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Use of OCA and APOLLO in Heliosat-4 method for the assessment of surface downwelling solar irradiance

Zhipeng Qu, Philippe Blanc, Mireille Lefèvre, Lucien Wald
MINES ParisTech, Centre for Energy and Processes, BP 207 – 06904, Sophia Antipolis, France
Philip Watts
European Organization for the Exploitation of Meteorological Satellites (EUMETSAT), Darmstadt, Germany
Marion Schroedter-Homscheidt, Gerhard Gesell, Lars Klueser
German Remote Sensing Data Center, German Aerospace Center (DLR), Postfach 1116, D-82234 Wessling, Germany

Abstract

We test two cloud products: Optimal Cloud Analysis (OCA) of EUMETSAT, and APOLLO from the German Aerospace Center (DLR), for the assessment of surface downwelling solar irradiance (SSI). Each product is input to the Heliosat-4 method, and the SSI estimates are compared to accurate measurements performed in the Baseline Radiation Network (BSRN). The performances obtained by the two products are compared. The overall performance of Heliosat-4 method by using different cloud products is given and conclusions on the benefit of each product for an operational Heliosat-4 are drawn.

1. INTRODUCTION

Satellite-based assessments of surface downwelling solar irradiance (SSI) are more and more used in the domain of solar energy. Performances are judged satisfactory for the time being. Nevertheless, requests for more accuracy are increasing, in particular in the assessment of the direct and diffuse components of the SSI. Attempting to reach these goals, a new direct method, called Heliosat-4 (Oumbe et al., 2009), is currently developed by the MINES ParisTech and the German Aerospace Center (DLR). This method is composed by two parts: a clear sky module based on the radiative transfer model (RTM) libRadtran, and a cloud-ground module using two-stream and delta-Eddington approximations and MODIS-derived ground albedo. Advanced products describing aerosols optical properties, and total column content in water vapor and ozone derived from meteorological satellites and recent Earth Observation missions are inputs to the Heliosat-4 method.

Among all the input products, cloud products are crucial for the assessment of SSI. Both EUMETSAT and DLR provide cloud physical parameter products derived from SEVIRI images with high spatial and temporal resolutions. These products are Optimal Cloud Analysis (OCA, Watts et al., 2011) of EUMETSAT (currently being operationally implemented) and APOLLO (AVHRR Processing scheme Over cLouds, Land and Ocean) product (Kriebel et al. 1989, 2003) of DLR. Both are potentially suitable for the assessment of SSI.

In this study, we will firstly describe the different characteristics of each product. Secondly, we will study means to integrate each product into the Heliosat-4 method in combination with the other products (aerosols, water vapor, ozone and ground albedo). Then, Heliosat-4 will be run for each product for a few stations pertaining to the Baseline Surface Radiation Network (BSRN) and accurately measuring the SSI. A comparison will be performed between the measurements and each series of estimates. Extensive statistic analysis as well as case studies will be performed in order to better understand the advantage and disadvantage of each product. The overall performance of Heliosat-4 method by using different cloud products will be given and conclusions on the benefit of each product for an operational Heliosat-4 will be drawn.

2. HELIOSAT-4 AND ITS INPUTS

A new method of assessment of SSI is being developed jointly by MINES ParisTech and DLR within MACC/MACC-II project. The objective is to supply information about global, diffuse and direct surface irradiance for use in various domains: solar energy, biomass, agriculture, human health, weather or climate.

The concept of the method Heliosat-4 is based on the separation of the calculation of the SSI in two parts (Eq. 1): irradiance of clear-sky with zero ground albedo, $I_c(\rho_g = 0)$, and the attenuation or enhance effects of the cloud and surface $f(cloud, \rho_g)$. Similarly, the operational implementation of Heliosat-4 is composed by two parts: a clear sky module based on the radiative transfer model libRadtran, and a cloud-ground module using two-stream and delta-Eddington approximations.

$$I = I_c(\rho_g = 0) * f(cloud, \rho_g) \qquad (1)$$

Within the MACC project, the clear-sky module, called McClear (Lefèvre et al., 2012), is composed of lookup tables based on RTM libRadtran and parameterization functions. The inputs to McClear are: aerosol properties (type, optical depth, and Angstrom coefficient), total water vapor column, total ozone column, and atmospheric profile. For the cloud-ground module, the inputs are the ground albedo and cloud properties (optical depth, cloud phase, water content and effective radius of cloud particles).

The Heliosat-4 method will operationally run within the MACC-II project from late 2013. The output of Heliosat-4 will be the global, direct and diffuse horizontal downwelling surface irradiance with a temporal resolution of 15 min and a spatial resolution of 3 km at nadir. The covered zone will be the field-of-view of the SEVIRI instrument aboard MSG.

3. THE CLOUD PRODUCTS

There are two cloud products, OCA of EUMETSAT and APOLLO of DLR, which derive from the MSG images with high temporal (15 min) and spatial resolution (3 km at nadir). The algorithms and data processing procedures are different between the two products. The available information about the cloud from these two products is also different. Table 1 shows the availability and characteristics of different cloud physical parameters for both products.

Parameters	APOLLO	OCA
Cloud optical depth (COD)	Range: 0-500 (minimal threshold 0.45)	Range: 0-250
Cloud layer	Single layer	Switch to two-layers in case of multilayer conditions
Cloud type	4 types: low, medium, high and thin cloud	No
Cloud classification	For fully covered pixels only: vertical extended, thin cloud, water cloud, multi-layer cloud, horizontally homogeneous cloud and the different compositions of these five classes	No
Cloud phase	Water cloud: low, medium and high cloud; Ice cloud: thin cloud.	One layer: explicitly (ice/water); Two-layers: upper layer – ice cloud; lower layer – water cloud
Cloud effective radius	No	One layer: for each cloudy pixel Two-layers: only for top layer
Cloud top temperature/pressure	For each fully covered pixel (temperature)	For each cloudy pixel, both layers if two layers (pressure)
Cloud coverage in %	For each cloudy pixel	Not at present stage
Cloud mask	Cloudy and clear over land,	Use EUMETSAT cloud mask

	ocean or snow/ice.	product CLM
Resolution	SEVIRI pixels (3 km at nadir), 15 min, day and night	SEVIRI pixels (3 km at nadir), 15 min, day time
Error estimation	No	All cloudy pixels

Table 1: Comparison between APOLLO and OCA.

In this study, we use the cloud optical depth and cloud phase for the calculation of SSI in Heliosat-4. For APOLLO, we use the cloud type to define the cloud phase. Among the four types of cloud in APOLLO, low, medium, high and thin cloud, the first three types are considered as water cloud and the last type, thin cloud, is considered as ice cloud. The thickest clouds are often high vertical clouds like *cumulonimbus* and are often covered by an ice top. However, the lower part of this cloud is often composed by water drops, and we consider that this lower part is the main factor for the attenuation of the solar irradiance. The thin cloud is often *cirrus* and will be considered as thin ice cloud. There is explicit information about the cloud phase for one layer condition in OCA. For two-layers situation, the upper layer is assumed to be ice cloud and the lower layer water cloud. In two-layers cases of OCA, the irradiance will be reduced by the combined optical effects of the two layers.

The cloud effective radius and water content are set as default values according to two cloud phases: effective radius of 20 µm, water content of 0.005 g/m^3 for ice cloud, 10 µm and 1.0 g/m^3 for water cloud.

4. VALIDATION

We have chosen four stations within the Baseline Surface Radiation Network (BSRN) for the validation (table 2). The BSRN stations measure global and direct surface solar irradiance every minute. The quality control is performed on each 1 min measurement. The validated 1-min data are then summarized to yield 15-min average SSI when at least 33% 1-min data are valid within the 15 min period.

Station	Country	Latitude	Longitude	Altitude (m)
Carpentras	France	44.0830°N	5.0590°E	100
Payerne	Switzerland	46.8150°N	6.9440°E	491
Sede Boqer	Israel	30.9050°N	34.7820°E	500
Tamanrasset	Algeria	22.7800°N	5.5100°E	1385

Table 2: tested BSRN stations.

Due to the difficulty of retrieving MSG data for the calculation of OCA, we have chosen the year 2008 but with selecting only one full day out of 16 days from 1st Jan as the validation period. Therefore, we have calculated the SSI for every 15 min for 23 days in 2008 in total.

The inputs parameters like aerosols properties, water vapor and ozone content are taken from the MACC reanalysis. MACC reanalysis is available every 3 h with a resolution of 1.125°. The MODIS BRDF/Albedo Product is used as the input of ground albedo. This product is available every 16 days and its spatial resolution is 5.6 km. OCA and APOLLO are used separately as the cloud product in combination with the other products (aerosols, water vapor, ozone and ground albedo).

The 15-min SSIs estimated by Heliosat-4 are compared to ground observations. The differences are synthesized by means of bias and root mean square error (RMSE).

Figure 1 shows the bias (left) and root mean square errors (RMSE, right) for the Heliosat-4 estimated global SSI. One can observe that the use of two different cloud products in Heliosat-4 gives different biases. It is not clear which one is better; the situation differs from one station to another. At Payerne, OCA offers a bias of 14 W/m², 17 W/m² smaller than that of APOLLO. Biases are similar for the other three stations. A deeper investigation with more stations is needed. It is believed that the performances in Payerne are due to the frequent presence of scatted cloud in this region. In terms of RMSE, OCA gives slightly better performance comparing to that of APOLLO.

Table 3 reports the bias, standard-deviation, RMSE, and correlation coefficient. One may observe that in terms of standard-deviation and correlation coefficient, OCA gives slightly better performance comparing to that of APOLLO, similar to the conclusion made for RMSE.

The performance of estimation of global horizontal irradiance of Heliosat-4 is similar to that reported by Beyer et al. (2009). Taking into account that we are dealing with summarization of 15 min less than 1 h and that the RMSE decreases when the summarization increases, we are confident that the RMSE for Heliosat-4 for summarization of 1 h should be similar or less than those of the existing methods.

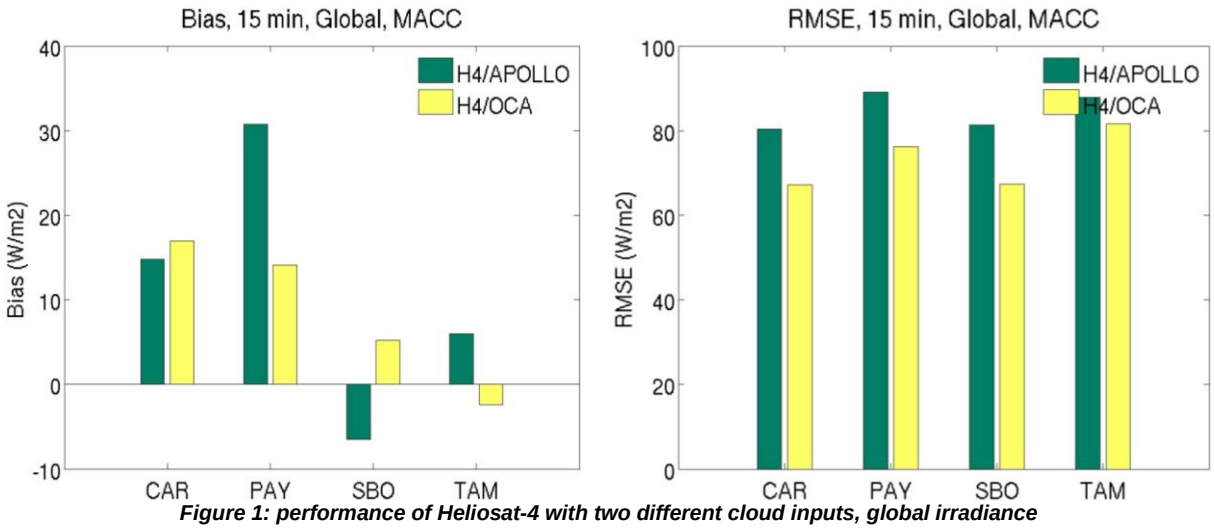


Figure 1: performance of Heliosat-4 with two different cloud inputs, global irradiance

Global	Mean (W/m²)	Bias (W/m²) APOLLO/OCA	Std (W/m²) APOLLO/OCA	RMSE (W/m²) APOLLO/OCA	CC APOLLO/OCA
Carpentras	345	15/17	79/65	80/67	0.95/0.96
Payerne	252	31/14	84/75	89/76	0.95/0.96
Sede Boqer	487	-6/5	81/67	81/67	0.96/0.97
Tamanrasset	551	6/-2	88/82	88/82	0.96/0.97

Table 3: performances of Heliosat-4 with APOLLO/OCA cloud products for global irradiance.

Figure 2 shows the bias (left) and RMSE (right) for the direct horizontal irradiance (DHI). For Carpentras and Payerne, the biases are very small with APOLLO, and much smaller than with OCA. This is contrary to the case of GHI. At Sede Boqer, OCA and APOLLO offer similar bias, while at Tamanrasset, OCA performs better. In terms of RMSE, OCA exhibits less or similar RMSE than APOLLO.

In table 4, one can observe that the bias is generally small except Sede Boqer. In terms of standard-deviation and correlation coefficient, the conclusion is similar to that of RMSE with slightly higher performance by using OCA except for the station Payerne. The RMSE in relative values are around 30 to 40% (RMSE divided by the corresponding mean value) which demonstrate satisfactory performance comparing to the existing methods.

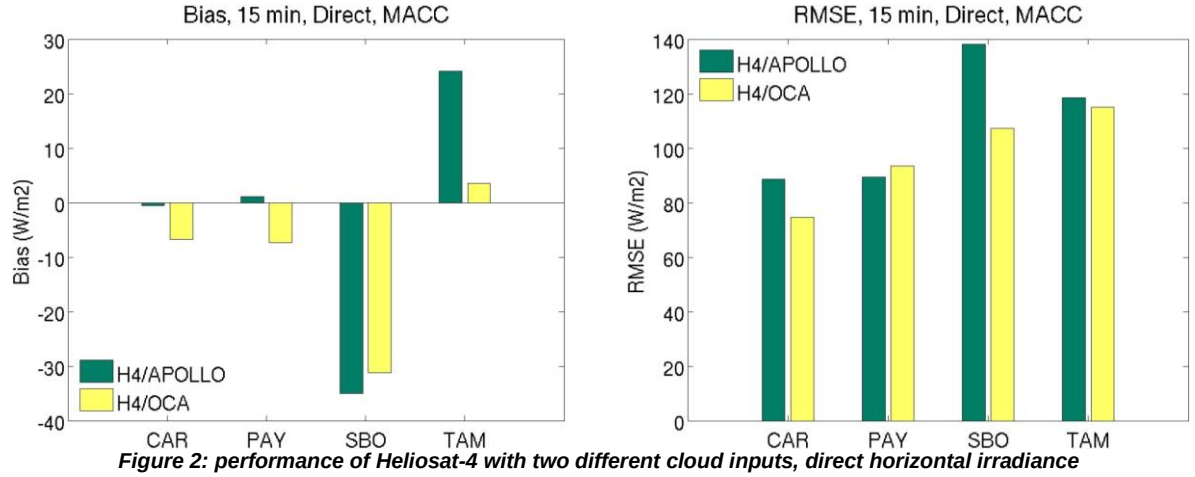


Figure 2: performance of Heliosat-4 with two different cloud inputs, direct horizontal irradiance

Direct	Mean (W/m²)	Bias (W/m²) APOLLO/OCA	Std (W/m²) APOLLO/OCA	RMSE (W/m²) APOLLO/OCA	CC APOLLO/OCA
Carpentras	209	-1/-7	89/74	89/75	0.92/0.94
Payerne	206	1/-7	89/93	89/93	0.84/0.84
Sede Boqer	345	-35/-31	134/103	138/107	0.81/0.86
Tamanrasset	367	24/4	116/115	119/115	0.89/0.89

Table 4: performances of Heliosat-4 with APOLLO/OCA cloud products for direct horizontal irradiance.

5. CASE STUDY

5.1. Very thin cloud detection

Within the 23 tested days, there are several cases for the stations Carpentras and Payerne where the detections of very thin clouds are different between OCA and APOLLO. One case is shown in figure 3 for the 28th January 2008 for Payerne. The calculated direct irradiances (red and black solid lines) are in steps of 15 min. The ground observation is shown in step of one minute (blue line) in order to better analyze the situation.

Between 10:00 and 12:00, around 12:30 and after 13:30, the ground measurements of direct irradiance show variation and these measurements are less than the clear-sky values (dashed red line, overlapped by black line). This indicates the presence of very thin clouds, probably *cirrus*. It seems that APOLLO has well detected the presence of these thin clouds, however, the estimated the cloud optical depth is too high (0.45, the minimal threshold of COD in APOLLO). The consequence is the underestimation of the direct irradiance by APOLLO. On the contrary, the information from OCA indicates that most of the instants for the same day are clear-sky instants. This is wrong but induces less error, in terms of bias and RMSE than APOLLO.

Figure 4 shows the COD estimated by APOLLO (left) and OCA (right) for 10:15 (UTC+0), 28th January 2008 for the window centered on Payerne (49x49 pixels). For APOLLO, the southern part of the window is entirely covered by clouds with low COD (dark blue). For OCA, the clouds are more scattered. The center pixel (line 25, column 25) which covers the station Payerne was under clear-sky according to OCA, and under cloudy sky according to APOLLO.

One should note that OCA does not produce directly cloud mask. It uses the EUMETSAT cloud mask product CLM. If the CLM classifies one pixel in cloudy situation, then the OCA algorithm will proceed to calculate the cloud properties; if not, the pixel will be considered as clear-sky.

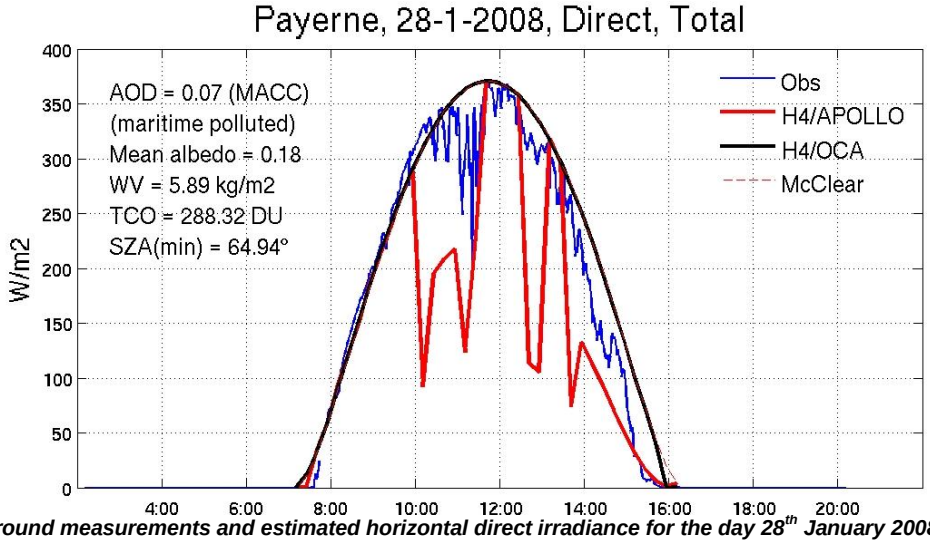


Figure 3: ground measurements and estimated horizontal direct irradiance for the day 28th January 2008, Payerne

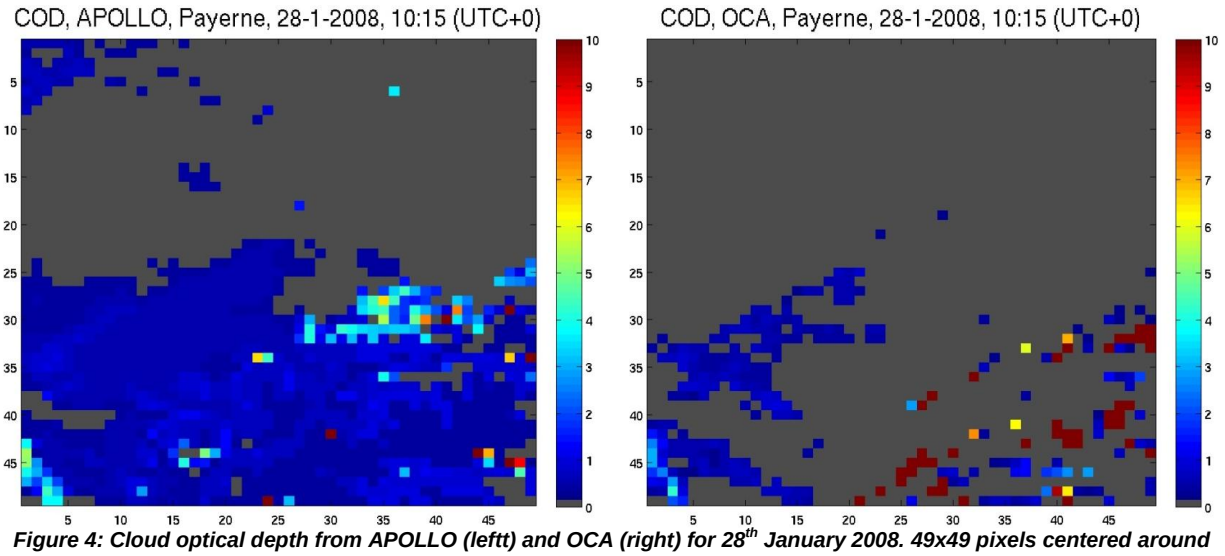


Figure 4: Cloud optical depth from APOLLO (leftt) and OCA (right) for 28th January 2008. 49x49 pixels centered around the station Payerne (position: line 25, column 25)

5.2. Ground/Cloud confusion

Confusion may occur between the ground and cloud for APOLLO. Figure 5 shows the comparison between observed data and the estimated direct irradiances for 3rd January 2008 at Sede Boqer. According to the measurement in blue line, it should be under clear-sky between 9:00 and 10:00 (UTC+0). The observed direct irradiance does not show large variation and the values are slightly greater than the calculated clear-sky values probably due to the errors in AOD value. By using OCA, the calculated direct irradiance, which is under clear-sky, is quite close to the observation. However, we obtained the irradiance close to zero with APOLLO due to its estimated COD of around 5.

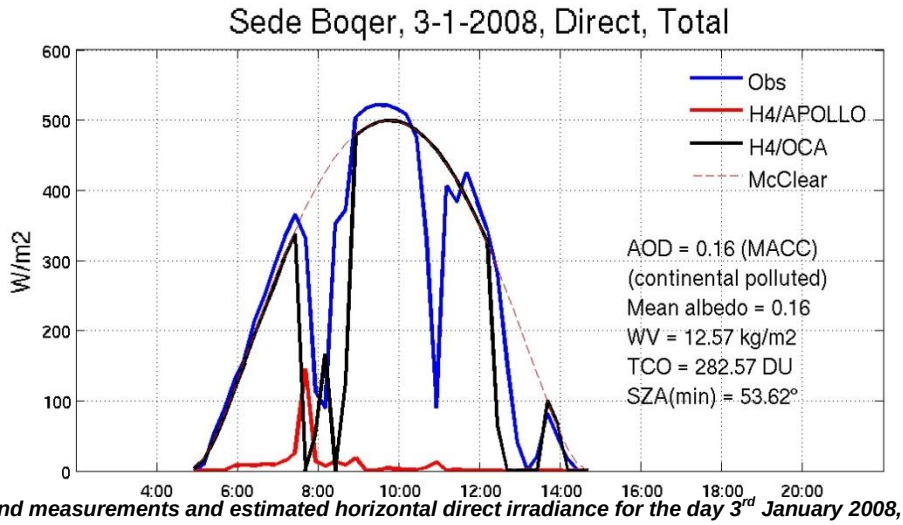


Figure 5: ground measurements and estimated horizontal direct irradiance for the day 3rd January 2008, Sede Boqer

Figure 6 shows the estimated COD values by APOLLO and OCA for the 49x49 pixels centered on Sede Boqer. Several similar structures of the distribution of cloud can be observed between the two cloud products. However, we can observe a large difference for the region in the centre-left: with clear-sky for OCA (grey color) and with COD larger than 5 for APOLLO (green and yellow). Therefore, there is probably a wrong classification of clear-sky and cloudy sky by APOLLO in this special case (winter, high ground albedo, high solar zenithal angle).

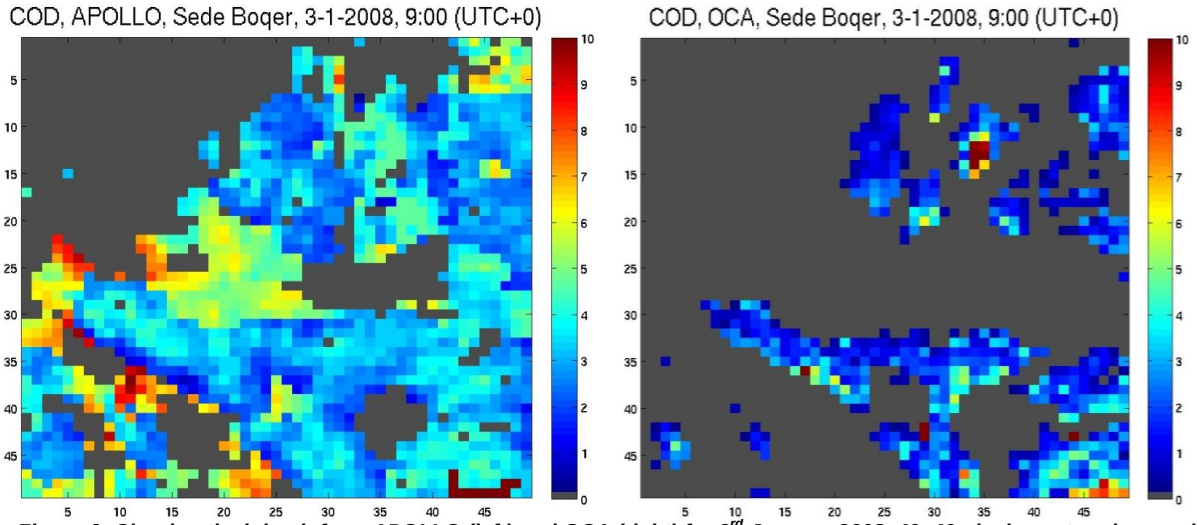


Figure 6: Cloud optical depth from APOLLO (left) and OCA (right) for 3rd January 2008. 49x49 pixels centered around the station Sede Boqer (position: line 25, column 25)

6. CONCLUSION

The cloud products OCA and APOLLO are both suitable for the use of estimation of SSI in Heliosat-4 method. The statistics for the sampling days and the chosen stations show satisfactory performances, especially for the estimation of direct irradiance.

In terms of RMSE, OCA show slightly better results for the concerning days. In terms of bias, it is not clear which one is better as the situation depends upon the station.

We have observed sometimes disagreements for the detection of very thin cloud between APOLLO and OCA. APOLLO indicates the presence of thin cloud with COD of 0.45 whereas OCA tends to indicate clear-sky. The actual situation seems to be in-between: very thin clouds with COD lower than 0.45.

For Sede Boqer in the winter, APOLLO tends to generate false alarms for the presence of cloud, likely due to the high ground albedo, low surface temperature and high solar zenithal angle.

7. ACKNOWLEDGMENTS

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