CROSS-VALIDATION OF SWERA's CORE RADIATIVE TRANSFER MODELS - PARTIAL REPORT.

Goal

The main goal of this report is to present and discuss the partial results obtained for the cross-validation task of the SWERA Project. Deviations of global horizontal solar estimates obtained using BRASIL-SR and SUNY-ALBANY models are compared with a reference model HELIOSAT and validated for three ground sites in Brazil.

Last update

This report was updated in 09/15/2003.

Comments

This partial report describes the results obtained by two of the core radiative transfer models adopted in the SWERA Project for global horizontal solar irradiation during the cross-validation step. They are BRASIL-SR and SUNY-ALBANY models (Martins, 2001; Stuhlmann et al. 1990; Perez et al., 2002). The results from other two other core models, NREL and DLR, are not yet available. Only global horizontal solar irradiation is available and discussed in this document. Results for the direct and diffuse solar components are in the process of computation and will be presented in the next report. The HELIOSAT was included as a reference model at this stage. The HELIOSAT model is widely employed for solar energy assessment in Europe and is well know by the solar energy community worldwide (Beyer et al., 1996; Cano et al., 1986).

Three sites provided ground measurements to the cross-validation step described in this work: Caicó, Florianópolis and Balbina. Table 1 shows the prime information for the three ground sites. They were chosen because of their high quality radiation data and also because they represent basically three of the major climatic environments in the tropics: The coastal semi-arid region, the pristine rain forest and a sub-tropical industrialized area. The geographical location is an important factor to be considered in order to evaluate the model's performance for different climate and environments.

Caicó is located in an area of large insolation all year round, with over 120 sunny days, and annual precipitation less than 700mm. For this reason, it is well suited for fine-tuning radiative transfer models in clear sky conditions. Caicó has a high annual mean temperature, around 28^{o}C, and the measurement site is in a flat land area with sparse brushwood-type vegetation. Caicó was installed and started operation in November 2002. Florianópolis ground site is located in a medium size city (under 400,000 inhabitants) in a coastal area of the Brazilian South region. Rains are fairly well distributed along the year and temperature ranges from 14^{o}C in winter to 28^{o}C in summer. The measurement site was installed in 1991 as part of "Baseline Solar Radiation Network" (BSRN) and provides data of direct normal incidence, global horizontal, and diffuse solar radiation.

Balbina site is located close to a large hydroelectric power plant in the middle of the Brazilian rain forest in the Amazon region. Mean temperature varies from 23^{o}C to 33^{o}C. Precipitation is high mainly during the rain season from November to April. During this season, it is common to observe cloudy skies in all satellite images at a specific site and time for an entire month. Therefore, systematic errors in the cloud cover index obtained from satellite images occur often. This important characteristic makes Balbina particularly attractive for model cross-validation and improvements. Although Balbina is one of the two BSRN sites in Brazil, it has a precarious maintenance linked to its remote location and associated logistic difficulties. As a consequence the database for Balbina is not complete and only a small set of solar radiation data were available to be used in this work. Balbina started operation in 1998 and provides global horizontal, diffuse and direct solar radiation data.

Table 1. Geographical information for the three cross-validation sites.

Site	Latitude Longitude	Altitude (m)	Month	Temp. (ºC)	RH (%)	Surface Albedo	Other information
Caicó	6º28'01''S 37º05'05''W	175,85	Nov	27,98	60,5	0,134	Installed to provided ground data to the SWERA Project
			Dec	28,25	64,6	0,136	
			Jan	28,06	74,6	0,138	
			Feb	28,22	82,9	0,145	
Florianópolis	27º34'18''S 48º31'42''W	12	Nov	21,53	86,2	0,164	BSRN site
			Dec	23,52	87,2	0,168	
			Jan	22,99	88,6	0,167	
			Feb	24,16	89,6	0,173	
Balbina	1º55'07''S 59º25'59''W	230	Nov	28,33	94,1	0,133	BSRN site
			Dec	27,83	95,1	0,134	
			Jan	26,91	95,4	0,131	
			Feb	27,03	95,1	0,133	

The BRASIL-SR and SUNY-ALBANY models produce global solar estimates for the following times: 8:45UTC, 11:45UTC, 14:45UTC, 17:45UTC, 20:45UTC. The temporal resolution of three hours was restricted to the availability of GOES images for South America. The model computing codes were adjusted to estimate the total solar radiation in a one-hour interval around the hour. Daily total estimates used for the cross validation were obtained by simply summing up the hourly estimates without any interpolation between consecutives satellite images.

The BRASIL-SR model adopts a threshold for solar zenith angle of 80^{o} in order to reduce errors with the atmospheric parameterization when the Sun is very low near to the horizon. For this reason, SUNY-ALBANY model provided more hourly estimates than the BRASIL-SR model since the solar zenith angle is larger than the threshold at 8:45UTC in Florianópolis and 20:45UTC in Caicó.

The HELIOSAT model uses METEOSAT images with a larger temporal and spatial resolution than the GOES-8 images used by the two other models. Table 2 shows a comparison between METEOSAT an GOES-8 images used in the cross-validation task. A visual comparison of both satellite images is presented in Figure 1.

Table 2. Characteristics of satellite images used to calculate cloud cover index – input data for the radiative transfer models.

Satellite	Model	Spatial resolution	Temporal resolution	Number of images per day
GOES-8	BRASIL-SR, SUNY-ALBANY	12km X 15km	3 hours	5
METEOSAT	HELIOSAT	4km X 4km	1 hour	12

Tables 3 and 4 show the relative Mean Bias Error (rMBE) and the relative Root Mean Square Error (rRMSE), respectively, for hourly and daily estimates obtained by each radiative transfer model. The relative value is the ratio between the error and the mean global solar irradiation in the time period analyzed.

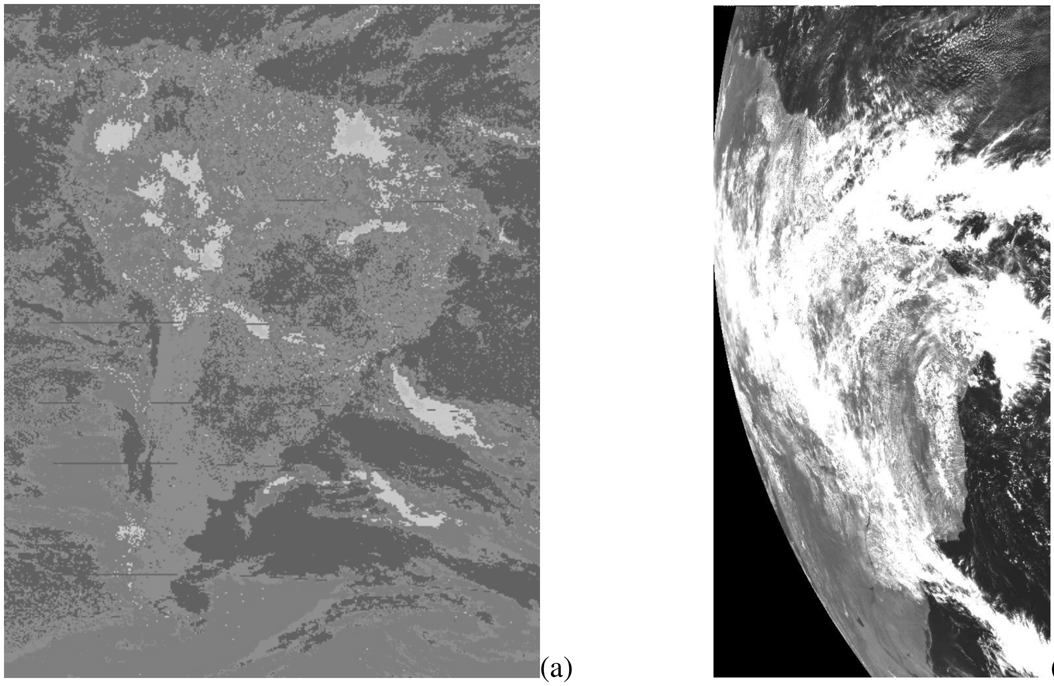

(a) (b)

Figure 1. Satellite images used in the cross-validation step obtained by (a) GOES-8 e (b) METEOSAT in the visible spectral range.

The SUNY-ALBANY estimates were provided by Richard Perez from State University of New York. It was necessary an extra handling of data to calculate de rMBE and rRMSE for daily estimates using the following criteria adopted in BRASIL-SR model:

- discard hourly estimates with solar zenith angle larger than 80^o;
- discard days with less than 3 estimates fulfilling the first criteria.

Values for the HELIOSAT deviations were directly provided by Hans Georg Beyer from Oldenburg University (Germany) and, therefore, would not meet the criteria described above. Furthermore the HELIOSAT model estimations have a larger spatial and temporal resolution owing to the use of the METEOSAT satellite data.

The Figure 2 shows a graphic comparison among rMBE and rRMSE values in hourly estimates obtained by each radiative transfer model. It can be noted that BRASIL-SR underestimate global solar radiation in Caicó but the absolute values are similar for all radiative transfer models. The BRASIL-SR model provided the lowest values for rRMSE in Caicó, except for November/2002 when HELIOSAT has presented an rRMSE 50% lower. In Florianópolis, all models presented similar rMBE values and BRASIL-SR provided estimates with lower rRMSE. The BRASIL-SR presented lower rMBE and rRMSE values in Balbina. The SUNY-ALBANY did not deliver the solar radiation estimates for Balbina until this moment.

Similar conclusions can be obtained for daily estimates from Figure 3. An important point deserves mention: the rMBE values for hourly and daily estimates are equals. It must be verified if the daily values are correct.

The Figures 4 and 5 show the “estimated values” versus “measured values” for hourly global horizontal solar irradiation in Florianópolis and Caicó, respectively. The Figures 6 and 7 present the same plot for daily values. Only BRASIL-SR and SUNY-ALBANY data are presented since HELIOSAT estimates did not delivered the corresponding results until now. As soon as these data are available, the report will be updated.

Table 3. The rMBE e rRMSE deviation values obtained for the hourly solar irradiation estimates in the three ground sites.

Month	Model	Ground Sites					
		Florianópolis		Caicó		Balbina	
		rMBE	rRMSE	rMBE	rRMSE	rMBE	rRMSE
November 2002	BRASIL-SR	-0,03	0,21	-0,05	0,21	dna**	dna**
	SUNY-ALBANY	nc*	nc*	nc*	nc*	dna**	dna**
	HELIOSAT	-0,01	0,23	-0,02	0,11	dna**	dna**
December 2002	BRASIL-SR	0,01	0,27	-0,01	0,17	dna**	dna**
	SUNY-ALBANY	nc*	nc*	-0,05	0,15	dna**	dna**
	HELIOSAT	nc*	nc*	0,03	0,18	dna**	dna**
January 2003	BRASIL-SR	0,02	0,26	-0,02	0,17	0,01	0,21
	SUNY-ALBANY	0,02	0,27	-0,01	0,22	nc*	nc*
	HELIOSAT	0,05	0,29	0,001	0,18	0,08	0,30
February 2003	BRASIL-SR	0,08	0,19	-0,04	0,18	-0,006	0,24
	SUNY-ALBANY	0,03	0,32	0,03	0,47	nc*	nc*
	HELIOSAT	0,09	0,24	0,01	0,20	-0,003	0,50

* nc - not calculated.
** dna – ground data not available.

Table 4. The rMBE e rRMSE deviation values obtained to the daily solar irradiation estimates in the three ground sites.

Month	Model	Ground Sites					
		Florianópolis		Caicó		Balbina	
		rMBE	rRMSE	rMBE	rRMSE	rMBE	rRMSE
November 2002	BRASIL-SR	0,01	0,09	-0,04	0,13	dna**	dna**
	SUNY-ALBANY	nc*	nc*	nc*	nc*	dna**	dna**
	HELIOSAT	-0,01	0,08	-0,02	0,05	dna**	dna**
December 2002	BRASIL-SR	0,01	0,12	-0,04	0,06	dna**	dna**
	SUNY-ALBANY	0,04	0,14	-0,05	0,07	dna**	dna**
	HELIOSAT	nc*	nc*	0,03	0,06	dna**	dna**
January 2003	BRASIL-SR	0,03	0,13	-0,006	0,06	0,04	0,12
	SUNY-ALBANY	-0,004	0,11	0,02	0,09	nc*	nc*
	HELIOSAT	0,05	0,12	0,001	0,07	0,08	0,14
February 2003	BRASIL-SR	0,11	0,13	-0,04	0,15	0,08	0,14
	SUNY-ALBANY	nc*	nc*	-0,02	0,26	nc*	nc*
	HELIOSAT	0,09	0,12	0,01	0,06	-0,003	0,24

* nc - not calculated.
** dna – ground data not available.

Looking at Figures 4, 5, 6 and 7, it can conclude that both models have presented similar behaviors. The plots presented comparable results for data dispersion with a slightly better result for the BRASIL-SR. The Tables 5 and 6 present the correlation factors between estimated and measured values of global solar irradiation. The correlation factors were obtained only for the SWERA's core radiative transfer models. It can be observed a good agreement between the models.

The lowest correlation factors were obtained for Caicó. The calculation procedure to obtain cloud cover index from satellite images is the most feasible reason for this lower correlation. As mentioned before, Caicó has a great number of clear sky days per year, and cloud types are mainly fair weather Cumulus, which are hard to detect in satellite images with the spatial resolution adopted in this task. This can produce two effects that reduce the correlation and increase deviations between estimated and measured values:

- projected shadows over ground radiometers;
- border effect (reflection) caused by broken clouds.

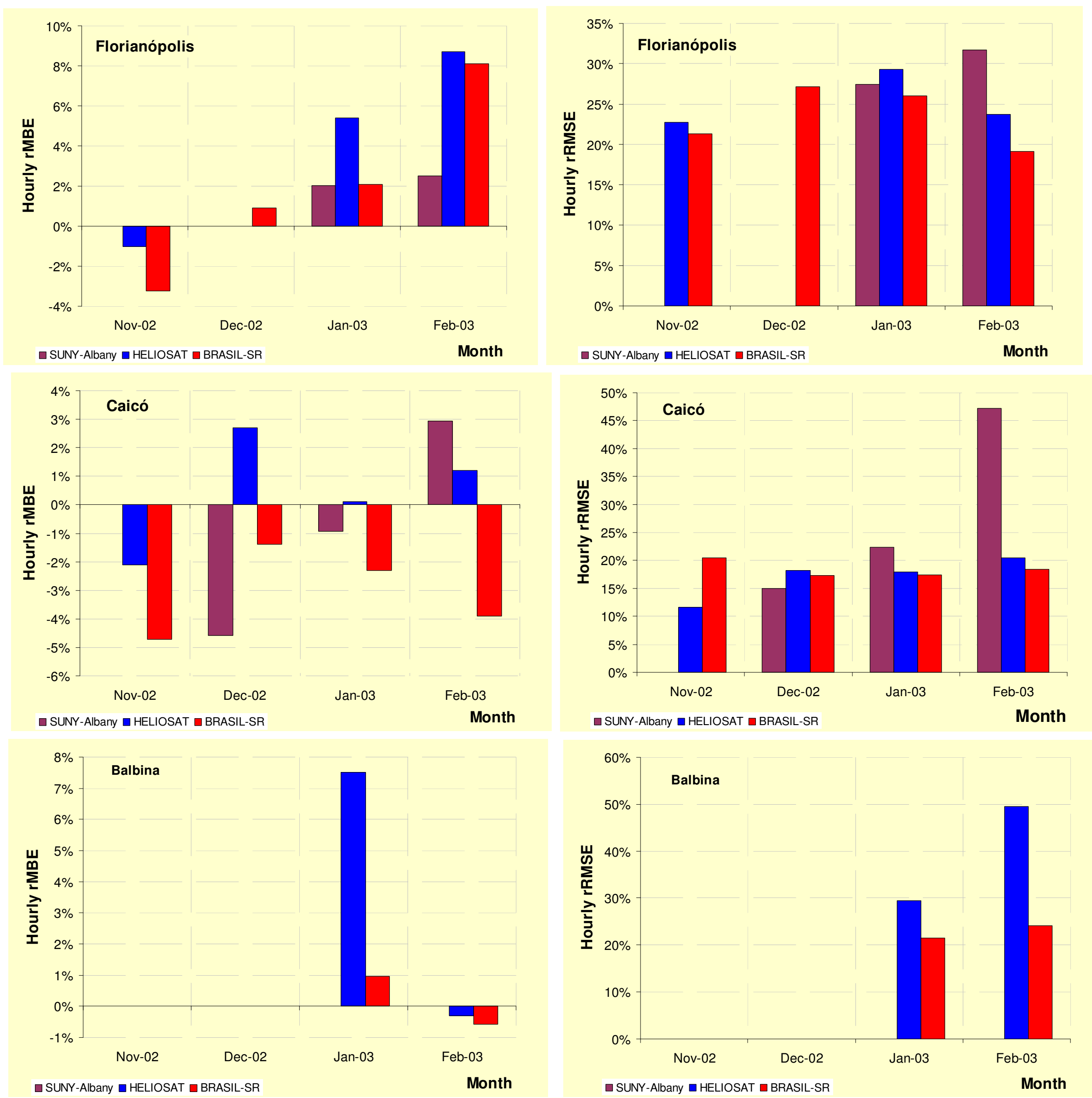


Figure 2. Comparison among rMBE and rRMSE values obtained for each model in all three ground measurement sites used in the cross-validation step.

An interesting aspect that deserves attention is the time scale behavior of both models in Caicó. The hourly estimates provided by SUNY-ALBANY model produced a better correlation factor than the daily estimates. The inverse behavior was presented by BRASIL-SR model.

The reason of very low correlation factors obtained for daily estimates in Caicó on November/2002 and in Balbina on January/2003 must be investigated. As soon as data from SUNY-ALBANY and HELIOSAT are available for the specific months at these sites, it will be possible to found a clue to get better results.

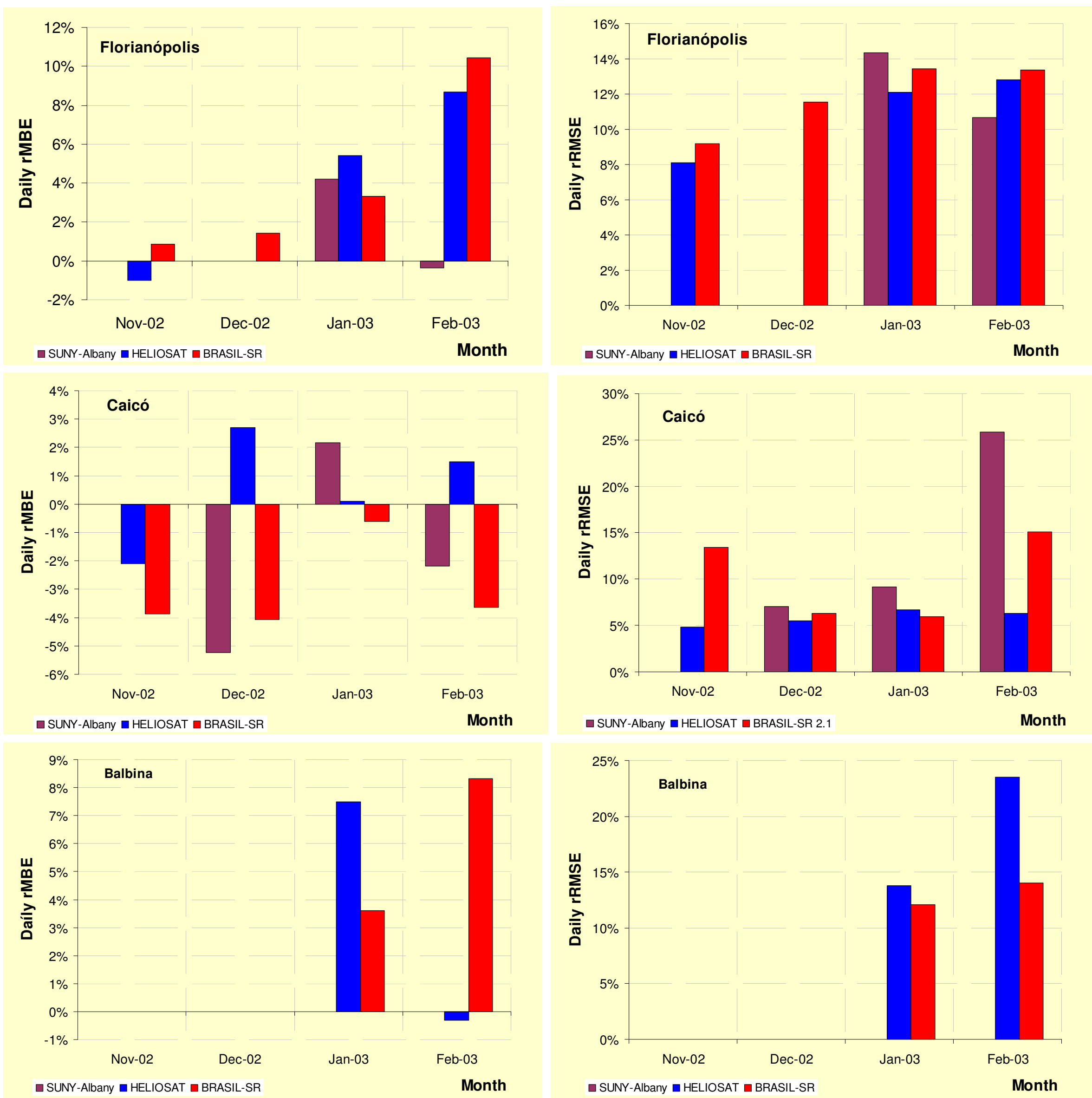
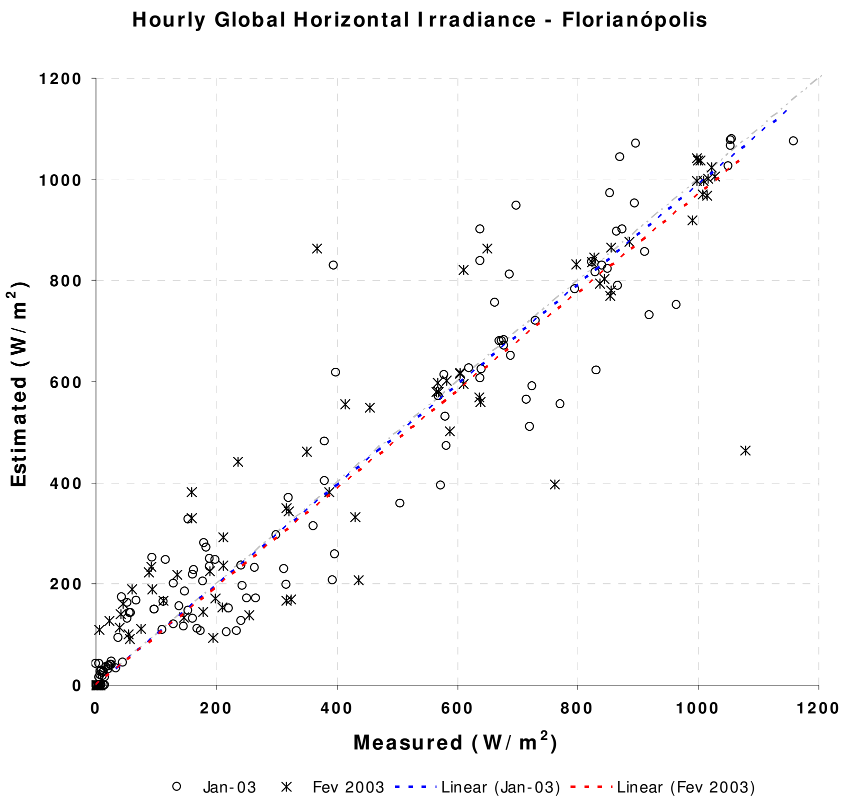


Figure 3. Comparison among rMBE and rRMSE values obtained for each model in all three ground measurement sites used in the cross-validation step.



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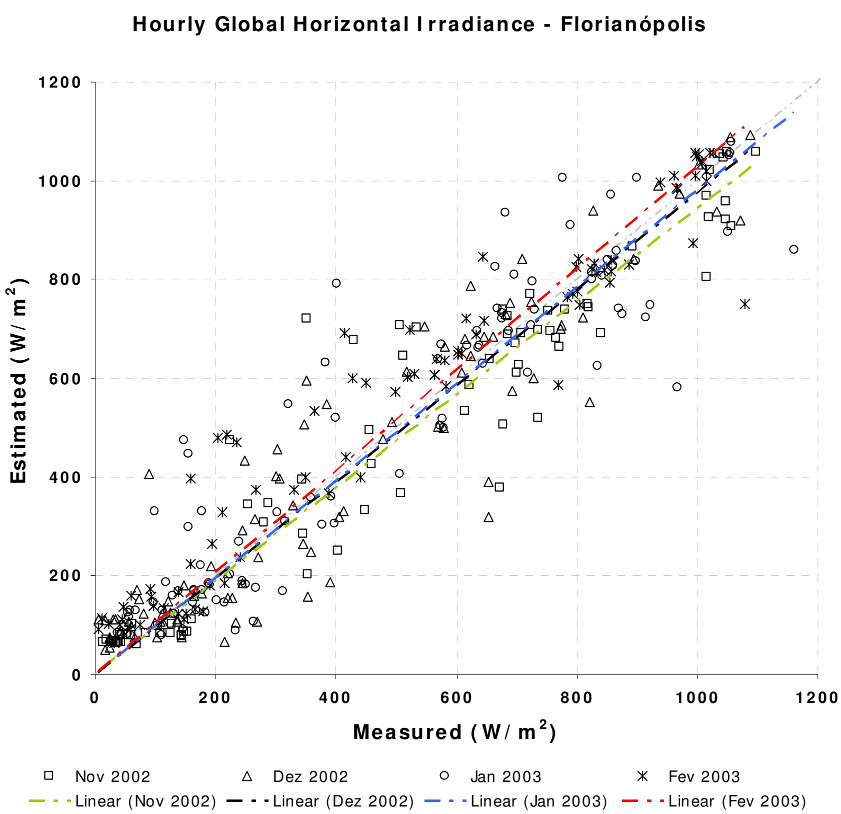
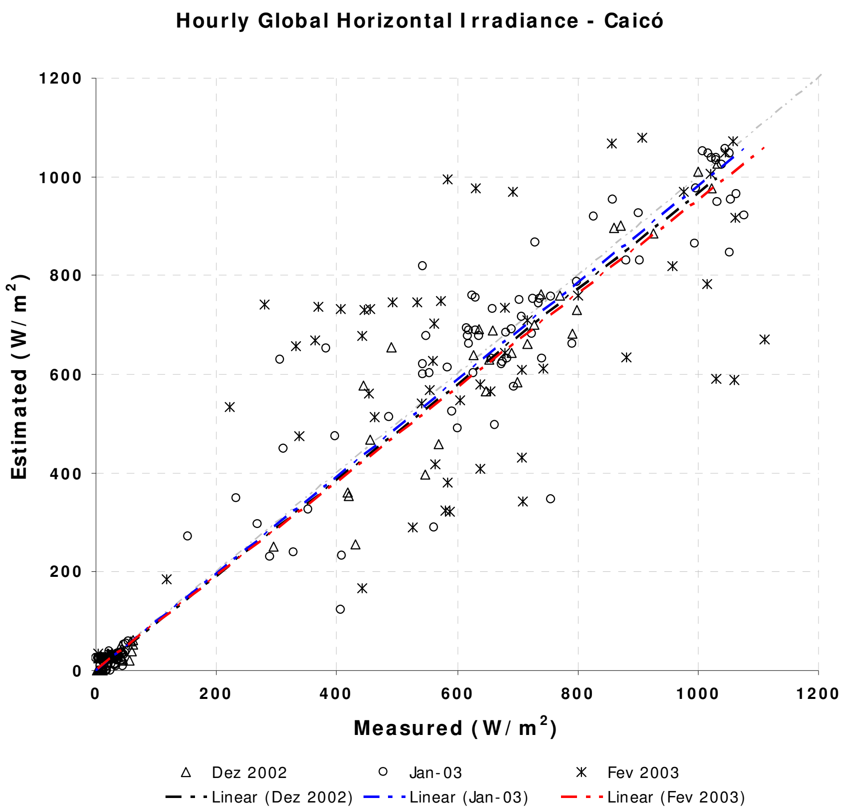


(b)

Figure 4. Estimated versus Measured values for hourly global solar irradiation in Florianópolis: (a) SUNY-ALBANY model and (b) BRASIL-SR model.



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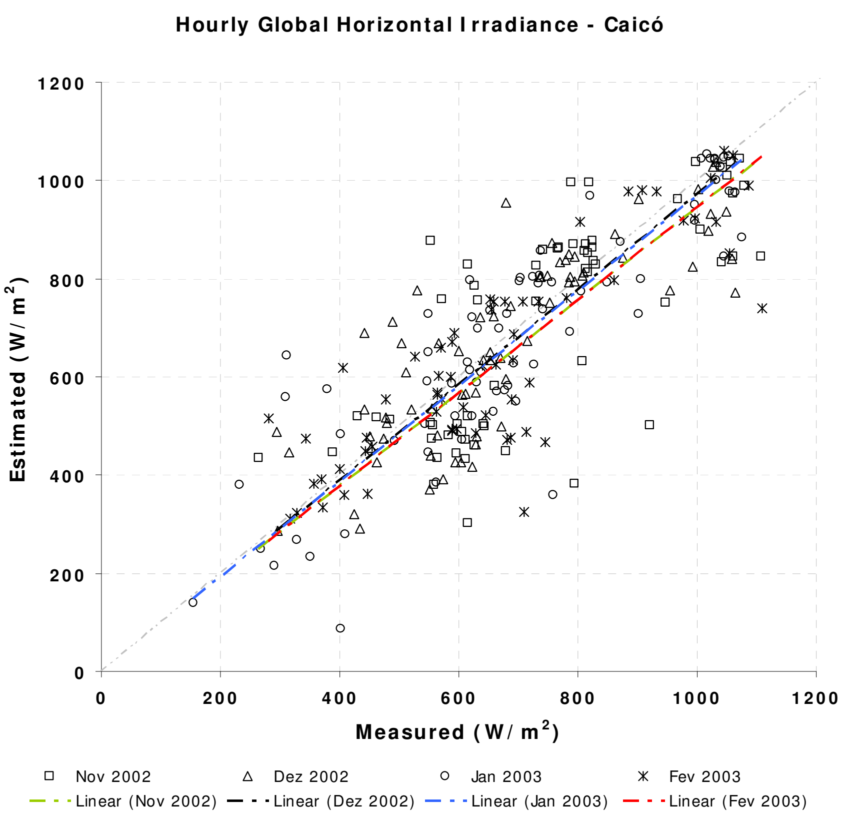
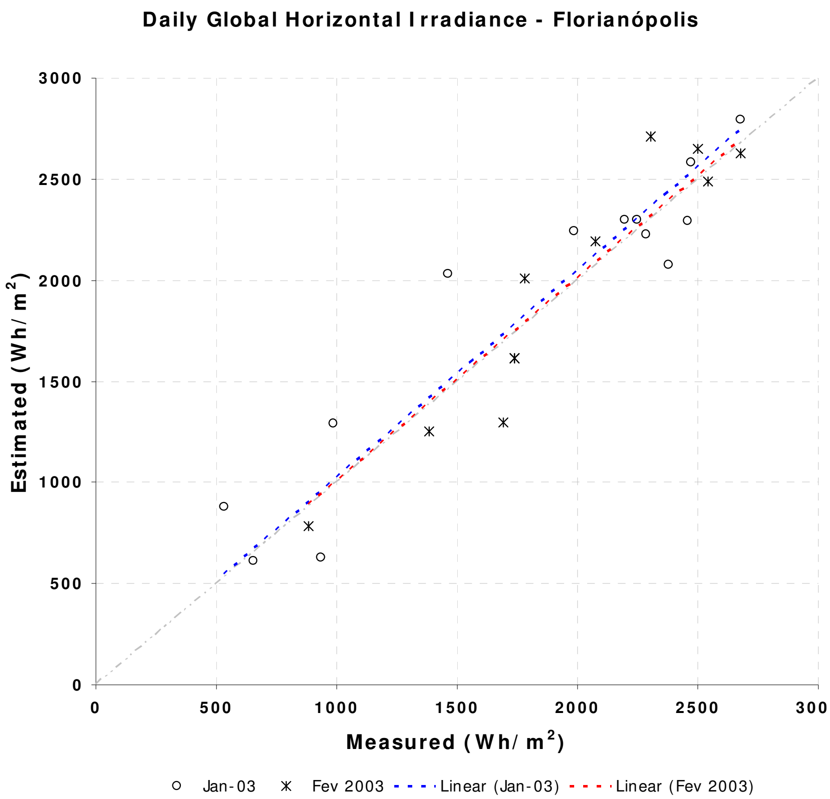


(b)

Figure 5. Estimated versus Measured values for hourly global solar irradiation in Caicó: (a) SUNY-ALBANY model and (b) BRASIL-SR model.



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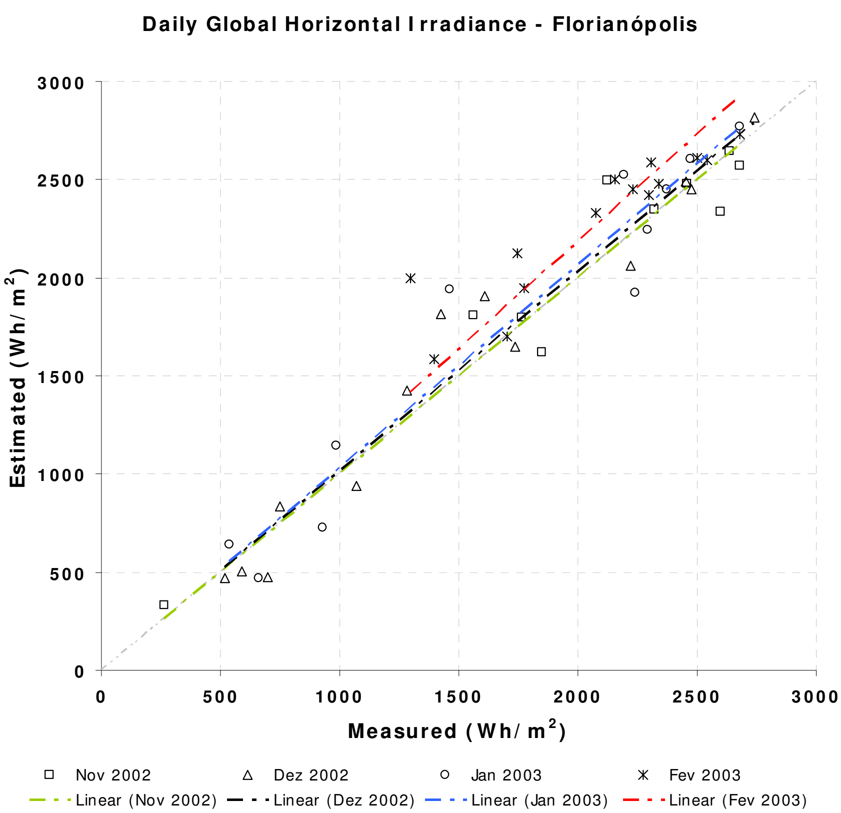
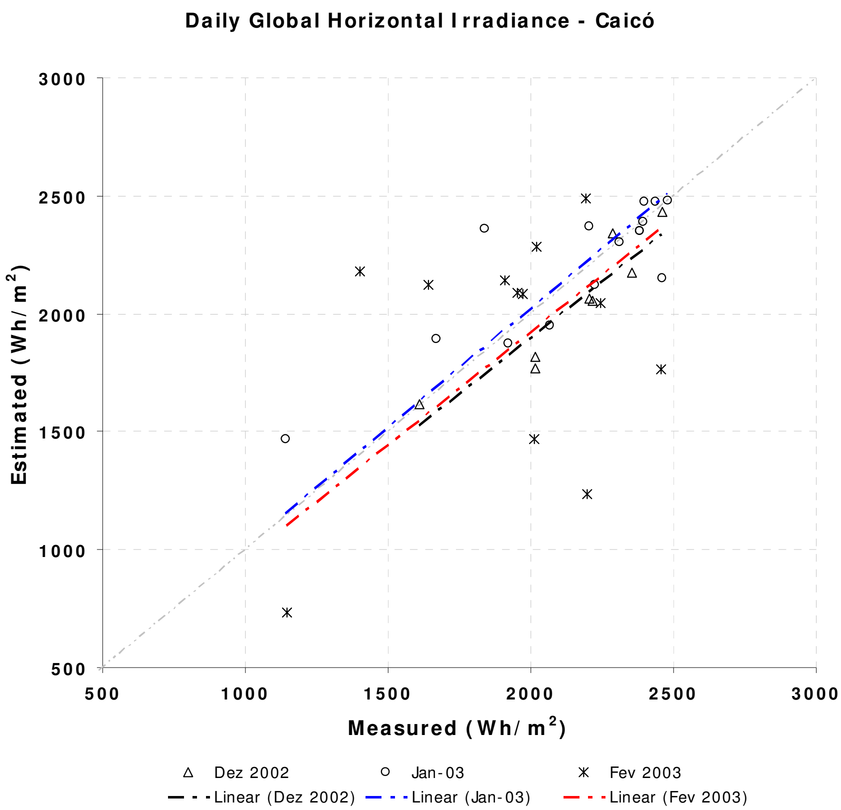
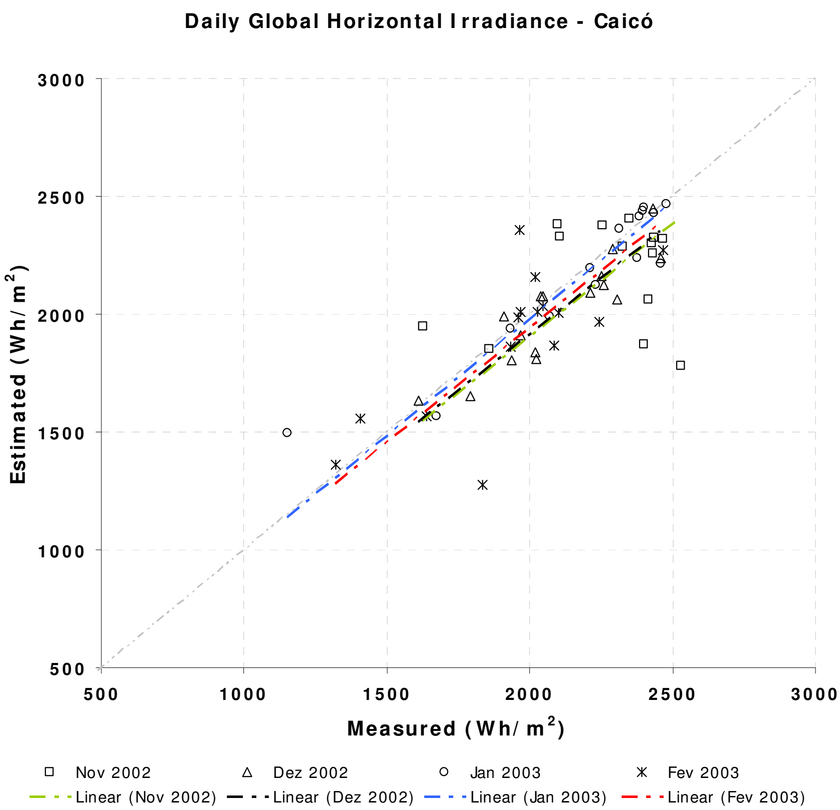


(b)

Figure 6. Estimated versus Measured values for daily sum of global solar irradiation in Florianópolis: (a) SUNY-ALBANY model and (b) BRASIL-SR model.



(a)



(b)

Figure 7. Estimated versus Measured values for daily sum of global solar irradiation in Caicó: (a) SUNY-ALBANY model and (b) BRASIL-SR model.

Table 5. Correlation factor among estimated and measured hourly global solar irradiation in all three ground sites used in cross-validation step.

Ground sites	Month	Radiative Transfer Models	
		BRASIL-SR	SUNY-ALBANY
Florianópolis	November 2002	0,95	nc*
	December 2002	0,94	nc*
	January 2003	0,92	0,96
	February 2003	0,97	0,95
	All data	0,95	0,96
Caicó	November 2002	0,75	nc*
	December 2002	0,82	0,98
	January 2003	0,87	0,97
	February 2003	0,84	0,88
	All data	0,83	0,94
Balbina	January 2003	0,93	nc*
	February 2003	0,92	nc*
	All data	0,92	nc*

* nc - not calculated.

Table 6. Correlation factor among estimated and measured hourly global solar irradiation in all three ground sites used in cross-validation step.

Ground sites	Month	Radiative Transfer Models	
		BRASIL-SR	SUNY-ALBANY
Florianópolis	November 2002	0,96	nc*
	December 2002	0,98	nc*
	January 2003	0,96	0,94
	February 2003	0,91	0,95
	All data	0,96	0,94
Caicó	November 2002	0,25	nc*
	December 2002	0,90	0,93
	January 2003	0,94	0,85
	February 2003	0,75	0,32
	All data	0,78	0,61
Balbina	January 2003	0,12	nc*
	February 2003	0,90	nc*
	All data	0,83	nc*

* nc - not calculated.

References

H. G. Beyer, C. Costanzo, and D. Heinemann. Modifications of the HELIOSAT procedure for irradiance estimates from satellite data. *Solar Energy,* 56, 121– 207, 1996.

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

F. R. Martins. Influência do processo de determinação da cobertura de nuvens e dos aerossóis de queimada no modelo físico de radiação BRASIL-SR. PhD. Thesis. INPE (Brazilian Institute for Space Research). São José dos Campos. Brazil, 2001.

R. Stuhlmann, M. Rieland, and E. Raschke. An improvement of the IGMK model to derive total and diffuse solar radiation at the surface from satellite data, J. Appl. Meteor., 18, 586-603, 1990.

R. Perez, P. Ineichen, K. Moore, M. Kmiecik, C. Chain, R. George and F. Vignola, (2002): A New Operational Satellite-to-Irradiance Model. Solar Energy 73, 5, pp. 307-317.