Solar Energy Resource Assessment in Brazil

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Summary

- Solar Radiation Mapping of Brazil
  - brief review
    - measurements - available and future ground data
    - first mapping initiatives
  - description of the BRAZIL-SR Model
- Outputs of the SWERA project
- Final remarks

Measured data available

- meteorological stations network from INMET and airports
  - meteorological observations
  - sunshine duration records
  - cloud cover at synoptical hours
  - actinographs
  - pyranometers
  - long term series
- PCDs network from INPE

Measured data available

- solarimetric stations supported by individual iniciatives
  - universities
  - utilities
  - agriculture research companies
  - regional weather services
  - characteristics
    - not standardized
    - short term time series
    - difficulties to recover
- new networks
  - BSRN - Baseline Surface Radiation Network
  - SONDA - Brazilian Repository System of Environmental Data for the Energy Sector

Solar Radiation Mapping of Brazil

- OLADE - first initiative to join data from different Latin-America countries
- Brazilian Solar Atlas using interpolation techniques (Tiba, 2000)
- Model GL (DSA/INPE)
- Model BRASIL-SR

Solar Radiation Mapping of Brazil

- "Atlas de Climatologia Solar" (OLADE, 1987) - first initiative to join data from different Latin American countries
  - only INMET stations
  - basically insolation data

Solar Radiation Mapping of Brazil

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Solar Radiation Mapping of Brazil

- "Atlas Solarimétrico do Brasil" (Tiba, 2000)
  - complete review of the measured data
  - maps obtained using interpolation techniques
  - monthly average maps of global solar radiation – derived from pyranometers and actinographs
  - monthly average maps of insolation – derived from sunshine records

Solar Radiation Mapping of Brazil

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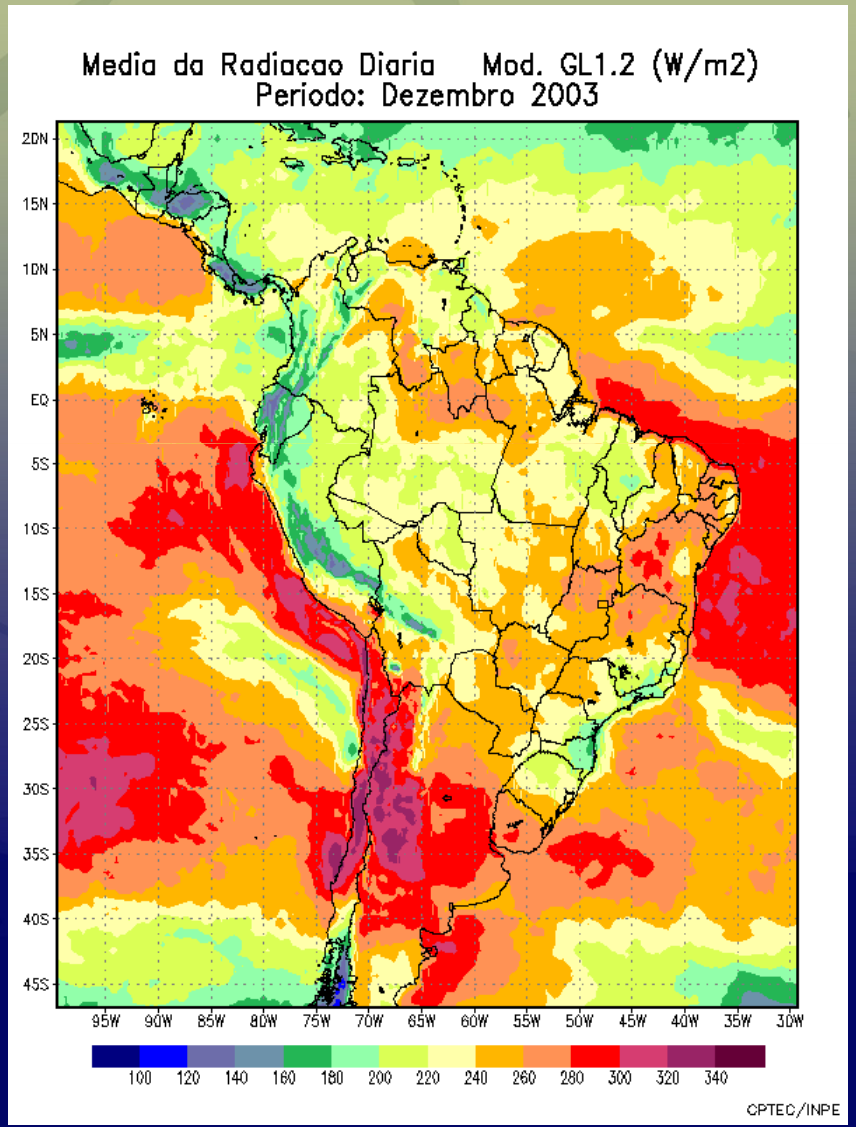
Solar Radiation Mapping of Brazil

Model GL

- physical model
- atmospheric aerosol is neglected
- two spectral intervals
  - visible (0.4 – 0.7 μm)
  - infrared (0.7 – 4.0 μm)
  - cloud cover is calculated from:

    C = (R - Rmin)/(Rmax - Rmin)



Solar Radiation Mapping of Brazil

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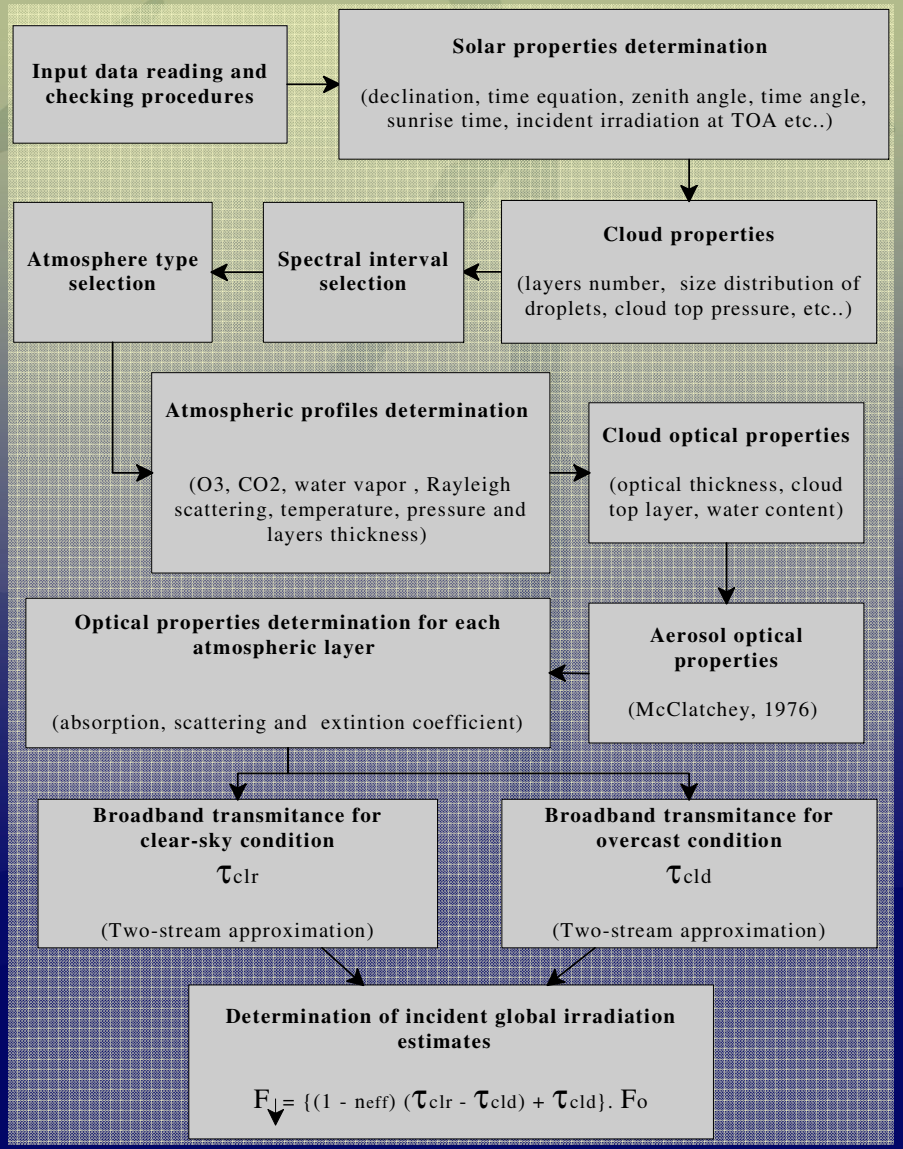
Model BRASIL-SR

Short description

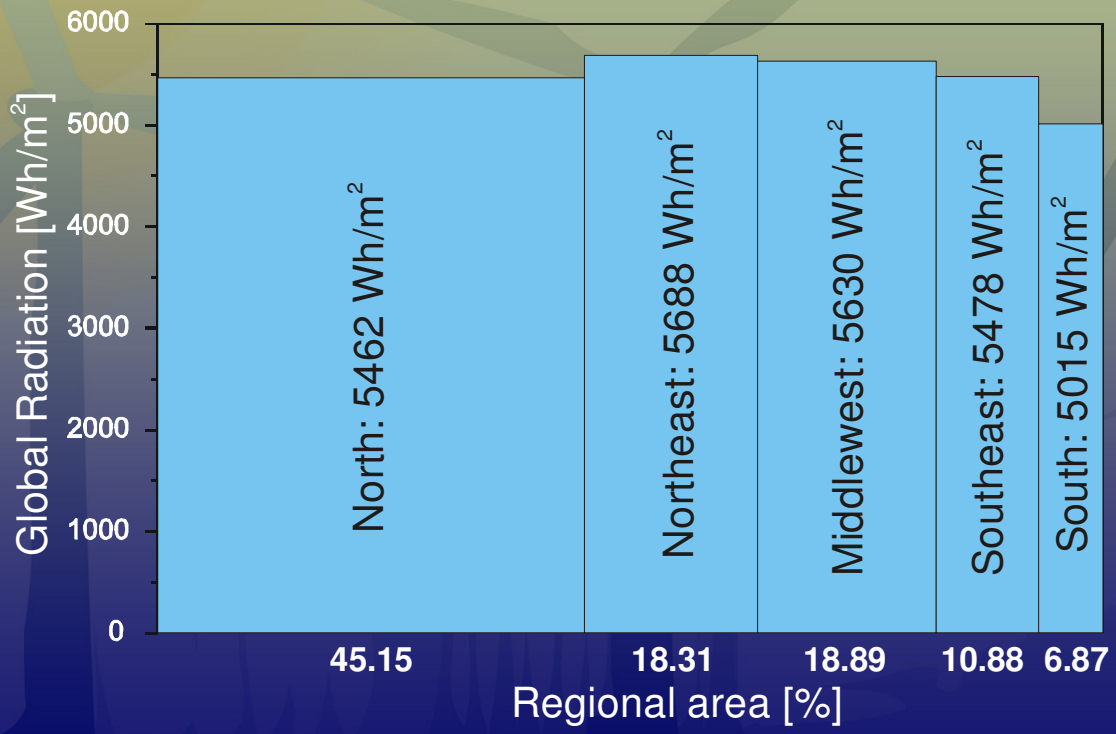
- Two-Stream approach
- 135 wavelength spectral intervals
- 37 atmospheric layers
- Atmospheric aerosols are taken in account
- Cloud cover data obtained from satellite images
- Radiative processes parameterization uses climatological data:
  - Temperature
  - Relative Humidity
  - Surface albedo
  - Visibility



Solar Radiation Mapping of Brazil

- "Atlas Irradiação Solar do Brasil" (Colle and Pereira, 1998)
  - GOES 8 images
  - images from 1995 to 1998
  - three hourly images
  - spatial resolution of 0.5 x 0.5°
  - solar radiation variability
  - comparison with other results (OLADE, IGMK)

Solar Radiation Mapping of Brazil



Yearly average of daily sums

Solar Radiation Mapping of Brazil

SWERA Project

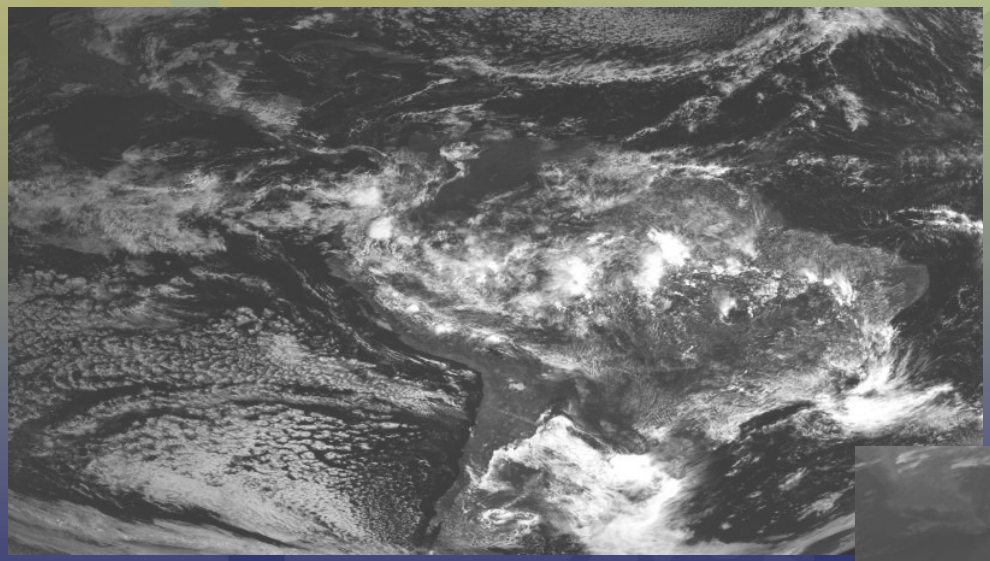
- improve the spatial and temporal resolution
- decrease the expected uncertainties
- consolidate the satellite derived maps methodology
- calculate another radiation components
- setup a continuous data collection in order to have a long term series in the future – SONDA Project

Solar Radiation Mapping of Brazil

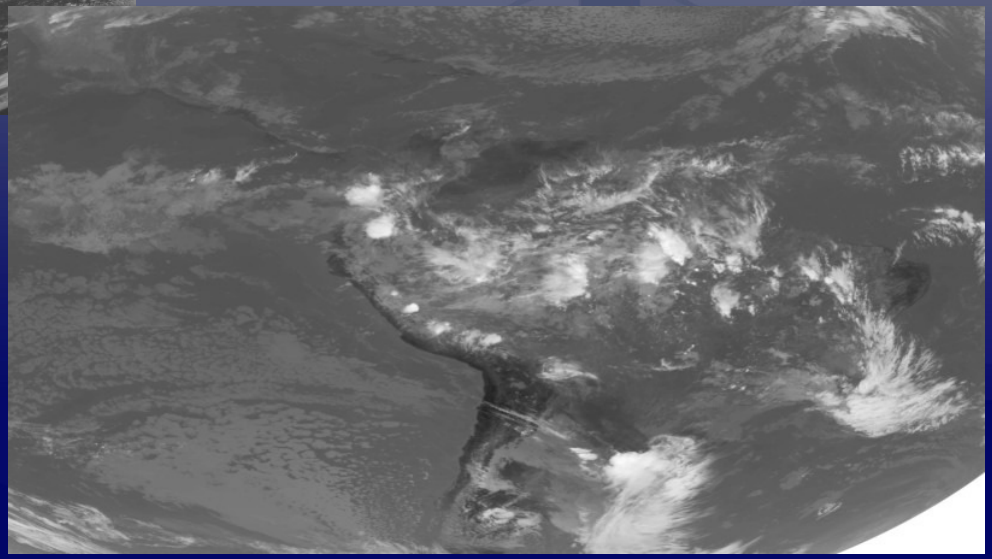
- BRASIL-SR Improvements
  - Altitude correction for precipitable water
  - algorithms to get effective cloud cover index
  - modeling of aerosols emitted by induced forest fires (in developing)
- Comparison with other models and expected uncertainties

Model BRAZIL-SR

GOES-12 images



Channel 1 – visible band (0,55-0,75mm)

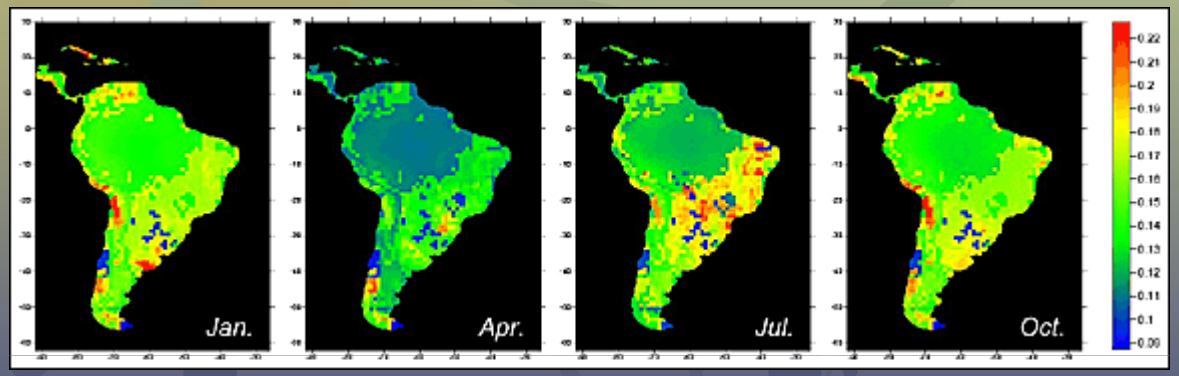


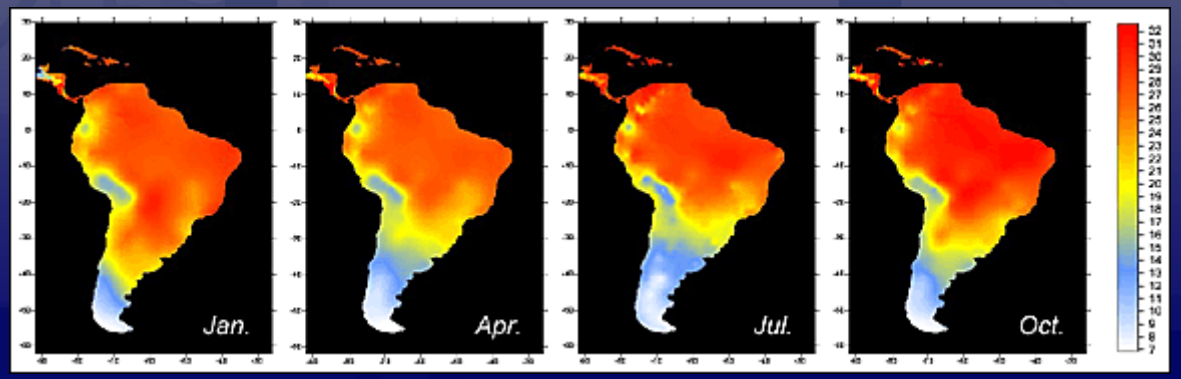
Channel 4 – infrared band (10,2–11,2µm)

Model BRAZIL-SR

Climatological data

Surface albedo





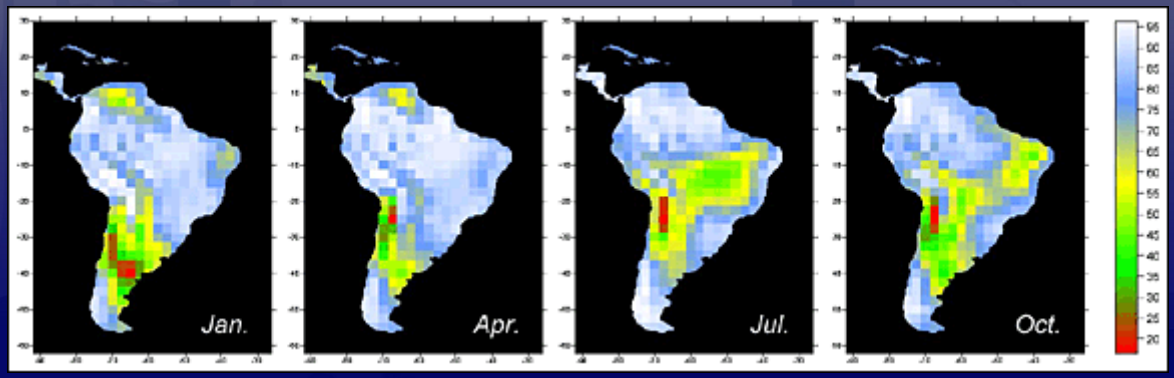
Temperature

Model BRAZIL-SR

Climatological data

Topography

Relative Humidity



SWERA CROSS-VALIDATION

ground site - Caicó

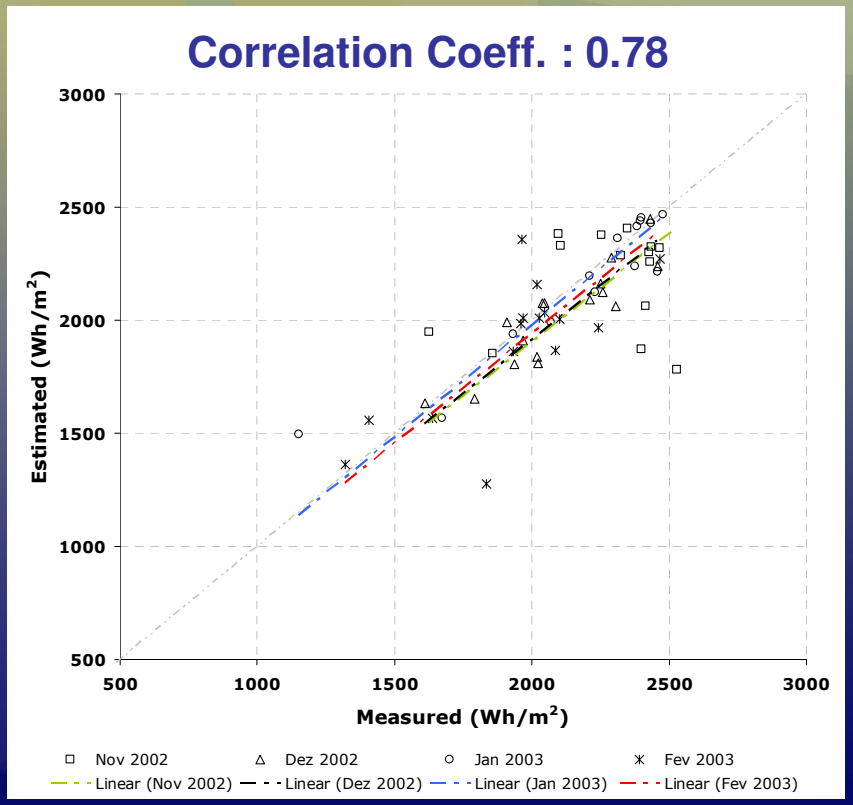
- **Semi-arid region of the Brazilian northeast**
  - Annual precipitation less than 700 mm
  - Flat land area with sparse brushwood type vegetation
  - Average albedo 13.3%
  - Large insolation - about 120 days/year
  - High annual mean temperature - 22 to 33 ºC

- **Nice place for clear-sky bias model fine tuning**

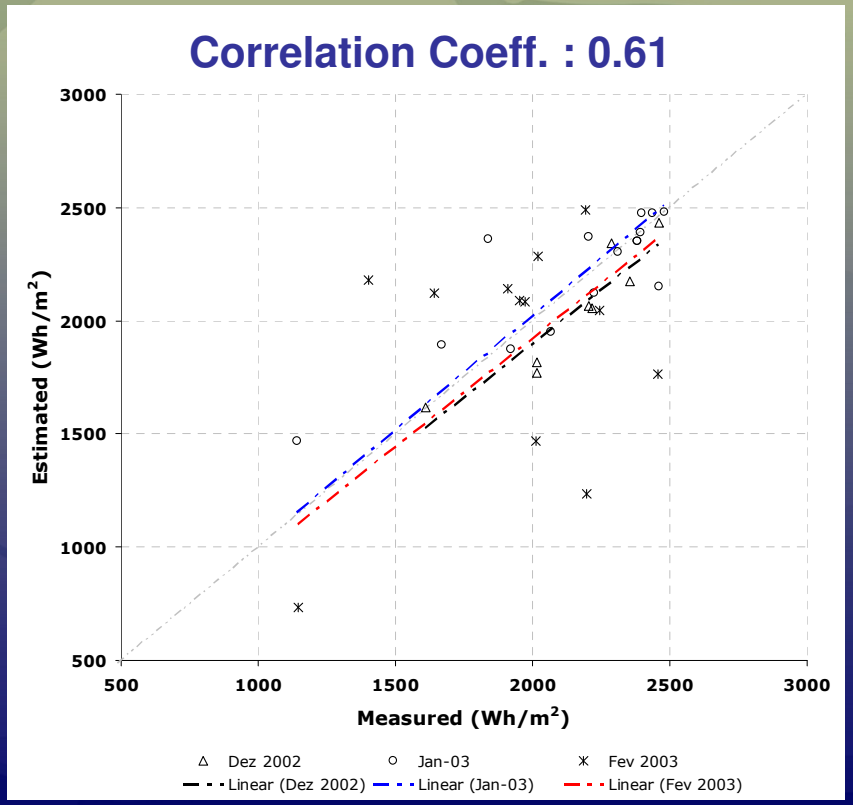
- **Producing data for global and direct incident horizontal solar radiation since November 2002.**

SWERA CROSS-VALIDATION

daily global irradiation



BRASIL-SR

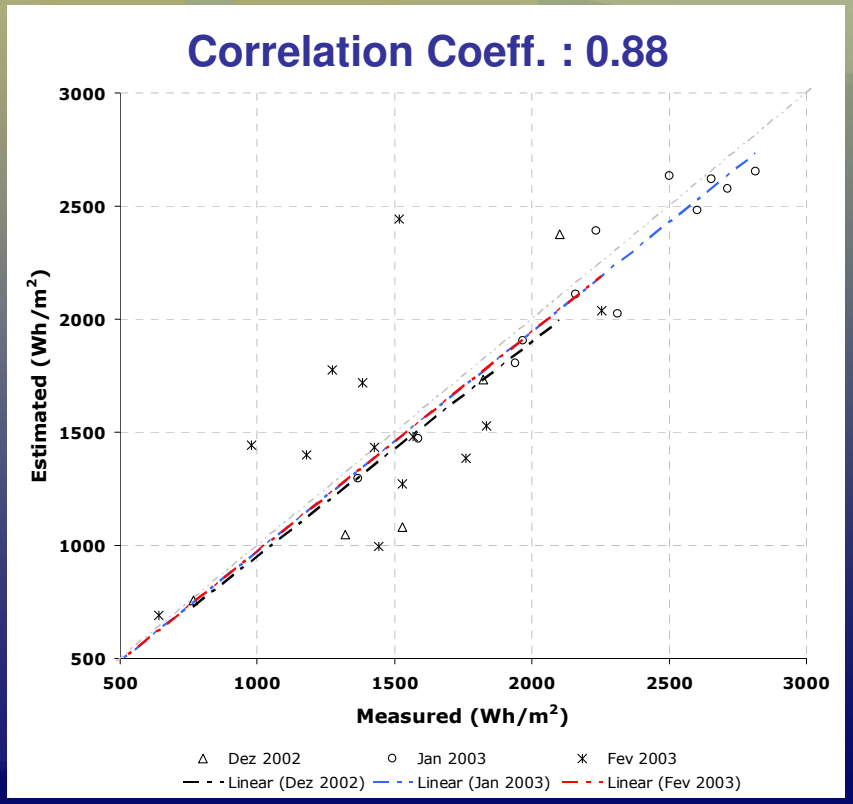


SUNNY-ALBANY

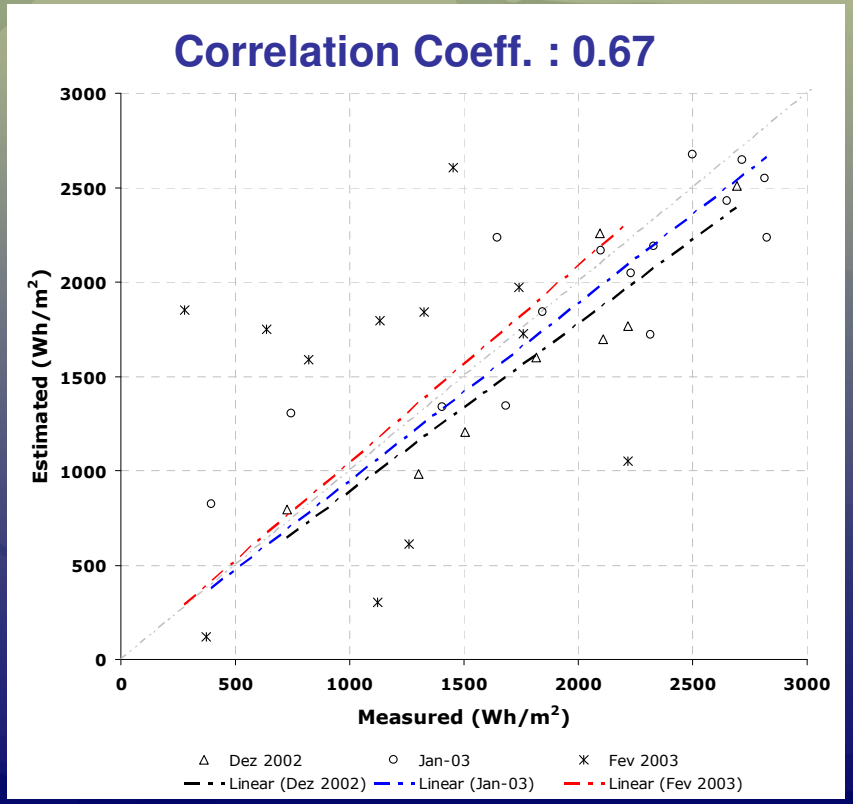
UNEP INPE CPTEC LABSOLAR EMC / UFSC

SWERA CROSS-VALIDATION

daily direct normal irradiation



BRASIL-SR



SUNNY-ALBANY

Outputs of the SWERA project

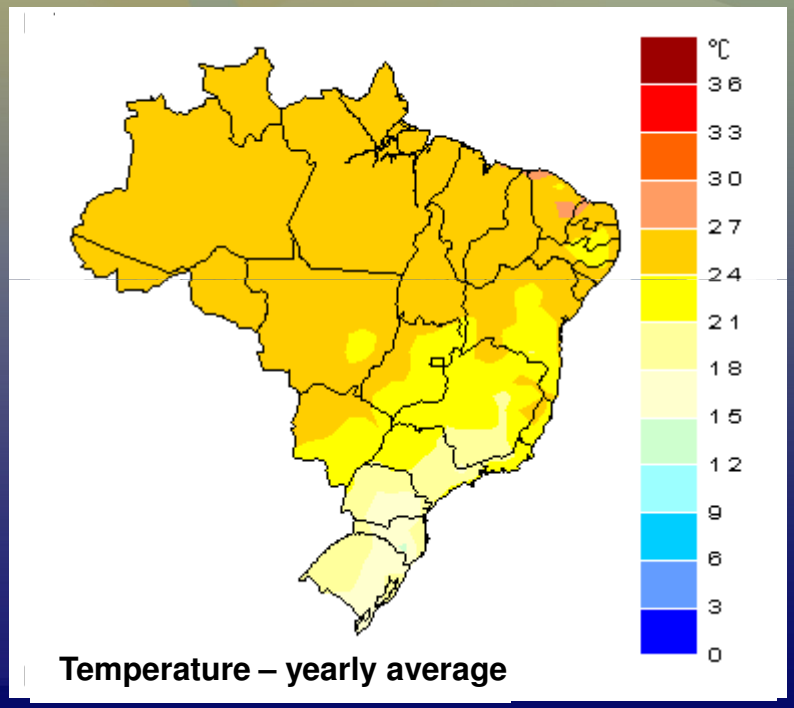
- Solar Radiation Maps
  - Global
  - Direct
  - Tilted
- Typical Meteorological Years - TMY

Outputs of the SWERA project
Solar Radiation

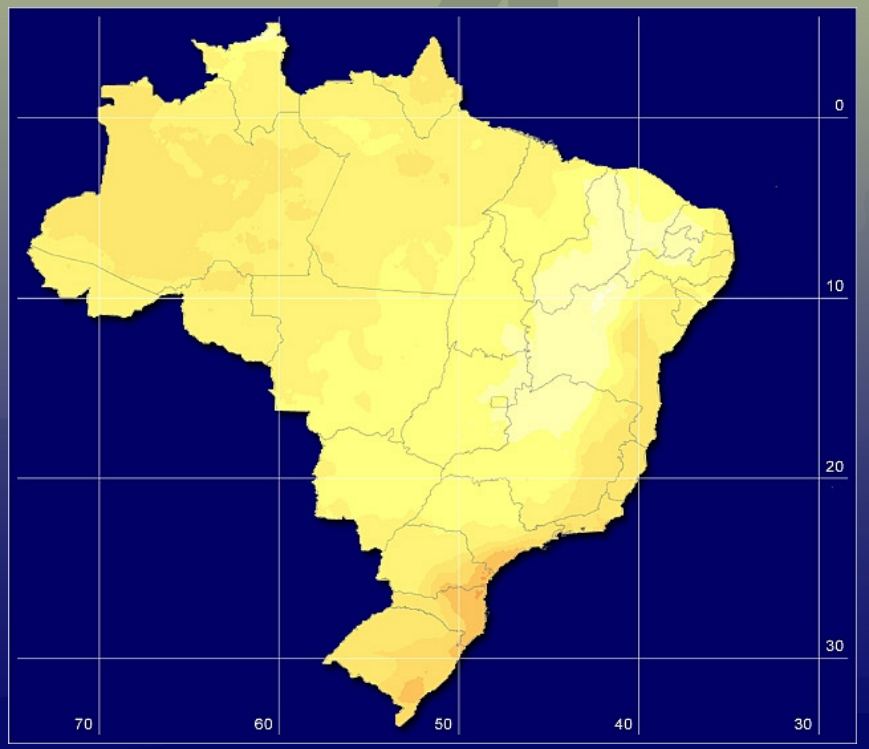
- spatial resolution ~ 10 x 10 km
- instantaneous values derived from three-hourly images
- interpolated daily sums
- monthly averages

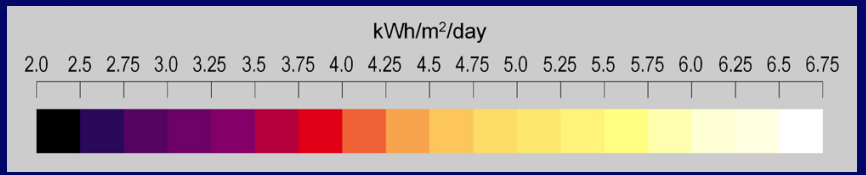
Global Radiation

Yearly average

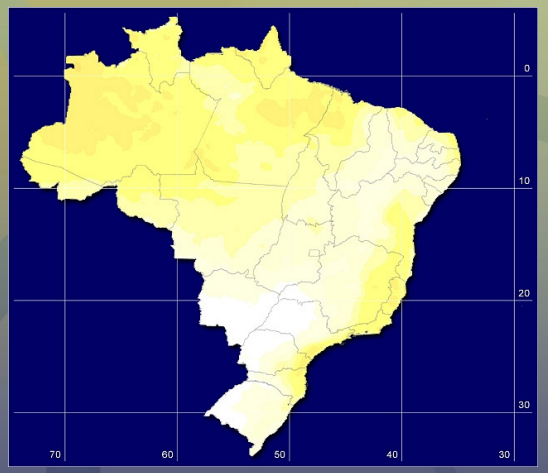


Temperature – yearly average

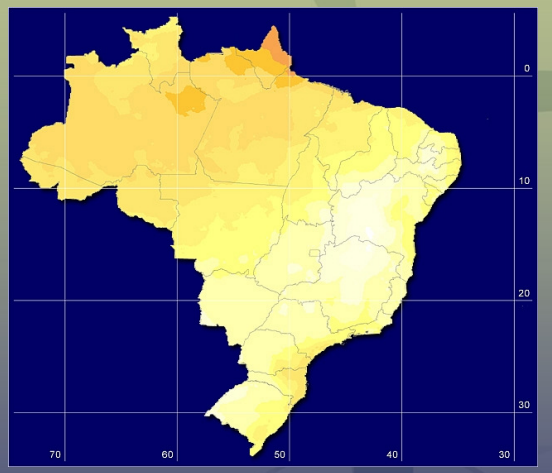




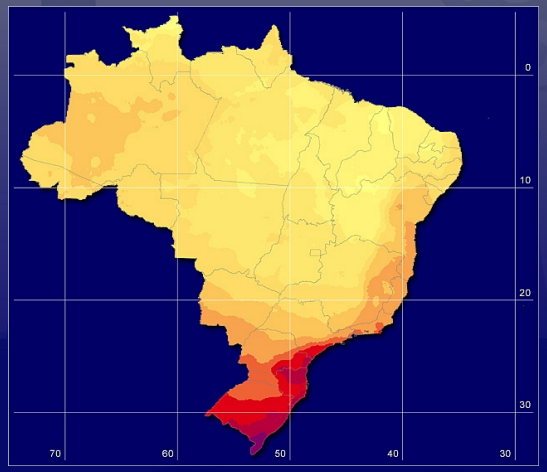
Global Radiation



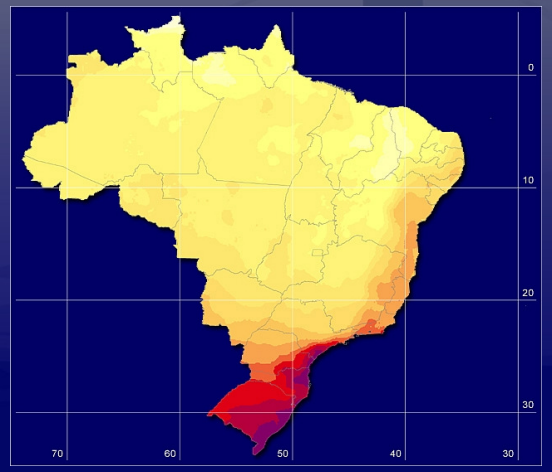
spring



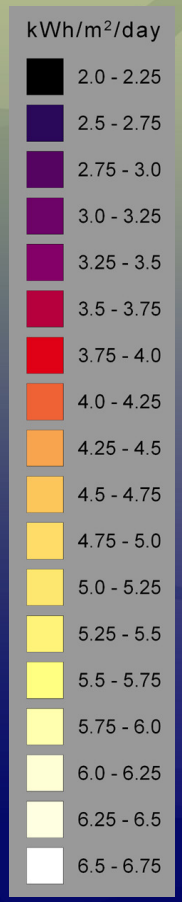
summer



autumn



winter



UNEP

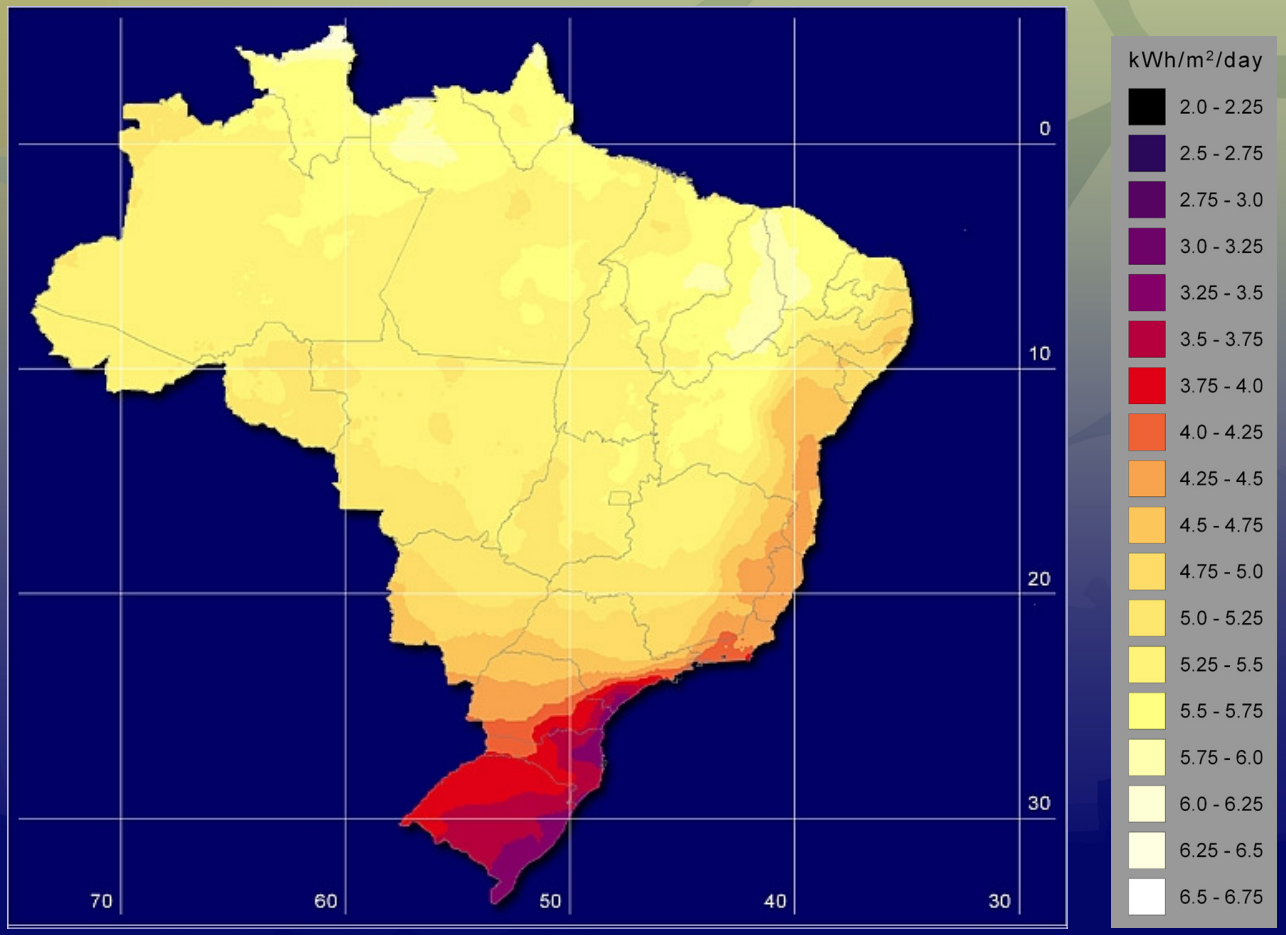
INPE

CPTEC

LABSOLAR
EMC / UFSC

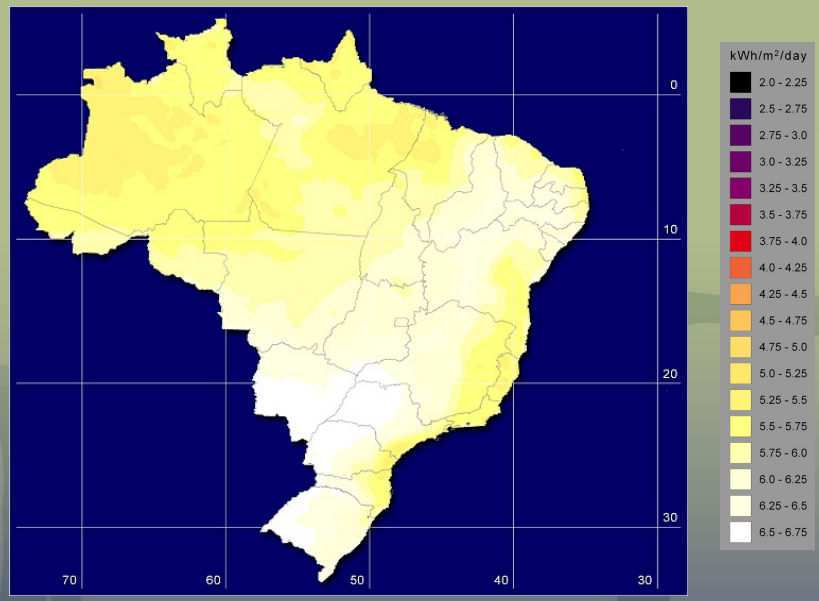
Global Radiation

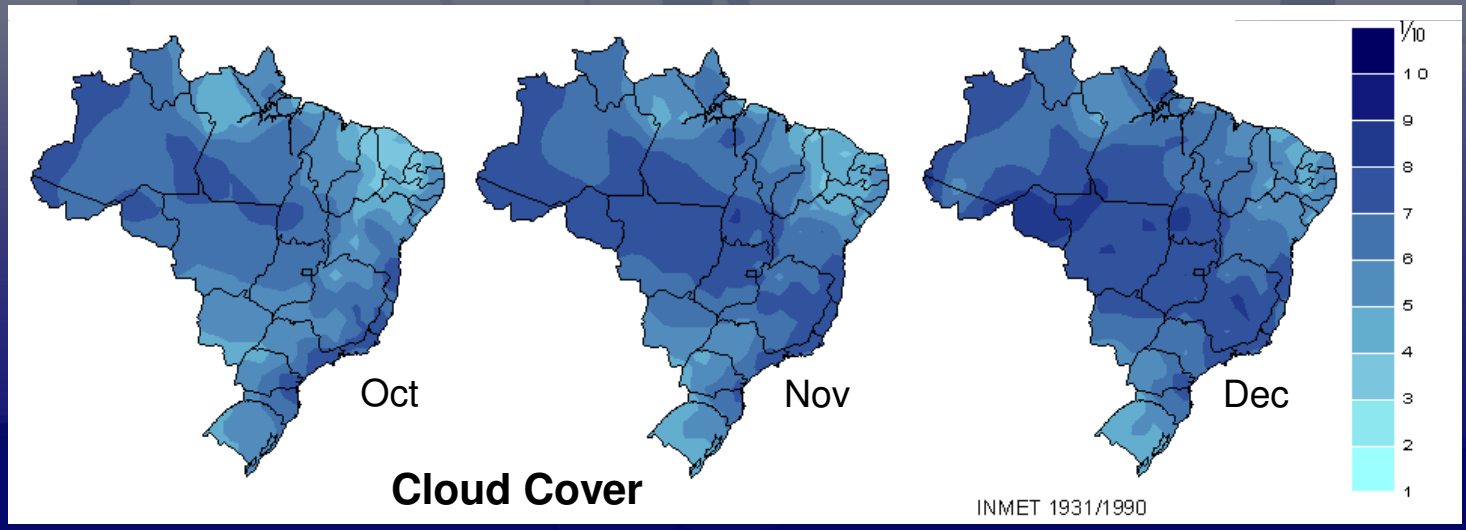
Seasonal maps



Global Radiation

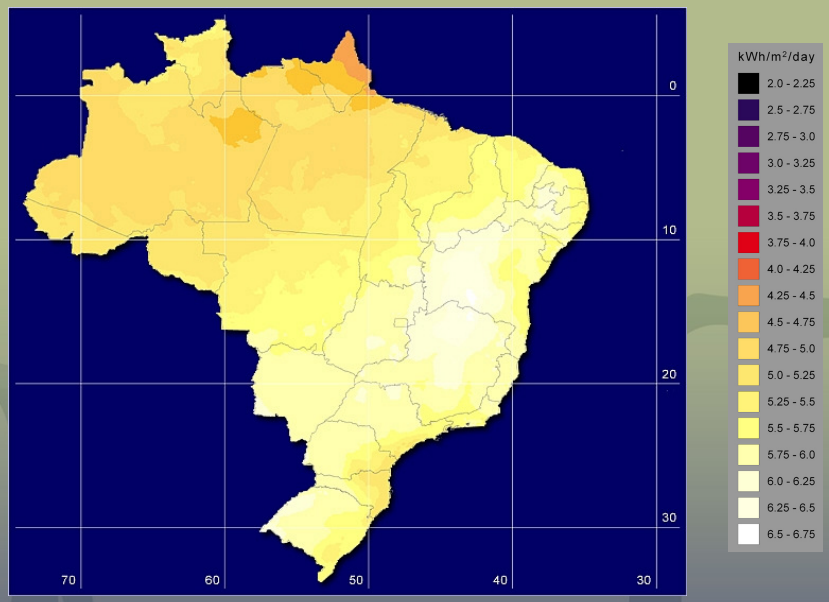
Spring

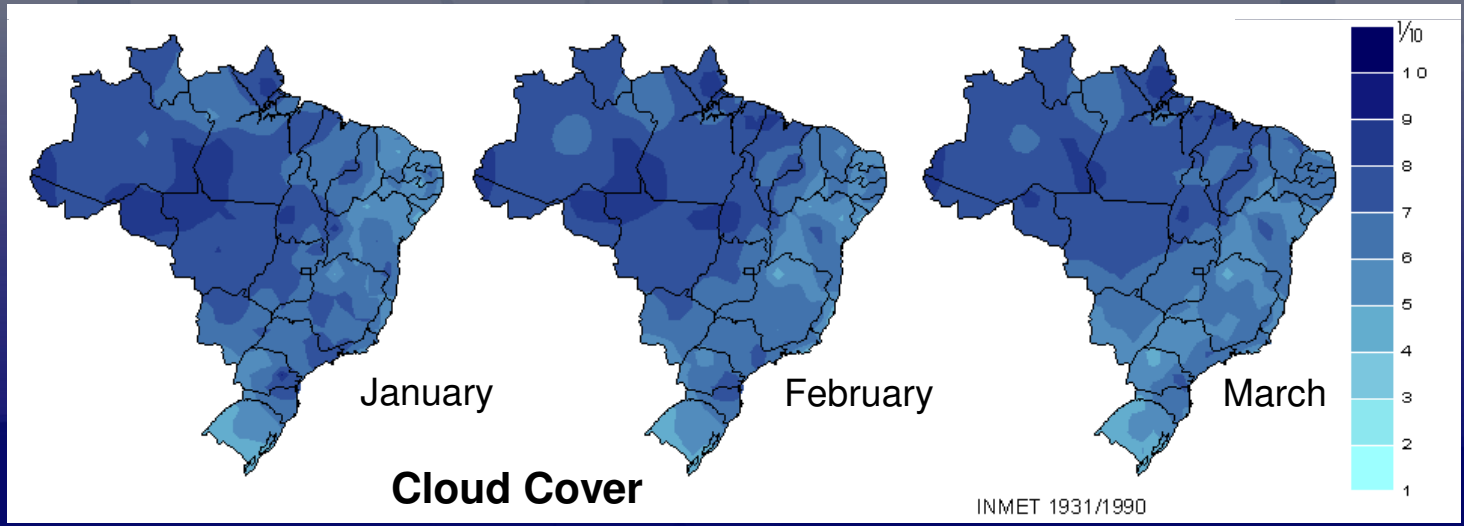




Global Radiation

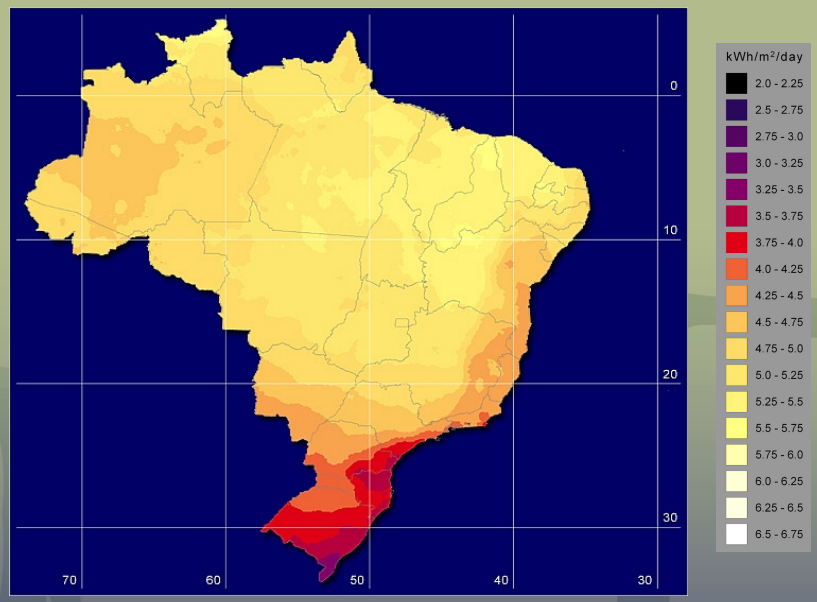
Summer

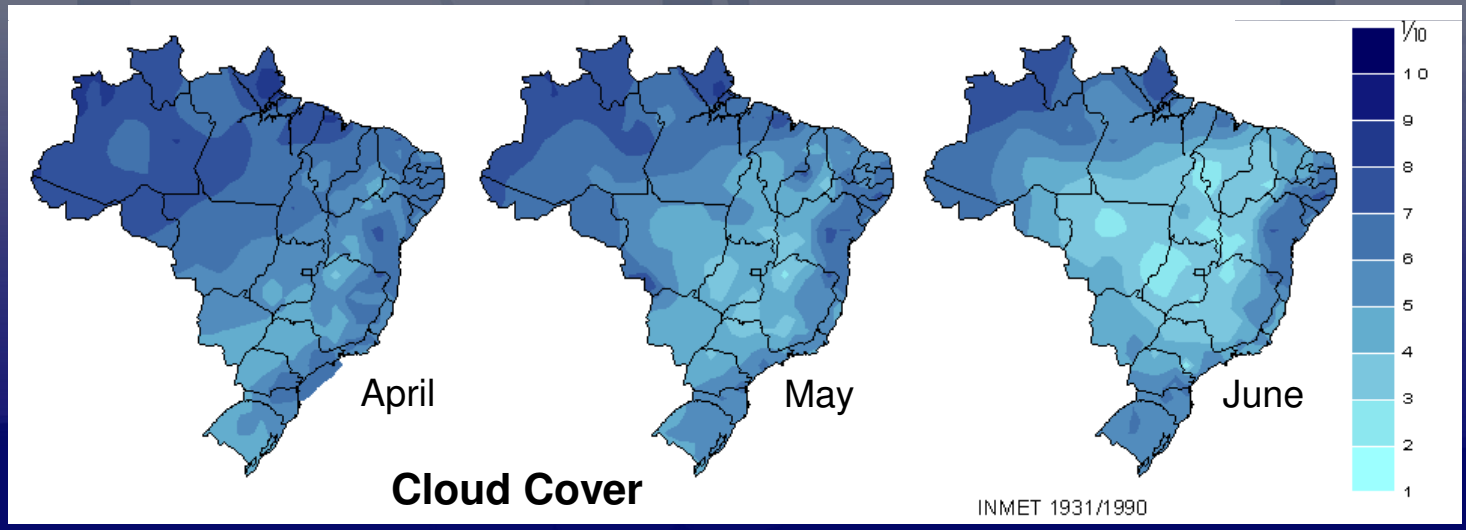




Global Radiation

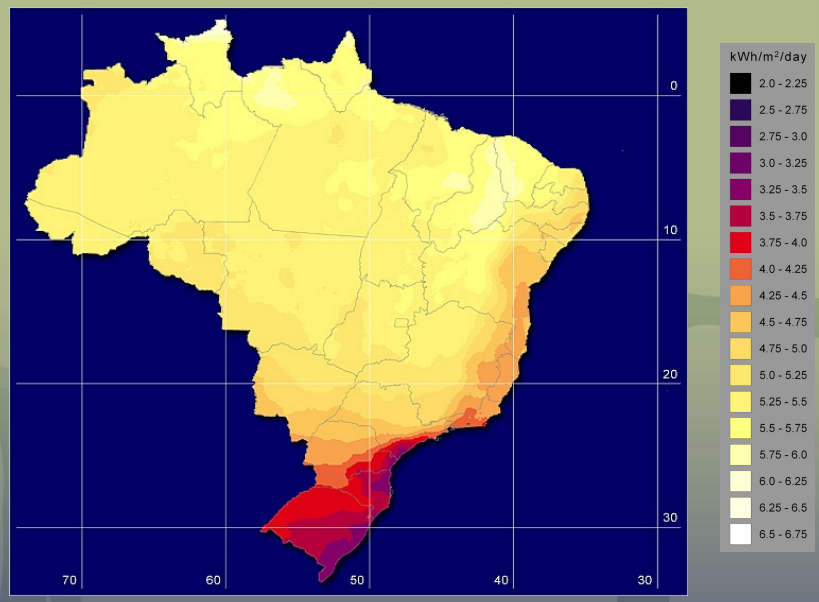
Autumn

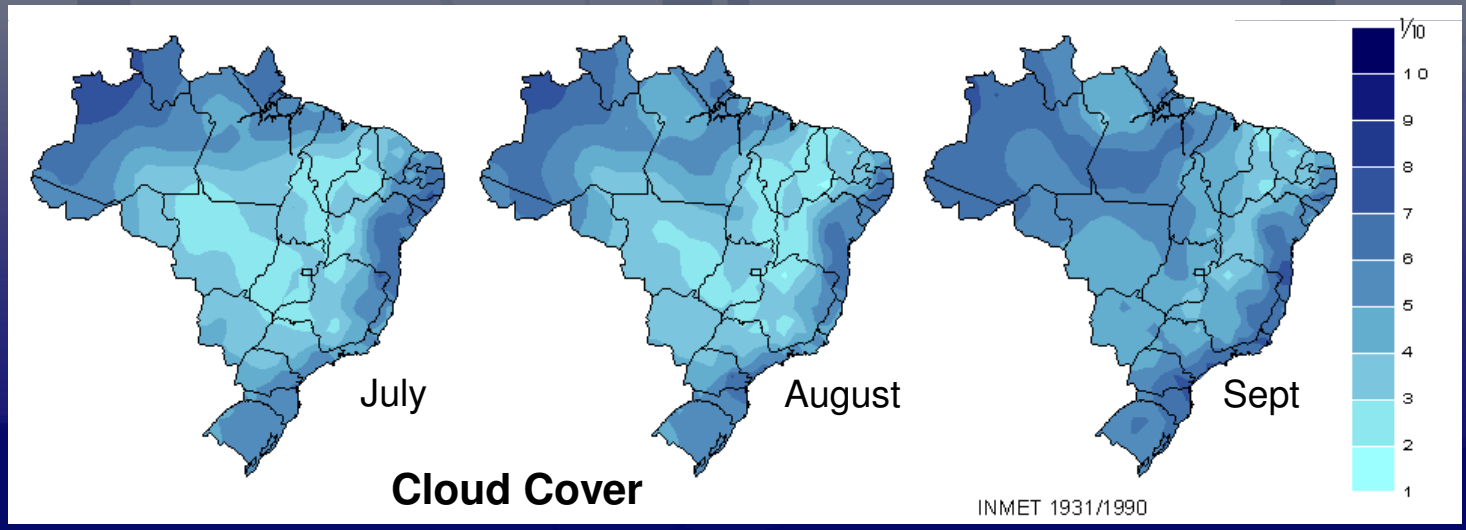




Global Radiation

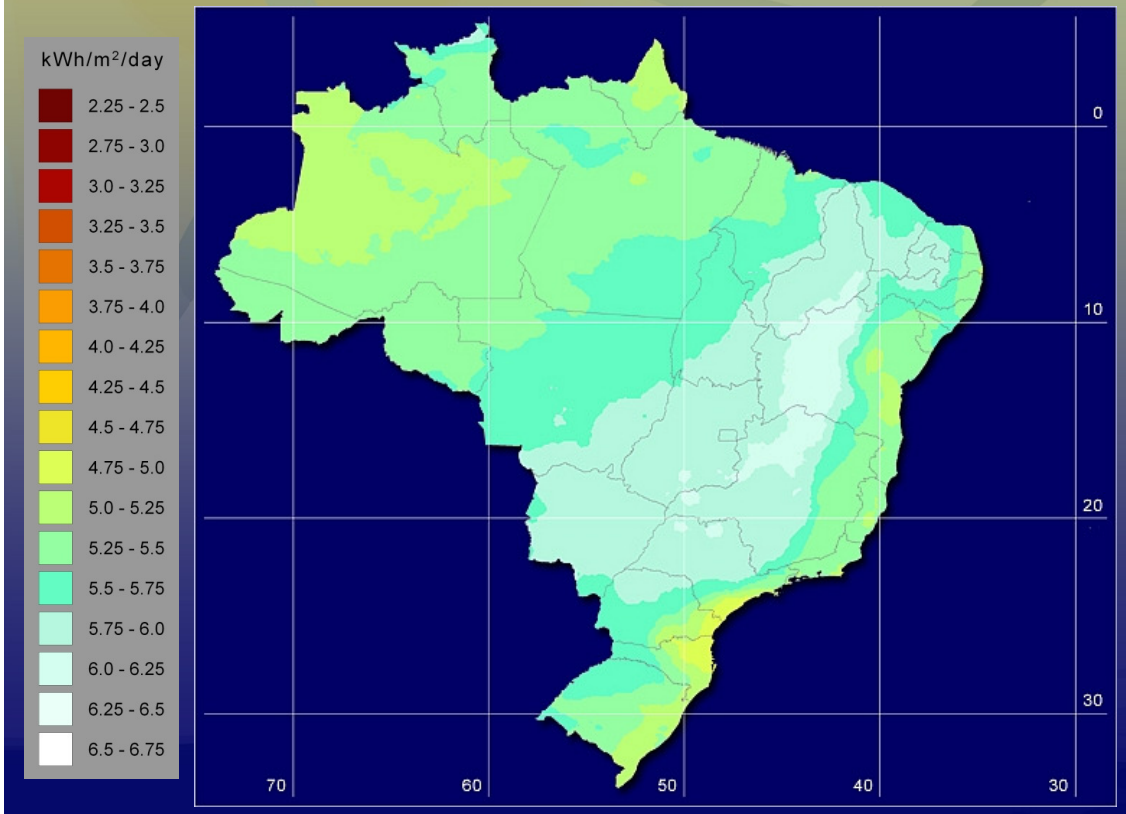
Winter

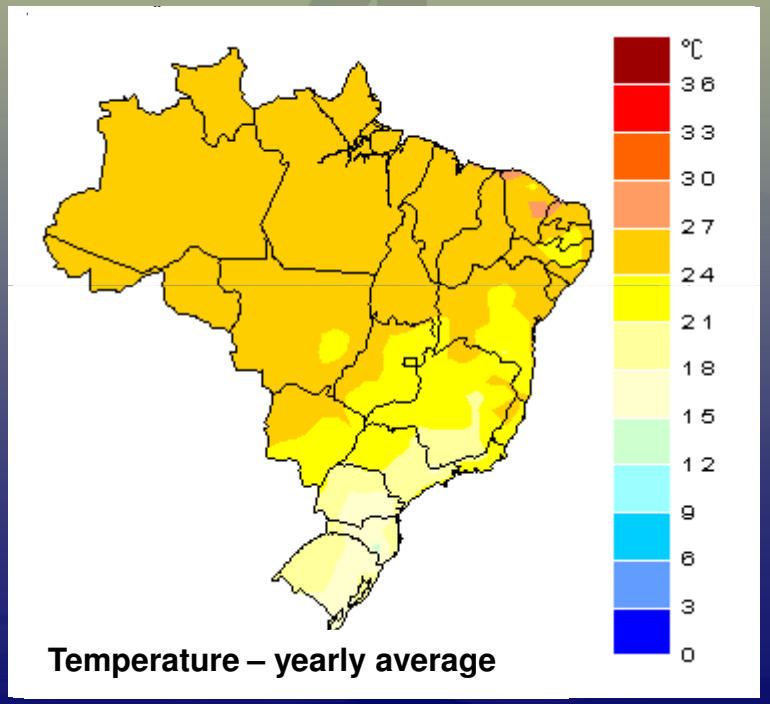




Tilted Radiation

Annual mean

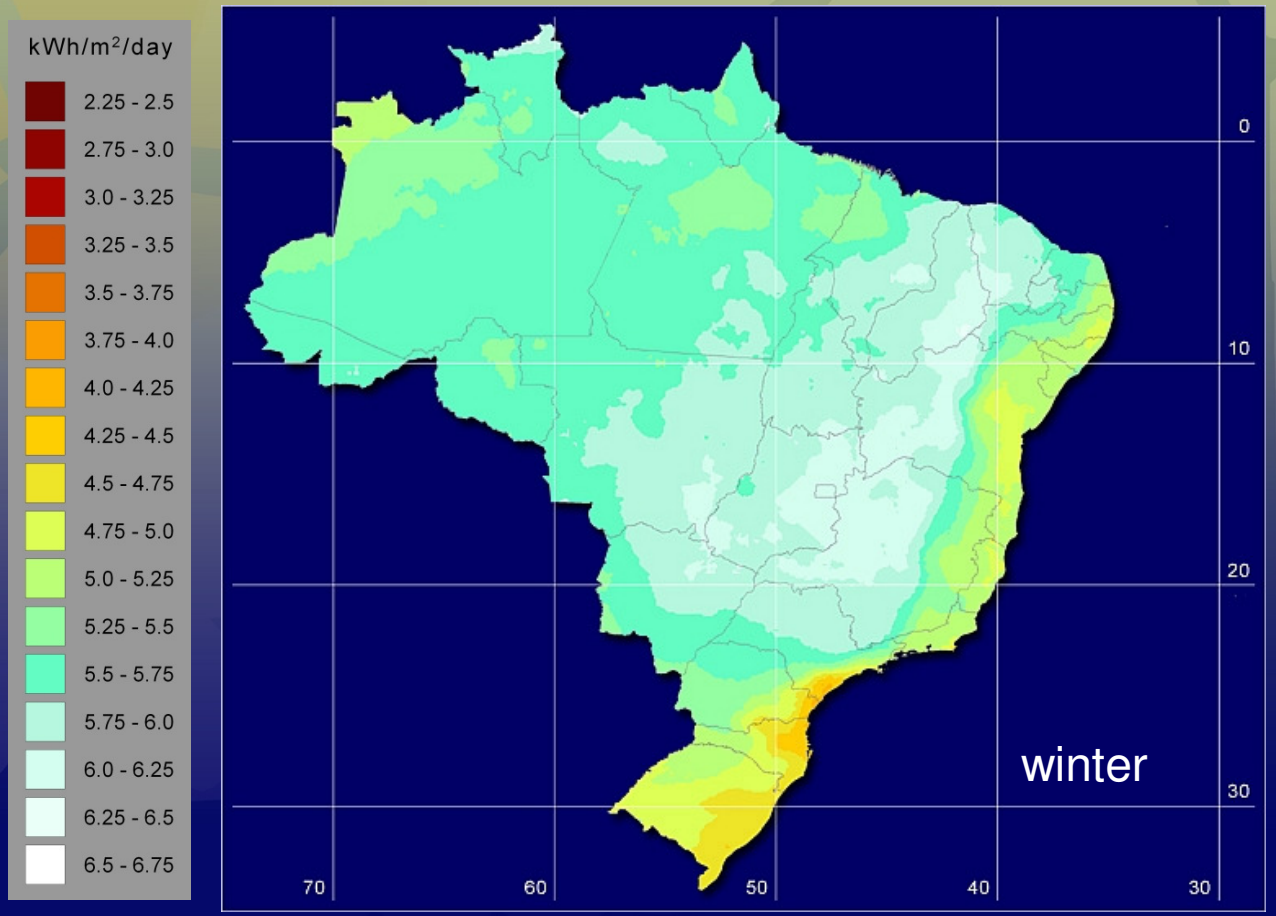




Temperature – yearly average

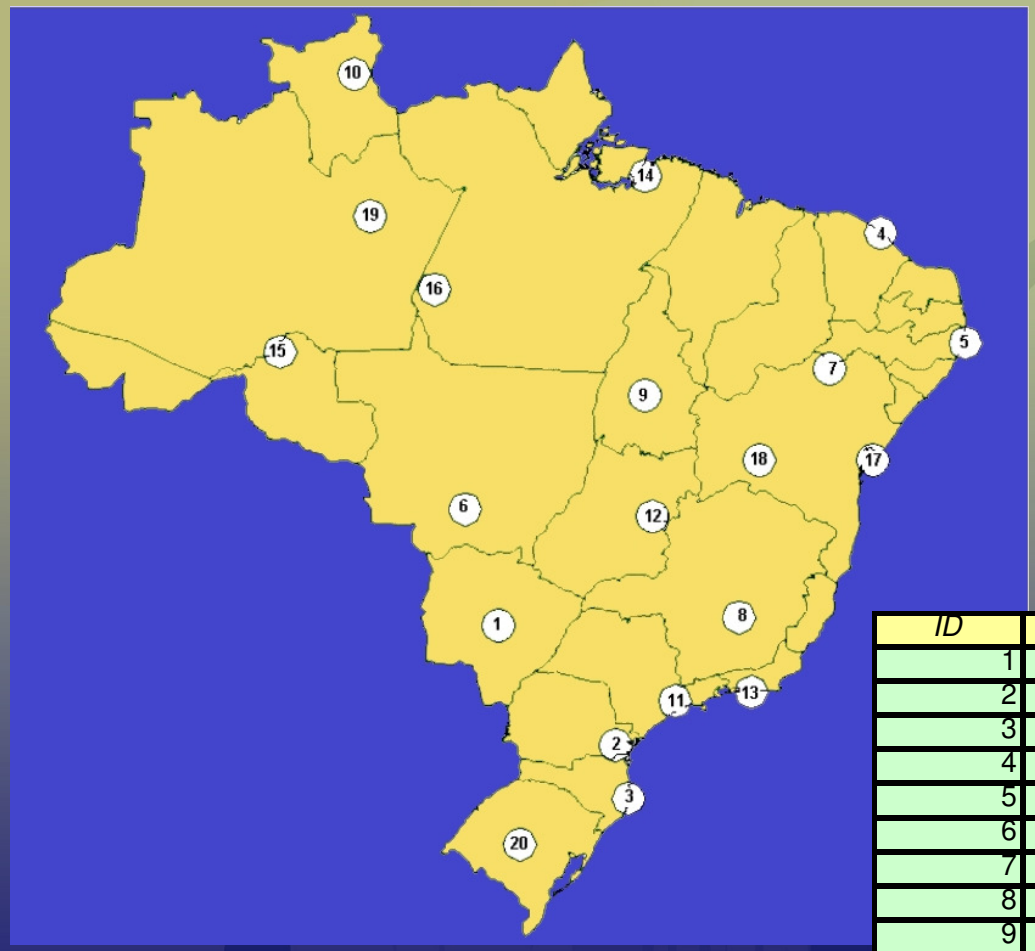
Tilted Radiation

Seasonal variability



Typical Meteorological Years

- 20 selected cities
- main cities and different climates
- derived from meteorological observations from measuring stations and airports
- Radiation data estimated from cloud cover
- Task being developed by NREL



Selected Sites for TMY

ID	latitude	alt	site	months
1	-20,467	556	"CAMPO GRANDE INTL BZ"	354
2	-25,517	908	"CURITIBA/AFONSO PEN BZ"	352
3	-27,667	5	"FLORIANOPOLIS ARPT BZ"	342
4	-3,783	25	"FORTALEZA/PINTO MAR BZ"	311
5	-8,067	19	"RECIFE/GUARARAPES BZ"	288
6	-15,650	182	"CUIABA/MARECHAL RON BZ"	281
7	-9,350	375	"PETROLINA AIRPORT BZ"	277
8	-19,850	785	"BELO HORIZ/PAMPULHA BZ"	277
9	-10,700	290	"PORTO NACIONAL ARPT BZ"	264
10	2,833	140	"BOA VISTA (CIV/MIL) BZ"	261
11	-23,617	803	"SAO PAULO/CONGONHAS BZ"	227
12	-15,867	1061	"BRASILIA (CIV/MIL) BZ"	224
13	-22,900	3	"SANTOS DUMONT/RIO BZ"	211
14	-1,383	16	"BELEM/VAL DE CAES BZ"	210
15	-8,767	88	"PORTO VELHO(CV/MIL) BZ"	205
16	-6,267	98	"JACAREACANGA BZ"	194
17	-13,017	51	"SALVADOR BZ"	193
18	-13,267	458	"BOM JESUS DA LAPA BZ"	162
19	-3,133	72	"MANAUS BZ"	148
20	-29,700	114	"SANTA MARIA BZ"	135

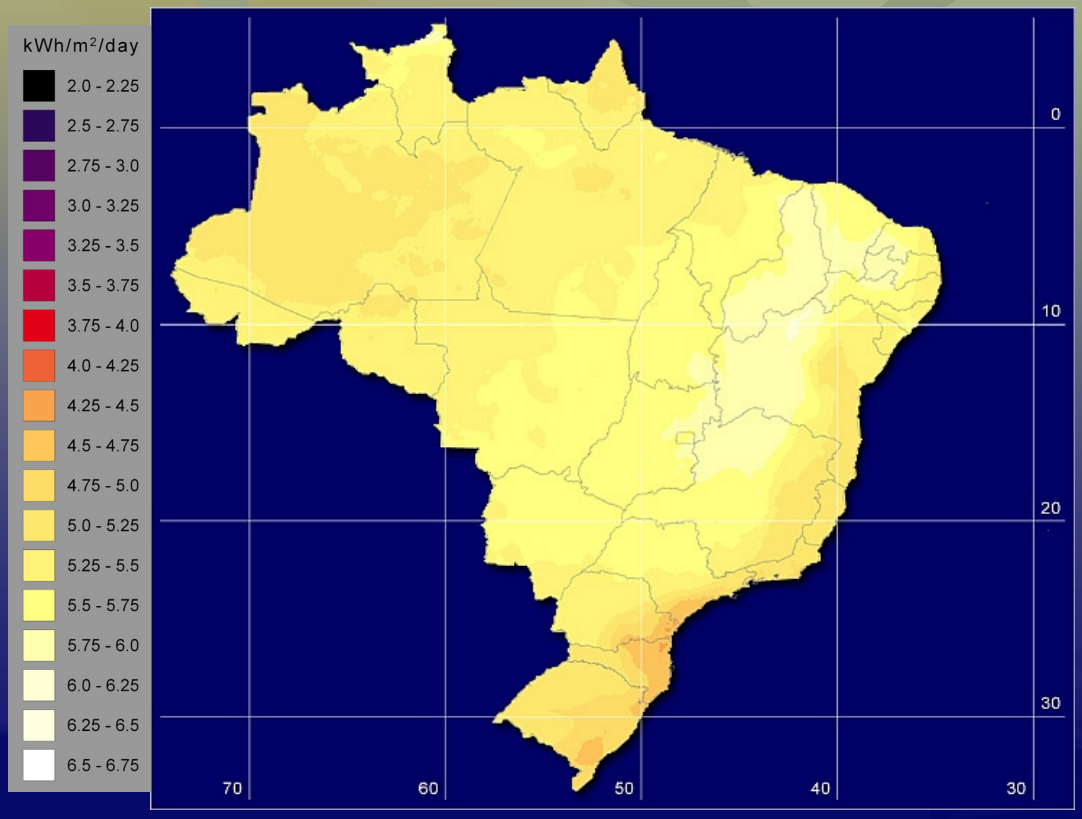
South America

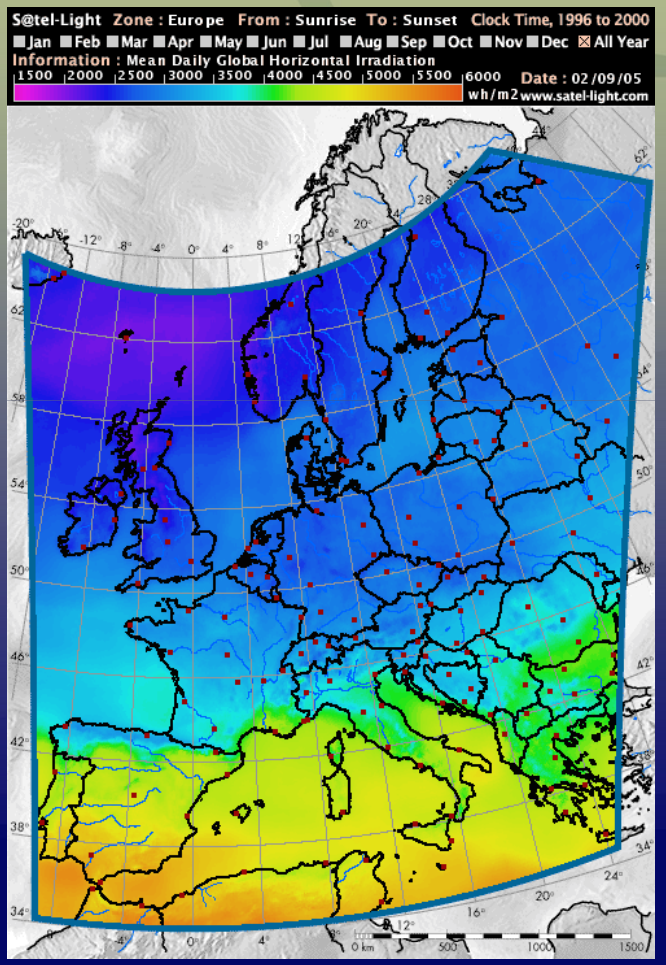
- spatial resolution ~ 40 x 40 km
- instantaneous values derived from three-hourly images
- interpolated daily sums
- monthly averages
- undefined uncertainties for Andes and southern part

South America

Final Remarks

Comparison between solar radiation in Brazil and Europe





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www.satel-light.com on 09.02.05

Final Remarks

- Further improvements
  - model was not validated yet for high mountains and high latitudes
  - satellite images database is not climatologically representative yet
  - a new methodology to determine the maximum and minimum effective satellite cloud cover is being developed
  - hourly satellite images from GOES 12 are now available for Southern Hemisphere

Final Remarks

- Marketing