LABREN Laboratório de Modelagem e Estudos de Recursos Renováveis de Energia

CCST INPE

Atlas Brasileiro de Energia Solar e Previsão de Radiação Solar no Brasil

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Centro de Ciência do Sistema Terrestre

MINISTÉRIO DA CIÊNCIA, TECNOLOGIA, INOVAÇÕES E COMUNICAÇÕES

BRASIL GOVERNO FEDERAL

outline

- LABREN - Laboratory for Modelling and Studies of Renewable Energy Resources - who are we?
- Background on solar energy assessment and second edition of Brazilian Solar Atlas
- Overview on solar irradiation forecast methods
- Evaluation of methods and conclusions

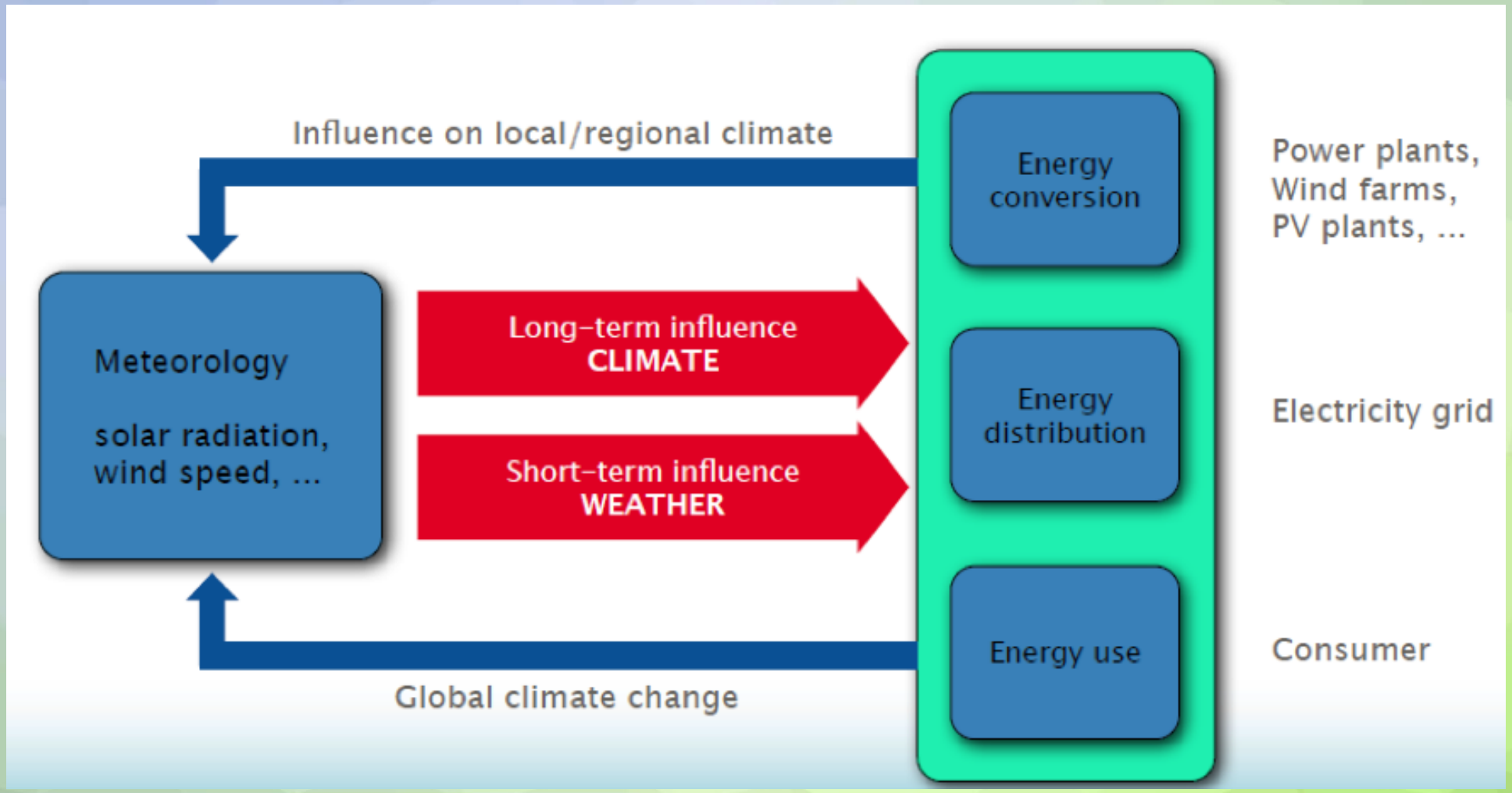
LABREN - LABoratory for modelling and studies of RENewable energy resources

Our multidisciplinary laboratory 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.

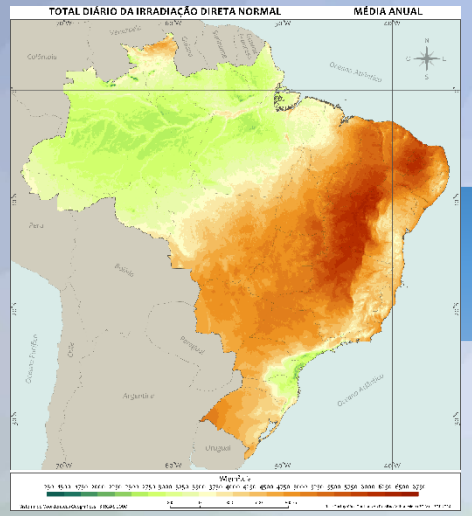
Research topics:

- Assessment of solar and wind energy resources;
- Short and medium-term forecast of solar and wind generation;
- Energy and global climate change;
- Site-specific measurements, characterization and modelling of solar and wind resources;
- And multidisciplinary subject related with energy meteorology research.

about energy meteorology...

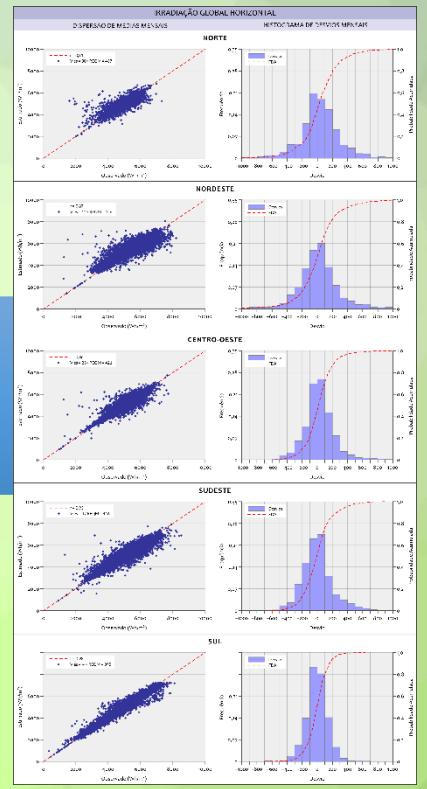


…and solar resource assessment



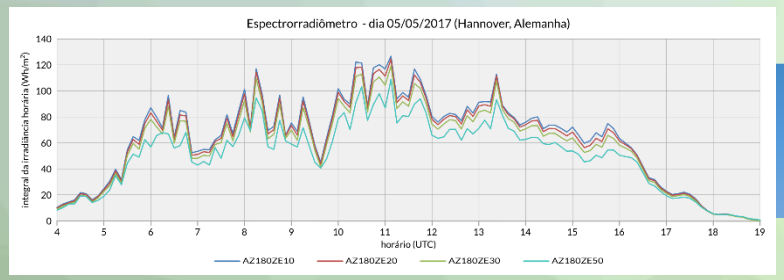
Solar energy potential

terrain, environment, latitude…



Data uncertainty

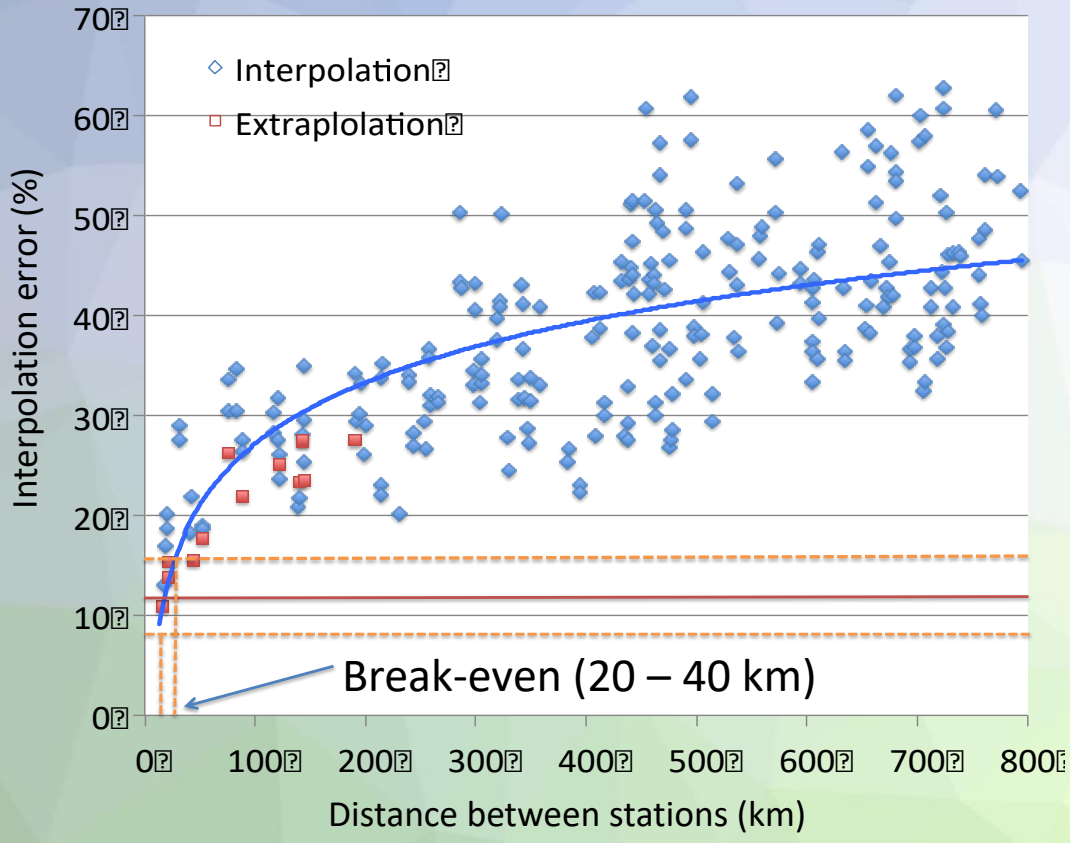
type of radiometer, operation & maintenance, model characteristic



Solar variability

meteorology, climate

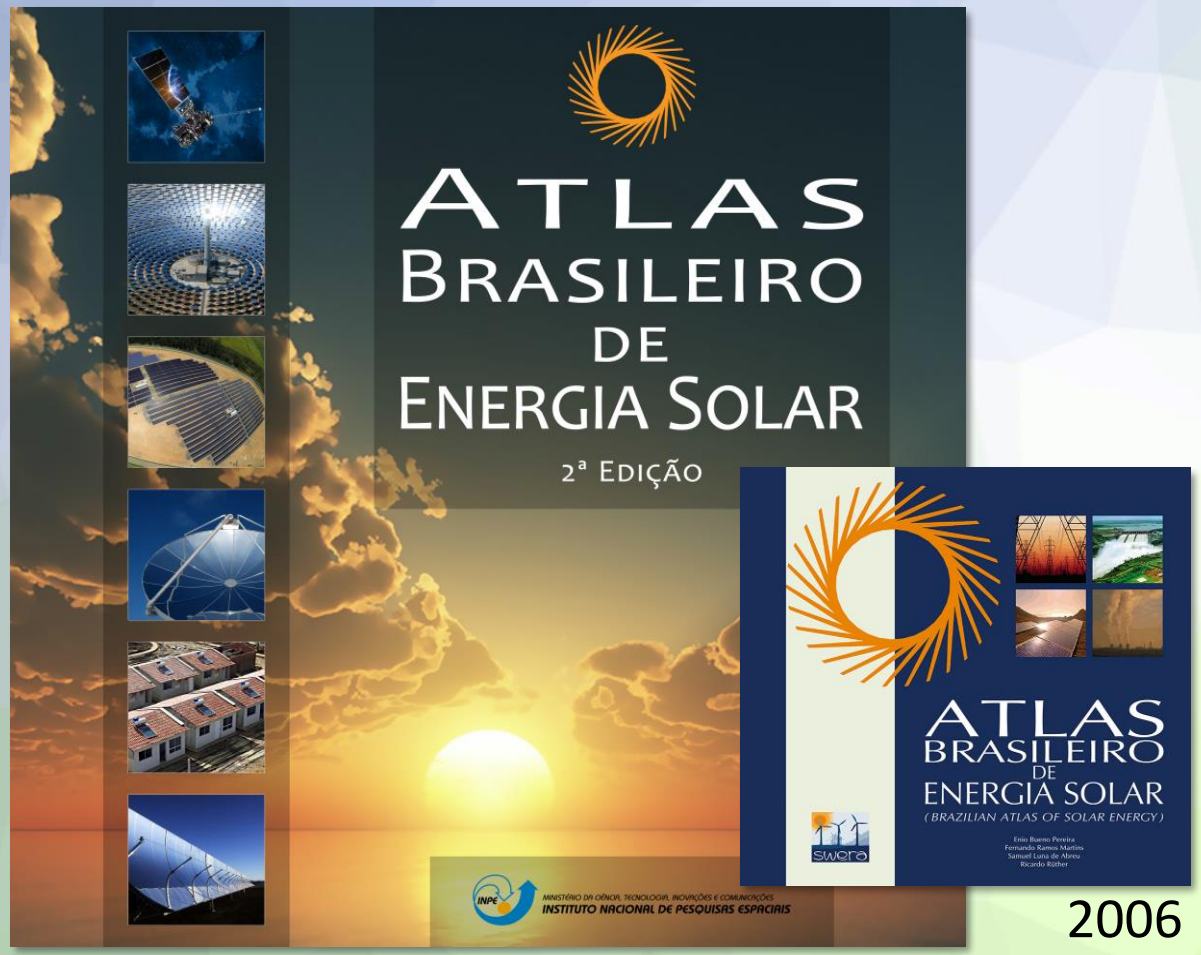
satellite model VS interpolation VS ground measurements



Benchmark for Brasil-SR satellite model

Região	r	Viés (Wh/m²)	Viés (%)	REQM (Wh/m²)	REQM (%)	Irradiação Global Horizontal Média Observada (Wh/m²)
Norte	0,81	30	0,6%	467	9,7%	4825
Nordeste	0,87	12	0,2%	456	8,3%	5483
Centro-Oeste	0,86	23	0,5%	421	8,3%	5082
Sudeste	0,91	4	0,1%	416	8,4%	4951
Sul	0,98	-4	-0,1%	395	8,9%	4444
Médio	0,89	12	0,2%	421	8,2%	5153

brazilian solar atlas - second edition

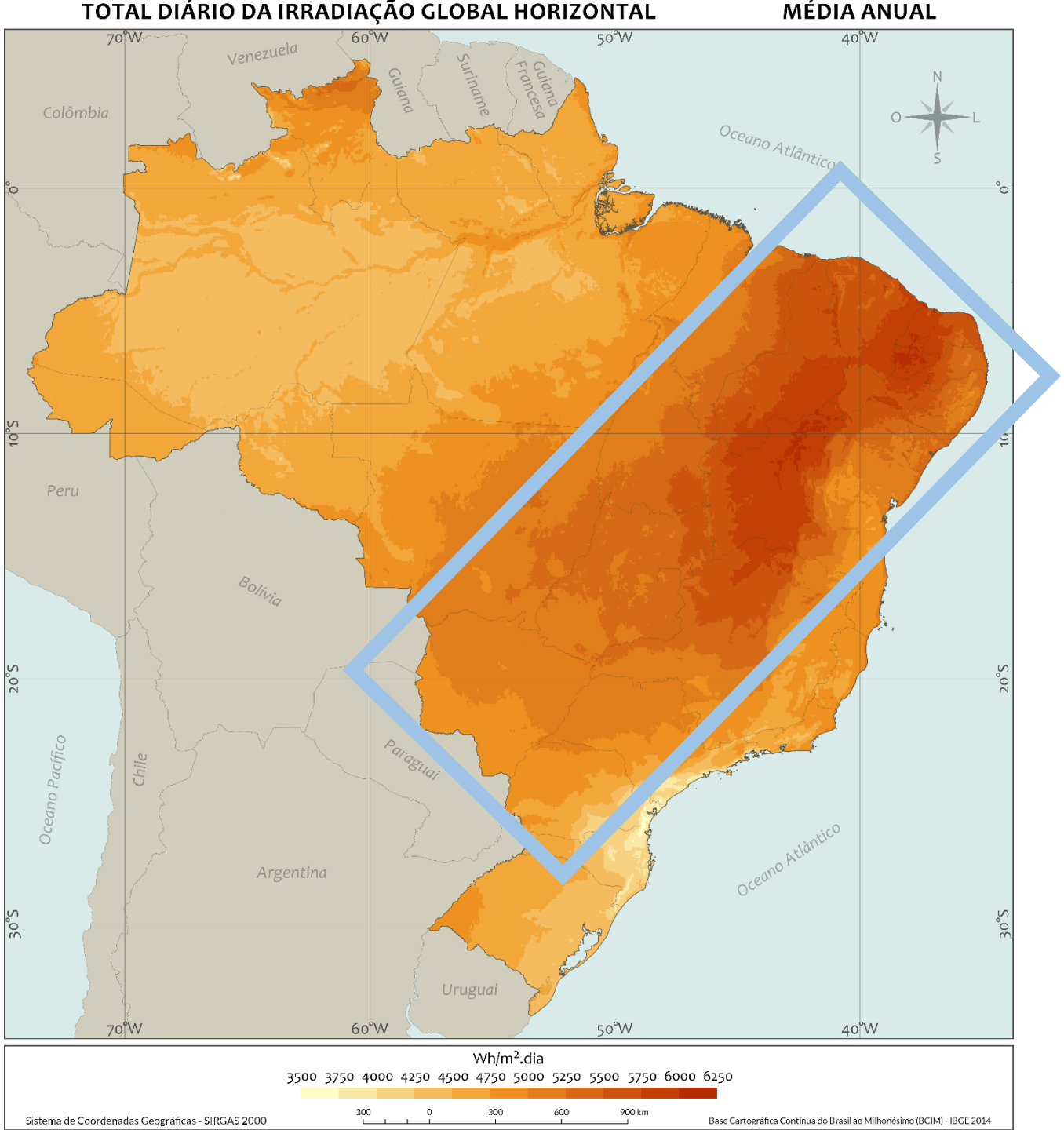


2006

An INPE accomplishment in association with

- 17 years of satellite data
- Spectral radiation transfer model
- Validation by using more than 500 ground sites
- National coverage

GHI annual mean



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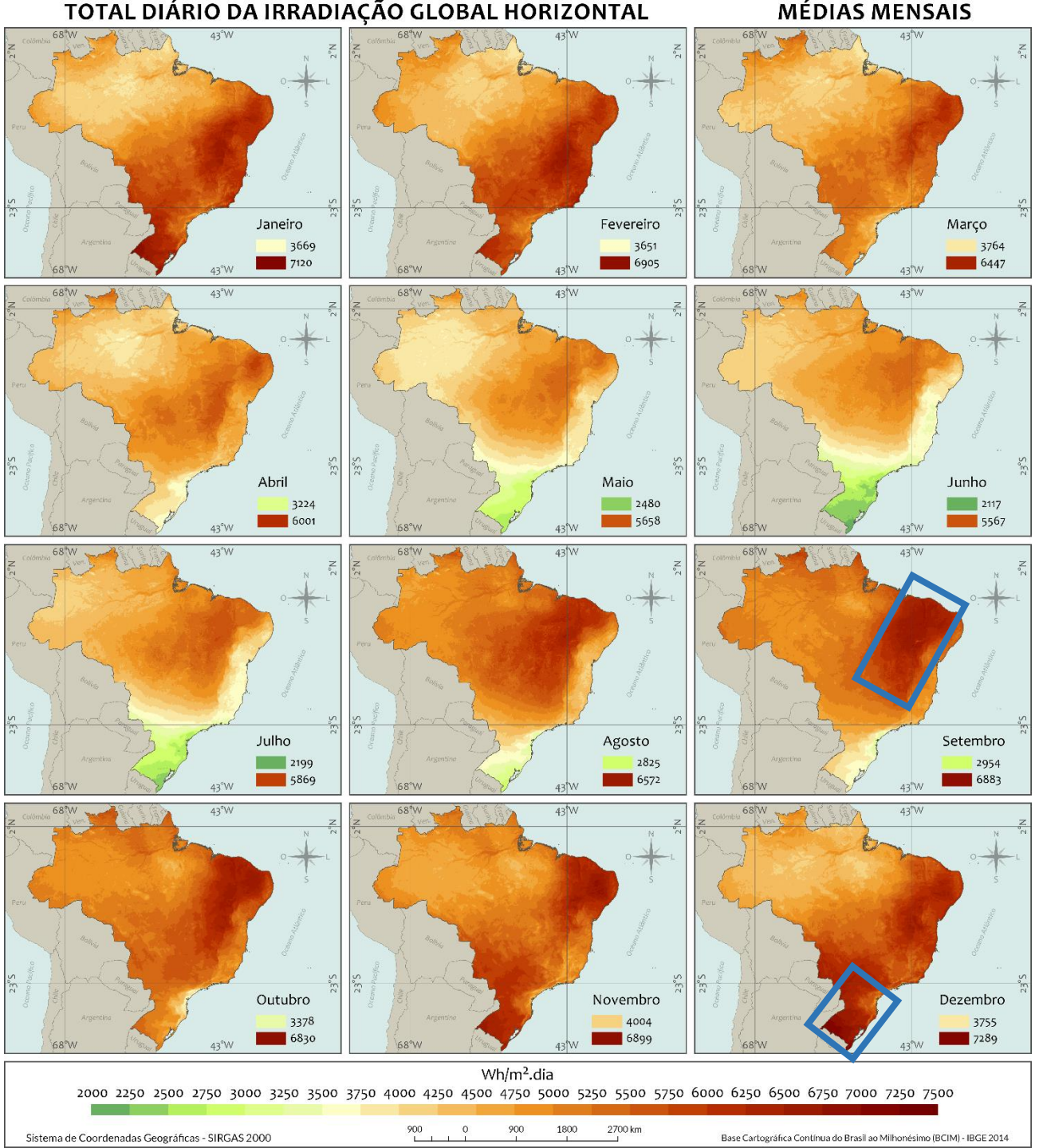
GHI monthly mean



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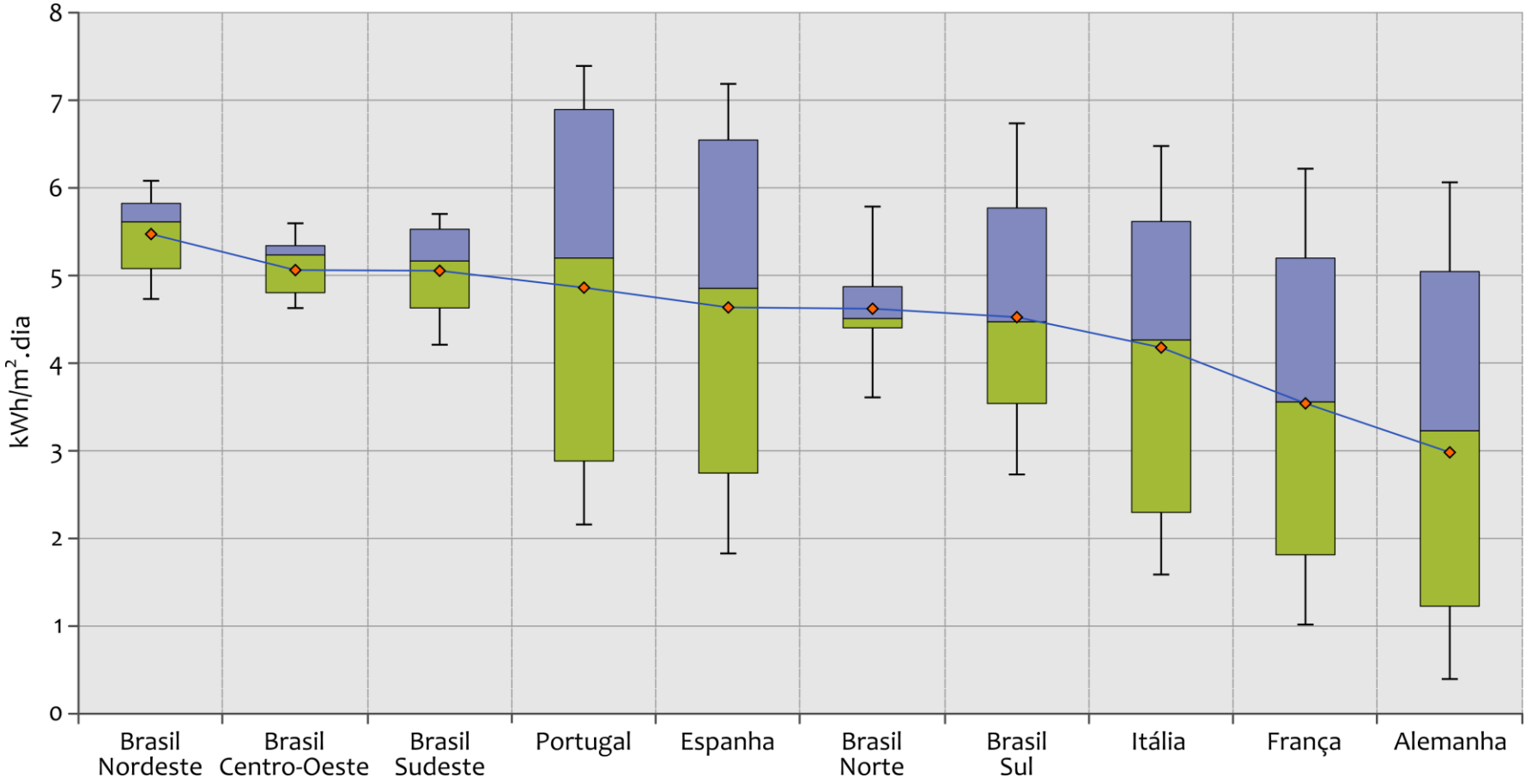
Brazil VS Europe: an overview

(monthly mean)



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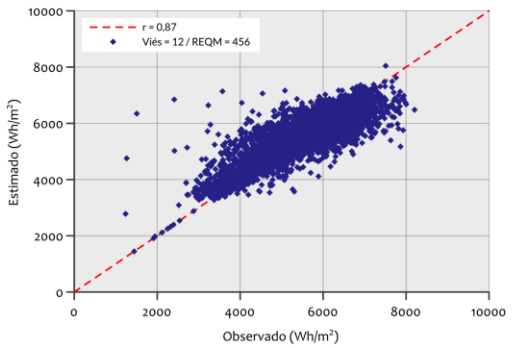
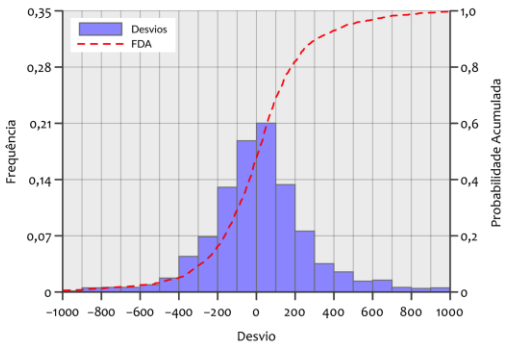
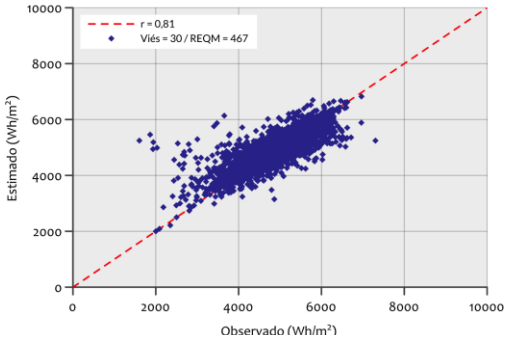
model validation (mean daily totals for global horizontal irradiation)

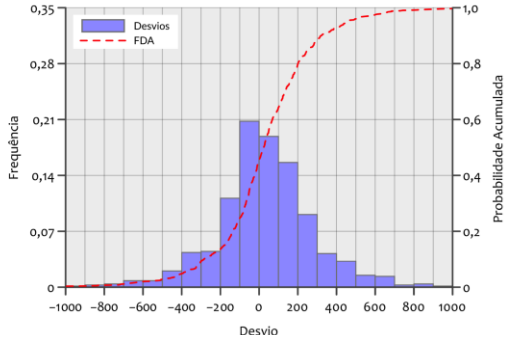
NORDESTE



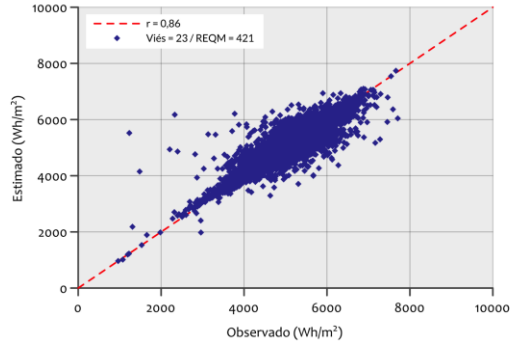


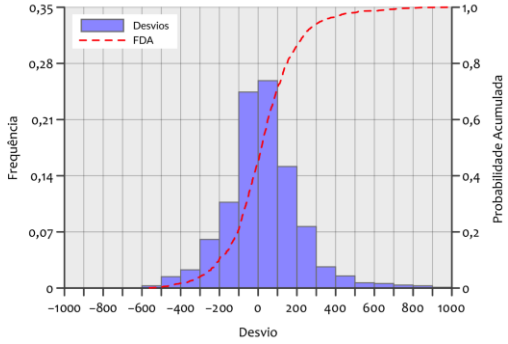
NORTE



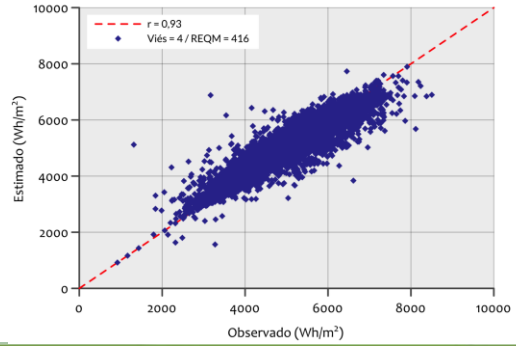


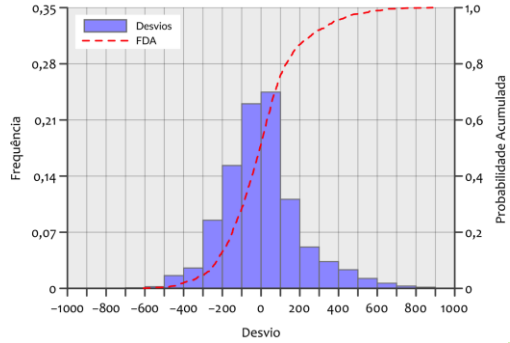
CENTRO-OESTE



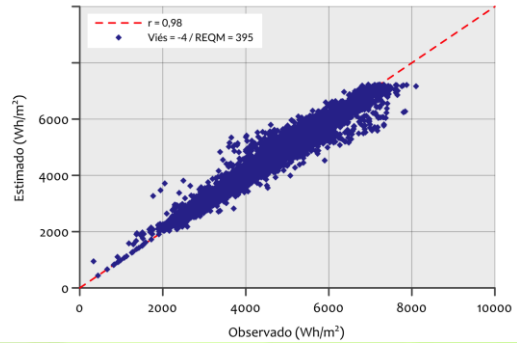


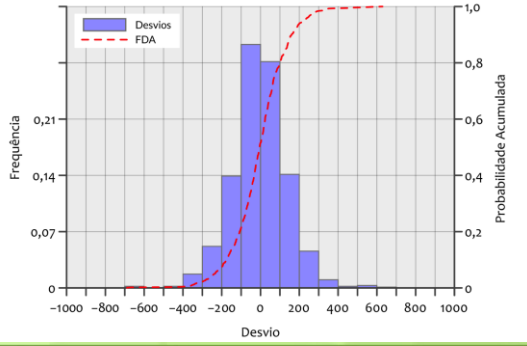
SUDESTE





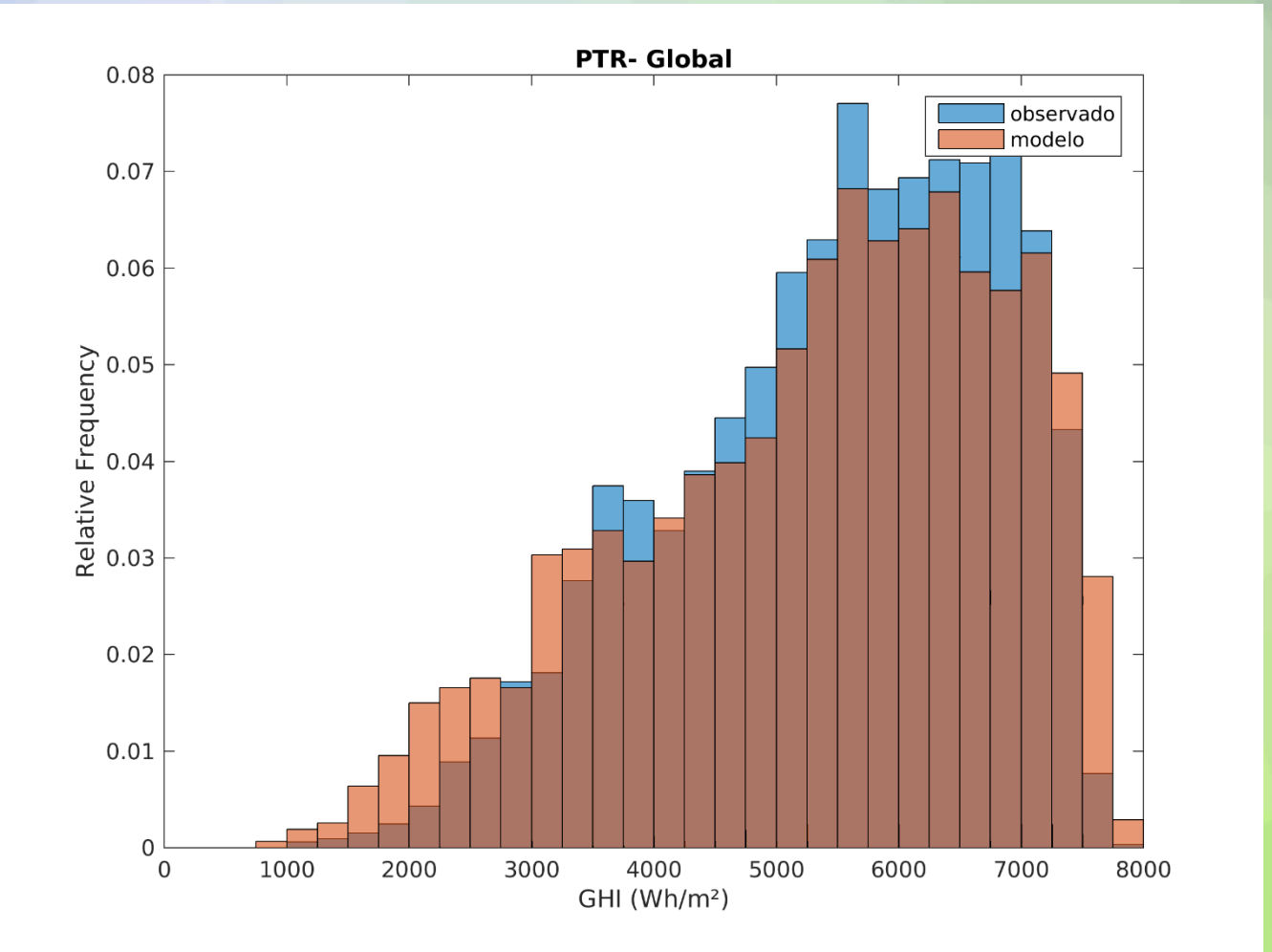
SUL





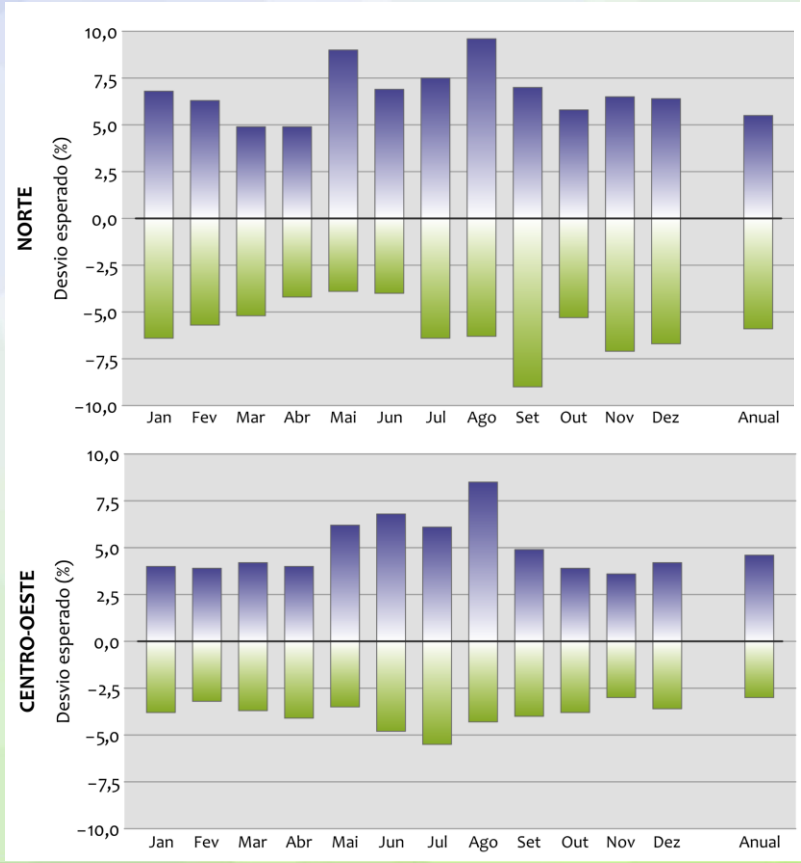
model validation (mean daily totals for global horizontal irradiation)

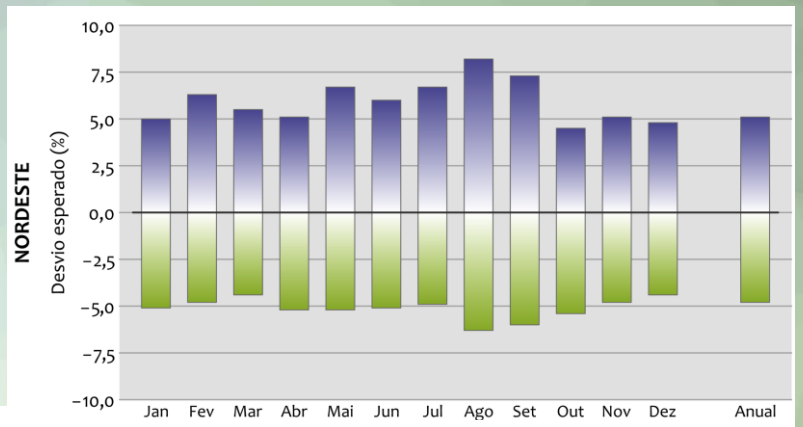
- Good agreement of distribution curves between observed and modelled values

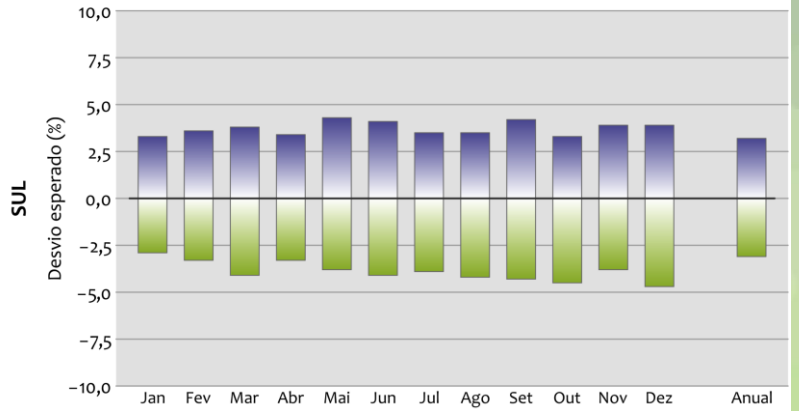


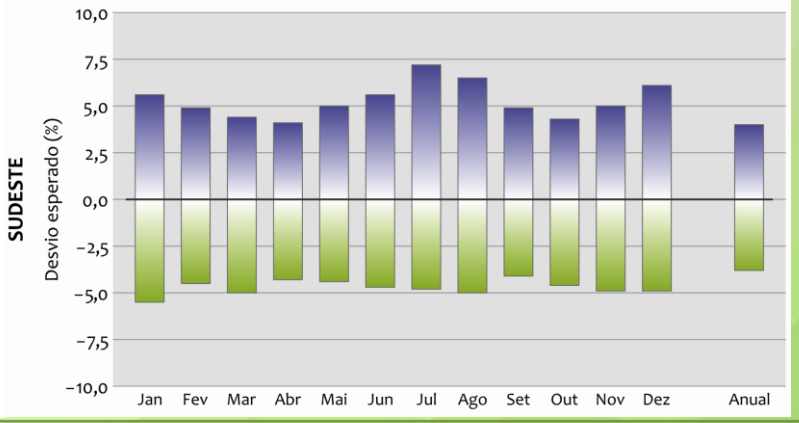
model uncertainties

- Maximum percentage deviation between modeled and observed - monthly average of daily global irradiation for the percentiles of 10% and 90%









model uncertainties

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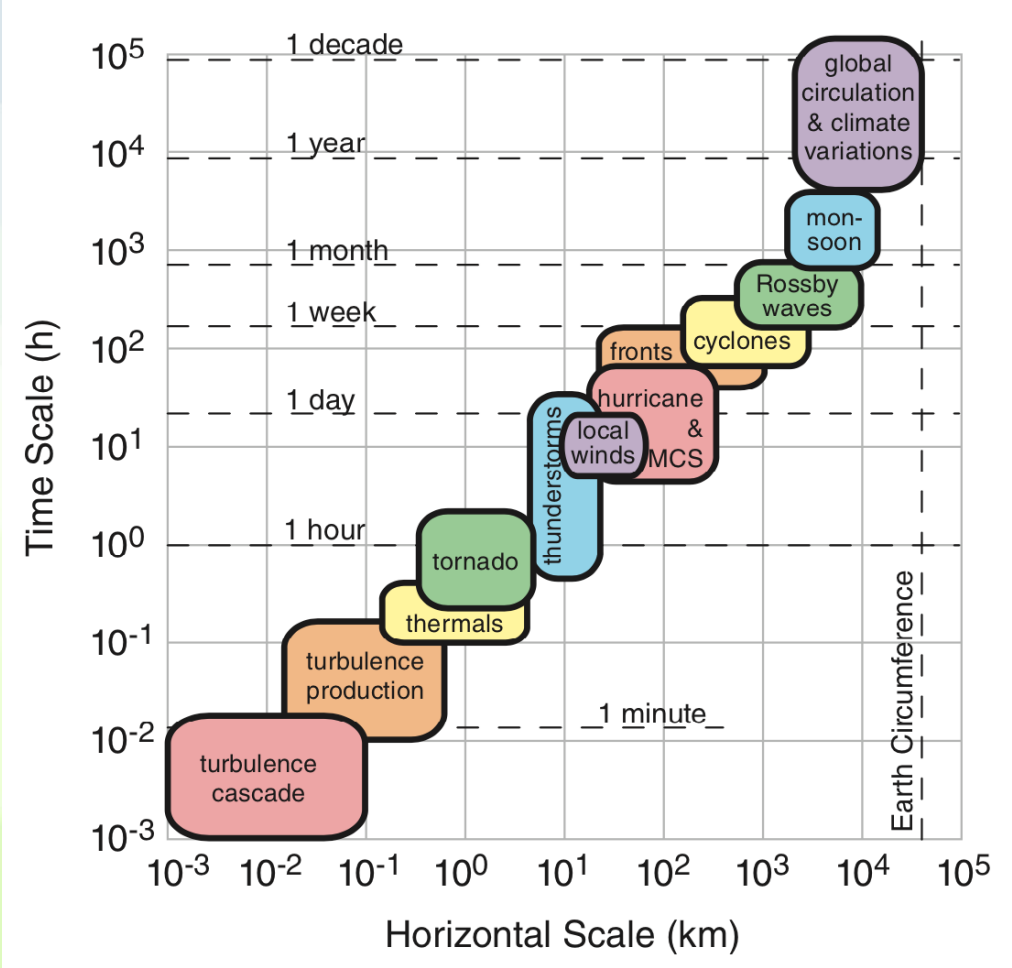
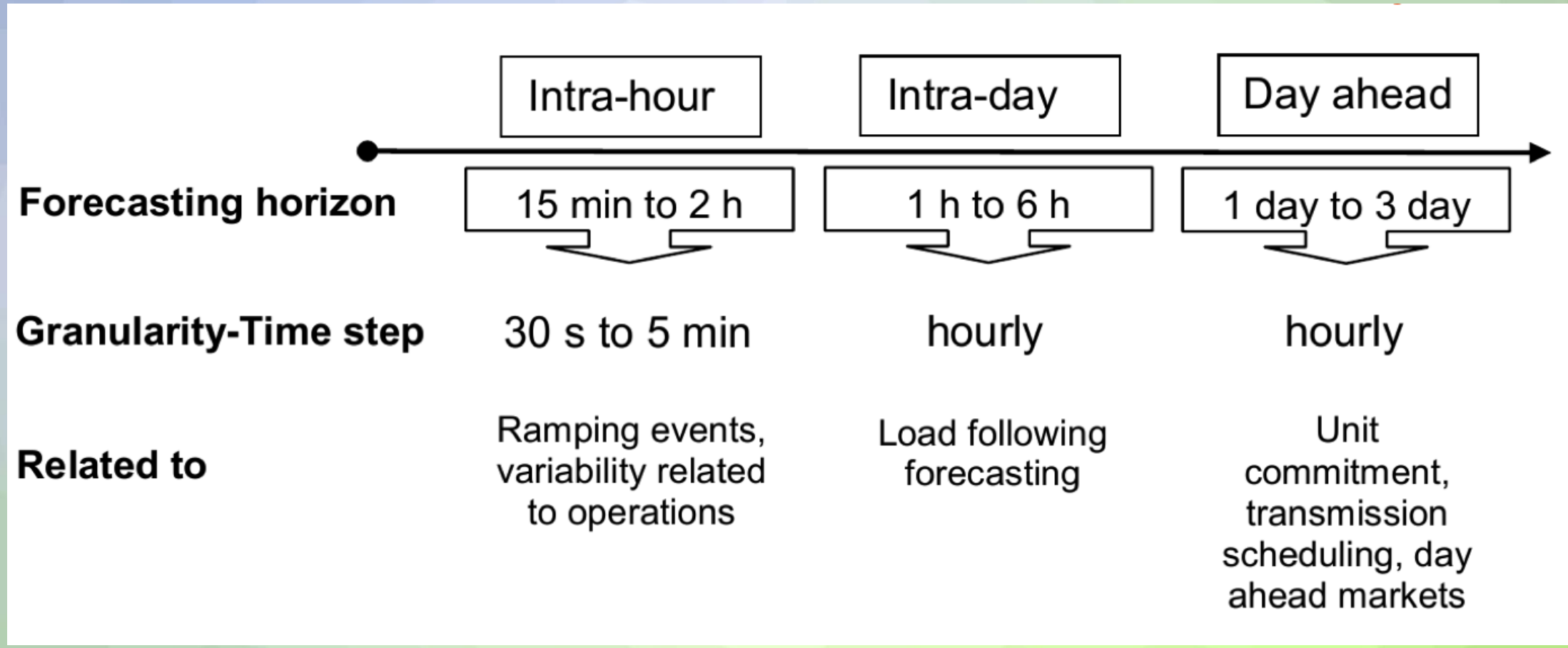
solar irradiation forecasting

solar irradiation forecasting methods

- To whom?
  - Transmission system operators or agencies (ONS, ANEEL)
    - Regional forecast
  - Direct market
    - Local forecast

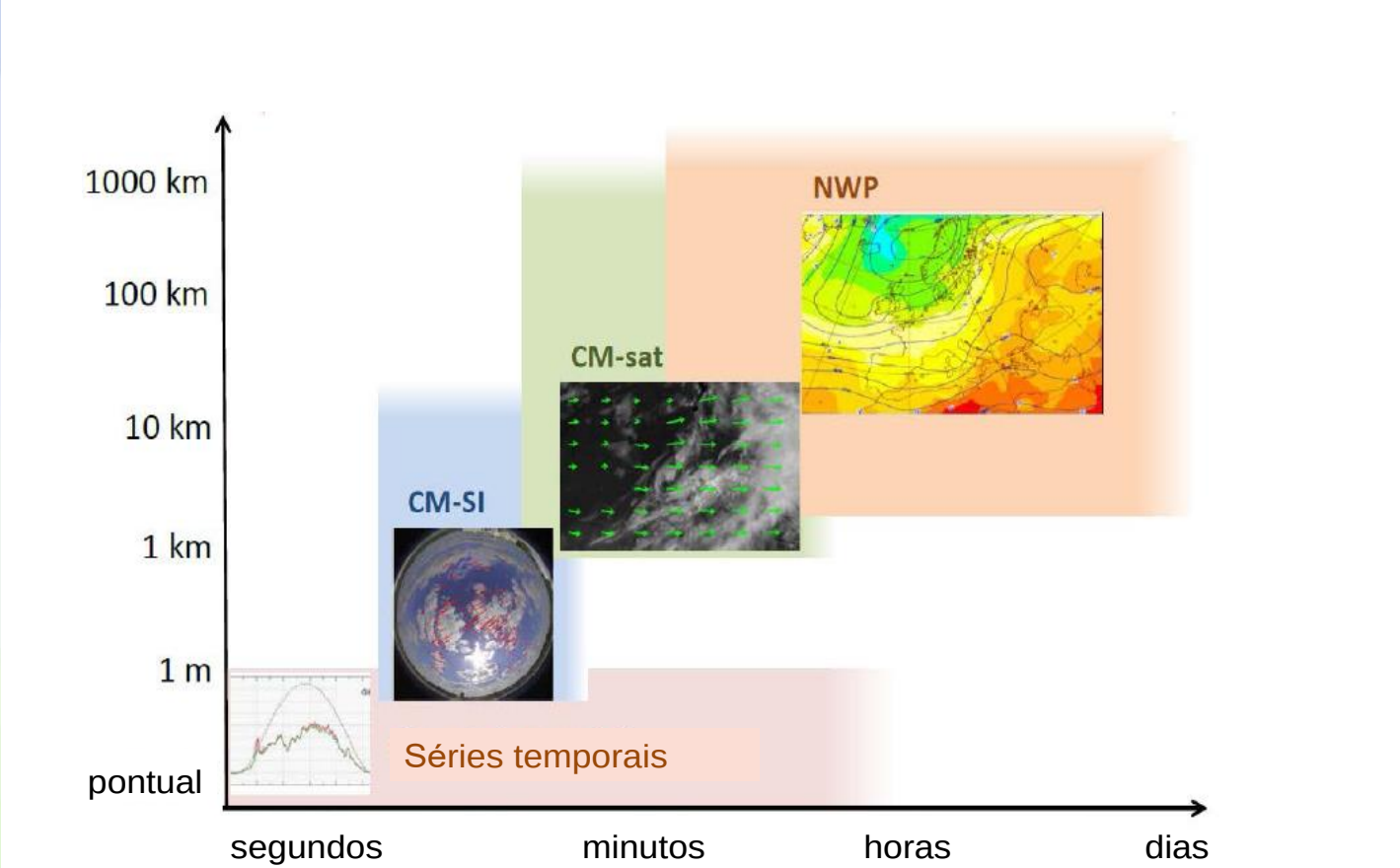


solar forecasting horizons



solar forecasting methodology

- Persistence from local ground measurements
- Cloud Motion from Sky Imagers - **CM-SI** – prediction with high spatial and temporal resolution forecasting of ramp effects (up to 30 minutes)
- Cloud Motion from Satellites - **CM-Sat** Uses satellite radiative transfer models (Ex: BRASIL-SR) providing regional forecasts for horizons from 30 minutes to 6 hours
- Numerical Weather Prediction - **NWP** Atmospheric models provides forecasts for vast regions on the horizon from 12h to 72h. They need adjustments through machine learning techniques (eg. neural networks)



The best method depends on the forecast horizon

persistence method (ground data)

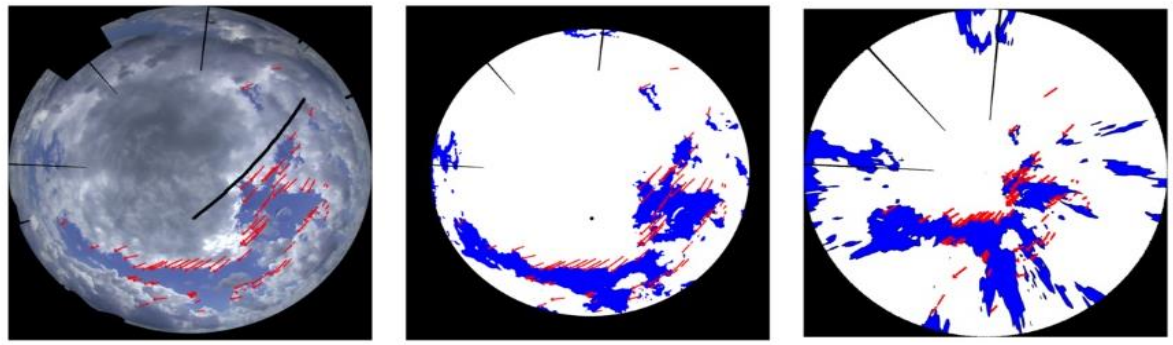
persistence:

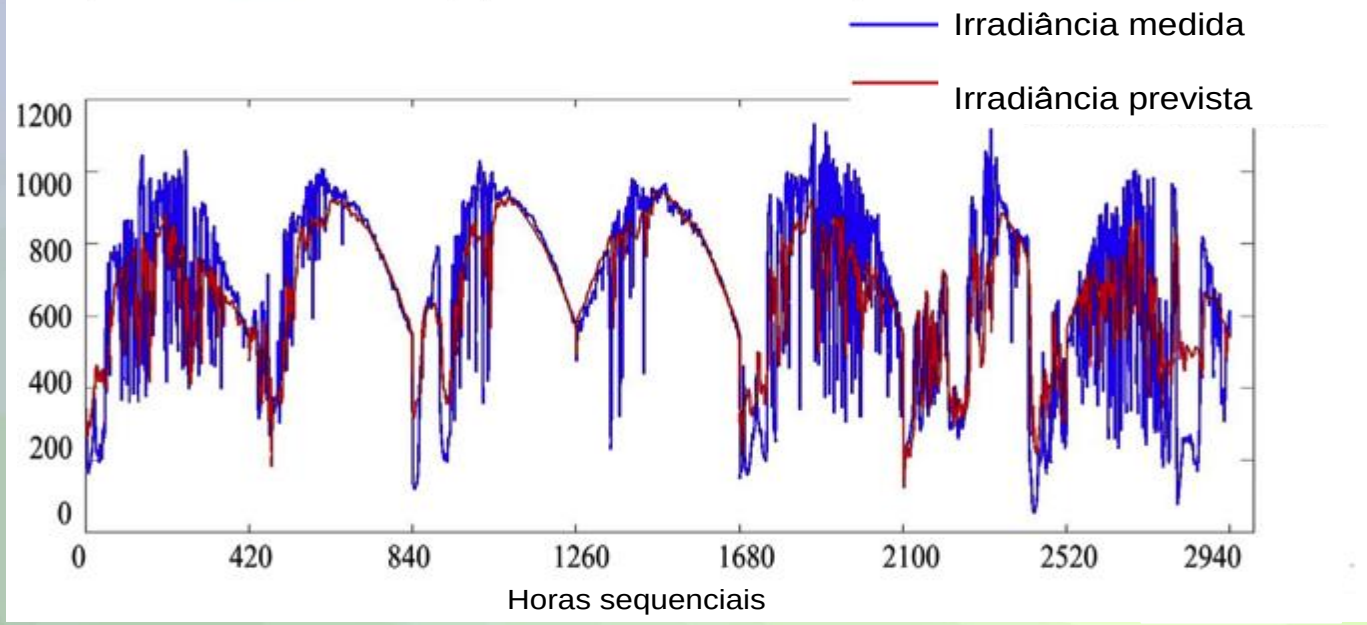
$$P_{pers} = \left\{ P_{meas}(t - \Delta t) \Big/ P_{clear}(t - \Delta t) \right\} \times P_{clear}(t)$$

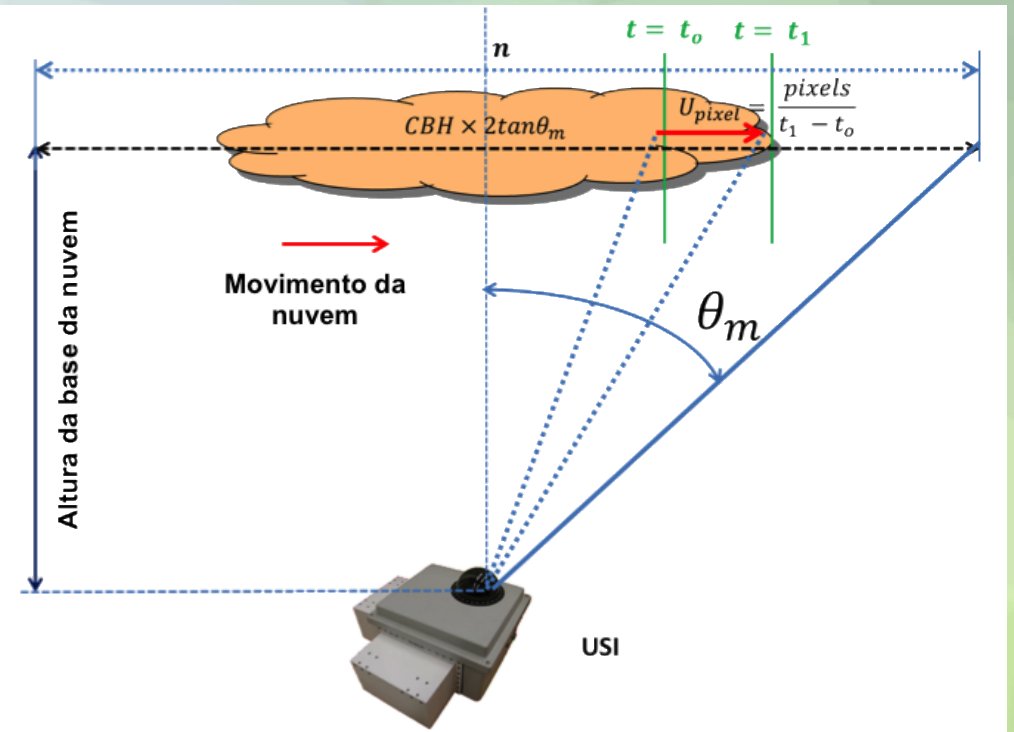
constant ratio of measured PV power P_{meas} to clear sky PV power P_{clear}

Post processing by statistical or machine learning methods

cloud motion from sky cameras

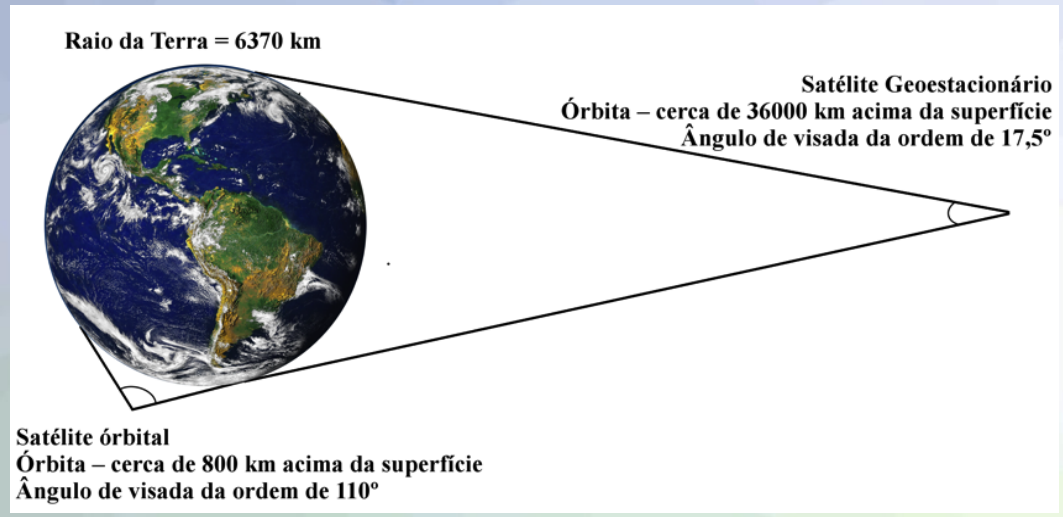


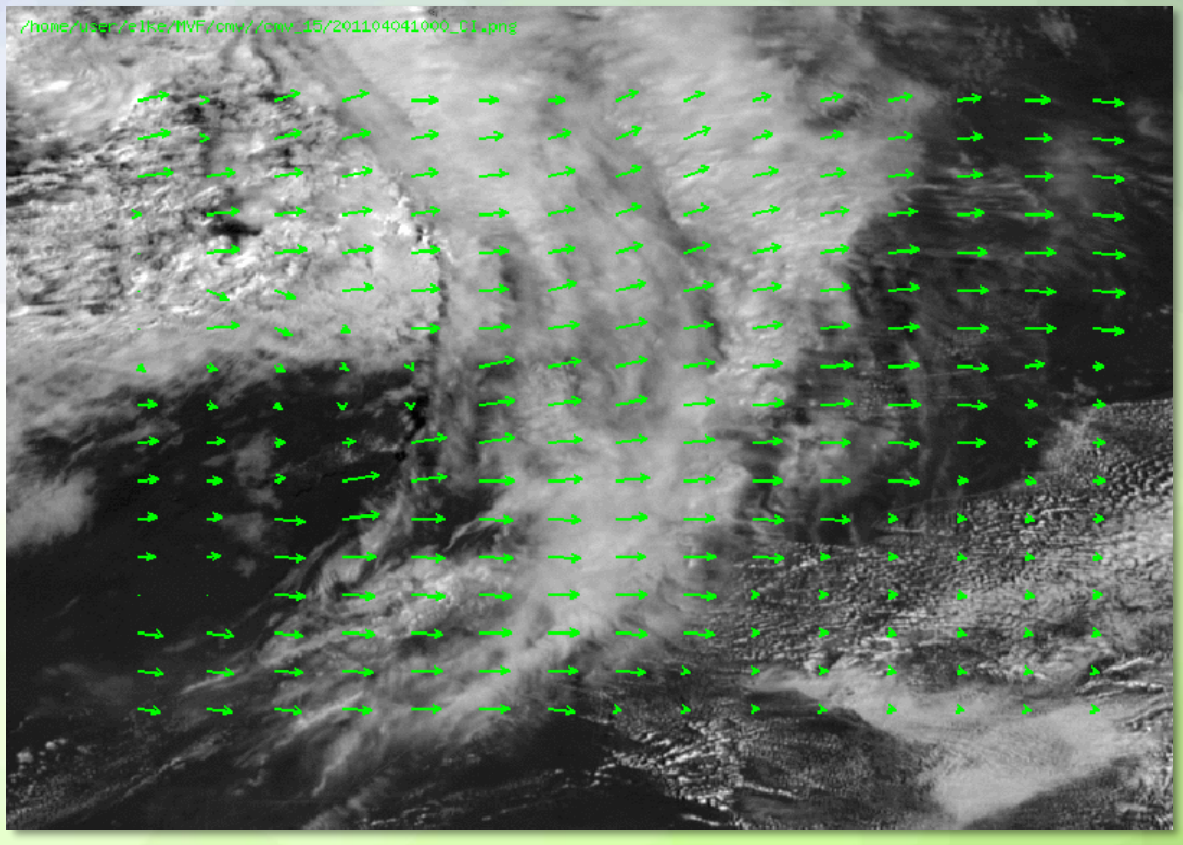




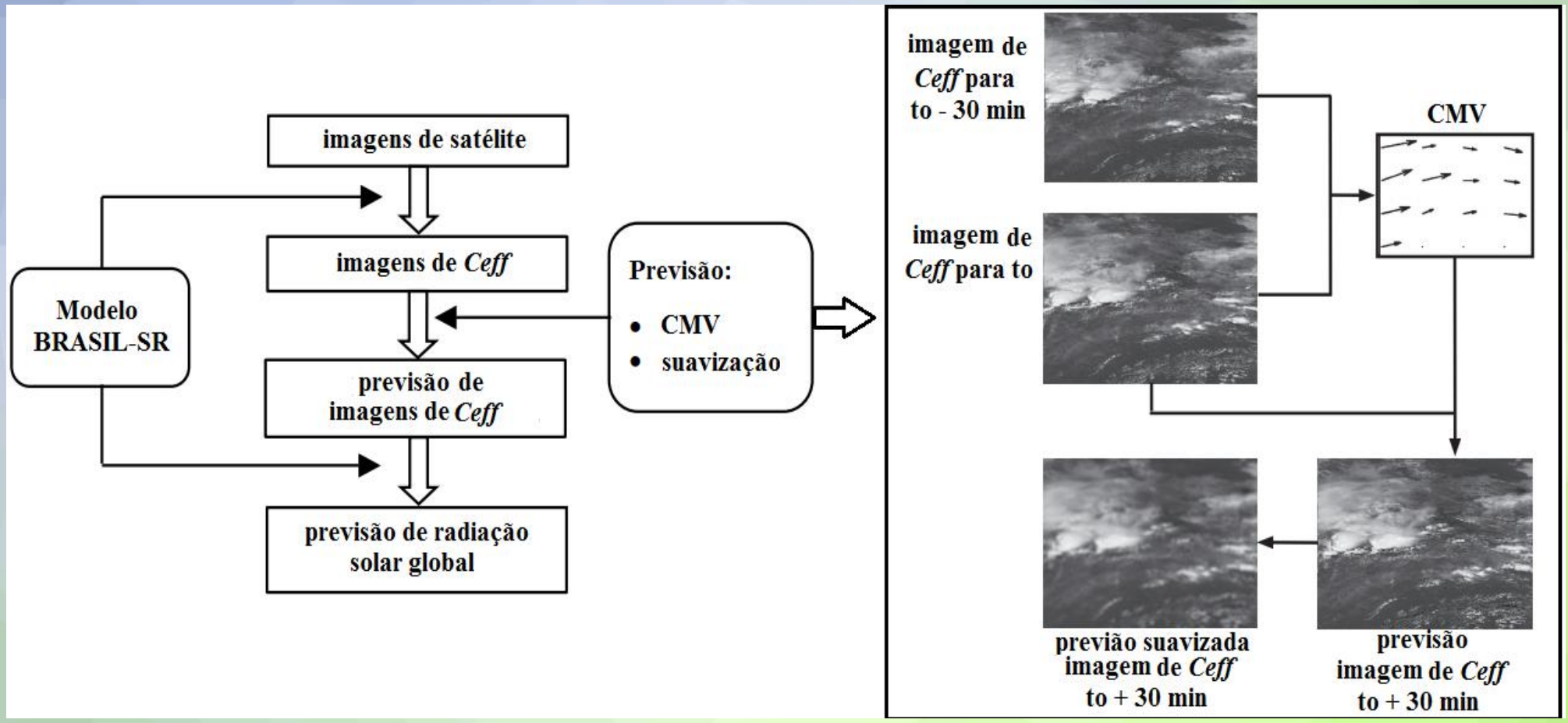
Comparison between predicted and measured 5-minute radiation in Taiwan (FU and CHENG, 2013)

cloud motion from satellite





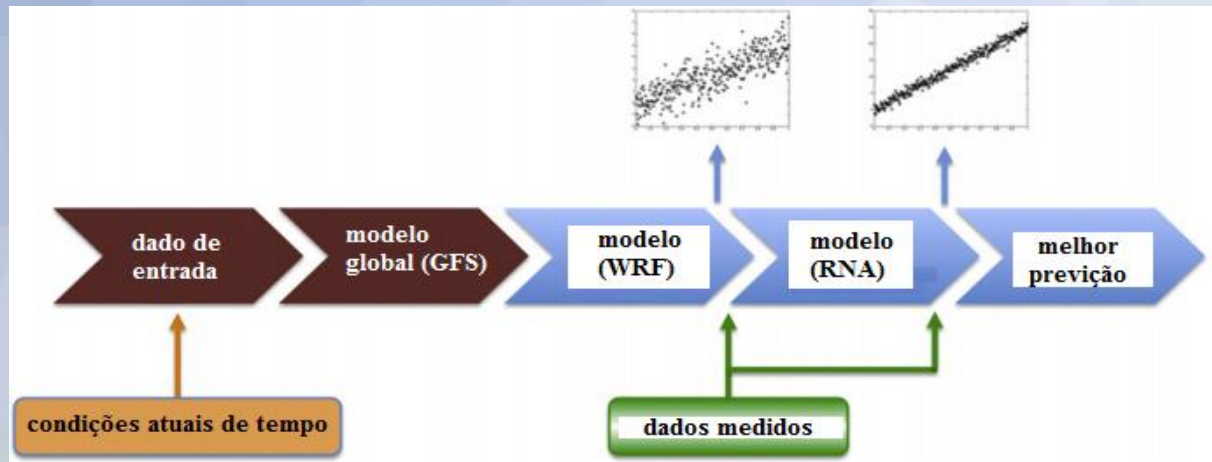
cloud motion from satellite

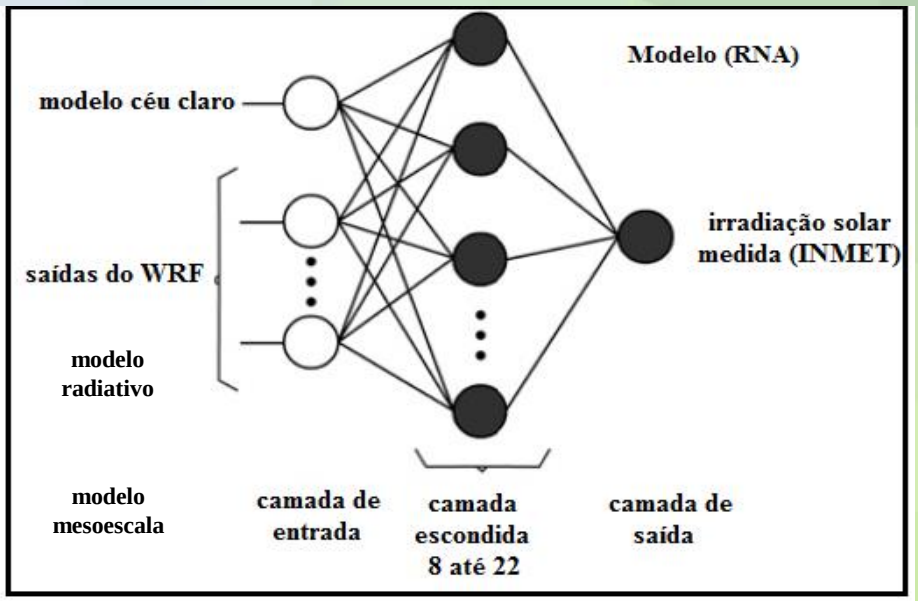


Short-term forecasting scheme (up to 6 hours in advance) using statistical methods on GOES satellite images.

numerical weather prediction

adjusted by artificial neural networks (ANN)

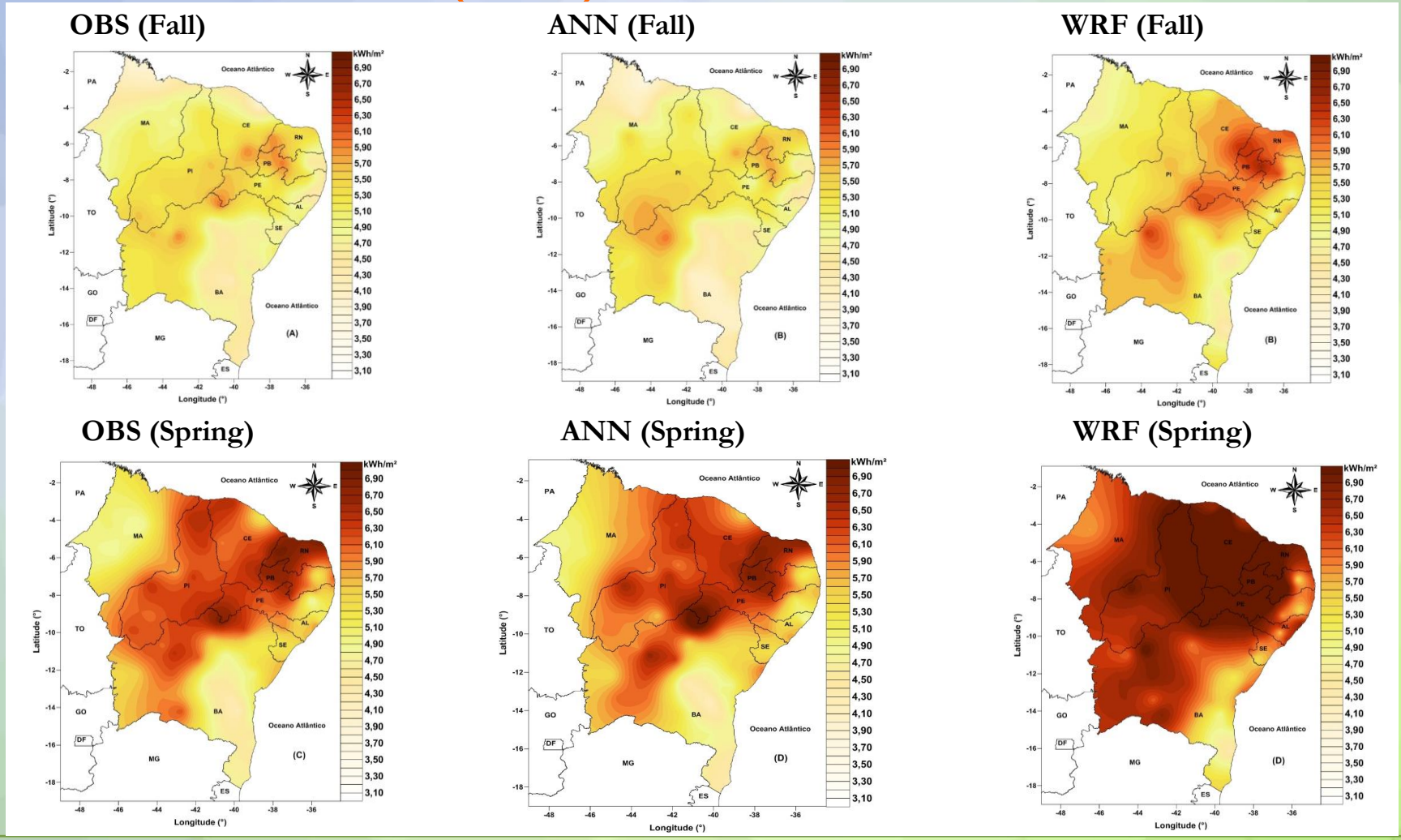




- ✓ Meteorological model output (WRF) fine-tuning using artificial neural network (ANN)
- ✓ ANN training performed with irradiance or local production data
- ✓ Predictions employ different methodologies for different time scales

numerical weather prediction

adjusted by artificial neural networks (ANN)



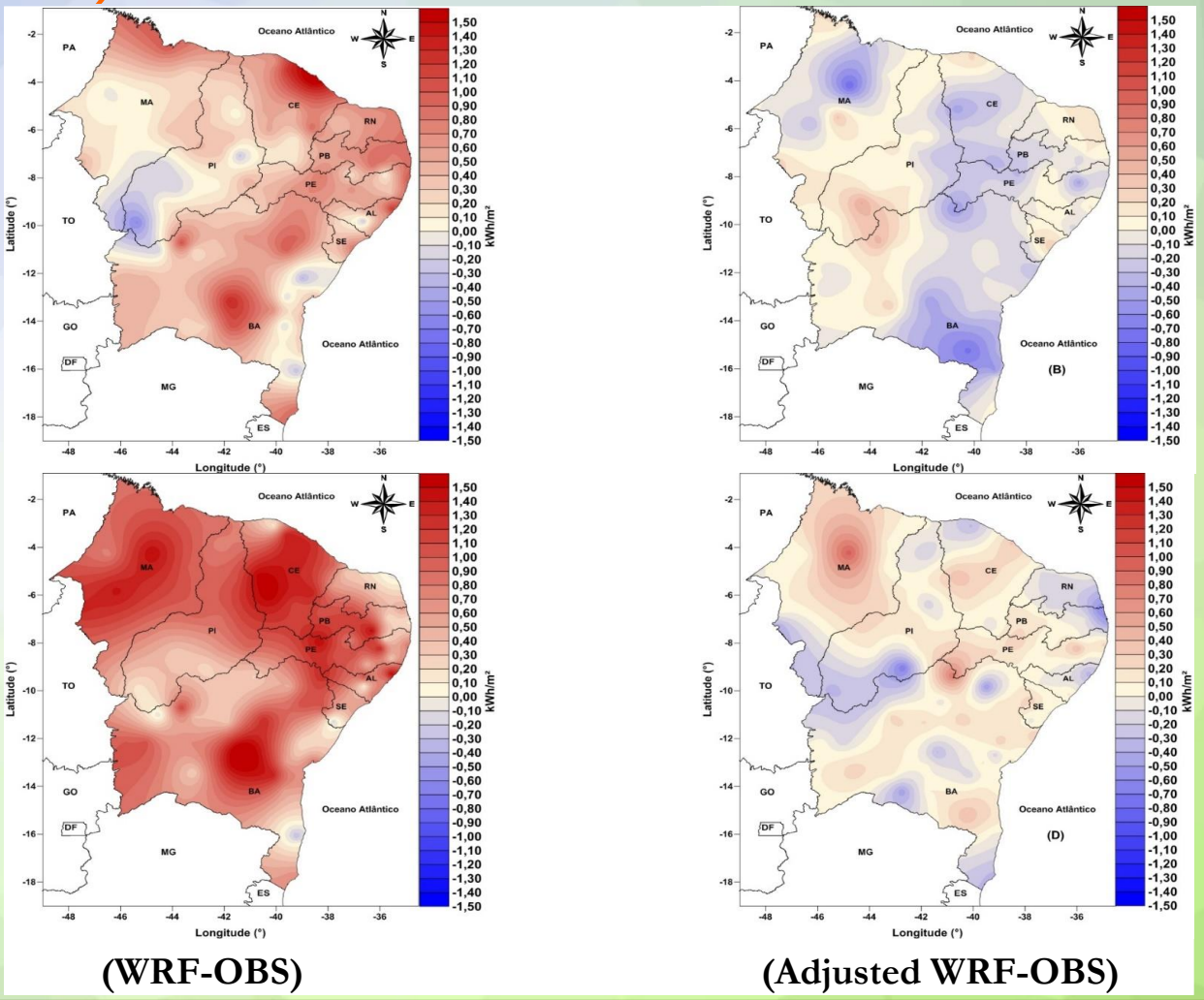
Resultados para a região nordeste (Lima, 2016)

numerical weather prediction

adjusted by artificial neural networks (ANN)

Fall

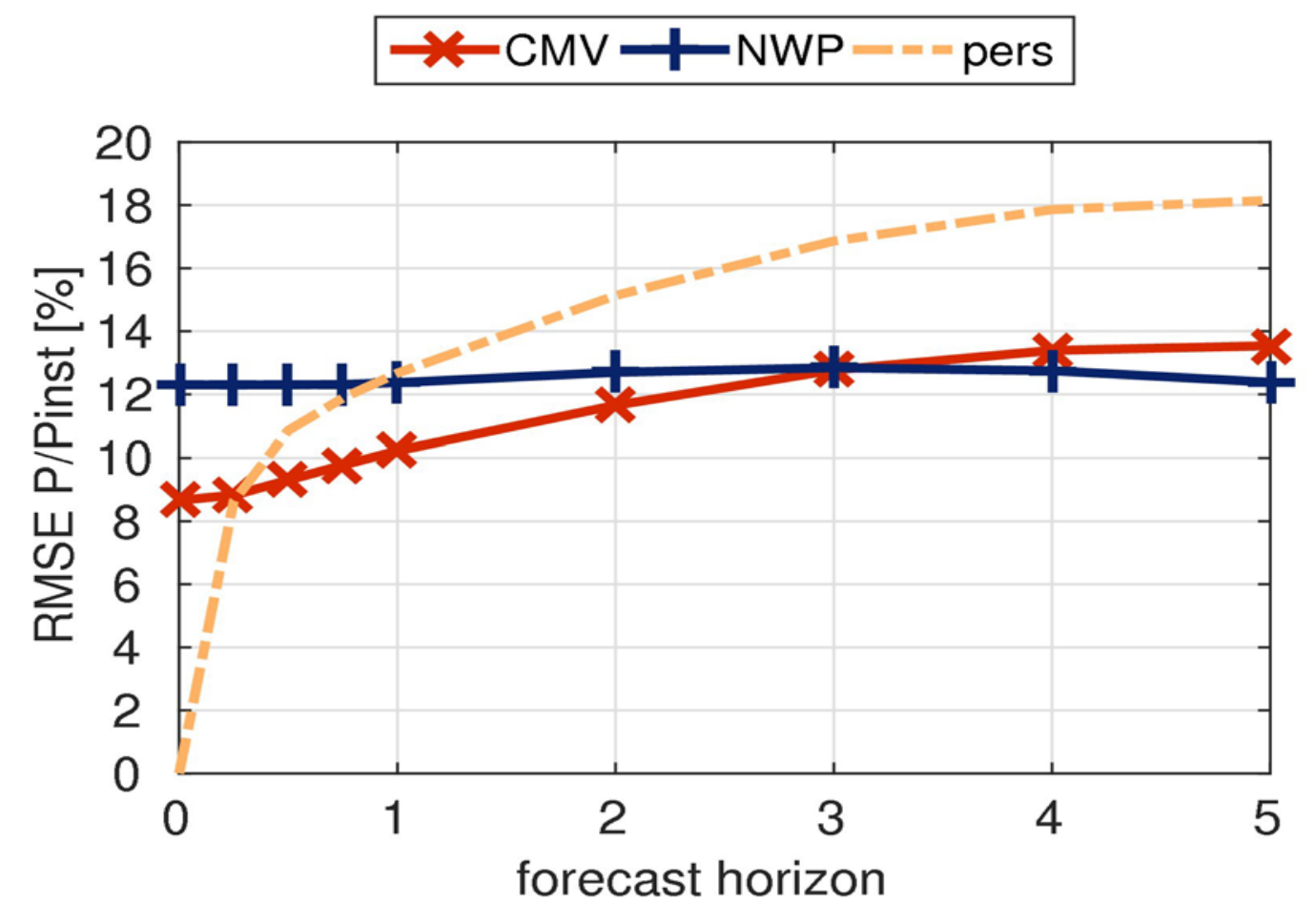
Spring



(WRF-OBS)

(Adjusted WRF-OBS)

evaluation: RMSE in dependence of forecast horizon

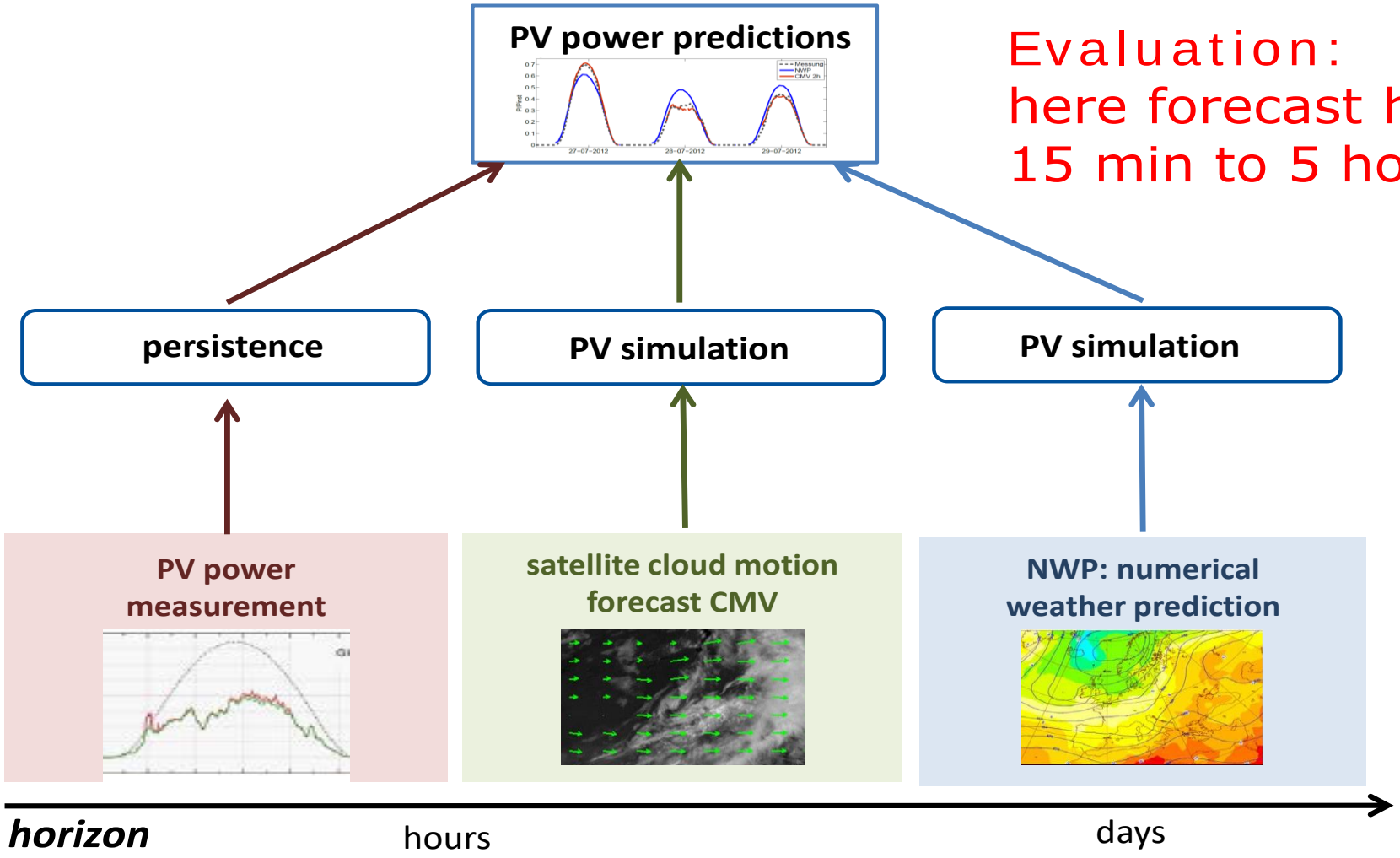


Persistence VS CMV VS NWP

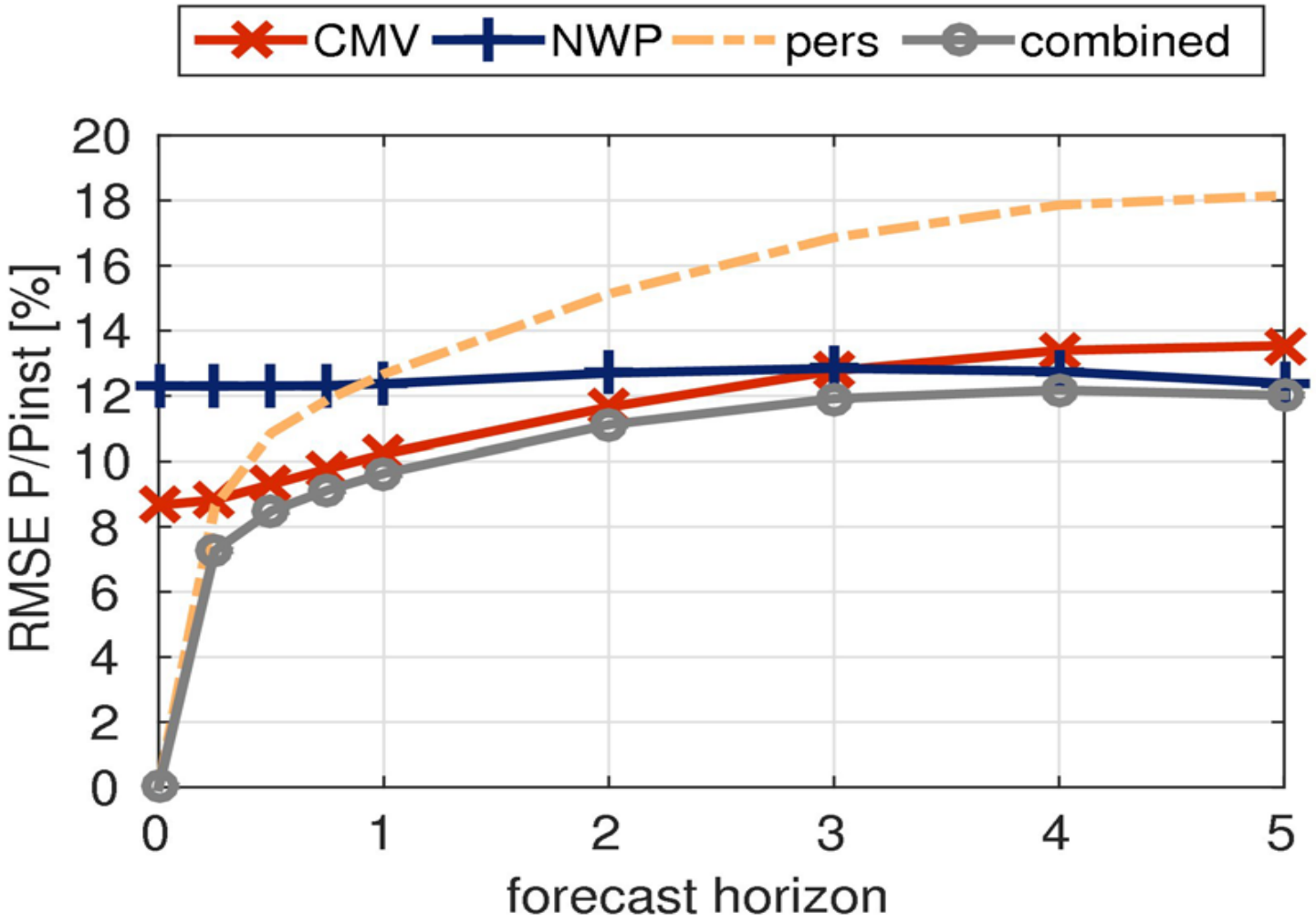
- CMV forecasts better than NWP based forecast up to 3 hours ahead
- Persistence better than CMV forecasts up to 10 minutes ahead

Fonte Lorenz et al. (2016

combining methodologies



RMSE in dependence of forecast horizon



combination of forecast models with linear regression:

$$P_{combi} = a_{NWP}P_{NWP} + a_{CMV}P_{CMV} + a_{persist}P_{persist} + a_0$$

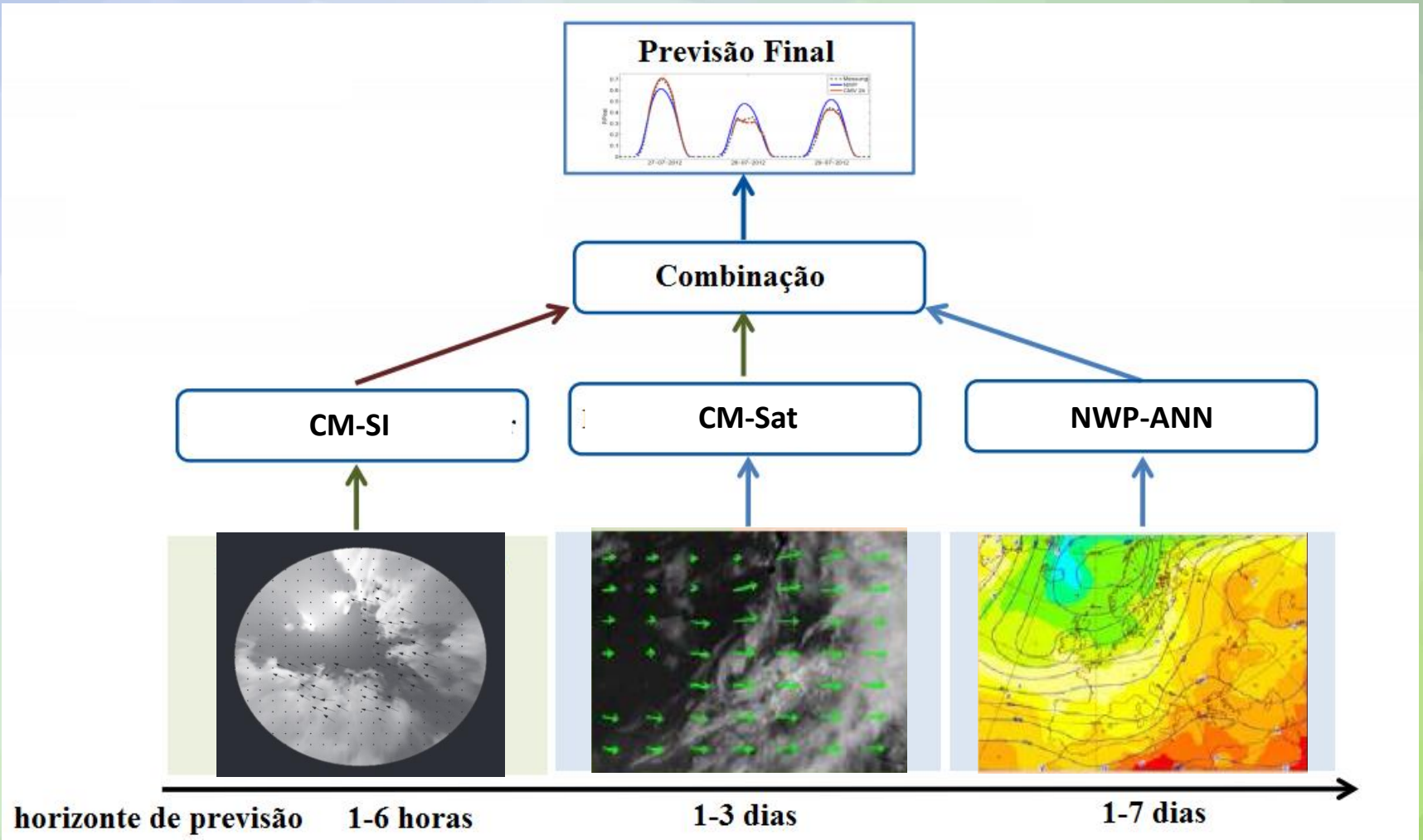
coefficients a_{NWP}, a_{CMV}, $a_{persist}$, a_0 are fitted to measured data in dependence of:

- forecast horizon
- hour of the day

Fonte Lorenz et al. (2016)

LABREN proposed sollution

- CM-SI: data from site-specific sky cameras
- CM-Sat: Regional satellite data (validated with SI)
- NWP: Numercal meteorological wodels



LABREN working on…

- Expertise in the LAB
- Two R&D projects running (NUBI and PREVER – ANEEL / Petrobras)
- Implementing and evaluating a combined methodology

Obrigado!

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http://labren.ccst.inpe.br

Results LABREN: Cloud detection methods (Ceff) by satellites and cameras

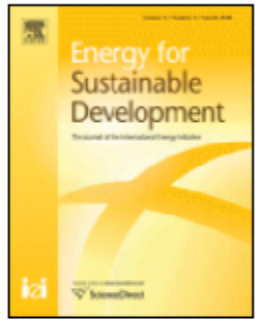
Useful for CM-SI and CM-Sat

Resultados recentes:

Energy for Sustainable Development 43 (2018) 15–22

Contents lists available at ScienceDirect

Energy for Sustainable Development

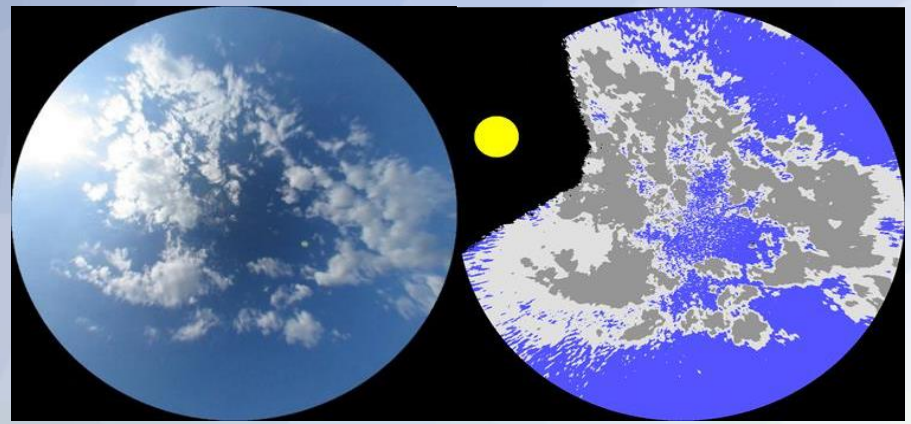


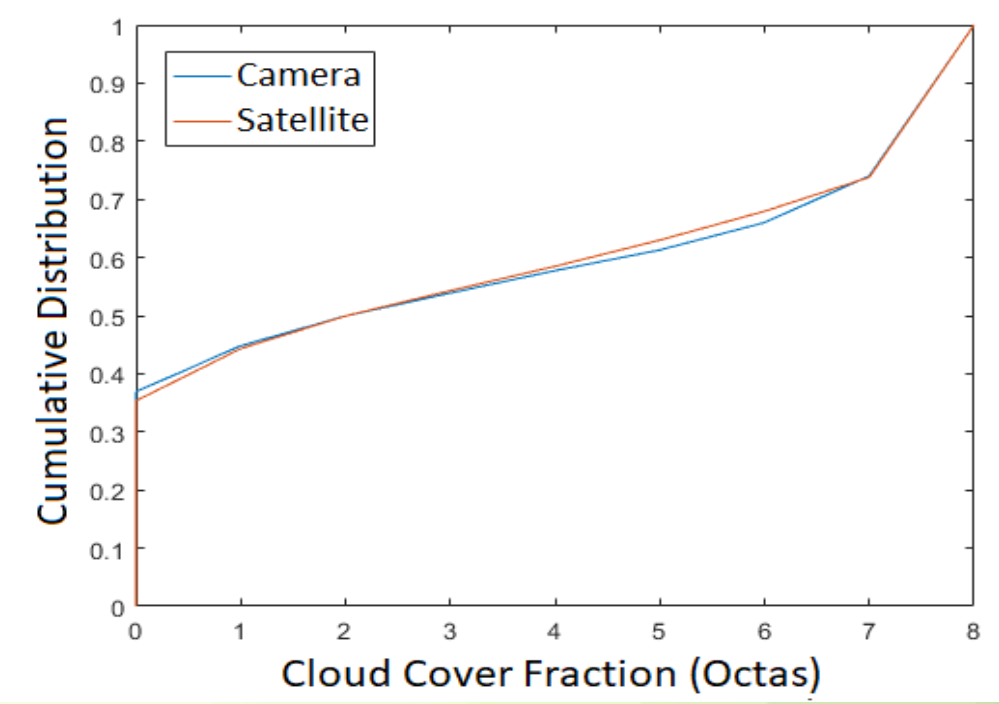
Comparison of methodologies for cloud cover estimation in Brazil - A case study

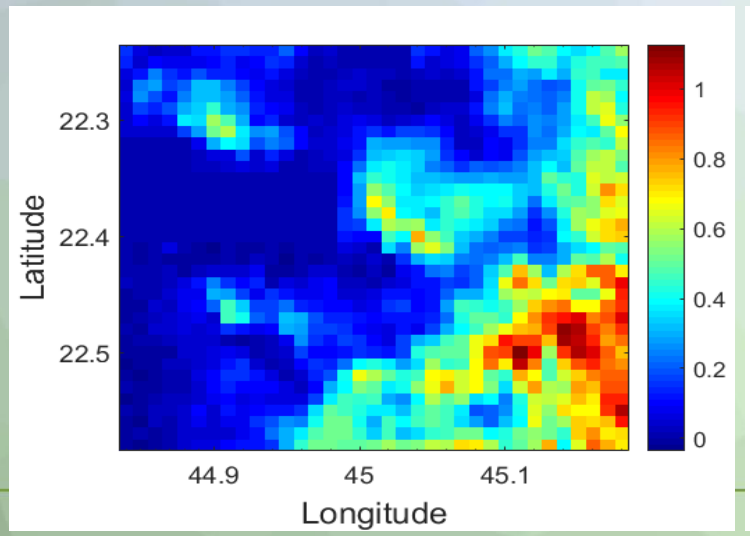
Eduardo Weide Luiz [a,*], Fernando Ramos Martins [b], Rodrigo Santos Costa [a], Enio Bueno Pereira [a]

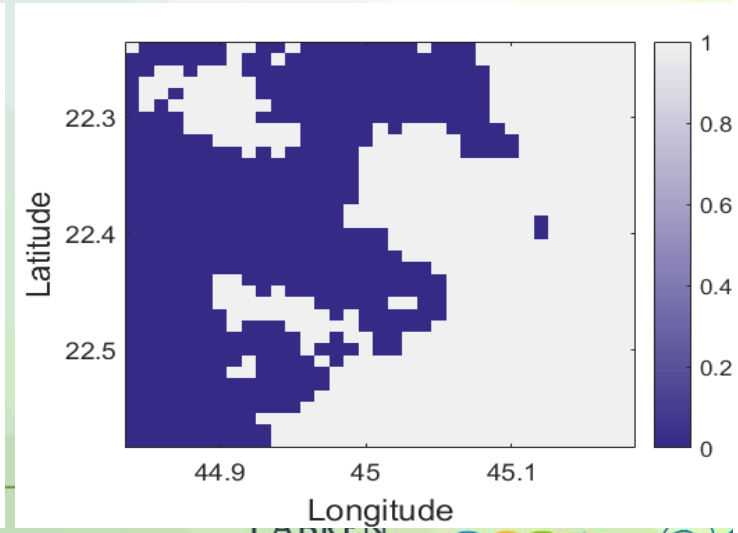
Sky cameras X Satellite images

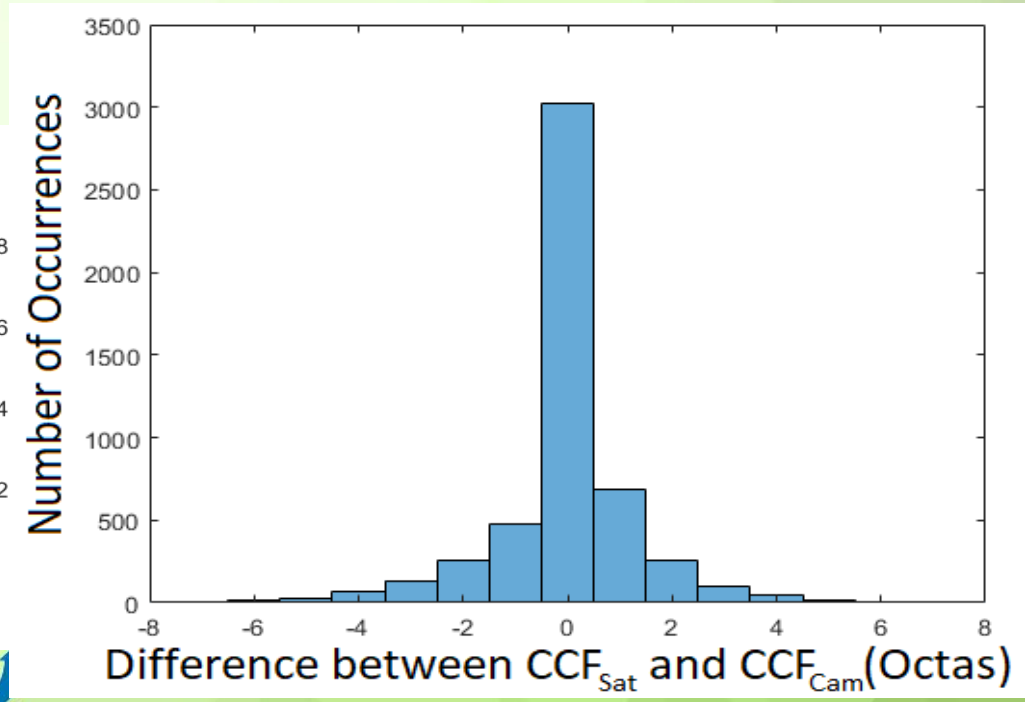
Satellite images calibrated with ground truth from sky cameras











LABREN Results: Ramp frequency mapping

Ramp variability Score (VS)

Solar Energy 167 (2018) 210–219

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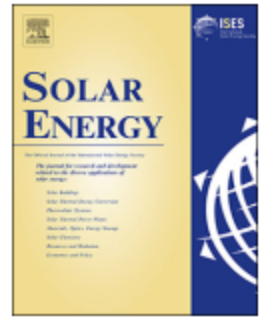


Analysis of intra-day solar irradiance variability in different Brazilian climate zones

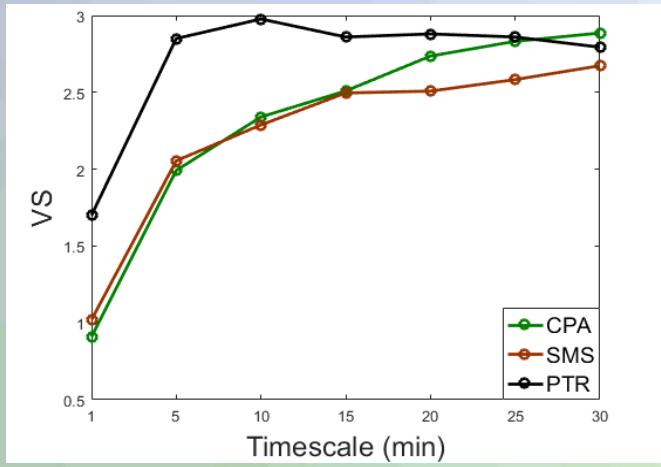
Eduardo Weide Luiz[a,*], Fernando Ramos Martins[b], André Rodrigues Gonçalves[a], Enio Bueno Pereira[a]

LABREN Results: Ramp frequency mapping

Ramp variability Score (VS)

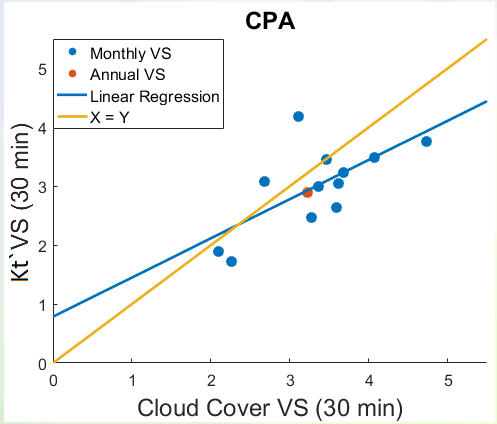
where is the value and is the probability of finding values higher than on the data set.

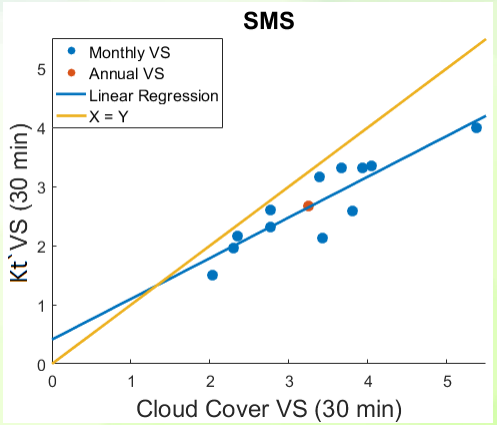
Surface

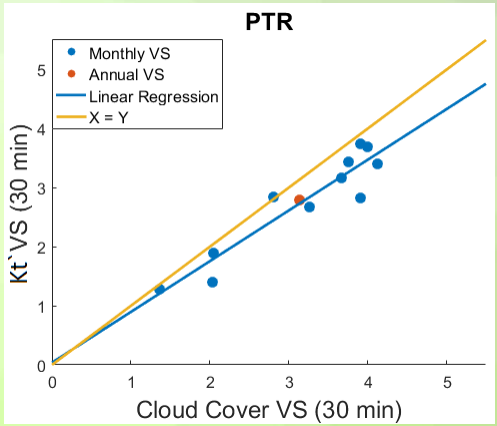


Annual Variability Score (VS) for different time steps () used in the ramp rates evaluation at the three ground sites. VS is non-dimensional.

Surface x Satellite







	30 minutes			5 minutes			1 minute		
	Corr.	Bias	RMSE	Corr.	Bias	RMSE	Corr.	Bias	RMSE
CPA	0.67	0.33	0.63	0.59	1.30	1.41	0.56	2.39	2.46
SMS	0.89	0.62	0.74	0.77	1.30	1.41	0.64	2.32	2.42
PTR	0.93	0.40	0.51	0.8	0.33	0.62	0.66	1.48	1.62

LABREN Results: Numerical forecast

Adjusted by Artificial Neural Networks (ANN)

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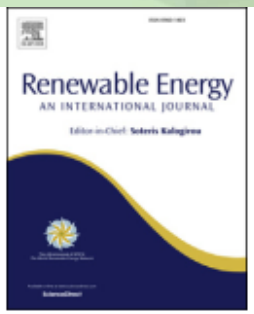

Forecast for surface solar irradiance at the Brazilian Northeastern region using NWP model and artificial neural networks

Francisco J.L. Lima [a,*], Fernando R. Martins [b], Enio B. Pereira [a], Elke Lorenz [c], Detlev Heinemann [b]

Effect of clouds on solar irradiance at the ground level