



Solar energy assessment and forecast

Brasil Solar Power

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e Inovação

GOVERNO FEDERAL
BRASIL
PÁTRIA EDUCADORA



Outline

- Background on solar energy assessment
- Overview on solar irradiation forecast methods
- Evaluation of methods and conclusions

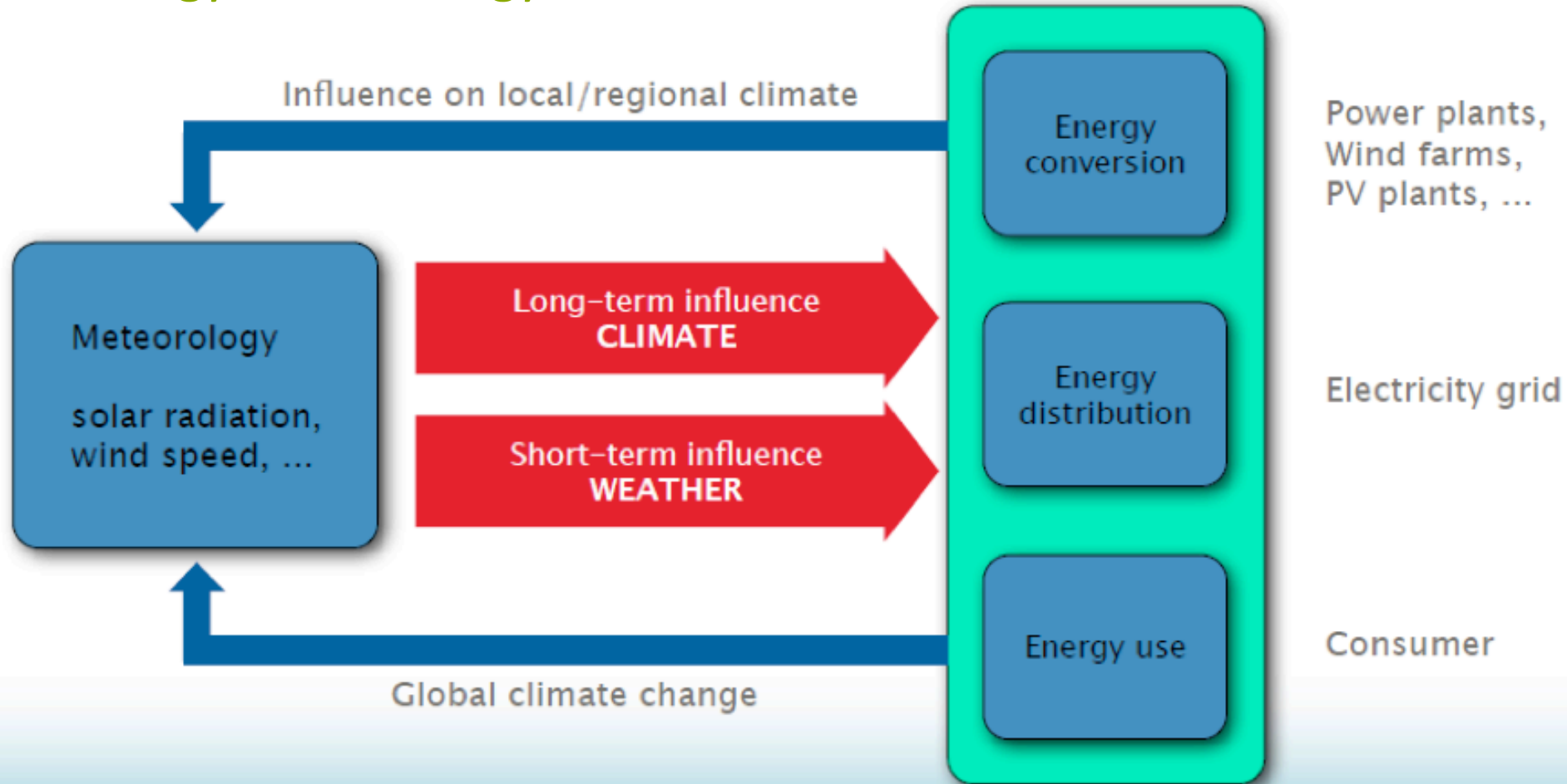
Background on solar energy assessment

Solar variability

Solar energy assessment

- Dispersed source (**low energy density**)
- Variable energy (**depends on weather and climate**)
- Barrier for penetration of solar technology
- Investments in this technology require secure information on:
 - The solar source;
 - Variability and trends;
 - complementarity hydro-wind-biomass, etc.

Energy meteorology



LABREN - Laboratory for Modelling and Studies of Renewable Energy Resources

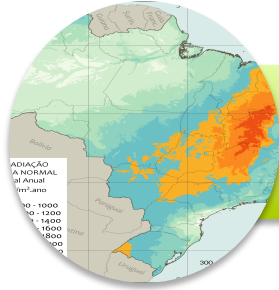
<http://labren.ccst.inpe.br>

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.

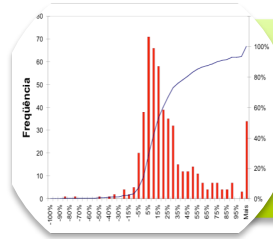
Research Topics:

- *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 resource assessment (three main principles)

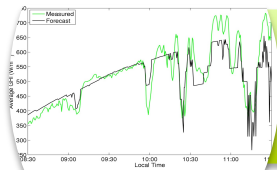


Solar energy potential
terrain, environment, latitude...



Data uncertainty

type of radiometer, operation & maintenance, model characteristic



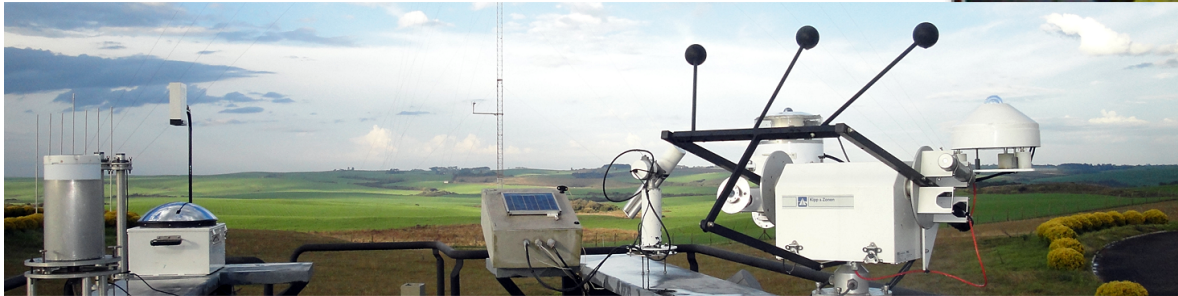
Solar variability

meteorology, climate

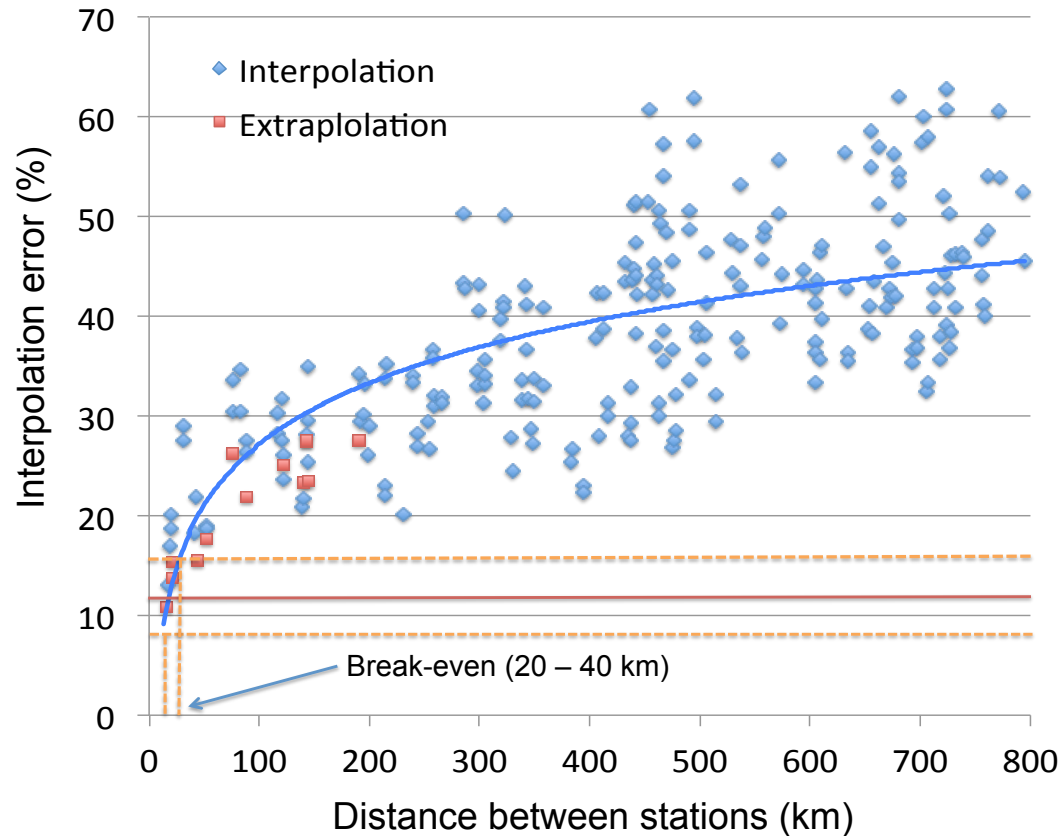
Solar energy potential

Solar energy potential

- Site-specific solar assessment
 - Model development
 - Feasibility of projects
 - Due- diligence
-
- Ground measurements
 - Public solarimetric stations and/or networks
 - Site-specific from projects - proprietary data



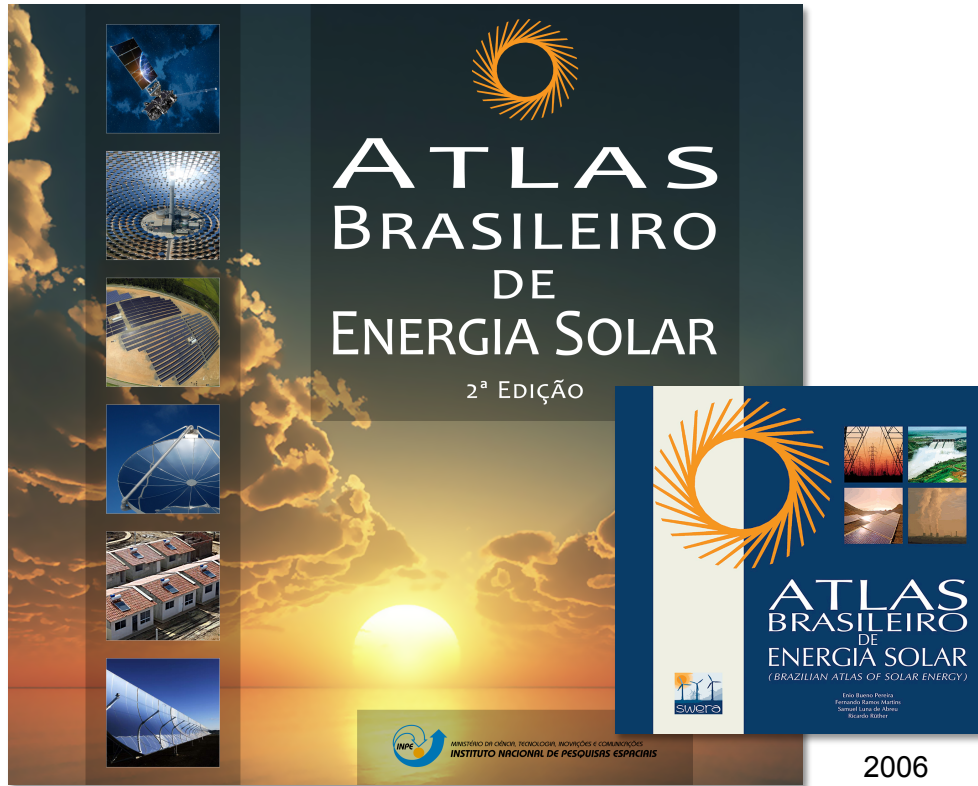
Satellite model VS Ground measurements



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

New Brazilian Atlas of Solar Energy - 2007



An INPE accomplishment in association with several national universities

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

Download pdf and shape format data at:

http://labren.ccst.inpe.br/atlas_2017.html

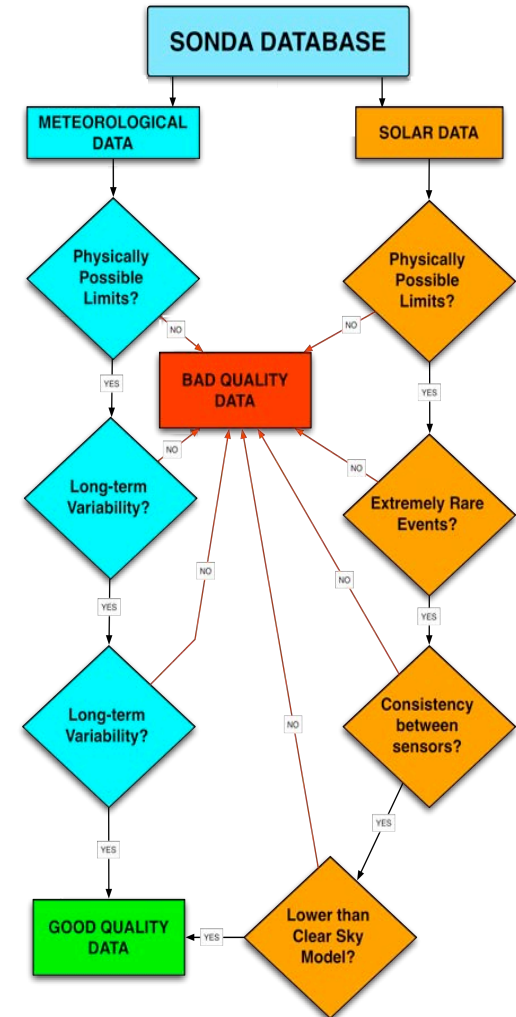
2006

Data uncertainty

Database Uncertainties

Ground data quality control

Category	Relevance		
	Very high	High	Medium
O & M			
Quality control			
Metadata			
Choice of sensors			
Installation methods			
Location			
Frequency			
Time range			
Calibration			
Data acquisition			
Availability			



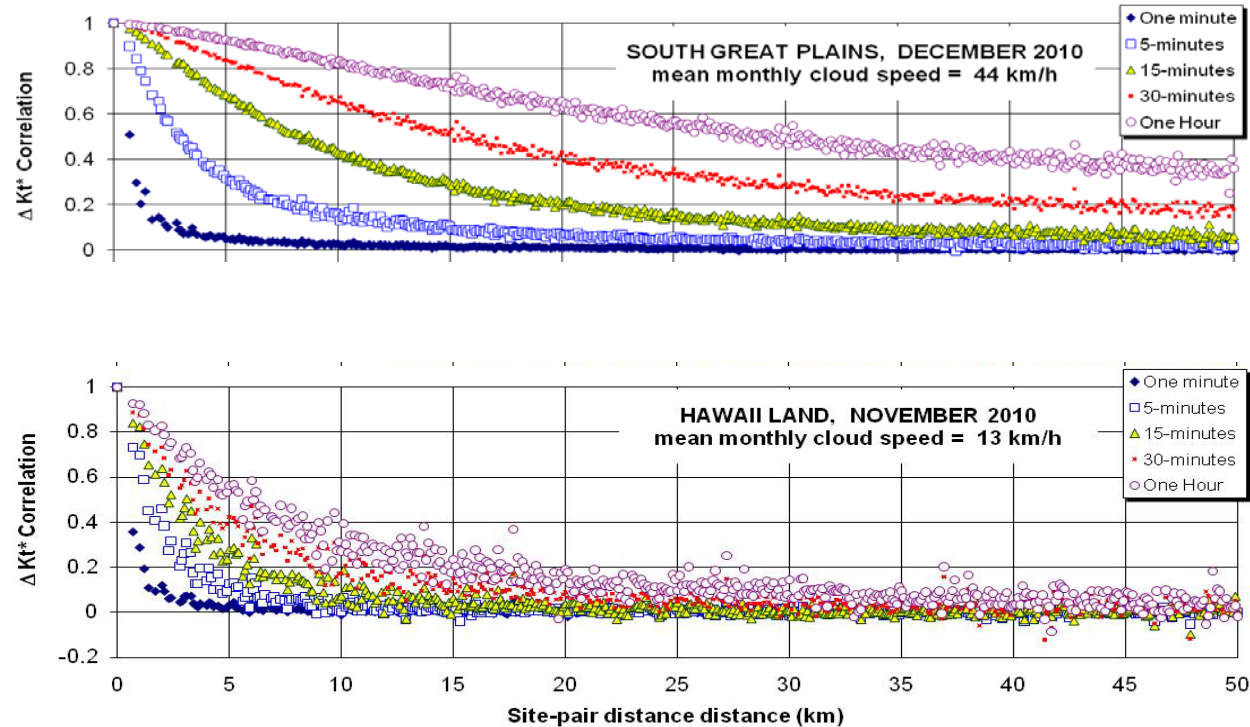
Solar variability

Solar variability

short term fluctuations

clearness index K_t

- Solar resource varies from site to site
- Correlation between each pair of radiometers varies with integration time

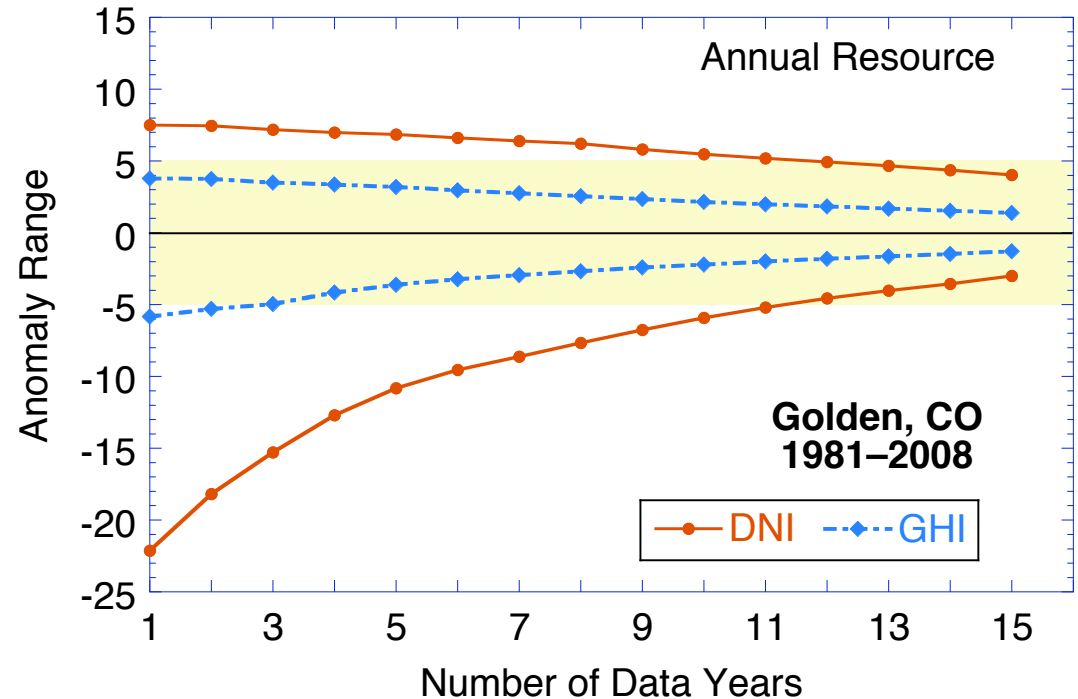


Source Perez et al., personal communication

Solar variability

long term fluctuations

- Measurements for long-term solar resource characterizations require years to complete, which is an unacceptable timeline for the rapidly emerging needs of solar energy applications.
- It takes many years to stabilize the solar irradiance for a given site
- This is an indication of the need to compare site-specific short term solar data with long term solar information from some other available regional source of information



Source Gueymard and Wilcox, 2009

Overview on solar irradiation forecast methods

Grid integration of PV Power: marketing

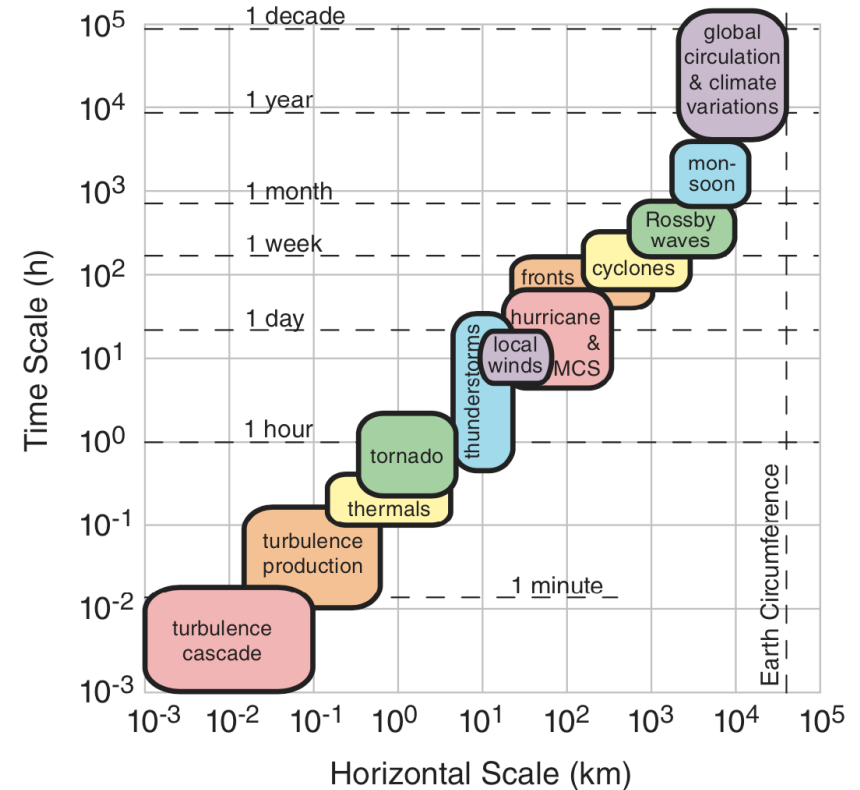
➤ by Transmission System Operators (ONS, ANEEL)

- Regional forecast

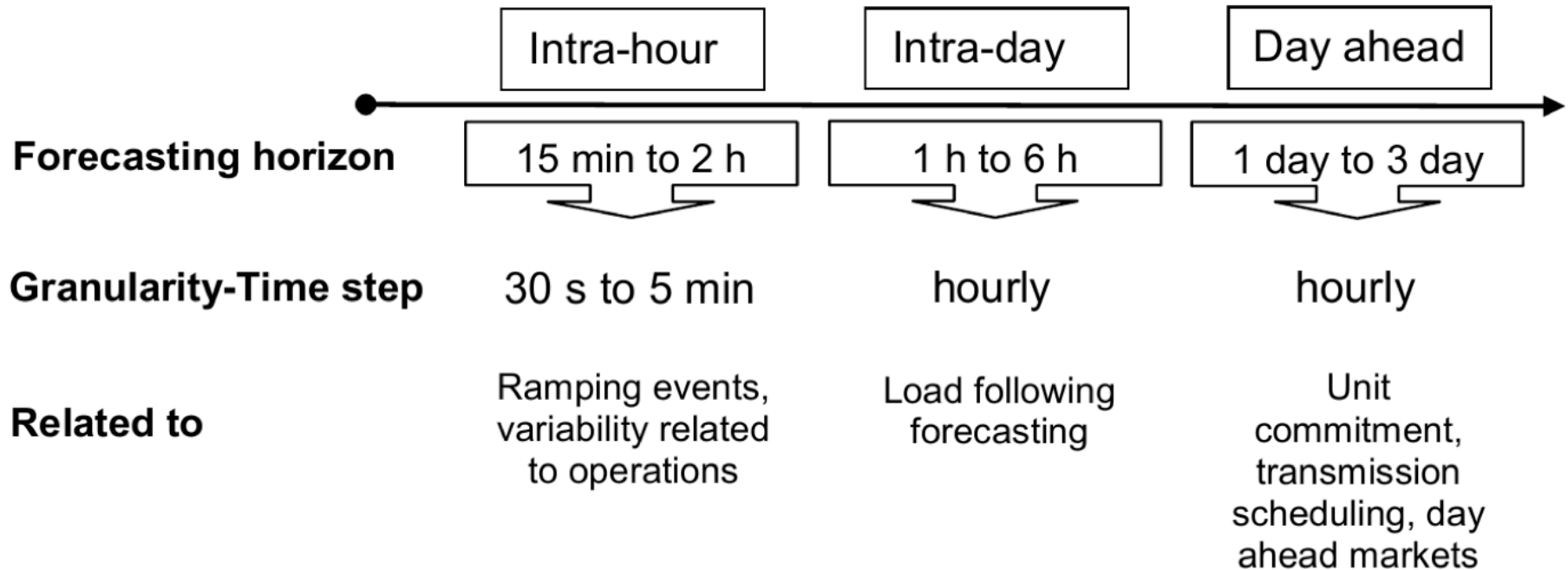
➤ direct marketing (solar plants)

- Local forecast

➤ Forecast horizons



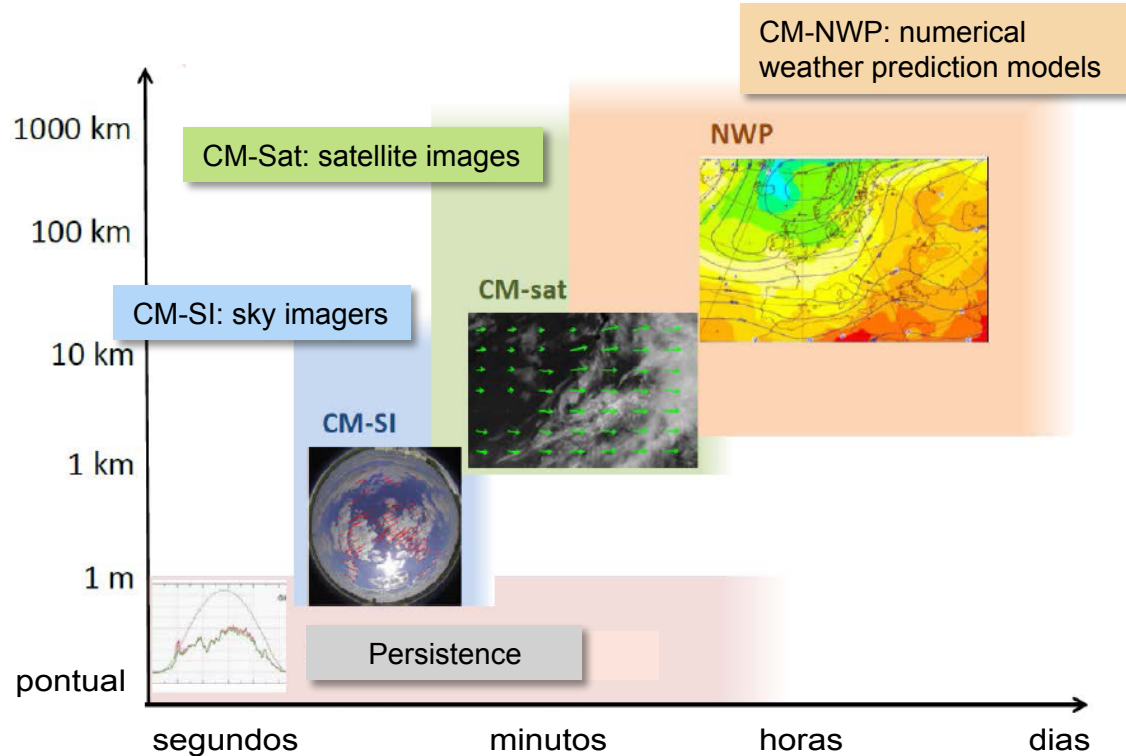
Solar forecasting horizons



Solar forecasting methodology

The best method depends on the forecast horizon

- Persistence from local ground measurements
- Cloud Motion from Sky Imagers - **CM-SI** prediction with high spatial and temporal resolution forecastings of ramp effects (30 minutes)
- Cloud Motion from Satellites - **CM-Sat** satellite radiative transfer models (Ex: BRASIL-SR) providing regional forecast horizons from 30 minutes to 6 hours
- Numerical Weather Prediction - **NWP** Atmospheric models provides forecast vast regions on the horizon from 12h to 7 days. They need adjustments through machine learning techniques (eg. neural network)



Ground data - Persistence method

Nowcast (minutes)

persistence:

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

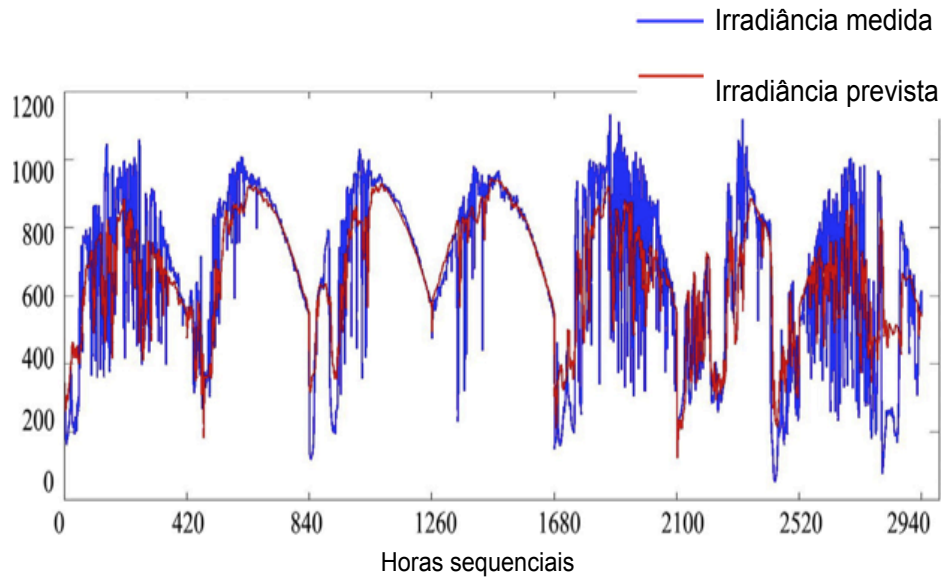
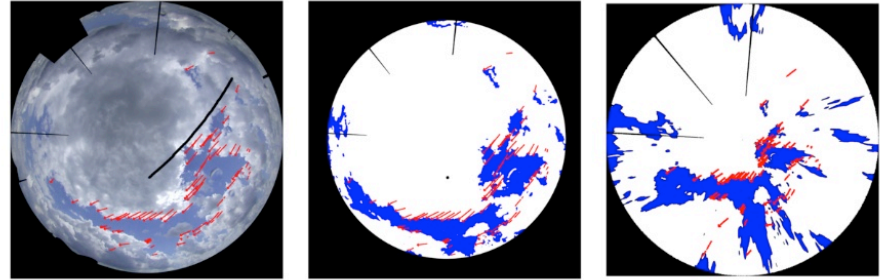
constant ratio of measured PV power P_{meas} to clear sky PV power P_{clear}

Post processing by statistical or machine learning methods

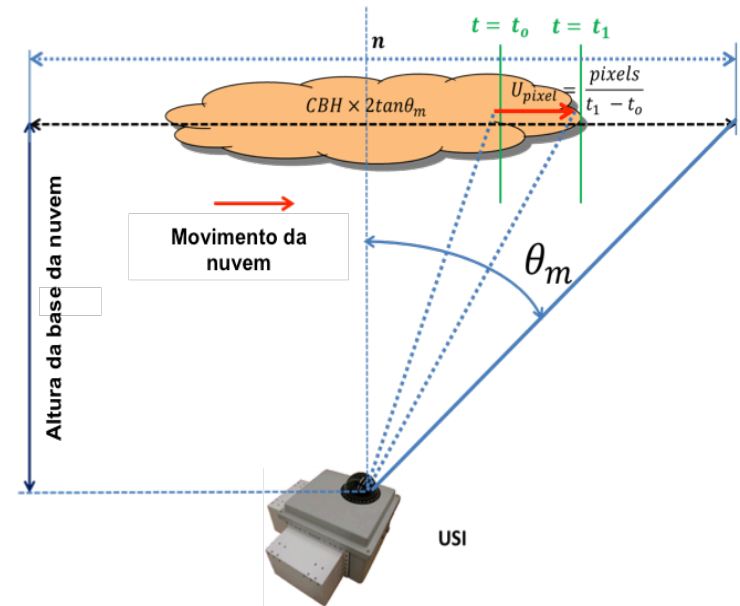
Cloud Motion from Sky Imagers - CM-SI

Sky cameras: nowcasting

Time horizon: 0 – 3h.



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



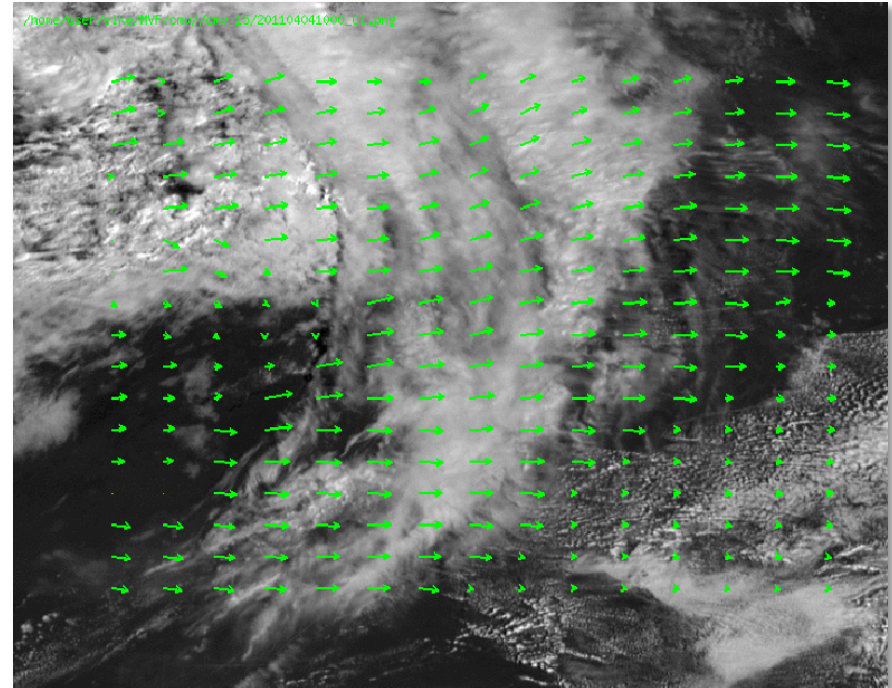
Cloud Motion from Satellites - CM-Sat

Raio da Terra = 6370 km

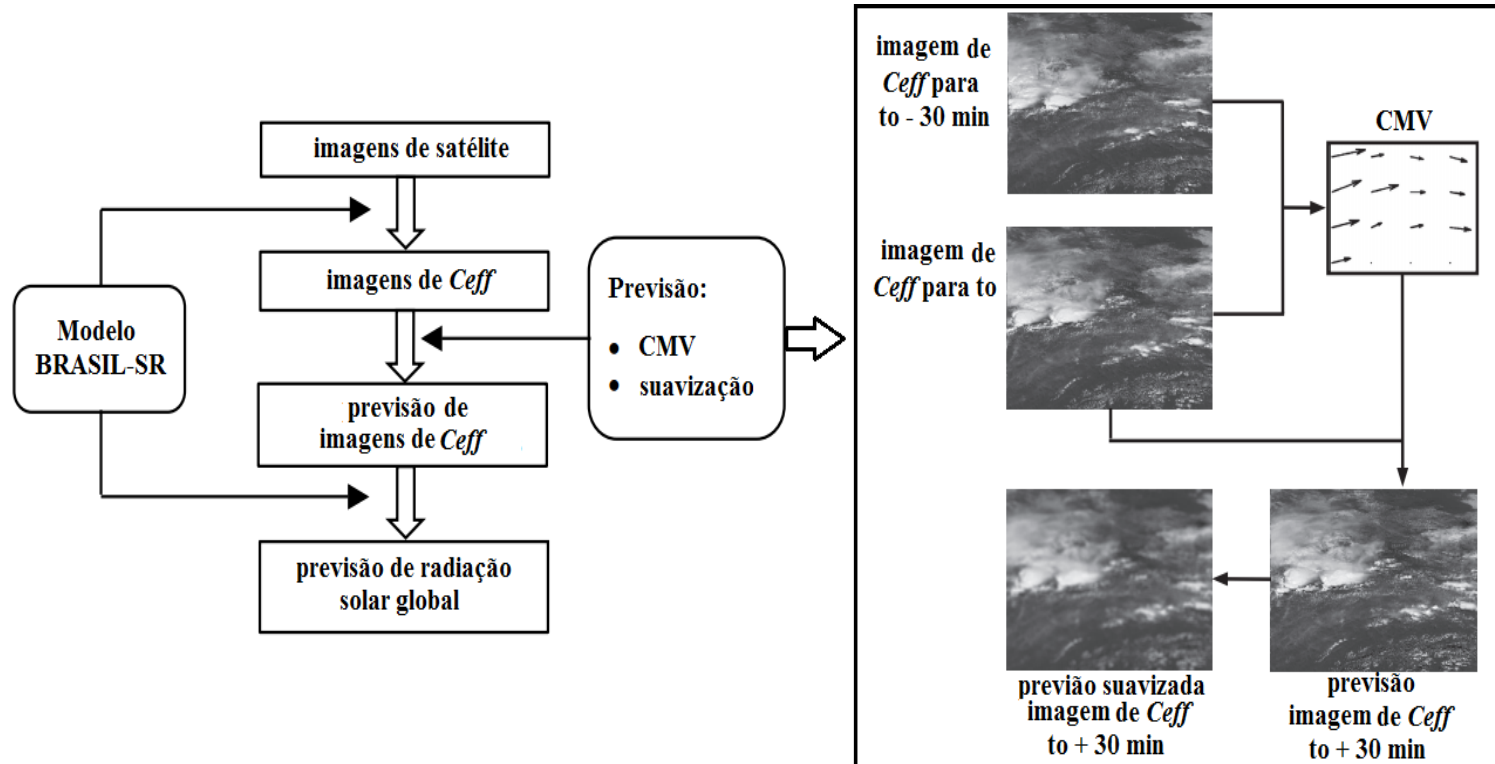


Satélite Geoestacionário
Órbita – cerca de 36000 km acima da superfície
Ângulo de visada da ordem de $17,5^\circ$

Satélite orbital
Órbita – cerca de 800 km acima da superfície
Ângulo de visada da ordem de 110°



Cloud Motion from Satellites - CM-Sat



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

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

Useful for CM-SI and CM-Sat

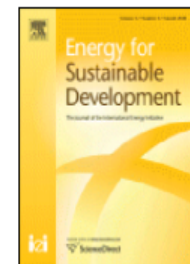
Resultados recientes:

Energy for Sustainable Development 43 (2018) 15–22



Contents lists available at [ScienceDirect](#)

Energy for Sustainable Development



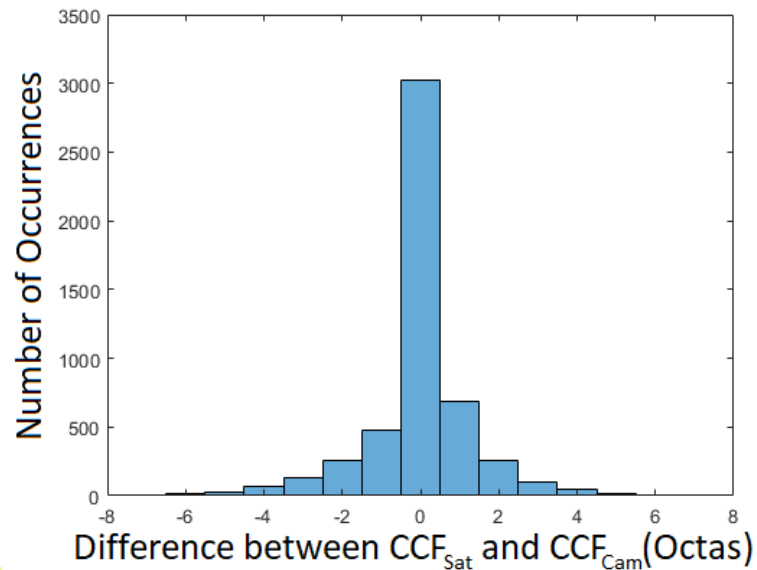
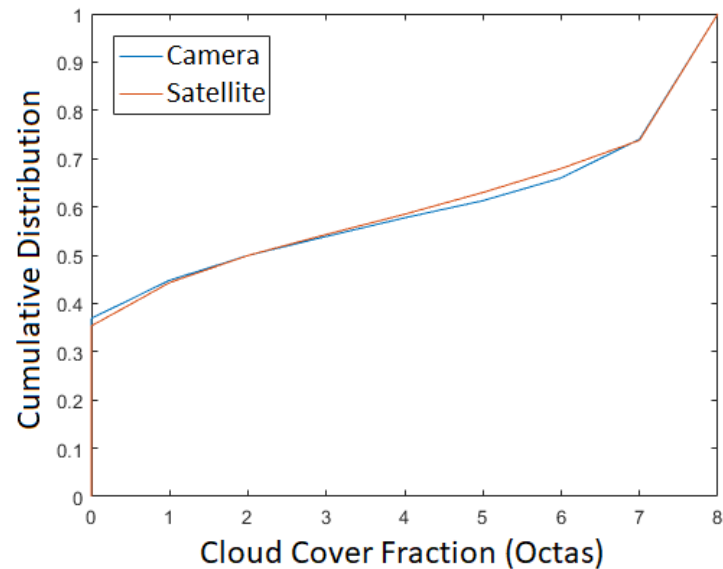
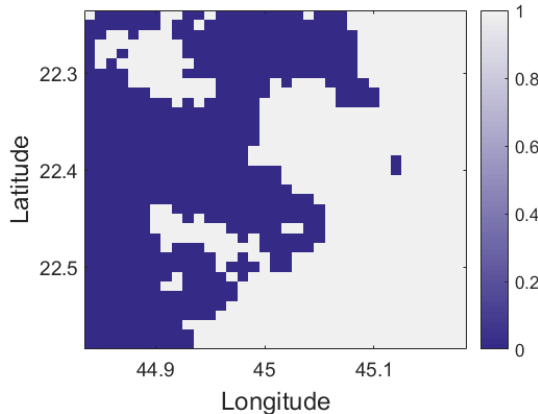
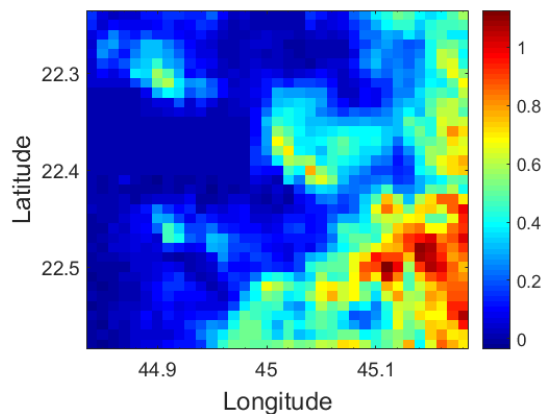
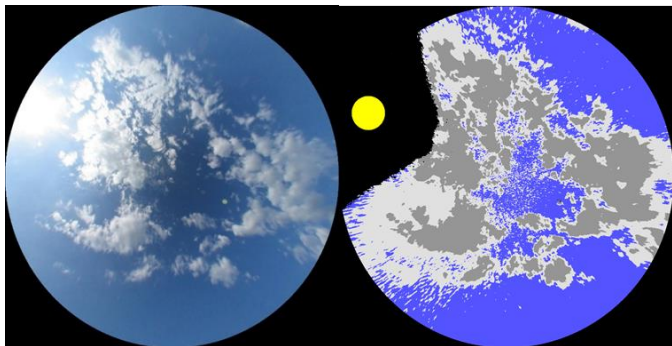
Comparison of methodologies for cloud cover estimation in Brazil - A case study



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)

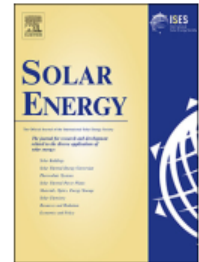
Solar Energy 167 (2018) 210–219



Contents lists available at [ScienceDirect](#)

Solar Energy

journal homepage: www.elsevier.com/locate/solener



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



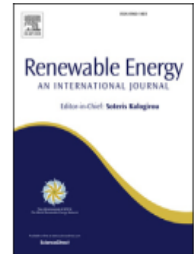
LABREN Results: Numerical forecast Adjusted by Artificial Neural Networks (ANN)



Contents lists available at [ScienceDirect](#)

Renewable Energy

journal homepage: www.elsevier.com/locate/renene



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

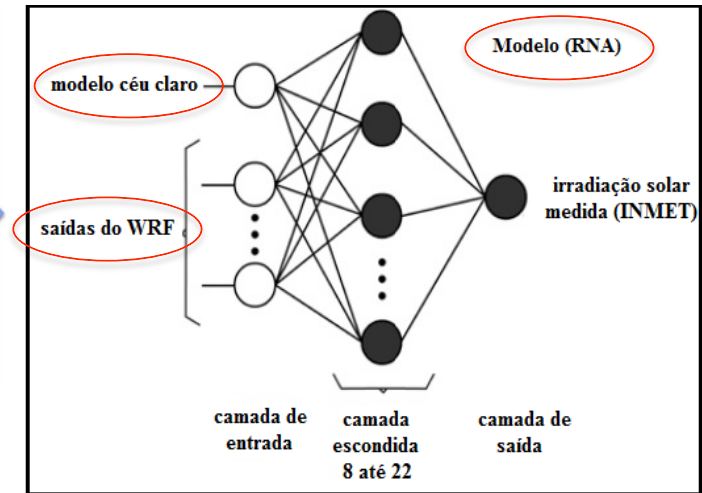
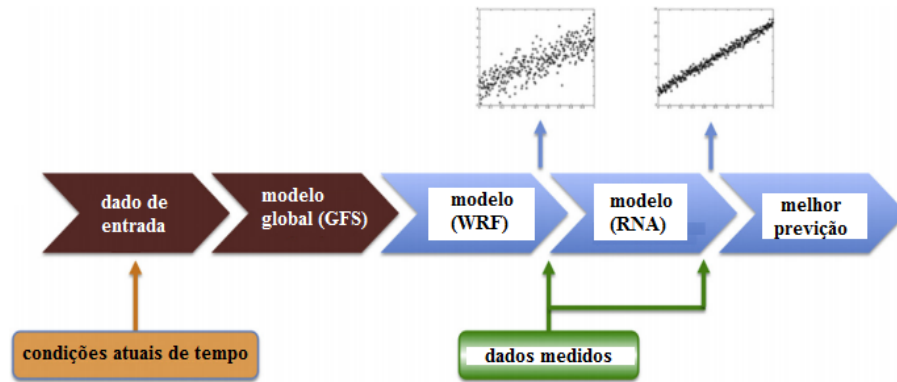


Francisco J.L. Lima ^{a,*}, Fernando R. Martins ^b, Enio B. Pereira ^a, Elke Lorenz ^c,
Detlev Heinemann ^b

LABREN Results: Numerical forecast

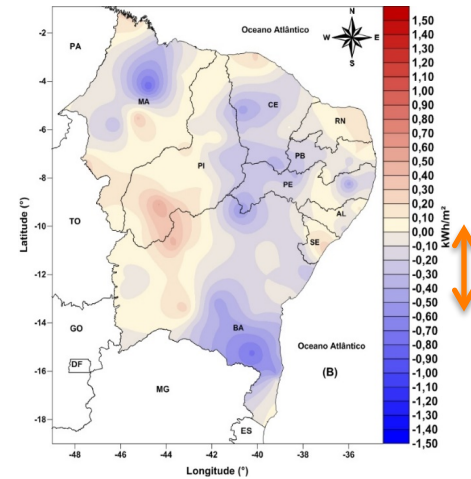
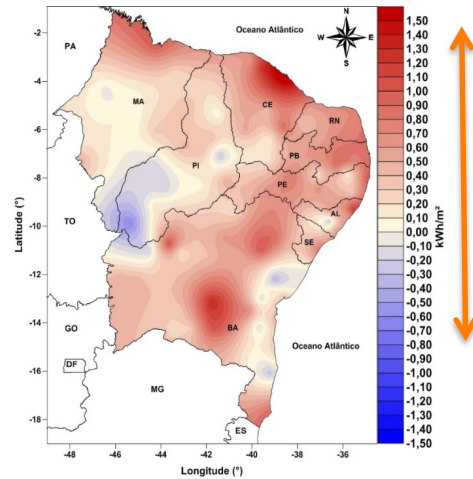
Adjusted by Artificial Neural Networks (ANN)

- ✓ 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

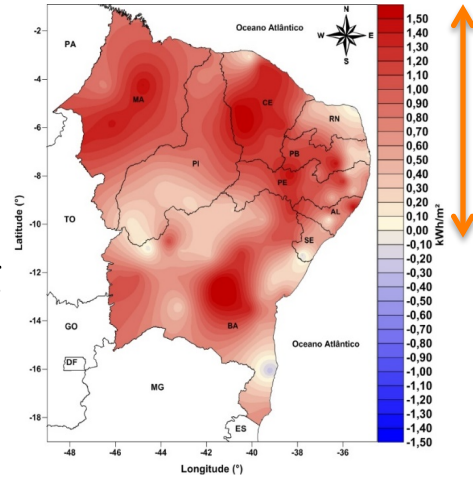


Differences from the adjusted regional forecast

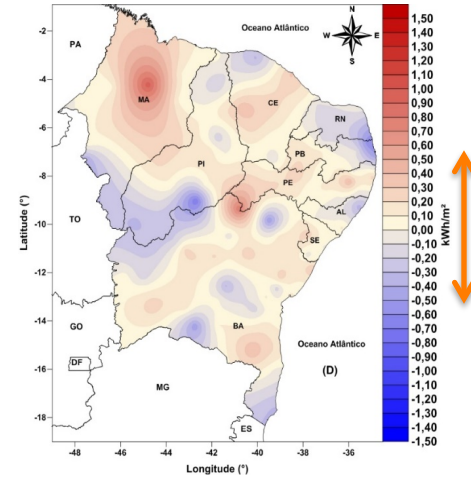
Fall



Spring



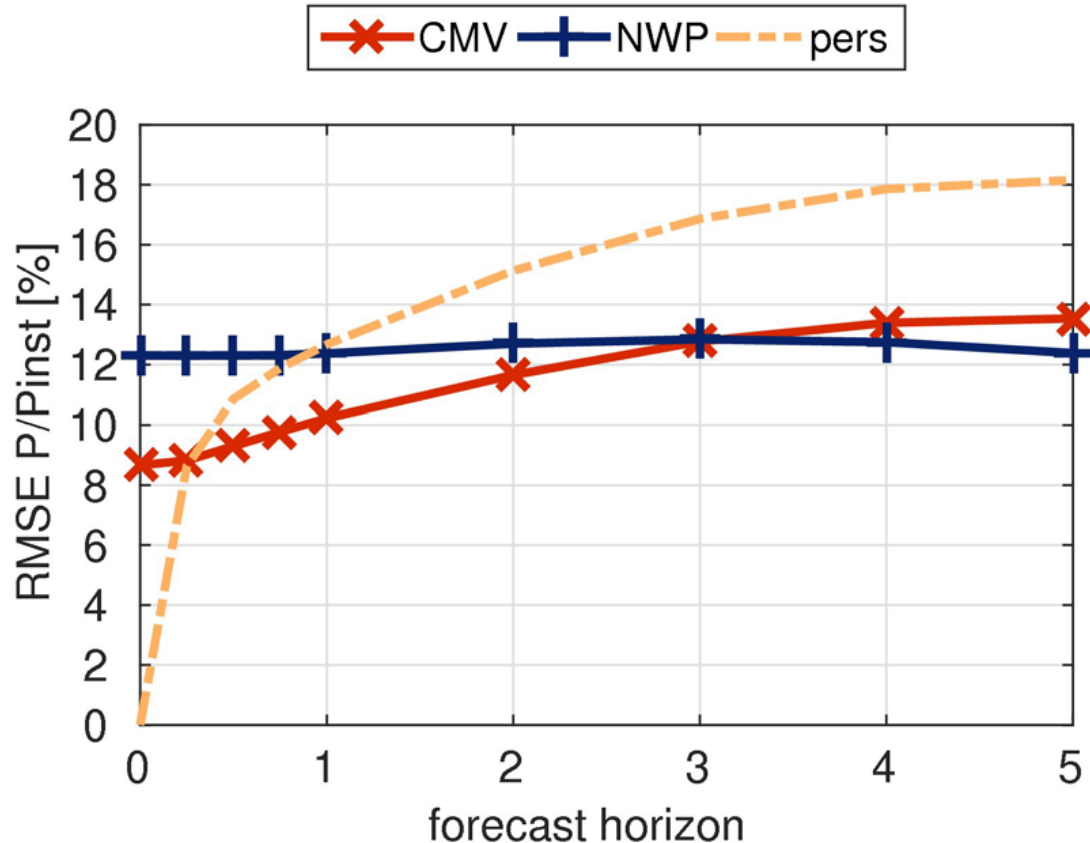
(WRF-OBS)



(Adjusted WRF-OBS)

Evaluation of methods and conclusions

RMSE in dependence of forecast horizon



Persistence

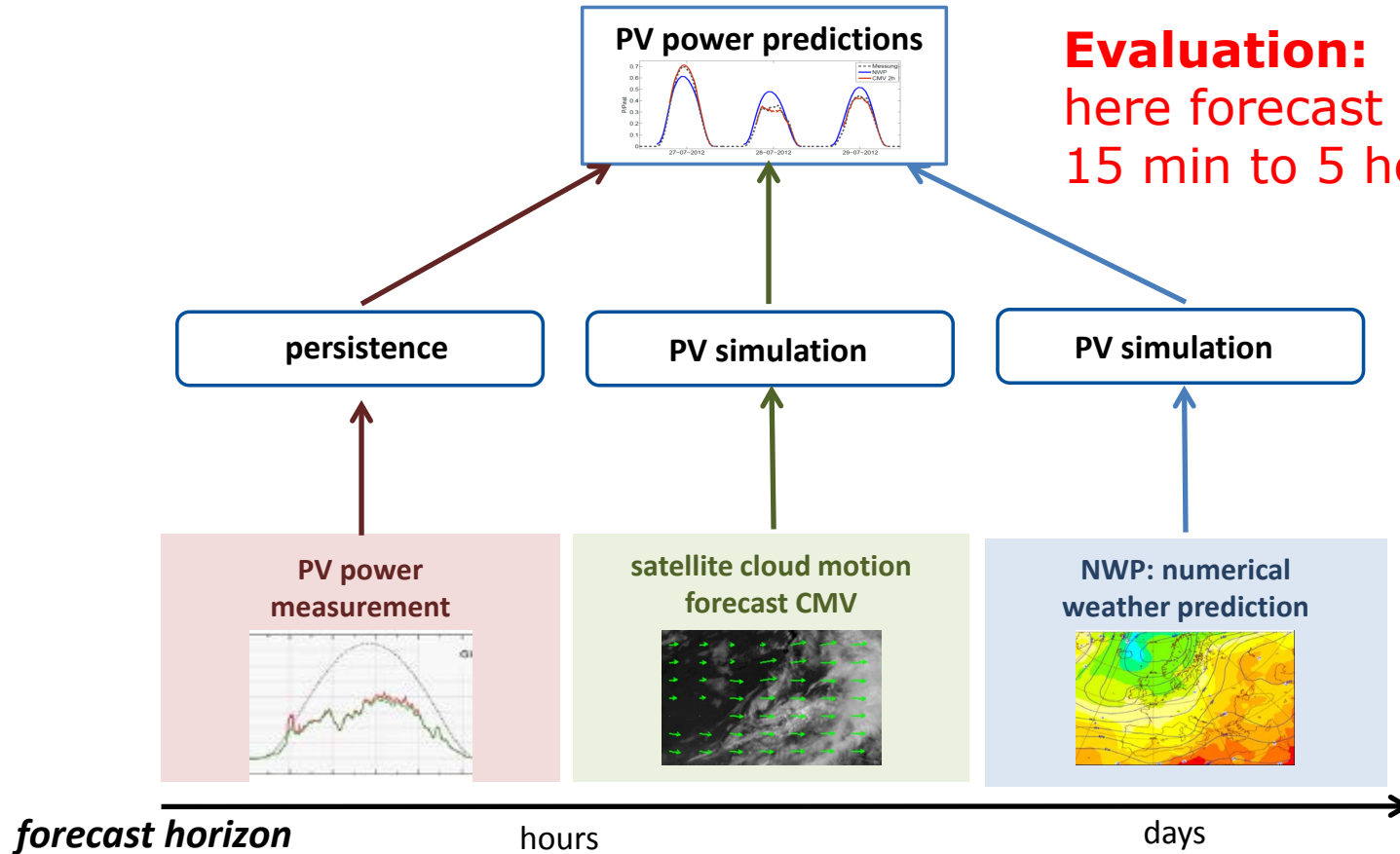
$$P_{pers} = \left\{ \frac{P_{meas}(t - \Delta t)}{P_{clear}(t - \Delta t)} \right\} \times P_{clear}(t)$$

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

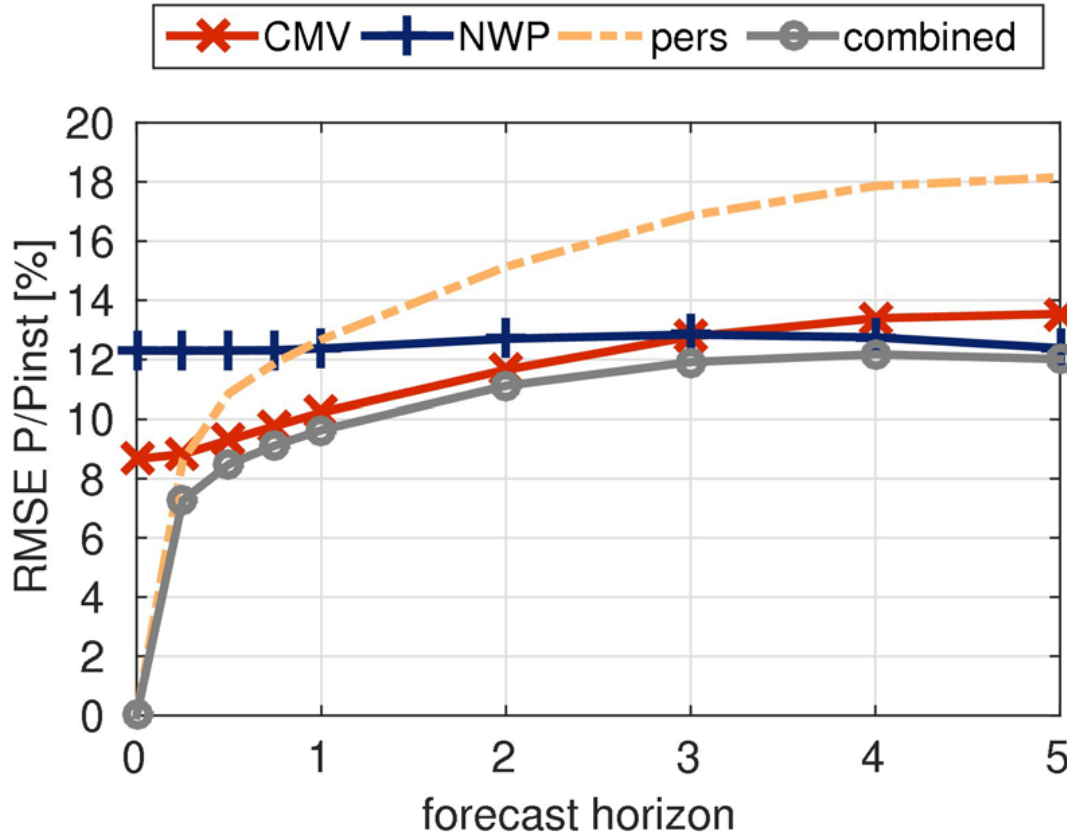
Combine Persistence + Satellite + Numerical model

Reported methodologies

Evaluation:
here forecast horizons
15 min to 5 hours ahead



RMSE in dependence of forecast horizon



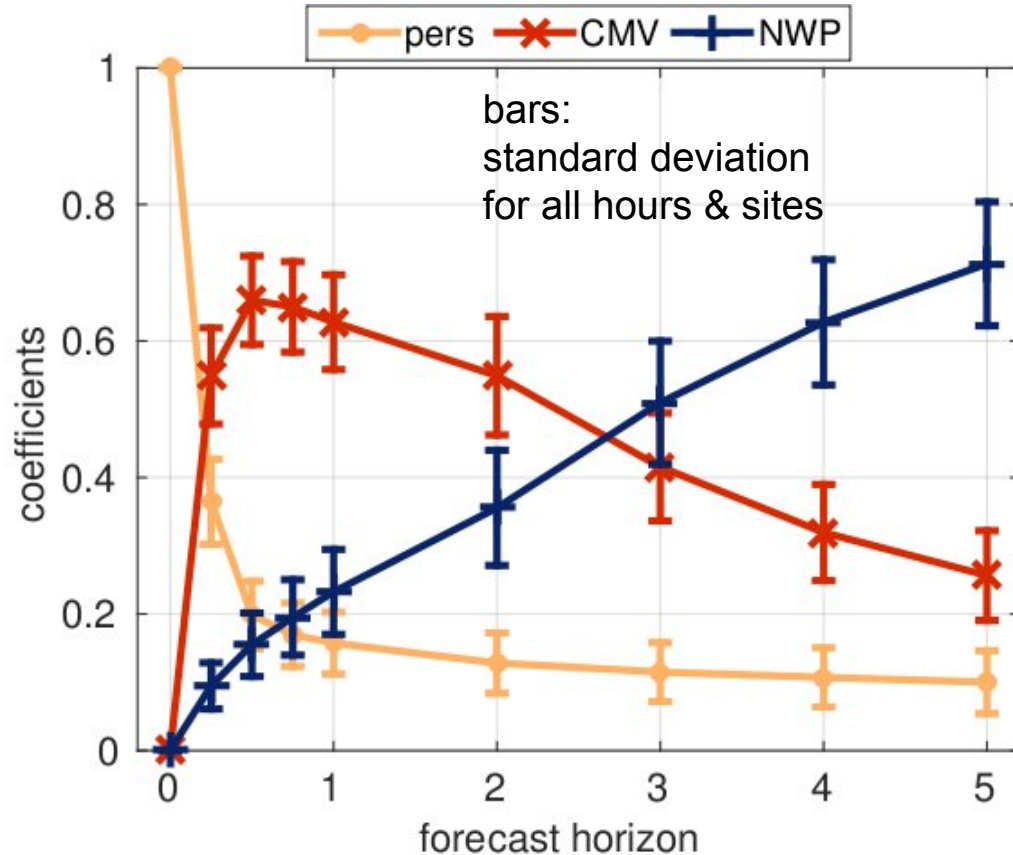
combination of forecast models with linear regression:

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

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

- forecast horizon
- hour of the day

RMSE in dependence of forecast horizon



combination of forecast models with linear regression:

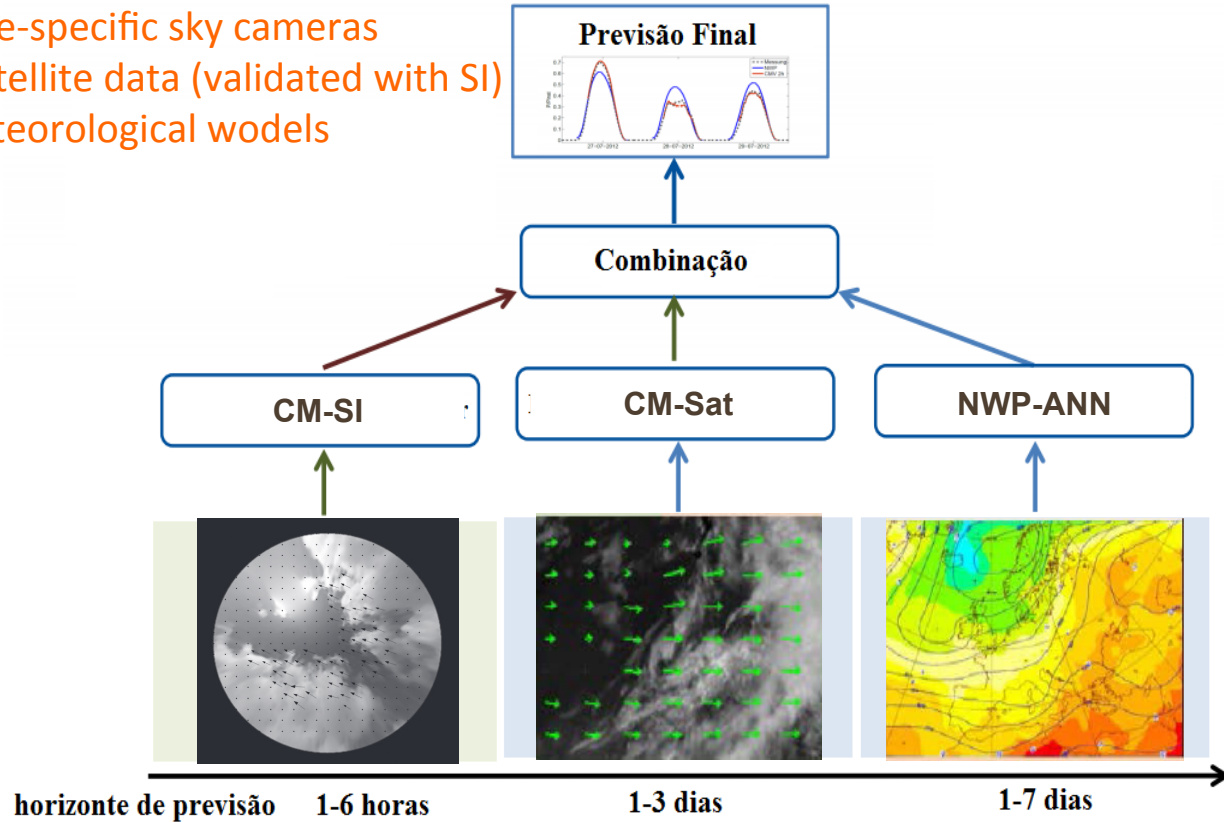
$$P_{combi} = a_{NWP}P_{NWP} + a_{CMV}P_{CMV} + a_{persist}P_{persist} + a_0$$

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

- forecast horizon
- hour of the day

LABREN Proposed forecasts

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





Laboratório de Modelagem e Estudos de
Recursos Renováveis de Energia

<http://labren.ccst.inpe.br/>

Thanks!



me