



Measurement and Prediction of Solar Resource

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Ministério da
Ciência, Tecnologia
e Inovação

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LABREN - Laboratory for Modelling and Studies of Renewable Energy Resources

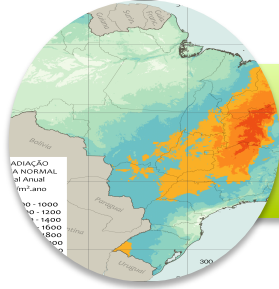
<http://labren.ccst.inpe.br>

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.

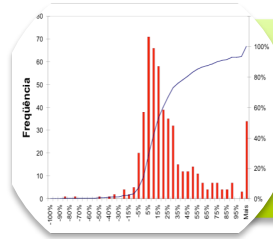
Research Topics:

- *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

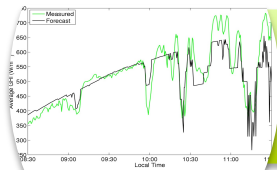


Solar energy potential
terrain, environment, latitude...



Data uncertainty

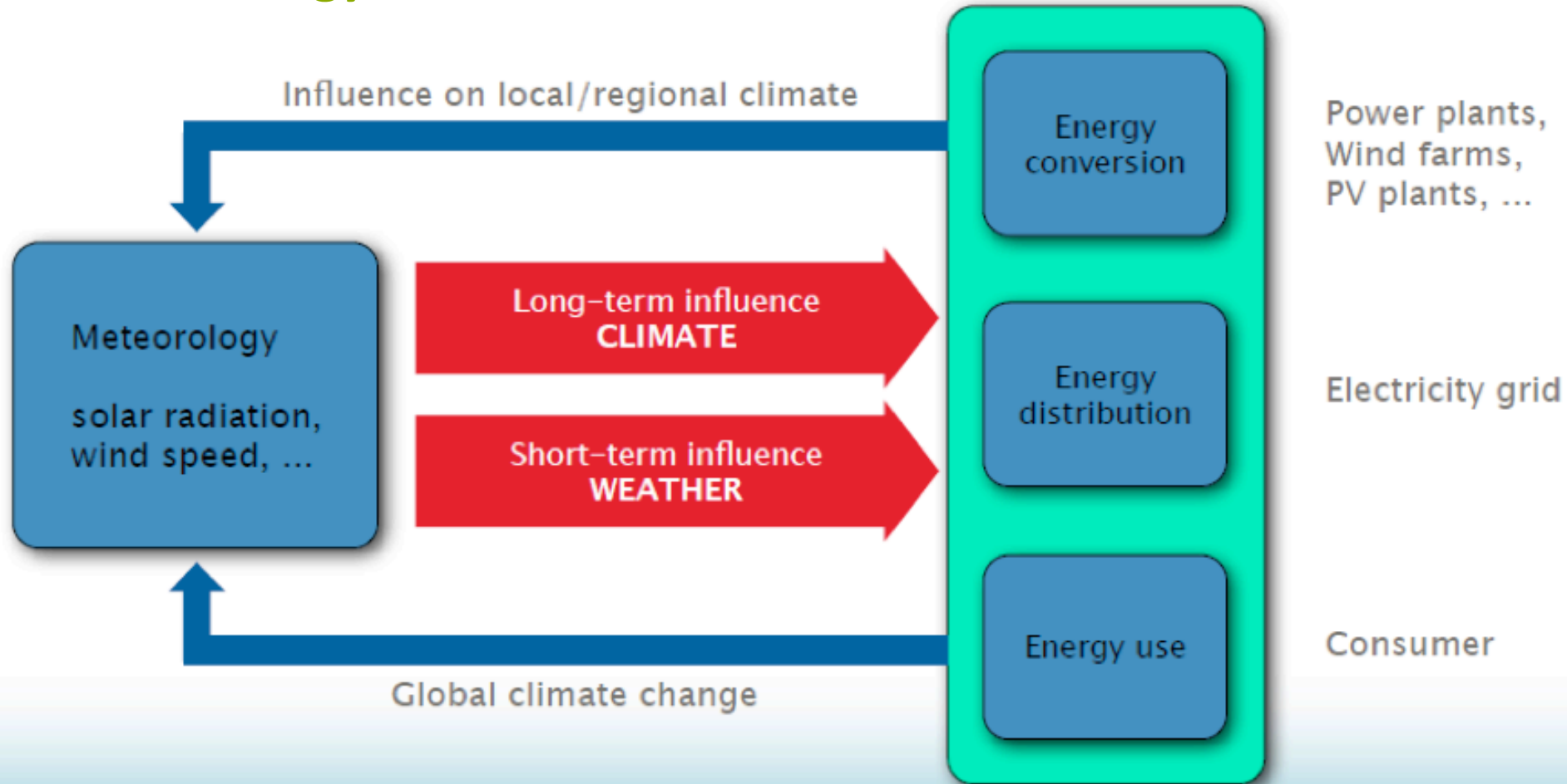
type of radiometer, operation & maintenance,
model characteristic



Solar variability

meteorology, climate

Solar Energy and weather

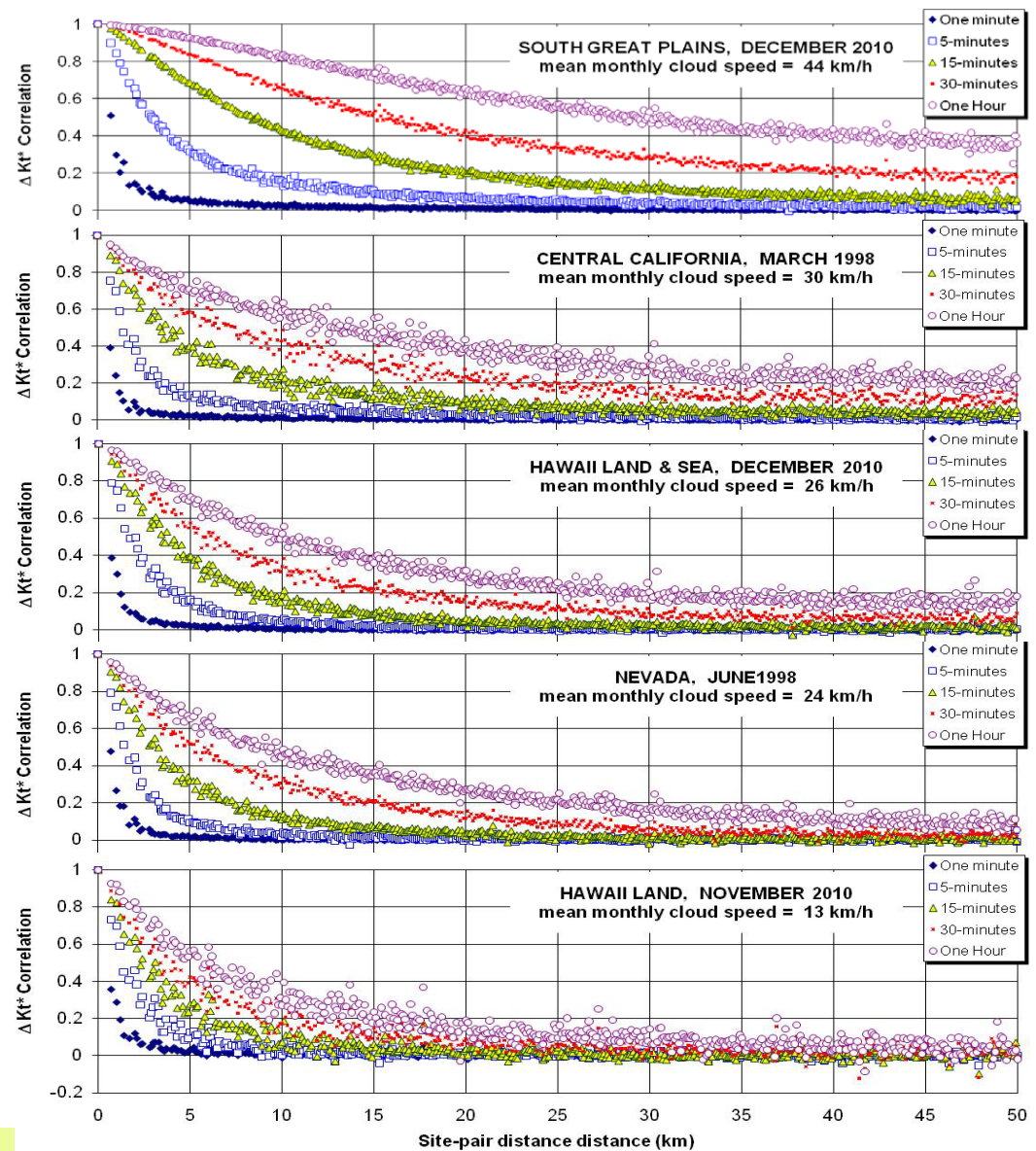


Solar resource

short term fluctuations

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

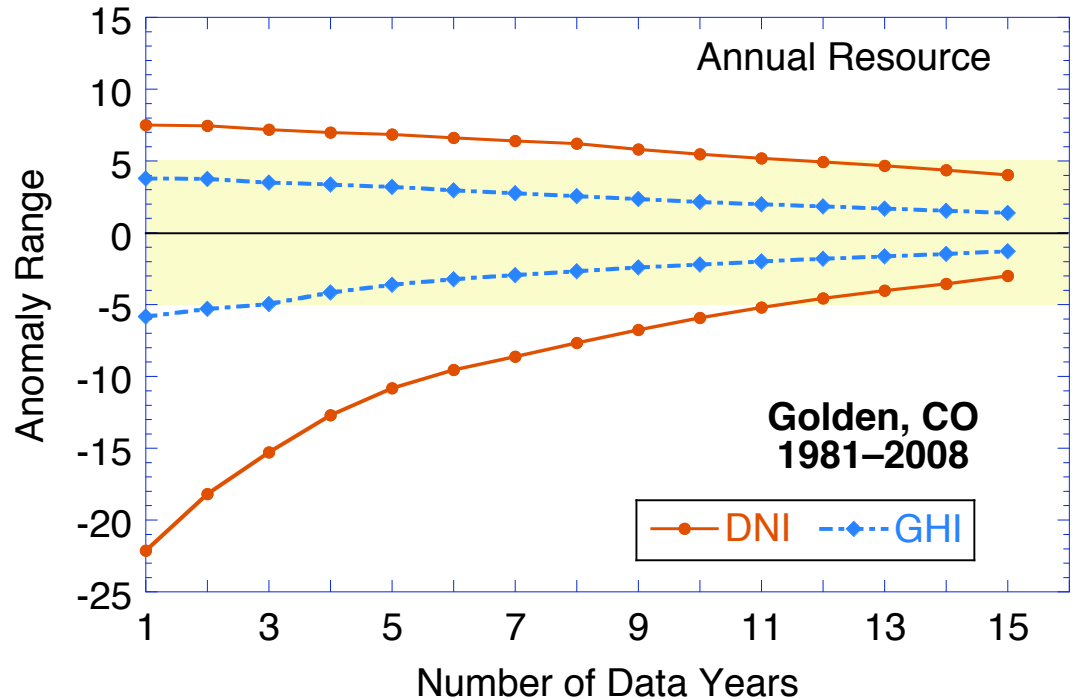
Source Perez et al., personal communication



Solar resource

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

Pre-feasibility phase

Assessment of solar energy potentials in large areas

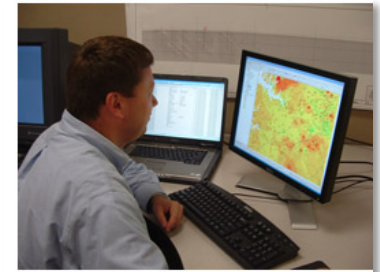
- Using a network of radiometers strategically distributed over the region of interest followed by the application of data interpolation techniques.



Pre-feasibility phase

Assessment of solar energy potentials in large areas

- Using a network of radiometers strategically distributed over the region of interest together with the application of interpolation of data
- Using computational models to estimate the incident solar irradiation by means of empirical relationships or the solution of the equation of radiative transfer in the atmosphere



Large areas – available information

-
- The collage features several covers of the 'Atlas Solarimétrico' series:
- Top Left:** A small blue cover titled 'Atlas Solarimétrico' with a sun icon and the date 'setembro 2007'.
 - Top Right:** A cover with a sunset scene and the title 'Atlas Solarimétrico de Minas Gerais'.
 - Middle Left:** An orange cover titled 'ATLAS RIO SOLAR' with a sun icon and the subtitle 'ATLAS SOLARIMÉTRICO DO ESTADO DO RIO DE JANEIRO'.
 - Middle Center:** A cover with a globe and the title 'Atlas Solarimétrico do Brasil'.
 - Middle Right:** A cover titled 'Atlas Solarimétrico do Ceará' with the years '1963 | 2008' and a large clock face.
 - Bottom Left:** A large cover titled 'ENERGIA SOLAR PAULISTA' with the subtitle 'Levantamento do Potencial' and a photo of solar panels.
 - Bottom Right:** The logo for 'LABREN' (Laboratório de Referência em Energia Solar) with the text 'LABORATÓRIO DE REFERÊNCIA EM ENERGIA SOLAR'.

Pre-feasibility phase

Solar energy assessment by using models

Dados para os modelos
computacionais

(Conds iniciais e de
contorno)



computador



Classification of models for solar assessment

Statistical Models

- use empirical formulas between measures of incident irradiation and satellite data
- restricted validity to the region studied

Classification of models for solar assessment

Statistical Models

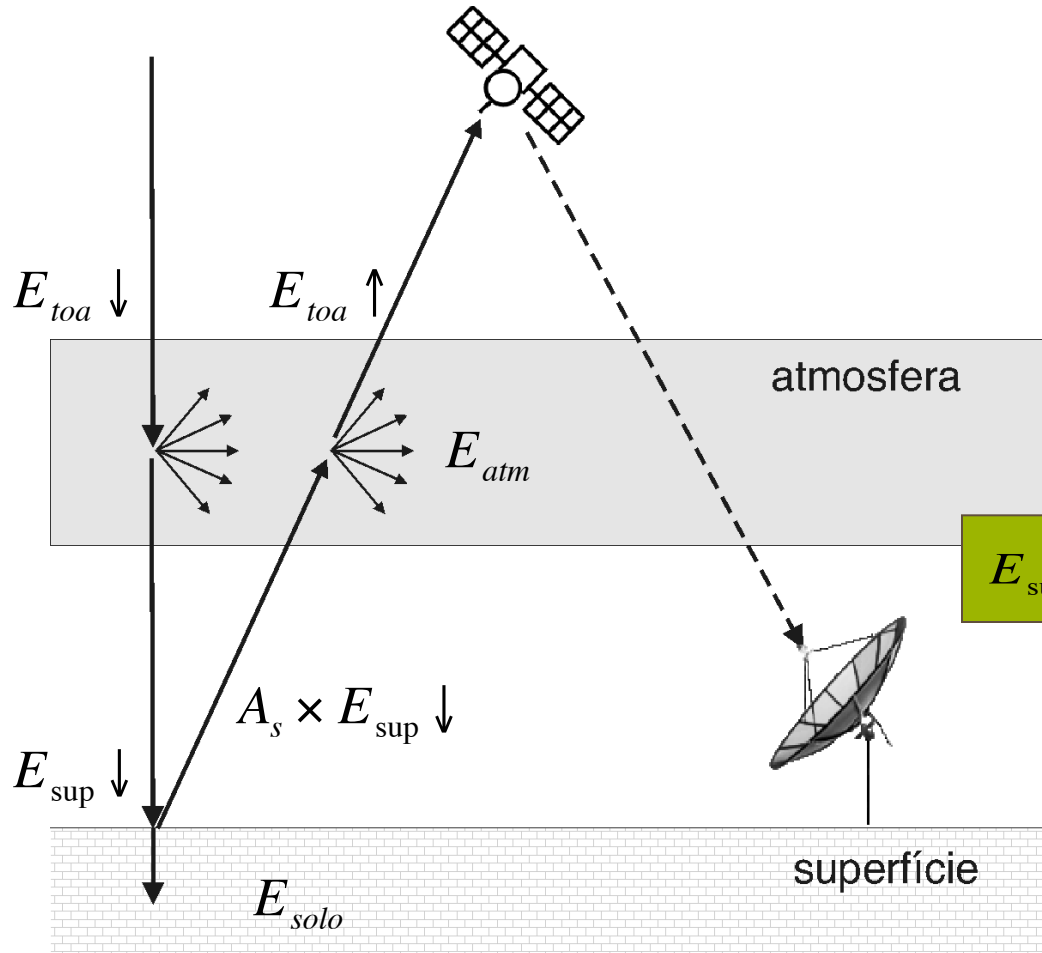
- use empirical formulas between measures of incident irradiation and satellite data
- restricted validity to the region studied

Physical Models

- Solve the equation of radiation transfer through parameterization of radiative processes that occur in the atmosphere
- need for knowledge of atmospheric and environmental conditions for radiative processes: the optical property of the clouds and the profile of atmospheric constituents such as aerosols, ozone, water vapor and other atmospheric gases

–

General principle of satellite models



$$E_{toa} \downarrow = E_{toa} \uparrow + E_{atm} + E_{solo}$$

but

$$E_{solo} = E_{sup} \downarrow \times (1 - A_s)$$

extracting $E_{sup} \downarrow$

$$E_{sup} \downarrow = (E_{toa} \downarrow - E_{toa} \uparrow - E_{atm}) / (1 - A_s)$$

two unknowns E_{atm} and A_s

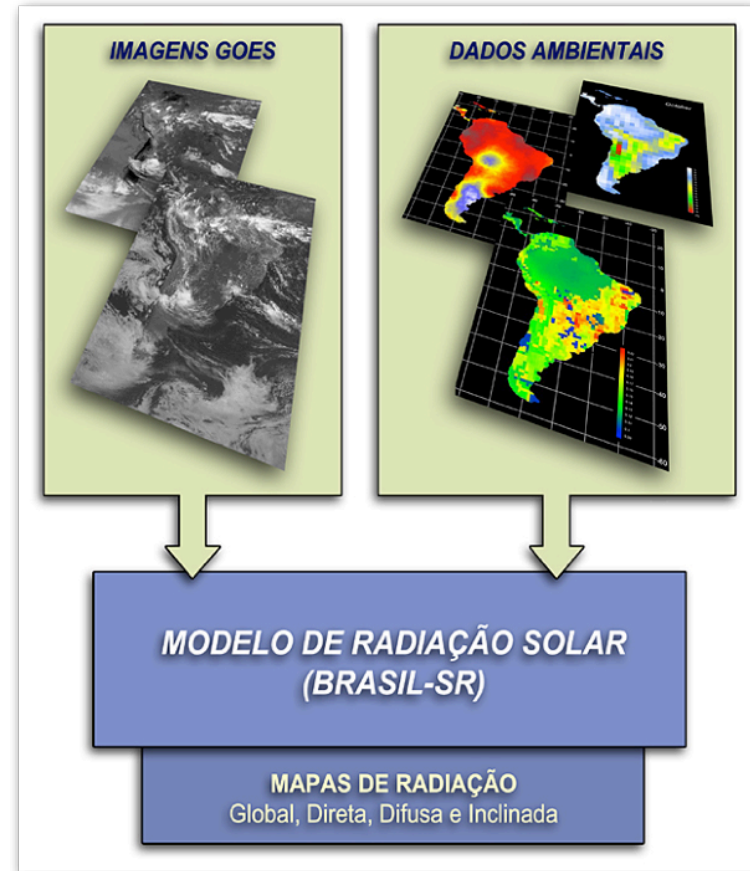
BRASIL-SR Model

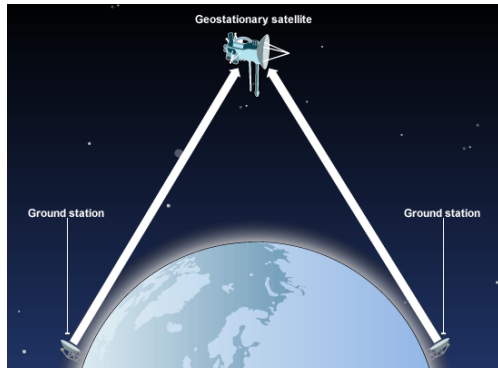
Two steps:

1) Handling input data:

- Satellite data
- Temperature
- Relative humidity
- Surface albedo
- Visibility
- Effective cloud cover

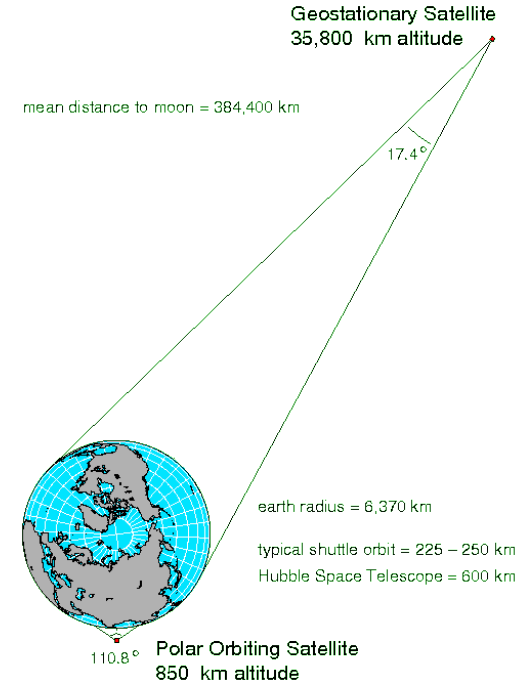
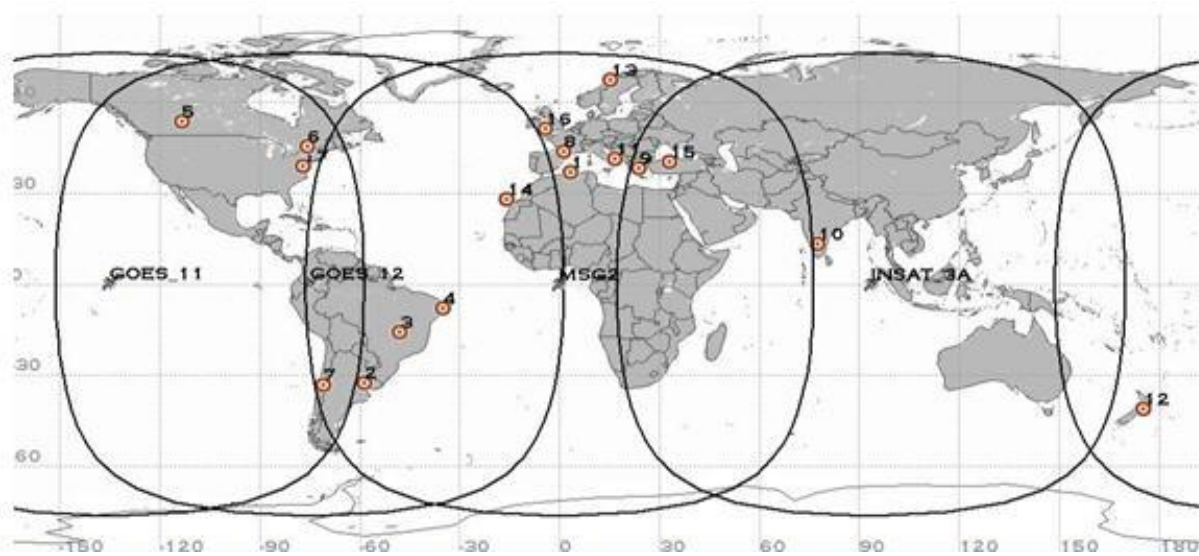
2) Atmospheric parameterizations and solving the radiative transfer equation





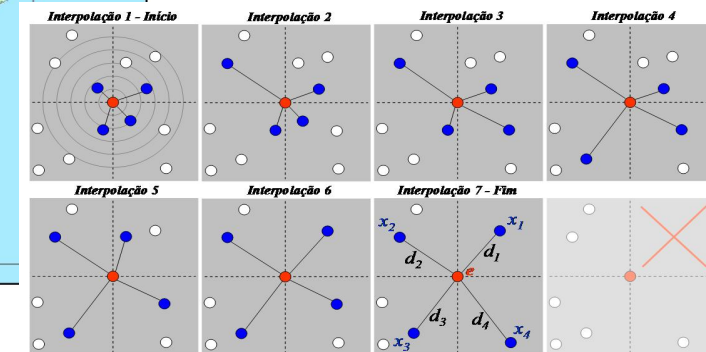
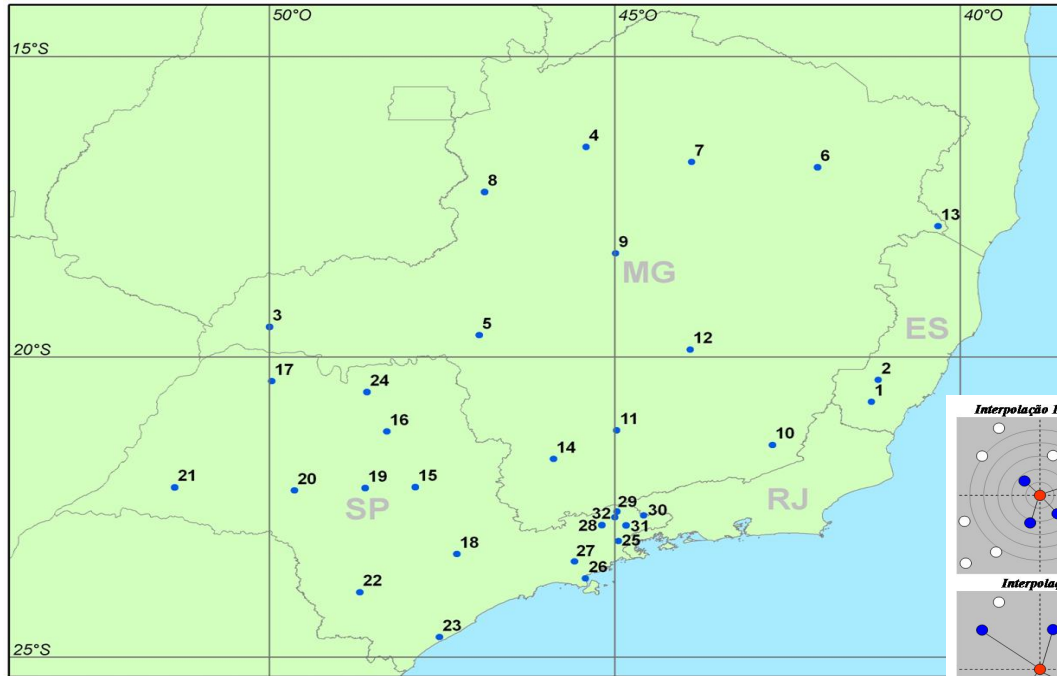
Geostationary satellites

Map of coverage of the Earth's surface



Space variability

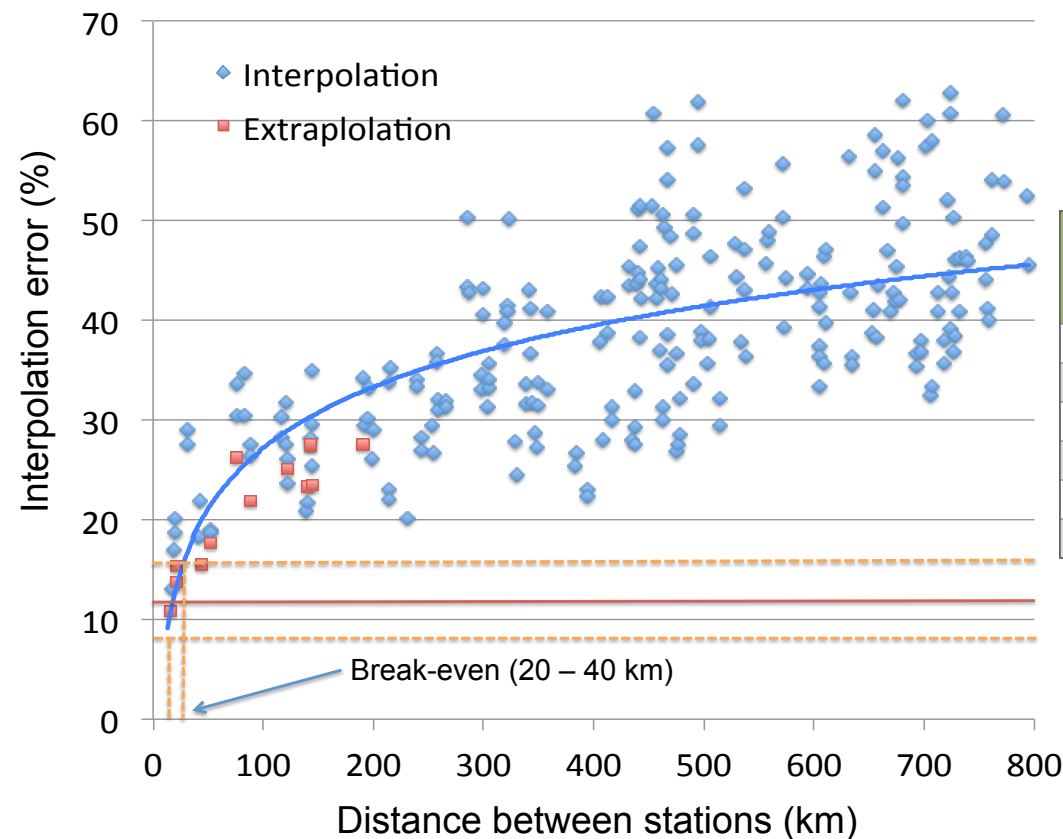
ground observations X satellite model



● Estações interpoladoras com valores de radiação x_i
● Estação interpolada com valor estimado de radiação e

Brazilian Solar Atlas

model deviation 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

Site-specific phase

Due- diligence and project

- Ground measurements
- Public solarimetric stations and/or networks
- Site-specific from projects
 - proprietary data



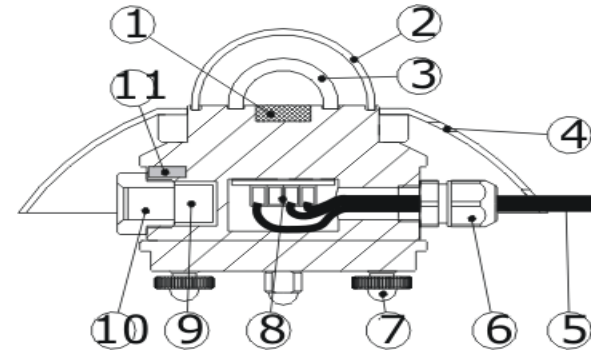
Pyranometer

Thermopile sensor

Measures solar irradiance (W/m^2) between in the shortwave range of the solar spectra ($0.3 - 2.8 \mu\text{m}$)

1. Solar energy is converted to electric current by a thermistor
- 2-3. Special glass domes to provide thermal insulation of the thermistor
4. Shield
11. Compensating thermistor (body temperature)

High accuracy (1% a 10%)

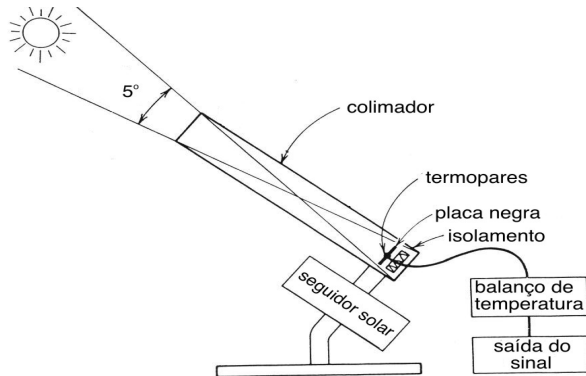


Pirheliometer

Measures the direct component of solar irradiance in W/m^2

(0,3 and 2,8 μm)

Must be guided by a Sun tracker to follow the direct Sun beams



Shading devices

For diffuse and longwave measurements

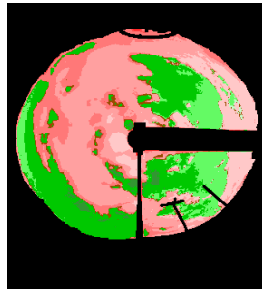
- Sun tracker
- Shading ring





Sky imager

- Maps the percentage of cloud cover in the sky
- Substitutes man-made observations (subjective data)
- Images must be processed to provide cloud cover percentage

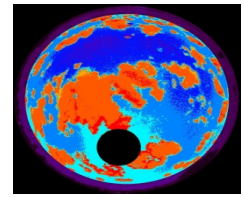


Application sky imagers

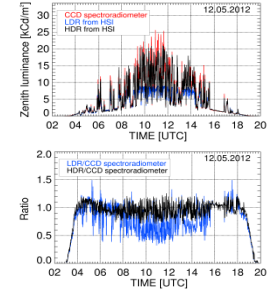
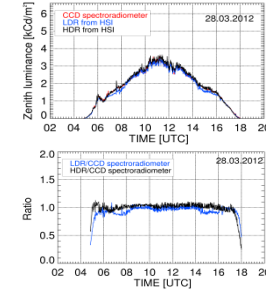
- Cloud cover
- Derivation of luminance
- General weather situation
- **Cloud type**



original Image



estimated cloud cover



Sun photometer

- Is a special type of pyrelimeter
- measures the solar irradiation in narrow absorption bands of solar spectra
- Must be guided by a Sun tracker
- Used to estimate the optical properties of aerosols and water vapor in the atmospheric column



Validação de modelos– levantamento de incertezas

SONDA rede nacional de coleta de dados radiométricos e anemométricos

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



14 sitios de coleta de dados locados estrategicamente nas principais zonas climáticas do país

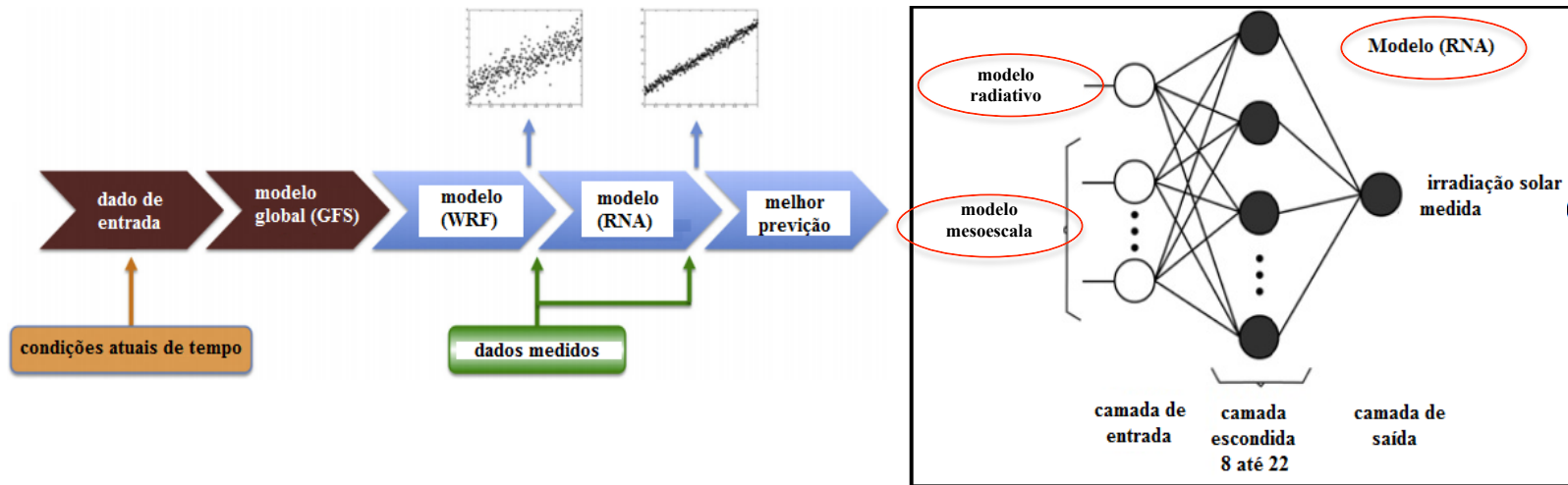


Forecasting of solar energy resource

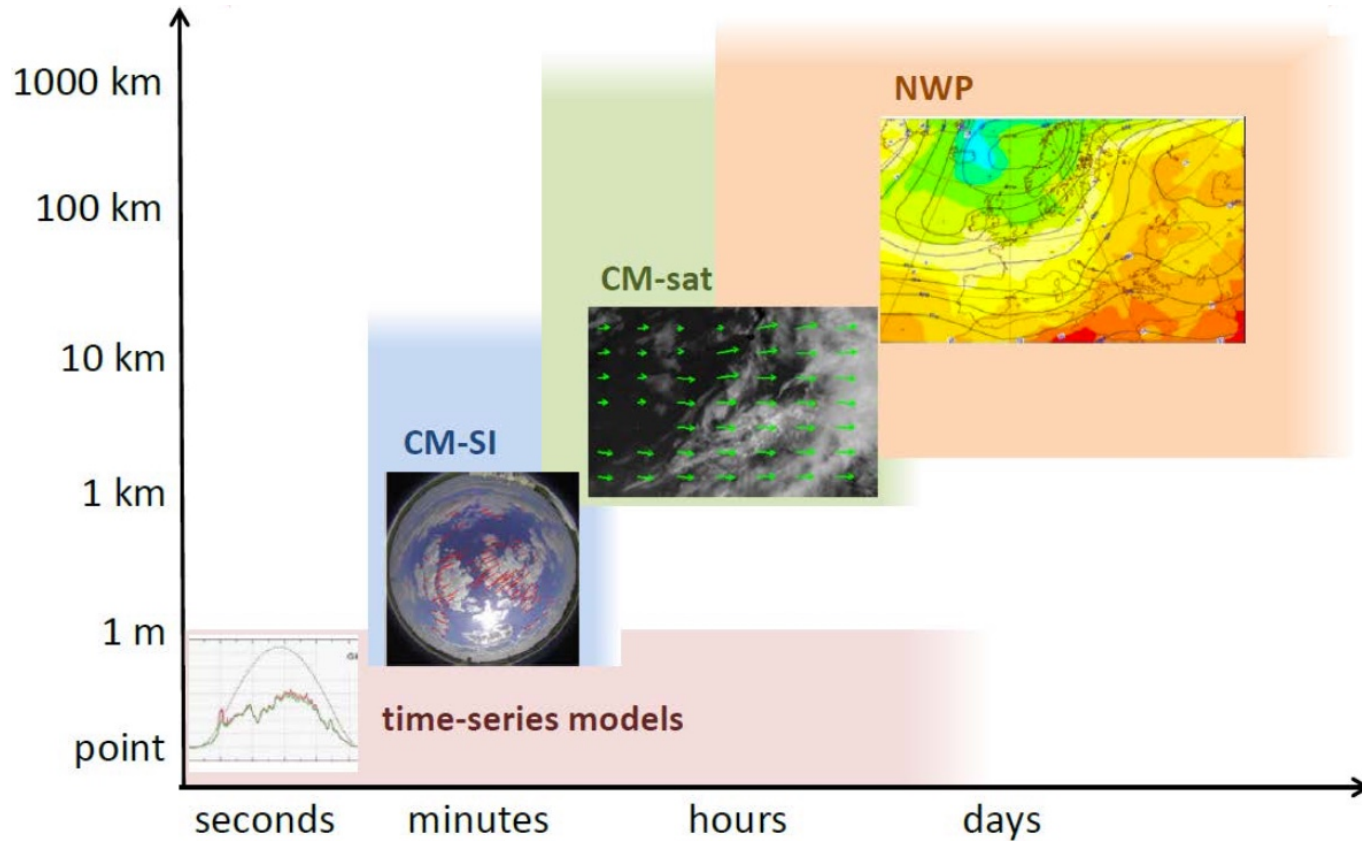
Forecast	Time horizon	Application	Methods
intra-hour	5–60 min	Real-time dispatch	Mostly persistence
Short-term	1–12 hours	Ramp forecasting, load-flowing, congestion management	Meteorological models adjusted by statistical techniques
Medium-term	Days ahead	Load forecasting, reserve requirement, market trading and congestion management	Meteorological models with post processing statistical or ANN corrections
Long term	Months ahead	Resource planning, contingency analysis, maintenance planning	Downscaling of climatological model forecasts
Climatological term	Years ahead	Planning and climate change scenarios	Global climate models adjusted by regional meteorological models

Forecasting of solar energy resource

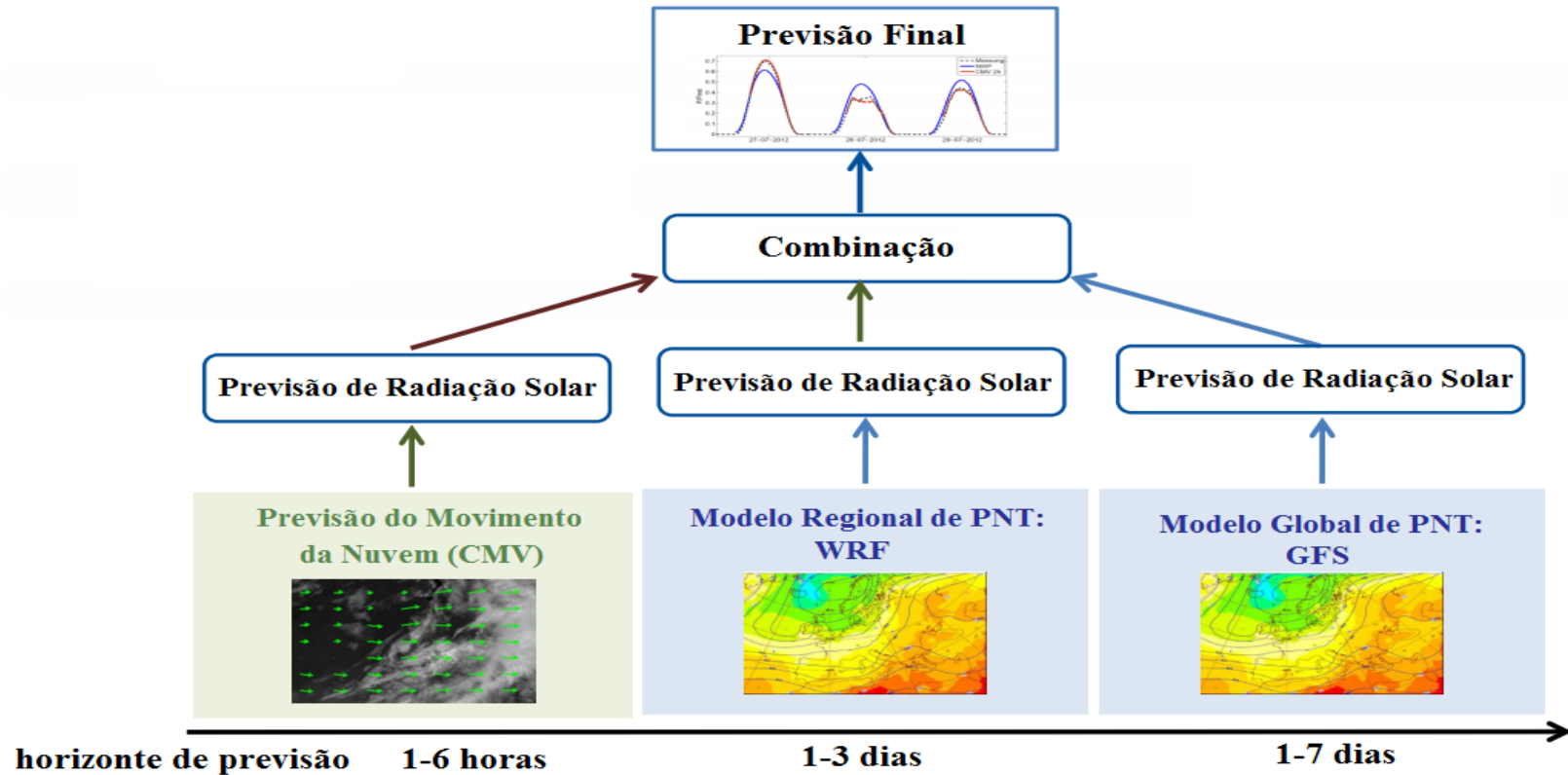
- ✓ Ajuste de saída de modelo meteorológico (WRF) com emprego de rede neural artificial (RNA)
- ✓ Treinamento da RNA realizado com dados de irradiância ou de produção local
- ✓ Previsões empregam metodologias distintas para escalas de tempo distintas



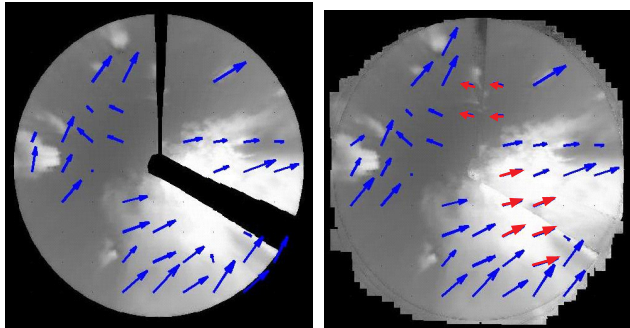
Forecasting of solar energy resource



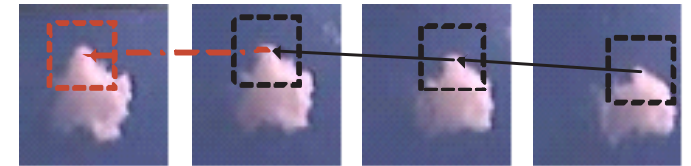
Forecasting of solar energy resource



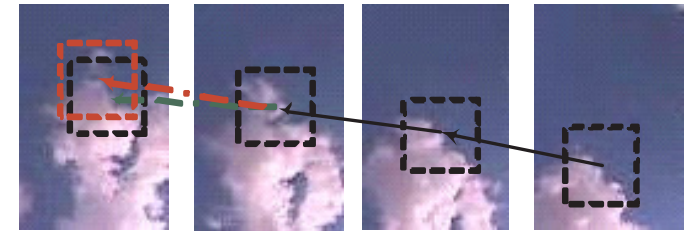
Forecasting of solar energy resource



Vectorization of cloud fields



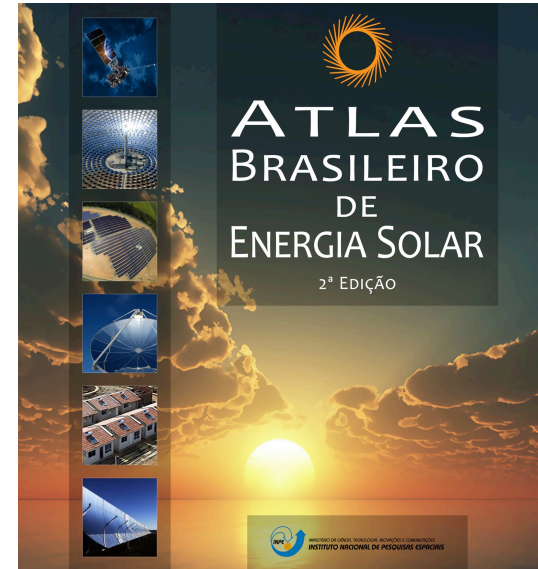
(a) Decision on displacement: 1st case.



New Brazilian Atlas of Solar Energy – 2017

Major improvements:

- Longer time series of satellite images 17 years
- Improved methodology for model assimilation of aerosol optical depth information
- Larger number and longer time series of ground-based validation data
- 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



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