HIGH RESOLUTION SOLAR ENERGY RESOURCE ASSESSMENT WITHIN THE UNEP-PROJECT SWERA

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ABSTRACT

To expand the world wide use of renewable energy a consistent, reliable, verifiable, and easily accessible database of solar energy resources is needed. Within the UNEP (United Nations Environment Programme) project SWERA (Solar and Wind Energy Resource Assessment, http://swera.unep.net), funded by GEF (Global Environment Facility), a global database of solar and wind energy resources will be set up. SWERA will provide, beside the wind products, global horizontal irradiance, which is mostly used to plan photovoltaic systems, and direct normal irradiance, which is needed for solar concentrating systems. For selected countries throughout the world, additionally high resolution data will be produced which is required to plan solar energy systems in detail. Within SWERA, the partners DLR, SUNY and INPE calculate solar irradiance with high temporal resolution of 1 hour and with a spatial resolution of 10km x 10km. By processing data from geostationary satellites we provide solar irradiance data for Cuba, El Salvador, Honduras, Nicaragua, Guatemala, Brazil, Ghana, Ethiopia, Kenya, China, Sri Lanka, Nepal, Bangladesh. In this paper we describe the ongoing work of developing this high resolution solar irradiance archive and cross-checking of the used solar irradiance algorithms for various satellite data.

THE SWERA PROJECT

The worldwide increasing need of energy must be satisfied by expanding the use of renewable energy, thus avoiding additional greenhouse effects. To strengthen the build up of more capacities for the use of renewable energy, reliable data of solar and wind energy are needed. Such data is scarce, specially in the solar belt or in developing countries. Thus, potential investors and governments lack basic information for planning and decision making on solar and wind energy that could be used in their countries.

To fill this gap, UNEP designed the project SWERA (Solar and Wind Energy Resource Assessment) by compiling such data in 13 countries and to facilitate investments in solar and wind energy projects [1,2]. SWERA is developing new informational tools for energy planners and project developers. These tools include regional and national maps of solar and wind energy resources and a geographical information system (GIS) that will allow easy access to the detailed information contained in these maps. These information tools can then be used to screen projects at their pre-investment planning stage. Through SWERA, UNEP encourages industry, investors, researchers, and government agencies to continuously share information that will facilitate decisions to deploy solar and wind energy projects.

SWERA is designed to deliver a number of important outcomes, including:

- Consistent, reliable, verifiable, and accessible global data on solar and wind energy resources for international and in-country investors and other stakeholders
- Better targeting and increased confidence associated with investment and development decisions for solar and wind energy projects
- Increased awareness among key stakeholders and decision makers of the potential to utilize solar and wind energy resources
- Increased local, provincial, national, and regional capacity to plan solar and wind energy projects

One product of SWERA is the high resolution (1h, 10km x 10km) solar irradiance data for the 13 countries shown in Fig. 1. Because measurements of reliable solar and wind data are scarce, DLR, SUNY and INPE will collaborate to develop one combined method for the direct and global irradiance based on METEOSAT and GOES satellite data. TERI (Tata Energy Research Institute) will provide access to INSAT data and will implement the new method for this satellite covering the Asian area. Within this same SWERA-Solar framework, UFSC/LABSOLAR(Federal University of Santa Catarina/Laboratory for Solar) in collaboration with INPE will apply an independent model, the BRASILSR [3] to map the entire South American continent however using three-hourly plus one-hourly synthetic GOES-8 data. This work will be described elsewhere. The application of two independent methods using different input data base (METEOSAT-7 and GOES-8) will provide a unique opportunity to cross validate and estimate uncertainties for distinct solar resources assessment methods. The other SWERA products related to wind energy and GIS data development will be described elsewhere.

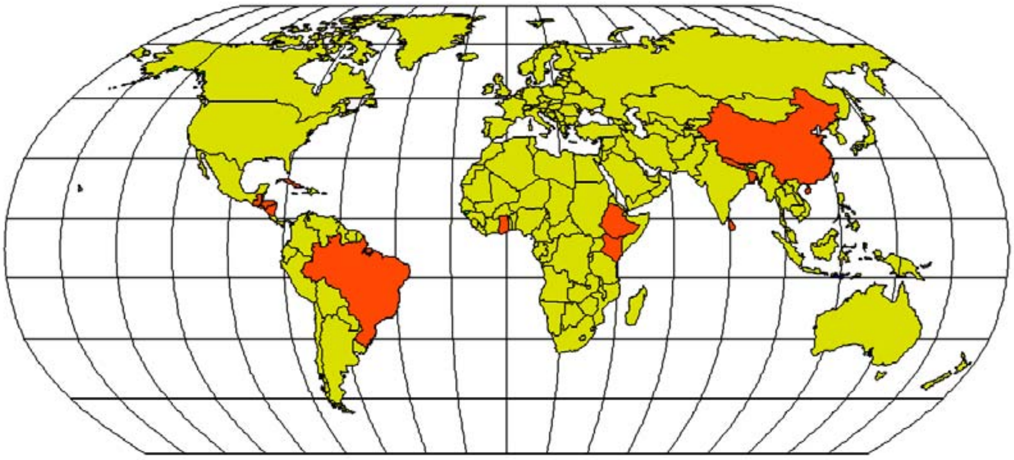

Figure 1: Participating countries for the high resolution solar irradiance assessment are Cuba, El Salvador, Honduras, Nicaragua, Guatemala, Brazil, Ghana, Ethiopia, Kenya, China, Sri Lanka, Nepal, Bangladesh

SOLAR ENERGY RESOURCE ASSESSMENT

Why using satellite data for solar energy assessment

Geostationary satellite data can be processed to produce geographically continuous, time and site specific solar resource information. Site specificity is crucial for the proper siting of solar thermal power plants whose performance is highly sensitive to microclimatic variations [4]. The map in figure 2-a illustrates that direct irradiance, driving this type of power plants, may vary considerably over short distances. It would take 100s' of well-maintained ground instruments to reproduce the features of the map.

Site/time specificity is needed when evaluating solar systems' interaction with other systems. For instance, in order to monitor the impact of dispersed PV systems upon a local electrical grid, one must know their site specific output at specific points in time corresponding to the electrical system data sampling (e.g., see [5]). Here again the satellite proves to be a powerful tool despite its accuracy limitation compared to a ground instrument. It turns out (Figure 2-b) that, beyond 25 km from a ground station, hourly satellite-derived [global] irradiances become more accurate than the same extrapolated from that station. For shorter time steps such as 1-minute data samples, the breakeven distance is only a few km. For daily data, the break-even distance is 50-70 km [6,7].

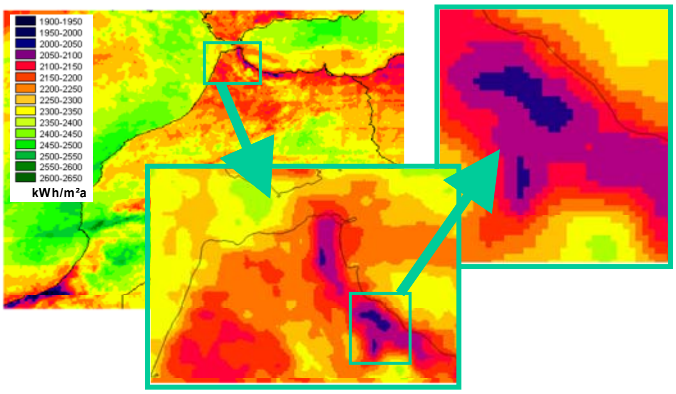

Figure 2-a: Example high resolution map of the Direct Normal Irradiance for Morocco

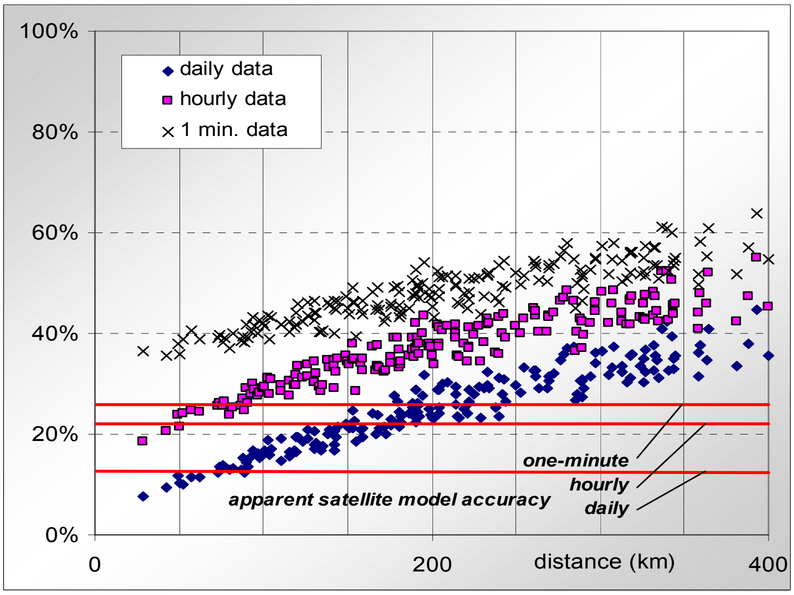

Figure 2-b: Degradation of global irradiance RMSE as a function of distance compared to apparent satellite-derived irradiance RMSE (red horizontal lines)

Methodology

Two different methods for calculating the Global Horizontal Irradiance (GHI) on the one hand and the Direct Normal Irradiance (DNI) on the other hand based on two different approaches for deriving cloud information from geostationary satellite data will be combined to gather consistent solar irradiance data.

The method for the GHI (Eqns.1 and 2) is developed by SUNY using a modified Kasten model [8] for the clear-sky irradiance with respect to the Linke Turbidity. The information about the cloudiness is taken from the VIS-channel from the GOES satellite [9]. The hourly cloudiness is represented by the Cloud-Index (CI). The following approach will be used:

$$\mathrm{GHI} = \left(0.02 + 0.98 \cdot \left(1 - \mathrm{CI}\right)\right) \cdot \mathrm{G}_{\mathrm{clear}} \tag{1}$$

with the modified Kasten model for

$$\mathrm{G}_{\mathrm{clear}} = 0.84 \cdot \mathrm{E}_0 \cdot \cos \mathrm{z} \cdot \exp\left(-0.027 \cdot \mathrm{am} \cdot \exp\left(-\mathrm{elev}/8000\right) + \exp\left(-\mathrm{elev}/1250\right) \cdot \left(\mathrm{TL} - 1\right)\right) \tag{2}$$

with the extraterrestrial solar irradiance (E_0), the solar zenith angle (z), air mass (am), ground elevation in meters (elev) and the Linke Turbidity (TL). At present, the TL is obtained from clear sky direct irradiance [10]. Within SWERA, clear sky direct irradiance will be obtained from a function of atmospheric Rayleigh scattering, absorption and scattering by aerosols and absorption by atmospheric gases, water vapor and by the ozone layer, using a zenith-angle independent modification of Kasten's formula [11].

The method for the DNI (Eqn. 3) is developed by DLR using the clear-sky parameterization model by Bird [12] with an additional transmission coefficient to take into account the attenuation of clouds. The used Cloud-Index is calculated by using the IR and VIS-channels from the METEOSAT satellite [13].

$$\mathrm{DNI} = \mathrm{E}_0 \cdot \tau_{\mathrm{R}} \cdot \tau_{\mathrm{Gas}} \cdot \tau_{\mathrm{Ozon}} \cdot \tau_{\mathrm{WV}} \cdot \tau_{\mathrm{Ae}} \cdot \tau_{\mathrm{Cl}} \qquad (3)$$

with the extraterrestrial solar irradiance (E_0) and the transmittance functions τ_i of the Rayleigh-atmosphere, mixed Gas (CO_2 and O_2), O_3, water vapor, aerosols and clouds. Both methods will be checked on consistency and will be combined for the solar energy resource assessment for the 13 countries shown in Fig.1.

Satellite data

The use of geostationary satellites is preferred for high resolution solar irradiance assessment because of the half-hourly scanning methods of these devices. Cloud motion and variations can be recognized with a better temporal resolution than by orbiting satellites. The spatial resolution is up to 2.5x2.5km² in the sub-satellite point depending on the used geostationary satellite system.

For SWERA, the following satellites are used as shown in Fig. 3:

- GOES-East for covering the participating countries in America, provided by INPE and SUNY
- METEOSAT-7 for covering the participating countries in Africa, provided by DLR
- METEOSAT-5 and INSAT for covering the participating countries in Asia, provided by DLR and TERI

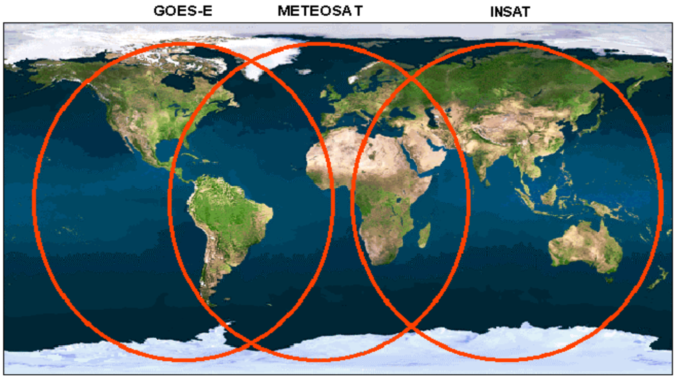

Figure 3: Coverage of used geosynchronous weather satellites

Due to the different positions of the participating countries within the satellite coverages and the different archived resolution of the satellite data, SWERA will provide 3 years of hourly solar direct and global irradiances with a spatial resolution of 10km x 10km.

Ground validation and cross-check

Ground validation and crosscheck will be performed in selected sites of Brazil, representing major climatic sub-regions as shown in Fig 4. These sites are in the process of instrument acquisition through a Brazilian founded project (FINEP/MCT, project SONDA), and are expected to be operational by beginning of 2003. Each of these cross-validation sites consists of fully equipped ground platform including global and spectral, direct and diffuse radiometers, all-sky camera and LIDAR for a fully automated – real time state of the sky monitoring, sunphotometer, nephelometer for ground visibility measurements and standard meteorological measurement. A short description of each of these validation sites follows:

1) Boa Vista (2.8°N, 60.6°W, 85 m altitude) in the Amazon region is predominantly a transition from the savanna to rain forest area. This site is under the influence of the ITCZ (Innertropical Convergence Zone) on cloudiness and is expected to show little change in surface irradiance through the year, with maximum

values during the dry months of August through October.

2) Terezina (9.4°S, 40.5°W, 376 m alt.). This site represents the harsh semi-arid area of the Brazilian northeast. The northeast region is under influence of the tropical high which is linked to the South Atlantic tropical anticyclone during the whole year which confer this semi-arid region a stable climatic regime. The site has one of the lowest cloud coverage indexes in the whole country (about 260 day per year of cloudless sky), which grants it an average solar irradiance of more than 6kWh/m^2.
3) Cuiabá (15.6°S, 56.1°W, 176 m alt.). This site is the best representative area of the savanna in Brazil. It is located in central Brazil near the deforestation rim of the Amazon, where the effect of biomasss burning is on most active. It is an important site to investigate the effects of the aerosols on solar irradiance.
4) Santa Maria (29.7°S, 53.8°W, 151 m alt.). It is located in the south of Brazil where seasonal effects on solar irradiance are most apparent. Also, the influence of the frontal systems associated to the Antarctic polar anticyclone contributes to the increase of cloudiness mainly during winter.

Other existing Brazilian solar stations and selected ground solar sites, also indicated in Fig 4, will be integrated into this validation network. The first six month of the project will be devoted to crosscheck the different satellite models over a region where METEOSAT-7 has its best surface coverage in Brazil. This region is indicated in the Fig 4 as several hues of yellow with the approximate angle of view for METEOSAT-7. The ground station will be located near the city of Caicó (6.5°S, 37.1°W, 151m alt.).

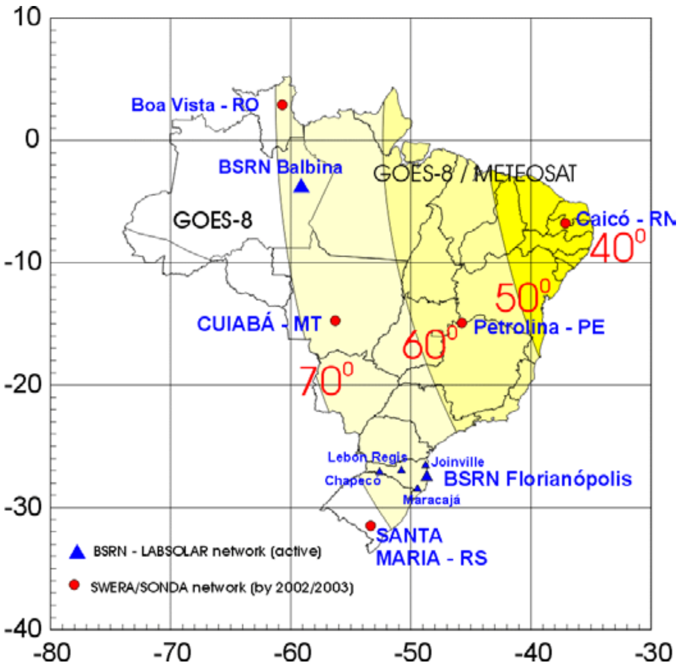

Figure 4. Solar validation and cross-comparison sites in Brazil

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