Solar Radiation Forecast using Artificial Neural Networks

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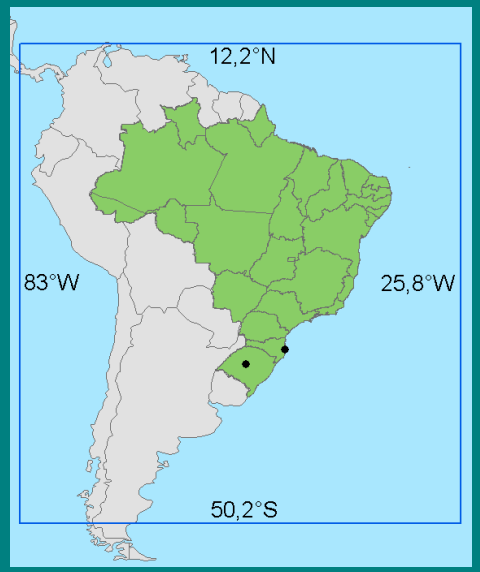
IRS-2008. Foz do Iguaçu, August, 03-08, 2008.

Rationale

- Climate Models: tool for weather forecast.
- Climate data provided by mesoscale models can be used in other applications like renewable energy planning or power generation management by energy sector companies or government decision makers
  - Forecasts for solar irradiation at the surface and wind velocity data can be used for:
    - PV systems operation and management;
    - Solar heaters design and projects and operation
    - Hybrid Systems management;
    - Interconected electricity distribution systems operation and management

Model Eta/CPTEC

Details on model Eta can be found in Mesinger *et al*. (1988), Janjić (1994) and Ničhović *et al*. (1998). The constant η-surfaces are relatively horizontal, so that the errors associated with the determination of the pressure gradient along a steeply sloped coordinate surface are minimized.



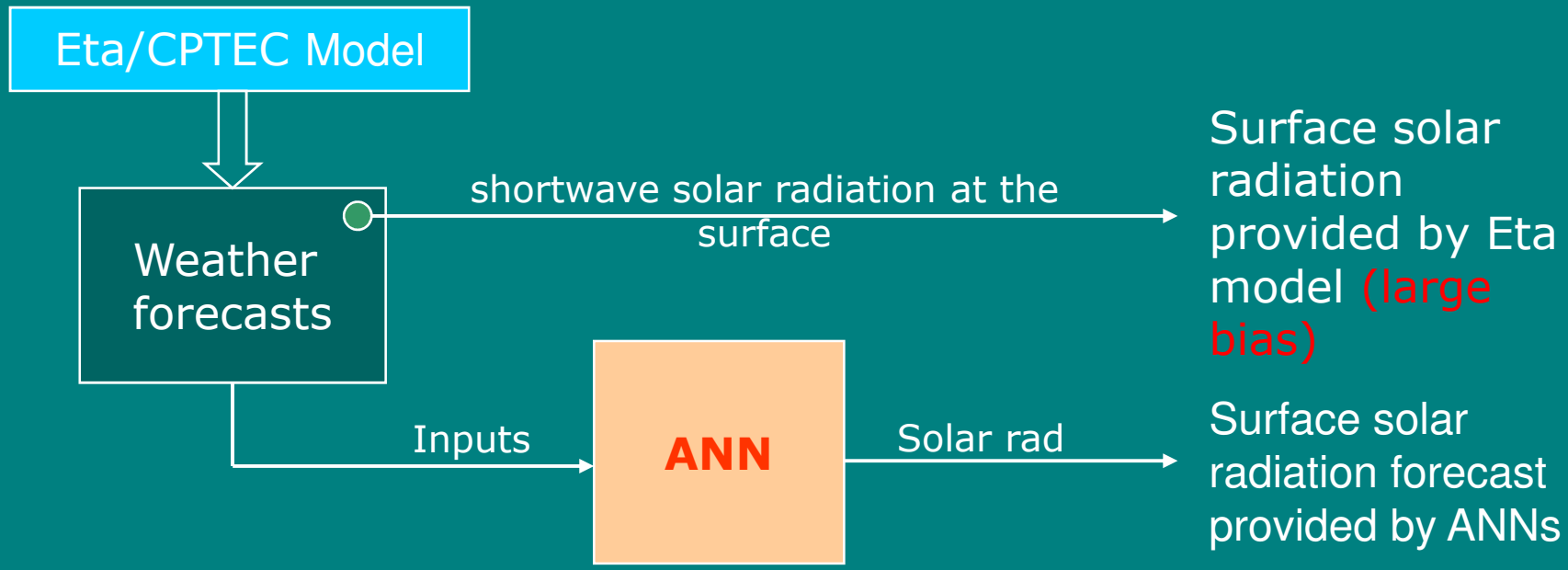
The main characteristics of model Eta/CPTEC were:

- optimized to the South America (50.2ºS-12.2ºN, and 83ºW-25.8ºW).
- configured to 40 km of horizontal resolution and 38 vertical layers.
- uses the schemes of Lacis and Hansen (1974) for SW modeling, and Fels and Schwarztkopf (1975) for LW modelling.
- uses initial conditions from NCEP analyses at 00UT and 12UT.
- uses the lateral boundary conditions taken from the CPTEC Atmospheric Global Circulation Model and updated every 6 hours.
- provides forecasts for 58 atmospheric variables: 49 of them are surface variables and the other nine variables are *profile variables* and values for 19 atmospheric pressure levels are supplied.

Model Eta/CPTEC

- Earlier studies have demonstrated that solar radiation data provided by Eta/CPTEC presents a larger bias than the required to manage several solar energy applications such as grid connected or hybrid photovoltaic (PV) systems (Hinkelman *et al*., 1999; Chou *et al*., 2002).

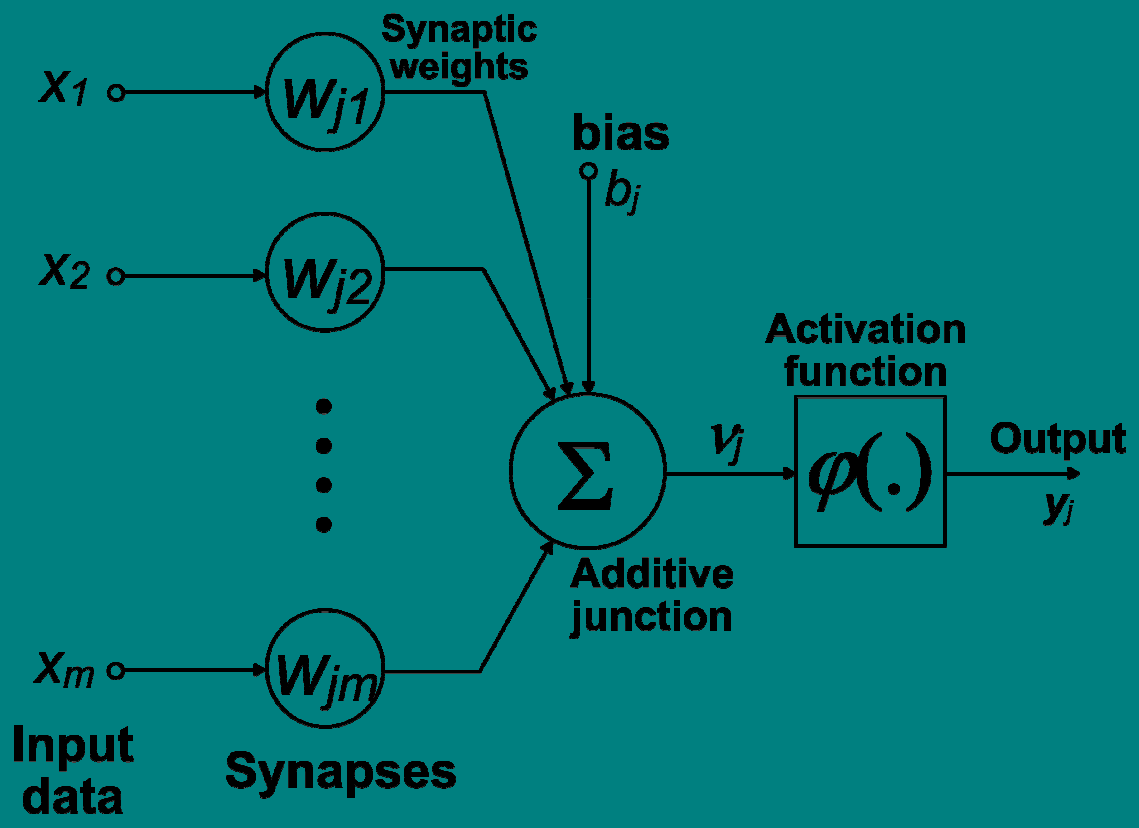
Goal



Refine the solar radiation forecasts provided by Eta model by using a statistical method based on Artificial Neural Networks (ANNs) in order to improve the reliability of the surface solar radiation forecasts supplied to energy sector.

Artificial Neural Network

- Computing system used to simulate the biological neurons.



Artificial Neural Network

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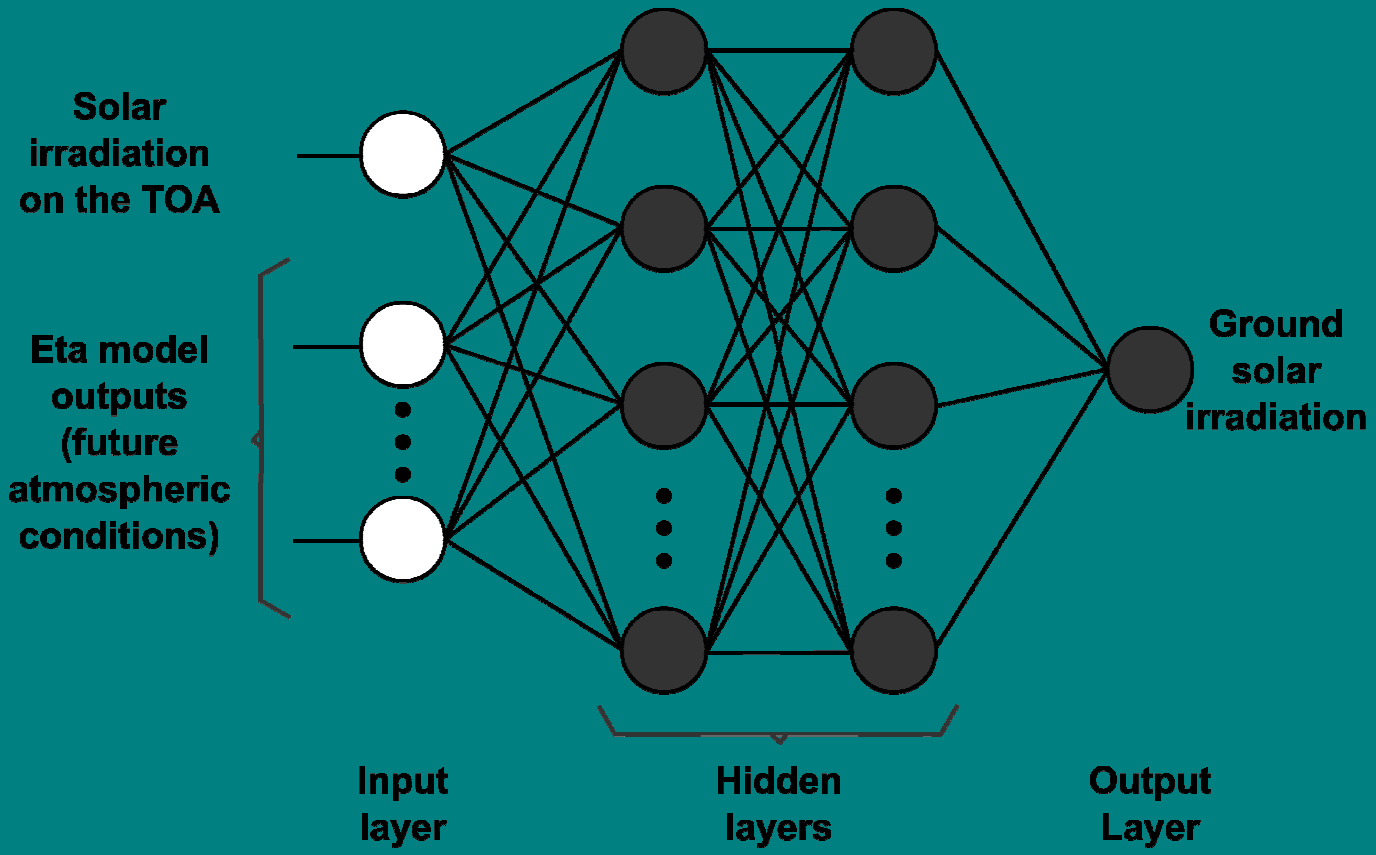


ANN´s Input and Output Data

Input data:

36

Climate data provided by Eta: pressure, temperature, relative humidity, zonal and meridional wind, heat fluxes at the surface, precipitation, cloud cover ratio, precipitable water, and others (total - 33 variables).

Others variables taking in account: TOA solar irradiation, solar zenith angle, air mass.

Output data:

Surface solar irradiation.

Artificial Neural Network

Two steps and three dataset are necessary to generate solar data forecasts by using the ANN:

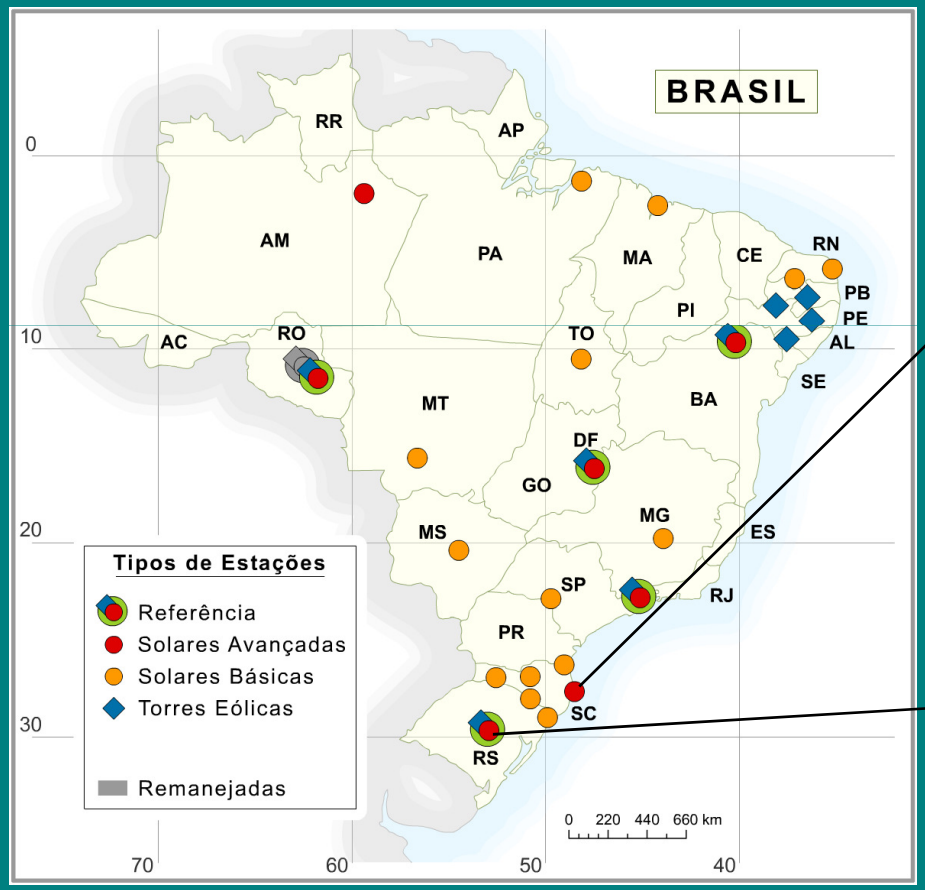
- The training step is the first procedure to set up the ANN. The training algorithm uses a ***training dataset*** to adjust the weights and bias in order to reduce the output deviations. The *Resilient Back propagation* algorithm were employed to the training step.

- The ***validation dataset*** is used to verify the performance of the ANN with an independent data sample, not directly used in training process, in order to check the generalization capacity and to find out the appropriate moment to stop the training.

- After training, the weights and bias were fixed, and adopted in simulations by using the ***investigation dataset*** as input data.

Ground Data – SONDA Network

Sistema de Organização Nacional de Dados Ambientais para o setor de energia – CPTEC/INPE
(www.cptec.inpe.br/sonda)



Florianópolis (SC) (Campus UFSC):
Latitude: 27,60º Sul
Longitude: 48,52º Oeste
Altitude: 12m
Data period: Jan/2002 – Out/2005.

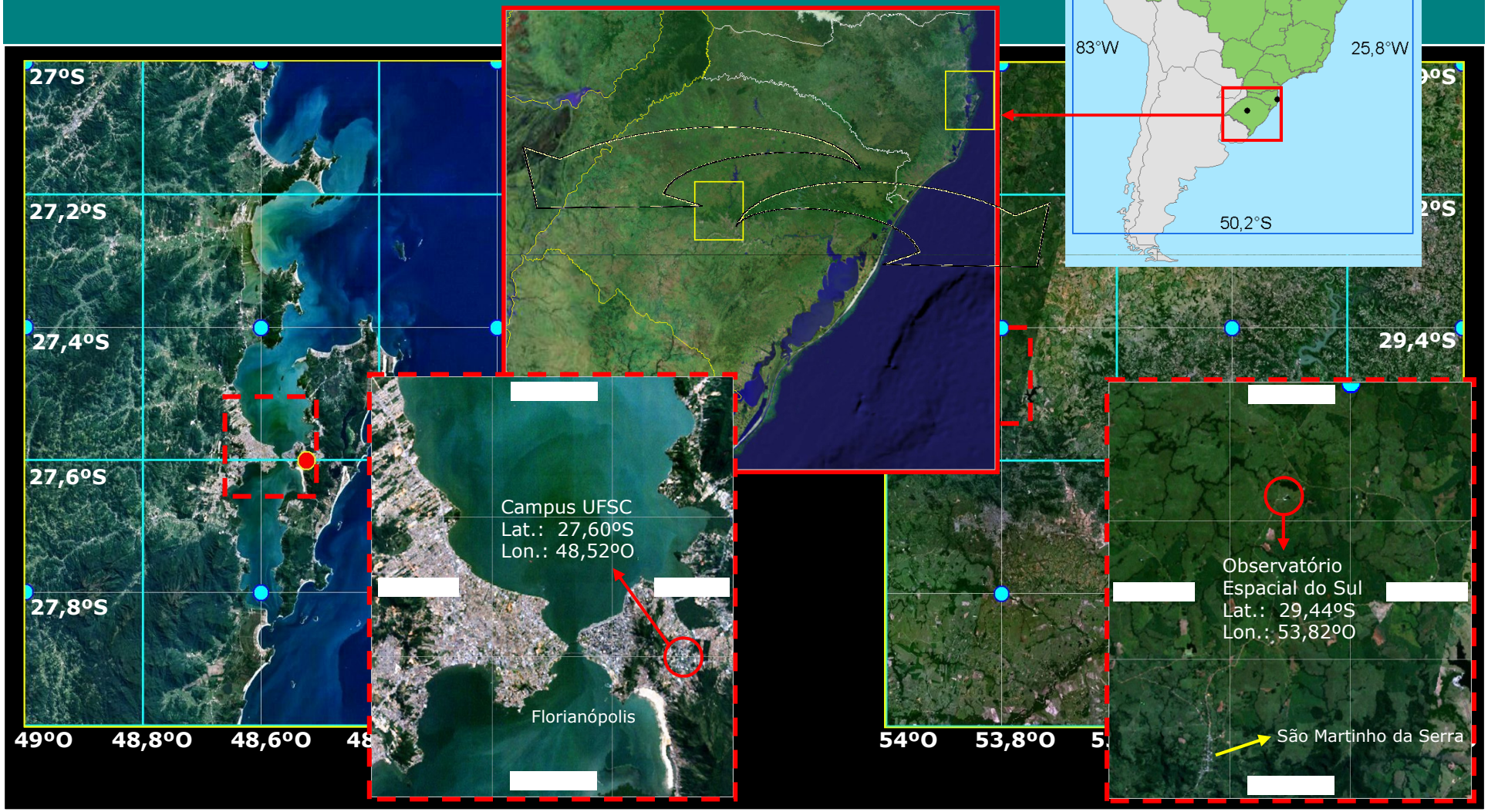
Ground Data – SONDA Network

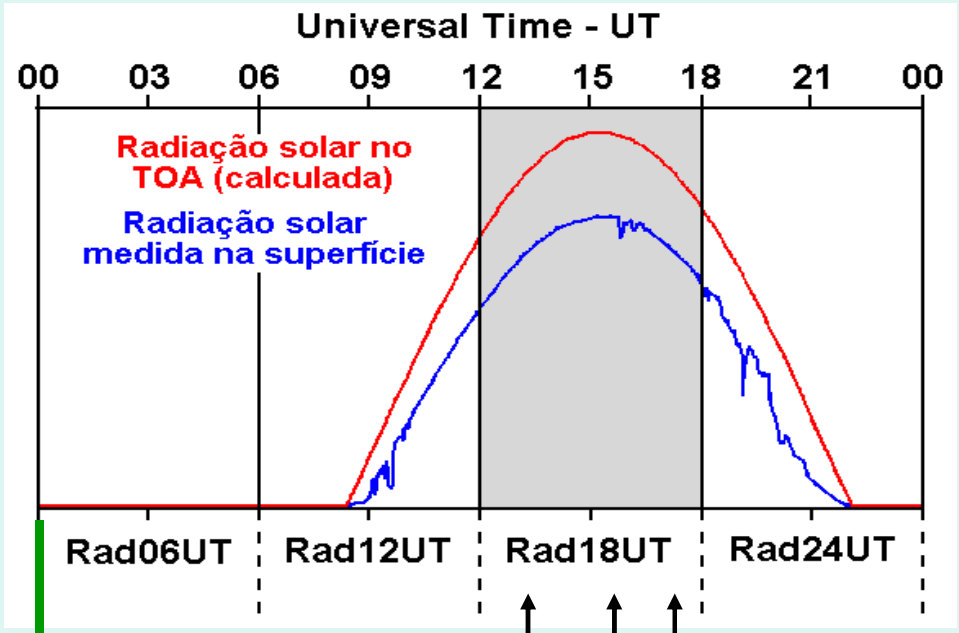
- The SONDA ground data were used for the ANNs training and validation. Besides that, ground data were used to compare the results between the two methods: model Eta/CPTEC and ANNs.

- The SONDA database was divided into three sets:
  - the *training set* (575 days for FLN and 236 days for SMS),
  - the validation set (288 days for FLN and 118 days for SMS) and
  - the investigation *set* (287 days for FLN and 118 days for SMS).

Eta outputs: climate data in grid points (0,4º) and 6h time resolution, (at synoptic times: 0, 6, 12 e 18UT).

33 output data provided for the nearest grid point from two SONDA sites were taken for this study.





Eta Output Running for 00UT (P00UT)

Eta

ANN

ANN

36 input data

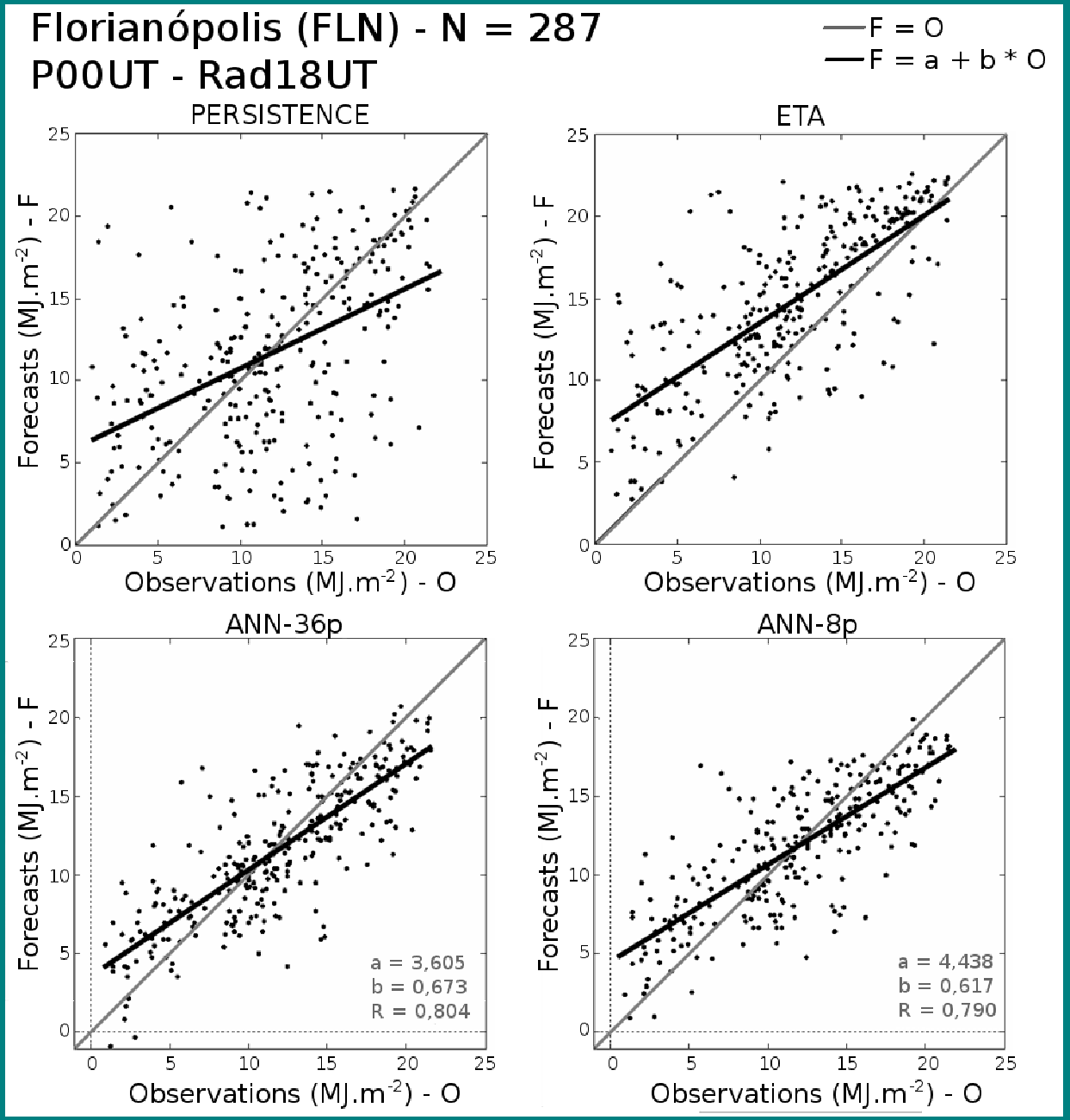
8 input data

33 climate data provided by Eta model

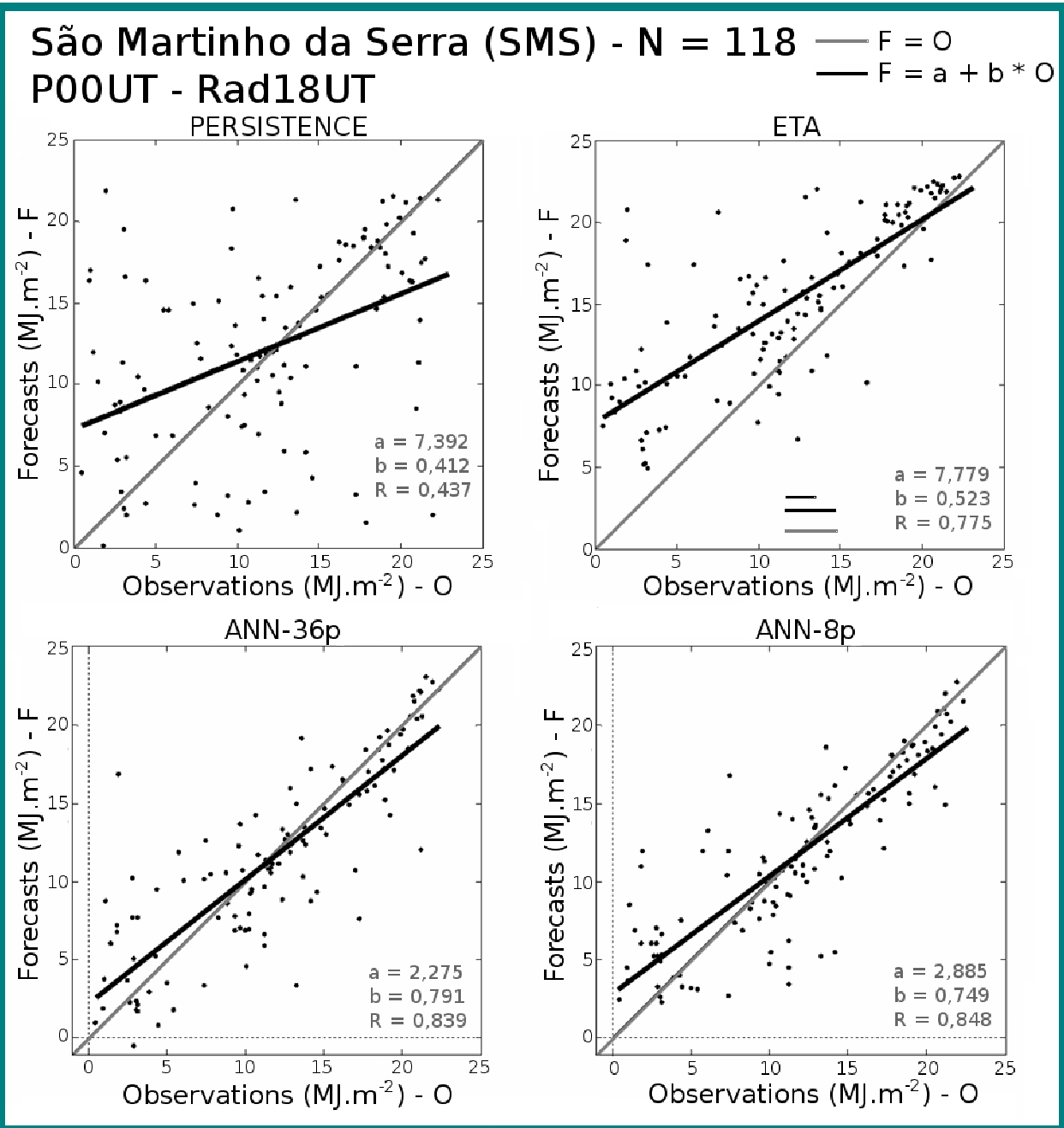
7

Calculated data:
TOA Solar irrad.
SZA and Air Mass

Ground Data vs. Solar Estimates



Ground Data vs. Solar Estimates



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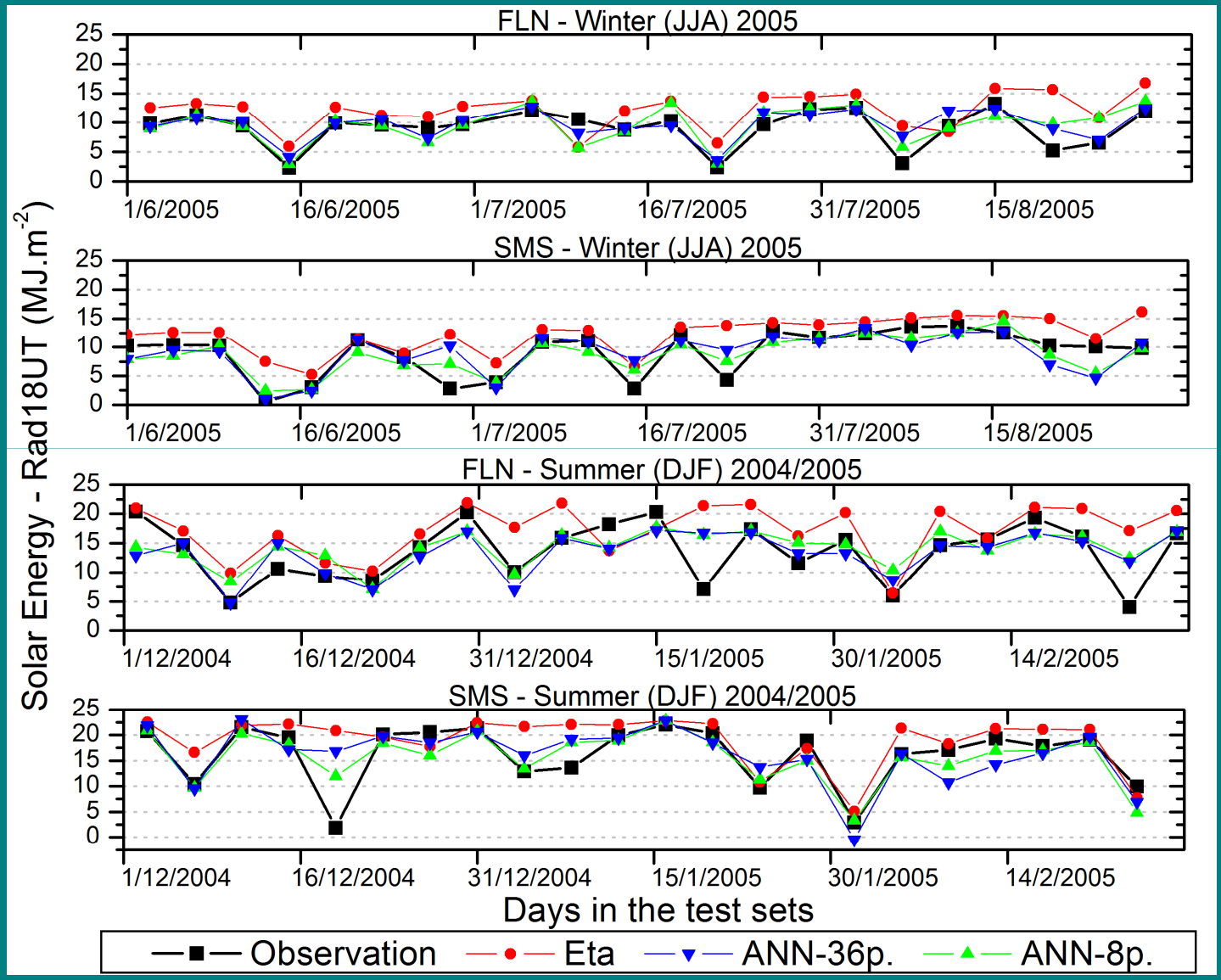

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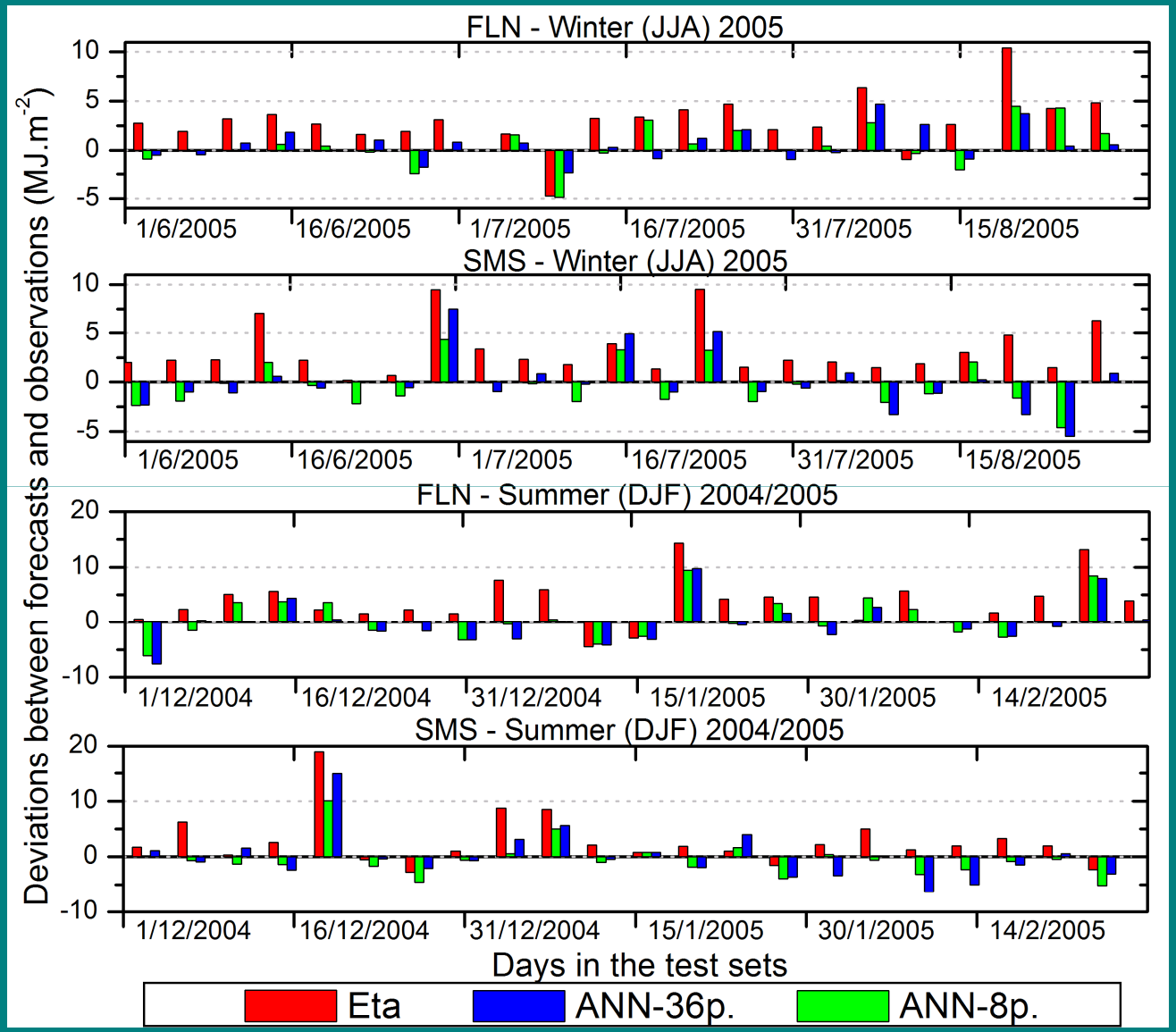

Deviatons and Performance Evaluation

Scores	Florianópolis			São Martinho da Serra		
	Eta	ANN-36p	ANN-8p	Eta	ANN-36p	ANN-8p
R	0.720	0.804	0.790	0.775	0.839	0.848
R^2	0.519	0.646	0.625	0.600	0.704	0.720
ME%	24.7%	-2.1%	-0.8%	28.0%	-1.7%	-0.7%
RMSE%	39.7%	26.2%	26.9%	43.2	28.8%	27.6%

All results obtained using investigation dataset.

Discussion and Conclusions

- The model Eta/CPTEC generated solar radiation flux estimates with bias around 25%.
- The comparison among estimates and ground data acquired in the SONDA sites showed a similar performance between the ANNs using 36 and 8 predictors
- It was found a set of 8 predictors: *solar radiation flux at TOA*, *relative humidity*, *surface temperature*, *precipitable water amount*, *zonal wind speed at 10-m height*, and predictors for *cloud fractions*.
- Both ANNs provide estimates for solar radiation flux at the surface better than the model Eta/CPTEC.
  - biases observed in the Eta/CPTEC estimates are larger
  - ANNs have improved the confidence (taking in account the RMSE) in estimates for solar radiation in more than 30% when compared to Eta/CPTEC.
  - improvements in predictability were observed in correlation coefficients as well: from 0.72 to 0.80 in FLN, and from 0.78 to 0.85 in SMS.

- Thanks for attention

- SONDA Network description and download the solar and meteorological data:
  - www.cptec.inpe.br/sonda

  - Email: fernando.martins@cptec.inpe.br