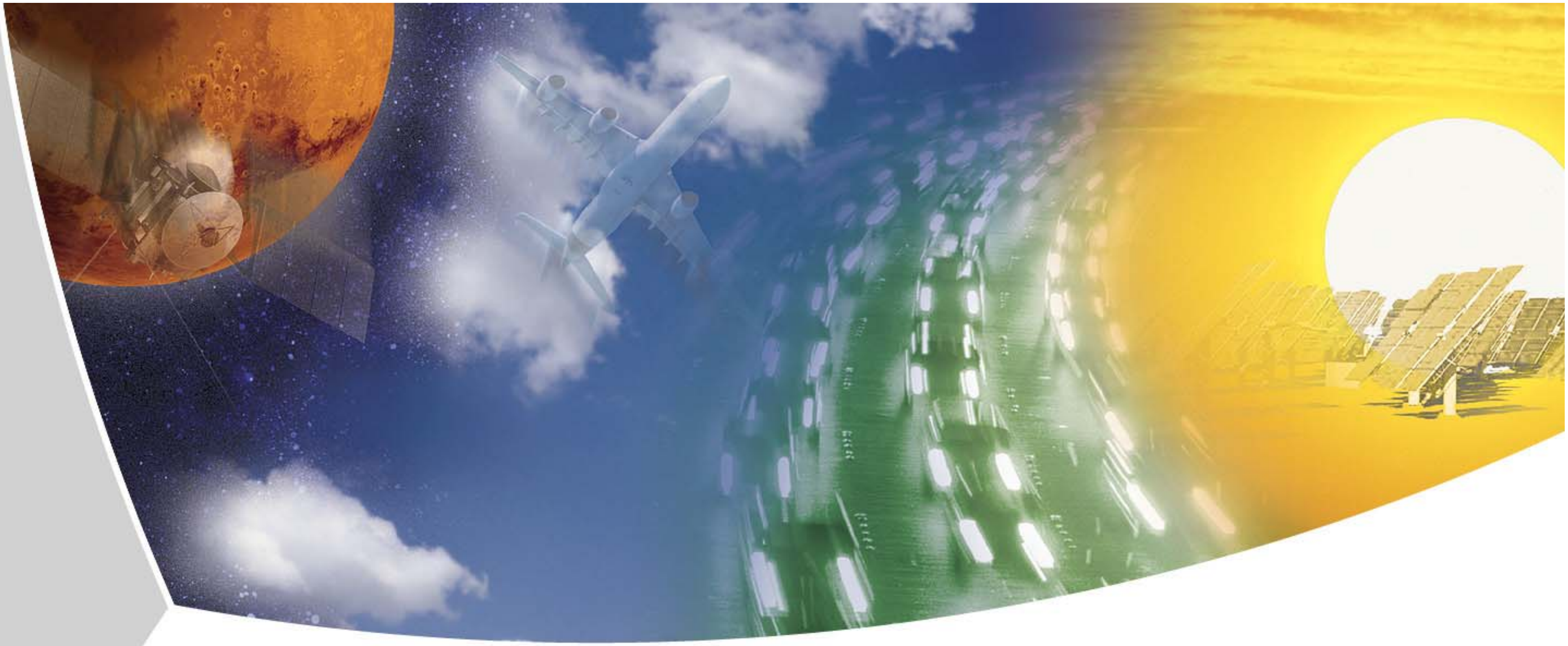


How to get bankable meteo data?

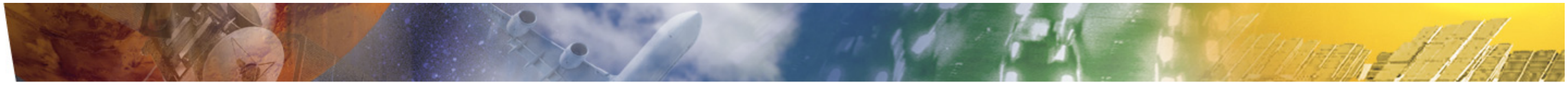
DLR solar resource assessment

Robert Pitz-Paal,
Norbert Geuder, Carsten Hoyer-Klick, Christoph Schillings

DLR Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

Solar resource assessment for solar power plants

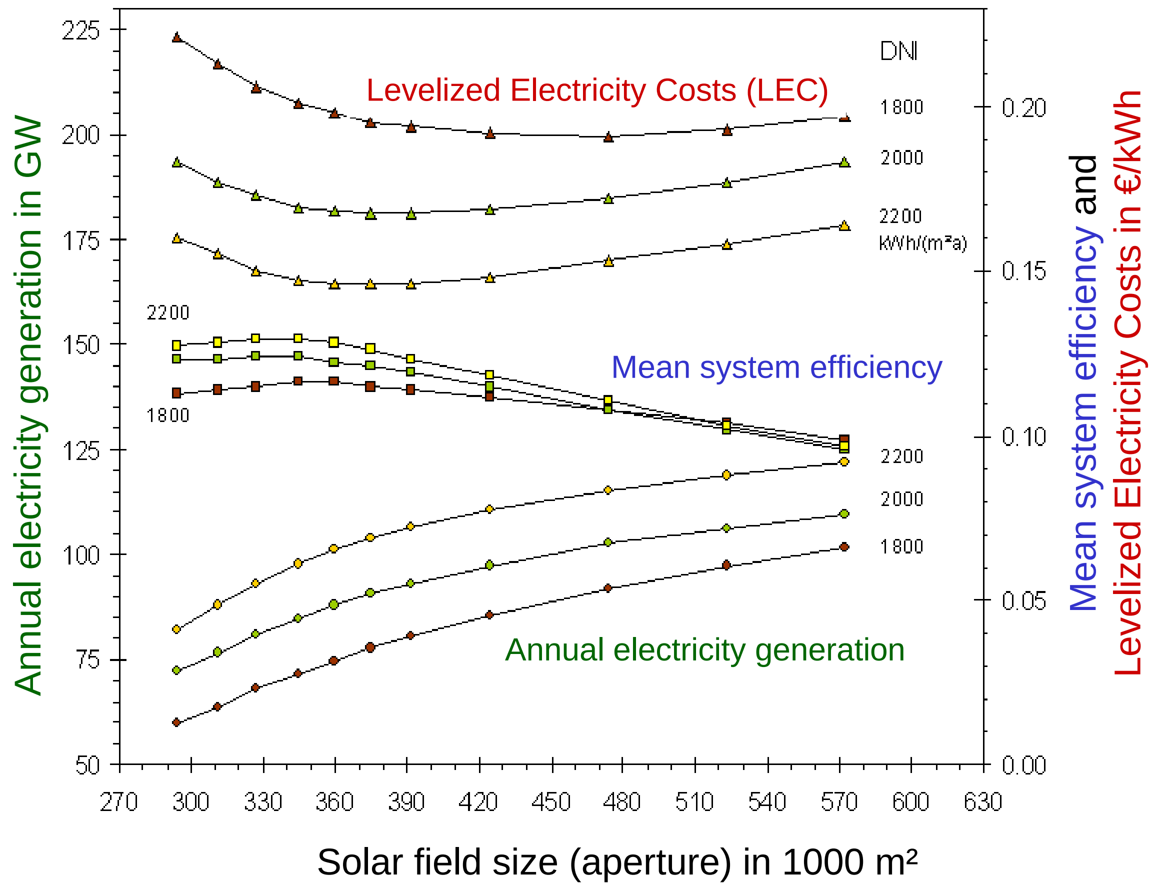
- Why solar resource assessment ?
- Characteristics of solar irradiation data
- DLR solar resource assessment:
  - ground measurements
  - satellite data
  - How to get bankable meteo data?
- Summary



Why is exact knowledge of the solar resource so important?

- High impact of the annual irradiation on the LEC
  - Irradiation is a crucial parameter for **site selection** and **plant design** and **economics** of plant

50 MW Parabolic Trough solar thermal power plant



Characteristics of solar irradiation data

What kind of irradiation data is needed?

- **Type:**
  - **DNI (Direct-Normal Irradiation)**
  - GHI (Global-Horizontal Irradiation)
  - DHI (Diffus-Horizontal Irradiation)
- **Source:**
  - ground measurements
  - satellite data
- **Properties of irradiation:**
  - spatial variability
  - inter annual variability
  - long-term drifts

Ground measurements vs. satellite derived data

Ground measurements

Advantages

+ high accuracy *(depending on sensors)*
+ high time resolution

Disadvantages

- high costs for installation and O&M
- soiling of the sensors
- sometimes sensor failure
- no possibility to gain data of the past

Satellite data

Advantages

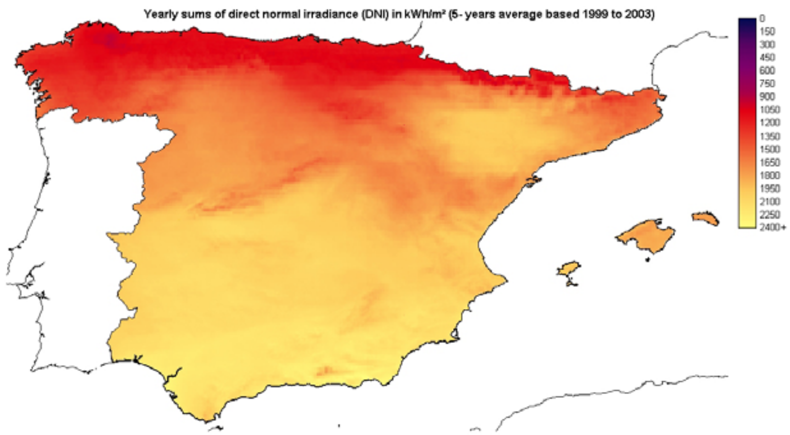
+ spatial resolution
+ long-term data *(more than 20 years)*
+ effectively no failures
+ no soiling
+ no ground site necessary
+ low costs

Disadvantages

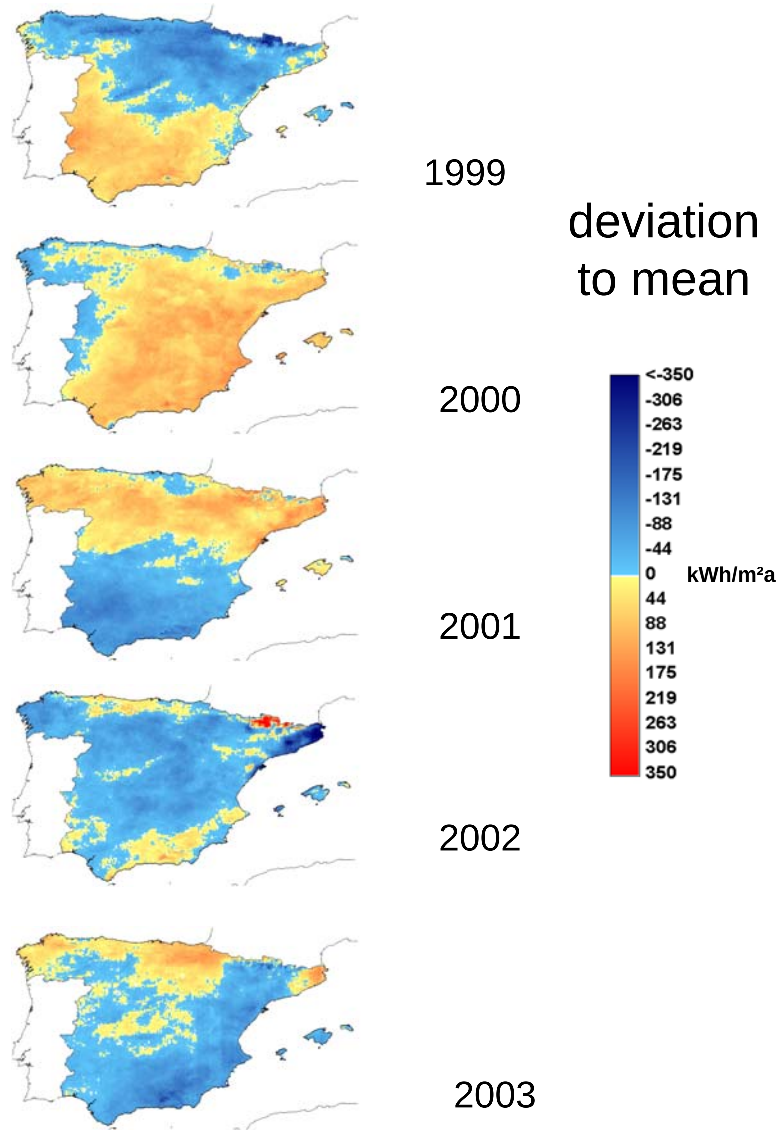
- lower time resolution
- low accuracy in particular at high time resolution

Inter annual variability

- Strong inter annual and regional variations

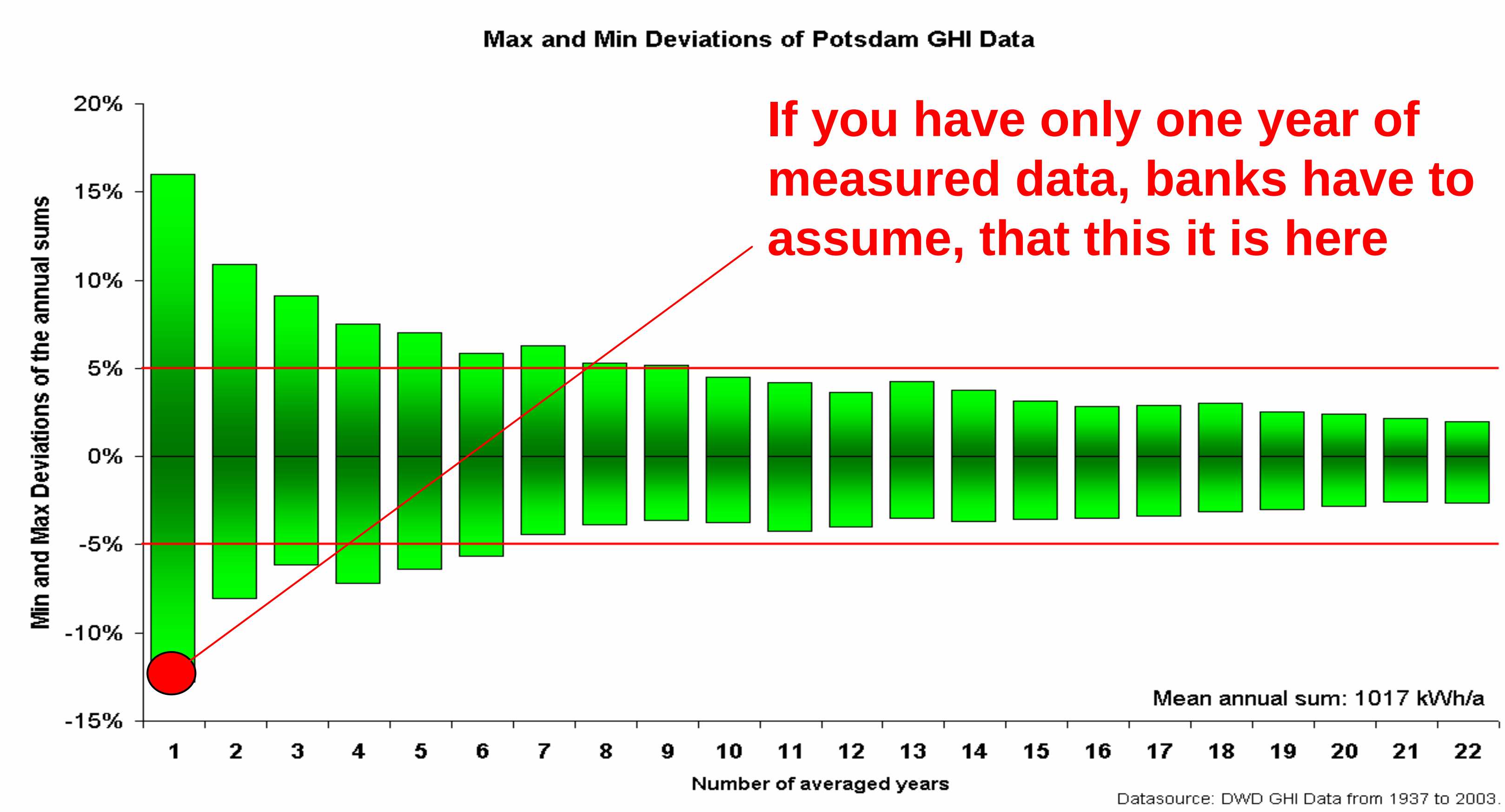


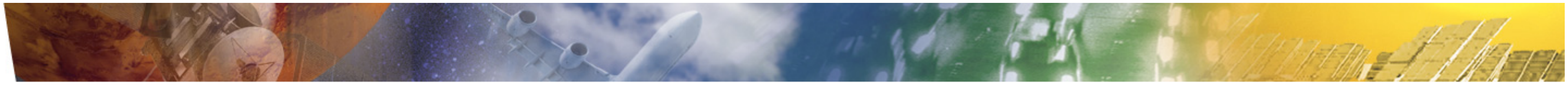
Average of the direct normal irradiance from 1999-2003



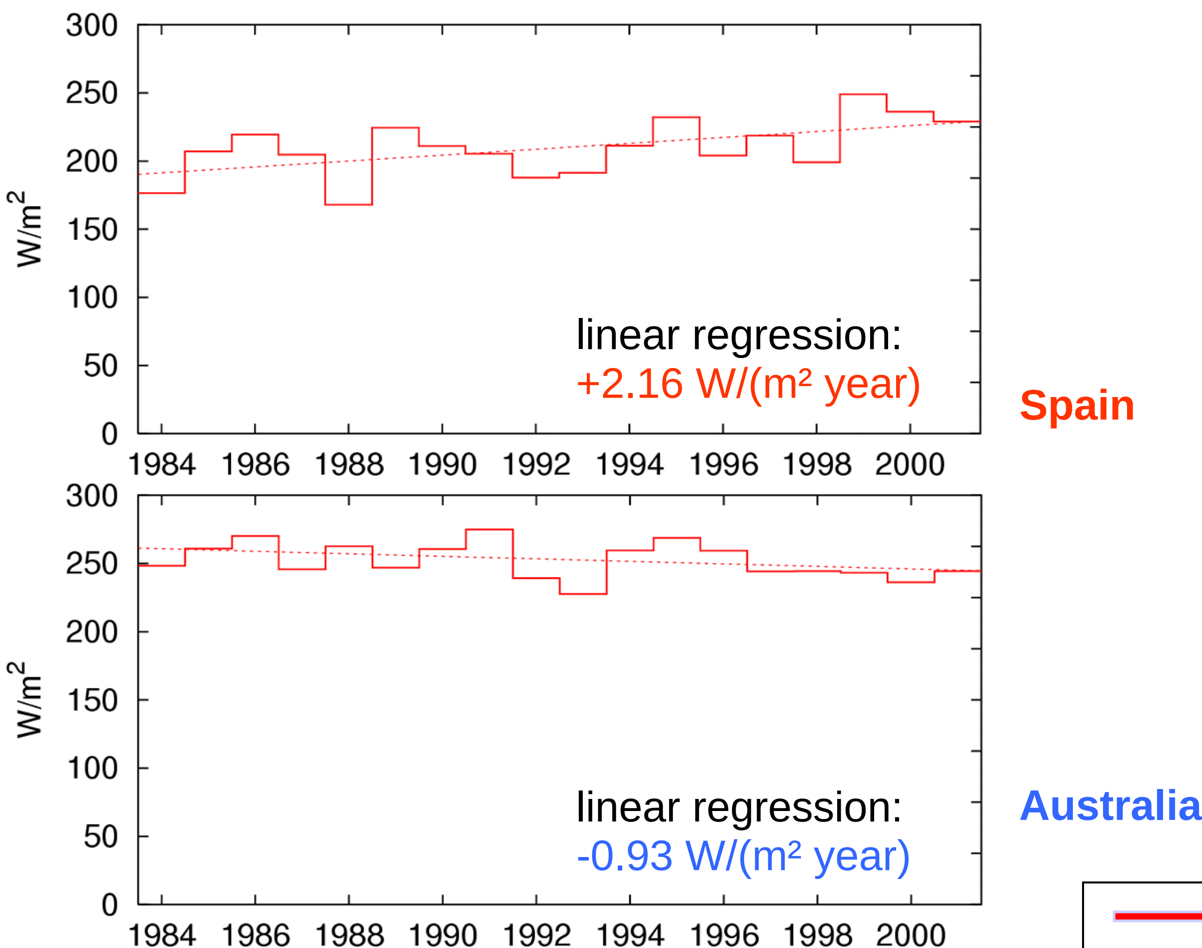
Long-term variability of solar irradiance

- 7 to 10 years of measurement to get long-term mean within 5%





Time series of annual direct normal irradiance



➚ **Long-term tendency**
may exist and
differs from site to site

How to get bankable Meteo Data?

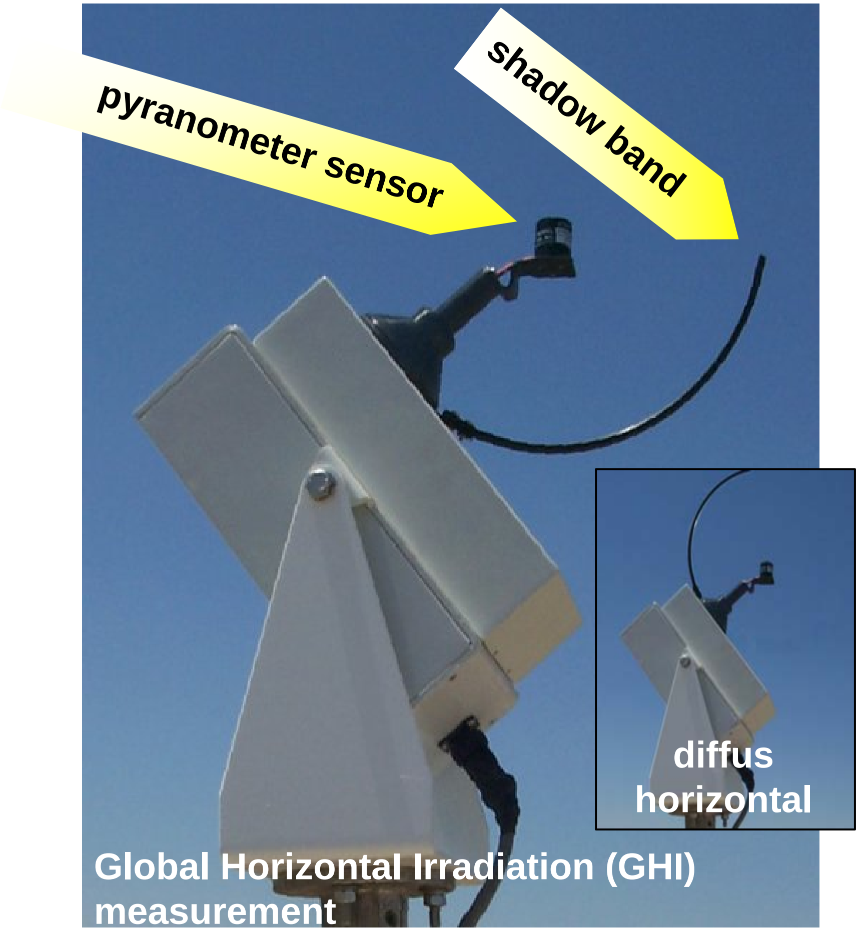
- Quality checked **ground measurements** to gain highly **accurate data**
- Derivation of irradiation from **satellite data** to get
  - **spatial distribution** and
  - **long-term time series**

Validation of the satellite data with accurate ground data

Result: accurate hourly time series, irradiation maps and long-term annual mean

Instrumentation for unattended abroad sites:

Rotating Shadowband Pyranometer (RSP)



Sensor: Si photodiode

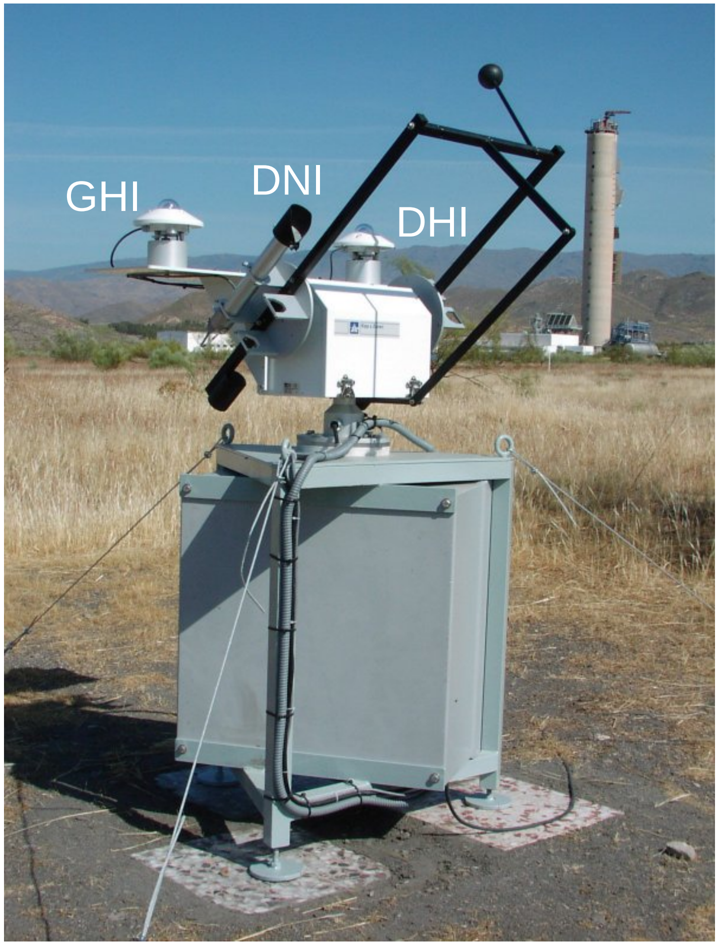
Advantages:

+ fairly acquisition costs
+ small maintenance costs
+ low susceptibility for soiling
+ low power supply

Disadvantage:

- special correction for good accuracy necessary *(established by DLR)*

Precise sensors *(also for calibration of RSP)*:



Thermal sensors:
pyranometer and pyrheliometer,
precise 2-axis tracking

Advantage:

+ high accuracy

+ separate GHI, DNI and DHI sensors
(cross-check through redundant measurements)

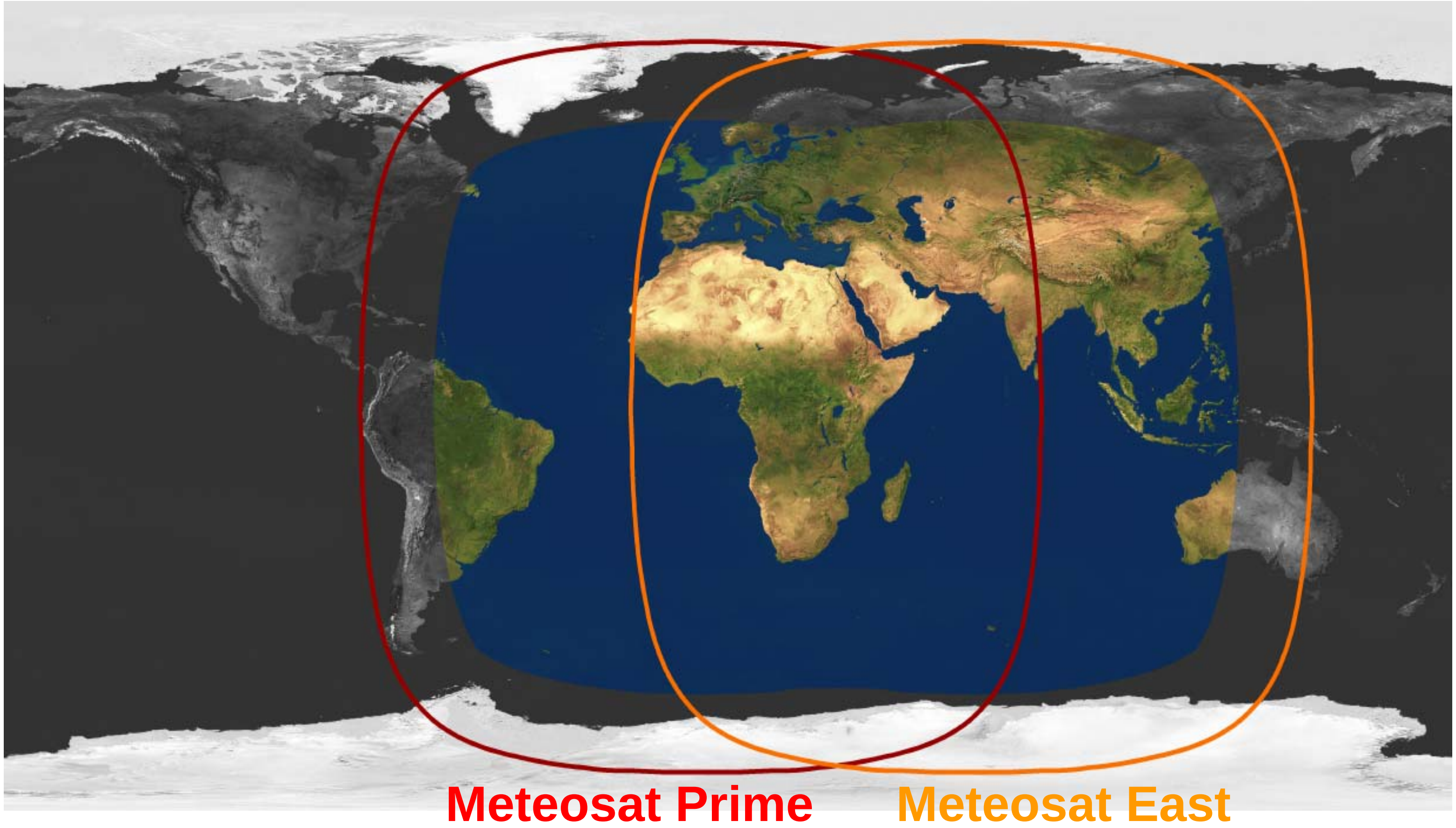
Disadvantages:

- high acquisition and O&M costs

- high susceptibility for soiling

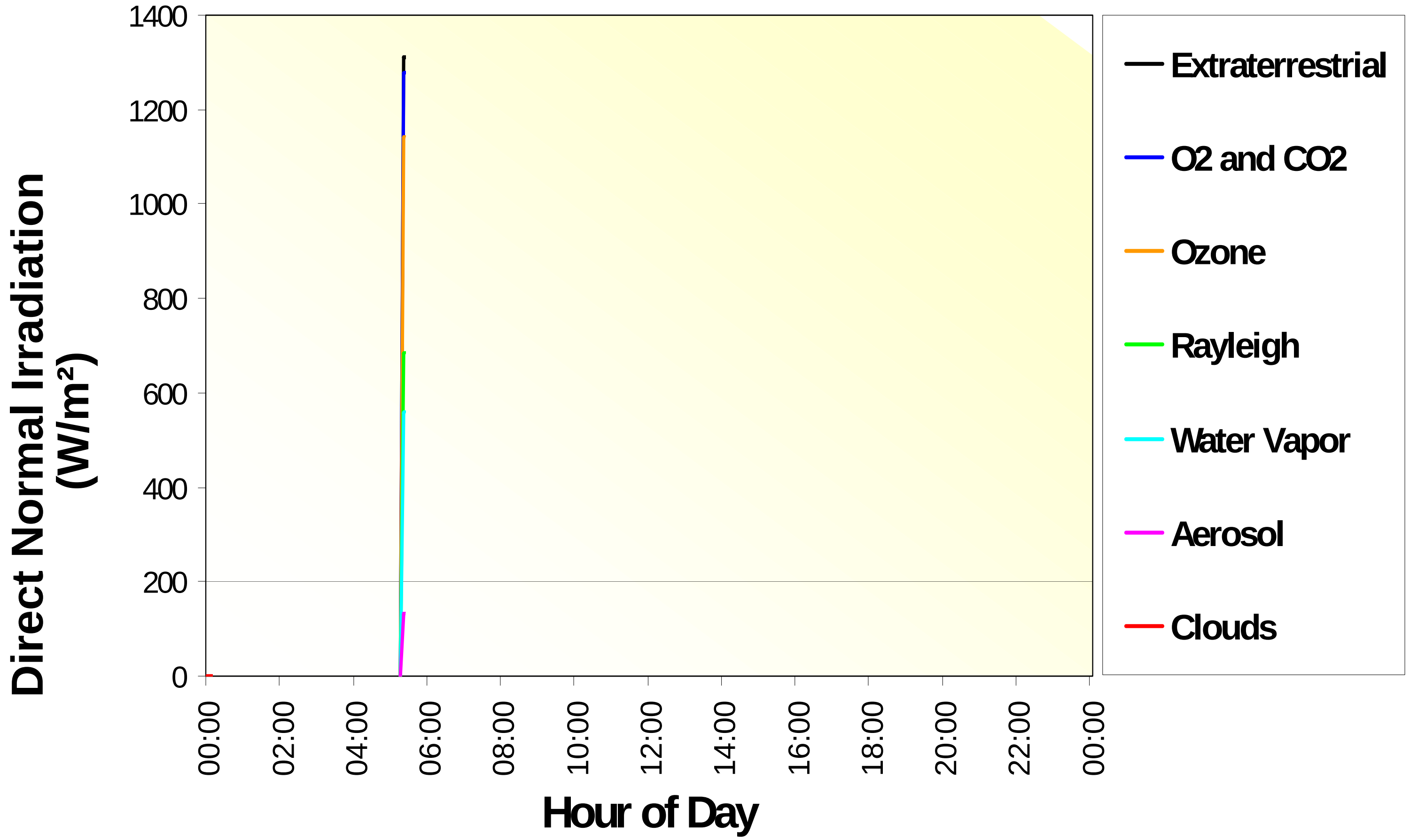
- high power supply

Satellite data: SOLEMI – Solar Energy Mining



- SOLEMI is a service for high resolution and high quality data
- Coverage: Meteosat Prime up to 22 years, Meteosat East 10 years (in 2008)

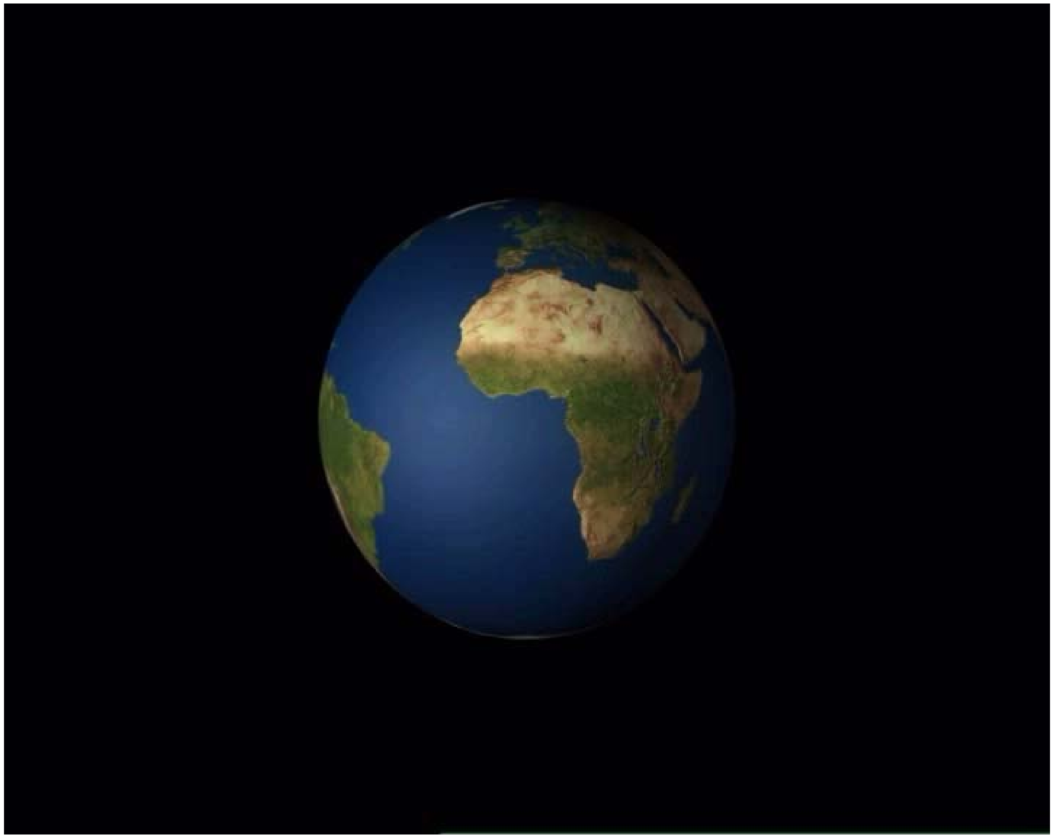
Radiative Transfer in the Atmosphere



How two derive irradiance data from satellites

- The Meteosat satellite is located in a geostationary orbit
- The satellite scans the earth line by line every half hour

How two derive irradiance data from satellites



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- The earth is scanned in the visible …

How two derive irradiance data from satellites

- The Meteosat satellite is located in a geostationary orbit
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- The earth is scanned in the visible and infra red spectrum

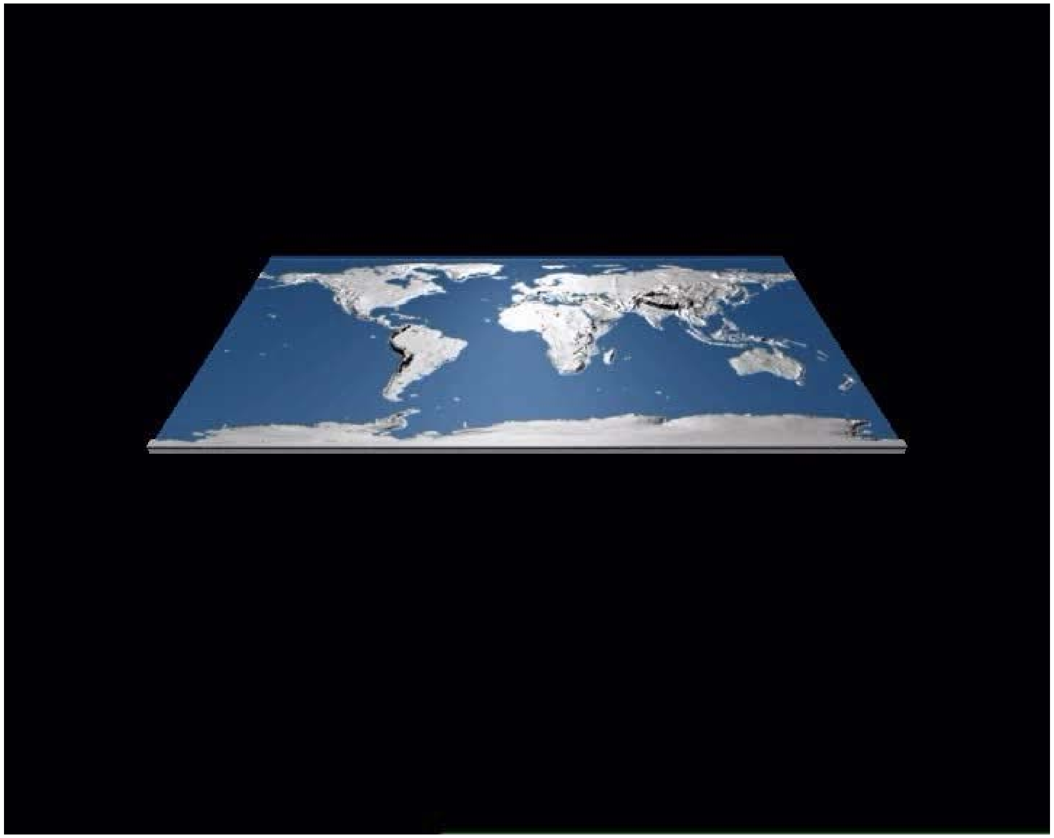
How two derive irradiance data from satellites

- The Meteosat satellite is located in a geostationary orbit
- The satellite scans the earth line by line every half hour
- The earth is scanned in the visible and infra red spectrum
- A cloud index is composed from the two channels

How two derive irradiance data from satellites

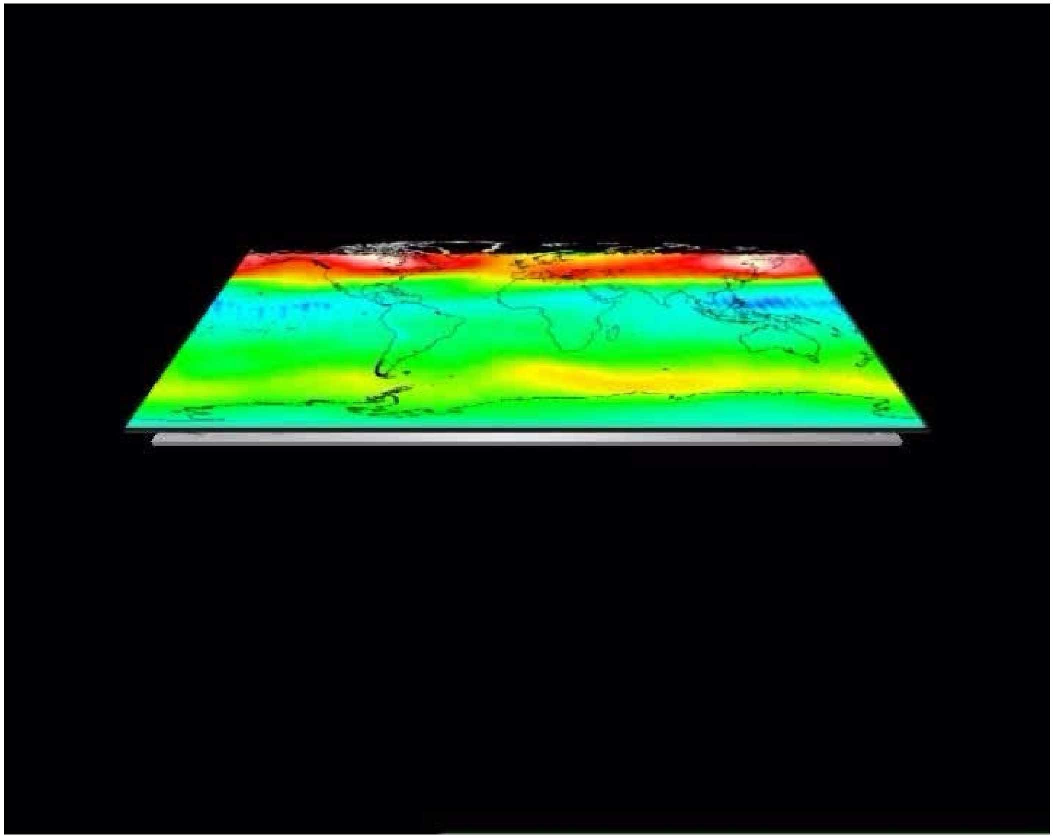
- Atmospheric transmission is calculated from global data sets
  - elevation

How two derive irradiance data from satellites



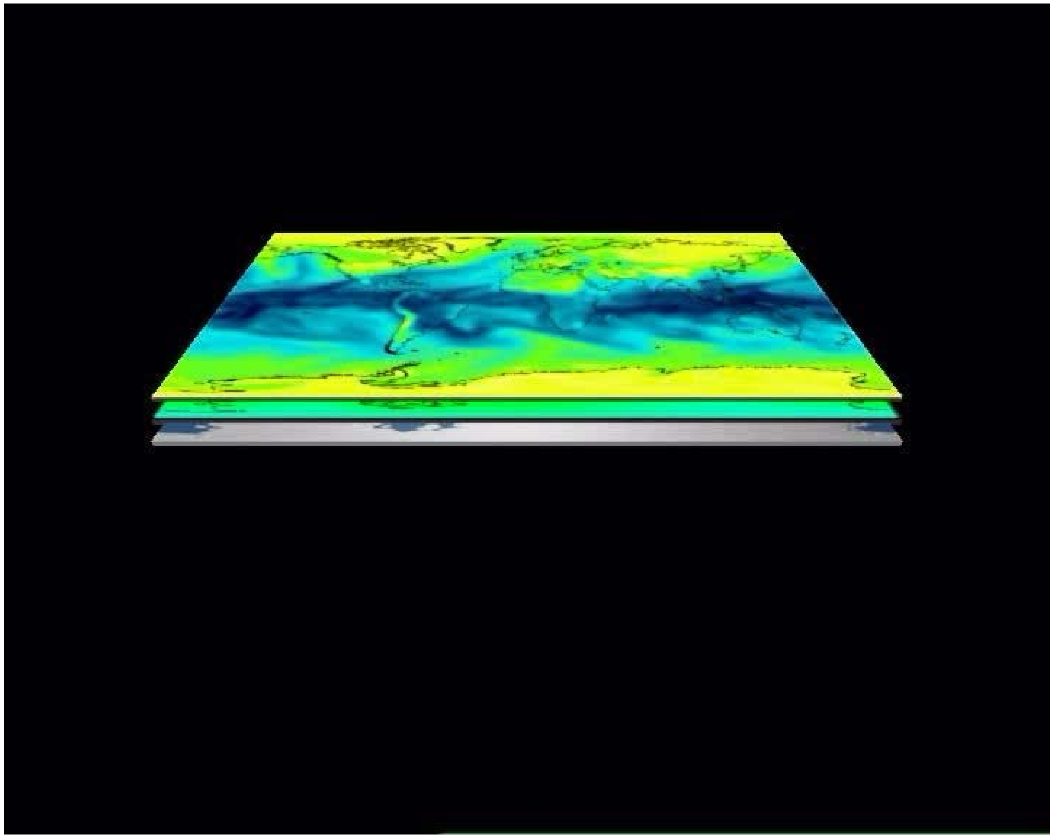
- Atmospheric transmission is calculated from global data sets
  - elevation
  - ozone

How two derive irradiance data from satellites



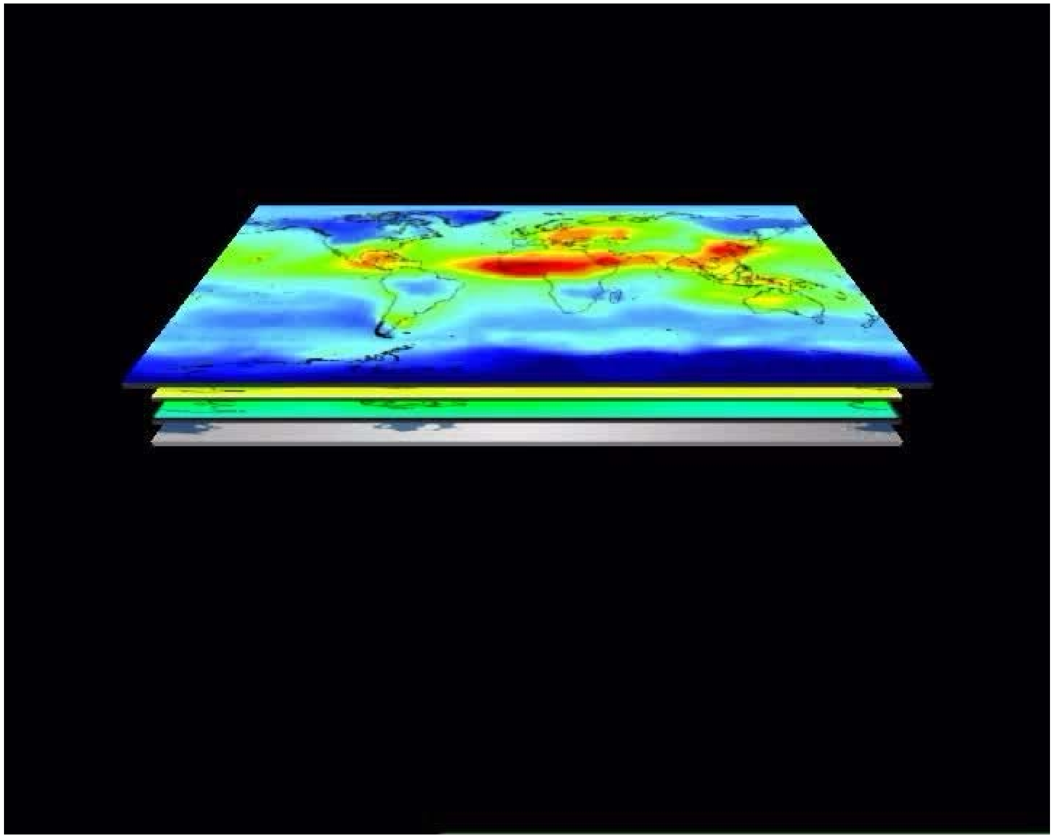
- Atmospheric transmission is calculated from global data sets
  - elevation
  - ozone
  - water vapor

How two derive irradiance data from satellites



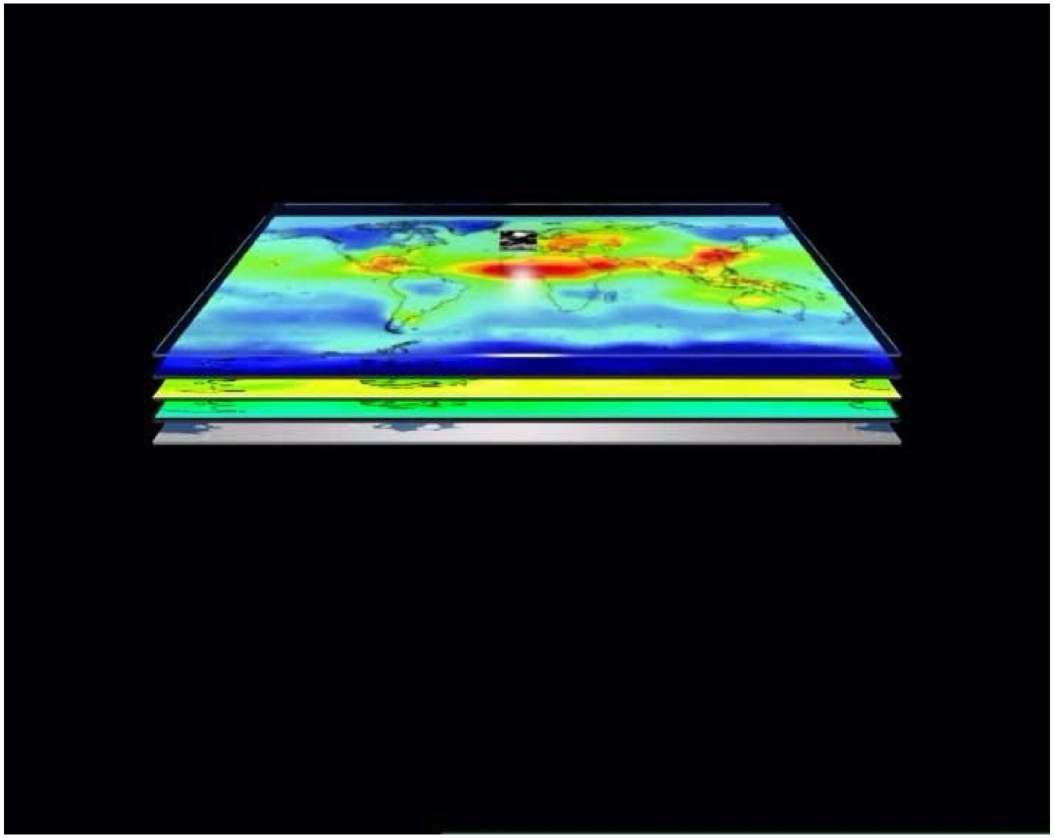
- Atmospheric transmission is calculated from global data sets
  - elevation
  - ozone
  - water vapor
  - aerosols

How two derive irradiance data from satellites



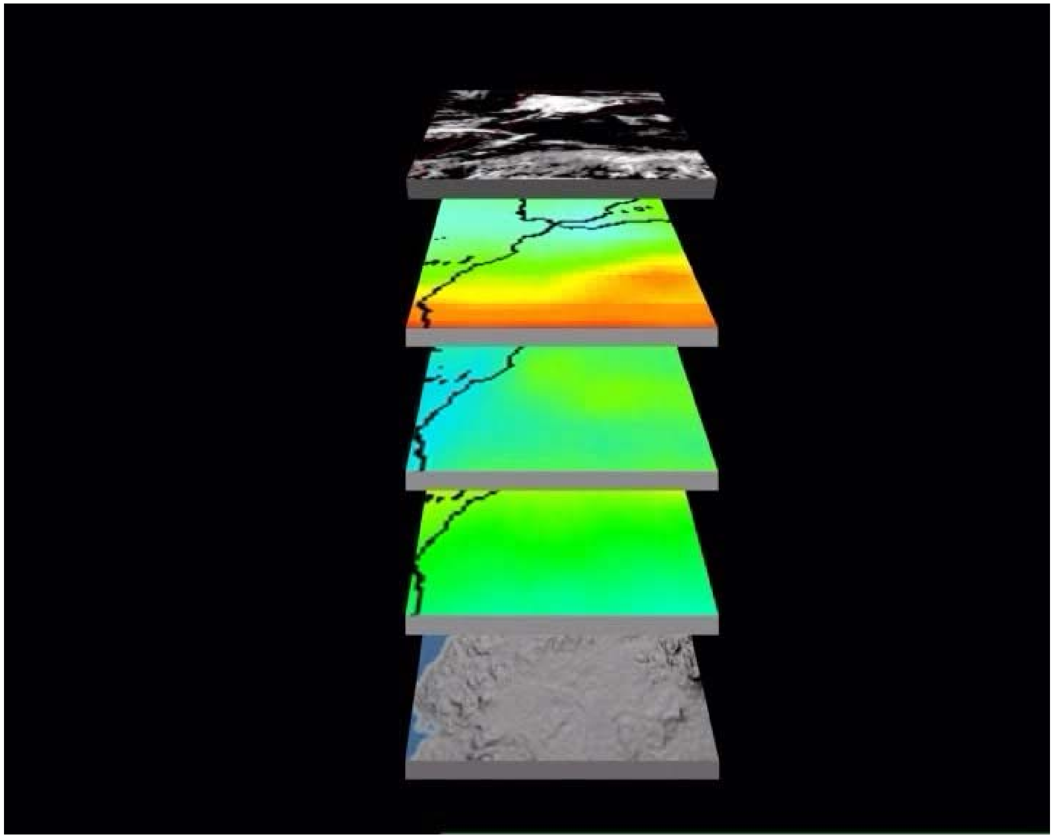
- Atmospheric transmission is calculated from global data sets
  - elevation
  - ozone
  - water vapor
  - aerosols
- The cloud index is added for cloud transmission

How two derive irradiance data from satellites



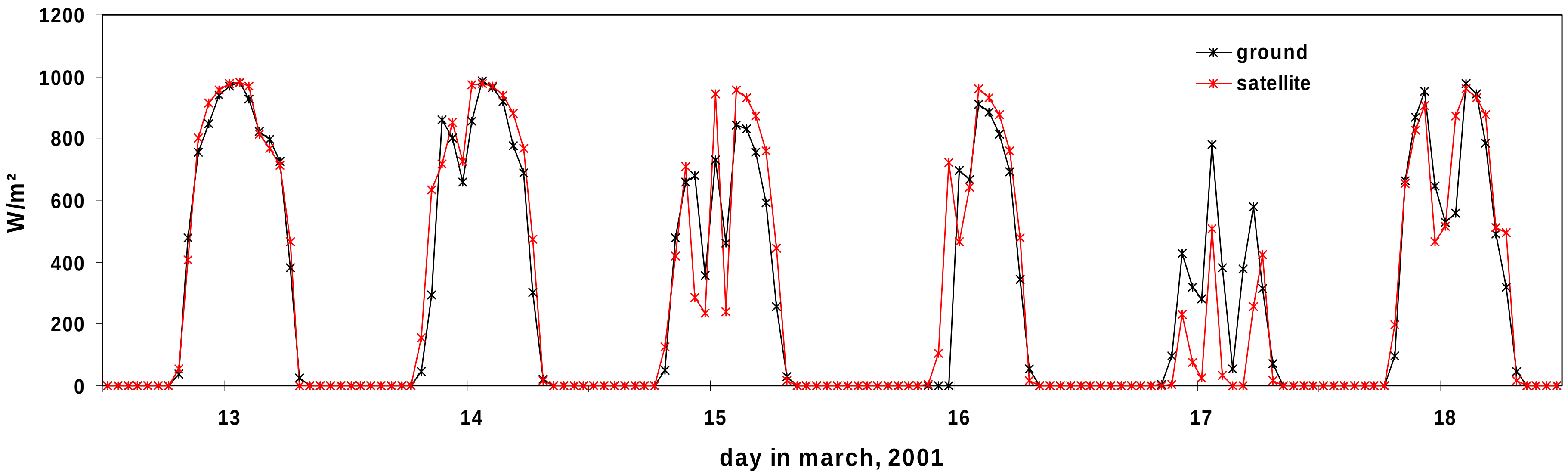
- Atmospheric transmission is calculated from global data sets
  - elevation
  - ozone
  - water vapor
  - aerosols
- The cloud index is added for cloud transmission
- All components are cut out to the region of interest

How two derive irradiance data from satellites

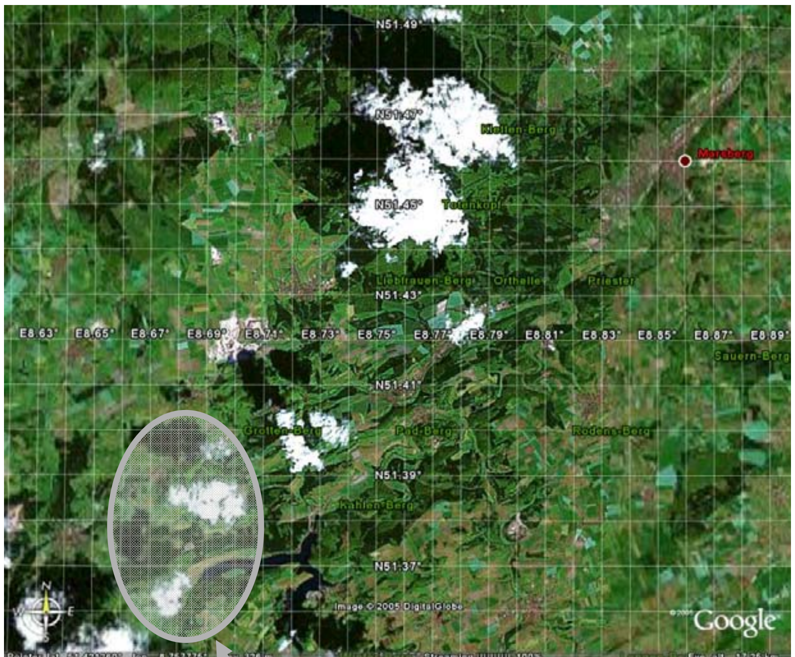


- Finally the irradiance is calculated for every hour

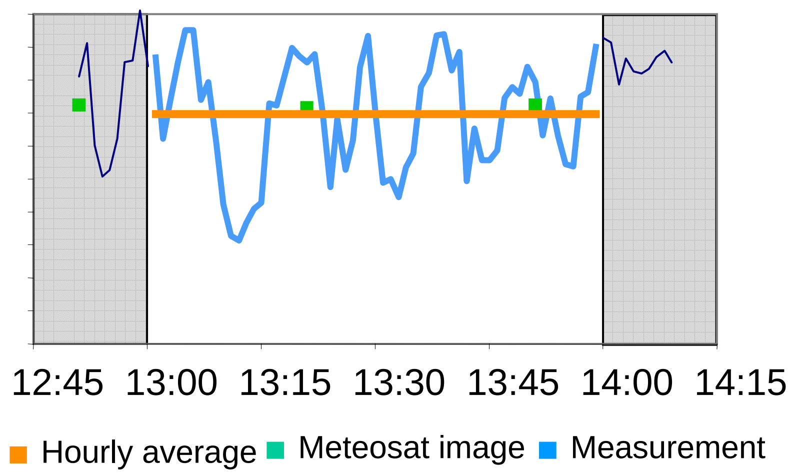
Example for hourly time series for Plataforma Solar de Almería (Spain)



Comparing ground and satellite data: time scales

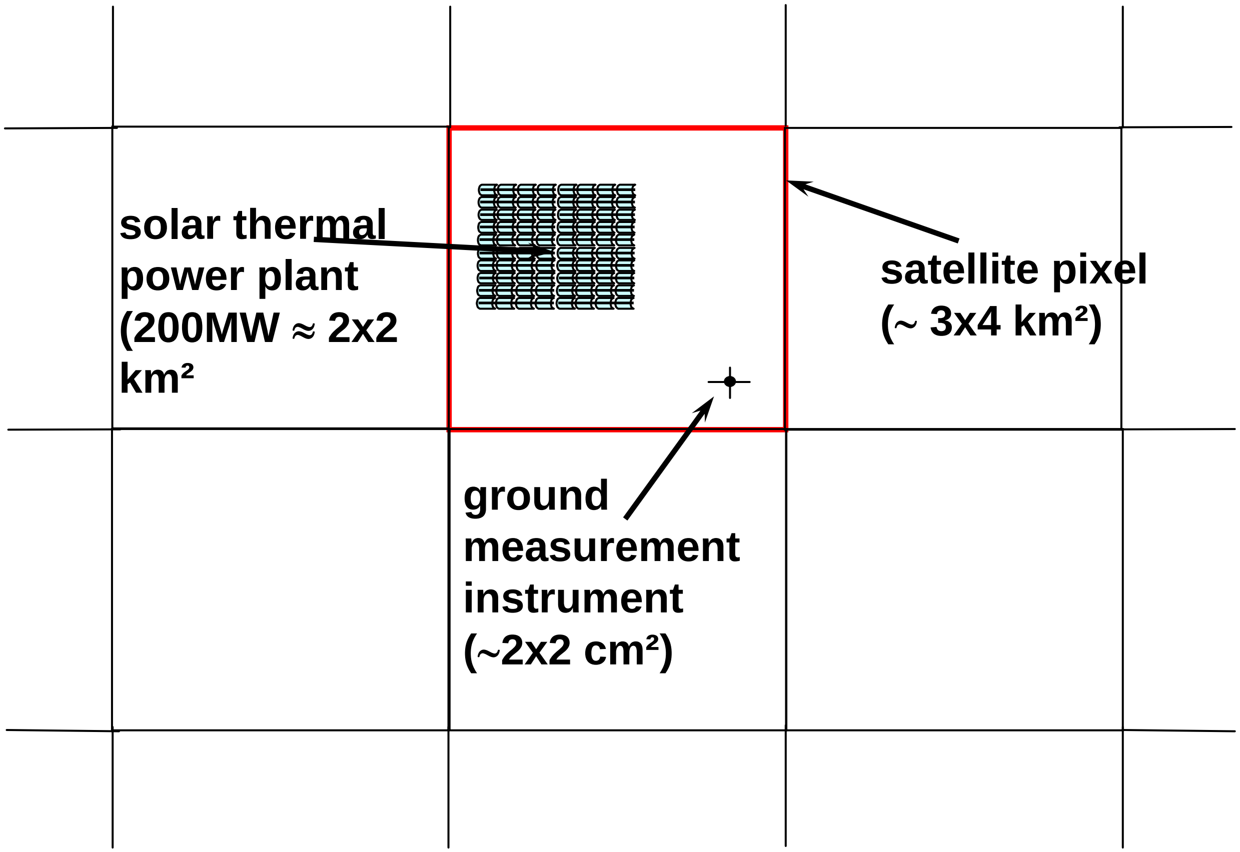


Hi-res satellite pixel in Europe



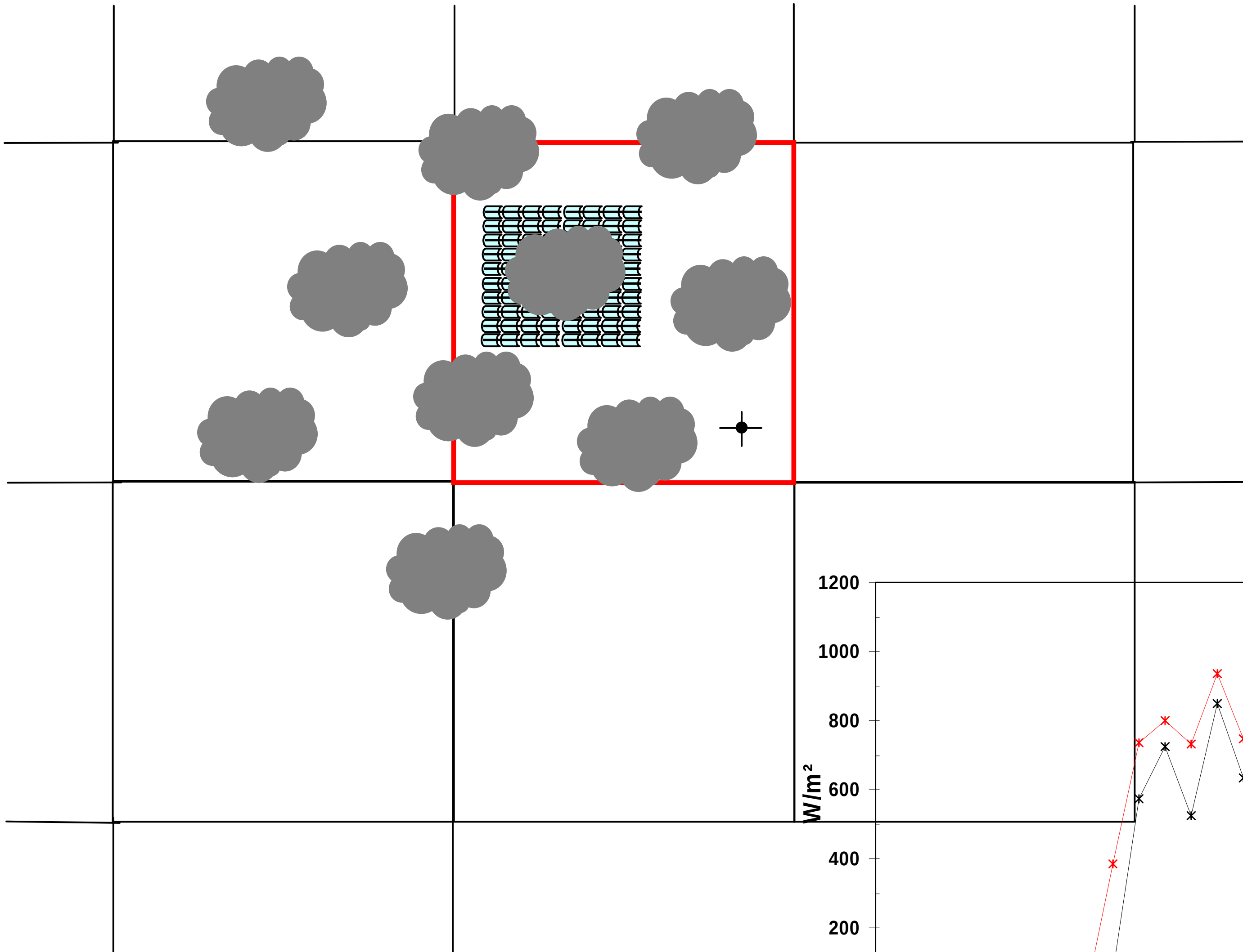
- Ground measurements are typically pin point measurements which are temporally integrated
- Satellite measurements are instantaneous spatial averages
- Hourly values are calculated from temporal and spatial averaging (cloud movement)

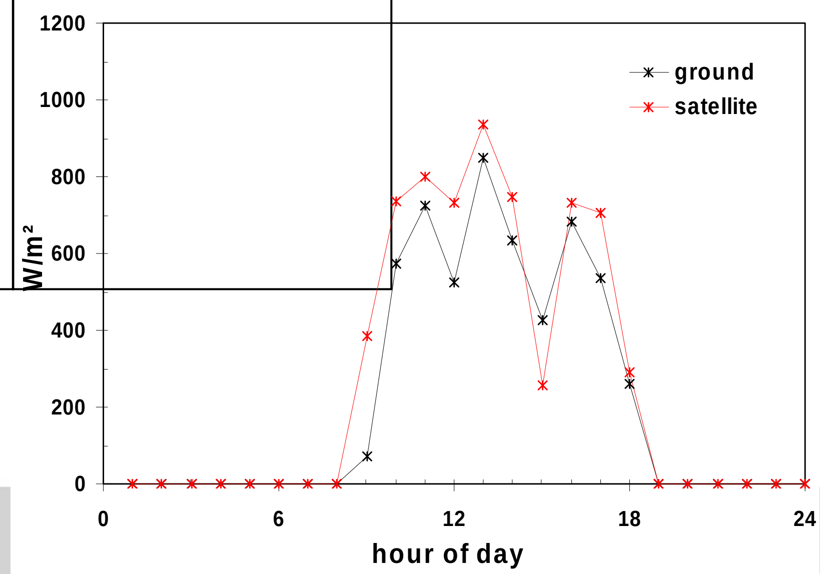
Comparing ground and satellite data: “sensor size”



Comparison with ground measurements and accuracy

general difficulties: *point versus area* and
time integrated versus area integrated

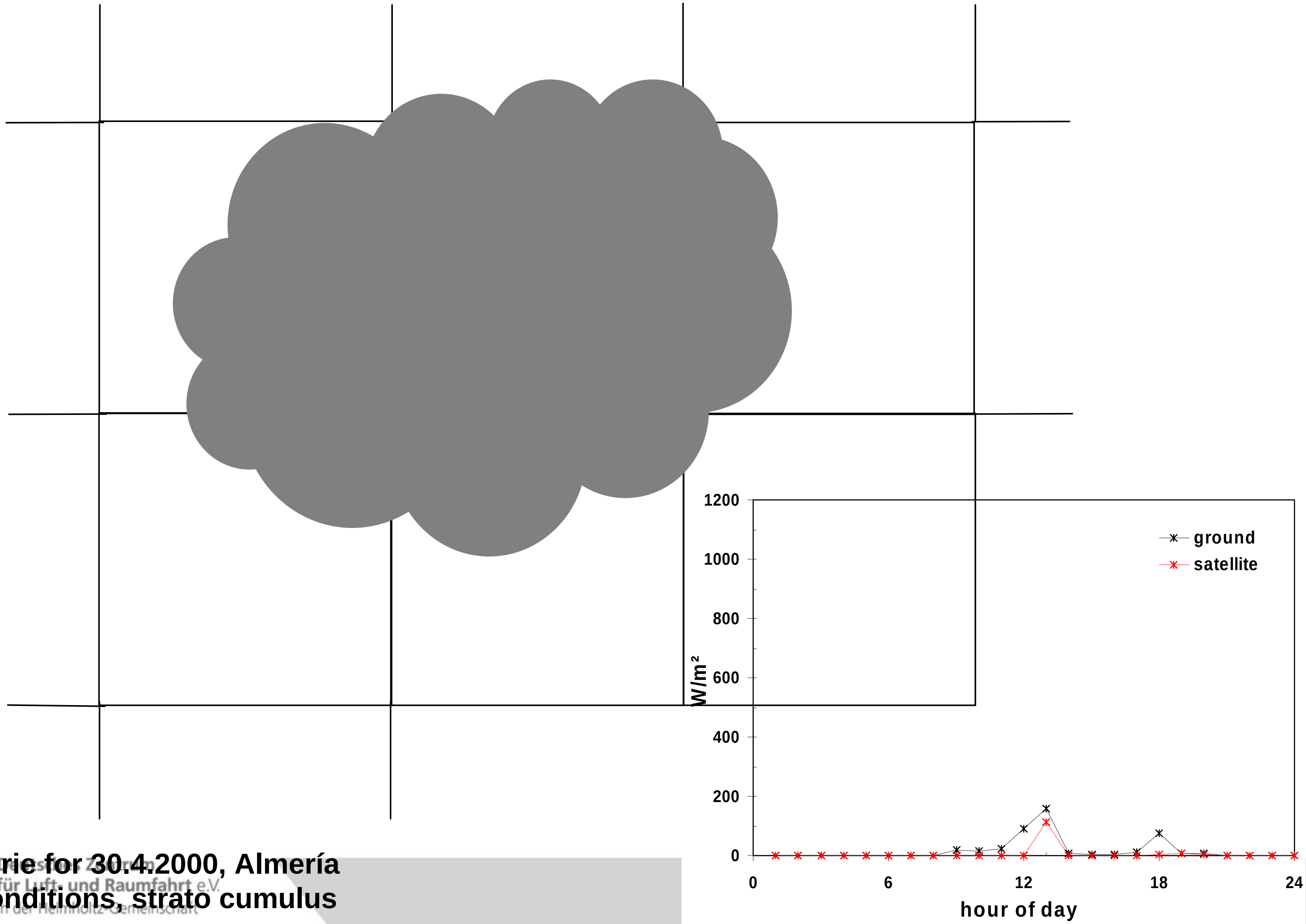




DNI time serie for 1.11.2001, Almería
Partially cloudy conditions, cumulus humilis

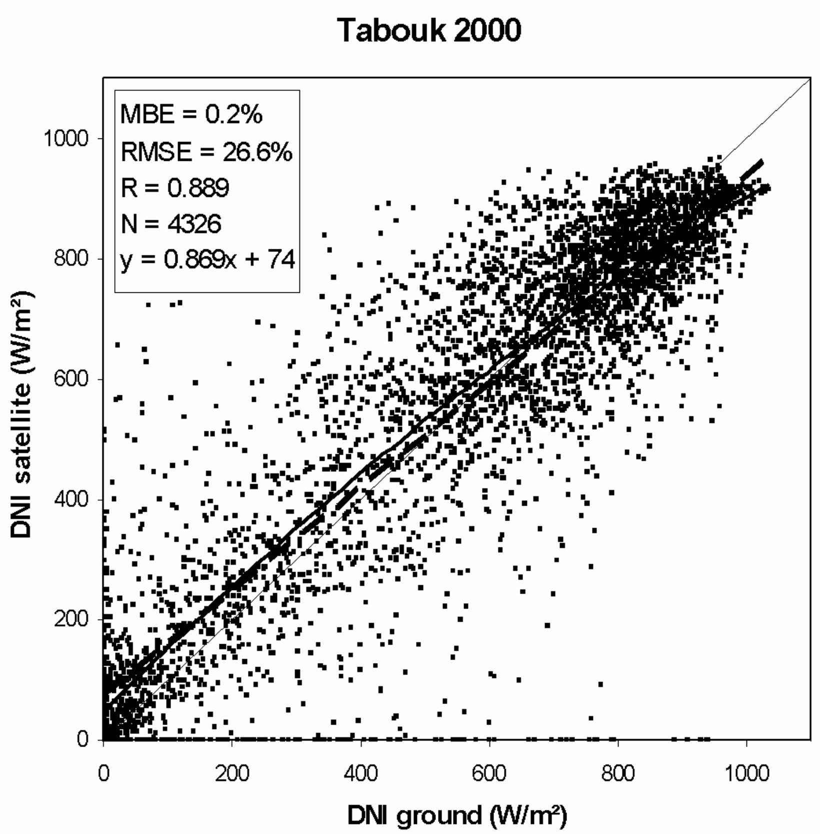
Comparison with ground measurements and accuracy

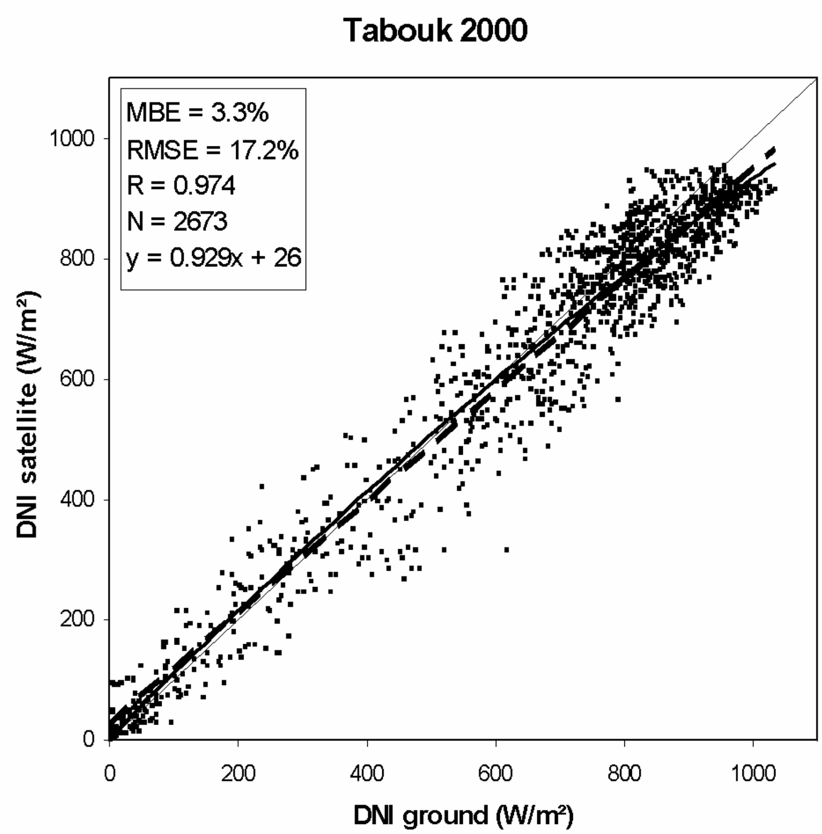
general difficulties: *point versus area* and
time integrated versus area integrated



DNI time serie for 30.4.2000, Almería
overcast conditions, strato cumulus

Validation in Tabouk, Saudi Arabia





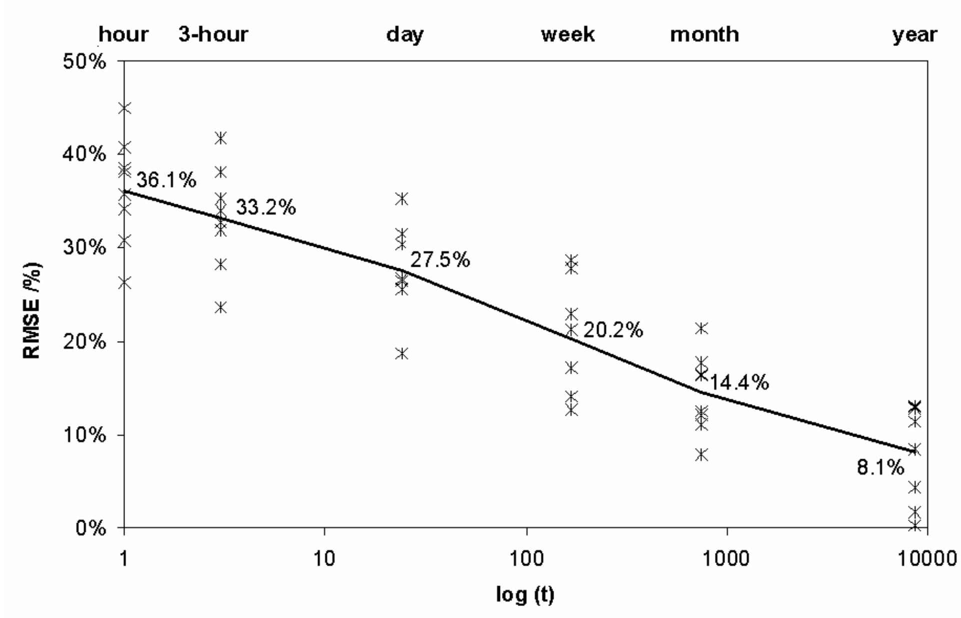
All Sky

Clear sky only

Validation results

RMSE (Root Mean Square Error)

Decreasing deviation between ground and satellite derived data with increasing duration of the integration time

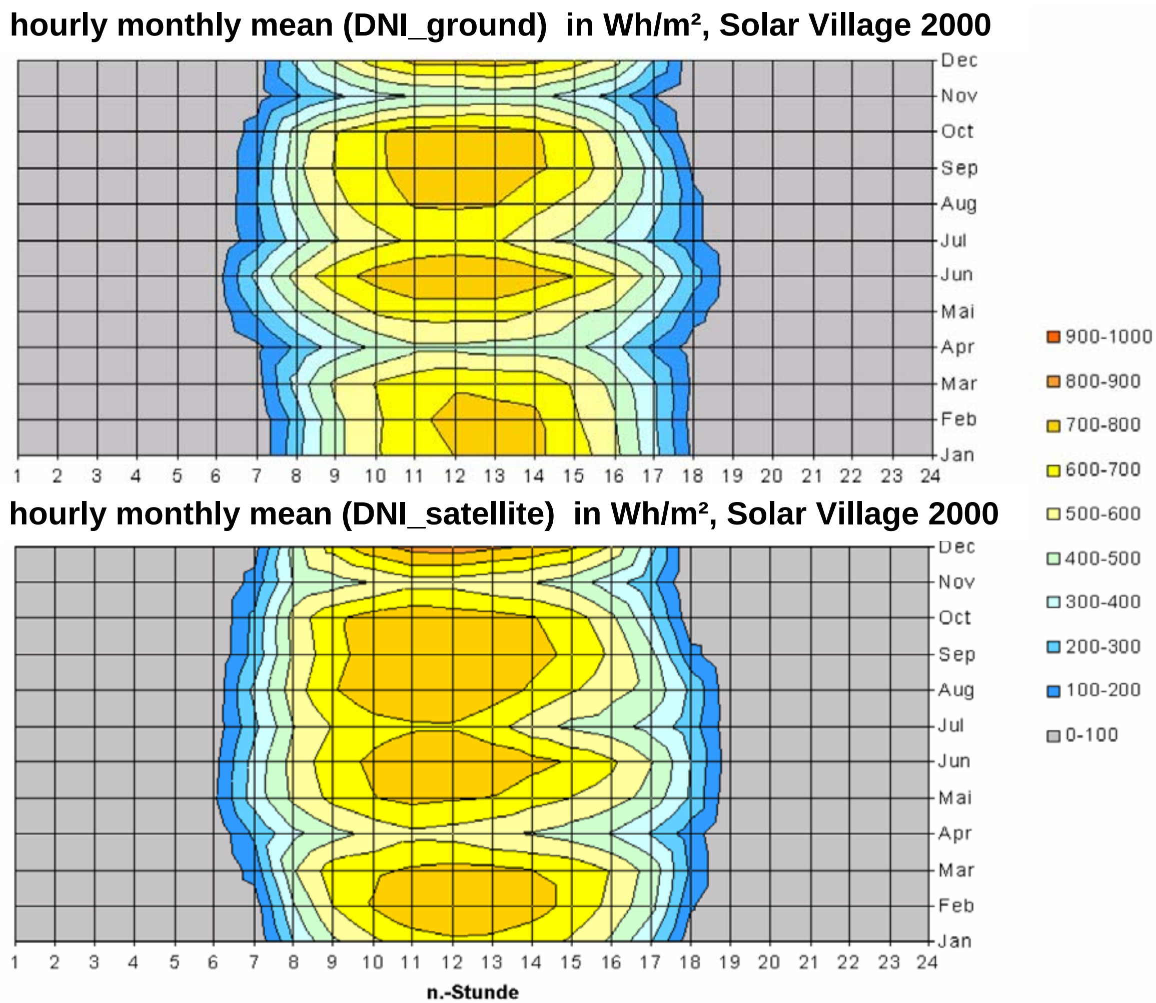


Bias

Variing within different sites

Site	bias
Measurement Network Saudi Arabia	+4.3%
Several Sites in Spain	-6.4% to +0.7%
Morocco	-2.0%
Algeria	-4.8%

Monthly ground and satellite derived irradiation data



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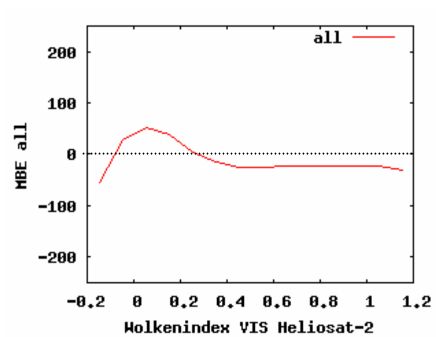
Validation of the data

Adjusting Ground and Satellite Data

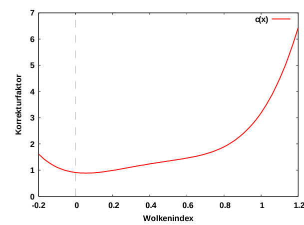
- Simple Method: Scaling with the Bias
  - E.g. with a Bias of -5%, every value is multiplied with 1.05
  - \+ Very easy to apply
  - \- Modification of frequency distribution at the extreme end
    a factor > 1 may produce unrealistic high values
    a factor < 1 may omit high values
  - Suitable for average values

Adjusting Ground and Satellite Data

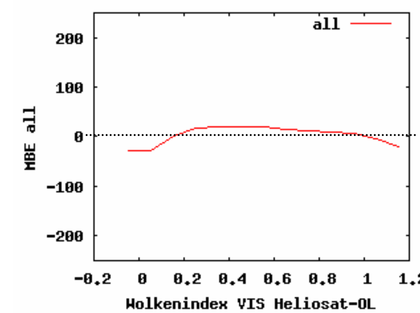
- Advanced Method: Error analysis and correction functions
  - Analysis of the Deviations:
    - At clear sky? (e.g. due to incorrect atmospheric data)
    - During cloud situations? (e.g. incorrect cloud modelling)
  - Development of a correction function dependent e.g. on the cloud index.



Bias before



Correction



Bias after

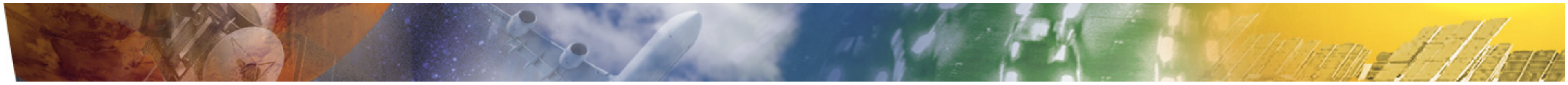
Summary

- **Ground measurements** are **accurate** but **expensive** and in suitable regions mostly **rare** (especially DNI)
- New ground measurements do **not** deliver time series **for the past**
- **Satellite data** offers **spatial resolution** and **long-term time series** of more than 20 years **into the past**
- **Combination** of ground and satellite date yields: irradiation **maps**, long term **annual means** and **time series** – all with **good accuracy**
- Realistic long term meteo data helps to **avoid risk surcharges** of banks due to conservative assumptions and **increase the financial viability** of your project

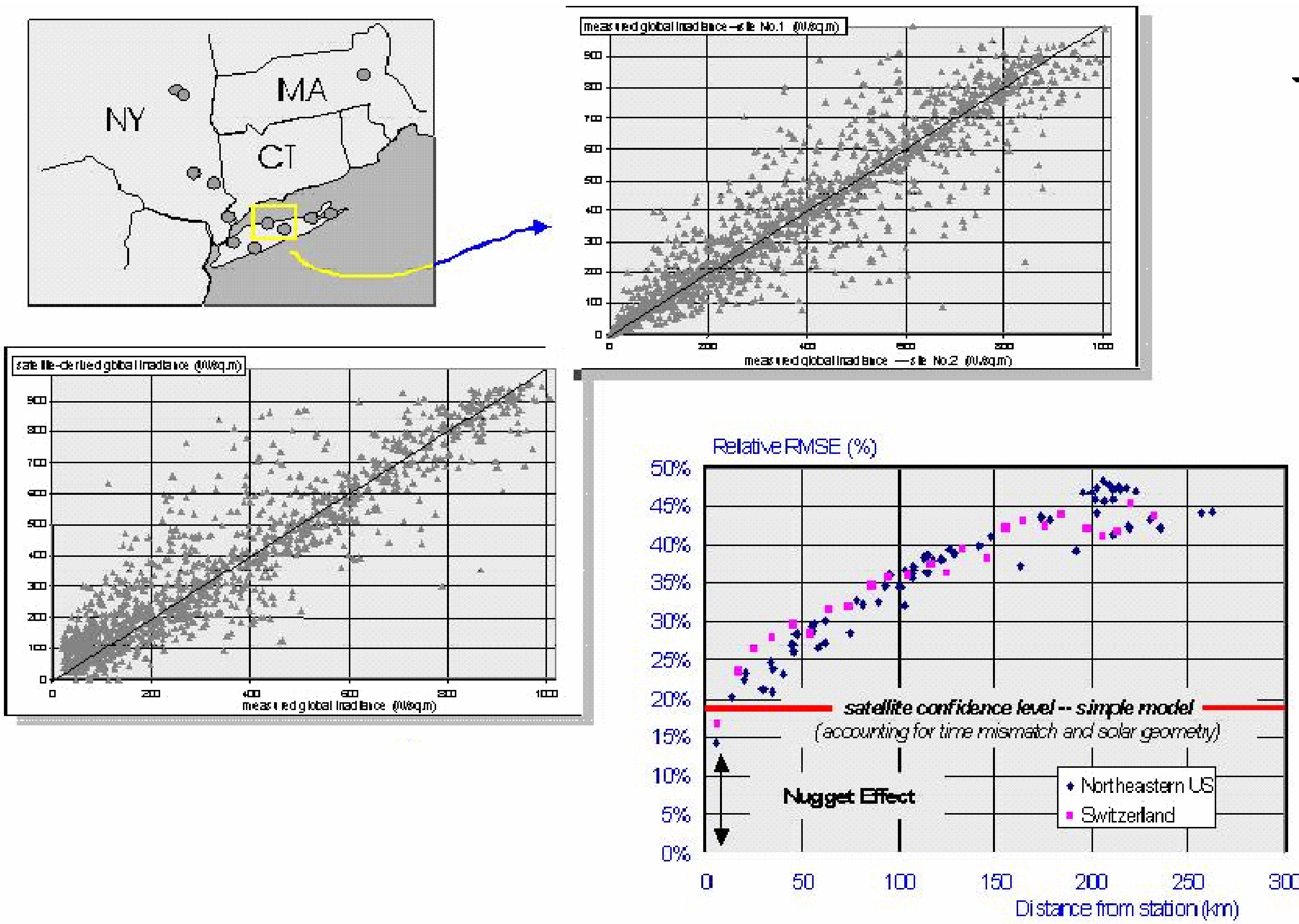
Thank you for your attention !

Acknowledgements

- Richard Meyer, Institute for Physics of the Atmosphere, DLR Oberpfaffenhofen
- Sina Lohmann, Institute for Physics of the atmosphere, DLR Oberpfaffenhofen
- Antonie Zelenka, MeteoSwiss, Zürich
- Volker Quaschning, FHTW Berlin



Satellite data and nearest neighbour stations



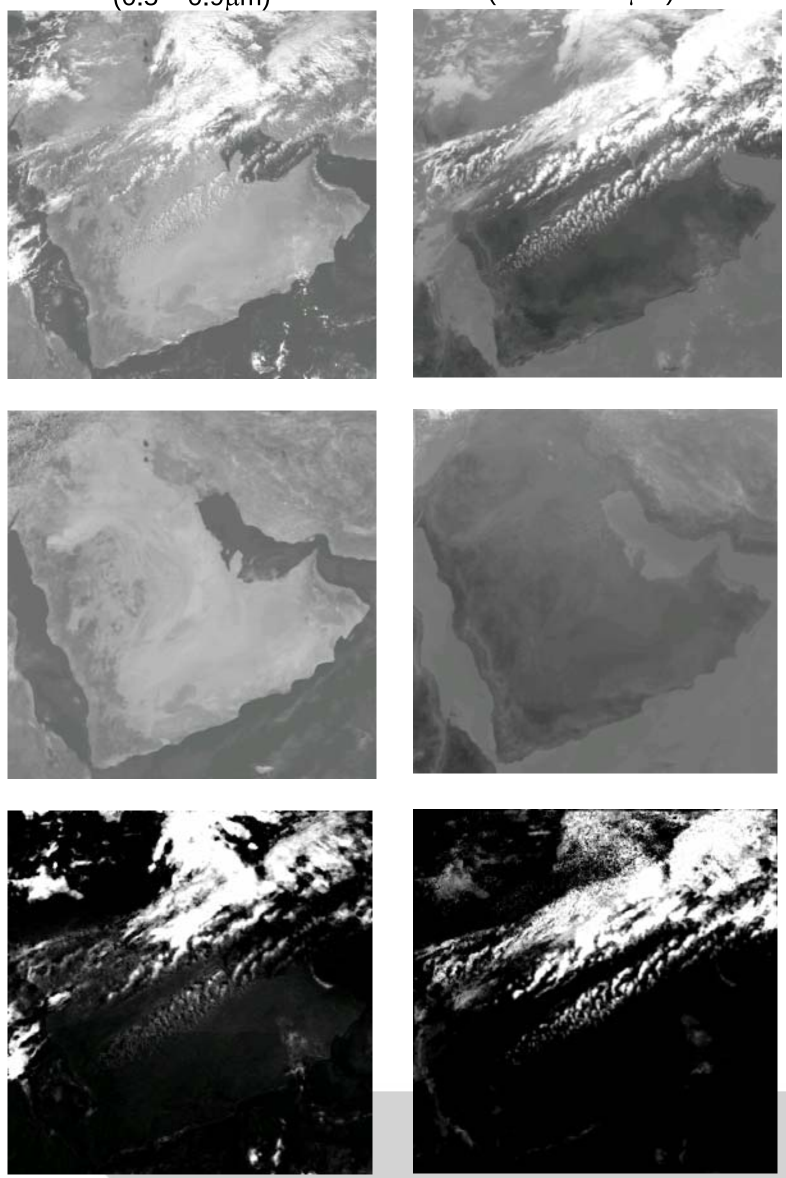
Perez et al., ASRC

- Satellite derived data fit better to a selected site than ground measurements from a site farther than 25 km away.

Derivation of the Cloud-Index from satellite images

Meteosat-7

	VIS-channel (0.5 – 0.9µm)	**IR-channel** (10.5 –12.5 µm)

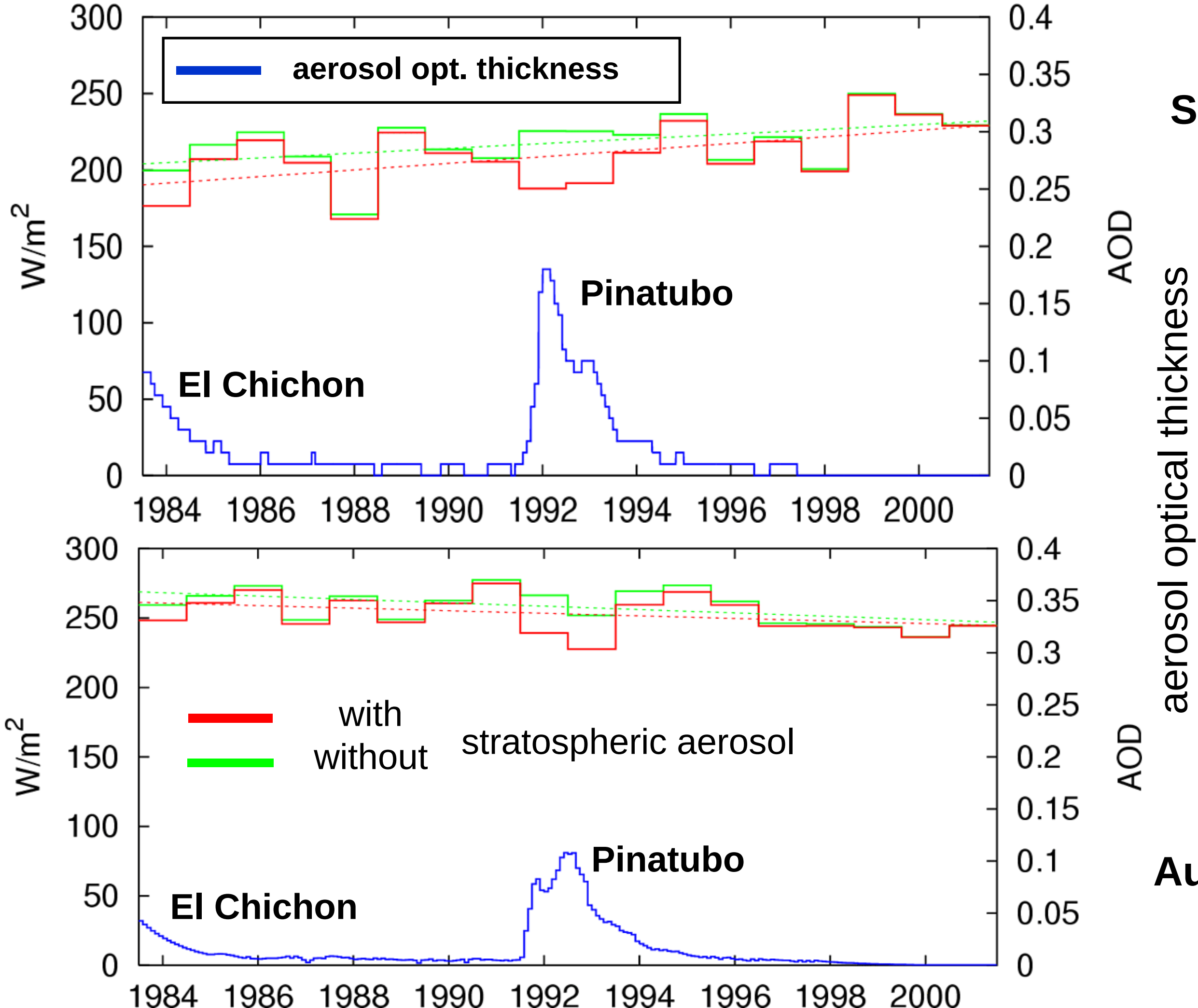


Original-image

Reference-image

Derived cloud information (Cloud-Index)

Time series of direct normal irradiance



Spain

linear regression:
2.16 W/(m² year)
1.56 W/(m² year)

Australia

linear regression:
- 0.93 W/(m² year)
- 1.22 W/(m² year)

	with
	without
stratospheric aerosol	