Documentation: Mesoscale Atmospheric Global Irradiance Code - MAGIC

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Chapter 1

INTRODUCTION

solar irradiance definition The surface solar irradiance (I) is defined as the incoming solar radiation at the surface in the 0.2 - 4.0 μm wavelength region.

aim of MAGIC The Mesoscale Atmospheric Irradiance Code is dedicated for the computing-efficient and accurate estimation solar surface irradiance (global irradiance) and direct irradiance in meso-scale. The method (clear sky)is based is based on Radiative Transfer Model (RTM) calculations, following a lookup table approach.

Lut approach: The idea behind the LUT approach for an irradiance retrieval scheme is to get equal results as with the direct usage of an RTM, but without the need to perform RTM calculations for each pixel and time, thus leading to an improved computing performance compared to the explicit use of RTM.
A lookup table (LUT) is a data structure, used to replace a runtime computation with a simpler interpolation operation within discrete pre-computed results. E.g. the LUT could contain the solar surface irradiance (or transmittance) for a variety of atmospheric and surface states. The solar irradiance for a given atmospheric state can be extracted from the LUTs by interpolation for each location and time.
Figure 1.1 illustrates the principle of the LUT approach. The special feature of MAGIC is the eigenvector hybrid LUT approach, which leads to accurate but computing efficient algorithm.
For clear sky situations the solar irradiance is directly determined from the look-up tables (Mueller et al., 2009), whereby for cloudy situations an interface to a normalised cloud albedo is provided in order to be able to treat also clouds, please see chapter 3 for details. For the clear sky state needed input data comes from climatologies and are provided within MAGIC, see chapter 5.

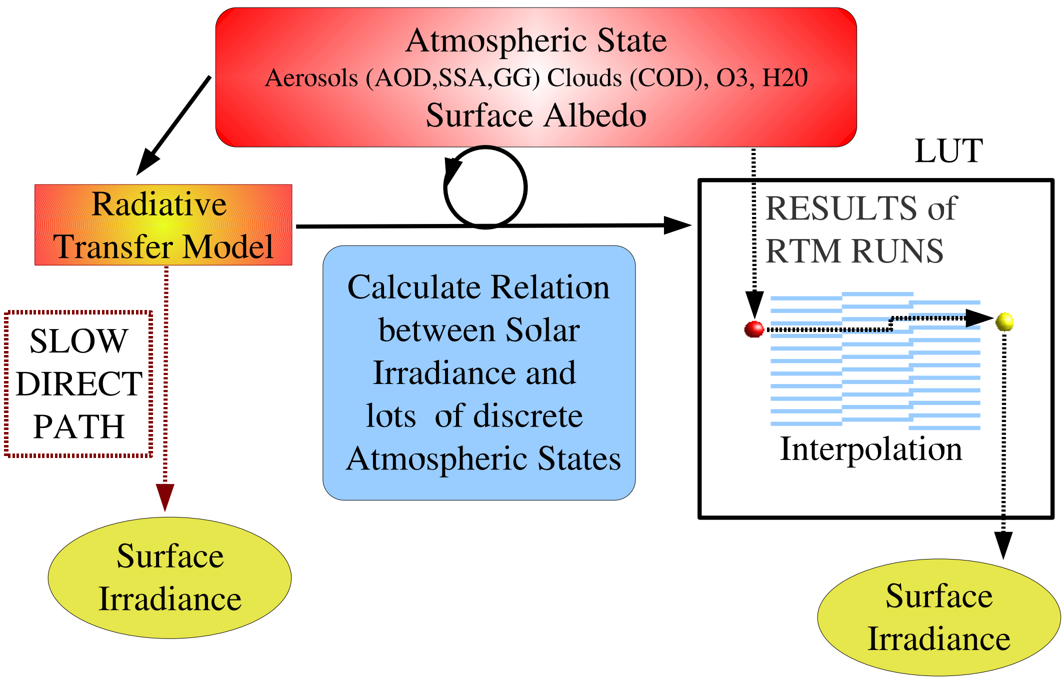

Figure 1.1: The principle of a LUT approach. The relation of the transmission to a manifold of atmospheric states is pre-calculated with a radiative transfer model (RTM) and saved in a look-up table (LUT). Based on the amount of considered atmospheric states the LUT table is large. 10^5 to 10^7 calculations are usually needed for the LUT approach if specific scientific optimisations are not applied.

Chapter 2

THE MAGIC Clear Sky APPROACH

2.1 Introduction into the new concept

Look-up tables work well but they have a significant disadvantage if generated and applied in a pure technical manner, referred hereafter as "pure technical" LUT.
A large number of RTM runs have to be performed in advance for the generation of the LUTs leading to big and cumbersome LUTs. Since recalculation of LUTs can be very time consuming and requires a big effort, the threshold for recalculation is high.
Still, a lot of operational processing time is needed due to interpolation within large multi-dimensional arrays. These limitations can be overcome by reducing the needed amount of RTM calculations as much as possible. Optimisation of the computing performance is quite important, because of the large amount of pixels that have to be processed. In this context the design of a LUT algorithm is always faced with the question how to reach a high computing speed without loosing significant accuracy.
Reducing computing time is especially important for the re-processing of large amounts of satellite data (in the order of several years to a few decades) to produce high-quality homogeneous time series suitable for climate monitoring purposes or solar energy applications.
In order to minimise the RTM runs needed to describe the interaction between the atmospheric state, the surface albedo and the surface solar irradiance (transmittance), the symmetries and principal components of the relation between the atmospheric transmission and state have been analysed, leading to the new approach of a eigenvector hybrid LUT approach discussed in more detail in the following sections and outlined afterwards. afterwards.

- Parameters with marginal effect on I (< 0.1 %) have been left out.
- The interpolation grid has been optimised.
- Inherent symmetries of the relation between the atmospheric state and transmission have been evaluated in order to define a basis system characterised by processes which can be treated as linearly independent on each other. In mathematical terms a basis coordinate system has been evaluated. For the linearly independent parameter set a "pure technical" LUT with (an) optimised interpolation grid has been calculated. For the processes which can be treated as linearly dependent on the basis coordinate

system parameterisations have been developed and applied in order to consider their effect on the solar surface irradiance. This approach is referred to be a "eigenvector" approach and is discussed in more detail in 2.2

The goal of the analysis has been the development of a new scheme which is characterised by high flexibility and accuracy combined with high computing performance. The amount of needed RTM calculations for LUTs can be reduced by several orders of magnitude.
The development of the LUT approach discussed hereafter is based on extensive sensitivity studies. The RTM model libRadtran (Mayer and Kylling, 2005) has been used for the computation of the LUTs and the analysis of the interaction between radiation and the atmosphere. 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 radiative transfer models (Koepke et al., 1998), (Van Weele et al., 2000), and radiation measurements (Mayer et al., 1997).

2.2 Meaning of Eigenvector approach

The pure mathematical definition of eigenvalues and eigenvectors can be extended to any operator H. H might be "rotate by 360 degrees" or "stretch in direction of y-axis" or operators in Quantum theory or in radiative transfer as in our case. In these cases, the concept of direction loses its ordinary meaning, and is given an abstract definition. We write $H(\vec{x})$ to mean 'the action of operator H on vector $\vec{x}$'. $\vec{x}$ might be a particular vector that is rotated or stretched or it might be a quantum state or some other object. A eigenvector of operator H is preserved by the operator H apart from a scalar multiplier k, hence, if for the operator H a vector $\vec{x}$ and a scalar k exists so that the following equation is true:
$H(\vec{x}) = k * \vec{x}$
then $\vec{x}$ is an eigenvector of operator H. This means that the vector changes only the length but not the "direction" and that his length (absolute value of the vector) is k times bigger than what it was before H acted upon it.
A vector is usually defined within a coordinate system. In our case the vector is defined as $\vec{I}$ the solar surface irradiance with a "direction" and length given by it's dependency on the parameters of the atmospheric state and surface albedo for a fixed solar zenith angle. Hence the initial coordinate system is given by the atmospheric state (surface albedo, single scattering albedo, asymmetry factor, water vapour, ozone, surface albedo), referred as $Astate$ in the following formulas.
In our case the operator is given by the effect of the radiative transfer model on $\vec{I}$ if a specific atmospheric parameter is varied. For water vapour variations the following relation is given.

$$RTM_{\delta H_2O}(\vec{I}_{Astate}) = k \cdot \vec{I}_{Astate} \tag{2.1}$$

As the effect of water vapour is predominantly independent on the underlying atmospheric state only the length but not the "direction" of $\vec{I}_{Astate}$ is changed if the operator $RTM_{\delta H_2O}$ is applied. In other words, k remains always the same number for a given δH_2O independent of $Astate$. Hence, $\vec{I}_{Astate}$ can be referred as an eigenvector related to the operator $RTM_{\delta H_2O}$ (also true for the operator $RTM_{\delta 0_3}$ and $RTM_{\delta SAL}$).
This is not the case for the operator $RTM_{\delta AOD}$, $RTM_{\delta ssa}$ or $RTM_{\delta gg}$, belonging to the effect of variations in the aerosol optical depth, the single scattering albedo and the asymmetry

parameter on $\vec{I}_{Astate}$, respectively. In descriptive terms the $\vec{I}_{Astate}$ vector does change the length and the "direction" concerning the application of operator $RTM_{\delta AOD}$, $RTM_{\delta ssa}$, $RTM_{\delta gg}$. k is variable and depends on $Astate$ for a given δAOD (also true for δssa and δgg).
As $\vec{I}$ can be referred as an eigenvector concerning the operator $RTM_{\delta H_2O}$ and $RTM_{\delta O_3}$ the atmospheric parameter H_2O and O_3 has not be considered within the basis coordinate system, hence within the calculation of the basis LUT.
In our approach all parameter associated with an operator for that $\vec{I}_{Astate}$ is an eigenvector are separated and not considered within the basis LUT and the respective operator processes are parameterised.
The remaining operators describe linear independent processes and the underlying atmospheric parameter are building the basis coordinate system.

2.3 The basis clear sky LUT

The basis clear sky LUT, containing the transmission for the linearly independent atmospheric clear sky radiation processes, consists of RTM results for aerosols with different Aerosol Optical Depth (AOD), single scattering albedo (ssa), and asymmetry parameter (gg). For the remaining parameters (water vapour, ozone, surface albedo), which correspond to linearly dependent processes, fixed values have been used for the calculation of the basis LUT: 15 kg/m^2 water vapour column, 345 DU ozone, and a surface albedo of 0.2. The effect of the solar zenith angle on the transmission, hence the solar irradiance, is considered by the use of the Modified Lambert Beer (MLB) function, leading to a huge reduction of the needed RTM calculations. The MLB function is discussed in detail in Mueller et al. (Mueller et al., 2004), including proof and verification of the MLB equations. In 2.3.1 only a short outline is given.
Using the basis LUT the atmospheric transmission can be derived for a given aerosol state by interpolation within the basis LUT for every SZA, but at this stage only for fixed water vapour, surface albedo and ozone values. In order to correct the effect of variations from the fixed values occurring in nature, the parameterisations described in section 2.4, 2.5 and 2.6 are applied.

2.3.1 Sun zenith angle dependency - The Modified Lambert-Beer function

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

$$B_\lambda = I_{0\lambda} * exp(\frac{-\tau_{0\lambda}}{cos(\theta_z)}) * cos(\theta_z) \tag{2.2}$$

where $\tau_{0\lambda}$ is the optical depth of the vertical column, B_λ is the direct radiation (beam) at ground for a solar zenith angle (SZA) of θ_z and $I_{0\lambda}$ is the extraterrestrial irradiance at wavelength λ. Direct monochromatic irradiance derived with this formula agrees well with the SZA dependent diurnal variation of explicit RTM results.
A good match for wavelength bands and solar surface irradiance and it‘s diffuse fraction is only possible if an additional "empirical" correction exponent a is used. Hence a correction of the optical depth, or equivalent to this, of the parameter $\frac{\tau}{cos(\theta_z)}$ is necessary.

$$I_{basis} = I_{0,enh} * exp(\frac{-\tau_0}{cos^a(\theta_z)}) * cos(\theta_z) \tag{2.3}$$

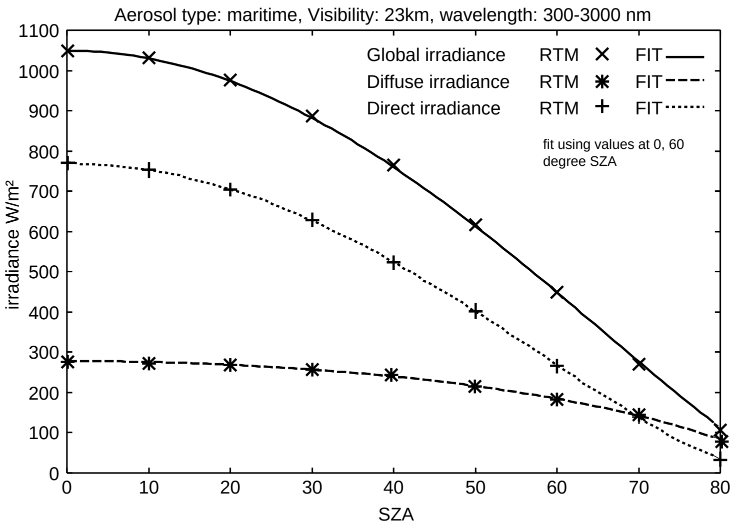

Figure 2.1: Comparison between RTM calculations and fit using the modified Lambert-Beer relation. Example for a fit of broadband irradiance. Global irradiance is synonymous to solar irradiance at the surface. Direct irradiance is the direct portion (beam) of the solar surface irradiance

The fitting parameter a is calculated based on a two RTM runs, one at $\theta_z = 0$ and the other at $\theta_z = 60°$, hence the correction parameters a_i can be calculated without the need for a numerical fit. $I_{0,enh}$ is based on the extraterrestrial irradiance at the top of atmosphere and estimated using equation 2.4. In order to match MLB function with RTM results I_0 has to be enhanced for solar surface irradiance and diffuse irradiance at low visibilities (high optical depth, high aerosol load). A general equation has been found which is applied to I_0 to get $I_{0,enh}$. Hence, $I_{0,enh}$ is used instead of I_0 for all atmospheric states.

$$I_{0,enh} = (1 + I_0 \cdot \frac{I_{diffuse}}{I_{direct} \cdot I}) \cdot I_0 \tag{2.4}$$

Here $I_{diffuse}$ and I_{direct} are the diffuse and direct fraction of the solar surface irradiance I. Using the MLB function (equation 2.3) only RTM calculations at 2 SZA have to be saved in the LUT compared to 7-9 for "pure technical" LUTs, without significant reduction of accuracy. Using the so-called Modified Lambert-Beer (MLB) function, the calculated direct irradiance as well as the solar surface irradiance can be reproduced very well (see Fig. 2.1). Extensive validation results can be found in (Mueller et al., 2004) and (Ineichen, 2006). It is important to notice that the fitting parameter a has different values for direct irradiance and solar surface irradiance.

2.4 Treatment of water vapour and ozone variations

RTM runs for the clear-sky case have been performed, in order to derive the atmospheric transmissivity correction for water vapour and ozone variations relatively to the fixed standard values (15 kg/m^2 and 345 DU).

The effect of variations in water vapour and ozone is predominantly independent of the atmospheric state (e.g. the aerosol load) and the surface albedo. Consequently, a basis LUT is calculated with fixed water vapour and ozone amounts (15 mm, 345 DU). The

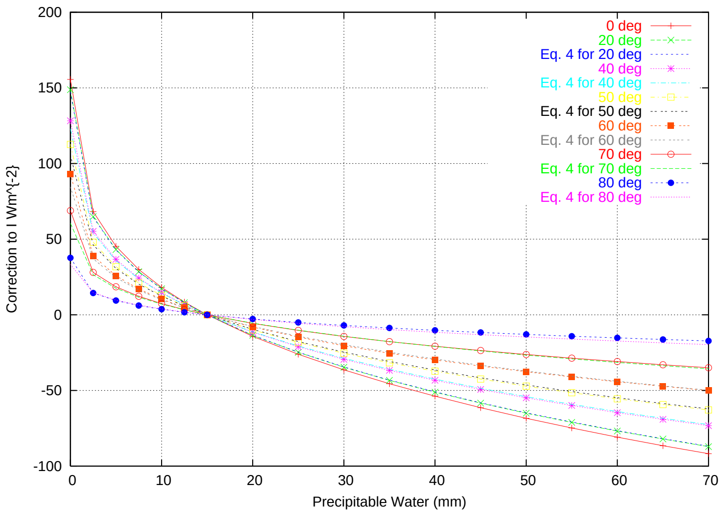

Figure 2.2: Differences between I^{h2o}_{basis} and I_{basis} estimated by explicit RTM calculations and by use of the correction formula (Eq. 2.5) for different solar zenith angles (0,20,40,50,60,70,80). The unit mm is equivalent to kg/m^2

effect of deviations of H_2O and O_3 on the solar irradiance relatively to the fixed values (used in the basis LUT) is quantified by application of the following correction:

$$I^{h2o}_{basis} = I_{basis} + \Delta I_{H_2O} \cdot cos^a \theta_z. \tag{2.5}$$

I_{basis} is the solar irradiance at the surface I derived from the basis LUT for fixed water vapour amount of 15mm, I^{h2o}_{basis} is the solar surface irradiance corrected for the actual water vapour amount, and θ_z is the solar zenith angle (SZA). ΔI_{H_20} is the difference between I for the 15 kg/m^2 water vapour and the I for the actual amount of water vapour, for $\theta_z = 0$ and a fixed standard atmosphere defined by rural aerosol type with an AOD of 0.2, a surface albedo of 0.2 and 345 DU ozone. ΔI_{H_2O} depends on the amount of water vapour. It is pre-calculated for 18 water vapour amounts and the algorithm uses the appropriate ΔI_{H_2O} value for the specific pixel and time. Hence, for fixed solar zenith angle equation 2.5 is equivalent to equation 2.1 if we consider that I^{h2o}_{basis} is equal to $RTM_{\delta H2O}(\vec{I}_{Astate})$
The validity of this formula was verified, and the best a value was found to be 0.88. The accuracy of this method is visualised in Fig. 2.2, which illustrates the quite small differences between explicit RTM runs and results derived using Eq. 2.5. The deviations are negligible (considerably below $1W/m^2$) for the majority of cases. Only for extreme conditions (high SZA, very high or low amount of water vapour), deviations between explicit RTM runs and parameterisation up to 5 W/m^{-2} can occur. However, small H20 amounts (< 2 kg/m^2) are unlikely to occur within the MSG disk and for H20 amounts above 65 kg/m^2 the error and uncertainty of H20 retrieval increases significantly due to saturation. Hence the parameterisation performs well (deviations below $1W/m^2$) for realistic atmospheric conditions and water vapour retrievals.
For ozone the same approach (form-invariant equation) is used. However the effect of ozone on the broadband solar surface irradiance is quite small, therefore only three pre-calculated ΔI_{O_3} values are needed.

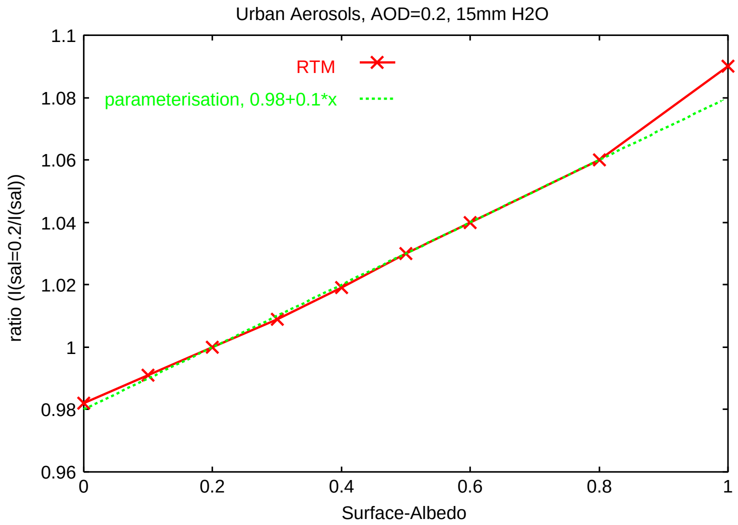

Figure 2.3: The ratio between the solar surface irradiance I for a fixed surface albedo of 0.2 and I for variable surface albedos. The dotted line corresponds to Eq. 2.6, and the solid line to explicit RTM runs. The RTM behaviour agrees well with the parameterisation of Eq. 2.6 in its linear region.

2.5 Correction of surface albedo

RTM calculations for a manifold of atmospheric states has been performed investigating the interaction of surface albedo and atmospheric clear sky state (aerosol load, water vapour,...). The effect of the surface albedo on the solar surface irradiance is predominantly independent on the atmospheric clear sky state. This enables the linearisation and parameterisation of the surface albedo effect on the solar surface irradiance, leading to the following formula.

$$I = I_{basis}^{h2o} * (0.98 + 0.1 \cdot SAL) \qquad (2.6)$$

I_{basis}^{h2o} is the solar surface irradiance derived from the basis LUT for a surface albedo of 0.2 after equation 2.5 has been applied. SAL is the variable surface albedo and I is the solar irradiance after the surface albedo correction has been applied. Figure 2.3 illustrates the predominantly linear behaviour of the surface albedo.

2.6 Sensitivity on atmospheric background profiles

The atmospheric background profile provides the vertical information on the total number density needed for the calculation of the Rayleigh scattering. In addition, it provides the vertical profile of water vapour and ozone, which are scaled according to the column amounts. Yet, using different background profiles (e.g. mid-latitude summer, polar winter, ...) has predominantly no effect on the solar surface irradiance. Consequently, in the new approach all RTM calculations are only performed for the US standard atmosphere rather than for 5 atmospheric background profiles as before in the CM-SAF prototype.

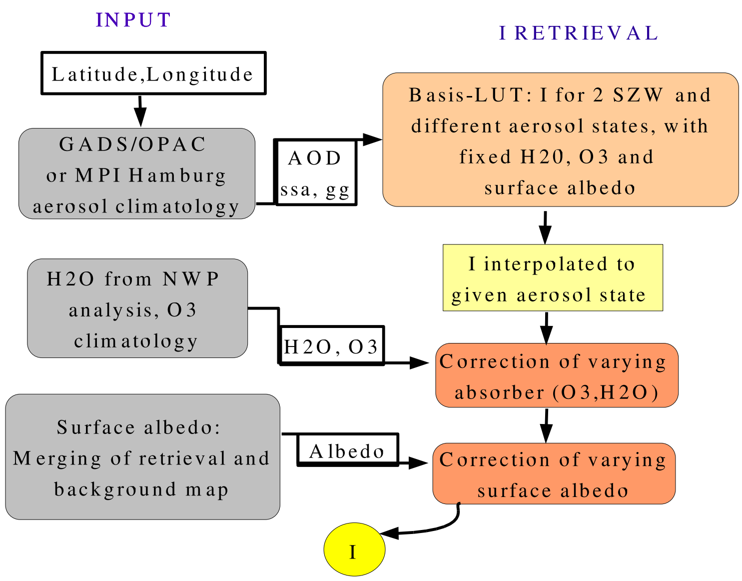

Figure 2.4: Diagram of the new clear sky LUT. NWP Numerical Weather Prediction. *I* is the solar surface irradiance.

2.7 Summary of clear sky approach

The basis look-up tables has been calculated for several aerosol optical depths and types and 2 sun zenith angles with fixed values of surface albedo (0.2) water vapour column (15mm) and ozone (345 DU) . The effect of variations in water vapour, ozone and surface albedo relative to the fixed values used in the calculation of the basis LUT is corrected by using the described correction formulas and parameterisation . Due to optimisations of the interpolation grid and the application of the water and ozone correction as well as the surface albedo parameterisation the amount of needed RTM calculations is enormously reduced. Applying the new method reduces the needed RTM calculations by a factor of 10000 without loosing accuracy. Table 2.1 illustrates the reduction of the needed RTM calculations. Contrary to the previous CM-SAF prototype algorithm, the clear-sky model no longer relies on top of atmosphere flux densities.

Table 2.1: Needed RTM runs

PARAMETER	RTM RUNS
Background atmosphere	1
Aerosol AOD and tye	**10*3*2
Solar Zenith Angle	*2
H20,O3	+10 +3
surface albedo	+0
TOTAL NUMBER OF RTM CALCULATIONS	173

Figure 2.4 illustrates the new clear-sky scheme and the context and order of the parameterisations.

Chapter 3

Treatment of clouds

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 e.g.Cano et al. (1986), **?** and Hammer et al. (2003). 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.
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. However, every geostationary satellite can be used (e.g. a Heliosat like method is also applied to GOES by e.g. Richard Perez). 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 **?** 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 $n \to 0$ and $n \to 1$:

$$\begin{aligned} n &\leq -0.2 & k &= 1.2 \\ -0.2 < n &\leq 0.8 & k &= 1 - n \\ 0.8 < n &\leq 1.1 & k &= 2.067 - 3.667 \cdot n + 1.667 \cdot n^2 \\ 1.1 &< n & k &= 0.05 \end{aligned} \tag{3.1}$$

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

$$G = k * G_{clear} \tag{3.2}$$

whereby $G_{clearsky}$ is provided by the MAGIC clear sky module described in section **??**.
It is possible to transfer cloud information from other sources into a cloud index. The important step is to normalise the cloud information. E.g. cloud optical depth can be normalised to a scale between zero (cloud free, COD=0) and $\tilde{1}$, with a normalisation factor derived by the 95 percentile of occurring COD values over the whole disk and for several month. Yet, the applied Heliosat formulas are only validated for cloud index or cloud cloud albedo respectively. But, to a first approximation every reasonable cloud information normalised to be between 0 and $\tilde{1}$ should work.
However, within the algorithm the cloud information is expected to be saved in a binary file as byte (range 0-255) or short integer type (range 0-1025). Hence the "float" value

between 0 and 1 has to be converted to a byte value (range 0-256) or short integer value (range 0-1024). In other words for byte data type a cloud albedo of 1 corresponds to a value of 256, and for a short integer it corresponds to a values of 1024. It is important to provide MAGIC the information whether byte scaling or short integer scaling is applied, which can be done by changing the respective value in the configuration file. For byte scaling 1 and for short integer scaling 2 has to be set as data type in the configuration file, the scaling is then performed automatically, please see chapter 5 for further details. However, it is recommended to use Heliosat based cloud information for GNU-MAGIC.
Using the Helisoat method solar irradiance from METEOSAT satellite data can be retrieved with a accuracy better than that derived from interpolated ground measurements (Perez et al., 2001) and (Perez et al., 1998). The Heliosat method has been used to generate cloud index data as basis for the surface solar irradiance and daylight data of the European database Satel-Light, which delivers valuable information to architects and other stake-holders (e.g. solar project managers) (Fontoynont et al., 1997). It has also been used within the SoDa service [1] (Wald et al., 2002) for the calculation of the solar surface irradiance. There exist also several derivatives of Heliosat, e.g Heliosat-2 (Rigolier et al., 2004) which is optimised as an operational processing chain for climatological data (HelioClim). Heliosat and derivatives are also the basis for the SOLEMI service (Solar Energy Mining, www.solemi.de, (Meyer et al., 2003)) and the ESA Envisolar project. (Environmental Information Services for Solar Energy Industries, www.envisolar.com)
A similar method for Meteosat First Generation data was developed by (Möser and Raschke, 1984), which is routinely applied at the German Weather Service (Diekmann et al., 1988). A similar method is also used for the GEWEX Surface Radiation Budget Project as a quality control algorithm (Gupta et al., 2001) and (Darnell et al., 1992). This algorithm known as Staylor algorithm is one of the two chosen by the World Climate Research Program (WCRP) SRB project for generating surface solar irradiance for the period March 1985 through December 1998. The results of this algorithm compared well with ground based measurements (Whitlock et al., 1995) and has been used to produce an short-wave dataset covering the 12-year period July 1983 through June 1995. In the meantime the SRB data set has been extended to June 2005.

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

Chapter 4

Direct Irradiance

The developed concept has also been applied to the retrieval of direct irradiance. In the clear sky case, the solar surface irradiance is estimated using the modified Lambert-Beer relation (Mueller et al., 2004). The same relation can be used for the calculation of the direct (beam) irradiance B, with the exception that instead of using $I_{0,enh}$ the extraterrestrial irradiance I_0 can be used. Thus, the MLB relation is

$$B = I_0 \exp(\frac{-\tau_0}{cos^a \theta_z}) cos\theta_z \tag{4.1}$$

where θ_z is the solar zenith angle, τ_0 is the vertical optical depth, I_0 is the extraterrestrial irradiance, B is the direct irradiance at the surface, and a is a constant.
Analogously to the retrieval of the solar surface irradiance a LUT for τ_0 and a was calculated, for fixed water vapour and ozone amounts. The LUT is three-dimensional, with the dimensions corresponding to aerosol optical depth (10 values), single scattering albedo (3 values), and asymmetry parameter (2 values).
The atmospheric transmissivity correction due to water is following a similar equation to Eq. 2.5

$$B_{basis}^{H_2O} = B_{basis} \Delta B_{H_2O} cos^a \theta_z \tag{4.2}$$

where B_{basis} is the direct irradiance from the LUT, ΔB_{H_2O} is the correction only due to water for a zenith angle of 0 degrees, and $B_{basis}^{H_2O}$ is the water-corrected direct irradiance for the zenith angle θ_z. The best a value was found to be 1.0. A similar formula is valid, when the correction with respect to ozone is considered.

$$B = B_{basis}^{H_2O} \Delta B_{O_3} cos^a \theta_z \tag{4.3}$$

where B is the water and ozone-corrected value and ΔB_{O_3} is the correction only due to ozone for a zenith angle of 0 degrees. In this case, the best a value is 0.7.
The ΔB_{H_2O} and ΔB_{O_3} values were pre-calculated and used directly from the algorithm during processing.
ΔB_{H_2O} for the current water and ΔB_{O_3} for the current ozone values are found by interpolation and then Eq. 4.2 and Eq. 4.3 are applied separately.
By this way the direct irradiance B is derived for clear-sky conditions. The extension to the cloud-contaminated or cloudy conditions (all-sky) is performed using the following relation between the cloudy sky direct radiation B_{all} and B :

$$B_{all} = B \left[k - 0.38(1-k)\right]^{2.5} \tag{4.4}$$

where k is the clear-sky index. This formula is an adaptation of the Skartveit diffuse model (Skartveit et al., 1998).

Preliminary validation has been performed, indicating that the accuracy is better than 15 W/m^2, which is a very promising result. However, extended validation activities are needed and will be performed before final conclusions on the accuracy can be drawn. The results will be documented in a forthcoming paper.

Chapter 5

Technical overview and input data

5.1 Input data

5.1.1 Slear sky

GNU-MAGIC comes with a complete set of clear sky information in order to enable the user the quick use of GNU-MAGIC.
However, the aerosol and water vapour data files can be replace by the users own favorites. The dimension of the used input for aerosol and water vapour information is not fixed but provided within the configuration file. However, in order to read in the data successfully the input data must have the same format as the MAGIC standard input, hence must fir the MAGIC interface for aerosol and water vapour information. Hence, for this version the user have to be take care to generate or transform his favourite aerosol or water vapour information data to the MAGIC format.
newline
For **aerosols** this is:
longitude, latitude, ssa (month 1-12), aod (month 1-12) in ASCII. Please see also the example climatologies. The definition of the longitude has to go from west to east whereby west of zero longitude the values are defined to be negative (max range -180 W to 180 E), and the latitude has to be defined from North to South, whereby South of the equator the values are defined to be negative (max range +90 Norht to -90 South degree).

```
longitude latitude ssa1 ssa2 .... ssa12 aod1aod2 .... aod12
```

There are two standard input options for the aerosol information:

- The GADS/OPAC climatology (Hess et al., 1998) using NCEP (Kalnay et al., 1996) relative humidity in order to consider the effect of relative humidity on aerosol optical depth, single scattering albedo and asymmetry parameter.
- The Kinne/CM-SAF aerosol climatology. The climatology has been prepared by MPI for DWD within the scope of a work contract. The date is freely available at www.cmsaf.eu (Data Access, Add on Products).

For **water vapour** it is:

```
longitude latitude h2o(1) h2o(2) .... h2o(12)
```

whereby the number in bracket stands for the respective month. The file has to be in ASCII. Please see also the example climatologies. The longitude has to start West with negative values being west of zero (-180 to 180), and the latitude has to be defined from North (90 degree) to South (-90 degree).

```
longitude latitude h2o1 h2o2  .... h2o12
```

The water vapour climatology (long term monthly means) results from the NCEP reanalysis Kalnay et al. (1996) are provided with MAGIC, data is available via web page.

www.cdc.noaa.gov/data/reanalysis

As an alternative to the NCEP water vapour climatology MAGIC comes with a water vapour climatology which is based on ECMWF reanalysis data. The climatology is in the MAGIC standart ASCII format described above and can be used insteat of the NCEP climatology. It has a higher spatial resolution
The SARB/CERES surface albedo background map and the CERES/IGBP landuse map

www-surf.larc.nasa.gov

are used in order to provide surface albedo information. A formula given in (Dickinson, 1983) is applied in order to consider the solar zenith angle dependency of SAL.
The treatment of the **surface albedo** is currently fixed. It can be not replaced by another source (map) without changing the source code.In the next version it will be possible to define other sources of surface albedo input within the configuration file. **Future versions will care for it.**
Because of the small effect of **ozone**, a climatology is not used in this version but the ozone value can be provided via the configuration file. **However, in the current version the ozone correction is not applied**.
The programmer of MAGIC does not warrant or assume any legal liability or responsibility for the accuracy, completeness or usefulness of the described input data

The core of MAGIC is the look-up table. The dimension of the look-up table is fixed in this version. If it is desired to calculate and use an own look-up table it is important that the hybrid LUT approach described in this document is carefully considered. Please contact my if you plan to calculate your own LUT. The format is as follows:

```
#header
ssa1  gg1
aod1  Iext tauG aG tauB aB
aod2  Iext tauG aG tauB aB
....
aod10 Iext tauG aG tauB aB

ssa2 gg1
aod1  Iext tauG aG tauB aB
aod2  Iext tauG aG tauB aB
....
aod10 Iext tauG aG tauB aB


ssa3 gg1
....

ssa1 gg2
....

ssa2 gg2
....

ssa3 gg2
aod1  Iext tauG aG tauB aB
aod2  Iext tauG aG tauB aB
....
aod10 Iext tauG aG tauB aB
#h2OHeader
#h2oheader
h2o(1)   dGh2o(1)  dBh2o(1)
h2o(2)   dGh2o(2)  dBh2o(2)
...       .....   ....
...       .....   ....
h2o(18)   dGh2o(18)  dBh2o(18)
#o3Header
o3(1)   dGo3(1)  dBo3(1)
o3(2)   dGo3(2)  dBo3(2)
o3(3)   dGo3(3)  dBo3(3)
```

5.1.2 Clouds

MAGIC comes with 2 example input files. Cloud index information covering 25 years will be available from the CM-SAF in 2010. On user request more images of cloud index data covering at least several years can be provided beforehand. Currently the cloud index format is an array of byte or short integer values saved in binary format. The dimension can be changed accordingly in the but the geolocation (latitude, longitude, solar zenith angle estimation) works currently only for full disk data.

```
rawtopgm -headerskip 256 -bpp 2 3712 3712 filename.XPIF >tmp.pgm
```

5.2 Software requirements and installation basis

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. There will be no support for GNU-MAGIC on a Microsoft Windows (no-)operating system.
Usually needed standard software:
bash, gcc, and *gcc libraries*.
All of this software is part of UBUNTU, DEBIAN, RED HAT, SUSE,.. Linux distributions. 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.
Additionally netcdf is recommended in order to be able to generate output in netcdf (ncgen). On demand the output of MAGIC can be provided in ASCII CDL format. With ncgen (part of netcdf library) the ASCII CDL format can be transformed to netcdf. The *netcdf* software is provided within most of the LINUX distributions as RPM or DEB package, installing is then simple by using the package manager of the respective distribution. If the *netcdf* software is not provided with your Linux distribution there should be no problem to find a appropriate 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 pre-compiled binaries for different Unix based operating systems can be found at:

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

5.3 Installation steps for Linux and Unix based computers

1 If not already installed on your maching please install the *netcdf* library (software). Netcdf is freely available, you can download it from the web. Netcdf is not needed by MAGIC but recommended !

2 Download magic-vN.tar.bz2 and put it in the disered directory, N is the version number. Uncompress it with:

```
bunzip2 magic-vN.tar.bz2
```

Afterwards unpack it using

```
tar xvf magic-vN.tar
```

3 Within the chosen directory you have now a directory *MAGICvN*, where N is the version number. In this directory you will find the source code, a pre-compiled binary and example configuration and script files. In the subdirectories *climatologies* and *luts* the needed climatologies and look-up table(s) are located. Go to the*MAGICvN* directory and type

```
gcc -lm -m32 magic-vN.c -o magic-vN.exe
```

Magic has been tested and compiled with gcc-3.3 and gcc-4.2. It is important to link the mathematical library (-lm flag, or -lmathlib) and it might be reasonable to compile with -m32 (32 bit mode). The name of the executable is defined with the -o flag. If you use another C compiler, please look in the manual for the associated flags. If the compilation works fine test MAGIC with

```
magic-vN.exe
```

MAGIC becomes all needed information from the configuration file

```
magic-config.inp
```

An example shell script is also provided in order to support the operational implementation of MAGIC

```
magic-vN.sh
```

The name of the output files are also defined in magic-config.inp In the example they are written to the out directory. There will be always a binary output (float, dimension is given in the configuration file) If only clear sky calculations are performed the output comes in a regular lat,lon grid and in ASCII CDL format.
If the cloud option is used (selectable with configuration file) it is assumed that the grid corresponds to the respective satellite projection, hence that the grid is irregular. MAGIC contains a geolocation subroutine which is based on a EUMETSAT routine for geolocation. This routine might also work for MSG or GOES. It calculates the needed latitude and longitude information. However, in the current version of MAGIC it is assumed that full disk information about the clouds is provided and not for sub-regions. In other words it is important that the map of the cloud information correspond to the map (full disk) of

the raw satellite images. As the aperture angle of the satellite is an important quantity of the geolocation subroutine, the geolocation fails if not the complete visible disk of the respective satellite is used.
A flag in the configuration file enables the user to switch on the regriding function. This function enables the ASCII CDL output for user defined subregions, which can be defined in the configuration file. Even with this flag switched on a full disk binary output is written in addition. Again the ASCII CDL output file can be converted with

```
ncgen output-cdl -o output.nc
```

to netcdf.
If the cloud flag is false, hence if MAGIC is used in the clear sky mode, the solar irradiance is calculated for the region given in the input file on a regular latitude longitude grid. The grid resolution can also be chosen.

MAGIC is completely driven by the configuration file *magic-config.inp*. **Afterwards a description of the configuration file is given.**

It is important to note that the (line & column)order of the parameter in the input must not be changed, else the program crashes. In the next version the input will be performed by findpar in order to get rid of this dangerous feature.

It is important to note that in the subsequent explanation of the configuration file everything after the → sign is only dedicated for explanation of the needed input and must not occur in the configuration file itself, else MAGIC fails. Please have a look at the configuration file which comes with MAGIC.

The name of the LUT and the dimension is included in the configuration file and can be changed but you should only change it if you know what you do !!
Please be aware that the dimension of the structure of the LUT is hard wired, and that the LUT hava a quite special format and content !!

```
##year,month,day,hour,minute(GMT)  -> comment line for the user.
2007                            -> the year
03                              -> the month
10                              -> the day of the year
12                              -> the hour (GMT)
00                              -> the minute (GMT)
##Dimension.and.name.of.aerosol.climatology -> comment line
144                             -> x-dimension (longitude dimension)
73                              -> y-dimension (latitude dimension)
climatologies/gads-nceprh.dat   -> the name of the aerosol climatology
##Dimension|and|name|of|H2O|climatology -> comment line
144                             -> x-dimension (longitude dimension)
73                              -> y-dimension (latitude dimension)
climatologies/h2oclim.dat       -> the name of the H2O(g) climatology
##name|and|of|LUT|albedo|and|landuse|map|DOnotCHANGE!!
luts/magic-clear.lut            -> name of LUT, do not change !
climatologies/albedo.map        -> name of albedo map, do not change
climatologies/IGBPa_2006.map    -> name of IGBP landuse mao, do not change.
345                             -> the ozone value, currently not used.
/*the|name|of|the|output|files|binary|ASCIIcdl*/
out/output-bin                  -> name of binary output file
out/output-cdl                  -> name of ascii output file
##CLOUDinterface
1             -> flag cloud calculation: 1:yes 0:no
2 256         -> data type in byte and header length of binary cloud file
3712 3712     -> dimension of the cloud input
satimages/200703071200_MSG_VIS008.CI.XPIF  -> name of file containing cloud input
0.0  18.0     -> position and aperture angle of satellite, scanning time for a line
-0.2 1.2      -> scalin facto of cloud index, see cloud chaper for details
1             -> regrid, only needed and applied if cloud flag is yes
##definition|of|the|region|lon-W|lon-E|lat-S|lat-N|resolution
-60  60  -40.0 45 0.15 0.15  -> the definition of the region (REG)
geo/nlon.dat    -> for later versions, external latitude information
geo/nlat.dat    -> longitude
geo/nsza.dat    -> sza information, currently not implemented.
\end{small}
```

Comments within example configuration file

The above described parameters are read in by MAGIC. Between the parameters there are lines containing comments beginning with ##. It is important to note that the position of the comment lines within the configuration file is hard wired, ## is only used to tell the user that this is a command line the program itself does not use. These comment lines are read it as a dummy string. As all formats for the read process are currently hard wired it is not possible to change the order of above de- scribed configuration commands without running in errors. E.g. it is possible to use other climatalogies with higher resolution, but the information about the name, xdim and ydim has to be always on the same position !! After the part which is read in (hence after the line geo/nsza.dat) there is a part in the example configuration file which is not read in by MAGIC and which is not needed to run MAGIC. It

contains only some explanations and user options. You can skip or leave it and you add your own comments, hints.

REG:
The region is defined by the longitude (west to east) the latitude (south to north) and the resolution in degree, longitude and latitude. West of zero longitude is negative and South of zero latitude is negative.
MAGIC comes with two already prepared options for aerosol climatology

```
######KINEE/MPI/Aerocom:
360
180
climatologies/aeronet_modmed.dat

or

######GADS/OPAC:
144
73
climatologies/gads-nceprh.dat
```

MAGIC comes with two already prepared options for water vapour

```
###NCEP
144
73
climatologies/h2oclim.dat

or

####ERA
1441
721
climatologies/h2oclim-era.dat
```

doy can be calculated with the bash command date.

```
date -d MON/DAY/YEAR +"%j"
date -d 03/07/2007 +"%j"
```

5.3.1 Output

The output is a binary file and a ASCII CDL file for the clear sky option and a binary file if the cloud interface is switched on. In this case also a CDL file can be generated if the regrid flag is set to true.
The developed method also includes the retrieval of direct irradiance. The first validation results of satellite based direct irradiance are encouraging.

ACKNOWLEDGEMENTS: **Acknowledgement to NCEP/NCAR SARB/CERES (NASA)for the open, easy and free web-access to their high quality data. Thanks to Stefan Kinne from MPI for the generation of the Aerosol climatology. Thanks to the people who generated the GADS/OPAC climatology. Thanks to the ECMWF for the high quality reanalysis data.**

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