



Radiative transfer model in the atmosphere and experimental solar data of Yaounde location

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Overviews

- Sun is the primary source of energy supplying the earth and controlling atmospheric phenomena.
- solar energy received on earth surface is also very useful
- Its study is important for the calculation and calibration of the performances of technological applications.
- Moreover, a well characterization of the solar radiation arriving on the ground could inform about the atmospheric phenomena which influenced its crossing, and consequently provide a better correction for sensors response while receiving a signal from outer space in its direction, or the correction to be made while receiving data from an extraterrestrial sender.
- Because of the electromagnetic nature of solar rays, its study can be transpose to other radiative transfer problems in the atmosphere, such as communication between terrestrial sites.

- Just few measurements stations of solar radiation are running today.
- Where these measurements are carry out, they are rarely done for various wavelengths and/or angles.
- Such data are on the other hand accessible by numerical calculation, by solving the radiative transfer equation (ETR) in the atmosphere.
- Difficult to take into account the non homogeneous nature of the clouds [1,2].
- Several recent studies showed that these non homogeneity have significant impacts on the transmitted radiation, calculated either for the thick and continuous clouds [3] or for dispersed clouds [4,5].
- Such structures must be studied with a multidimensional radiative transfer model, as for example the one of Stephens [6] judiciously exploited recently by Evans [7] which breaks up the angular part of radiance into spherical harmonics while the space part is simply discretized by finite differences.
- We found it important to make a comparison between results of this model and the experimental data collected on the Cameronian site of Yaounde[8-13].
- Detect its forces, weaknesses and the possible improvements which could be done to guarantee a prediction free from any significant variation with reality.
- The first part is devoted to the description of the model. In the second, the model results are compare to the values resulting from experimental measurements.

Material

- Hourly solar irradiation data considered in this study have been measured at Yaounde meteorological station (latitude: $3^{\circ}52$ N; longitude: $11^{\circ}32$ E; altitude: 753 m), using Epley pyranometers associated with Licor integrators [8]. Excel 2003 was the computation and analysis software used in the study, while Fortran 90 is the programming tools used for the numerical calculation codes.

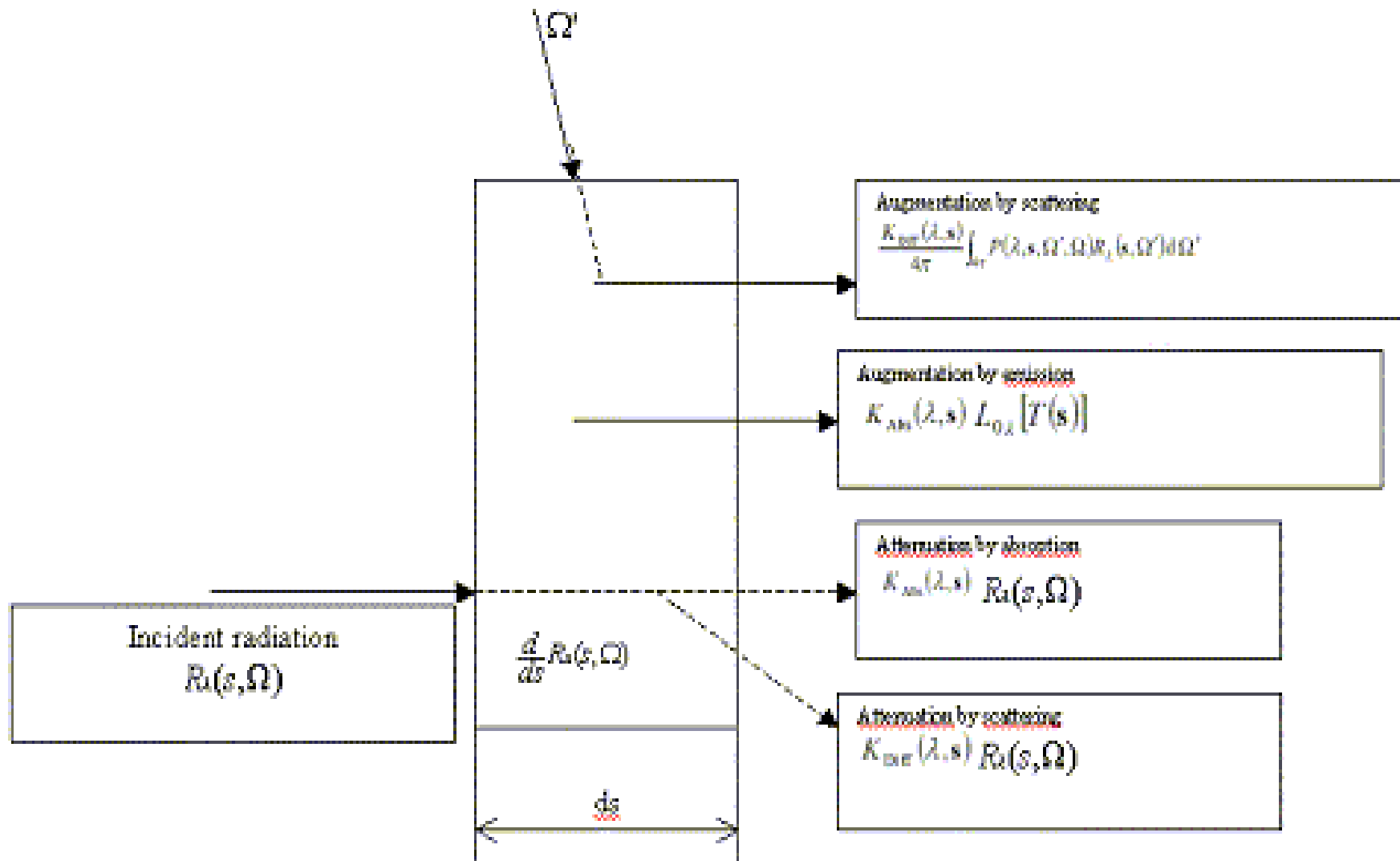
Method description

- The radiative Transfer Equation (RTE) described in mathematical form, energy exchanges when a radiation with a specific wavelength λ is propagated according to a given Ω direction through a volume element. This equation can be written in the form

$$\frac{d}{ds}R_{\lambda}(s,\Omega)=-[K_{abs}(\lambda,s)+K_{Diff}(\lambda,s)]R_{\lambda}(s,\Omega)+K_{abs}(\lambda,s)L_{\lambda}[T(s)]+\frac{K_{Diff}(\lambda,s)}{4\pi}\int_{4\pi}P(\lambda,s,\Omega',\Omega)R_{\lambda}(s,\Omega')d\Omega'$$

Braking this equation into its components, we can realize that the model assumes the variation of radiance in the medium as the result of four atmospheric phenomena

Components of RTE



Spherical harmonics introduction

The spherical harmonics methods replace the squaring diagram of the DOM by a representation of the radiance field in series of spherical harmonics. The radiance field can thus be evaluated simultaneously according to all directions of space and hemispherical flux can easily be deduced from the development of the radiation field according to the spherical harmonics base. The accuracy of the results depends however on the truncation order imposed on the spherical harmonics base.

If $\{y_l^m(\Omega)\}_{\substack{l \leq L \\ |m| \leq l}}$ indicates a truncated spherical harmonics base with the order L , it is shown that the scattering integral can be reduced by the following relation [15]:

$$\frac{\omega_o}{4\pi} \int_{4\pi} P(\Omega', \Omega) R(s, \Omega') d\Omega' \approx \omega_o \sum_{l=0}^L \frac{\chi_l}{2l+1} \sum_{m=-l}^l R_l^m(s) Y_l^m(\Omega)$$

Where $R_l^m(s)$ is the (l,m) order component of radiance in spherical harmonics base, as defined by the following relation:

$$R(s, \Omega) \approx \sum_{l=0}^L \sum_{m=-l}^l R_l^m(s) Y_l^m(\Omega)$$

χ_l is the development coefficient in Legendre polynomials series of the phase function, defined by the relation:

$$P(\cos\theta) \approx \sum_{l=0}^L \chi_l P_l(\cos\theta)$$

The SHDOM code is thus structure as follow :

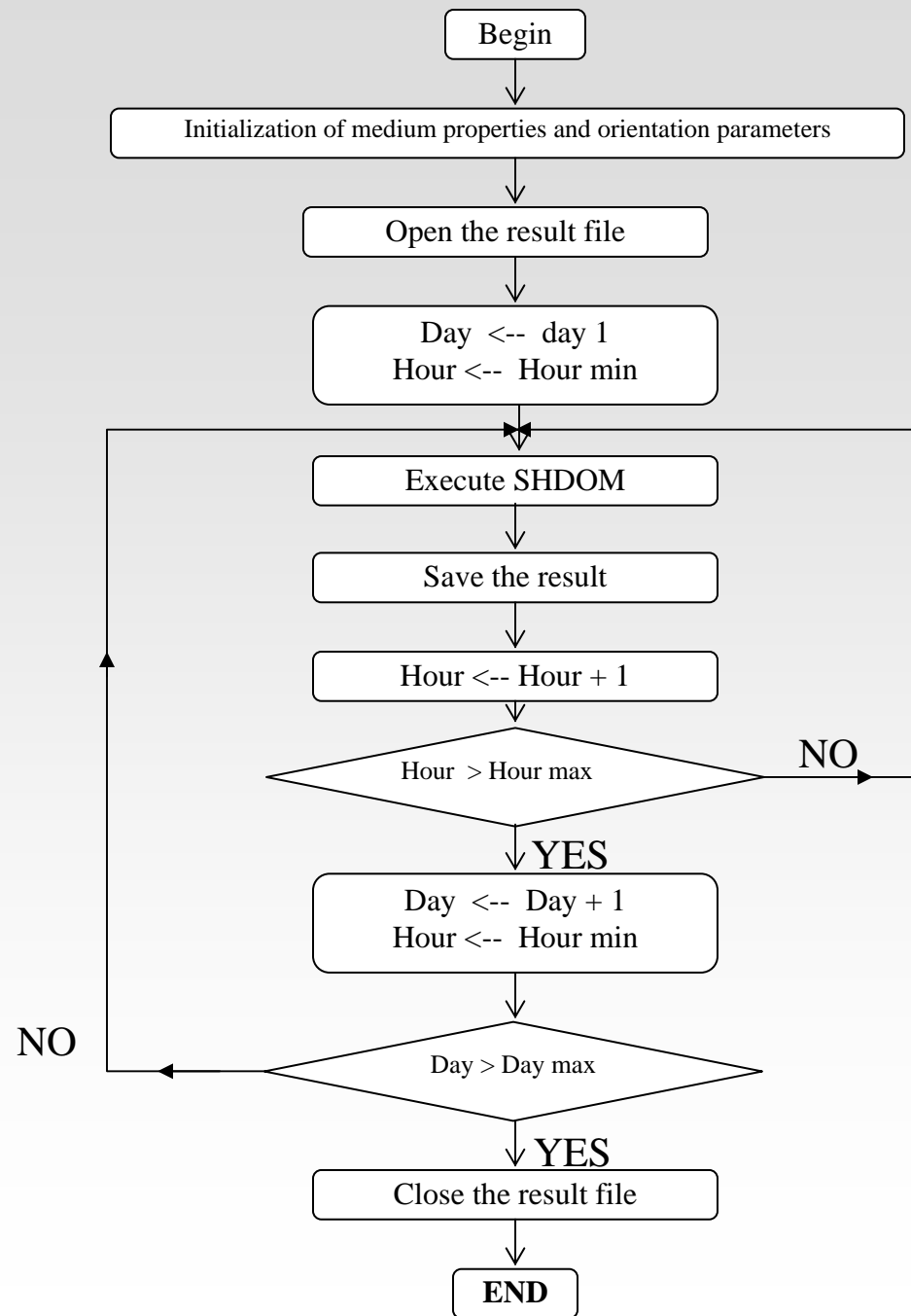
- 1. the RTE is integrated spatially according to each discrete ordinate without taking into account the scattering integral, that allows initialisation of the system.
- 2. The scattering integral is evaluated using the radiance field calculated at the preceding stage.
- 3. The RTE is integrated spatially according to all the discrete ordinates by taking into account the scattering integral calculated at the preceding stage.
- 4. Stages 2 and 3 are continued until results convergent according to a preset criterion.

Forces

Spherical Harmonics Discrete Ordinate Method: SHDOM, is an iterative method of resolution of RTE which cumulates the speed of evaluation of the scattering integral on a basis of spherical harmonics with the effectiveness of the calculation of radiation propagation along discrete ordinates in three dimensions of space. The interpolation of the optical properties makes it possible to calculate radiance in any point of the medium by taking account of the scattering character of mediums such as the atmospheric scenes. The method goes successfully through validations tests on 1D, 2D and 3D simulated mediums[14], particularly while requesting less computing times.

Application to solar radiance calculation.

- SHDOM was applied to evaluate solar radiance on a Cameroon location. Indeed, an outer loop was established taking the SHDOM like one of its components. What made it possible to calculate hourly radiation received on the ground, taking into account the geographical positioning parameters of the considered location.
- The resulting algorithm can be presented as on the figure below:



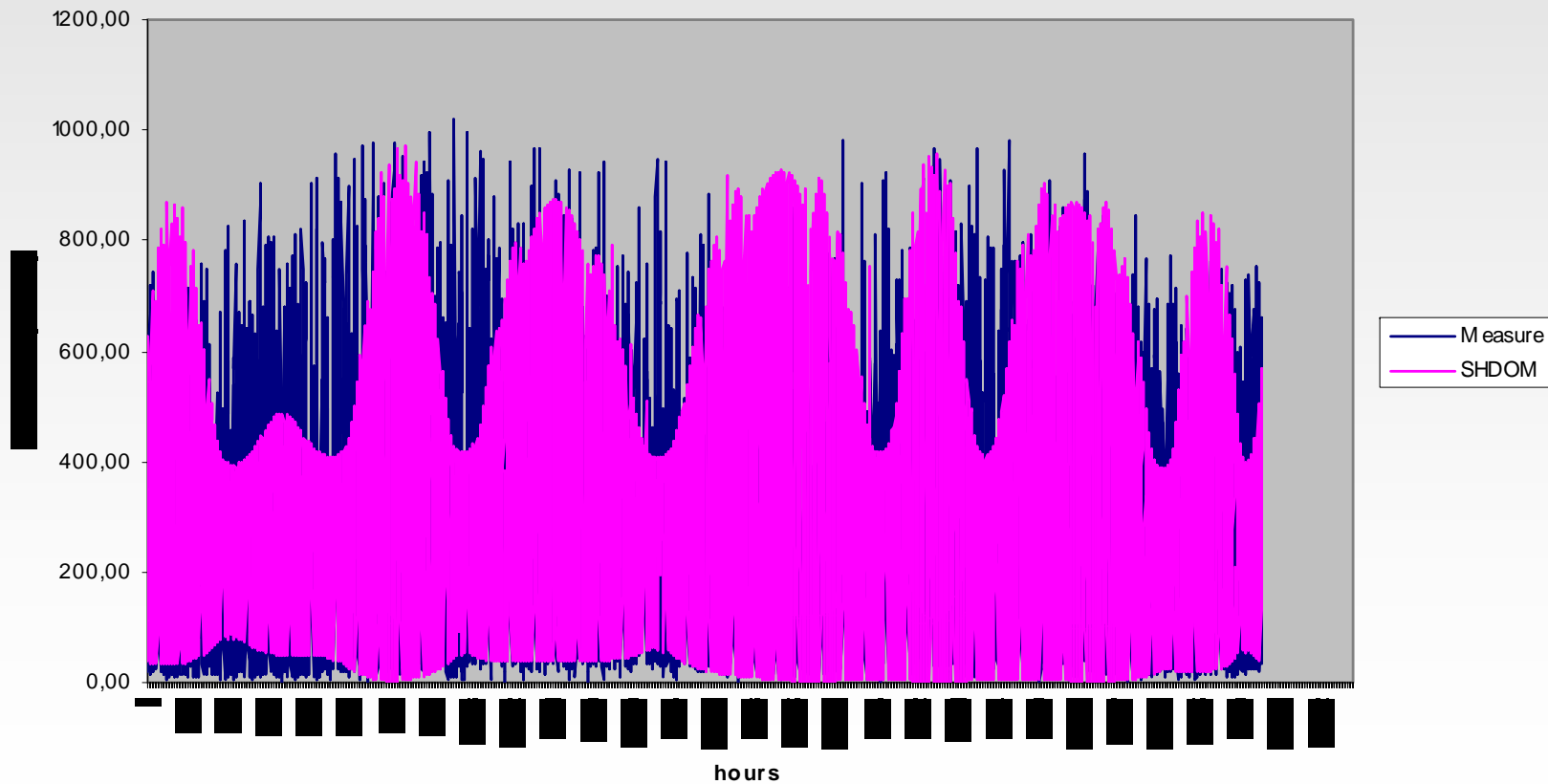
Results and Discussion

The results were obtained after running the code. As they consist of normal plan radiation, they were convert to match the experimental results, by finding their component on horizontal plane. This process permit us to find the global radiation, according to a linear correlation derived from data, justified by the spectral range consider while running the code.

Two particular scales were then consider, the **hourly scale** and the **daily** one.

Hourly scale

Fig, 1 : Comparison between SHDOM and hourly measurement

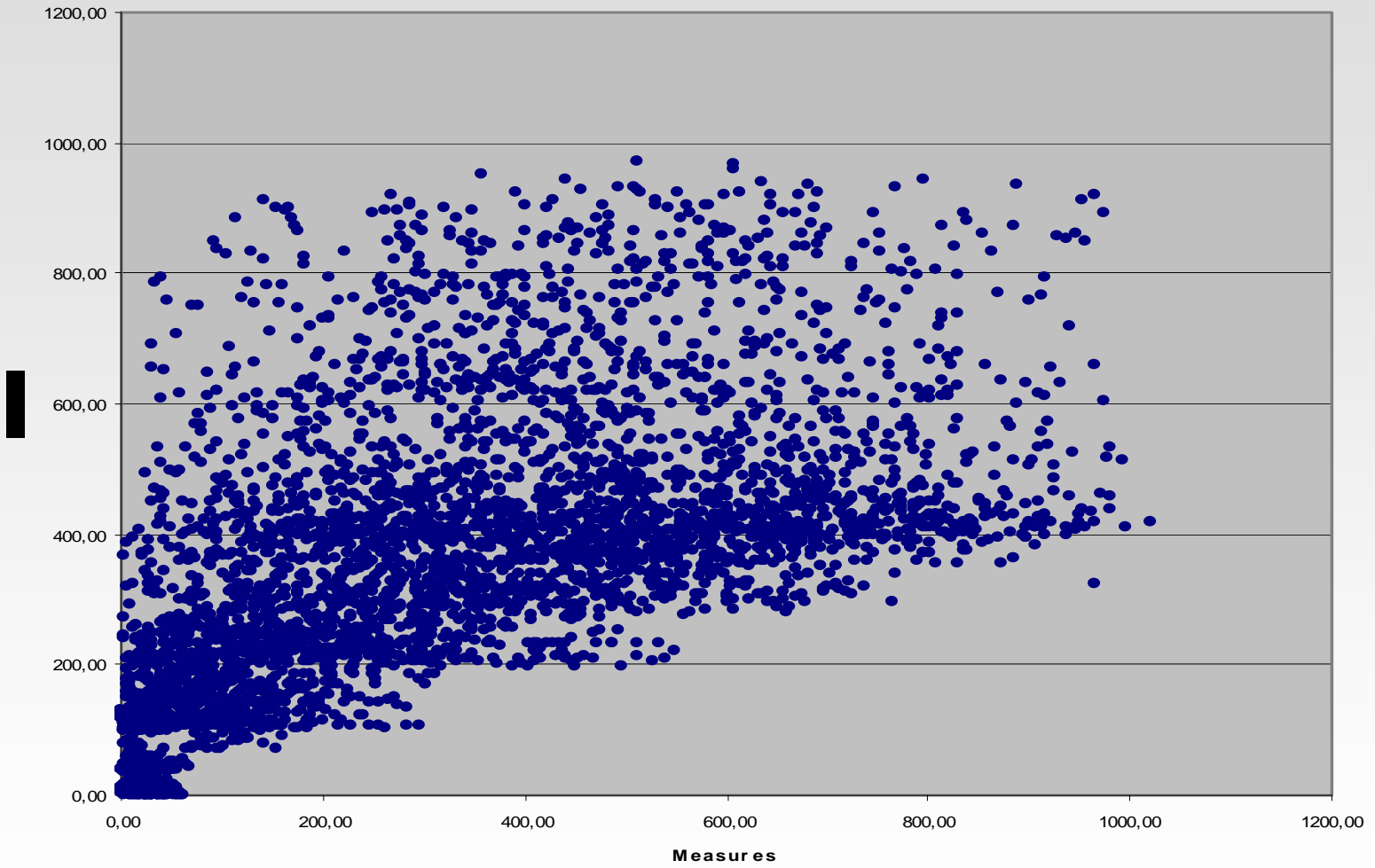


This figure shows a good accordance with the variation order of solar irradiation.

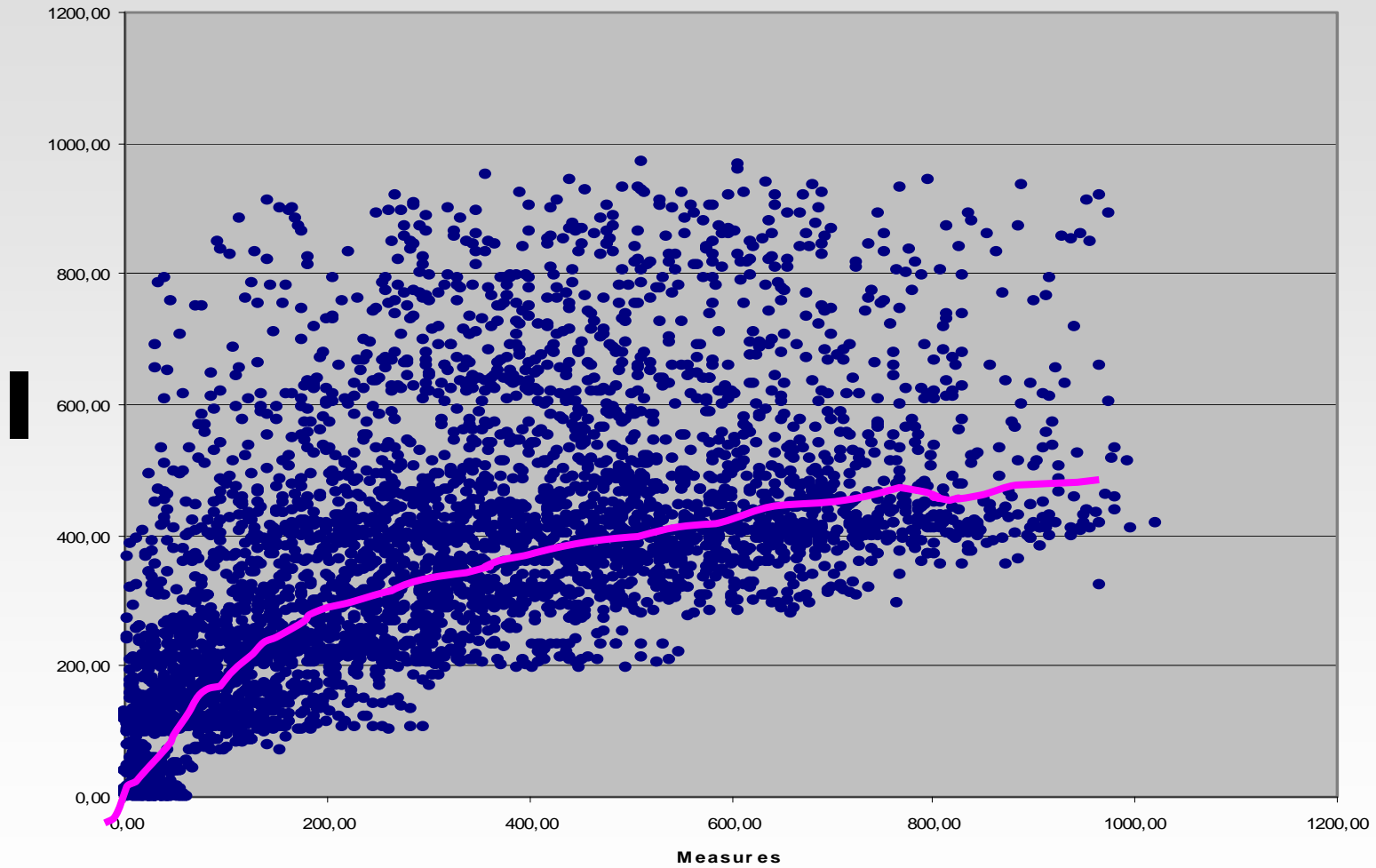
A bad correspondence from a day to another. We assume it to be a consequence of the static character of medium properties.

The sparse points on the next picture may be related to the overcasts days, which were found by a previous study to be more than 18% of days in Yaounde.

Fig, 2 : SHDOM - M easures



Fig, 3 : SHDOM - Measures



This figure also shows the existence of a polynomial correlation between SHDOM result and measures

The Correlation was found using the least square method, after defining inclusion criterion, to avoid lost of precision induced by sparse points.

Those criterion were :

$$\begin{cases} SHDOM < 600 \\ SHDOM < \frac{1}{3} Mesures + 375 \end{cases}$$

That result to the following regression equation:

$$Mesures \approx a(SHDOM)^2 + b(SHDOM)$$

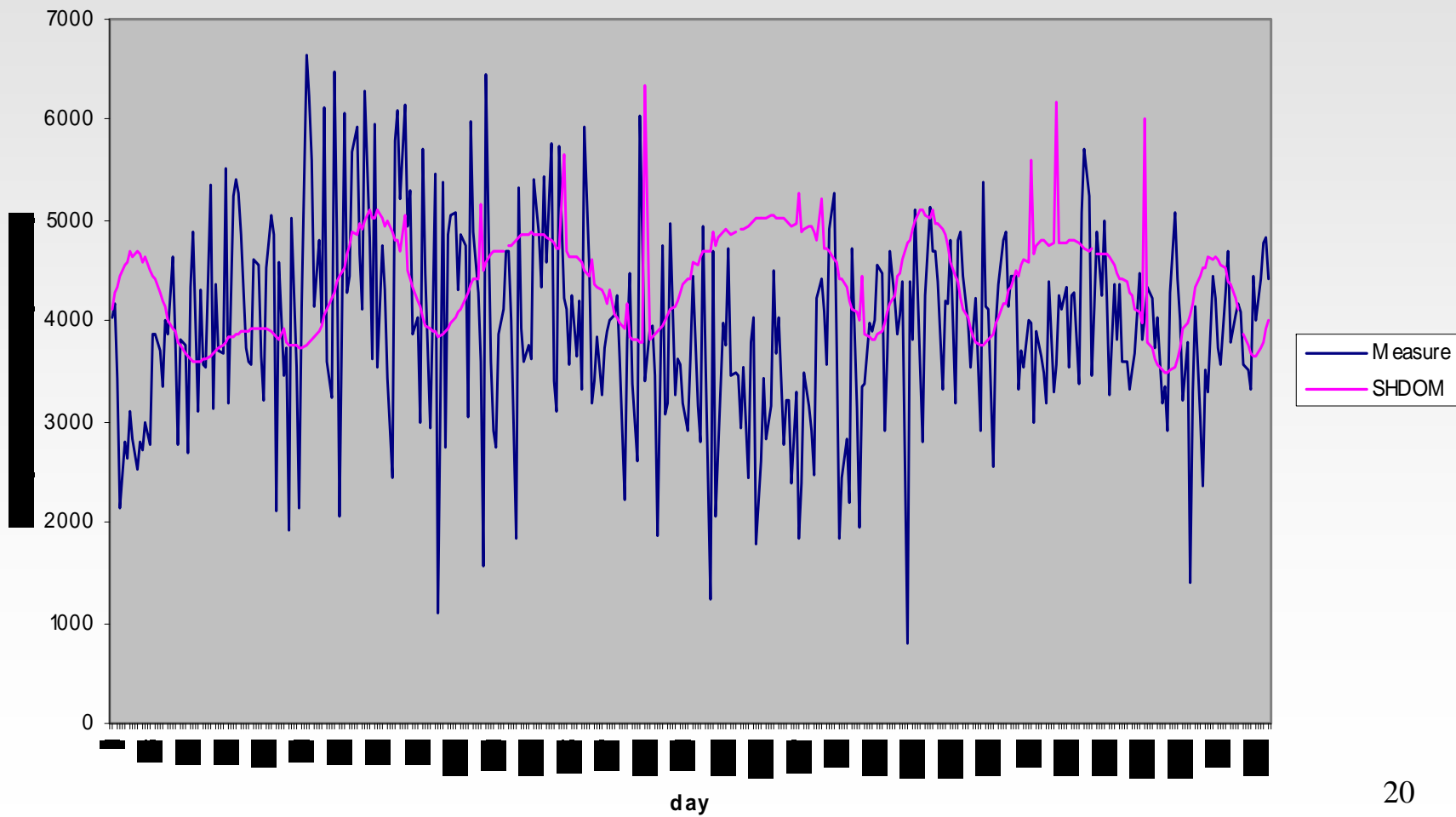
$$a = +0.00275$$

$$b = -0.1$$

Without more details information on the medium properties, this correlation could be used to correct the results of SHDOM to fit the experimental data of Yaounde.

Daily scale

Fig, 4 : comparison between SHDOM results and daily measurements



Looking the results shown on figure 4, we can make the following remarks:

In daily scale the model give better results, with a good variation range.

It exist however differences between measures and results, which may be link to a weak spatial and temporal characterisation of the medium properties.

This lack of information may be reduce after a statistical study of satellite images.

	Measures	SHDOM	Ratio Mes/SHDOM
average	3928	4384	0,9
standard deviation	982	488	0,2

In daily scale, the similarities between SHDOM and measures does not show a statistically significant error.

Conclusion and perspectives

This study revealed a :

- possible correlation between SHDOM results and measures according to hourly scale
- similarity between SHDOM results and measures according to daily scale, with a non statistically significant error.
- It also point out the forces and weaknesses of SHDOM, particularly its speed and the need of a better characterisation of the medium.

With the following perspectives :

- Use satellites observations to make a better characterisation of the medium
- Improve the code with a dynamic consultation of medium properties.
- Reverse the code to determine spatial and temporal distribution of atmospheric weather.
- Investigate the interaction of solar rays with the electrically charged media, in other to specify the amount of solar rays who's magnitude is disturb by those types of medium.

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Thank you