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Chapter 1

Overview

Aim and structure of the report This report gives an overview about the current all sky working version, whereas the clear sky module, already described in D8.1, is an important part of the all sky working version. In order to enable a good readability, and to provide an overview about the whole scheme the clear sky module is described in section 2.2. It has to be mentioned that this description is similar to that documented in D8.1. Yet some corrections, updates and upgrades of this description has been performed.

Section 2.3 gives an overview about the current status and planning with respect to the cloudy sky module, as well as an description of the cloud module currently used within the all sky working version. As a consequence of the delay of the MSG launch the current all sky working version is not based on MSG data nor on retrieved cloud properties, such as cloud optical depth, cloud fraction or cloud height. The concepts for the new SOLIS scheme are ready and basic algorithms are programmed, but they have to be adapted to and tested with MSG data. This step is on the one hand a pure technical task on the other hand, important parameters of the scheme have to be tested and ”tuned” as well. Additionally the optimal way for the treatment of clouds has to be appointed (e.g. section 2.3.2). The performing of these steps is just possible when reliable MSG data are available, which can be expected to be in spring/summer 2003. Yet beside the adaption of the scheme also some conceptual things have to be declared in more detail (e.g. section 2.3.5). For that reason why the current status of the all sky scheme is described in section 2.3, including an outlook about the next steps, especially the steps that will be performed when reliable data are available. Afterwards, the used cloud module of the all sky working version (based on Meteosat) is described in section 2.4. In chapter 3 and 4 a technical description of the all sky scheme with respect to the clear sky (chapter 3) and the cloud module (chapter 4) is provided.

Chapter 2

WP3000: The SOlar Irradiance Scheme, SOLIS

2.1 Introduction

Geostationary weather satellites like the current Meteosat provide cloud information with a high spatial and temporal resolution. Such satellites are therefore not only useful for weather forecasting, but also for the estimation of solar irradiance since the knowledge of the light reflected by clouds is the basis for the calculation of the transmitted light. Additionally an appropriate knowledge of atmospheric parameters involved in scattering and absorption of the sunlight is necessary for an accurate calculation of the solar irradiance.
The operationally working methods Heliosat ([Beyer et al., 1996],[Hammer, 2000] and Heliosat-2 [Rigollier et al., 2001] uses statistical methods and semi-empirical formulas for the calculation of solar irradiance. They use cloud information from the current Meteosat satellite and a turbitidy climatology for the calculation of the clear-sky irradiance.
The Meteosat Second Generation satellites (MSG) will provide not only higher spatial and temporal resolution than his predecessor Meteosat, but also the potential for the retrieval of atmospheric parameters such as ozone and water vapour. With satellites like GOME/ATSR-2 also the retrieval of aerosol information is possible. This more detailed knowledge about atmospheric parameters allows to set up a new calculation scheme based on radiative transfer models.
This new scheme will be based on the integrated use of a radiative transfer model, whereas the information of the atmospheric parameters retrieved from the MSG satellite (clouds, ozone, water vapour) and from the GOME/ATSR-2 satellites (aerosols, ozone) will be used as input to the RTM based scheme.[1]
So far, the working version of the clear sky scheme has been finished and a concept for the whole scheme has been developed. A all sky working version has also be performed, but it has to be adapted to MSG with respect to technical read and write processes and improved cloud modules has to be implemented. Within the next sections the design and the main concepts of the scheme are described, as well as the scientific work behind. The technical details of the all sky working version are documented in chapter 3 and 4.

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

2.2 WP3010: The clear sky module

2.2.1 Introduction

The clear sky scheme described below is characterised by a new approach, so far not used in any of the existing solar irradiance schemes. Therefore a more detailed description of the ”concept” is provided in the following sections. A more technical description of the clear sky working version is provided in the appendix (see section 3).

2.2.2 The new clear-sky module

MSG will scan the earth atmosphere in a very high spatial resolution (see table 2.1), 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 parameters on the solar irradiance. Instead of doing this a new more powerful and more flexible method – the integrated use of RTM within the scheme based on a modified Lambert-Beer relation – will be applied within the HELIOSAT-3 project.
The integration of RTM into the calculation schemes, instead of using just pre-calculated look-up tables, is only possible if the necessary computing time can be decreased enormously. For this purpose a tricky functional treatment of the diurnal solar irradiance variation has to be applied. Thus making an appropriate operational use of a RTM within the calculation schemes possible.
The basis (or starting point) of the integrated use is the assumption that daily values of the clear-sky atmospheric parameters in 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 and is not linked with restrictions of the model because of the reasons listed below.

- Principle restrictions in the art of retrieval limits the available input with respect to the temporal and spatial resolution of the atmospheric clear sky parameters. E.g. the retrieval of aerosols from satellite is handicapped by the small aerosol reflectance and the perturbation of the weak signal by clouds and surface reflection. For that reasons retrieval of daily values in 100x100 km resolution with a ”global” coverage in an appropriate accuracy is a task for the far future.
- The resolution is in consistence with the compilation of data requirements
- The temporal daily fluctuations of solar irradiance are in general dominated by the fluctuations of clouds and the cloud information is used in its high temporal and spatial resolution (MSG pixel resolution).
- The usage of the modified Lambert-Beer function, described later on, should enable the correction of derivations from the daily average of the clear sky irradiance in an easy and fast manner.

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

Table 2.1: *Improvements in METEOSAT resolution*

Since daily values of the atmospheric parameters (O_3,H_2O,aerosols) within a region of 100x100 km (50x50km) can be assumed to be sufficient, the diurnal variation of the solar irradiance is just dependent on the Solar Zenith Angle (SZA, θ_z). The RTM calculates the diurnal variation of the solar irradiance for each region using the atmospheric parameters as input. The cloud effect and hence the temporal fluctuation of the diurnal clear sky irradiance caused by clouds is considered for each pixel without the ”need” for an explicit use of a RTM (for a more detailed description see section 2.3). As a consequence not every pixel has to be processed with the radiative transfer model. With the modified Lambert-Beer function, described in detail in section 2.2.3, the diurnal variation of the clear sky irradiance can be matched very well. As a consequence the RTM calculations necessary to define the diurnal variation of the clear sky irradiance can be reduced enormously. Using the modified Lambert-Beer function only 2 RTM calculations are necessary to define the complete diurnal variation of the clear sky irradiance for a given atmospheric state. As a consequence, independent if a pixel is cloudy or not, 2 RTM calculation are enough to calculate the solar irradiance for the whole (e.g. 100x100 km) region, where it is important to note that the cloud information is used for each pixel in the high spatial and temporal MSG resolution. How the coupling of the clear scheme with the cloudy sky scheme will be performed is described in detail in section 2.3. In figure 2.1 the spatial and temporal linkage between the clear sky and the cloudy sky module is illustrated.

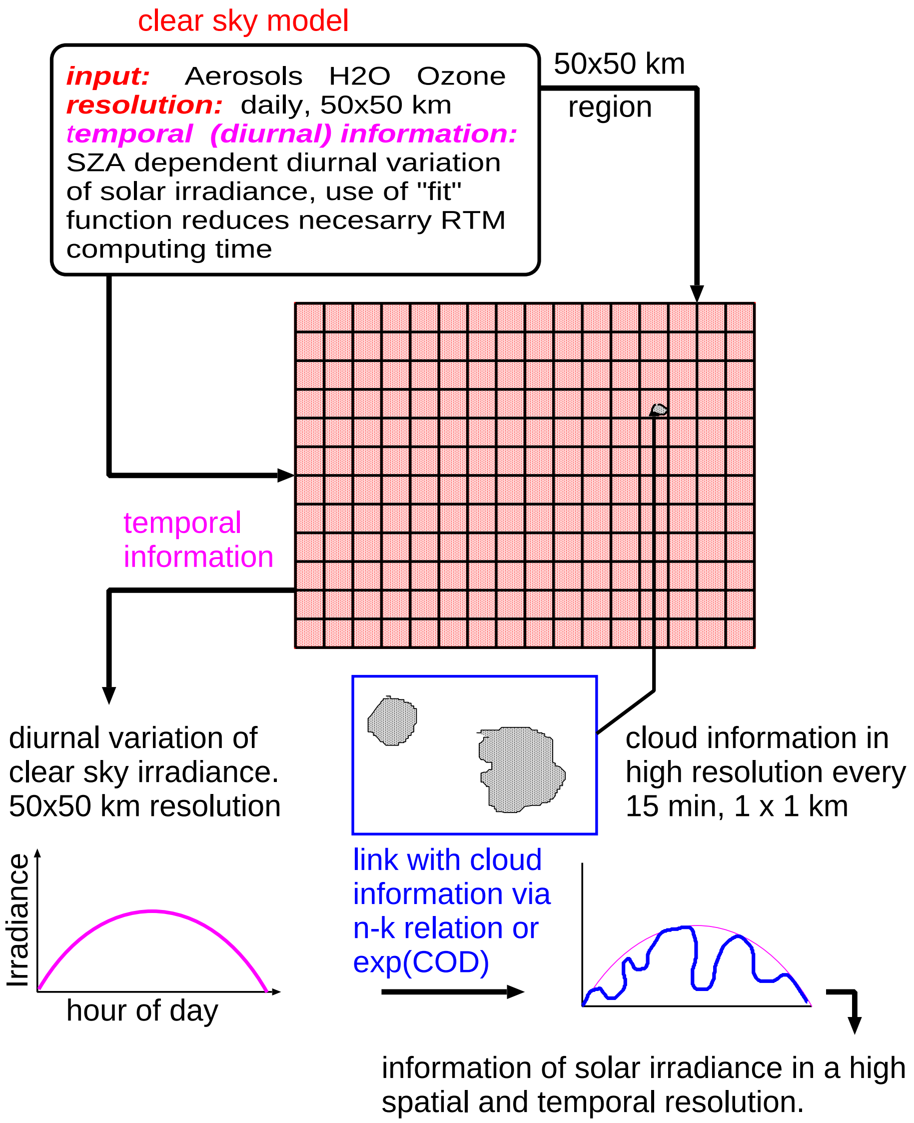

Figure 2.1: *Diagram of the spatial and temporal linkage between clear-sky and cloud information.*

2.2.3 The modified Lambert-Beer function

The described modified Lambert-Beer relation and their application within solar irradiance schemes is a totally new approach. The function and their application within the code was developed within the HELIOSAT-3 project at the University of Oldenburg.

Direct irradiance

The Lambert-Beer relation is given by

$$I = I_0 * exp(\tau) \tag{2.1}$$

where τ is the optical depth
Considering path prolongation and projection to the earth surface leads to.

$$I = I_0 * exp(\frac{\tau}{cos(\theta_z)}) * cos(\theta_z) \tag{2.2}$$

This formula describes the behaviour of the direct monochromatic radiation in the atmosphere, hence an effective optical depth τ can be estimated for all SZA (θ_z).

$$\tau = ln(I/I_0) \tag{2.3}$$

Using equation (2.3) for θ_z=0 leads to τ_{0d}. If we are dealing with **monochromatic radiation** then τ is constant, hence τ equals τ_{0d} for all SZA.
If we are dealing with **wavelength bands** τ is not constant, but changes smoothly with increasing SZA . τ_{0d} is then just the effective optical depth at θ_z=0, The reason for that is the non-linear nature of the exponential function.
Hence a correction of the optical depth τ_{0d}, or equivalent to this, of the parameter $\frac{\tau_{0d}}{cos(\theta_z)}$ is necessary.

$$I_{direct} = I_0 * exp(\frac{\tau_{0d}}{cos^a(\theta_z)}) * cos(\theta_z) \tag{2.4}$$

Using this function the calculated direct radiation can be reproduced very well (see Fig. 2.4). The Modified-Lambert-Beer (MLB) parameter a is calculated based on two RTM calculations.

Global irradiance

As explained above a correction of formula 2.2 is necessary for direct radiation if the formula is applied to wavelength bands, hence it is necessary for global radiation too. But in addition to the wavelength band effect the Lambert-Beer law is no longer ”valid” for monochromatic radiation due to the effect of scattered photons that are ”coming back”. This effect is mainly described (considered) by the usage of the effective optical depth τ_0. As a consequence, using the effective optical depth the Lambert-Beer is still a (relative) good approximation for ”monochromatic” global radiation. But due to e.g. the atmospheric vertical inhomogeneity the change in the amount of photons coming back due to changes in SZA is not described by $1/cos(\theta_z)$ in detail. Hence a correction of formula 2.2 is necessary even for monochromatic incoming radiation, in order to yield a better match between RTM calculated and function values (see for example figure 2.2). Since the Lambert-Beer relation, using the effective optical depth τ_0, is still a (relative) good approximation if the incoming radiation is monochromatic, it is not so surprising that for wavelength bands the function

$$I_{global} = I_0 * exp(\frac{(\tau_{0g})}{cos^b(\theta_z)}) * cos(\theta_z) \tag{2.5}$$

is (similar to the direct radiation case) also a good ”fitting” function for global radiation (see Fig. 2.4).

Diffuse irradiance

The Lambert-Beer relation describes the attenuation of the incoming radiation. The incoming diffuse radiation at the top of the atmosphere is negligible. The source of the diffuse radiation is the attenuation of the direct radiation due to scattering processes. Hence the Lambert-Beer law is related to the irradiance of diffuse radiation but does not describe the irradiance of diffuse radiation, since diffuse radiation can not be described in terms of attenuation of incoming radiation (see Fig. 2.3). However fitting with the modified Lambert-Beer relation works very well (see Fig. 2.4). Since the scaling with cos(x) is not appropriate for diffuse radiation it is skipped and equation (2.6) is used for fitting.

$$I_{diffuse} = I_0 * exp(\frac{(\tau_{0dif})}{cos(\theta_z)^c}) \tag{2.6}$$

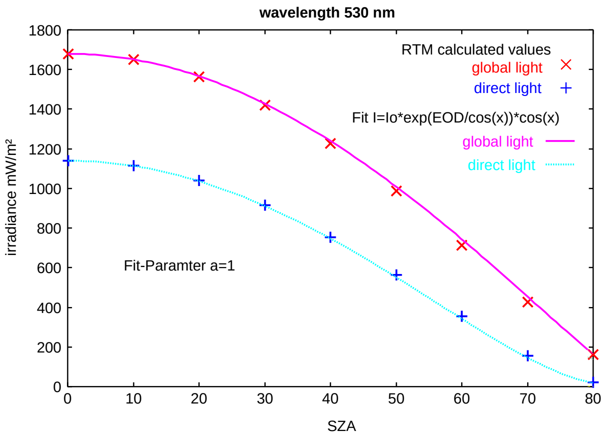

Figure 2.2: *Illustration: For monochromatic radiation the Lambert-Beer relation is still a good approximation for the calculation of global irradiance if the effective optical depth (EOD) is used. In order to yield a better match a correction of formula 2.2 (the Lambert-Beer relation) is necessary*

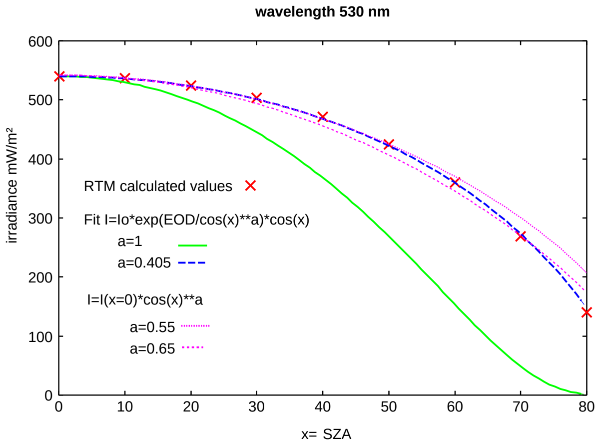

Figure 2.3: *Since the modified Lambert-Beer relation does not describe the behaviour of diffuse radiation, a correction of the Lambert-Beer relation is absolutely necessary. Fitting with a simple cosine relation lead to a much poorer agreement. (EOD=effective optical depth)*

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 degree $(a \cdot cos^3(x) + b \cdot cos^2(x) + c)$ (see Fig. 2.5). 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. 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”. More over the parameter can be calculated without the need for a numerical fit.
The function was tested for many different atmospheric states, e.g four different aerosol types, four different visibilities (5, 10, 23, 50), different water amounts, different standard atmospheres. Additionally it was tested that the fit also works if another RTM model (instead of libradtran) is used for the RTM calculations. There are no reasons to assume that there exist a atmospheric state for that the fit does not work very well. Hence it can be assumed that the fit works very well for all atmospheric states.
For our purpose the sense of a 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 (which are very small, less than 8W/m^2 below a SZA of 85 Deg.).
At low visibilities (high optical depth, high aerosol load) I_o has to be enhanced for global and diffuse radiation. For that purpose a general formula has been developed.

2.2.4 Improvements linked with the described clear sky module

- Modified Lambert-Beer relation enables the integrated use of RTM within the clear-sky module of the scheme. The integrated use of RTM is linked with high flexibility relating to the input of the atmospheric state, changes in theory and the desirable output parameters.

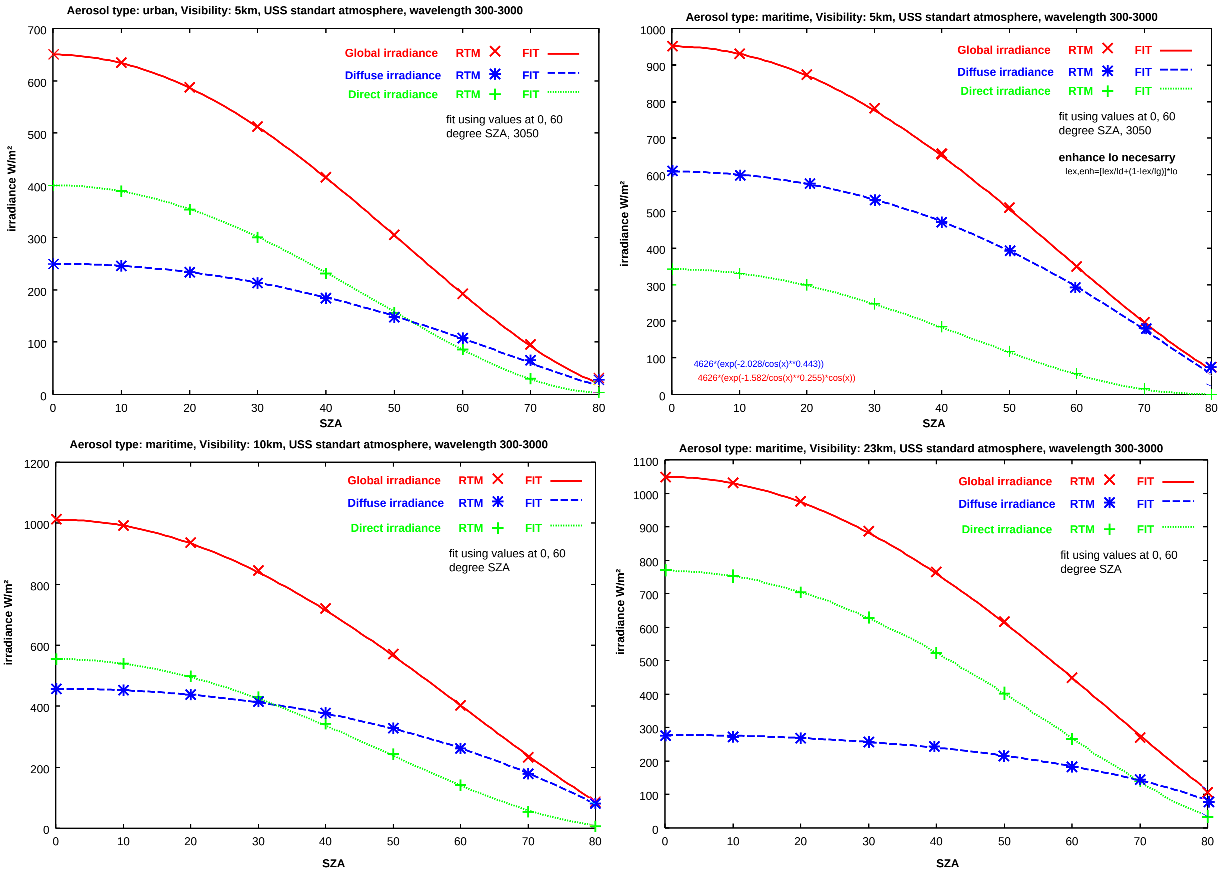

Figure 2.4: *Comparison between RTM calculations and fit using the modified Lambert-Beer relation, for different atmospheric states*

- Spectral information is automatically provided, using the correlated-k option provided within the RTM libRadtran package (http://www.libradtran.org/). Usage of RTM is expected to improve the information of the angular distribution of diffuse irradiance.
- Consistent calculations of global, direct and diffuse radiation for clear sky cases within one single scheme considering different aerosol types and not only turbidity. Hence a improved estimation of the relation between diffuse and direct radiation is possible, especially for clear sky situations. The separated use of H20 and aerosols instead of turbidity is a need for accurate information of the spectral distribution of irradiance.
- It seems that deviations of the atmospheric state from the average (O_3, H_2O, aerosols) can easily be corrected with the modified Lambert-Beer law. A correction of the effective optical depth τ_0, whereas the a,b,c parameter remain unchanged, leads to a good match between RTM calculated and function values for H20. For aerosols similar tests have to be performed.

2.3 WP3020: The cloudy sky module

2.3.1 Overview about the concepts of the cloudy sky modules

An operational usage of a RTM for the treatment of heterogenous clouds (whether directly or via the usage of pre-calculated look-up tables) is not possible. The limitations of 3-D cloud modelling do not enable realistic RTM calculations of 3-D cloud problems in an operational manner. Just case studies can be performed because the necessary 3-D cloud input information

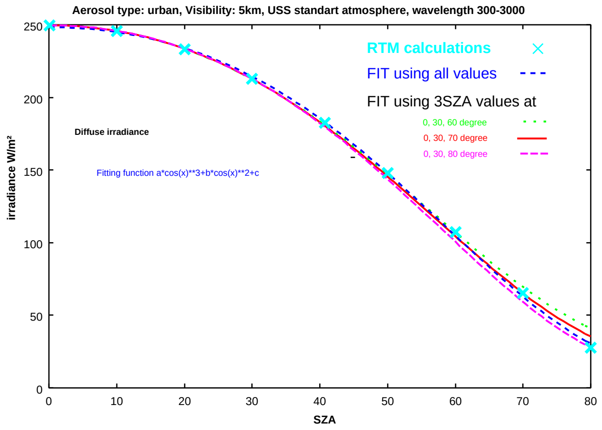

Figure 2.5: *Comparison of the fit using a polynomial of third degree and the RTM calculations*

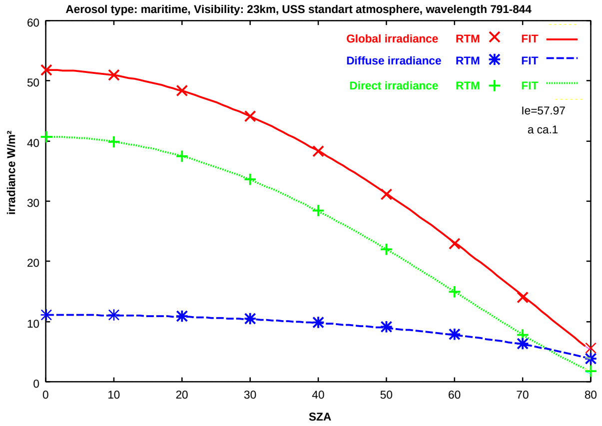

Figure 2.6: *Comparison between RTM calculations and fit using the modified Lambert-Beer relation. Example for fit within a small wavelength band*

is not available operationally. Hence with respect to the use of a RTM the problem is the non-availability of realistic specification of heterogenous clouds from measurements. MSG will not provide sufficient information about 3-D cloud characteristics. No other satellite or measurement setup provides this information for the needed temporal resolution and spatial coverage.
Beside these problems an explicit or integrated use of RTM is not practicable since the needed calculation time of 3d-RTM models is too large for an operational adaption. Even homogenous clouds cannot be treated explicitly in an operational manner with a RTM (MSG pixel resolution). As a consequence of the things mentioned above, the integrated usage of the RTM within the scheme is related to the clear-sky scheme. Considering the cloud effects there are two options that will be available to the user, see description below.

Using n-k relation Within this option the effect of clouds on the solar irradiance is considered by using the relation between cloud index n and clear sky index k (n-k relation). This relation was empirically found within previous studies and is described in detail in [Beyer et al., 1996] and [Beyer et al., 2003]. It is used in the Meteosat based Heliosat method. The *n-k* relation is robust and validated. It leads to relative small Root Mean Square Deviations (RMSD) between measured and calculated solar irradiance for daily and monthly means. Nevertheless, an improvement of the *n-k* relation using physically retrieved cloud parameters is in preparation. For this purpose studies have been performed in order to investigate the question if the n-k relation can be improved by using the enhanced cloud information retrieved from MSG (cloud mask, COD, effective radii). Additionally, the effect of broken clouds have been investigated in order to study the effect on the global irradiance. Beside the described aim – to improve the n-k relation – such studies improve the understanding of the interaction between cloud parameters like cloud height and LWP [2] or the effect of broken clouds on the calculated irradiances. Therefore, they support the development of the COD based scheme, briefly described in the next paragraph. For the final version of the solar irradiance scheme the usage of the n-k relation is planned in a way that the corrections based on additional cloud parameters like COD can be switched on (hybrid) or switched of (pure n-k). The reason for this is that the retrieval of cloud optical properties like COD and cloud fraction needs a large amount of computing time, while the calculation of the cloud index is very fast. In order to offer the users high flexibility with respect to the needed

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[2] LWP and COD can be used alternatively to describe cloud effects

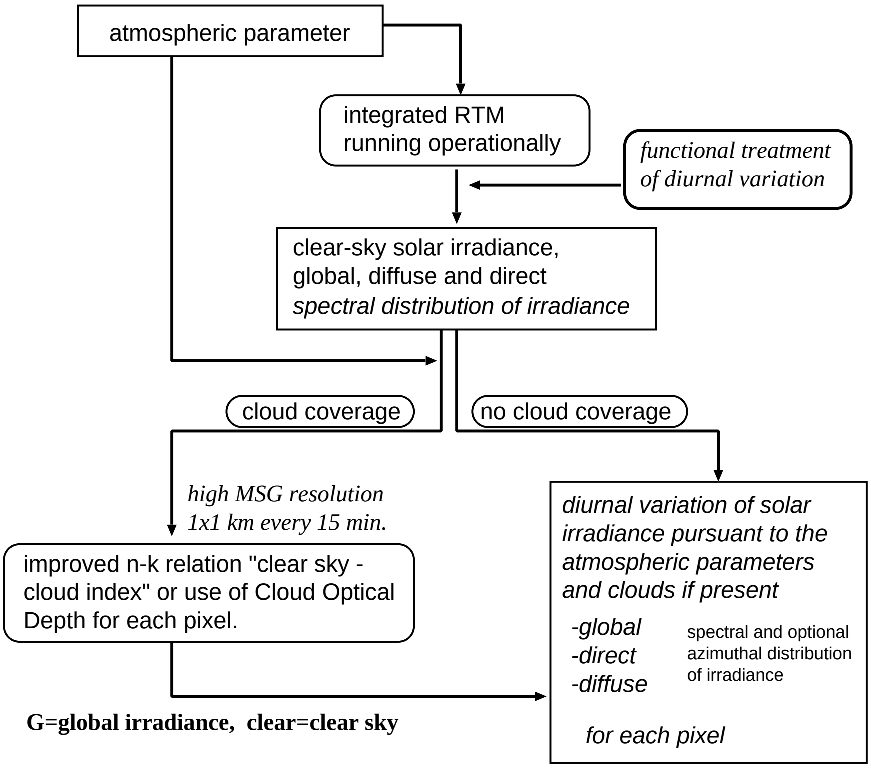

Figure 2.7: *Overview of the new calculation scheme*

computing power and accuracy both ways will be offered.

Using COD based code Based on the information of the cloud optical depth (COD) which will be (is) retrieved operationally with the DLR software, the direct irradiance can be calculated using formula 2.7

$$I^{dir} = I^{dir}_{clearsky} * exp(\frac{COD}{cos(\theta)}) \tag{2.7}$$

where θ is the solar zenith angle, COD stands for the cloud optical depth retrieved with the DLR software, I is the direct surface irradiance and $I_{clearsky}$ the clear sky irradiance calculated with the described clear sky module. Within this formula clouds are assumed to be homogenous.
The current idea for the calculation of the global irradiance is based on the definition of an effective cloud optical depth applied to global irradiance GCOD. This GCOD is defined by equation 2.7 for global irradiance. This means that the GCOD is the quantity that leads to the relation between the global solar irradiance and global clear sky irradiance in the same way as equation 2.7.

$$I^{global} = I^{global}_{clearsky} * exp(\frac{COD}{cos(\theta)}) \tag{2.8}$$

This definition of GCOD pose the problem to find the correct GCOD in dependence of COD retrieved from the MSG satellite data. Calculating the direct and global irradiance first, the diffuse irradiance can be determined by subtracting the global from the direct irradiance.
Figure 2.7 illustrates the new scheme and the integrated use of the the RTM within the clear sky scheme.

2.3.2 Status: Corrections of n-k relation using retrieved cloud parameter

The proposed corrections are based on several studies performed by UIB and are documented in the working papers available at *http://www.heliosat3.de/documents/*. A brief overview about this studies is also documented in the mid-term report. The final application and implementation of the possible $n - k$ correction worked out in this studies is just possible after the first reliable MSG data are available as well as the selection of the best way to correct n or the $n - k$ relation respectively. Such data was not available so far, but can be expected for late spring. Below a list of ”possible” improvements of n-k scheme using retrieved cloud parameters from WP2020 are described. Afterwards the ongoing steps after availability of MSG data is described.

1 CLOUD HEIGHT:

the cloud-height seems to affect the reflectivity (cloud index) but not the global radiation. Hence, the cloud height should be taken into account by correcting the cloud index with it. This would be more physical correct than correcting the n-k-relationship. Such a physical approach would ease further corrections. Both models and empirical study indicates that the cloud index is too high when clouds are high, and vice versa. Quantitatively how much n should be lowered for each meter (or hPa) of height can only be determined when data is available from MSG (processed by MSG Scenes-Software) A corrected cloud index n might be something like:

$$n = \frac{(\rho - a \cdot Z - \rho_{ground})}{(\rho_{cloud} - \rho_{ground})} \tag{2.9}$$

where Z is the cloud height in meters or hPa and ρ the reflectivity, and a is a parameter to be tuned to measurements .

2 CLOUD OPTICAL DEPTH (COD):

The COD is today more or less incorporated in the traditional cloud index (together with cloud fraction). However, after a cloud is fully covering, thickening of a cloud will eventually not increase the reflection (cloud index), while it will become darker under the cloud, due to increased absorption within the cloud. Therefore it would be physically most meaningful to include the COD as a parameter in the k-n regression. In this case, only for high cloud index (thick and covering cloud) would the COD yield extra information which is not already incorporated in the cloud index. This correction should only be applied when the parameter cloud fraction is 1.

3 CLOUD FRACTION:

The cloud index is shown to correlate well with ground based estimates of cloud cover. An idea would be to replace the cloud index by cloud fraction (and cloud optical depth) in the scheme. This would mean that the additional channels of MSG are being utilized to avoid some of the problems related to the present cloud index:

- normalising reflectivity by extraterrestrial radiation is unphysical when the reflecting source is lower in the lower atmosphere (clouds/ground), backscatter from the atmosphere has to be accounted for. A question is if the corrected backscatter also is represented by the cloud index (inconsistency ?).
- a time series is needed to calculate the cloud index

  - reflection (n) is not isotropic, giving biases depending on the sun-satellite-ground geometry. Additionally the cloud index depends on cloud height. Any correction to this is only related to what the satellite receives, and not to the physics affecting global radiation.

4 GROUND REFLECTIVITY:

Due to shadows, the ground albedo is varying with the sun-ground-satellite angles. Investigation of Meteosat-reflectivities shows that this effect can be parameterised in a simple way, so that a scalar albedo can be determined, and the directional reflectance can be found by this parameter and one or more of the three angles. In a similar way the reflection from clouds can be parameterised to relate the directional radiance to the properties of the clouds. The parameterisation of these effects will be further studied by using data from Meteosat.

Ongoing of work

After the first dataset of reliable MSG data is available, work will continue as follows.
The first step would be to gather ground measurements for a number of stations. For each of these stations, the following parameters will be collected to form a dataset:

- time (date, month, year, hour)
- sun-ground-satellite angles (solar elevation, satellite elevation, co-scattering angle, azimuth angle)
- measured global radiation
- raw satellite counts for broadband VIS channel (+ 0.6um and 0.8um channels?)
- Cloud Optical Depth
- cloud fraction
- cloud height

Since measured global radiation is hourly averages, the MSG-data will be weighted together to match the time period of the ground measurements.
The next step would be to calculate a cloud index from the time series of the raw satellite counts. Here the algorithms for backscatter-correction (C_{atm}), calculation of ground albedo (ρ_{ground}) and calculation of cloud albedo (ρ_{cloud}) from previous Heliosat-versions will used. Possible improvements are by the time of writing being investigated by radiative transfer models and study of Meteosat-7 data. From the cloud index, a clear sky index will be calculated with the ”old” relationship. This relationship is also a subject to be improved in this process.
The third step will be to calculate the clear sky radiation with SOLIS. The measured global radiation will be divided by this clear sky radiation, yielding a clear sky index to be compared with the MSG-derived clear sky index calculated in step two (above).
The forth step will be to analyse the difference (RMSD and MBD) between the measured and derived clear sky indexes. The differences will be analysed in light of the different values of all the above mentioned parameters. Any trends of the MBD should be investigated closely, to see if any of the algorithms above (step 2 and 3) could be modified to correct for the observed trend. Here also improvements are hoped for by including the new parameters: cloud height,

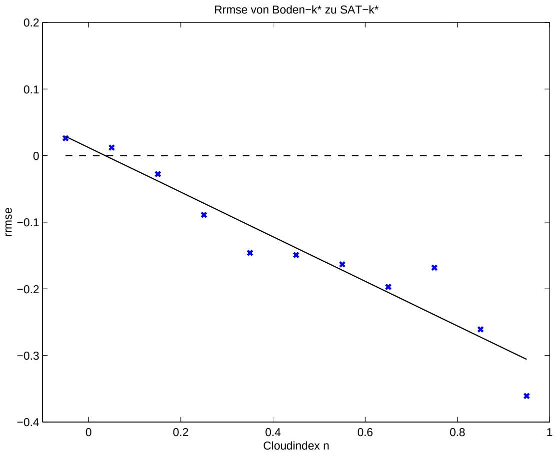

Figure 2.8: *Rrmse for clearsky index versus cloud index with regression. Cloud index is summarised to bins with a width of 0.1*

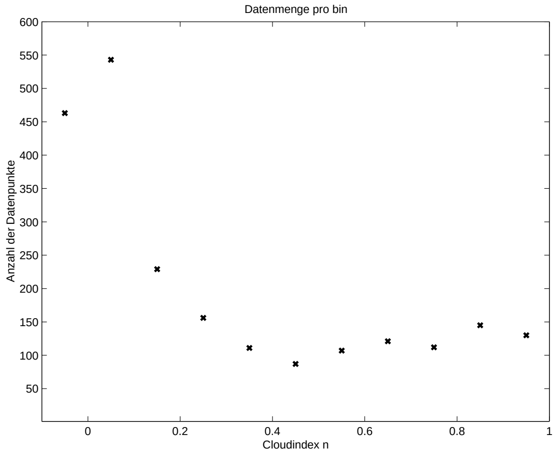

Figure 2.9: *Amount of data versus bins of cloud index.*

cloud fraction and COD. By repeating steps 2-4, hopefully the algorithms will converge towards giving smaller deviations from the ground measurements.

2.3.3 Status of cloud retrieval software

The MSG scenes software is running at the DLR and the University of Oldenburg. Hence test data sets of macrophysical cloud parameter like cloud height and cloud fraction can be derived within days after reliable MSG data will be available. The COD retrieval within the Apollo scheme [Saunders and Kriebel, 1988] is based on a method from [Stephens, 1978] and [Stephens et al., 1984] . The Apollo COD part for the retrieval of the cloud optical depth is ready but a SEVIRI interface (needed for MSG) has to be implemented. In addition to the Apollo scheme a algorithm based on the Nakajima [Nakajima and King, 1990] approach will be developed within the next month. This algorithm enables the combined retrieval of the cloud microphysical parameter cloud optical depth and effective radii.

2.3.4 Correction of n-k for ”broken cloud effects”

Calculations with the radiative transfer model SHDOM has been the initial point of some ideas for several empirical studies with the scope to correct the current n-k relation for ”broken cloud” effects. The SHDOM studies are briefly described in the mid-term report. They indicate that subject to specific cloud situations a mean bias in the calculated solar irradiance occurs for moderate viewing geometries. Hence if there would be a correlation between the cloud index and the specific cloud situations in a statistical manner it should be possible to find a ”parameterisation” or correction formula in order to improve the n-k relation for moderate viewing geometries. In order to investigate this empirical studies has been performed. A first empirical study was made using ground data of Freiburg, Germany for May to August 2001. This data was compared with the satellite derived data. In figure 2.8 the relative root mean square error (rrmse) of the clearsky index is plotted against the cloud index. The rrmse is given for n-bins with a width of 0.1. The figure illustrates that the Heliosat method underestimates the irradiance and this underestimation increases with increasing cloud index.
Because of less data for $n < -0.1$ and $n > 1$ the empirical study is limited to $-0.1 \leq n \leq 1$. Figure 2.9 shows the amount of data for each bin. A first correction was made with the help of a

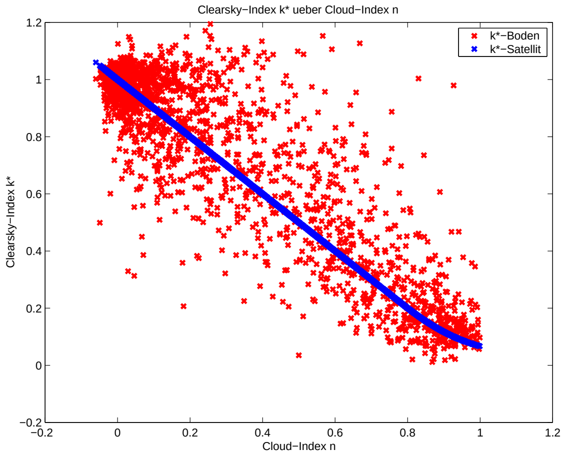

Figure 2.10: *Clearsky index versus cloud index for the current n-k-relation. Blue: satellite derived data. Red: ground data.*

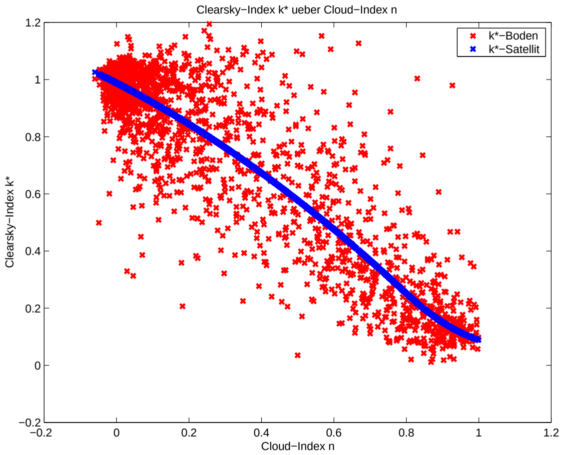

Figure 2.11: *Clearsky index versus cloud index for the corrected n-k-relation. Blue: satellite derived data. Red: ground data.*

very simple regression as shown in figure 2.8. The regression is given by

$$y = 0.0121 \ - \ 0.3348 \cdot x \tag{2.10}$$

Using this function it is possible to correct the clearsky index. First the clearsky index k is calculated with the current n-k-relation and then corrected by

$$k = k + k \cdot (-0.0121 \ + \ 0.3348 \cdot n) \tag{2.11}$$

The correction leads to significant differences in the n-k-relation as shown in figure 2.10 and 2.11. The rrmse for the irradiance without the correction is 0.234 and with the correction 0.215, also the rrmse for the clearsky index decreases from 0.337 to 0.328. In a further study this correction has been applied to another data set, leading also to an reduction of the rrmse. Consequently, it could be expected that this correction leads in general to a reduction of the rrmse, but this has to be checked in more detail within further empirical studies.
Yet it has to be mentioned that the currently performed studies also indicate that the reduction of the rrmse is mainly due to the reduction of the rrmse of relative ”few” outliers. As a consequence of the definition of the rrmse this relative ”few” outliers have an significant effect on the overall rrmse. Within this scope it has to be further investigated if the rrmse is an appropriate error quantity for the error analysis. Anyway first studies indicates that the vast majority of the outliers have a high variability, whereby the variability is defined as the standard deviation of the cloud index of a mean pixel area (5x5 pixels). Using the rrmse as relevant error quantity it seems to reasonable to perform a division of the data points dependent on the variability, having at least two different variability classes for the data points. For the assignment of the data points to the classes an appropriate threshold has to be defined. After that similar corrections for the different classes can be performed with the goal to get a further improved n-k relation. A similar approach has been tested by C. Hoyer with promising results.

2.3.5 Current status of COD based cloud module

In order to find an efficient parametrisation to calculate radiative conditions under clouds using the cloud optical depth, sensitivity studies were performed using the radiative transfer model SBDART. This new parametrisation has to be fast enough to convert all pixels of an image of the

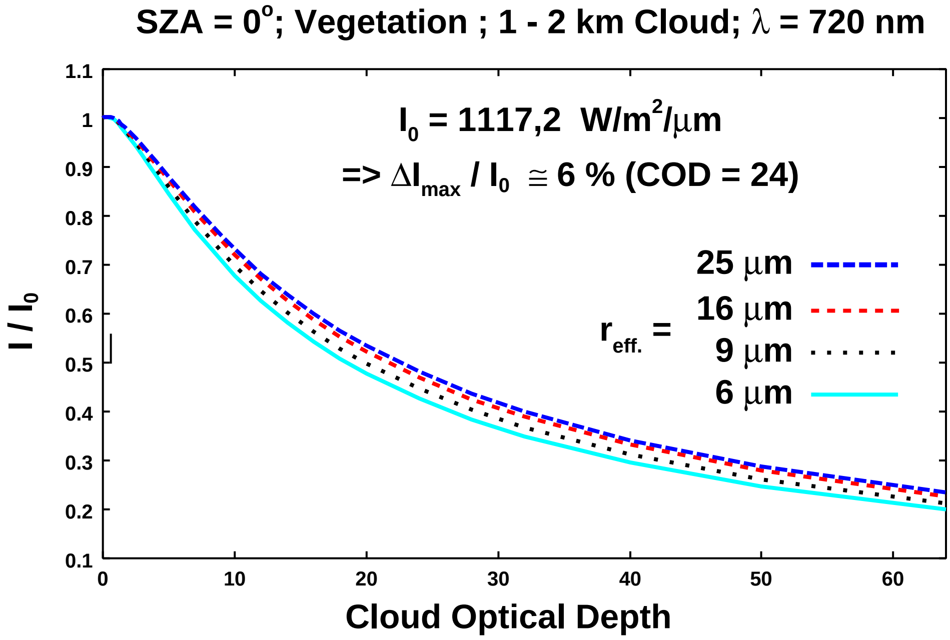

Figure 2.12: *Varying intensity at ground level under a cloud with optical depth compared to the clear sky intensity for different effective droplet radii*

new satellite *Meteosat Second Generation* (MSG) within 15 minutes. It should be more accurate than the currently used cloud index method as well.

The model restricts the calculations to plan-parallel homogeneous cloud layers, but allows the investigation of their radiative properties at different wavelengths, optical depths and size distributions of water droplets. Furthermore, their heights and thicknesses are variable and different illumination geometries can be considered. SBDART also provides standard atmospheres, e.g. mid-latitude winter. Ground reflection is specified by type models like vegetation, sand, and snow but deals only with isotropic cases.

First of all, the dependence of irradiance at ground level on varying cloud optical depth was studied by using the atmospheric model for mid-latitude winter. The biggest deviations in intensity were pointed out by comparing the relationship for different droplet size distributions within clouds of different height and depth. This was done for different sun zenith angles, ground types, and two wavelengths (strong absorbing (720 nm) and weak absorbing (550 nm)).

Figure 2.12 gives an example for such a comparison. Here the effect of the size distribution, described by the effective droplet radius $r_{\mathrm{eff.}}$ within a cloud between 1 km and 2 km at 720 nm, is presented in relation to the clear sky case. The environmental situation is given by the sun in the zenith and a ground model for vegetation.

Collecting the results off these simulations the biggest deviations in intensity arise with the sun in the zenith, optical depth of 24 or the biggest realized, and between the most extreme cases of effective radii. Actually, the consequence of curves converges with increasing radius.

While the effect of cloud height and depth is neglectable for ground types with low reflection (vegetation, sand), they have to be kept in mind for strong reflecting surfaces like snow. The biggest deviations are realized in the latter case between thin clouds with the most extreme altitude difference.

As a result of all simulations a reduced set of situations and physical properties is found, for

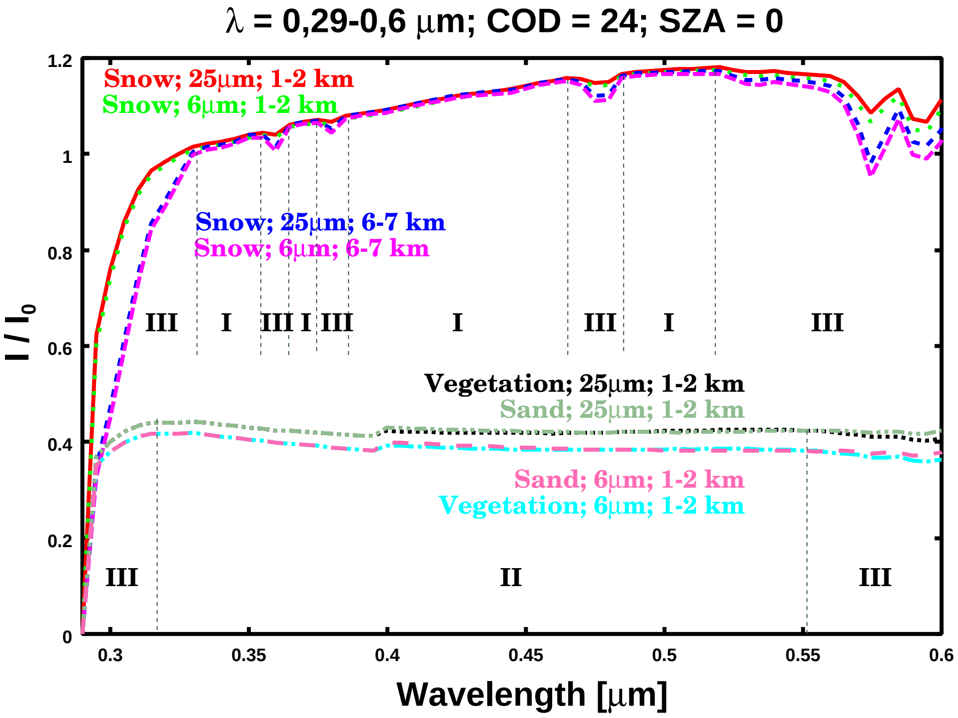

Figure 2.13: *Wavelength range calculation (290-600 nm) and classification according to the relation between the clear sky intensity and the intensity under clouds for three types of ground and extreme effective droplet radii. Additionally in the case of snow it is necessary to distinguish between extreme cases of cloud heights. The same simulation for an optical depth of 64 resembles the identified classification*

which calculations of the whole electromagnetic spectrum are possible. The target of such simulations is a classification of wavelength ranges within which the number of physical properties the irradiation at ground level is sensible to is probably even smaller. Here is to distinguish between three classes: insensible to any cloud property (I), systematic sensibility to some cloud properties (II) and individual sensibility (III).

Figure 2.13 is an example for such a classification between 290 nm and 600 nm. While a classification for snow grounds seem to be very complicated, vegetation and sand grounds reveal a much simpler behaviour. Especially between 320 nm and 550 nm (class II) the irradiance does not depend on a certain ground type but only on the effective droplet radius. According to the fact that this is not only the case for an optical depth of 24, a parametrisation for all optical depths is possible. For this case the surface irradiance depends only on the cloud optical depth, the effective droplet radius and the sun zenith angle between 320 and 550 nm.

Ongoing work By using the radiative transfer code SBDART, sensitivity studies revealed those properties of clouds that dominate the radiative conditions under them. With a reduced set of physical properties for each classified wavelength region (I+II) it is possible to develop a fast and still accurate parametrisation.

The next step will be to generate such parametrisations for the calculation of irradiance This will be done only for cases of low ground reflection, because the situation above snow seems to be too complicated and not of high interest. For the low reflecting cases height and depth of clouds are neglectable and the optical depth, effective droplet radii and sun zenith angles describe all major influences.

Altogether with the APOLLO [Stephens et al., 1984] software, developed and provided by the DLR which generates the cloud optical depth, a major task of the Heliosat 3 project will hopefully be reached soon in that way. With the adaption of the Nakajima scheme to MSG the effective radii will be retrieved in addition to the cloud optical depth. With that the last missing information for accurate calculations be available.

2.4 Description of the current working version

The working version consists of two main modules, the clear sky module and the module for the consideration of clouds. The SOLIS clear sky model is described in section 2.2

In the working version of the cloud module clouds are treated using the n-k relation, details of the n-k method are documented in [Beyer et al., 2003] and [Beyer et al., 1996]. Here a brief outline of the method is given.

The basic idea of the n-k method is to deal with atmospheric and cloud extinction separately. In a first step a cloud index, which is based on the measured radiance at the satellite, is derived from METEOSAT imagery. This step uses the fact that the planetary albedo measured by the satellite is proportional to the amount of cloudiness. After correction of the effect of atmospheric backscattering and ground reflection described in more detail in [Beyer et al., 2003] the cloud index n can be derived. The derived cloud index is then correlated to the cloud transmission, described with the clear sky index k, which relates the actual ground irradiance G to the irradiance of the cloud free case $G_{clearsky}$. This relationship is basically $k = 1 - n$ with minor modifications for $n \rightarrow 0$ and $n \rightarrow 1$:

$$\begin{array}{rl} n \leq -0.2 & k = 1.2 \\ -0.2 < n \leq 0.8 & k = 1 - n \\ 0.8 < n \leq 1.1 & k = 2.067 - 3.667 \cdot n + 1.667 \cdot n^2 \\ 1.1 < n & k = 0.05 \end{array} \tag{2.12}$$

Based on the so derived clear sky index the global irradiance can be calculated using

$$G = k * G_{clear} \tag{2.13}$$

whereby $G_{clearsky}$ is provided by the SOLIS clear sky module described in section 2.2.

In the previous Heliosat versions the diffuse component of the ground irradiance is calculated using a statistical model of [Skartveit et al., 1998]. The model is based on hourly values of the global irradiance. It uses the clearness index k_T, the elevation of the sun and an hourly variability index σ_3 for the calculation of the diffuse fraction. The direct irradiance is then be derived by subtracting the diffuse component from the global irradiance.

The hourly variability index σ_3 is calculated from the clear sky indices of three consecutive hours. If k_i is the clear-sky index of the hour i in question, then σ_3 is defined as:

$$\sigma_3 = \sqrt{\frac{(k_i - k_{i-1})^2 + (k_i - k_{i+1})^2}{2}}. \tag{2.14}$$

In the all sky working version of SOLIS an new approach for the calculation of the diffuse/direct irradiance has been implemented, in order to use - and benefit from - the enhanced capabilities of the SOLIS clear sky module, described in 2.2.4.

The main intention behind the new model is to use the information of the direct irradiance derived within the clear sky module for the calculation of the all sky direct and diffuse components. As a

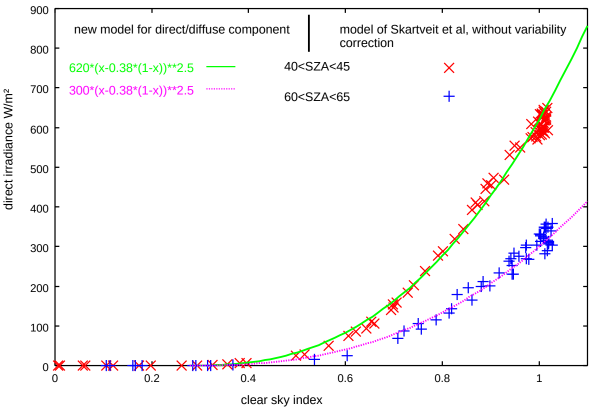

Figure 2.14: *Comparison between the [Skartveit et al., 1998] and the direct/diffuse model using equation 2.15. The variability correction has been swithced off. Hence for the new direct/diffuse model just formula 2.15 has been used. The direct irradiance is plottted against the clear sky index, derived with the Heliosat method*

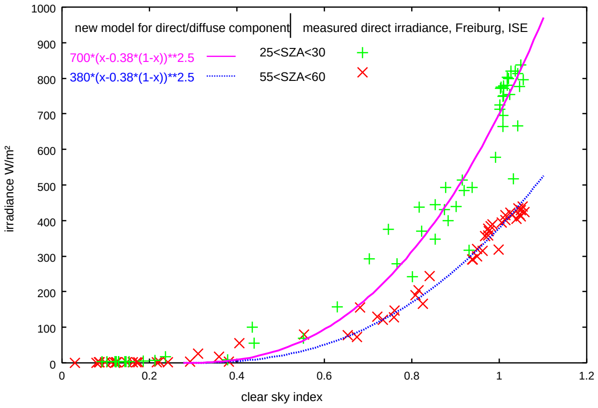

Figure 2.15: *Comparison between the measured direct irradiance (June 2001) and the fit based on the new direct/diffuse model. The direct irradiance is plottted against the clear sky index derived from the ground based measurements. The measurements are from the "Fraunhofer Institute for Solar Energy Systems"*

consequence the diffuse/direct model is no longer based on the global irradiance but uses instead the direct clear sky irradiance. Additionally instead of the clearness index the clear sky index is used to describe the effects of clouds on the direct clear sky irradiance. In contrast to current Heliosat method, where it is handled the other way round, the direct irradiance is calculated first. The diffuse irradiance is then derived by subtracting the direct component from the global irradiance. The reason for that is discussed later on.
In order to calculate the direct all sky irradiance formula 2.15 is used.

$$I_{dir} = I_{dir,clear} * (k - A * (1 - k))^b \tag{2.15}$$

Within this formula the effect of the clouds is represented by clear sky index k. It is important to note that the cloud index can be used instead as well ($k \simeq 1 - n$). A is set to 0.38 (the k value where direct irradiance vanishes) b is "currently" set to 2.5 . The choose of this values is based on comparisons between the [Skartveit et al., 1998] diffuse model and the new approach as well as on brief comparisons with measurements. Hence A,b should be seen as not finally fixed. In a second step a variability index (either 2.14 or the spatial standart deviation of n) is used to correct for the cloud variability. For that step the variability model, described in [Skartveit et al., 1998] has been adapted to the SOLIS direct component approach.
Figure 2.14 presents a draft comparison between the direct irradiance based on formula 2.15 and the irradiance based on the [Skartveit et al., 1998] model, whereby the variability correction has been swithced off for this comparison. Figure 2.15 provides comparison between measurements of direct irradiance (1h means) performed from the "Fraunhofer Institute for Solar Energy Systems" and the direct irradiance based on formula 2.15. In order to have enough data points the SZA region was chosen to be 5 degree. This leads to an additional scattering of the data points.
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 wavelength band of the SOLIS clear sky model. Consequently the all sky working version provides, in extension to previous Heliosat methods (e.g. Heliosat and Heliosat-2), spectral resolved irradiances. Since the cloud index is independent on the wavelength it can be assumed that for surfaces with small albedo the

derived spectral distribution should be a good approximation to the real one, provided that the clear sky atmospheric parameter matches the reality well. For surfaces with high reflection in wavelength regions where large absorption occurs (e.g. Water vapour bands) it has to be expected that the calculated irradiance has to be corrected, due to an increase of multiple scattering below the clouds, leading to an increase of the effective optical depth. The magnitude of this effect in the different wavelength bands and possible correction has to be and will be further investigated within the next months.
An advantage of using the direct irradiance as preliminary quantity is that macrophysical parameters can easily be adapted to improve the model, e.g cloud fraction in combination with geometry can be used to describe the amount of clear sky irradiance blocked by clouds. Especially planning of thermal power plants will benefit from improvements in the accuracy of the calculated direct irradiance.
It has to be mentioned that the cloud module described here is just a starting point. Improvements in the calculation of the spectral distribution as well as improvements of the direct/diffuse model will be also investigated within WP3030 and WP3040.

Ongoing work when reliable MSG data are available

I Adaption of the described working version to MSG data

II Implementation of the ”best” correction procedures for the cloud index n or the n-k relation respectively

III Implementation of the COD based option for the treatment of clouds

IV Optimisation of the scheme and realisation of the modular concept/design.

2.5 Improvements linked with the described new scheme

- Modified Lambert-Beer relation enables the integrated use of RTM within the clear-sky module of the scheme. The integrated use of RTM is linked with high flexibility relating to the input of the atmospheric state, changes in theory and the desirable output parameters.
- Spectral information is automatically provided, using the correlated-k option provided within the RTM libRadtran package (http://www.libradtran.org/). Usage of RTM is expected to improve the information of the angular distribution of diffuse irradiance.
- Consistent calculations of global, direct and diffuse radiation (all sky situations) within one single scheme considering different aerosol types and not only turbidity. Additionally a new direct diffuse model has been implemented. All in all a improved estimation of the relation between diffuse and direct radiation could be expected.

- An advantage of using the direct irradiance as preliminary quantity is that macrophysical parameters can easily be adapted to improve the model, e.g cloud fraction in combination with geometry describes can be used to describe the amount of clear sky irradiance blocked by clouds

- Clear and easy linkage with cloudy sky scheme possible, whereas the treatment of the heterogenous cloud effects is not restricted.

Chapter 3

Technical description: Working version of the SOLIS clear sky module

A working version of the clear sky scheme has been performed within the HELIOSAT-3 project. With respect to the contents, the working version is described in section 2.2. Here technical issues related to the use of the working version are explained.

3.1 Computer requirements

Required Hardware A modern (ordinary) PC is fast enough to run the clear sky module operationally.

Operating system The working version is designed for Linux or Unix operating systems. Using a machine based on these operating systems is emphatically recommended. Running the program under the Microsoft Windows operating system is linked with a lot of problems and principle restrictions and is therefore not recommended, but possible. For the working version no support will be supplied for computer running on the MS-Windows operating system. The CYGWIN software is necessary prerequisite (http://sources.redhat.com/cygwin) to get the working version running. CYGWIN is a UNIX environment for Windows developed by Red Hat.

3.2 Software requirements and installation basis

Usually needed standard software:
awk, bash, gcc, f77, and some *libraries*.
All of this software is part of SUSE Linux or DEBIAN Linux distribution. Every other Linux distribution should contain this software as well. If parts of this software are missing on your machine, which usually should not be the case, installing the software can be performed by using the package manager of the respective distribution, (e.g SUSE Linux – Yast can be used, DEBIAN Linux – dselect can be used).
Additionally netcdf is necessary for the usage of the working version of the clear sky module. [1]
The *netcdf* software is provided within most of the LINUX distributions as RPM or DEB package, Installing is simple by using the package manager of the respective distribution, (e.g SUSE Linux, Yast can be used to install netcdf DEBIAN: dselect can be used). If the *netcdf* software is

---

[1] For our purposes we have to use the correlated-k option of libRadtran. In order to use this option the netcdf software is necessary to read the cross section information of atmospheric molecules. Principle usage of ASCII data is possible but currently not implemented.

not provided with your Linux distribution there should be no problem to find a appropriate RPM package on the Internet.
With respect to UNIX based system it has to be expected that netcdf is not part of the standard UNIX environment. Yet information about the installation of *netcdf* on UNIX is available at:

http://www.unidata.ucar.edu/packages/netcdf/index.html

and more detailed information how to install *netcdf* is available at:

http://www.unidata.ucar.edu/packages/netcdf/INSTALL.html

Some precompiled binaries for different Unix based operating systems can be found at:

http://www.unidata.ucar.edu/packages/netcdf/binaries.html

The working version contains an integrated radiative transfer model, called *libRadtran*. This radiative transfer model needs to be installed too, but it is ”easy” to install libRadtran. However, it is urgently recommended to install netcdf before. *libRadtran* will then automatically detect netcdf and will proceed the installation including the necessary steps in order to use *netcdf*. The libRadtran package can be downloaded from the official libRadtran web-page.

http://www.libradtran.org

On this page detailed installation instructions can be found. Please note libRadtran is provided under the GNU public license.
The working version cannot be run without the tools developed at the University of Oldenburg. This tools are archived in a tar file called solis-tools.tar and can be downloaded at:

http://www.heliosat3.de/intern/tools

3.3 Installation steps for Linux and Unix based computers

1 Install the *netcdf* software, if necessary download the software before.

2 Download and install the *libRadtran* RTM package. Follow the instruction provided within the libRadtran package or via the *libRadtran* home-page. After the successful installation a libRadtran main directory will be on your machine.

3 Run some tests with libRadtran in order to check if everything works well.

4 Download the file *solis-tools.tar* from:

    http://www.heliosat3.de/intern/tools

  Copy the file in the sub-directory ”tools” within the libRadtran main directory. Getting the tools prepared for the usage within the working version is performed with the following command:

```
tar xvf solis-tools.tar
```

5 Test the working version.

3.4 Running the clear sky module

Currently the whole clear sky module is operated (driven) with one central script.
In the first part of the script the necessary input parameter for the radiative transfer model libRadtran are defined. Information relating to the format and the definition of this parameter can be found in the libRadtran user-guide. In principle the user can leave or better should leave all parameters unchanged, except parameters related to the atmospheric input (aerosols, H_2O and ozone) as well as the selected wavelength bands. E.g. the following lines have to be adapted with respect to the given atmospheric state and the desired wavelength region:

```
h2o_mixing_ratio  3350   # H2O mixing ratio in the lowermost level
aerosol_season 1         # Summer season
aerosol_haze 4           # Aerosol type below 2km
aerosol_visibility 50.0  # Visibility,
                           or alternatively for the new
                           libRadtran version
aerosol_set_tau_550      # Set the aerosol optical depth at
                           550 nm,other wavelengths are scaled
                            accordingly
ozone_column  300.       # Scale ozone column to 300.0 DU
wvn 307 3001             # Wavelengths considered
```

libRadtran provides different format options for the definition of these quantities, e.g for aerosols the use of Angstrom coefficients instead of the definition given above is possible.
For the final version the development of a GUI interface is aimed for. Additionally an interface for the operational input of atmospheric data (HDF format) will be developed.
In the second part of the script the *awk* tools are called up. These tools perform the calculation of the effective optical depth and the correction parameter α. With these information the modified Lambert-Beer relation and therewith the diurnal variation of the clear sky irradiance is completely defined. Within the script of the working version also plots are prepared that compare the diurnal variation defined by MLB with the explicit model runs. The plots are saved in a postscript file.
The definition of the input parameters is the first step. After that the whole model can be executed simply by the call:

```
kato.sh  directory-name file-name
```

where directory-name and file-name characterises the output directory and the output files, e.g.

```
kato.sh  outdir myfile
```

will safe the ”output” files *myfile.inp, myfile.out, myfile-l.out, myfile.ps* in the *outdir* directory. The files *myfile.out* and *myfile-l.out* provide the result (output) of the model run. *myfile.inp* shows again the input defined within the shell script. This input file of a respective run is saved together with the output files in the *outdir* directory to enable a better controlling and archiving of the results. The file *myfile.ps* in the *outdir* directory is the postscript file containing the diagrams

3.4.1 Output of the clear sky module

The output of the clear sky module are spectral resolved global, direct and diffuse irradiance on the earth surface. The diffuse, direct and global irradiance are saved in the files ending with **-l.out* and **.out* (e.g. *myfile-l.out*, *myfile.out*). The **-l.out* file provides the information of the solar irradiance for the different wavelength bands (spectral selective solar radiation data, radiation data for each wavelength band). The **.out* file contains the values for a whole wavelength region (broadband radiation data, integrated over several wavelength bands e.g. 306-3001 nm). The irradiance given for the wavelength bands is the irradiance integrated within the wavelength band.

For the linkage between the cloud module and the clear sky module the MLB-parameter (the "fitting" parameter) are saved in the files **.fit* **and** **-l.fit* **They are read in by the cloud module. The respective call of the cloud module is performed within a script, see chapter 4**

The wavelength region can be selected by the user (it has not to be 306-3001 nm), in accordance to the wavelength bands described below.

```
# Wavelength bands for the Kato et al. [1999]
# correlated k-technique
#
# Columns:
#  1  band number
#  2  start wavelength [um]
#  3  end wavelength   [um]

 1  2.401185e-01  2.724815e-01
 2  2.724815e-01  2.834140e-01
 3  2.834140e-01  3.068408e-01
 4  3.068408e-01  3.277722e-01
 5  3.277722e-01  3.625000e-01
 6  3.625000e-01  4.075000e-01
 7  4.075000e-01  4.520458e-01
 8  4.520458e-01  5.176806e-01
 9  5.176806e-01  5.400000e-01
10  5.400000e-01  5.495000e-01
11  5.495000e-01  5.666000e-01
12  5.666000e-01  6.050000e-01
13  6.050000e-01  6.250000e-01
14  6.250000e-01  6.667000e-01
15  6.667000e-01  6.841772e-01
16  6.841772e-01  7.044486e-01
17  7.044486e-01  7.426139e-01
18  7.426139e-01  7.914788e-01
19  7.914788e-01  8.444581e-01
20  8.444581e-01  8.889693e-01
21  8.889693e-01  9.749063e-01
22  9.749063e-01  1.045744e+00
23  1.045744e+00  1.194188e+00
24  1.194188e+00  1.515940e+00
25  1.515940e+00  1.613451e+00
26  1.613451e+00  1.964798e+00
27  1.964798e+00  2.153464e+00
28  2.153464e+00  2.275190e+00
29  2.275190e+00  3.001893e+00
```

```
30  3.001893e+00  3.635417e+00
31  3.635417e+00  3.991003e+00
32  3.991003e+00  4.605654e+00
```

The format of the output **-l.out* and **.out* files is described in detail in the libRadtran manual. Here the format of the *.out file is outlined.
Example of an output file:
1. 2. 3. 4. column: SZA, global, direct, diffuse irradiance

```
  0.1 1012.30 554.93 457.37
 10.0 993.32 540.49 452.82
 20.0 937.01 498.10 438.91
 30.0 845.17 430.45 414.72
 40.0 721.38 342.71 378.67
 50.0 570.97 242.35 328.62
 60.0 403.03 140.62 262.41
 70.0 232.97  54.22 178.75
 80.0  87.60   5.94  81.67
```

The ouput format of the fit files **.fit* **and** **-l.fit***:** A # is used as an identifier for the lines containing the MLB-parameter. This identifier enables the program to detect automatically the array dimensions which are dependent on the number of chosen wavelength bands. Behind the identifier # the MLB-parameter are listed in the following manner.
column 1: Identifier #
column 2: I_o corrected extraterrestical irradiance
The following columns contains the parameter effective optical depth and correction parameter a,b,c for global, direct and diffuse clear sky irradiance.
column 3,4: global; τ_{0g}, b (as in 2.5)
column 5,6: direct; τ_{0d}, a
column 7,8: diffuss; τ_{0dif}, c
Example:

```
# 1766.9  -0.51  0.34  -0.75  0.48  -2.08  0.24
```

I_0 τ_{0g} b τ_{0d} a τ_{0dif} c

The output format for the different wavelength bands is the same but contains one line for each wavelength band.

Chapter 4

Technical description: Working version of the SOLIS cloud module

4.1 Installation steps for Linux and Unix based computers

The pre-condition for the installation of the cloud module is the successful installation of the clear sky module.

Necessary steps Read the license file readme-license (you find it on Heliosat3 web page directory solis). If you acccept the licence you are allowed to use SOLIS. Download the file *solis-cloud.tar* from the Heliosat server or request for a cdrom.
Copy the file in your libradtran directory. e.g */home/someone/libradtran-0.99*
After that unpack the file using the command

```
tar xvf solis-cloud.tar
```

If everything has worked correct you should find now a directory called *solis*. Within this directory there are some subdirectories.

```
/c             the source-codes in c
/c/FKT         functions used within the source code
/exe           the executables (in older versions bin has been used
               instead of exe) the central compilation script ccnr_r
/0008          test data set of cloud index from august 2002,
               based on 012 raw images (Eruope and more)
```

If the cloud module is aimed for running on a non-LINUX machine two numerical recipes codes has to be compiled first (the same is true if you use Linux on a machine with AMD processor due different processor architectures).

```
    cc -ansi -c nrutil.c
    cc -ansi -c nrutil_b.c
```

leading to the respective object files, *nrutil.o nrutil_b.o* If the script *ccnr_r* located in the *exe* directory is used the object files are automatically linked to the respective ”solis” executable.
Before using *ccnr_r* for compilation the name of a main (central) directory has to be checked in the script ccnr_r. The default is

```
   PATHC=$HOME/solis
```

It might by necessary to change this default, dependent on the chosen name of the main directory and the machine.
If possible use for all compilations the gcc (Gnu c) compiler.

Use of ccnr_r Change from the main directory (e.g. solis) to the sub-directory *exe*. Then call *ccnr_r* followed by the name of the code you like to compile, for our case use the command

```
ccnr_r n2irr-solis-v1x1
```

ccnr_r compiles the source code *n2irr-solis-v1x1.c* located in the sub-directory *c* and puts the executable to the sub-directory *exe* ,provided that the compilation was successfully.
Within the directory *exe* the executables can be executed by using the script described in the next section.

4.2 Running the cloud module

Currently the whole clear sky module is operated (driven) with one central script (*solis-cloud.sh*). Within the script solis-cloud.sh the program *n2irr-solis-v1x1* is called. In order to execute this program in a correct manner the necessary input parameter has to be defined before running the script. Hence open the script *solis-cloud.sh* and change the necessary parameter in the program call.

```
n2irr_solis-v1x1 -i /home/prelx222/richard/solis/0008/02150700.hel
-o $1 -l 230 -c 222 -h 2 -v 1 -b 0214 -e 0240
```

The character with a minus in front tells the program which parameter will be provided to the c-program, the number or string afterwards are the parameter provided to the program.
The options and the parameters are, respectively:

```
 -i <imgagefile> : VIS input file specifier
                   the directory has to be changed
                   insteadt of /home/prelx222/richard/
                   you have to use the name of your
                   home directory.
                   the image has to be within the time
                   duration characterised with -b -e
                   Please use the absolute directory path,
                  ,else the images will not read in
                  (hence do not use somthing like
                     ../../solis/0008/02150700.hel).
-o <outputfile> : name provided via the solis-cloud call,
                  do not change $1
-l      : line of pixel < 768
-c      : column of pixel < 1280
          these parameters are used to select
          the location
-h      : number of horizontal pixels for region
-v      : number of vertical pixels for region
          -h 2 and -v 1 result in 5*3 pixel mean
```

```
                   of cloud index, recommended
         -b      : first day: example 0214 =  year 2000 day 214
         -e      : last day : example 0240 =  year 2000 day 240
         -q      : quiet mode, displays errors only
         -?      : displays this help message

 -t providing a value via t has currently no effect on
   the turbidity, the map-value is used anyway.
```

Please do not take pixels at the image edges. the program is not save to it, when calculating the mean. Future versions will care for it.
For the final version the development of a GUI interface is aimed for. Additionally an interface for the operational input of atmospheric data (HDF format) will be developed. The linkage between clear sky and cloud module will be automated.
The definition of the input parameters is the first step. After that the whole model can be executed simply by the call:

```
solis-cloud.sh  directory-name file-name
```

where directory-name and file-name characterises the input directory and the input files containing the modified Lambert-Beer parameters as well as the prefix name of the output file (ending with *.rad*) e.g.:

```
solis-cloud.sh  mydir myfile
```

will read in the ”input” files *myfile.fit*, *myfile-l.fit* from the *mydir* directory. Additionally it will produce the output files *myfile.rad* and *myfile-l.rad* The output file contains the time series of the solar irradiance for the specified location (site).

Important the input file containing the MLB parameter has to exist else an error occurs.

4.2.1 Output of the cloud module

The output files will end with **.rad*, whereas the prefix is provided within the solis-cloud call, e.g.

```
solis-cloud.sh  mydir myfile
```

provides the output file *myfile.rad* and *myfile-l.rad* in the directors *mydir*. The file with the label *-l* contains the wavelength resolved data, the other one the wavelength integrated data.
The output-format and contents of the output file *e.g myfile.out*, containing the wavelength integrated data are.
DOY, GMT, cos(zen), G(clearsky), image(y/n), n(1Pix), n(morePix), stdev(n(morePix), G(global), G(direct), GH(global), GH(diffuse), GH(clearsky)

```
DOY=day of year
GMT=Greenwich Mean Time (UT)
cos(zen)=cosine of the solar zenith angle
G(clearsky)= global clear sky irradiance, SOLIS model value
image(y/n)= image flag, image present 1, no image 0
```

```
n(1Pix)=cloud index of the central pixel (above the chosen site
(lat,lon))
n(morePix)= mean cloud index of the 3x5 or 5x5 pixels
            (depends on the settings of -h and -v, e.g -h2 -v 2
             -> mean of 5x5 pixels)
stdev(n(morePix)=standard deviation of n(morePix).
                 n(morePix)-> mean value of cloud index
                 stdev(n(morePix)-> "variation"
G(global),G(direct)= SOLIS global and direct irradiance
                     respectively, for the given cloud
                     situation.
GH(global),GH(diffuse)= Heliosat global and diffuse irradiance
                     respectively, for the given cloud situation.
                     Current Heliosat version, diffuse model
                     based on Skartveit et al 1998
GH(clearsky)     = clearsky irradiance derived with the
                   turbidity based clear sky model
```

The GH values are optional.
The wavelength resolved data (e.g. output file *myfile-l.rad*) is provided in the format.
DOY, GMT, cos(zen), G(clearsky), image(y/n), n(1Pix), n(morePix), stdev(n(morePix), G_1(global), G_1(direct), G_2(global), G_2(direct), ..., G_l(global), G_l(direct).
$i=1,2,...,n$ labels the respective wavelength band and l is the amount of the wavelength bands, hereby.

4.3 Outlook: The modular concept of the scheme

The integrated use of the RTM within the clear-sky module together with automatically provided spectral information are an optimal basis for a modular design of the scheme (final version). Since different applications vary with respect to the necessary input and output information including different wavelength regions, a modular concept is linked with a lot of advantages. The current way of running the clear sky module is briefly described in sections 3.4. For the final version an interface for the operational input of the atmospheric data will be developed. An object oriented programming language like C++ is well suited to develop such an interface. Further details concerning the interface between the C++ based frame for the solar irradiance scheme and the atmospheric data has been discussed at the technical workshop, performed on December the 11 th 2002.

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