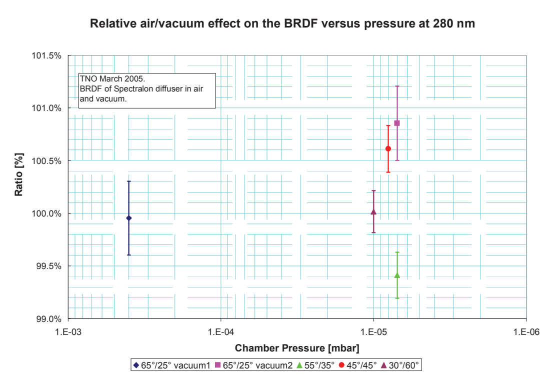


Fig. 3. Ratio of the BRDF measurements in air and vacuum at 280 nm vs chamber pressure.

4. SPECTRAL FEATURES

During the SCIAMACHY on-ground calibration noise like features where discovered in the spectra from the sun-port. It was found that these features where reproducible for the same angle of illumination. The noise like structure is of such nature that it can interfere with the data product retrieval. Hence it was necessary to find a way do minimize the effect. In the case of the SCIAMACHY instrument a second diffuser was introduced in the instrument which could minimize the features by rotating the diffuser averaging out the patterns.

The origin of these features was found to be interference patterns from the diffuser. The structure of the diffuser creates speckle patterns on the detector. Speckles are known from coherent sources such as lasers. The light from the earth or the sun is not coherent, so normally no interference patterns would be expected. However due to the narrow bands of the spectrometers pixels the light on a individual pixel has a high coherence length.

To explain the origin of the spectral features the following example is given. Consider a white light source with a relative flat spectrum. This spectrum is measured with a high resolution calibrated spectrometer via a diffuser. From the spectrometer a flat response would be expected, however small noise like structures are observed.

On each pixel of the spectrometer a speckle pattern is imaged. This speckle pattern changes from pixel to pixel changing the total energy from pixel to pixel. This creates small fluctuations of the signal from pixel to pixel. Hence a noise like pattern.

The research on the spectral features has been done by modelling and by measuring. The behaviour of the spectral features is modelled using speckle theory. The model predicts the size of the speckles and the contrast on the detector surface and by that the signal coming from this detector. The model uses the diffuser properties and the optical lay-out of the spectrometer for this calculation.

To measure spectral features a special measurement strategy is used. The BRDF is measured with a narrow band spectrometer for two different positions of the diffuser. The two different positions of the diffuser was such that the BRDF can be considered the same but the speckle pattern is statistically independent. The ratio of the two BRDFs gives the spectral feature spectrum.

To quantify the spectral features a spectral feature amplitude is introduce the SFA. This SFA is a function of wavelength and is defined as the standard deviation of the spectrum value with respect to one. In principle a large number of independent spectra would be needed to determine the SFA, but it was found that a comparable results can be reached with only two different spectra. Taking the average over a small band of the (ratio) spectrum gives the same result as averaging over a number of independent spectra. This was proven by both the modelled results as with measured results.

Tests were done for the five diffusers mentioned before. With respect to spectral features the tested diffusers can be divided into three groups:

1. Surface diffuser (aluminium diffuser), the light scatters from the surface of the diffuser. Most of the light will be scattered only once.
2. Volume diffuser (Spectralon, Fluorion, White tile), the light scatters from the bulk of the material. The light will be scattered on multiple times.
3. Quasi volume diffuser (QVD), this diffuser is a piece of quartz which is roughened at two sides, one of the sides is coated with aluminium. The bulk of the light will be scattered at least three times; at the first rough surface, at the aluminium surface and again at the rough surface. By this a volume diffuser like behaviour is established.

It is expected that a large number of scattering events will minimize the spectral features.

The measurements have been performed for a number of spectral bands ranging from 240 nm up to 1600 nm. As expected the aluminium diffuser has the strongest spectral features. The other diffuser give results which are more or less comparable.

In figure 4 the SFA for the aluminium diffuser is shown. The SFA increases linear with wavelength except for the UV area. The UV part is measured with a prism as dispersing element, whereas the other parts of the spectrum are measured with a grating. The grating gives a near constant spectral resolution. With the prism the spectral resolution changes over the spectrum.

The linear behaviour was already predicted by the model from the speckle theory. The theory however is true for surface diffuser. For the volume diffusers the behaviour is still near linear for a large part of the spectrum but it can be expected to behave differently when a large spectral range is considered. This has been observed for the QVD.

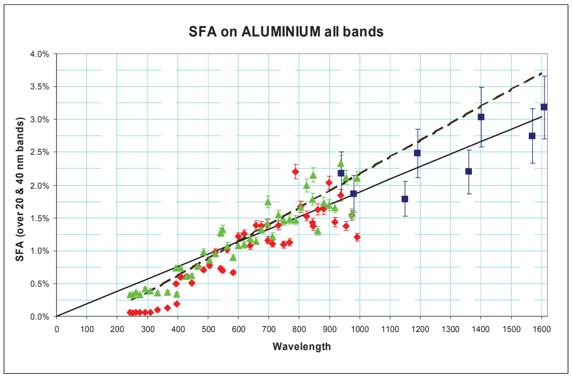


Fig. 4. Results of the Spectral Features measurements on an aluminium diffuser (green = winter 2004; red = summer 2005; blue = spring 2005).

From the measurement results a comparison of the different diffusers is made with respect to there spectral feature behaviour. The results are given in the table below. As can be seen the aluminium diffuser has the highest values. The volume diffusers are more or less comparable. The QVD is comparable to the volume diffusers for 450 and 900 nm and slightly higher for 1400 nm. The design of the QVD can be changed such that it is more optimized for longer wavelength.

Table 1. SFA values of the different diffusers.

Diffuser type	SFA value		
	450 nm	900 nm	1400 nm
Aluminium (surface)	0.5%	1.7%	2.6%
Spectralon (real volume)	0.14%	0.7 %	1.3 %
Fluorion (real volume)	0.14%	0.7%	1.5%
White tile (real volume)	0.2%	0.6%	1.55%
QVD (quasi-volume)	0.13%	0.6%	1.7%

5. SPECTRAL FEATURES OF THE MERIS INSTRUMENT

The MERIS instrument is a mid-resolution spectrometer with varying bandwidths around 10 nm. Width these kind of bandwidths no spectral features are expected as found for SCIAMACHY (resolution 0.1 nm). However for speckle not only spectral coherence but also spatial coherence is important. The narrow field of view per pixel of MERIS will introduce this coherence.

In the figures below observation from the MERIS instrument are shown. The red lines show the ratio between two sun angles with a small angular difference. The blue lines show the ratio between two sun angles with a large angular difference. It is obvious that the large angular difference give higher "spectral" features.

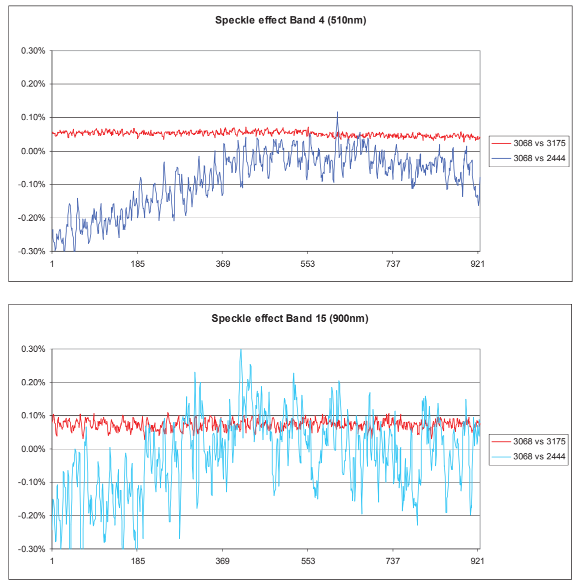


Fig. 5. Observations made by the MERIS instrument for two different bands. The ratio is shown for a small sun angle difference (red) and a large sun angle difference (blue).

The model was used to see if it could reproduce the SFA of MERIS. The SFA is a standard deviation which can be compared to the peak-peak values divided by 6. The results of the SFA calculation is shown in figure 6. What is found is that the model is able to predict quantitatively the amplitude of the spectral features. The SFA values calculated with the model deviates from the MERIS observation by less than a factor 2. This means that the model can be used to give a good prediction of what order of magnitude of SFA can be expected for an optical design.

Note the at the band around 760 nm the SFA curve has a peak. This peak corresponds with the smallest bandwidth of the corresponding band (i.e. 3.75 nm while the bandwidth of the other bands of MERIS is typically 10 nm).

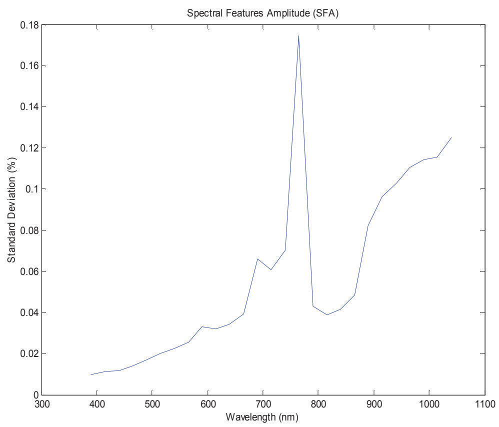


Fig. 6. SFA calculation for MERIS instrument.

6. CONCLUSION.

The BRDF of a diffuser can be different between air and vacuum. This difference increases from 0.1 % at 1000 nm up to a few percent at 280 nm.

The spectral features are caused by speckle patterns on the detector. The more coherent the light the higher the spectral features.

From the tested diffuser the volume diffusers and QVD have the lowest spectral features. It has to be remarked that the performance of the QVD is dependent on the mechanical design of this diffuser.

With the model it is possible to predict the spectral feature behaviour qualitatively and quantitatively.

More details on this topic can be found in the final report from the study [2].

1. In orbit detection of spectral features in SCIAMACHY. B. Ahlers, G. Bazalgette Courrèges-Lacoste, C. Schrijvers. SPIE vol. 5570, p. 401-410, 2004.

2. Enhancement of diffusers BSDF Accuracy, ESA contract 18432/04/NL/AR, Final report. TNO-ESA-RP-DIFF-04 issue 2, 16-11-2005.