EUMETSAT Satellite Application Facility on Climate Monitoring

The EUMETSAT Network of Satellite Application Facilities

CM SAF Climate Monitoring

Validation Report

Meteosat Surface Radiation - SRI

Edition 1

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Spectrally Resolved Irradiance **CM-107**

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Author	Richard Müller	CM SAF scientist		17/10/2012
Editor	Rainer Hollmann	Science Coordinator		
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AD 1	CM SAF Product Requirement Document	SAF/CM/DWD/PRD/2.0

Reference Documents

Reference	Title	Code
RD 1	Algorithm Theoretical Basis Document	SAF/CM/ATBD/SRI/1.2

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1 Executive Summary

This CM SAF report provides information on the validation of the spectrally resolved surface radiation of the CM SAF Meteosat Edition 1.0 data sets derived from SEVIRI/GERB and MVIRI sensors onboard of first and second generation Meteosat satellites.
This report presents the validation of
Spectrally Resolved Irradiance, SRI – CM-107
available from 1991 to 2011.
The data set is validated against available reference data sets from surface measurements. For these data sets, the accuracy is defined based on the bias derived from the validation with the reference data and evaluated against the accuracy requirements as given on in the product requirements document (PRD) [AD 1], reported for each band in the section 9.2 (Appendix).
Spectrally resolved irradiance clearly fulfil the accuracy requirements as specified in the Product Requirements Document (PRD) [AD 1].

Table 1-1: Summary of the accuracy of the CM SAF MSG surface radiation data sets. Between 400 and 1200nm the difference between surface measurements and satellite based date are in the order of the measurement uncertainty.

Data Set	Threshold / Target / Optimal Accuracies in W/m2	Dataset Accuracy
SRI	15 / 10 / 8 * fraction of spectral band of VIS corresponds roughly in relative units to ~ 12 / 8 / 6 % per band	Target accuracy achieved in all bands. < 5 %, 400-1100 nm < 12% 1100-1500 nm

The basic accuracy requirements are defined in the product requirements document (PRD) [AD 1], and the algorithm theoretical basis document (ATBD) describes the individual parameter algorithms [RD 1].

2 The EUMETSAT SAF on Climate Monitoring

The importance of climate monitoring with satellites was recognized in 2000 by EUMETSAT Member States when they amended the EUMETSAT Convention to affirm that the EUMETSAT mandate is also to “contribute to the operational monitoring of the climate and the detection of global climatic changes". Following this, EUMETSAT established within its Satellite Application Facility (SAF) network a dedicated centre, the SAF on Climate Monitoring (CM SAF, http://www.cmsaf.eu).
The consortium of CM SAF currently comprises the Deutscher Wetterdienst (DWD) as host institute, and the partners from the Royal Meteorological Institute of Belgium (RMIB), the Finnish Meteorological Institute (FMI), the Royal Meteorological Institute of the Netherlands (KNMI), the Swedish Meteorological and Hydrological Institute (SMHI), the Meteorological Service of Switzerland (MeteoSwiss), and the Meteorological Service of the United Kingdom (UK MetOffice). Since the beginning in 1999, the EUMETSAT Satellite Application Facility on Climate Monitoring (CM SAF) has developed and will continue to develop capabilities for a sustained generation and provision of Climate Data Records (CDR’s) derived from operational meteorological satellites.
In particular the generation of long-term data sets is pursued. The ultimate aim is to make the resulting data sets suitable for the analysis of climate variability and potentially the detection of climate trends. CM SAF works in close collaboration with the EUMETSAT Central Facility and liaises with other satellite operators to advance the availability, quality and usability of Fundamental Climate Data Records (FCDRs) as defined by the Global Climate Observing System (GCOS). As a major task the CM SAF utilizes FCDRs to produce records of Essential Climate Variables (ECVs) as defined by GCOS. Thematically, the focus of CM SAF is on ECVs associated with the global energy and water cycle.

Another essential task of CM SAF is to produce data sets that can serve applications related to the new Global Framework of Climate Services initiated by the WMO World Climate Conference-3 in 2009. CM SAF is supporting climate services at national meteorological and hydrological services (NMHSs) with long-term data records but also with data sets produced close to real time that can be used to prepare monthly/annual updates of the state of the climate. Both types of products together allow for a consistent description of mean values, anomalies, variability and potential trends for the chosen ECVs. CM SAF ECV data sets also serve the improvement of climate models both at global and regional scale.
As an essential partner in the related international frameworks, in particular WMO SCOPE-CM (Sustained COordinated Processing of Environmental satellite data for Climate Monitoring), the CM SAF - together with the EUMETSAT Central Facility, assumes the role as main implementer of EUMETSAT’s commitments in support to global climate monitoring. This is achieved through:

- Application of highest standards and guidelines as lined out by GCOS for the satellite data processing,
- Processing of satellite data within a true international collaboration benefiting from developments at international level and pollinating the partnership with own ideas and standards,
- Intensive validation and improvement of the CM SAF climate data records,
- Taking a major role in data set assessments performed by research organisations such as WCRP (World Climate Research Program). This role provides the CM SAF with deep contacts to research organizations that form a substantial user group for the CM SAF CDRs,
- Maintaining and providing an operational and sustained infrastructure that can serve the community within the transition of mature CDR products from the research community into operational environments.

A catalogue of all available CM SAF products is accessible via the CM SAF webpage, www.cmsaf.eu. Here, detailed information about product ordering, add-on tools, sample programs and documentation is provided.

3 Introduction

The spectrally resolved irradiance data set derived from the Meteosat satellite data contain information on the solar spectrum at the surface The spectrally resolved surface irradiance shortwave (SRI) is based on the retrieval of the surface irradiance using the effective cloud albedo derived from the RMIB top of atmosphere albedo [RD 1] or from the MVIRI HRV channek [RD 1]. SRI is available as monthly averages and daily averages between 1991 and 2011 on a 0.05°-regular longitude-latitude grid.

4 Validation Data Sets

The validation of the surface radiation data sets is conducted against surface measurements from two stations located in Stuttgart Germany and Loughborough England. The complete solar spectrum is not measured operationally by national weather services or research institutes. Hence, measurements are very seldom and usually performed within the scope of commercial solar energy applications. The reference data is not freely available.
Hence, the two data sets of spectral measurements are used for the validation of the method. They cover one year and are specified in Table 4-1. Both data sets were quality checked by the institutes that carried out the measurements. Please note, that these measurements are performed on a tilted plane, because they are intended to be used within photovoltaic performance studies.
To make the datasets comparable they were averaged to hourly values. Moreover, they have been integrated to the spectral bands used in our approach. As the instruments are limited within the interval of 300 to 1,700 nm, we can perform this integration for the 20 Kato bands defined within the interval of 317–1,613 nm. Both data sets have been used in a preceding study in a comparison with SOLIS (SOLar Irradiance Scheme) [22].

Table 4-1: The table provides information about the used surface measurements.

Dataset	Loughborough	Stuttgart
Location	52.77°N, −1.23°E	48.75°N, 9.11°E
Provided by	CREST, Loughborough University	IPE, Stuttgart University
Period	Sep 2003–Aug 2004	2008
Apparatus	Horiba, custom build	Stellarnet EPP 2000C UV-VIS, EPP 2000 NIR INGAS
Temporal resolution	2 min scan, every 10 min	1 min scan every min., delivered as 15 min average
Spectral resolution	10 nm	1 nm
Spectral range	300 to 1,700 nm	300 to 1,700 nm
Orientation	20° East	South
Tilt	52°	33°
Completeness original data	40%	98%
Completeness hourly data	35%	97%

The transformation of the data from the tilted plane to the horizontal plane is performed with the established method of Klucher [Klucher, 1979]

5 Validation

The strategy for the validation of the CM SAF MSG surface radiation data sets follows the CM SAF Product Requirements Document [AD 1]. For the spectrally resolved surface incoming solar radiation (SRI) the accuracy of the data set is validated with available surface observations.
The accuracy requirements applicable for this validation report are following user needs, consolidated within the PCR-4 process.

5.1 Methodology

According to the PRD [AD 1] the validation of the CM SAF SRI data set is based on the comparison with available surface measurements. The measures for the verification with surface measurements are the bias, absolute bias and partly RMSE. To account for uncertainties in the surface measurements and possible errors introduced by calculating the temporal averages from surface observations, an uncertainty of 5-8 % is assumed for the spectral irradiance derived from the surface observations. The quality of the data sets is assessed by comparisons with the specified accuracy in the PRD [AD 1]

5.2 Validation results

Different aspects were used for validation of the data retrieved with SPECMAGIC. First, the retrieved annual averages of SRI have been compared with measurements for each wavelength band for cloud free skies. Cloud free cases are classified by the ratio between diffuse and global irradiance, for a ratio below 0.3 clear sky cases are assumed. The applied error measures, Root Mean Square Deviation (RMSE) and Bias, are based on comparison of hourly values and are defined in the Appendix. Please note that the comparison on hourly basis leads to high values of the root mean square deviations. Therefore, the absolute and relative bias values are the main quantities applied for the evaluation of the ability of the method to provide accurate spectral resolved irradiance. The resulting spectra are given for both sites together with the bias in Figure 1.

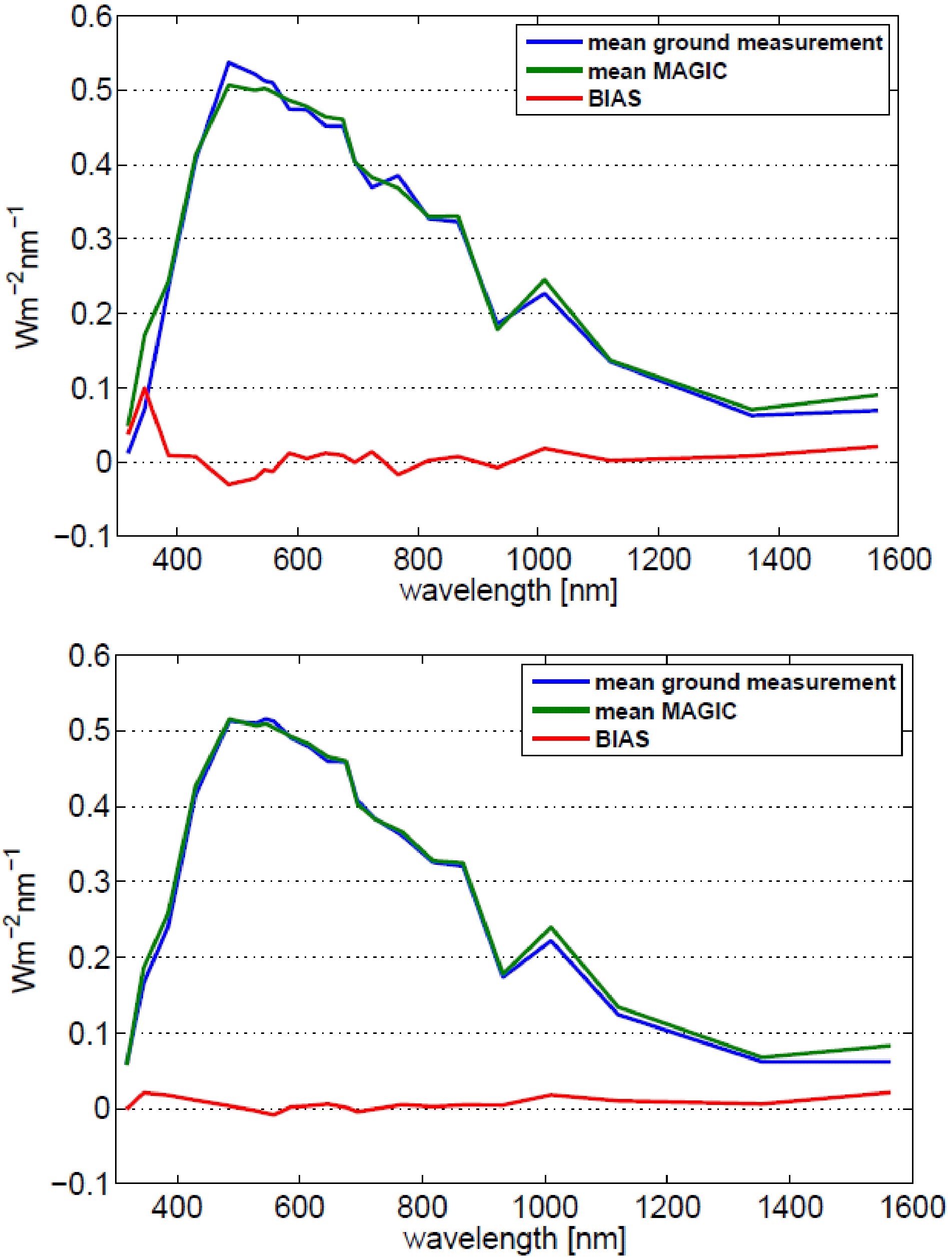

Figure 1: Average spectrum of Kato bands measured at Loughborough (top) and Stuttgart (bottom) in comparison with SPECMAGIC. The bias is given in addition.

In general a good agreement between the retrieved and the measured spectrum is apparent. The retrieved annual spectrum is in better agreement with Stuttgart measurements. This is also depicted in the bias. The bias is closer to zero at Stuttgart than at Loughborough. The good match in the UV at the Stuttgart site in contrast to the mismatch at the Loughborough site might be a result of an outdated calibration of the instrument in the UV where aging and blurring of optical devices happens much faster. The bias shows no striking spectral feature or trend between 400 and 1400 nm.

Secondly, SPECMAGIC has been compared with SOLIS [Müller et al., 2004] for cloud-free skies. SOLIS follows a concept of integrated radiative transfer runs, but takes benefit of the modified Lambert–Beer relation in order to improve the computing performance [Müller et al, 2004]. The use of identical atmospheric input for SOLIS and SPECMAGIC avoids the occurrence of differences in the comparison that are induced by uncertainties in the atmospheric input. As the MLB approach is applied in both schemes also uncertainties induced by this approach are avoided. Hence, the comparison results provide information about the accuracy of the applied hybrid eigenvector approach and parameterizations for water vapor, ozone and surface albedo corrections relative to explicit radiative transfer modeling for typical atmospheric conditions.

Figure 2 shows the comparison results. It is observed that the SPECMAGIC annual spectrum is in good agreement with the SOLIS annual spectrum. However, the bias indicates a slight tendency of SPECMAGIC to underestimate the SOLIS results for wavelength bands with $\Lambda < 700$ nm and to overestimate the SOLIS results for wavelength bands with $\Lambda > 700$ nm.

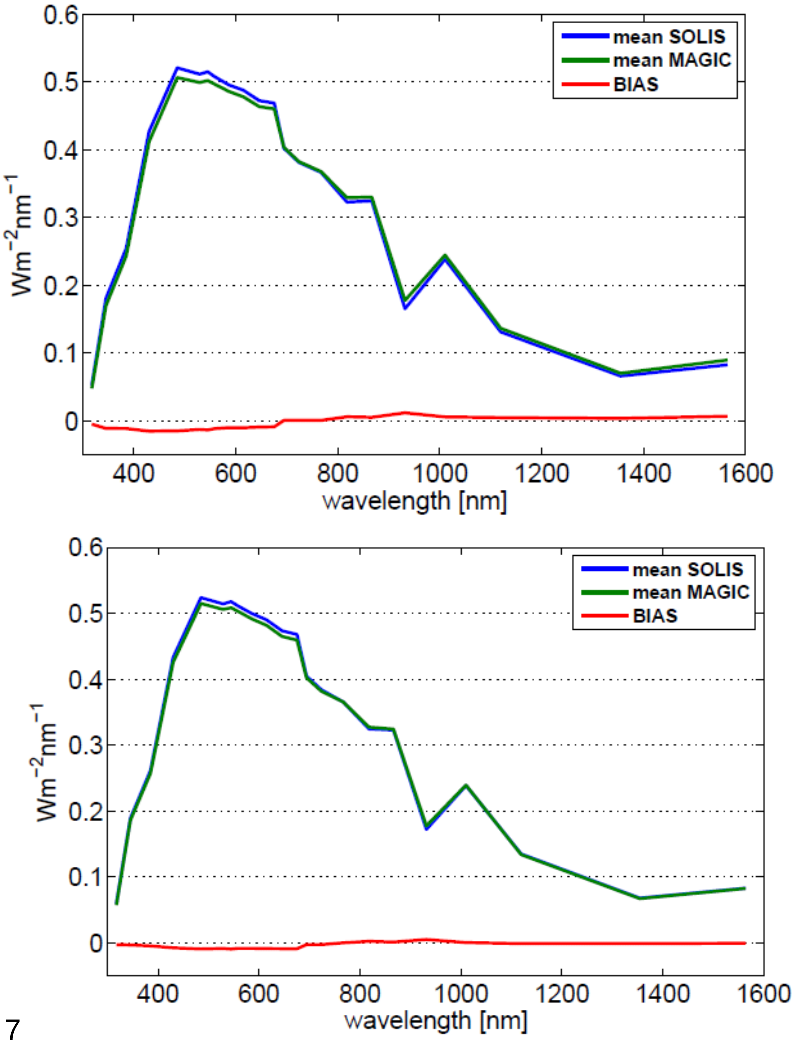

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Figure 2: Average spectrum of Kato bands measured at Loghborough (top) and Stuttgart (bottom) in comparison with SOLIS. The bias is given in addition.

The relative bias and root mean square deviation (RMSE) resulting from the comparison of SPECMAGIC with the ground measurements are illustrated for both sites in Figure 3.
In order to investigate differences in the spectral features between cloudy and cloud free situations, the respective statistical quantities are diagrammed separately in addition. It can be seen that the relative RMSE is dominated by the cloudy situations, and it is significantly reduced for clear sky situations. A striking feature is the large all sky relative bias above 1,300 nm. For clear sky irradiance an significant increase in the relative bias is also apparent, which indicates that the clear sky model might be a main driver. However, the results indicate that also the spectral cloud correction contributes significantly to the bias. Further analysis is needed before final conclusions can be drawn, especially as systematic measurement errors can not be excluded a priori, but have to be seriously taken into account. Below 1,200 nm the retrieval shows a good performance. This indicates that the applied spectral correction of clouds works well here.

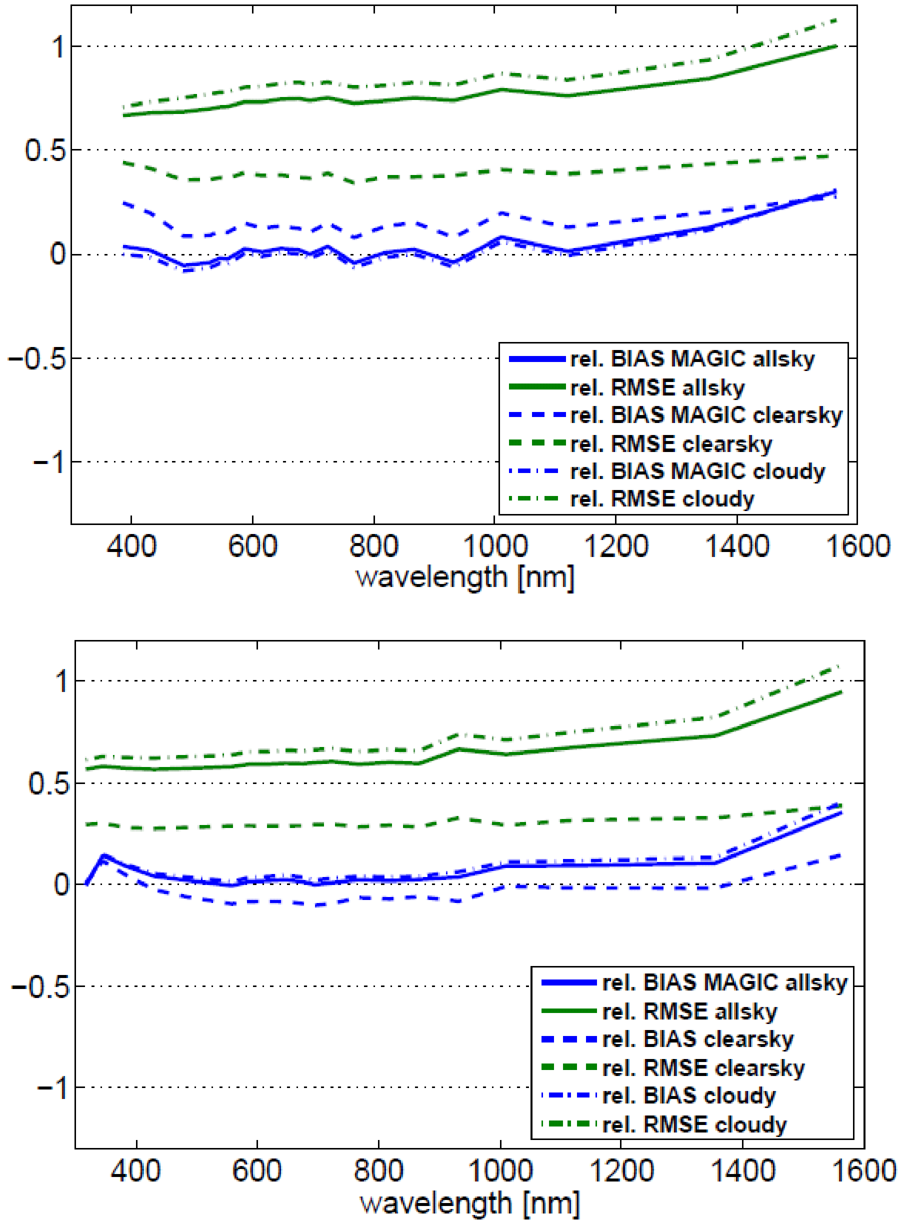

Figure 3: Relative bias and RMSE of SPECMAGIC retrieval with respect to ground measurements performed at Loughborough (top) and Stuttgart (bottom) for all situations, clear sky and cloudy sky.

The final analysis concentrates on four wavelength bands.We use an ozone absorption band centered around 345 nm (328–363 nm). A second band is chosen in the visible range (center 485 nm, 452–517 nm). The third band is a water vapor absorption band (center 931 nm, 889–975 nm). The following band is a near infrared band that is not affected by water vapor absorption (center 1,010 nm, 975–1,046 nm). For these four bands the yearly course is given for both sites in Figure 4 and Figure 5. The irradiance values at the specified bands are normalized with the broadband irradiances to concentrate the analysis on purely spectral effects. The monthly averages as well as the 10th and 90th percentile of normalized irradiance are given in these figures.

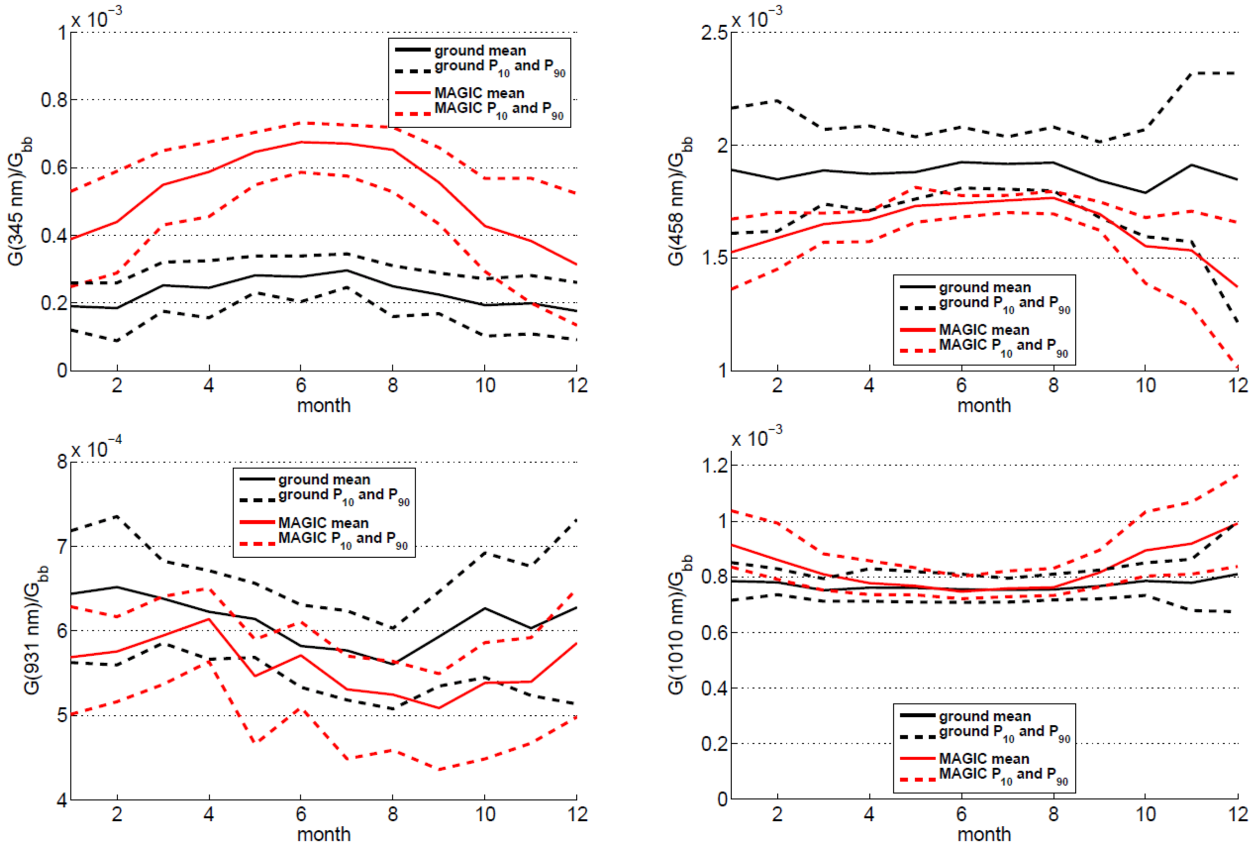

Figure 4: Annual course of normalized irradiance for four wavelength bands for Loughborough. Comparison of measured data and SPECMAGIC retrievals

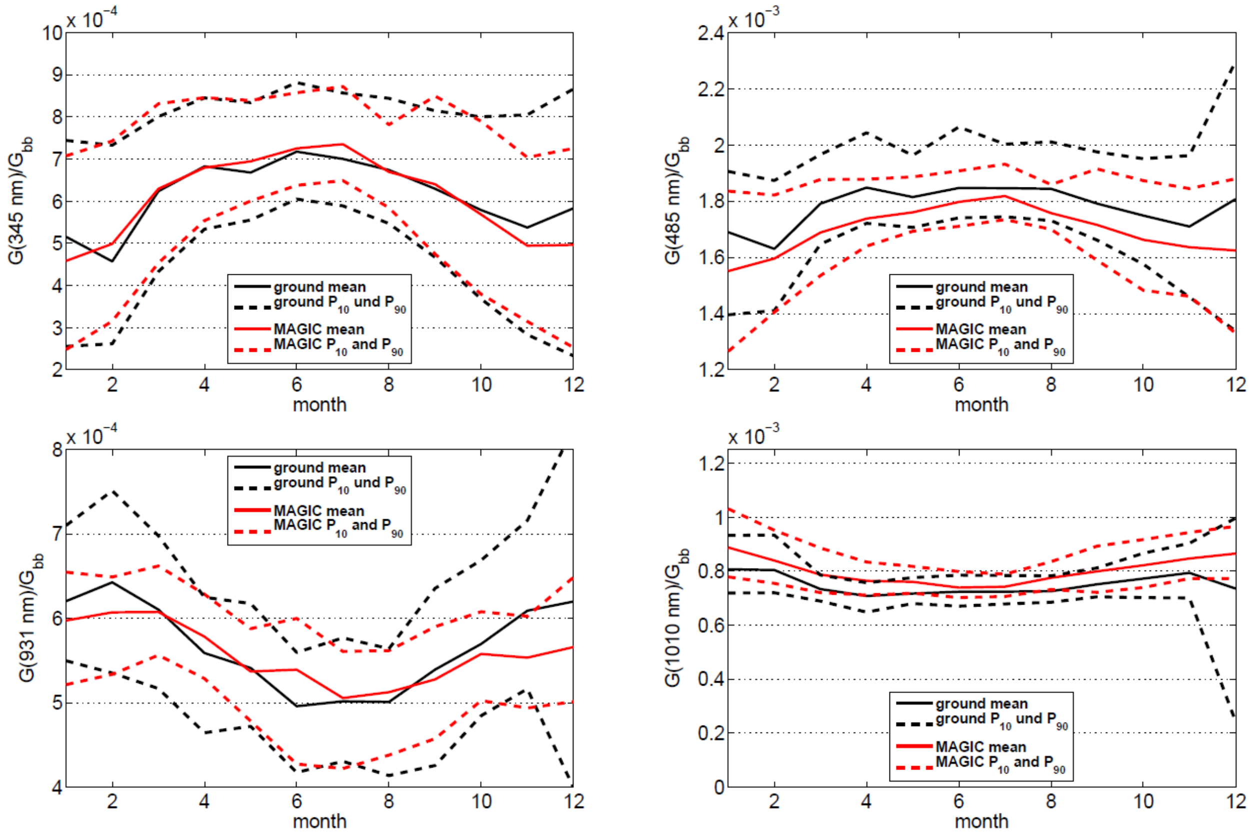

Figure 5: . Annual course of normalized irradiance for four wavelength bands for Stuttgart. Comparison of measured data and SPECMAGIC retrievals.

The validation of the SPECMAGIC retrievals shows that the annual cycle of the four chosen bands are similar for both sites. In summer the UV and VIS bands have a higher share in the broadband irradiance than in wintertime. The opposite is apparent for the water vapour and NIR bands. However, a remarkable misfit between SPECMAGIC and ground measurements occurs at Loughborough for the UV band. Here, the ground measurements shows only a slight annual cycle, which seems to be unlikely. The more pronounced annual cycle given by SPECMAGIC seems to be more realistic. The good match of the annual cycle at Stuttgart supports this hypothesis. This is another hint for an outdated or misaligned calibration in the UV at Loughborough, which has been already indicated by the comparison of the annual averages (see e.g. Figure 1). The difference of the WV absorption band at Loughborough needs further investigation. The observations at Stuttgart show an overall good agreement with SPECMAGIC

The basis for the physical model and the retrieval of spectrally resolved irradiance has been the MAGIC broadband algorithm [Müller et al, 2009]. It is the first time that the eigenvector-hybrid LUT approach has been exploited for the retrieval of the spectrally resolved irradiance. The method is validated with spectral measurements of two sites in Europe for 22 spectral bands. The validation results demonstrate that the retrieval performs well. The accuracy is in the range of the uncertainty of surface measurements, which is about 5-8%, with exception of the UV and NIR (≥1,200 nm) part of the spectrum, where higher deviations occur. There is a need to investigate the differences in the UV spectra in more detail. However, it might be that at least parts of the differences are due to calibration issues as a consequence of aging (blurring) of the optical devices in the UV resulting from the photochemically very aggressive UV radiation.

The comparison with measurements on tilted planes shows evidence for the ability of the method to provide spectral resolved irradiance on horizontal surfaces accurately. Spectrally resolved irradiance on horizontal surfaces is needed for climate monitoring and analysis, but for many application, e.g., for land surfaces, daylight applications and photosynthetic active radiation, irradiance on tilted planes is also of great importance. Beside these applications, the performed comparisons with measurements on tilted planes have demonstrated the ability of SPECMAGIC to provide accurate data also for solar energy applications.
The treatment of spectrally resolved cloud transmission by the discussed method might fail in bands with strong water/ice absorption (e.g., 1.6, 2.2 micron) as these effects are strongly dependent on cloud droplet size. Variations in droplet size are not explicitly considered by the applied method. Hence, the spectrally resolved irradiance in these spectral regions should be handled with care and might be unreliable.

6 Conclusions

We presented the validation of the CM SAF MSG spectrally resolved surface radiation data set based on the requirements as defined in the CM SAF PRD [AD 1]. The data set fulfils the target accuracy requirements. However in the of the UV (<=400) and NIR (≥1,200 nm) part of the spectrum high relative deviations occur. Hence, the spectrally resolved irradiance in these spectral regions should be handled with care. However, due to the difficulties of measuring spectrally resolved irradiance the differences apparent in this region might be also due to measurement uncertainties.
Spectrally resolved irradiance on horizontal surfaces is needed for climate monitoring and analysis, but for many application, e.g., for land surfaces, daylight applications and photosynthetic active radiation, irradiance on tilted planes is also of great importance. Beside these applications, the performed comparisons with measurements on tilted planes have demonstrated the ability of SPECMAGIC to provide accurate data also for solar energy applications.

7 References

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8 Glossary

AVHRR: Advanced Very High Resolution Radiometer
AOD: Aerosol Optical Depth
CAL: Effective cloud albedo
COT Cloud optical depth
GADS/OPAC: Global Aerosol Data Set / Optical Properties of Aerosols and Clouds
GERB: Geostationary Earth Radiation Experiment
K: Clear sky index.
LUT: Look-up table
MVIRI: Meteosat Visible-InfraRed Imager
NOAA: National Oceanic and Atmospheric Administration
NCEP: National Center for Environmental Prediction
RTM: Radiative Transfer Model
SID: Surface Direct Irradiance (beam).
SIS: Solar Surface Irradiance
SZA: Sun Zenith Angle
SSA: Single Scattering Albedo

9 Appendix:

9.1 Statistical Measures

Bias: The bias (or mean error) is simply the mean difference between the two considered datasets. It indicates whether the dataset on average overestimates or underestimates the reference dataset (e.g., ground measurement denoted as o).

$$\text{Bias} = \frac{1}{n}\sum_{k=1}^{n}(y_k - o_k) = \bar{y} - \bar{o} \qquad (23)$$

Relative Bias: is the Bias divided by the absolute value of the reference.

$$\text{Bias} = \frac{\bar{y} - \bar{o}}{\bar{o}} \qquad (24)$$

Standard deviation (SD): The standard deviation SD is a measure for the spread around the mean value of the distribution formed by the differences between the generated and the reference dataset.

$$\text{SD} = \sqrt{\frac{1}{n-1}\sum_{k=1}^{n}((y_k - o_k) - (\bar{y} - \bar{o}))^2} \qquad (25)$$

Root Mean Square Deviation: The root-mean-square deviation (RMSD) or root-mean-square error (RMSE) results from the bias and the standard deviation and is defined as follows. It measures beside the bias also the scatter of the data.

$$\text{RMSE} = \sqrt{BIAS^2 + SD} \qquad (26)$$

Relative Root Mean Square Error: is the RMSE divided by the absolute value of the reference data set.

$$\text{RMSE} = \frac{\sqrt{BIAS^2 + SD}}{\bar{o}} \qquad (27)$$

9.2 Optimal, target and threshold accuracy per band.

1st column: Kato band
2nd 3rd 4th column: Optimal, target and threshold accuracy in W/m²
Accuracies are estimated based on the incoming irradiance at the top of atmosphere.

256.300 0.0236316 0.0295395 0.0443092
277.948 0.0133518 0.0166898 0.0250347
295.127 0.0679668 0.0849585 0.127438
317.306 0.0907776 0.113472 0.170208
345.136 0.206608 0.25826 0.387391
385.000 0.317201 0.396501 0.594751
429.773 0.461104 0.576379 0.864569
484.863 0.753925 0.942406 1.41361
528.840 0.244837 0.306046 0.45907
544.800 0.104061 0.130076 0.195115
558.050 0.185381 0.231727 0.34759
585.800 0.408255 0.510318 0.765478
615.000 0.201326 0.251658 0.377487
645.850 0.391626 0.489532 0.734298
675.439 0.155332 0.194165 0.291248
694.313 0.171022 0.213777 0.320666
723.531 0.300568 0.37571 0.563565
767.046 0.350273 0.437842 0.656763
817.968 0.339636 0.424545 0.636817
866.714 0.253702 0.317128 0.475692
931.938 0.435101 0.543876 0.815814
1010.320 0.302111 0.377638 0.566458
1119.970 0.506079 0.632599 0.948898
1355.060 0.72327 0.904088 1.35613
1564.700 0.152491 0.190613 0.28592
1789.120 0.363942 0.454927 0.682391
2059.130 0.116034 0.145043 0.217564
2214.330 0.0572774 0.0715967 0.107395
2638.540 0.189174 0.236468 0.354702
3318.660 0.068166 0.0852075 0.127811
3813.210 0.021988 0.027485 0.0412275
4298.320 0.0237655 0.0297069 0.0445604