SolarPACES 2013

APOLLO Cloud Product Statistics

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Abstract

In order to assess the potential electricity production of a solar plant, industry usually uses long term time series of irradiation data. In addition to this, it is possible to obtain from long term satellite images a statistical description of the clouds in the zone of interest. As the clouds are one of the main influencing parameters to the solar irradiation, this additional information can be very valuable to understand location-dependent characteristics when selecting a solar generator's location and to decide on the type of technology most appropriate for the site. The APOLLO (AVHRR Processing scheme Over cLouds Land and Ocean, originally developed for the AVHRR instrument) methodology delivers cloud mask, cloud classification, cloud optical depth , and cloud top temperature as cloud physical parameters for all MSG (Meteosat Second Generation) SEVIRI (Spinning Enhanced Visible and InfraRed Imager) pixels with a temporal resolution of 15 minutes during daytime since 1st February 2004. Based on a long term result of APOLLO at a given point, we introduce a new use of this data, the APOLLO Cloud Product Statistics, to determine the typical cloud situations and spatio-temporal patterns at the location of interest. Together with state of the art solar irradiation estimations, these statistical results can be used to determine several important factors for the choice of the best suited solar technology to use.

In the main section, the statistics at the pixel location and in a 49x49 pixel zone around the point are described for a one year time series. Examples of the use of these statistical results are presented to better understand the type of sky patterns at the location.

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1. Introduction

In a preliminary study for finding the best location for a future solar plant over a large area, it is common to use solar irradiation maps of the GHI (Global Horizontal Irradiation) and DNI (Direct Normal Irradiation) annual average. These maps are used in GIS (Geographic Information System) software with additional land data (altitude, slope, land use, utilities and roads) to determine this best location from multiple criteria. As the clouds are one of the main influencing parameter to solar irradiation, the knowledge of the typical cloud situations in one location can be valuable additional information to differentiate between two locations with a similar ranking in the GIS analysis.

The assessment of the future electricity production of a solar plant project is made using long term irradiation time series. These time series are produced from satellite irradiation data which cannot represent correctly the intra hourly high frequency irradiation changes. The MSG satellite takes a picture every 15 minutes with a pixel size of 3x3 km² at its best. The derived irradiation time series from the satellite images are thus not very representative for time steps of less than one hour. A location with a high DNI maybe not suitable for a given solar technology when rapid variations of irradiation are frequent due to low altitude scattered cumulus in the zone.

The simple APOLLO [1, 2] statistics give the percentage of clear, cloudy and snowy cases at the location. The cloud type distinguishes between optically thick water/mixed phase clouds blocking all direct irradiance and optically thin ice clouds allowing some direct irradiance to the ground. The cloud type percentage of cases and the average cloud type evolution during the days are also computed. This information helps in determining the type of solar technology to use and if there are typical patterns during the day (clouds in the afternoon in summer for instance).

The analysis of a 49x49 pixels zone around the point leads to the understanding of the compactness of the cloudy situations, overcast situation or scattered, broken and isolated clouds. Finally, the analysis reveals also the distribution of the cloudy periods, of the cloud type periods and of the ramps during the day (changes from cloudy to clear and vice versa) up to a temporal resolution of 15 minutes.

2. The APOLLO methodology at a glance

The APOLLO methodology uses multiple spectral channels of the METEOSAT Second Generation satellite (MSG) to discriminate between different cloud types as shown in Figure 1 and Figure 2.

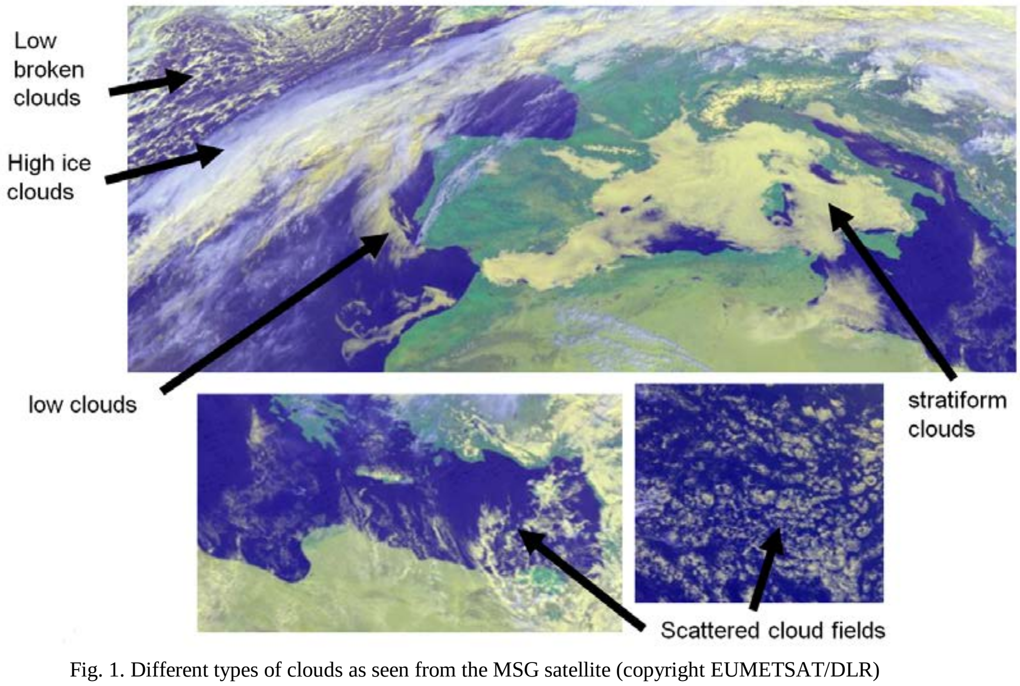

Fig. 1. Different types of clouds as seen from the MSG satellite (copyright EUMETSAT/DLR)

Fig. 2. Water/mixed phase clouds (left) and thin ice clouds (right), as seen from the ground (Karlsruher Wolkenatlas, copyright B. Mühr)

The APOLLO methodology delivers cloud mask, cloud classification, cloud optical depth, and cloud top temperature as cloud physical parameters for each MSG SEVIRI pixel in a temporal resolution of 15 minutes during daytime, for the period 1st February 2004 onwards – currently until the end of 2012 (8 years). The covered zone is [60°N,60°S,60°E,60W], with a resolution of 3x3 km² at the nadir of the satellite [0°, 0°]. This resolution is about 4x5 km² to 5x6 km² in Europe. The following parameters are computed and stored:

- Cloud mask and Snow
- Cloud coverage (0-100%)
- Cloud type (low, medium, high level water/mixed phase clouds; thin ice clouds)
- Cloud optical depth, Cloud top temperature

Additionally, a cloud classification scheme delivers information on:

- Vertically extended cold, very thick cloud-layers
- Thin clouds, warm and thick water clouds
- Multi-layer clouds, stratiform clouds

3. Statistics delivered by the APOLLO Cloud Product Statistics service

3.1. Cloud mask

The cloud mask number distribution in Table 1 shows that for the Ulm (Germany) location pixel, the weather is cloudy 77% of the time in 2010. Any solar installation system installed there needs to use effectively the irradiation diffuse component.

Table 1. Cloud mask number distribution in Ulm (Germany) for year 2010.

Cloud mask	% of all cases
Clear	22
Snow	1
Cloudy	77

3.2. Cloud type

The cloud type can also be represented as a global number distribution for all the time slots, Table 2, or as a 2D histogram showing the changes in cloud type as a function of the hour of the day, Figure 3.

In Ulm (Germany), 35% of the day time, there are medium height water clouds. The more elaborated 2D histogram shows also that the medium height water clouds are predominant. In addition it shows that the clear sky periods, were the irradiation will be at its relative maximum, are occurring more often at the beginning of the morning or at the end of the day where their frequency increases up to 35% from the 22% average.

Table 2. Cloud type number distribution in Ulm (Germany) for year 2010.

Cloud type	% of all cases
Clear	22
Low height water clouds	11
Medium height water clouds	35
High water clouds	12
High thin ice clouds	20

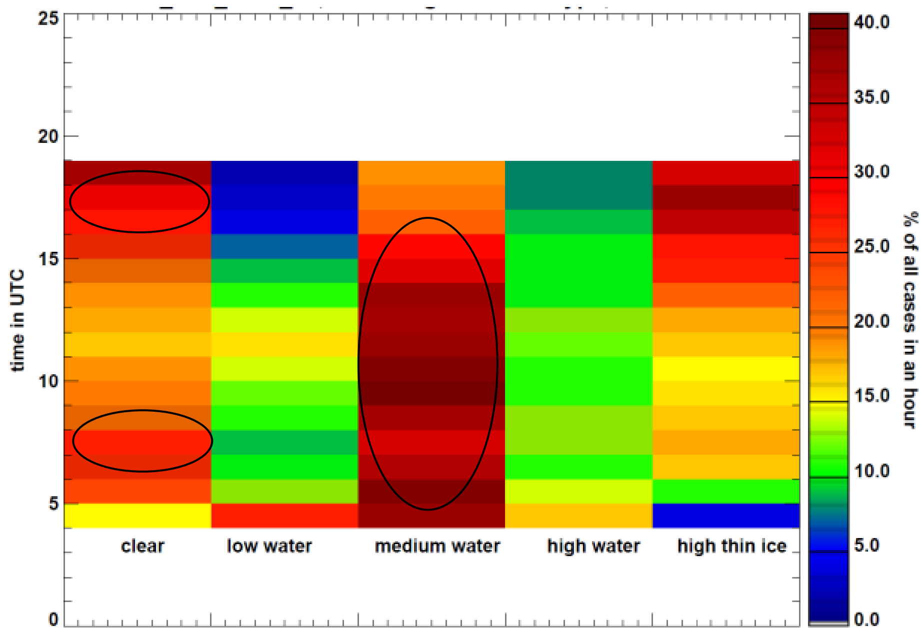

Fig. 3. Cloud type daily histogram in Ulm (Germany) for year 2010

3.3. Cloud overcast type

With the computed APOLLO data at the pixel location of interest, it is possible to classify the cloud overcast type and use it for instance to optimize a PV (Photo Voltaic) panel tilt angle or to give additional information for DNI dependant solar installations.

Armstrong et al. [3] shows that the optimum tilt angle (OTA) is a function of latitude in cloud free regions of the sun belt with dominating DNI and that in regions where the diffuse part dominates (> 45°N) the OTA is smaller. OTA becomes a function of latitude, frequency of clouds and their type.

With a classification into: clear, bright overcast, dark overcast and partly cloudy.

- clear (1) = at least 90% cloud free pixels; a clear pixel is defined as having max 10% cloud coverage.
- bright overcast (2) = more than 50% of cloudy pixels, but at least 20% of them are thin ice clouds only
- dark overcast (3) = more than 50% of cloudy pixels, but more than 80% of them are not thin ice clouds
- partly cloudy (4) = the rest

For Cologne (Germany) and Almeria (Spain), the statistics are shown Table 3.

Table 3. Cloud overcast type number distribution in Cologne (Germany) and Almeria (Spain) for year 2009.

Cloud type	Cologne - % of all cases	Almeria - % of all cases
Clear	12	34
Bright overcast	11	7
Dark overcast	30	13
Partly cloudy	47	46

In Cologne, the dark and bright overcast situations where the diffuse component of the irradiation is predominant represent 41% of the cases. The OTA for PV panels will thus be relatively small in the Germany location.

In Almeria, where there are CSP (Concentrated Solar Power) plants relying on DNI, one can also verify that - besides frequent clear sky conditions - there are only 8% of situations of bright overcast (high thin ice clouds). This is a typical situation with a sharp decrease of the DNI due to the scattering of the direct irradiation (and the increase of apparent the sun disk angle), even though there is no significant decrease of the GHI.

3.4. Cloud scatteredness

The analysis is extended further in a 49x49 pixel window around the location of interest. In this window, several values are computed, most interestingly the number of cloud elements and the clouds shape complexity from the fractal box counting dimension. This fractal box counting dimension represent the complexity of the clouds shape and evolves from zero (a point) through one (a line) to two (an area). In most cases, it lies between one and two if the cloudy pixels clusters in the window are several pixels wide. Specific combinations of these two parameters can be used to define a cloud compactness indicator and are summarized in Table 4.

Table 4. Cloud compactness indicator from fractal box dimension and number of cloud elements in the 49x49 pixel window

Fractal box dimension	Nb of cloud elements	Cloud compactness indicator
2	1	Overcast
1.7 to 1.9	<=5	Few large clouds
1.8 to 2	>5	Broken clouds
0 to 1.7	<=5	Isolated clouds
0.5 to 1.8	>5	Scattered clouds

With these elements, a 2D histogram (for the cloudy time slots only) is plotted which gives a global information on the cloud cover at the location when clouds are present in the zone.

Figure 4 shows two examples of the results, the first one for Cologne (Germany) and the second one for Almeria (Spain). The horizontal axis shows the number of clouds in the 49x49 pixel zone and the vertical axis shows the fractal box counting dimension. The color represents the number of days for each situation in percents of the cloudy days for the period.

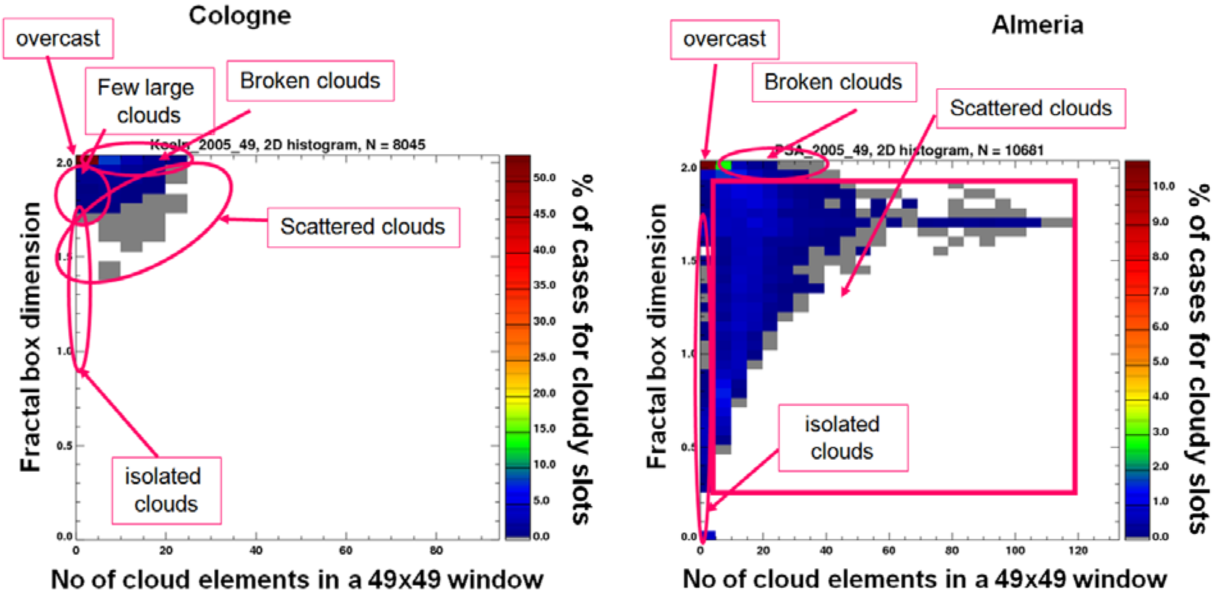

Fig. 4. Fractal box dimension and No of cloud elements 2D histogram in Cologne (Germany) (left) and Almeria (Spain) (right) for year 2005

It is clearly visible that in Cologne, the cloudy days are mostly overcast or with a few large clouds or broken clouds. In Almeria, the scattered clouds or isolated clouds skies are more frequent. For the scattered cloud cases, the consequences on the PV or CSP systems can be multiple. The overshooting of the GHI [4] can lead to ramps in irradiance within seconds. For a PV system, this will move the power converter operation mode outside optimum efficiency range and lead to a reduction in system lifetime. For a CSP system, the rapid changes in direct irradiance will have non-linear effects in heat transfer fluids, creating difficulties to operate the plant in a very efficient manner.

An extreme example of such a situation is illustrated in Nairobi (Kenya). Fig. 5 shows on the left side a Google Earth image of the typical small low level cumulus present nearly daily in this area. The yellow square represents the size of the MSG pixel in this area. In the same figure, on the right side, a 2 minutes frequency daily GHI evolution is shown. The blue curve is the satellite data, the green curve is the results from the ground station measurements and the black line is the clear sky GHI. The satellite irradiation is very close to the measured irradiation for the continuous clear sky period in the middle of the afternoon. It is also clear that the satellite data cannot represent the numerous and extremely fast irradiation variations during the rest of the day. There are multiple occurrences of GHI overshooting above the clear sky value.

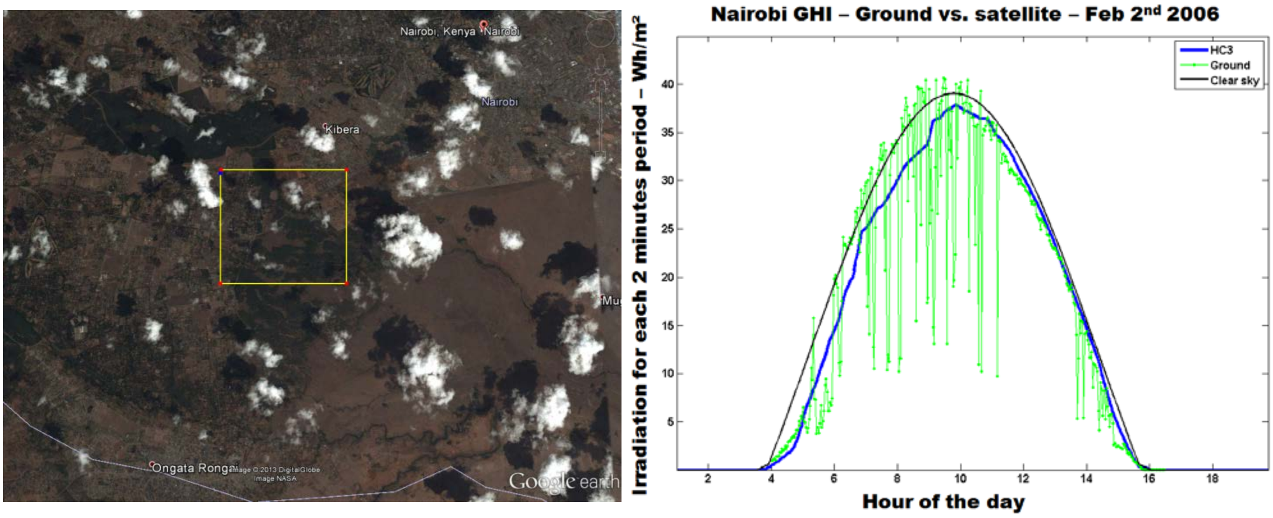

Fig. 5. Typical cumulus clouds in Nairobi (left) – Ground measured GHI and satellite GHI in Nairobi for Feb. 2nd 2006 (right)

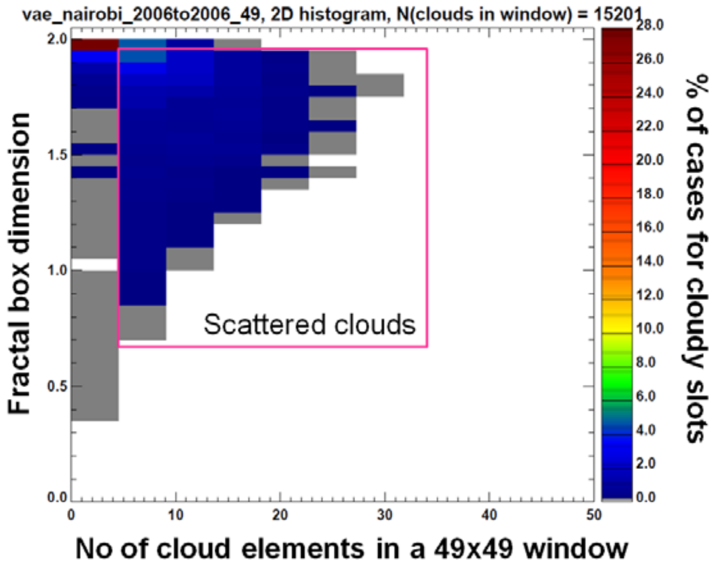

Fig. 6. Fractal box dimension and No of cloud elements 2D histogram in Nairobi for year 2006

The APOLLO statistics are telling that the zone is cloudy 60% of the day time. There are many low/medium height clouds in the morning (typically cumulus clouds) while during the day it gets less cloudy. The compactness plot in Figure 6 shows a cumulative large percentage of cases in the scattered clouds area zone. In addition to this, another statistic measures the duration of the cloudy periods for each type of cloud. For the low level water clouds (cumulus without the presence of long-term stratus in the lower layers), 72% of the cloud duration period are lower than 1 hour and 40% less than 15 minutes. All this tends to confirm the presence of many low level clouds with a high scatter and it fits to the overshooting irradiances due to reflections at the side of cloud elements and the fast change from low to high and back to low irradiances.

3.5. Ramps

In the statistics a ramp is defined as a change from cloudy to clear and vice versa in the cloud mask at the pixel location, from one time slot to the next. The distribution of the number of ramps per days is an important parameter to consider in the design of a CSP system. A day with a large number of ramps may cause system operation issues and it is thus important to know if this occurs often.

Figure 7 is showing the distribution of the number of ramps per day in 2005 for Cologne (Germany - 1283 ramps in total for the 365 days period) and Almeria (Spain – 1081 ramps in total for the 365 days period). In Cologne, only 10% of the days have no ramps at all versus 33% of the days in Almeria.

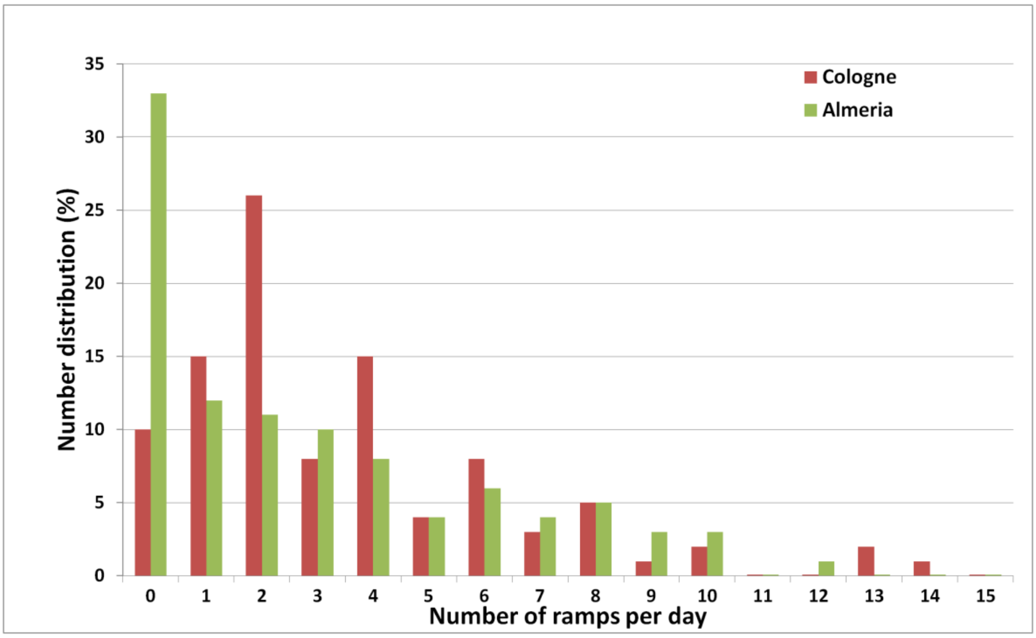

Fig. 7. Number distribution of the Nb of ramps per day in Cologne (Germany) and Almeria (Spain) for year 2005

4. Testing procedure and future Web service

Currently, a testing phase of the APOLLO Cloud Product Statistics service is ongoing on several stakeholders' solar plants sites, for PV and CSP installations. At the end of this phase, a guideline document on how to use the statistics in order to complement the information from the satellite irradiation time series will be produced. Some further statistics will be also added in answer to the stakeholder requests, like the number distribution of the clouds optical depth.

After this test phase, a Web service for delivering the statistics for any pixel of the MSG covered zone will be put in place and accessible through the SoDa web site (www.soda-is.com).

Acknowledgements

The authors thank ESA for its support under the contract 4000107680/13/I-AM, Expansion of the market for EO Based Information Services in waste management, renewable energy and ecosystem services assessment.

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