



Project title:

**Energy-Specific Solar Radiation Data
from Meteosat Second Generation (MSG):
The Heliosat-3 Project**

Project Acronym:

HELIOSAT-3

Contract No.:

NNK5-CT-2000-00322

Project No.:

NNE5-2000-00413

Title:

Sunsat
the new program for processing high resolution
data of Meteosat-8

Main Author:

R. Kuhlemann (Oldenburg University)

Contributing Author:

A. Hammer (Oldenburg University)

Date:

June 2005

Deliverable:

D 8.2; D13.1

Preface

The work presented in this report is part of the deliverables D8.2 and D13.1 for the European research project Heliosat-3. It belongs to workpackages 3020 (cloudy sky scheme) and 4010 (solar energy processing chain). The Heliosat-3 project is supported by the fifth frame-work program of the European Commission under contract number NNK5-CT-2000-00322.

Sunsat

the new program for processing high resolution data of Meteosat-8

Rolf Kuhlemann and Annette Hammer

20.6.2005

Outline:

- Introduction
- Data base improvement
 - Wrong image information
 - Necessary geolocation
 - Satellite movement compensation
- Adapting the Heliosat-1 procedure
 - Formats
 - Parameters
 - Atmospheric correction
 - Errors caused by cloud shades
- The new program *Sunsat*
 - Structure
 - Headers and names
 - Usage
- Results

Introduction

A first step towards the implementation of the Heliosat-3 procedures has been the adaption of the “old” Heliosat-1 [1] software to the data of Meteosat-8 in VCS/XPIF format [2]. The development was focused on high resolution data in the visible wavelength range (HRV channel) with $1 * 1 \text{ km}^2$ spatial (Nadir) and 15 minutes temporal resolution.

Prior the description of the new program it is necessary to mention of the data base, some image failures and how to get around with them. Furthermore, it has been necessary to geolocate the data. Distortions and shifted images have been observed, and it is described how to compensate for these effects.

The next step has been the adaption of the “old” Heliosat-1 procedure and its features to the new type of data. An arising problem with shades, especially cloud shades and a way to solve this problem is described.

Finally, the structure, the properties, and the usage of the new program are presented.

Data base improvement: Wrong image information

The data base of raw images in Oldenburg was checked, in order to find those with missing segments and other disturbances. They have been extracted from the data base together with images shifted with respect to the majority of all images have been extracted from the data base. This has obviously reduced the data base, but not to critical amounts. Nevertheless, there have been 20 - 30 images each in July, August, and September for example.

Data base improvement: Necessary geolocation

It was found by projection of the received VCS-XPIF data on accurate maps of Europe, that the high resolution data of Meteosat-8 are distorted [3]. This investigation revealed, that an individual geolocation of many sites is necessary and that it is possible to correct for the found mistakes by modifying line- and column-offsets. Therefore, the new program includes options for additional offsets to recorrect the local geolocation (see chapter: The new program **Sunsat** - Usage). Site lists containing the found values has been generated [3].

Later, it was found that the detected distortions are a specific property of the VCS-XPIF data, generated by the receiving software of the company VCS. The original HRIT data, transmitted by EUMETSAT, contain only a few shifted images. Consequently, the switch of the whole data processing chain to these HRIT data is planned.

Data base improvement: Satellite movement compensation

A **colocation** (spatial match) of the high resolution images of Meteosat-8 was found to be necessary. Because the investigation of shifted images would have

been too slow, if applied to the subset of the whole of Europe, the subset of the Canary Islands has been used.

Tests with an old detection routine for determining back shift vectors, which was successfully used while processing Meteosat-7 data [4], failed, when applied to high resolution Meteosat-8 data. Therefore, it is planned to apply a different *back shift algorithm*, proposed by Lucien Wald [5]. These routines will be used for operational processing as well (ESA-project *ENVISOLAR*). For the moment, it is decided to leave the data base as it is, except some shifted images, detected visually and shifted back manually.

While looking on our images of the Canary Islands, a similar small movement between 8:45 and 9:00 has been found for many days. Too small and too common to remove these images, this has been the reason for an investigation of the temporal variability of the geolocation.

Ground albedo images of different slots and months have been compared. As this means an average of ground values at a certain pixel at a certain time the results have to be interpreted as systematic deviations between months or between slots. The strategy of the investigation was, to look on the coast lines after subtracting one image from the other. An (averaged) image movement produces coast line artefacts giving an idea of its extend. The “amount” was detected visually as the fraction of coast line pixels moved (times the distance moved).

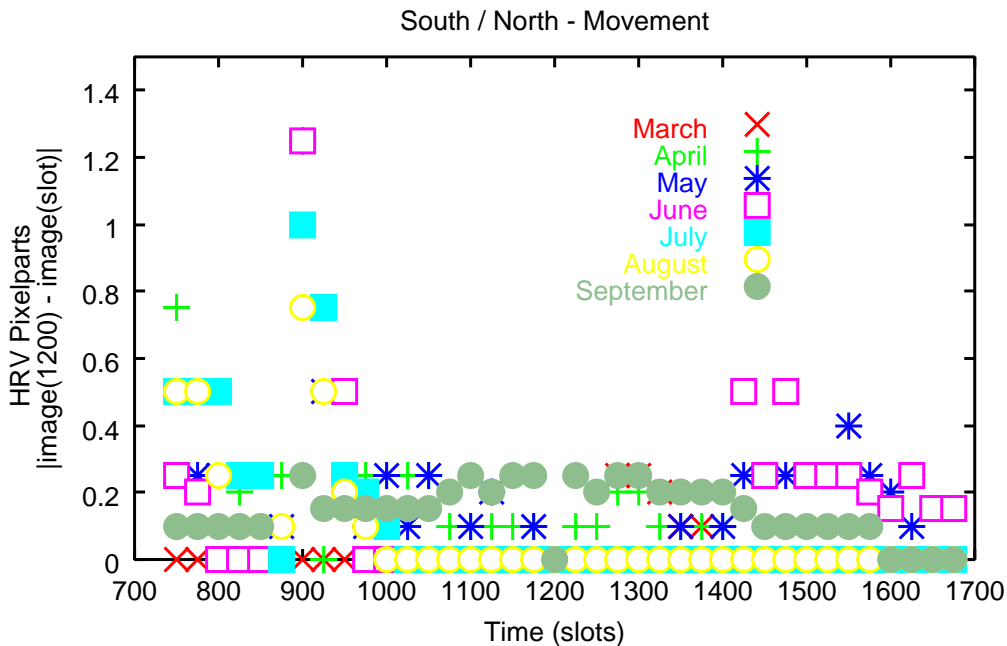


Figure 1: Temporal ground albedo shifts detected visually for Europe in comparison to the ground albedo of June (12:00).

Figure 1 confirms the observed shifts between 8:45 and 9:00 and that it reaches 1.2 pixels. One reason would be an according conduction of Meteosat-8 by EU-

METSAT, but for approving that, a more detailed analysis would be necessary. A comparison between months and different directions revealed shifts up to 1.5 pixels.

Altogether, these results show that satellite movement is recognizable, but not critical and, this is of importance, completely within the range, the planned *back shift algorithm* (3 pixels in one direction) is able to compensate.

Adapting the Heliosat-1 procedure: Formats

To process Meteosat-8 data, the “old” software code was modified in the way that it is able to process 2 byte data for each pixel, to read and use the header information of each image, and to write all generated images with similar headers. According to the fact that it has not been possible to write headers of the same length (256 bytes), all written images have headers with 260 bytes length, and the new program distinguishes between these types by recognizing the ending (XPIF, X260).

Adapting the Heliosat-1 procedure: Parameters

Within the Heliosat-1 procedure in its present form [6] there are some parameters to optimize and adapt to new satellite data. The first is the radiometer offset C_R to be determined for each channel of interest (here HRV, VIS006, VIS008). It was found to be the same for all three channels ($C_R = 51$).

For reasons of comparability the counts C are normalized to get reflectivities $\rho = (C - C_R)/(\cos(\Theta))$. With these reflectivities it is possible to determine the next parameter, the maximum cloud reflectivity ρ_c . According to its optimization within the *SoDa* project, it should be defined in the way that 96% of all counts are below this value [7]. The resulting value for all three channels of Meteosat-8 has been $\rho_c = 650$.

The *cloud index*, giving the attenuation of irradiance under clouds, is determined by $n = (\rho - \rho_g)/(\rho_c - \rho_g)$. ρ_g is the ground reflectivity of the earth surface. To get results of good quality, ρ_g images should be free of artefacts (cloud rests and shadows). ρ_g is generated by using the frequency distribution of all reflectivities ρ of a monthly slot at a certain pixel. Within such distributions ground reflection values ρ are assumed to accumulate around the value ρ_g and build up a land peak. Consequently, the half width σ_{ground} of such land peaks is used to determine ρ_g , where the parameter σ_{ground} has to be optimized. This optimization has been tried by minimizing the *bias* between calculated and measured global irradiances (Figure 2). This has been done for two *Clear Sky* models, one of the “old” Heliosat-1 method [6], and another with the SOLIS method, developed by Müller et al. within the Heliosat-3 project [8].

While the *rmse* remains stable with varying σ_{ground} , the *bias* increases with increasing σ_{ground} . The minimization of the *bias* ended up with such different values for the three months (April, May, June), that this “mathematical” optimization

failed.

Therefore, a visual determination of σ_{ground} has been applied and has given a value of $\sigma_{ground} = 23$. For such a qualitative optimization the amount of cloud rests should be as small as possible, but the iteration should not collapse in the way of producing a significant amount of “dark pixels” (see chapter: Adapting the Heliosat-1 procedure: Errors caused by cloud shades).

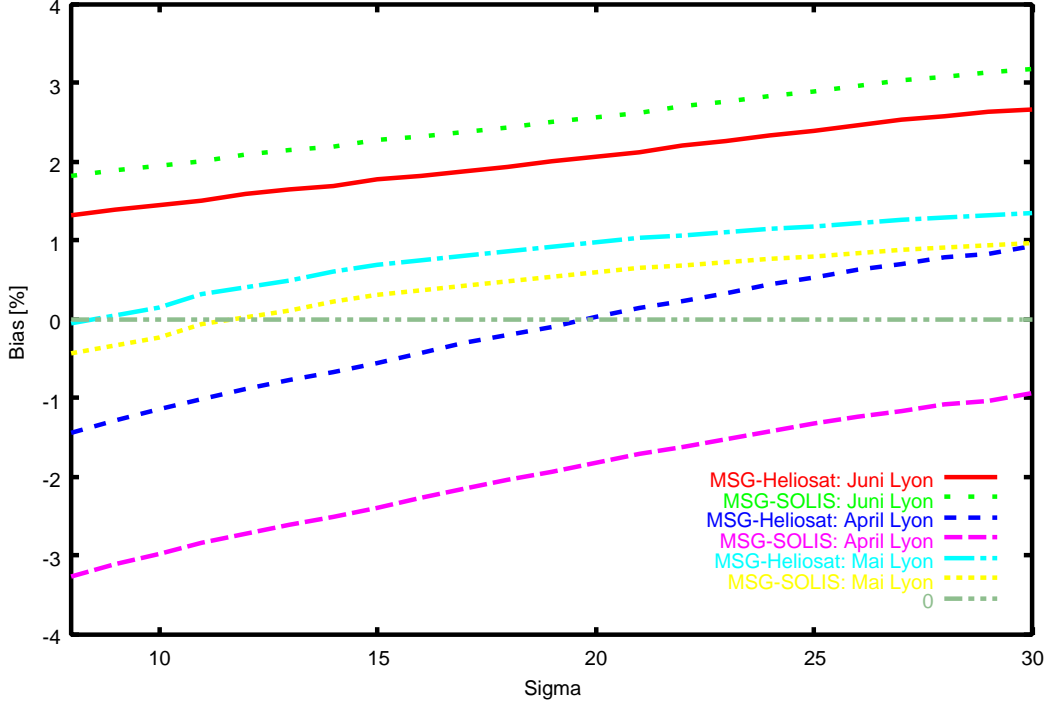


Figure 2: Bias between calculated and measured data of Vaulx-en-Velin for the months April, May, and June. Calculated data are derived with two different *Clear Sky* models (Heliosat-1, SOLIS).

Adapting the Heliosat-1 procedure: Atmospheric correction

To extend the angular validity of the procedure to large sun zenith angles a new atmospheric correction was developed for all visible channels, just like A. Hammer did it for data of Meteosat-7 [6]. To get the whole range for all three angles (sun zenith angle Θ , satellite zenith angle Φ , sun satellite angle Ψ) subsets of the equatorial region and Southern Africa were added to those of Europe and the Canary Islands.

By taking only ocean pixels into account, which are assumed to represent vanishing reflectance, the atmospheric backscatter was put in angle bins for all three angles and step by step parameterized.

$$C_{atm}(\Theta, \Phi, \Psi) = f_1(\Theta) * f_2(\Phi) * f_3(\Psi) = \frac{C - C_R}{\cos(\Theta)} \quad (1)$$

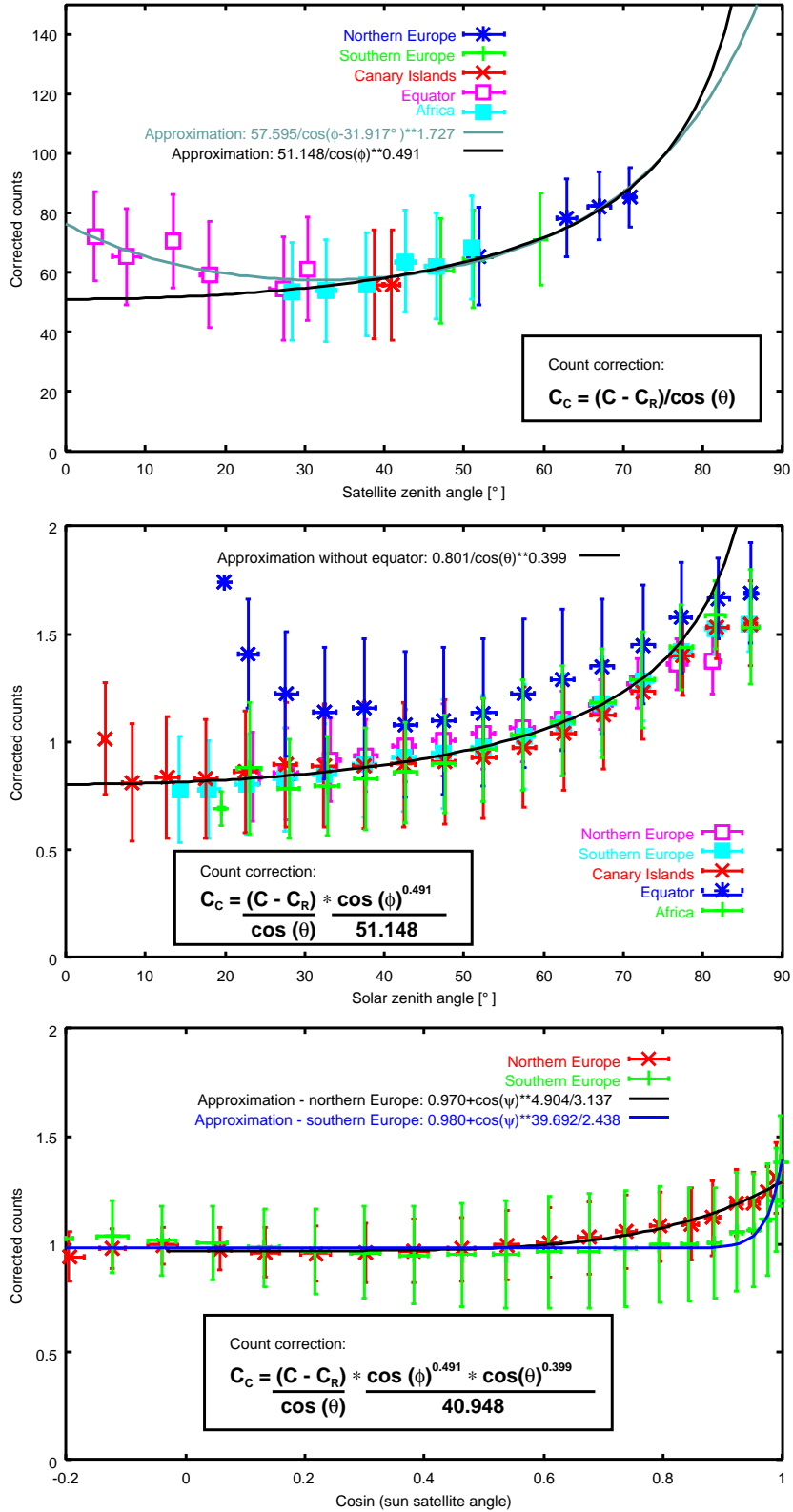


Figure 3: Step by step parameterization of the backscatter signal of the atmosphere and its dependency on the satellite zenith angle (top), the solar zenith angle (middle), and the sun-satellite angle (bottom). Every approximation has been done with the corrected counts of the previous steps.

Figure 3 gives as example the development of the atmospheric correction for high resolution data of Meteosat-8. It was found, that the data of the equatorial region are strongly influenced by total reflections of the ocean surface. The smaller satellite angle and solar zenith angle are, the stronger is this effect [9]. Therefore, the parameterization has been developed without equatorial data. After the approximation of the dependency of the satellite zenith angle (Figure 3 (top)), the counts, pre-corrected with the radiometer offset C_R and the cosin correction ensuring comparability, have been manipulated in the found way. The next angle dependency has been parameterized with the recorrected count of all former steps (Figure 3 (middle, bottom)).

The adaption of the Rayleigh-like dependency on the sun satellite angle, formerly used by Hammer et al. [6], failed. Furthermore, it has been necessary to distinguish between Northern and Southern Europe for the approximation of this dependency. The resulting structure of the atmospheric correction, developed here, is:

$$C_{corr.} = \frac{C - C_R}{\cos(\Theta)} - C_{atm}; \quad C_{atm} = \frac{a}{\cos(\Phi)^b * \cos(\Theta)^c} * \left(d + \frac{\cos(\Psi)^e}{f} \right) \quad (2)$$

Channel	a	b	c	d	e	f
HRV North	40.948	0.491	0.399	0.970	4.904	3.137
HRV South	40.948	0.491	0.399	0.980	39.692	2.438
VIS008 North	22.914	0.646	0.414	0.957	14.888	3.562
VIS008 South	22.914	0.646	0.414	1.028	13.235	4.811
VIS006 North	37.901	0.506	0.379	0.956	7.369	3.627
VIS006 South	37.901	0.506	0.379	1.021	14.014	8.491

Table 1: Coefficients of the atmospheric correction for different channels and regions.

The derived atmospheric correction has been included in the computer code together with a new maximum cloud reflectivity ($\rho_c = 580$), necessary for such calculations, if an atmospheric correction is applied.

Calculated global irradiances have been compared with ground measured data for Vaulx-en-Velin in April, May, and June 2004 as well as such calculations without an atmospheric correction. It was found, that the quality is not improved by using an atmospheric correction. Therefore, the atmospheric correction was omitted, because it lowers the calculation speed. Table 2 gives first validation results, generated by Elke Lorenz with 41 measuring stations in Germany. They belong to operational processing, which means, that the actual ground albedo is calculated with the last 30 days.

Satellite	Met-7	Met-7	Met-8	Met-8
Error	bias	rmse	bias	rmse
March (16.3.-)	-3.48	25.55	-5.03	22.39
April	-0.88	26.17	-3.52	20.90
May	-6.3	22.93	-4.67	19.35
June (-16.6.)	-3.38	22.28	-4.92	18.97

Table 2: *RMSE* (%) and *BIAS* (%) for validations between calculated irradiance data (hourly values) for Meteosat-7 and Meteosat-8 compared with ground measurements in Germany (41 stations).

Adapting the Heliosat-1 procedure: Errors caused by cloud shades

The physical reason for *dark pixels* within raw data and calculated ground albedos has been found to be shades, especially cloud shades. In contrast to Meteosat-7 the data of Meteosat-8 (HRV) is strongly contaminated with such effects due to their higher spatial resolution of 1 km * 1 km (Nadir).

To overcome this problem within the *Cloudy Sky* module a modified ground albedo algorithm was developed. It takes the increment of the ground albedo iteration into account. Assuming that the sequence of iterative steps is a monotone decreasing function without shade contamination, an increasing increment detects shades by a sudden increase of the step width. This type of detection avoids the input of fixed thresholds between ground and shade reflectances which would not be valid for all places and times.

To maintain the shade detection process a new parameter σ_{shade} is introduced, which gives the necessary enlargement of the increment. After the detection of a shade, the according grey value is omitted from the sequence.

Figure 4 shows, that the shade problem has been solved perfectly, although a different problem arises. With decreasing number of slot counts (suppressed shade values) the probability of cloud rests increases. This happens, if there are only cloud values left in the sequence of a slot.

As shade looks like a *Clear Sky* situation with dark ground albedo, although it is a *Cloudy Sky*, the next step is the construction of a sensible *cloud index* value for these cases. This is done in the way of a reconstruction by taking advantage of the used *Clear Sky* model. The used model within Heliosat-1 has been developed by Fontoynt et al. within the European project Satel-light [10]. Such a model determines a *clear sky index* for a given *cloud index*. Therefore, a shade value gives an according *clear sky index* and allows the assignment of a corresponding *cloud index*. Such a reconstruction conserves the statistical properties of the whole procedure.

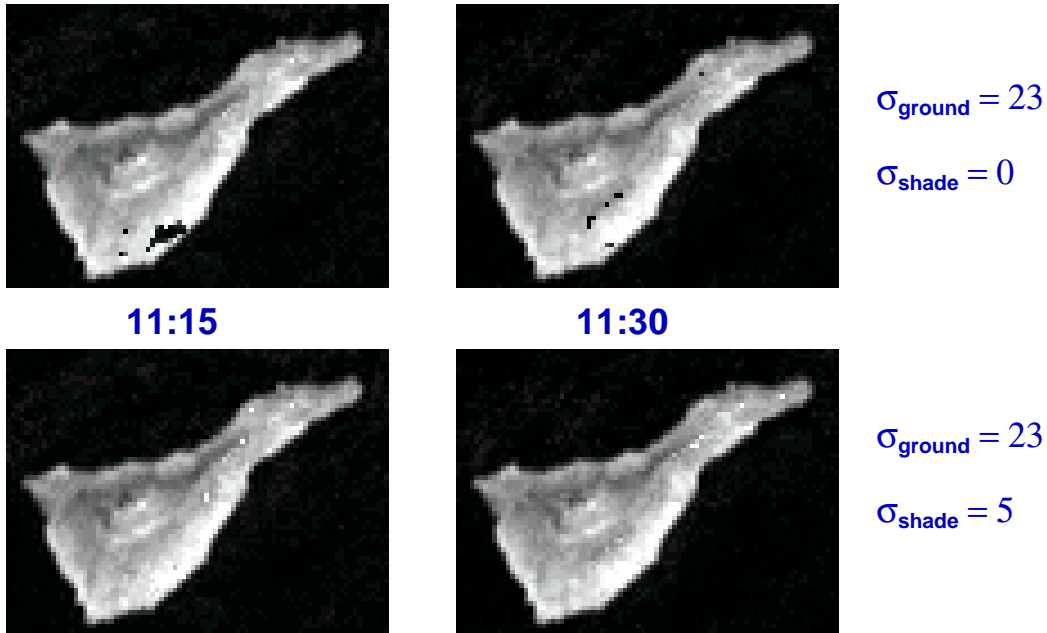


Figure 4: Calculated ground albedos of Tenerife for December 2004 and slots 11:15 and 11:30 using HRV data of Meteosat-8. Top images are generated without shade detection ($\sigma_{shade} = 0$) and bottom images with cloud detection ($\sigma_{shade} = 5$).

A comparison of calculated global irradiances with ground measured data allows the optimization of both parameters σ_{ground} and σ_{shade} . First results for Vaulx-en-Velin between March 2004 and January 2005 show, that the opportunity to reduce σ_{ground} improves the procedure significantly ($\Delta rmse > 1\%$).

It was found, that the best results are generated with values of $\sigma_{ground} = \sigma_{shade} = 1$. This means, that the procedure iterates the lowest available ground value beside clouds and shades. It seems, that systematic errors caused by a fixed value of ρ_c are compensated under these circumstances. Such an effect was already found by E. Lorenz within the ESA project ENVISOLAR.

Further validations for other sites in Europe and on the Canary Islands for all available HRV data (March 2004 - now) are ongoing.

Although it is not validated up to now, a modified algorithm for the calculation of the ground albedo is included in the new program **Sunsat**, containing routines which detect and suppress cloud shades (see chapter: The new program **Sunsat**: Usage).

New program **Sunsat**: Structure

The final version of the new program to generate ground albedo and *cloud index* values from data of Meteosat-8 has not only a new name, it is also reorganized in order to get an easier overview and a more comfortable program management.

While the main code is as short as possible, functions and algorithms are excluded and collected according to their character. The following list gives an overview:

- `info_new.fkt` (all header informations of the images)
- `msg_new.fkt` (*geosat*, *geomsg*, *EOT*, *coszen*, *timeoffset* - library of functions)
- `algo_new.fkt` (*cos_correction_new*, *ground_albedo*, *ground_albedo_shade* - library of algorithms)
- `msg_new.h` (header informations about functions and algorithms)
- `nrutil.h`, ... (numerical recipes)

New program **Sunsat**: Headers and names

The new program **Sunsat** is able to process data with headers of both 256 and 260 header length, even different types in one slot list are possible. It identifies this length by interpreting the format name “.XPIF” for original VCS/XPIF or “.X260” for selfproduced pseudo-XPIF data. According to this convention, original HRIT data transmitted by EUMETSAT and processed directly, have an “.X260” format. *Cloud index* images have still the old “.hel” name, ground albedos “.alb”.

New program **Sunsat**: Usage

The usage of the new program is similar to the past. A list of all images of a slot of a certain month and the paths for all images are needed. The necessary additional column- and line-offsets are determined by x and y (see site list in [3]). Because of the included cloud shade algorithm, it is possible to maintain the statistical parameters for the ground albedo and the cloud shade algorithm by options a and s.

The best results have been found with a ground albedo parameter $\sigma_{ground} = 23$ if cloud shade detection is switched off ($\sigma_{shade} = 0$). That’s why they are default values.

If the cloud shade algorithm is switched on, the program prints out some information about the amount and relation of the found shades compared with the amount of all pixels. Summarizing, the following options need to be fixed to start **Sunsat**:

- `-l slotlist`
- `-b image path`
- `-g ground albedo path`

- -c cloud index path
- -a σ_g (default: 23)
- -s σ_{shade} (default: 0 (no shade algorithm))
- -x additional column – offset
- -y additional line – offset

Results

With the new program **Sunsat** the Heliosat-1 procedure is adapted to data of Meteosat-8 (VCS/XPIF-format). All necessary parameters have been optimized, but a newly developed atmospheric correction did not gain improvements. Failures of the procedure when processing high resolution data are mainly caused by cloud shades. Therefore, the algorithm to iterate the ground albedo was modified and better results were reached.

It was found, that an accurate data base in terms of geolocation and colocation is necessary to process high resolution data.

References

- [1] C. Cano, J.M. Monget, M. Albuissou, H. Guillard, N. Regas, L. Wald: A method for the determination of the global solar radiation from meteorological satellite data. *Solar Energy* **37**, 31-39 (1986)
- [2] <http://rst.vcs.de/download/content/show/03142154113>
- [3] Heliosat-3 deliverable of Kuhlemann et al. (Geolocation of high resolution data of Meteosat-8 (VCS-XPIF format))
- [4] A. Hammer, D. Heinemann, C. Hoyer, E. Lorenz: Treatment of errors in METEOSAT derived cloud index images due to partial sensor failures or satellite displacements. *Fourth SoDa meeting report* Lyon (6 / 2001)
- [5] IEA standard quoted by Lucien Wald in personal communication
- [6] A. Hammer: Anwendungsspezifische Solarstrahlungsinformationen aus Meteosat-Daten, *Phd Thesis*, 56 (2000)
- [7] A. Hammer, D. Heinemann, C. Hoyer: Effect of Meteosat VIS Sensor Properties on Cloud Reflectivity *Third SoDa meeting report* Bern (1 / 2001)

- [8] Müller, R. W., Dagestad, K. F., Ineichen, P., Schroedter, M., Cros, S., Dumortier, D., Kuhlemann, R., Olseth, J. A., Piernavieja, C., Reise, C., Wald, L. and Heinemann, D.: Rethinking satellite based solar irradiance modelling - The SOLIS clear sky module. *Remote Sensing of the Environment* **91** 160 - 174 (2004)
- [9] see e.g.: F.M. Bréon, *Remote Sens. Environ.* **43**, 193-207 (1993)
- [10] M. Fontoynont et al.: *Satellight: A WWW server which provides high quality daylight and solar radiation data for Western and Central Europe*. 9th Conference on Satellite Meteorology and Oceanography, Paris 1998, 434-437.