RETHINKING SATELLITE BASED SOLAR IRRADIANCE MODELLING

R. W. Mueller [1], D. Heinemann [1], C. Reise[8], M. Schroedter

1-University of Oldenburg, FB8, D-26111 Oldenburg;
8-Fraunhofer Institute for Solar Energy Systems; 9-German Aerospace Center

ABSTRACT

Accurate solar irradiance data are not only of particular importance for the assessment of the radiative forcing of the climate system, but also absolutely necessary for an efficient planning and operation of solar energy systems. The recently started European project Heliosat-3 will supply high quality solar radiation data by taking advantage of the enhanced capabilities of the new Meteosat Second Generation (MSG) satellites. This goal will be achieved by the development and establishment of a new type of calculation scheme. This new type will be based on radiative transfer models (RTM) using the information of atmospheric parameters retrieved from the MSG satellite (clouds, ozone, water vapour) and the ERS-2/ENVISAT satellites (aerosols).

This paper focuses on the description of the clear sky module of the new scheme, especially on the integrated use of a radiative transfer model. The linkage of the clear sky module with the cloud module is also briefly described in order to point out the benefits of the integrated RTM use for the all sky situations. The integrated use of a RTM within the new SOlar Irradiance Scheme SOLIS is applied by introducing a new fitting function called the modified Lambert-Beer (MLB) relation. Consequently, the modified Lambert-Beer relation and its role for an integrated RTM use are discussed. Comparison of the calculated clear sky irradiances with ground based measurements and the current clear sky module demonstrates the advantages and benefits of SOLIS. For example, spectral resolved data as well as the possibility to use enhanced information of atmospheric parameters. Since SOLIS provides spectral resolved irradiance data, it can be used for different applications. Beside improved information for the planning of solar energy systems, the calculation of photosynthetic active radiation, UV-index and Illuminance is possible.

1 INTRODUCTION

Satellite based Remote Sensing is a central issue in monitoring and forecasting the state of the earth´s atmosphere. Geostationary satellites such as METEOSAT or GOES provide cloud information in a high spatial and temporal resolution. These satellites are therefore not only useful for weather forecasting, but also for the estimation of solar irradiance, since the knowledge of the radiance reflected by clouds is the basis for the calculation of the transmitted irradiance. Additionally, a detailed knowledge about atmospheric parameters involved in scattering and absorption of sunlight is a further necessity. An accurate estimation of the downward solar irradiance is not only of particular importance for assessing the radiative forcing of the climate system, but also absolutely necessary for an efficient planning and operation of solar energy systems and the estimation of the energy load. Solar resource assessment from geostationary satellites constitutes a powerful alternative to meteorological ground network for both climatological and operational data (**?**).

In the context of a secure and environmental friendly energy supply renewable energy systems will be the energy source of the future (**?**) . Wind energy has become an important energy source in Europe (e.g. 15 % in Denmark), it is still increasing impressively. The usage of solar energy will increase enormously in the next 10 years as well. For an optimal and sufficient usage of solar energy and for the integration into the electricity grid, accurate solar irradiance data in a high spatial and temporal resolution are necessary. Solar irradiance schemes provide these data using weather satellites such as METEOSAT and MSG. Currently, most of the operational calculation schemes for solar irradiance are semi-empirical and based on statistical methods. They use cloud information from the current METEOSAT or GOES satellite and climatologies of atmospheric parameters, e.g. turbidity (characterising the combined effect of aerosols and water vapour), see **?** and references therein. The Heliosat method (**?**) and (**?**) is certainly one of the most known. It converts METEOSAT satellite data into irradiance with a better accuracy than interpolated ground measurements could provide (**?**) and (**?**). It is applied routinely in real time at the University of Oldenburg since 1995. It has permitted to establish the server Satel-Light, which delivers valuable information on daylight in buildings to architects and other stakeholders (**?**). It has also been used within the SoDa project [1] (**?**) for the calculation of the solar irradiance. Furthermore there exists derivates of Heliosat, e.g Heliosat-2 (**?**) which is optimised as an operational processing chain for climatological data. With the launch of the Meteosat Second Generation (MSG) satellite the possibilities for monitoring the earth atmosphere, have improved enormously. The MSG satellite will not only provide higher spatial (1km) and temporal (15 minutes) resolution, but also offers with its 11 channels from 0.6 to 13 mm the potential for the retrieval of atmospheric parameters such as additional cloud parameters, ozone, water vapour column, and with restrictions aerosols. These capabilites plus the synergy with other sensors, such as those aboard ERS-2 and ENVISAT (GOME and SCIAMACHY), permit to attain a refinement in the solar irradiance modelling. These refinements necessitate a rethinking in satellite based solar irradiance modelling, going ahead with a drastic revision of the current Heliosat processing scheme. The current Heliosat scheme can not exploit the enhanced information about the atmosphere provided by the improved satellite capabilities. Thus, it was necessary to develop a new scheme, which will be able to exhaust the enhanced capabilities of MSG (SEVIRI) and ENVISAT (SCIAMACHY). The accuracy of the calculated irradiance is expected to increase significantly with a scheme that can exhaust the capabilities of the new satellites. The new calculation scheme has to be fast, accurate and should provide - in contrast to Heliosat and Heliosat-2 - spectral resolved solar irradiance data.

As a consequence of the things mentioned above the new scheme is based on the integrated use of a radiative transfer model (RTM), whereas the information of the atmospheric parameters retrieved from the MSG satellite (clouds, ozone, water vapour) and from the GOME/ATSR-2 instruments aboard the ERS-2 satellites (aerosols, ozone) will be used as input to the RTM based scheme.[2] The direct integration of a RTM into the calculation schemes - instead of using pre-calculated look-up tables - is only possible if the necessary computing time can be kept small. For this purpose a functional treatment of the diurnal solar irradiance variation is applied. This allows an appropriate operational use of a RTM within the calculation scheme.

This paper focuses on the description of the new clear sky module, especially on the integrated use of the radiative transfer model (section 2) . The linkage of the clear sky module with the cloud module is briefly described in order to point out the benefits of the integrated RTM use for all sky situations as well.

A new function, called modified Lambert-Beer relation, is applied to allow the integration of the RTM to the new SOLIS scheme. Details are discussed in section 2. In section **??** the intrinsic precision of the beam model is investigated.

In section **??** the new SOLIS clear sky module is compared with measurements and the current Heliosat clear sky module. The atmospheric data used for this comparison are described in section **??**. The improvement of the new clear sky module is discussed based on this comparison taking into account principle benefits and limitations of the new method.

2 SOLIS - THE NEW SCHEME

2.1 Overview

The capabilities of the MSG satellite and sensors like SCIAMACHY are enormously improved compared to those of there predecessors METEOSAT and GOME. In order to benefit from these enhanced capabilities a new calculation scheme based on radiative transfer models (RTM) is developed. The information about the atmospheric parameters retrieved from the MSG satellite (clouds, ozone, water vapour) and from the GOME/ATSR-2 instruments (aerosols, ozone) will be used as input to the RTM based scheme.[3] The integrated usage of the RTM within the scheme is related to the clear-sky scheme using the well established *n*-*k* relation of the Heliosat method (**?**)

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[1] Integration and exploitation of networked Solar radiation Databases for environment monitoring project.

[2] In the near future the information from GOME/ATSR-2 will be replaced by SCIAMACHY/AATSR on ENVISAT.

[3] In the near future the information from GOME/ATSR-2 will be replaced by SCIAMACHY/AATSR on ENVISAT.

Table 1: Improvements in METEOSAT resolution

	spatial res. (sub sat. point)	temporal resolution	spectral channels
MSG	1km	15 min	12
METEOSAT	2.5km	30 min	3

and (**?**) or the Cloud Optical Depth (COD) option to consider cloud effects. It is important to note that the integrated use of the RTM within the clear sky module is linked with an enormous improvement for all sky situations as well. It is not a restriction of the model. This issue will be discussed in more detail in section **??**. On the other hand, the benefits and needs of the described clear sky module can only be understood if it is seen in the context of its main purpose – the operational satellite based solar irradiance modelling with a large geographical coverage. Keeping this in mind, it is also necessary to describe briefly the treatment of the clouds and the basics of the linkage between the clear sky module -described in detail in this paper- and the cloud modules, which are partly still under development. The cloud modules will be discussed in more detail in a forthcoming paper after reliable MSG data will be available.

Using n-k relation:

The Heliosat method was originally proposed by **?** and later modified by **?** and **?**. The basic idea of the Heliosat method is a two step approach. In a first step a relative normalised cloud reflectivity – the cloud index – is derived from METEOSAT images. The derived cloud index is correlated to the clear sky index k, which relates the actual ground irradiance G to the irradiance of the cloud free case $G_{clearsky}$. Consequently, in addition to the cloud index derived from the satellite signal a clear sky model, providing $G_{clearsky}$, is necessary for the estimation of the actual ground irradiance.

The *n-k* relation is powerful, validated and leads to small Root Mean Square Deviation (RMSD) between measured and calculated solar irradiance for almost homogenous cloud situations (RRMSD of 13-15 % for hourly values (**?**)). With MSG data it can be expected that the treatment of clouds using the current n-k will be improved only due to the higher spatial and temporal resolution. Nevertheless, an improvement of the *n-k* relation using physically retrieved cloud parameters is in preparation (see e.g. **?** and **?**).

Using COD based code:

Within this option the information of the cloud optical depth (COD) is used to consider the cloud effect. The COD will be retrieved operationally from MSG with software from the German Aerospace Center (DLR), based on the Apollo (**?**) and (**?**) or Nakajima (**?**) method. The RTM model SBDART (**?**) has been used to find a parameterisation in order to relate the all sky irradiance to the clear sky irradiance. Within this parameterisation also the effective radii, derivable with the **?** based scheme can be used. The derived parametrisation needs some fine-tuning and has to be tested with MSG data. It will be discussed in more detail in a forthcoming paper.

Independently which way is chosen for the treatment of clouds, the basis for the calculation of the all sky radiation is the clear sky module. More over, the clear sky situations are the most energy efficient. This exhausts the importance of an accurate and powerful clear sky module, which is described in detail in the next section.

2.2 Basic considerations

MSG will scan the atmosphere with a very high spatial resolution (see Table 1, e.g approximately 2.5 million pixels have to be processed every 15 min. for Europe). Thus, the computing time necessary to calculate the solar irradiance for each pixel has to be very small to make an operational usage of the solar irradiance scheme possible. One possibility to manage the computing time problem, with respect to RTM applications, is the use of look-up tables to consider the effect of atmospheric parameter on the solar irradiance. Instead of doing this a new, more powerful and flexible method, the integrated use of RTM within the scheme based on a modified Lambert-Beer relation, will be applied.

The integration of a RTM into the calculation schemes, instead of using pre-calculated look-up tables, is only possible if the necessary computing time can be decreased enormously. For this purpose, a ingenious functional treatment of the diurnal solar irradiance variation had to be applied. Thus making an appropriate explicit operational use of a RTM within the calculation schemes possible.

Starting point of the integrated use is the assumption that daily values of the atmospheric clear sky parameters in

Figure 1: Diagram of the spatial and temporal linkage between clear-sky and cloud information.

a spatial resolution of 100x100 km or 50x50 km are sufficient. This assumption is reasonable for solar energy applications in consideration of accuracy and operational practicality. It is not linked with significant restrictions of the model. These is discussed in detail in

Since daily values of the atmospheric parameters (O_3, H_2O, aerosols) within a region of 100x100 km (50x50 km) can be assumed to be sufficient, the diurnal variation of the solar irradiance is dependent only on the Solar Zenith Angle (SZA, θ_z). The RTM calculates the diurnal variation of the solar irradiance for each region using the daily atmospheric parameters as input. The cloud effect and hence the temporal disturbance of the diurnal clear sky irradiance of each pixel is considered by using the *n-k* relation or the COD option, see section 2.1. As a consequence, not every pixel has to be processed with the RTM. With the modified Lambert-Beer function, the diurnal variation of the clear-sky irradiance can be matched very well. Therefore, the number of RTM calculations necessary to define the diurnal variation of the clear sky irradiance can be reduced enormously. Only 2 RTM calculations are necessary to define the complete diurnal variation of the clear sky irradiance for a given atmospheric state. These 2 RTM calculation are enough to calculate the solar irradiance for the whole region (100x100 or 50x50 km), independent whether a pixel is cloudy or not. It has to be remembered that the effect of clouds is considered by using the *n-k* relation or the COD option.

Figures 1 illustrates the new scheme and the integrated use of the RTM within the clear sky scheme. The used modified Lambert-Beer (MLB) function is discussed in detail in the next section.

2.3 The Modified Lambert-Beer function

The Lambert-Beer relation within the scope of atmospheric application and monochromatic irradiance is given by (0)

where τ is the optical depth and within the scope of atmospheric radiation, I is the direct radiation at ground with sun in zenith, I_0 is the extraterrestrial irradiance. For direct monochromatic irradiance the SZA dependent diurnal variation of the irradiance described by this formula matches the results of explicit RTM results very well, once the optical depth is calculated at a SZA of 0 degree.

A good match for wavelength bands and global or diffuse irradiance is only possible if an additional correction parameter a is used. Hence a correction of the optical depth, or equivalent to this, of the parameter $\frac{\tau}{cos(\theta_z)}$ is necessary.

$$I = I_0 * exp(\frac{-\tau_0}{cos^a(\theta_z)}) * cos(\theta_z) \tag{1}$$

Using the so-called Modified Lambert-Beer (MLB) function, the calculated direct radiation as well as the global irradiance can be reproduced very well (see Fig. **??**) as well as reference. The fitting parameter a is calculated based on a second RTM calculation, e.g at a SZA of 60 degree.
It is important to notice that the fitting parameter a has different values vor direct and gloabl irradiancec

2.3.1 General remarks

The usage of the modified Lamber-Beer function is physically motivated, but it is actually a fitting function. This is especially obvious for the case of diffuse radiation. In principle, it is possible to fit the RTM calculations with any appropriate function, for example, a modified polynomial of third or higher degree $(e \cdot cos^3(x) + f \cdot cos^2(x) + g)$. Hence the big advantage of the modified Lambert-Beer function is not the feasibility to fit the RTM calculations, but that it is possible to yield a very good match between fitted and calculated values by using only 2 SZA calculations (e.g. better match than reachable with a polynomial of third degree). This is possible since the change of the irradiance with SZA is related to the Lamber-Beer law, hence using the modified Lambert-Beer relation ´´the degrees of freedom can be reduced´´. Moreover, the parameters a, b, c can be calculated without the need for a numerical fit, respectively.
The function was tested for many different atmospheric states, e.g four different aerosol types, five different visibilities (5, 10, 23, 50, 100), different water vapour amounts, different standard atmospheres, and surface models. There are no reasons to assume that there exist an atmospheric state for that the fit does not work very well.
Additionally, the MLB fit has been tested using another RTM (SBDART (**?**) instead of libRadtran 2.4) to show the independency of the MLB fit on the used RTM.
For our purpose, the sense of an appropriate fitting function is to save calculation time without losing ´´significant´´ accuracy. The question if a fitting function is usable for that purpose depends on the difference between the fitted values and the RTM calculated values. The differences are usually less than 8 W/m^2 for high SZA and less than 5 W/m^2 for SZA below 70 degrees.
At low visibilities (high optical depth, high aerosol load) I_o has to be enhanced for global and diffuse radiation. Therefore, a general equation has been found which is applied to I_0 to get $I_{0,enh}$.

$$I_{0,enh} = (1 + I_0 \cdot \frac{I_{diffuse}}{I_{direct} \cdot I_{global}}) \cdot I_0 \tag{2}$$

It is important to note that in SOLIS $I_{0,enh}$ is used within the MLB relation for all atmospheric states instead of the original I_0. Hence, I_0 in the equation 5,6 and 7 is $I_{0,enh}$. In order to consider the effect of refraction, and to use the modified Lambert-Beer relation also for a SZA of 90 degree the SZA is stretched at high SZA.

2.4 Radiative Transfer Model

The radiative transfer model (RTM) used within the clear-sky module is the model libRadtran. libRadtran is a collection of C and Fortran functions and programs for calculation of solar and thermal radiation in the Earth's atmosphere (A. Kylling and B. Mayer, http:// www.libradtran.org). It has (also) been validated by comparison with other models (**?**), (**?**), and radiation measurements (**?**).
libRadtran offers the possibility of using the correlated-k approach of **?**. The correlated-k method is developed to compute the spectral transmittance (hence the spectral fluxes) based on grouping of gaseous absorption coefficients. The main idea is to benefit from the fact that the same value of the absorption coefficient k is encountered many times over a given spectral interval. Thus, the computing time can be decreased by eliminating the redundancy, grouping the values of k, and performing the transmittance calculation only once for a given value of k. Using the correlated-k option, the spectral resolved data can be calculated operationally in MSG pixel resolution, a new feature, so far not implemented in the Heliosat or Heliosat-2 method.
In addition, libRadtran is very flexible with respect to the atmospheric input, e.g. different possibilities for the input of the aerosol information can be chosen by the user.
Since the correlated-k option of libRadtran is used within SOLIS, the described procedure for the calculation of the global, direct, and diffuse irradiance is performed not only for the broadband wavelength region but for each

Figure 2: Comparison between RTM calculations and fit using the modified Lambert-Beer relation. Example for fit within a small wavelength band

wavelength band of the SOLIS clear sky model. The SOLIS wavelength bands are in accordance with correlated-k (**?**) wavelength bands. The spectral output is provided in 30-80 nm wide wavelength bands between 306.8 and 3001.9 nm, which is sufficient for solar energy applications. Also additional wavelength bands below 306.8 nm or above 3001.9 nm can be used. The MLB relation works very well for the spectral resolved data, see figure 2 as an example.

2.5 Comparison of measurements and model, Freiburg, August 2000

Cloud-free situations were selected according to the cloud-index derived with the Heliosat method from METEOSAT images. A situation was assumed to be cloud-free if the cloud index n of the respective pixel was within the interval from -0.03 to 0.03 and the spatial variation of the cloud index was less than 0.02. The possibility still exists that some situations with little cloud cover are included, which especially effects the direct irradiance, leading to an increasing statistical uncertainty.

The ground measurements have originally a temporal resolution of 10 seconds. They are averaged to 30 minutes means in accordance to the temporal resolution of the satellite. The point in time, when the pixel above the measurements station is scanned from the satellite lies in the middle of the 30 minutes averaging window.

From the GOME ozone retrieval, the ozone is set to 275 Du. Yet it has to be mentioned that ozone has no big effect on the broadband irradiance, but on the UV. Based on the derived $H_2 0$ vertical columns, a content of 15 mm $H_2 0$ is used for the August model runs.

The turbidity map provides a turbidity of 4 for the respective months. That corresponds to a visibility of 34 km and an aerosol optical depth (AOD) of 0.23 respectively. The conversion of turbidity to visibility has been performed with the radiative transfer model MODTRAN (**?**) based on the work of **?**.

GADS/OPAC provides an AOD of 0.18-0.25 for relative humidities between 50 and 80 % and urban as an aerosol type. In order to study the effect of different aerosol types, the calculations has been performed for rural and urban aerosols. The range of the AOD is in consistency with the visibility derived from the Linke turbidity climatology. The average relative humidity for the clear sky days was approximately 50 %, leading to an AOD of 0.18.

For this comparison a visibility of 34 km has been used. It has to be noted that whether urban or rural aerosols are used, no significant differences in the calculated direct solar irradiance occur. Hence just the results for the urban aerosols are diagrammed. Additionally, the results of the Heliosat clear sky model, described in **?**, are plotted. The figure **??** illustrates that the SOLIS clear sky model matches the SZA dependency of the measurements very well.

In the case of global irradiance the chosen aerosol type has a significant effect on the global irradiance. Using the Heliosat clear sky model or any other model that is just based on turbidity, the effect of different aerosols on the global irradiance can not be considered, because the information about the atmospheric state is redundant. The turbidity ”defines” the direct irradiance, but not the aerosol type and hence not its effect on the global irradiance. This effect is even significant for the measurement site, but is higher for sites with higher aerosol load (see figure **??**), or for sites characterised by special types of aerosols events, like desert storms or biomass burning. That is a drawback of Heliosat-1 and 2 , but demonstrates the advantages of the SOLIS model. Additionally, changes in stratospheric aerosols, e.g an increase of the load after a volcanic eruption, can not be treated with the current Heliosat method without a re-fitting of the empirical equation. Using SOLIS, just the enhanced aerosol load has to be changed in the input file and the effect is considered.

The input of a turbidity of 4 leads to a good match for the global irradiance, but to a significant underestimation of the direct irradiance. Using the aerosol information provided by the OPAC/GADS climatology (AOD of 0.18, urban aerosol type) as input, the calculated global and direct irradiance matches the measurements very well, as shown in figure 3 and figure 4. The relative root mean square error is 1.9 % for global and 4.2 % for direct irradiance with a relative bias of 0.6 and 0.5 % respectively. Consequently, a consistent match between measurements and calculated direct and global irradiance is possible using information about the aerosol optical depth, the aerosol type and the water content ”separately”. Using only turbitidy information it is not possible to get a consistent match, even if the uncertainties in the turbidity input were taken into account. Since the turbidity defines the attenuation of the direct irradiance this indicates that the choosen turbidity is too low. Yet decreasing the turbidity to values around 3 leads to a better match between the measurements and the Heliosat modelled direct irradiance on the one hand, but it leads to an overestimation of the global irradiance on the other hand. The reason is the redundant information of the turbitiy in comparison with a separated treatment of aerosol type, aerosol optical depth, and water vapour.

The turbidity ”defines” the effect on the direct irradiance, but not the aerosol type and hence not its effect on the global irradiance. This effect is even significant for the measurement site, but is higher for sites with higher aerosol load (see figure **??**), or for sites characterised by special types of aerosols events, like desert storms or biomass burning. That is a drawback of Heliosat-1 and 2 , but demonstrates the advantages of the SOLIS model.

Moreover, reliable information of the spectral distribution of the irradiance cannot be derived by using only turbidity, without any additional information about the atmospheric state. Additionally, changes in stratospheric aerosols, e.g an increase of the load after a volcanic eruption, can not be treated with the current Heliosat method without a re-fitting of the empirical equation. Using SOLIS, just the enhanced aerosol load has to be changed in the input file and the effect is considered.

The relation between global and direct irradiance cannot be defined by one value but depends mainly on the aerosol type in combination with the aerosol load and the water vapor content. Especially the aerosol type has a significant effect on the relation between global and direct irradiance. Moreover, reliable information of the spectral distribution of the irradiance cannot be derived by using only turbidity, without any additional information about the atmospheric state.

As already mentionened, the temporal and spatial resolution of the the GADS/OPAC aerosol climatology is coarse. In order to check whether the urban aerosols with a AOD of 0.18 are a reliable input for the Freiburg comparison, a cross-check with data from the DWD station in Mannheim has been performed with the same atmospheric input. The station Mannheim has been choosen, because it is not so far away from Freiburg and both regions are characterised by a similar micro-climate - cities within the rhine valley climate. The choosen atmospheric input resulted in a good match between the measurments and the SOLIS ouput for Mannheim, the bias was below 1 per mill and the relative root means square was 3.5 %. The aerosol information seems to be reliable for this region in August 2000.

2.5.1 Spectral resolved irradiance data

Using the same atmospheric input (urban aerosol, AOD=0.18), the measured and calculated illuminance has been compared for August 2000, Freiburg. The illuminance is a measurement of a quantity of light as perceived by the human eye. In order to calculate the illuminance the spectral resolved irradiance output of SOLIS is weighted with the light-sensitivity of the human eye. The so derived value is than multiplied with 0.683 in order to convert W/m^2 to Klux. The measurments and the calculation matches very well, demonstrating that the spectral output of the model is reliable, see figure 5. In addition the model results for rural aerosols are also diagrammed.

Figure 3: Comparison between SOLIS and measurements using the GADS/OPAC information for the aerosols. The calculated Heliosat clear sky irradiance is also diagrammed. The differences betwen the models are mainly due to the different atmospheric input information, see figure **??**.

2.5.2 Effect of H_2O

The effect of H_2O is twofold, a direct and an indirect effect. The direct effect is due to the absoption in the H_2O bands, taking place in specific wavelength bands. The indirect effect is due to an possible increase or decrease of the relative humidity. In order to derive the relative humidity also the ambient temperature is necessary. Changes in the relative humidity have an effect on the aerosol optical depth of hygroscopic aerosols like rural and urban aerosols. Consequently, the indirect effect takes place throughout the whole wavelength region (295-3320 nm).
Changes in H_2O can be superimposed by changes in relative humidity with respect to the direct H_2O effect on the solar irradiance. Yet together with information about the ambient temperature, the retrieved daily H_20 values can be used to consider the direct and indirect $H2O$ effect on the irradiance.
Additionally it has to be remembered that the used GADS/OPAC aerosol information is coarse. Changes in the aerosol content within a season due to transport processes are not considered, but effect the measurements.
Conseqeuntly, it cannot be expected that changes in the H_2O amount leads to visible differences in the measurements as it would be if only the direct effect would take place.

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REFERENCES

Figure 4: Comparison between SOLIS and measurements using the GADS/OPAC information for the aerosols.

Figure 5: Mesaured and modelled illuminance, clear sky situations, Freiburg August 2000