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AN OPERATIONAL TOOL FOR THE FINE-SCALE MAPPING OF THE INCIDENT SOLAR RADIATION USING SATELLITE IMAGES : THE HELIOSAT STATION

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ABSTRACT

An operational tool for the fine-scale mapping of the incident solar radiation is presented. It makes use of meteorological satellite images to produce accurate maps of global radiation. Satellite data are directly received by a cheap HF receiver and processed into a personal computer IBM-PC, using the already known Heliosat method. The first prototype was realised in 1985. Now a Heliosat station is routinely operated by Agence Française pour la Maitrise de l'Energie since January 1987.

1. INTRODUCTION

The density of the radiation measurement network at ground level in well-covered countries is still low and the average distance between stations is around 150-200 km. This is not sufficiently refined to take into account smaller scale variations which are important for the use of solar energy. In other parts of the world, the networks are even more sparse and particularly in countries where solar energy is sorely needed, as Africa.

On the other hand, meteorological geostationary satellites provide images of cloud fields over the whole surface of the Earth, usually in two spectral ranges : the visible and the thermal infrared, with a ground resolution of 1 km to 10 km depending on the instrument and the latitude of measurement. The time interval of these observations varies between 30 minutes and 3 hours.

Proper processing of these satellite data provides a wealth of information useful in the production of solar atlases, particularly for those areas where no traditional observations are available. But these satellite data also make it possible to investigate spatially small-scale variations of available solar energy, knowledge of which is needed for planning purposes.

A great number of studies clearly demonstrate that satellite data can be used succesfully for mapping both the global radiation at ground level and the cloud coverage over very large areas such as continents with spatial resolution of about 5 to 30 km and with an accuracy better than 10% of the incident radiation (Grüter et al.[6], Möser and Raschke[9], Tarpley[11], Gautier et al.[5], Cano et al.[1], Diabaté et al.[3], Michaud-Regas[7], Möser and Raschke[10]).

This research phase has been followed by an operational one for the routine production of global radiation maps or derived data (cloud coverage, albedo) throughout the world. The first effort reported was by Gautier et al.[5] who mapped the hourly global irradiation during three months. Now many works are in progress for much longer periods. For example, the Centre de Télédétection et d'Analyse des Milieux Naturels (CTAMN) de l'Ecole Nationale Supérieure des Mines de Paris (ENSMP) and the French Meteorological Office undertook their routine in 1983 and the German Meteorological Office in 1984.

However such routines are mostly operated within meteorological organizations with large computing means and to our opinion are not suitable for use and

operation by the people involved in the solar energy business. One of the purposes of the Heliosat program of CTAMN/ENSMP was to define an operational tool for routine production of radiation maps to fill this gap. Since it has been shown (Grüter et al.[6], Cano et al.[1]) that besides their use in solar climatology such maps are of great interest in various domains ranging from solar building architecture to agroclimatology, some specifications were drawn to meet these goals. This tool must be cheap, very simple, easy to use and to maintain. It also must comprise a direct reception for Earth observing geostationary satellites (Meteosat, GMS, GOES). The conversion of satellite data into global radiation maps must be accurate. It must only require satellite data and must not demand too much computing-time. This real-time system must also provide some capacities in image processing color display and print-outs.

This tool has been realized and is commercially now available. It is called the Heliosat station. After careful examination of the published methods for the proceessing of the satellite data, the method of Cano et al.[1] was choosen and slightly modified to become the Heliosat method (Diabaté et al.[3]). Technical review of the widespread hardware (reception system, computer, graphics means) and of their cost both in purchase and in maintenance was made to select the components of the system.

Therefore the Heliosat station comprises :

- a software to convert satellite data into maps of global radation,
- a software providing some features in image processing,
- a HF receiver with antenna to receive analog satellite data (WEFAX format),
- a personal computer, such as an IBM-PC
- a satellite signal digitizing board to go into the PC,
- a PC graphic board to display color maps.

These components are now briefly described taking into account that only the software and the digitizing board were designed by CTAMN.

2. DESCRIPTION OF THE HELIOSAT METHOD

The Heliosat method has been already described (Diabaté et al.[3]), so only a brief description of it is presented here.

The basic remote sensing data are taken from any geostationary satellite observations in the visible spectral range. Once received and stored onto the computer harddisk, a satellite image is pre-processed using geometric correction with landmark correlation, noise filtering, and normalization of digital counts by the spectral irradiance which would be measured by the sensor after it has been reflected on an horizontal plane located at each pixel under clear sky.

Because the digital counts can be directly related to the upward radiance, and since most continental surfaces may be considered as lambertian for the observation angles under concern (except for water and snow) within a small error, the transformation is equivalent to the computation of an image of the albedo of the ground with variable cloudiness. In fact, the exact relationship between the upward radiance and digital count is unknown, because the satellite usually has no or low-quality calibration. However, for convenience , we will call albedo the quantity resulting from the normalization, which is proportional to the actual albedo.

The basic idea of the method is that the amount of the cloud cover over a given area statistically determines the global radiation for that area. Thus the processing is divided into two steps. A cloud cover index is derived for each location (i,j) called a pixel, of the original satellite image and subsequently used in a second step for a statistical estimation of the global radiation (figure 1).

The appearance of a cloud in the field of view of the satellite sensor will result into an increase of the apparent albedo. Therefore, the amount of the cloud coverage per pixel is provided by the following quantity called cloud index :

$$n^t(i,j) = (\rho^t(i,j) - \rho(i,j)) / (\rho_c - \rho(i,j))$$

where :

$\rho^t(i,j)$ is the apparent albedo at pixel (i,j) and at instant t,

$\rho(i,j)$ is the ground albedo for clear sky,

ρ_c is the mean value of the cloud albedo,

$n^t(i,j)$ is the cloud index at pixel (i,j) and at instant t.

This cloud cover index ranges from 0 to 1 and can be interpreted as the percentage of the cloud cover per pixel. It also provides an indicator of the transmission of an atmospheric column above the pixel, with low values corresponding to a high transmission factor.

The total atmospheric transmission factor K(i,j) is defined as the ratio of global radiation at ground on a horizontal surface G(i,j) to the horizontal irradiance outside the atmosphere $G_0(i,j)$:

$$K(i,j) = G(i,j) / G_0(i,j)$$

Referring to the above definition of the cloud index, the global ground irradiation at time t is expressed as a linear combination

$$G^t(i,j) = n^t(i,j)\, G_b(i,j) + (1 - n^t(i,j))\, G_c(i,j)$$

where G_b and G_c are the global ground irradiation for overcast and clear skies, respectively.

For each of these extreme conditions, one can define a transmission factor, respectively K_b and K_c, which is supposed to be constant for a given hour. This hypothesis leads to the following linear relation :

$$K^t(i,j) = n^t(i,j)\, K_b(i,j) + (1 - n^t(i,j))\, K_c(i,j)$$

$$= n^t(i,j)\, (K_b(i,j) - K_c(i,j)) + K_c(i,j)$$

$$= a(i,j)\, n^t(i,j) + b(i,j).$$

The coefficients a(i,j) and b(i,j) define a linear regression between the global transmission factor $K^t(i,j)$ and the cloud cover $n^t(i,j)$. Once these coefficients are known at the ground stations, a method of interpolation between the stations is applied in order to define the complete field of coefficients a and b for the studied area and for each hour interval.

3. DESCRIPTION OF THE COMPONENTS OF THE HELIOSAT STATION

The Heliosat station is composed of software and hardware. Besides the algorithms for the conversion of satellite data into global radiation, the sotfware performs automatically the following operations: storage of data onto the harddisk, optimal contrast enhancement and false colors display, accurate navigation and noise filtering. In a standard fashion, three images are processed a day, each giving a map of the hourly global radiation. Once the last hourly map produced, the daily global radiation is computed and displayed. At the end of each month, the above quantities are time-averaged per pixel. These monthly means are displayed and saved both for archiving and for further processing.

The Heliosat software presents also some features the user may select at his will: display any of the images stored on the disk, choose the slots of acquisition and extract some statistics for any location present in any of the images (global radiation and albedo are mostly used).

The image files provided by the Heliosat station follow the CARTO-PC standard. Therefore any Heliosat image can be processed using this performant image processing software. This allows the user to undertake sucessfully any particular task making use of Heliosat images while still having a general and flexible system. Comparisons of maps and digital cartography are examples of such particular purposes.

Briefly described, the hardware of the Heliosat station is composed of a satellite data receiver with antenna

and of a personal computer such as an IBM-PC with digitizing and graphic boards. A color printer may be added (figure 2). The satellite receiver is of analog type and allows the decoding of the so-called WEFAX format emitted by the meteorological geostationary satellites observing the Earth. Such receivers are made by numerous producers and are well-spread throughout the world. They are cheap and do not require any maintenance.

The personal computer is connected to the receiver through a analog-digital converter especially designed for this purpose. This board decodes and digitizes the analog signal and sends it to the PC. Images are displayed onto a color screen using a graphic board. Various graphic standards are supported by the Heliosat software.

4. DISCUSSION

The various components of the Heliosat station have been carefully tested.

A routine was undertaken in Jan. 1983 to check the validity and the accuracy of the Heliosat method (Demarcq[2]). It ended in August 1985, 32 months later. The comparison of the predicted global radiation versus the observed radiation for 30 ground stations demonstrates that the error in the reconstruction of both the instantaneous hourly global radiation G_h and the monthly average of G_h is less than 0.06 kWh/m^2 (Michaud-Regas[7], Diabaté et al.[3]). When compared to other methods, Heliosat ranks as one of the most accurate.

The Heliosat station as described above exists at CTAMN since August 1985 and a copy of it was delivered to Agence Française pour la Maîtrise de l'Energie which has run it since January 1987. Examples of the maps it supplies are presented in Figures 3 and 4.

The production of an hourly global radiation map requires about 100 minutes for a PC-XT and 60 minutes are needed for the daily map. Processing hourly maps to obtain monthly means takes about 5 minutes. These times are only indicative and depend strongly upon the hardware used as the processors are becoming more and more performant. For example, times must be divided by at least a factor 3 if one uses a PC-AT.

The Heliosat station brings an up-to-date scientific method to the end users in the field of solar energy. It is cheap and needs no maintenance. Its capability in receiving and processing the satellite data allows the user to forecast the displacement of the cloud field on a very short-term basis.

Engineers appreciate the detailed maps of global radiation it gives to evaluate the dimensioning of solar buildings. Furthermore derived products such as albedo maps are of great interest for climatologists or for vegetation studies (Diabaté et al.[4], Moussu et al.[8]).

5. ACKNOWLEDGMENTS

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6. REFERENCES

1. Cano D., Monget J. M., Albuisson M., Guillard H., Regas N., and Wald L., A method for the determination of the global solar radiation from meteorological satellite data. Solar Energy, 37, 1, 31-39, (1986).

2. Demarcq H., Etude de la zone de dilution rhodanienne, observations des zones de production dans le Golfe du Lion et estimation de l'éclairement solaire global en Méditerranée Occidentale. Thèse 3ème Cycle. Université Aix-Marseille II, (1985).

3. Diabaté L., Demarcq H., Michaud-Regas N., and Wald L., Estimating incident solar radiation at the surface from images of the Earth transmitted by geostationary satellites : the Heliosat Project. International Journal of Solar Energy, (1987).

4. Diabaté L., Michaud-Regas N., and Wald L., Mapping the ground albedo of Western Africa using Meteosat visible data. Its time evolution during 1984 and its relations to the vegetation. Submitted to Remote Sensing of Environment, (1988).

5. Gautier C., Diak G. and Masse S., A simple physical model to estimate incident solar radiation at the surface from GOES satellite data. Journal of Applied Meteorology, 19, 1005 (1980).

6. Grüter W., Guillard H., Möser W., Monget J. M., Palz W., Raschke E., Reinhardt R. E., Schwarzmann P., and Wald L., Solar Radiation from satellite images, Solar Energy R & D in the European Community Series F, Solar Radiation Data, Vol. 4, D. Reidel Publishing Co, (1986).

7. Michaud-Regas N., Mise en oeuvre et validation d'une méthode opérationnelle et automatique pour l'évaluation d'atlas solaires en Europe à l'aide de mesures satellitaires Météosat. Thèse de Doctorat de Sciences. Univ. Paris VII, (1986).

8. Moussu G., Diabaté L., Wald L., The use of geostationary satellite visible data for the mapping of the ground albedo, Submitted to International Journal of Remote Sensing, (1988).

9. Möser W., and Raschke E., Mapping of global radiation and of cloudiness from Meteosat image data. Meteorl. Rdsch., 36, 33-41 (1983).

10. Möser W., and Raschke E., Incident solar radiation over Europe estimated from Meteosat data. Journal of Climate and Applied Meteorology, Vol. 23, No 1, 166-170 (1984).

11. Tarpley J. D., Estimation incident solar radiation at the surface from geostationary satellite data. Journal of Applied Meteorology, 18, 1172, (1979).

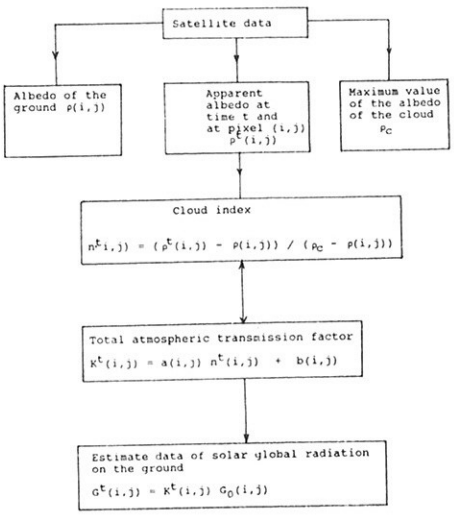


Figure 1 : Synoptic scheme of the Heliosat method.

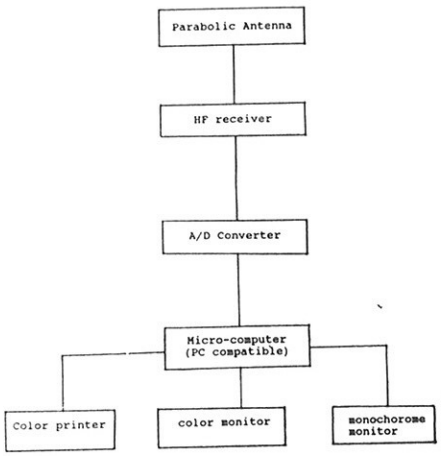


Figure 2 : Synoptic scheme of the Heliosat station.

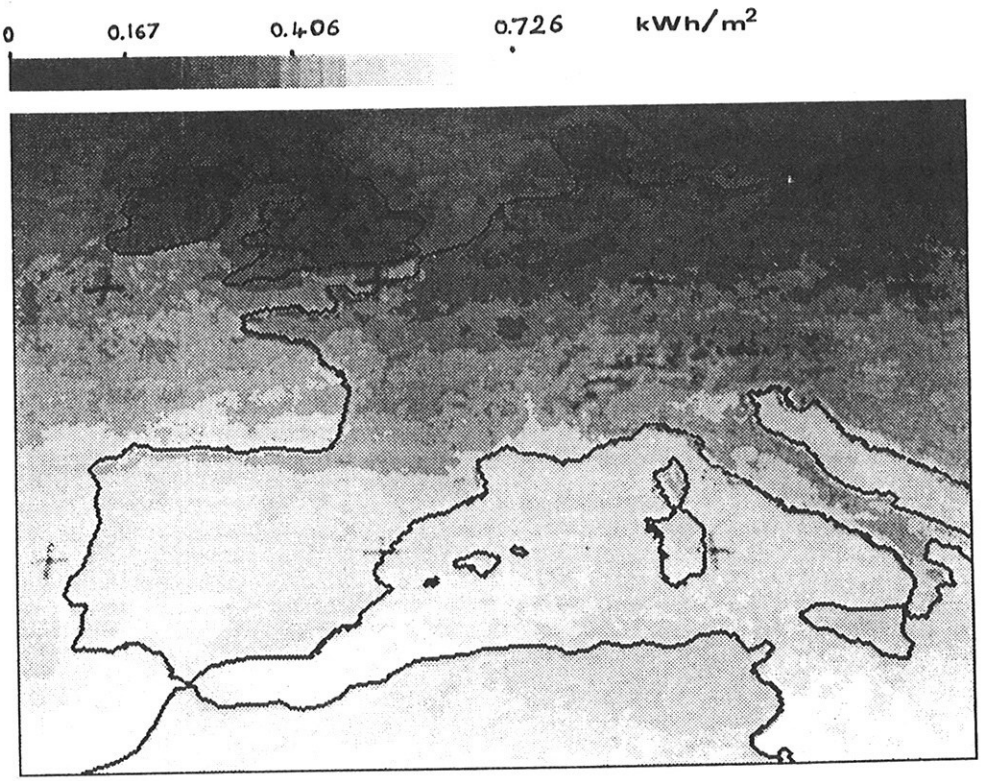


Figure 3 : Map of the hourly global radiation observed between 12 and 13h UT and averaged over the year 1983 for Europe. Radiation increases from black to white.

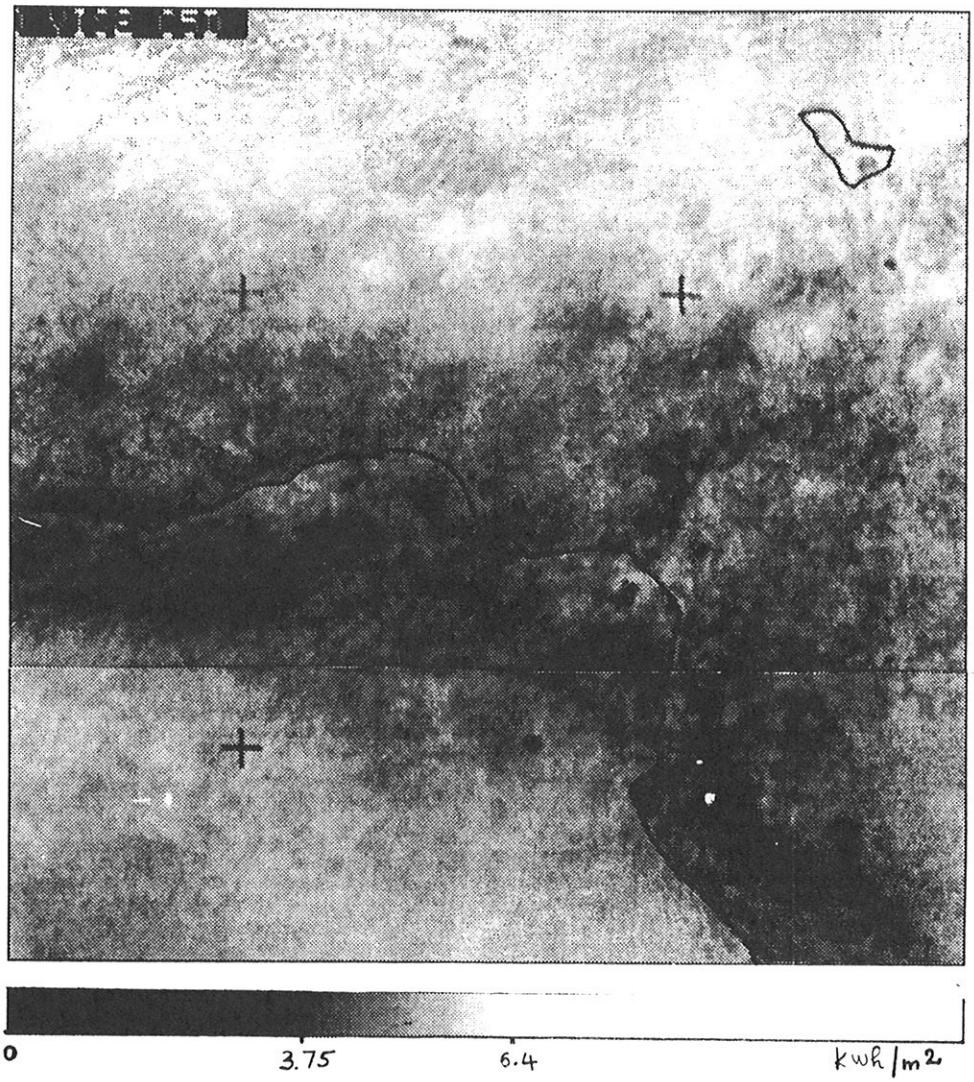


Figure 4 : Map of the daily global radiation averaged over June 1984 for West Africa. Radiation increases from black to white.