Sección Especial / Special Section: V Workshop on Lidar Measurements in Latin America

Camagüey's solar radiation rescued dataset: preliminary applications

La serie rescatada de observaciones de radiación solar de Camagüey: aplicaciones preliminares

Juan Carlos Antuña[1,*], Carlos Hernández[1], René Estevan[1], Boris Barja[1], Aramís Fonte[2], Teresita Hernández[1], Juan Carlos Antuña Jr.[3]

1. Grupo de Óptica Atmosférica de Camagüey, Centro Meteorológico de Camagüey, INSMET, Cuba.
2. Departamento Científico, Centro Meteorológico de Camagüey, INSMET, Cuba.
3. Facultad de Ciencias Informáticas, Universidad de Camagüey, Cuba.

(*) Email: anadelia@caonao.cu S: miembro de SEDOPTICA / SEDOPTICA member

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ABSTRACT:

Applications of the Camagüey station solar radiation dataset are shown. The dataset has been rescued by the Grupo de Óptica Atmosférica de Camagüey team, consisting in hourly observations of direct, diffuse and global radiation belonging to the period 1981 to 2007. They have been reprocessed and quality controlled by properly designed computer software, generating a digital dataset in use for research and services. Applications in atmospheric research are described covering the calculation of the frequencies of hourly and monthly clear sky conditions, the evaluation of the tropospheric aerosols radiative effects and the evaluation of a radiative transfer model adjustment to the climatic conditions of Camagüey. Also, using clear sky observations and the Bouger-Lambert-Beer law, the broadband aerosol optical depth has been calculated. The solar radiation data rescue process, the applications and the results derived are completely new for Cuba and for the Caribbean. Service applications are provided at the web page "Diagnostic of the Solar Radiation in Camagüey". The site contains both hourly observations in real time and historical values of solar radiation variables for the period 1981 to 2007. Perspectives and future applications, already in progress or in design phase, are described.

Key words: Solar Radiation, Data Rescue, Aerosols, Radiative Forcing, Clear Sky.

RESUMEN:

Se muestran las aplicaciones de la serie de observaciones de radiación solar de Camagüey. Esta serie de datos está siendo rescatada por el Grupo de Óptica Atmosférica de Camagüey y consiste en observaciones horarias de radiación directa, difusa y global correspondiente al periodo 1981 al 2007. Las observaciones han sido reprocesadas y sometidas a control de calidad empleando un software desarrollado específicamente con esos propósitos, generando una serie de datos digitales que se encuentra en uso tanto con fines de investigación como de servicios. Se describen las aplicaciones en investigaciones de la atmósfera, que incluyen la determinación de las frecuencias de ocurrencia, horarias y mensuales, de condiciones de cielo despejado y las evaluaciones de los efectos radiativos de los aerosoles troposféricos y de los resultados de la adaptación de un modelo de transferencia radiativa a las condiciones climáticas de Camagüey. Además, empleando la ley de Bouger-Lambert-Beer, se han calculado el espesor óptico por aerosoles en banda ancha. El rescate de las observaciones de radiación solar, así como las aplicaciones y resultados derivados del mismo son completamente nuevos para Cuba y para el Caribe. Aplicaciones al servicio se brindan en la página Web "Diagnóstico de la radiación Solar en Camagüey". Este sitio contiene observaciones horarias en tiempo real así como valores históricos de las variables que caracterizan la radiación solar para el periodo 1981-2007. Se describen finalmente las perspectivas y aplicaciones futuras que se encuentran en fase de implementación o diseño.

Palabras clave: Radiación Solar, Rescate de Datos, Aerosoles, Forzamiento Radiativo, Cielo Despejado.

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1. Introduction

Although solar radiation is the main source of energy of the climate system and the fact that its measurements have been conducted regularly for many years by meteorological stations all over the world, there is a lack of available detailed information of this parameter, mainly in the tropical region. Many of the early records in the tropics are still in paper records, making then very difficult to use for intensive and regional studies. In addition the quality of such records is a pending issue, because the manual processing and quality control of such datasets is a source of human errors. That situation makes long time solar radiation records data rescue a very necessary but challenging task, as it has been recognized recently [1].

The Grupo de Óptica Atmosférica de Camagüey (GOAC) team (former Camagüey Lidar Station) has been conducting the whole process of rescuing almost 40 years of solar radiation measurements conducted at Camagüey, Cuba [2]. This task has been conducted with a complete research cycle strategy. It consists not only in rescuing, digitizing, processing and quality controlling the dataset, but combining it with developing and implementing research and services applications of the versions of the datasets already available.

The paper includes a brief explanation of the data rescue project, followed by the description of applications already developed and implemented and the results obtained. Finally

perspective and applications both under implementation and development are exposed

2. Solar radiation rescued dataset

Solar radiation measurements at Camagüey Meteorological Station (21.4°N, 77.9°W, 122m a.s.l.) began at the end of the sixties and are still being conducted. Instrumentation, provided by the Hydro-Meteorological Service of the former Soviet Union, consisted in a manually operated actinometric station type Yanishevski [3]. The dataset consists mainly of hourly observations of direct, diffuse and global radiation. A recent project, designed and conducted by the GOAC team, has rescued these dataset [2,4]. The observations of the period 1981 to 2009 have already been rescued, reprocessed and subject to quality control by properly designed computer software. The processing results which have already passed the quality control have been used to generate a digital dataset in use for research and services that are described below.

Upon the project execution progresses new versions of the dataset have been produced, using the results of the processed observation that have already passed the quality control. The version 1.0 covered the period January 1985 to December 2007, with a completeness of an 88.2 % of all the possible observations for the whole period. Version 2.1 extends from May 1981 to October 2009, almost 30 years, with an 83 % of completeness. An intensive work is under way for reviewing; checking and reprocessing the observations that did not passed the quality control. Version 2.2 is expected to cover almost the same period but having higher completeness.

3. Applications and results

3.1. Clear sky monthly and hourly frequencies

Clear sky conditions are very important from several points of view. Those are the most appropriated conditions for conducting solar radiation instruments calibrations. Another application of the information on clear sky conditions is the comparison among instruments. Those conditions are also used to test model simulations, to evaluate their adjustments to real measured situation and for determining non-perturbed conditions in radiative forcing calculations. The criteria we used for selecting clear sky conditions, reported in the literature, were that the cloudiness index should be equal or lower to 1/10 of the sky covered by clouds [5].

Figure 1 depicts the monthly and hourly frequencies of clear sky conditions at Camagüey for the period 1984 to 2007.

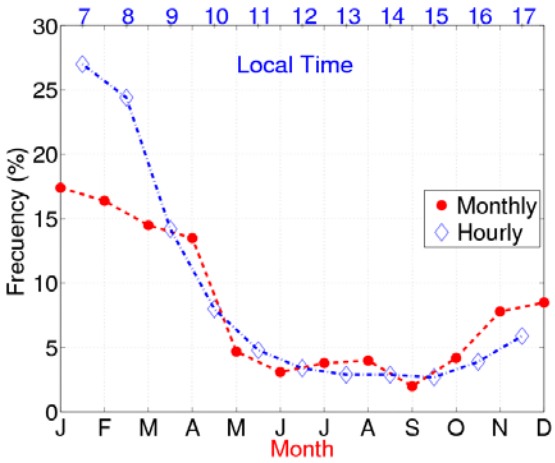

Fig. 1. Monthly and hourly frequencies of the clear sky conditions at Camagüey, Cuba.

As expected, clear sky conditions are more frequent during the dry season, because of the lower presence of clouds, with maximum values between January and March in the order of 15 % and minimum values in summer with magnitudes lower than 5 %. Regarding the hourly frequency, the clear sky conditions decrease from around 25% in the hours after sunrise to values below 5% after midmorning. A set of 14 days with clear sky conditions at all the hours was selected and is being used intensively both in research and service activities, conducted by the GOAC team, as it is described below.

3.2. Aerosol optical depth calculations

Values of the solar direct beam for the hourly observation under clear sky conditions were selected and the Bouger-Lambert-Beer law was

applied to derive the broadband aerosol optical depth (BAOD), using the algorithm developed by Gueymard [6]. Different sources of information and assumptions were accounted for to parameterize the atmospheric components optical depths. Monthly mean integral content of water vapor for Camagüey, derived by a recent study [7] was used. The integral concentration of ozone was calculated using TOMS available data for the site [8]. In the cases of the stratospheric and tropospheric nitrogen dioxide and the uniformly mixed gases annual mean values from the US Standard Atmosphere were used [9].

Monthly mean BAOD values and its standard deviations are shown in Figure 2. The seasonal cycle is evident, with minimum values in winter, between 0.1 and 0.2, and maximums during the summer ranging from 0.2 to 0.4. The last ones are associated to the arrival of Saharan Dust to the Caribbean [9,10]. Results are similar to the observations registered in Barbados (13.18 ºN; 59.43 ºW) for the period 1996-1999 using solar photometry [10]. The high values of the standard deviations, also registered at Barbados [10], demonstrating the high level of variability of the BAOD in the order of 50 %.

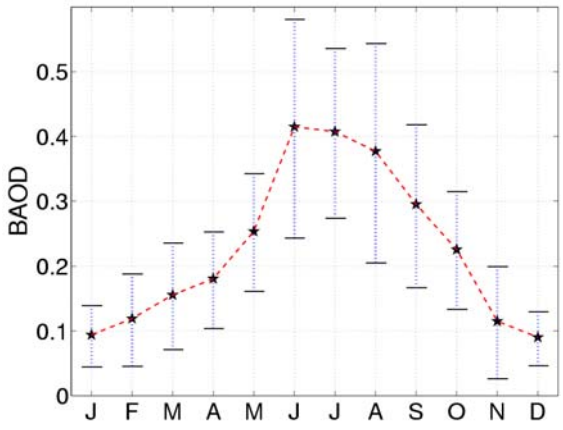

Fig. 2. Monthly mean BAOD for Camagüey, 1985-2007.

Hourly mean BAOD values show an increase trend during the course of the day. It increases from around 0.13 at 7 LT to approximately 0.26 between 14 and 16 LT in the afternoon. The BAOD trend was -1.46×10^{-3} year^{-1} for the whole period 1985-2007, significant at a 99.5 % level. That result is in agreement with reports in other regions of the planet [9]. Hourly trends of the BAOD, between 7 and 12 LT, are negatives and statistically significant at 99.5 % level. After noon the trends are positive but not significant. Information about the aerosols optical depth, for so large period of time, has been obtained by first time for Cuba and the Caribbean.

3.3 Evaluating radiative transfer code adjustment

The GOAC team adapted the GFDL (Geophysical Fluid Dynamics Laboratory) column radiative transfer code [11] for its use on PCs and at the same time adjusted its parameterization of the atmospheric conditions to the ones in Camagüey. The quality of the adjustment was validated using hourly solar radiation measurements of 14 clear sky days. For each hour for the 14 days surface fluxes were calculated with the code using the hourly BAOD derived with the algorithm described previously. Then the Percent Differences Coefficient (PDC) for each hour was calculated accordingly to the formula below [12].

$$PDC(\%)=\frac{F^{\downarrow sfc}_{\text{simulated}}-F^{\downarrow sfc}_{\text{measured}}}{\frac{1}{2}\left(F^{\downarrow sfc}_{\text{simulated}}+F^{\downarrow sfc}_{\text{measured}}\right)}\times 100\,. \qquad (1)$$

Figure 3 shows the PDC values per hour. Biggest values of the PDC occur at the hours near sunrise and sunset, as expected, because the errors in the measurements are higher, due to the instrument-sun observing geometry and the consequently maximum values of the optical path. Between 8 and 16 LT the mean value of PDC is 12%. If all the hours are included the mean value of the PDC is 18%. Both results demonstrate a good adjustment of the numerical model parameterized to the atmospheric conditions for Camagüey [12]. That conclusion is based in two main facts. The errors in the observations of the direct beam ranges between 5 and 10% and that the accuracy of this radiative transfer code for the atmospheric absorbed, downward surface, and upward top of the atmosphere fluxes is in general around 10% [11].

3.4. Tropospheric aerosols solar radiative forcing

Radiative forcing in the surface ($\Delta F^{\downarrow}_{sfc}$) produced by tropospheric aerosols was calculated using

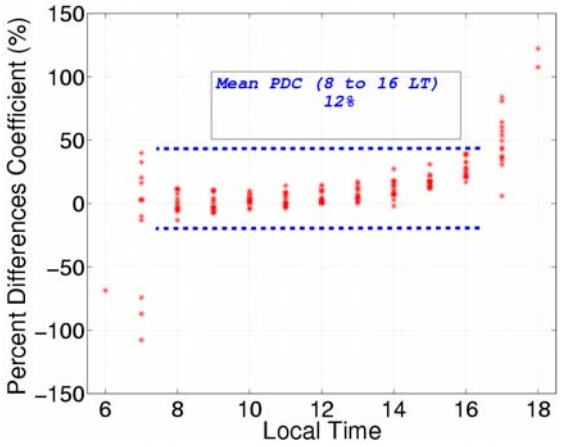

Fig. 3. PDC between simulations and the measurements.

the definition $\Delta F^{\downarrow}_{sfc}=F^{\downarrow}_{sfc,dust}-F^{\downarrow}_{sfc,bg}$ and clear sky observations. $F^{\downarrow}_{\mathrm{sfc,dust}}$ and $F^{\downarrow}_{sfc,bg}$ are the descending radiative fluxes at the surface under dusty and under background conditions respectively. Experimental and simulated fluxes for the same hours the same days were used to estimate the radiative forcing. Experimental calculations were conducted using the 1985-2007 solar radiation dataset [4]. Numerical calculations used the GFDL radiative transfer code adapted for Camagüey [12] and the hourly BAOD values described previously [9]. Table I shows the values of $\Delta F^{\downarrow}_{sfc}$ for selected days at 12 LT. All the values, both measured and simulated, are negatives, showing the predominance of the aerosols albedo effect. The ratio of simulated to measured $\Delta F^{\downarrow}_{sfc}$ is ~0.6, showing under-estimations in the numerical simulations [13]. The magnitudes of the $\Delta F\downarrow_{sfc}$ are negative, with absolute values higher than 23 Wm^{-2}. The value of -23 Wm^{-2} defines a threshold [14]; negative values of the radiative forcing with absolute magnitudes higher than this value are characterized as "strong cooling". That is the case for our results as was pointed out previously.

3.5. Solar radiation diagnosis service

A system has been developed for publishing in real time the hourly manual solar radiation observations. Historical values of the variables, for the period 1981 to 2009, are also available at the web page "Diagnostic Service of the Solar Radiation in Camagüey" [15]. This is the first ever regular service of solar radiation information provided in the country. A new set of automatic meteorological stations will be installed in the existing six meteorological stations located in the Camagüey province. Such stations will include a global radiation sensor. The information from such instruments is planned to be added to the service.

Table I
Values of $\Delta F^{\downarrow}_{sfc}$ (Wm^{-2}) for selected cases.

Date	12 LT	
	Experim.	Model
16/04/1986	-104.7	-36.2
30/04/1986	-47.7	-28.3
26/03/1987	-14.9	-28.6
13/08/1987	-146.0	-88.6
4/04/2000	-103.7	-24.8
12/03/2001	-54.9	-33.6

3.6. Perspectives and future applications

Several tasks are been conducted in parallel. The Version 2.2 is expected to be completed by the early months of 2011. The actinometric observations of the period 1970 to 1980, which are been rescued currently, plus the last months of 2009 are planned to be incorporated to the Version 3 of the dataset, expected by the end of 2011. That version is expected to be subject to stricter quality control tests. The algorithms of these tests will be included in the new version (Version 3) of the processing and quality control software for the dataset of solar radiation measurements, planned for the beginning of 2011. It is expected that it will include state of the art of the algorithms, more robust and strict quality control procedures, including consistency checks (both in space and time) for the whole dataset. Another important improvement is expected from the ongoing process for assessing the stability and trends of the technical features of the complete set of instruments used during the almost four decades the dataset covers. The current and future new actinometric measurements will be incorporated to the next versions of the dataset.

A more long time framework Climatology of the solar radiation in Camagüey will be derived

under completion of the rescue, processing and quality control of the whole period 1970 to 2010. Trends will be evaluated and analyzed in the context of the studies on solar dimming-brightening in the Wider Caribbean already conducted at the GOAC. Real time derivation of BAOD, for clear sky observations, will be included in a future Aerosols Diagnostic Information Service. Robust evaluations of the tropospheric aerosols radiative forcing are being conducted.

Both the solar radiation data rescue procedure and the Diagnostic Service are planned to be extended in the near future to the rest four manual actinometric stations in operation in the country.

4. Concluding remarks

A solar radiation data rescue project has been conducted at Camagüey, Cuba, rescuing almost 40 year of observations. Several applications of the rescued dataset have already been conducted covering both research and service interests. More applications are planned and envisaged.

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