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# Quality Control of Solar Radiation Data within Sonda Network in Brazil: Preliminary results.

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## Abstract

The assessment of renewable energy resources requires supplementary site specific ground data to validate the solar irradiation databases derived from satellite information by using numerical modeling of radiative processes in atmosphere. The quality control is a key aspect of any data acquisition program in order to guarantee reliability and allow comparison analysis between different observational datasets. The Brazilian Institute for Space Research (INPE) has implemented the Brazilian Environmental Data Organization System (SONDA) network to provide solarimetric and meteorological data to support the Brazilian energy sector regarding to the information demand on solar and wind energy resources. Currently, a better understanding on solar resource variability (seasonal and interannual) is becoming increasingly required since the growth of the solar energy share in Brazilian Electricity Matrix is very likely for the next years. This work presents a detailed description of the SONDA network and all procedures adopted to ensure the data quality before deliver for free public access.

key-words: Solar radiation database, Remote sensing, Quality Control, SONDA network

## 1. Introduction

The modern lifestyle demands a continuous and reliable supply of energy. The human development, as indicated by socio-economic parameters, is strongly related to per capita consumption of energy so that a strong increase in energy demand is expected along the next decades as a result of the improvement on living conditions in emerging economies like Brazil (Asif, M and T. Munee, 2007).

The energy planning, as well as renewable power plant projects, requires reliable information and data to support decision-making processes by investors, energy entrepreneurs, and government and non-government organizations (Pereira and Lima, 2008; Moradi, 2009; Tang et al., 2010; Journeé and Bertrand, 2011, Martins and Pereira, 2011). In order to reduce the lack of information, the Centre for Earth System Science at Brazilian Institute for Space Research (CCST/INPE) has been working in research activities related to solar and wind resource assessment since second half of 1990's. After the SWERA project funded by UNEP (Brew-Hammond, 2011), the SONDA network has been the only research program specific designed to deliver reliable meteorological and solarimetric data to support the Brazilian energy sector.

The measurements sites are strategically located to evaluate and characterize the solar energy resource in all typical regional climate conditions in Brazilian territory. All SONDA database is deliver for public access at http://sonda.ccst.inpe.br/ and it can be used as benchmark for development and validation of numerical models. The quality tests and procedures used in the SONDA database are in accordance with the standard requirements of the Baseline Surface Radiation Network (BSRN).

This paper aims in describing the SONDA network, presenting the location and configuration of the measurement sites, describing the quality control algorithm and, the preliminary results achieved with quality control. The typical features of solar energy resource in Brazil are discussed as well. The paper will first describe briefly the solar energy resource in Brazil and the SONDA network in section 2. In section 3 the quality control procedure used for SONDA database will be presented.


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## 2. Data

Currently, the SONDA network has 18 measurement stations distributed throughout Brazilian territory as shown in Figure 1.Thirteen of them are managed by CCST/INPE and partner institutions operate the other five sites. Figure 2 presents some pictures of measurement sites operating in Southern, Northeastern and Midwestern regions of Brazil. The following criteria were considered to decide on measurement site locations:

a) Representativeness - the site location should be representative of a typical regional climate;

b) Physical security – the location should be inside a closed area under supervision of security team;

c) Topography and Obstacles – areas should be free of physical obstacles that may affect the measurements and avoiding areas with complex terrain orography;

d) Land use – sites should be located in areas with low chance of land use changes during the lifetime of the station to prevent future no-expected obstacles that could affect the data;

e) Electricity and Internet – areas close to electricity grid and inside the coverage area of INTERNET services or areas assisted by cell phone service.

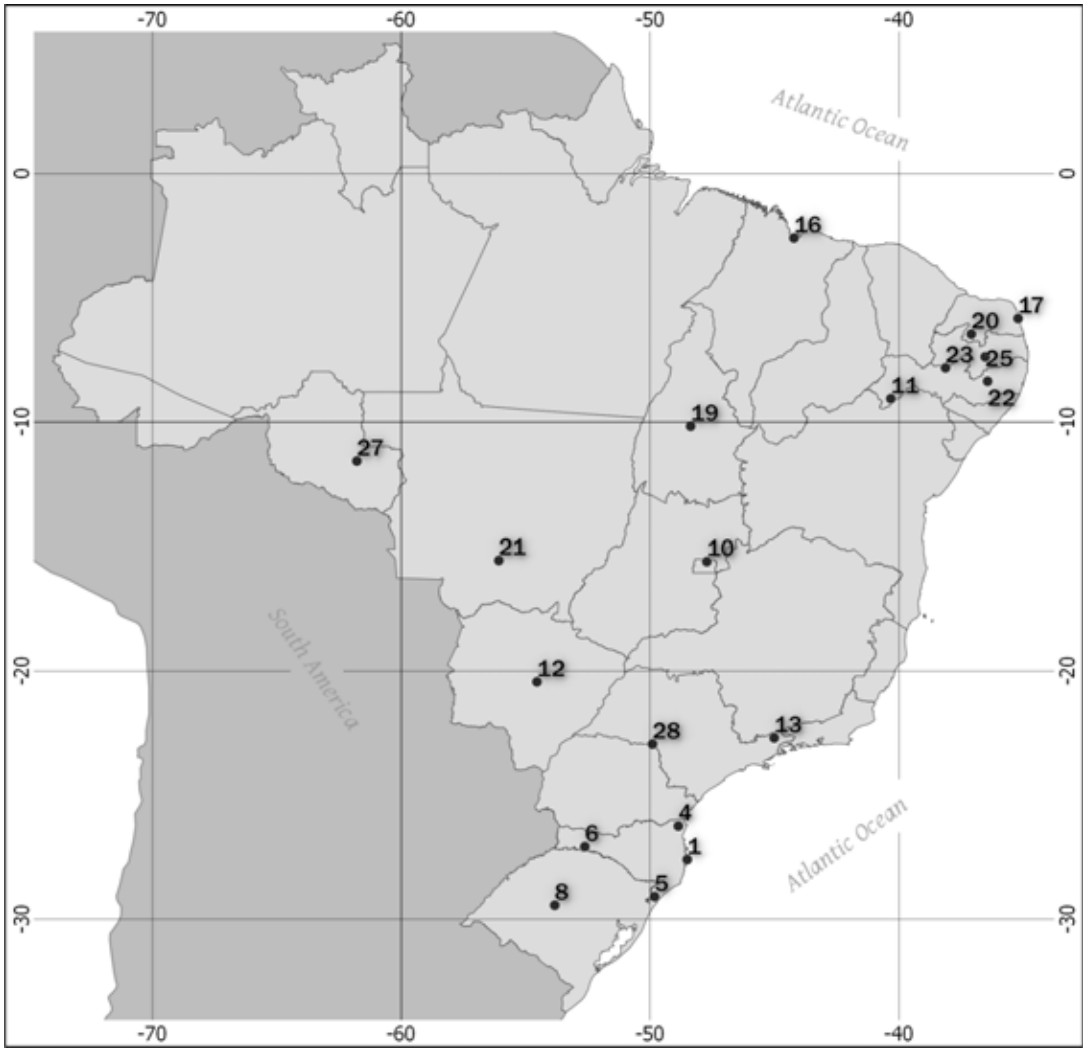


**Fig. 1: Location map of SONDA measurement sites. The ID number for each measurement site is listed in Table 2.**

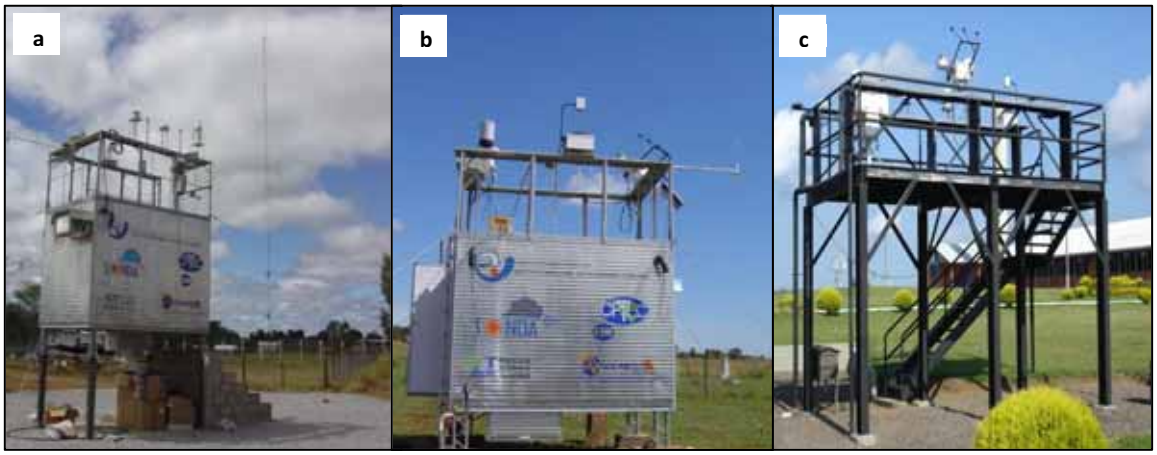


**Fig. 2: Measurement sites operating in a) Northeastern (Petrolina - PE), b) Midwestern (Brasília - DF) and c) Southern (São Martinho da Serra - RS) regions of Brazil.**

There are three classes of measurement sites in SONDA network. They are classified as solar (S), anemometric (A) or solar and anemometric (SA) and the differences among them are described at Table 1. This paper is focused in solar radiation database and, therefore, only classes S and SA will be considered. As it can be notice from Figure 2, the physical configuration of the measurement site depends on the infrastructure available for each location. Only sensors class 1, manufactured by Kipp & Zonen or Eppley Lab is being used in SONDA network to acquire solar radiation data. All the measurement sites meet the quality criteria established by World Meteorological Organization (WMO) and four of them are providing data to the Baseline Surface Solar Radiation (BSRN).

**Tab. 1: List of observed data in each class of measurement sites in SONDA network.**

| Variables | Unit | Type | | |
|---|---|---|---|---|
| | | *S* | *A* | *SA* |
| Wind speed at 25 m | $m\ s^{-1}$ | | • | • |
| Wind direction at 25 m | ° (degree) | | • | • |
| Temperature at 25 m | °C | | • | • |
| Wind speed at 50 m | $m\ s^{-1}$ | | • | • |
| Wind direction at 50 m | ° (degree) | | • | • |
| Temperature at 50 m | °C | | • | • |
| Surface air temperature | °C | • | | • |
| Relative humidity | % | • | | • |
| Atmospheric pressure | *mbar* | • | | • |
| Precipitation | *mm* | • | | • |
| Wind speed at 10 m | $m\ s^{-1}$ | • | | • |
| Wind direction at 10 m | ° (degree) | • | | • |
| Global radiation | $W\ m^{-2}$ | • | | • |
| Direct radiation | $W\ m^{-2}$ | • | | • |
| Beam radiation | $W\ m^{-2}$ | • | | • |
| Long wave radiation | $W\ m^{-2}$ | • | | • |
| PAR radiation | $\mu mol\ s^{-1} m^{-2}$ | • | | • |
| Illuminance | *kLux* | • | | • |

**Tab. 2: List of measurement sites in the SONDA network including ID number, geographic position and time frame of available data.**

| ID | Name | Code | Lat. (°S) | Lon. (°W) | Alt. (m) | Station type | Period |
|---|---|---|---|---|---|---|---|
| 1 | Florianópolis | FLN | -27.6017 | -48.5178 | 31 | *S* | 2004-now |
| 4 | Joinville | JOI | -26.2525 | -48.8578 | 48 | *S* | 2004-now |
| 5 | Sombrio | SBR | -29.0956 | -49.8133 | 15 | *S* | 2003-now |
| 6 | Chapecó | CHP | -27.0800 | -52.6144 | 700 | *S* | 2004-2010 |
| 8 | São martinho | SMS | -29.4428 | -53.8231 | 489 | *SA* | 2004-2012 |
| 10 | Brasília | BRB | -15.6009 | -47.7131 | 1023 | *SA* | 2004-now |
| 11 | Petrolina | PTR | -9.0689 | -40.3197 | 387 | *SA* | 2004-now |
| 12 | Campo Grande | CGR | -20.4383 | -54.5383 | 677 | *S* | 2004-now |
| 16 | São Luíz | SLZ | -2.5933 | -44.2122 | 40 | *S* | 2005-now |
| 17 | Natal | NAT | -5.8367 | -35.2064 | 58 | *S* | 2007-2012 |
| 19 | Palmas | PMA | -10.1778 | -48.3619 | 216 | *S* | 2004-now |
| 20 | Caicó | CAI | -6.4669 | -37.0847 | 176 | *S* | 2002-2008 |
| 21 | Cuiabá | CBA | -15.5553 | -56.0700 | 185 | *S* | 2004-now |
| 22 | Belo Jardim | BJD | -8.3675 | -36.4294 | 718 | *A* | 2004-2005 |
| 23 | Triunfo | TRI | -7.82722 | -38.1222 | 1123 | *A* | 2004-2007 |
| 25 | São João do Cariri | SCR | -7.3817 | -36.5272 | 486 | *A* | 2004-2009 |
| 27 | Rolim | RLM | -11.5817 | -61.7736 | 252 | *SA* | 2005-2009 |
| 28 | Ourinhos | ORN | -22.9486 | -49.8942 | 446 | *SA* | 2006-2011 |

The stations are located in typical macro climatic zones existing in Brazil: Coastal area and Semi-arid area of Northeastern region, Highlands and Savanna area in Midwestern, Amazon region, Southeastern and Southern regions of Brazil.

The low relative humidity, shortage and irregular rainfall, and high temperatures, that can exceed 40 degrees in the long dry season, characterize the climate in Semi-arid zone of Northeastern region of Brazil. Rainfall is less than 700 mm annually, and usually occurs between January and May. The Petrolina (11) and Caicó (20) measurement sites are located at this region.

The coastal area of Northeastern region presents a moist climate with temperatures ranging between 25°C and 31° Call year round with a strong maritime influence. During summer, the average rainfall ranges between 2,000 and 3,000 mm. The Natal (17) measurement site is located at this climate zone.

The wet equatorial climate occurs in the coastal area of Maranhão where the São Luiz (16) measurement site is located. High precipitation rates (between 1,800 and 2,200 mm per year), high temperatures and high air humidity are the major features of this climate region.

The climate in Midwest region is described as tropical semi-humid presenting two distinct seasons: a wet summer with rainfall occurring from October till March, and a dry winter, extending from April to September. The Brasilia (10) measurement site is located at the Central Highlands where a very low relative humidity value prevails during winter months, mainly in August. The sites Cuiabá (21) and Campo Grande (12) are located in floodplain, called as Pantanal. This area is one of the hottest places in the country. Pantanal is usually under the influence of the trade winds coming from the Northeast and heavy rains along the wet season.

The prevailing climate In Brazilian Northern region is the humid equatorial, characterized by high temperatures and large amounts of rainfall. Precipitation ranges between 1700 and 3000 mm per year, but its spatial and temporal distribution are quite complex in the region. There is a dry season all around Amazon region but it occurs in distinct periods for different zone. The, temperatures generally oscillates around 26° C all year round. . In some areas at the Western part of Amazon occurs the phenomenon known as “friagem“, caused by cold air masses moving through Midwestern region from the South Atlantic Ocean. The measurement sites located at Rolim de Moura (27) and Palmas (19) are in .this climate zone.

Although the climate in Southeastern region can be classified into four distinct zones, most of the region presents the tropical climate. The, annual average of temperature is around 22° C and the region presents two typical seasons: a rainy season extending from October till April, and a dry season ranging from May to

September. The coastal region is naturally more humid, and influenced by the South Atlantic Ocean. Ourinhos(28) is the only measurement site in Southeastern region. A new measurement site is being implemented in 2014 in the Eastern area of São Paulo state and data will be available soon.

Finally, the Southern region is a subtropical climate zone presenting average temperature between 16° C and 20° C. The lowest temperatures in Brazilian territory are observed in this region. In addition, daily cycle presents large temperature range. During the wintertime, temperatures can drop down to 0 °C or below, with occurrences of frost, or sporadic events of snow precipitation in high altitude areas. The seasons are quite distinct and the precipitations is well distributed on the entire region and throughout the year.. This region suffers great influence of Atlantic Polar Mass during the winter time causing large cloudiness and rainfall. The measurement sites São Martinho da Serra (8), Chapecó (6), Sombrio(5), Florianópolis(1) and Joinville, SC (4) are located in this region.

## 3. Methodology

The ground data acquisition is essential in order to get knowledge and developed new technologies on solar energy area, mainly regarding resource assessment and forecasting. However, the data acquisition without quality control has no application. The data quality is a key issue in order to provide confidence and reliability for comparison analysis among observed data and outputs provided by numerical models based on empirical relationship or numerical solution of radiative transfer equation in atmosphere.

The SONDA quality control algorithm is based on a set of statistical tests and comparisons to reference values in order to evaluate the database reliability and point out the presence of suspicious data due to electrical noise, equipment malfunctioning or lack of maintenance. The SONDA data files are delivered for public access at the SONDA website only after a quality control evaluation by using such algorithm.

The Figure 3 presents the schematic diagram for the SONDA quality control algorithm. The Figure 4 lists all the quality criteria used by the quality control algorithm (QC) algorithm. The QC evaluate meteorological data (air temperature, atmospheric pressure, relative humidity, wind speed and direction and precipitation) acquired at SONDA sites by using criteria established by the US Meteorological Resource Center (WBMET (http://www.webmet.com) accessed in October, 2013), and the World Meteorological Organization (WMO). Some adjustments were necessary due to particular features regarding the prevailing climate zones occurring in Brazil.

The quality control algorithm for solar radiation data is quite similar to the QC program used by WMO for BSRN. In the first step, ground data are compared to the reference thresholds for physically possible values in order to identify suspicious observational data. In the second phase, ground data are compared extremely rare values, in which outliers are identified in SONDA database. The third step aims at investigating data consistency by comparing measurements acquired by different sensors. Although these tests eliminate most of the errors, some data still showed some suspicion. One small change in criterion used to identify rare values in DNI data was necessary due to typical atmospheric conditions in Brazil. The reference value established for BSRN proved too restrictive signaling many real DNI data as suspicious. Thus, it was necessary to implement another step, phase 4, where the global, diffuse (beam) and direct irradiation are compared to output data provided by the clear sky model proposed by Iqbal (1983), called Parametrization Model C.

The Parametrization Model C is based on two studies developed by Bird and Hulstrom (1981a, b) and it is described in details in Iqbal (1983).The Parameterization model C provides outputs for the DNI $(I_{beam})$by using the following equation:

$$I_{beam} = 0.9751\, I_{sc}\tau_r\tau_O\tau_g\tau_w\tau_a\,, \qquad \text{(eq.1)}$$

where$\tau_r\,, \tau_O, \tau_g, \tau_w$and $\tau_a$are the transmittances due to Rayleigh scattering, ozone, uniformly mixed gases, water vapor and aerosol, respectively. The constant 0.9751 is due to spectral issues in methodology used for model development.


**Fig. 3: Schematic Diagram for quality control algorithm used in SONDA database before deliver at INTERNET.**

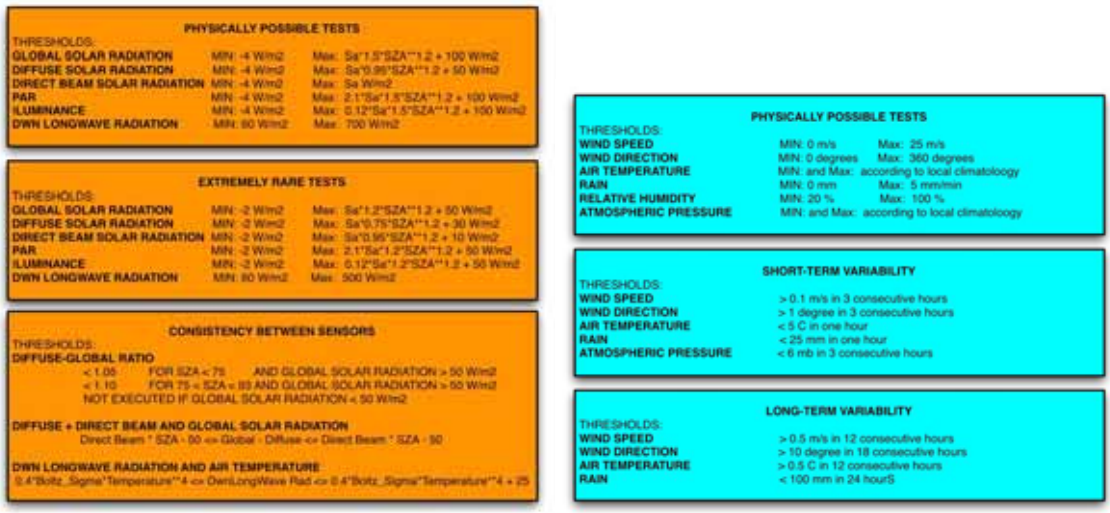


**Fig. 4: Quality criteria used in SONDA quality control algorithm.**

The model estimates the solar diffuse irradiance by using the following expression:

$$I_{dif} = (I_{beam}\cos\theta_z + I_{dr} + I_{da})\rho_g\rho_a \,/\, (1 - \rho_g\rho_a)\,, \qquad \text{(eq.2)}$$

where $\theta_z$ is the zenital angle, $I_{dr}$ is the Rayleigh-scattered diffuse irradiance after the first pass through the atmosphere, $I_{da}$ is the aerosol-scattered diffuse irradiance after the first pass through the atmosphere, $\rho_g$ is the ground albedo and $\rho_a$ is the albedo of the cloudless sky. The global solar irradiance on a horizontal surface is given by

$$I_{glo} = I_{beam}\cos\theta_z + I_{dr} + I_{da} + I_{dm}\,, \qquad \text{(eq.3)}$$

where $I_{dm}$ is the multiply scattering processes.

It is important to emphasize that the SONDA QC algorithm aims at stamping suspicious data but not take it off the database files. All SONDA data files available for public access contains both good and suspicious data, but the last one are flagged in order to leave for the user to decide if it should be used or not.

In following chapter, results obtained from a QC evaluation performed for some SONDA sites are presented and discussed. The evaluation is based on comparison analysis of indexes $\boldsymbol{K}$, $\boldsymbol{K_t}$ and $\boldsymbol{K_n}$. The K index is the ratio between diffuse solar irradiance $(I_{dif})$ and global solar irradiance $(I_{glo})$ calculated by:

$$K = \frac{I_{dif}}{I_{glo}}, \qquad \text{(eq.4)}$$

The $K_t$ index is a ratio between global solar irradiance $(I_{glo})$ and extraterrestrial solar irradiance $(I_0)$ on a horizontal surface:

$$K_t = \frac{I_{glo}}{I_0}, \qquad \text{(eq.5)}$$

Finally, the $K_n$ index is a ratio between direct normal irradiance $(I_{beam})$ and extraterrestrial solar irradiance $(I_0)$ on a horizontal surface:

$$K_n = \frac{I_{beam}}{I_0}, \qquad \text{(eq.6)}$$

## 4. Results

In order to evaluate the skill of SONDA QC algorithm to identify suspicious data, it was performed for data acquired in three measurements sites, São Martinho da Serra (site number 08 in Southern of Brazil), Brasilia (site number 10 in Midwestern region) and Petrolina (site number 11 in Brazilian Northeastern region). The timeframe of acquisition data was strategically chosen in order to encompass time periods presenting operation and maintenance problems and difficulties.

The Figure 5 shows the scatter plots for $\boldsymbol{K}$ vs. $\boldsymbol{K_t}$ and $\boldsymbol{K_n}$ vs. $\boldsymbol{K_t}$ obtained by using solar irradiance data acquired throughout December/2013 at Petrolina (site number 11) located in Northeastern region of Brazil. The QC algorithm flagged suspicious data and they are indicated by red dots in Figure 5. There were a lot of operation and maintenance issues concerning sun tracker during 2010. The QC algorithm was able to identify suspicious data acquired when sun tracker was not accurately aligned with the sun position. Data presenting Kt values larger than 0.8 were marked as suspicious in the fourth step of QC due to observational data for global solar irradiance was larger than the surface solar irradiance data provided by the clear sky model.

It can be noticed that most of suspicious data are due to bad functioning of solar tracker system required for direct beam and diffuse solar irradiance measurements. Nevertheless, there are some data (less than 10%) marked as suspicious in the range of good data (red points in the green area of scatter plots). Until this moment, the reason for these results is not clear and it is under investigation. Similar results were obtained for São Martinho da Serra and Brasília (Figures 6 and 7).

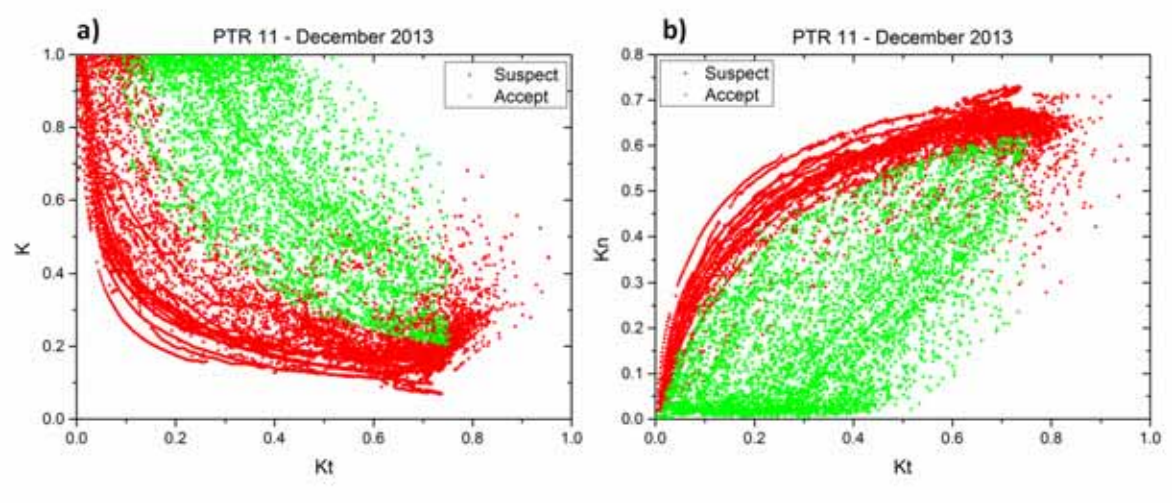


**Fig. 5: Preliminary results provided by QC algorithm performed for data files acquired at Petrolina (11) to a) K vs. $K_t$ and b) $K_n$ vs. $K_t$.**

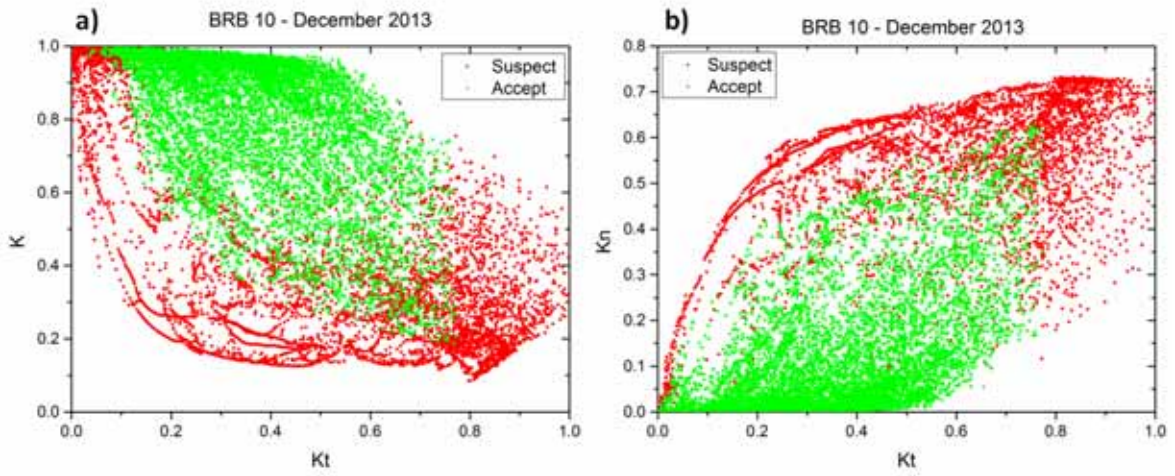


**Fig. 6: Preliminary results provided by QC algorithm performed for data files acquired at Brasília (10) to a) K vs. $K_t$ and b) $K_n$ vs. $K_t$.**

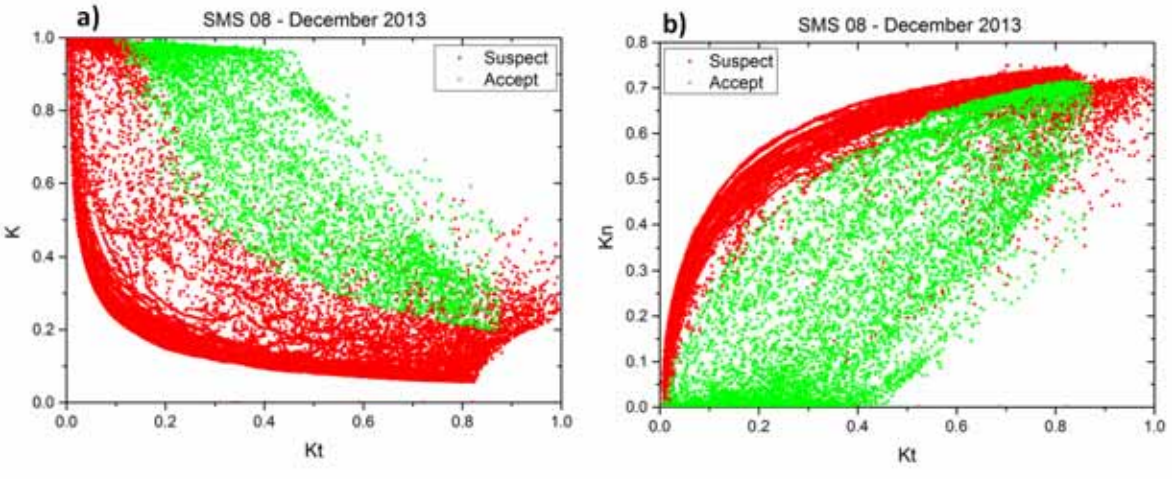


**Fig. 7: Preliminary results provided by QC algorithm performed for data files acquired at São Martinho da Serra (08) to a) K vs. $K_t$ and b) $K_n$ vs. $K_t$.**

## 5. Conclusions

This paper presents a short description of SONDA network implemented and operated by the Brazilian Institute for Space Research in order to acquire and provide reliable data for scientific community working on numerical modeling applied to renewable energy sector. All observational data base are available after quality check through SONDA website (http://sonda.ccst.inpe.br/). Data acquired in four measurement sites (São Martinho da Serra, Florianópolis, Brasília e Petrolina) integrate the Baseline Surface Radiation Network (BSRN) managed by WMO.

In addition, the paper describes the quality control algorithm fully implemented at the SONDA database. The major goal is to provide solar and wind data together with information on the confidence and reliability of observational data acquired in the SONDA data acquisition network. The purpose of QC algorithm is to point out suspicious data due to operation and maintenance problems during acquisition time period. None data is removed from the database but suspicious data are flagged in order to give a chance for the user to decide on the suitability of data for his particular purpose. The preliminary results show that the quality control procedures are consistent with the goals established. Nevertheless, there are some cases requiring more investigation in order to explain why some data in range of good data are being classified as suspicious. The complete article on the SONDA network data is under review.

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