2nd Workshop on Satellites for Solar Energy Assessments February 3-4, 1999

Presentations

Sponsored by the U.S. Department of Energy
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NREL

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Presentations

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Introduction

The 2nd Workshop on Satellites for Solar Energy Assessments was held on 3-4 February, 1999 at the Golden Hotel in Golden, Colorado. This workshop was part of the Solar Resource Assessment Task funded by the National Center for Photovoltaics at the National Renewable Energy Laboratory (NREL). NREL is supported by the U.S. Department of Energy.

This workshop brought together researchers in satellite data analysis and experts in solar energy technologies to review the current status of techniques and products of solar data derived from weather satellite imagery. Of the more than 40 participants, many were representatives from U.S. government, laboratory, and university organizations. Federal agencies and laboratories that were represented included the National Aeronautics and Space Administration, the National Oceanic and Atmospheric Administration, and NREL. Participants also included experts in the use of solar energy for building design and concentrating solar power technologies. In addition, researchers from seven other countries (Canada, France, Switzerland, Germany, Mexico, Brazil, and Japan) as well as Puerto Rico, attended the workshop. Many of these foreign visitors were invited to give presentations on the status of research in their country.

Presentations were given on new techniques for developing climatological estimates of the solar resource at all locations on earth at a resolution of 100 km, and of developing estimates at half-hour intervals at resolutions of 10 km or less in specific locations. This workshop report provides copies of each of the presentations given by the invited speakers.

At the conclusion of the workshop, a roundtable discussion was held. Out of this discussion, the users of the data expressed a strong interest in the types of products that the satellite research community can provide. The data users also offered additional ideas of their own in which the researchers can provide even more valuable information in the future. A number of specific research topics were identified, including the idea of incorporating other key meteorological information, such as temperature and relative humidity, into the solar radiation data sets. Although satellite data should still be supplemented by quality ground measurements made at strategic locations, it is clear from this workshop that satellite techniques have become so advanced that they now represent a reasonably accurate tool for developing large area solar resource assessments, particularly in locations where ground data are limited, and for developing high resolution site/time-specific data that can be used for assessing the performance of PV technologies.

The workshop organizers hope you find this workshop summary useful, and encourage you to contact us for additional information, and to send us your comments and questions. Complete contact information can be found in the Attendee List.

Dave Renné, Center for Renewable Energy Resources (NREL)
Richard Perez, Atmospheric Sciences Research Center, State of New York at Albany

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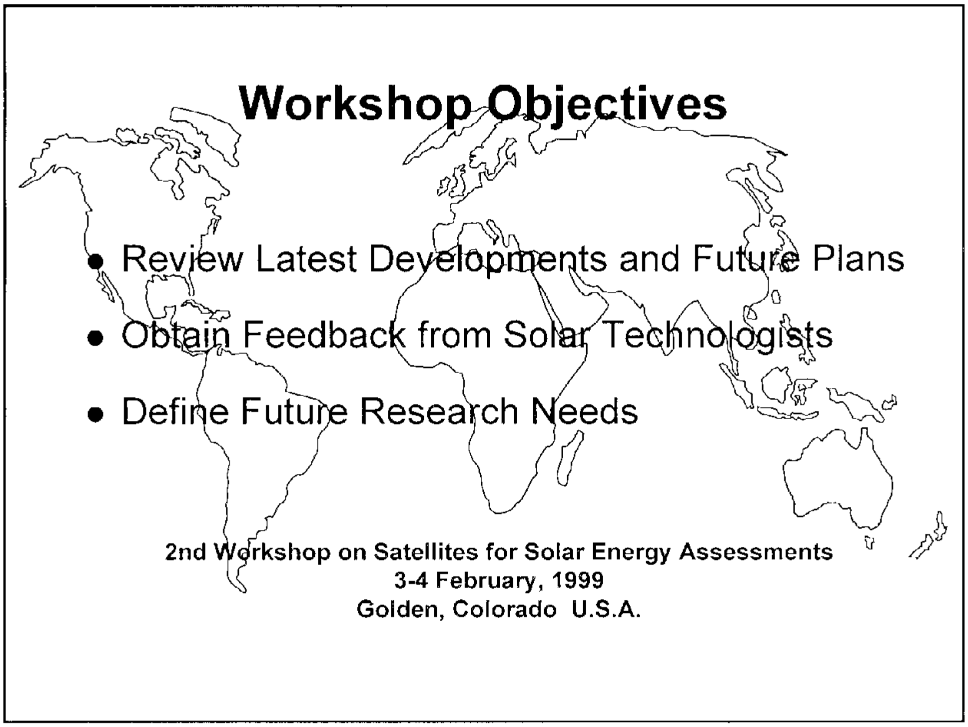

Presentation: Workshop Objectives by Dave Renne, NREL

Satellites and Sensors: Satellite Missions Impacting the Estimation of Solar Irradiance

Paul Stackhouse
NASA Langley Research Center
Hampton Virginia

In this talk, an overview of present and future satellite missions is presented with the perspective of improving the estimation of solar irradiance at the earth's surface. To properly introduce the discussion, the uncertainties in the estimation of solar irradiance at the surface are discussed briefly. These uncertainties range from the calibration of the instrumentation, to spatial/temporal problems, uncertainties in the radiative properties of clouds, aerosols, and surface. Then several planned and proposed satellite missions are discussed showing how some of these uncertainties should be addressed with the advances in satellite technology. Although, some geosynchronous platforms will be mentioned, emphasis will be given to polar orbiting missions since geosynchronous missions are discussed in the presentations following this one.

In the near future, the satellite missions of importance to the solar energy community are the called Tropical Rainfall Measurement Mission (TRMM) and the Earth Observing System (EOS) satellites those sponsored by NASA's Earth System Enterprise EOS-AM1 and EOS-PM1. These satellites contain multispectral imagers, multi-angle cameras, broadband multi-angle radiometers, and spectrometers to infer atmosphere, cloud, aerosol, and surface properties. The CERES (Clouds and Earth's Radiant System) instrument package, which is present on all three platforms, provides multi-angular views of broadband solar and thermal infrared radiance that are inverted to estimate top-of-atmosphere (TOA) radiative fluxes constraining the radiant flux of the atmospheric column. Temporal overlap between at least two and possibly all satellites will provide the best temporal and spatial sampling of these fluxes to date. Several solar irradiance products are planned from the CERES Surface and Atmospheric Radiation Budget (SARB) group at 1 Degree resolution for scientific research. Potentially, these data will represent a very accurate source of solar irradiance estimates for solar energy assessment projects.

Besides the EOS missions several other missions are outlined that will lead to advances of our understanding of clouds and aerosols. Some of these missions are to be flown in conjunction with the EOS-PM platform and others are on completely separate platforms many to be flown by various space agencies around the world. Most of these missions do not plan solar insolation products, but the scientific knowledge gained may have a profound effect on the improvement of current techniques. Finally, I summarize the planned launches and mission lifetimes and surmise when these data might be available to the solar energy community at large.

Satellites and Sensors

Satellite Missions Impacting
the Estimation of Solar Irradiance

Paul Stackhouse Jr., NASA Langley Research Center

Satellite Data Analysis Center / NASA Langley Research Center

Presentation Outline

- Uncertainties in the estimation of solar insolation from space
- Current satellite platforms used for solar insolation estimation
- Near term/future satellite platforms to improve past/future solar insolation estimates

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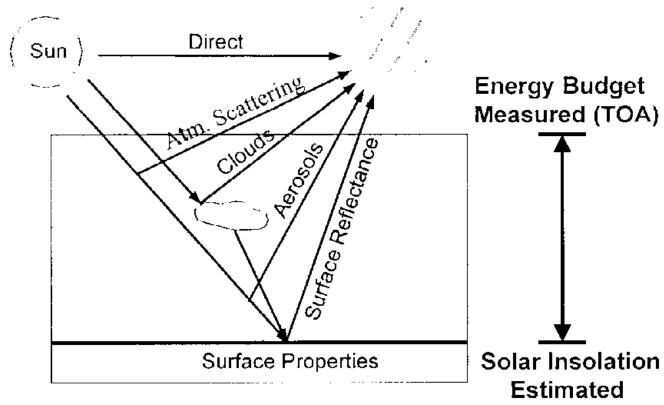
Presentation: Satellites and Sensors by Paul Stackhouse, NASA

Solar Energy Sources to Spacecraft



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Cloud Radiative Property Issues

- **Cloud Composition**
  - phase (ice or water, refractive indices)
  - particle distribution, shape, and density (single-scattering properties: extinction, absorption, phase function)
- **Cloud Appearance**
  - cloud fraction (view angle dependence)
  - height (effects phase and emittance properties)
  - thickness/shape (vertical development, total mass)
  - multi-layering (scattering between cloud layers)
  - heterogeneity (horizontal propagation of energy)

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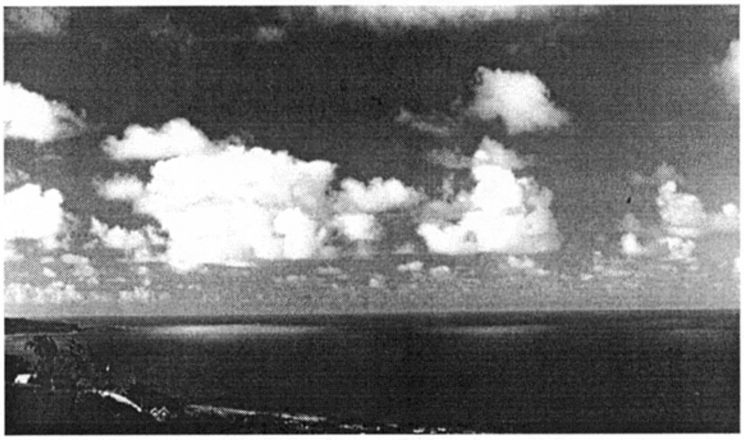
Cloud Inhomogeneity

Effects both surface and satellite observations



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Aerosol Radiative Property Issues

- **Aerosol Composition**
  - chemical composition (sulfur, carbon, quartz: refractive indices)
  - particle distribution, shape, and density (normal or bimodal: single-scattering properties)
- **Aerosol Structure**
  - height (volcanic, industrial, biomass burning, dust)
  - thickness (total mass, profile)
  - spatial/temporal distribution

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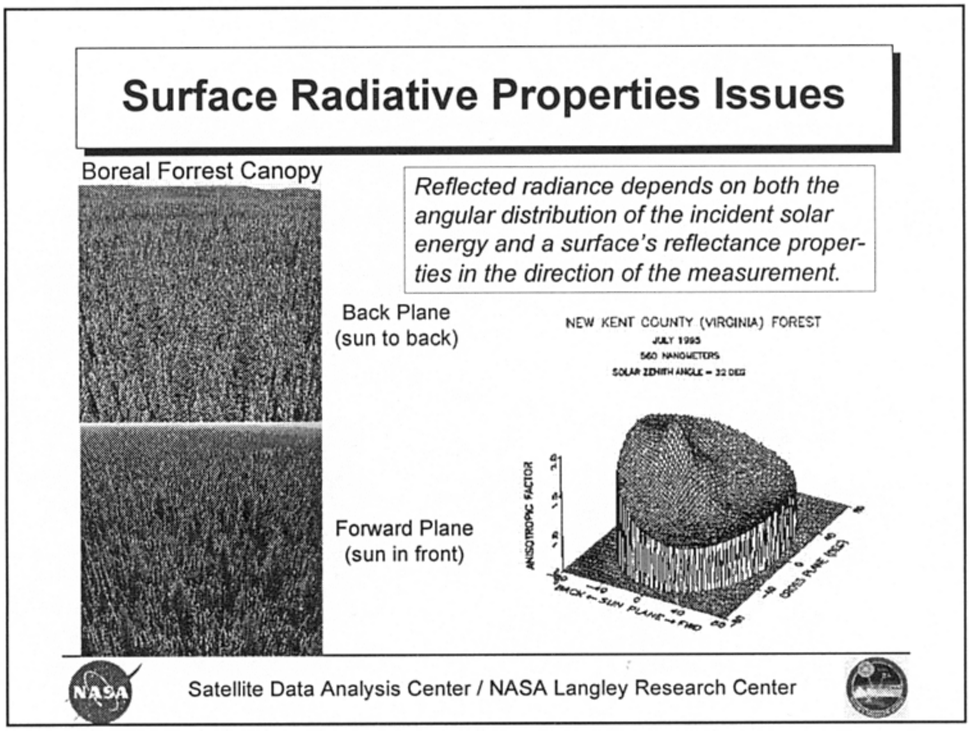

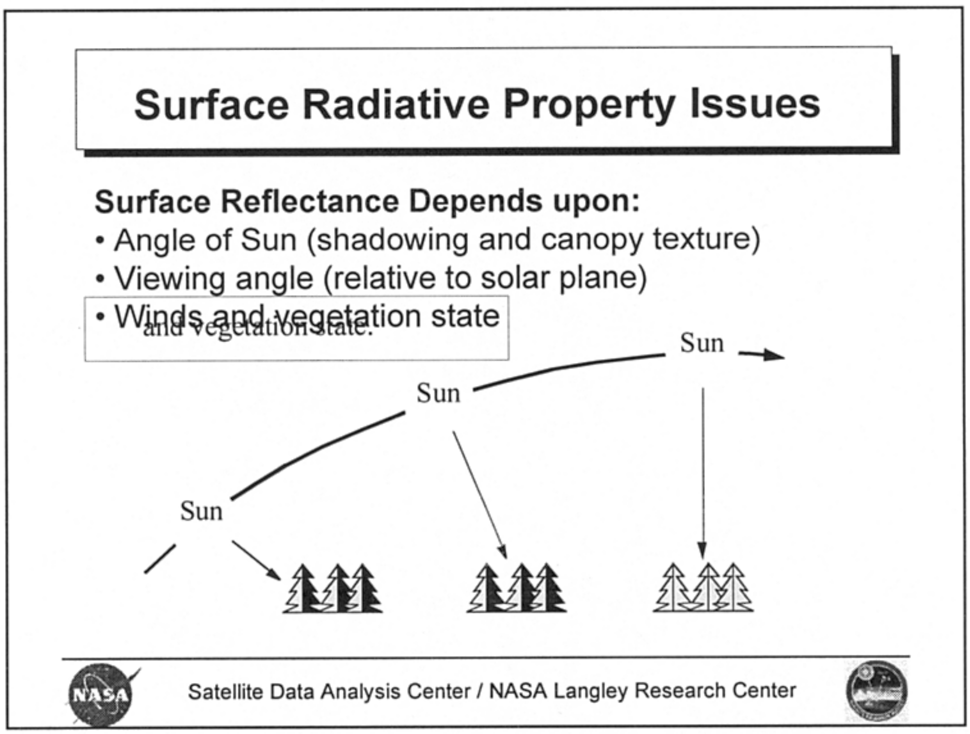

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Past/Current Satellite Missions

Sensor/Agency	Launch Date	Spectral Channels l. mm	Comments
AVHRR/NOAA	since 1979	4 bands [0.64] [0.83] [3.75] [11.5]	Nadir viewing scanner, operational
TM-Landsat/NASA	since 1982	6 bands [0.47-2.20]	Nadir viewing scanner
MSS-Landsat/NASA	since 1971	4 bands [0.55-0.90]	Nadir viewing scanner
VISSR-GOES/NOAA	since 1975	1 band [0.66]	Geostationary, operational
SAGE I, II/NASA	since 1979	7 bands [0.38-1.08]	Solar occultation
TOMS-Nimbus 7 /NASA	since 1978	2 bands [0.34-0.38]	Nadir viewing scanner
OCTS-ADEOS/ NASDA	1996-97	9 bands [0.41-o.86] and 3.9	Nadir viewing scanner

Source: NASA RA NRA-97-MTPE-16

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Past/Current Satellite Missions

Sensor/Agency	Launch Date	Spectral Channels l. mm	Comments
POLDER-ADEOS/ CNES-NASDA	1996-97	8 bands [0.44-0.91] 3 polarized bands multiview angles	Nadir viewing scanner
ERBE-ERBS & NOAA/ NASA	1984/1998	3 broad channels [0.3 - 50] [0.3 - 5] [8 - 12]	Low resolution nadir scanner
SeaWiFS-SeaStar/ NASA	1997	8 bands [0.41-0.86]	Nadir viewing scanner
LITE/NASA	1993	3 laser wavelengths [1.06] [0.53] [0.35]	Nadir viewing lidar on the Space Shuttle

Source: NASA RA NRA-97-MTPE-16

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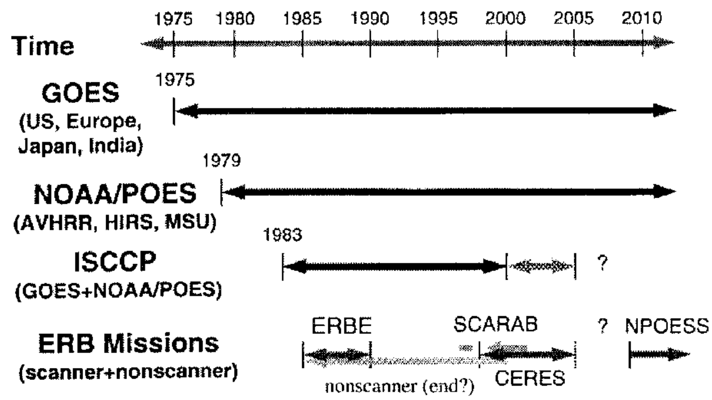
Time Line of Satellite Missions Useful For Solar Insolation Estimates



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Sample Future Missions: Clouds, Aerosols, Surface

Sensor/Agency	Launch Date	Spectral Channels # [micrometers]	Comments
CERES-TRMM, EOS AM1, & PM1/NASA	Nov 97/ Jul 99/ Dec 00	3 broad channels [0.3 – 50; 0.3 – 5; 8 – 12]	20 km resolution, azimuthal & cross-track scanning
MODIS-EOS AM1 & PM1/NASA	Jul 99/ Dec 00	12 bands [.41 – 2.10, 3.96]	Nadir viewing scanner
MISR-EOS AM1 & PM1/NASA	Jul 99/ Dec 00	4 bands [0.47 – 2.10]	9 view angles
MERIS-ENVISAT/ESA	May 00	15 bands [0.4 – 1.02]	Multiple angle viewing
AATSR-ENVISAT/ESA	May 00	7 bands [0.55 – 12.0]	1 km, Two angle view
GLI-ADEOS II/NASDA	1999	12 band [0.41- 2.10]	Nadir viewing scanner
POLDER-ADEOS II/ NASDA	1999	8 bands [.44 -.91], 3 polarized	Nadir viewing scanner and multiview
SAGE III-Meteor/NASA	Jul 99	9 bands [0.29 - 1.55]	Solar occultation

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TRMM and EOS Satellite Instrumentation

- **Tropical Rainfall Measurement Mission**
  - Clouds and the Earth Radiant Energy System (CERES)
  - Visible InfraRed Scanner (VIRS)
  - Precipitation/Lightening instrumentation
- **EOS-AM**
  - Moderate Resolution Imaging Spectroradiometer (MODIS)
  - Advanced Spaceborne Thermal Emission Radiometer (ASTER)
  - Multi-angle Imaging Spectroradiometer (MISR)
  - Measurement of Pollution in the Troposphere (MOPITT)
  - Clouds and the Earth Radiant Energy System (CERES)
- **EOS-PM**
  - Clouds and the Earth Radiant Energy System (CERES)
  - Moderate Resolution Imaging Spectroradiometer (MODIS)
  - Advanced Microwave Scanning Radiometer-EOS (AMSR-E)
  - Advanced Microwave Sounding Unit (ASMU)
  - Atmospheric Infrared Sounder (AIRS)

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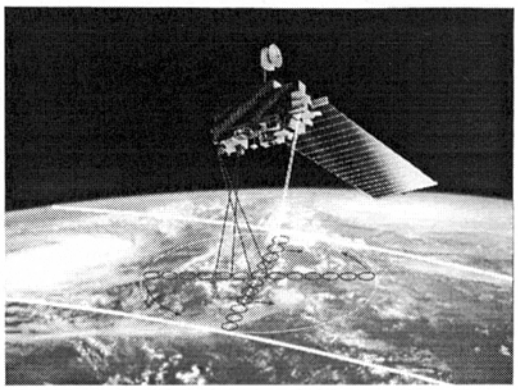
Clouds and the Earth Radiant Energy System (CERES)

- **Provided by NASA Langley Research Center and built by TRW.**
- **Long-term measurements of Earth's radiation budget through observations of short and longwave radiation.**
- **Broadband scanning thermistor bolometer package with 20 km resolution. Two identical scanners carried to operate in x-track and biaxial scan modes. Each scanner has three channels: shortwave infrared for reflected sunlight, longwave for Earth-emitted thermal IR, and total channel.**



(Source: Bordi *et al.*, 48th Congress of the International Astronautical Federation, Torina, Italy, 6-10 October 1997)

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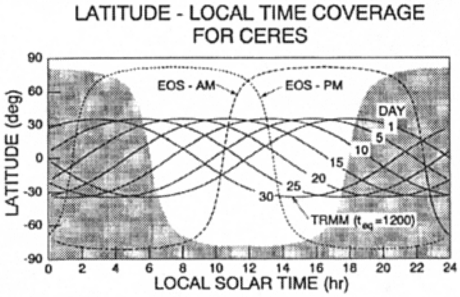
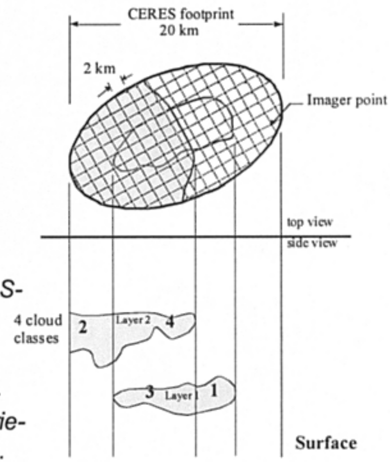
CERES Temporal and Spatial Sampling





The tri-satellite configuration with TRMM, EOS-AM and EOS-PM result in the sampling of all local times in a month between 35° N and S.

The CERES based surface fluxes at the footprint level are computed using convolved retrievals of cloud, aerosol, and surface properties.

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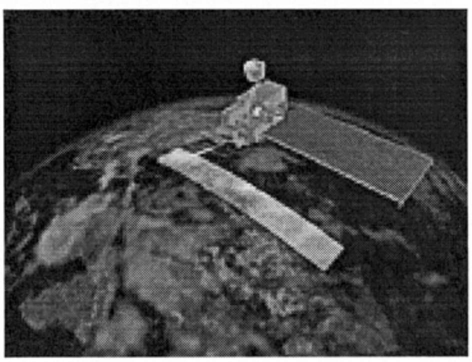
Moderate Resolution Imaging Spectroradiometer (MODIS)

- **Provided by NASA Goddard Space Flight Center and built by Hughes SBRS.**
- **Measurement of comprehensive global biological and geophysical processes including: surface temperature (land and sea), ocean color, global vegetation and deforestation, clouds and aerosols, and snow cover.**
- **Cross-track scanning imaging radiometer with 36 bands from visible to thermal IR and spatial resolutions of 250m, 500m, and 1km at nadir. 2330 km swath for global coverage in 2 days.**
- **Provides imager data required for CERES surface fluxes**



(Source: Bordi *et al.*, 48th Congress of the International Astronautical Federation, Torina, Italy, 6-10 October 1997)

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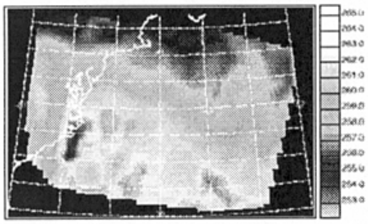
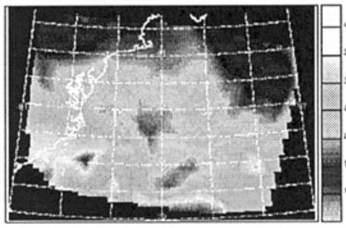
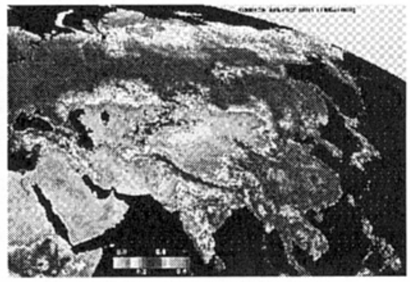
Sample MODIS Data Products





MODIS Atmospheric Profiles.



Growing Season Average NDVI of Asia Derived from the Advanced Very High Resolution (AVHRR) Pathfinder Data Set. Monthly NDVI was calculated as the average of three 10-day composites. The monthly values were further averaged over the 9-year period of record before Mount Pinotubo eruption (1982-1990) to obtain long-term average monthly NDVI values.

(Source: Bordi *et al.*, 48th Congress of the International Astronautical Federation, Torina, Italy, 6-10 October 1997)

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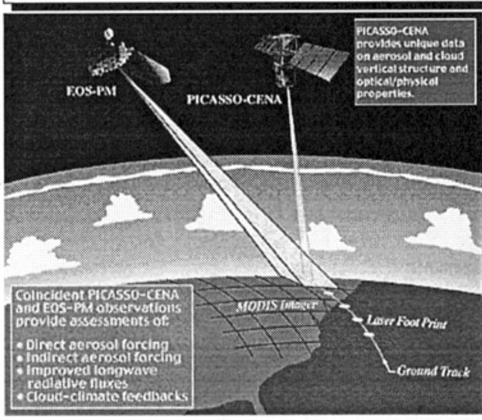
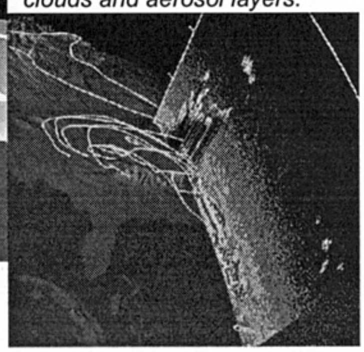
NASA Special Missions: PICASSO-CENA



Lidar measurements in conjunction with the MODIS imager improves cloud and aerosol radiative properties for solar flux estimates.

Vertical Lidar backscatter profiles from the space shuttle LITE experiment. Yellow lines trace trajectories of air into clouds and aerosol layers.



Satellite Data Analysis Center / NASA Langley Research Center

Presentation: Satellites and Sensors by Paul Stackhouse, NASA

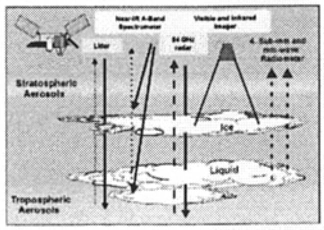
NASA Special Missions: CloudSat

MEASUREMENT OBJECTIVES:

- PROFILE THE VERTICAL STRUCTURE OF CLOUDS
- MEET MAJOR SHORTFALLS IN CLOUD AND AEROSOL OBSERVATIONS, USING ACTIVE AND PASSIVE INSTRUMENTS
- ASSESS THE PERFORMANCE OF PASSIVE INSTRUMENT SUITES ON OTHER SATELLITE PLATFORMS; VALIDATE AND IMPROVE THEIR MULTILAYER CLOUD AND AEROSOL RETRIEVALS

MISSION PERFORMANCE CAPABILITIES:

- Cloud height /base
  - Radar: 250m - 500 m resolution
  - Lidar: < 100 m resolution
- Cloud properties
  - Two-dimensional profile of optical depth, ice content, liquid content, particle size
- Visibility
  - Along-track slant range visibility
- Precipitation occurrence and amount
- Sub-visual cirrus
  - Optical depth and altitude.
- Aerosols
  - Optical depth and layer thickness



Spacecraft #1 — Spacecraft #2 Icesat or PICASSO

Formation fly

Sensor Specifications:

1. **RADAR:** 94 GHz, sensitivity -30 to -36 dBZ
2. **LIDAR:** 532/1064 nm, sensitivity ~1E-6/m/s
3. **THERMAL IR CAMERA:** 2 channel radiometer
4. **VIS IMAGER/SPECTROMETER:** with high spectral resolution (A-band) spectrometer for detection of thinnest cirrus/aerosols

3 & 4 common to both spacecraft:

Source: Dr. Graeme Stephens, Colorado State Univ.

Satellite Data Analysis Center / NASA Langley Research Center

Atmosphere

- **Surface/Atmospheric State**
  - **Surface State: Land and Ocean**
    - MODIS, MISR, ASTER, POLDER, AM SR, MERIS, GLI, AATSR
    - TOPEX, NSCAT, Precip and Surface Radars
  - **Atmospheric State: Temperature/Humidity:**
    - AIRS/AMSU/MHB + 4-D Assimilation: 2000-2005/9, MIPAS
    - NPOESS + 4-D Assimilation: 2005/9 and beyond
    - Geostationary + 4-D: *Future TBD*
    - DIAL lidar for moisture vertical profiles + 4-D: *Future TBD*
  - **Atmospheric State: Winds:**
    - T(z) + 4-D
    - Geostationary moisture field winds + 4-D: *Future TBD*
    - Lidar winds+ 4-D: *Future TBD*

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Cloud and Aerosol Properties

- **Aerosol Properties:**
  - MODIS, MISR, POLDER, MERIS, GLI, AATSR
  - PICASSO lidar/A-band
- **Cloud Properties:**
  - MODIS, MERIS, GLI, AMSR
  - PICASSO lidar/A-band: (most cloud layers)
  - CloudSat cloud radar (all but thinnest cloud layers): *Future TBD*
  - Submm/Far-Infrared for Ice Water Path/Ice Particle Size: *Future TBD*

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Global Radiative Energy Fluxes

- **TOA Radiative Fluxes:**
  - CERES + MODIS
  - *CERES beyond 2005: Future TBD*
- **Surface/Atmosphere Radiative Fluxes:**
  - CERES + MODIS TOA Fluxes (constraint)
  - PICASSO + CLOUDSAT cloud/aerosol vertical properties
  - MODIS, MERIS, GLI cloud/aerosol area properties
  - MODIS/MISR/AMSR Surface Properties
  - AIRS/AMSU/MHB + 4-D Assimilation => T(z),q(z)

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Current and Future Data Streams from Meteosat Geostationary Satellites for Solar Energy Applications

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Data from the geostationary satellite Meteosat have been widely used for the derivation of solar surface irradiance for different kinds of applications.

However, a limitation has been the restriction to only two useful spectral broadband radiometer channels (0.44-0.96 mm, 10.7-12.5 mm). This does not allow for the extraction of specific information of cloud properties affecting the downward radiant flux. Due to this limitation statistical algorithms currently perform with equal quality as compared to more sophisticated radiative transfer based techniques.

This situation will change significantly with the new Meteosat 2nd Generation (MSG) satellites the first of which will start its operation in late 2000. Main features of this new satellite are completely revised radiometer instruments with 12 narrow-band channels which allow for a much more detailed identification of atmospheric parameters. This holds especially for the cloud radiative characteristics. In addition, temporal and spatial resolutions are both enhanced by a factor two.

The presentation will give a brief overview of the present Meteosat generation and will focus on a description of the new MSG satellite regarding its technical improve-ments and is enhanced set of products.

The potential benefits of this satellite for improvinf the satellite-based algorithms will be discussed. Finally, the envisaged access to these data streams for the solar energy community is mentioned.

Current and Future Data Streams from Meteosat Geostationary Satellites for Solar Energy Applications

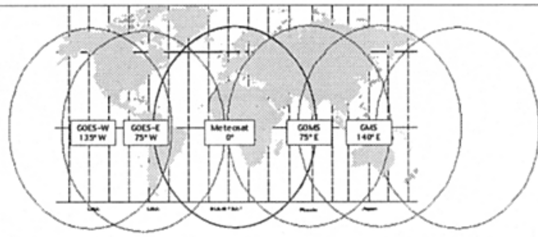
Detlev Heinemann
Carl von Ossietzky University Oldenburg
Faculty of Physics
Hans Georg Beyer
University of Applied Science (FH) Magdeburg
Department of Electrical Engineering

Contents

- Current Situation: Meteosat Operational Programme (MOP)
- Next Generation: Meteosat Second Generation (MSG)
- Data Access
- Potential Benefits for Surface Solar Energy Assessment
- Summary

Presentation: Current and Future Data Streams by D. Heinemann and H.G. Beyer

CGMS Nominal Geostationary Image Data Coverage



CGMS XXIII, May 1995

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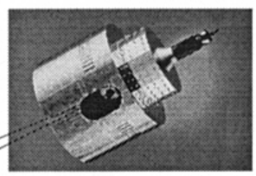
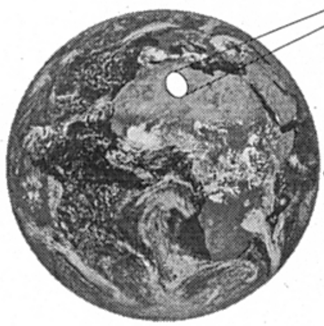
Meteosat





- first European geostationary satellite system
  (seven satellites since 1977)
- characteristics:
  - spectral channels:

VIS	0.5 – 0.9 μm
WV	5.7 – 7.1 μm
IR	10.5 – 12.5 μm

  - spatial resolution: 2.5 km (VIS)
  - 30 min repeat cycle

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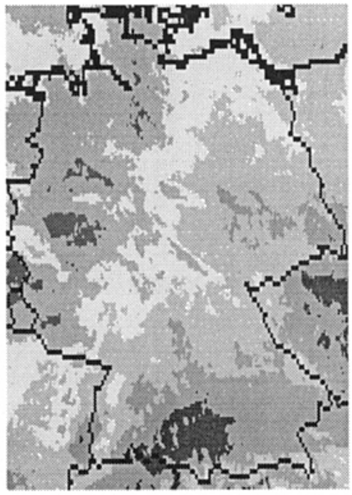
Example: Monthly Means of Global Irradiance

Germany, April 1998

< 83	
83 - 92	
93 - 102	
103-112	
113-122	
122-130	

kWh/m²



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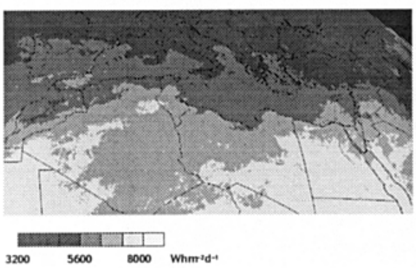
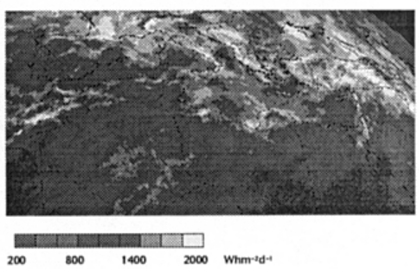
Example: Radiation Map for Mediterranean Area





Monthly Mean Daily Sums
(April 1995)

Additional information: standard deviation for daily sums

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Meteosat Second Generation Programme

Major Improvements

- SEVIRI imager with 12 spectral channels
- 15 minute cycling of imaging
- 1 km horizontal image resolution for the HRV channel
- Geostationary Earth Radiation Budget (GERB) instrument
- all-digital data transmission
- nominal lifetime of 7 years
- enhanced set of products

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Meteosat Resolution

	1st Generation (MOP)	2nd Generation (MSG)
Radiometric	8 bit	10 bit
Spatial	2.5 km	1 km
Temporal	30 min	15 min
Spectral	3 channels	12 channels

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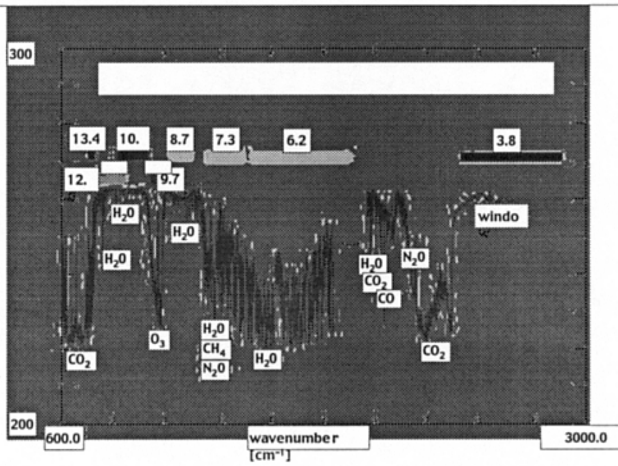
99 % Energy Bandwidths of SEVIRI Channels in the Infrared



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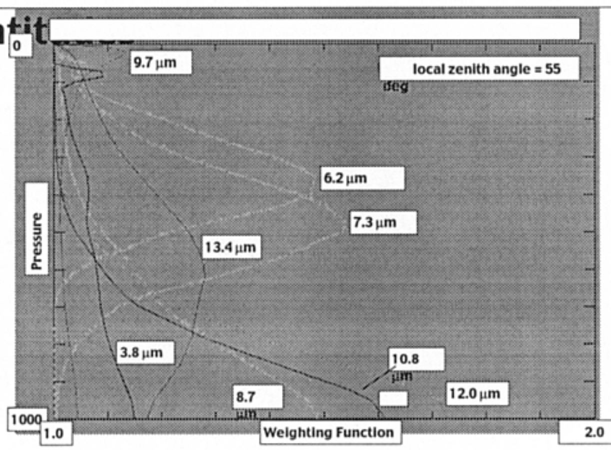
Mean Weighting Functions of SEVIRI Channels at Mid Latit



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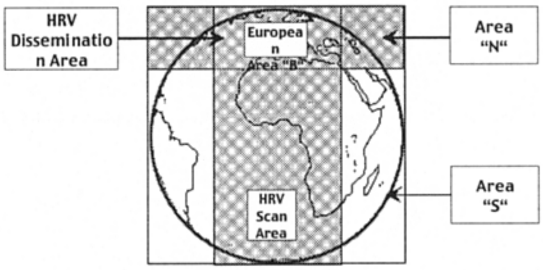
MSG Scan Modes



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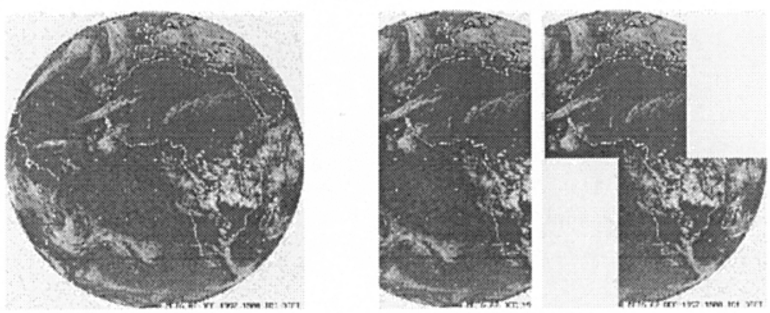
MSG Data Coverage



All Channels except HRV

Nominal and Alternative HRV Coverage

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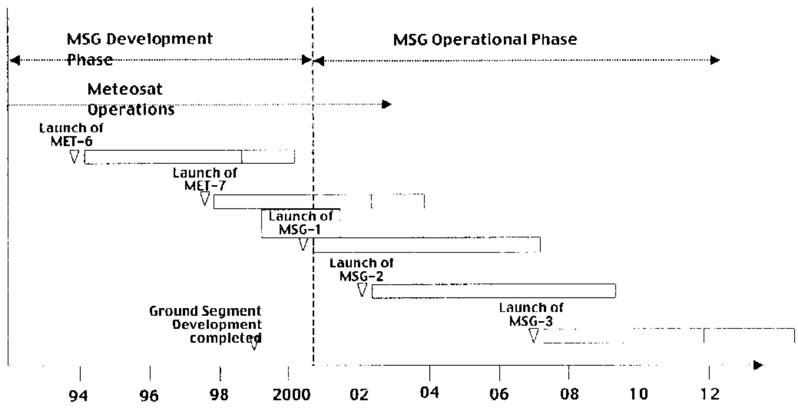
Timescales for the MSG Programme



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Processing of MSG observations

Level 1.0 data — raw image data

Level 1.5 data — radiometric/geometric correction, linearization of detector output, calibration, image navigation, remapping of image into reference image raster, dissemination in near-real time

Level 2.0/3.0 data — Meteorological/geophysical fields extracted from level 1.5

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MSG Archive and Retrieval Facility

Data Access by users from archive

- various formats (level 1.0, level 1.5, ..)
- various media (electronic transfer, CD-ROM, photographic images)
- regular or on-off basis

- Usually free of charge for research projects and educational use
- Access to real time HRI data is granted by national meteorological services
- Data policy for HRI data is still under discussion within EUMETSAT

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Problems

- Uncertainties in atmospheric and surface parameters
- Clouds: characterization, inhomogeneity
- Sensor calibration
- Different space and time scales of satellite and surface data

→

Retrieval of direct/diffuse components

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Calibration of VIS/NIR channels

- pre-launch characterization
- calibration campaign after first MSG launch (aircraft)
  goal: 5 % absolute accuracy
- radiative transfer modelling of outgoing radiances
- monitoring of long-term degradation of optical elements
- satellite intercalibration
- vicarious calibration: selection of target areas
- expected overall accuracy 5-10 %

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Cloud Processing

- objectives: identification of cloud type and phase; retrieval of cloud parameters
- main products of MSG: cloud flag /scene analysis), cloud type (cloud analysis), cloud top temperature and height
- first analysis (10.8 μm, 0.6/0.8 μm): albedo, brightness temperature
- fine analysis of spectral behaviour: low/high clouds (3.7 μm), cirrus identification (10.8 μm vs 12.0 μm), snow/ice covered land surface (0.6 μm), sunglint (3.7 μm)
- problem to solve: selection of adequate combination of spectral channels to seperate cloud type characteristics; influenced by atmospheric condi-tions and sun-satellite geometry

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Use of Radiative Transfer Models

- on-line generation of meteorological products
- off-line applications (e.g. climate studies)
- sensor calibration
- evaluation of specific parameterizations

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Benefits for Surface Solar Energy Assessment

- improved cloud detection/classification
- scale effects – fractional clouds
  – time/space mismatch between surface
  and satellite data
- calibrated VIS signals
- real-time products (using ancillary information, NWP output)

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Summary

- Promising new capabilities of next satellite generation
- Additional information, higher accuracy
- Combination satellite data / RTMs
- Inference of small-scale irradiance structure by joint use of satellite and ground data

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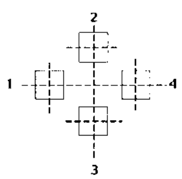
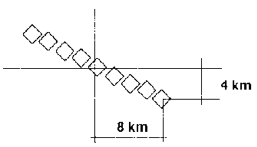
Meteosat Pixel Size

1st Generation (MOP)	2nd Generation (MSG)

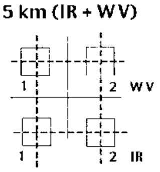
2.25 km (Visible)



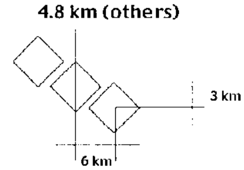
1.4 km (HRV)



5 km (IR + WV)



4.8 km (others)



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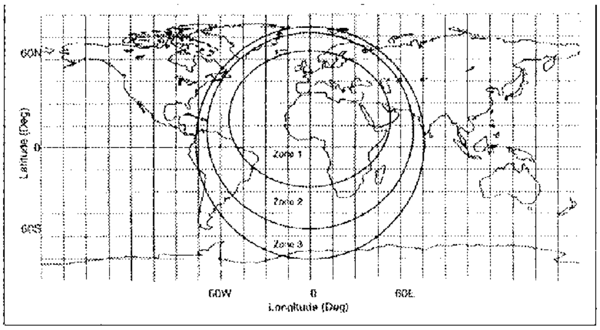

Zone 1 Central Zone: includes a large part of central and southern Europe
Zone 2 Nominal Zone: includes all the Eumetsat member states, most of Africa and
locations at which the elevation to the satellite is greater than or equal to 10
degrees
Zone 3 Global Zone: includes all locations in the field of view of the satellite, normally
where the elevation to the satellite is greater than or equal to 5 degrees. This

Access to Geostationary Satellite Data Streams (GMS)

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There are five geostationary meteorological satellites surrounding the globe. This report introduces the GMS-5 operated by Japan Meteorological Agency (JMA). JMA's fifth satellite GMS-5 was launched in March 1994 and nicknamed 'HIMAWARI' or sunflower in Japanese. It is stationary at an altitude of 35800 kilometers above the equator, 140 degrees of east longitude.

The Visible and Infrared Spin Scan Radiometer (VISSR) carried by GMS-5 is composed of three infrared sensors (10.5-11.5mm 11.5-12.5mm, 6.5-7.0mm) and an array of four visual (and near IR) sensors (0.55-0.9mm). While GMS-5 itself spins at 100 revolutions per minute, sensors scan the globe from the North Pole to the South Pole in 25 minutes every hour. This makes the visual sensor array capture an image of 13376 pixels by 10000 lines with 6 bit depth. Each of the infrared sensors captures an image of 6688 pixels by 2500 lines with 8 bit depth. The resolutions on the surface right under the GMS-5 are 1.25km/pixel for the visual sensor array and 5km/pixel for each of the infrared sensors.

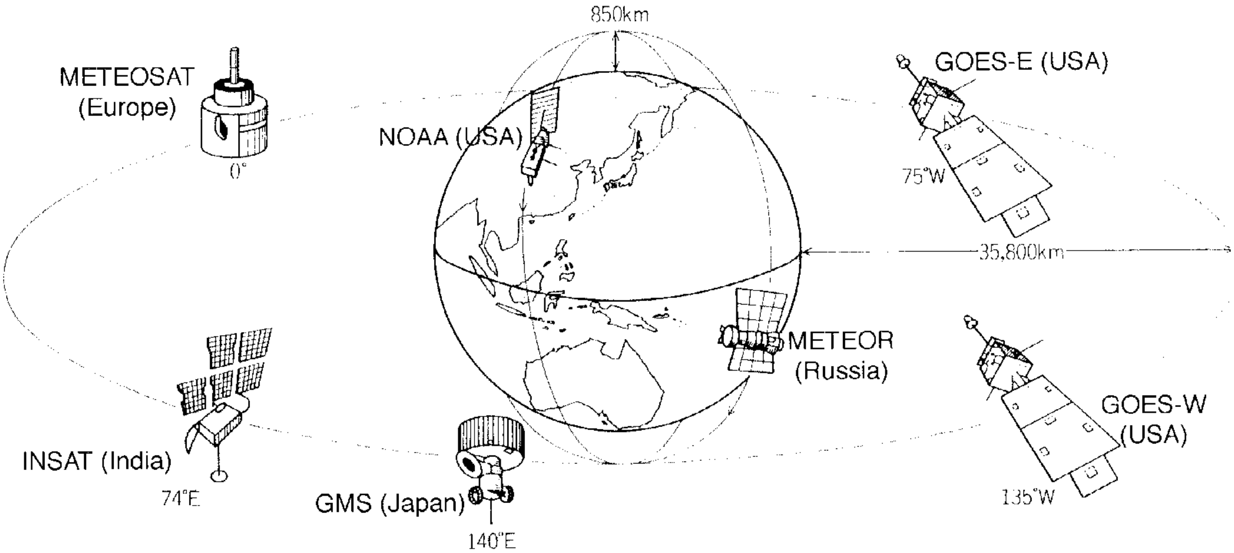
Captured VISSR signals are transferred to Commanding and Data Acquisition Center (CDAS) located in a suburb of Tokyo. Received VISSR signals are quality controlled and transferred to Data Processing Center (DPC) in Tokyo, then stored in magnetic disks and tape cartridges with observation parameters (time, orbit, calibration, etc.). VISSR data are available as CDROM, magnetic tape, microfilm, or printed paper from Japan Meteorological Business Support Center (JMBSC).

At the CDAS, VISSR data are also re-sampled into Stretched VISSR (S-VISSR) signals. The image size of S-VISSR data is 9166 pixels by 10000 lines for the visual images and 2293 pixels by 2500 lines for infrared images. At the same time, calibration tables of VISSR signals (0-5 volts) and digital image values (0-63 or 0-255) are generated. S-VISSR data are transmitted to GMS-5 and reflected to the ground for the Medium Scale Data Utilization Stations (MDUS). MDUS, i.g. broadcasting stations and weather forecast compa-nies, receive S-VISSR data using parabolic antenna and other facilities. Some research institutes provide images reduced from S-VISSR via anonymous FTP. Japan Meteorological Business Support Center (JMBSC) also provides monthly reduced data as CDROM.

CDAS also produces WEFAX images. VISSR data are re-sampled to 1710 pixels lines by 800 lines with 6bit depth. The latitude, longitude and coast are also drawn over the image. WEFAX images are transmitted to GMS-5 and reflected to the ground for the Small Scale Data Utilization Stations (SDUS). WEFAX images are able to be received with relatively affordable facilities ($10,000-$40,000), however overlayed coastlines cause trouble in data analysis.

As an application of GMS-5 images, the results of correlation analysis between VISSR data and surface observed global and direct irradiance are introduced.

Geostational meterological satellites and polar orbiting satellites by the World Weather Watch program



2[ND] Workshop on Satellite for Solar Energy Assessments, February 3-4, 1999, Golden, Colorado, USA

Geostational meterological satellites operated by Japan Meteorological Agency (JMA)

Satellite	Launching date	Longtitude	Sensors	Stabilizer
GMS-1	Jul 14, 1977	140°E	VIS, IR	Spin
GMS-2	Aug 11, 1981	140°E	VIS, IR	Spin
GMS-3	Aug 3, 1984	140°E	VIS, IR	Spin
GMS-4	Aug 6, 1989	140°E	VIS, IR	Spin
GMS-5	Mar 18, 1995	140°E	VIS, IR1, IR2, IR3	Spin
MTSAT	August, 1999	140°E	VIS, IR1,IR2, IR3, IR4	Three-Axis

Note: MTSAT (Multi-functional Transport SATellite) is planned to be operational in March 2000.

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Visible and Infrared Spin Scan Radiometer (VISSR) of GMS

Satellite	Sensor	Channel	Wavelength [mm]	Image Resolution [pixels x lines]	Surface Resolution [km/pixel]	Quantization [bit]
GMS-5	VS	Visible & Near IR	0.55 - 0.95	13376 x 10000	1.25	6
	IR1	Split window	10.5 - 11.5	6688 x 2500	5.0	8
	IR2	Split window	11.5 - 12.5	6688 x 2500	5.0	8
	IR3	Water vapour	6.5 - 7.0	6688 x 2500	5.0	8
MTSAT	VS	Visible	0.55 - 0.80		1.0	6
	IR1	Split window	10.3 - 11.3		4.0	10
	IR2	Split window	11.5 - 12.5		4.0	10
	IR3	Water vapour	6.5 - 7.0		4.0	10
	IR4	Near IR	3.5 - 4.0		4.0	10

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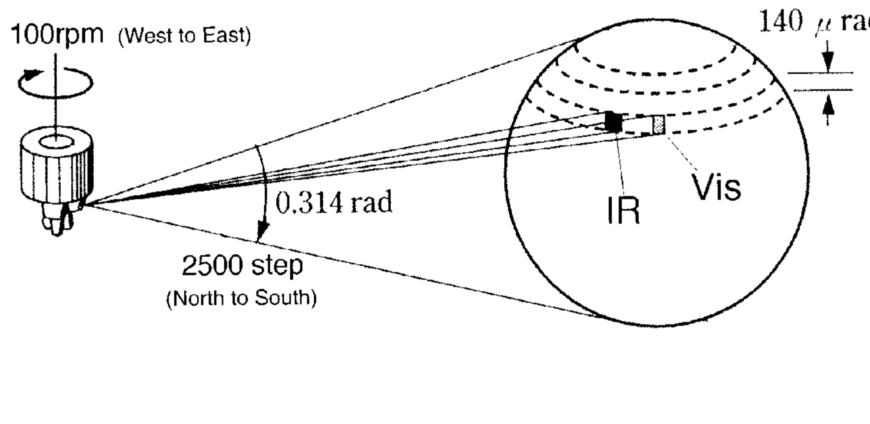
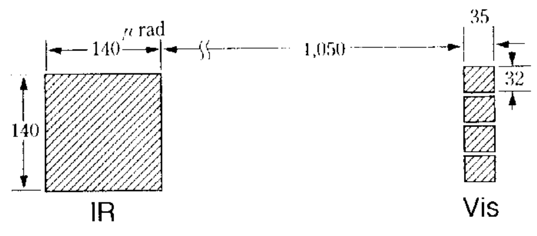
Scanning of the Globe



Arrangement of visible sensor array and infrared sensor



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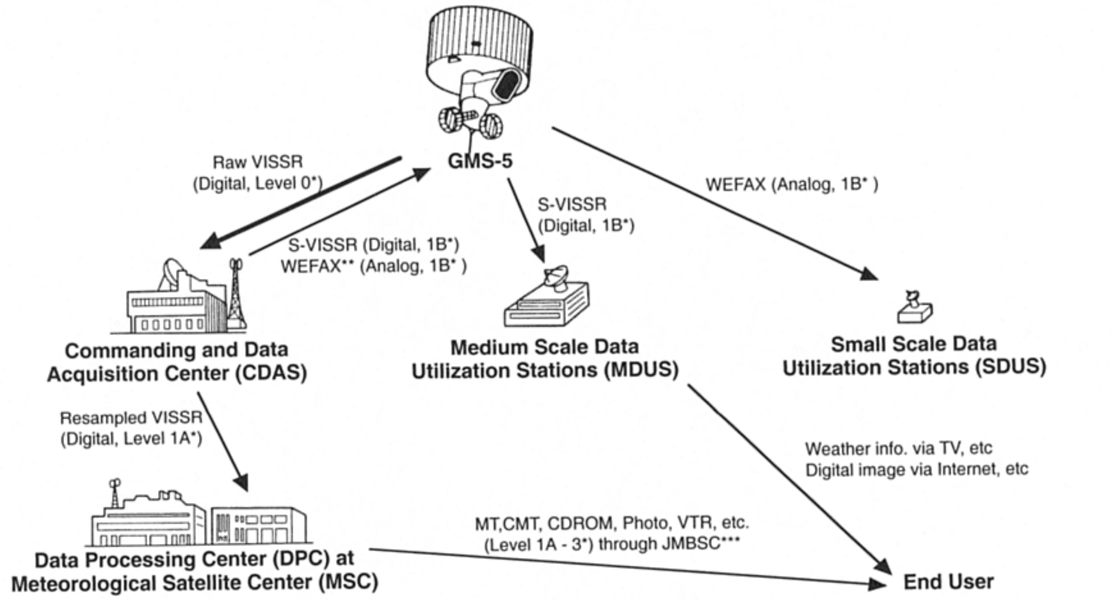
Data transfer between GMS-5, JMA centers and other stations



*** Data levels of VISSR / S-VISSR**

Level 0	Raw data from sensors
Level 1A	Level 0 with parameters (time, orbit, calib, etc)
Level 1B	Converted to temparatures or albedo.
Level 2	Interpreted to meteo. elements (cloud cover, wind, etc).
Level 3	Statistically analized in spans of time and space.

** Lines of coasts, longtitude and latitude are overlayed to WEFAX images.
*** JMBSC = Japan Meteorological Business Support Center

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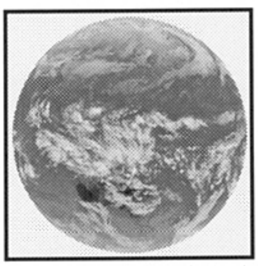
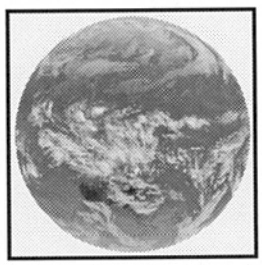
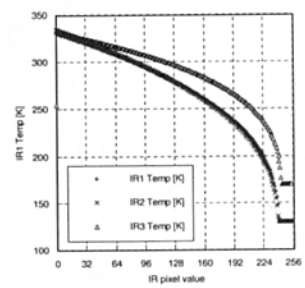
Data Format: VISSR, Stretched VISSR (S-VISSR)



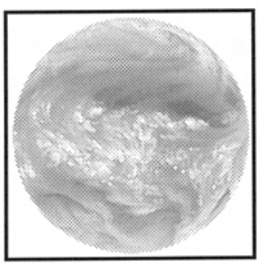
IR1: 10.5 - 11.5 μm, Split window
VISSR: 8bit, 6688 x 2500, 5km, 16MB
S-VISSR: 8bit, 2291 x 2291, 5km, 5MB



IR2: 11.5 - 12.5 μm, Split window
VISSR: 8bit, 6688 x 2500, 5km, 16MB
S-VISSR: 8bit, 2291 x 2291, 5km, 5MB

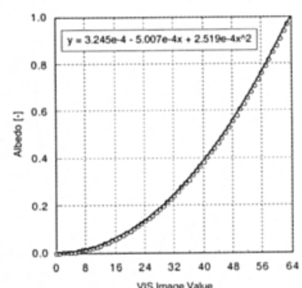


Calibration data for IR1, IR2 & IR3



IR3: 6.5 - 7.0 μm, Water vapour
VISSR: 8bit, 6688 x 2500, 5km, 16MB
S-VISSR: 8bit, 2291 x 2291, 5km, 5MB

VIS: 0.55 - 0.95 μm, Visible & Near IR
VISSR: 6bit, 13376 x 10000, 1.25km, 96MB
S-VISSR: 6bit, 9164 x 9164, 1.25km, 60MB



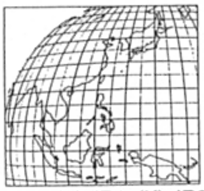
Calibration data for VIS and the regression curve

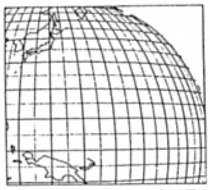
Note: These images and calibration data were downloaded from NASA's archive (ftp://rsd.gsfc.nasa.gov/pub/Weather/GMS-5/).
MTSAT will replace the S-VISSR format with the High Resolution Imager Data (HiRID) format to send 10 bit images.

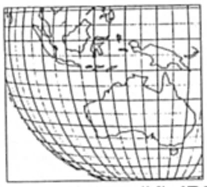
2ND Workshop on Satellite for Solar Energy Assessments, February 3-4, 1999, Golden, Colorado, USA

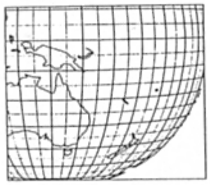
Presentation: Access to Geostationary Satellite Data Streams (GMS) by Yoshiaki Uetani

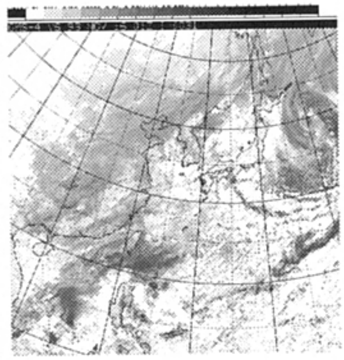
Data Format: WEFAX

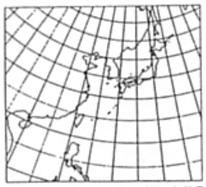

Image(A): IR1, (K): IR3

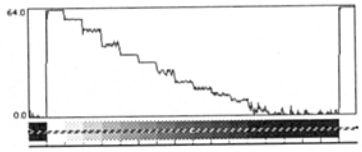

Image(B): IR1, (L): IR3


Image(C): IR1, (M): IR3


Image(D): IR1, (N): IR3


Image(I): VIS


Image(H): IR1, (I): VIS
mapped by polar stereo projection, 6 bit, 800 x 800, 5km



Profile of the grayscale

Note: MTSAT will introduce the digital Low Rate Information Transmission (LRIT) in March 2000. It will quit sending the analog WEFAX in March 2003.

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Data Availability

(a) VISSR / S-VISSR Offline data (Level 1A - 3):

- Agent: Japan Meteorological Business Support Center (JMBSC) (http://www.jmbsc.or.jp)
- Media: Depends on data format (MT, CMT, CDROM, BW/color print, 16mm movie film, VTR tape, etc).
- Cost: Depends on media (ex. Meteorological Satellite Monthly Report CDROM: 2600yen=$20 per disk, MT: 8000yen)

(b) S-VISSR Realtime data (Level 1B): Medium Scale Data Utilization Stations (MDUS)

- Facility: Parabola antenna, reciever, workstation & software
- Cost: Free for the data while JMA keeps copiright. A set of facility costs approx. 40,000,000yen, excluding data strage.

(c) WEFAX Realtime data (Level 1B): Small Scale Data Utilization Stations (SDUS)

- Facility: Parabola antenna, reciever, PC & software
- Cost: Free for the data while JMA keeps copiright. A set of facility costs 1000,000-4000,000yen, excluding data strage.

(d) Voluntary MDUS through Internet (selected)

(1) NASA and University of Hawaii (http://rsd.gsfc.nasa.gov/goesg/earth/Weather/main.html).
S-VISSR data are converted into various formats.
Full globe images of VIS, IR1, IR2 & IR3 with calibratio tables in HDF format are very usefull for quamtitative analysis.
GIF and JPEG images are convenient to handle for viewing.

(2) Institute of Industrial Science at University of Tokyo (http://www.tkl.iis.u-tokyo.ac.jp/SatIAN/Welcome.html).
GMS-5 S-VISSR and NOAA AVHRR are received with parabola antennas.
The 100TB strage never overflows.

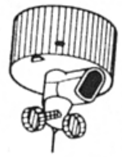
(3) Department of Information Science, Kochi University (http://weather.is.kochi-u.ac.jp/archive-e.html).
S-VISSR data from IIS, Univ. Tokyo are transformed into longitude/latitude coordinate in various resolutions.
The square images are more convenient than NASA's full disk images for quantitative analysis.
Downloading a lot of data in one stroke is forbidden because the lower capacity of Internet in Japan.

2ND Workshop on Satellite for Solar Energy Assessments, February 3-4, 1999, Golden, Colorado, USA

Presentation: Access to Geostationary Satellite Data Streams (GMS) by Yoshiaki Uetani

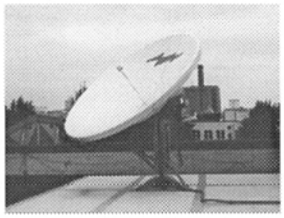
Medium Scale Data Utilization Stations (MDUS)

Institute of Industrial Science, Univ. Tokyo

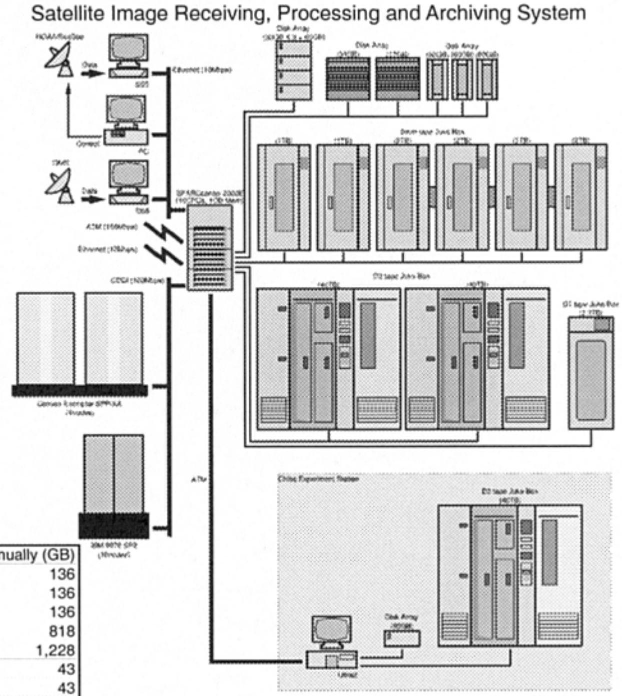


S-VISSR

3.7m Parabolic Antenna



Satellite Image Receiving, Processing and Archiving System

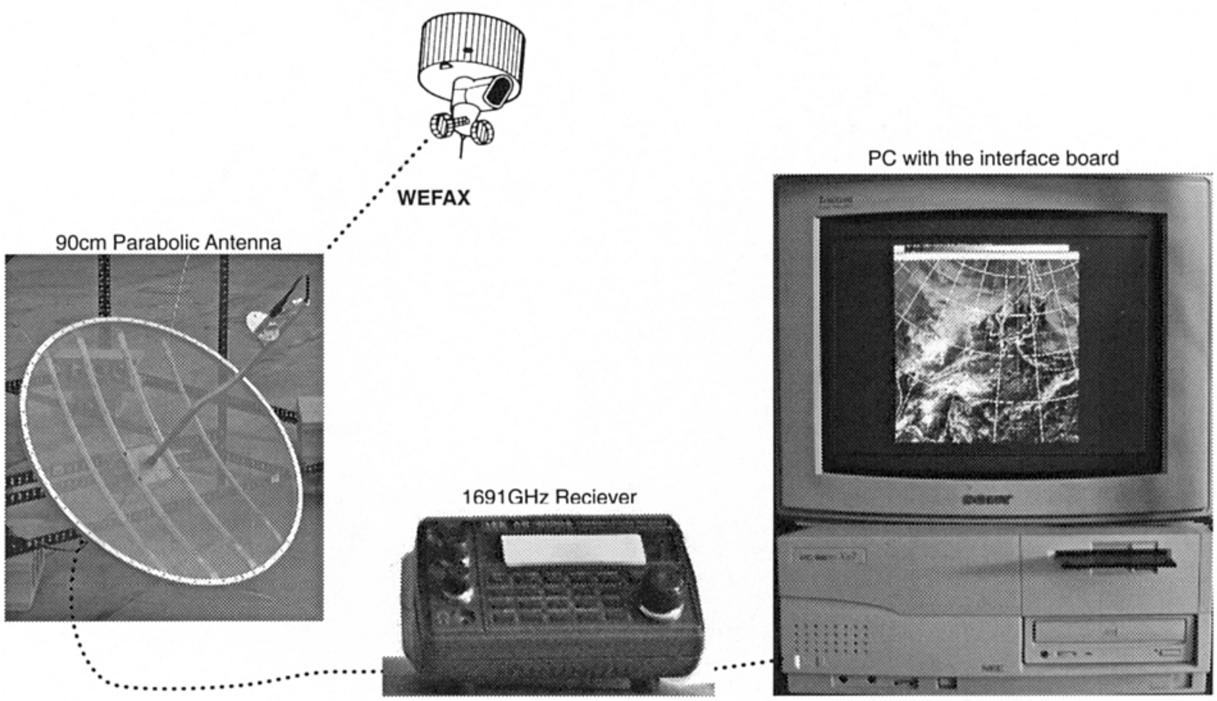


Annual requirement for data strage

Image type	bit/pixel	pixel	line	Hourly (MB)	Daily (MB)	Monthly (GB)	Annually (GB)
VISSR (IR1)	8	6,688	2,500	16	383	11	136
VISSR (IR2)	8	6,688	2,500	16	383	11	136
VISSR (IR3)	8	6,688	2,500	16	383	11	136
VISSR (VIS)	6	13,376	10,000	96	2,296	67	818
VISSR (Total)				144	3,444	101	1,228
S-VISSR (IR1)	8	2,291	2,291	5	120	4	43
S-VISSR (IR2)	8	2,291	2,291	5	120	4	43
S-VISSR (IR3)	8	2,291	2,291	5	120	4	43
S-VISSR (VIS)	6	9,164	9,164	60	1,442	42	514
VISSR (Total)				75	1,802	53	642

Small Scale Data Utilization Stations (SDUS)

Department of Architecture, Fukuyama University



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Presentation: Access to Geostationary Satellite Data Streams (GMS) by Yoshiaki Uetani

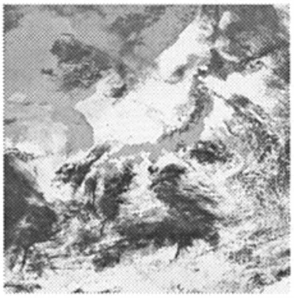
Application of GMS-5 data

Regression analisys of global irradiance and direct irradiance

Satellite data:	VISSR images and calibration data by Meteorological Satellite Monthly Report CDROM (JMBSC).
Surface data:	Global irrad., direct irrad., cloud amount, etc. obserbed by the Fukuoka Meteorological Observatory.
Total # of data:	2857 set (hourly data from July 1, 1996 to March 31, 1997)

VS970318.Z03

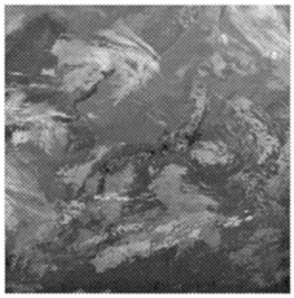
50°N



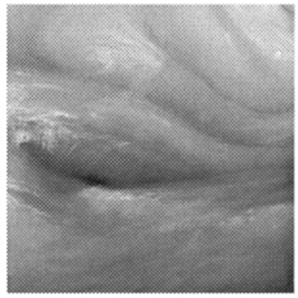
20°N

120°E 150°E

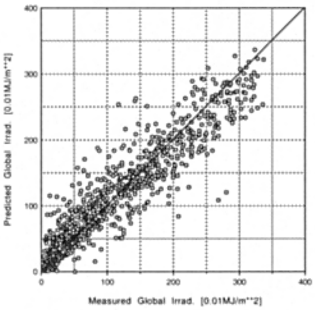
IR970318.Z03



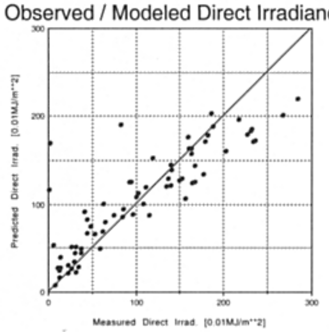
WV970318.Z03



Observed / Modeled Global Irradiance



Observed / Modeled Direct Irradiance for clear skies



2^ND Workshop on Satellite for Solar Energy Assessments, February 3-4, 1999, Golden, Colorado, USA

Acknowledgements

This work is supported by the Iwatani Naoji Memorial Fund 1998 and the Grant-in-Aid of the Ministry of Education, Science and Culture, 1998. The image processing is performed using the public domain NIH Image program written by Wayne Rasband at the U.S. N.I.H.

References

(1) Kiyoshi Tuchiya: Remote Sensing Gai-ron, Asakura sho-ten, 1990 (in Japanese).
(2) Kisho(Meteorological) Handbook, Asakura sho-ten, 1995 (in Japanese).
(3) Zukai Kisho-no-Daihyakka, Ohm-sha, 1997 (in Japanese).
(4) Kisho-gaku-Jiten, Tokyo-shoseki, 1998 (in Japanese).
(5) S. Q. Kidder, T. H. Vonder Haar: Satellite Meteorology-an Introduction, Academic Press, 1995.

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Access to GOES Satellite Data

Brian Motta
Colorado State University
NOAA/NESDIS Cooperative Institute for Research in the Atmosphere (CIRA)
Fort Collins, CO
www.cira.colostate.edu

Since the start of the NOAA Geostationary Operational Environmental Satellite (GOES) program in the United States, one of the main challenges has been the ingest, archival, and subsequent use of the data. As technology and equipment have changed over the years, the storage media has changed from videotapes and hardcopy printouts to mass storage devices and high capacity tape drives.

This presentation will address the various archives and projects directed at archiving GOES data sets and the best ways for researchers to obtain the data sets. The basic data formats available from the archives will be explained briefly in the context that they relate to the type of software which will be used. Use of NOAA's GOES data has been widespread in recent radiation experiments. Further, NOAA has developed a special data archive at the National Geophysical Data Center in Boulder, CO which contains data sets from the Space Environment Monitoring instruments aboard the GOES satellites.

Currently, NOAA's requirements for the next generation of satellites are being gathered from users such as the national weather service and military services in addition to the wider user community. Plans are revised and updated on a yearly basis and presented at the national American Meteorological Society meetings held each January. Of particular interest this year was the use and exploitation of the GOES sounder data. The GOES sounder produces data in 19 different spectral bands and can be used to create vertical profiles in non-cloudy regions in addition to the images like those produced from the 5 spectral band imager.

An Overview of GOES Satellite Data Availability

Brian Motta
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NOAA/NESDIS Cooperative Institute for Research in the Atmosphere (CIRA)
Foothills Campus
Fort Collins, CO 80523-1375
http://www.cira.colostate.edu
3 February 1999

RAMM-CIRA

Outline

- Retrospective Data
  - National Archives, Pathfinder, Others
- Real-time Data Access
  - Direct Readout, Data Distributors, Internet Sources
- Software
- Summary

RAMM-CIRA

Presentation: Access to GOES by Brian Motta, CSU

Retrospective Data in National Archives

(raw data)

- National Climatic Data Center (www.ncdc.noaa.gov)
  - GOES - Geostationary Satellite Archive System (www.ssec.wisc.edu/gsas/)
    - **Holdings: GOES E/W, 1978 to present; global 1978-1979**
    - **Data format: GARS (McIDAS AREA)**
    - **Cost: $75 per scene from NCDC; $16 per image via McIDAS system**
    - **Software: McIDAS, MERLIN, GEMPAK, WXP, VIS-5D, VIA-AD, etc.**
  - AVHRR - Satellite Active Archive (www.saa.noaa.gov)
    - **Holdings: Global coverage, March 1, 1994 to present**
    - **Data format: NOAA/NESDIS Level 1B**
    - **Cost: 10 Mbyte data set free**
    - **Software: GeoVu data browser from NGDC**
      http://apex.ngdc.noaa.gov/seg/geovu/geovu.shtml

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Retrospective Data Pathfinder Products

- GOES - Univ. of Wisconsin (GOESPRODS@SSEC.WISC.EDU)
  - Radiances
    - **Holdings: hourly, May 1987- Nov 1988**
    - **Data format: 26 Mbytes/image in McIDASAREA format, GIF browse**
    - **Cost: free**
    - **Software: McIDAS, MERLIN**
- AVHRR - NASA/GSFC (xtreme.gsfc.nasa.gov)
    - **Holdings: July 1981 to present**
    - **Data Format: 228 Mbytes/image in HDF**
    - **Cost: Free or Min. cost of reproduction**
    - **Software: ftp.ncsa.uiuc.edu/HDF**

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Retrospective Data GCIP Data

- GEWEX Continental International Project (GCIP) Satellite Data Source Module **(http://wwwghrc.msfc.nasa.gov/gcip/sdsm.html)**
  - ✍ Long list of satellite data and products and related efforts
  - ✍ Radiation Projects (DOE ARM, NASA ISCCP, NASA EOS, etc.)
  - ✍ Hydrology/land surface projects
  - ✍ Numerous links to other resources

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Real-time Data Access by Direct Readout

- Telonics, Inc.
  932 E. Impala Avenue
  Mesa, AZ 85204-6699
  (602) 892-4444
- Hughes Information Technology Company
  16800 Centretech Parkway
  Aurora, CO 80011-9046
  (303) 344-6000
- Global Imaging
  201 Lomas Santa Fe Drive
  Suite 380
  Solana Beach, CA 92075
  (619) 481-5750

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Real-time Data Access
Data Distributors

- UW-Madison Space Science and Engineering Center (SSEC)
- UNIDATA (NSF-UCAR)
- RAMSDIS (NOAA-NESDIS/RAMM/CIRA/CSU)
- NOAAPORT (NWS data broadcast -remapped satellite)
- Commercial Sources/Vendors
  - WSI, Alden, DTN/Kavouras, Hughes, Harris, Terascan
- Internet Sources/Servers
  - http://wwwghcc.msfc.nasa.gov/GOES/ (GIFs & AREAs)

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Real-time Data Access

UW-Madison Space Science and Engineering Center (SSEC)

- Databases (www.ssec.wisc.edu/operations)
  - Global Satellite (GOES, GMS, Meteosat, and Polar/POES)
  - Conventional Meteorological data (current and archived)
  - GOES Archive (1978 to present)
- Access through McIDAS software and data feeds
- Data Costs
  - Approximately $0.75/Mbyte

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Real-time Data Access

UNIDATA (NSF-UCAR)

- Serves the University Community (www.unidata.ucar.edu)
  - Software
    - **McIDAS**
    - **GEMPAK**
    - **WXP**
  - Data (North America)
    - **NWS Family of Services**
    - **Wisconsin Satellite/Internet Broadcast**
  - Cost - free to UNIDATA members

RAMM-CIRA

Real-time Data Access

(RAMSDIS NESDIS-RAMMT-CIRA-CSU)

- RAMM Advanced Meteorological Satellite Demonstration and Interpretation System (www.cira.colostate.edu)
  - Demonstrate the value of digital satellite data for the NWS
  - Software: McIDAS-OS/2 based with special applications
  - Data:
    - Real-time satellite and conventional
    - Customized to site (48 image/graphic loops)
  - Cost: none to NWS. Low-cost PC-based option.

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Realtime Data Access

(NOAAPORT)

- NOAA's 5-channel data distribution service to AWIPS sites
- Products tailored to NWS sites
- Software: commercially available
- Data: remapped satellite and conventional data/products
- Cost: data delivery is free but ground station and software needed initally. "AWIPS Lite" now commercially available.

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GOES Space Environment Monitoring

- National Geophysical Data Center (www.ngdc.noaa.gov)
  - Boulder, CO
  - SEM URL http://julius.ngdc.noaa.gov:8080/production/html/GOES/index.html
  - Solar and sun activity data http://www.ngdc.noaa.gov/stp/stp.html

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Summary

- GOES data now take on many forms (graphic images, counts, calibrated radiances, etc.)
- Most data are served in real-time on the internet at no cost
- Archived data tend to be expensive
- Utilize DOE, NOAA, NASA, and other agency projects to obtain access to suitable data sets
- Experience has shown that established software packages that offer support and compatible data formats lead to the most productive users.

NOAA

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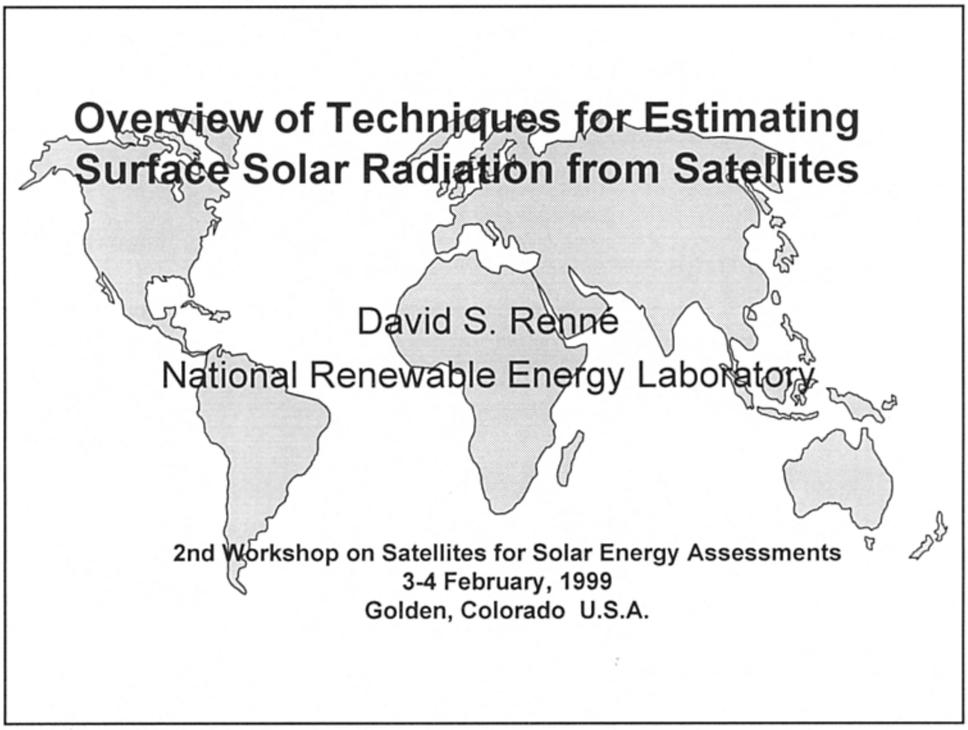
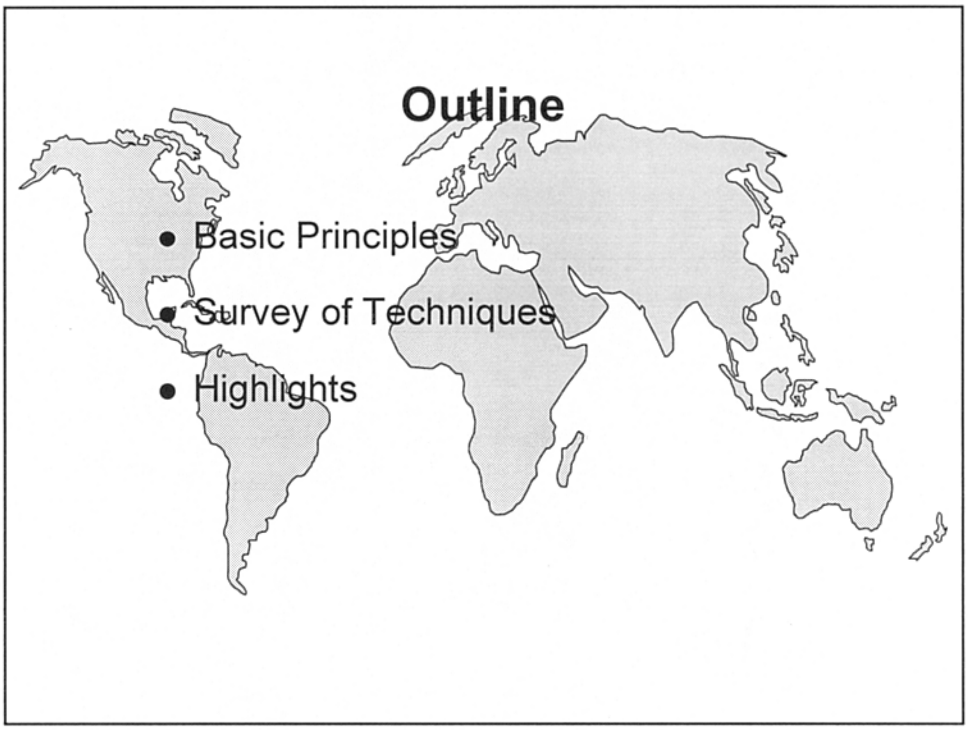
Presentation: Access to GOES by Brian Motta, CSU

Overview of Techniques for Estimating Surface Solar Radiation from Satellites

David S. Renné
National Renewable Energy Laboratory
Golden, Colorado U.S.A.

This presentation provides a summary of the use of satellite technology, originally developed for purposes of understanding weather and climate, in determining the distribution and characteristics of the solar resource around the world. Satellite technology allows us to view large areas of the earth's surface at any given time, and provide detailed, high-resolution data on the surface and cloud conditions over these areas. For the past 20 years, researchers involved in satellite image processing have been developing ways of estimating the downward solar flux at the earth's surface from the information "seen" at the satellite platform. This has resulted in new information about the distribution and characteristics of the solar resource that could never be obtained from the limited ground network that is currently available around the world. Such information contributes to the expansion of solar technologies, and for determining new applications of solar technologies in configurations not deemed possible twenty years ago, because of the then lack of key information. The presentation includes a look at why a quantitative understanding of the solar resource is necessary for successful and cost-effective deployment of solar technologies. The main empirical and physical approaches used to convert imagery collected at the satellite to estimates of surface solar flux, and the uncertainties associated with these estimates are reviewed. For the global horizontal solar resource it is seen that, under a variety of conditions, monthly-average daily total satellite-derived estimates can compare with surface measurements to within 10% or so, or even better under clear-sky conditions. The differences between satellite and ground observations can increase under partly cloudy conditions, over coastal or snow-covered areas, or for shorter than monthly averaging times.



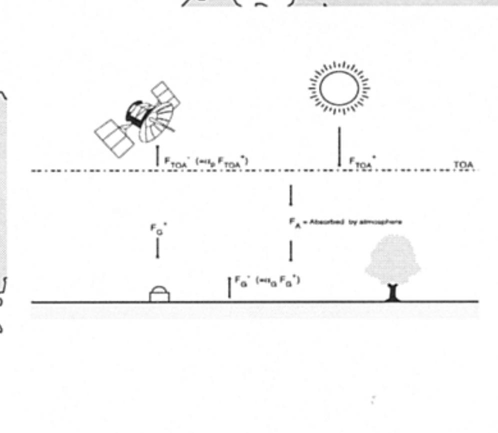


Presentation: Overview by Dave Renne, NREL

The Fritz, Rao and Weinstein (1964) Relationship

$$F_{TOA}^{+} - F_{TOA}^{-} = F_{G}^{+}(1 - \alpha_G) + F_A$$

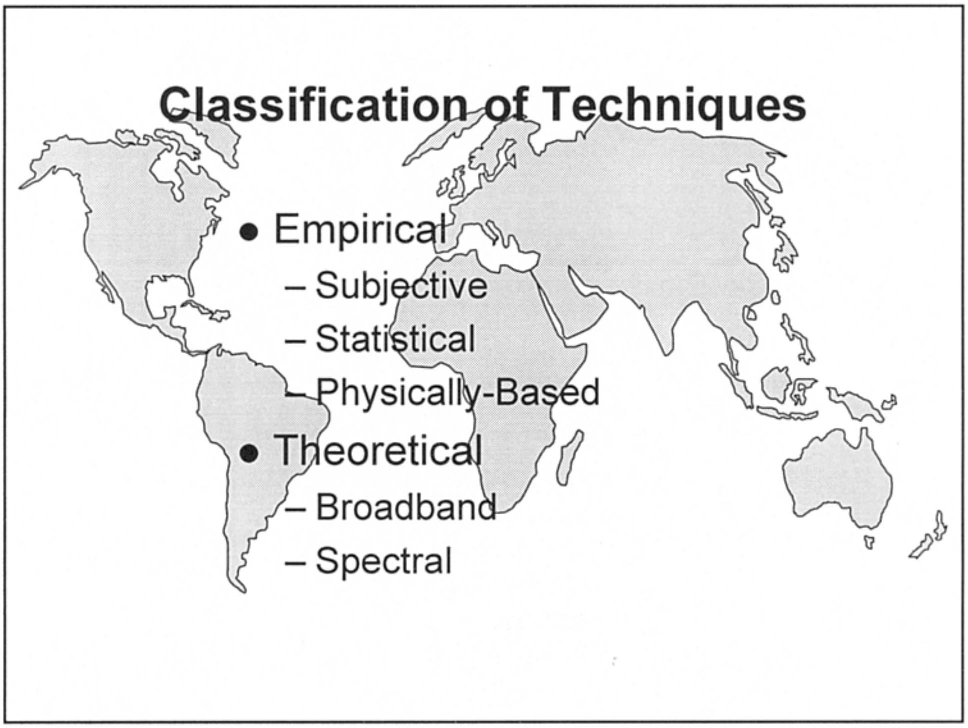
α_G = ground albedo

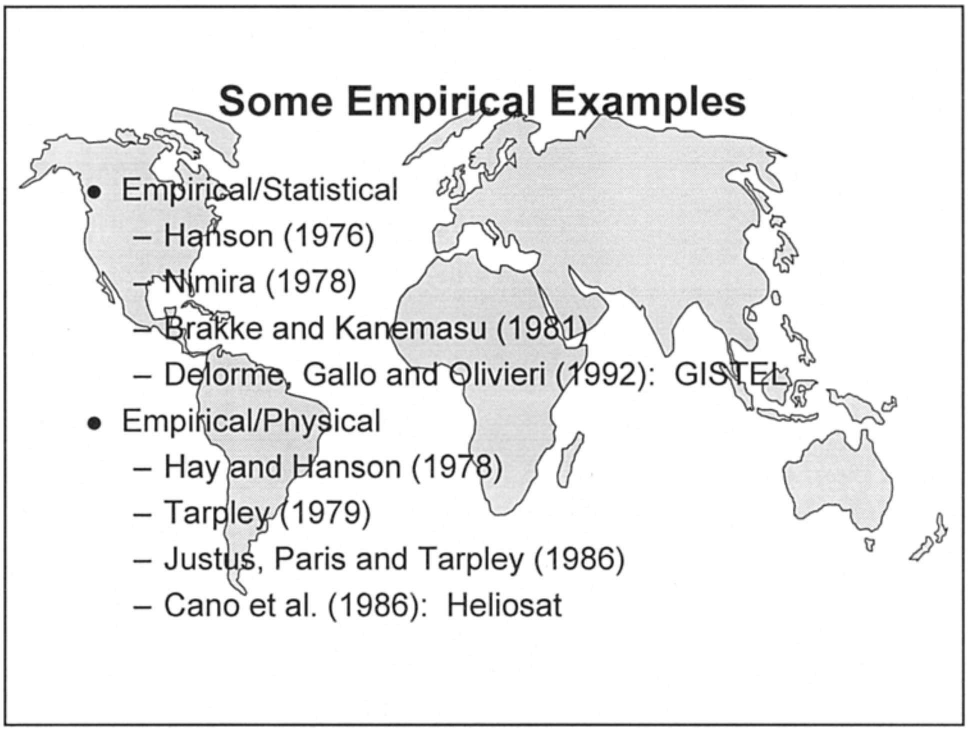


Sources of Solar Beam Attenuation

- Clouds
- Aerosols
- Water Vapor
- Rayleigh Scattering
- Ozone
- Other Atmospheric Gases

Presentation: Overview by Dave Renne, NREL



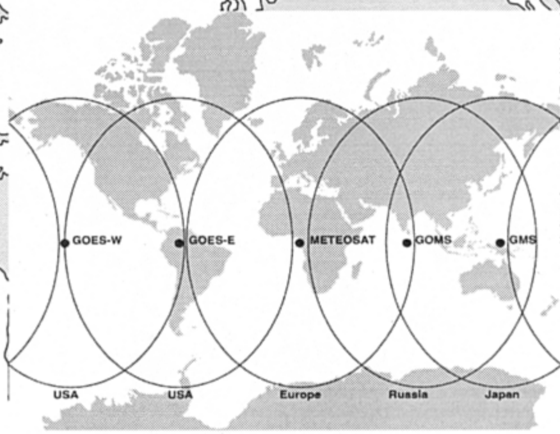


Presentation: Overview by Dave Renne, NREL

Some Theoretical Examples

- Broadband
  - Gautier, Diak and Masse (1980)
  - Marullo, Dalu and Viola (1987)
  - Dedieu, Deschamps and Kerr (1987)
  - Darnell et al. (1988)
- Spectral
  - Moser and Raschke (1983): IGMK
  - Stuhlmann, Rieland and Raschke (1990): IGMK+
  - Pinker and Ewing (1985)
  - Pinker and Laszlo (1992)

Most Techniques Use Geostationary Satellite Observations



Presentation: Overview by Dave Renne, NREL

Summary of Results
(Differences between Satellite and Ground Measurements)

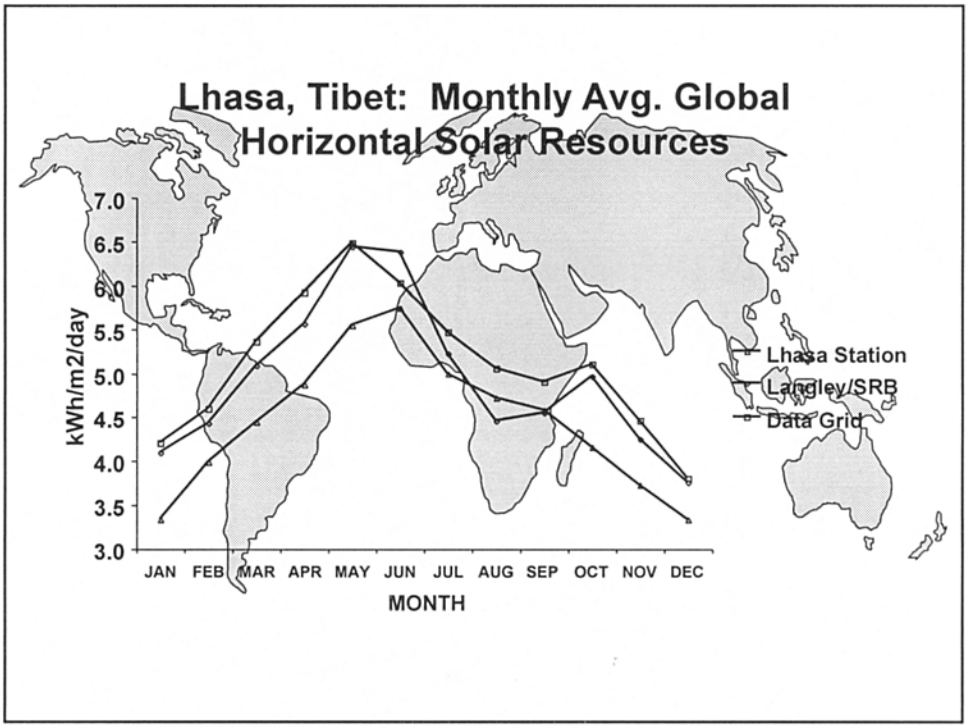
- Empirical
  - Seasonal, Monthly: <10%
  - Daily: 10% - 20%
  - Hourly: >20%
- Theoretical
  - Monthly: <7%*
  - Daily: 10% - 20%
  - Hourly: 20%

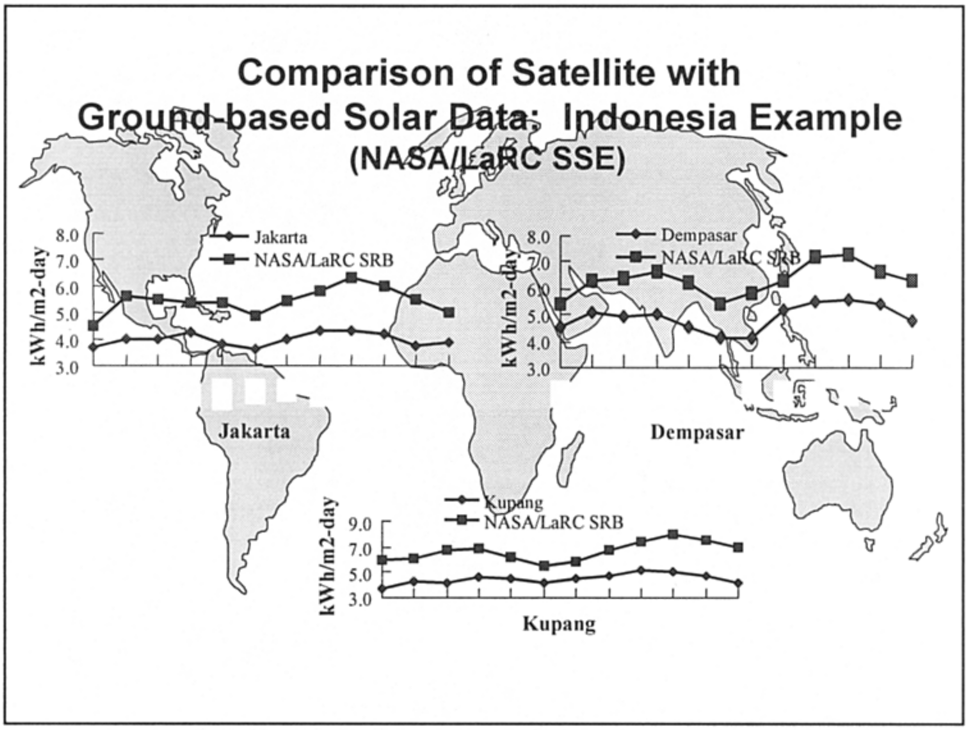
*Higher in some cases, e.g. using Meteosat for Brazil

General Conclusions

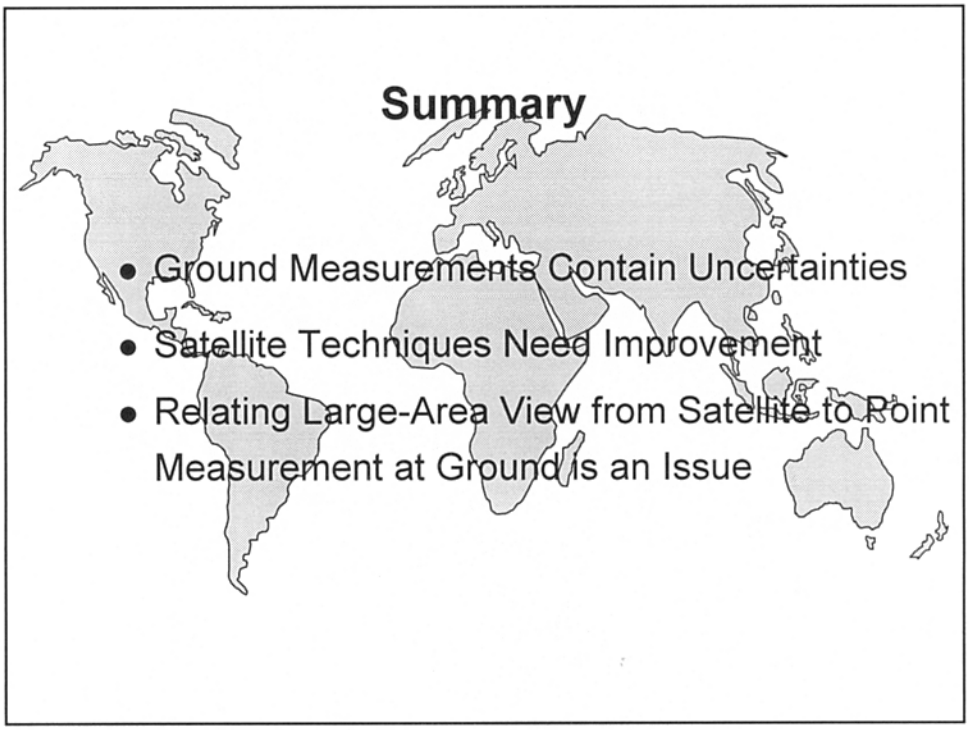
- Theoretical Generally Perform Slightly Better than Empirical
  - Seasonal, Monthly Values
  - Large Grid Sizes
- Empirical May be Simpler and More Practical for Certain Applications
  - Higher Spatial Resolutions
  - Hourly, Daily Values
- Surface Measurements for Validation Important

Presentation: Overview by Dave Renne, NREL





Presentation: Overview by Dave Renne, NREL



Presentation: Overview by Dave Renne, NREL

Effective Accuracy of Satellite Predicted Irradiance

Richard Perez, Antoine Zelenka and David Renné

Estimates of hourly global irradiance based upon geostationary satellite data with a ground resolution of a few kilometers reproduce ground-measured value with a relative Root Mean Square Error (RMSE) of typically 20-25%. However, this "observed" RMSE does not represent the intrinsic accuracy of satellite data-to-irradiance conversion models. Indeed, much of this RMSE results from the difference between a time integrated, point-specific measurement—the ground-measured irradiance– and a time specific, spatially (pixel-wide) integrated measurement—the satellite-derived irradiance.

We present quantitative estimates of the respective contribution of each component—intrinsic satellite model error, point-pixel discrepancy and ground measurement inaccuracy —amounting to the observed "conventional" RMSE. This presentation is made from the standpoint of a user having to rely on site/time specific data. From such a standpoint, the intrinsic or "effective" RMSE of satellite-derived irradiance is estimated to be of the order of 12%.

EFFECTIVE ACCURACY OF SATELLITE-DERIVED IRRADIANCE

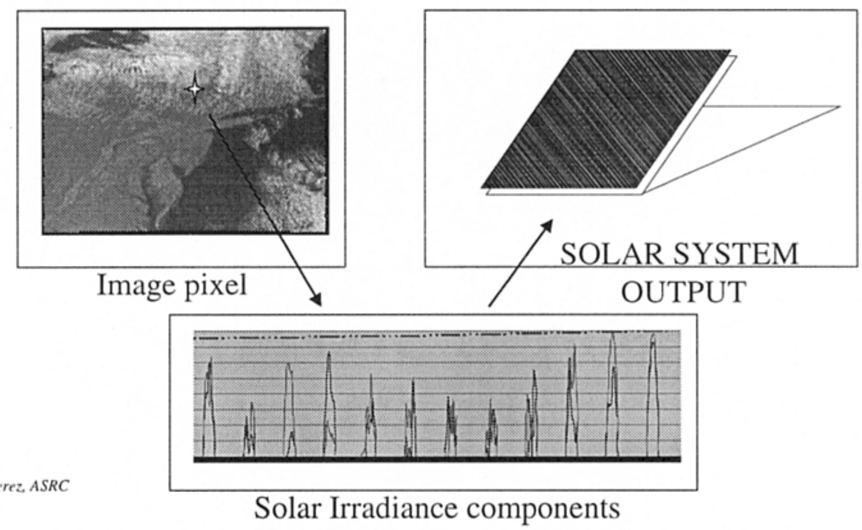
Richard Perez

Antoine Zelenka

Dave Renné

How precise ?

Site/time-specific data
Site-specific statistics



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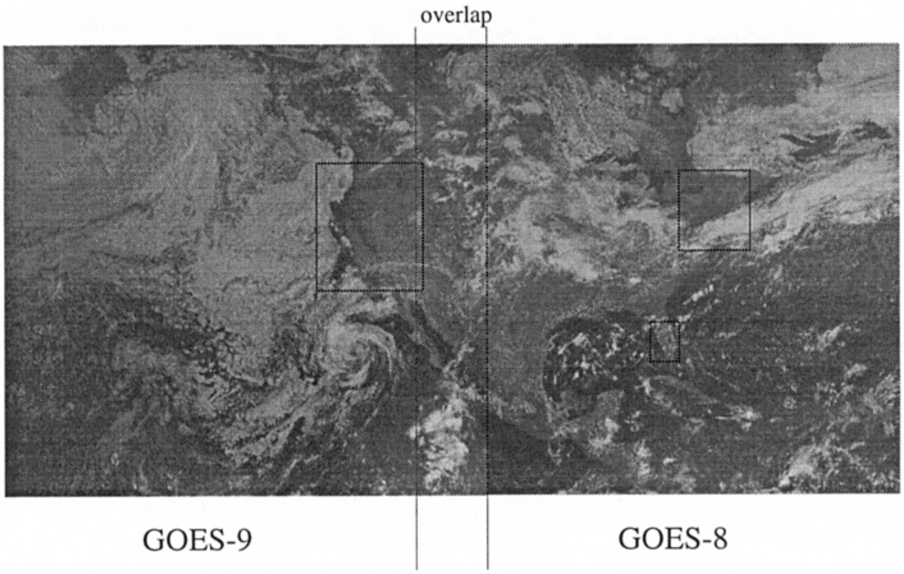
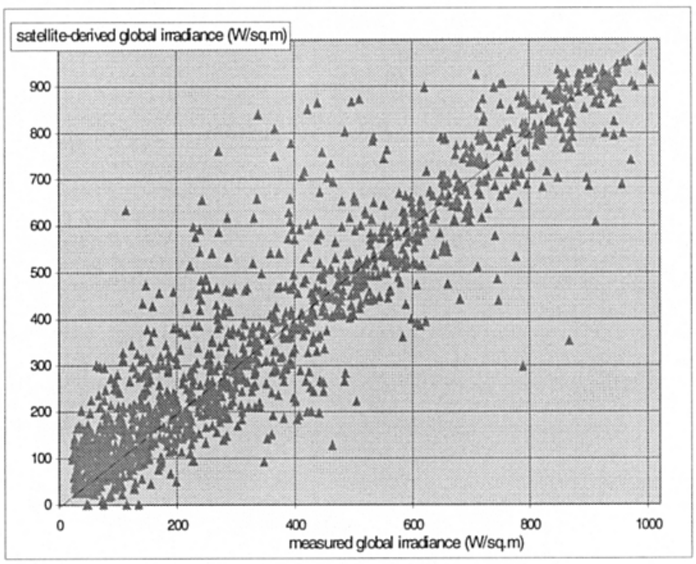


Re-gridded GOES images archived at ASRC

Perez et al.

Perez et al., ASRC



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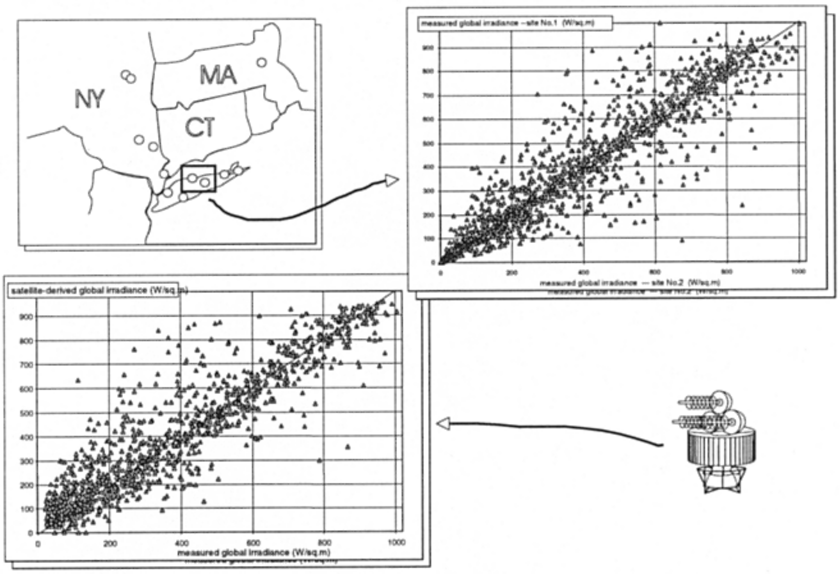
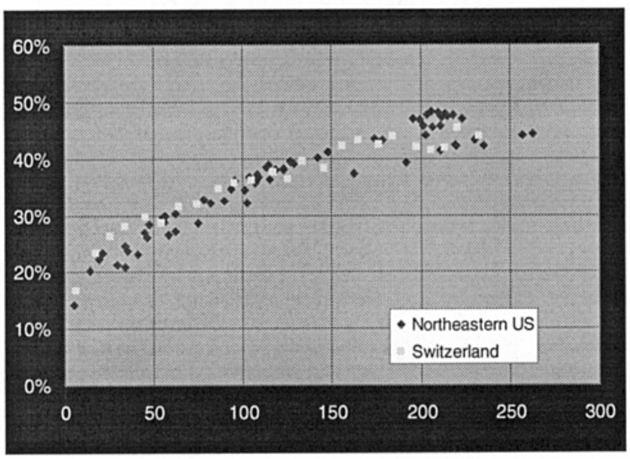


Perez et al., ASRC

Hourly RMS Error as a function of station distance

satellite becomes more accurate beyond 15 km



Satellite's Effective Accuracy ~ 6 %

Perez, Seals, Zelenka & Renné

ASRC - NREL - NYSERDA

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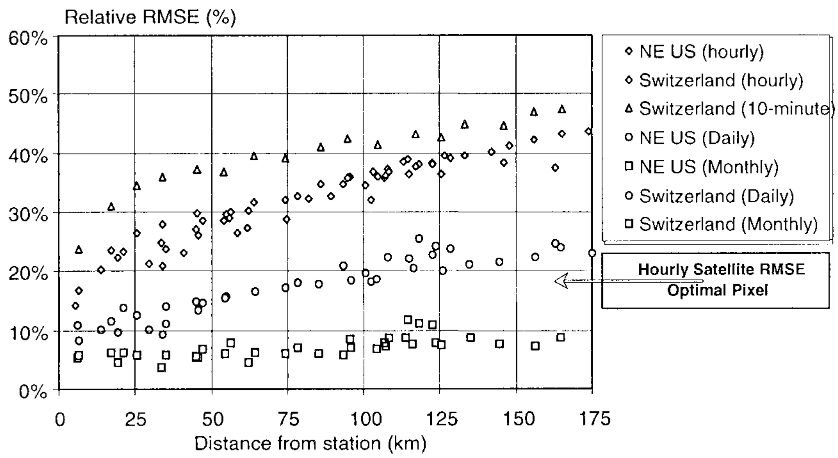
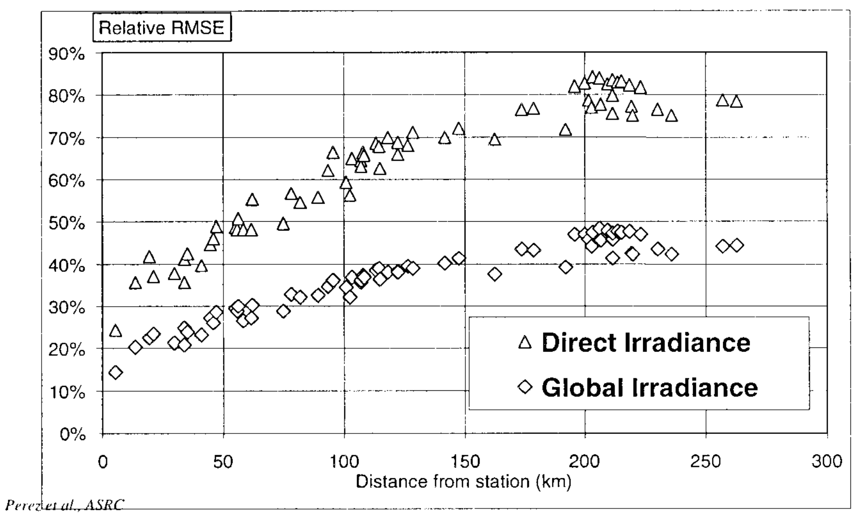
10-min, Hourly, Daily and Monthly Extrapolation RMSE as a function of station distance



Hourly Global and Direct Irradiance Extrapolation RMSE as a function of station distance



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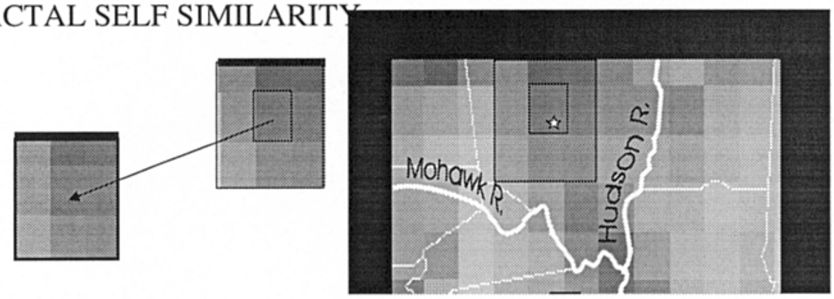
EXPERIMENTAL DETERMINATION OF EFFECTIVE ACCURACY

- CLOUD FRACTAL SELF SIMILARITYASSUMPTION
- LOCALLY HOMOGENEOUS CONDITIONS

Perez et al., ASRC

Experimental determination of Effective Accuracy
FRACTAL SELF SIMILARITY



Fractal self similarity suggests that:

Irradiance observed by at some point within a pixel will be found at a larger spatial scale in a neighboring pixel

Hence an experimental measure of effective accuracy is

$RMSE_{eff} = (\Sigma \text{ (station - pixel*)})^{1/2}$

where pixel = any 1 of 9 pixels, whichever happens to be most accurate at a any given point in time*

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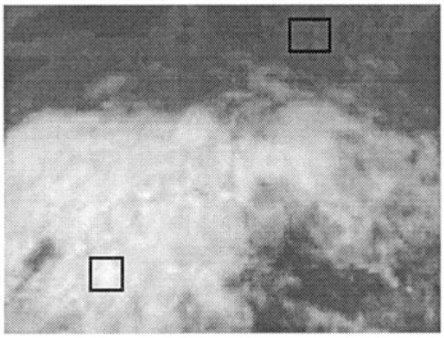
Presentation: Effective Accuracy of Satellite-Derived Irradiance by R. Perez, A. Zelenka, and D. Renne

Experimental determination of Effective Accuracy
LOCALLY HOMOGENEOUS CONDITIONS



$$RMSE_{eff} = (\Sigma (station - pixel^*))^{1/2}$$

where pixel = Closest pixel, but only considered when neighbors are within ± 5 %*

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EXPERIMENTAL DETERMINATION OF EFFECTIVE ACCURACY

- CLOUD FRACTAL SELF SIMILARITYASSUMPTION
- LOCALLY HOMOGENEOUS CONDITIONS

ground truth site	"classical" closest pixel RMSE	self-similarity effective RMSE	homogeneous effective RMSE
New Paltz (NY)	22%	11%	14%
waltham (Mass)	21%	12%	14%
Mc Arthur (NY-LI)	20%	10%	13%
Albany	23%	11%	17%
All sites	**22%**	**11%**	**15%**

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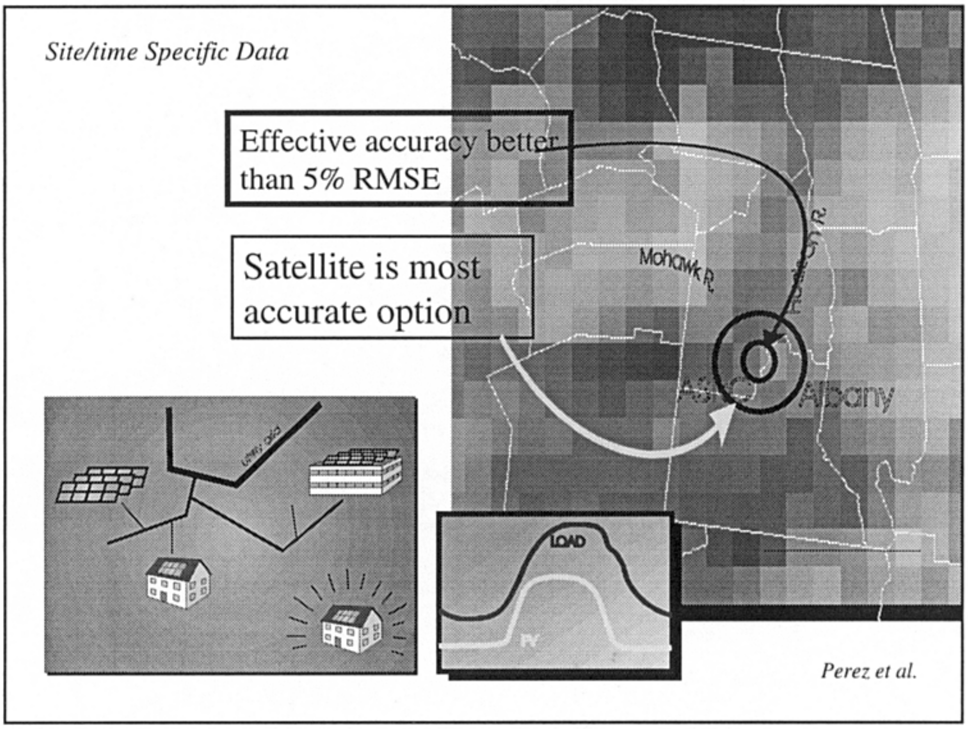

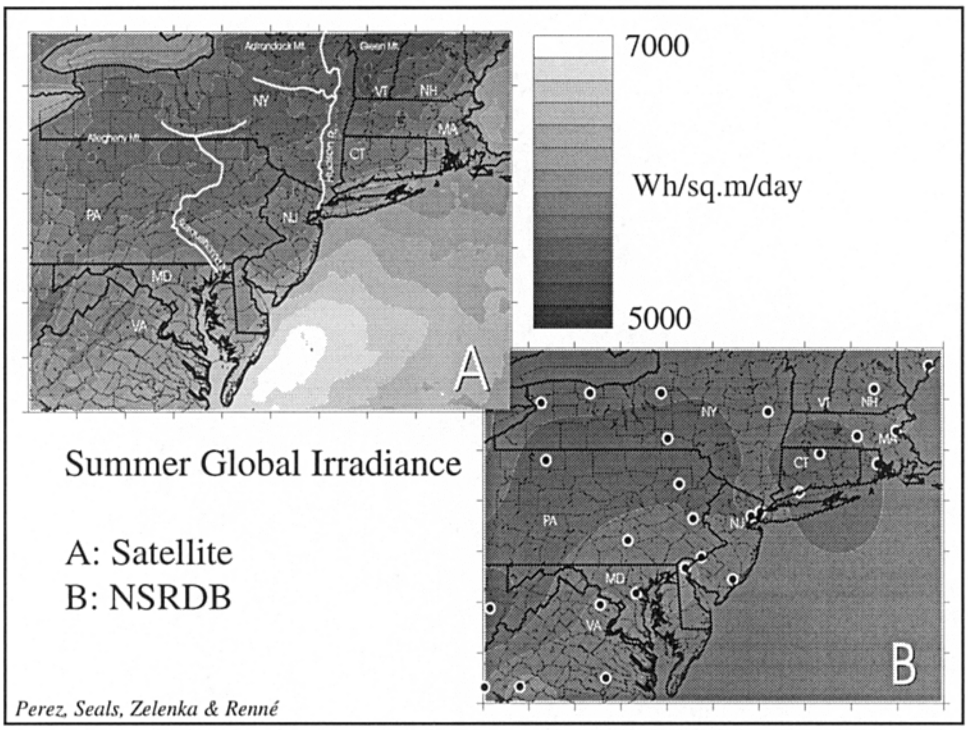

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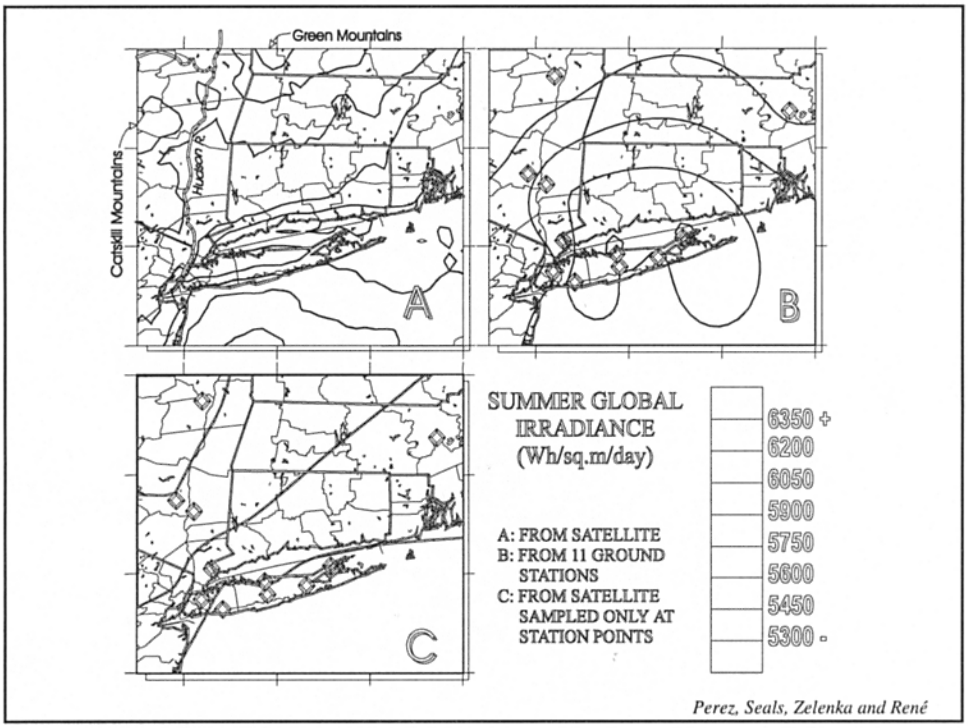

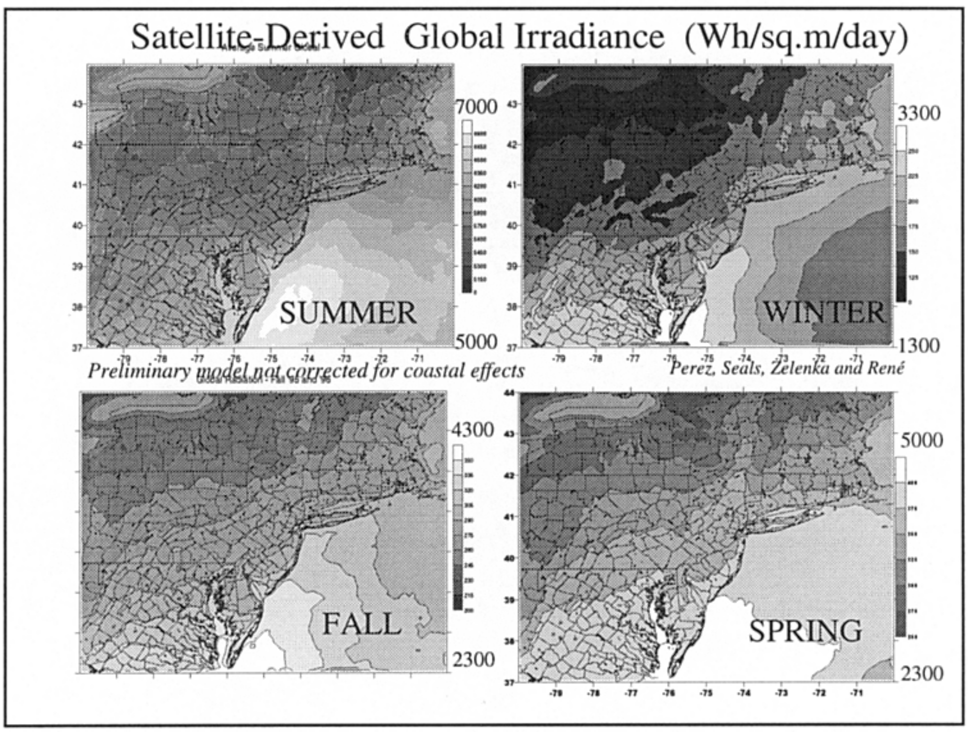

Presentation: Effective Accuracy of Satellite-Derived Irradiance by R. Perez, A. Zelenka, and D. Renne

CONCLUSIONS

Predicting site-time specific irradiance

- Although point-specific precision may never be better than 20-25%
- Pixel-wide precision (5X5 km) is more likely of the order of 10-15%
  - Impact on ground truth investigations
  - Increased acceptability for solar energy investigations
- Conclusion is reached using very simple model

Perez et al., ASRC

Using Radiative Transfer Calculations to Assess Limits for the Retrieval of Surface Irradiance Components from Satellite Information

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Calculation schemes for the radiative transfer in the atmosphere offer a tool to assess the possibilities for the retrieval of detailed information on the irradiance from satellite signals. For this purpose we applied the MODTRAN code, a reference for the simulation of the atmosphere-radiation interaction.

MODTRAN was used to test the influence of atmospheric conditions on both the direct and diffuse components of solar surface irradiance and the outgoing flux as seen by sensors of a satellite. This reveals information on the coupling of the different fluxes. From this information, the limits for the inference of the ground data from the satellite signal at different wavelength bands and from additional information on the state of the atmosphere (i.e. typical aerosol and water vapor content) may be derived.

We will present results for both clear sky and over-cast situations. It is shown that visible channel informa-tion alone is not sufficient for an exact calculation espe-cially of the downward diffuse flux. The possible contri-bution of theinfrared channel for adding information for both clear and cloudy skies is assessed. In this context we will also briefly point out the problems arising from the existence of broken cloud fields.

The presentation concludes with an short outlook on options resulting from the use of next generation sa-tellites offering sensors with an improved wavelenth resolution.

Subject:

Radiative transfer models may be used to analyse the influence of the physical properties of the atmosphere on

- downward radiation at ground level

and

- (backscattered) radiation as registered by the satellite sensor

This gives information on the strength of

- the link satellite signal (visible + infrared) ⇔ irradiance at ground level

and

- possible need for additional data.

Radiative transfer calculations

Interaction radiation $\leftrightarrow$ atmosphere

Basic processes:

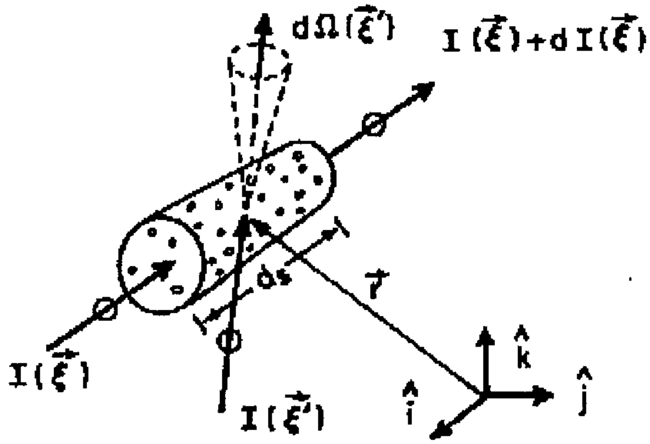
- scattering
- absorption
- emission (for infrared radiation)

by:

- air molecules
- aerosols
- water vapor
- water droplets (microscopic)
- cloud geometry (macroscopic)

Scattering

scheme for radiative flow through a volume element:



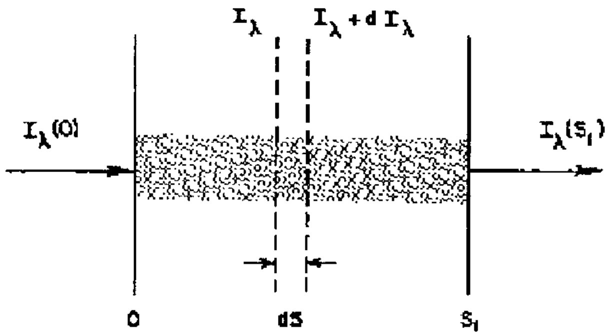
main active constituents:

- air molecules
- aerosols
- water vapor
- cloud droplets

to be described by their

- quantity
- geometry
- directional scattering properties
  (Rayleigh, Mie)

Absorption



main active constituents:

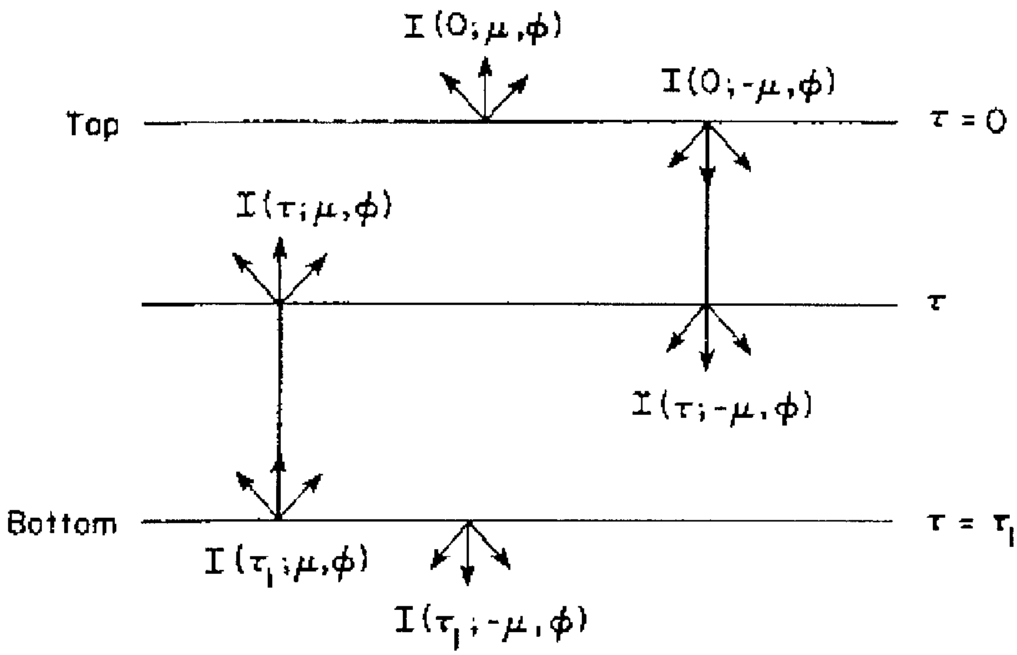
- water vapor
- aerosols
- liquid water

described by their quantity

Radiative Transfer in the Earth Atmosphere

upward (to satellite) and downward (radiation at ground level) intensities

scheme: plane parallel atmosphere



Tools:

MODTRAN

- state-of-the-art for clear atmosphere
- based on detailed molecular absorption data base
- not specialized for cloudy atmospheres
  - two-stream approximation
  - limiting assumptions in case of multiple scattering
  - only in recent version more sophisticated assessment)

- therefore not optimal for radiance calculations
  ok for flux calculations

SBDART

- more specialized in simulation of satellite signals
  (i.e. good representation of radiances)
- more 'screws' for changing cloud properties
- better modeling of cloud-radiative interaction

both are highly time consuming

alternative: pre-calculation of look-up-tables for a set of geometry-atmospheric state parameters

Aim

use radiative transfer models to analyse the relationship between

radiance as seen by the satellite

and

downward surface irradiance

necessary inputs:

data on

- temperature profile
- aerosols, water vapor (profiles)

  ⇒ visibility, (turbdity)

- water content of clouds, drop size

  ⇒ optical thickness, liquid water path

Conclusion

influence of turbidity on downward irradiance (especially the diffuse component) is only poorly reflected in the satellite signal

Additional use of the infrared (IR) signal ?

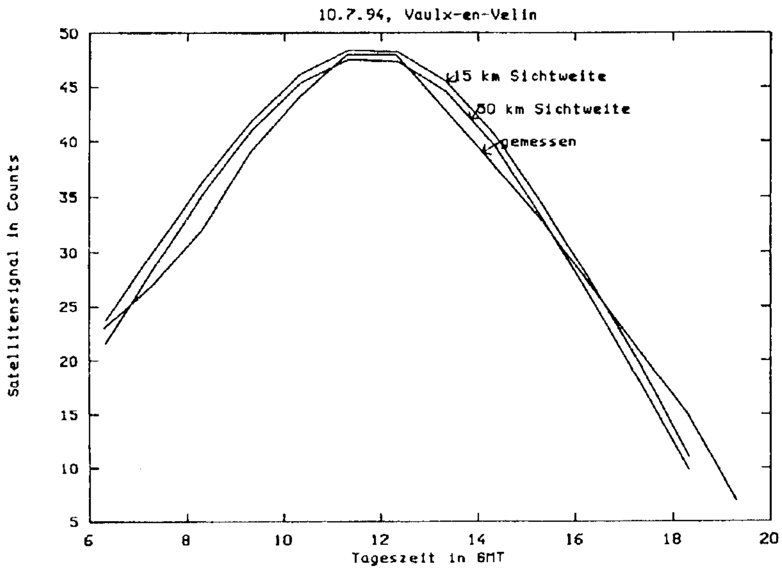
⇒ IR signal gives only little information on turbidity (influence of the (unknown) ground temperature is more prominent

⇒ need for more ground based information on turbidity

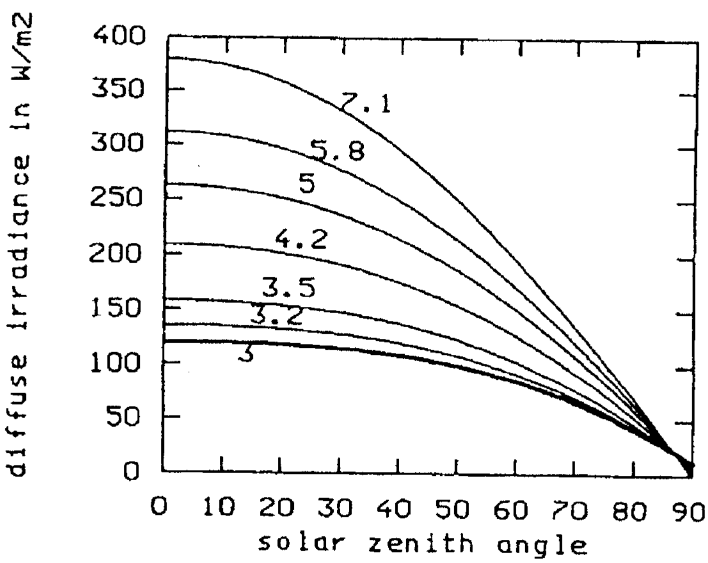
1. Clear Sky

clear atmosphere, variation of **turbidity (visibility)**

satellite signal 50°N, June; parameter: visibility



diffuse irradiance at ground level (parameter: turbidity)



2. Overcast Sky

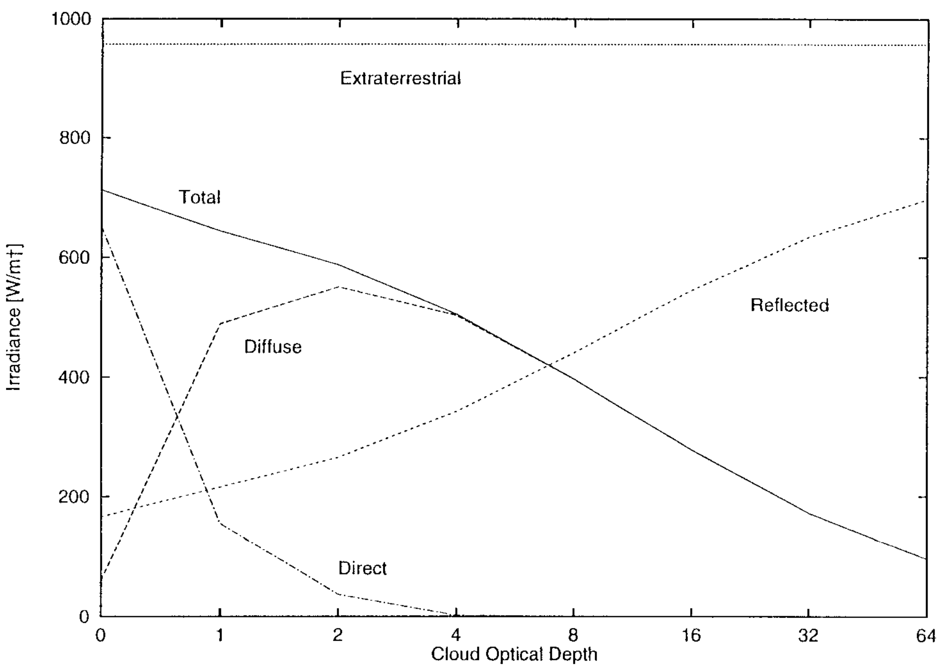
cloudy atmosphere, variation of the optical thickness of clouds

here: only homogeneous cloud cover

cloud characterized by:

- optical depth, droplet size
- cloud height

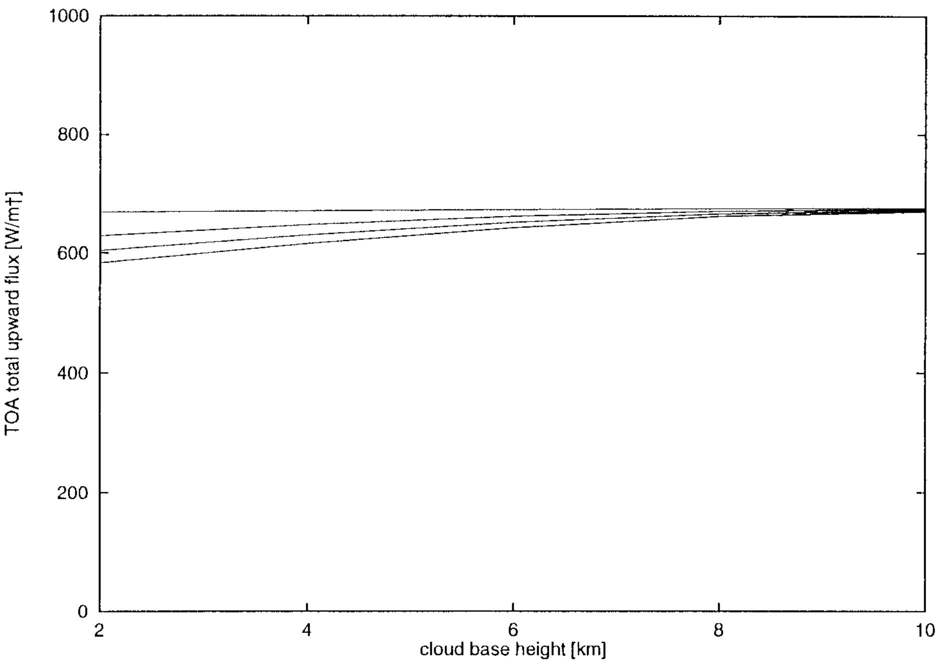
upward and downward flux as function of cloud optical depth:



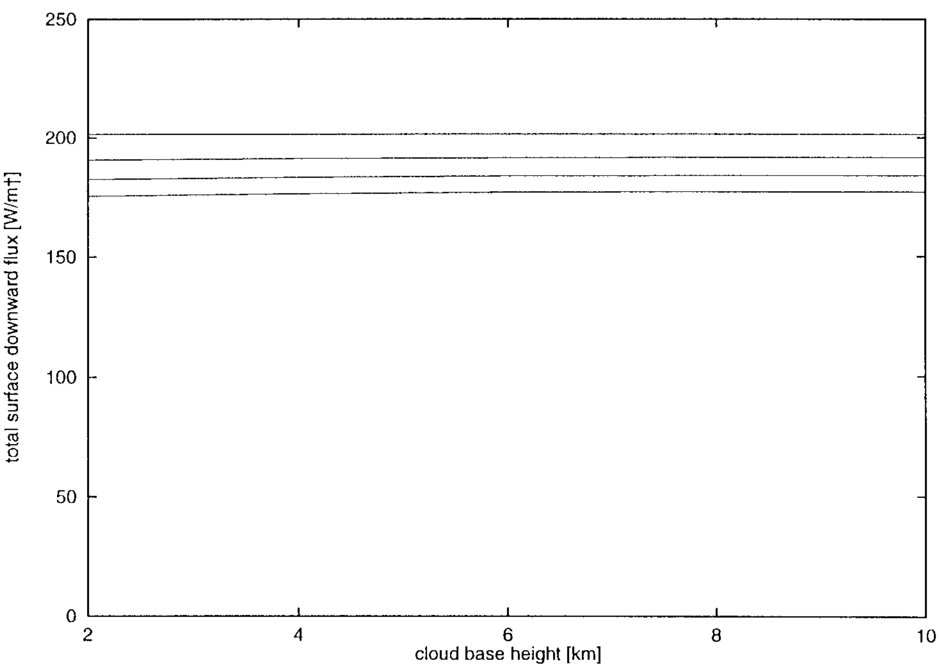
variation of downward and upward flux with cloud base height

(optical depth: 32)

upward:



downward flux:



Conclusion

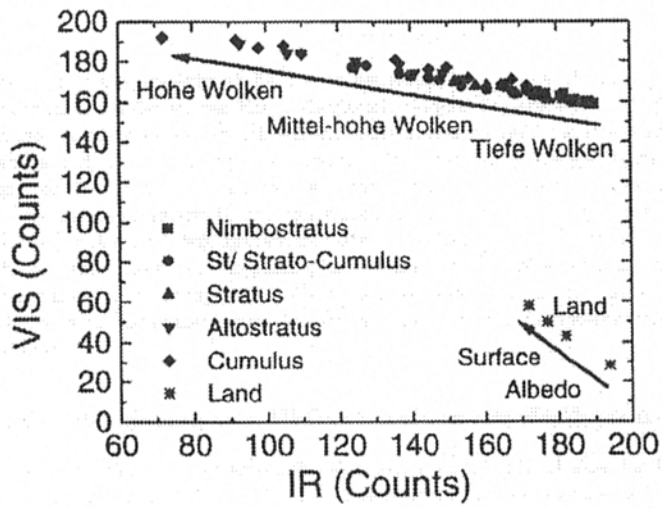
optical thickness has the dominating influence on both the VIS signal and the diffuse radiation at ground level

minor effects: cloud height, size distribution of droplets

3. Broken Clouds

evidence:

relation of VIS and IR signal for overcast and clear sky from radiative transfer model:

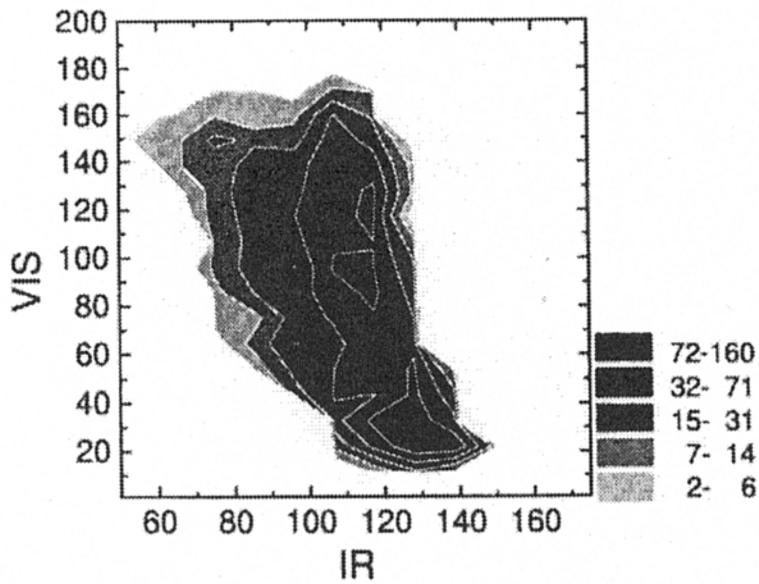


high

medium high

low clouds

empirical relation :



⇒ for a spatial resolution of 10 km x 10 km intermediate (broken cloud field) conditions are prominent simple approach to deal with broken clouds:

independant (sub)pixel assumption

- satellite signal is the mean signal from independant subpixels
- each subpixel is either cloudy (parmeter: cloud optical thickness) or clear
- cloud fraction determines mix of pixels cloudy and clear

⇒

both VIS and IR signal are effected by the product of optical thickness and cloud fraction

IR signal additionally sensitive to the (unknown) cloud top height

→ cloud fraction can not be gained from the VIS and the IR signals

Conclusion: even with the independant pixel assumption the diffuse to direct ratio (for broken cloud flields governed by the cloud fraction) is not strongly linked to the satellite signal for the respective pixel

Remark

From Monte Carlo simulations it is known, that the independent pixel assumption is only of limited validity

cloud field reflectance and absorptance are influenced by its morphology (given by e.g. its fractal characteristics)

⇒ the macroscopic geometry of the cloud field introduces additional unknown parameters to the problem

Areas for Further Research

Interference of pixel cloud fraction from multiple pixel characteristics
(evidence: successful empirical methods to link diffuse fraction with hourly variations of surface irradiance)

tool: use of ground-based cloud imagery
irradiance data with high time resolution

→ use of scaling properties of the cloud field to derive subpixel characteristics ?

Predicting Direct and Other Irradiance Components

Dr. Pierre Ineichen
University of Geneva

Chaining the models from a satellite image to diffuse or direct radiation components has the disadvantage to carry over the biases and dispersions from one components to the other. The study of the relationship between satellite count, global irradiance and other solar and illumination resource components will be presented, bringing a particular attention to low solar elevation situations (below 20∞) which are very important in northern latitudes. The investigation is based on data from two geostationary satellites, METEOSAT and GOES, backed by ground measurements in Europe and the northeastern USA.

The study of different clear sky normalizations lead to the conclusion that a linear correlation between the global clearness index and the irradiance (like the heliosat method) would be inaccurate for low solar elevations, and therefore for high latitude regions. We developed a model that directly relates an elevation dependent clearness index to the cloud index. This methodology presents a definite advantage because it can be generalized to address the clearness index of other solar radiation components, besides global irradiance, such as direct irradiance, diffuse illuminance, etc.

The correlations described in the presentation were developed on the data from Geneva and evaluated on other independent data sets (from Europe and United States). The use of independent data for the derivation and the validation of the models shows that those can be used in a wide range of locations, even if the applicability has to be assessed for other specific climates.

2nd workshop on

Satellites for Solar Energy Assessment

Prediction of non-global irradiance components

Pierre Ineichen
GAP - CUEPE
University of Geneva
Switzerland

Introduction
The direct way
The multiparameter model
The models
The results

Presentation: Prediction of Non-Global Irradiance Components by Pierre Ineichen

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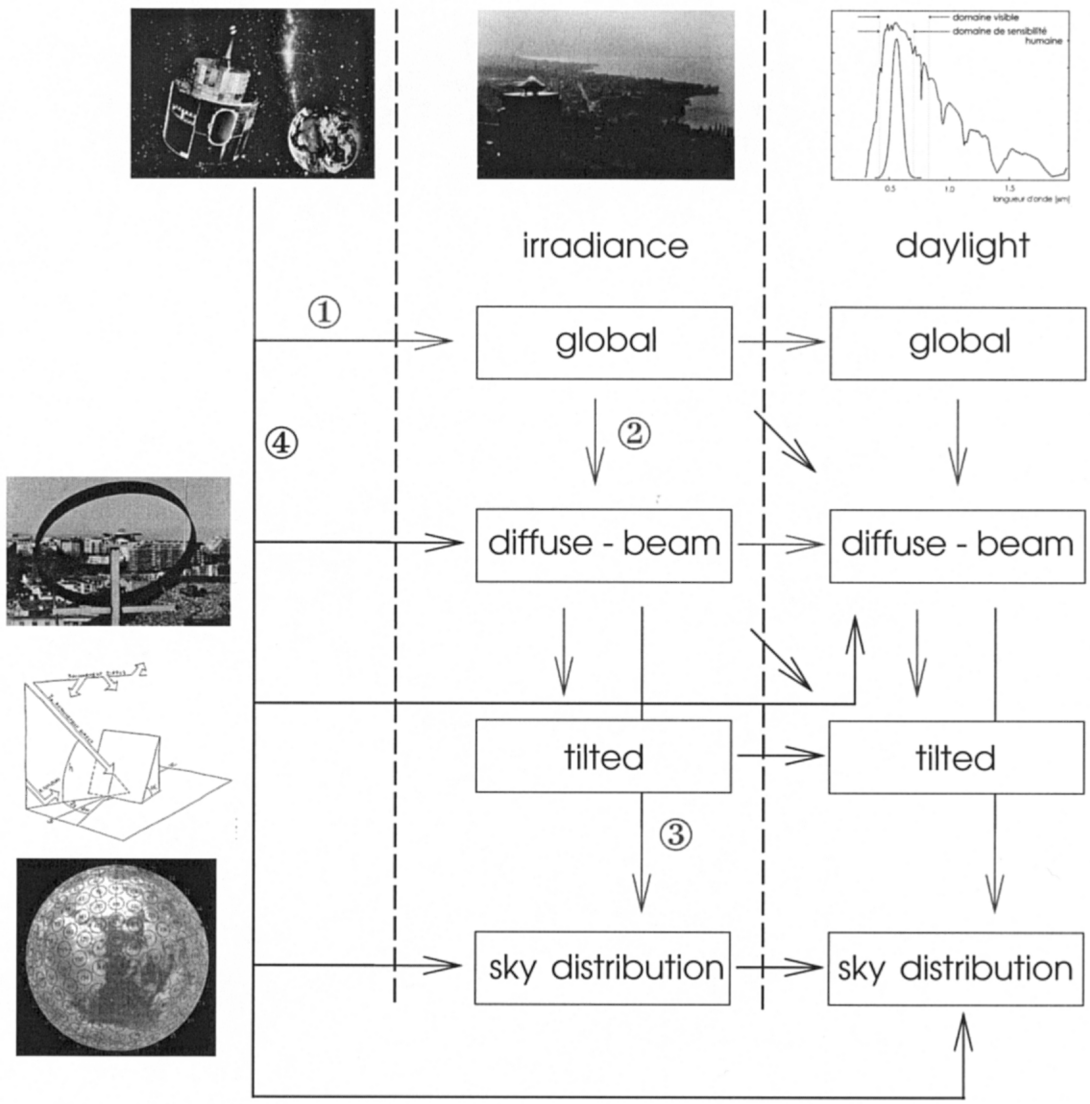
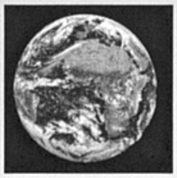
From satellite image to ground component



① traditional or improved heliosat method
② global-to-diffuse or to-beam model
(Perez, Skartveit & Olseth, etc.)
③ luminance & radiance distribution model
(Perez, Kittler, CIE, Brunger, etc.)
④ direct way from pixel to irradiance and daylight components

Pierre Ineichen - University of Geneva *Golden January 3, 1999 - 2*

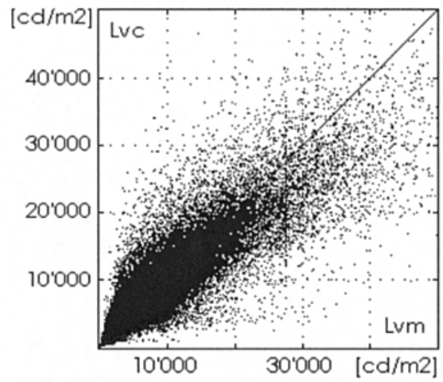
Presentation: Prediction of Non-Global Irradiance Components by Pierre Ineichen



Why to follow the direct way?

1st motivation

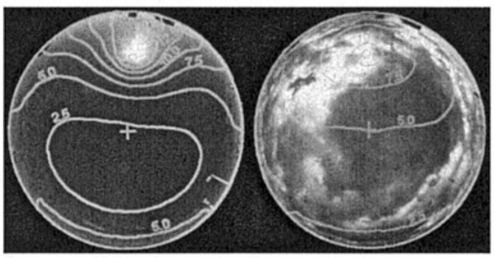
- the modelled sky radiance/luminance distribution has a high dispersion



the models are usually symetric to the sun direction,

the cloud distribution is site dependent (*random?*),

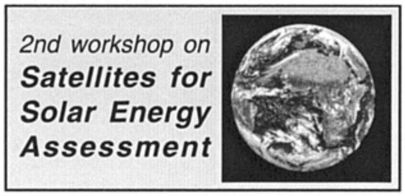
geostatistical model (Perez), but they need local statistical informations



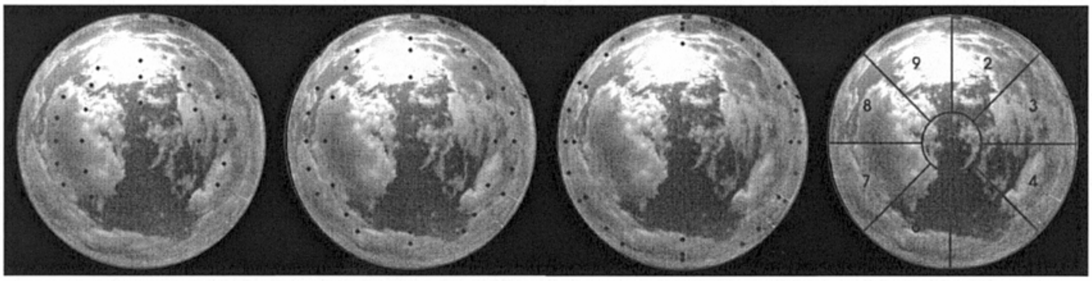
- the satellite image has a directional property

use of the surrounding pixels to take into account the cloud distribution

Radiance/luminance distribution from satellite image

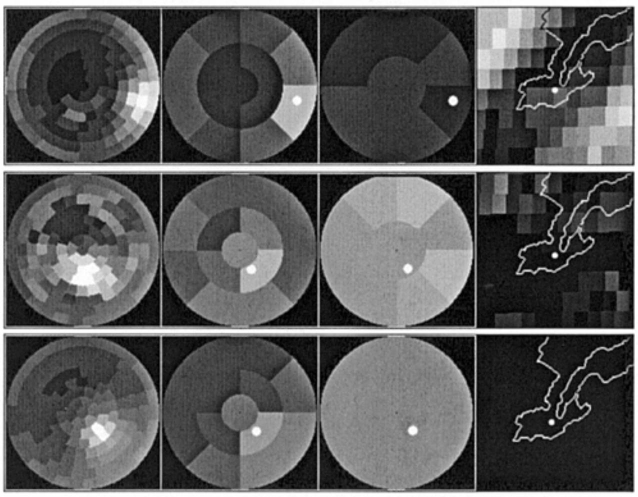


- the *apparent position* of the pixel depends on the cloud altitude:



clouds at 10'000m | at 5'000m | at 1'000m | the 9 zones

- the results obtained with a luminance model



145 zones | 13 zones | model | cloud index

- the model does not take into account the influence of the sun (circumsolar diffuse),
- the cloud altitude is difficult to evaluate even with the IR channel.

Conclusions

the use of a traditional model on the *heliosat global* gives better results!

we developed a luminance model => diffuse model

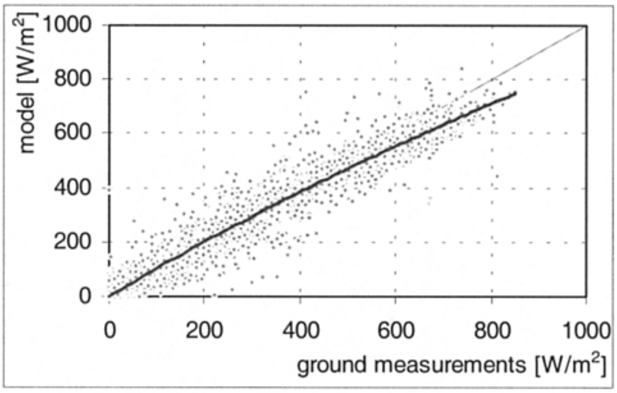
Presentation: Prediction of Non-Global Irradiance Components by Pierre Ineichen

2nd workshop on **Satellites for Solar Energy Assessment**

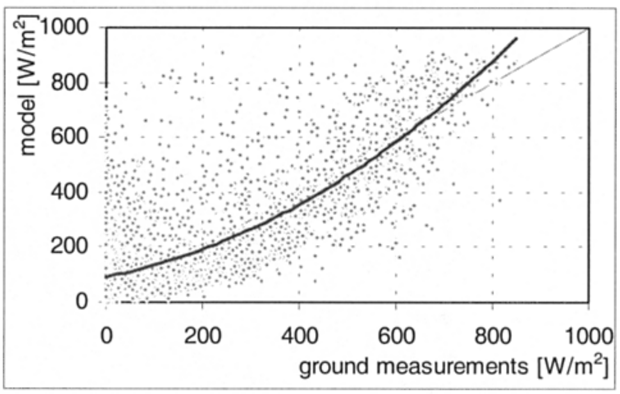
Why to follow the direct way ?

2nd motivation

- the heliosat method gives the global component with a precision of about 30%.
- the use of a global-to-direct (or diffuse) model gives good results on ground measurements:



- the chaining of the two models enhances the dispersion:



- the derivation of a direct way model will avoid the cumulative bias and dispersion.

Presentation: Prediction of Non-Global Irradiance Components by Pierre Ineichen

Why a multiparameter model?

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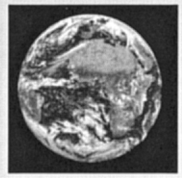
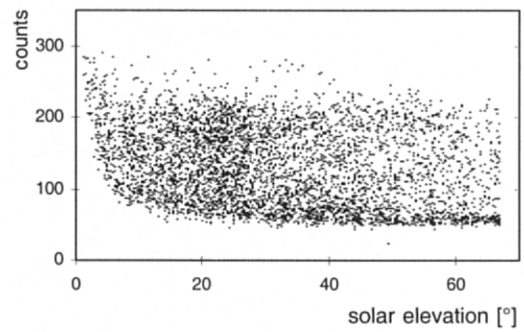
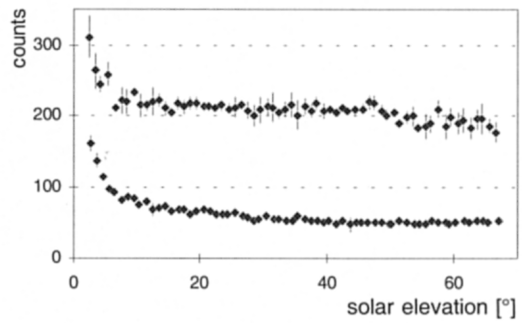


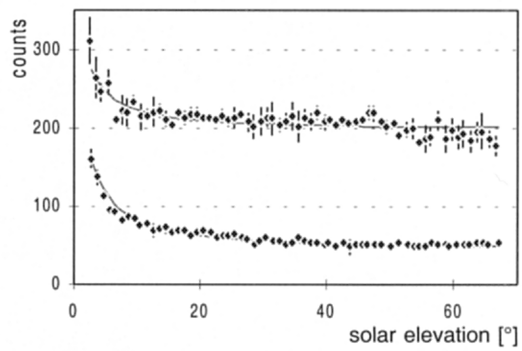
- the raw counts are retrieved from the satellite image



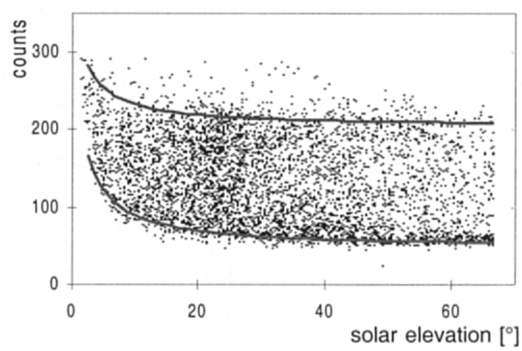
- the upper and lower boundaries are determined by extracting the 10% highest and lowest count values



- a best fit is done on the two series of points



- the two curves represent the influence of the optical air mass on the measured reflectance



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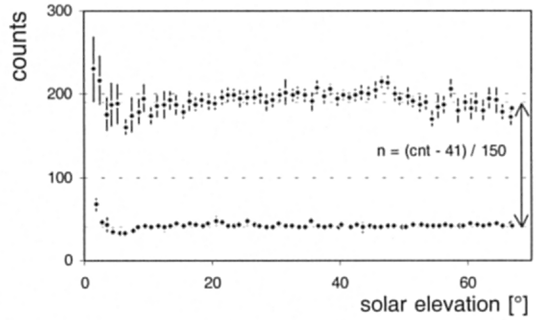
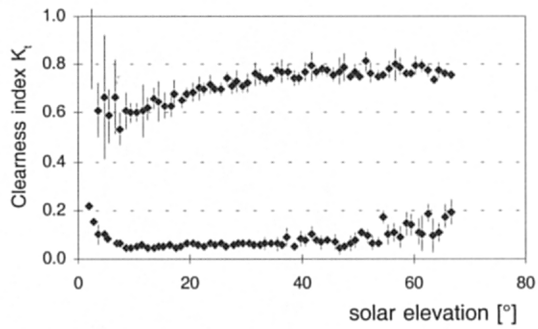
Why a multiparameter model?

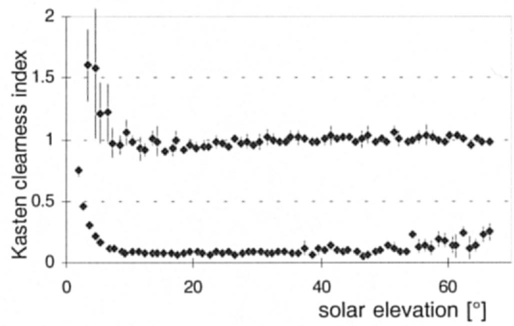
- the counts are corrected for the optical air mass and the backscatter angle effects, a cloud index is derived,



- the ground measurements are normalised to obtain the clearness index



- or using a clear sky model as proposed by Kasten

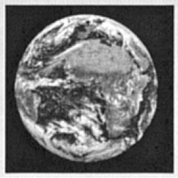


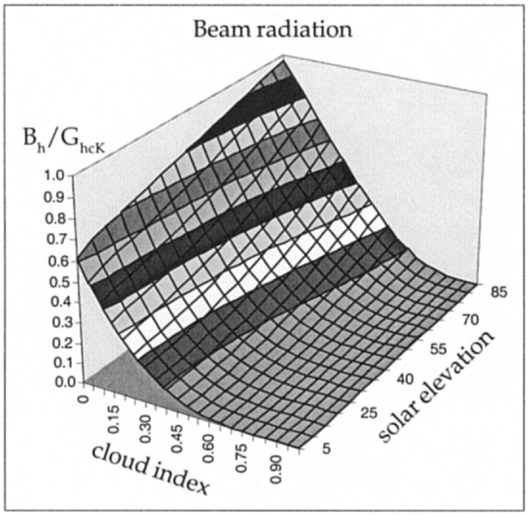
Conclusion

the work done to obtain geometry-independent counts is partly lost by the use of geometry-dependent clearness indices.

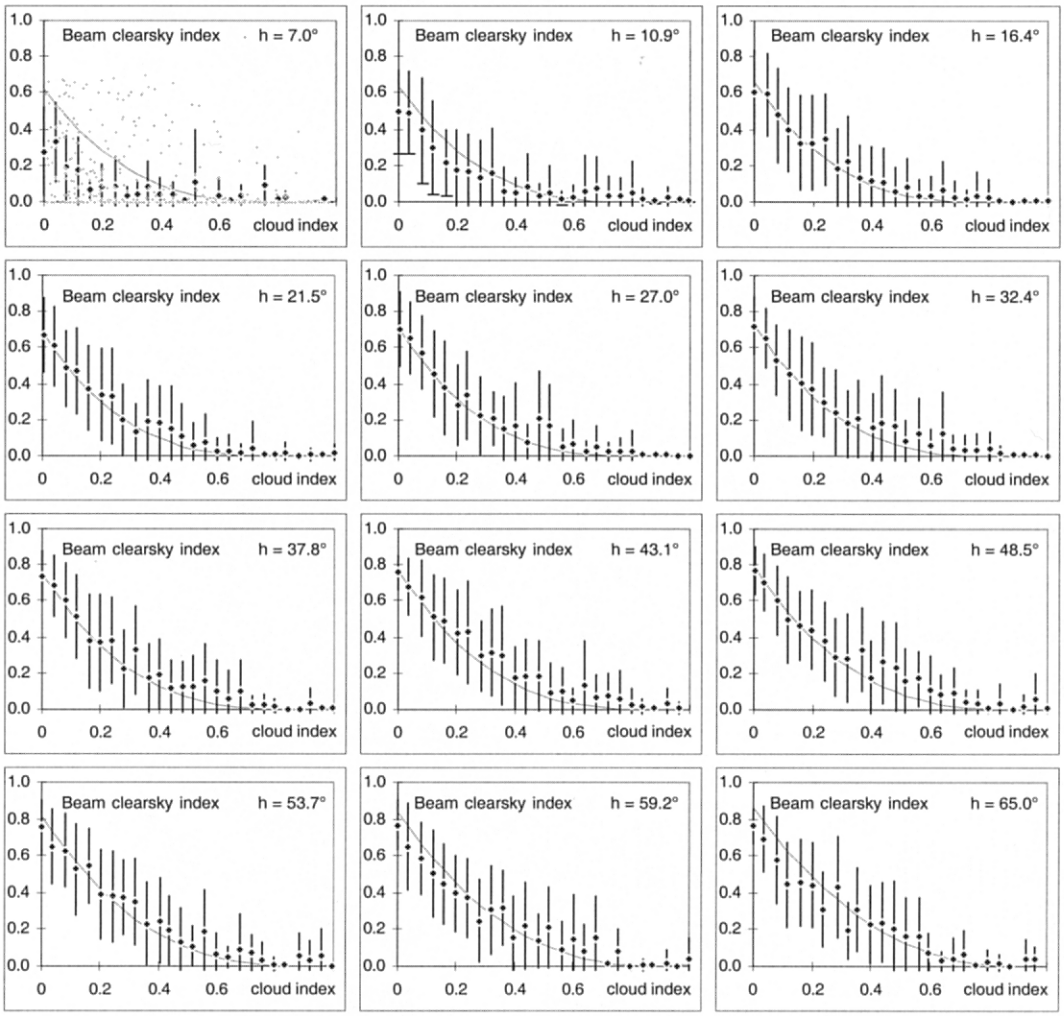
Beam model

2nd workshop on
Satellites for Solar Energy Assessment





- normalisation with the Kasten clear sky model (the clear sky model includes monthly turbidity values)
- two parameters model: cloud index and solar elevation,
- the model is quadratic with the solar elevation and cubic with the cloud index

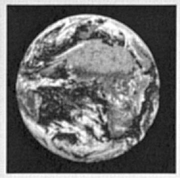


Pierre Ineichen - University of Geneva *Golden January 3, 1999 - 8*

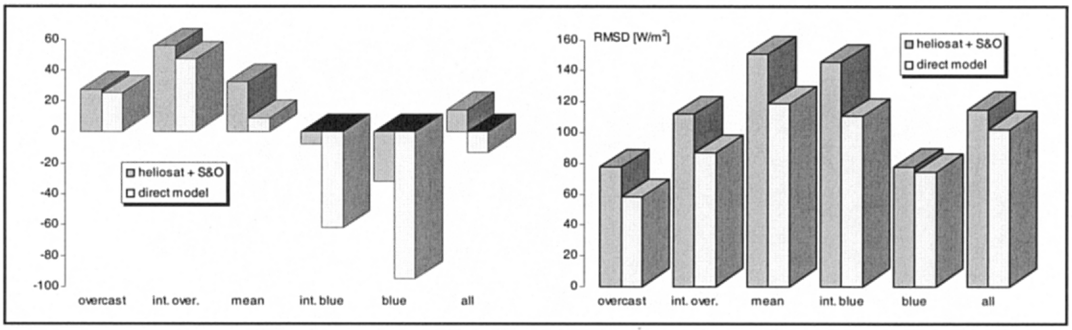
Presentation: Prediction of Non-Global Irradiance Components by Pierre Ineichen

Beam model:
MBD & RMSD results

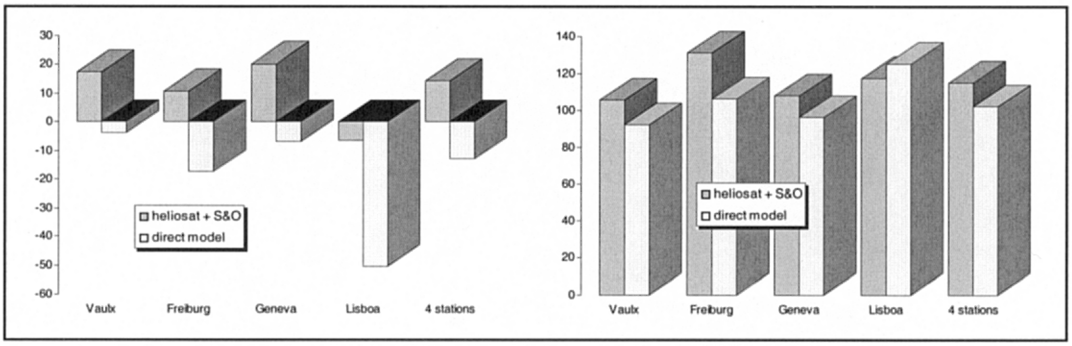
2nd workshop on
Satellites for Solar Energy Assessment



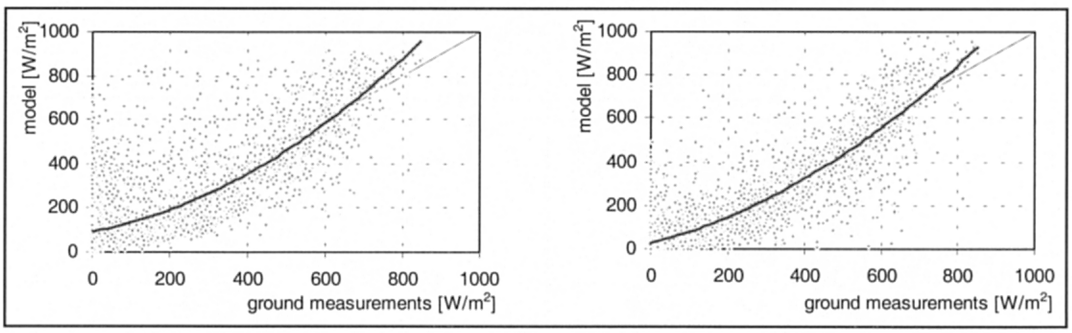
- mean bias difference (MBD) and root mean square difference (RMSD) between model and measurements for five sky types:



- for four european stations:



- comparison between two chained models and the direct model:

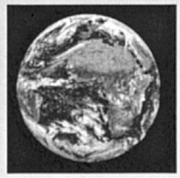


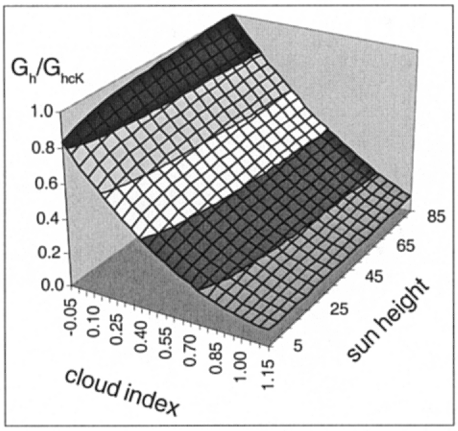
Pierre Ineichen - University of Geneva *Golden January 3, 1999 - 9*

Presentation: Prediction of Non-Global Irradiance Components by Pierre Ineichen

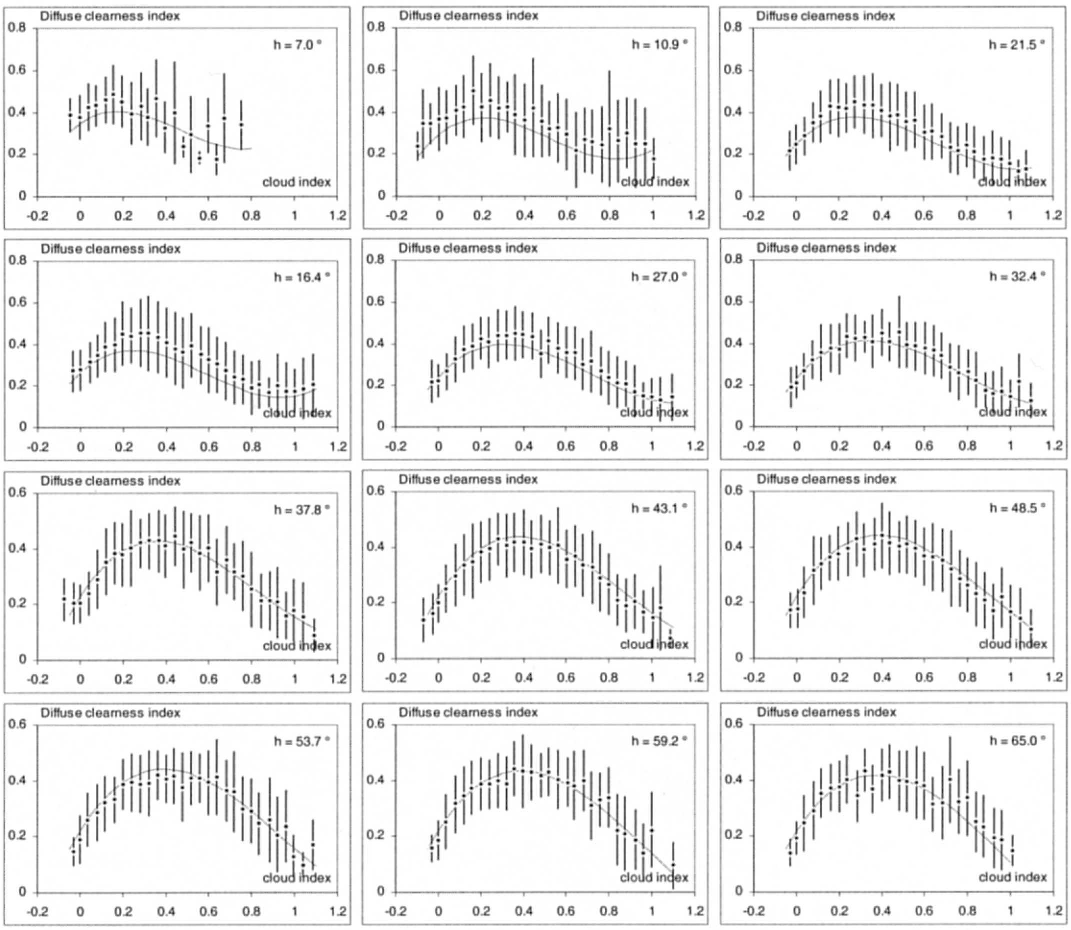
Diffuse and global models

2nd workshop on
Satellites for Solar Energy Assessment





- normalisation with the Kasten clear sky model (the clear sky model includes monthly turbidity values)
- two parameters model: cloud index and solar elevation.

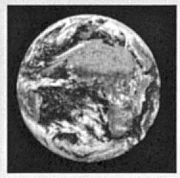


Pierre Ineichen - University of Geneva *Golden January 3, 1999 - 10*

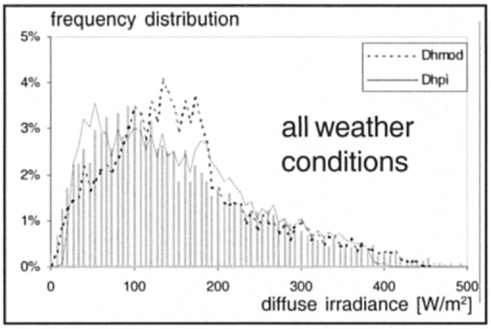
Presentation: Prediction of Non-Global Irradiance Components by Pierre Ineichen

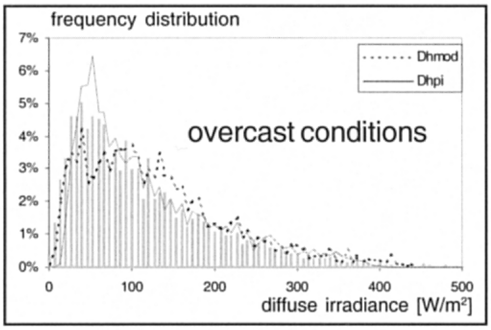
Diffuse model:
frequency distribution results

2nd workshop on **Satellites for Solar Energy Assessment**

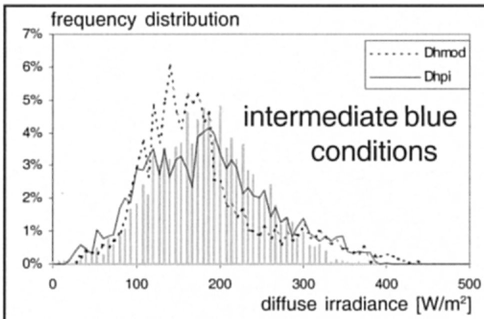


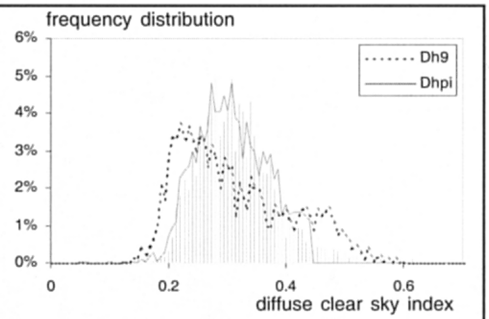
- The frequency distribution analysis can be done in two different ways: in term of radiation or in term of normalized radiation,

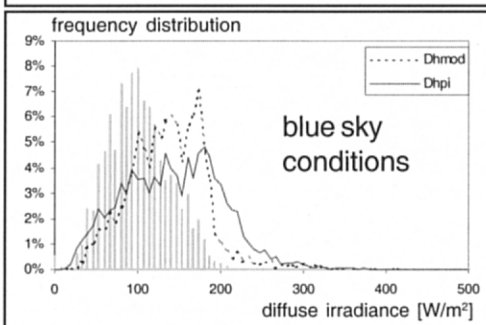


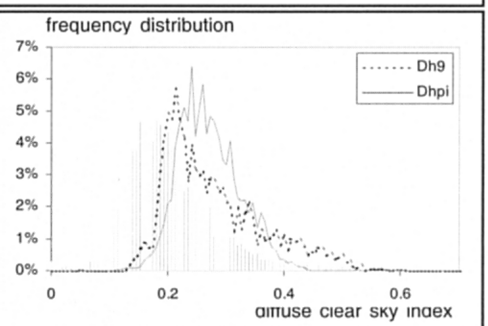


- the absolute radiation frequency distribution gives the probability to have a certain level of radiation: it is the parameter to use when the time distribution of the radiation is not a first priority,
- the relative radiation probability is expressed in term of a radiation level that should occur for a given solar geometry or a given time and day of the year.



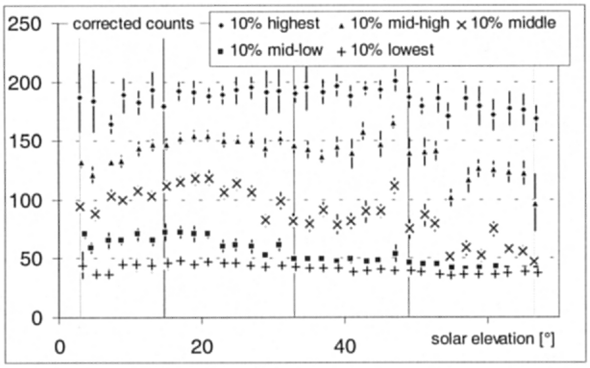


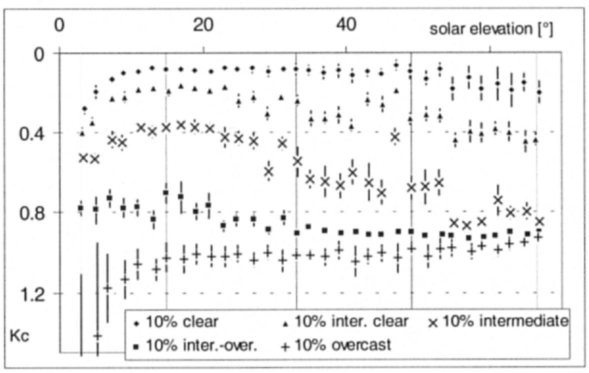


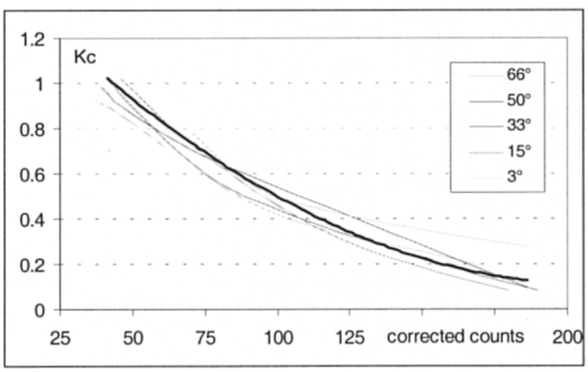


Presentation: Prediction of Non-Global Irradiance Components by Pierre Ineichen

Conclusions







- the evaluation of radiation components from satellite images goes through a correlation between normalized radiations and corrected counts,
- the lowest counts with a very low dispersion correspond to high radiation levels, with high fluctuation, and inversely,
- the relation between the clearness index and the cloud index (or the counts) is not linear (here for the global radiation), and depends on solar elevation,
- this work is a first attempt to evaluate the non-global components directly from a satellite image; it gives slightly better results on a restricted data set. It has to be generalized and assessed.

Presentation: Prediction of Non-Global Irradiance Components by Pierre Ineichen

Combining Ground and Satellite Data

Antoine Zelenka
Swiss Meteorological Institute, 8044 Zurich, Switzerland

External data inputs, such as satellite imagery, can greatly improve spatial interpolation between the nodes of radiation measuring networks. Reciprocally, network measurements can improve the accuracy of satellite-based radiation estimates. An adequate technique for these data fusion processes is the bi-variate geostatistical interpolation called co-kriging.

Consider the satellite estimates, g, as the better sampled, but less accurate co-variable capable of refining the spatial resolution of an interpolation procedure based on the less well sampled, but more accurate principal variable, G, delivered by the radiometric network. Global irradiation G at any location x is then obtained from the bi-linear estimator

$$G(x) = \Sigma\ w\ (x_i, x)\ G(x_i) + \Sigma\ v\ (x_k, x)\ g(x_k) \quad (1)$$

where the first sum stands for the contribution of the network, with G(xi) being the measured value at the site xi, while the second accounts for the contribution of the satellite-based estimates g at each pixel xk. The first sum runs over those network sites i, the second over those pixels k, which lie within the pre-chosen search domain around x. Unbiasedness is enforced by requiring that $\Sigma w_i = 1$ and $\Sigma v_k = 0$. Both conditions, together with that of minimum variance of estimation, allow a unique determination of the weights wi and vk under only very general assumptions.

The weights v predominate in the regions where g and G correlate well, while the weights w predominate when the latter correlation degrades. Thus, the resulting G(x) matches the network's values (within prescribed limits) but respects as much as possible the fine structure defined by the satellite.

The main advantage of co-kriging is that it yields a value for the variance of estimation for every x, a value essential to any solar system planning and design activity. Its main drawback is that it cannot be run completely automatically, because it requires expert selection of functions describing the structure of the fields $G(x_i)$ and $g(x_k)$.

Continuous, stand-alone estimations, as in the case of hourly irradiation, have therefore to benefit from ground observations in some other way. For example, if the network measures also the direct beam at several sites, then essential turbidity information can be input on-line to the satellite model.

COMBINING GROUND AND SATELLITE DATA

Antoine Zelenka

USING <u>GROUND MEASUREMENTS</u> TO IMPROVE SATELLITE ESTIMATES

NETWORK MEASUREMENTS

Radiation monitoring networks (or, at worst: meteorol. networks delivering insolation-related quantities)

Consider simple, robust models with only one to two parameters, delivering estimates for hourly irradiation with 20%-25% RMSE* as compared to the network measurements.

* „state of the art“ values (Gautier and Landsfeld obtain 18%. Gautier C. and Landsfeld M., 1997. Surface solar radiation flux and cloud radiative forcing for the ARM/SGP: A satellite, surface observations and radiative transfer model study. J. Atmos. Sci. 54, 1289-1307.)

IMPROVING THE ESTIMATES:
Require that the satellite estimates match the ground measurements at the network nodes within certain limits.

Note: This is not equivalent to shifting the satellite-derived G(<u>x</u>) surface rigidly „up“ or „down“ above the <u>x</u> plane in order to remove the estimation bias (leaves the RMSE almost unchanged if the bias is not too large). Rather, add local trends to the surface, so that it matches the nodes without loosing it's fine structure.

POINT MEASUREMENTS

Elaborate programmes at carefully selected sites during special observing periods:

Surface SW & LW irradiance and componenets (=> turbidity), radiosondes, LIDARs, SODARs, RADARs, aircrafts, etc. provide thorough characterisation of the vertical structure of the atmosphere, as well as micro- and macrophysical properties of clouds.

=> integration of equation of radiative transfer along the line of sight to the satellite and for the downward flux density at the surface.

Charlock T. P. and Alberta T. L., 1996. The CERES/ARM/ GEWEX Experiment (CAGEX) for the retrieval of radiative fluxes with satellite data. *Bull. Amer. Meteor. Soc.*, **77**, 2673-2683.

Chou M.-D. and Zhao W., 1997. Estimation and model validation of surface solar radiation and cloud radiative forcing using TOGA COARE measurements. *J. Climate*, **10**, 610-620.

Inadequate for large amount of data as regional insolation mapping with high spatial resolution or for long-term high temporal resolution datasets.

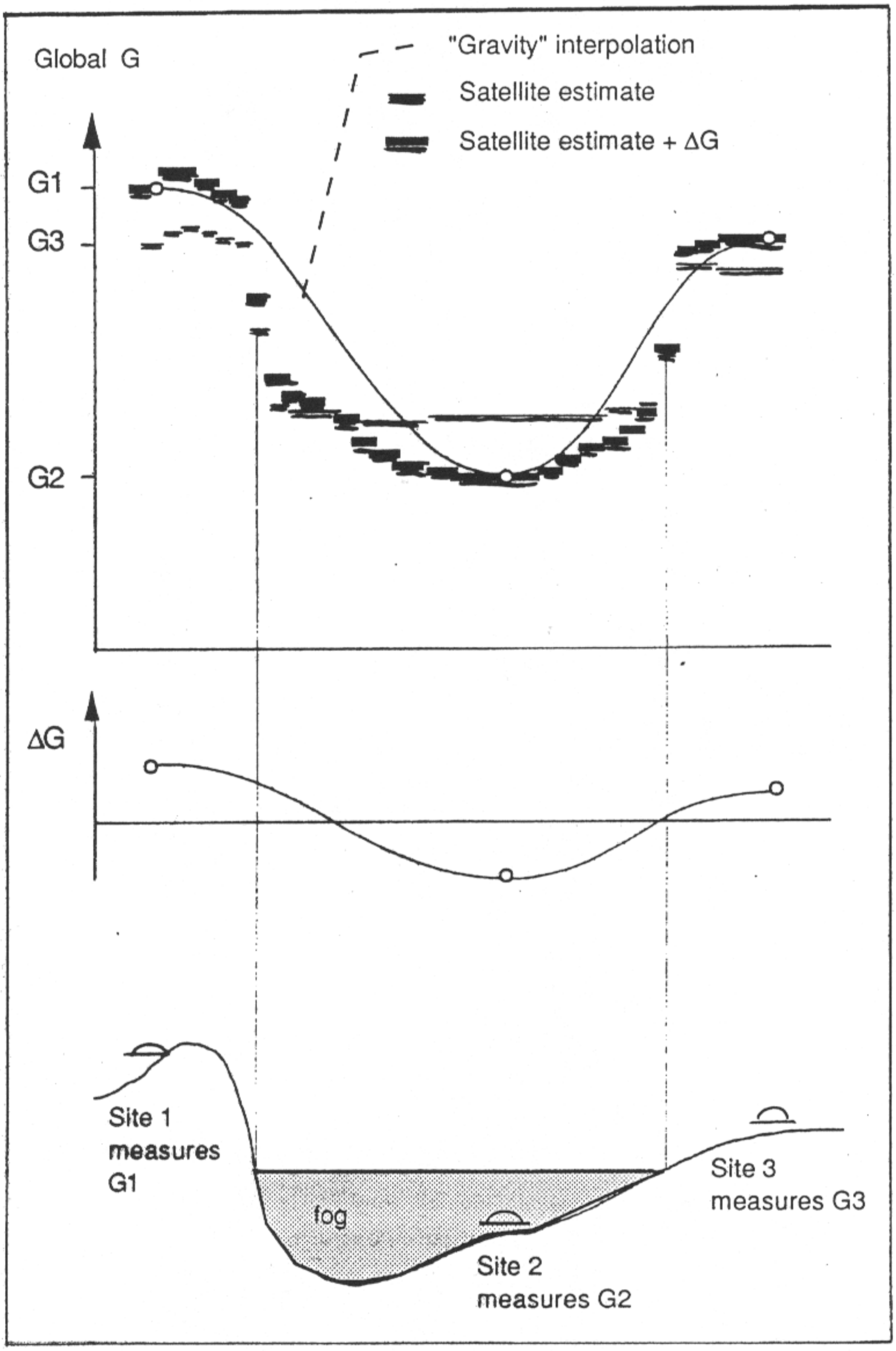


Fig. 5.3.1: Mere interpolation between sites 1, 2 and 3 misses the sharp transitions at the fog boundaries. Satellite estimates render them correctly in location but not necessarily in absolute value. Application of an interpolated, i.e., location-dependent correction ΔG = G(meas)-G(sat) leads to predictions which reproduce the measurements without real loss of spatial resolution. The discrete, discontinuous shape of the satellite estimates is intended to mimic the pixel size of the satellite image.

VPP

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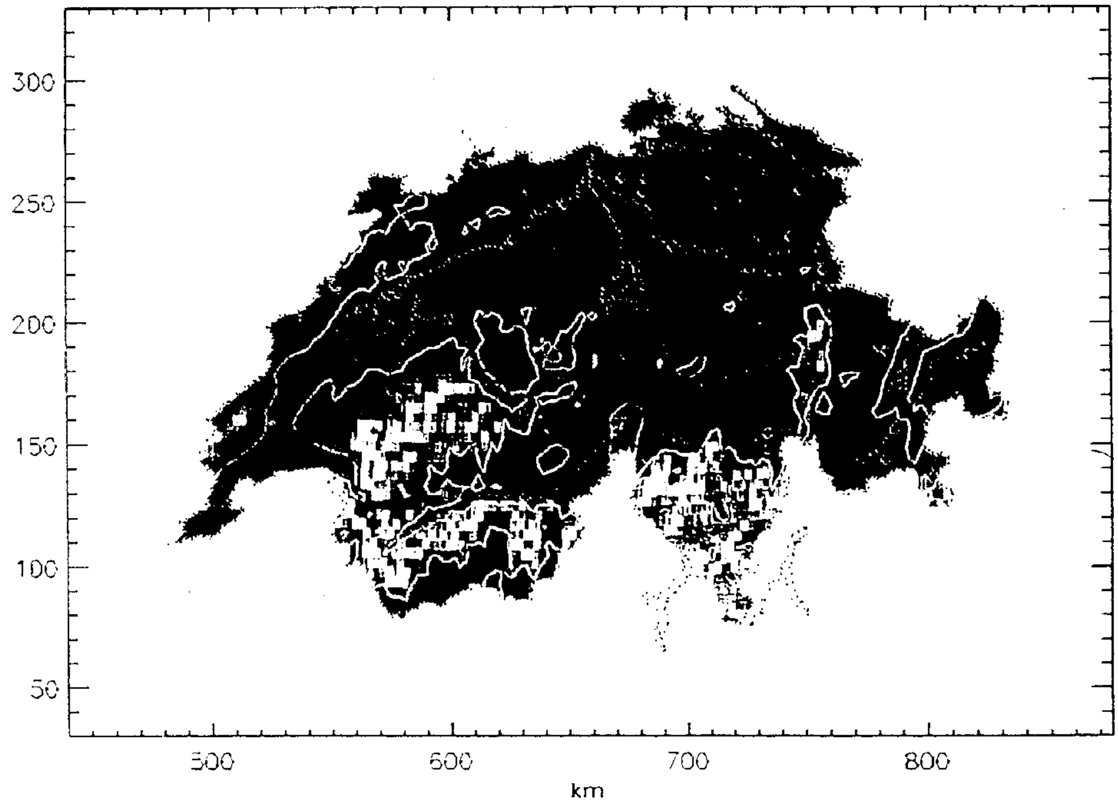
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azk

E13

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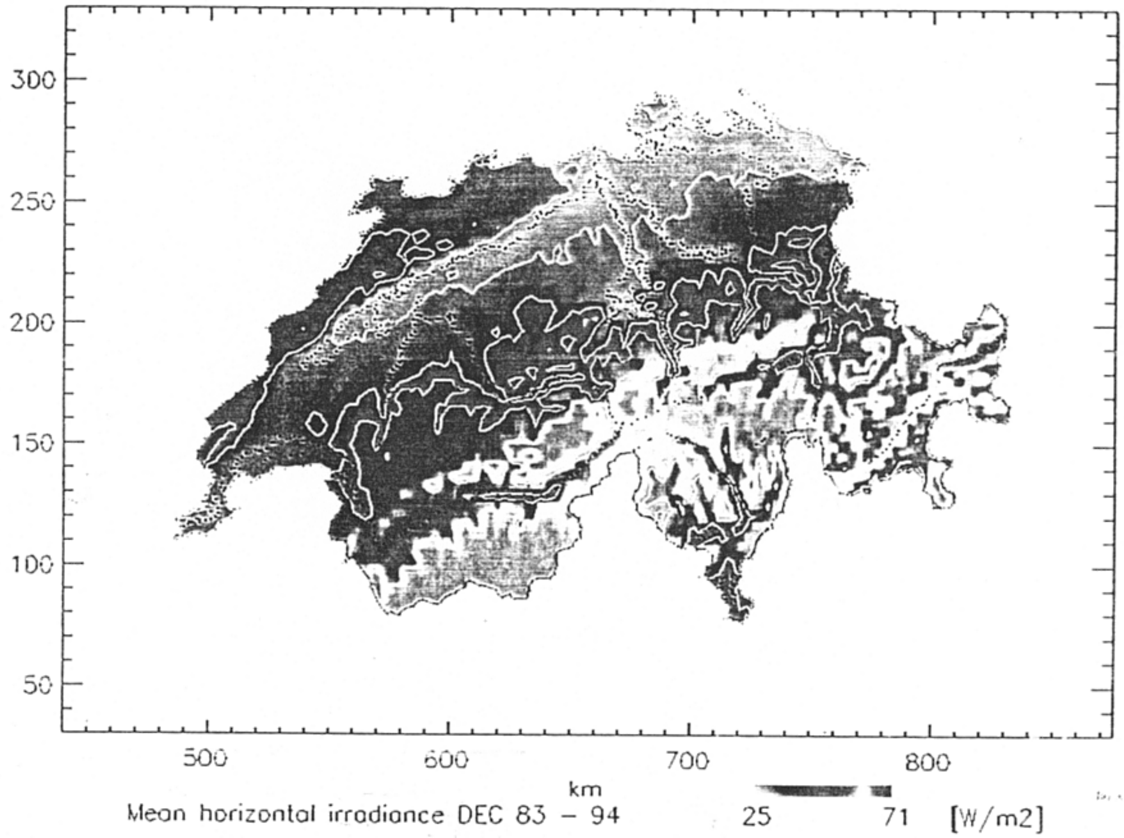
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250
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600
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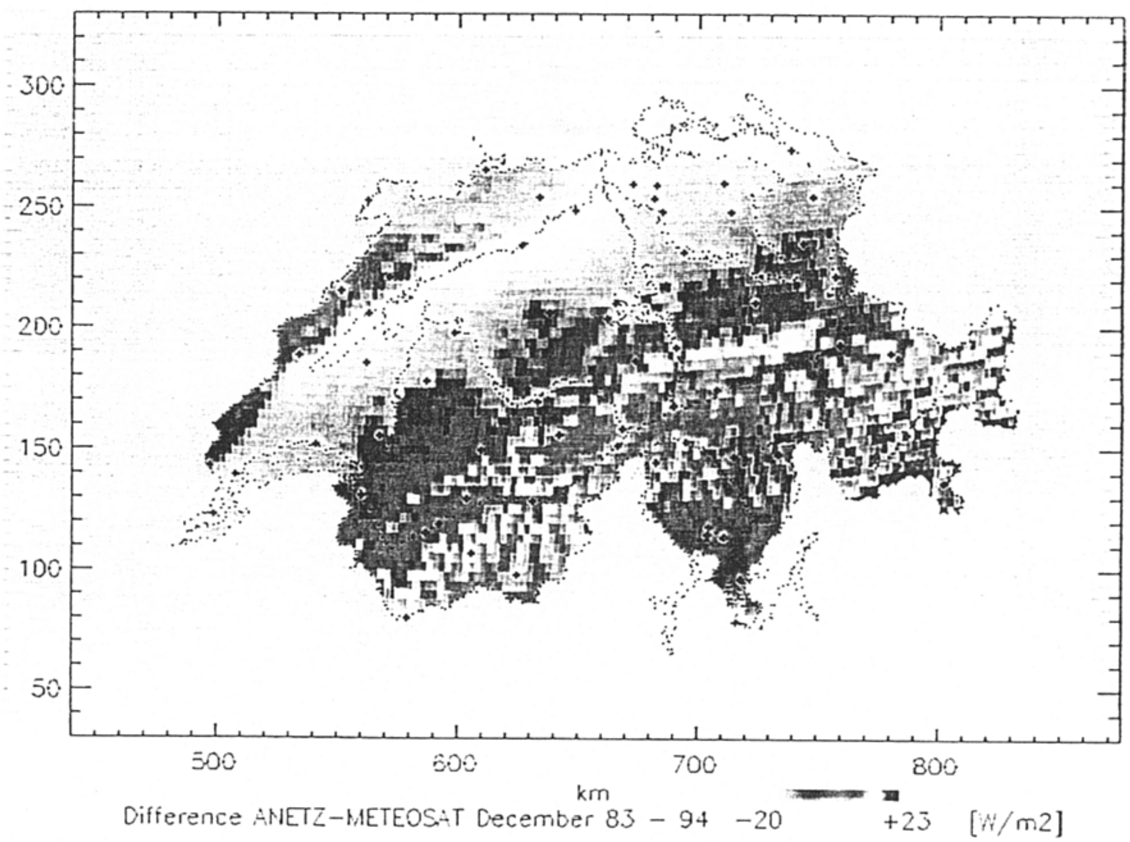
800
km
Mean horizontal irradiance DEC 83 - 94
25
71
[W/m2]


300
250
200
150
100
50
500
600
700
800
km
Difference ANETZ-METEOSAT December 83 - 94
-20
+23
[W/m2]

VPP

azk

E13

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Job started at	27-SEP-1995 19:49:55

Kriging in the Intrinsic Case

Hypotheses: *Field Z(x) is "weakly stationary of order two"*

Introducing the Variogram function $\gamma(h)$

$$E[Z(x+h)-Z(x)] = 0$$

$$Var[Z(x+h)-Z(x)] = 2\,\gamma(h) \quad (\textit{independent of } x)$$

Formulation:

Weights — *Measured values at network nodes*

Linear Estimator $\quad Z_0^* = \sum_\alpha \lambda^\alpha Z(x_\alpha)$

No bias $\quad E[Z_0^* - Z_0] = 0$

Optimum $\quad Var[Z_0^* - Z_0]$ *minimal*

Ordinary Kriging equations: *Build empirical variogram $\gamma(h)$*

$$\sum_\beta \lambda^\beta \gamma_{\alpha\beta} + \mu_0 = \gamma_{\alpha 0}$$

$$\sum_\alpha \lambda^\alpha = 1$$

Variance of Estimation Z_0^* $\quad (\sigma^2)^* = -\gamma_{00} + \sum_\alpha \lambda^\alpha \gamma_{\alpha 0} + \mu_0$

Limits within which Co-K results have to honour measured values at the network nodes:

Recall the results of the *effective RMSE* presentation: the limits are defined by the intercomparison noise originating from

- the time/space disparity between the satellite-derived and the ground data,
- from measuring errors (ground and satellite),
- from the genuine micro-variability of the irradiance field at the sub-pixel scale.

This **intercomparison noise** has been found to amount to **about 19% RMSE**. The result of the data fusion process can deviate by this amount from the network's measurements.

Co-K drawback: Variography requires expert knowledge and should not be automated.

=> Co-K is not suited for unattented permanent hourly retrievals.

Acceptable alternative:

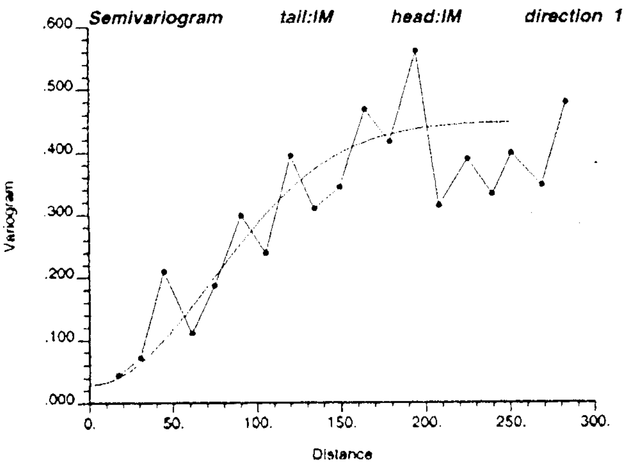
Use pre-chosen weights to interpolate the differences ground minus satellite at the network nodes. Add map of differences to satellite map (as in example above).

6.2. Cokriging für den Juli 1993

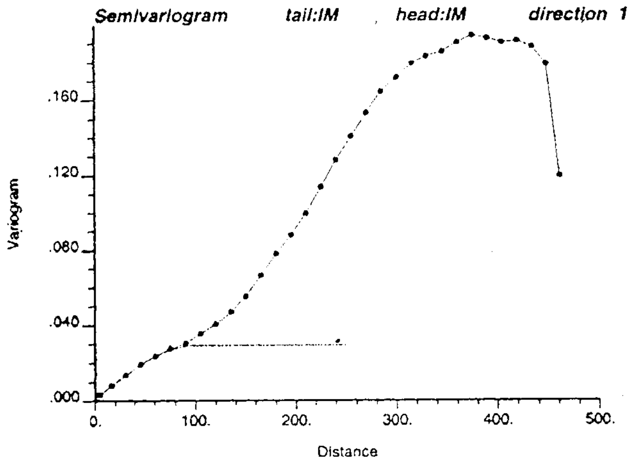
Für die Interpolation mit Cokriging wurde das Programm *cokb3dm.exe* aus GSLIB benutzt. Um die Interpolation durchzuführen, müssen die beiden Variogramme der beiden Datensätze sowie deren Crossvariogramm vorhanden sein. Diese drei Variogramme müssen die Cauchi-Schwarz-Relation

$$|\gamma_{12}(h)| \leq \sqrt{[\gamma_1(h)\gamma_2(h)]}$$

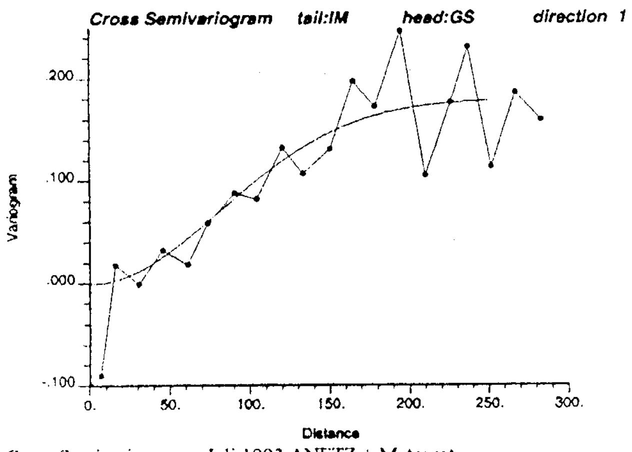
für jeden Punkt des Variogrammes erfüllen, was hier vollumfänglich der Fall ist.



Semivariogramm Juli 1993 ANETZ



Semivariogramm Juli 1993 Meteosat



Cross Semivariogramm Juli 1993 ANETZ + Meteosat

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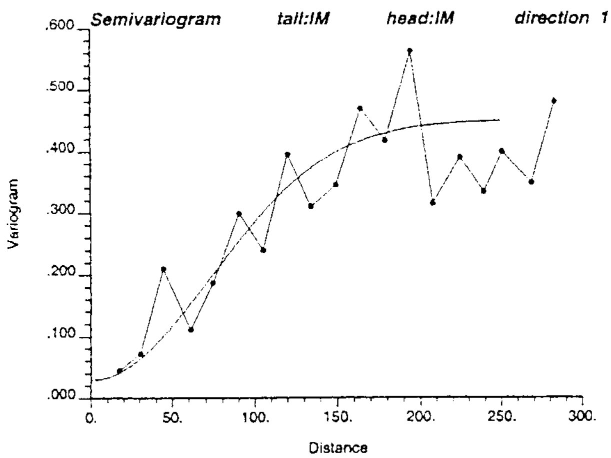
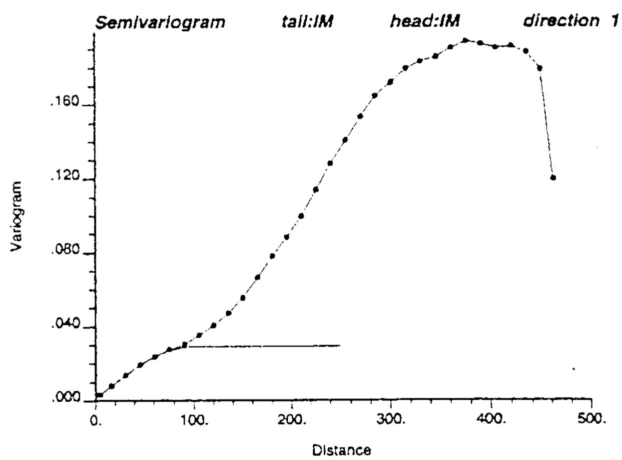
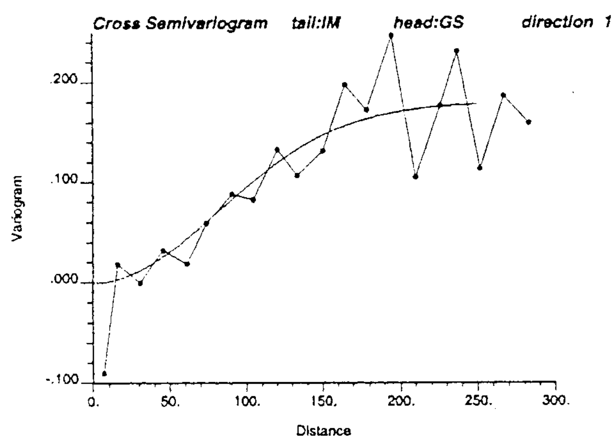


Semivariogramm Juli 1993 ANETZ



Semivariogramm Juli 1993 Meteosat



Cross Semivariogramm Juli 1993 ANETZ + Meteosat

Die Interpolation brachte die beiden Karten auf den nächsten zwei Seiten hervor. Die erste ist die eigentliche Interpolation in kWh/m², sie zeigt einige Änderungen im Vergleich zur Kriging-Karte, speziell im kleinräumigen Bereich sind feinere Strukturen vorhanden. Im Grossen und Ganzen sind sich die beiden Karten aber sehr ähnlich. Die zweite Karte stellt die dazugehörige Schätzvarianz dar, die zur Fehlerabschätzung benutzt wird. Im Vergleich zum Kriging sind die Werte durchwegs kleiner, was auf grössere Genauigkeit im Schätzprozess hindeutet. Allerdings sind die Unterschiede geringer als erwartet. Speziell aber die hohe Schätzvarianz der beiden Dreiecke Basel-Chasseral-Bern sowie Wädenswil-Chur-Disentis hat stark abgenommen, was zeigt dass die Meteosatdaten dort einen nicht zu unterschätzenden Einfluss auf die Schätzung haben. Somit lässt sich die Aussage machen, dass eine

Co-kriging

Bi-variate geostatistical interpolation with bi-linear estimator

$$\mathbf{G(\underline{x}) = \Sigma\ w(\ \underline{x}_i,\ \underline{x}\ )\ G(\underline{x}_i) + \Sigma\ v(\ \underline{x}_k,\ \underline{x}\ )\ g(\underline{x}_k)}$$

First sum accounts for the contribution of the network measurements G at stations $\underline{x}_i$

Second sum accounts for the contribution of the satellite-based estimates g at each pixel $\underline{x}_k$.

The first sum runs over those network sites i, the second over those pixels k, which lie within a pre-chosen search domain around $\underline{x}$.

Unbiasedness is enforced by requiring that $\Sigma w_i = 1$ and $\Sigma v_k = 0$. Both conditions, together with that of minimum variance of estimation, allow a *unique* determination of the weights w_i and v_k under only very general assumptions.

The weights v predominate in the regions where g and G correlate well, while the weights w predominate when the latter correlation degrades.

When main and co-variable correlate perfectly, then co-kriging reduces to to kriging interpolation of the differences between both variables.

The main advantage of co-kriging is that it yields a value for ***the variance of estimation*** for every $\underline{x}$, a value essential to any solar system planning and design activity

Promising alternative

Consider the following, extremely simple satellite model:

$$\tau_{atm}(n) = \tau_{atm}(0)\ (\ 1 - n\ )$$

where $\tau_{atm}(n)$ and $\tau_{atm}(0)$ are the atmospheric transmittances for the cloudy and clear sky, respectively. The cloudiness is expressed with the cloud index n (Cano *et al.*, 1986)

$$n = (\ \alpha_{toa} - \alpha_{toa,min}\ ) / (\ \alpha_{toa,max} - \alpha_{toa,min}\ )$$

α_{toa} is the instantaneous planetary albedo,

$\alpha_{toa,min}$ corresponds to a clear, clean and dry sky,

$\alpha_{toa,max}$ corresponds to a heavily overcast sky.

Clear sky transmissivity

Model of Kasten *et al.* (1984), derived from 10 years of observations by the radiometric network of the German Weather Service:

$$\tau_{atm}(0) = 0.84\exp(-0.027 T_L m)$$

Suggestion:
Use an RSR network to derive Linke's turbidity factor T_L

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PERFORMANCE EVALUATION

Swiss network 4/94

Daily Data

NETWORK KRIGING	———	17%
SATELLITE ALONE	———	17%
CO-KRIGING	———	13.5%

Existing NASA Satellite-Derived Surface Insolation Products

Charles H. Whitlock and Roberta C. DiPasquale
Analytical Services & Materials, Inc.
One Enterprise Parkway, Suite 300
Hampton, VA 23666-5845

Donald E. Brown, William S. Chandler, and Xuwu Xiang
Science Applications International Corporation
One Enterprise Parkway, Suite 300
Hampton, VA 23666-5845

Nancy A. Ritchey
Computer Sciences Corporation
3217A North Armistead Ave
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This paper reviews three NASA surface insolation data sets that are now available free of cost to the public from the NASA Distributed Active Archive System (DAAC). All three data sets cover the entire globe using a 280-km grid system. Two are science data sets, and one is formulated for commercial applications in the Solar Energy industry. The first science data set is the Version 1.1 World Climate Research Program's Surface Radiation Budget data for the period from March, 1985 through December, 1988. The second science Surface Radiation Budget data set contains both insolation and longwave radiation products for the period between July 1983 and June 1991. The third data set is commercially oriented and was developed at the request of the DOE National Renewable Energy Laboratory. Accuracies and limitations of these satellite products will be discussed on a region-by-region basis.

Existing activities to improve NASA's commercial application data sets will also be presented.

EXISTING NASA SATELLITE-DERIVED SURFACE INSOLATION PRODUCTS

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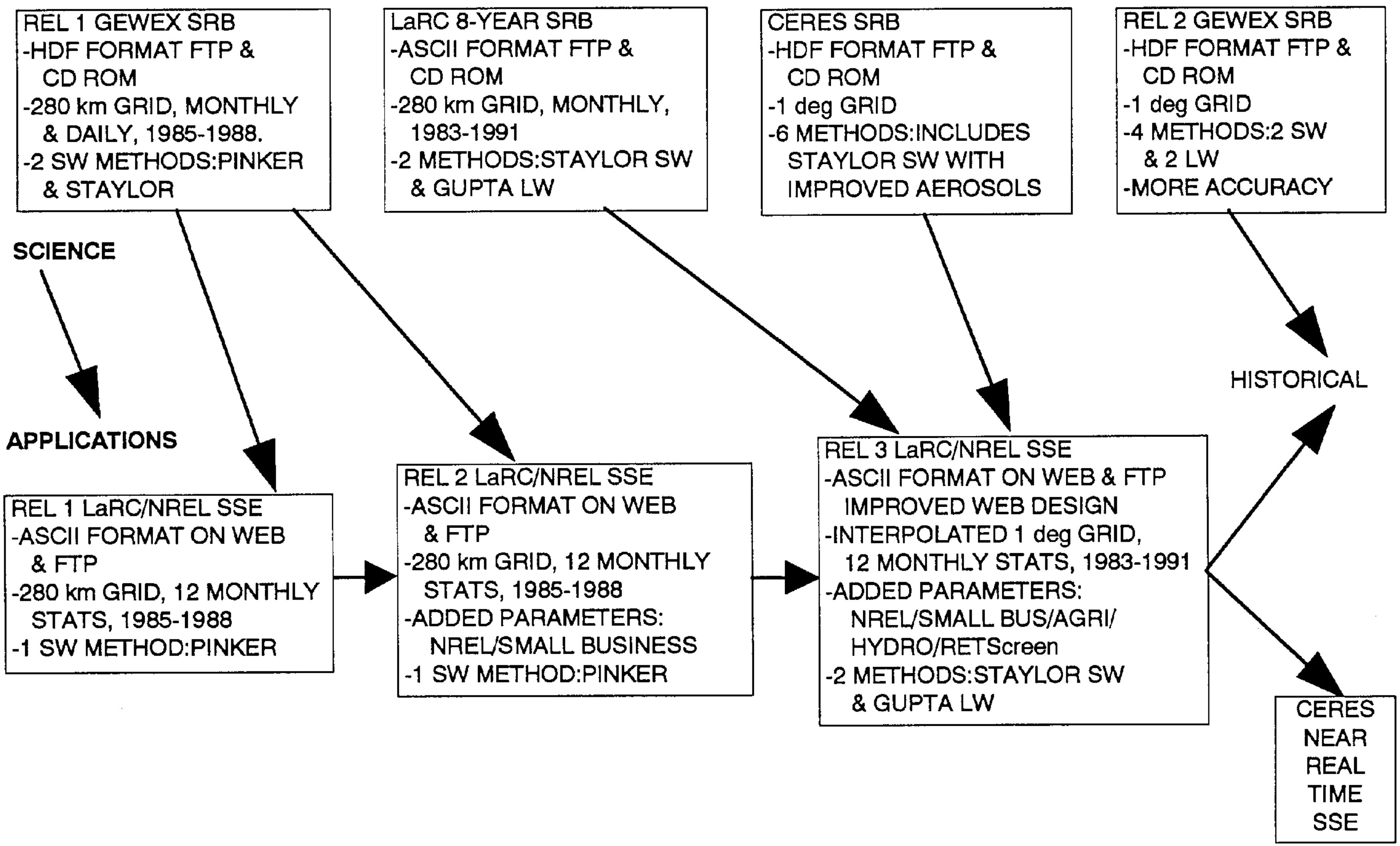
Presented
at the
DOE 2nd Workshop on Satellites for Solar Energy Assessments
February 3-4, 1999
Golden, Colorado

NASA "OFFICIAL" SRB ACTIVITIES



"OFFICIAL" = APPROVED FOR RELEASE THROUGH EOS DAAC SITES.

Presentation: Existing NASA Satellite-Derived Surface Insolation Products
By Charles H. Whitlock and Roberta C. DiPasquale

SSE WEB SITE PARAMETERS

(STATISTICS FOR 12 MONTHS)

RELEASE 1 → **RELEASE 2** → **RELEASE 3**

RELEASE 1

-SW INSOLATION:
- AVG, MAX,MIN
- MULTI-DAY MAXS
- MULTI-DAY MINS

-3-HR DIURNAL:
- SOLAR ELEVATION
- SW INSOLATION
- CLOUD % & OPT DEPTH

-AVERAGE:
- AEROSOL OPT DEPTH
- COL WATER VAPOR
- AIR TEMP
- CLOUD % & OPT DEPTH

RELEASE 2

-IMPROVED TERMINOLOGY

-SOLAR AZIMUTH

-BACK-UP SYS DESIGN INFO

-SURPLUS OUTPUT INFO

RELEASE 3

-LW IRRADIANCE

-WINDS

-PRECIPITATION

-PAR IRRADIANCE

-VARIOUS TEMP PARAMETERS

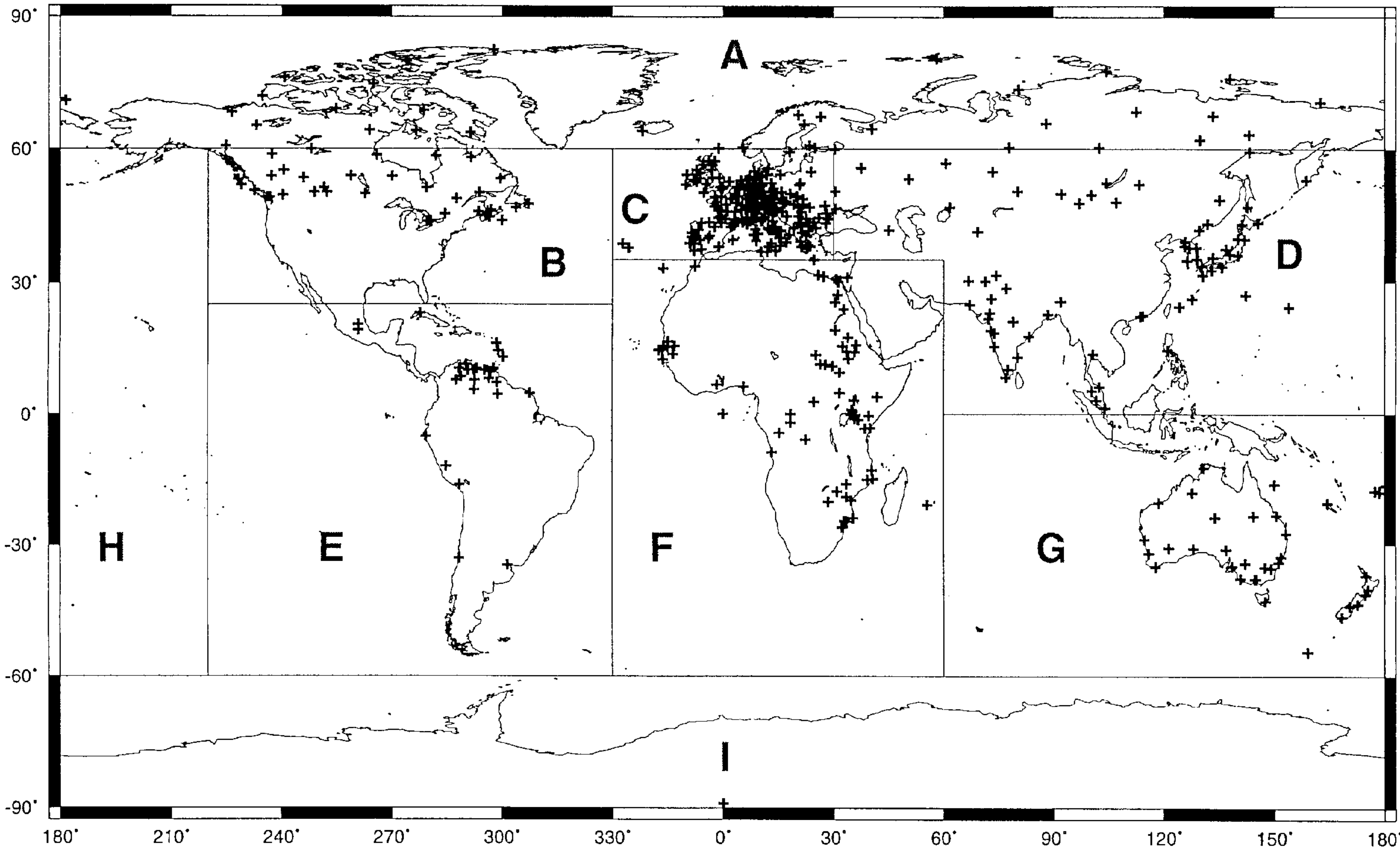
-SPECIFIC HUMIDITY

-RELATIVE HUMIDITY ??

-PRESSURE

-SURF ALBEDO

Presentation: Existing NASA Satellite-Derived Surface Insolation Products
By Charles H. Whitlock and Roberta C. DiPasquale


A
B
C
D
E
F
G
H
I
90°
60°
30°
0°
-30°
-60°
-90°
180°
210°
240°
270°
300°
330°
0°
30°
60°
90°
120°
150°
180°

1986 sites

COMPARISON OF PINKER AND STAYLOR RESULTS OVER GLOBE

VER 1.1 WCRP/SRB FOR OCTOBER 1986

	PINKER MTD		STAYLOR MTD	
REGION	BIAS %	RMS %	BIAS %	RMS %
A	2.6	20	-1.1	21
B	3.1	14	-0.6	15
C	5.8	15	2.6	14
D	9.6	16	7.5	15
E	6.6	18	2.7	18
F	2.1	12	1.1	12
G	4	10	0.9	9
AVERAGE =	4.8	15.0	1.9	14.9

NOTE: GROUND SITE DATA COURTESY NREL AND WRDC IN ST PETERSBURG.

PRESENT ACCURACY OF RELEASE 1 & 2 SSE INSOLATION VALUES

~RMS FOR FLAT & LOW-MOUNTAIN CELLS

REGION	JAN	APRIL	JULY	OCT
EAST & WEST EUROPE	10%(+)	5%(+)	10%(+)	10%(+)
CENTRAL ASIA	15%(-)	10%(-)	10%(-)	10%(-)
CENTRAL NORTH AMERICA	5%	10%	10%	10%
CENTRAL AFRICA	30%(+)	15%	40%(+)	10%(+)
ASWAN DESERT	8%(-)	8%(-)	8%(-)	8%(-)
CONGO RAINFOREST	30%(+)	8%(-)	20%(+)	10%
AMAZON RAINFOREST	20%(+)	20%(+)	20%(+)	20%(+)
GUIANA HIGHLANDS OF SOUTH AMERICA	30%	20%(+)	25%(+)	10%(+)
KOUMAC, NEW CALEDONIA	10%	10%(-)	10%(-)	5%(-)
FIJI	15%(+)	15%(+)	15%(+)	15%(+)
KWAJALEIN	5%(-)	5%(-)	5%(-)	5%(-)
BERMUDA	5%(-)	5%(-)	5%(-)	5%(-)
WEST PACIFIC ASIA COASTAL CITIES	8%	35%(+)	25%(+)	10%(+)
SOUTH POLE	20%(-)	NA	NA	NA
ANTARCTIC COASTAL ICE SHELF	20%(-)	NA	NA	NA

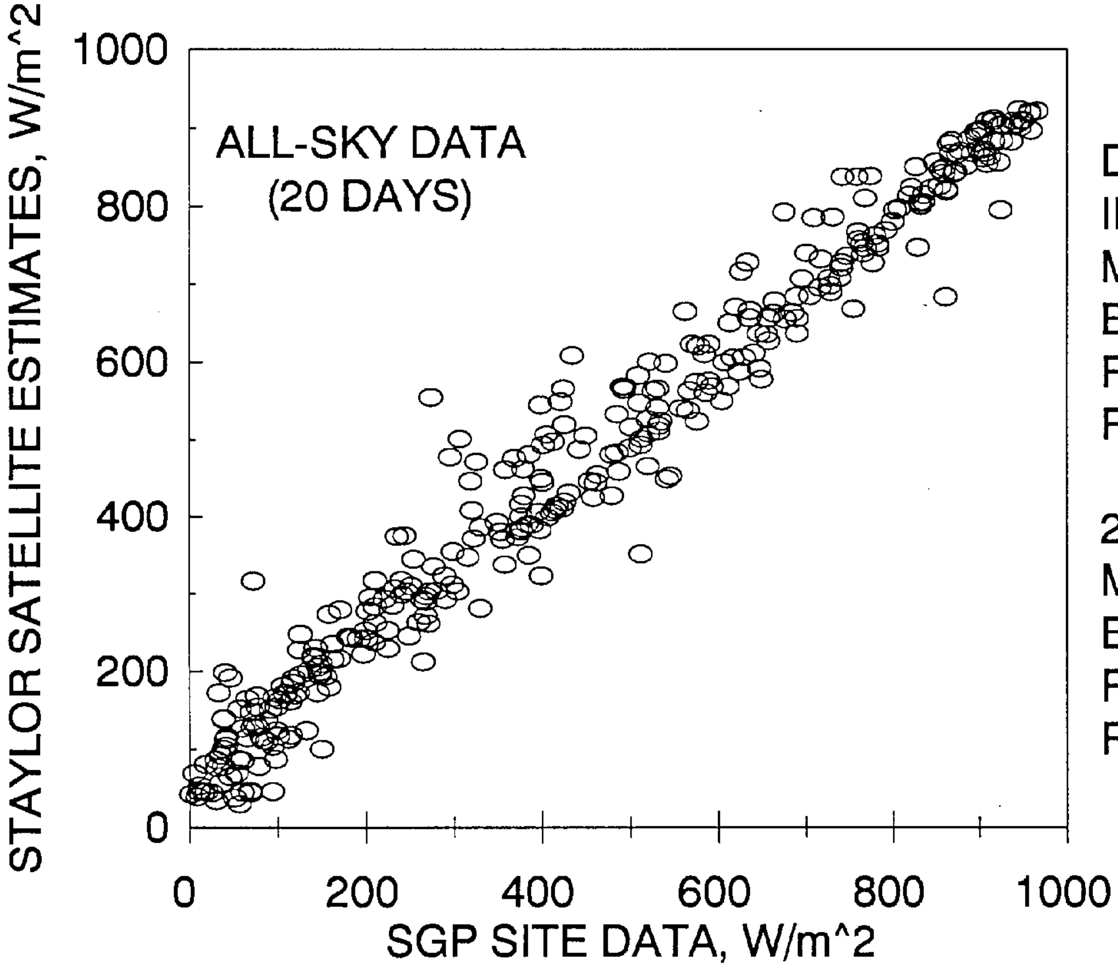
(+) INDICATES SATELLITE BIASED HIGHER THAN GROUND SITE DATA.
(-) INDICATES GROUND SITE > SATELLITE.
GROUND SITE DATA COURTESY SWISS FEDERAL INSTITUTE OF TECHNOLOGY IN ZURICH

SUMMARY:

1. **VALUES ARE ERRATIC AT COASTLINES NEAR MOUNTAINS.**
2. **LARGE (+) VALUES ARE CAUSED BY HIGH POLLUTION IN AEROSOLS.**
3. **LARGE (-) VALUES OVER BARE SNOW & ICE ARE CAUSED BY SATELLITE OPTICS.**

STAYLOR VS SGP ARM DATA FOR APRIL 1994

NOAA 1/2 HR DATA AVERAGED +/- 15 MIN



DAYLIGHT
INSTANTANEOUS:
MEAN = 421 W/m^2
BIAS = +4.6%
RMS = 16.5%
POINTS = 346

24-HR DAILY:
MEAN = 161 W/m^2
BIAS = +4.6%
RMS = 7.9%
POINTS = 20

PROBABLE BEST ACCURACY USING OPERATIONAL SATELLITES:

BIAS < 5%

STD ERR (W/O BIAS) = 5%

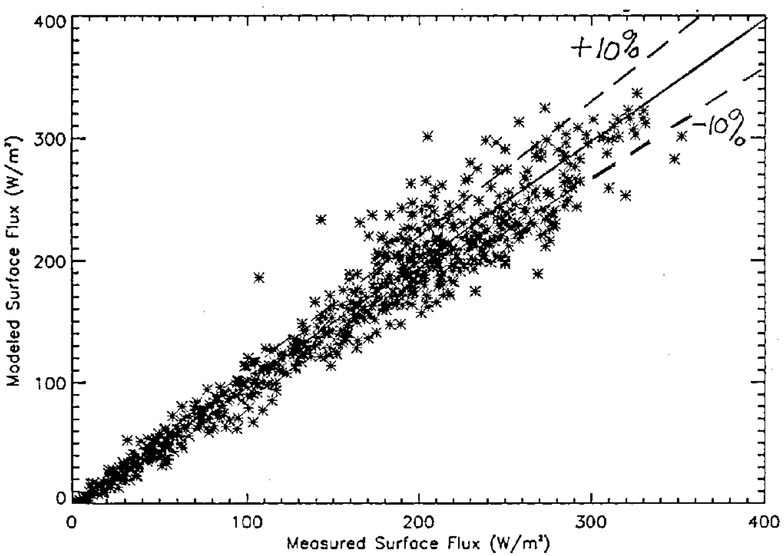
EFFECT OF TUNING STAYLOR AEROSOLS ON ALL-SKY VALUES

12 MONTHS OF GEBA[1] DATA IN 1986 W/O COASTS OR HIGH MOUNTAINS

(SATELLITE - GROUND SITE)

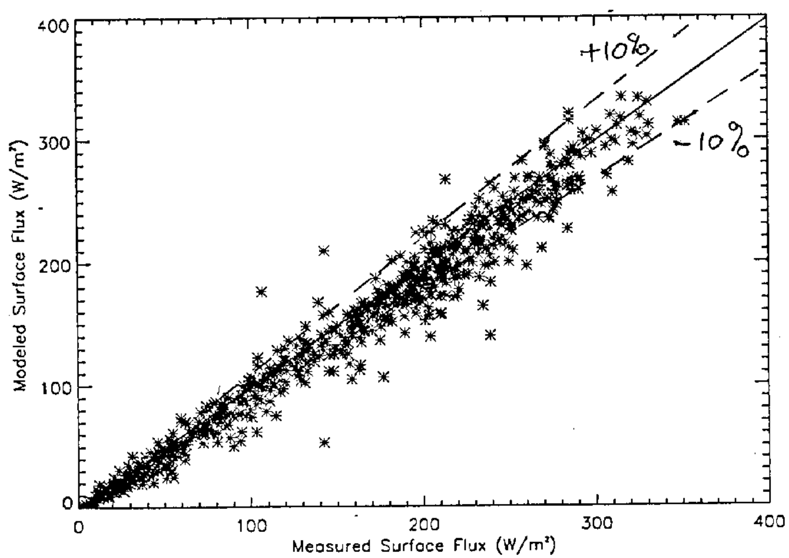
(A) WITHOUT TUNING

BIAS = -3.2%
RMS = 13.4%
POINTS = 781



(B) WITH TUNING

BIAS = -6.7%
RMS = 12%
POINTS = 779



AEROSOL TUNING REMOVES LARGE POLLUTION ERRORS !

[1]GEBA COURTESY SWISS FEDERAL INSTITUTE OF TECHNOLOGY IN ZURICH

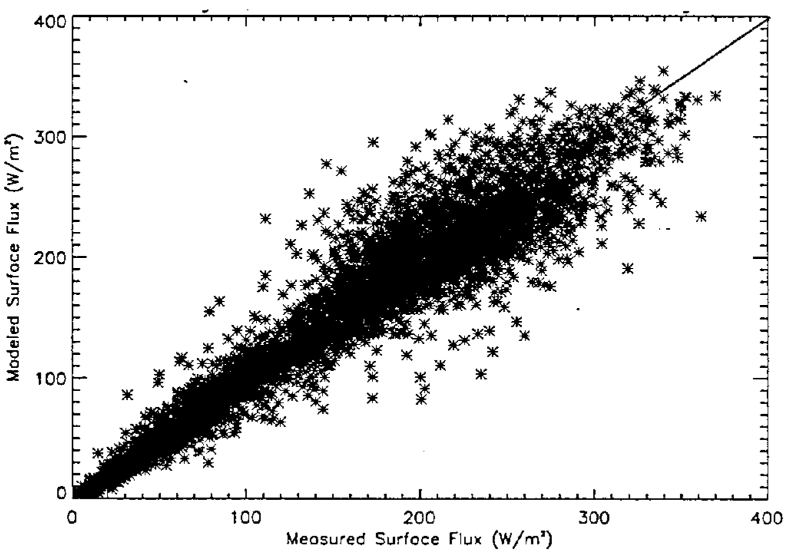
EFFECT OF INTERPOLATING STAYLOR 280km TO 1-DEG GRID

12 MONTHS OF WRDC[1] DATA IN 1986 WITH COASTS & HIGH MOUNTAINS

(SATELLITE - GROUND SITE)

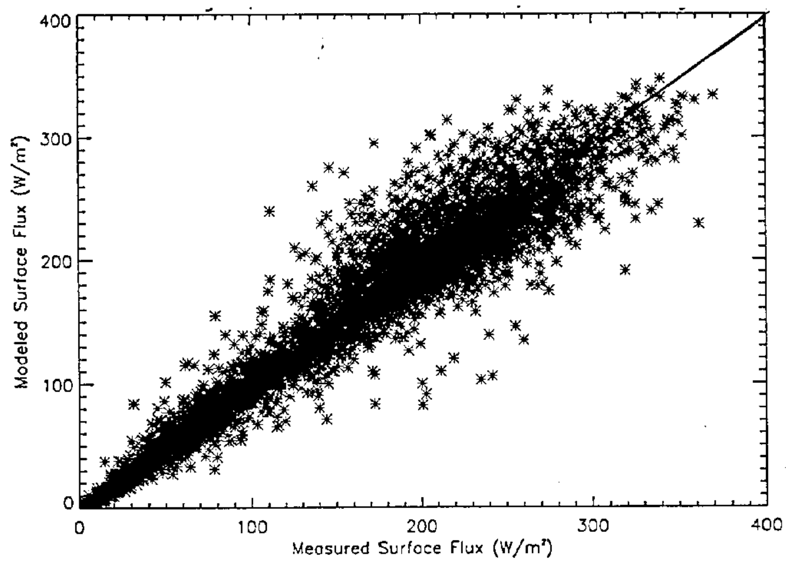
(A) ORIGINAL 280 km

BIAS = -0.6%
RMS = 14.9%
POINTS = 3542
OUTLIERS > ±25% = 2.6%



(B) INTERPOLATED 1°

BIAS = -1.7%
RMS = 15.0%
POINTS = 4923
OUTLIERS > ±25% = 2.1%



ACCURACY STATISTICS UNAFFECTED BY GRID INTERPOLATION!

[1]WRDC COURTESY NREL & WORLD RADIATION DATA CENTER IN ST. PETERSBURG.

Global Solar Insolation Estimations at 1 Degree Resolution

Paul Stackhouse
NASA Langley Research Center
Hampton Virginia

Stephen Cox, Roberta Dipasquale, Shashi Gupta
Analytical Services and Materials, Inc.
Hampton Virginia

In this talk, we present an overview of the NASA Langley Research Center (LaRC) Surface Radiation Budget (SRB) Project Release 2 data set. This project run under the auspices of the World Radiation Climate Programme (WCRP)/Global Energy and Water Cycle Experiment (GEWEX) is primarily aimed at producing a climatology of global surface radiative fluxes in both shortwave (SW, 0.2–5.0 micrometers) and longwave (LW, 4.0–100 micrometers). Although, the primary objectives of the project are to provide fluxes for the atmospheric science and climate communities, a continuous long-term record of global solar insolation will provide data sets useful solar energy related and many other applications. The Release 2 data set is significantly upgraded from the Version 1.1 WCRP SRB SW 4-year data set (from which the commercial SSE Release 1 is derived) and the NASA LaRC 8-year data set. Among many

upgrades the most important are: the addition of a LW flux algorithms, the increase of resolution from 280 km to 1 degree equal angle, and the use of reanalysis meteorology from a data assimilation project. This Release 2 data set will provide SW and LW radiative fluxes for at least a 10 year climatology (1984–1993) over the globe at the 1 degree resolution. The fluxes will be produced at a variety of time scales including 3-hourly, daily, monthly and monthly averaged 3-hourly.

The WCRP/GEWEX SRB Release 2 data set is to be based upon the International Satellite Cloud Climatology Project's (ISCCP) "DX" pixel level data set containing radiance and cloud retrieval information sample to a nominal resolution of 30 km. Previous SRB products from NASA LaRC used the ISSCP C1 level cloud and radiance data products that were processed to the 280 km equal area grid. The ISCCP "D" series data set represents an upgrade from the "C" series including the provision for ice cloud retrievals and better ice/snow determination. The pixel level ISCCP DX data set is averaged and processed to a 1 degree equal angle based grid system. This data set is also planned to be archived

and released. Many cloud and surface parameters relevant to surface insolation can be derived from these data. Besides the upgraded and higher resolution cloud and radiance data, several other new input data sets are used in Release 2 data set. The most important of these is the reanalysis meteorological data set used to supply temperature and humidity profile information and some relevant surface parameters. Other new data inputs include the 1.25 degree resolution TOMS Ozone data.

After presenting an overview of the upgrades described above, we show some preliminary results from limited processing. Regional and global distributions of surface SW fluxes will be presented and these fluxes will be compared with surface and satellite observations for validation. We will also provide an updated schedule for the archival and release of the new WCRP/GEWEX SRB Release 2 climatology data set.

WCRP/GEWEX
Surface Radiation Budget Project

Global Solar Insolation Estimations at 1 Degree Resolution

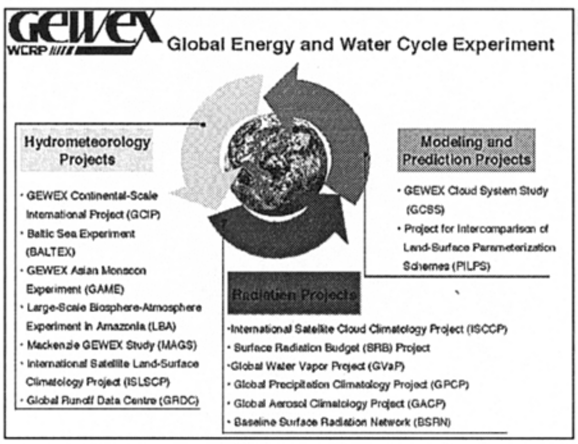
Paul Stackhouse Jr.
NASA Langley Research Center

S. Cox, R. Dipasquale, S. Gupta
Analytical Services and Materials, Inc.

D. Brown
Science Applications International, Corp.

Satellite Data Analysis Center / NASA Langley Research Center

SRB Project Role Within WCRP/GEWEX



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Presentation: Global Solar Insolation Estimates by Paul Stackhouse, NASA

SRB Project Objectives

- Develop a high quality climatological data set of surface radiative flux quantities for research, industry, and education (WCRP/GEWEX data set).
- Evaluate the data set using surface observations, other SRB data sets (i.e., ISCCP SRB, CERES SARB) with the goal of developing methods of reducing errors and uncertainties.
- Analyze the data set to assess the climatology and sensitivity of radiative fluxes on a variety of spatial and temporal time scales.

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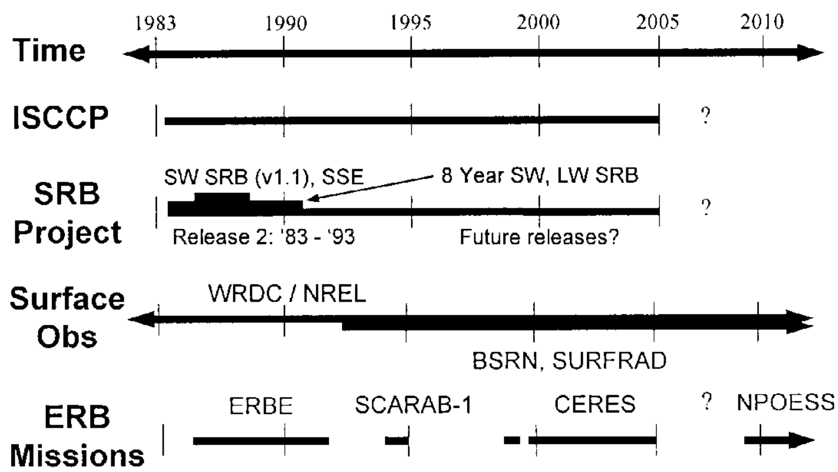
SRB Project Product Timeline



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SRB Project History

- **WCRP SRB (Release 1) and SSE:**
  - *Outputs:* SW daily & monthly surface fluxes (280 km) for 1985 - 1988
  - *Inputs:* ISCCP C1 (includes TOVS), ERBE Fluxes and ADM's, 5 climatological aerosols types
  - *SW Algorithms:*
    - Pinker and Laszlo (1993): NB-BB conversion of ISCCP radiances to TOA fluxes using ERBE ADM's, Atmospheric Reflection/Transmission lookup table using Δ-Eddington 2-S; retrieves surface albedo, PAR and diffuse insolation.
    - Staylor (Darnell et al., 1988): Daily averaged SW insolation using broadband transmittance formulation w/ empirical fits of gaseous, aerosol absorbers, effective cloud transmittance; surface albedo retrieved from ERBE fluxes.

SRB Project History

- **NASA LaRC 8 Year SRB:**
  - *Outputs:* SW & LW daily & monthly surface fluxes (280 km) for 1983 - 1990
  - *Inputs:* ISCCP C1 (+TOVS), ERBE Fluxes and ADM's, 5 climatological aerosols
  - *Algorithms:*
    - SW - Staylor
    - LW - Gupta (1992): RT based parameterizations for clear/cloudy downwelling LW flux weighted w/ cloud fraction, reanalysis meteorology, CERES surface emissivity

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SRB Project Goals for Release 2

- Provide global surface and top-of-atmosphere radiative fluxes plus relevant input parameters at 1 degree equal angle resolution.
- Provide flux quantities at 3-hourly intervals and averages of 3-hourly monthly, daily, and monthly.
- Meet the following accuracy criteria (RMS error):

Flux Quantity	SW Error ($W\ m^{-2}$)	SW % Error (195 $W\ m^{-2}$)	LW Error ($W\ m^{-2}$)	LW % Error (327 $W\ m^{-2}$)
3-hourly	40	20	35	11
Daily	30	15	25	8
3-hourly Monthly	20	10	20	6
Monthly	15	8	15	5

WCRP/GEWEX SRB Release 2

- **Inputs:**
  - ISCCP DX:
    - sampled VIS/IR radiances; retrievals of cloud and surface quantities (30 km nominal resolution)
    - averaged to 1 degree (equal angle) based grid similar to CERES SARB (processed at LaRC DAAC; discussions w/ ISCCP to make new output product)
  - DAO GEOS-1 (or ECMWF) reanalysis: P, T, q profiles
  - TOMS Ozone Data (nominal 1.25° resolution)
  - ISCCP Ice/Snow maps (1° resolution)
  - CERES Surface Characterization Maps
  - Climatological Aerosol Maps: evaluating Global Aerosol Data set w/ RH dependence (Koepke *et al.*, 1997, BAMS)

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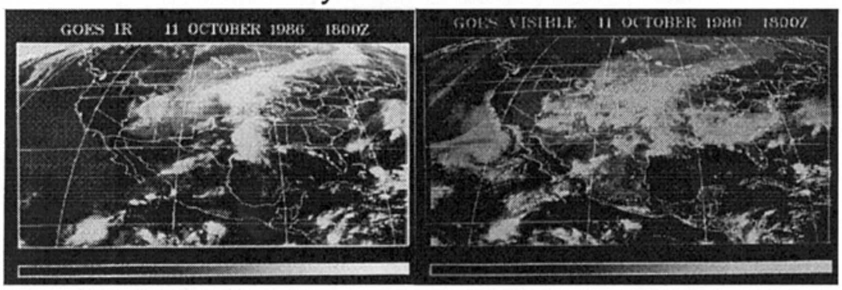
SRB Gridded Inputs: Infrared and Visible Images from GOES

ISCCP combines the GOES, METEOSAT, and GMS Geostationary Satellites with NOAA POES AVHRR observations every 3 hours from July 1983 through at least the year 2000.

Case Study: GOES 11 October 1986



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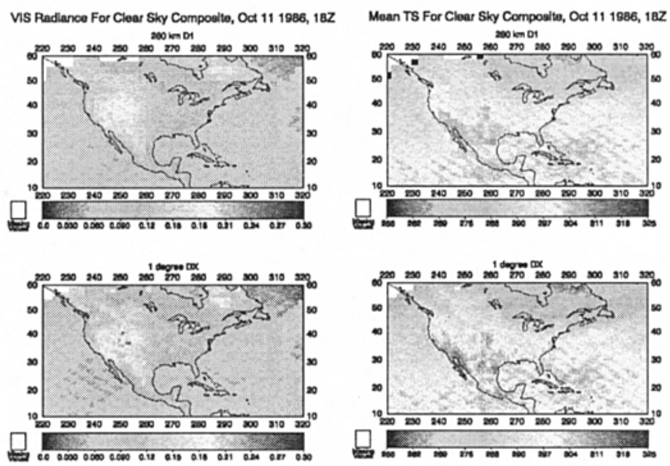
SRB Gridded Inputs: Visible Radiances and Skin Temps

280 km Inputs

1 Deg. Inputs



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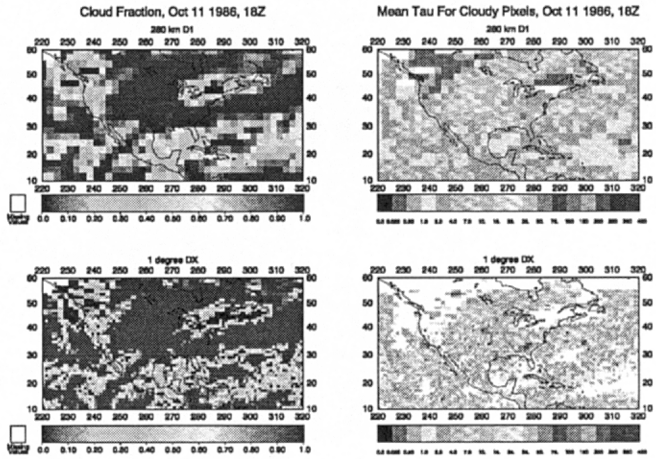
SRB Gridded Inputs: Cloud Fraction and Optical Depth

280 km Inputs

1 Deg. Inputs



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WCRP/GEWEX SRB Release 2

- **Algorithms:**
  1. GEWEX SW (Pinker-Laszlo) - Δ-Eddingtion 2-S based method
  2. GEWEX SW QC (Staylor) - physical-empirical method
  3. GEWEX LW (Stackhouse) - uses CERES LW 2/4 S RT model (Fu et. al., 1997), random cloud overlap, non-black surfaces, reanalysis meteorology, CERES spectral surface emissivity.
  4. GEWEX LW QC (Gupta, 1989, 1992) - RT based parameterizations for clear/cloudy downwelling LW flux weighted w/ cloud fraction, reanalysis meteorology, CERES surface emissivity
- **Outputs:**
  1. Surface and TOA flux quantities provided on 3-hourly, daily, 3-hourly monthly, and monthly basis
  2. 1 degree equal-angle output products (fluxes plus intermediary)
  3. Specialized data subsets for users

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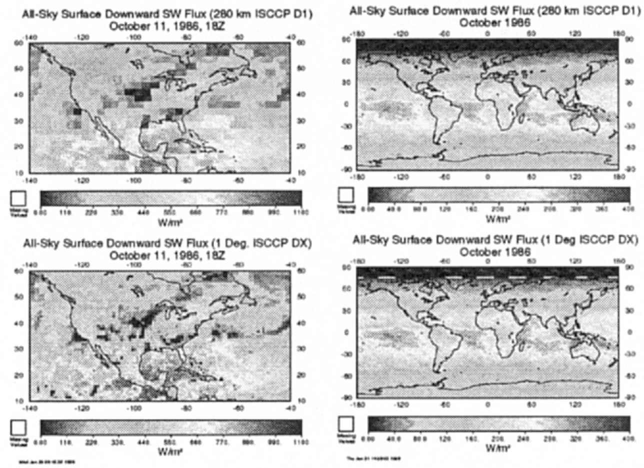
SRB GEWEX SW (Pinker/Laszlo) Fluxes: One time & Monthly Averaged

280 km Outputs

1 Deg. Outputs



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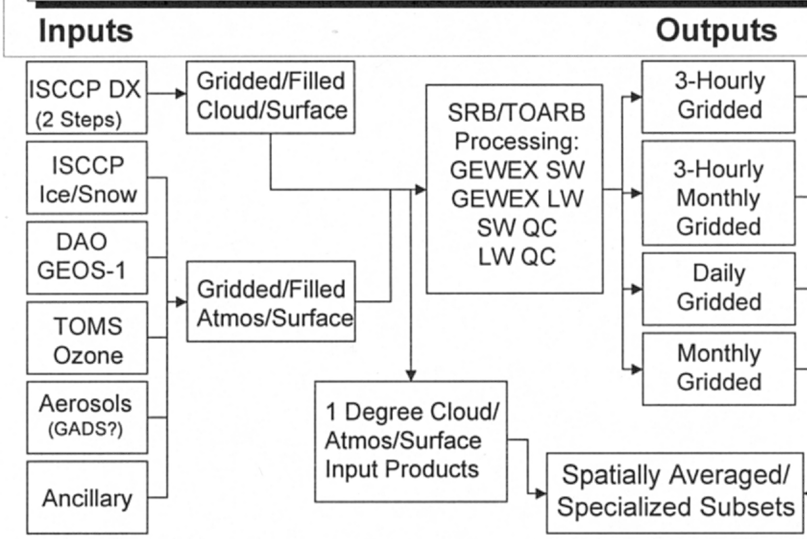
SRB Project Data Flow (Release 2)



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SRB Project Validation

- **Input Parameter Sensitivities/Processing Errors**
  - calibration uncertainties for input data sets (i.e., radiance)
  - sampling/gridding/filling errors
  - uncertainties of derived parameters (i.e., cloud retrieval errors, atmospheric profile errors)
    - water vapor sensitivities: comparisons in collaboration w/ University of Maryland (R. Pinker).
    - polar cloud properties TOVS vs ISCCP DX Gridded in collaboration w/ Rutgers University. (J. Francis)

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SRB Project Validation

- **Surface Observations**
  - process surface observations (WRDC, BSRN, NOAA CMDL, local networks) to temporal scales comparable to output
  - typical comparisons to observations involve matching monthly averaged surface observations to calculated fluxes
    - explore relationships between parameters
  - improvements/enhancements to comparisons
    - address temporal/spatial mismatches
    - provide measure of variability of time series (higher moment statistics, histogram, correlation)
    - characterization by climate region and/or atmospheric condition
- **Other SRB Data Sets**
- **ERBE TOA Flux Observations**

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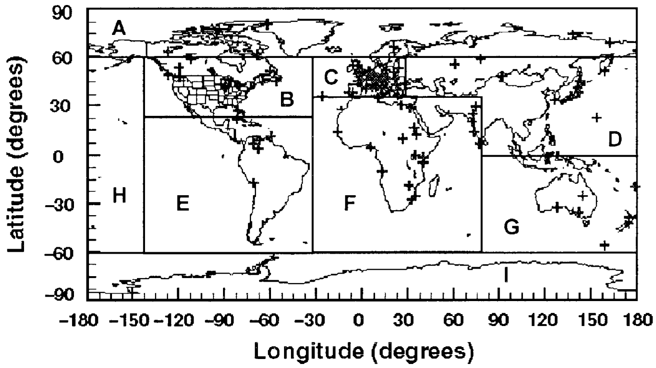
SRB Project Validation

- *Surface sites from the Global Energy Balance Archive (subset of WRDC surface sites) and FIRE I in 1986.*
- *Analysis performed by latitude, regions (see below), and surface types*



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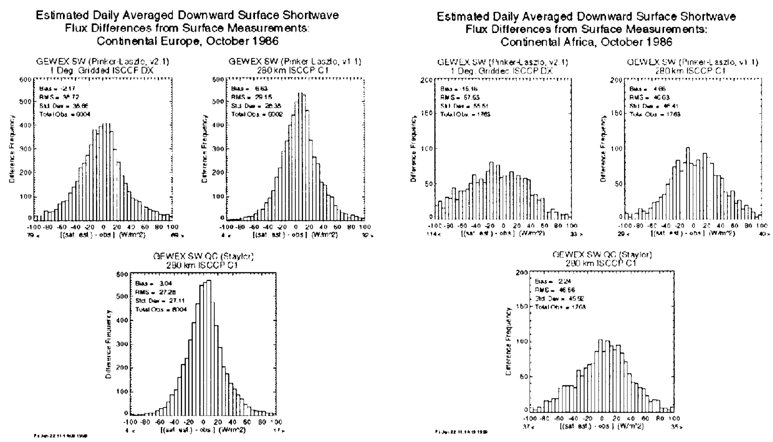
SRB Validation Plan

- *Statistical analysis of the daily averaged differences by regions*



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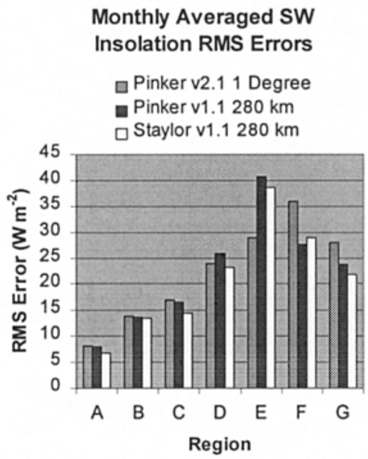
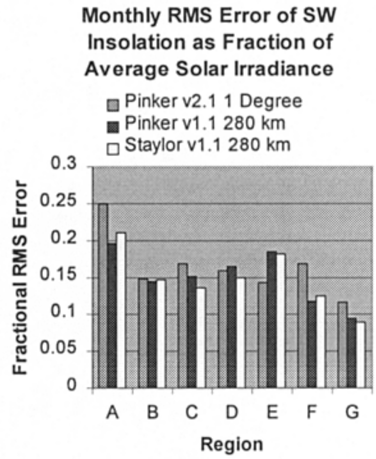
SRB Project Validation





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SRB Project Aerosol Activities

- **Release 2 Aerosol Strategy**:
  - evaluate Global Aerosol Data Set (GADS) of Kropke *et al.,* (1997) in collaboration w/ Dr. R. Pinker's group at UMd.
  - GADS includes haze type parameterizations using relative humidity
- **Archive biomass burning smoke likelihood maps:**
  - completion of biomass emissions maps using DMSP and smoke trigger parameterization from GPCP data
  - supplement with remote sensing from ISCCP DX, TOMS, etc.
  - Trajectory modeling with NASA LaRC Trajectory Model (LTM)
- **Release 3 Aerosol Strategy**:
  - participate in Global Aerosol Climatology Project (GACP)
  - use background aerosol maps with biomass burning aerosol maps

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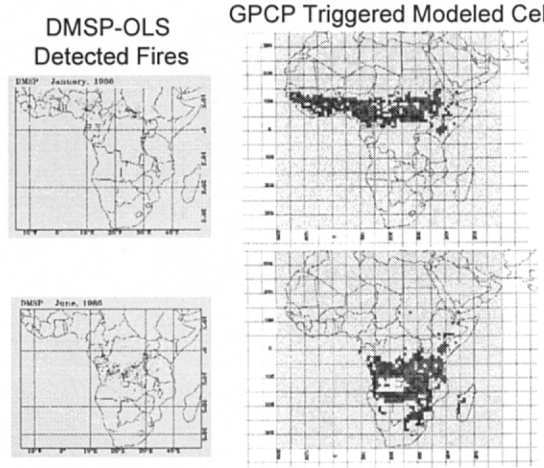
Biomass Burning Aerosols from DMSP

DMSP-OLS Detected Fires

GPCP Triggered Modeled Cells

January 1986

June 1986



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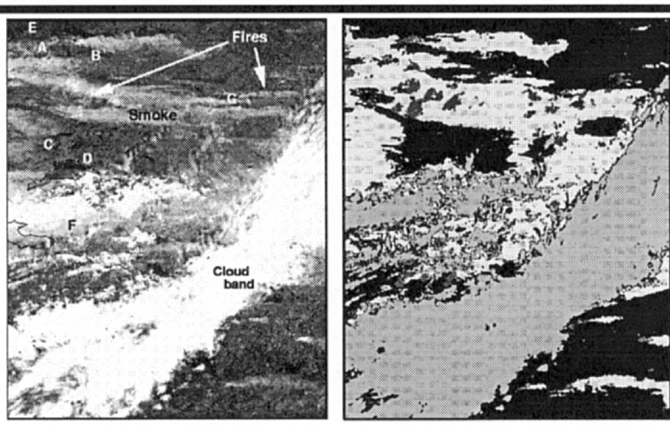
Biomass Burning Aerosols from AVHRR



False color image formed from:

Red: BTD (3.7 – 11 μm)
Green: 0.83 μm reflectance
Blue: 11 μm brightness temperature

clear | cloud | smoke | fire

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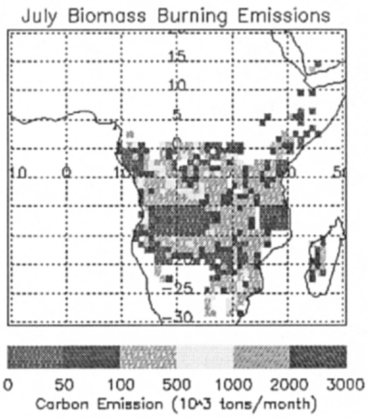
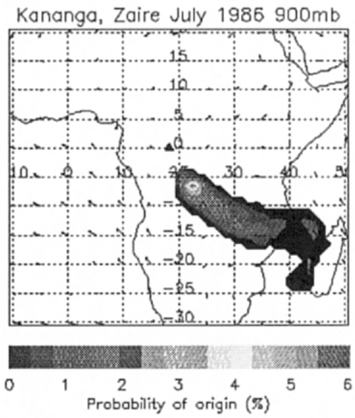
Biomass Burning Aerosols from Trajectory Modeling





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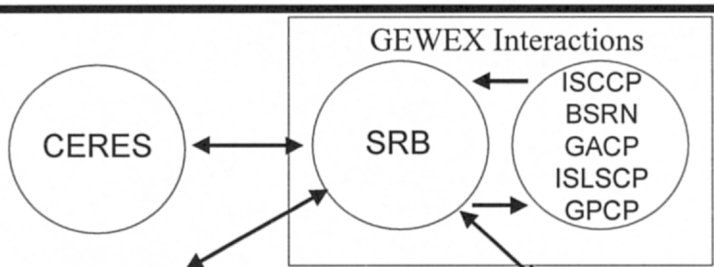
SRB Collaborative Relationships



Research and Validation

- U.Md. (R. Pinker): SW, aerosols, error and sensitivity
- NREL (D. Renne): validation data sets
- NASA LaRC (B. Baum, J. Olson, R. Pierce, D. Cahoon): aerosol retrievals, biomass burning maps
- Rutgers (J. Francis): polar cloudiness and LW fluxes
- VPISU (M. Haeffelin): flux integration, surface flux
- DRI (D. Mitchell): cirrus cloud radiative properties
- CSU (P. Gabriel): radiative transfer algorithms

SRB Users

- Climate research and modeling
- Renewable energy industries
- Hydrological applications
- Agricultural applications
- Oceanographic research
- Biological research

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Presentation: Global Solar Insolation Estimates by Paul Stackhouse, NASA

Summary

- **Present Activities**
  - preparing for release 2 of WCRP/GEWEX SRB
    - evaluation of ECMWF and GADS
  - collection/analysis validation data sets
  - sensitivity/validation tests
    - develop collaborative relationships w/ other investigators
- **Near Future**
  - Archival/documentation of Release 2 data sets
  - Sensitivity/Validation w/ surface observations and other SRB data sets

Satellite Data Analysis Center / NASA Langley Research Center

WCRP/GEWEX SRB Release 2: Current Schedule

- **Initial Test Months: August, 1999**
  - evaluate GEOS-1 and compare to ECMWF
  - background aerosol distributions
  - complete adaptation of algorithms for new inputs
  - process and validate 8 test months for surface and top-of-atmosphere fluxes
- **Initial Two Test Years: October, 1999**
  - process and validate two test years
  - algorithm sensitivity testing
  - archive data sets
- **Process Remaining Years: March, 2000**
  - validate where/when possible
  - archive product data sets

Satellite Data Analysis Center / NASA Langley Research Center

Presentation: Global Solar Insolation Estimates by Paul Stackhouse, NASA

The European Solar Radiation Atlas and the Satellight Web Server

Dominique Dumortier
LASH-ENTPE
R69518 Vaulx-en-Velin
France

In the past three years, two European projects have relied to the use of satellite images to produce solar radiation information: The European Solar Radiation Atlas and the SATELLIGHT Web Server.

The European Solar Radiation Atlas (ESRA) is based on 10 year (1981-1990) monthly mean observed data in about 340 stations and long term series of daily observed data in 89 stations. Meteosat satellite images have been used to produce maps of monthly daily means of irradiation (1981-1990) for all Europe. The ESRA which is available on a CD-ROM (PC format) offers a user friendly access to the database. It allows to produce and draw derived data (irradiation on tilted surfaces, illuminances...) and to compute the performance of simple types of solar application (solar water heater, photo-voltaic systems, passive solar heating of buildings).

The SATELLIGHT web server gives a free access to two years (1996 and 1997) of half hour daylight and solar radiation data in Western and Central Europe (from Lisbon to Moscow). The data are computed from images provided by the METEOSAT satellite, every half hour, and cover an area of about 10 km by 10 km. The web server produces information for the whole of Europe (or for 13 zones in Europe) or for a given site (selected by clicking on a map or by using a geographic name database). The user can select a period of time, one or more parameters: sunshine duration, sky type, irradiances, illuminances (on horizontal and tilted surfaces) and statistics: integrated values, mean values, cumulative frequency curves. Results will be presented in tables and graphs using the GIF and the PDF formats. They will be of use to engineering firms working in energy and lighting, to industrials developing lighting, shading or control systems, to urban planners and to the entire agricultural sector. The SATELLIGHT Internet server will be officially accessible on April 1, 1999 and open to selected beta testers in January 1999 (http://satellight.entpe.fr).

The European Solar Radiation Atlas (ESRA)

The SATELLIGHT web server

Dominique Dumortier, Light and Radiation
Group, ENTPE, Lyon, France

2nd Workshop on Satellites
For solar energy assessments
February 4, 1999

ESRA and SATELLIGHT

Funded by the European Union

Production of solar radiation database for end users

ESRA: Database on CD-ROM

- 10 year monthly daily means (1981-1990)
- Ground stations and interpolation with help of SRB

SATELLIGHT: Database on the Internet

- 2 years of half hour values (1996-1997)
- Entirely based on Meteosat data

The ESRA

Three year research project: March 1995 to March 1998

Improvement of the ESRA done in the 1980s:

- Use of CD-ROM
- Solar and meteorological data from over 340 stations
- Solar radiation maps derived from the ground stations
- Algorithmic chains to derive other parameters
- Application toolbox *(PV systems, solar water heater...)*

The ESRA development team

M. Scharmer (GET consulting firm, Germany)

R. Dogniaux (Université de Louvin, Belgium)

G. Czeplak (Deutsche WetterDienst)

H. G. Beyer, L. Wald (Ecole des Mines de Paris, Sophia-Antipolis, France)

P. Littlefair (Building Research Establishment, United Kingdom)

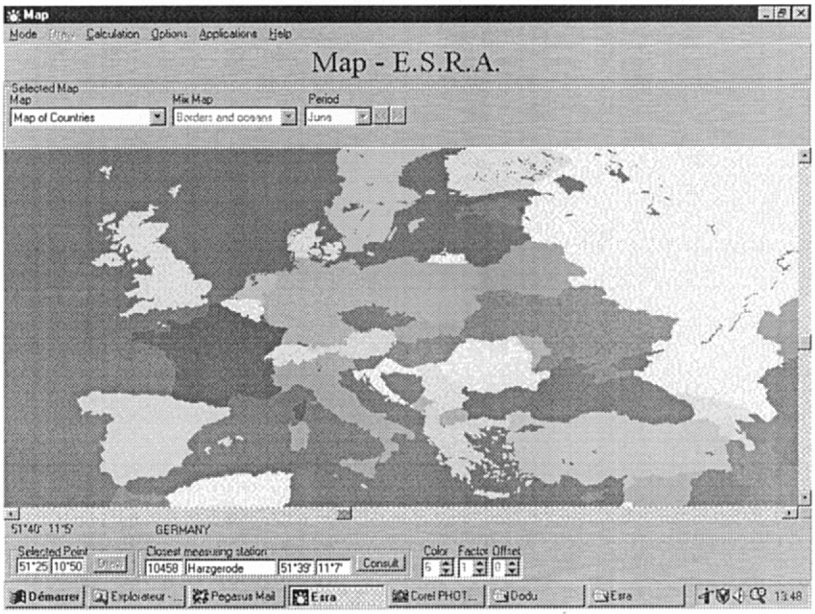
(Voikovo Institute, Sankt Peterburg, Russia)

(INETI, Portugal)

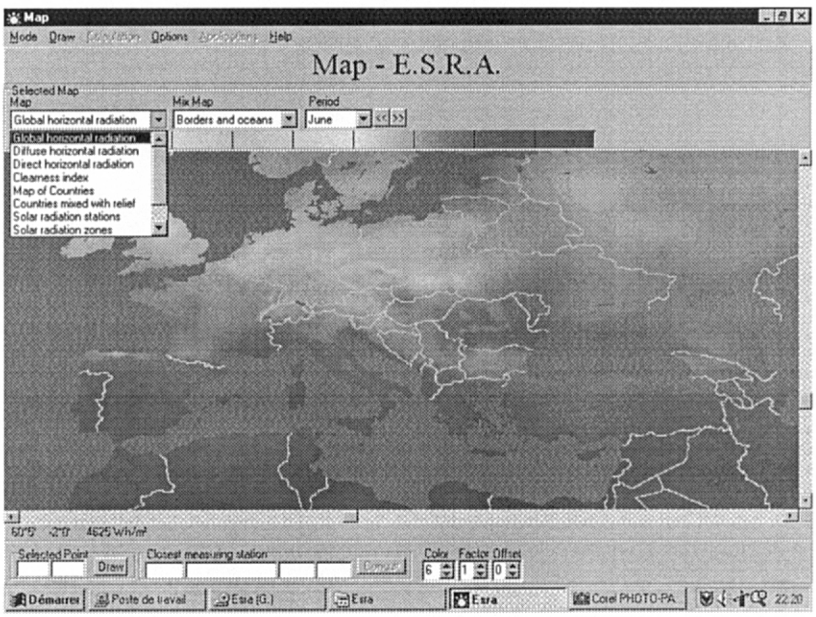
The ESRA CD-ROM will be available this Spring

Presentation: The European Solar Radiation Atlas by D. Dumortier, ENTPE

ESRA Map mode showing countries

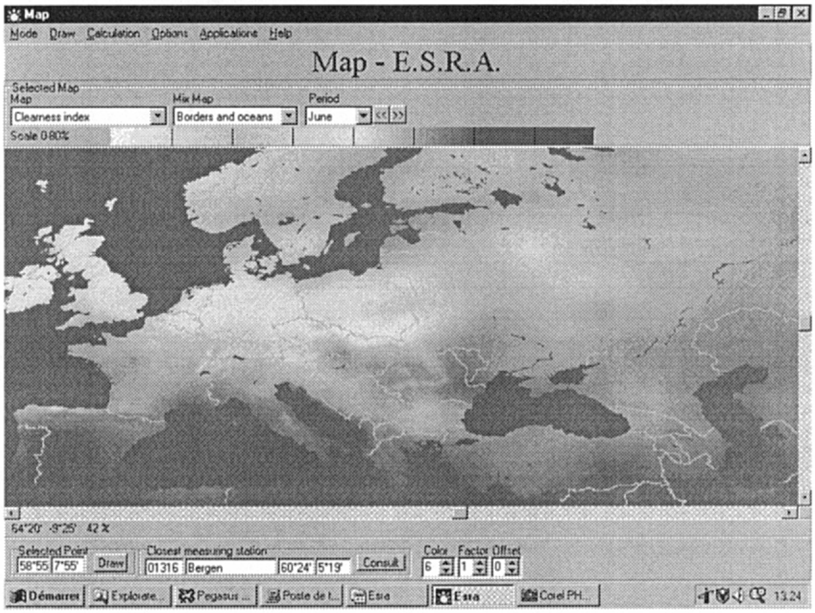


Selection of maps

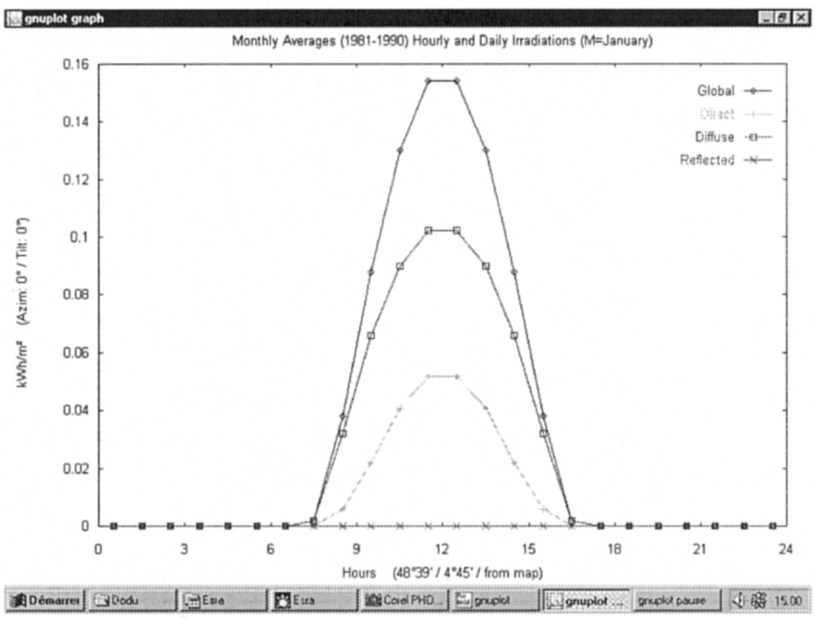


Presentation: The European Solar Radiation Atlas by D. Dumortier, ENTPE

Example of clearness index map

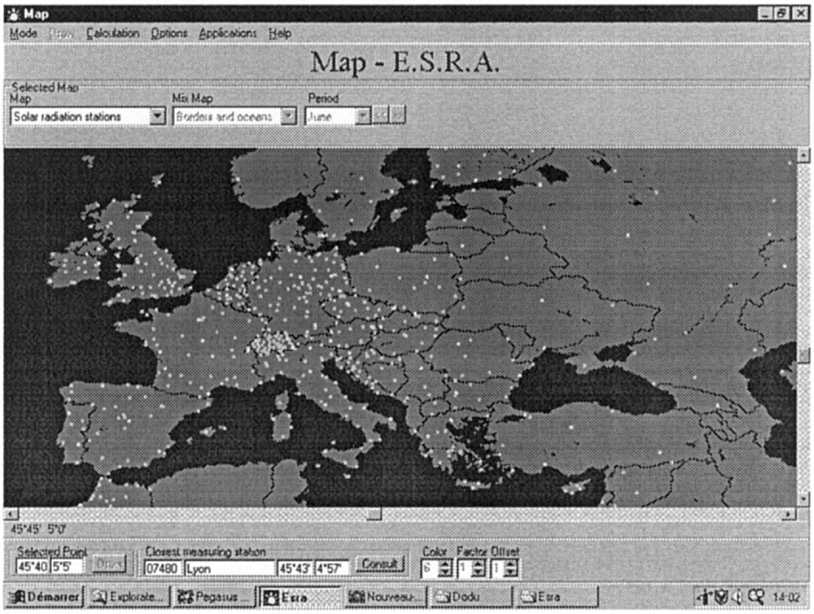


Information can be derived directly from maps

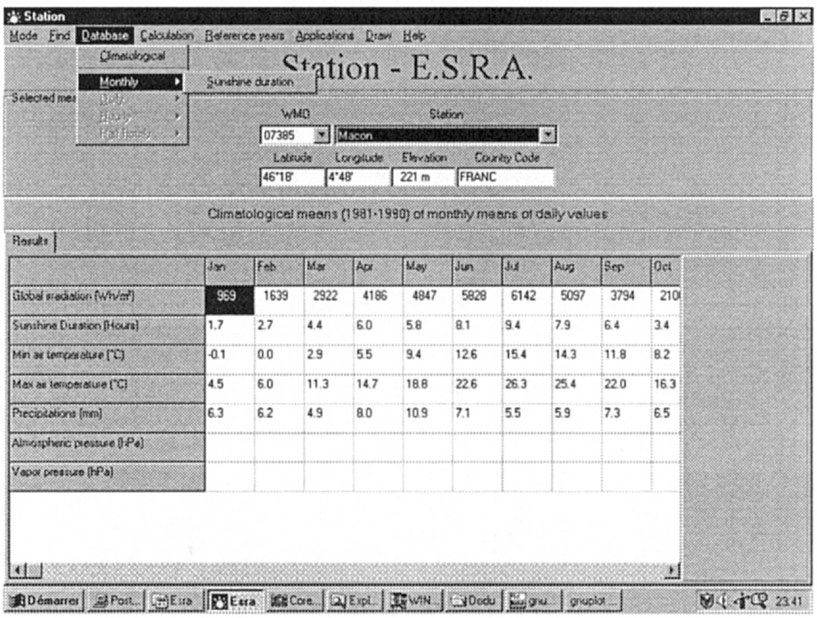


Presentation: The European Solar Radiation Atlas by D. Dumortier, ENTPE

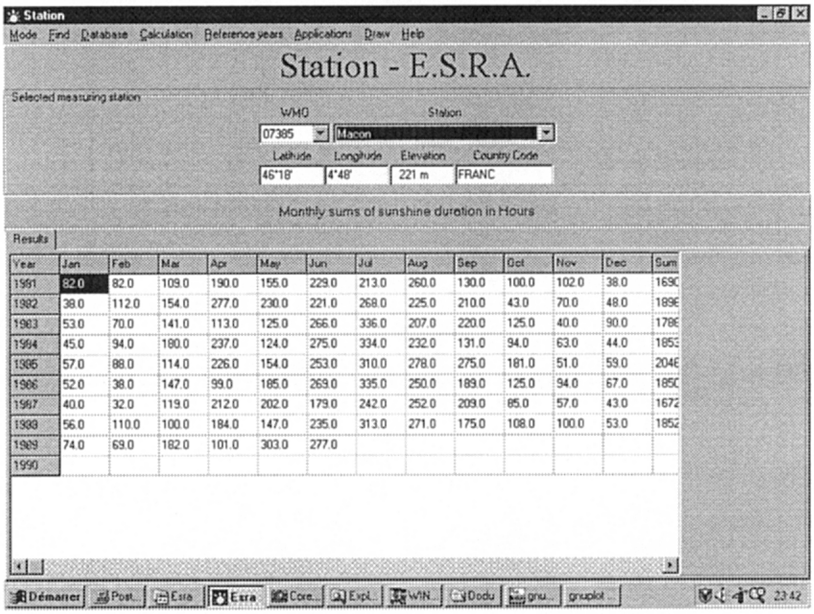
ESRA ground stations



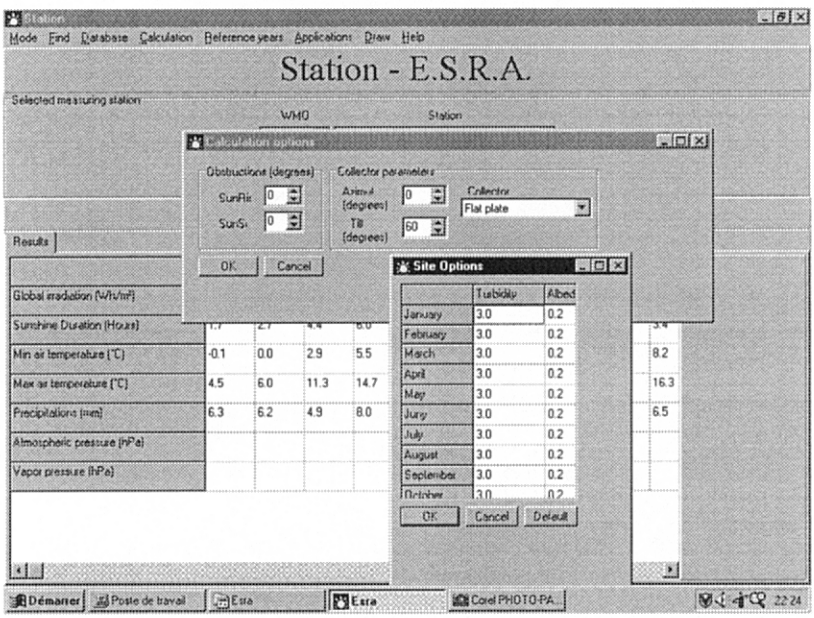
Options of the Database menu in Station mode



Monthly sunshine duration information

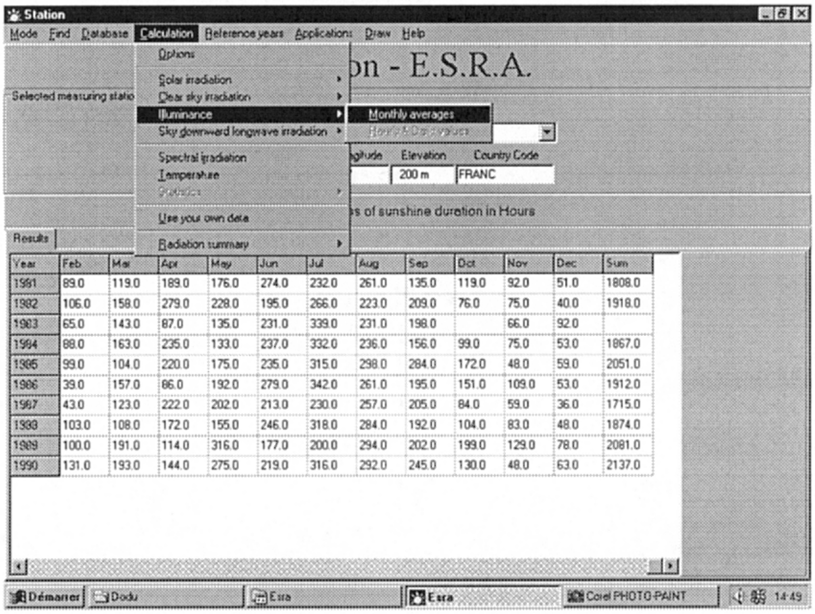


Selection of surface type and site options



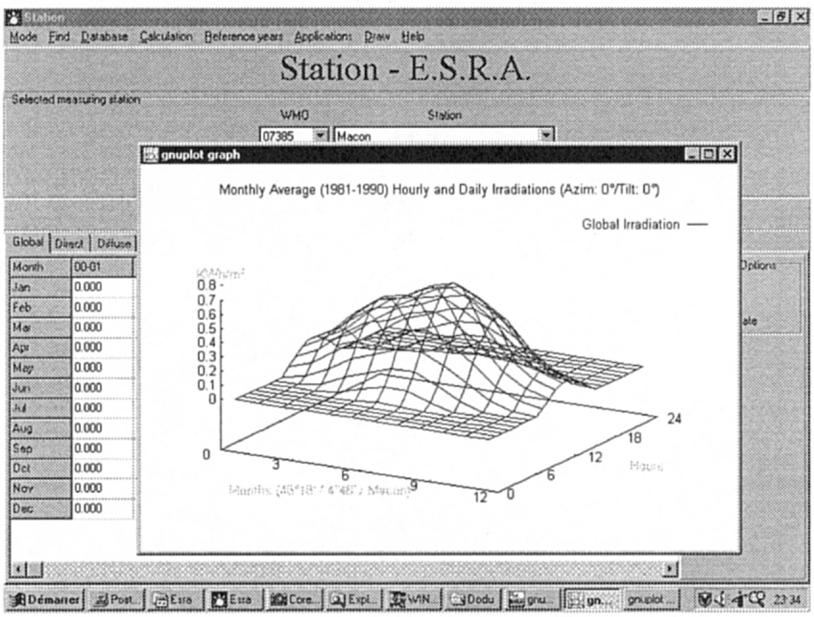
Presentation: The European Solar Radiation Atlas by D. Dumortier, ENTPE

Options of the Calculation menu



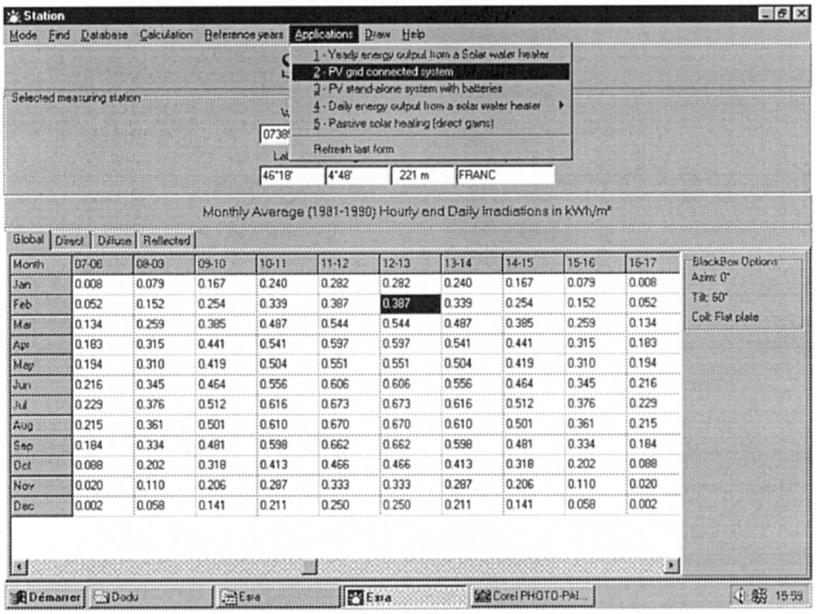
Year	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
1981	89.0	119.0	189.0	176.0	274.0	232.0	261.0	135.0	119.0	92.0	51.0	1808.0
1982	106.0	158.0	279.0	228.0	195.0	266.0	223.0	209.0	76.0	75.0	40.0	1918.0
1983	65.0	143.0	87.0	135.0	231.0	339.0	231.0	198.0		66.0	92.0	
1984	88.0	163.0	235.0	133.0	237.0	332.0	236.0	156.0	99.0	75.0	53.0	1867.0
1985	99.0	104.0	220.0	175.0	235.0	315.0	298.0	284.0	172.0	48.0	59.0	2051.0
1986	39.0	157.0	86.0	192.0	279.0	342.0	261.0	195.0	151.0	109.0	53.0	1912.0
1987	43.0	123.0	222.0	202.0	213.0	230.0	257.0	205.0	84.0	59.0	36.0	1715.0
1988	103.0	108.0	172.0	155.0	246.0	318.0	284.0	192.0	104.0	83.0	48.0	1874.0
1989	100.0	191.0	114.0	316.0	177.0	200.0	294.0	202.0	199.0	129.0	78.0	2081.0
1990	131.0	193.0	144.0	275.0	219.0	316.0	292.0	245.0	130.0	48.0	63.0	2137.0

The Draw menu allows to plot data

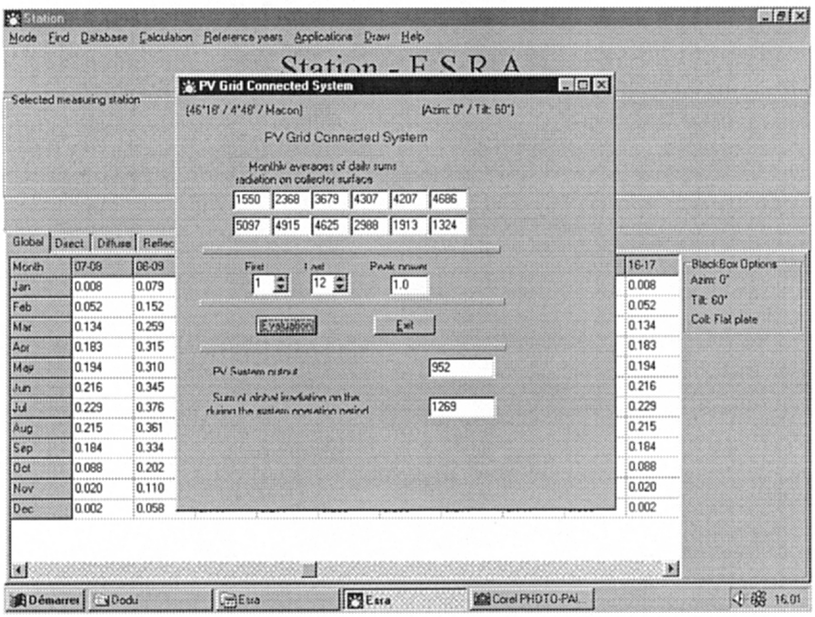


Presentation: The European Solar Radiation Atlas by D. Dumortier, ENTPE

Options of the Application menu



PV grid connected system application



Presentation: The European Solar Radiation Atlas by D. Dumortier, ENTPE

S@telLight
The European Database of Daylight and Solar Radiation

3 year+ research project: January 1996 to March 1999

Objectives:

- Make two years of half hourly data available (1996 and 1997)
- Allow the user to:
  - look at variations over Europe
  - select a site in an easy way
  - define his own parameters/ his own statistics
- Provide application examples (daylighting to start with...)

S@telLight
The European Database of Daylight and Solar Radiation

Expected use of the data

- Design of daylighting systems
- Design of solar controls
- Design of solar collectors
- Analysis of demand of electricity
- Materials degradation
- Agriculture
- Marine biomass evolution...

Presentation: The European Solar Radiation Atlas by D. Dumortier, ENTPE

The SATELLIGHT official team

M. Fontoynont, D. Dumortier (ENTPE, Lyon, France)

D. Heinemann, A. Hammer (University of Oldenburg, Germany)

J. Olseth (DNMI-Bergen, Norway)

A. Skartveit (University of Bergen, Norway)

P. Ineichen (University of Geneva, Switzerland)

C. Reise (Fraunhofer Institut, Freiburg, Germany)

J. Page (Sheffield, United Kingdom)

L. Roche (Building Research Establishment, United Kingdom)

H.G. Beyer (University of Magdeburg, Germany)

L.Wald, C. Rigollier (Ecole des Mines de Paris, Sophia-Antipolis, France)

SATELLIGHT coverage of Europe

Meteosat image of
640 by 384 pixels:
a total of 241,913 pixels
(10 km by 10 km each)

48 Countries in Western
and Central Europe

Presentation: The European Solar Radiation Atlas by D. Dumortier, ENTPE

Computation of the global horizontal irradiance available on ground

Use of the clear sky index (Modified Heliosat method)

$$k_{cloudless} = \frac{Eeg}{Eeg_{cloudless}}$$

$n \leq -0.2 \quad k_{cloudless} = 1.2$

$n > -0.2$ & $n \leq 0.8 \quad k_{cloudless} = 1 - n$

$n > 0.8$ & $n \leq 1.1 \quad k_{cloudless} = 2.0667 - 3.6667n + 1.6667n^2$

$n > 1.1 \quad k_{cloudless} = 0.05$

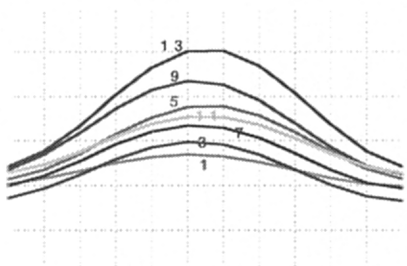
References: Heliosat (Cano, Beyer), Cloudless (Kasten, Dumortier)

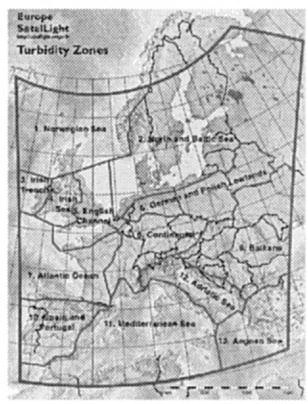
$$k_{cloudless} = \frac{Eeg}{Eeg_{cloudless}}$$

Monthly turbidity variations

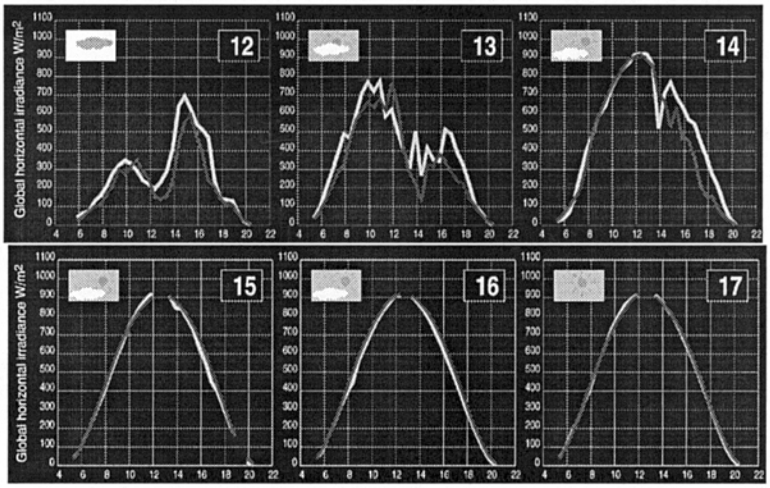
Model based on monthly values from ESRA stations

13 zones of turbidity variations





Comparison between global horizontal irradiance measured on ground and satellite estimates



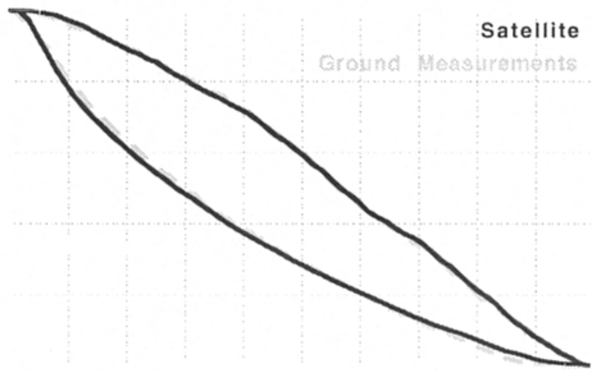
—— Ground measurements —— Satellite

Comparison between global horizontal irradiance measured on ground and satellite estimates

Gävle (Sweden)	**mbe:-1%**	**rmse:26%**
Nantes (France)	**mbe:-1%**	**rmse:33%**
Genève (Switzerland)	**mbe:-2%**	**rmse:32%**
Vaulx-en-Velin (France)	**mbe:-1%**	**rmse:34%**
Lisbon (Portugal)	**mbe:-2%**	**rmse:21%**

Presentation: The European Solar Radiation Atlas by D. Dumortier, ENTPE

Comparison between global horizontal irradiance measured on ground and satellite estimates



Computation of the diffuse horizontal irradiance available on ground

Presentation: The European Solar Radiation Atlas by D. Dumortier, ENTPE

Computation of additional parameters

Based on global and diffuse horizontal irradiances

Illuminances *(Olseth/Skartveit luminous efficacy model)*

Irradiances and illuminances on tilted planes

(Hay model modified by Olseth and Skartveit)

Sky luminances *(Perez sky luminance model)*

S@telLight
The European Database of Daylight and Solar Radiation

The Web server development

D. Dumortier *(Coordination and development - ENTPE)*

C. Pinnédon *(Interface design)*

J. Clerc *(W3 server and Database development-NCTech)*

S. Monéger *(W3 server and Database development-NCTech)*

The server is developed entirely in Java, on a Sun

Workstation Ultra 10/300 with 40 Go storage capacity

Presentation: The European Solar Radiation Atlas by D. Dumortier, ENTPE

Web server database

Two years of cloud index values for 241,913 pixels

(computed from Meteosat images - PostGres SQL)

Preprocessed statistical results as maps

(to speed up map creation - Unix binary files)

An altitude database

(the average over a 5 ' by 5 ' area)

A database of 750,000 geographic names

(with latitude , longitude)

S@telLight
The European Database of Daylight and Solar Radiation

The server is still in development.

It will open officially on June 1, 1999

http://satellight.entpe.fr

Ready for a quick tour of the server !

Presentation: The European Solar Radiation Atlas by D. Dumortier, ENTPE

Solar Radiation Measurements in Brazil by Using Satellite Techniques

E. B. Pereira[1], F.R. Martins[1], S. L. Abreu[2], P. Couto[2], R. Sthulmann[3], and S. Colle[2]

1) INPE, C. Postal 515, S.J.Campos, SP – 12201-970, Brazil
2) UFSC/EMC/Labsolar, C.P. 476, Florianópolis, SC – 88040-900, Brazil
3) GKSS Forschungzentrum, D-21502 Geesthacht, Germany

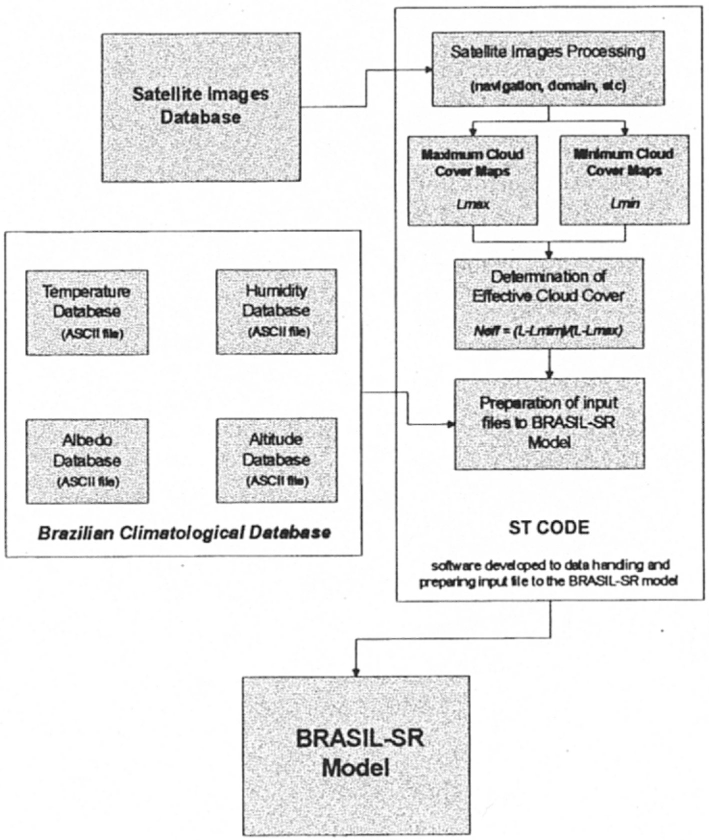
A radiation model originally developed in Germany (GKSS-Geesthacht) was adapted and improved to operate in Brazil by a joint collaboration between the Federal University of Santa Catarina (UFSC) and the Brazilian National Institute for Space Research (INPE). It is a physical model that employs the visible narrow-band response of a geostationary satellite to estimate the broadband solar radiation at surface. The model was validated by using surface pyranometers and is in operation since 1995. The first edition of Brazilian national Satellite Atlas of Solar Radiation has just being issued in conjunction with the Brazilian National Institute of Meteorology (INMET). This presentation is a review of this model, the latest improvements, and the main results of its application in Brazil. The model is being improved to take into account some local environmental characteristics that are only poorly assessed so far. The intensive cloud convection which is associated with the inter-tropical convergence zone (ITCZ); and the manmade changes in the biosphere–atmosphere interaction, triggered by deforestation and land clearings are among the most important factors. The development of specific procedures of cloud screening and surface validation of cloud fraction will be described. In addition, it will be reported the first results of a study aimed at the estimation of the effects of biomass burning combustion byproducts injected into the atmosphere by the widely used practice of land clearings for farming and cattle growth. The magnitude of this effect, however, remains a controversial issue particularly as regards to the aerosols.

This work was made possible by grants from FAPESP, CELESC, and CNPq.

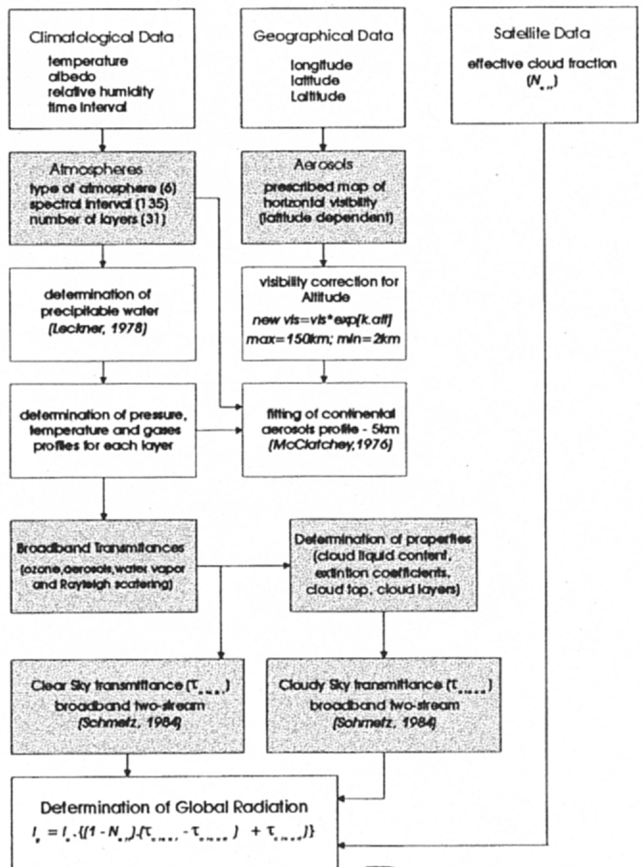
convênio *INPE* - UFSC

Block diagrams of the BRASIL-SR satellite model

(A) Input of satellite data and model parameters
(B) Radiation transfer model



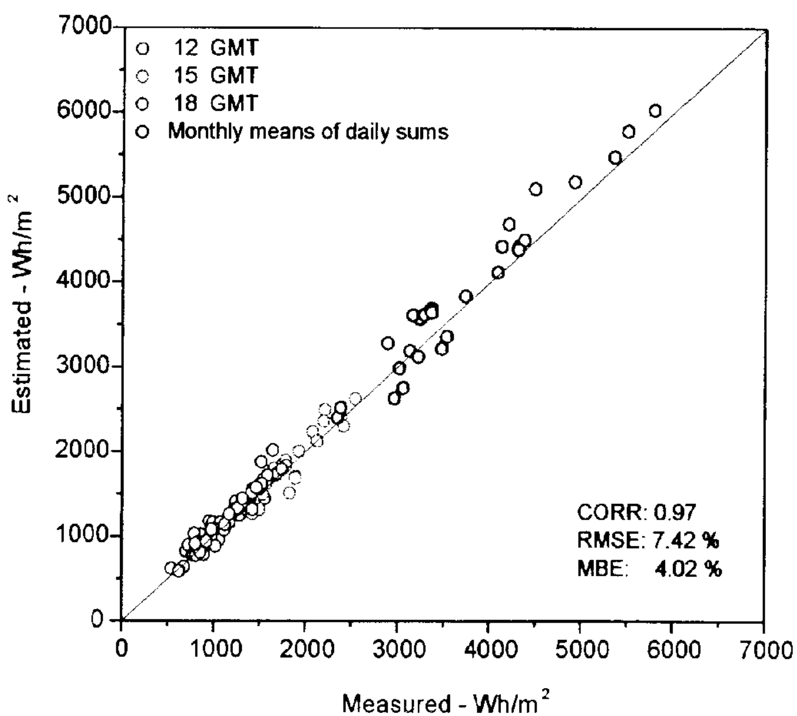
A

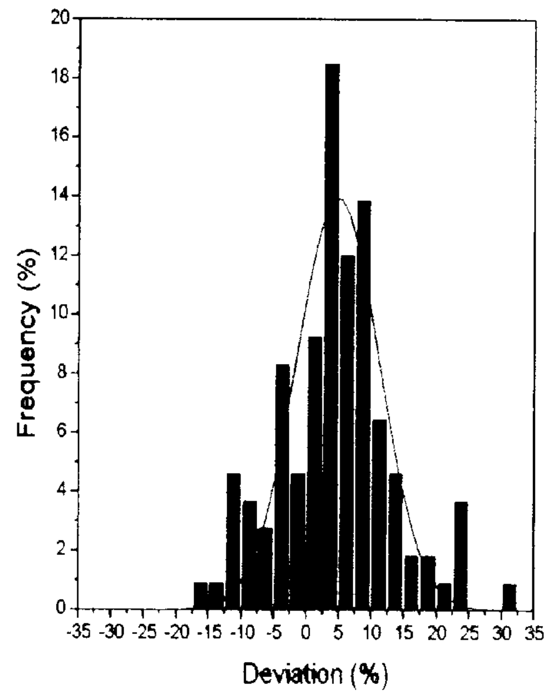


B

Model versus measured solar irradiation

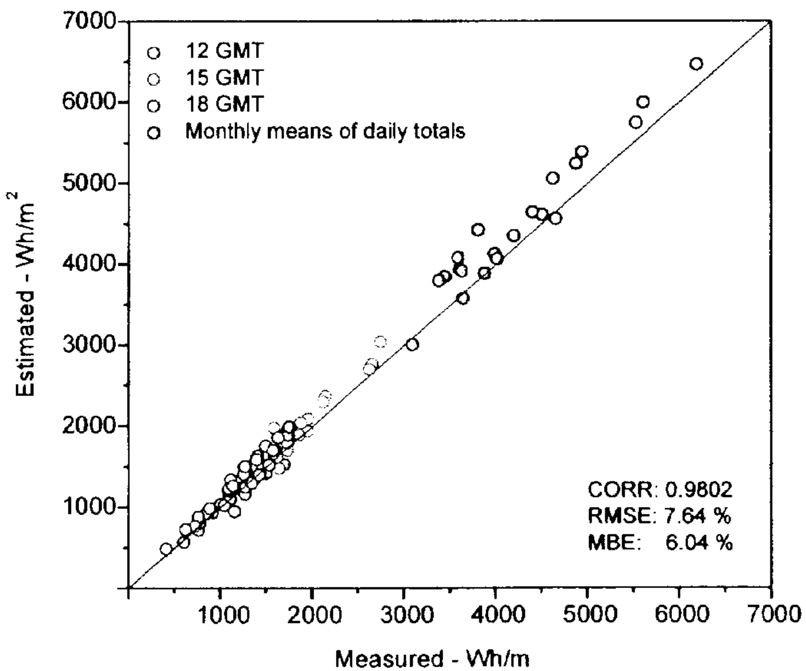
BSRN - Florianópolis (27.60° S 48.57° W) altitude 10 m

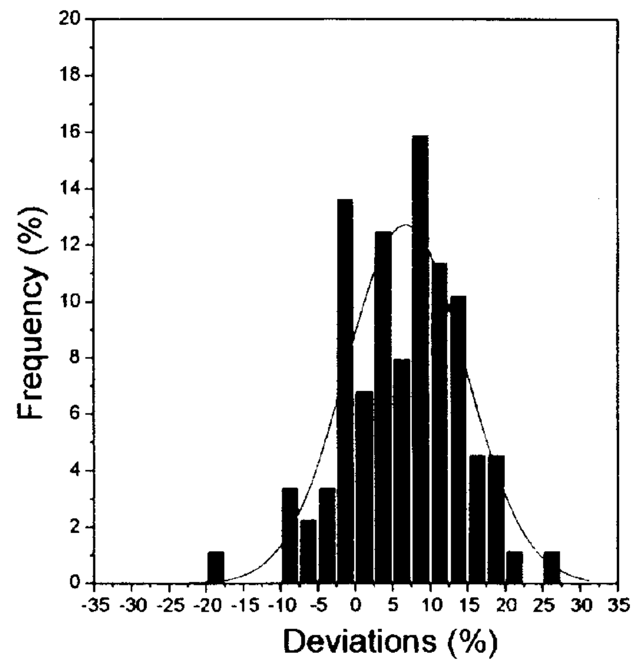




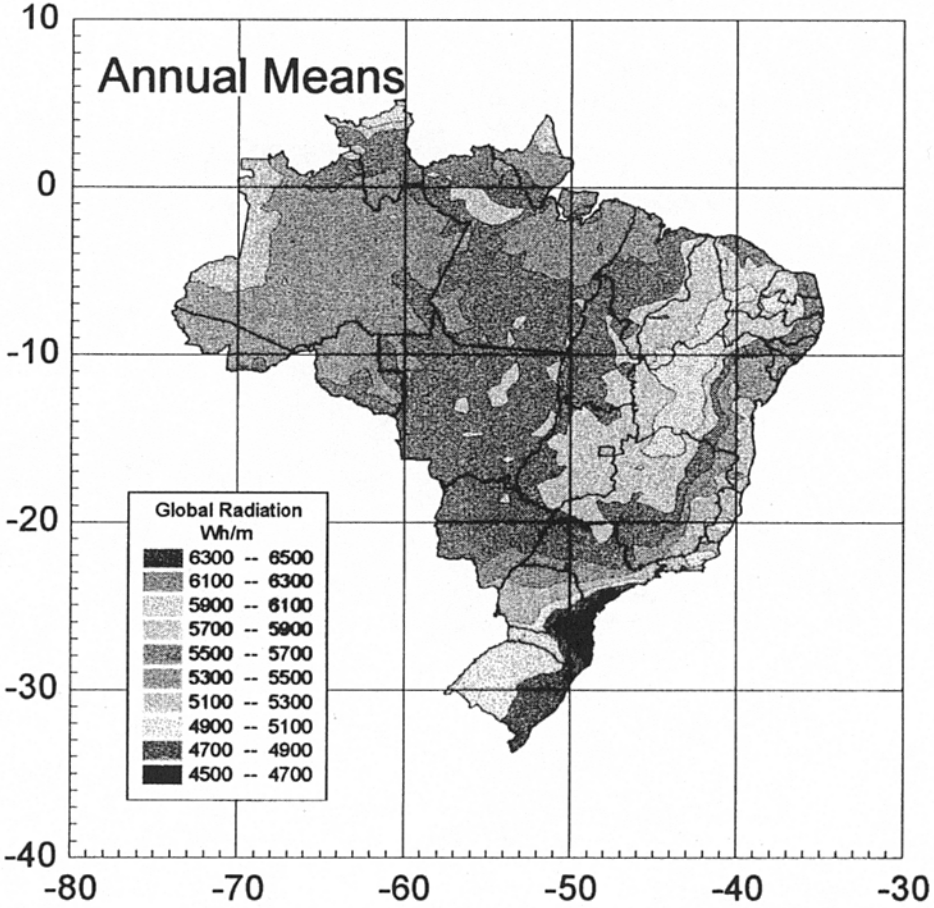
Model versus measured solar irradiation

Lebon Regis (26.98° S 50.71° W)
altitude 1036 m



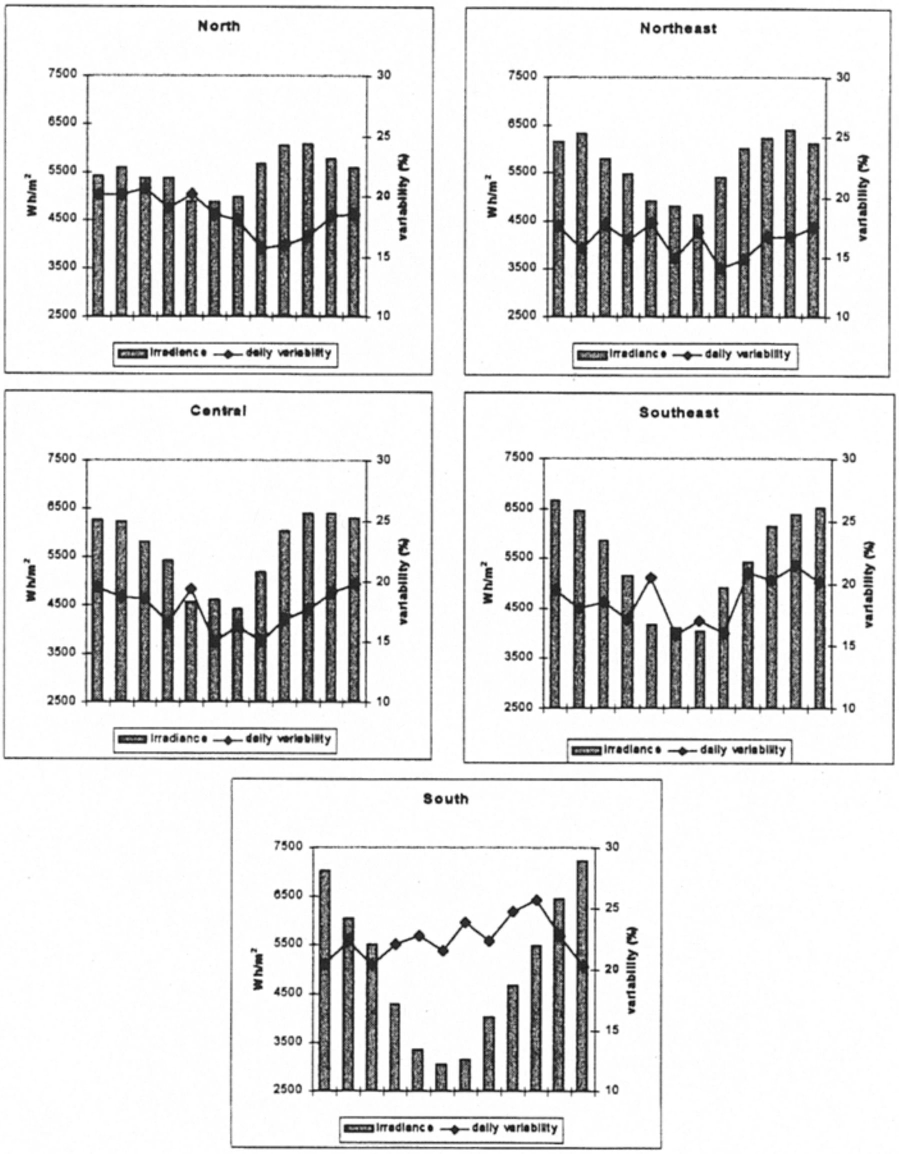


Mean Annual Global Horizontal Solar Irradiation and Monthly Deviations from the Annual Mean



Regional Variability of the Solar Irradiation

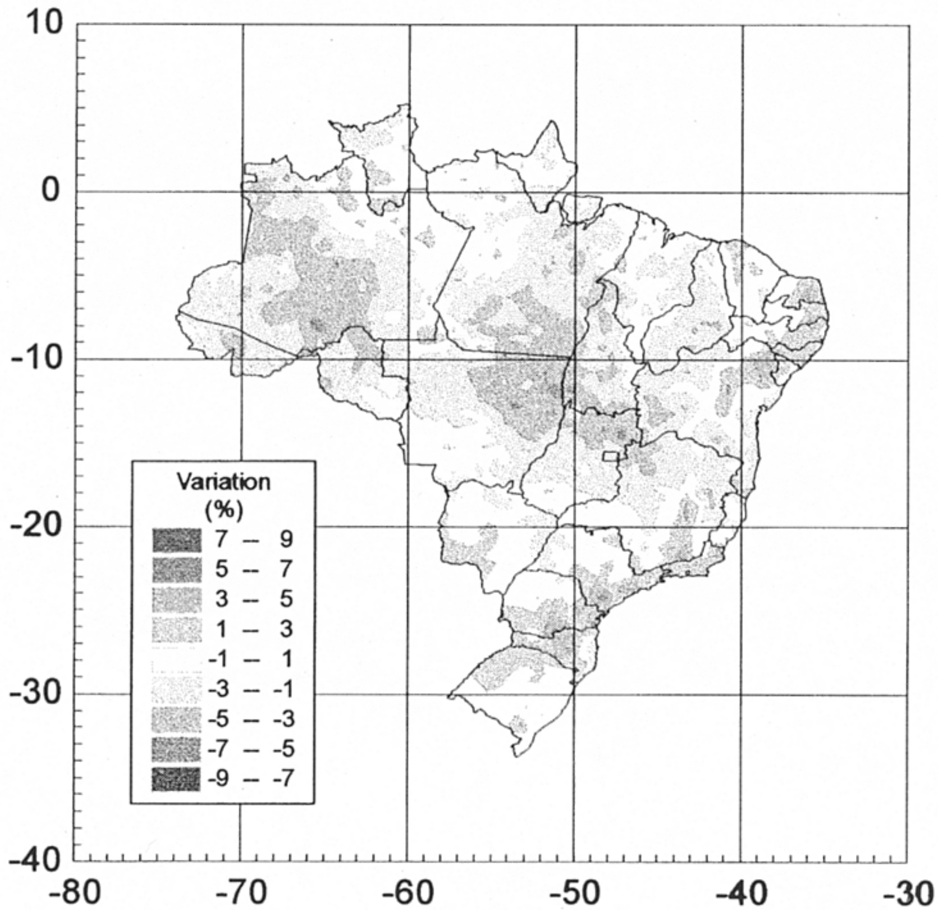
(for the five main climatic areas of Brazil)



Presentation: Solar Radiation Measurements in Brazil by Enio B. Pereira, et. al.

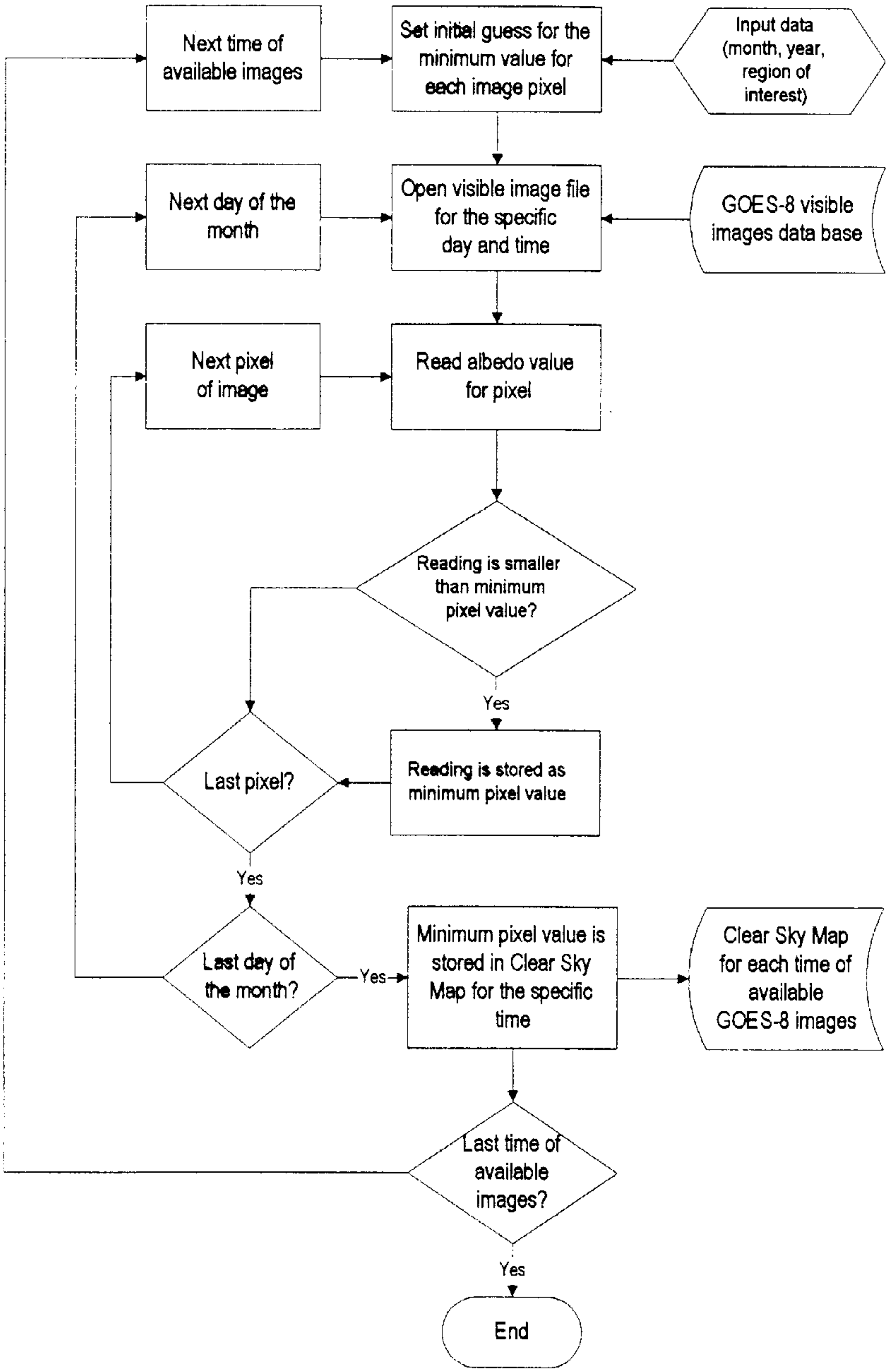
Inter-annual Relative Variability

(1996 - 1997)



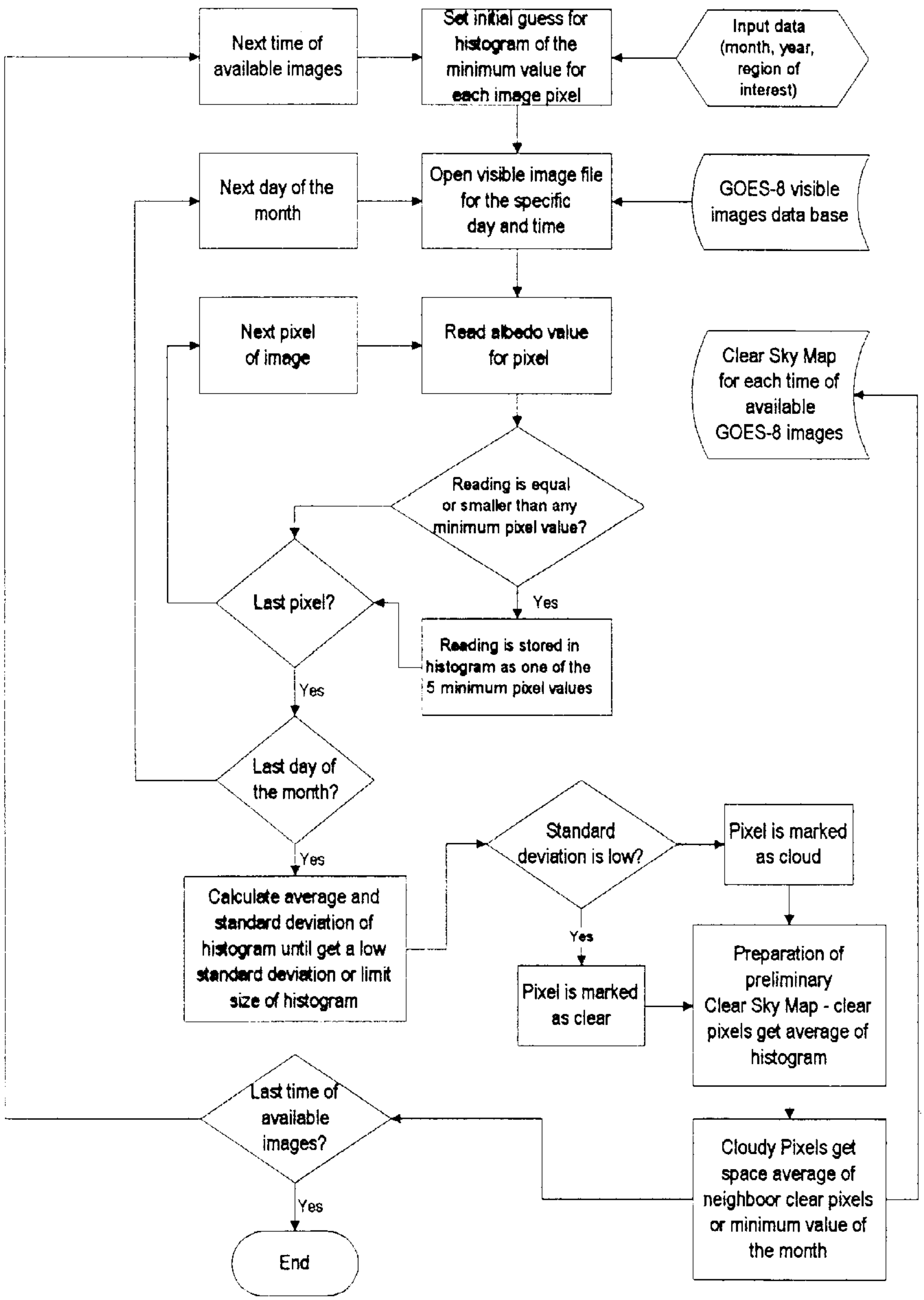
Block Diagrams of Clear Sky Composite Image

Minimum visible value - Method #1 (Standard in BRASIL-SR)



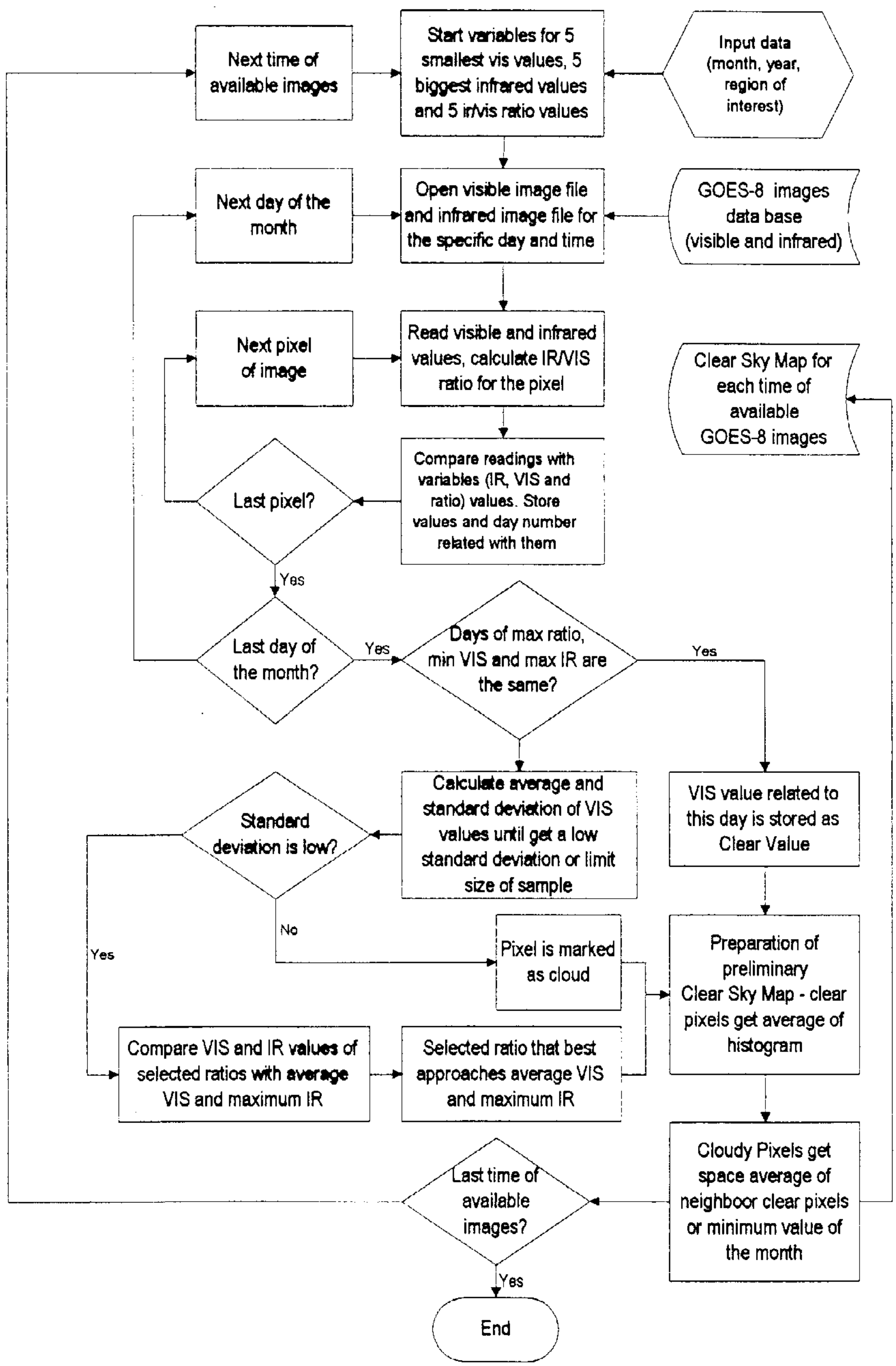
Block Diagrams of Clear Sky Composite Image

Average of five smallest visible values - Method #2



Block Diagrams of Clear Sky Composite Image

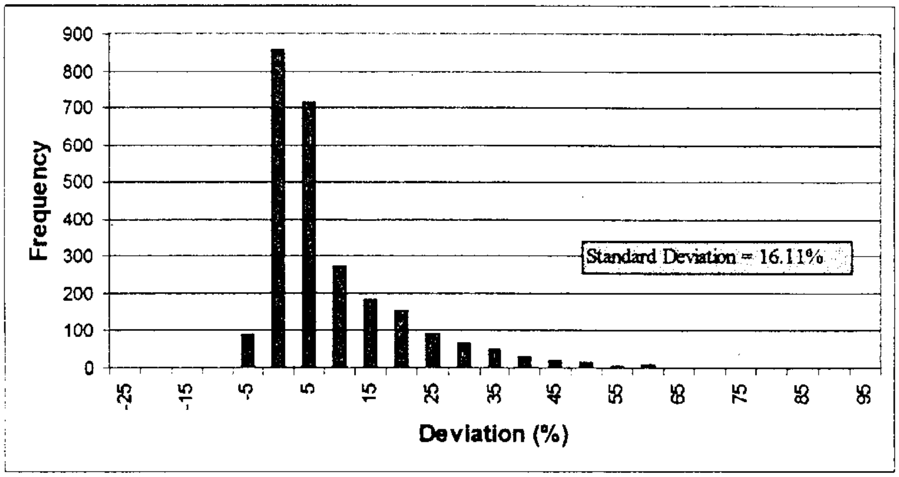
Better infrared/visible ratio - Method #3



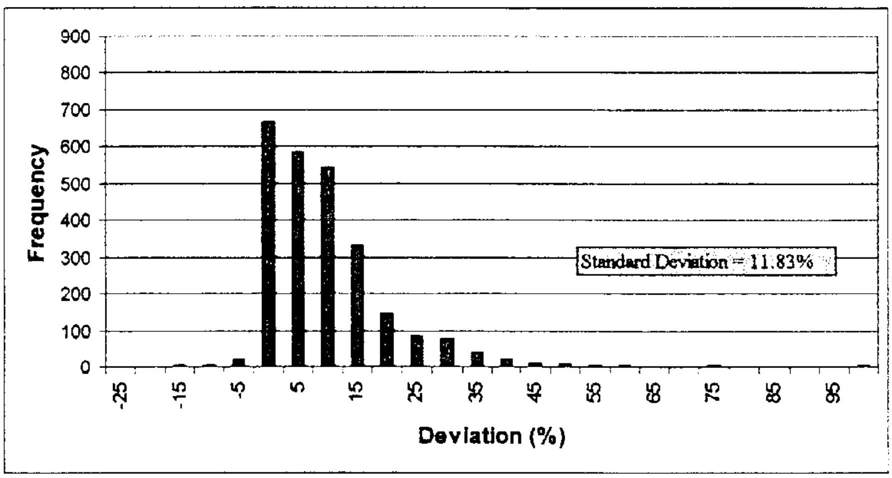
Presentation: Solar Radiation Measurements in Brazil by Enio B. Pereira, et. al.

Comparative Analysis

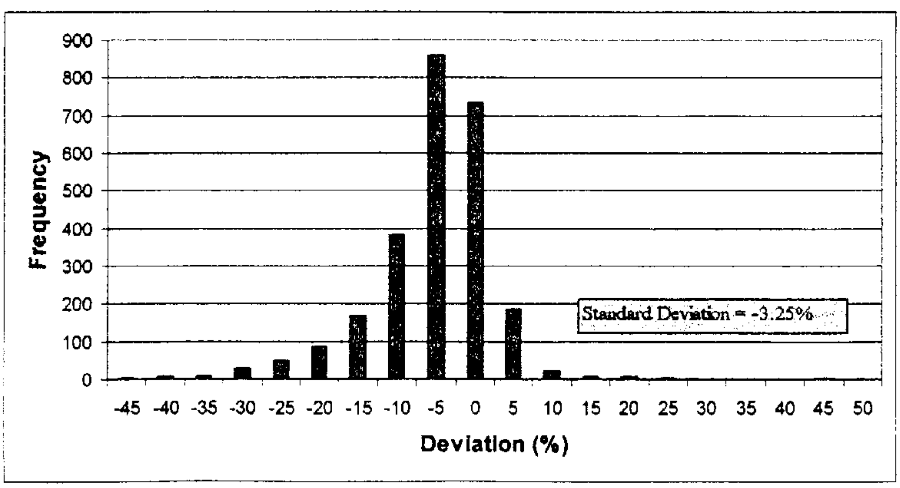
(A) Relative deviation between Method 2 and Method 1
(B) Relative deviation between Method 3 and Method 1
(C) Relative deviation between Method 3 and Method 2



(A)



(B)

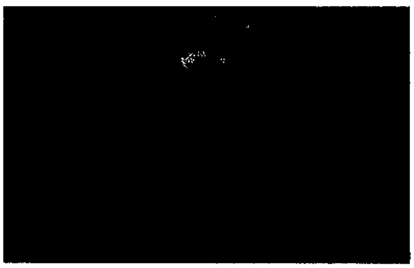


(C)

Composite Images

Florianópolis sector (45W to 55W and 25S to 35S)

(A) Clear Sky Image
obtained through Method 1

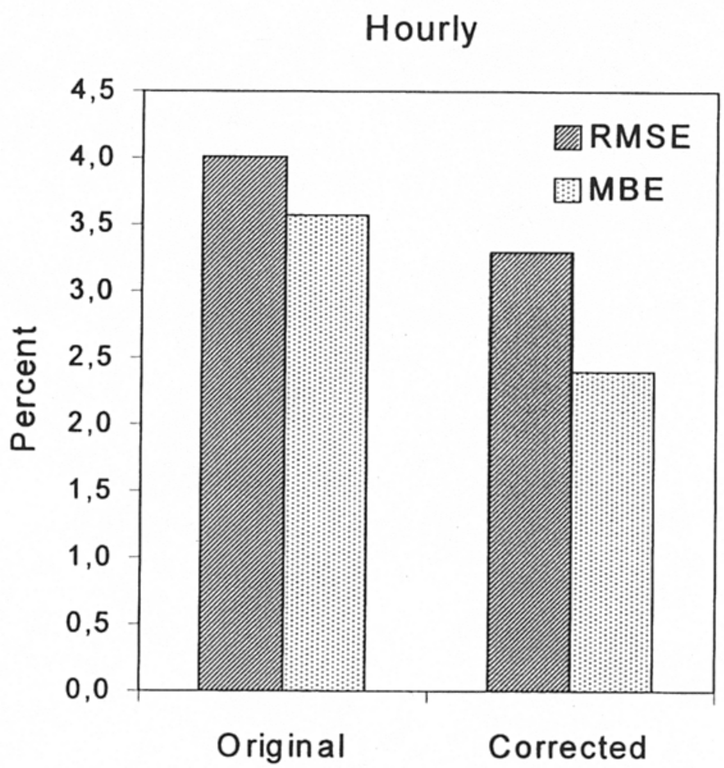


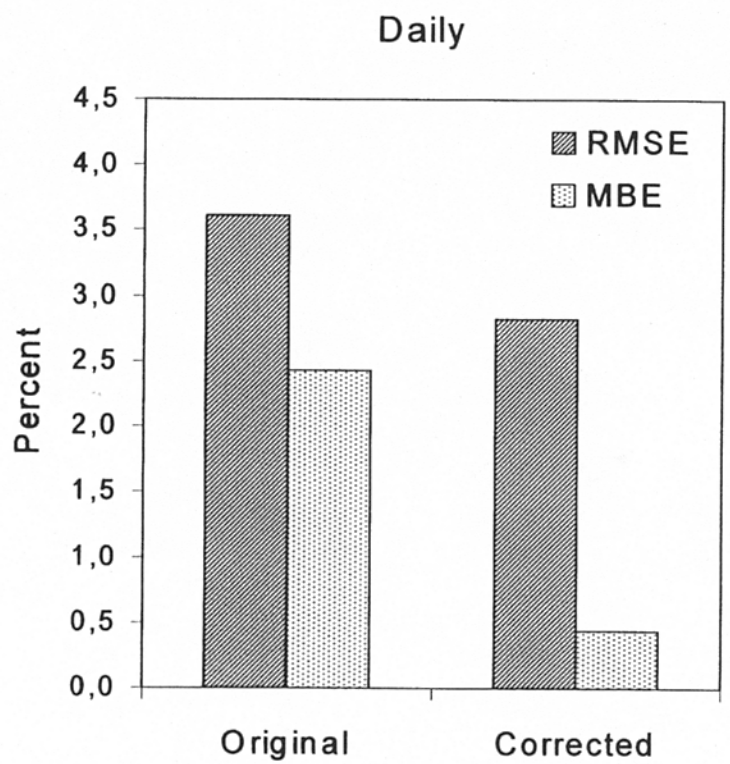
(B) Clear Sky Image
obtained through Method 2

(C) Clear Sky Image
obtained through Method 3

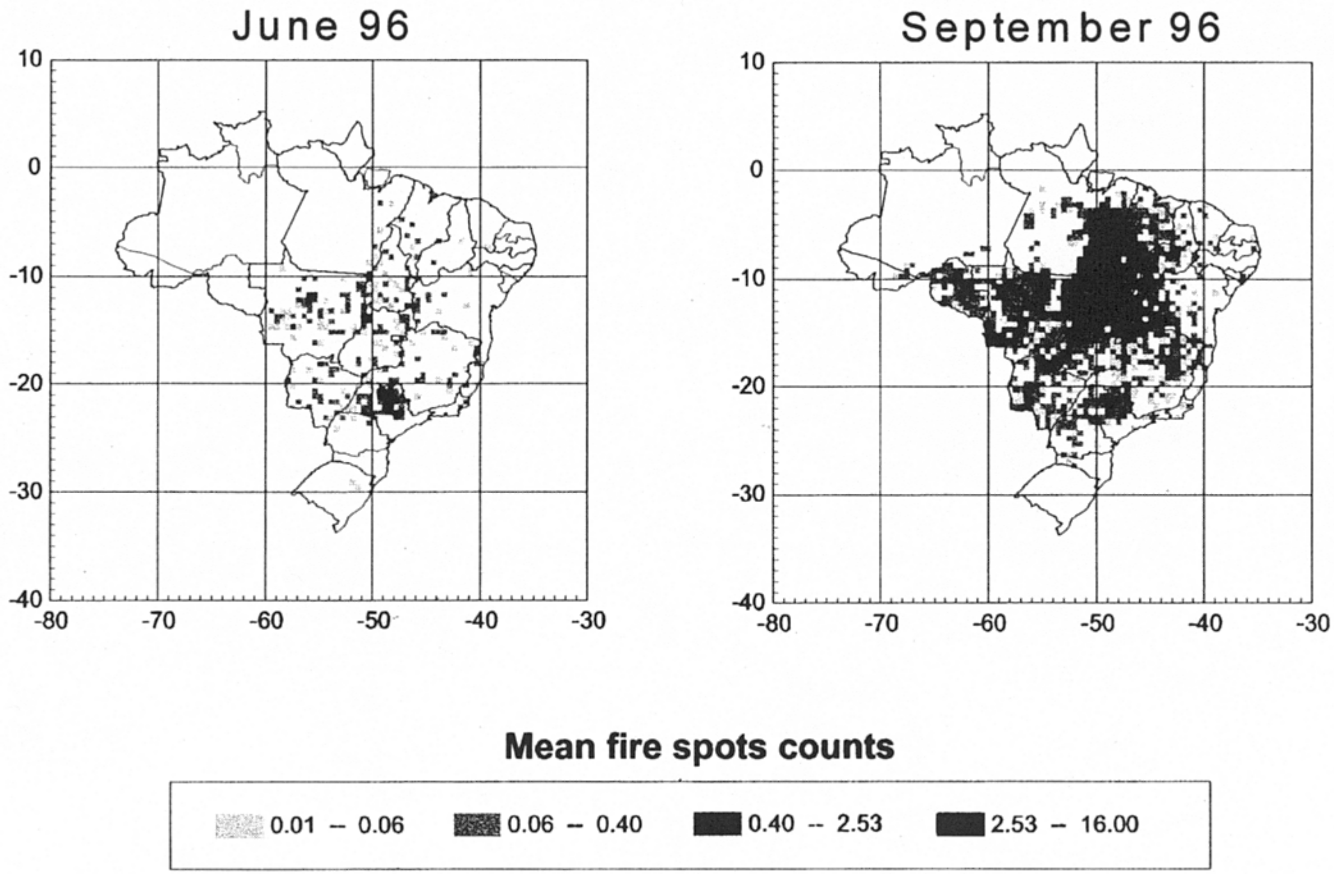
Correction for altitude effects on model deviation

Water vapor is 50% distributed within the first 5km of the atmosphere. This affects the model estimations of solar radiation in targets located at high altitudes. Thus, it was necessary to modify the calculation of the precipitable water while keeping the relative humidity constant. This was made by reducing the vertical profile of temperature through a wet adiabatic curve between the sea level and the target level.



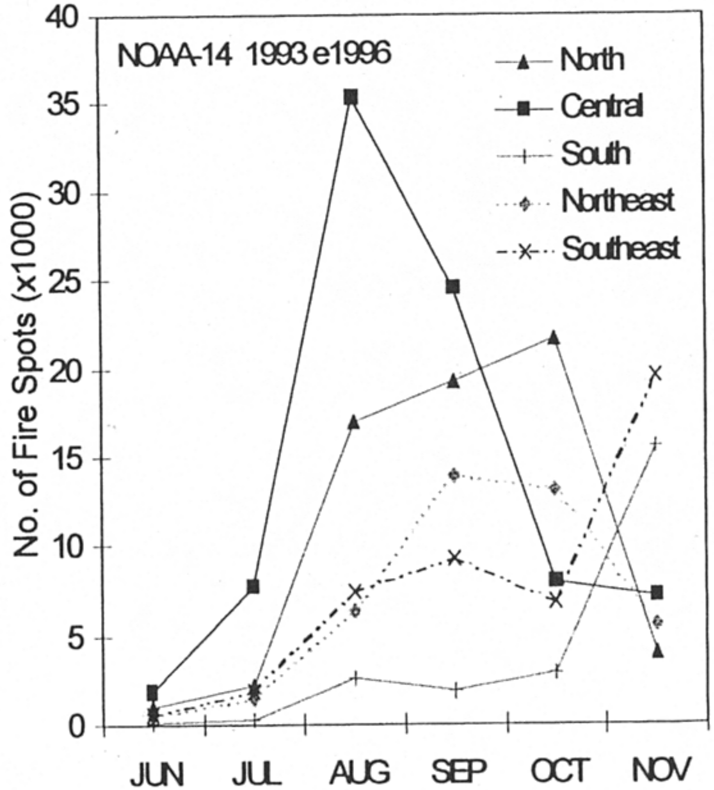


Geographical distribution of the total number of fire spots counted during the months of June and September of 1996. Data were calculated by using NOAA-12 AVHRR thermal sensor



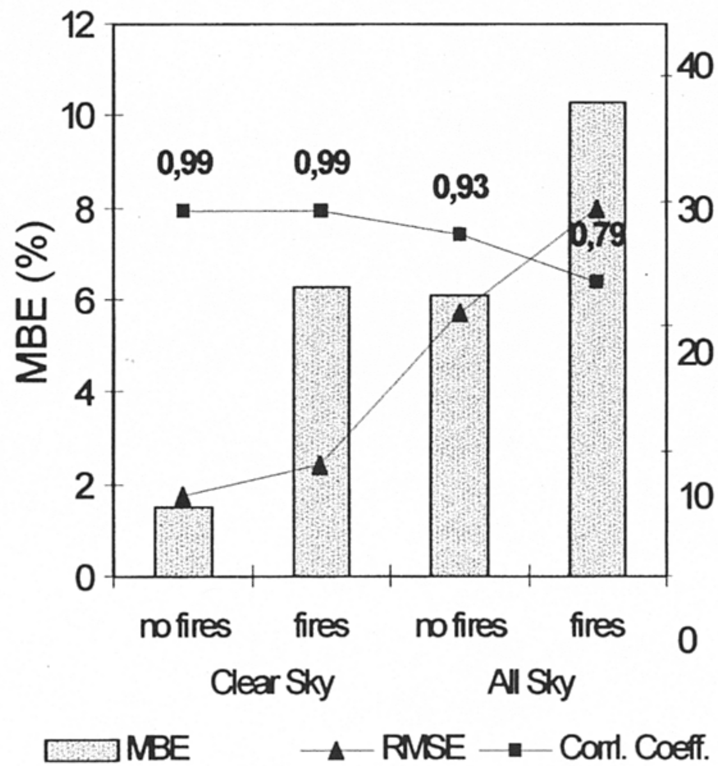
Number of fire spots in the five main climatic regions of Brazil

- Fire spots are detected by the NOAA-14 AVHRR satellite sensor at channel 3 (3.55 - 3.93 μm).
- Data are routinely acquired by CPTC-INPE and available at: www.cptec.inpe.br/products/queimadas
- Fires as small as 30m can be detected.
- Qualitative method - the number of fire spots is proportional to the area hit by fires.

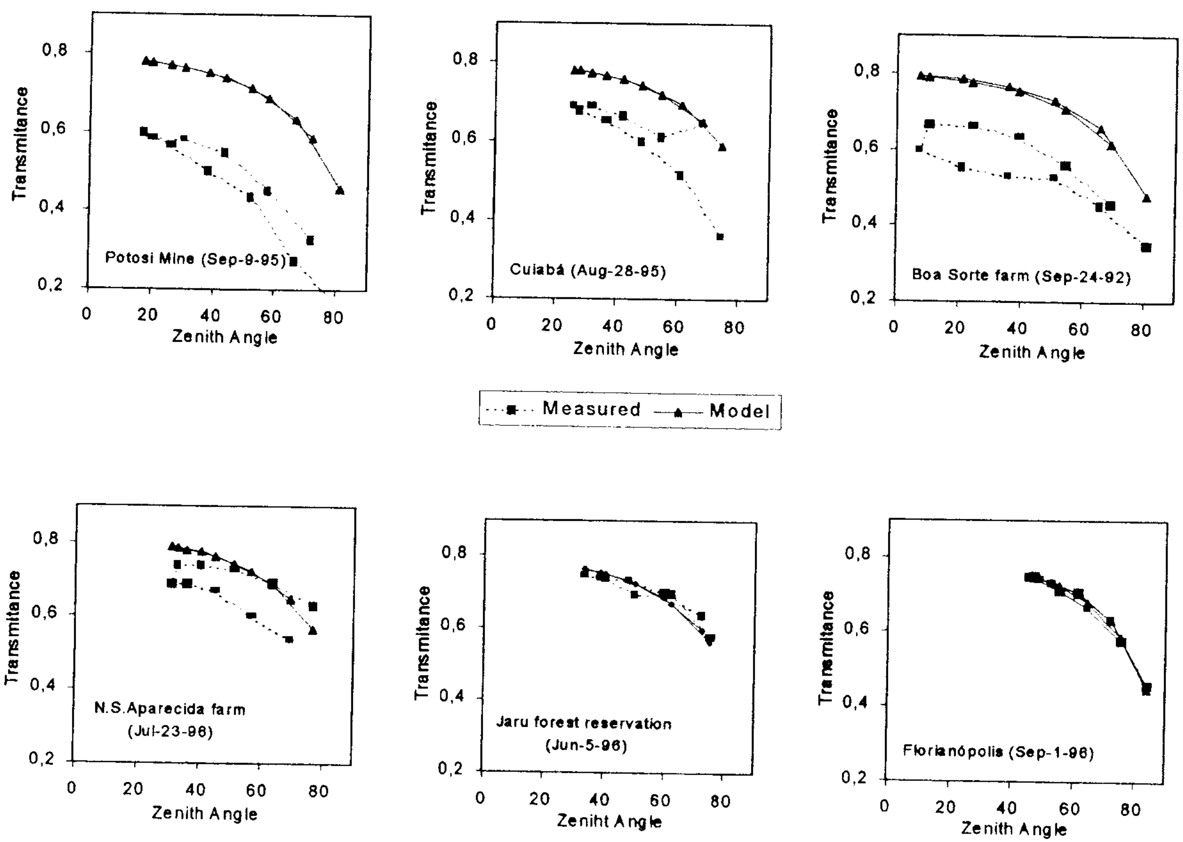


Variation of systematic errors (MBE) and random errors (RMSE) between daily sums of ground data and model estimations

- 235 clear-sky days from March trough October.
- Data split into two categories - for sites within and outside the biomass burning regions.
- Correlation Coefficients are indicated as a blue dashed line.
- Systematic deviation is about 4 times larger inside the burning region during clear sky days.



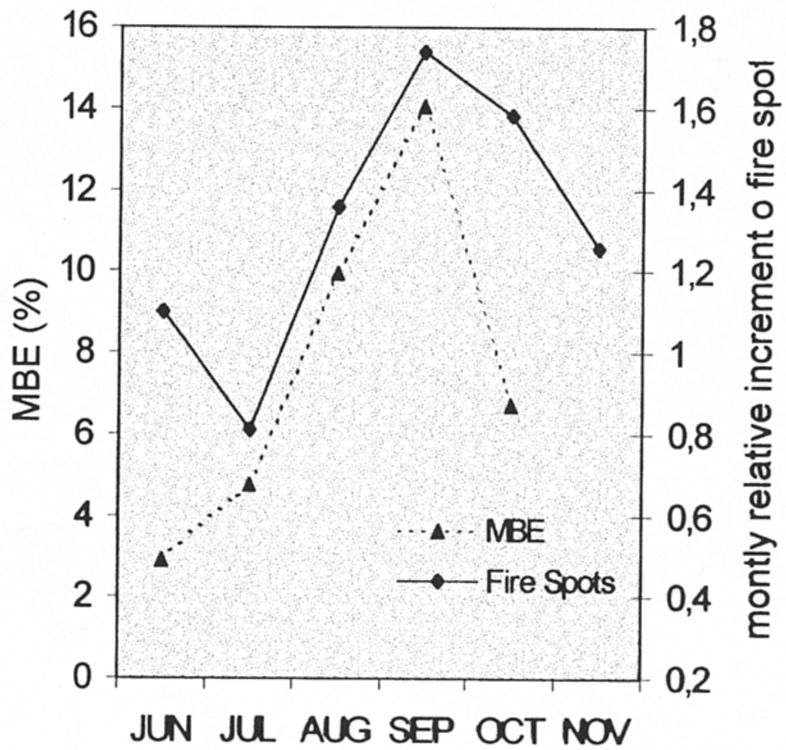
Impact of biomass fires on light transmittance versus solar zenith angle for several cases.



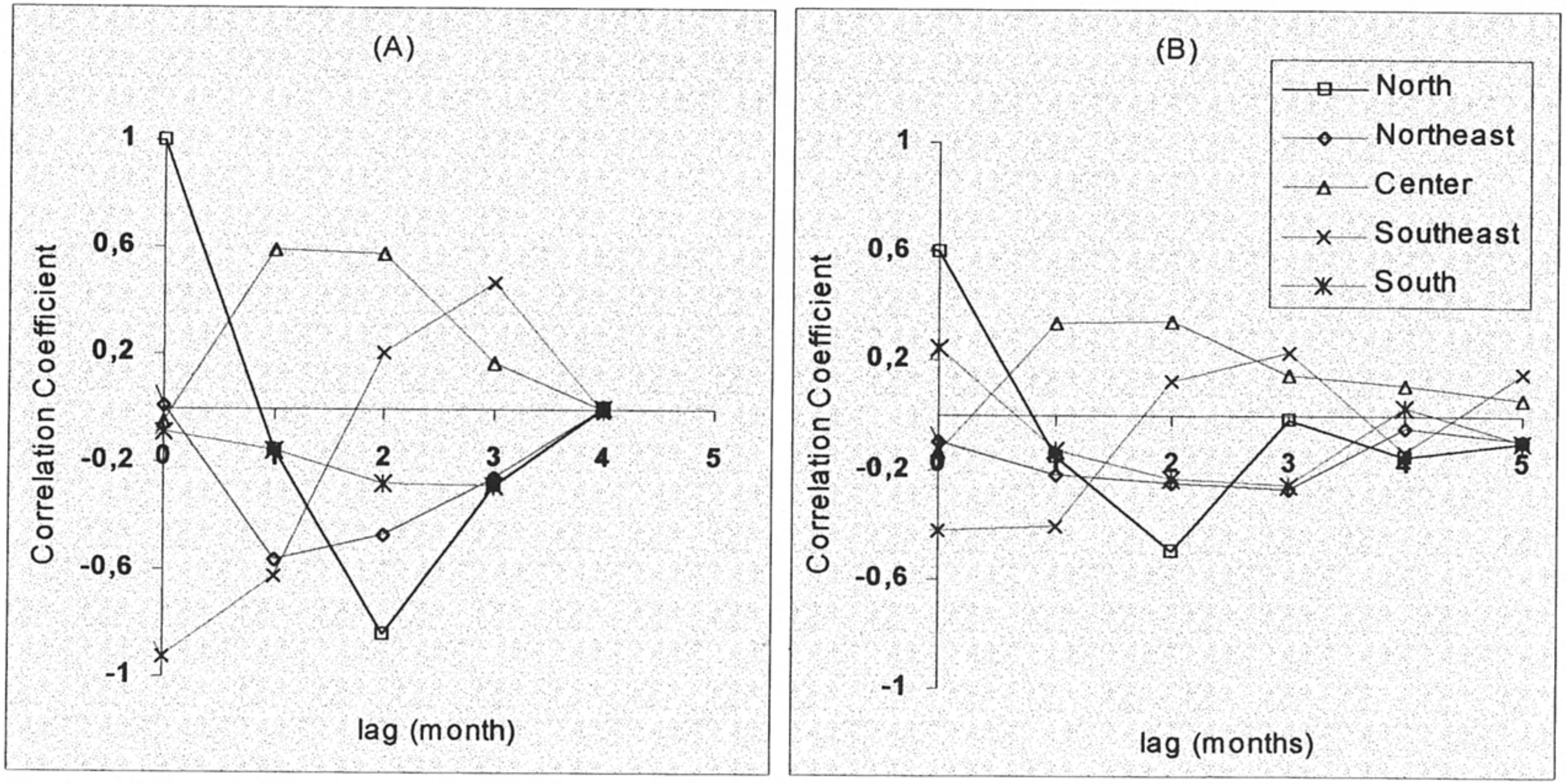
Time series for the MBE and number of fire spots in the Amazon region of Brazil.

- The maximum MBE is found for September when biomass burning activity in the area is also at its maximum

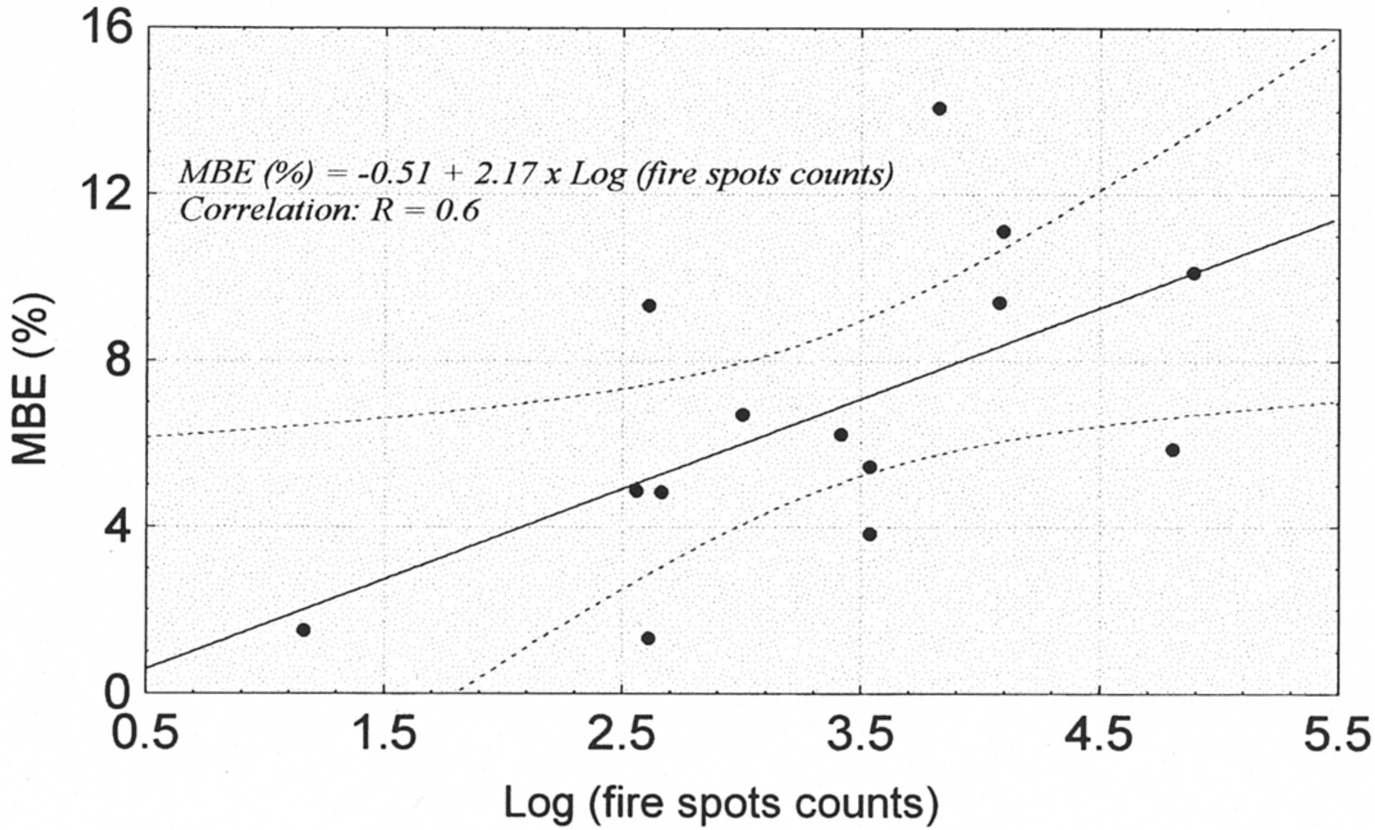
- The agreement between these two curves suggests that the two variables are linked to each other



Cross correlation between time series for MBE and fire spots performed for validation sites located in the biomass burning area (A) and for a site outside this area, in Florianópolis (B).

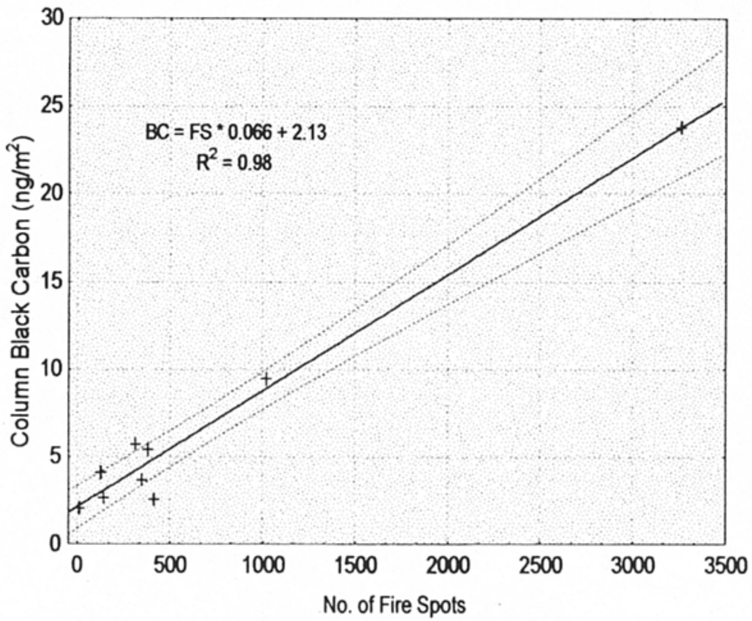


Plot of the relative mean bias error (MBE) and the logarithm of the number of fire spots counted inside a 2.5° circle of investigation around the ground solar station. The doted line represents the 95% confidence level for the straight-line fitting



Correlation coefficients between fire products and fire spots during biomass burning season

- Column concentrations of fire products were estimated by integrating over vertical profiles of data obtained during SCAR-B field mission in the Brazil (1995);
- Fire spots were counted inside 2.5° circles of investigation centered at each column concentration data site;
- Al major fire products presented positive correlation with the fire spots.

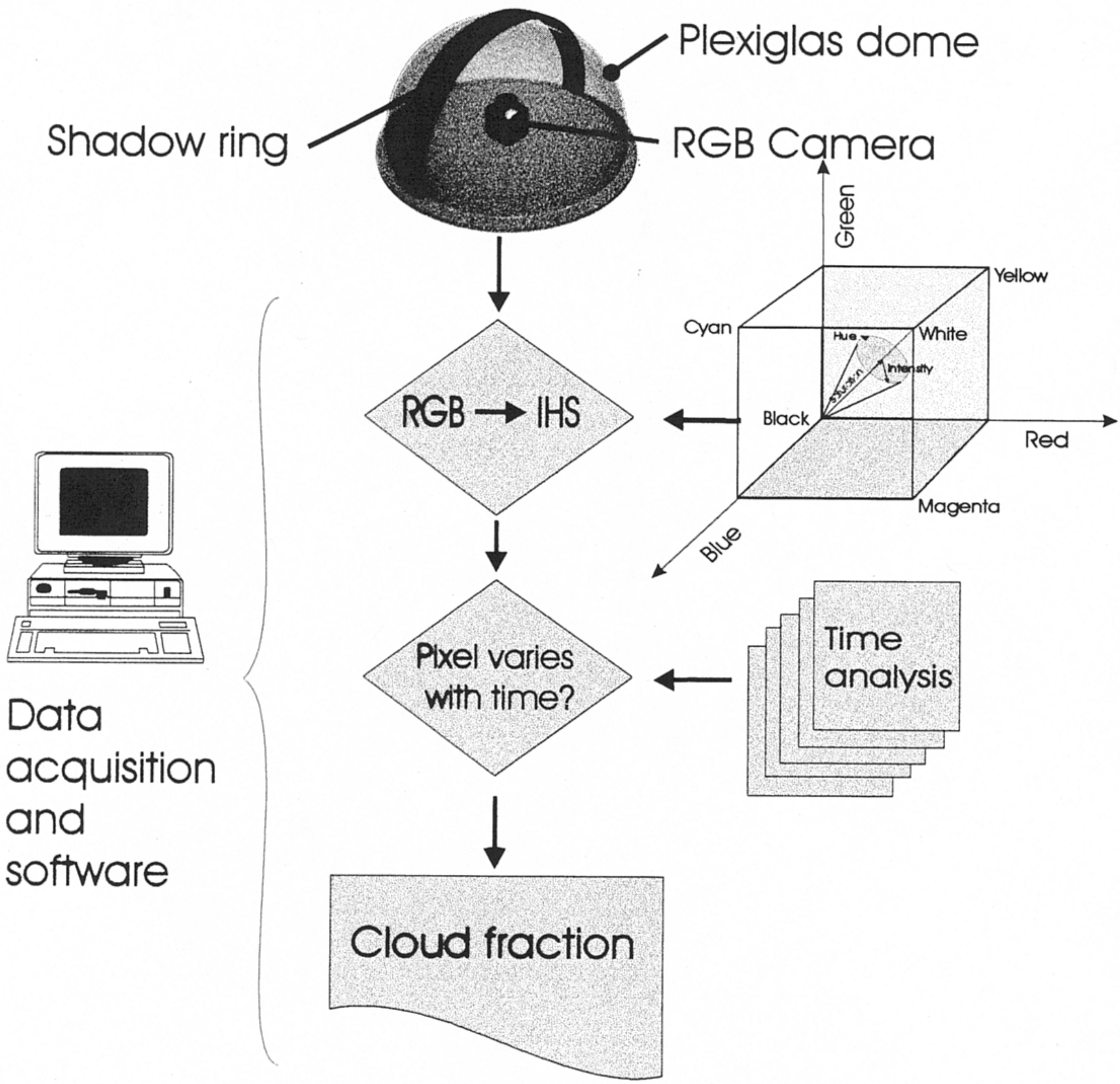


Combustion Product	Correlation Coefficient (R^2)	N° of profiles
Total aerosol mass	+0.98	5
Black Carbon	+0.98	9
Submicron particle count number	+0.95	5
CH_4	+0.90	5
N_2O	+0.65	5
CO	+0.45	5

* the + indicates a positive correlation

Automatic Cloud Fraction Monitor

(ground data validation for satellite models)



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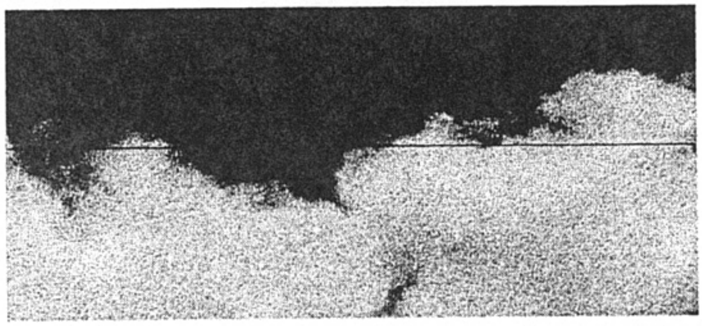
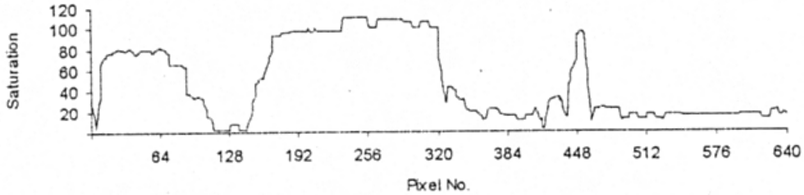
Result of Cloud Fraction Discrimination

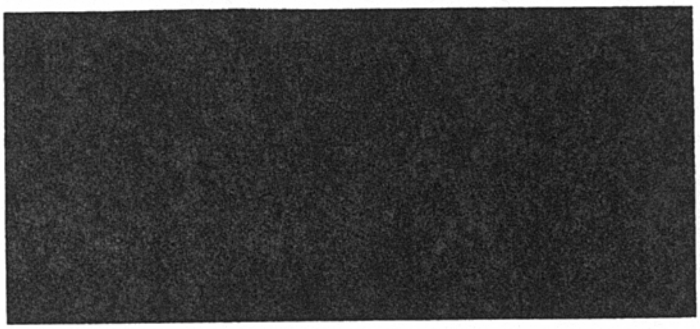
Line 152



Raw image from camera



Scan of line 152



Saturation map

Cloud discrimination code

Clouds = 58.7 %
Clear Sky = 40.3%
Transition = 1,63%

Final statistics

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SOLAR RADIATION IN THE AMAZON DURING THE LBA

SUBMITTED TO THE: *Large-Scale Biosphere-Atmosphere Experiment in Amazonia*

Principal Investigator:

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OBJECTIVES:

- To enhance the existing network for ground-truth of satellite derived data.
- To provide a data basis on solar radiation at ground level over Brazilian Amazonian territory for various application and scientific processes.

MILESTONES:

- Set up of four ground stations for solar radiation and basic meteorological data acquisition in distinct sites of the Amazon region.
- Provide on a routine basis qualified-compiled ground-truth radiation data for several satellite applications.
- Derive, on a routine basis, surface solar global, diffuse and photo-synthetically active radiation data using the BRAZIL-SR radiation model.
- Validate and inter-compare some existing satellite-based models for solar radiation.
- Set up of a historical data archive of visible/infrared GOES-8 satellite images for Brazil.
- Measure and compile aerosol concentration profiles data in the Amazon troposphere.
- Study of the effects of burning of biomass on the radiation measurements and estimations

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Ground Solar Radiation Sites

- Set-up three Solar radiation stations for global and diffuse radiation, and basic ground meteorological measurements – air temperature, wind speed, pressure, (UFSC-INPE-BMBF/Germany)
- Locations are: The Hydro-electrical power plant of Coaracy Nunes (Macapá)
  São Gabriel da Cachoeira (Northeast of the Amazonas)
  Hydro-electrical power plant of Samuel (Southeast of Roraima)
- Existing BSRN site at Balbina (UFSC - WMO/BSRN)

Provide Ground Radiation Data for Various Applications

- Radiation data from these four radiation measurement sites will be provided on a routine basis qualified ground radiation data (global and diffuse short-wave)
- Data will be acquired via telephone modem at a 2-minute sampling interval from our ground radiation reference station in Florianópolis, SC
- Qualification, storage and distribution of ground radiation data will be made by LABSOLAR

Derive Surface Radiation Data by Radiation Model

- The BRAZIL-SR radiation model will be employed on a routine basis to derive surface radiation data for SW-global, SW-diffuse, and photosynthetically active radiation.
- Model radiation data will be generated and distributed by INPE

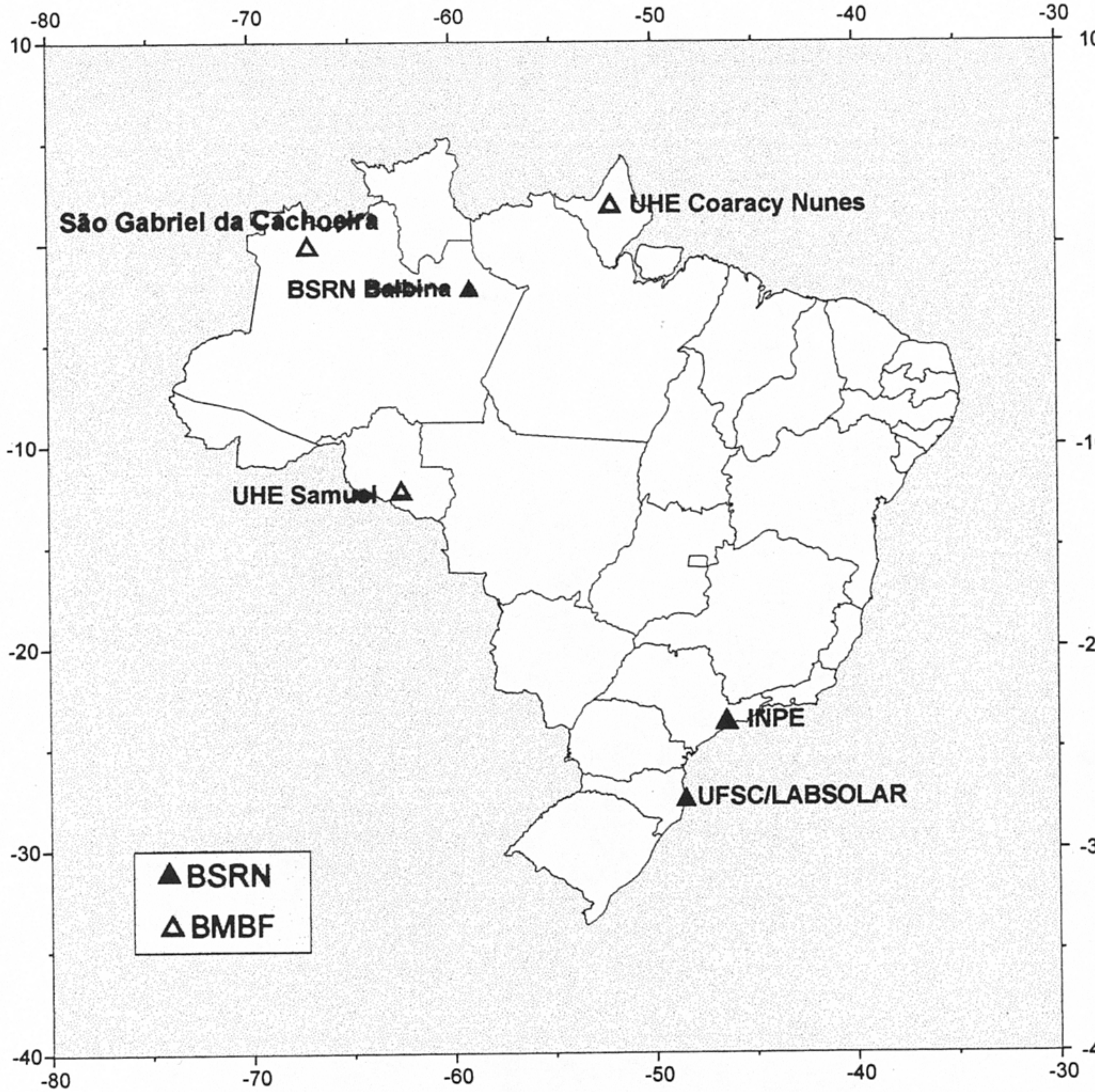
Radiation Model Validation

- Several radiation model validation will be performed during LBA by using the ground data provided by this project and also by using the infra-structure available by other LBA projects
- A study on ground data interpolation versus satellite predictions will be a by-product of this work
- By now, four radiation model groups agreed to participate in this validation experiment: the INPE/UFSC/GKSS (Enio, Colle, etc.), the SUNY (Perez and colab.), The Albany (Pinker and colab.) and the NREL (Renee crew) groups.

Parameterization of the Aerosol in Model Predictions

- The strong influence of aerosols from burning of the biomass during the dry season will be studied in order to implement radiation models to take this effect into account
- This will be made by using sunphotometric data (both existing, and to be implemented by this project), and also field measurements in airborne missions

Ground Stations



Presentation: Solar Radiation Measurements in Brazil by Enio B. Pereira, et. al.

Products and Projects in South America

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The talk will cover a review about products developed in the past 20 years with emphasis on the currently available products derived either from ground station data or satellite images. Monthly means of incoming global radiation derived from satellite is compared with the estimates derived from the Angström method, as published by OLADE Organización Latinoamericana de Energía.

An illustrative analysis is presented to show that the uncertainty of the monthly means of global radiation data available for South America is too large, for the purpose of feasibility analysis of photovoltaic plants.

A brief report concerning the projects underway in South America is also presented. Very few countries have devoted significant effort in research to assess solar radiation data, in spite of the fact solar energy market is growing.

Special effort should be addressed to bring together the national capabilities in order to undertake a project to assess solar radiation over South America.

PRODUCTS FOR SOLAR ENERGY USERS

1. Solar radiation atlas of OLADE - Organización Latinoamericana de Energía

The distribution of global irradiation is derived from data collected from meteorological ground stations of all South American countries. These data were measured by pyranometers (P) and sunshine duration recorders (SDR) or actinographs. The global and direct irradiation are estimated by the empirical equations of Angström. A single equation is fitted for all South America. The period of measurements and the type of instruments used is given in Table 1. The quality of the data as well as the traceability of the radiometers are not reported. The data is presented graphically and numerically for the station locations.

Table 1

COUNTRY	Max Years	P	H	U	TOTAL
Argentina	22	37	96	106	239
Bolivia	7	17	25	0	42
Brazil	18	17	336	0	353
Chile	24	59	1	0	60
Columbia	9	0	90	0	90
Ecuador	25	0	63	47	110
El Salvador	24	13	8	0	21
Falkland Islands	3	1	0	0	1
Guyana	8	0	15	1	16
Paraguay	9	0	16	0	16
Peru	3	5	61	0	66
Surinam	5	0	19	0	19
Uruguay	5	5	0	0	5
Venezuela	29	29	63	0	92

Max Years: Maximum number of years of data.
P: Irradiance measured using pyranometer.
H: Data calculated from cloud cover information or bright sunshine hours.
U: Data from source lacking information on instrumentation.

Source: University of Lowell Photovoltaic Program - International Solar Irradiation Database - 1991

2. Atlas of Solar Radiation of Brazil
Edited by the University of Pernambuco, Recife
Authors: Prof. Naum Fraidenreich and Shigueru Tiba

The work reports data obtained from Angström technique derived from ground truth collected by actinographs and pyranometers installed in the meteorological stations of INMET - Brazilian Weather Service. The accuracy of the estimated data is not carried out. Data is presented in graphical form obtained by linear interpolation from station locations.

3. Atlas of Global Solar Irradiation in Brazil - 1st Version Derived from Satellites
Edited by INMET - Brazilian Weather Service, November 1998
Authors: Prof. S. Colle and Dr. E. B. Pereira

The data is presented in graphical images as well as in multimedia form. The description of the physical model used to compute the incoming global radiation on the surface as well as the validation procedure and results are reported by E. B. Pereira in the present workshop. The numerical data for three hour, daily and monthly basis for spatial resolution of 0,5º x 0,5º is available in optical disk archives at LABSOLAR. The comparison between the present version and OLADE version was carried out over Brazilian territory. The OLADE data is interpolated from data of station locations by the kriging technique before the comparison is made. The relative deviation for each pixel is obtained by the following equation:

$$D(\%) = (R_{SAT} - R_{OLADE}) \times 100 / R_{SAT}$$

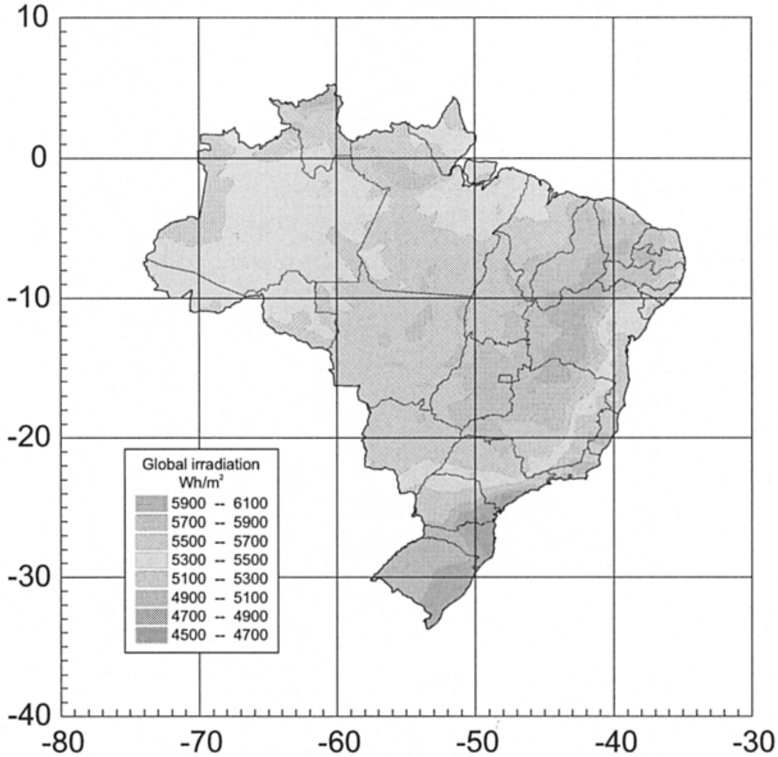
where R is the irradiation in Wh/m^2.

The best agreement between OLADE and satellite versions is verified for the winter season. The greatest deviations are observed in the Amazon region and Southern regions. Smaller deviations are observed in the Northeastern region. MBE and RMSE are shown in Table 2. The next figures shows the graphical images of deviations as well as the corresponding frequency histograms, for the yearly and monthly basis.

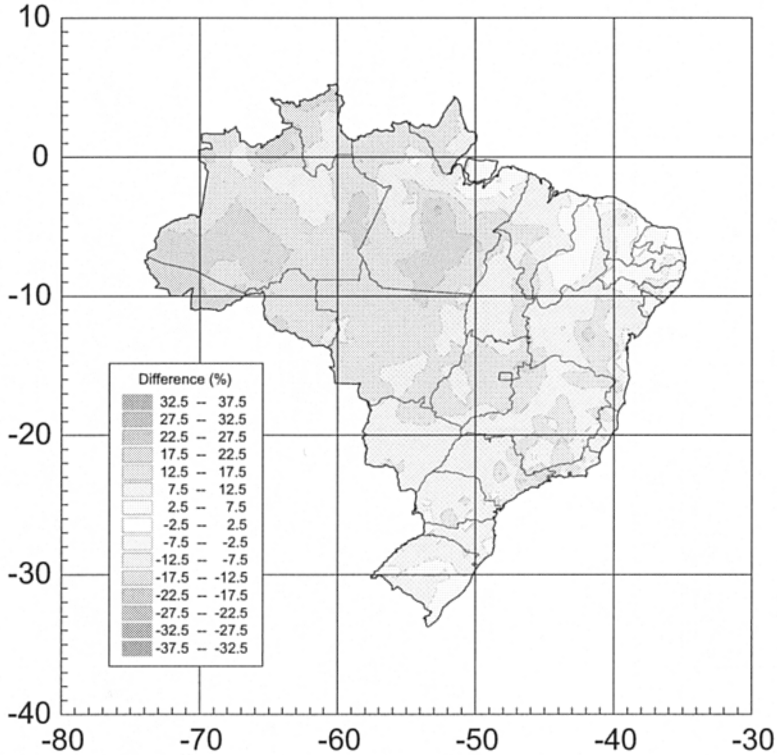
Table 2

Period	MBE	RMSE
Yearly	12,78	17,46
Jan	19,54	26,26
Feb	20,30	27,26
Mar	14,17	19,32
Apr	16,27	23,08
May	5,66	11,68
Jun	9,06	14,93
Jul	-2,35	12,86
Aug	5,07	12,04
Sep	15,72	22,91
Oct	13,53	20,63
Nov	13,71	20,48
Dec	16,40	22,71

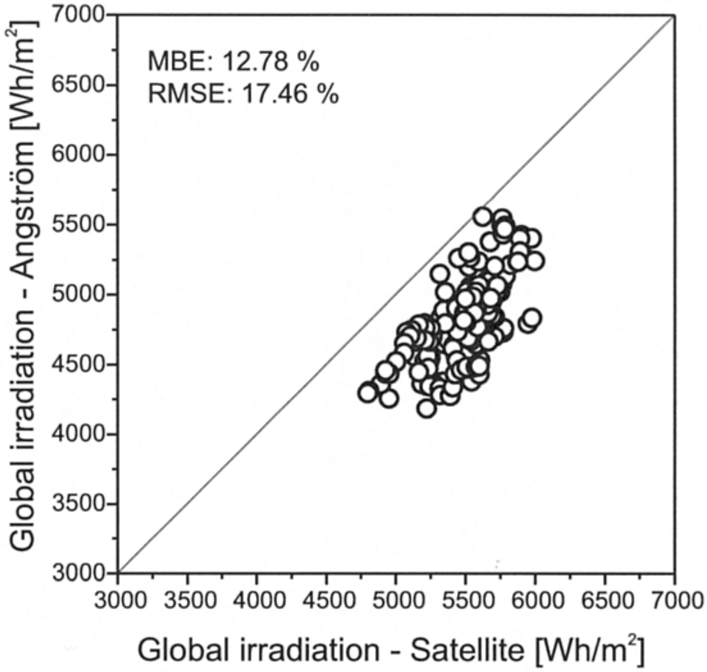
ANNUAL MEAN



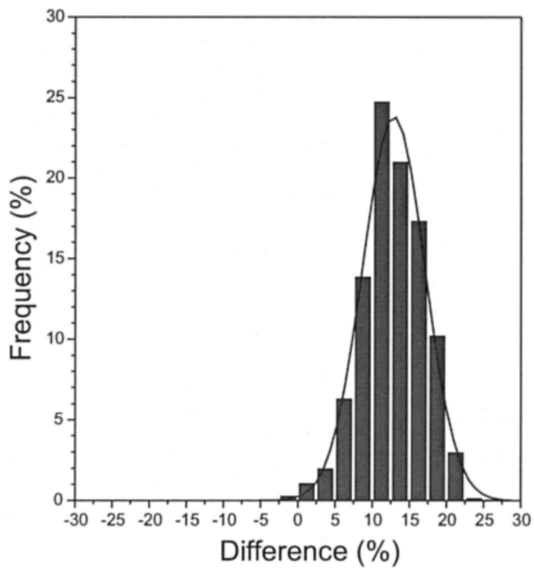
Annual mean derived from satellite data - GOES 8



Difference between satellite derived data and OLADE data (%)

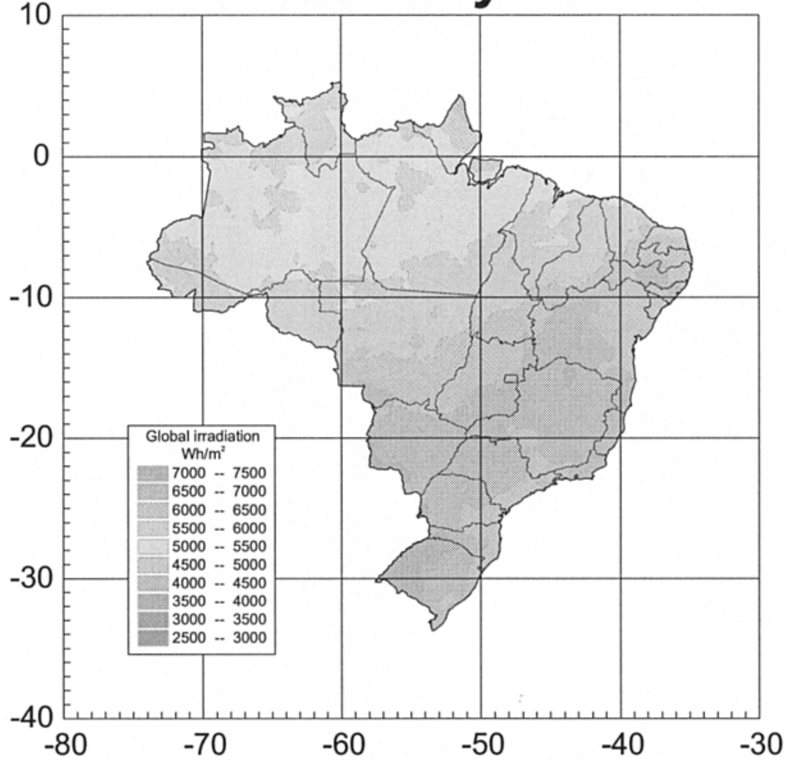


Comparison between satellite derived data and OLADE data

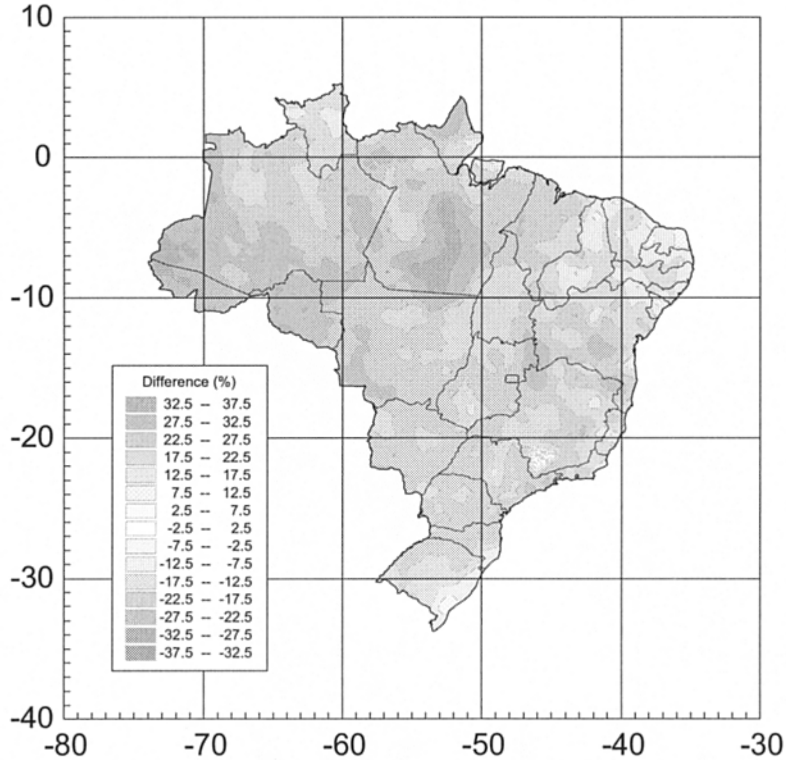


Difference between satellite derived data and OLADE data (%)

January

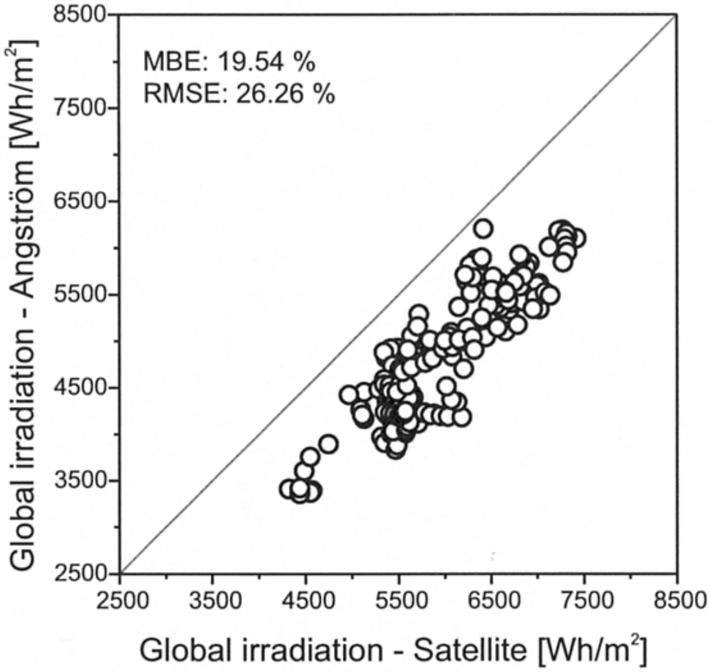


Monthly mean derived from satellite data - GOES 8

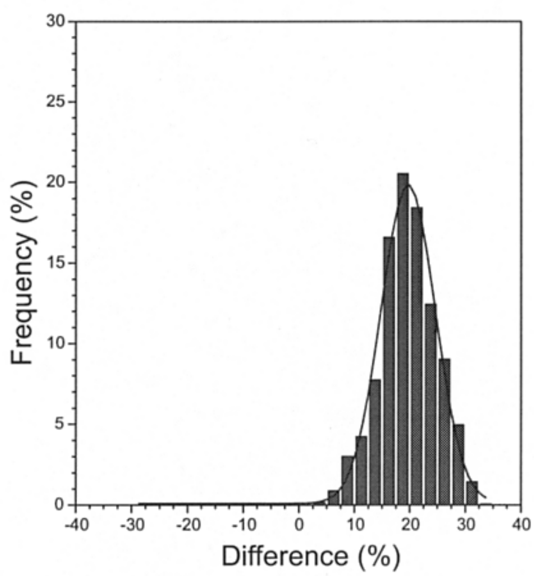


Difference between satellite derived data and OLADE data (%)

January

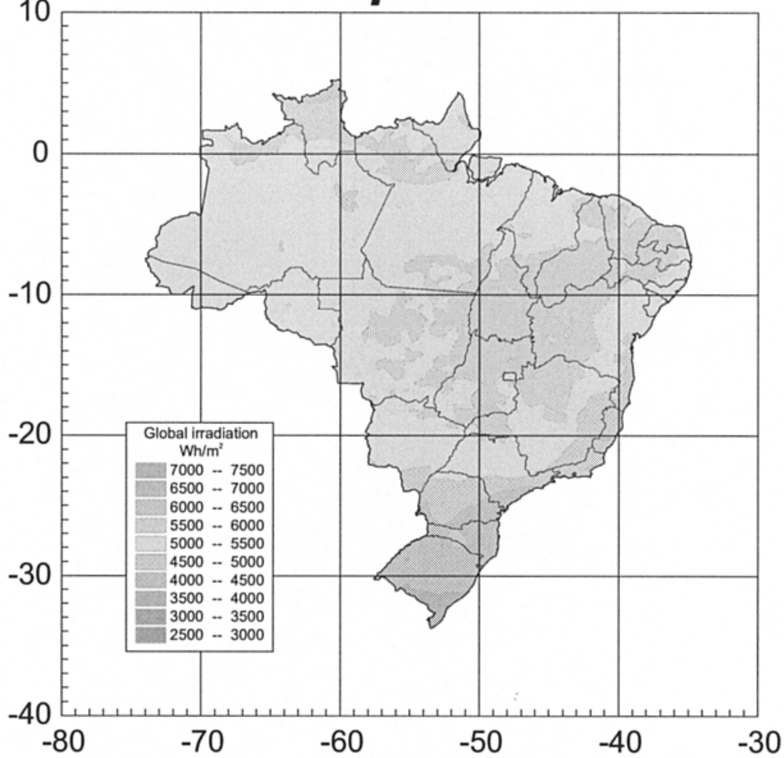


Comparison between satellite derived data and OLADE data

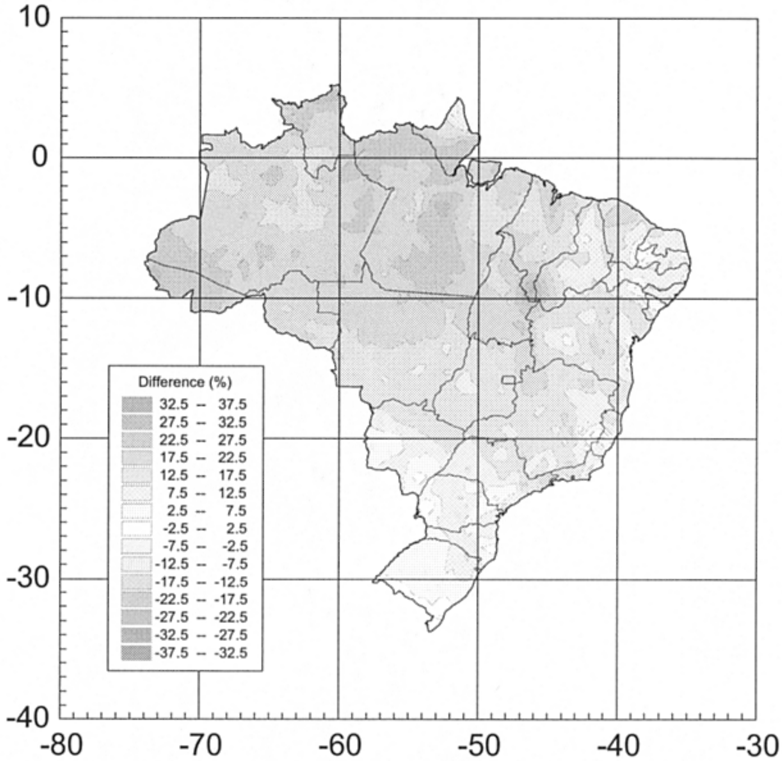


Difference between satellite derived data and OLADE data (%)

April

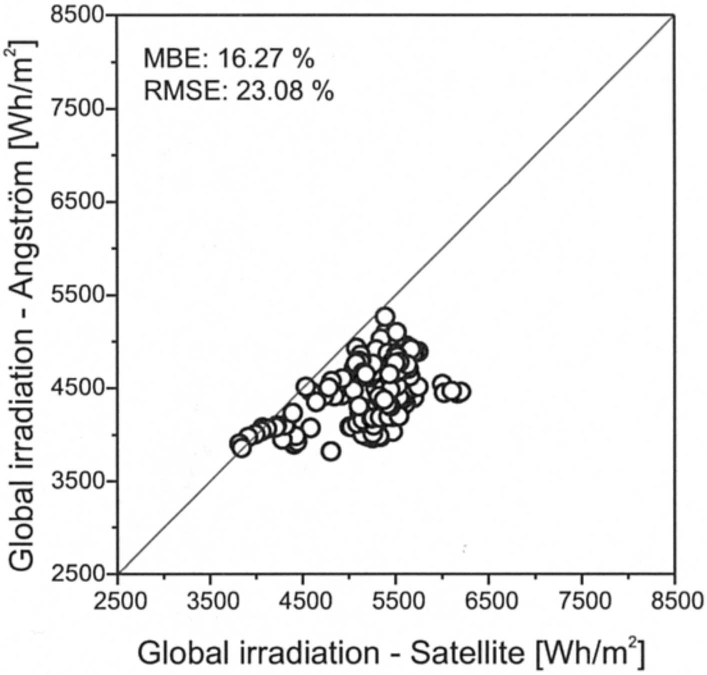


Monthly mean derived from satellite data - GOES 8

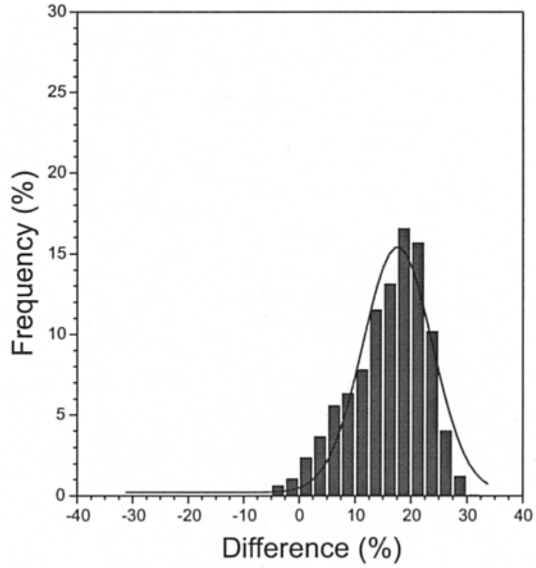


Difference between satellite derived data and OLADE data (%)

April

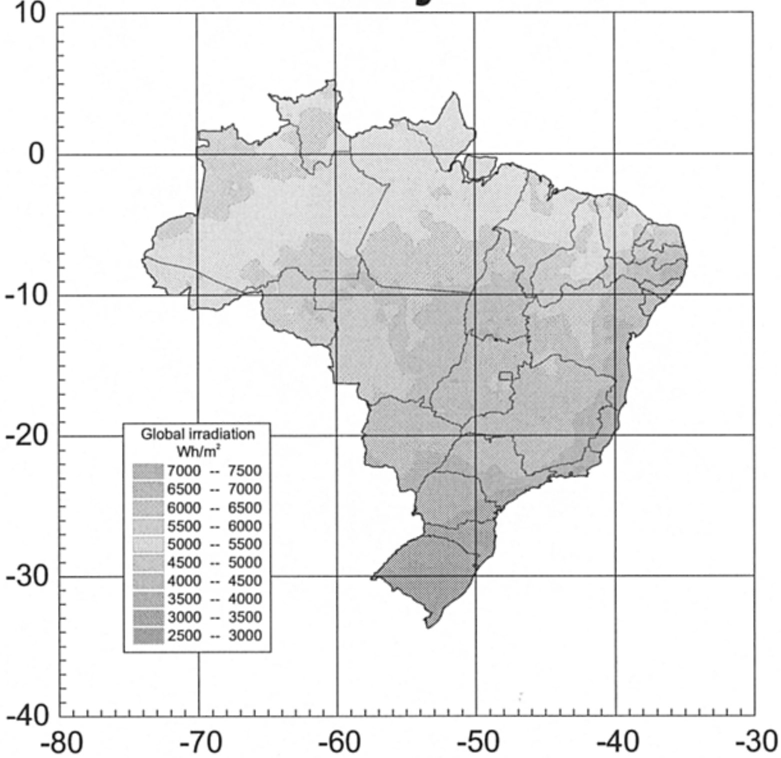


Comparison between satellite derived data and OLADE data

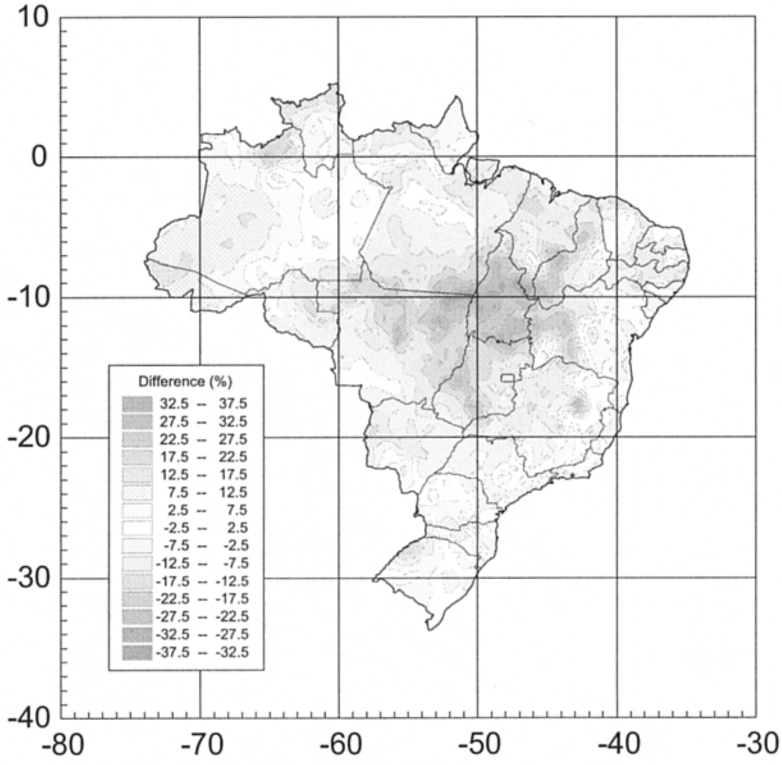


Difference between satellite derived data and OLADE data (%)

July

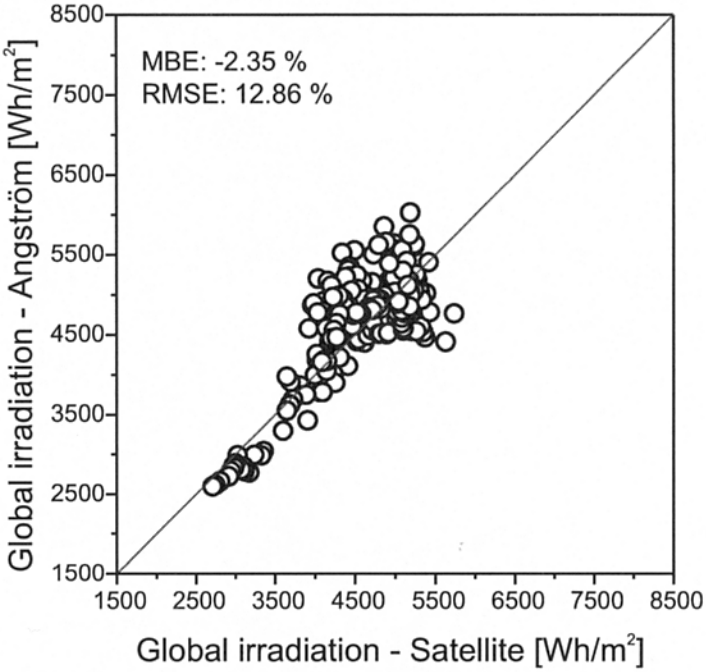


Monthly mean derived from satellite data - GOES 8

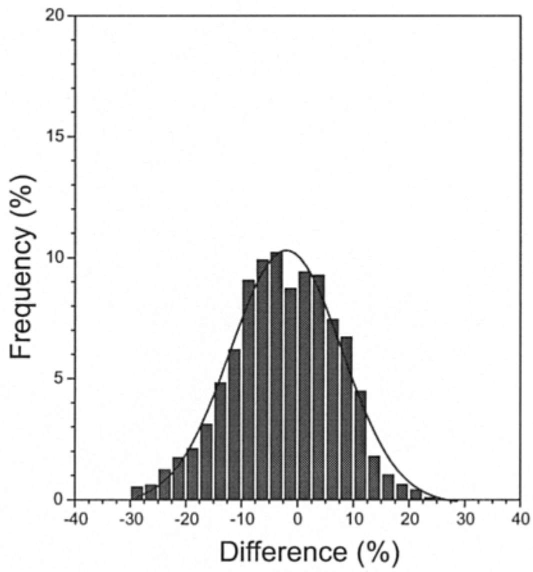


Difference between satellite derived data and OLADE data (%)

July

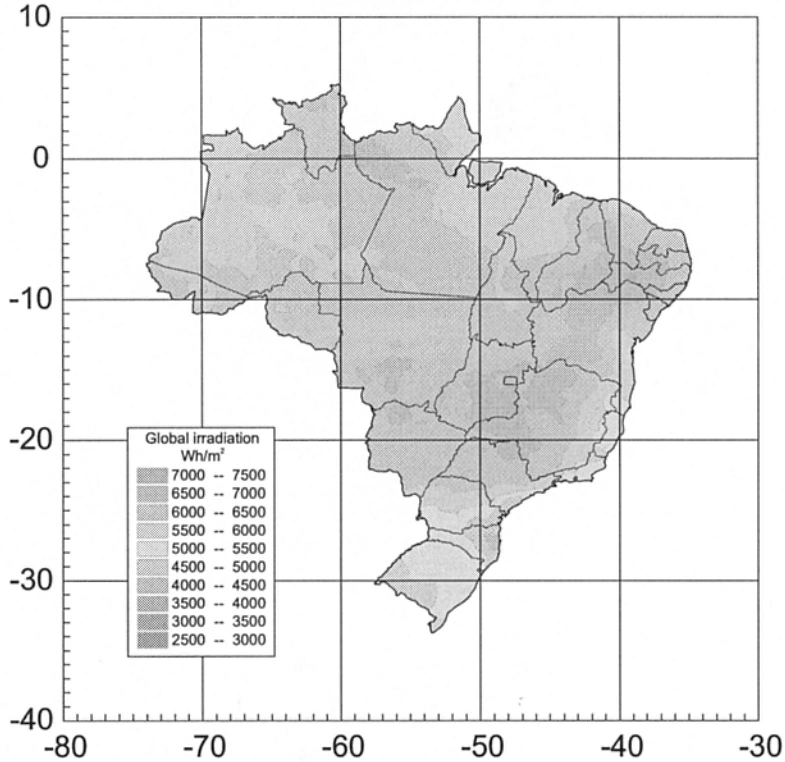


Comparison between satellite derived data and OLADE data

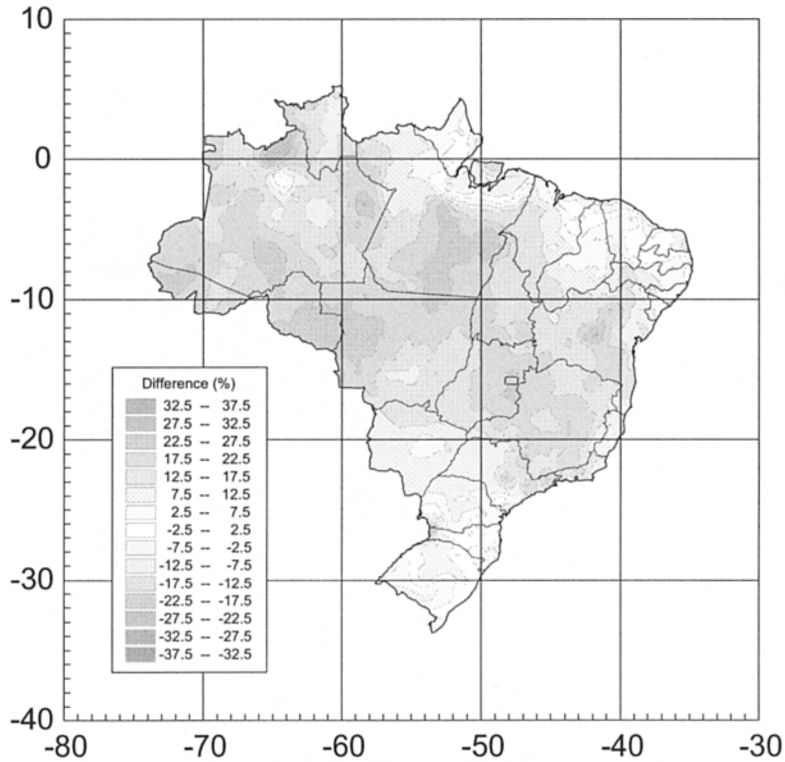


Difference between satellite derived data and OLADE data (%)

October

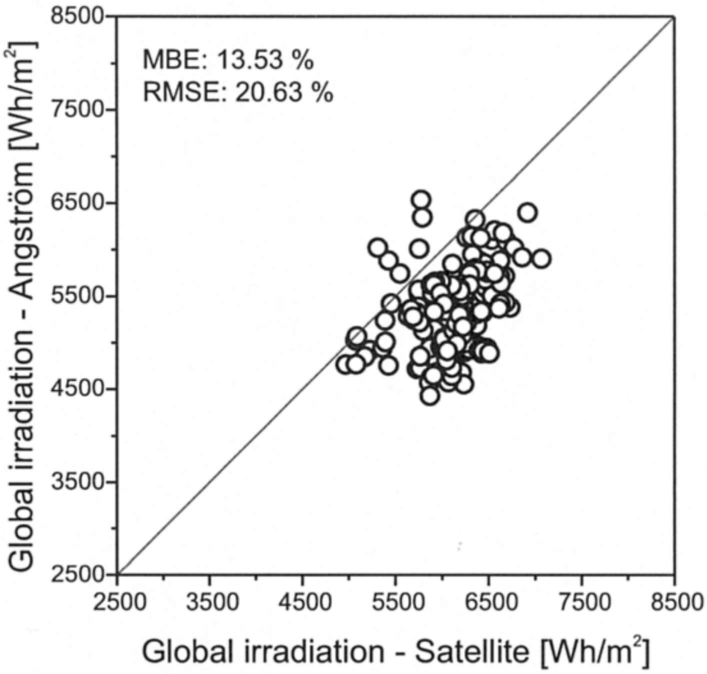


Monthly mean derived from satellite data - GOES 8

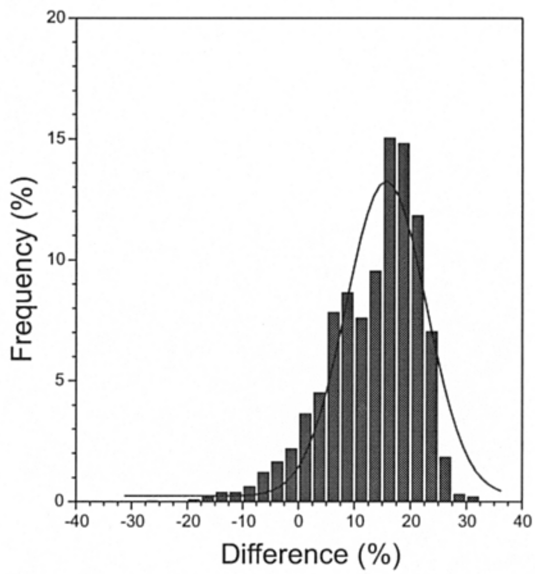


Difference between satellite derived data and OLADE data (%)

October



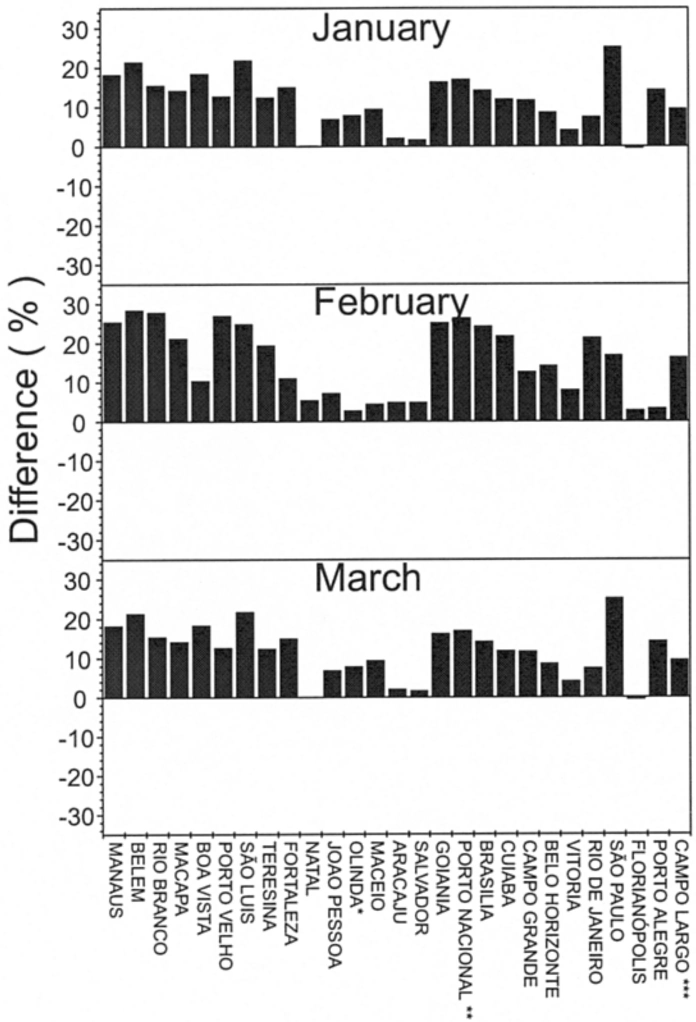
Comparison between satellite derived data and OLADE data



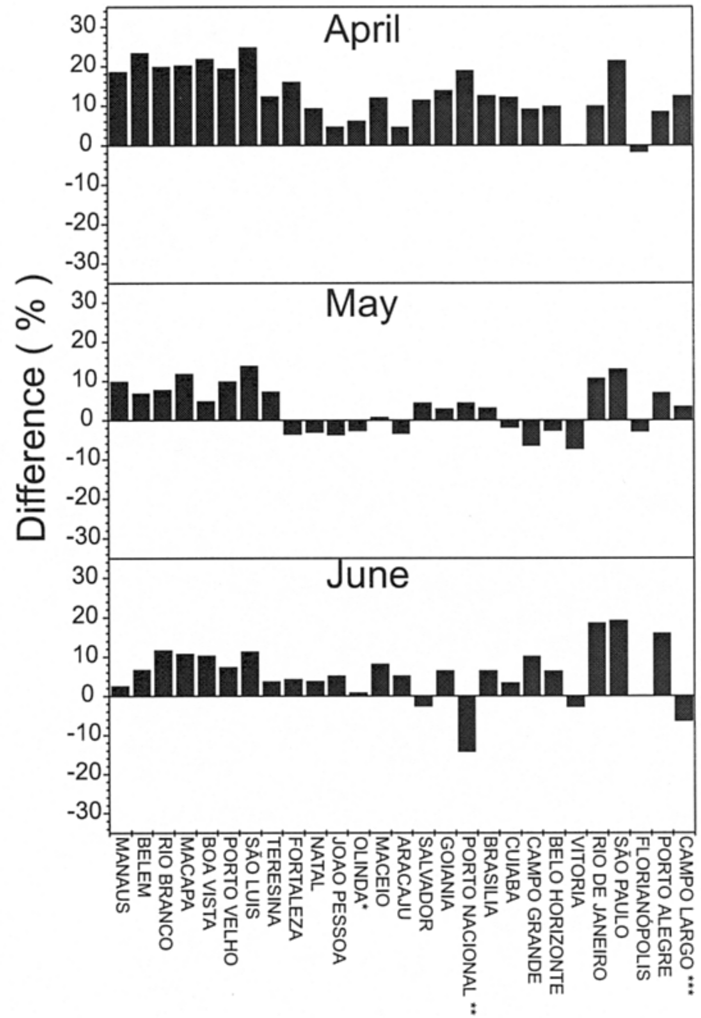
Difference between satellite derived data and OLADE data (%)

Brazilian Sites

SITE COMPARISON



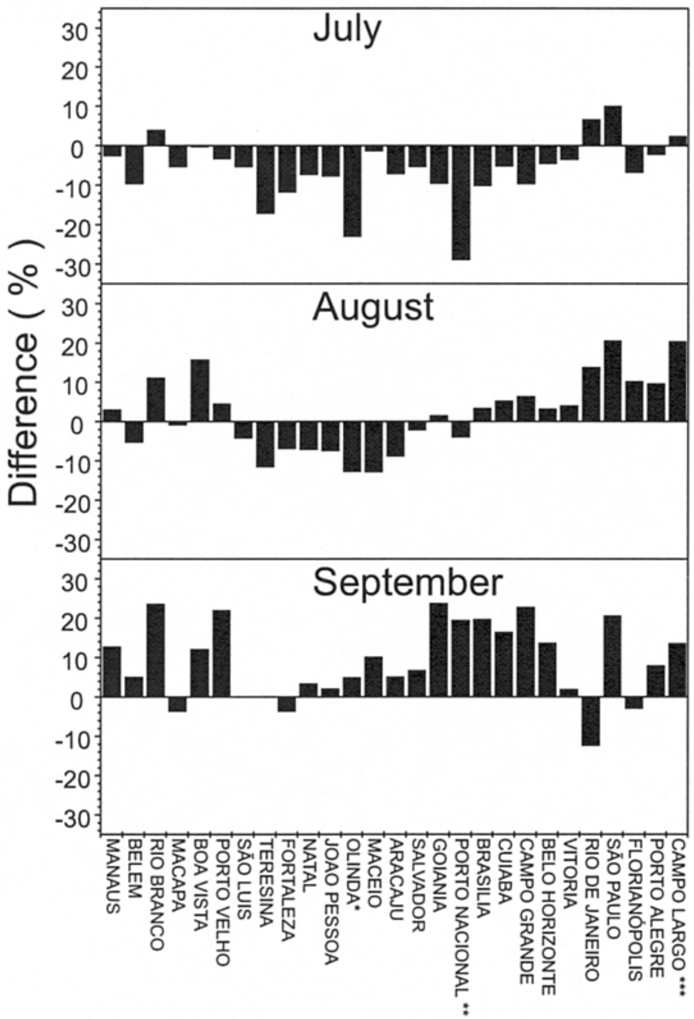
Difference between satellite derived data and OLADE data (%)



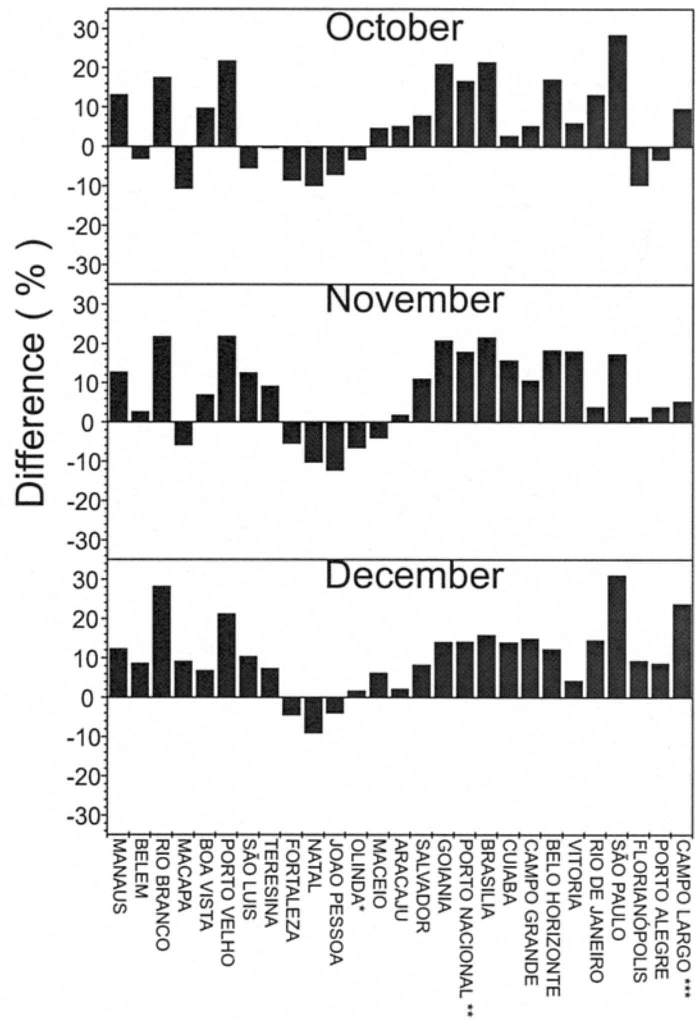
Difference between satellite derived data and OLADE data (%)

* Nearest site to Recife (PE) ** Nearest site to Palmas (TO) *** Nearest site to Curitiba (PR)

SITE COMPARISON



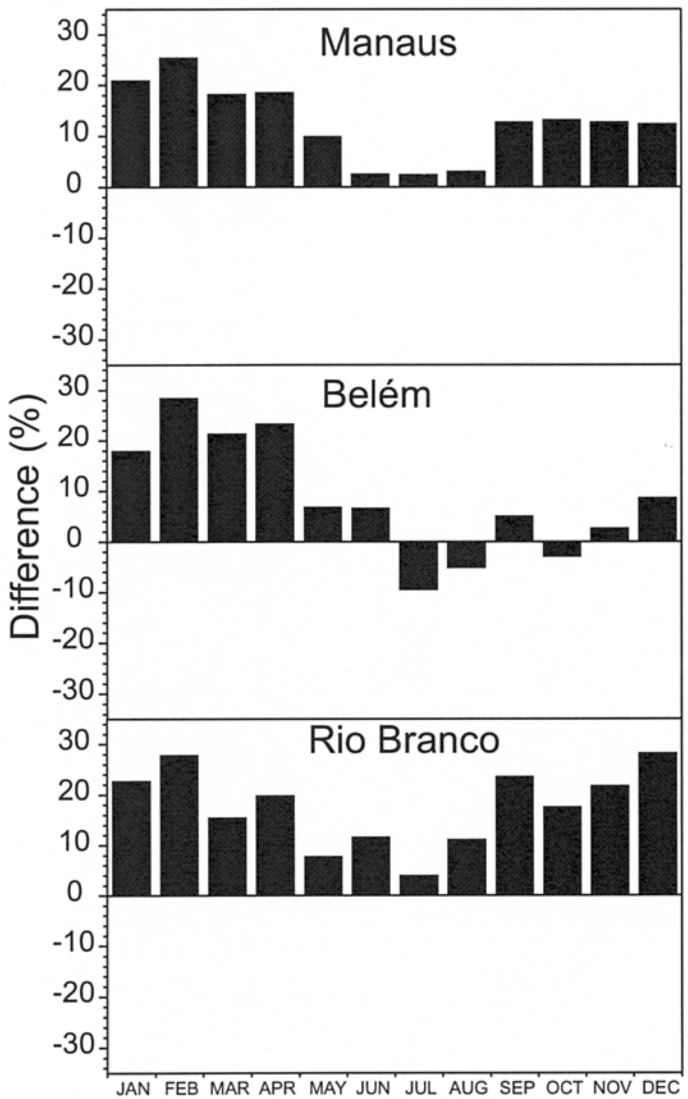
Difference between satellite derived data and OLADE data (%)



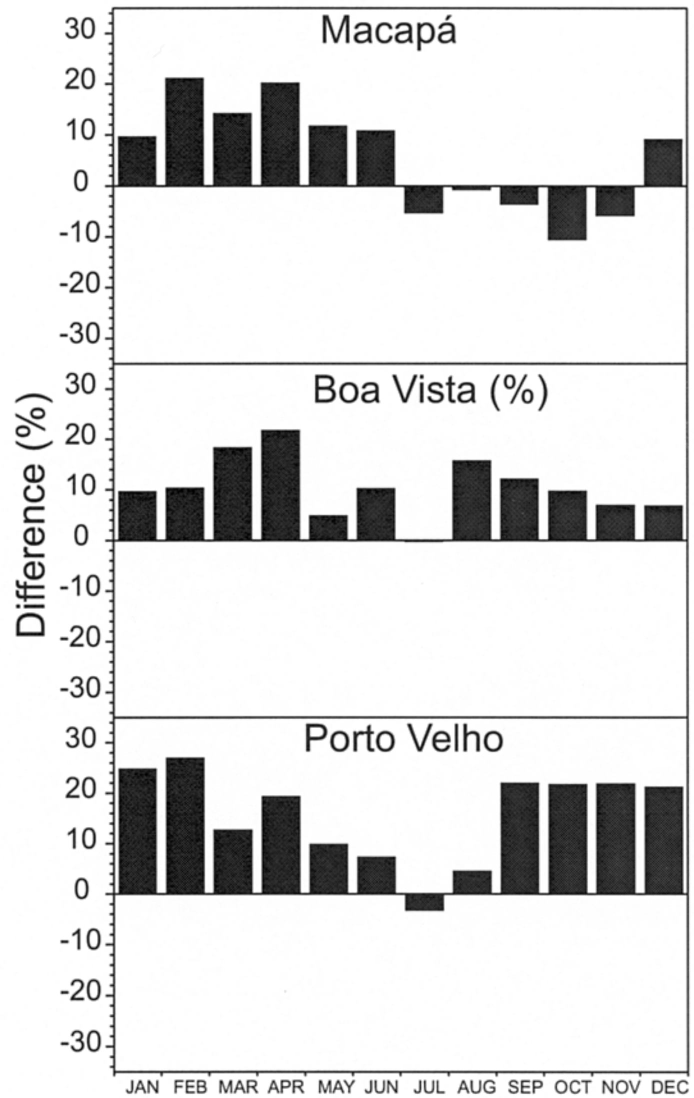
Difference between satellite derived data and OLADE data (%)

* Nearest site to Recife (PE) ** Nearest site to Palmas (TO) *** Nearest site to Curitiba (PR)

MONTHLY COMPARISON

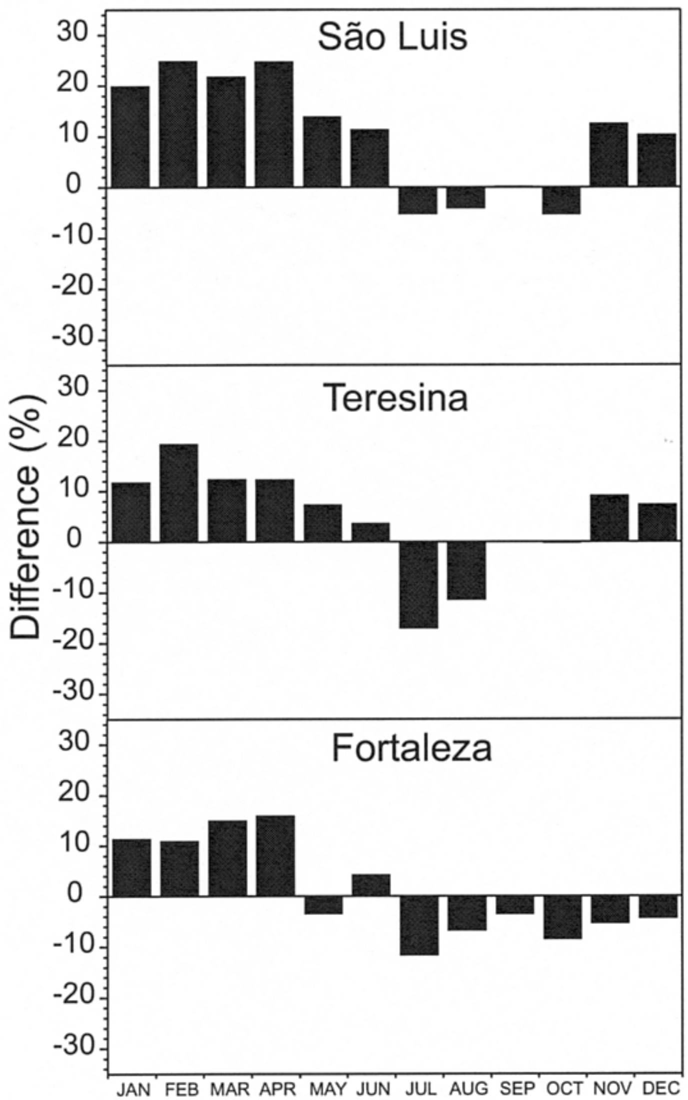


Monthly difference for Brazilian capitals (%)

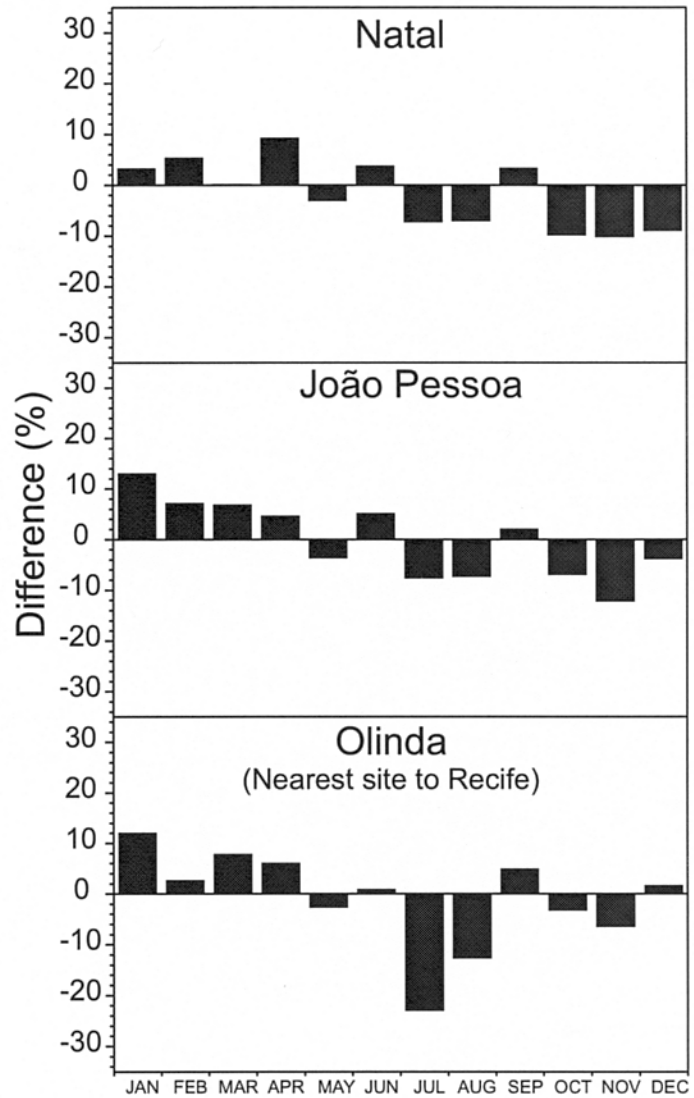


Monthly difference for Brazilian capitals (%)

MONTHLY COMPARISON

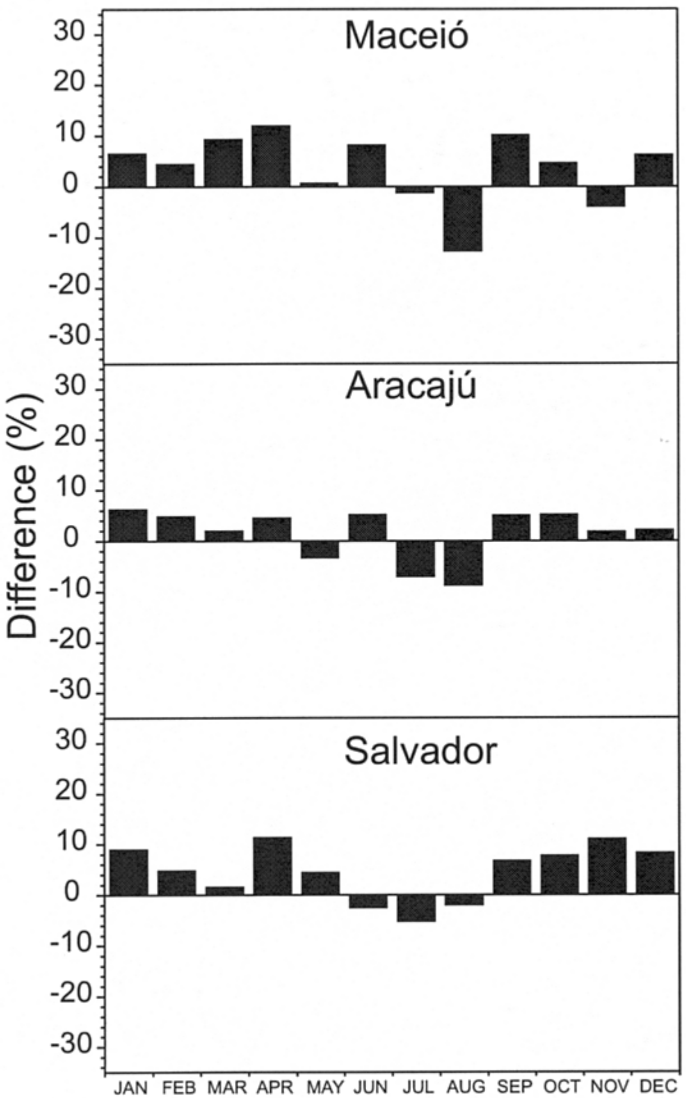


Monthly difference for Brazilian capitals (%)

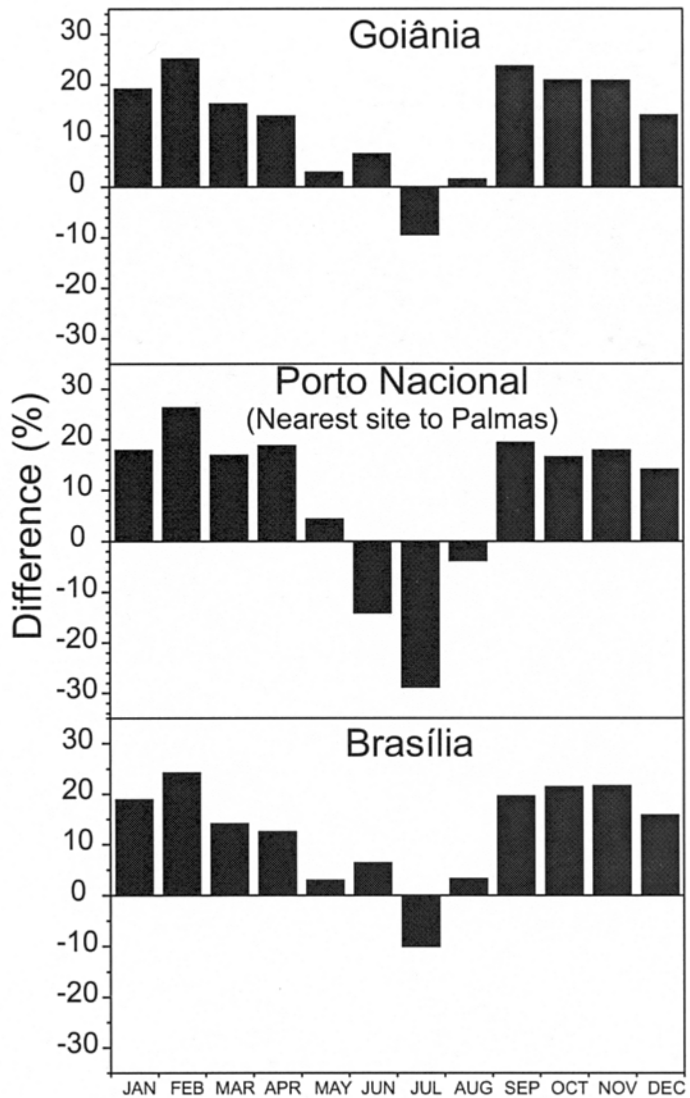


Monthly difference for Brazilian capitals (%)

MONTHLY COMPARISON

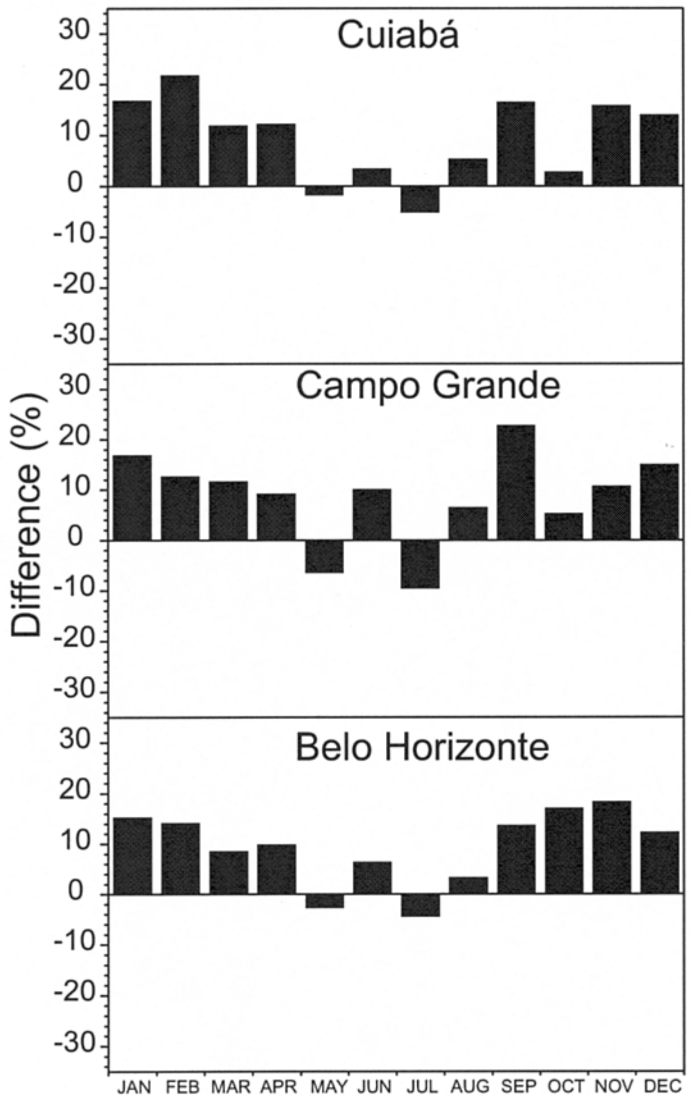


Monthly difference for Brazilian capitals (%)

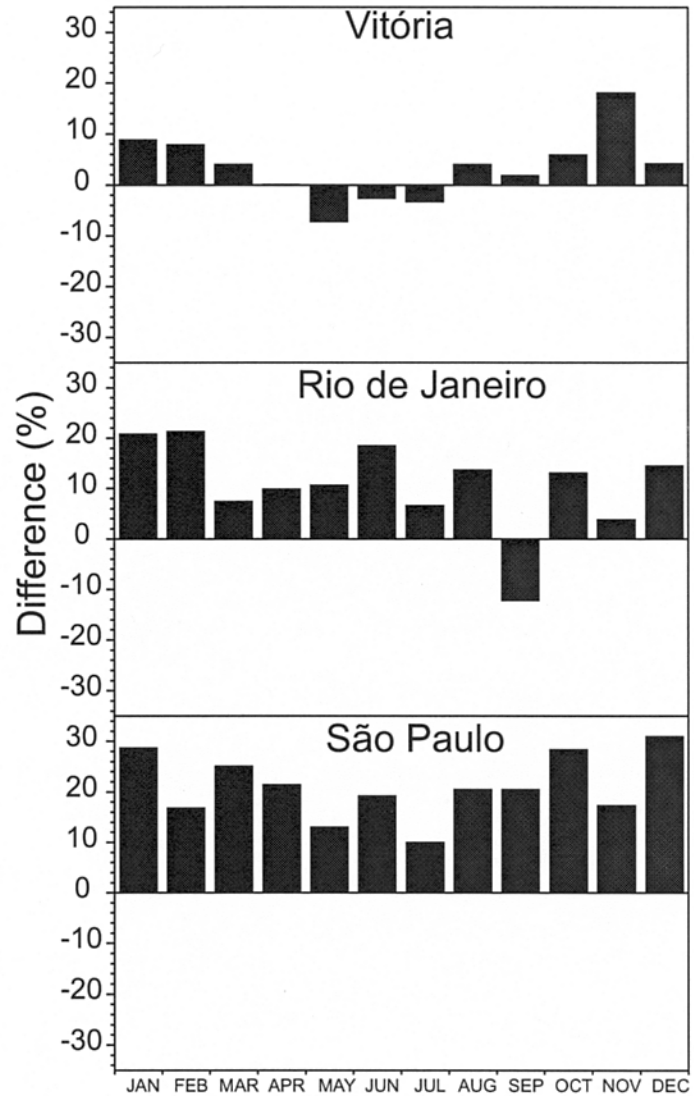


Monthly difference for Brazilian capitals (%)

MONTHLY COMPARISON

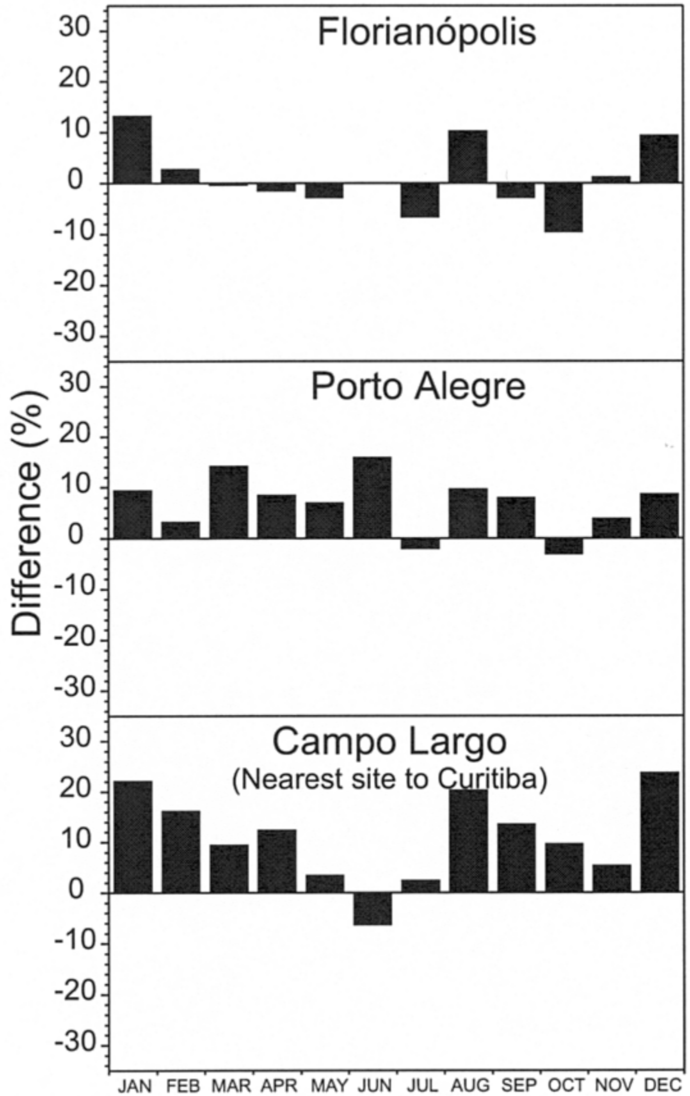


Monthly difference for Brazilian capitals (%)



Monthly difference for Brazilian capitals (%)

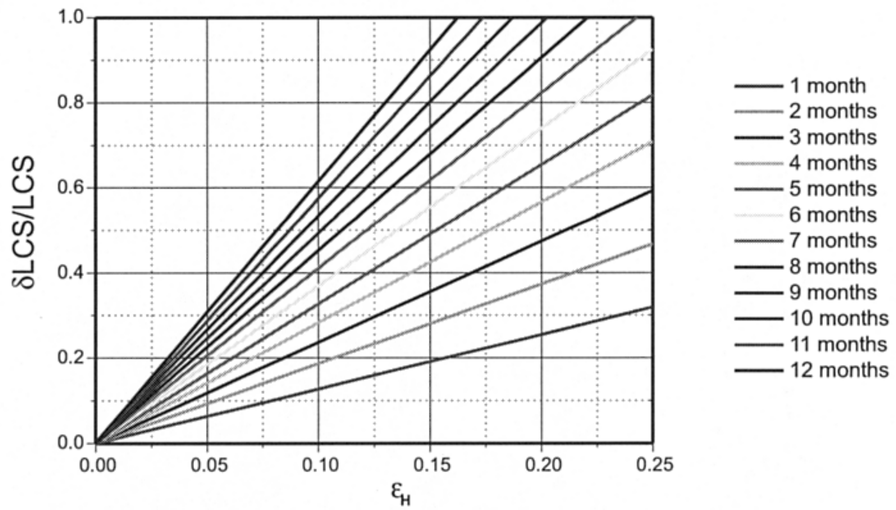
MONTHLY COMPARISON



Monthly difference for Brazilian capitals (%)

Remarks

Uncertainty of monthly means of global radiation in horizontal surfaces plays an important role in the economical analysis of PV plants. The sensivity of the uncertainty of the LCS - Lifetime Cost Savings of PV plants, in relation to the uncertainty of monthly means of global radiation is shown below. The Figure shows different sensivity straight lines obtained by the P1 - P2 method, for twelve cases of uncertain months (1 month, 12 cases), (2 months, 66 cases), (3 months, 12! / 3! (12 - 3!) = 220 cases), (etc.). The straight lines represent the average of the results for the respective set of cases. It shows that 5% of uncertainty in the monthly means of twelve months corresponds to 30% of uncertainty in the LCS, for the particular case of US$ 4,60 / Wp of a PV panel and the electrical energy cost of US$ 31,80 / GJ (the full analysis is presented in a paper submitted to the 1999 ISES Conference - Jerusalem).



The uncertainty evaluation requires the computation of the correlation coefficient between each two monthly means yearly series. These correlation coefficients appears to stabilize for 30 years series, as is shown in the next tables, for the case of NREL data series for Miami, Los Angeles and Houston. The results for the Brazilian cities of Manaus (Amazon), Campo Grande (southwest) and Porto Alegre (south) are rather poor, once the monthly means are available only for 18 years.

GLOBAL SOLAR RADIATION DATA - BRAZIL - INMET

C = complete
EN = N days estimated
FN = N days failed
BLUE BOX = void

São Luis	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Jan			E1	C	E5	C	E1	C	E1	E2	E2		
Feb		E2	C	E5	C	E4	C	C	E1	C	E3-F1		
Mar		C	E2	E1	E2	E2	E1	C	E1	E2			
Apr			E6		E2	E1	E1	C	C	C			
May	E12		C		C	E4	E2	C	E1	E5			
Jun	E3		E4		E1	C	F4	C	E1	E2			
Jul	E5		C	E2	E1	E6	E7	C	C	C			
Aug	E12	C	E2	E2	E3	E2	C	C	C	E4			
Sep	E12	E2	E4	E2	C	E4	C	C	C	E2			
Oct	E4	E1	E2	E3	E2	C	C	C	C	C			
Nov	E12	E2	E2	E5	E1	C	C	E3	E3	E1			
Dec	E3	E2	E5	F3	E4	C	E2	E1	E3	E1			

Manaus	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Jan			F24	C	E1	C	C	C	C	C	F1	C	C
Feb			E5	C	E2	C	C	C	C	C	C	C	C
Mar			E1	C	E2	E1	C	C	C	E1	F1	C	C
Apr			C		E1	C	C	C	C	C	C	E1	C
May					E1	E1	E2	E1	C	E2	C	E1	C
Jun	E2		C		E3	C	C	C	C	C	E2	C	C
Jul	E3		E2	C	C	E1	C	C	C	C	C	C	C
Aug	E1	E1-F1	C	C	C	E1	C	C	C	C	E1	C	C
Sep	E1	E5	E10	C	E1	C	C	C	C	C	E3	C	E1
Oct		E5	E2	C	E1	C	E1	E3	C	C	E7	C	E1
Nov		C	E4	C	C	C	C	E1	C	C	E1	E1	E1
Dec		E3	E6	C	C	C	E1	C	C	E2	F1	C	C

Fortaleza	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Jan		E4	C	C	E2	E1	C	C	C	C	C	E1	
Feb		E1	E1	E1	E2	E1	C	E1	E1	E1	C	E2	
Mar		E6	C	E4	E3	C	C	C	C	E1	C	C	
Apr		E1	E2		E6	E2	C	E1	E3	C	E1	E1-F16	
May		E2	C		E1	E6	C	C	E1	E2	C		
Jun	E1	E1	E3		E2	E1	C	E1	C	F2	C		
Jul	E1	E1	E1-F1	E1	E1	C	E1	C	E2	E2	C		
Aug	E1	E3	C	E3	E1	C	C	E1	C	E1	C		
Sep	C	C	C	C	C	C	C	E1	E2	E1	C		
Oct	E1	E1	E1	E3	E1	E1	C	C	C	C	E1		
Nov	E4	E6	C	C	E5	C	E1	C	C	C	E1		
Dec	C	E5	E2	C	E3	C	C	C	C	E1	C		

GLOBAL SOLAR RADIATION DATA - BRAZIL - INMET

C = complete
EN = N days estimated
FN = N days failed
BLUE BOX = void

São Luis	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Jan			E1	C	E5	C	E1	C	E1	E2	E2		
Feb		E2	C	E5	C	E4	C	C	E1	C	E3-F1		
Mar		C	E2	E1	E2	E2	E1	C	E1	E2			
Apr			E6		E2	E1	E1	C	C	C			
May	E12		C		C	E4	E2	C	E1	E5			
Jun	E3		E4		E1	C	F4	C	E1	E2			
Jul	E5		C	E2	E1	E6	E7	C	C	C			
Aug	E12	C	E2	E2	E3	E2	C	C	C	E4			
Sep	E12	E2	E4	E2	C	E4	C	C	C	E2			
Oct	E4	E1	E2	E3	E2	C	C	C	C	C			
Nov	E12	E2	E2	E5	E1	C	C	E3	E3	E1			
Dec	E3	E2	E5	F3	E4	C	E2	E1	E3	E1			

Manaus	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Jan			F24	C	E1	C	C	C	C	C	F1	C	C
Feb			E5	C	E2	C	C	C	C	C	C	C	C
Mar			E1	C	E2	E1	C	C	C	E1	F1	C	C
Apr			C		E1	C	C	C	C	C	C	E1	C
May					E1	E1	E2	E1	C	E2	C	E1	C
Jun	E2		C		E3	C	C	C	C	C	E2	C	C
Jul	E3		E2	C	C	E1	C	C	C	C	C	C	C
Aug	E1	E1-F1	C	C	C	E1	C	C	C	C	E1	C	C
Sep	E1	E5	E10	C	E1	C	C	C	C	C	E3	C	E1
Oct		E5	E2	C	E1	C	E1	E3	C	C	E7	C	E1
Nov		C	E4	C	C	C	C	E1	C	C	E1	E1	E1
Dec		E3	E6	C	C	C	E1	C	C	E2	F1	C	C

Fortaleza	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Jan		E4	C	C	E2	E1	C	C	C	C	C	E1	
Feb		E1	E1	E1	E2	E1	C	E1	E1	E1	C	E2	
Mar		E6	C	E4	E3	C	C	C	C	E1	C	C	
Apr		E1	E2		E6	E2	C	E1	E3	C	E1	E1-F16	
May		E2	C		E1	E6	C	C	E1	E2	C		
Jun	E1	E1	E3		E2	E1	C	E1	C	F2	C		
Jul	E1	E1	E1-F1	E1	E1	C	E1	C	E2	E2	C		
Aug	E1	E3	C	E3	E1	C	C	E1	C	E1	C		
Sep	C	C	C	C	C	C	C	E1	E2	E1	C		
Oct	E1	E1	E1	E3	E1	E1	C	C	C	C	E1		
Nov	E4	E6	C	C	E5	C	E1	C	C	C	E1		
Dec	C	E5	E2	C	E3	C	C	C	C	E1	C		

GLOBAL SOLAR RADIATION DATA - BRAZIL - INMET

C = complete
EN = N days estimated
FN = N days failed
BLUE BOX = void

Floriano	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Jan		E2	E2	E1	E6	E4	F10	E1	E1	F3		E4	E1
Feb		E2	E1	E6-F1	E1	C	C	E2	E5	C		C	C
Mar		E5	C	E7	E2	E7	C	E24	C	E3-F2		E1	C
Apr		E3	C		F1	E2	E1		E7	E2-F1		E1	C
May	E8	E2	E6		F5	E1	E3		C	E3		E2	E2
Jun	E4	E3	E2		F6	F1	E3		E2	E1-F1		C	E1
Jul	E6	C	E1	C	E1-F1	C	C	F23	C	F4	E8	C	C
Aug	E2	C	E1	C	E10	E3	E2	C	C	C	C	E3	
Sep	E3	E3	E4	F6	E3	C	E2	E4	E2	F5	C	E1	
Oct	E4	C	E8-F3	E8	E2	C	E1	C	E2		C	C	
Nov	E5	E4	E4	E1	C	C	E3	C	E3		E2	E1	
Dec	C	E2	E4	E2	E3	E6	C	C	C		C	C	

Carolina	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Jan			E16	E31	E1	E1	C	E4	E2	F23			
Feb	E3	E3	E4	C	C	E1	C	C	E3				
Mar	E3	C	C	E1	C	E3	C	E26	C				
Apr	C	C	C		C	E1	C	C	E2				
May	E3	C	E6		E1	C	C		C				
Jun	E2	C	E2		C	C	C		C	E4			
Jul	E5	C	E16	E1	C		C	C		C			
Aug	E4	C	E16	E1-F1	E10	E7	C	E1		C			
Sep	E5	C	E4	E1	E6	C	E1			E1			
Oct	E5	E1	E8-F3	C	E2	F1	F1	E1	E3	E1			
Nov	E10	E5	E4	E1	E2	C	E5	E1	E1	C			
Dec	E4	C	E4	C	E2	C	C		E3	F23			

Cuiabá	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Jan			C		E31	C	C	C	C	C	E1	E1	
Feb		E2	E2	E28	E10	C	E19	E1	C	C	C	E1	
Mar		C	C	E31	C	E1		C	C	C	C		
Apr		E3	E4		C	C		E1	C	C	C		
May		E1	C		C	C		C	C	C	C		
Jun		C	E1		C	C		E1	C	C	C		
Jul		C	C	C	C	C		C	E1	E1	C		
Aug	E1	C	E2	E1	C	C	E9	E1	C	C	C		
Sep	C	E1	E5	C	C	C	C	C	C	E1	E1		
Oct	E4	E1	C	C	C	C	C	C	C	C	C		
Nov	E3	E1	E11	E2	C	C	C	C	C	E1	C		
Dec	E2	E1	E31	E22	C	E2	E1	C	C	E1	E1		

GLOBAL SOLAR RADIATION DATA - BRAZIL - INMET

C = complete
EN = N days estimated
FN = N days failed
BLUE BOX = void

São Paulo	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Jan	C	C	C	E1	E11	C	E22	E2	E2	C			
Feb	E2	C	C	E1	E27-F1	C	E2	E1-F13	F23	E4			
Mar	C	C	F6	C	E31	C	C	E1	F21	C			
Apr	E3	C	E2		E30	C	C			C			
May	E1	E4	C		F9	C	C		C	C	F3		
Jun	C	C	C		C	C	C		C	F2	C		
Jul	E1	E1	C	C	C	C	C		E1	E1	C		
Aug	C	C	C	E4	C	E2	E5		C	C	C		
Sep	C	C	E1	E1	C	C		F23	C	C	C		
Oct	C	C	E1	C	C	C		C	C	C	C		
Nov	C	E1	C	E1	C	C		C	C	C			
Dec	C		C	C	E2	C	E17	C	E1	C			

Curitiba	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Jan	E2	C	E4	E1	C	E1	C	C	C	C	C	C	
Feb	E2	E1	E1	E3	C	C	C	C	C	C	C	E1	C
Mar	E2	E1	E1	C	E2	E5	E3	C	E1	C	C	C	
Apr	E2	E1	E3		C	E10	C	C	C	C	E1	C	E1
May	C	E4	C		C	E3	E4	C	C	F1	E2	C	C
Jun	E4	E1	E2		E1	E15	C	C	C	F1	E1	C	C
Jul	E1	E3	E4	C	C	E31	F1	E1	C	C	E2-F1		C
Aug	E9	E1	C	E1	C	C	C	E1	C	C	E1	C	C
Sep	C	C	E1	C	C	E1	E1	E1	C	C	C	C	C
Oct	C	C	C	C	E1	C	E2	C	C	E1	C		C
Nov	E1	C	E3	C	C	C	C	C	C	C	C		C
Dec	C		C	E1	C	E5	C	C	C	C	C	C	E1

SL.Gonsaga	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Jan							F1	C	F1	C	F1	F2	C
Feb							F1	F1	C	F1	C	C	C
Mar							C	F1	F1	F1	F1	C	C
Apr							C	F1	C	C	C	F1	F1
May							F1	F1	C	C	C	C	F1
Jun							C	F4	C	F4	F2	C	C
Jul							F2	C	C	F1	C	C	F2
Aug							F1	C	C	C	C	C	C
Sep							F1	F1	C	F1	C	F5	C
Oct							F1	F2	C	C	C	C	C
Nov							F1	C	C	C	C	C	F1
Dec							C	F1	C	C	F1	C	F1

GLOBAL SOLAR RADIATION DATA - BRAZIL - INMET

C = complete
EN = N days estimated
FN = N days failed
BLUE BOX = void

Caravelas	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Jan	E4	E5	E7	E4	E1	E1	E1	C	E1	F1		F3	C
Feb	E2	E3	E10	E3	C	E3	C	E1		C		C	E1
Mar	E6	E12	E3	E3-F1	C	E2	E1	E1	E1	E1		C	C
Apr	E6	E9	E3		E1	E2	F1	C	E1	E2	E2	E2	
May	E1	E3	E4		E3	E1	E3	C	C	E2	C	E1	
Jun	E3	E4	C		C	E5	C	C	E1	E2	E2	C	
Jul	E3	E6	E3	E8	E2	C	E2	E1	E1	E2	C	E1	
Aug	E3-F1	E7	E3	E3	E3	C	C	E5	C	C	C	C	
Sep	E5	E7	E4	C	E3	E1	C	C	C		C	C	
Oct	E1	E5	E7	C	C	C		C	E4	E1	E1	C	
Nov	E2	C	E8	E1	E4	F1	E2	E2	E1	C	E1	C	
Dec	E2	E6	E10	E3	E1	C	E1	C	E1		C	C	

BELÉM	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Jan				F2	E31	C	C	E1	E2	C			
Feb			E2	C	E28	C	C	C	E4	E1			
Mar			E1	C	E31	C	C	C	E2	E1			
Apr			E3		E30	E1	C	C	C	C			
May	E20	E6	C		E31	E31	C	C	E1	E2			
Jun	E5	E1	C		E30	E30	C	C	C	E2			
Jul	E3		E1	C	E31	E31	C	C	C	E1			
Aug	C	E3	E1	C	E31	E31	C	C	C	C			
Sep	E27	C	C	C	E30	E19	C	E1	E1	E4			
Oct		C	C	C	E4	E1	C	C	C	E2			
Nov		E2	C	E1	E1	C	C	E2	E2	E4			
Dec		E1	E2	F18	E1	C	C	E1	1E	F23			

Boa Vista	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Jan					C	C	C	C				F2	
Feb				C	C	F1	C	F2				F10	
Mar				F1	C	C	C	C				C	
Apr					C	F1	C	C				C	
May					C	F1	C	C				C	
Jun					E1	C	F1					C	
Jul				C	C	C	C	F2				F10	
Aug				C	C	F1	F1	F10					
Sep				F1	F1	C	C						
Oct				C	C	C	C						
Nov				F2	C	C	C						
Dec				C	E1	C	C						

GLOBAL SOLAR RADIATION DATA - BRAZIL - INMET

C = complete
EN = N days estimated
FN = N days failed
BLUE BOX = void

C.GRANDE	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Jan			E31	E2	C	E1	C	C	C	C	C	C	C
Feb		E2	E28-F1	E2	C	C	C	C	C	E2	C	C	C
Mar		E2	E31	C	C	E2	C	C	E1	F6	E1	C	C
Apr			E30		C	E2	C	C	C	E2	C	E1	C
May			E31		E2	E2	E2	C	C	E6	C	C	C
Jun			E30		C	E1	C	C	C	E4	C	E1	C
Jul			E31	C	C	C	C	F13	C	C	C	C	C
Aug	C		C	C	C	C	C	F25	E1		C	C	E2
Sep	E1		E3	E1	C	E1	C	C	C		E1	C	C
Oct	C		E31	C	E1	E1	C	C	E2		C	C	C
Nov	E2		E2	E4	E1	C	E1	C	C		C	C	C
Dec	C		C	C	E2	C	C	C	C	E1	C	C	C

Petrolina	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Jan	E4	E2	E1	E2	E1	E1		E1	C		C		
Feb	E8	E1	E5	E1	E3	E2		F1	C		E3		
Mar	E7	E4	C	E2	E1	E3	E19	E2		E6	F2 E1		
Apr	E7	C	E1		C	E4	F2	C		E1-F3	E2	E1	
May	E17	E4	E6		C	C	F1	E2		E2-F1	C	E2	
Jun	C	E1	E5		C	C	C	C		F1	E1	C	
Jul	E17	E1	E1	E2	C	C	E2	E1		C	E1	C	
Aug	E4	E3	E1	E3	E1	E1	C	E1		E1		C	
Sep	C	E3	E3	E5	E2	F1	C	C		E2		C	
Oct	E2	E1	E2	E2	C	E2	F2	C	F2	E1			
Nov	E1	C	E9	E1	E30	E1	E4	F15	F9	E1			
Dec	C	E6	E6	C	E6	E31	E2	E9	F7	C			

Salvador	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Jan	E1	E2	E2	C	C	E3	C	C	E1				
Feb	E1	C	C	C	C	C	C	E1	E1				
Mar	E1	C	C	E1	E1	C	C	E1					
Apr	C	E1	C		C	E2	C	E2				E11	
May	C	C	C		E2	C	C	E1				E4	
Jun	E1-F1	C	C		E1	E12	C	F1				E6	
Jul	E1	C	E3	C	C	E31	C	F18				C	
Aug	E2	C	E2	C	E1	E31	C	C					
Sep	E1	C	E3	C	E6	E2	E1	E1				C	
Oct	E2	C	C	E1	E1	C	C	C				C	
Nov	E6	E1	E1	C	C	C	E1	E1				F19	
Dec	E3	C	C	C	C	C	C	C					

LABSOLAR / NCTS EMC / UFSC

GLOBAL SOLAR RADIATION DATA - BRAZIL - INMET

C = complete
EN = N days estimated
FN = N days failed
BLUE BOX = void

P Nacional	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Jan							C	F4	C		C	F6	
Feb							C	C	F18		F2	F6	
Mar							F1	C			F1	F2	
Apr							C	C			F2		
May							F3	C			C		
Jun							C	C		F12	C	C	
Jul							F1	C		C	C	F1	
Aug							C	C		F2	C	F6	
Sep							C	F8		F12	C	C	
Oct							C	F8		C	F1	F3	
Nov							F3	C		C	F1	F5	
Dec							F1	C		C	C	F18	

Brasilia	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Jan	C	E3	E3	E2	E2	C	E1	E1	E2	C	E2	E2	E3
Feb	C	E3	C	E4	E10	E1	E1	C	E4	C	E1	C	C
Mar	E2	C	E1	E2	E8	C	E1	E5	E3	E3	C	E1	E1
Apr	E1	E2	E2		E24	C	C	C	E8	E5	C		E1
May	E2	C	C		E2	E2	C	E1	E1	E3	E5	C	E1
Jun	C	C	E1		E10	C	C	C	C	E1	C	F15	E4
Jul	E4	E1	E1	E3	E3	C	F1	C	E1	E2	E3	C	C
Aug	E2	E1	C	E1	C	E1	E1	E1	E2	C	E2	C	C
Sep	E15	E2	E2	C	E10	C	E1	E3	C	C	E1	E6	E1
Oct	E2	C	E2	E3	C	E3	E2	C	E2	E1	E1	C	E2
Nov	E12	E2	E4	E2	E2	E1	E3	E2	E2	E1	E1	C	C
Dec	C	E4	E4	F1	C	E1	E1	E2	E1	E3	C	C	E5

Bagé	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Jan							C	F1	C		C	C	C
Feb							F1	C			C	F2	C
Mar							F3	F1			C	C	C
Apr							C	F6			C	C	F1
May							C				C	C	C
Jun							C				F1	C	F12
Jul							C			C	C	C	
Aug							F1			C	C	C	
Sep							C			C	C	C	
Oct							C			C		C	C
Nov							C			C	C	C	C
Dec							C	F18		C	C	C	C

GLOBAL SOLAR RADIATION DATA - BRAZIL - INMET

C = complete
EN = N days estimated
FN = N days failed
BLUE BOX = void

P. Alegre	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Jan	E9	C	C	C	C	C	C	C	C	C	C	C	C
Feb		C	C	C	C	C	C	E9	C	F1	C	C	E1
Mar		C	C	C	E1	C	C	E18	F4	C	C	C	C
Apr		C	C		C	C	C	C	C	C	C	E2	E3
May	E11	C	C		C	C	C	E2	C	C	C	C	C
Jun	C	C	C		E1	C	C	E2-F1	E1	C	C	C	C
Jul	C	C	C	C	F22	C	C	C	C	C	C	C	C
Aug	C	C	E1	C	E29	C	C	C	C	C	C	C	C
Sep	E1	C	E1	C	E29	C	C	C	C	C	C	E1	E2
Oct	C	C	C	C	C	C	C	F17	E3	E1	C	C	C
Nov	C	C	C	C	E1	C	C	C	C	C	E1	E1	C
Dec	C	C	C	C	C	C	C	C	C	C	E2	E3	C

Houston Cross Correlation of Monthly Means - 30 YEARS 1961 to 1990

ρ	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
jan	1											
feb	0,180	1										
mar	0,068	-0,048	1									
apr	-0,004	0,160	0,359	1								
may	-0,081	0,174	-0,044	0,232	1							
jun	-0,022	0,158	-0,142	0,110	0,006	1						
jul	-0,110	0,186	-0,002	0,158	0,056	0,019	1					
aug	0,123	-0,185	-0,225	0,068	0,258	0,052	0,098	1				
sep	0,123	-0,484	-0,285	-0,112	-0,139	0,051	-0,182	0,230	1			
oct	-0,363	-0,387	0,191	0,016	-0,160	0,279	-0,248	-0,055	0,106	1		
nov	-0,191	-0,307	-0,176	-0,038	0,131	0,149	-0,087	0,233	0,327	0,389	1	
dec	-0,266	-0,329	-0,342	-0,045	0,285	0,024	0,008	-0,008	0,259	0,123	0,374	1

Houston Cross Correlation of Monthly Means - 29 YEARS 1962 to 1990

ρ	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
jan	1											
feb	0,178	1										
mar	0,069	-0,047	1									
apr	0,001	0,170	0,359	1								
may	-0,079	0,181	-0,045	0,226	1							
jun	-0,036	0,143	-0,142	0,148	0,027	1						
jul	-0,147	0,169	0,008	0,239	0,101	-0,129	1					
aug	0,116	-0,204	-0,225	0,092	0,277	-0,002	0,009	1				
sep	0,124	-0,484	-0,285	-0,114	-0,140	0,055	-0,200	0,236	1			
oct	-0,362	-0,385	0,190	0,011	-0,164	0,305	-0,255	-0,046	0,106	1		
nov	-0,197	-0,317	-0,175	-0,028	0,139	0,127	-0,149	0,219	0,330	0,396	1	
dec	-0,266	-0,329	-0,342	-0,047	0,285	0,028	0,015	-0,006	0,259	0,122	0,377	1

Houston Cross Correlation of Monthly Means - 28 YEARS 1963 to 1990

ρ	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
jan	1											
feb	0,175	1										
mar	0,068	-0,049	1									
apr	-0,001	0,168	0,358	1								
may	-0,069	0,213	-0,038	0,248	1							
jun	-0,050	0,127	-0,155	0,142	0,110	1						
jul	-0,141	0,219	0,022	0,277	-0,013	-0,030	1					
aug	0,130	-0,192	-0,224	0,104	0,229	0,059	-0,088	1				
sep	0,120	-0,496	-0,289	-0,118	-0,119	0,033	-0,180	0,264	1			
oct	-0,362	-0,386	0,190	0,011	-0,172	0,317	-0,279	-0,048	0,106	1		
nov	-0,194	-0,313	-0,173	-0,025	0,124	0,151	-0,193	0,209	0,338	0,397	1	
dec	-0,282	-0,356	-0,358	-0,057	0,369	-0,029	0,111	0,045	0,246	0,126	0,402	1

Houston Cross Correlation of Monthly Means - 27 YEARS 1964 to 1990

ρ	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
jan	1											
feb	0,201	1										
mar	0,064	-0,044	1									
apr	0,004	0,164	0,360	1								
may	-0,069	0,216	-0,038	0,248	1							
jun	-0,070	0,158	-0,162	0,150	0,111	1						
jul	-0,146	0,229	0,021	0,279	-0,013	-0,036	1					
aug	0,143	-0,212	-0,222	0,101	0,230	0,075	-0,086	1				
sep	0,128	-0,514	-0,288	-0,120	-0,119	0,042	-0,178	0,261	1			
oct	-0,359	-0,402	0,192	0,009	-0,172	0,329	-0,278	-0,053	0,104	1		
nov	-0,209	-0,301	-0,177	-0,021	0,125	0,138	-0,197	0,220	0,346	0,404	1	
dec	-0,300	-0,343	-0,364	-0,053	0,372	-0,047	0,108	0,055	0,254	0,133	0,396	1

Houston Cross Correlation of Monthly Means - 26 YEARS 1965 to 1990

ρ	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
jan	1											
feb	0,201	1										
mar	0,074	-0,044	1									
apr	-0,033	0,167	0,397	1								
may	-0,087	0,217	-0,029	0,222	1							
jun	-0,080	0,158	-0,158	0,134	0,102	1						
jul	-0,160	0,229	0,028	0,264	-0,026	-0,043	1					
aug	0,137	-0,213	-0,219	0,090	0,225	0,071	-0,091	1				
sep	0,091	-0,552	-0,281	-0,240	-0,177	0,016	-0,226	0,258	1			
oct	-0,342	-0,411	0,180	0,082	-0,146	0,359	-0,264	-0,042	0,205	1		
nov	-0,234	-0,307	-0,168	-0,070	0,106	0,128	-0,216	0,215	0,314	0,462	1	
dec	-0,341	-0,356	-0,357	-0,127	0,354	-0,068	0,088	0,044	0,191	0,200	0,373	1

Houston Cross Correlation of Monthly Means - 25 YEARS 1966 to 1990

ρ	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
jan	1											
feb	0,253	1										
mar	0,094	-0,046	1									
apr	-0,013	0,164	0,396	1								
may	0,108	0,203	-0,048	0,222	1							
jun	-0,125	0,166	-0,156	0,139	0,159	1						
jul	-0,183	0,232	0,029	0,266	-0,018	-0,045	1					
aug	0,217	-0,229	-0,226	0,083	0,177	0,086	-0,089	1				
sep	0,124	-0,560	-0,284	-0,244	-0,229	0,021	-0,225	0,253	1			
oct	-0,399	-0,408	0,183	0,086	-0,131	0,356	-0,266	-0,032	0,210	1		
nov	-0,185	-0,326	-0,176	-0,080	0,034	0,145	-0,216	0,194	0,309	0,481	1	
dec	-0,319	-0,371	-0,365	-0,135	0,333	-0,057	0,092	0,025	0,185	0,211	0,360	1

Los Angeles Cross Correlation of Monthly Means - 30 YEARS **1961 to 1990**

ρ	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
jan	1											
feb	0,197	1										
mar	0,238	0,166	1									
apr	-0,247	0,044	0,172	1								
may	0,206	0,180	0,132	-0,135	1							
jun	-0,103	0,239	0,009	-0,027	0,166	1						
jul	-0,400	0,035	-0,327	-0,132	0,060	0,024	1					
aug	0,077	0,040	0,065	-0,031	0,023	0,259	0,139	1				
sep	-0,092	0,171	0,061	0,087	0,381	0,014	0,263	-0,093	1			
oct	0,123	0,061	-0,037	-0,472	-0,041	0,000	0,132	0,100	-0,177	1		
nov	0,042	-0,120	-0,080	0,120	0,095	0,240	-0,087	-0,078	0,152	0,008	1	
dec	-0,047	-0,297	-0,254	-0,047	-0,119	0,258	-0,026	0,127	-0,126	-0,002	0,382	1

Los Angeles Cross Correlation of Monthly Means - 29 YEARS **1962 to 1990**

ρ	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
jan	1											
feb	0,174	1										
mar	0,223	0,143	1									
apr	-0,284	0,005	0,149	1								
may	0,187	0,152	0,112	-0,175	1							
jun	-0,114	0,231	0,000	-0,042	0,157	1						
jul	-0,395	0,051	-0,321	-0,119	0,074	0,029	1					
aug	0,094	0,063	0,081	-0,010	0,042	0,269	0,132	1				
sep	-0,100	0,165	0,055	0,079	0,379	0,011	0,268	-0,088	1			
oct	0,121	0,057	-0,041	-0,487	-0,046	-0,001	0,134	0,103	-0,179	1		
nov	0,049	-0,114	-0,074	0,132	0,104	0,244	-0,091	-0,084	0,155	0,009	1	
dec	-0,033	-0,284	-0,243	-0,033	-0,104	0,267	-0,034	0,117	-0,121	0,001	0,380	1

Los Angeles Cross Correlation of Monthly Means - 28 YEARS **1963 to 1990**

ρ	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
jan	1											
feb	0,232	1										
mar	0,226	0,150	1									
apr	-0,283	-0,005	0,149	1								
may	0,166	0,218	0,114	-0,172	1							
jun	-0,089	0,186	0,000	-0,048	0,196	1						
jul	-0,382	0,011	-0,324	-0,125	0,099	0,005	1					
aug	0,059	0,148	0,084	-0,002	-0,001	0,331	0,172	1				
sep	-0,126	0,225	0,056	0,085	0,362	0,041	0,295	-0,132	1			
oct	0,148	0,011	-0,042	-0,498	-0,019	-0,032	0,115	0,149	-0,158	1		
nov	0,057	-0,134	-0,074	0,130	0,114	0,240	-0,098	-0,075	0,164	0,002	1	
dec	-0,031	-0,302	-0,243	-0,031	-0,103	0,270	-0,037	0,124	-0,121	-0,001	0,380	1

Los Angeles Cross Correlation of Monthly Means - 27 YEARS 1964 to 1990

ρ	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
jan	1											
feb	0,233	1										
mar	0,229	0,170	1									
apr	-0,285	0,003	0,135	1								
may	0,174	0,202	0,172	-0,155	1							
jun	-0,089	0,177	0,023	-0,038	0,172	1						
jul	-0,391	0,029	-0,374	-0,146	0,157	0,029	1					
aug	0,059	0,160	0,063	-0,012	0,030	0,350	0,153	1				
sep	-0,126	0,226	0,057	0,085	0,376	0,042	0,300	-0,134	1			
oct	0,152	-0,004	-0,011	-0,492	-0,065	-0,053	0,152	0,171	-0,160	1		
nov	0,057	-0,139	-0,066	0,135	0,105	0,236	-0,091	-0,069	0,165	-0,006	1	
dec	-0,037	-0,290	-0,343	-0,037	-0,009	0,341	-0,118	0,088	-0,131	0,065	0,429	1

Los Angeles Cross Correlation of Monthly Means - 26 YEARS 1965 to 1990

ρ	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
jan	1											
feb	0,150	1										
mar	0,212	0,140	1									
apr	-0,289	0,018	0,138	1								
may	0,138	0,139	0,157	-0,152	1							
jun	-0,053	0,284	0,041	-0,043	0,208	1						
jul	-0,460	-0,070	-0,405	-0,143	0,125	0,064	1					
aug	0,085	0,230	0,074	-0,016	0,050	0,339	0,179	1				
sep	-0,170	0,174	0,041	0,091	0,357	0,071	0,276	-0,119	1			
oct	0,200	0,083	0,007	-0,505	-0,035	-0,084	0,194	0,157	-0,135	1		
nov	0,071	-0,130	-0,061	0,134	0,116	0,231	-0,082	-0,075	0,176	-0,016	1	
dec	0,066	-0,131	-0,332	0,066	0,072	0,304	-0,038	0,051	-0,071	-0,007	0,448	1

Los Angeles Cross Correlation of Monthly Means - 25 YEARS 1966 to 1990

ρ	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
jan	1											
feb	0,141	1										
mar	0,212	0,140	1									
apr	-0,265	0,061	0,151	1								
may	0,130	0,129	0,157	-0,127	1							
jun	-0,027	0,334	0,046	-0,157	0,247	1						
jul	-0,452	-0,049	-0,411	-0,224	0,147	0,010	1					
aug	0,113	0,271	0,079	-0,113	0,077	0,287	0,137	1				
sep	-0,177	0,168	0,040	0,120	0,353	0,093	0,294	-0,107	1			
oct	0,192	0,072	0,006	-0,503	-0,045	-0,057	0,219	0,190	-0,143	1		
nov	0,122	-0,091	-0,063	-0,011	0,174	0,126	-0,182	-0,209	0,224	0,031	1	
dec	0,079	-0,118	-0,334	0,079	0,086	0,280	-0,065	0,019	-0,064	0,006	0,437	1

Miami Cross Correlation of Monthly Means - 30 YEARS 1961 to 1990

ρ	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
jan	1											
feb	0,190	1										
mar	0,292	0,228	1									
apr	0,146	0,005	0,494	1								
may	0,265	0,221	0,122	0,182	1							
jun	0,290	-0,058	-0,025	0,223	0,250	1						
jul	0,085	0,334	0,226	0,401	0,290	0,391	1					
aug	-0,234	-0,061	-0,047	0,297	-0,082	0,020	0,302	1				
sep	-0,080	0,423	0,015	0,358	0,274	0,140	0,266	0,285	1			
oct	0,103	0,147	0,439	0,442	0,066	0,163	0,112	-0,196	0,358	1		
nov	-0,178	-0,065	-0,072	-0,090	-0,210	-0,284	-0,160	0,089	0,039	-0,054	1	
dec	0,043	0,264	0,083	-0,046	0,109	-0,060	0,133	0,228	0,218	0,087	0,631	1

Miami Cross Correlation of Monthly Means - 29 YEARS 1962 to 1990

ρ	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
jan	1											
feb	0,195	1										
mar	0,304	0,213	1									
apr	0,153	-0,013	0,477	1								
may	0,268	0,216	0,113	0,175	1							
jun	0,300	-0,077	-0,061	0,200	0,244	1						
jul	0,093	0,321	0,195	0,380	0,284	0,370	1					
aug	-0,232	-0,076	-0,075	0,282	-0,091	-0,002	0,284	1				
sep	-0,074	0,423	-0,084	0,321	0,277	0,071	0,203	0,255	1			
oct	0,119	0,121	0,405	0,415	0,050	0,117	0,054	-0,252	0,257	1		
nov	-0,175	-0,087	-0,113	-0,126	-0,226	-0,327	-0,205	0,066	-0,051	-0,120	1	
dec	0,052	0,248	0,039	-0,088	0,098	-0,104	0,091	0,205	0,131	0,016	0,615	1

Miami Cross Correlation of Monthly Means - 28 YEARS 1963 to 1990

ρ	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
jan	1											
feb	0,215	1										
mar	0,309	0,195	1									
apr	0,151	0,018	0,491	1								
may	0,290	0,140	0,090	0,215	1							
jun	0,298	-0,053	-0,053	0,193	0,284	1						
jul	0,095	0,327	0,193	0,385	0,288	0,374	1					
aug	-0,243	-0,018	-0,058	0,269	-0,036	-0,020	0,296	1				
sep	-0,073	0,436	-0,087	0,325	0,282	0,074	0,202	0,265	1			
oct	0,128	0,067	0,396	0,445	-0,007	0,137	0,050	-0,223	0,257	1		
nov	-0,177	-0,078	-0,110	-0,130	-0,224	-0,332	-0,204	0,059	-0,050	-0,114	1	
dec	0,058	0,210	0,024	-0,073	0,052	-0,091	0,087	0,246	0,129	-0,016	0,632	1

Miami Cross Correlation of Monthly Means - 27 YEARS 1964 to 1990

ρ	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
jan	1											
feb	0,212	1										
mar	0,349	0,275	1									
apr	0,170	0,068	0,423	1								
may	0,297	0,161	0,045	0,187	1							
jun	0,305	-0,035	-0,110	0,163	0,272	1						
jul	0,117	0,419	0,052	0,302	0,262	0,356	1					
aug	-0,241	0,001	-0,119	0,241	-0,054	-0,037	0,267	1				
sep	-0,087	0,416	0,026	0,455	0,334	0,115	0,352	0,318	1			
oct	0,133	0,087	0,379	0,430	-0,023	0,123	0,001	-0,244	0,308	1		
nov	-0,178	-0,085	-0,101	-0,123	-0,221	-0,329	-0,203	0,066	-0,065	-0,110	1	
dec	0,058	0,214	0,021	-0,081	0,051	-0,093	0,090	0,246	0,138	-0,018	0,633	1

Miami Cross Correlation of Monthly Means - 26 YEARS 1965 to 1990

ρ	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
jan	1											
feb	0,217	1										
mar	0,328	0,275	1									
apr	0,178	0,068	0,426	1								
may	0,337	0,163	0,057	0,187	1							
jun	0,343	-0,034	-0,102	0,163	0,268	1						
jul	0,153	0,423	0,066	0,304	0,256	0,351	1					
aug	-0,231	0,002	-0,111	0,242	-0,060	-0,043	0,262	1				
sep	-0,085	0,416	0,028	0,455	0,334	0,114	0,352	0,318	1			
oct	0,065	0,086	0,361	0,444	-0,003	0,147	0,026	-0,234	0,322	1		
nov	-0,226	-0,088	-0,119	-0,124	-0,213	-0,324	-0,193	0,075	-0,063	-0,146	1	
dec	-0,037	0,221	-0,021	-0,085	0,081	-0,073	0,128	0,284	0,151	-0,104	0,631	1

Miami Cross Correlation of Monthly Means - 25 YEARS 1966 to 1990

ρ	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
jan	1											
feb	0,218	1										
mar	0,328	0,299	1									
apr	0,178	0,075	0,426	1								
may	0,334	0,128	0,056	0,188	1							
jun	0,340	-0,079	-0,103	0,164	0,261	1						
jul	0,156	0,494	0,066	0,304	0,265	0,358	1					
aug	-0,226	0,070	-0,111	0,244	-0,045	-0,031	0,258	1				
sep	-0,096	0,383	0,027	0,462	0,321	0,100	0,368	0,352	1			
oct	0,068	0,118	0,362	0,445	0,003	0,152	0,024	-0,244	0,337	1		
nov	-0,221	0,032	-0,121	-0,129	-0,191	-0,313	-0,216	0,038	-0,016	-0,166	1	
dec	-0,033	0,286	-0,020	-0,086	0,092	-0,066	0,124	0,275	0,169	-0,109	0,633	1

LABSOLAR / NCTS EMC / UFSC

Manaus Cross Correlation of Monthly Means - 18 YEARS 1961 to 1978

ρ	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
jan	1											
feb	0,605	1										
mar	0,581	0,413	1									
apr	0,439	0,615	0,407	1								
may	0,239	0,420	0,310	0,330	1							
jun	0,372	0,500	0,276	0,124	0,385	1						
jul	-0,009	0,351	-0,094	0,322	0,482	0,335	1					
aug	0,137	0,349	-0,258	0,388	0,387	0,197	0,652	1				
sep	0,224	0,425	0,316	0,445	0,701	0,380	0,566	0,436	1			
oct	0,440	0,523	-0,191	0,602	0,392	0,334	0,179	0,209	0,413	1		
nov	0,595	0,610	0,296	0,289	0,516	0,277	0,233	0,469	0,438	0,299	1	
dec	0,340	0,484	0,474	0,272	0,299	0,108	0,353	-0,085	0,450	0,397	0,198	1

Manaus Cross Correlation of Monthly Means - 17 YEARS 1962 to 1978

ρ	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
jan	1											
feb	0,576	1										
mar	0,548	0,371	1									
apr	0,375	0,578	0,344	1								
may	0,189	0,385	0,267	0,271	1							
jun	0,436	0,565	0,332	0,201	0,437	1						
jul	-0,066	0,318	-0,153	0,274	0,458	0,377	1					
aug	0,029	0,277	-0,413	0,274	0,332	0,288	0,640	1				
sep	0,154	0,377	0,257	0,372	0,682	0,454	0,543	0,358	1			
oct	0,475	0,557	-0,180	0,678	0,417	0,330	0,194	0,256	0,453	1		
nov	0,552	0,579	0,192	0,108	0,480	0,429	0,156	0,326	0,342	0,391	1	
dec	0,333	0,482	0,471	0,264	0,290	0,122	0,346	-0,127	0,449	0,404	0,186	1

Manaus Cross Correlation of Monthly Means - 16 YEARS 1963 to 1978

ρ	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
jan	1,000											
feb	0,609	1,000										
mar	0,521	0,426	1,000									
apr	0,375	0,585	0,350	1,000								
may	0,155	0,412	0,219	0,268	1,000							
jun	0,417	0,591	0,298	0,198	0,418	1,000						
jul	-0,101	0,338	-0,219	0,271	0,441	0,360	1,000					
aug	-0,007	0,298	-0,506	0,271	0,308	0,267	0,630	1,000				
sep	0,078	0,458	0,141	0,392	0,673	0,429	0,531	0,319	1,000			
oct	0,450	0,594	-0,323	0,687	0,391	0,305	0,166	0,226	0,408	1,000		
nov	0,550	0,590	0,178	0,105	0,475	0,424	0,147	0,319	0,343	0,385	1,000	
dec	0,291	0,535	0,414	0,264	0,248	0,076	0,317	-0,191	0,375	0,363	0,173	1,000

Manaus Cross Correlation of Monthly Means - 15 YEARS 1964 to 1978

ρ	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
jan	1											
feb	0,623	1										
mar	0,562	0,429	1									
apr	0,343	0,602	0,393	1								
may	0,084	0,445	0,289	0,198	1							
jun	0,399	0,597	0,322	0,168	0,394	1						
jul	-0,209	0,371	-0,187	0,196	0,338	0,360	1					
aug	-0,088	0,319	-0,500	0,205	0,200	0,230	0,567	1				
sep	0,017	0,479	0,187	0,346	0,633	0,407	0,470	0,239	1			
oct	0,432	0,602	-0,400	0,676	0,361	0,287	0,111	0,183	0,382	1		
nov	0,618	0,602	0,158	0,161	0,610	0,470	0,258	0,427	0,431	0,432	1	
dec	0,302	0,535	0,415	0,277	0,276	0,080	0,357	-0,197	0,399	0,372	0,172	1

Porto Alegre Cross Correlation of Monthly Means - 18 YEARS **1961 to 1978**

ρ	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
jan	1											
feb	0,370	1										
mar	0,052	-0,128	1									
apr	-0,126	0,036	0,235	1								
may	0,282	0,096	0,318	-0,025	1							
jun	0,159	-0,127	0,346	0,147	0,215	1						
jul	0,164	0,070	-0,317	0,106	0,144	0,161	1					
aug	0,056	-0,162	-0,114	-0,144	0,237	0,302	0,229	1				
sep	0,110	-0,046	-0,411	-0,026	-0,287	-0,158	-0,127	0,187	1			
oct	0,200	-0,165	-0,356	-0,288	0,092	0,502	0,200	0,595	0,362	1		
nov	0,413	0,192	-0,035	-0,512	0,168	0,259	-0,087	0,308	0,328	0,465	1	
dec	0,056	0,037	0,192	0,286	0,152	0,300	-0,170	0,266	-0,194	0,137	-0,006	1

Porto Alegre Cross Correlation of Monthly Means - 17 YEARS **1962 to 1978**

ρ	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
jan	1											
feb	0,360	1										
mar	0,051	-0,133	1									
apr	-0,100	0,095	0,253	1								
may	0,268	0,060	0,322	0,047	1							
jun	0,173	-0,108	0,351	0,115	0,250	1						
jul	0,166	0,075	-0,317	0,105	0,152	0,160	1					
aug	0,021	-0,246	-0,129	-0,032	0,172	0,377	0,254	1				
sep	0,179	0,040	-0,458	-0,207	-0,213	-0,248	-0,154	0,442	1			
oct	0,208	-0,155	-0,356	-0,327	0,110	0,498	0,200	0,670	0,375	1		
nov	0,404	0,167	-0,039	-0,489	0,135	0,288	-0,085	0,265	0,475	0,486	1	
dec	0,022	-0,027	0,199	0,449	0,081	0,373	-0,175	0,154	-0,029	0,174	-0,076	1

Porto Alegre Cross Correlation of Monthly Means - 16 YEARS **1963 to 1978**

ρ	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
jan	1											
feb	0,346	1										
mar	-0,041	-0,174	1									
apr	-0,140	0,084	0,230	1								
may	0,353	0,048	0,301	0,033	1							
jun	0,059	-0,169	0,255	0,073	0,219	1						
jul	0,284	0,114	-0,242	0,151	0,204	0,344	1					
aug	-0,070	-0,291	-0,243	-0,070	0,142	0,291	0,384	1				
sep	0,153	0,029	-0,523	-0,224	-0,231	-0,331	-0,124	0,430	1			
oct	0,126	-0,202	-0,509	-0,389	0,074	0,419	0,340	0,634	0,359	1		
nov	0,353	0,145	-0,135	-0,544	0,106	0,197	0,002	0,200	0,464	0,436	1	
dec	-0,169	-0,101	0,037	0,465	0,016	0,184	-0,001	-0,011	-0,112	-0,008	-0,281	1

Porto Alegre **Cross Correlation of Monthly Means - 15 YEARS** **1964 to 1978**

ρ	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
jan	1											
feb	0,384	1										
mar	0,159	-0,182	1									
apr	0,072	0,099	0,087	1								
may	0,361	0,051	0,266	-0,036	1							
jun	0,236	-0,173	0,161	-0,064	0,183	1						
jul	0,385	0,117	-0,310	0,112	0,189	0,325	1					
aug	-0,256	-0,311	-0,145	0,073	0,202	0,425	0,446	1				
sep	-0,493	0,033	-0,419	0,270	-0,191	-0,150	-0,047	0,326	1			
oct	-0,058	-0,223	-0,431	-0,274	0,142	0,601	0,417	0,588	0,090	1		
nov	0,151	0,161	0,069	-0,420	0,217	0,430	0,074	0,050	0,073	0,308	1	
dec	-0,153	-0,100	0,011	0,481	0,005	0,170	-0,009	0,012	-0,093	0,020	-0,285	1

4. Satellite Derived Solar Radiation for Argentina

The radiation distribution was determined by the regression equation of Tarpley and the validation against the ground truth of 80 pyranometers is reported by Friulla et. All. in **Solar Energy**, International Journal, in 1982. The atlas derived from this work is not available is South America.

PROJECTS IN SOUTH AMERICA

1. ARGENTINA

A project is being developed in partnership with Spain and Portugal. The project focuses the assessment of solar irradiation data from ground stations. The coordinator of the project is Dr. H. Grossi - Gallegos. To the best of my knowledge, the proposed method to obtain the distribution of solar radiation is not published. We are still in contact with Dr. Grossi in order to get more details about the organization of the project as well as the technical informations concerned.

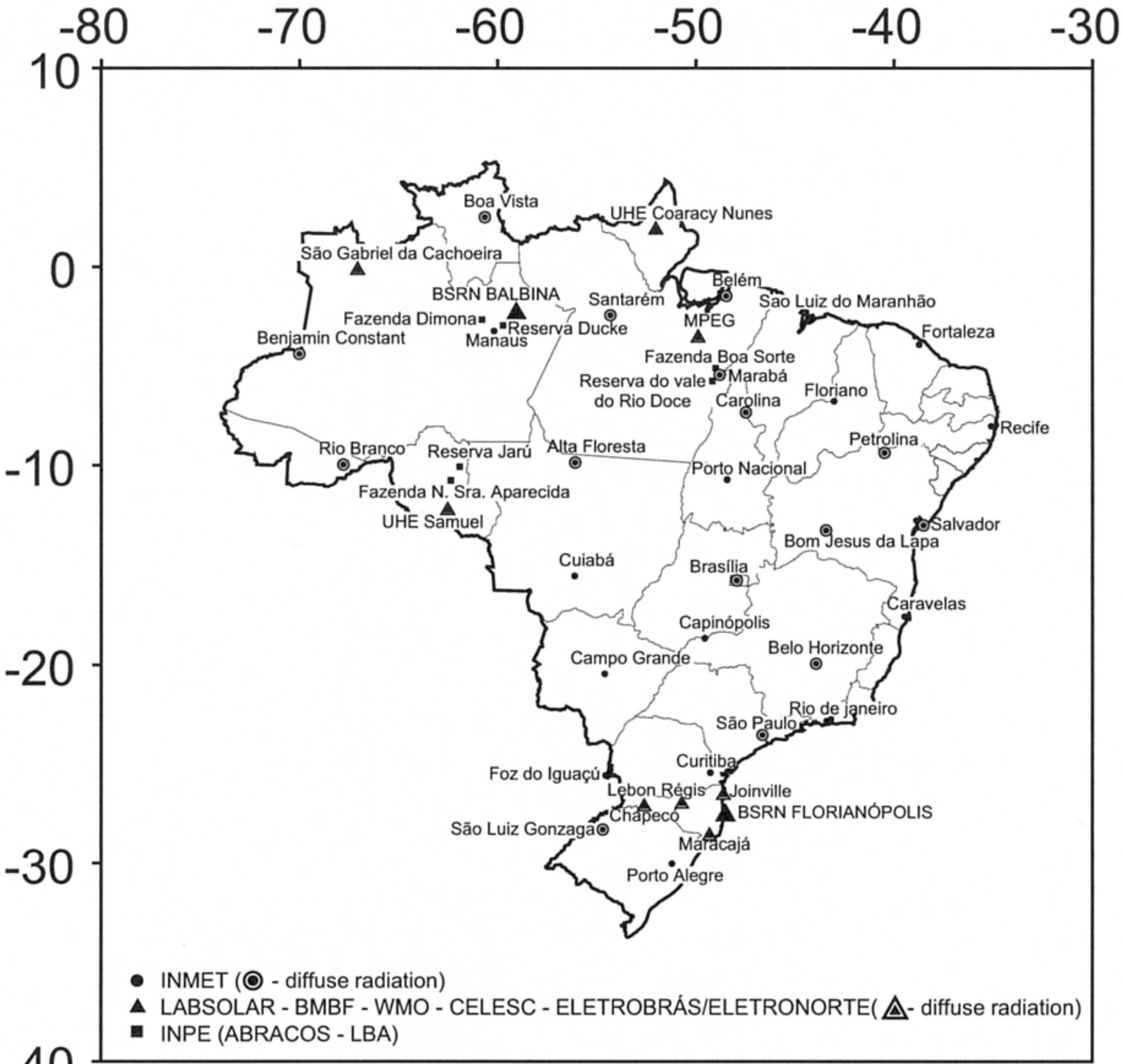
2. BRAZIL

The aim of the project is the assessment of the global, direct and diffuse irradiation as well as the solar irradiation on inclined surfaces for PV and other applications. The project is organized under the leadership of LABSOLAR/NCTS with the partnership of INPE (Brazilian Institute for Space Research) and INMET. Minor partners are the utility company ELETROBRAS (Federal) and CELESC - Utility Company of the State of Santa Catarina.

Goals of the project:
(i) - To rebuild the National Ground Station Network - RSNA (the old network is completely out of work since 1991);
(ii) - To validate satellite derived radiation (SDR) for Brazilian territory;
(iii) - To provide radiation data of highest quality for scientific use (BSRN goal);
(iv) - To extend the computation of SDR to South America;
(v) - To validate SDR for South America (it is presently the most difficult task). The location an type of the ground stations is shown in the next figure.

National Ground Stations Network - RSNA

(INMET, LABSOLAR, BMBF, BSRN/WMO, INPE, SIVAM, USP, UFPA, URGS, ...)



LABSOLAR/NCTS EMC / UFSC

Project Status:

- 6 stations of LABSOLAR (2 BSRN), 2 GAW - INMET stations, 3 stations of INPE are available.
- The computer model (Brazil-SR) is fully operational at LABSOLAR.
- INPE provides the GOES 8 VIS images with one hour and three hour resolution.
- RSNA is planned in the frame of the deployment of the new standard meteorological stations of INMET which are presently being installed.
- ICA - International Cooperation Agency is responsible for the procurement and purchasing the radiometers and shade rings.
- The funds planned for the project proposed to INMET is still not available.

Present Needs:

- An international cooperation project for South America should be planned.
- The budget should be planned and the funds should be independent of national governments.
- The scientific staff should be defined by an international scientific committee.
- The project should be financed by an international agency.
- Minor financial counterparts should come from national agencies.

Climatological Solar Radiation Modeling and Mapping

Ray George
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Golden, Colorado 80401

The National Renewable Energy Laboratory (NREL) estimates surface shortwave radiation for solar energy performance evaluation using a variety of techniques, including surface measurements and models based on surfacemeteorological data. Recently, NREL has begun the use of climatological cloud estimates on a 40 km regular grid to model and map the solar radiation climate (direct normal, diffuse, and global) in areas of the world where surface data do not exist. In this presentation we will discuss the use of the Climatological Solar Radiation (CSR) model, and the climatological data inputs (clouds, water vapor, aerosols, ozone, and albedo) needed for its use.

Currently, the model is being run, and maps created, for international locations of interest. These have included India, the Middle East, North Africa and the Mediterranean, and China, as well as the original study of the U.S., Mexico, and the Caribbean. Total cloud cover data are estimated on a 40 km grid using the USAF RTNEPH (Real-Time Nephanalysis) seven-year climatologies. Opaque cloud amount is parameterized from RTNEPH observed total and layered cloud amounts. Aerosol optical depth comes from a variety of sources including AVHRR and GADS (Global Aerosol Data Set). Precipitable water vapor is from the NVAP 5-year climatologies on a 100 km grid. Albedo is from the Canadian Centre for Remote Sensing (CCRS), ozone is from 11 year TOMS climatologies.

Recently the model has been modified to produce radiation estimates on tilted surfaces. We will discuss the use of the CSR model, input parameters, and output products.

National Renewable Energy Laboratory

Climatological Solar Radiation Modeling and Mapping

Ray George
National Renewable Energy Laboratory

2nd Workshop on Satellites for
Solar Energy Assessment
February 4, 1999
Golden, CO

Center for Renewable Energy Resources

National Renewable Energy Laboratory

Seen on a Climate Change Web Site...

"... all models are wrong.

Some models are useful..."

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NREL Solar Radiation Products

- National Solar Radiation Data Base (NSRDB) -U. S. only, 30 year time series, measured and modeled radiation.
- NSRDB derived products - Solar collector manual, buildings manual, TMYs.
- **Solar Radiation Data Grids**

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Uses of a Solar Data Grid

- Siting Of Solar Energy Systems
- Performance Evaluation for proposed solar systems at any location
- Accurate spatial analysis of derived parameters (e.g. PV system payback periods, CO_2 emissions prevented, etc.)

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CSR model

- CSR (Climatological Solar Radiation)
- Written by Dr. Gene Maxwell
- A simplified version of the METSTAT model used to produce the NSRDB

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Inputs to CSR model

Monthly Climatological Means of ...

- **Total & Opaque Cloud Cover**
- **Precipitable Water Vapor**
- **Aerosol Optical Depth**
- **Atmospheric Pressure**
- **Surface Albedo**
- **Ozone**

For each grid cell...

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Products of CSR model

Monthly mean values of...

- Global Horizontal
- Direct Normal
- Diffuse
- Global on a tilted surface

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Data Gridding Strategy

- Use climatological variables by month as inputs.
- Rely on climate and weather community to provide quality long term INPUTS.
- Use manual intervention, bogusing to improve quality of inputs.
- Use surface observations to validate and improve model OUTPUTS.

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Advantages of CSR modeling

- Fairly low compute time
- Allows for QC of a region in a few days
- Leverage big climatological datasets
- Knowledge-based spatial analysis and bogusing of climate maps.
- Statistically linked to surface databases
- Output can be easily used with GIS.

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Disadvantages of CSR modeling

- No direct creation of time series
- Results unrepresentative if inputs unrepresentative.
- Current (RTNEPH) cloud data are weak in equatorial areas.
- Uneven results, satellite vs. surface cloud data.

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CSR model algorithm

- … First choose a representative day for each month
- Then, for each 5 minute time step…
  - Calculate Direct Normal
  - Calculate Diffuse
  - Sum to get Global Horizontal
  - Use Perez algorithms to get tilt values.

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Normalized Direct Normal Radiation

$$Kn = T_R\, T_O\, T_{UM}\, T_W\, T_A\, T_{OPQ}\, T_{TRN}$$

Where The Direct Normal Transmittances Are:

- T_R for Rayleigh scattering,
- T_O for ozone absorption,
- T_{UM} for uniform mixed gas absorption,
- T_W for water vapor absorption,
- T_A for aerosol absorption and scattering,
- T_{OPQ} for opaque cloud absorption, and
- T_{TRN} for translucent cloud absorption

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Normalized Diffuse Horizontal Radiation:

$$Kd = Ks_{CLS} + Ks_{OPQ} + Ks_{TRN} + Ks_{GRFL}$$

Where The Effective Scattering Transmittances Are:

- Ks_{CLS} for clear skies (Rayleigh and aerosol),
- Ks_{OPQ} for opaque clouds,
- Ks_{TRN} for translucent clouds, and
- Ks_{GRFL} for multiple cloud to ground reflections

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CSR Cloud Inputs - RTNEPH

- RTNEPH = Real-Time Nephanalysis
- Worldwide 40 km grid, polar projection
- 3-hourly data for 7 years (1985-1991)
- Surface data preferred, then satellite
- Twice-daily DMSP polar orbiter.
- Total, Low, Middle, High cloud amounts.

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CSR Cloud Inputs - RTNEPH

- RTNEPH averages for all daylight hours.
- Ratio of high clouds to all clouds.
- Parameterize to get translucent cloud fraction, valid only for surface locations.
- Grid translucent, resample, compute opaque cloud amount for each location.

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Water Vapor Input - NVAP

- NASA/CSU Water Vapor Climatology
- Data on 1X1 degree (100 km) grid
- 5 years data (1988-1992)
- Rawinsonde data, corrected for instrument changes
- SSM/I, TOVS satellite water vapor retrievals

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Aerosol Optical Depth Inputs

- Annual means estimated from any source
- Where direct normal surface data exist, values are backed out using Beer's Law
- AVHRR over water - 1989-1991, seasonal means, 1X1 degree
- GADS - theoretical estimates, 550 km resolution, winter and summer means.

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Ozone, Albedo Inputs

- Ozone from TOMS, 120 km resolution, 11 years (1979-1990)
- Albedo from Canadian Centre for Remote Sensing (CCRS), 280 km.

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(Near) Future Directions

- Calculate Radiation on tilted surfaces, model deployment scenarios.
- Find better sources of aerosol data
- Continue to improve our GIS technology
- Use more recent years of RTNEPH data, OR....
- Switch to different cloud input such as ISCCP

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PVSAT: Remote Performance Check for Grid Connected PV Systems Using Satellite Data

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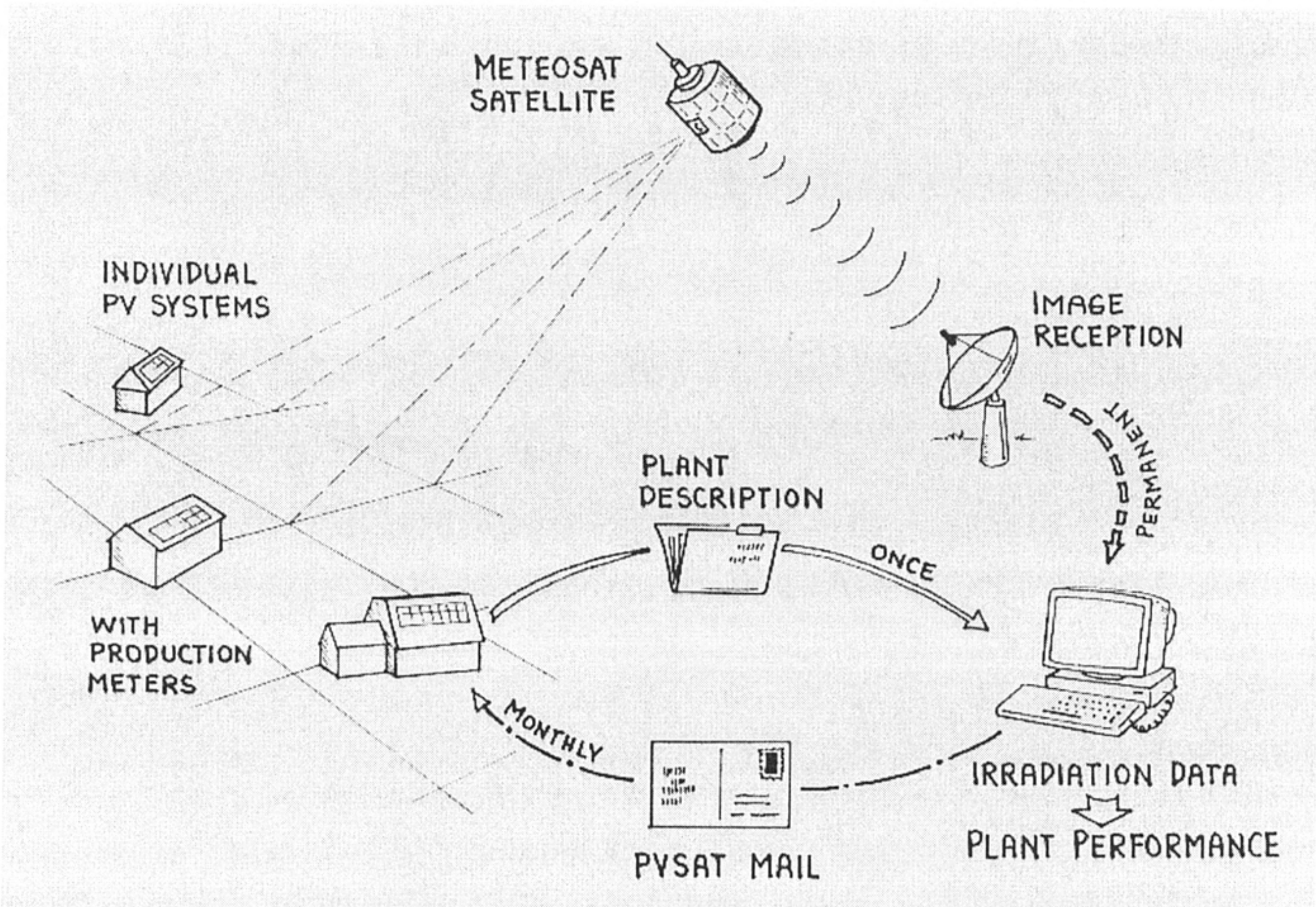
Small photovoltaic (PV) systems (i.e. in the power range of 1 to 10kWp) regularily do not include any long term surveillance mechanism.As most system operators are not PV specialists, partial system faults or decreasing performance may not be recognized. Regarding a number of several thousand systems being in operation today, remarkable losses in energy production may occur.

The European research project PVSAT will set up a remote performance check for small grid connected PV systems. No additional hardware installation will be necessary on site. The site specific solar irradiation data will be derived from satellite images rather than from ground based measurements. On the basis of monthly irradiation time series, monthly values of PV system yield will be calculated and distributed automatically via postcard, fax or e-mail (whatever is most suitable) towards the system operators. This procedure will remind the system operator periodically to check the performance of his installation. In this way, a high system performance will be ensured over the whole lifetime of a PV system.

At this time, we will not be able to show real results of a working PVSAT procedure, as the project has started some 8 months ago. Instead, we will present the project outline and the specific tasks of our work, including a discussion of accuracy issues (which kind of failures may be detected) and of the end users' (small systems' operators) benefits.

PVSAT:

Remote Performance Check for Grid Connected PV Systems Using Satellite Data



EU Joule III: Contract JOR-CT98-0230

Fraunhofer Institut Solare Energiesysteme

Presentation: PVSAT by C. Reise, ISE

Project Partners:

Fraunhofer ISE,
Freiburg (D)

Enecolo AG,
Mönchaltdorf (CH)

Utrecht University,
Utrecht (NL)

Universität Oldenburg,
Oldenburg (D)

Energy Consulting, Aix en Provence (F)
Fachhochschule Magdeburg, Magdeburg (D)

Deutscher Fachverband Solarenergie e.V. (D)
Deutsche Gesellschaft für Sonnenenergie e.V. (D)
Energiebüro Christian Meier (CH)
Organisatie voor Duurzame Energie (NL)

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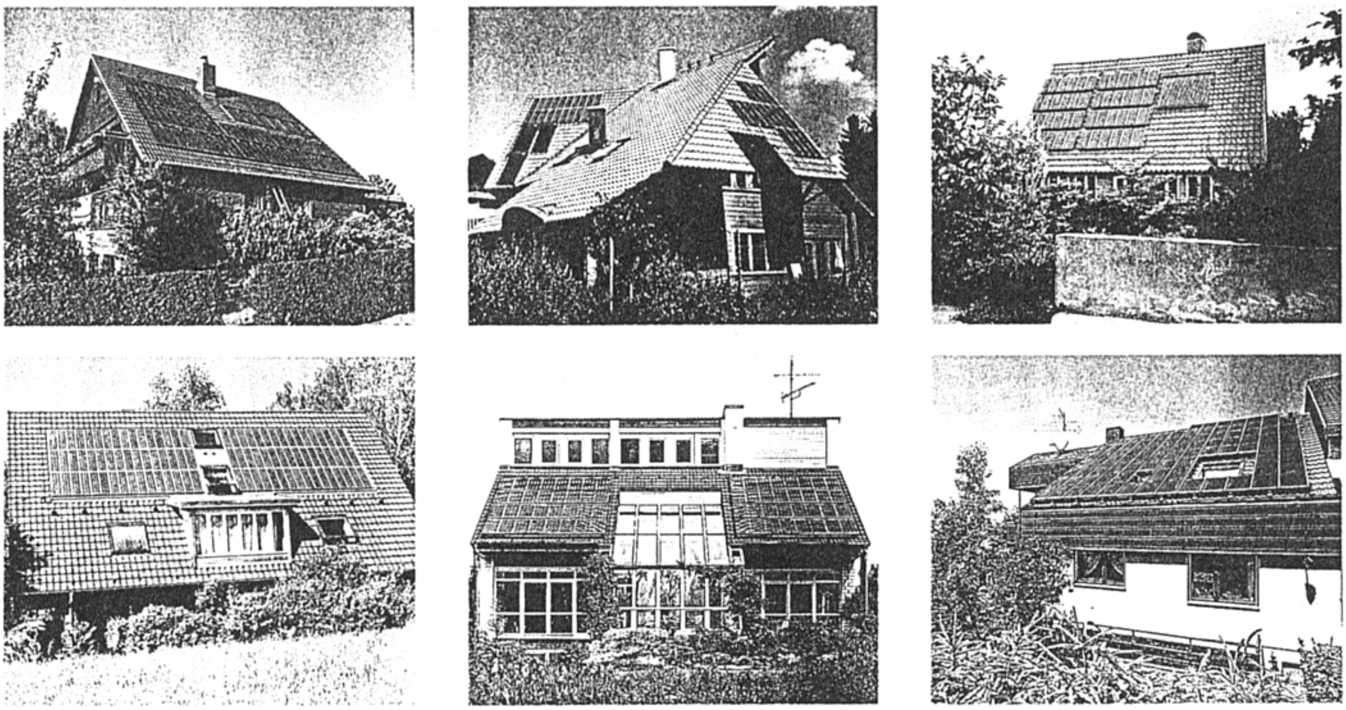
Solar Electricity from a Thousand Roofs



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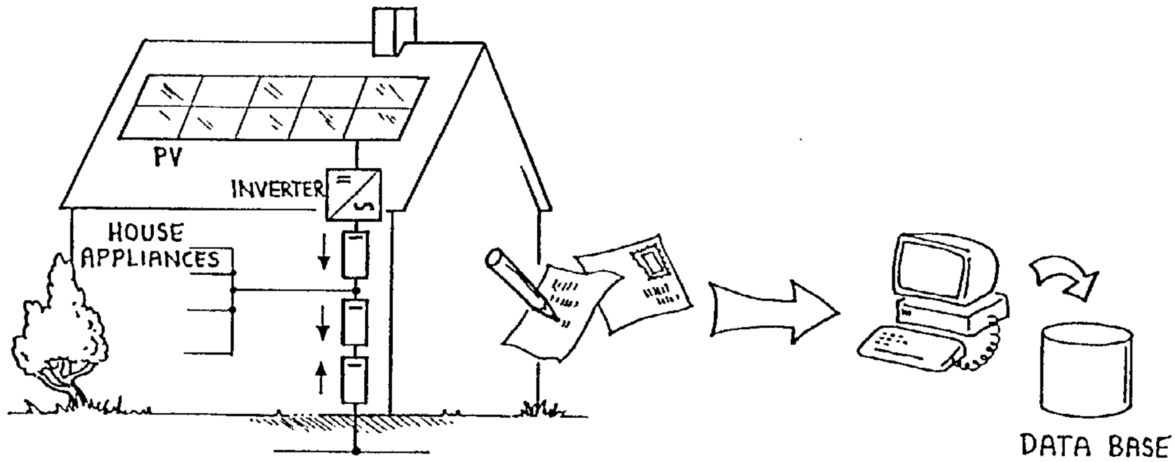
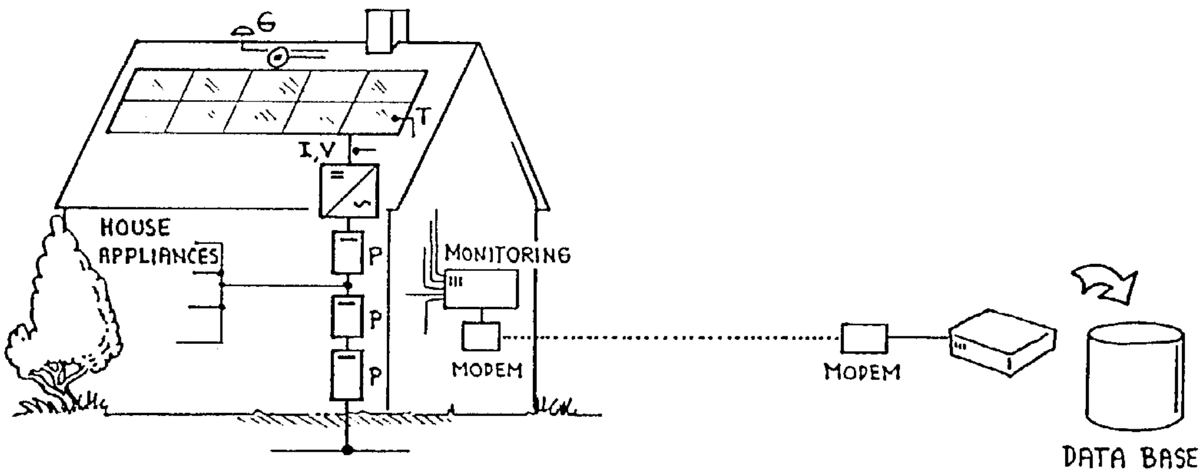
Monitoring within the 1000 Roofs Programme



All systems: global monitoring on monthly base



100 systems
(since 1996: 40 systems):
5 minute mean values

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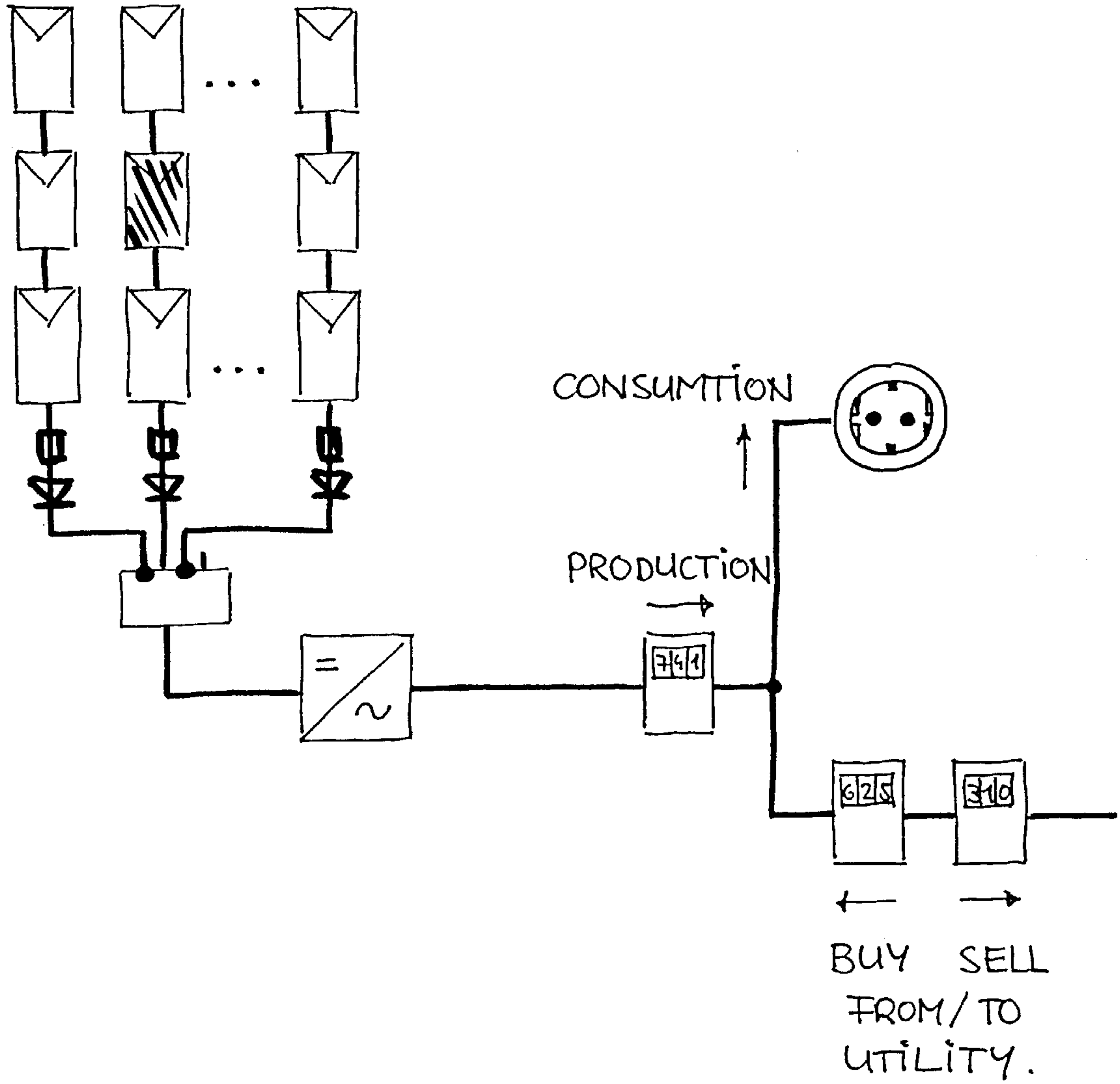
Defects in PV Systems

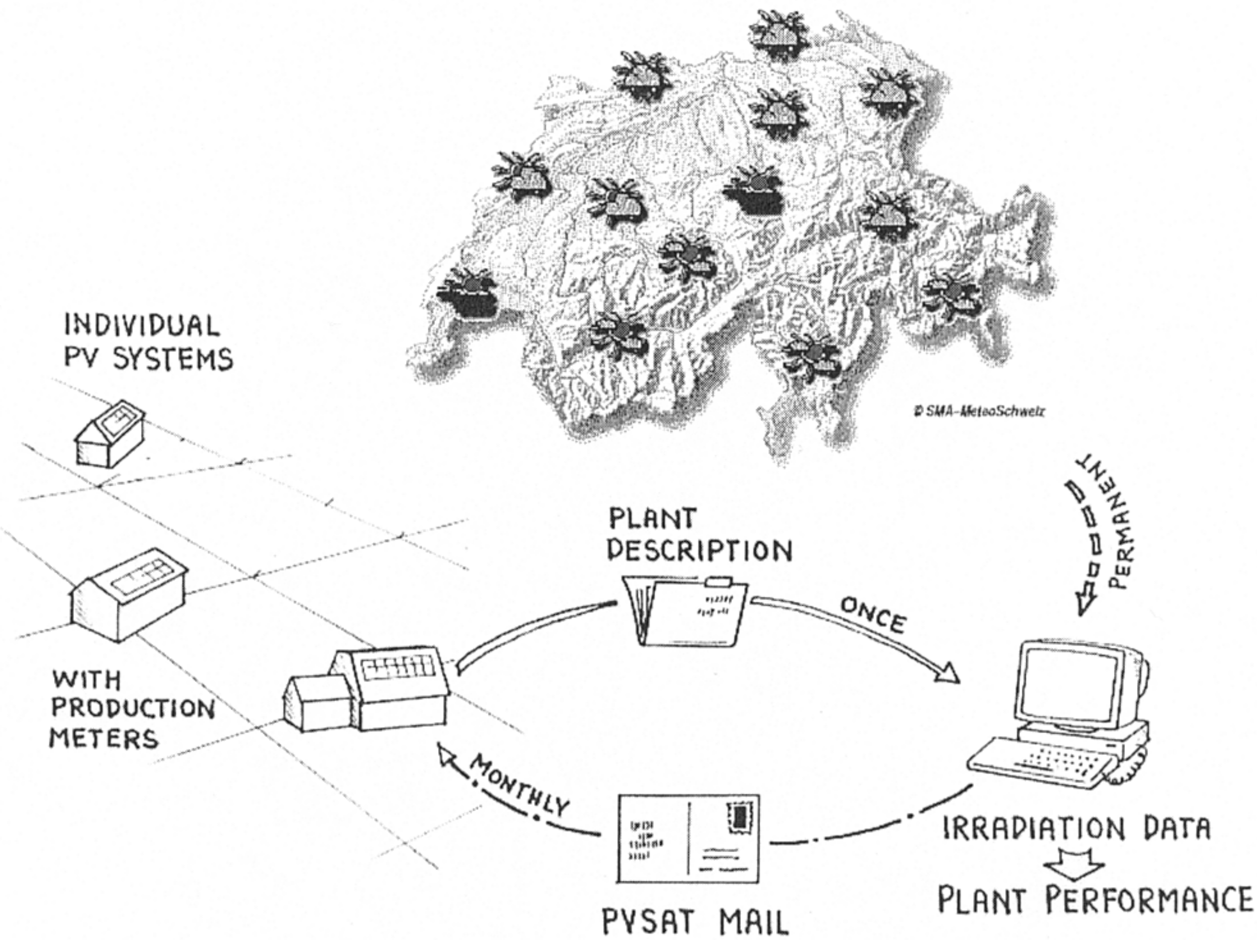
500 failures	in 2000 site-years of operation
200 failures	related to the PV generator
Reasons:	loose terminal connections (43 %) module defects (14 %) string diode defects (14 %) string fuse defects (29 %)

Typical Grid Connected PV System



IMIPP:

Remote Performance Check for Swiss Grid Connected PV Systems Using Ground Data



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Calculation		
Plant	xxx	
Date	month/year	
Irradiation 1	1.107,00	
Percentage	30%	
Irradiation 2	1.041,00	
Percentage	40%	
Irradiation 3	1.082,00	
Percentage	30%	
Total	1.073,10	
Calculation	/ 36	29,81
R-Factor	1,26	37,56
Shading	1,00	37,56
Temp.coefficient	1,05	39,44
Soiling	1,00	39,44
Ageing	0,99	39,04
Snow	0,94	36,70
Efficiency	0,90	33,03
Performance	2,91	96,11
simulated performance per month		96,00

SMA-data		...	...	Dec 96	Jan 97	Feb 97	...	...
1	La Dôle							
2	Payerne							
3	Jungfraujoch							
4	...							
...	...						1.107	
...	...						1.041	
69	...						1.082	
70	Plaffeien							
71	Roblei							
72	Würenlingen							

Plant-data	Jan	Feb	Mar	...	Oct	Nov	Dec
R-factor				1,26			
Shading				1			

SMA-Station(s)	1	2	3	
Percentage	30%	40%	30%	

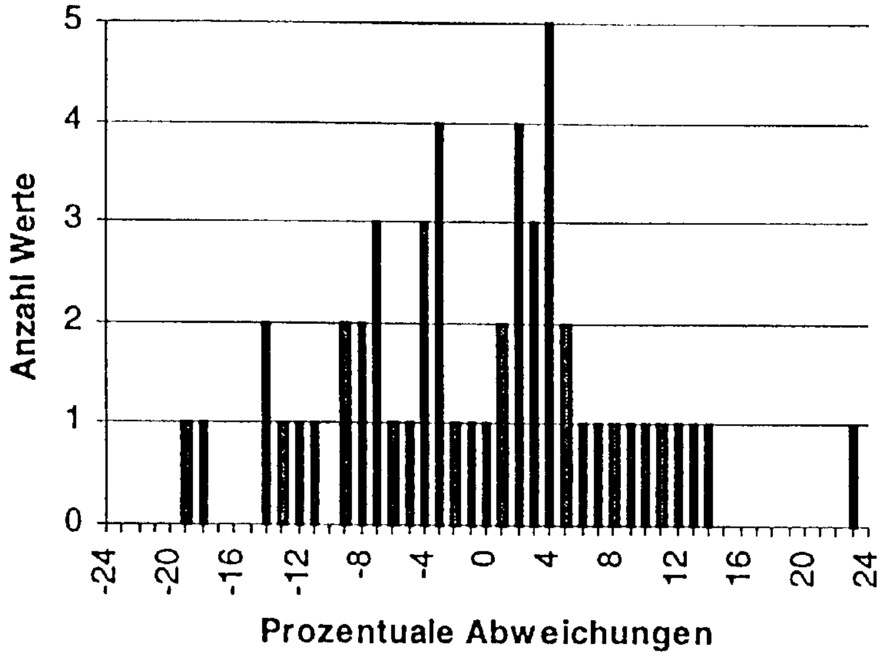
Modul	SDZ
Quantity	104
Performance	2,91
Temperatur coefficient	0,004
Converter	Solcon
Efficiency	0,9
Sea Level	450
Orientation	Nord
Starting of Plant	1.7.92

meteo data	Jan	Feb	March	...	Oct	Nov	Dec
average day/month temp.				8,7			

Monthly factors	Nord	Süd	Ost	West
Soiling	1			
Snow at 400m a. sea-level	0,95			
Snow at 800m a. sea-level	0,90			
Snow at 1200m a. sea-level				
Snow at 1600m a. sea-level				
Snow at 2000m a. sea-level				

Prediction accuracy

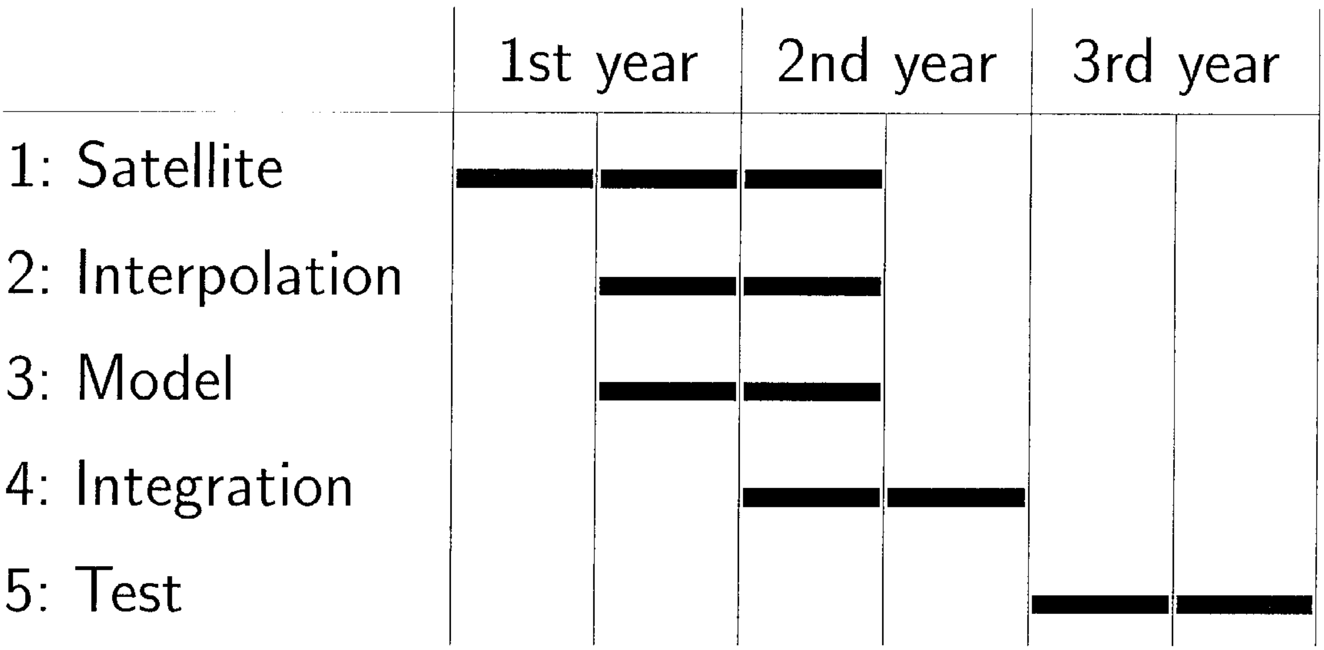
IMIPP estimation vs. observed plant yield



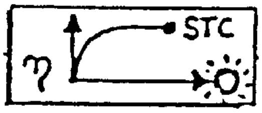
Project Structure

Task 1	Satellite data production
Task 2	Ground interpolation techniques
Task 3	PV system model
Task 4	PVSAT integration
Task 5	Test & evaluation

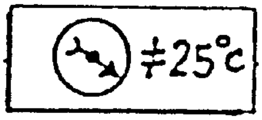
Project time schedule



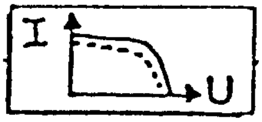
PV system modelling



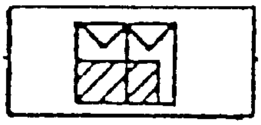
Irradiation affects efficiency



Temperature affects efficiency

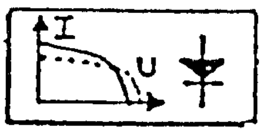


I/V-curve fit correction

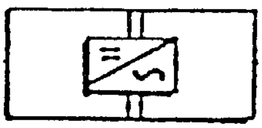


Shading losses

MPP tracking mismatch



Cables, diodes, fuses,
I/V-curve mismatch



Inverter losses

Fraunhofer Institut
Solare Energiesysteme

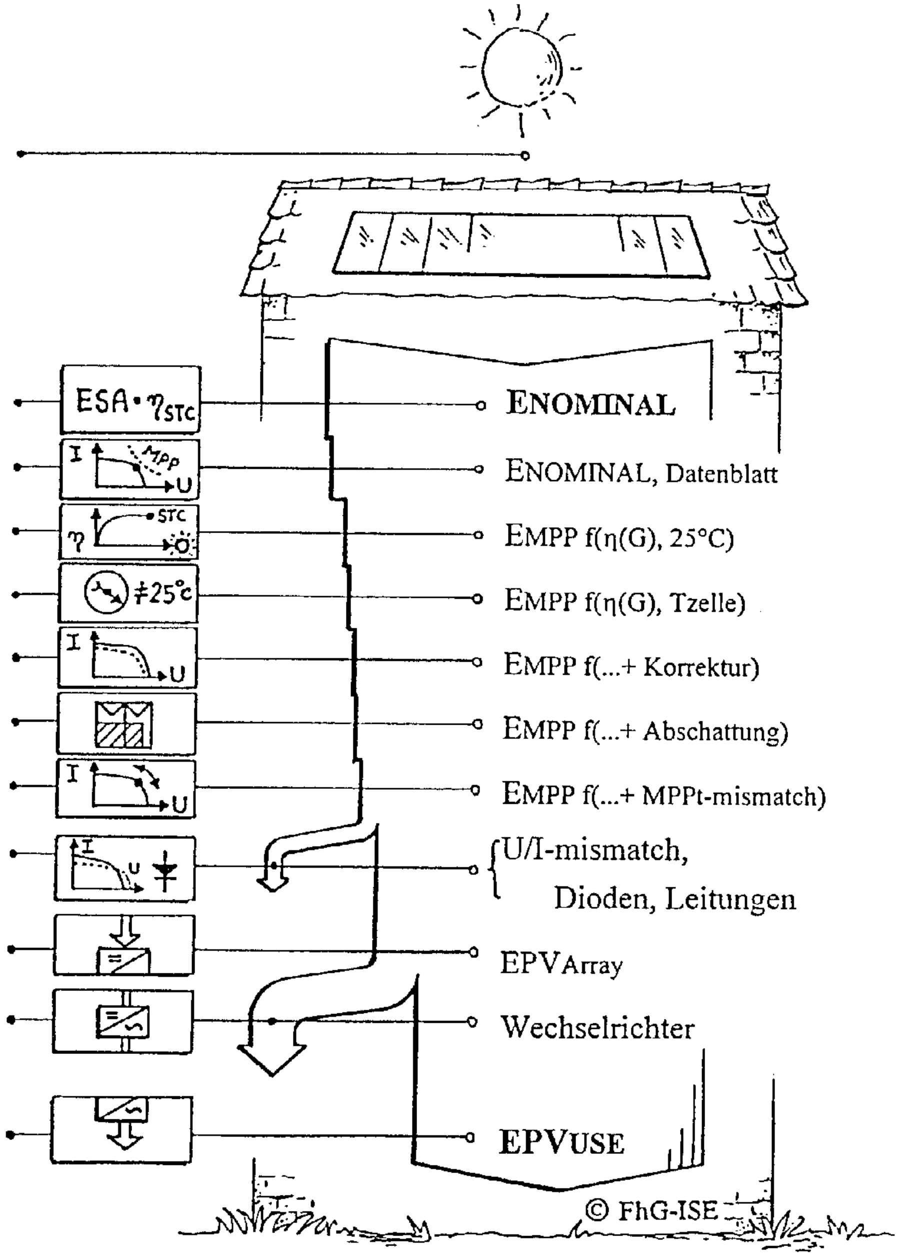
Presentation: PVSAT by C. Reise, ISE

1000 Roofs Programme

Energy Flow Analysis

2.544	$P_{NOMINAL}$	[kW_p]
20.48	Generatorfläche	[m^2]
20072	$ESA_{28°}$	[kWh]
12.42	η_{STC}	[%]

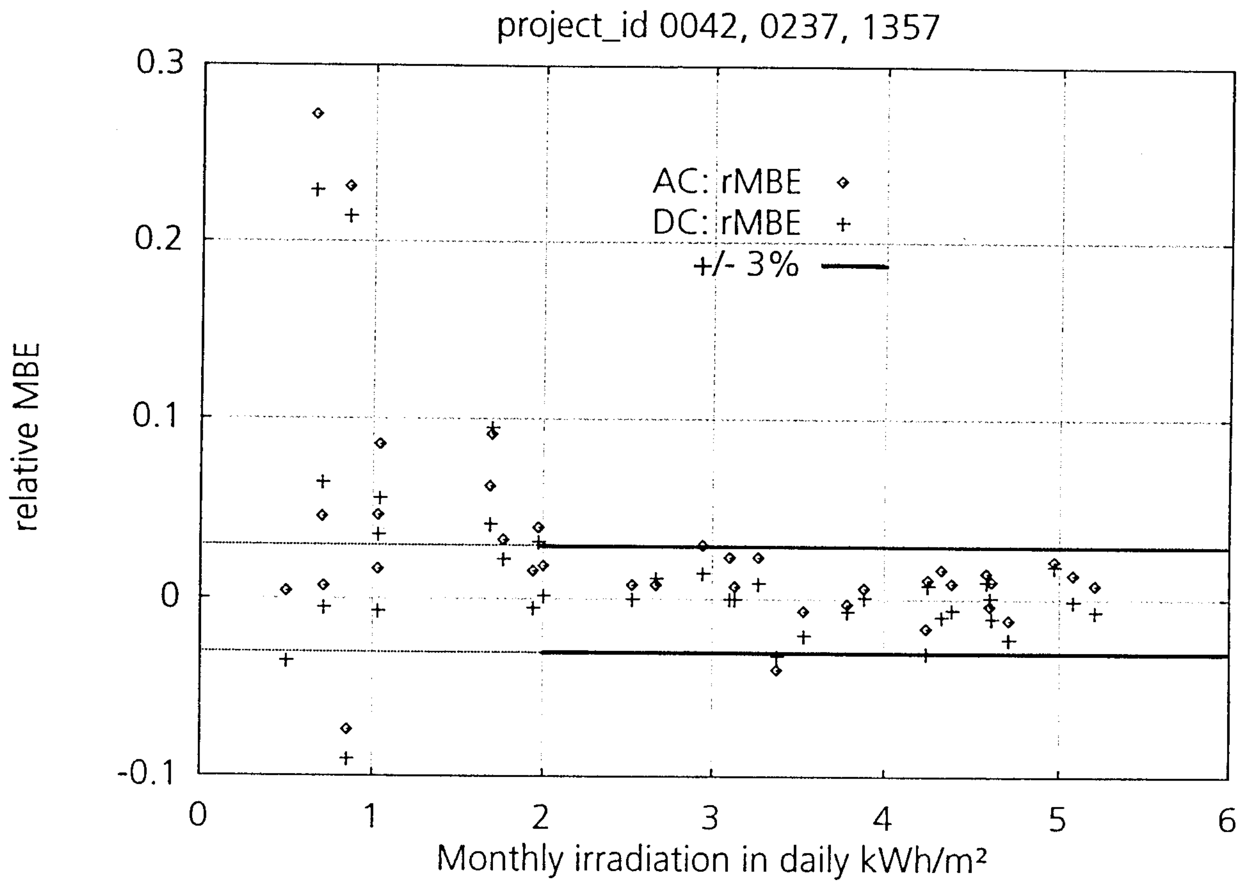
Messung		**Simulation**	
kWh	%	*kWh*	%
2493	**100**	*2493*	**100**
		2485	99.7
		2386	95.7
		2237	89.7
		2215	88.9
		2170	87.0
		2133	85.6
			3.6
2128	85.4	*2044*	82.0
	5.1		4.5
2000	**80.2**	*1931*	**77.5**



Fraunhofer Institut Solare Energiesysteme

Presentation: PVSAT by C. Reise, ISE

Base level, 3 systems



* Mean Bias Error of simulated and measured AC power generation remains in a bandwidth of approx. +/- 3% for monthly irradiation > 2 kWh/m² per day

* With the exception of shading periods, the mean bias error is within +/- 10% in low irradiation periods

---

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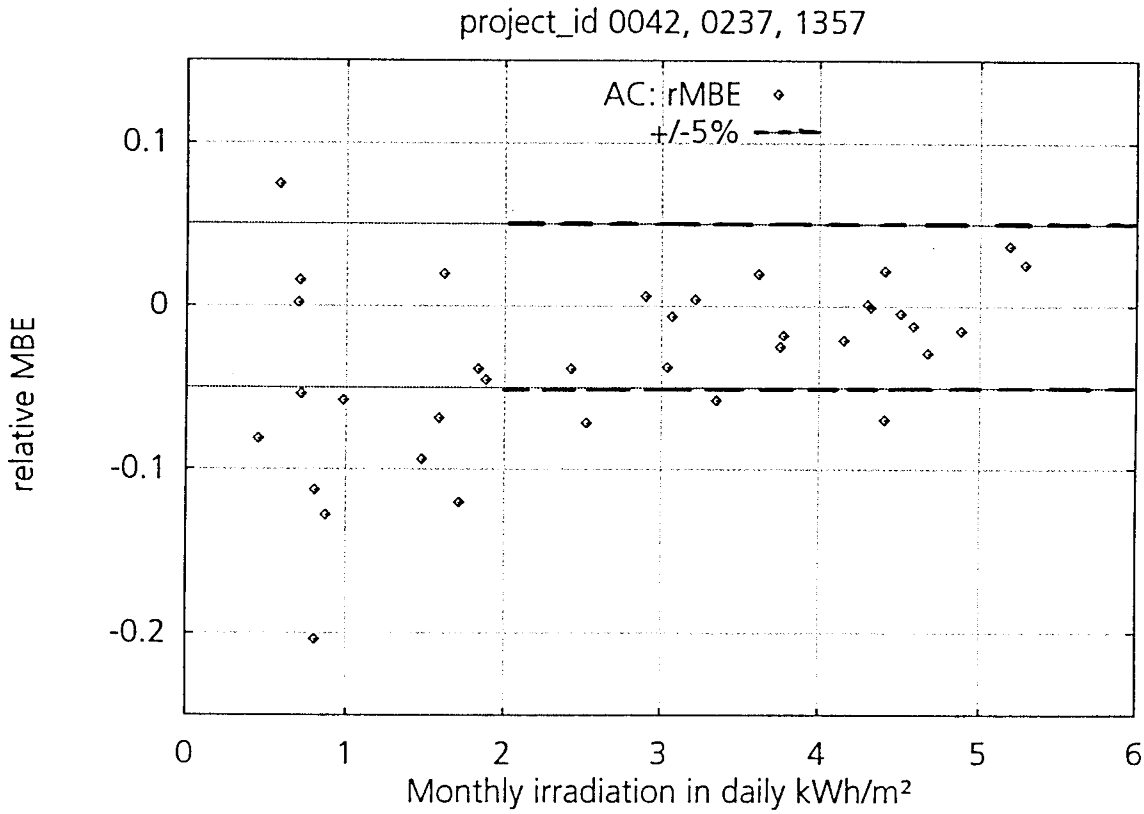
Presentation: PVSAT by C. Reise, ISE

PV system modelling

Simplifications with level 2:	Constant mismatch factors
	Module temperature calculated from ambient temperature
	Module irradiation calculated from horizontal values

Level 2, three systems



Result of level 2 simulation:

The use of measured horizontal irradiation approximately doubles the mean bias error of simulated AC power generation compared to the measured values:

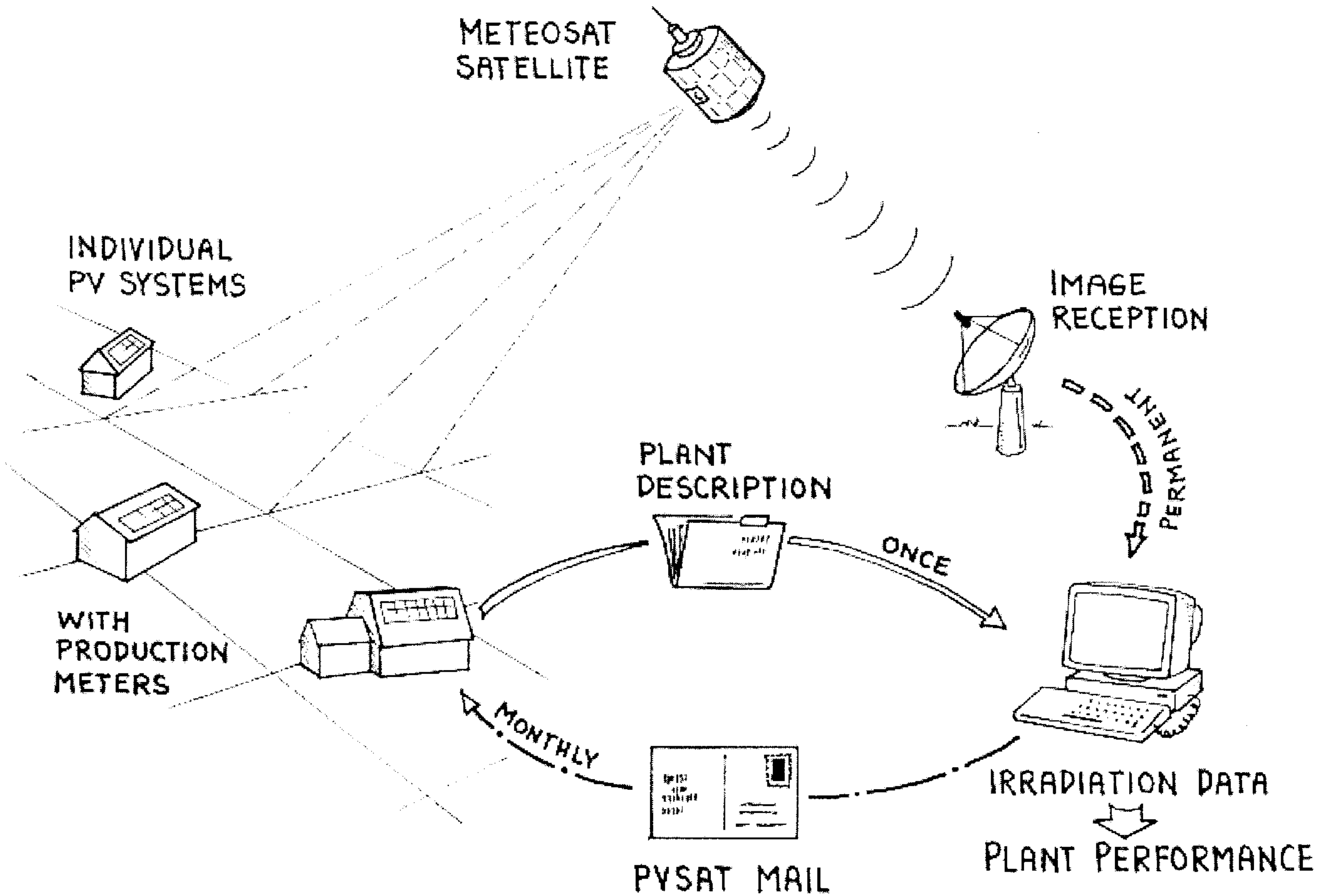
* The error exceeds the ±5% margin and is < ±10% for monthly irradiation > 2 kWh/m² per day
* In low irradiation periods, errors of > +/- 10% may be observed

Fraunhofer Institut Solare Energiesysteme

Presentation: PVSAT by C. Reise, ISE

PV system modelling

Simplifications with level 2:	Constant mismatch factors
	Module temperature calculated from ambient temperature
	Module irradiation calculated from horizontal values
Further problems:	Ambient temperature estimated
	Insufficient component data
	No site specific knowledge
	Irradiation from satellite data



Presentation: PVSAT by C. Reise, ISE

Operational Photovoltaic and Solar Energy Applications

Richard Perez

Because it is continuous in time and in space, and because it is site and time specific, satellite-derived solar resource assessment information adds a new dimension to the investigation of the operational performance of solar energy system. Sometimes, this added dimension provides a new insight that can have a substantial impact on the assessment of the feasibility and the value of these systems.

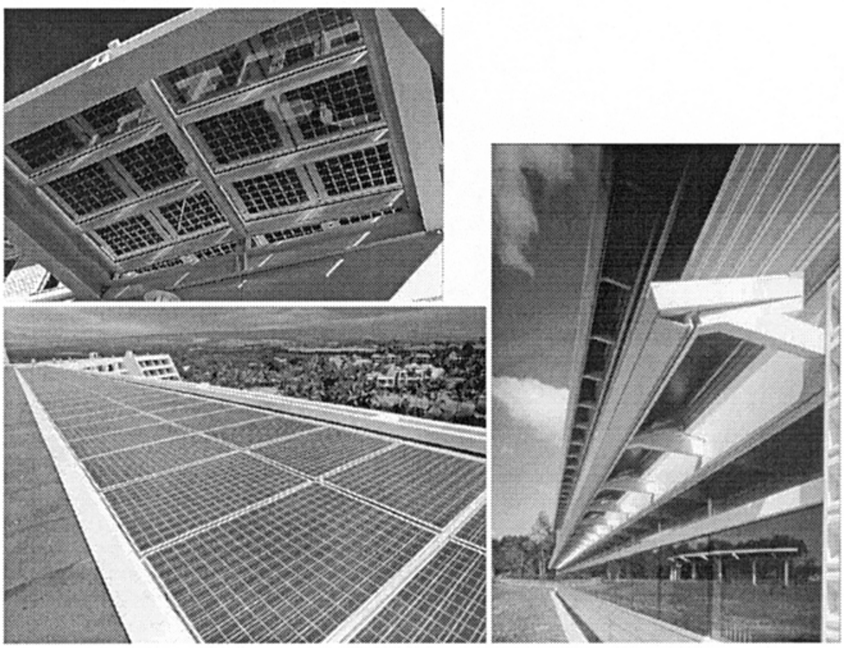
Two examples where access to the satellite resource made a substantial difference are presented:

(1) The first example is the determination of the effective capacity of photovoltaics and the resulting impact on the geographical distribution of PV markets for commercial applications.

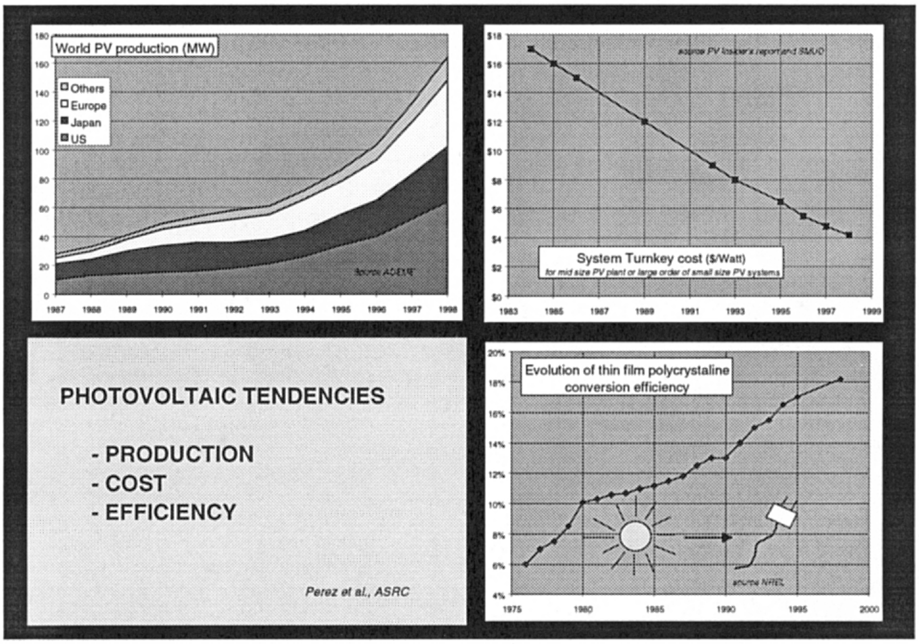
(2) The second example includes case studies assessing the ability of PVs to help prevent and/or to relieve the effects of regional or localized power outages.

OPERATIONAL PV AND SOLAR ENERGY APPLICATIONS

Richard Perez

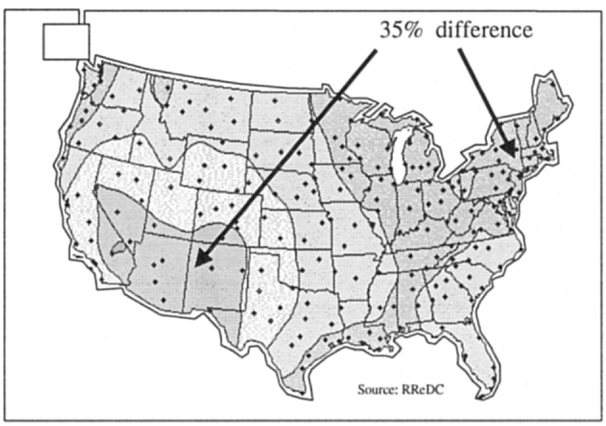


Presentation: Operational PV and Solar Energy Applications by Richard Perez, ASRC



Common misconceptions about PVs in the northeast

- No Sun



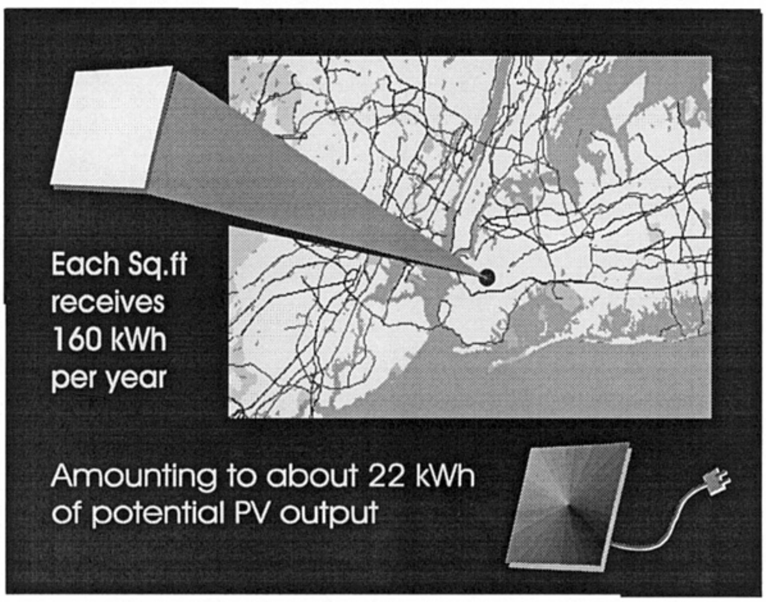
Perez et al., ASRC

Presentation: Operational PV and Solar Energy Applications by Richard Perez, ASRC

Common misconceptions about PVs in the northeast

- No Sun
- No Space

Perez et al., ASRC



Perez et al., ASRC

Presentation: Operational PV and Solar Energy Applications by Richard Perez, ASRC

Common misconceptions about PVs in the northeast

- No space
- No sun
- **No reliability**
- **Too Expensive**

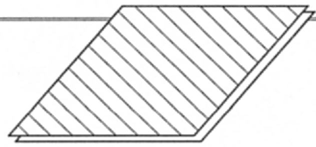
Perez et al., ASRC

PV Reliability

- **Effective capacity**
  Delivering power when needed
- **Performance in emergency situations**
  Solution to power outages

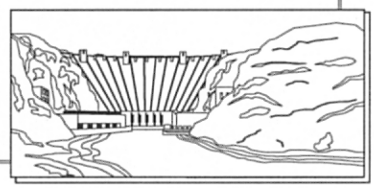
Perez et al., ASRC

Effective Capacity
% ELCC *



1 kW of PV

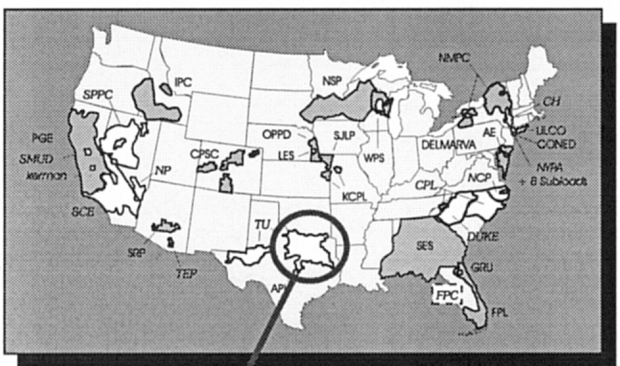
= % ELCC kW of ideal power generation unit



e.g., 100 kW of PV with 80% effective capacity amounts to 80 kW of ideal power generation

Perez et al., ASRC

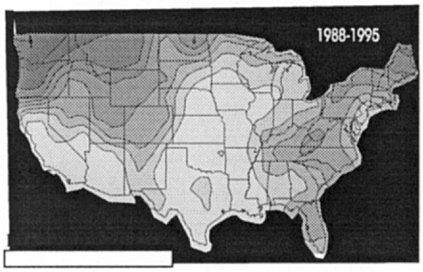
* ***E****ffective* ***L****oad* ***C****arrying* ***C****apability*
Increase in available capacity at constant LOLP



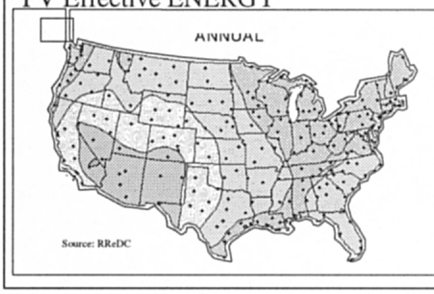
Solar Radiation Data
Arbitrary location
Arbitrary time, past, current (and forecast)

Perez et al., ASRC

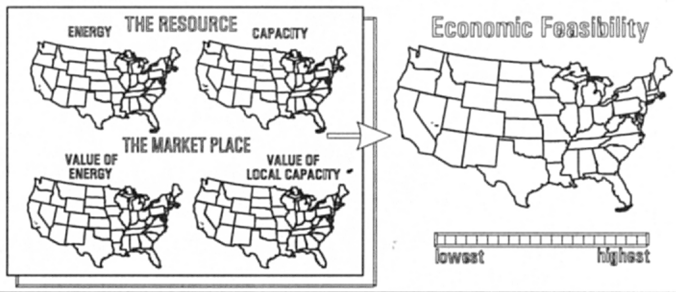
PV Effective CAPACITY



PV Effective ENERGY



Market implications



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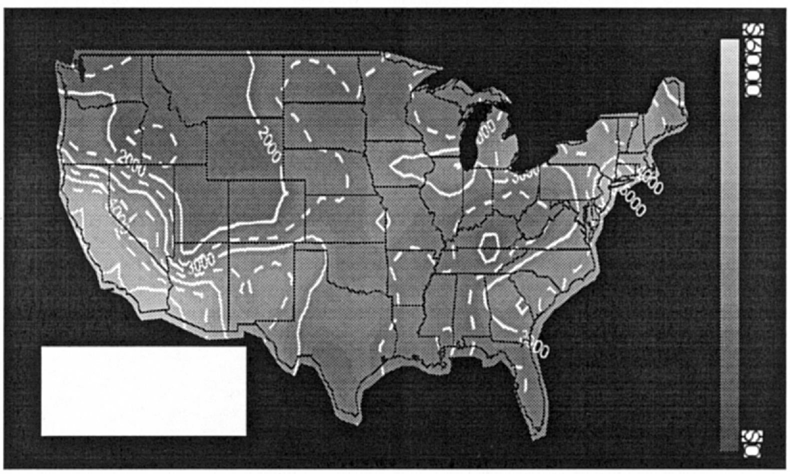
fx 518-437 8711

Perez, Wenger & Herig



COMMERCIAL DEMAND-SIDE PV

BREAKEVEN TURNKEY PV SYSTEM COST (2-axis trk. Systems)

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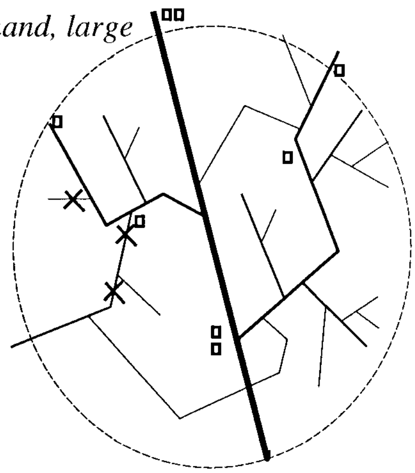
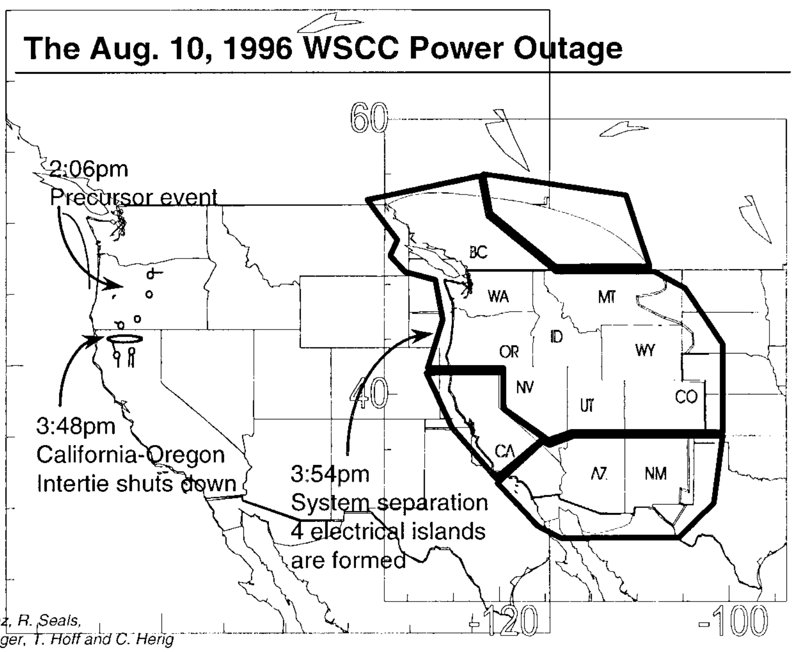
POWER OUTAGES

- **Regional Grid-wide Blackouts (Brownouts)** *Causes: High demand, large power transfers, cascading effects*
- **Localized Power Line outages** *Causes: severe weather*



Perez et al., ASRC



R. Perez, R. Seals, H. Wenger, T. Hoff and C. Herig

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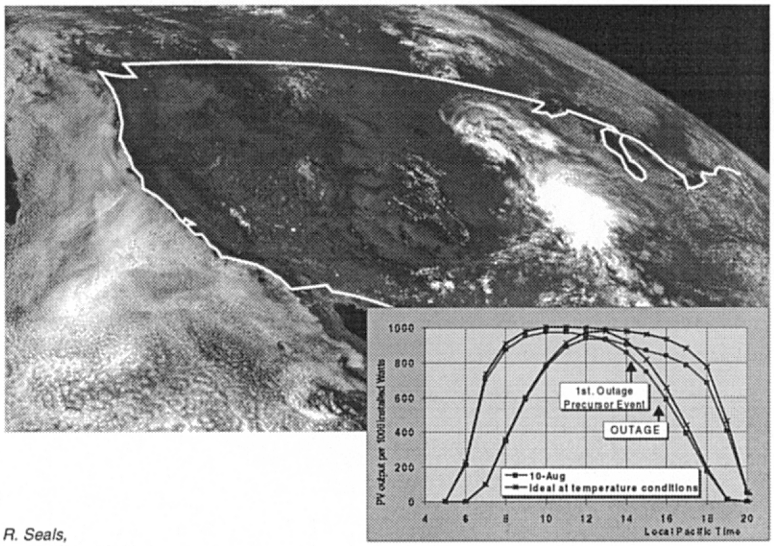
The Aug. 10, 1996 WSCC Power Outage

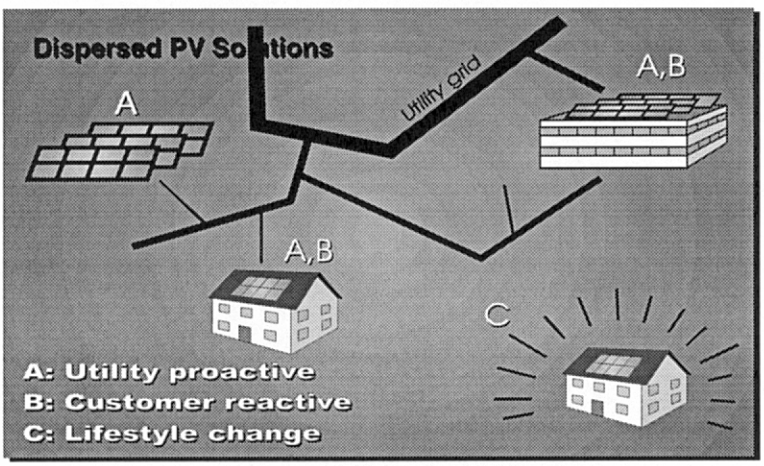
GOES-9 view of the western USA at 11:00am



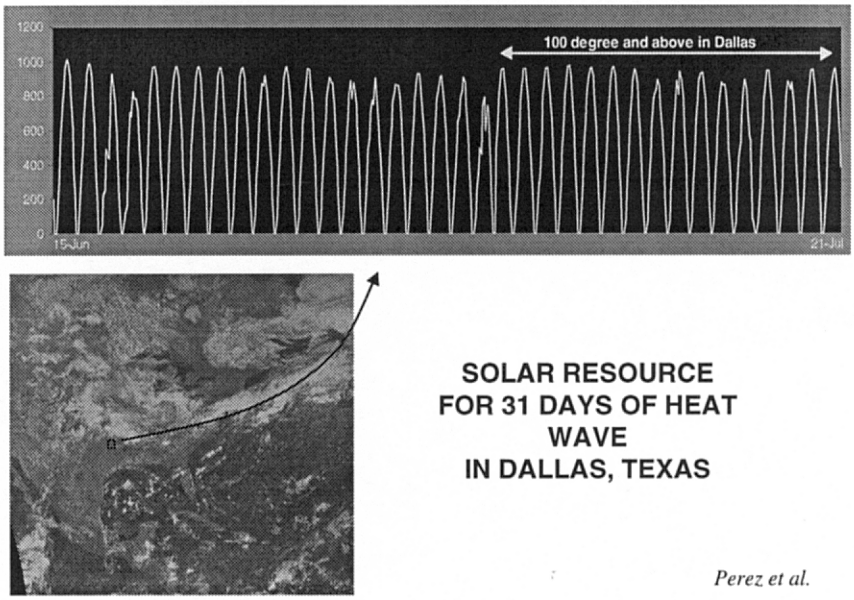
R. Perez, R. Seals,
H. Wenger, T. Hoff and C. Herig

Aug. 10, 1996 WSCC Power Outage

R. Perez, R. Seals,
H. Wenger, T. Hoff and C. Herig

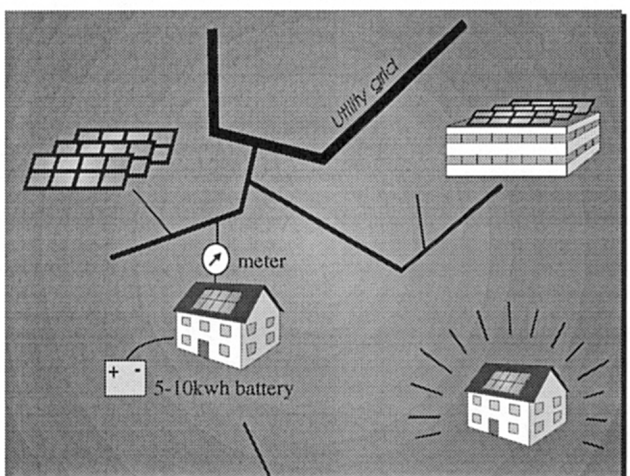


Had a dispersed PV resource throughout the WSCC service area been in place, the outage would have likely been prevented



SOLAR RESOURCE FOR 31 DAYS OF HEAT WAVE IN DALLAS, TEXAS

Perez et al.

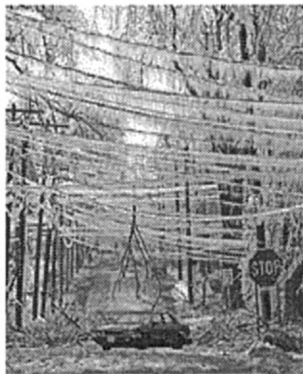


Grid-Connected PV with emergency storage

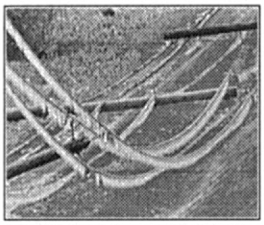
Perez et al., ASRC

Ice Storm 98
- New York
- New England
- Quebec

Courtesy CNN



Courtesy NYSEMC

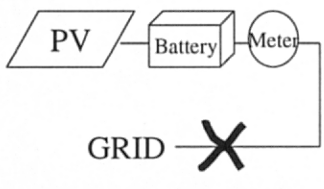


Courtesy CNN

Millions out of power
Many for several weeks

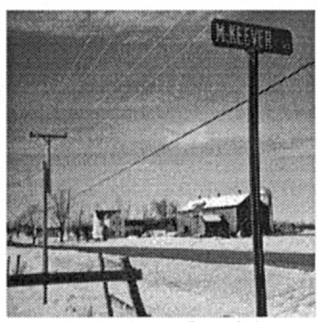
Courtesy Niagara Mohawk

Ice storm 98
Net metered PV



Courtesy Justin Byington

Courtesy Niagara Mohawk



Courtesy Justin Byington

Perez et al.

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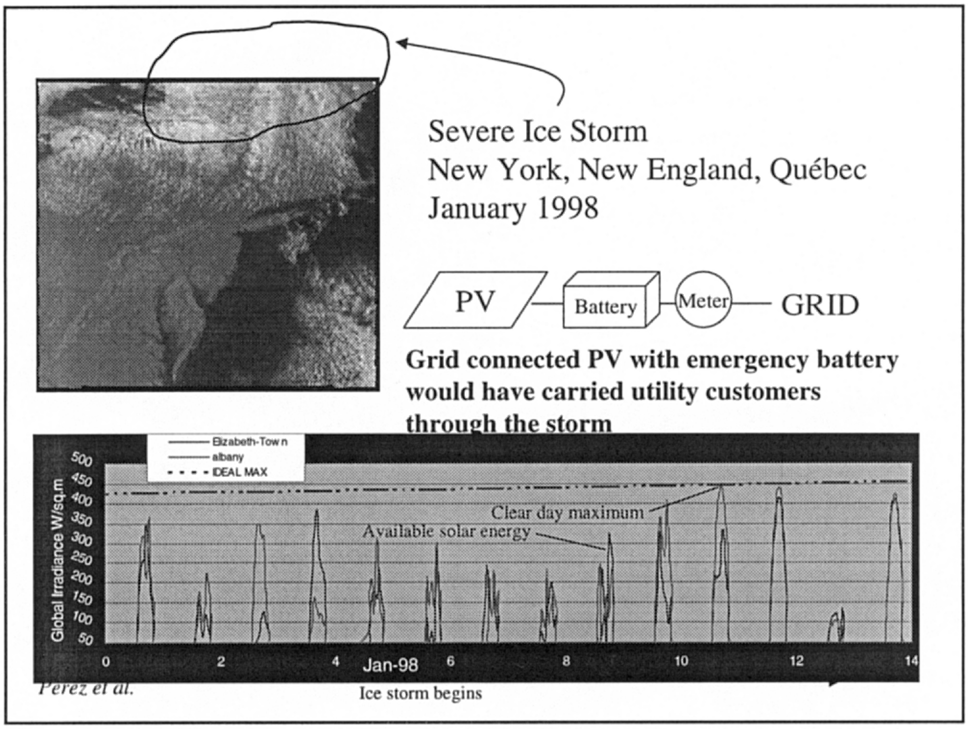

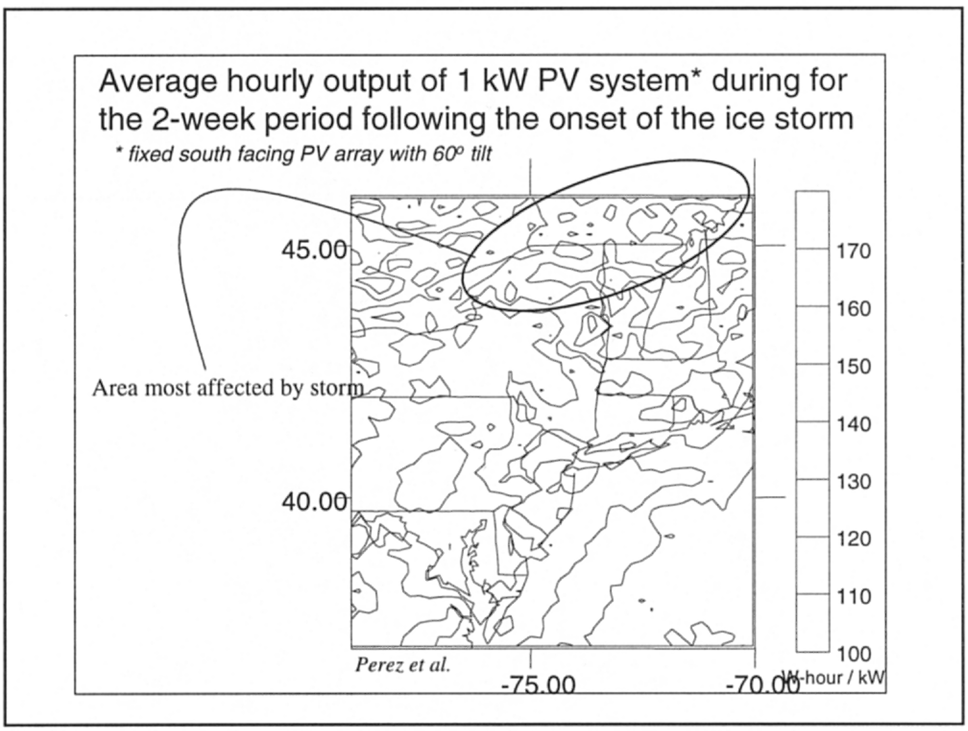

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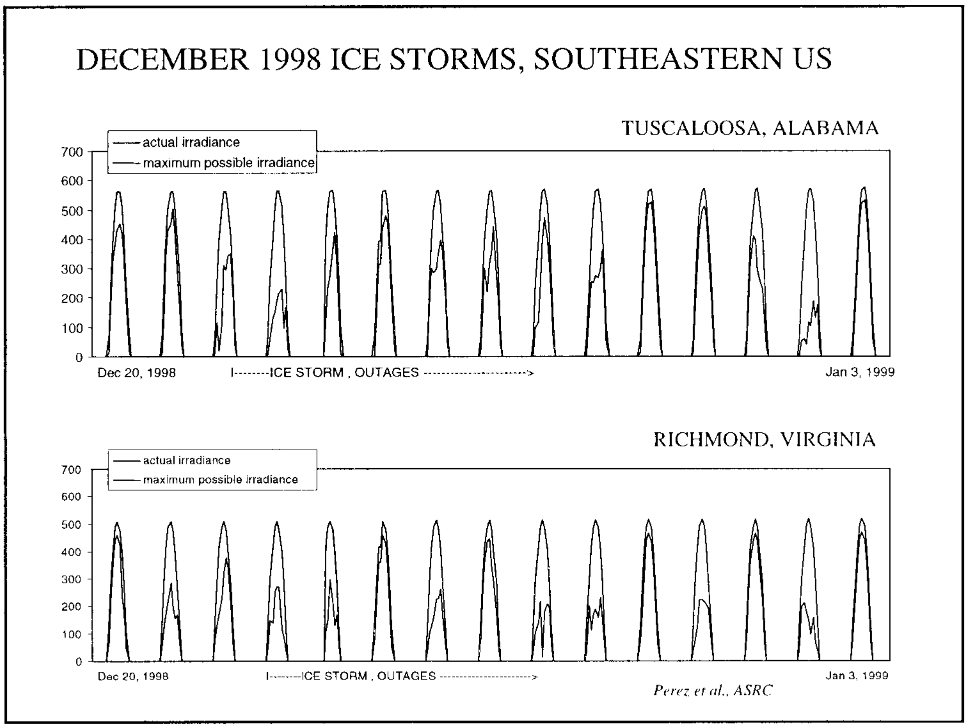
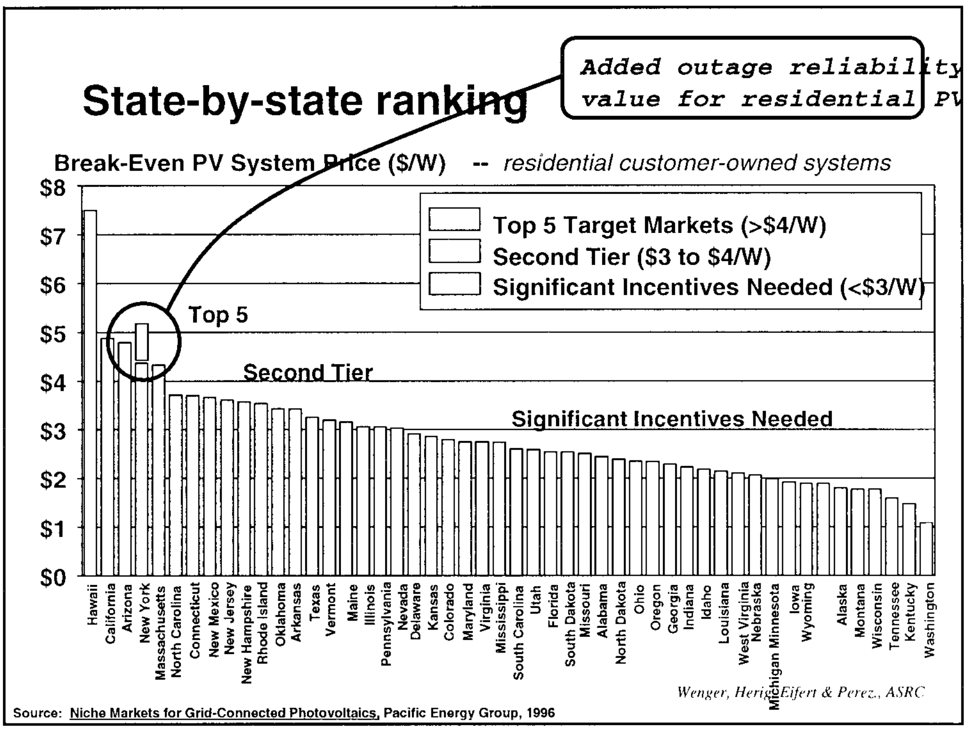




Presentation: Operational PV and Solar Energy Applications by Richard Perez, ASRC

Research and Development Issues for the Future

Martin Rymes

Satellite-based solar energy resource estimation methods have been developed to such an extent that the R&D issues have shifted from primary model development to refinement of models. These issues tend to separate into three primary areas: physics, surface/satellite correlations, and innovation applications. The critical physics issue is the determination of accurate cell-by-cell/frame-by-frame estimates of atmospheric contaminants such as aerosols, precipitable water, and ozone, as well as refined algorithms for estimating the opacity and thickness of clouds. In the future, surface-based measurements of these atmospheric properties will be supplanted by satellite-based estimates, preferably through multiband spectral analysis from the same satellites that provide the visible cloud-cover image. The refinement limit is the smallest [(grid-cell) x (time-interval)] nugget for which the uncertainty of satellite-based estimation exceeds the uncertainty of a comprehensive ground-based measurement network. When satellite-based techniques are pushed beyond this limit, a new metric for accuracy will be developed that will loosen (and ultimately sever) the reliance on high time-series correlations with surface measurement stations. Such a metric may take the form of cumulative frequency distributions of estimated energy levels and/or days of autonomy. Finally, new applications for satellites will be developed that meet future energy developers' needs in ways that surface measurement networks never can. Examples of these applications are forecasts of "blackout storms," detailed qualitative microscale maps, and regional maps of "solar climate" zones.

Research and Development Issues for the Future

Martin Rymes
NREL

Near Future: next 5 years

Far Future: 6 - 20 years

Issues We Share

- Input: data sources
- Process: model refinements
- Validation: correlation with surface measurements
- Output: uniquely satellite-based products

Presentation: R&D Issues for the Future by Martin Rymes, NREL

2nd Workshop on Satellites for Solar Energy Assessments

Research and Development Issues for the Future

Input: Data Sources

Aerosols

Anisotropic Diffuse Sky

Backscattering Ratio

Clouds:
- **Height**
- **Opaque and Translucent Amount**
- **Thickness**

Ozone

Precipitable Water

Snow & Ice

Turbidity

2nd Workshop on Satellites for Solar Energy Assessments

Research and Development Issues for the Future

Sources of Input Data: Today & Near Future

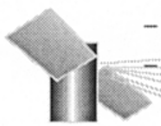
Presentation: R&D Issues for the Future by Martin Rymes, NREL

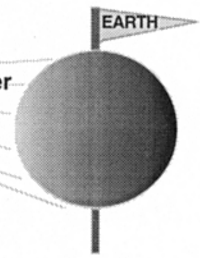
Research and Development Issues for the Future

Sources of Input Data: Far Future

Same satellite makes ALL necessary measurements through multispectral scans

- Ensures space/time coincidence
- BUT must find spectral correlations to:
  - aerosols
  - cloud thickness
  - precipitable water





But what about scattered clouds?
-- Do we use fractals?

Or the 3 GB/day of data?

2nd Workshop on Satellites for Solar Energy Assessments

Research and Development Issues for the Future

Model Refinements: Near Future

- Try to match surface measurements
- Need GOOD surface measurements
- 9 or more surface stations per grid cell
- Soundings located near surface network
- Soundings, surface, satellite at the same time period, not differing years!

Presentation: R&D Issues for the Future by Martin Rymes, NREL

Research and Development Issues for the Future

Model Refinements: Far Future

ASSUME:

- We trust the physics
- We trust the inputs
- We trust the satellite multispectral correlations to inputs

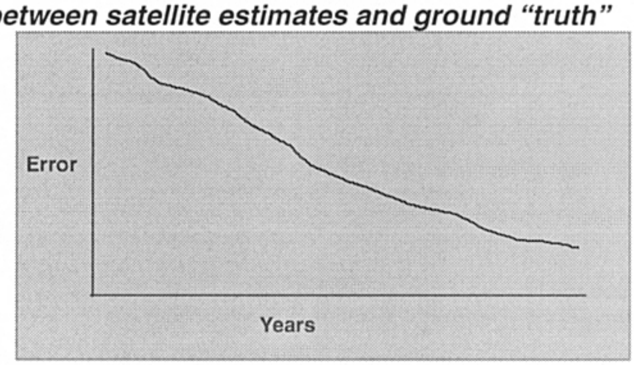
EMPHASIS:

- Proper satellite bandwidths for maximum information extraction
- Image-by-image autocorrelation and trend analysis
- Sophisticated image enhancement techniques

Research and Development Issues for the Future

Correlation with Surface Measurements: Near Future

Researchers will still try to reduce the "error" between satellite estimates and ground "truth"



However, "error" cannot be reduced below 5 intrinsic "nuggets"...

Presentation: R&D Issues for the Future by Martin Rymes, NREL

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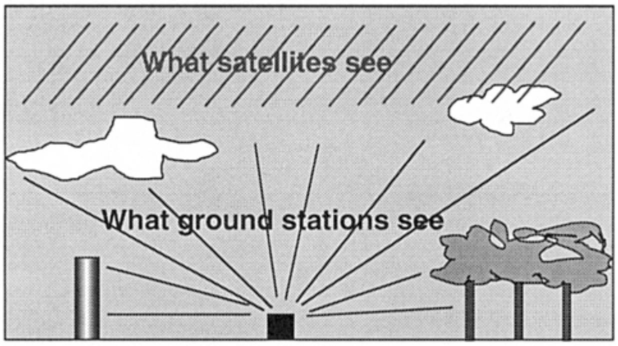
Research and Development Issues for the Future

Correlation with Surface Data: Far Future

Nugget #1: The Field-of-View Problem



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Research and Development Issues for the Future

Correlation with Surface Data: Far Future

Nugget #2: Pixel Noise Problem:

err = k / [(cell size)(time interval)]1/2

NOTE: These Poisson statistics are based ONLY on satellite pixel error.

$$\varepsilon \propto \frac{1}{\sqrt{\Delta A \Delta t}}$$

- **(Cell Dimensions) / 2 = error X 2.**
- **Monthly => Daily = error X 5.**
- **Daily => Hourly = error X 5.**

Presentation: R&D Issues for the Future by Martin Rymes, NREL

2nd Workshop on Satellites for Solar Energy Assessments

Research and Development Issues for the Future

Correlation with Surface Data: Far Future

Nugget #3: Relative-Size Problem
One satellite pixel = vast land area

Nugget #4: Wind Problem
Satellite "snapshots" do not observe changing cloud patterns WITHIN time interval

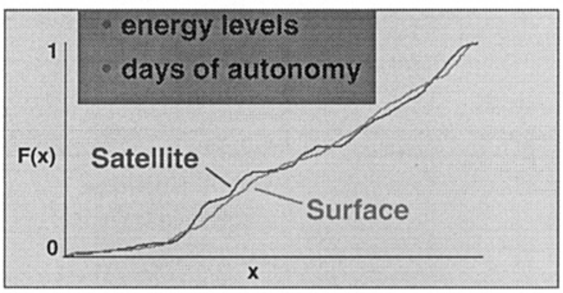
Nugget #5: Ground "Truth" Problem
The best surface measurements have intrinsic uncertainty...but most are not the best!

2nd Workshop on Satellites for Solar Energy Assessments

Research and Development Issues for the Future

Correlation with Surface Data: Far Future

- **Replace time-series matching with correlations that are useful to solar energy community:**
  - **cumulative frequency distributions of:**
    - energy levels
    - days of autonomy



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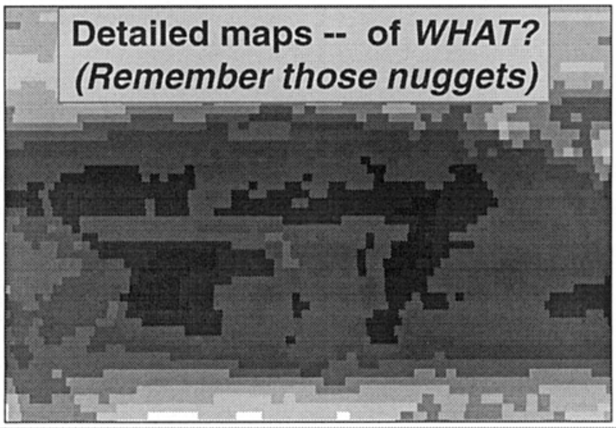
Research and Development Issues for the Future

Uniquely Satellite-Based Products: Near Future



2nd Workshop on Satellites for Solar Energy Assessments

Research and Development Issues for the Future

Uniquely Satellite-Based Products: Near Future

Solar Weather Forecasting

- Prediction of blackout days
- "Choppy" clouds -- bad for solar thermal systems
- Rough estimates of available solar energy

Benefits:

- Plant shutdowns are anticipated
- Hybrid switchovers are planned
- Home use: "careful" days are scheduled

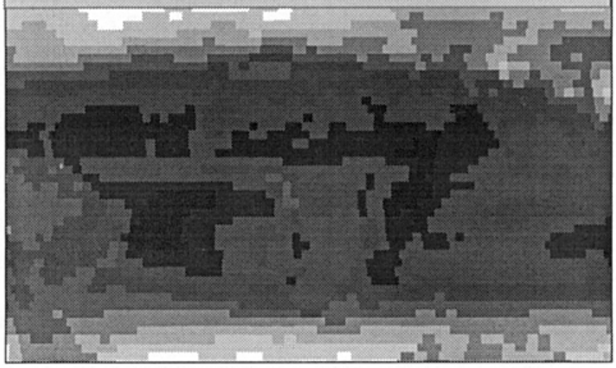
Presentation: R&D Issues for the Future by Martin Rymes, NREL

2nd Workshop on Satellites for Solar Energy Assessments

Research and Development Issues for the Future

Uniquely Satellite-Based Products: Far Future

Detailed "space truth" solar energy maps



2nd Workshop on Satellites for Solar Energy Assessments

Research and Development Issues for the Future

Uniquely Satellite-Based Products: Far Future

"Weather Channel" Solar Forecasts

- Widely available on common television stations
- As accurate as standard meteorological forecasts
- Up to 5 days projected
- Creates consumer "solar awareness"

Presentation: R&D Issues for the Future by Martin Rymes, NREL

Research and Development Issues for the Future

Uniquely Satellite-Based Products: Far Future

Detailed "Solar Climate" Maps

- 20 - 200 standard zones based on:
  - seasonal monsoons
  - monthly diurnal cycles
  - clear / scattered clouds / cloudy
  - topography, elevation, & latitude
  - precipitable water
- 1 km resolution

2nd Workshop on Satellites for Solar Energy Assessments

Research and Development Issues for the Future

Uniquely Satellite-Based Products: Far Future

Detailed "Solar Climate" Maps

- Static zones aid in domestic, industrial, and utility planning, similar to:
  - soil maps
  - topographic maps
  - water maps
- Measurement and research stations will be deployed in unknown zones

Presentation: R&D Issues for the Future by Martin Rymes, NREL

Research and Development Issues for the Future

Far Future: The Death of the Surface Measurement Network?

NO.

- **People live on the Earth. "Space truth" will never replace "ground truth."**
- **Satellite weather forecasts are always supplemented with the local weather station. Solar is no different.**
- **New satellite-based methods require new surface-based measurements and networks.**

Research and Development Issues for the Future

CONCLUSIONS

Near Future:

- Surface provides most input data
- Surface determines truth
- Satellite-derived products are spatially detailed clones of surface products

Far Future:

- Satellite provides most input data
- Satellite determines truth
- Satellite-derived products radically different from surface products
- Surface stations provide validation and "reality" link

Presentation: R&D Issues for the Future by Martin Rymes, NREL

Future prospects in Satellite data use for solar energy and daylight : information for environmental, R&D and marketing activities

Marc Fontoynont
ENTPE - National Engineeringg School of State Public Works
Department of Civil Engineering and Building Sciences
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Marc.Fontoynont@entpe.fr

Satellites have demonstrated their reliability and accuracy and they can be considered as a reasonable alternative to produce data on solar energy and daylight by comparison with measurement campaigns conducted at ground level.

These data can be considered as a strategic information for activities requiring :

- quick access to data file
- quick decision making
- quick sizing of system
- quick production of maps

But the real challenge today stands in the use of communication technology to deliver the information with a format well adaptated to the users. The future of the satellite data processing depends on our ability to process the data far beyond the only delivery of climatic parameters. There is a potential to include in the data processing task the simulation of systems (solar systems, building components and controls, indoor and outdoor environmental behaviour, etc.) in order to produce more strategic design parameters expressed in size, power, optical performance and of course Euros or dollars.

Our practice of research activities with the industry and design groups has allowed us to identify a whole field of activities where research laboratories involved in climatic data assessment would have the responsability to process and adapt these data so that they can be used on a regular basis.

Our presentation will demonstrate some case studies where the satellite derived data could be used on an every day basis. They have been selected in fields such as city planning, window design, shading material design, controls, photovoltaics, optical systems for the building, agriculture, etc.

Future prospects in satellite data use for solar energy and daylight

Marc Fontoynont

Light and Radiation Group, ENTPE, Lyon, France

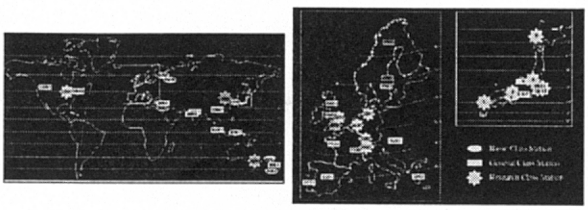
What is the future ?

What was the future ?

The future was: coordinate ground measurements

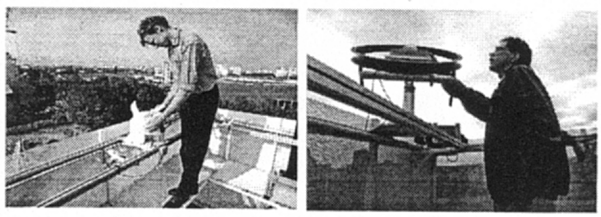
The future was: deliver data wordwide from satellite or ground measurement using modern communication technology (web servers and CD-ROM)

The future was: coordinate ground measurements



International Daylight Measurement Programme, 1998
50 ground stations, server developed and managed by by D. Dumortier, ENTPE
http://www.idmp.entpe.fr

Which confidence in large networks of ground stations?



Solar Radiation and Daylight Measurement maintenance and quality control

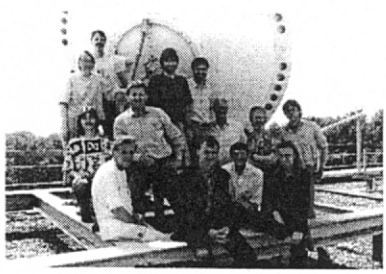
The future was: deliver data wordwide from satellite or ground measurement using modern communication technology (web servers and CD-ROM)

Satellight

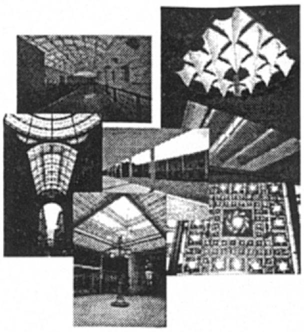
Commission of the European Communities

Programme EC-DGXII-JOULE
January 1996 - March 1999
Delivery March 1999

European Server of Solar Radiation and Daylight Data



M. Fontoynont, D. Dumortier (Coordination) - *Ecole Nationale des Travaux Publics de l'Etat, Vaulx-en-Velin, France*
L. Roche - *Building Research Establishment, Garston, United Kingdom*
J.A. Olseth, A. Skartveit - *Geophysical Institute, University of Bergen, Bergen, Norway*
C. Reise - *Fraunhofer Institut für Solare Energiesysteme, Freiburg, Germany*
P. Ineichen - *Group of Applied Physics, Geneva, Switzerland*
J. Page - *Expert for the European Commission, Sheffield, United Kingdom*
L. Wald - *Ecole Nationale Supérieure des Mines de Paris, Sophia-Antipolis, France*
D. Heinemann, A. Hammer - *University of Oldenburg, Oldenburg, Germany*
H.G. Beyer - *University of Magdeburg, Magdeburg, Germany*



Fields of applications:

Architecture & building engineering

Glazing technology

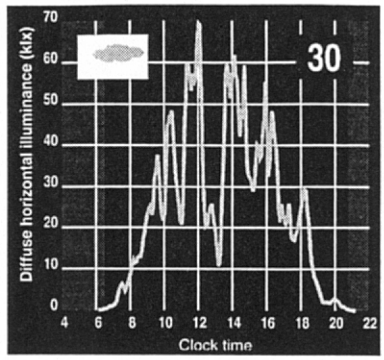
City planning issues, daylight access

Input data for softwares Energy demand

Parameters for controls

Solar systems,Agriculture

Requirement 1: supply information on variability



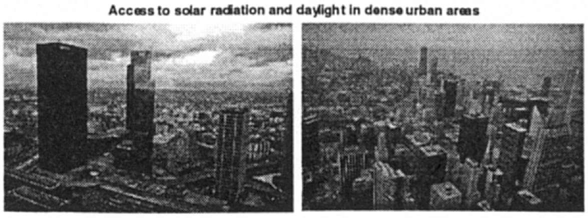
Requirement 2 : Cover continuously Western and Central Europe

Zone du programme Satellight

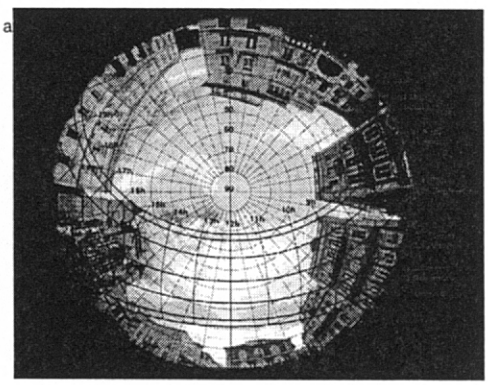
Review of specifications regarding the type of data to be supplied by a web-server of solar radiation and daylight.

Example in daylighting applications

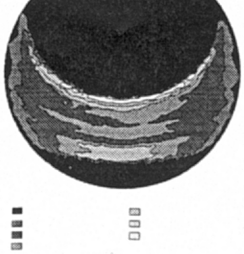
Access to solar radiation and daylight in dense urban areas



Solar a

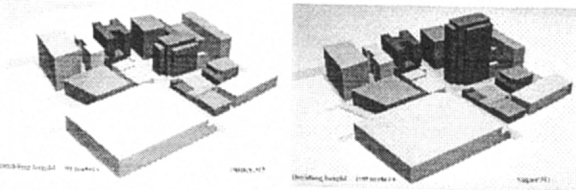


Solar access / climatic



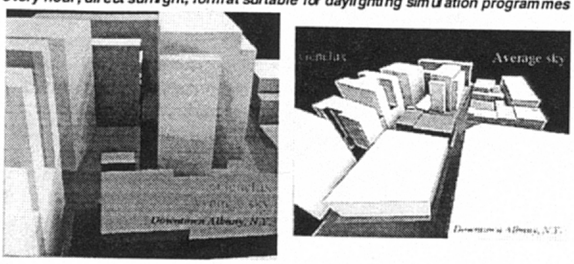
Annual average
of luminance
around sun
for lighting
simulations

Study conducted by ENTPE, ASRC, Doyle Mc Cutchen San Francisco)

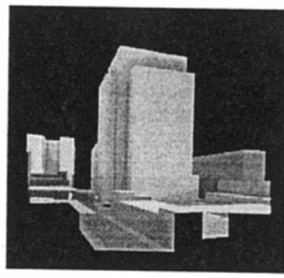


Assessment of the financial impact related to the construction
of a high rise building in downtown Albany, N.Y. :
Impact on <u>annual lighting consumption and rental rates</u>

Need for illuminances probabilities, sky luminances distributions, every hour, direct sunlight, format suitable for daylighting simulation programmes



Optical simulations with genelux-web, climatic data from ASRC.



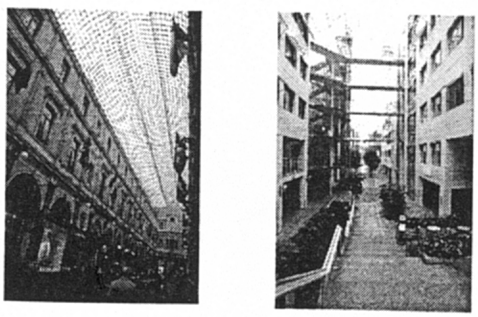
Impact on the annual lighting consumption of neighbouring office buildings:

- **+ $ 12,500 per year (height 50 m)**
- **+ $ 20,000 per year (height 100m)**

Impact on rental value :

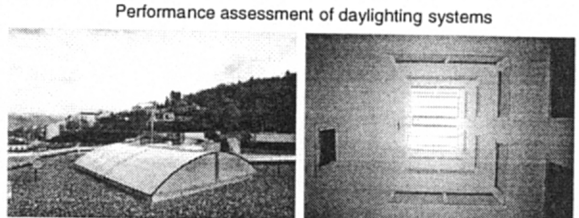
- **- $ 130,000 per year (height 50 m)**
- **- $ 200,000 per year (height 100 m)**

Access to daylight in dense urban areas: design and city planning rules

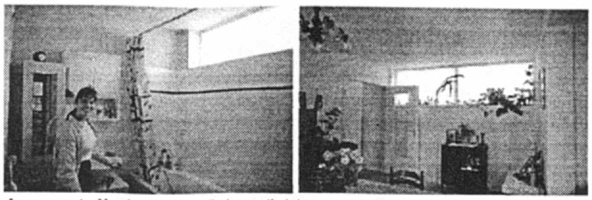


Hours per year of access to daylight and sunlight

Performance assessment of daylighting systems

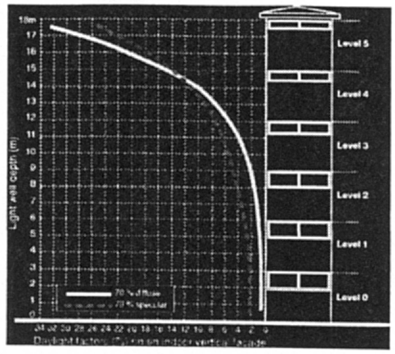


Puits de lumière, Unieux, Loire

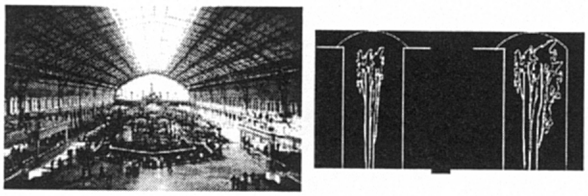


Assessment of luminous fluxes (lm) supplied by secondary daylighting systems at each level
Monthly and annual sums (lumen.hours) Probabilities to exceed illuminances indoor.

Selection of finish in lightwell and window size variations
Climatic data required: frequencies of zenith luminances

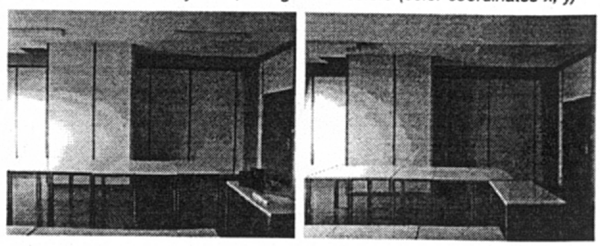


Growing of plants indoor, Photomorphism



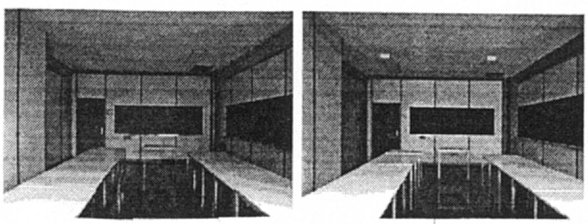
Directionnality of daylight (global irradiances and illuminances)
Integrated values

Input data for lighting softwares and computer graphics:
Luminances of the sky vault, sunlight and colors (color coordinates x, y)



Réality

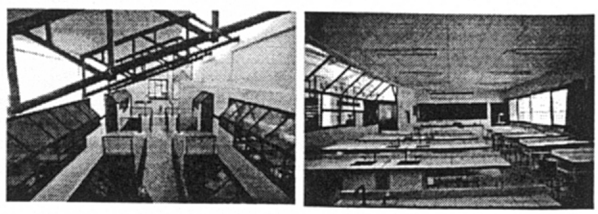
YART / LISSE
ENTPE-ESMSE



Reality

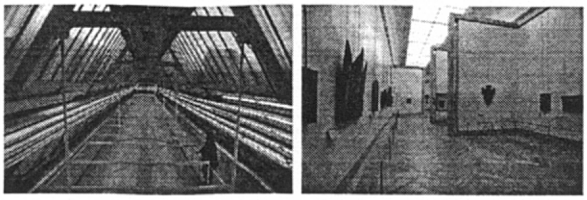
YART / LISSE
ENTPE-ESMSE

For predesign: frequencies of diffuse horizontal illuminances, color temperatures
For software calculations: sky luminances



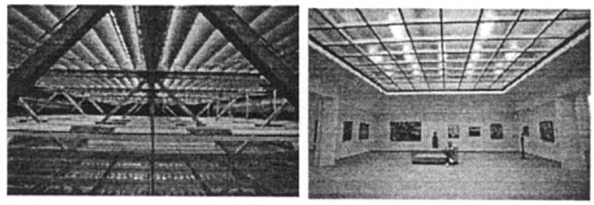
Collège de Modane

Light box design: probabilities of global illuminances on tilted glazings, color of incoming daylight.
Shading design and control: probabilities of global illuminances on tilted glazings
All information within schedule of occupancy



Salle des Sept Mètres, Musée du Louvre, Paris

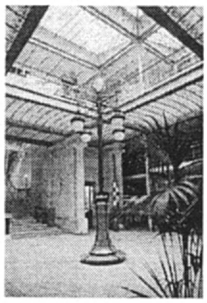
Design of system, management of fins position

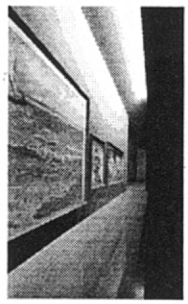


Neue Staatsgalerie, Stuttgart

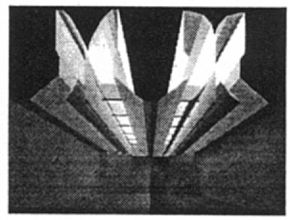
Hours of efficient daylighting?

Waucquez department store, Brussels



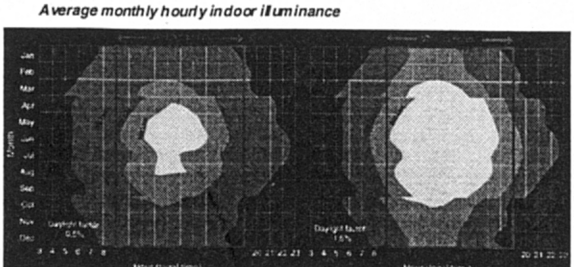


Musée de Grenoble



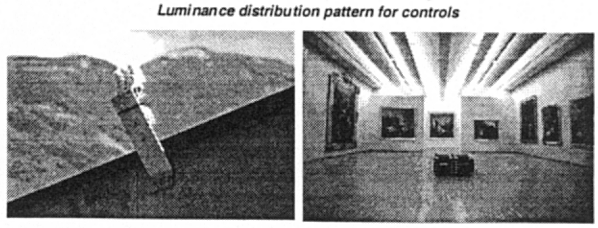
Role of aperture design and finishes

Average monthly hourly indoor illuminance



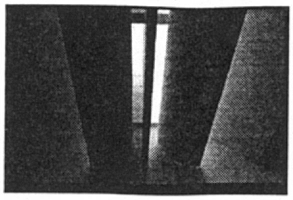
Daylight strategy: minimum daylight factor, shading issues as a function of the occupancy.

Luminance distribution pattern for controls



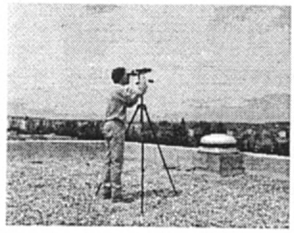
Musée de Grenoble

Color temperature, xy coordinates, spectral distribution

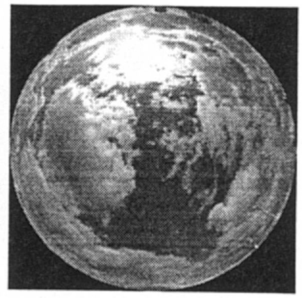


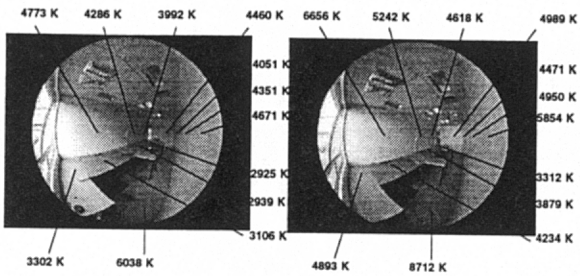
Musée de Grenoble

Vitrages Interpane



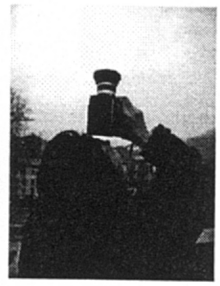
Mesures spectrales, ENTPE



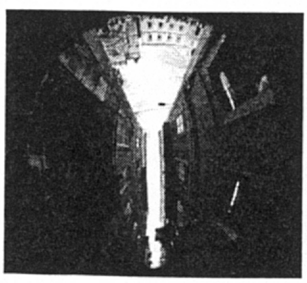


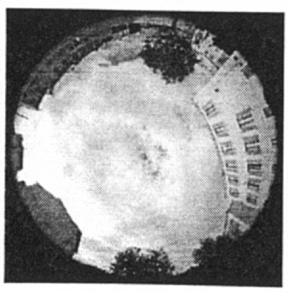
Températures de couleur à l 'intérieur d 'un local

Need for distribution of luminances on the sky vault:
Essential for daylighting applications

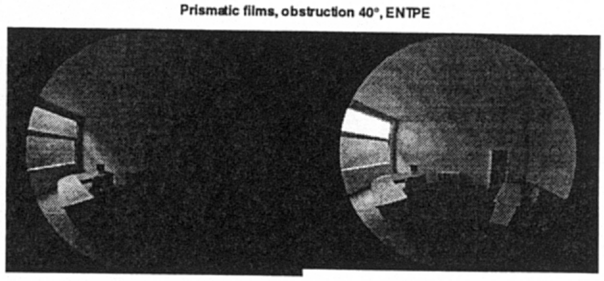


On site control of luminances for monitoring





Prismatic films, obstruction 40°, ENTPE

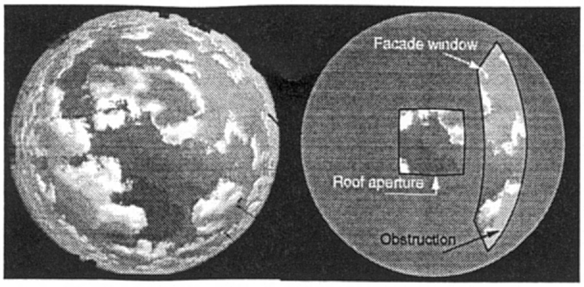


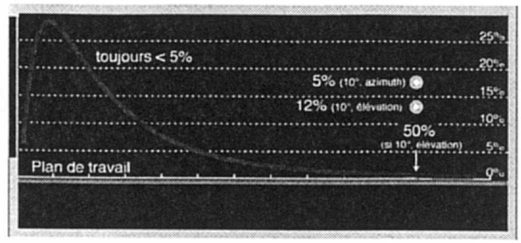
Reference

With prismatic film, NPL*

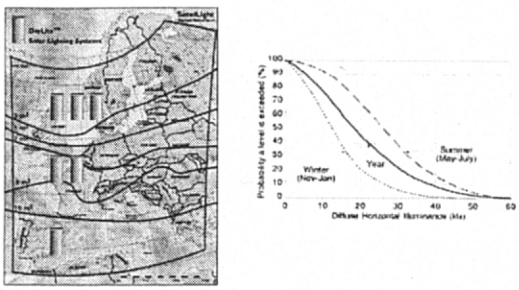
Luminance of product, glare

* National Physical Laboratory





Tests de sensibilité avec le logiciel Genelux



Direct industrial application: sizing parameters with respect to climate and use

Structure of data bases needed for applications in solar energy and daylighting:

1. A climatic data base

2. System parameters

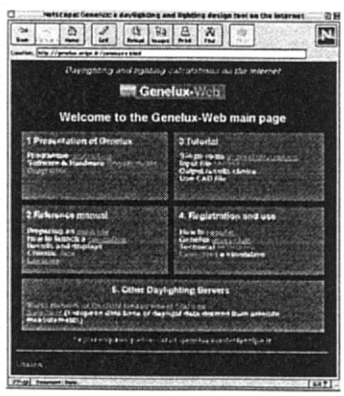
3. Use parameters (profiles, etc.)

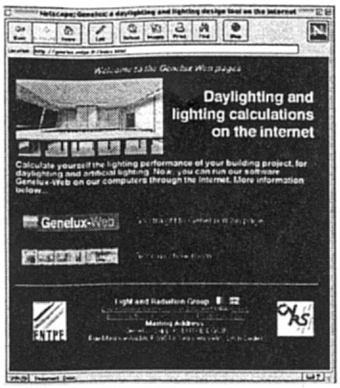
Example in Daylighting:

1. Illuminances, luminances and color information every 30 minutes

2. Optical simulation of the geometry and photometry (data base of materials)

3. Well known schedules, lighting requirements





The future of climatic data bases:

Relate data base to <u>applications</u> (adapt precision to problem)
Express climatic sensitivity in terms of <u>size, cost, performances indices</u>
(see presentation of Richard Perez)

Create <u>links</u> with software users and the industry

Create tools for <u>rapid decision</u> making

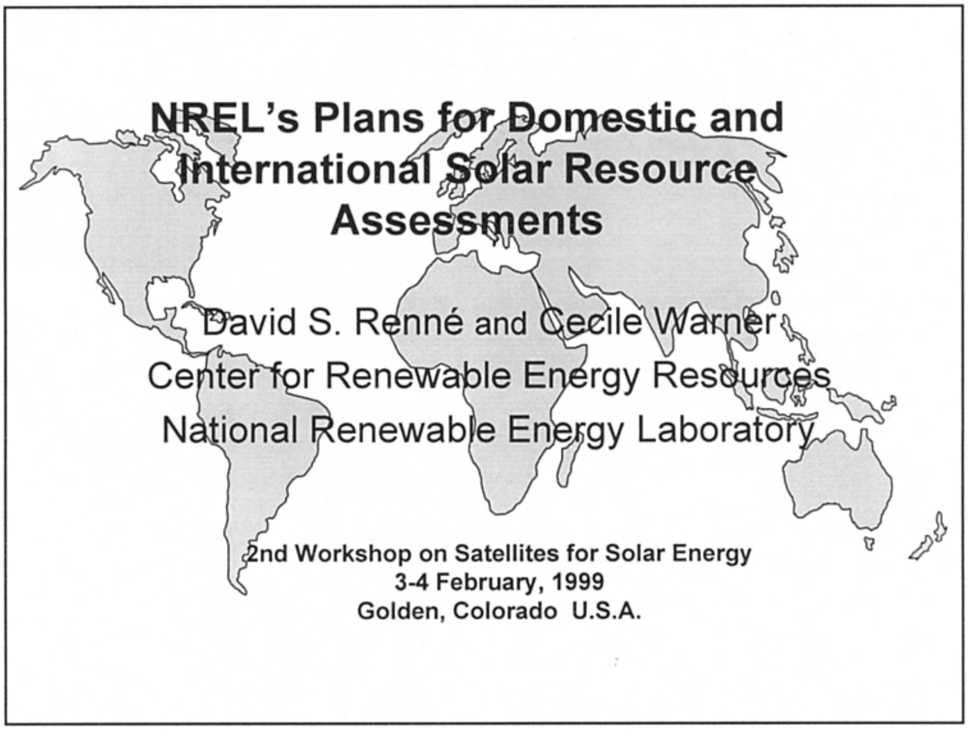
Ease <u>product marketing</u> activities worwide in the field of solar energy related activities

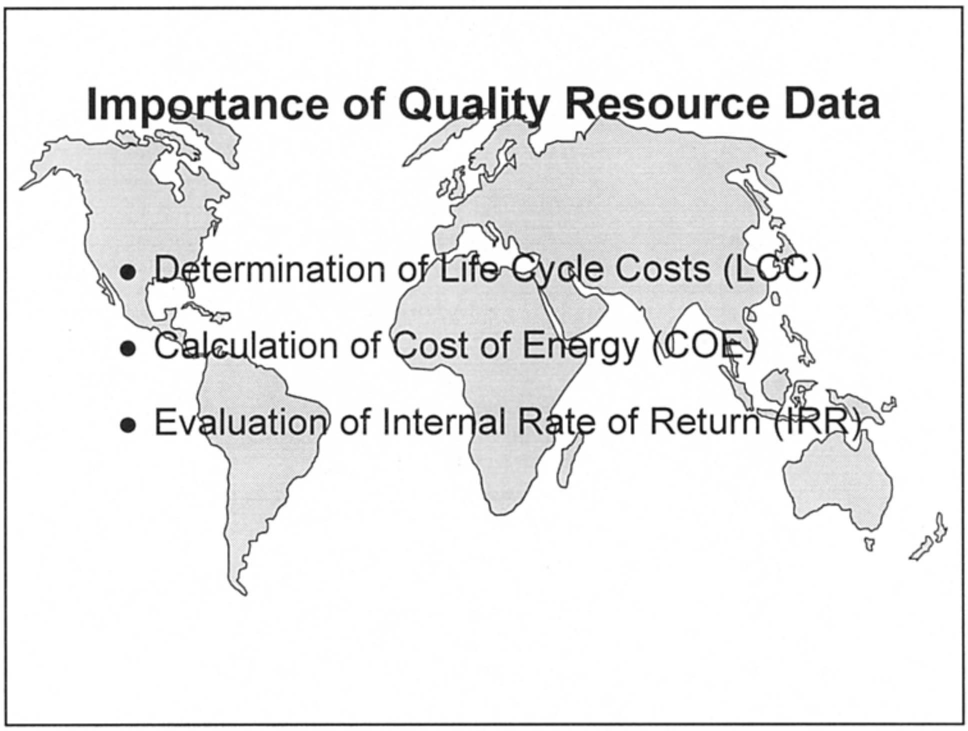
NREL's Plans for Domestic and International Solar Resource Assessments

Dave Renné and Cecile Warner
and
The NREL Solar Resource Measurement and Assessment Team*
National Renewable Energy Laboratory
Golden, Colorado U.S.A.

Over the past several years the National Renewable Energy Laboratory's Solar Resource Assessment Team has focused its efforts on three primary areas: (1) development and implementation of quality measurement activities; (2) development of tools for mapping large area solar resource assessments and 3) development and dissemination of products for the U.S. industry and governmnet planners. In (1) we continue operation of the Solar Radiation Research Laboratory in Golden, support to a national measurement program, and development of data quality assessment software. In (2) we develop and support research in modeling approaches and the use of Geographic Information Systems for displaying and analyzing results of large-area assessments. In (3) we develop refined solar resource products such as Typical Meteorological Year data sets, and distribute all of our products through media such as the Renewable Resource Data Center Web site, and an internet-based interactive Map Server. With our primary support coming from National Center for Photovoltaics, funded by the U.S. Department of Energy, we anticipate that our work will continue down these three paths, and that our collaborations with other agencies and organizations such as universities and the National Aernautics and Space Administration, will be strengthened. Partnerships such as these allow us to leverage signficant public investments in satellite and data archiving techniques so that we can all work together in providing the renewable energy industry with the best possible products for expanding U.S. and world-wide deployments of solar technologies.

*In alphabetical order: Mary Anderberg, Afshin Andreas, Liz Brady, Ted Cannon, Ray George, Pamela Gray-Hann, Beverly Kay, Bill Marion, Daryl Myers, Ibrahim Reda, Martin Rymes, Tom Stoffel, Jim Treadwell, Steve Wilcox.





Presentation: NREL's Plans by Dave Renne and Cecile Warner, NREL

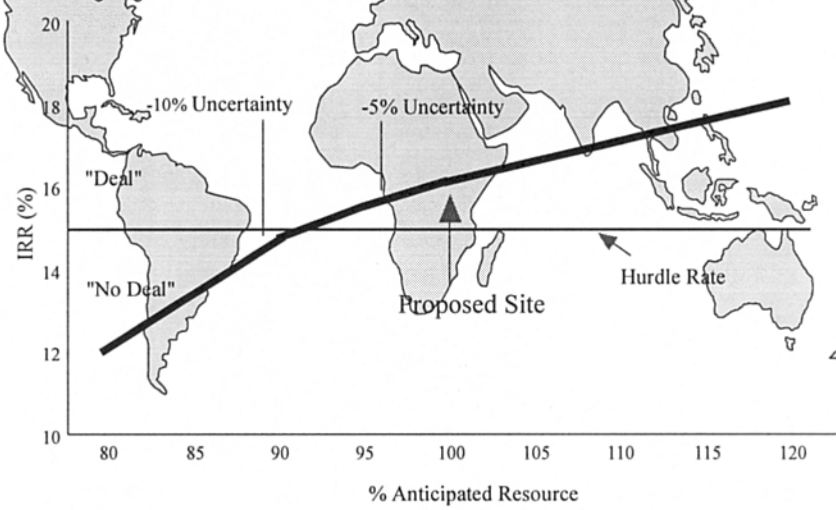
LCC: Total Lifetime Cost of System Designed to Meet Specific Load

LCC = f(Initial Costs + O&M Costs + Major Repairs + Fuel Costs - Salvage Value)

Initial Costs = f(System Size to Meet Loads)

System Size = f(Resource)

The Role Of Resource Data in Investor Decisions



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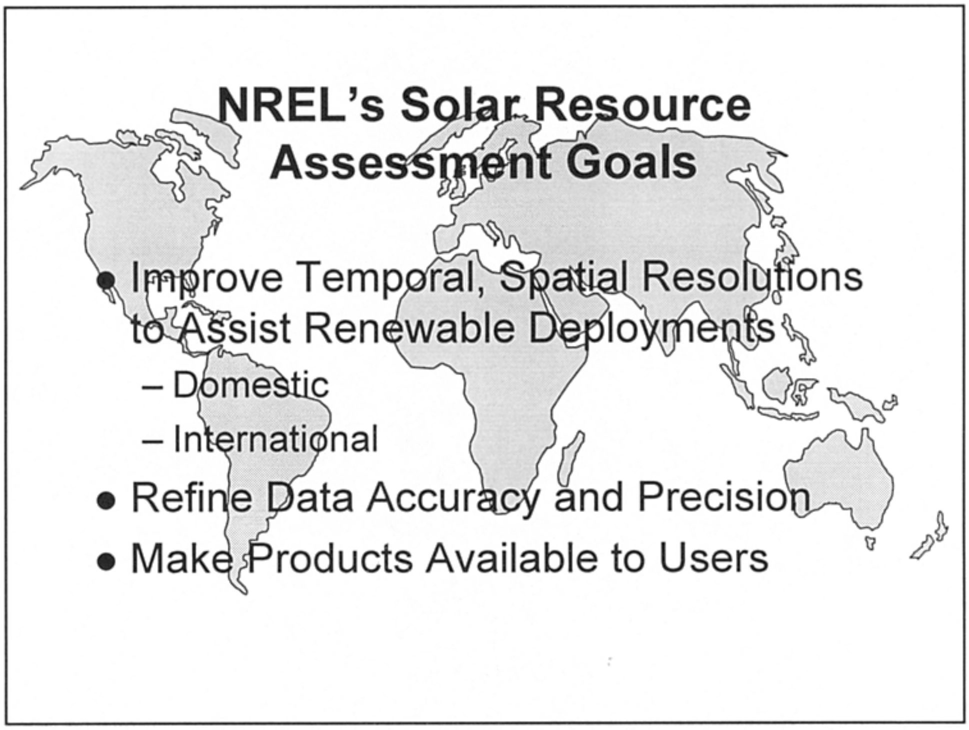

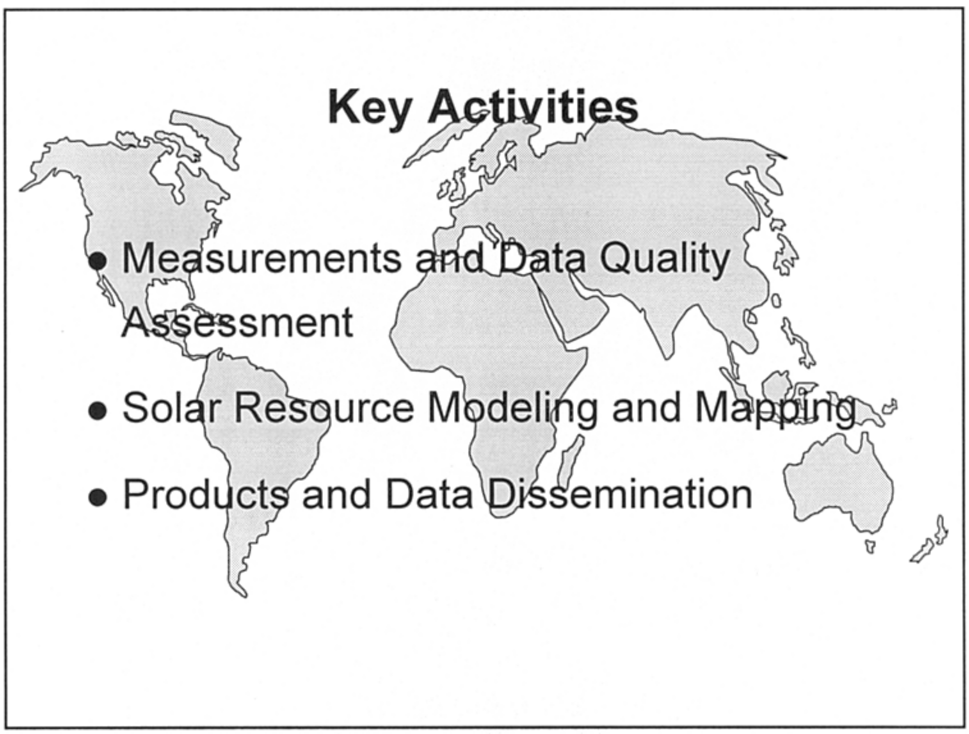

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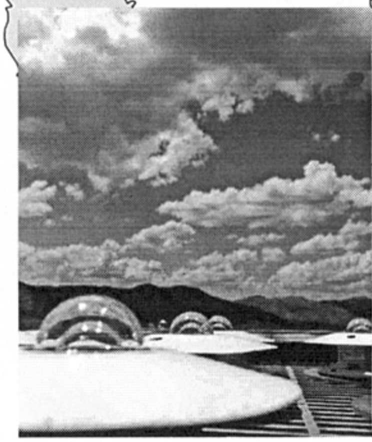
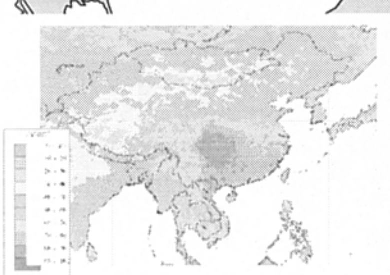
Measurement Activities



- Solar Radiation Research Laboratory
  - Measurement System Testing
  - Calibrations
- Support to National Measurement and Research Programs
- Data Quality Assessments

Solar Resource Mapping

Percent Cloud Cover: Annual



- CSR Model Applications
- GIS Analysis
- Collaborations
  - NASA/LaRC
  - Universities
  - International Satellite Researchers

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Products and Dissemination

- Data Products (TMY's, Manuals, Maps)
- Renewable Resource Data Center

  http://rredc.nrel.gov
- GIS Internet-Based Map Server
- GIS Analyses

Future Plans

- Refine Resource Mapping Capabilities
- Develop Products for Specific Applications and Technologies
  - Grid-connected systems
  - Off-grid systems
- Provide GIS-Based Analyses
- Disseminate Products through RReDC, Map Server

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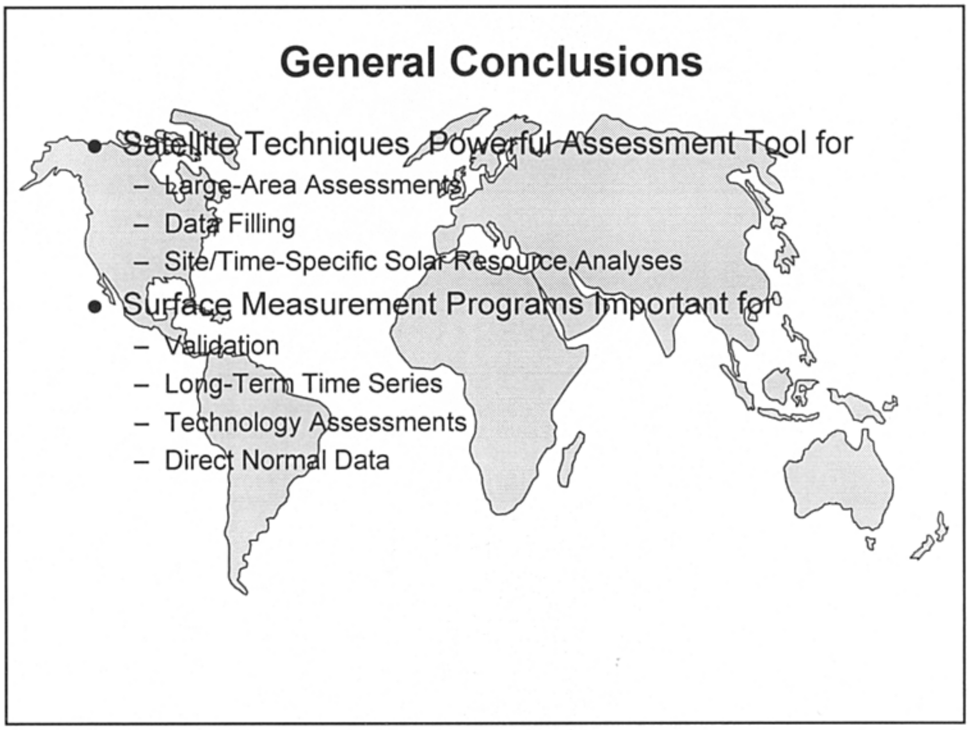

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