ICEM 2017
4th International Conference Energy & Meteorology

Solar energy assessment for Brazilian territory:

Improved atmospheric modeling and greater reliability of solar resource maps

(Presented by: Andre Gonçalves)

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Laboratory for Modelling and Studies of Renewable Energy Resources

http://labren.ccst.inpe.br

The multidisciplinary laboratory LABREN-CCST-INPE, carries out research and teaching activities in energy meteorology and in the climate system influence on energy resources making use of satellite data, computational modelling and observational data.

Research Topics:

- *Assessment of solar and wind energy resources*
- *Short and medium-term forecast of solar and wind generation*
- *Energy and global climatic changes*
- *Site-specific measurements, characterization and modelling of solar and wind resources*

Solar Energy Assessment in Brazil - Available information

- Most of the available information sources for Brazilian territory are State Governments initiatives through hiring by bidding
- Almost all of them are based on statistical interpolation of ground observations

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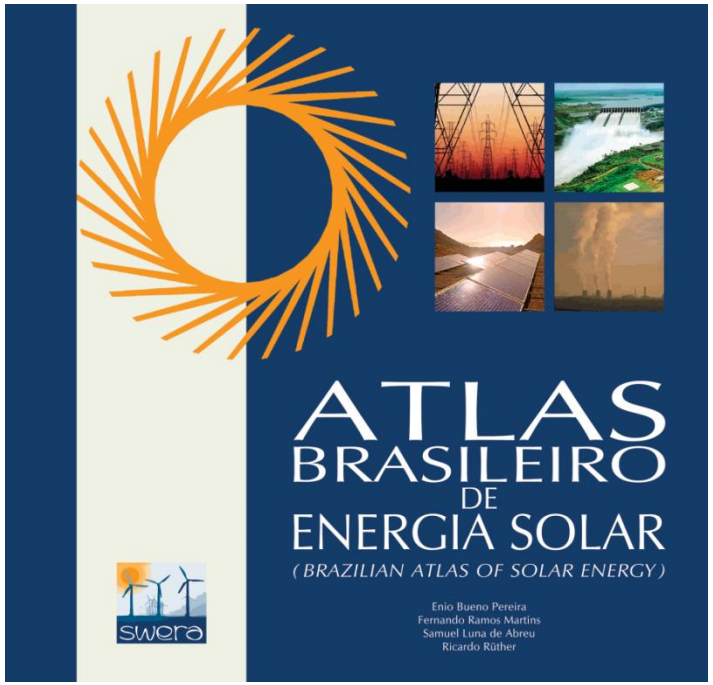
Brazilian Atlas of Solar Energy – First edition

Key features:

- based on 10 years of satellite images (GOES) – from 1995 till 2005 and climatological data provided by meteorological data acquired throughout Brazilian territory
- radiative transfer model BRASIL-SR adapted for Brazilian conditions
- poor representation of aerosols contribution to the radiative transmittance
- difficulties to get reliable evaluation of cloud cover due to low time resolution of satellite data
- similar performance compared to numerical models used to solar energy assessment around the world
- daily total outputs presenting bias around 6% for GHI and 15% for DNI (ground data for DNI presented poor quality)



Colaborating Institutions:
INPE
UFSC

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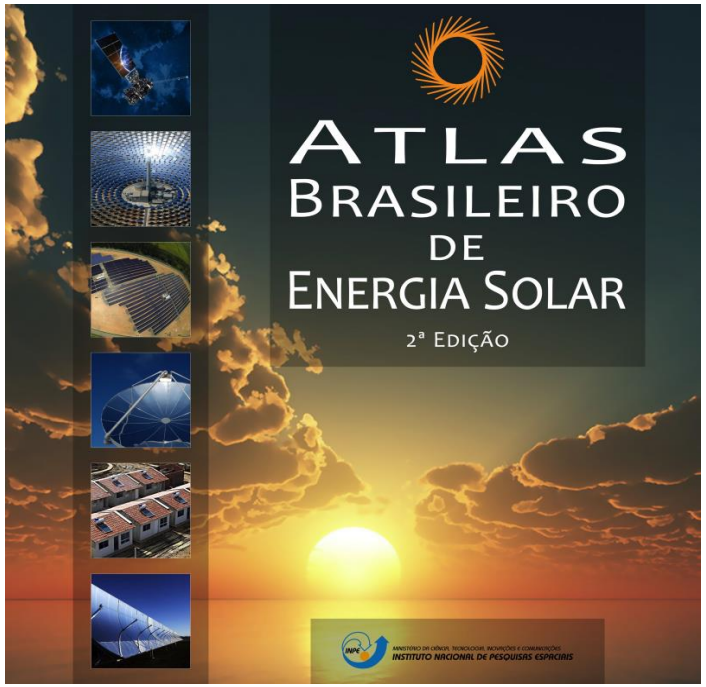
New Brazilian Atlas of Solar Energy – 2017

Major improvements:

- Longer time series of satellite images
- Improved methodology for model assimilation of aerosol optical depth information (MACC + inSitu)
- Larger number and longer time series of ground-based validation data (> 500 ground stations)
- Statistical post-processing (bias removal)
- More detailed information on resource variability: decadal, seasonal, and monthly
- More detailed information on level of confidence
- More comprehensive prognostics and what-if scenarios for CSP, CPV, and Solar Cooling



Colaborating Institutions:
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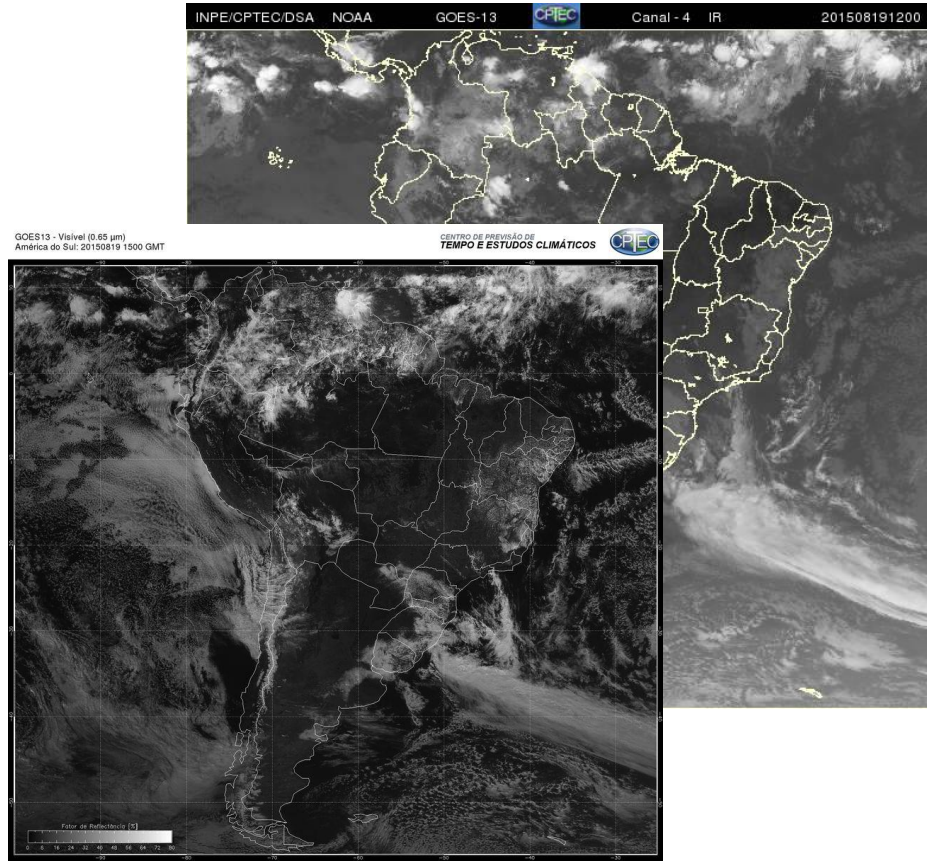
Satellite images

In the new version of the Atlas the Brazil-SR model uses a series of images of 17 years, 60% longer than in the previous version

- Digital images form GOES satellites for VIS and IR channels from 1999 to 2014
- Combined products from different generations of GOES (GOES 8, GOES, GOES 10 15, etc.) and their respective properties
- Ground resolution varies but were all reduced to 4km at the equator
- Time resolution varies as well, from every three hours to every 15 minutes.



Model Validation

Ground data acquisition and handling

SONDA network (BSRN & AeroNet)
First class radiometers

INMET network (Automatic Weather Station)
Second class radiometers

- SONDA network

  http://sonda.ccst.inpe.br/

- INMET network

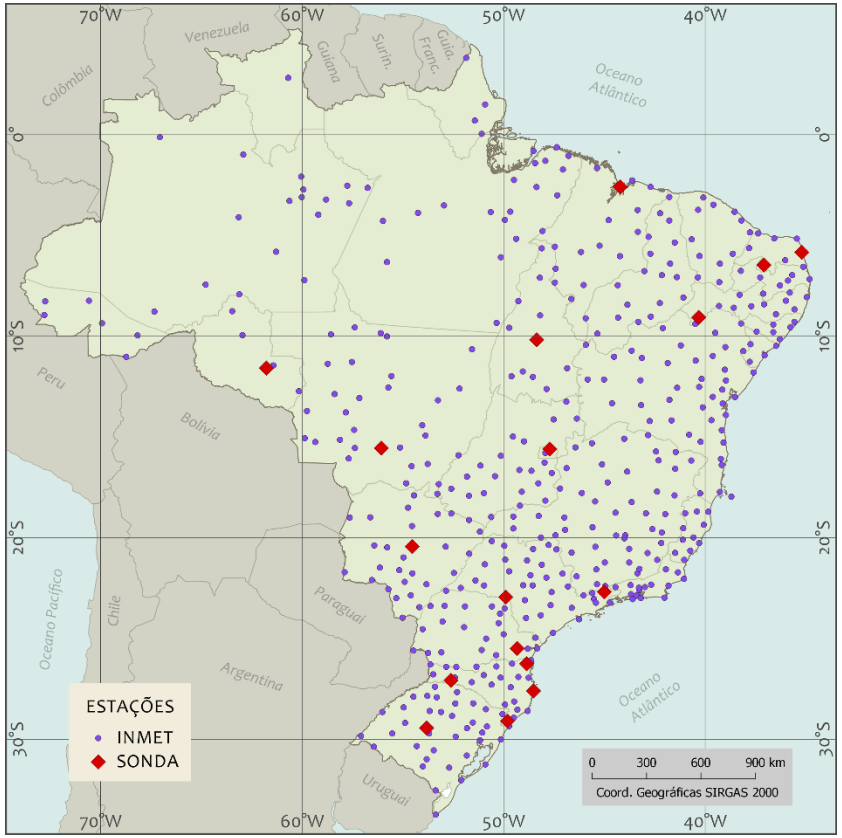
  http://www.inmet.gov.br/

Data acquisition sites managed by LABREN

Estação	Tipo	UF	Altitude (m)
Belo Jardim	A	PE	718
Brasília	SA	DF	1023
Cachoeira Paulista	S	SP	574
Caicó	S	RN	176
Campo Grande	S	MS	677
Cuiabá	S	MT	185
Ourinhos	SA	SP	446
Palmas	S	TO	216
Petrolina	SA	PE	387
Rolim de Moura	S	RO	252
São Luiz	S	MA	40
São João do Cariri	A	PB	486
São Martinho da Serra	SA	RS	489
Triunfo	A	PE	1123

Data acquisition sites managed by partners and collaborators

Estação	Tipo	UF	Altitude (m)
Chapecó	S	SC	700
Curitiba	S	PR	891
Florianópolis	S	SC	31
Joinville	S	SC	48
Natal	S	RN	58
Sombrio	S	SC	15



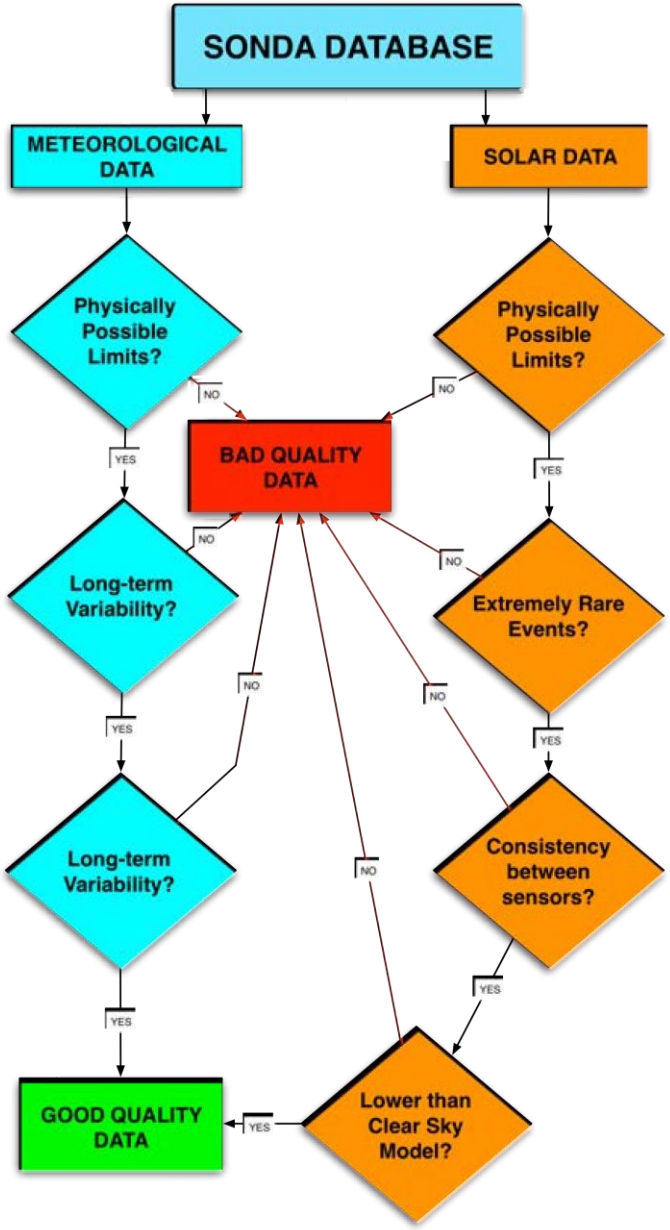
Database Uncertainties

Ground data quality control

site setup and sensor installation

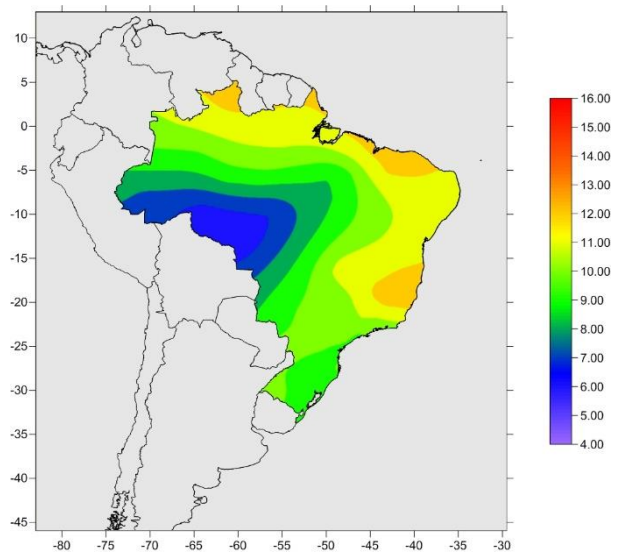
maintenance and operation (logistics, distance, communication links)

Environmental conditions (lightning, shadow, birds and other small animals);

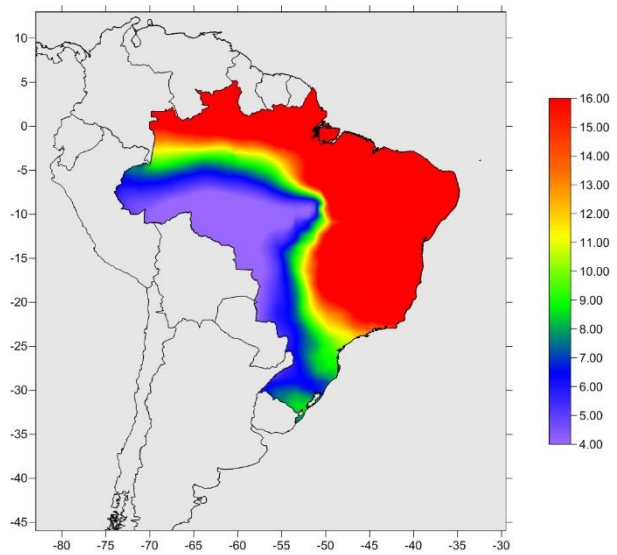


Improved methodology for aerosol assimilation

- Model assimilation of aerosol optical depth



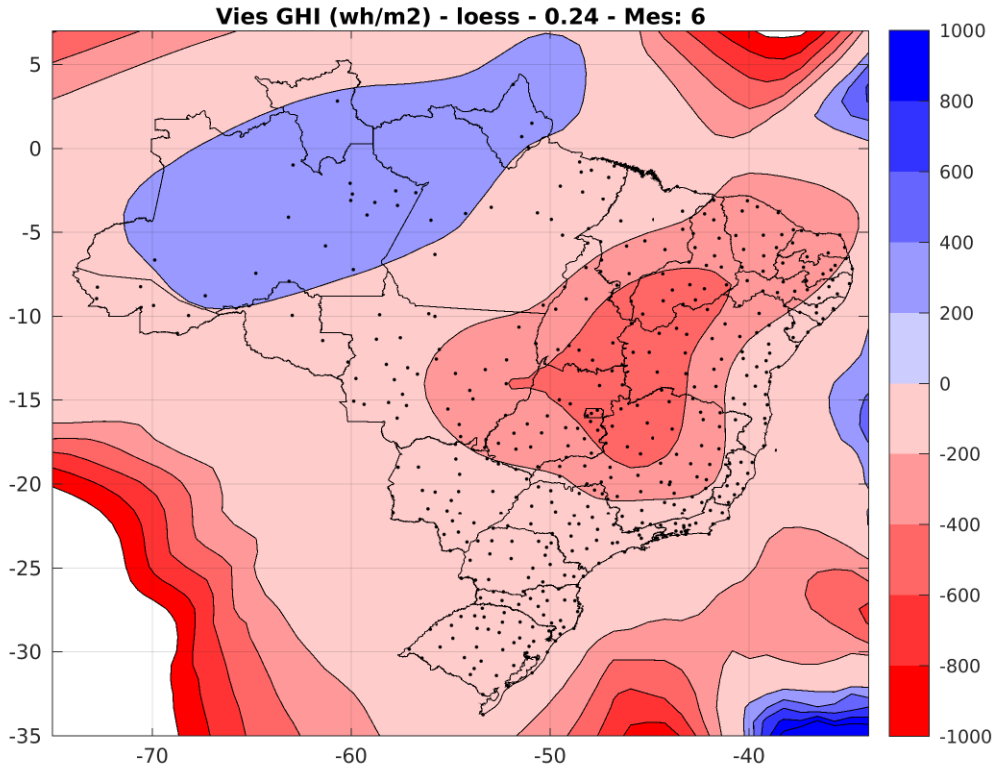
INMET Visibility – (Observed In Situ)



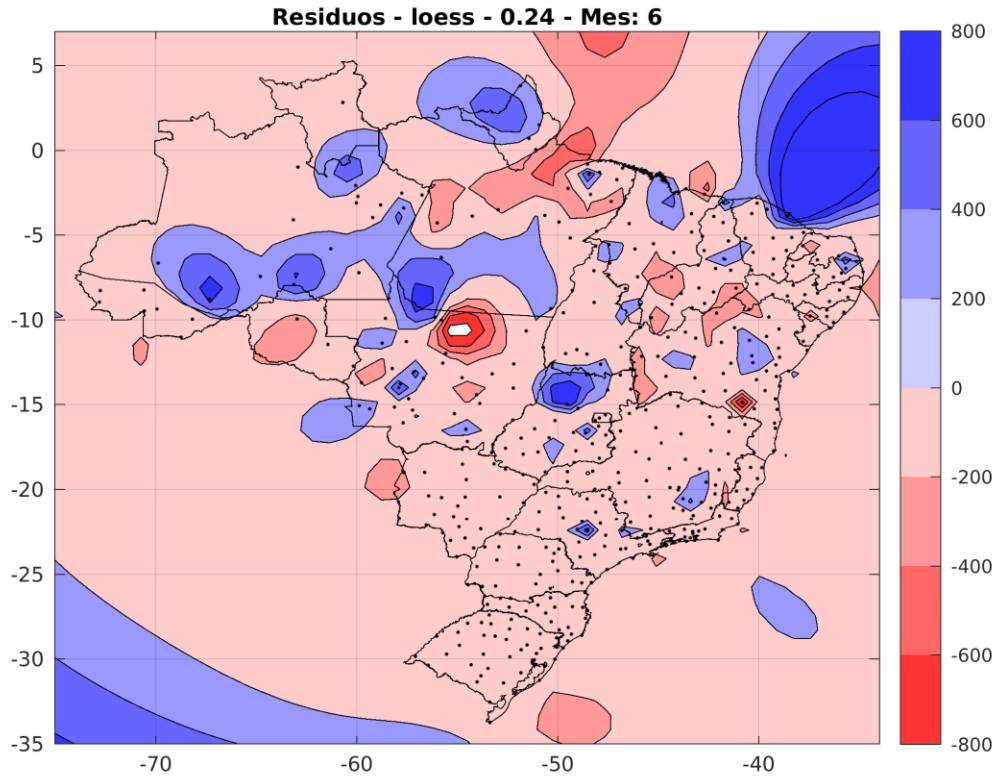
Visibility calculated from AOT550 - MACC (Monitoring Atmospheric Composition and Climate – ECMWF)

Statistical post-processing

- Monthly bias modelled spatially (local 3-D regression) from 503 ground stations

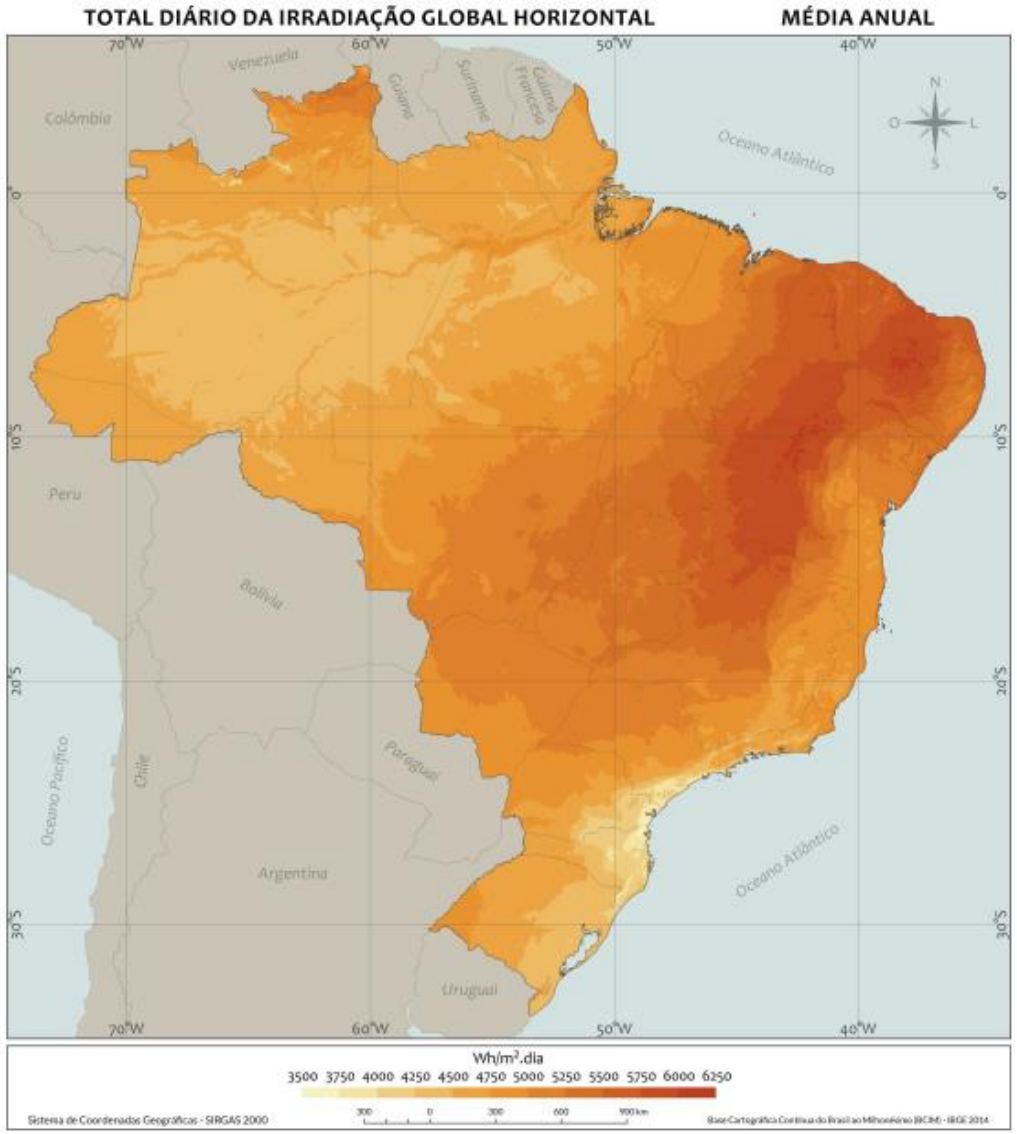


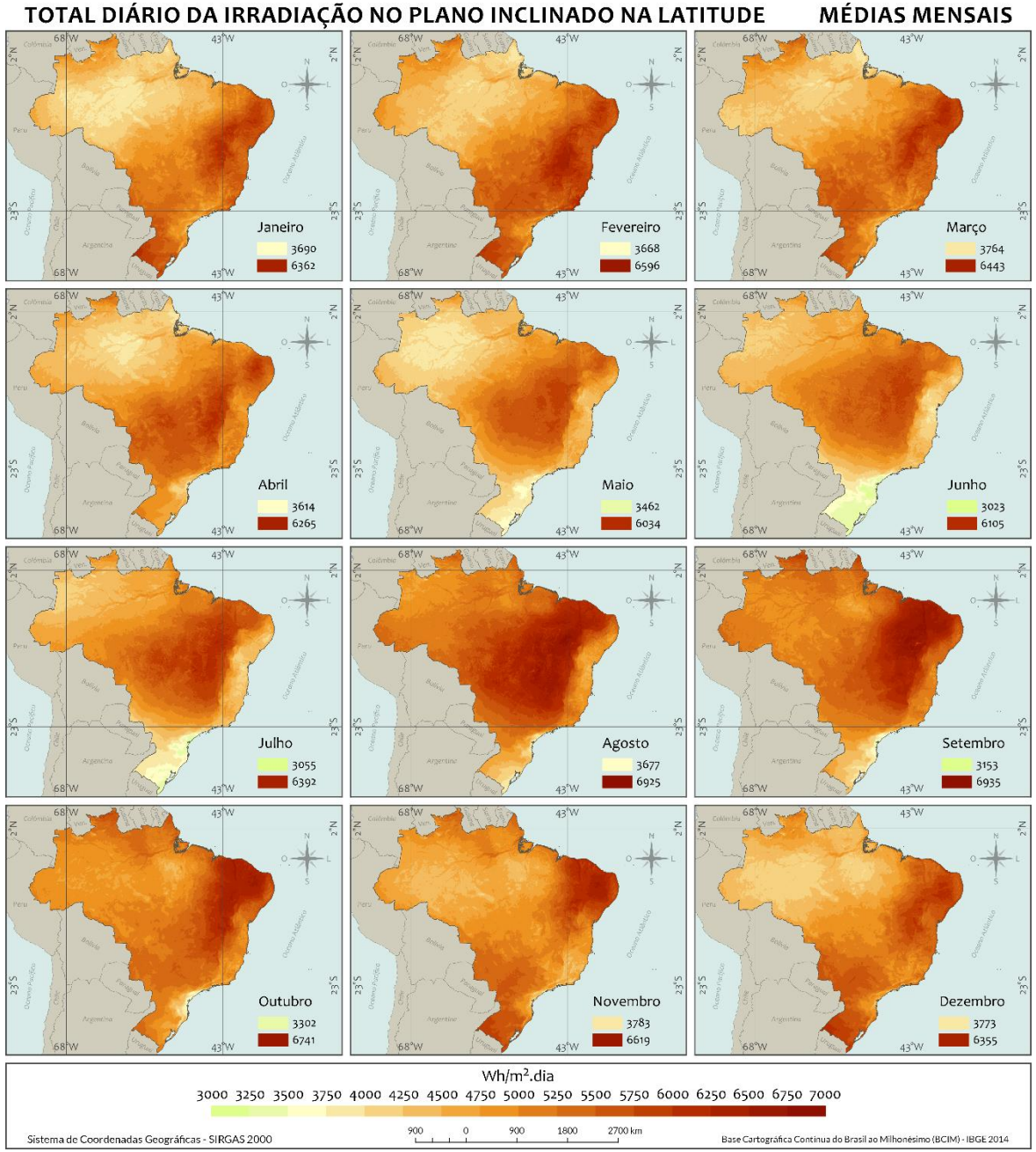
Bias modeled for June



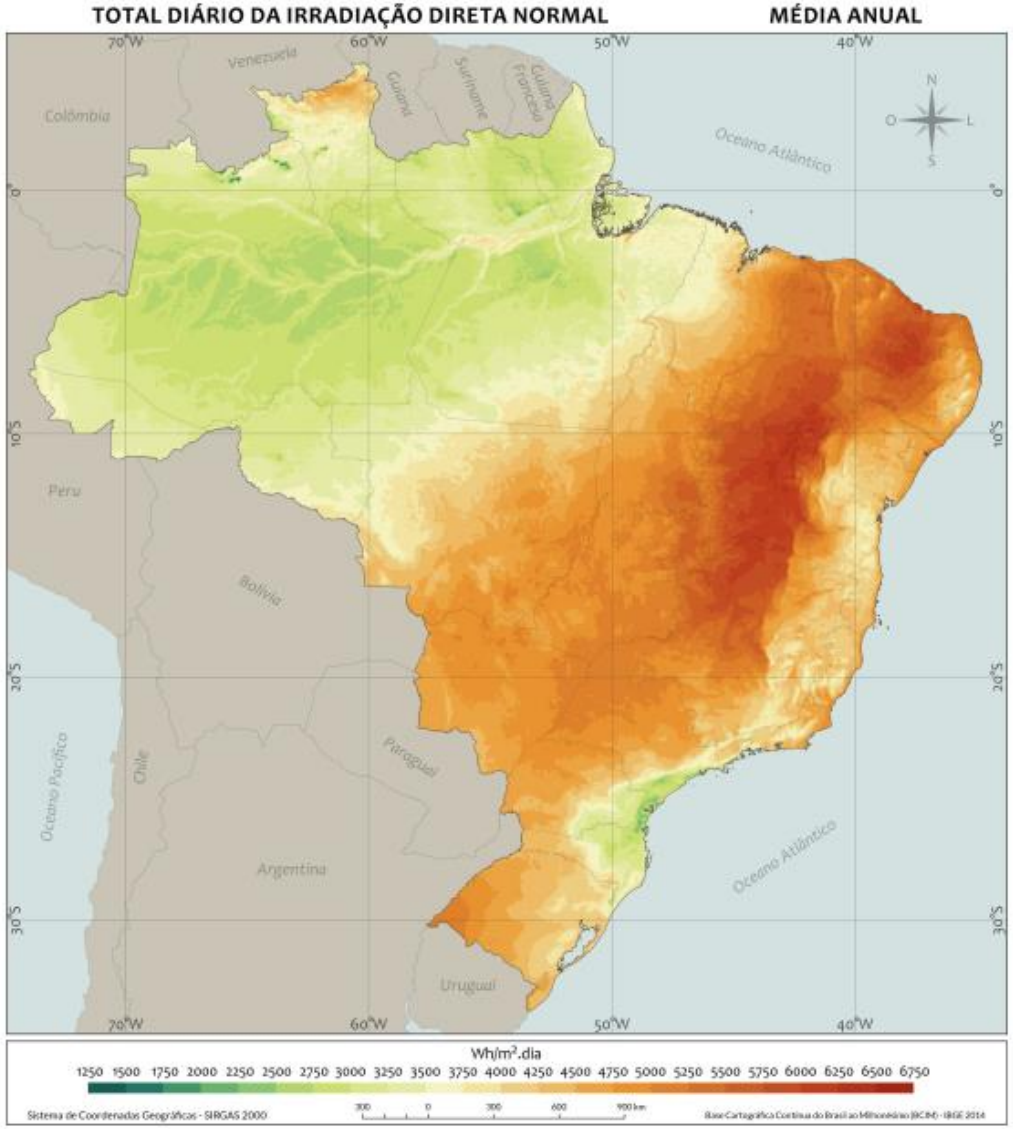
Residuals for June

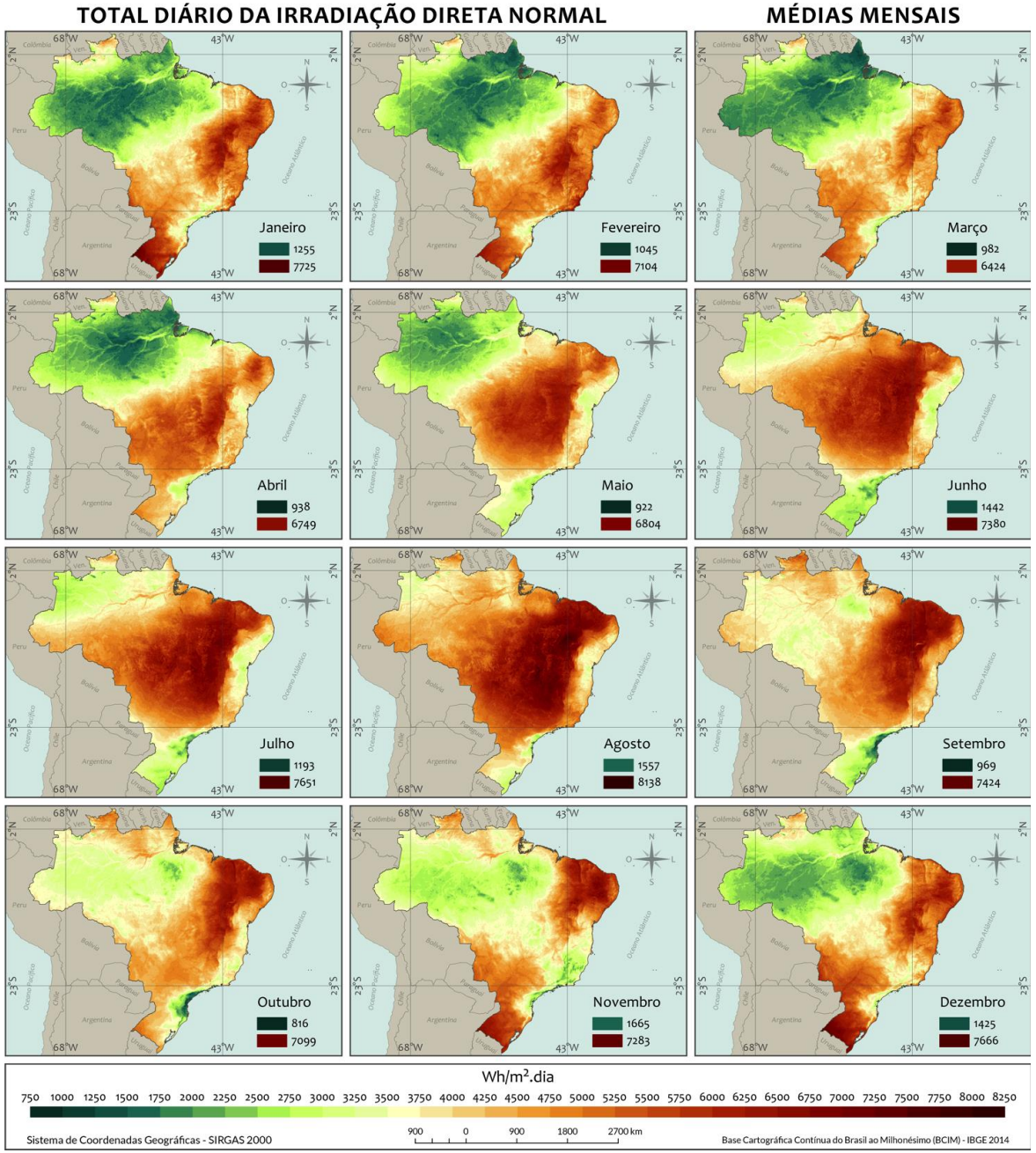
Global Horizontal Irradiation





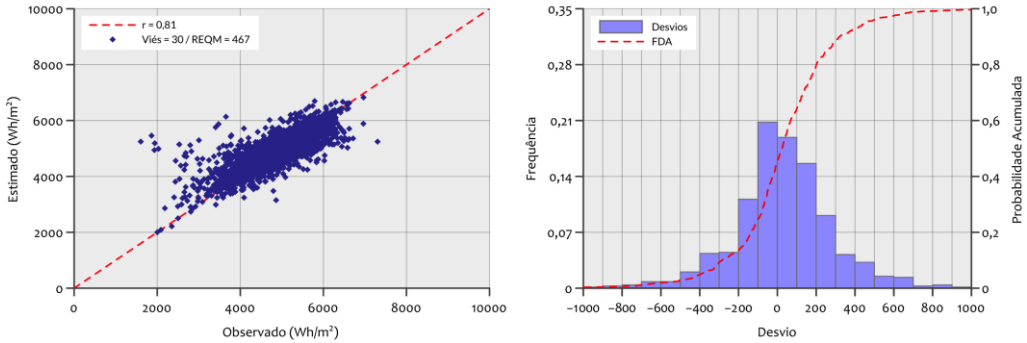
Direct Normal Irradiation



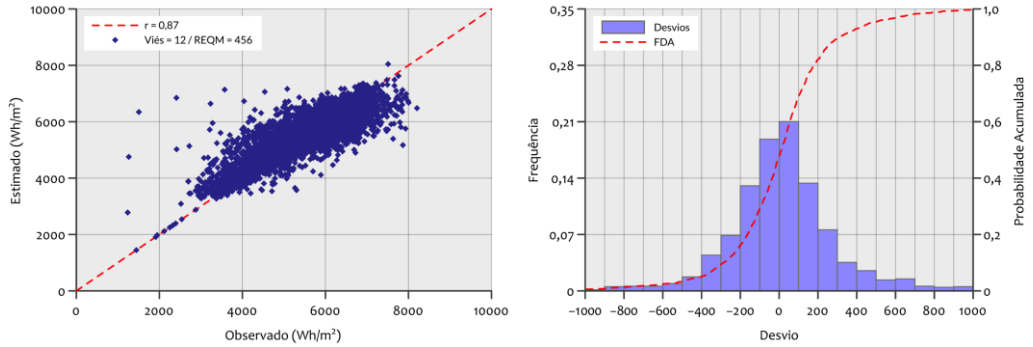


Model Validation (mean daily totals for global horizontal irradiation)

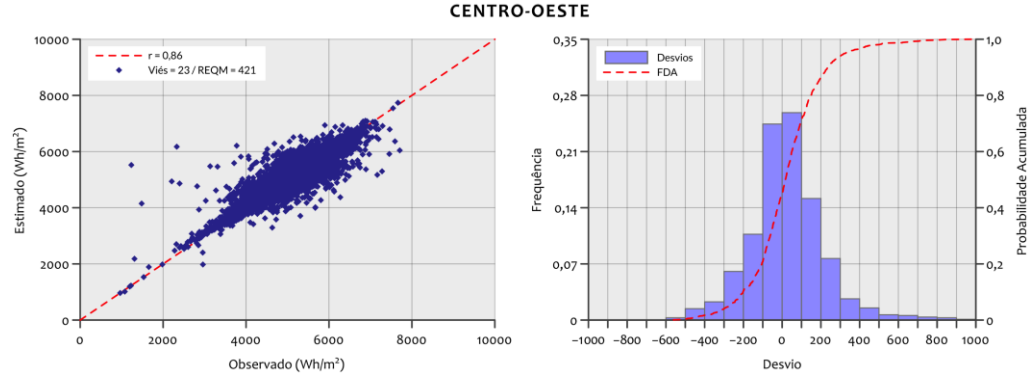
NORTE



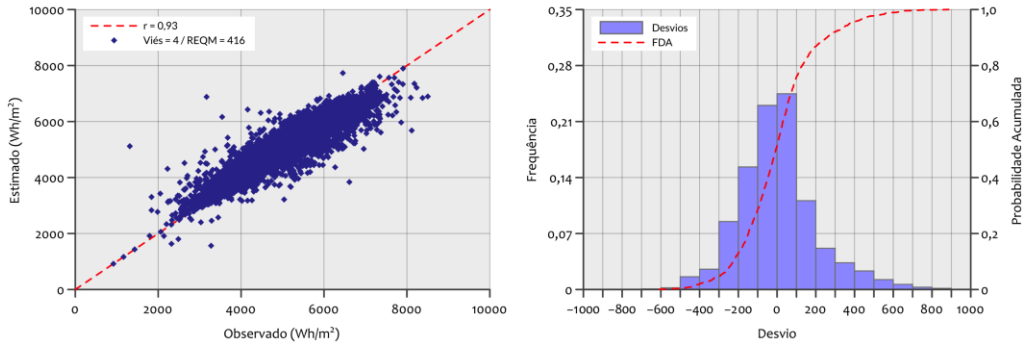
NORDESTE



CENTRO-OESTE



SUDESTE



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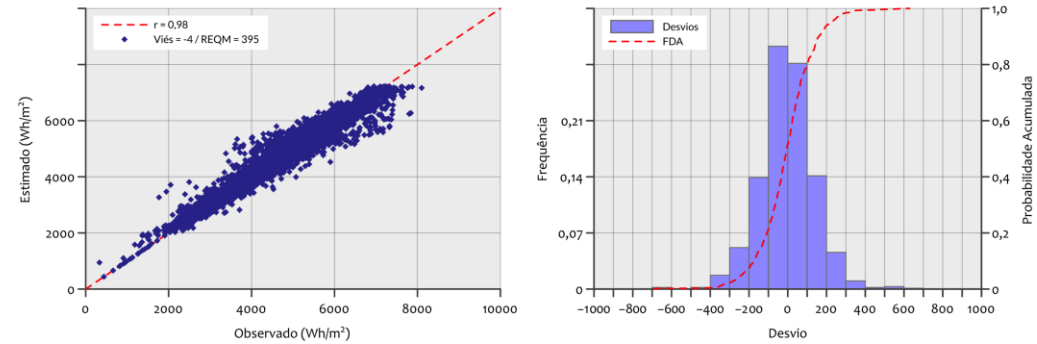
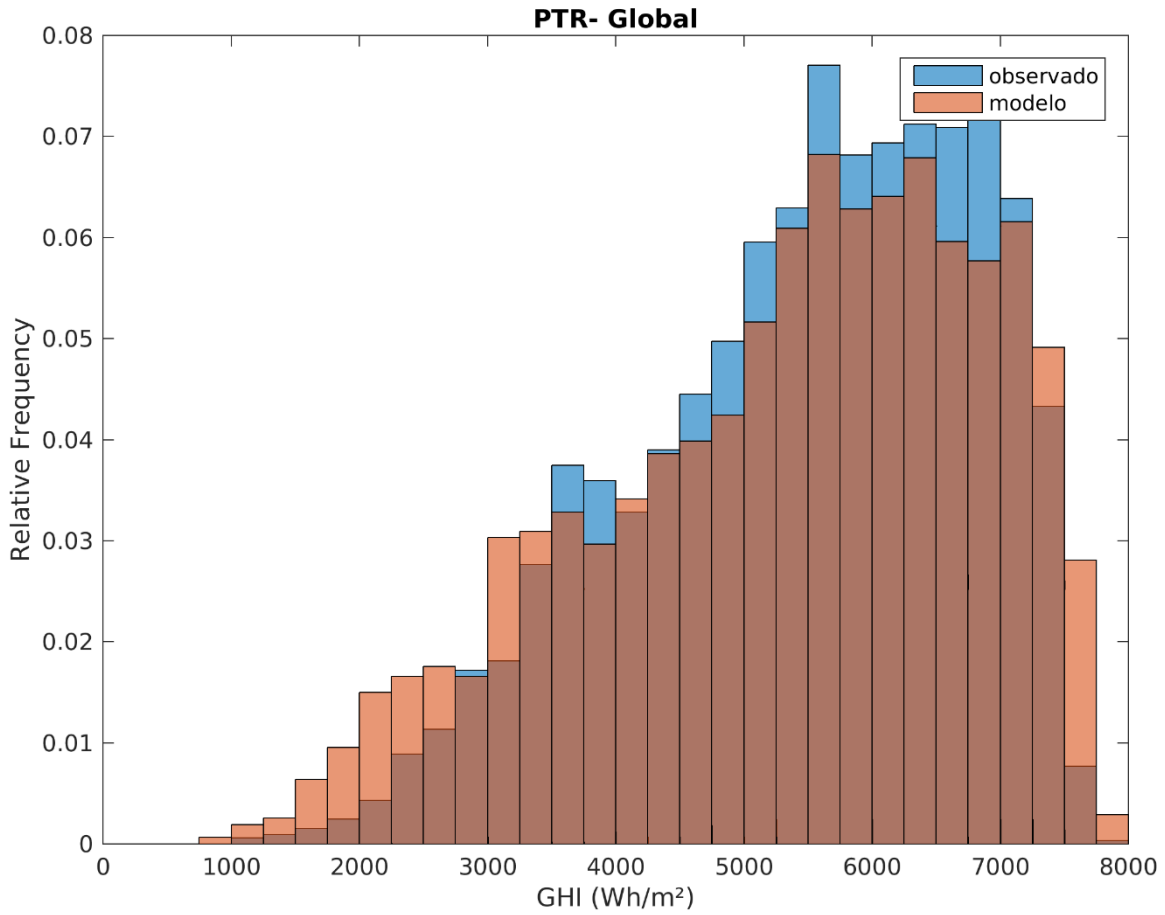
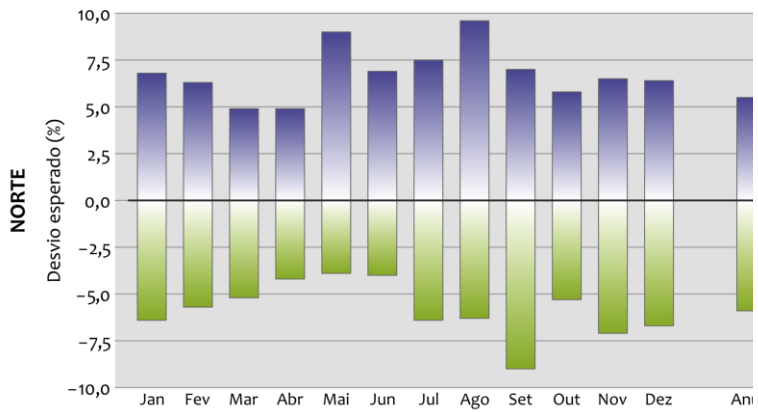


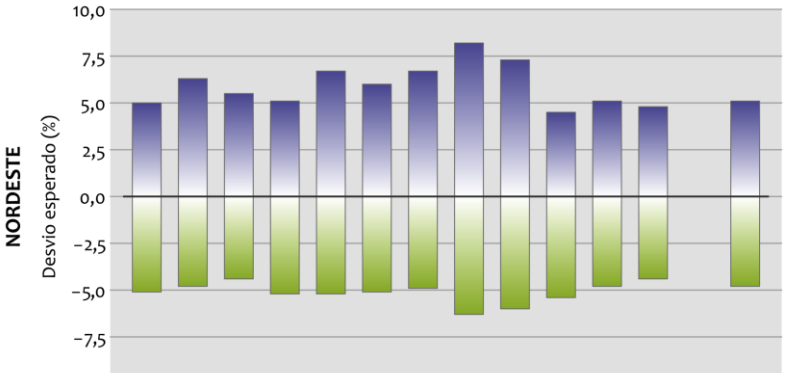
Model Validation (mean daily totals for global horizontal irradiation)

Good agreement of distribution curves between observed and modelled values

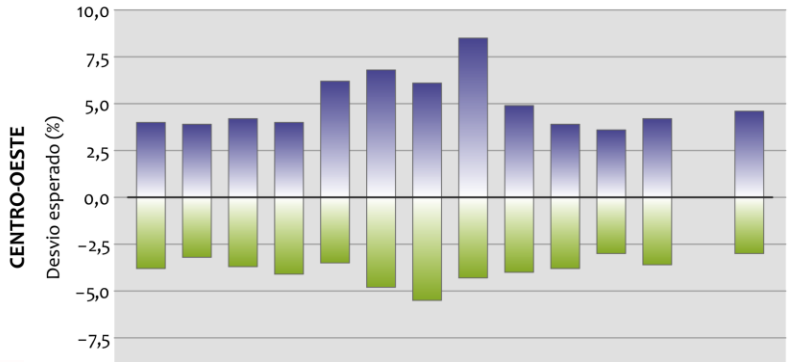


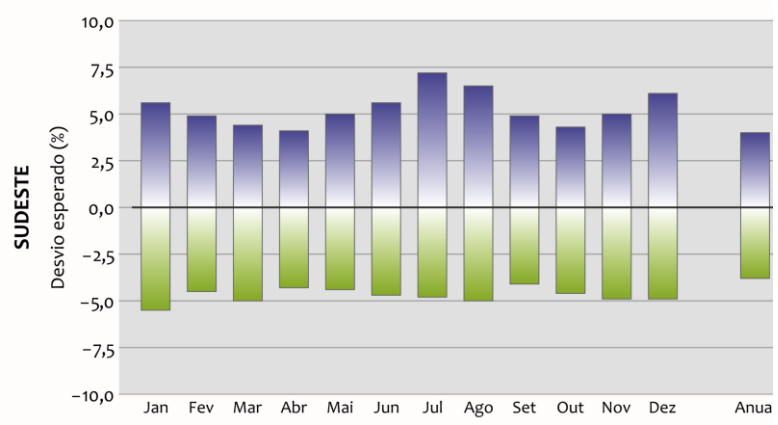
Model Uncertainties (mean daily totals for global horizontal irradiation)

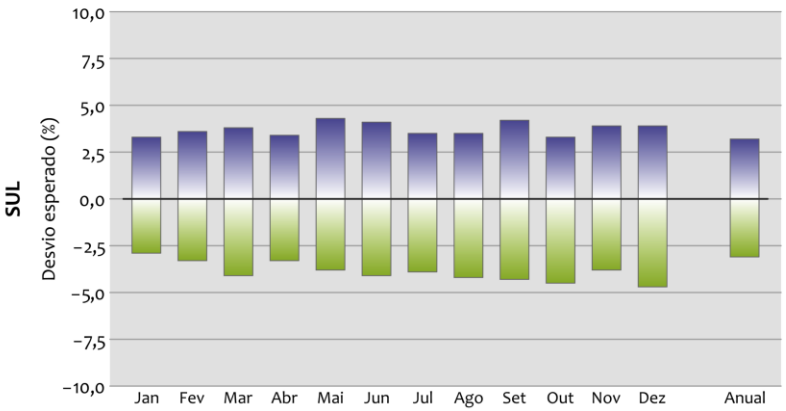




Maximum deviation from modeled to observed monthly average of daily global irradiation for the interval between percentiles P10 and P90

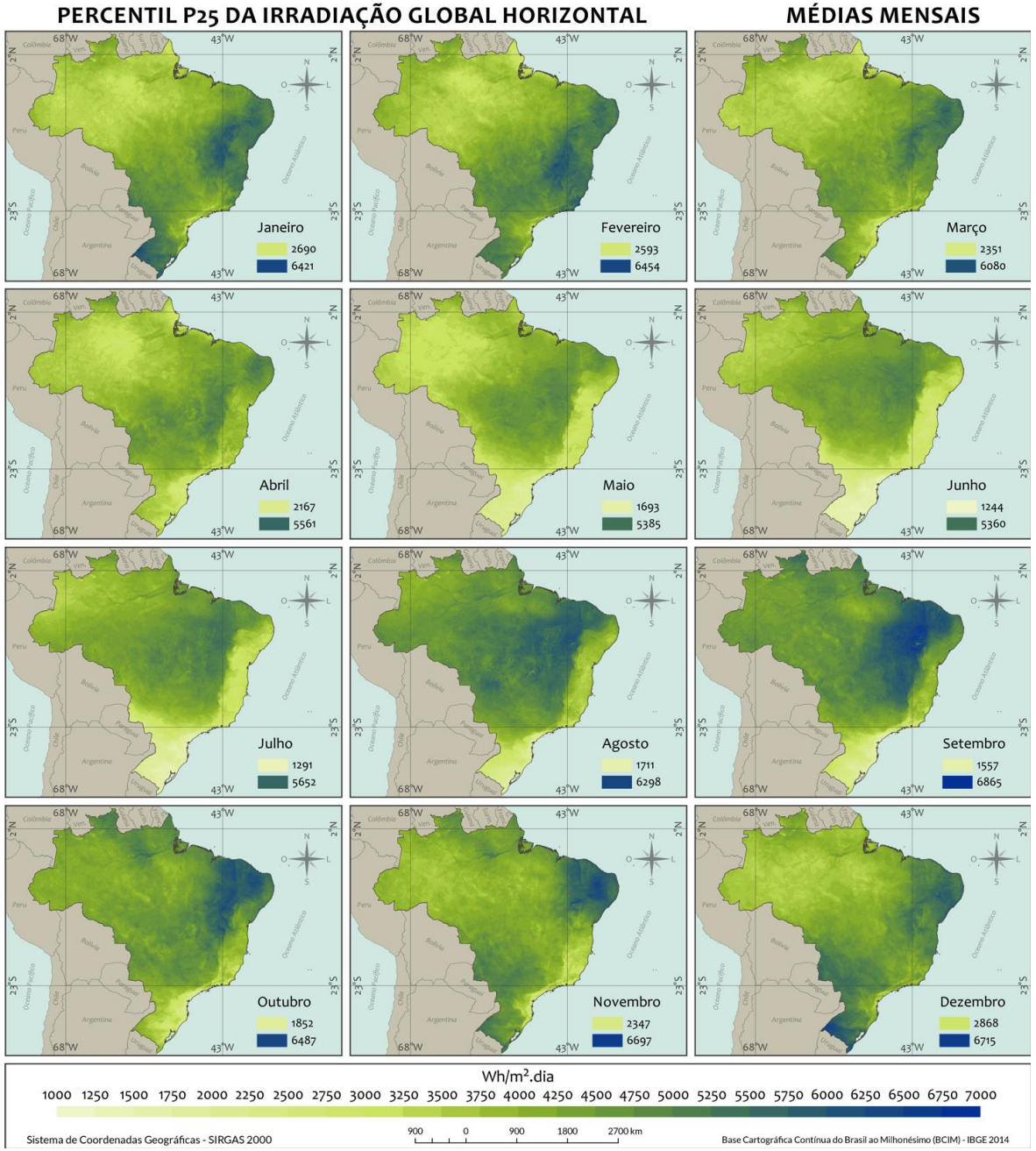






Model Uncertainties (daily global horizontal irradiation)

Region	Bias (Wh/m²)	Bias (%)	RMSE (Wh/m²)	RMSE (%)	Area averaged GHI
North	30	0,6	467	9,7	4825
Northeast	12	0,2	456	8,3	5483
Center-West	23	0,5	421	8,3	5082
Southeast	4	0,1	416	8,4	4951
South	-4	-0,1	395	8,9	4444
Mean	12	0,2	421	8,2	5153



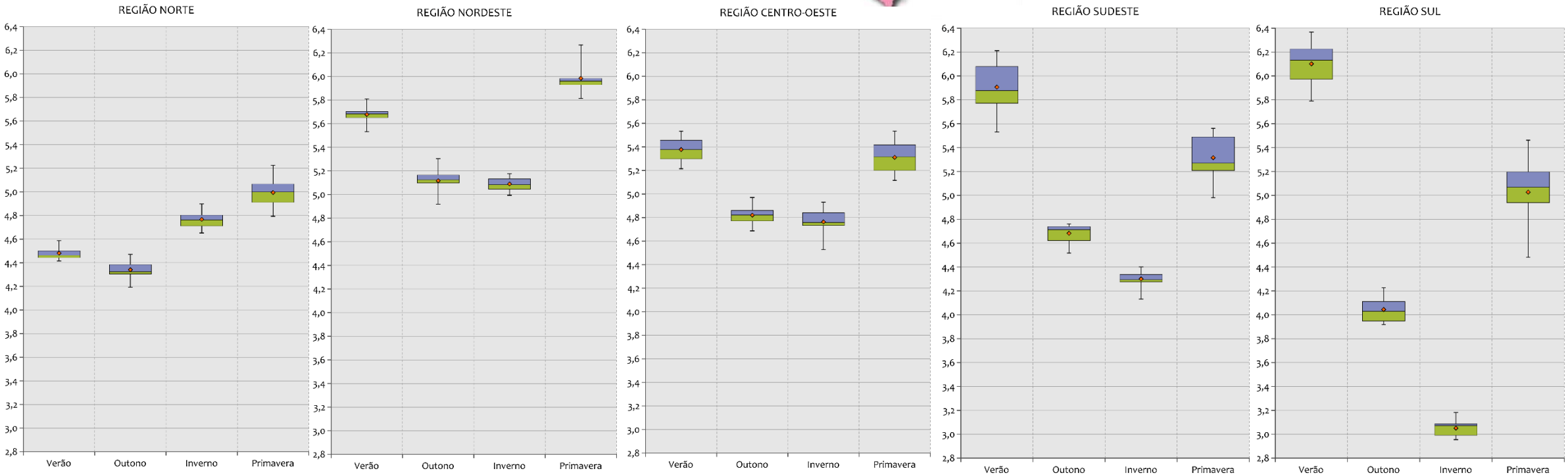
Variability

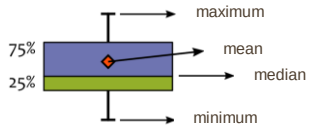
daily totals of global horizontal irradiation

The percentile (P25) values of global irradiation are between 1.24 and 6.86 kWh/m².day,
i.e. 75 % of the days are above these values (more sunny)

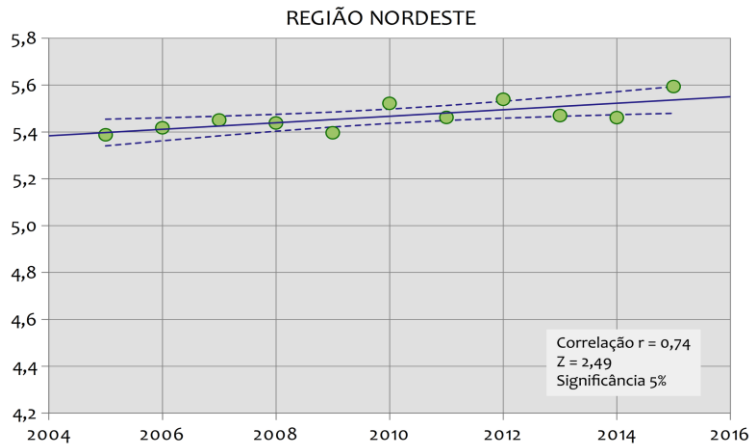
Seasonal Variability

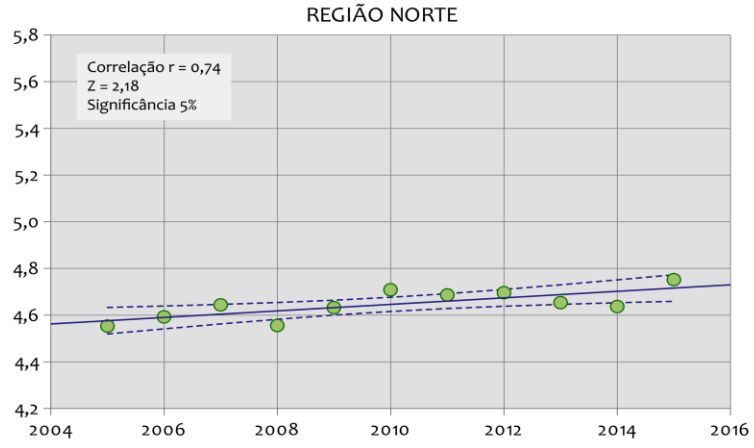
daily totals of global horizontal irradiation



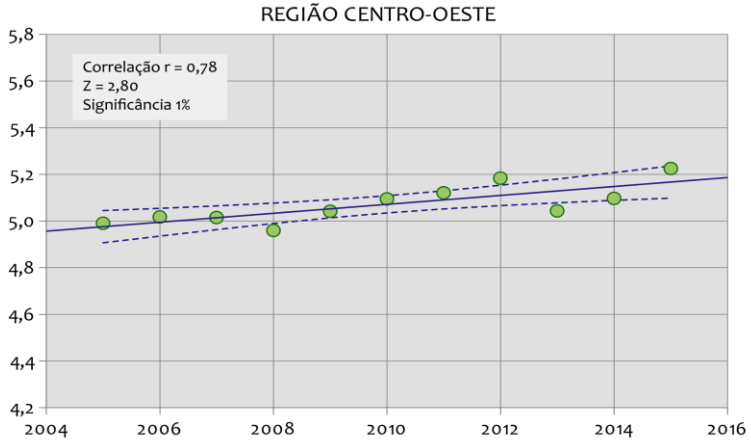


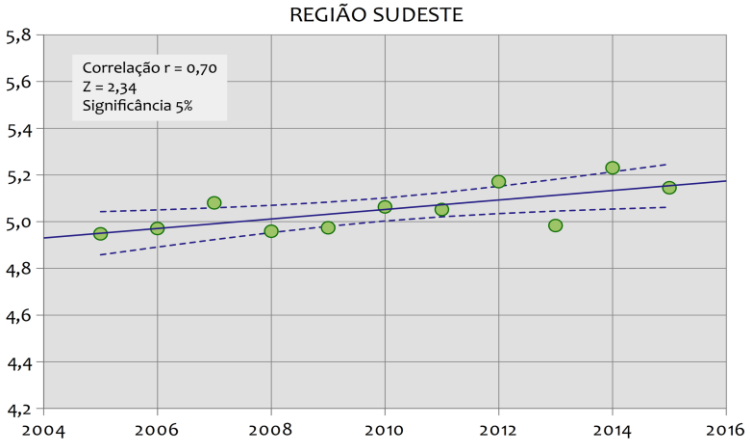
Trends (mean daily totals for global horizontal irradiation)

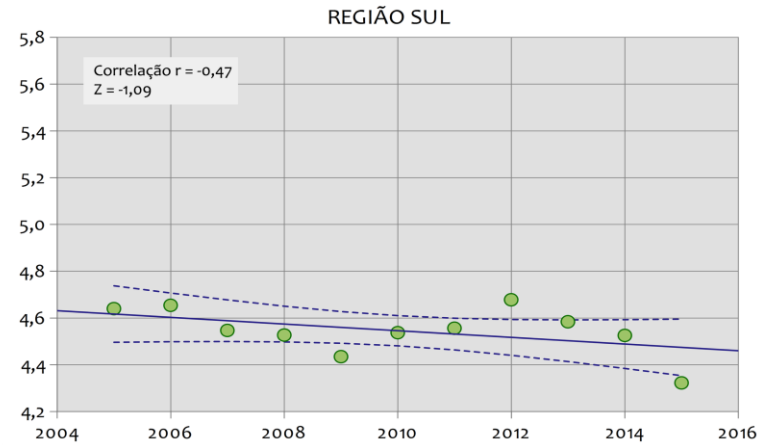




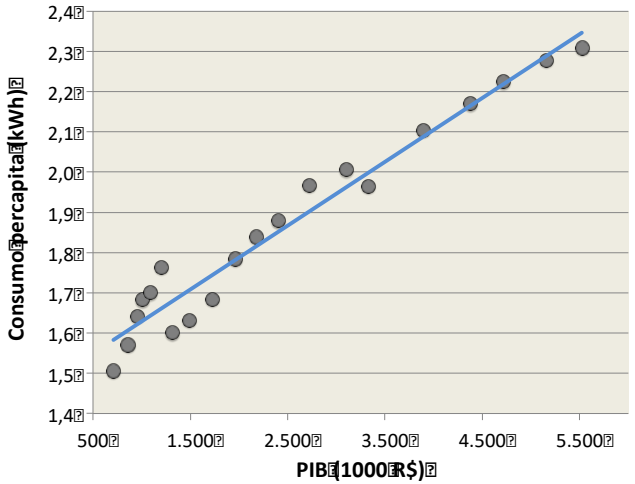
Mann-Kendall trend analysis at 5% confidence level

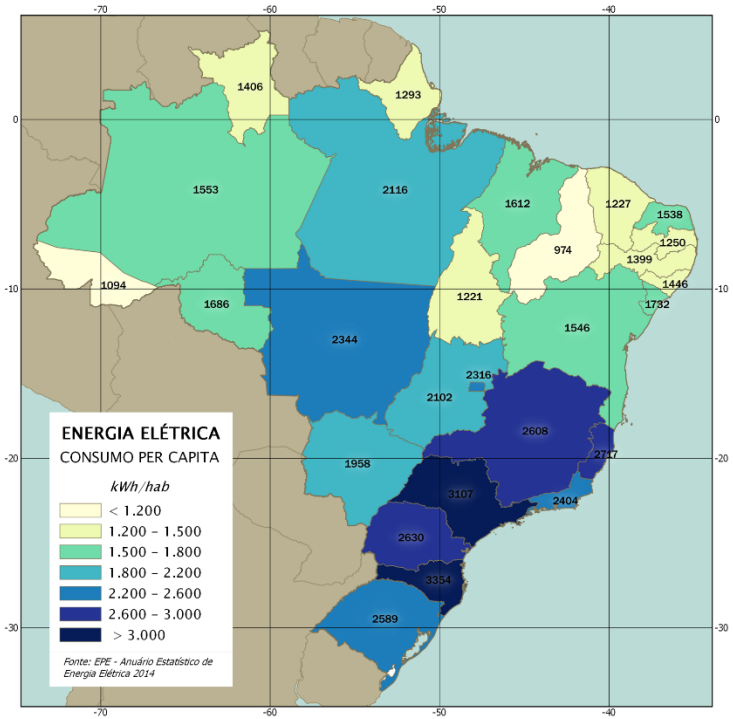


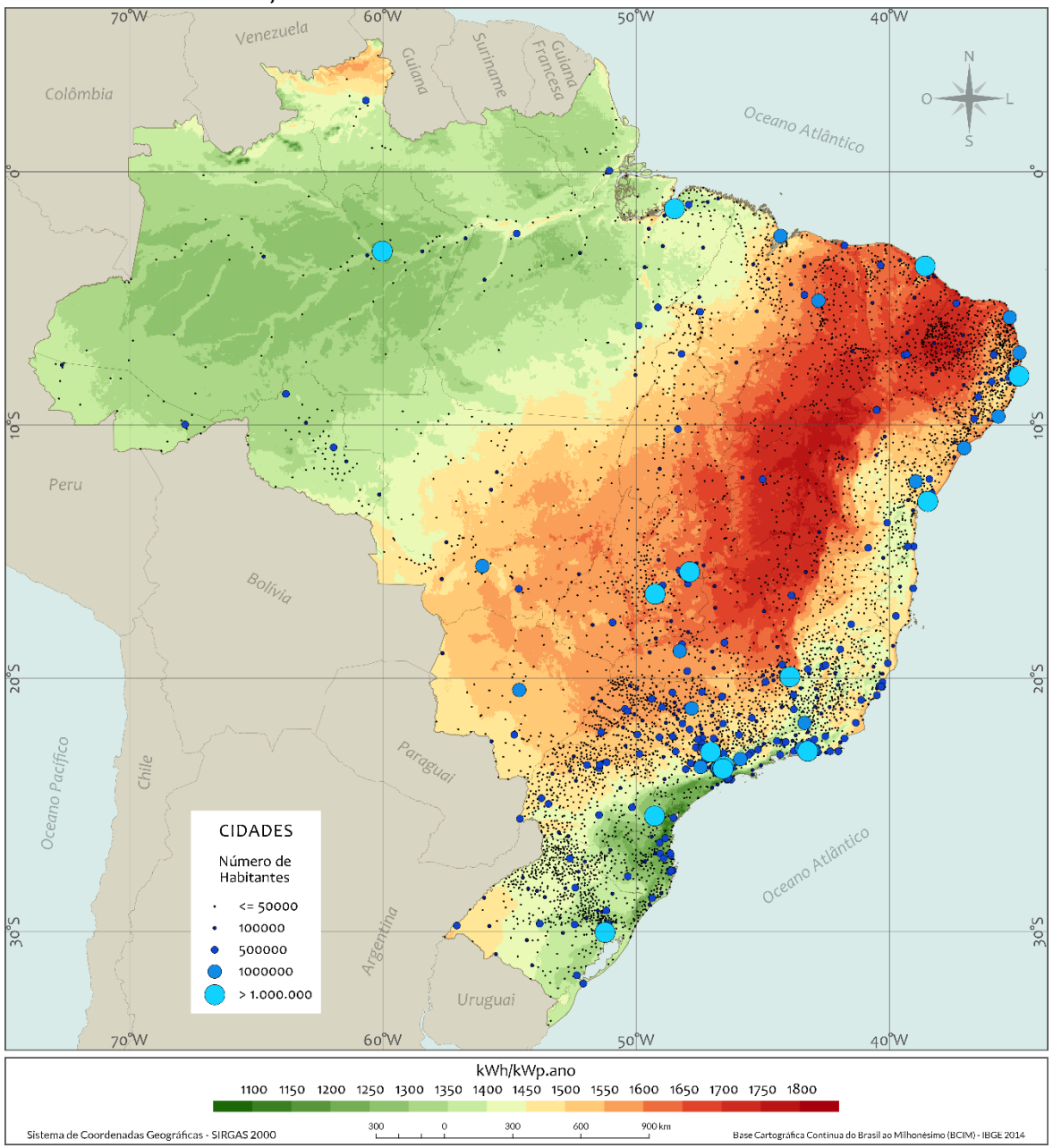




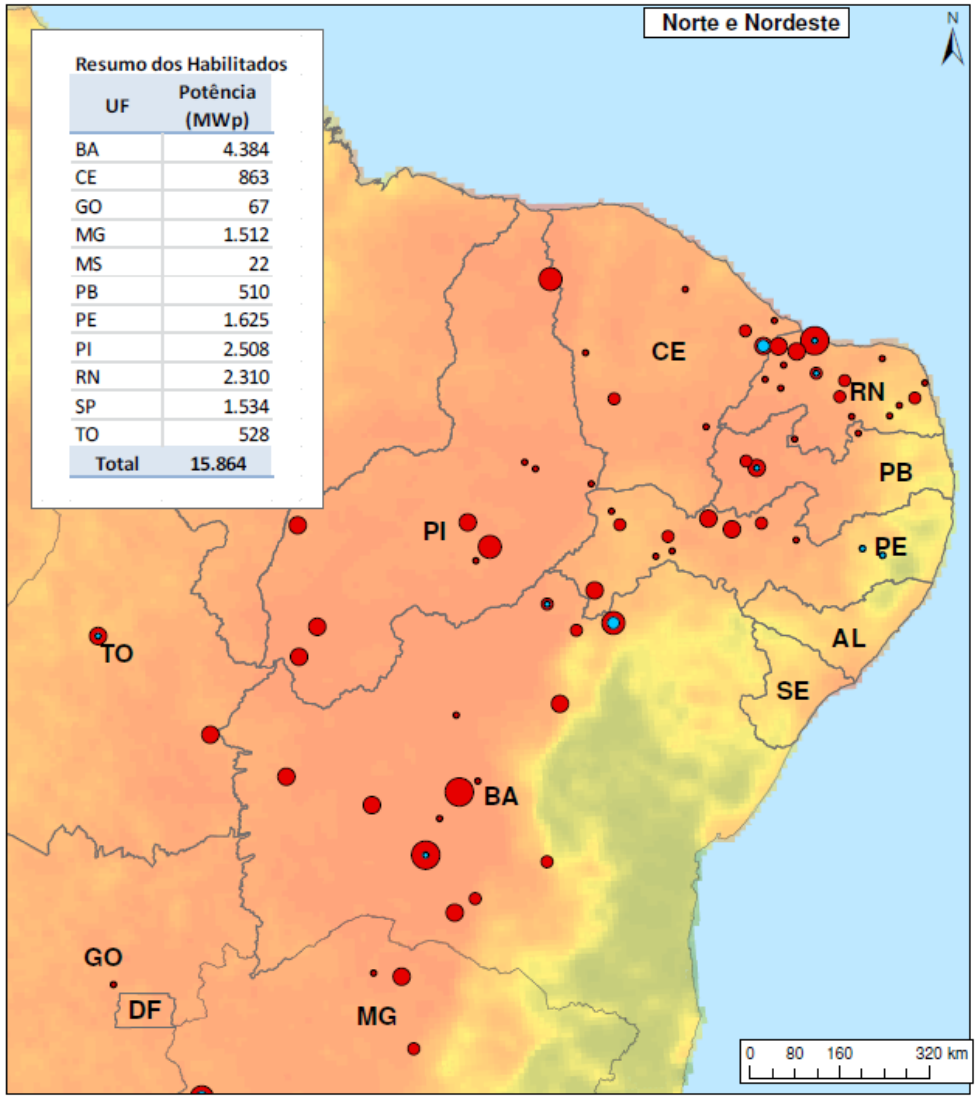
Photovoltaic Potential (kWh/kWp)

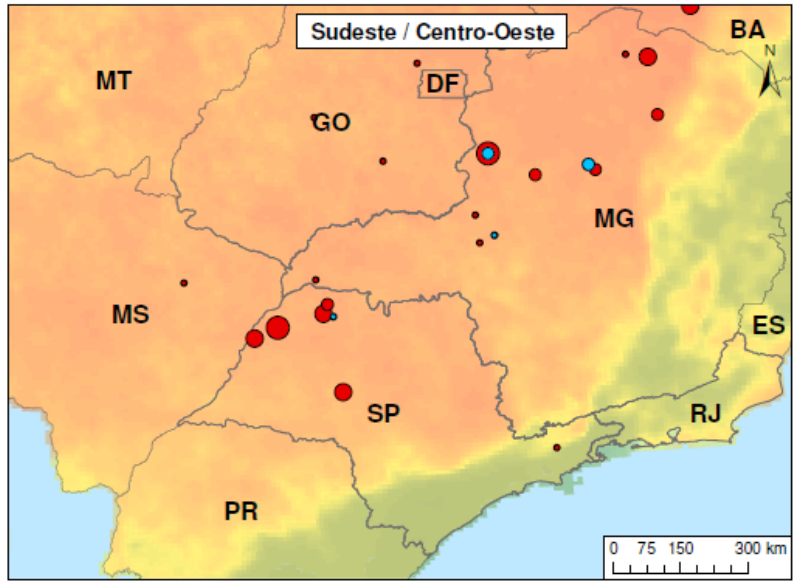


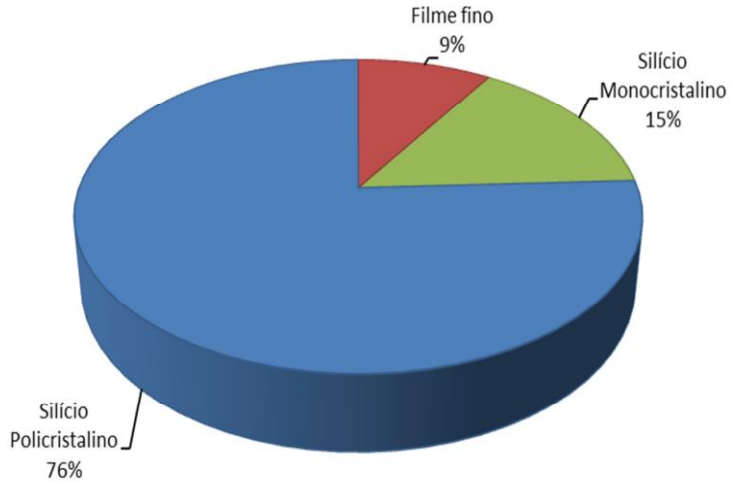




Energy auctions (authorized projects for electric power generation from photovoltaic solar)



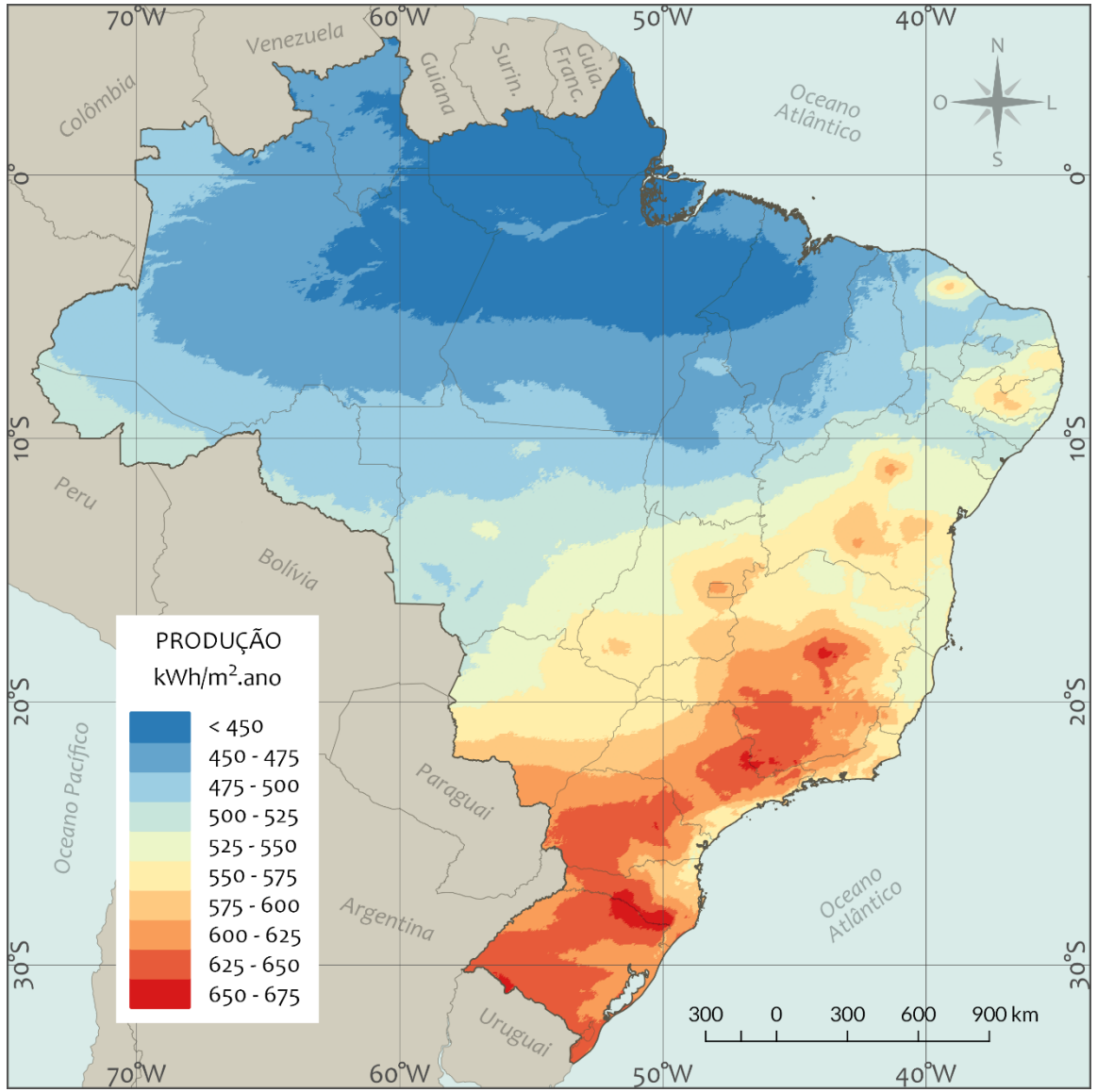




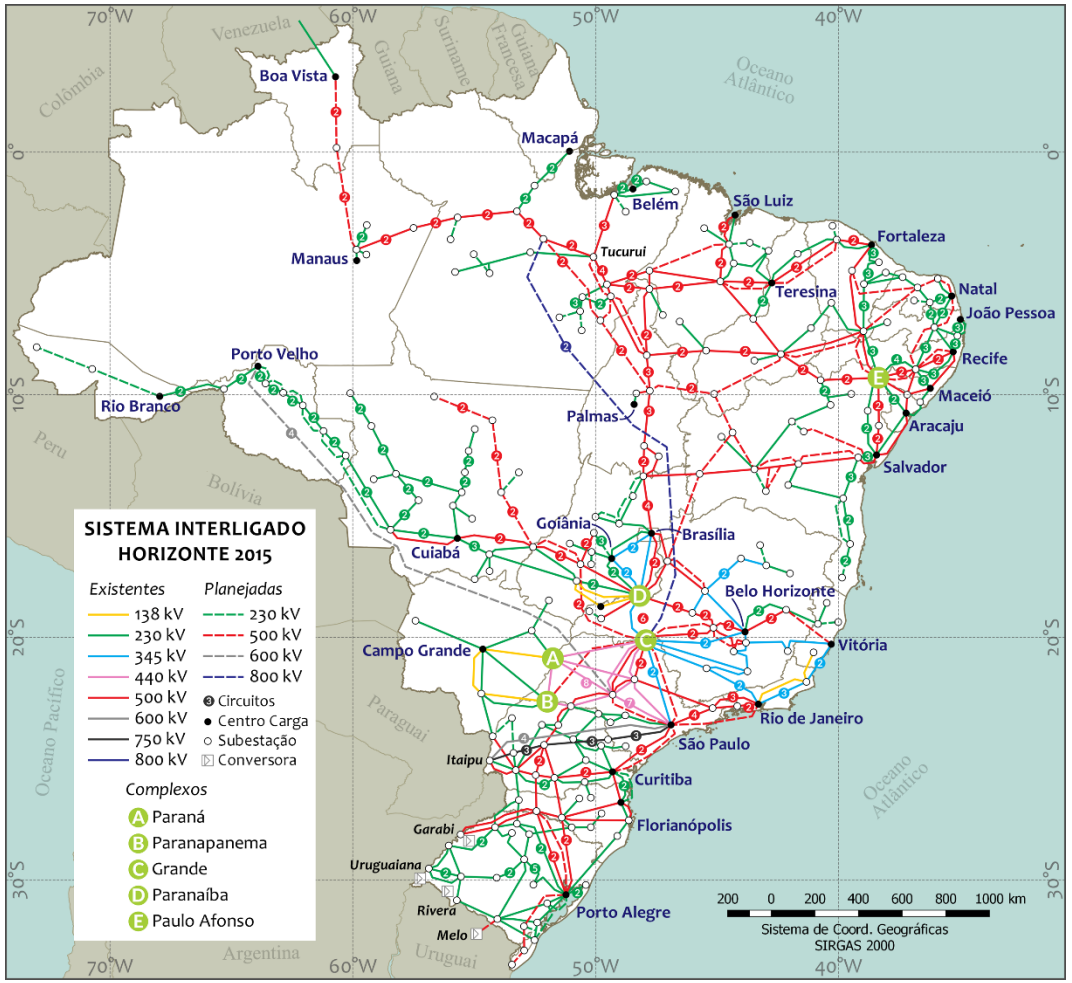
Solar Thermal (hot water)

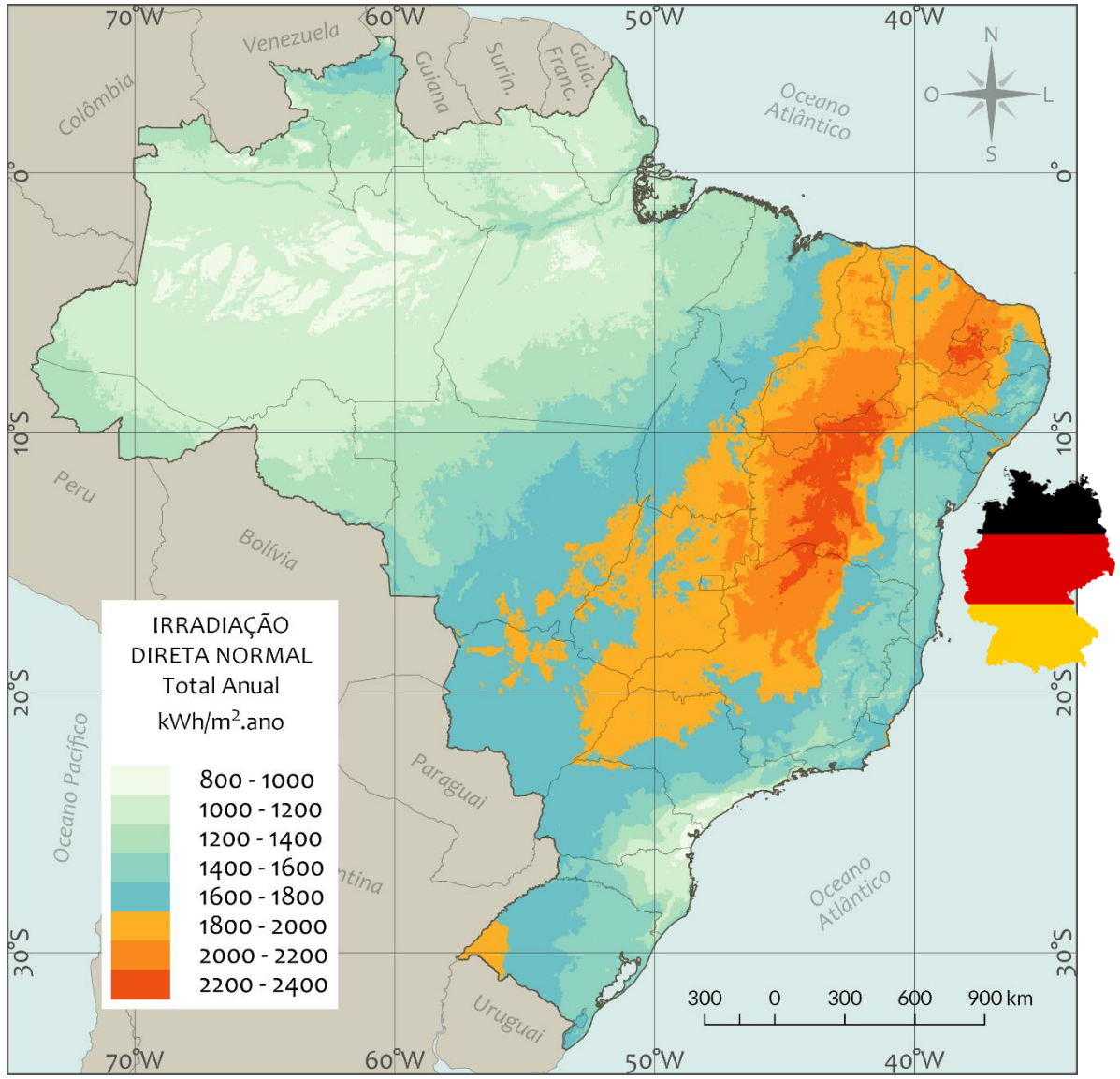
Production of thermal energy for solar collector area installed using a reference system

- a flat plate collector with glass cover (efficiency curve as IEA, 2015);
- tank volume equal to the volume of water consumed on a daily basis;
- relationship between tank volume and collector area of 75 litres/m²;
- daily consumption of 300 litres of water heated to 30° C;
- the cold water temperature is equivalent to monthly average ambient temperature location



Potential for CSP (kWh/m².year)





Acknowledgements

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