IRRADIATION MEASUREMENTS ON GROUND

EEP Workshop, Windhoek, Namibia

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CSP Services

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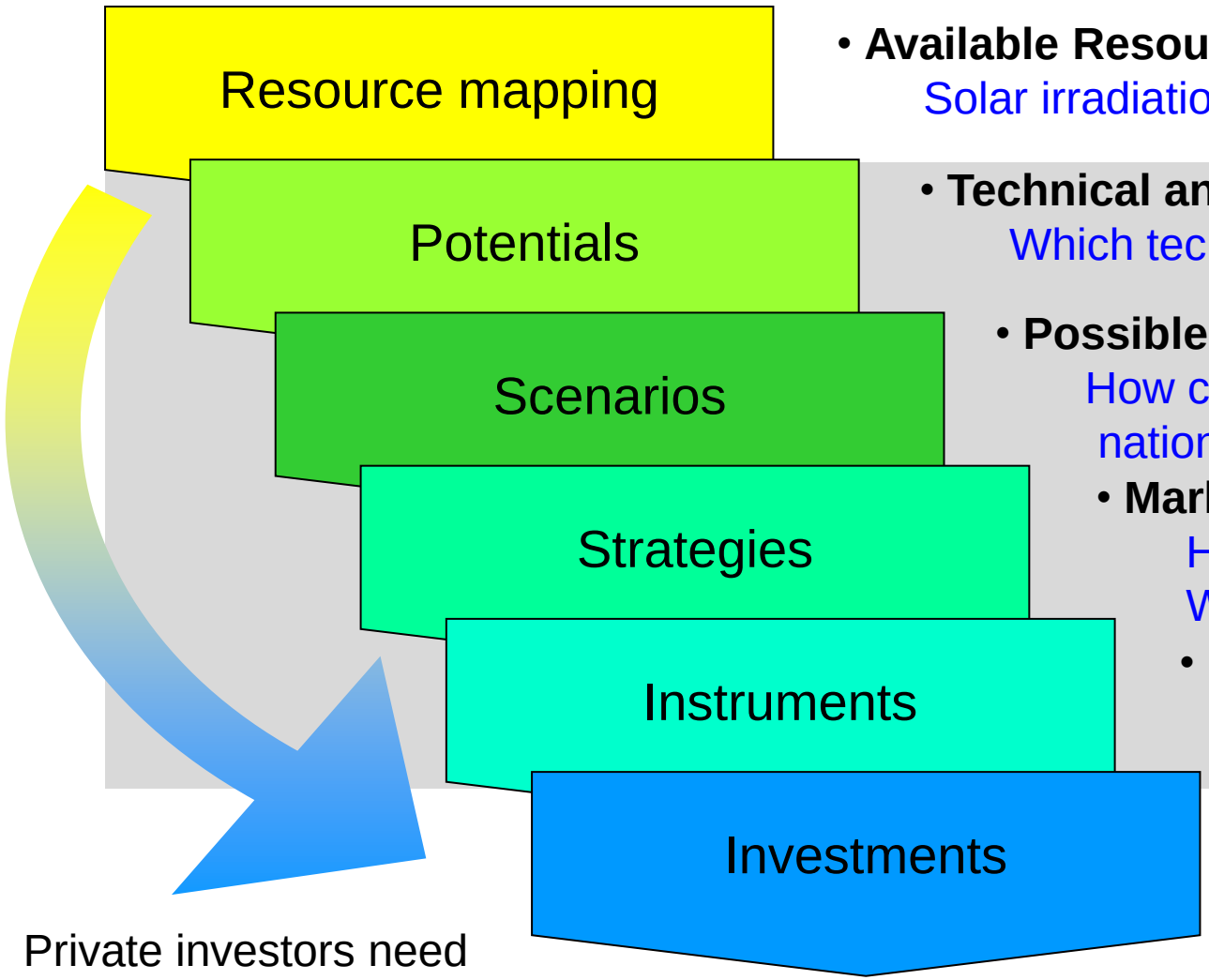
GETTING RENEWABLE ENERGY TO WORK



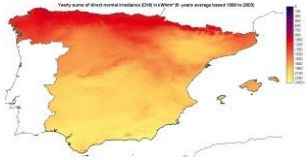
- **Available Resources**
  Solar irradiation is the „fuel“ of solar power plants
- **Technical and economic potentials**
  Which technologies are feasible?
- **Possible capacity development**
  How can they contribute to the national energy system?
- **Market introduction**
  How to get them into the market?
  Where to start?
- **Political and financial instruments**
  Legislation, incentives
- **Private investments**

Political + Economic Framework

Private investors need resource data for investments

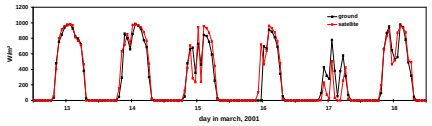
PROJECT DEVELOPMENT FOR RENEWABLE ENERGY SYSTEMS

Resources (Atlas)

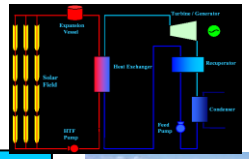


Project development

Resources (time series)

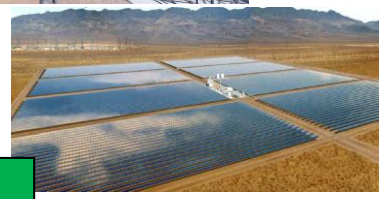


Engineering



Construction

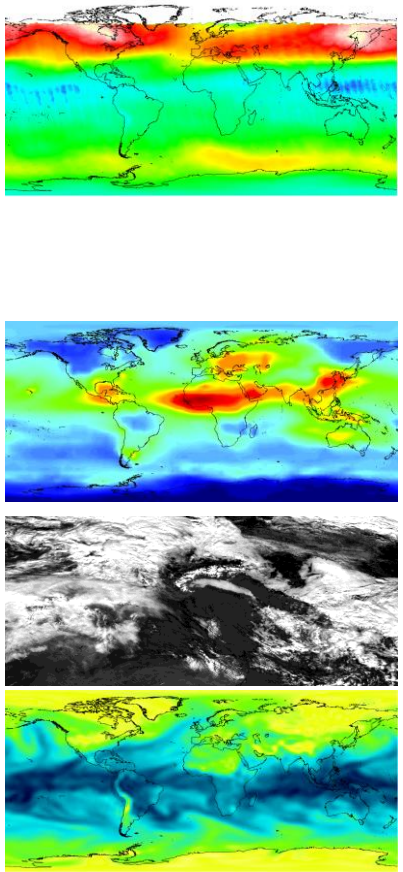
Commissioning

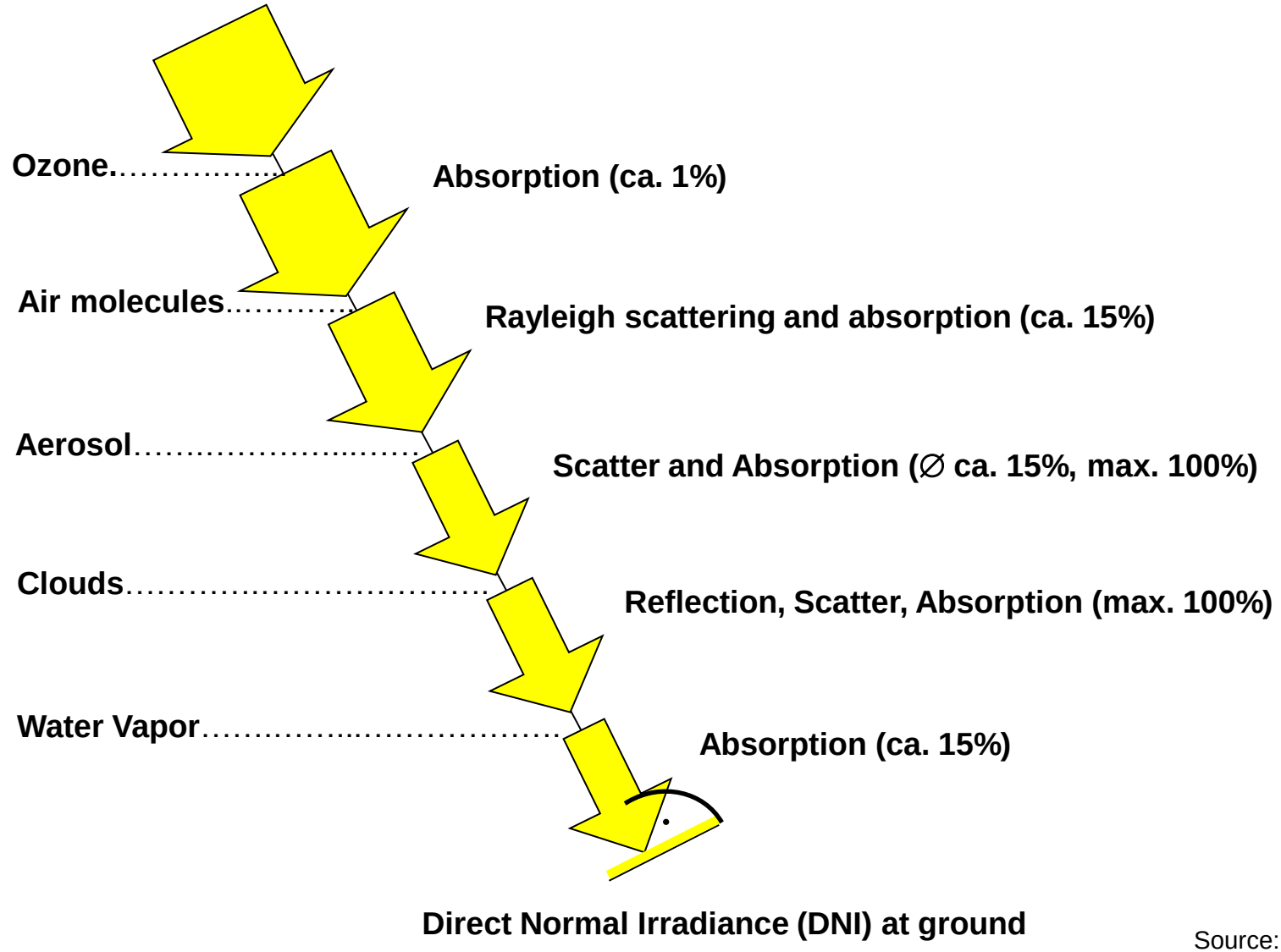


Operation

- Finding suitable sites with high resolution maps and economic evaluations
- Detailed engineering with site specific data with high temporal resolution as input to simulation software

PATH OF SOLAR RADIATION THROUGH THE ATMOSPHERE

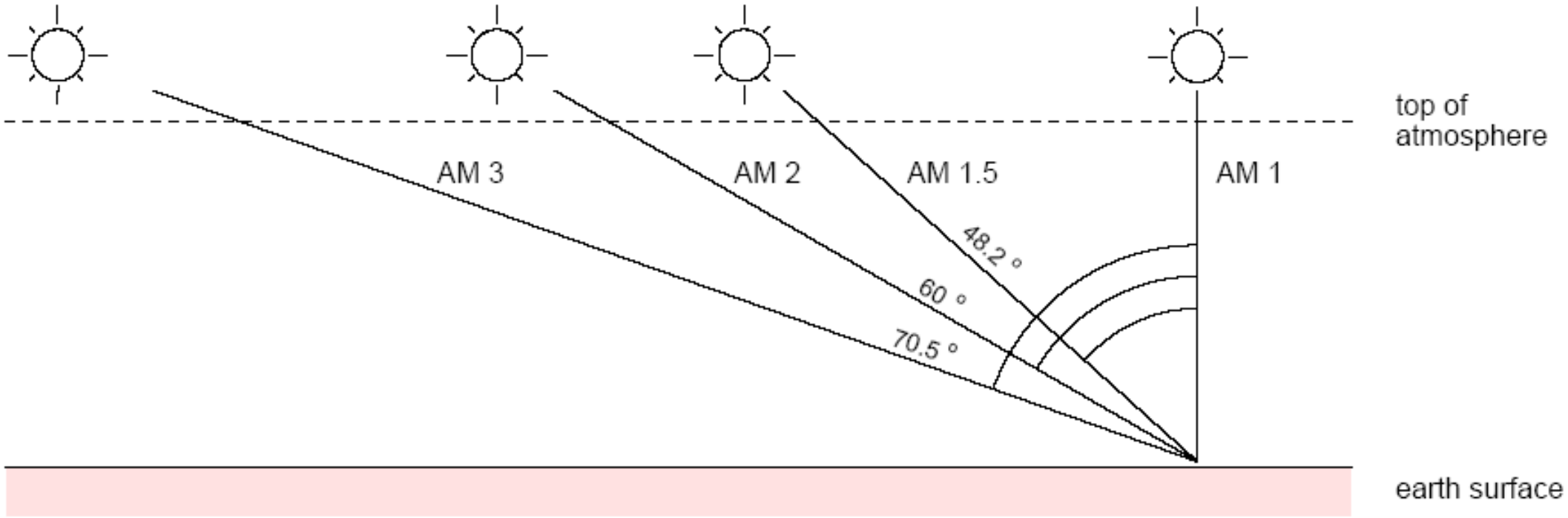




Source: DLR

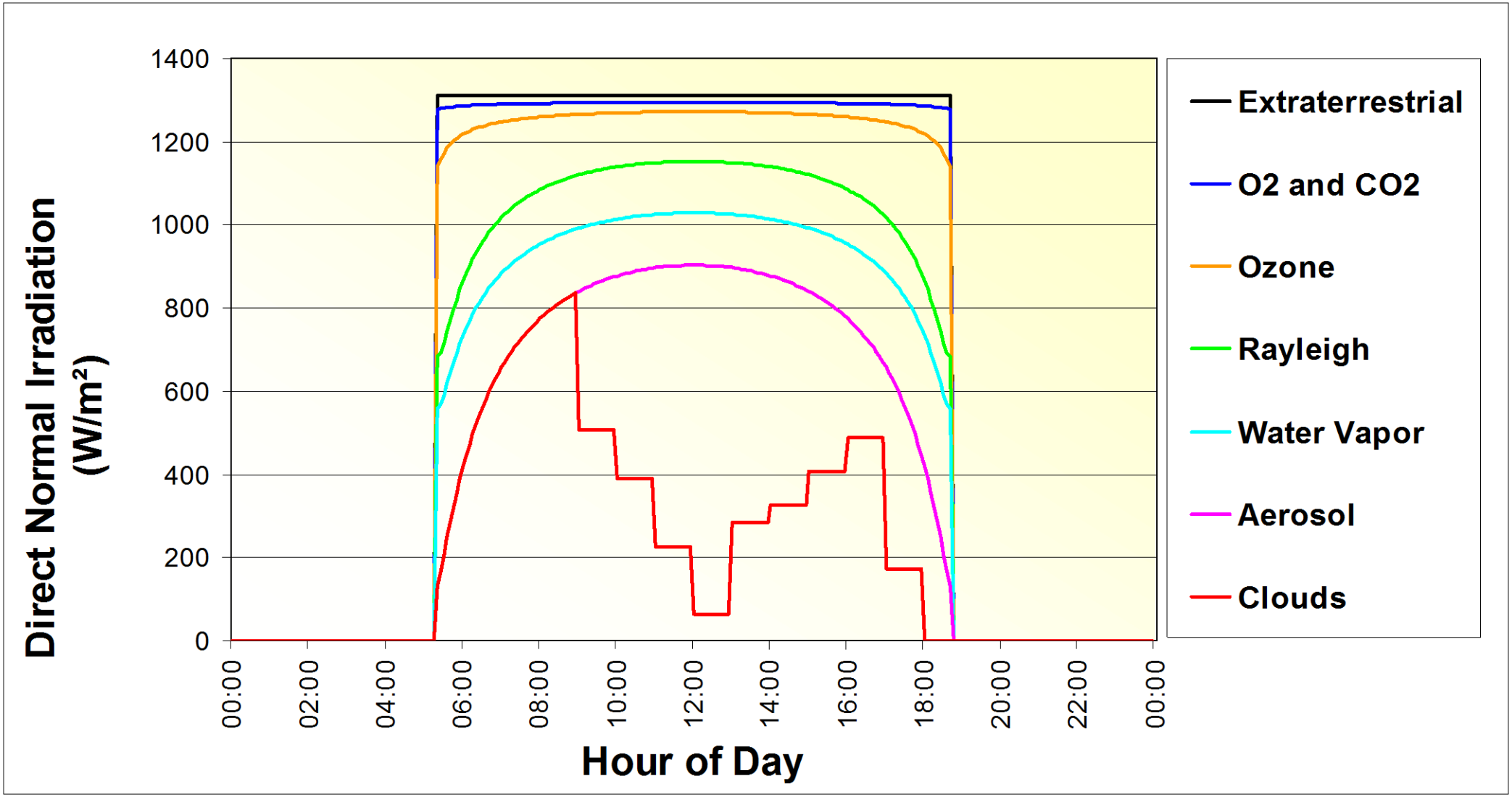
INFLUENCE OF AIR MASS ON IRRADIATION

AM = 0 (outside of atmosphere)



Source: DLR

RADIATIVE TRANSFER TROUGH THE ATMOSPHERE



Source: DLR

CHARACTERISTICS OF SOLAR IRRADIATION DATA

- **Component:**
  - DNI (Direct-Normal Irradiation)
  - DHI (Diffus-Horizontal Irradiation)
  - GHI (Global-Horizontal Irradiation)

- **Source:**
  - ground measurements:
    - precise thermal sensors: thermopiles
    - Rotating Shadowband Irradiometers
  - satellite data

- **Properties of irradiation:**
  - spatial variability
  - inter-annual variability
  - long-term drifts

DIRECT, DIFFUSE AND GLOBAL IRRADIANCE

When measuring solar irradiance, the following components are of particular interest:

- Direct normal irradiance (DNI)

  (also: beam irradiance)

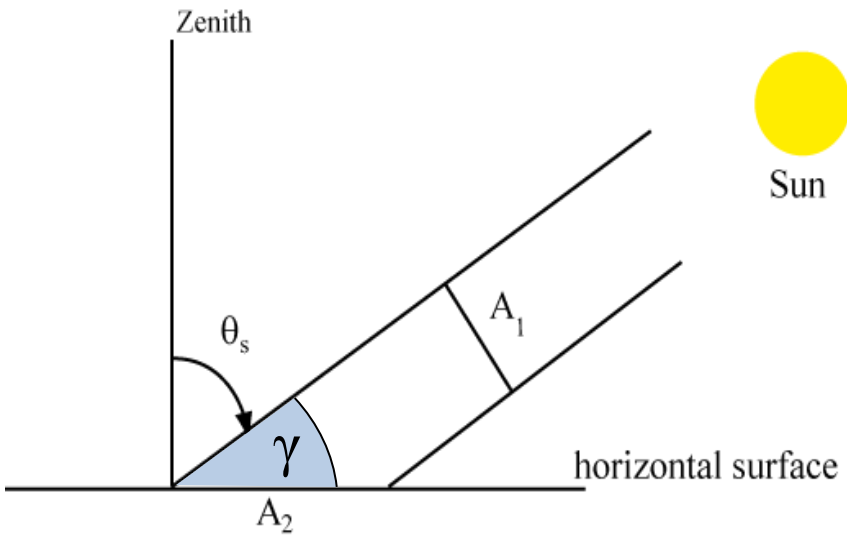
- Diffuse horizontal irradiance (DHI)

  (also: diffuse sky radiation)

- Global horizontal irradiance (GHI)

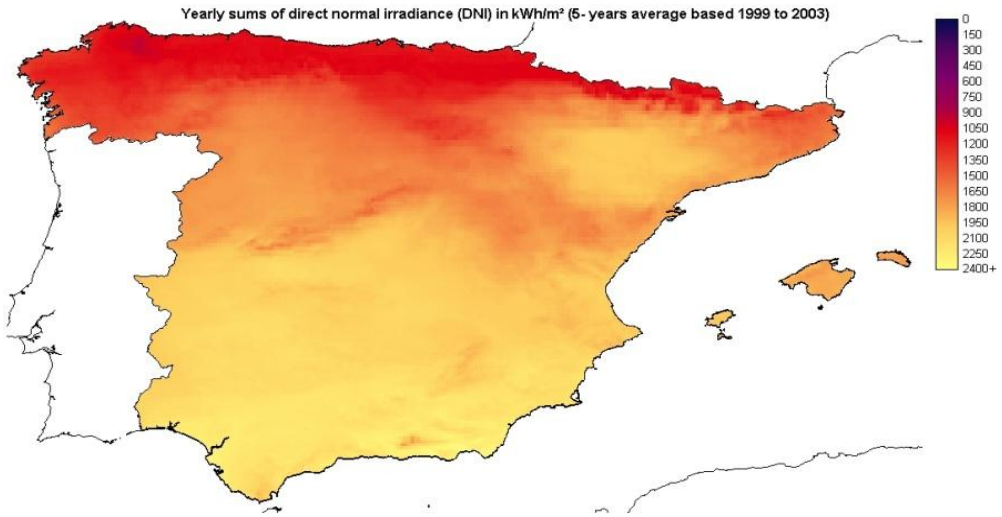
  (also: total solar irradiance)

Zenith angle θ,
solar elevation γ



$$GHI = DHI + DNI * \sin(\gamma)$$

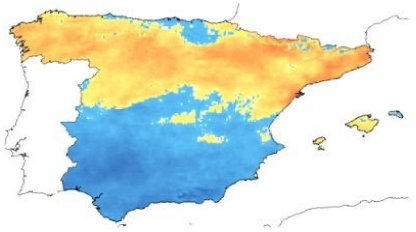
INTER-ANNUAL VARIABILITY



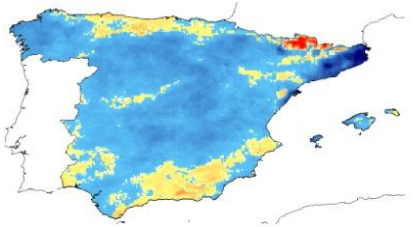
Average of the Direct Normal Irradiance
from 1999-2003

1999

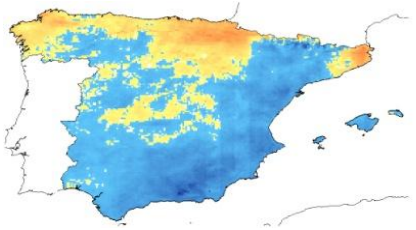
2000



2001

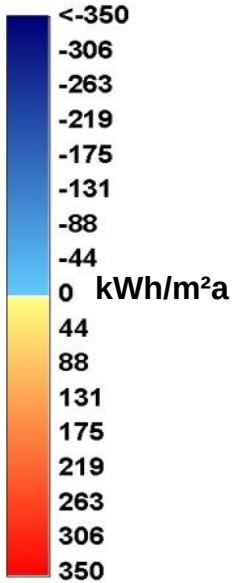


2002



2003

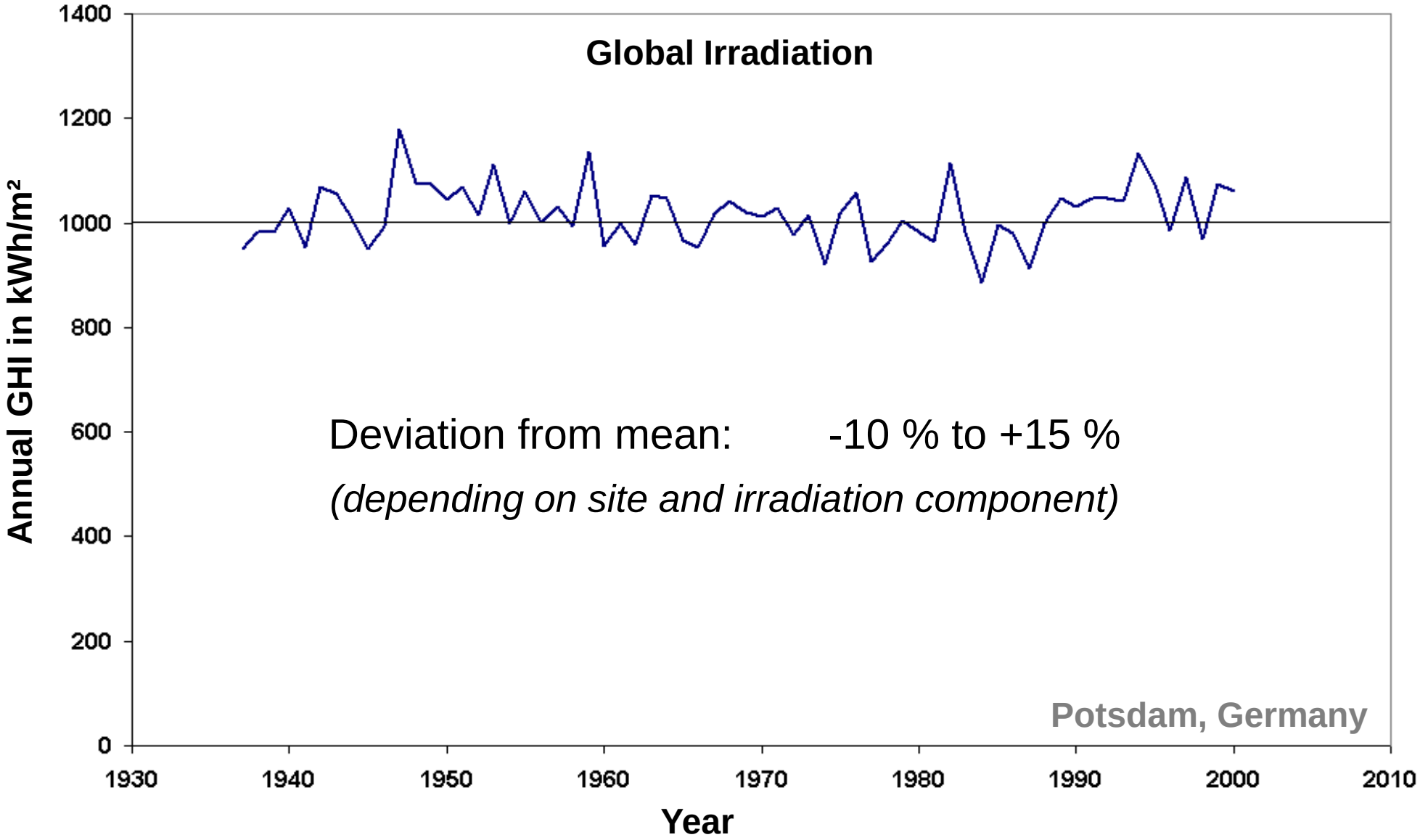
deviation to mean



Strong inter-annual and regional variations

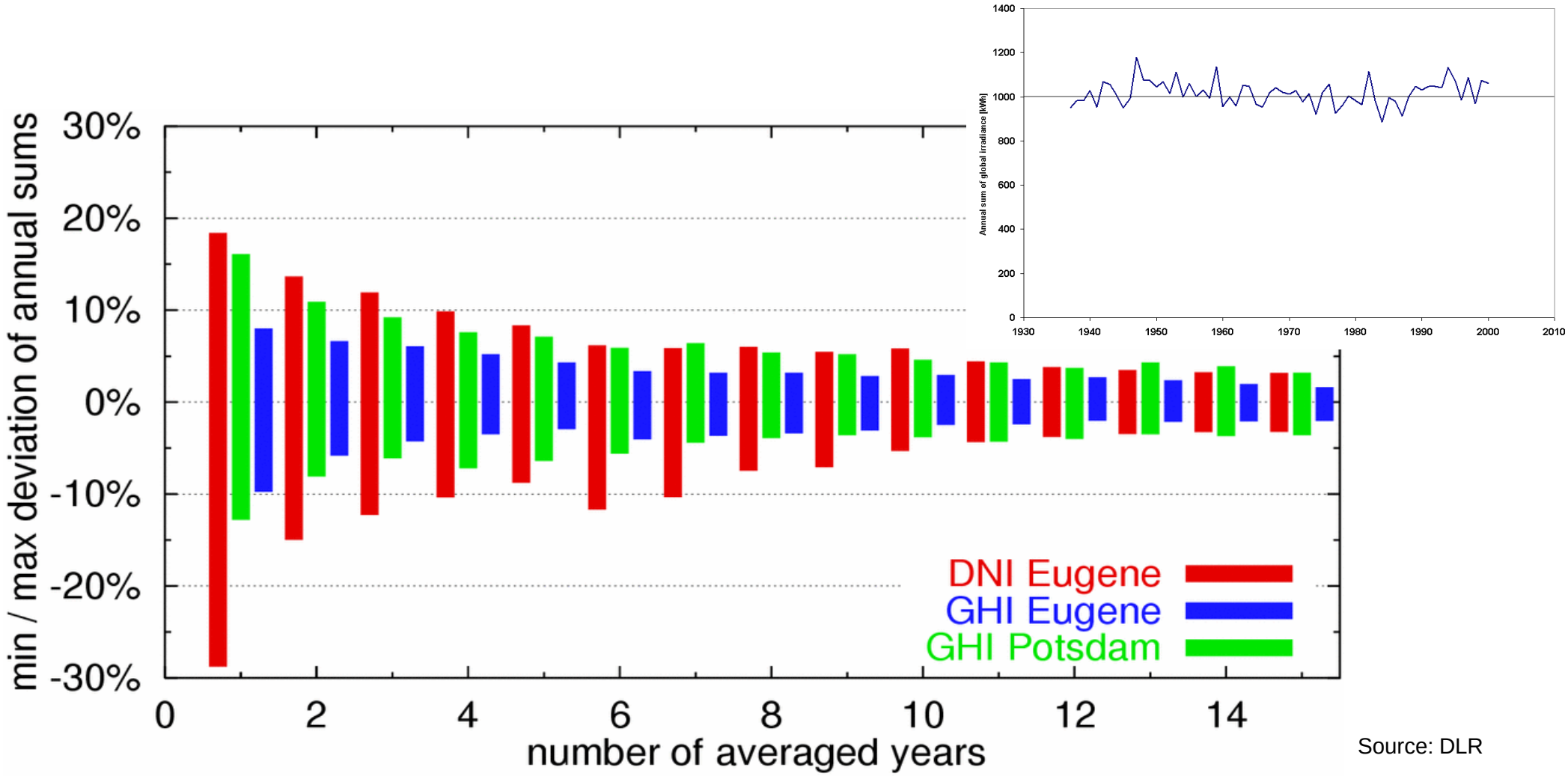
Source: DLR

LONG-TERM VARIABILITY OF SOLAR IRRADIANCE



Source: German Weather Service (DWD) / Volker Quaschning

LONG-TERM VARIABILITY OF SOLAR IRRADIANCE



Source: DLR

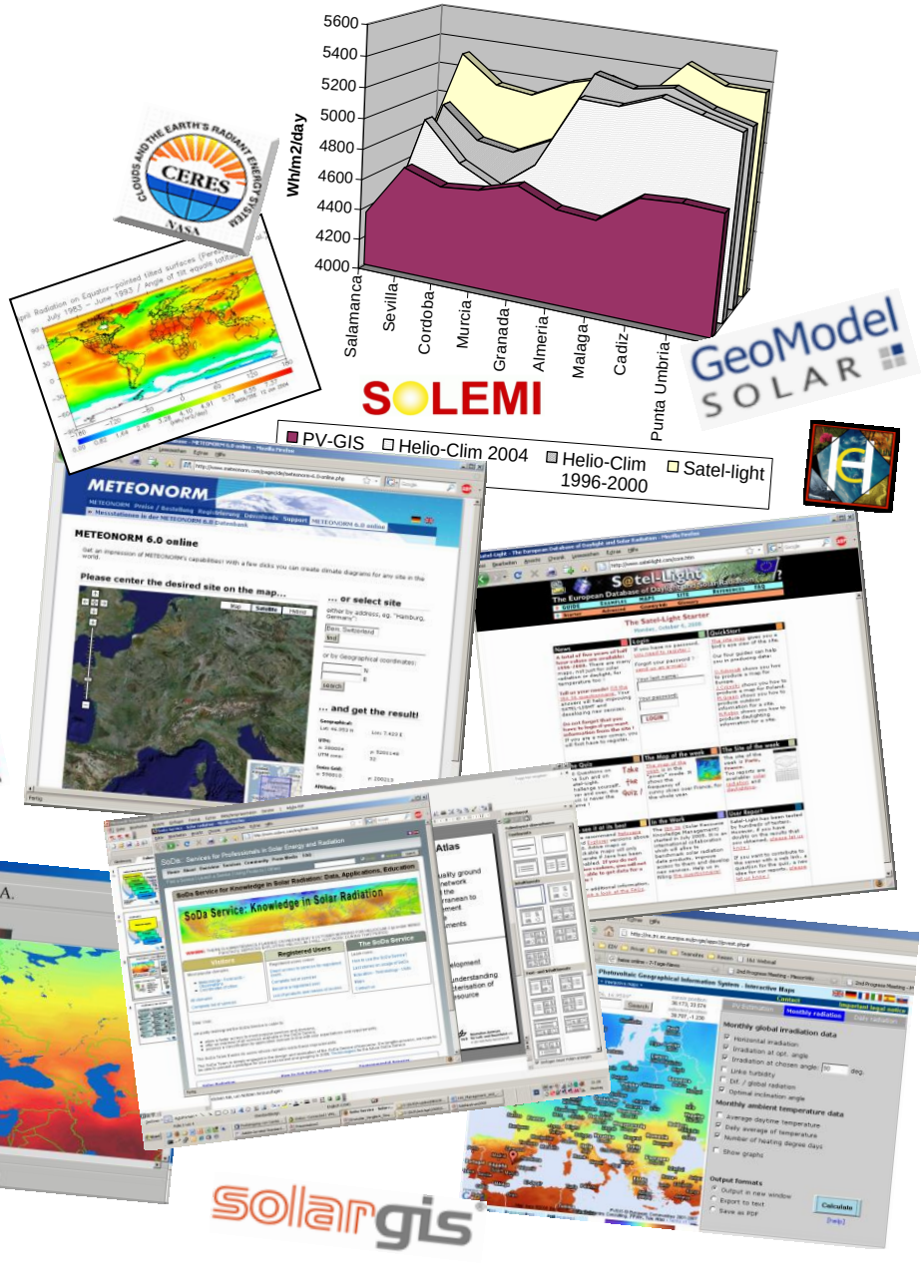
7 to 10 years of measurement to get long-term mean within 5%

COMPARING SOLAR IRRADIATION DATA FROM DIFFERENT SOURCES

Several sources for solar resource data available:

- different origines of data:
  satellite data or ground measurements,
  differing sensors and measurement methods
- covering different periods
- different access mechanism and data format
- different and unknown data quality and accuracy
- Results are difficult to compare

There is a number of data sources, but this creates uncertainty of the results, especially as they usually do not coincide



UNCERTAINTY OF SATELLITE DERIVED ANNUAL DNI

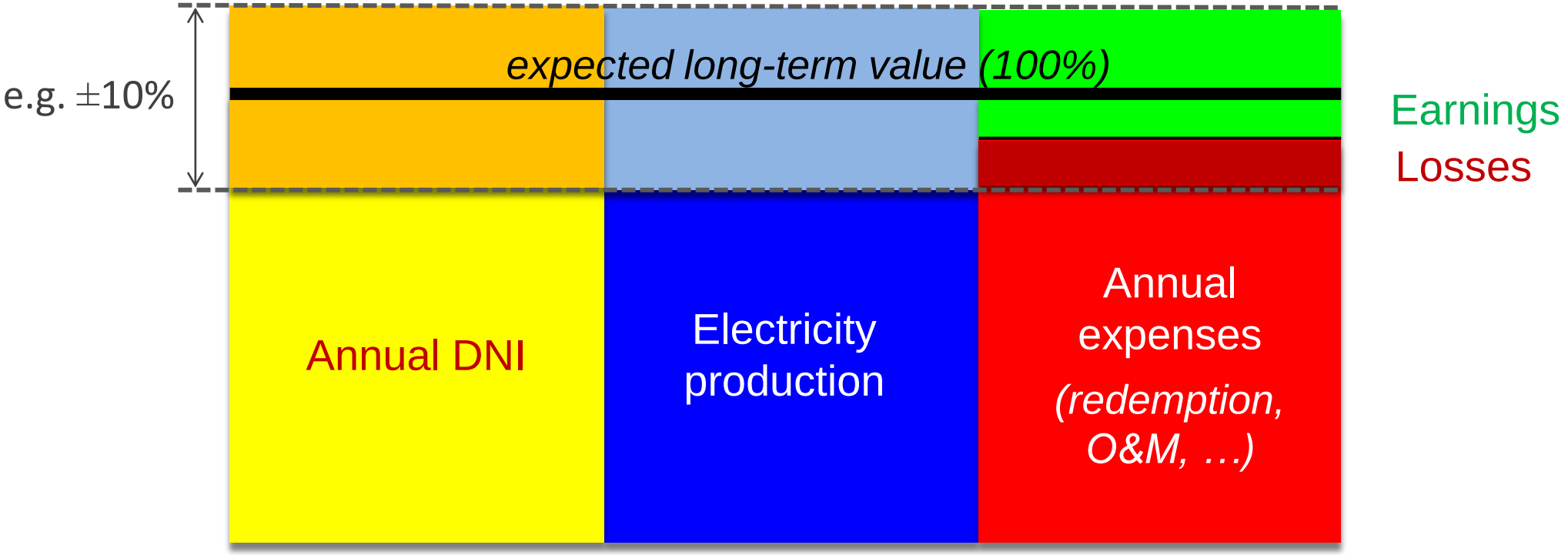
Direct Normal Irradiance, DNI	Bias		Root Mean Square Deviation, RMSD		
	[W/m^2]	[%]	hourly [%]	daily [%]	monthly [%]
Aggeneis (South Africa)	-24.7	-3.7	18.3	11.5	5.2
De Aar (South Africa)	-6.0	-1.0	16.8	9.9	2.4
Sede Boqer (Israel)	-34.1	-5.5	23.9	16.0	6.4
Paulputs (South Africa)	-53.6	-7.8	18.0	12.4	9.3
Sonbesie (South Africa)	-33.6	-6.4	20.1	12.1	7.8
Upington (South Africa)	-40.6	-6.0	19.7	12.4	7.8
Durban (South Africa)	-22.4	-5.8	32.2	20.3	8.0
Tamanrasset (Algeria)	24.5	3.9	21.6	16.4	5.6

Source: GeoModel

Generally a bias of <10 % is stated for satellite DNI,
in single cases deviations of 20 % and more were found!

What if my prospected plant is affected?

IMPACT OF SOLAR RESOURCE UNCERTAINTY ON PLANT RENTABILITY



With ***thoroughly*** performed measurements on ground an accuracy of approximately 2 % is achievable

GROUND MEASUREMENTS VS. SATELLITE DERIVED DATA

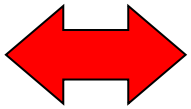
Ground measurements

Advantages

+ high accuracy
  (depending on sensors and maintenance)
+ high time resolution

Disadvantages

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



Satellite data

Advantages

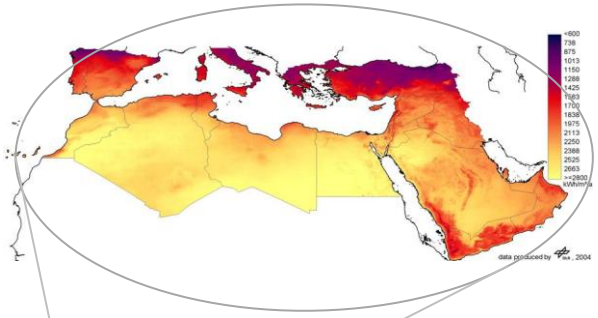
+ spatial resolution
+ long-term data *(more than 20 years)*
+ effectively no failures
+ no soiling
+ no ground site necessary
+ low costs

Disadvantages

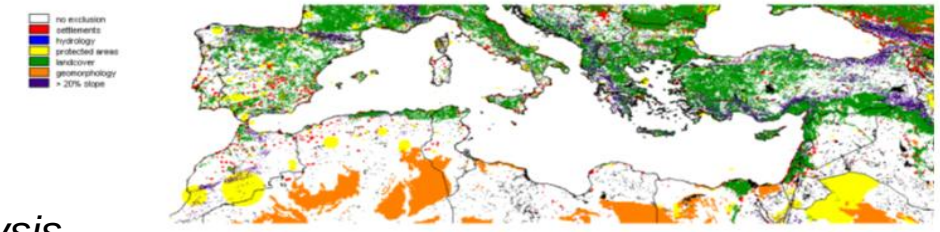
- lower time resolution
- low accuracy at high time resolution

GENERAL PROCEDURE AT SOLAR RESOURCE ASSESSMENT

Irradiation map: *spatial distribution*



Geographical data: *land use, etc.*



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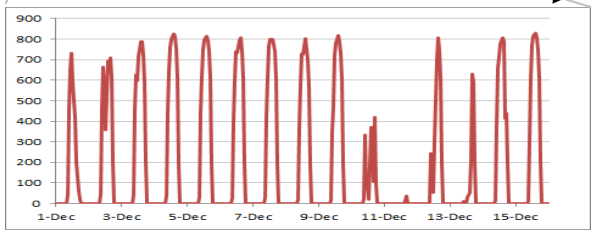
GIS analysis

Selection of promising **sites**



Long-term time series
(>10 years)

adjustment

Meteorological Station:
Accurate irradiation data

Plant design, inter-annual variability, uncertainty analysis, financing, …

OBJECTIVES FOR MEASUREMENTS ON GROUND

1. **Solar Resource Assessment:**

   usually **validation** of **satellite data** via precise measurements on ground

   with an accuracy of 1 to 2 %

   → comparison with satellite data for long-term analysis,

   determination of the expectable **solar resource**

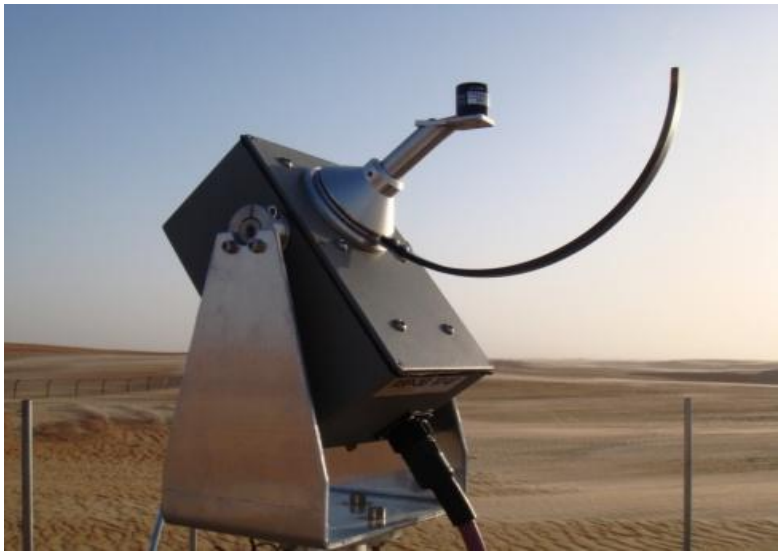
2. **Monitoring** of operational **power plants**, evaluation of efficiency

   (other conditions and requirements on the performance of measurements)

INSTRUMENTS FOR MEASUREMENT OF IRRADIANCE

- <u>Silicon photodiode:</u>
  Rotating **S**hadowband **I**rradiometer (RSI)
  or
  Rotating **S**hadowband **P**yranometer (RSP)
  or
  Rotating **S**hadowband **R**adiometer (RSR)

  Station costs: 13‘000 – 25‘000 USD



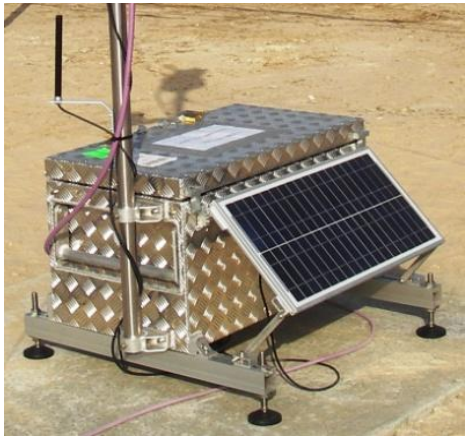
- <u>Thermopile Sensors:</u>
  pyrheliometer and
  pyranometer,
  solar tracker with shading assembly,
  ventilation

  Station costs: 35‘000 – 55‘000 USD

AVAILABLE EQUIPMENT: MDI AUTOMATIC WEATHER STATION

- RSP sensor for GHI and DHI measurement (DNI calculated)
- Combined ambient temperature and relative humidity sensor
- Barometric pressure sensor
- Wind speed and wind direction measurement
- Precipitation sensor

MDI instrument control box containing PV panel, battery, datalogger and communication modem



AVAILABLE EQUIPMENT: MHP AUTOMATIC WEATHER STATION

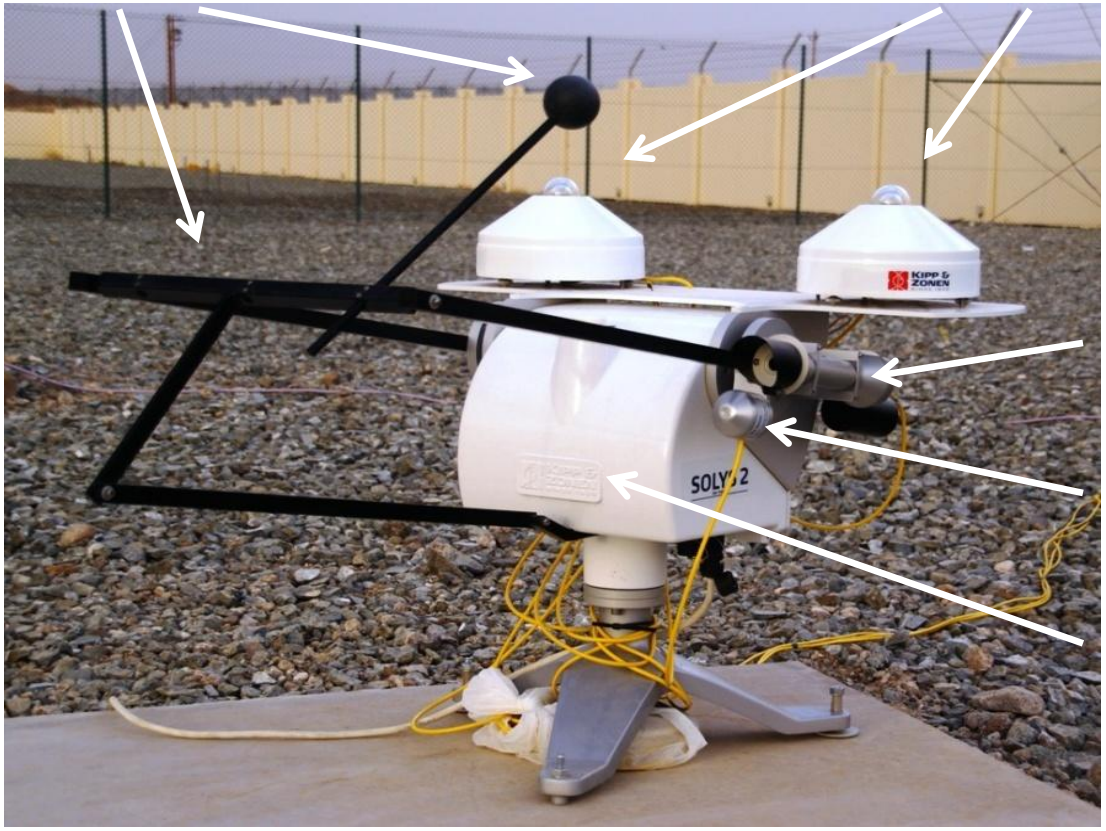
- Pyranometer for GHI, DHI measurements
- Pyrheliometer for DNI measurement, mounted on sun tracker
  - → redundant measurement, compare DNI measured with pyrheliometer with DNI calculated from GHI, DHI
- Same optional sensors as MDI station

CSPS instrument control box containing grid power connection, UPS, datalogger and communication modem

TERMOPILE SENSORS

Shading assembly with shading ball

CMP21 Pyranometer (GHI, DHI shaded) with ventilation unit CVF3

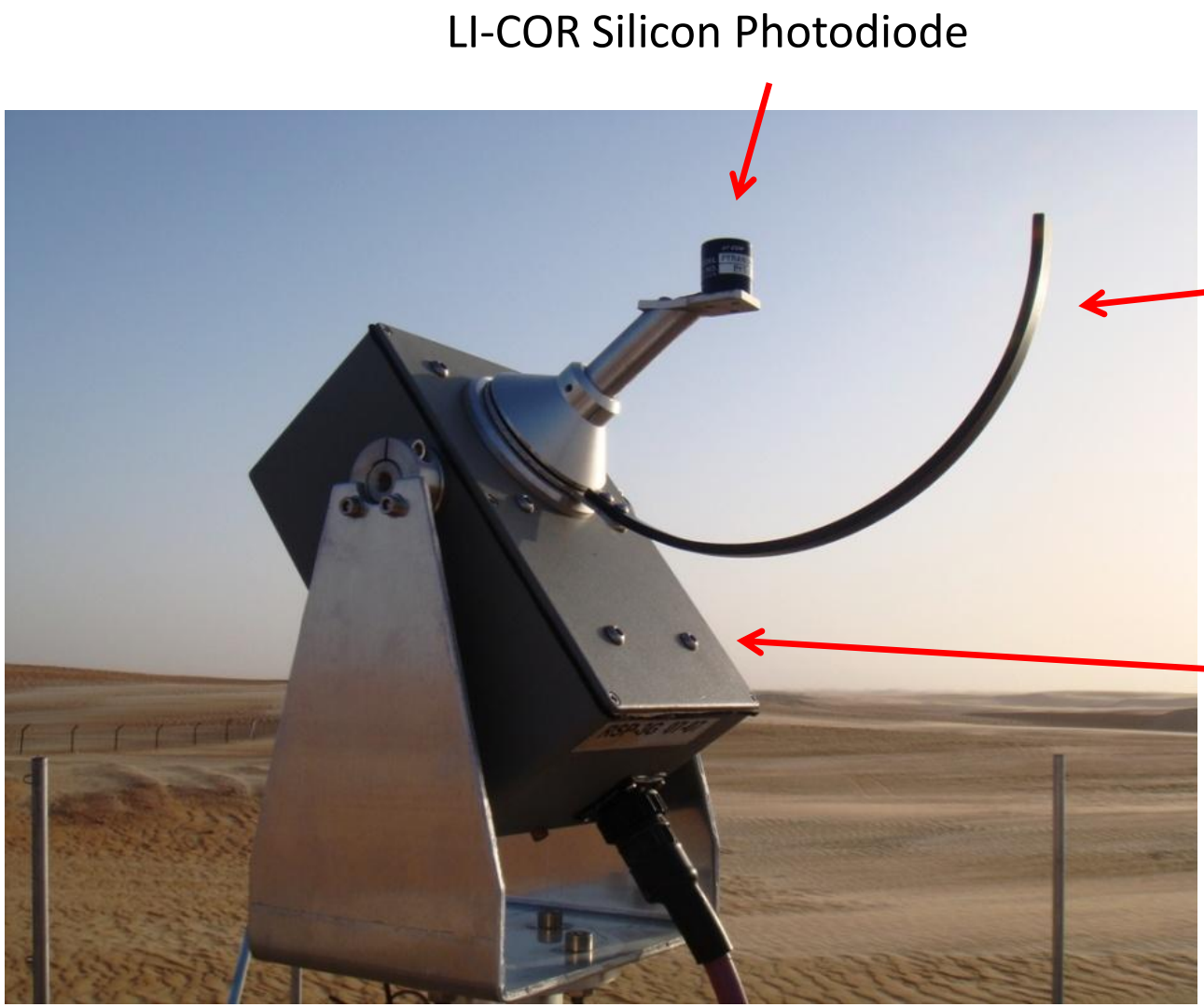


CHP1 Pyrheliometer (DNI)

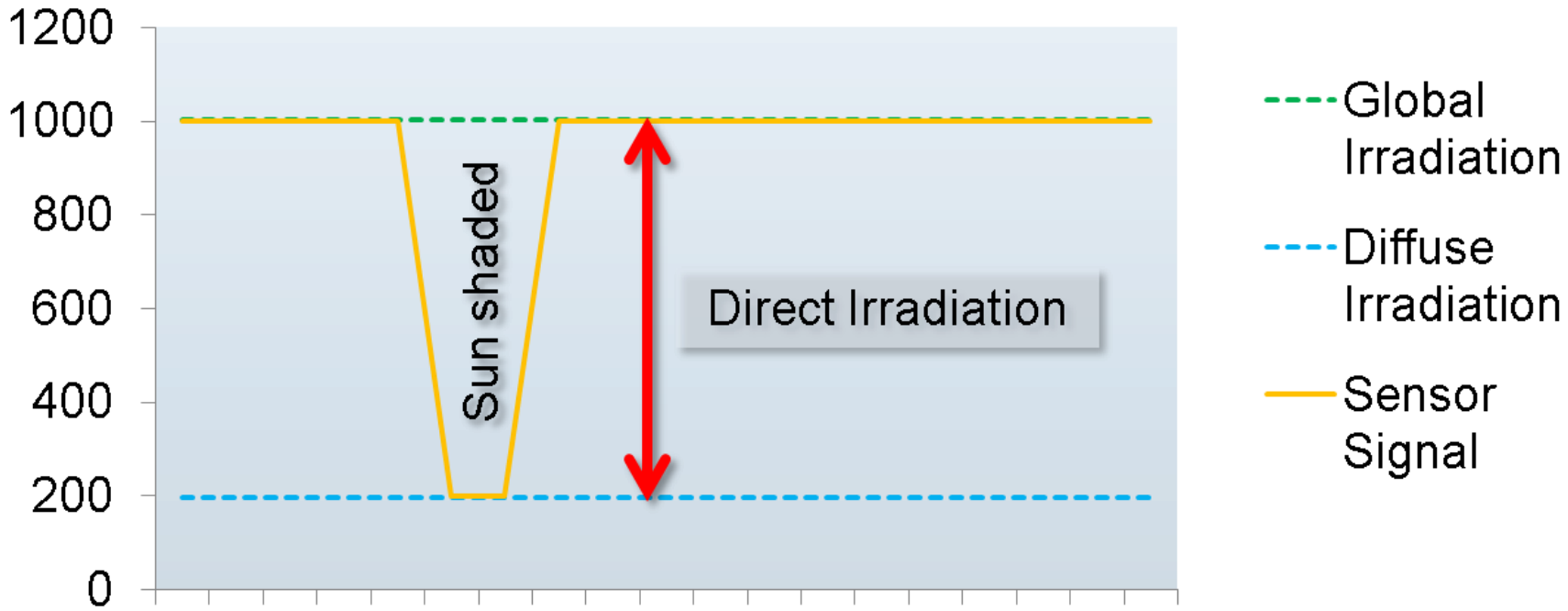
Sun sensor

Solys 2 sun tracker

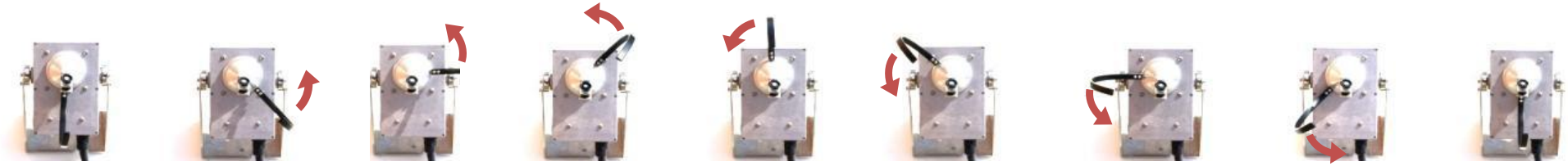
ROTATING SHADOWBAND IRRADIOMETER (RSI)



RSP – PRINCIPLE OF MEASUREMENT

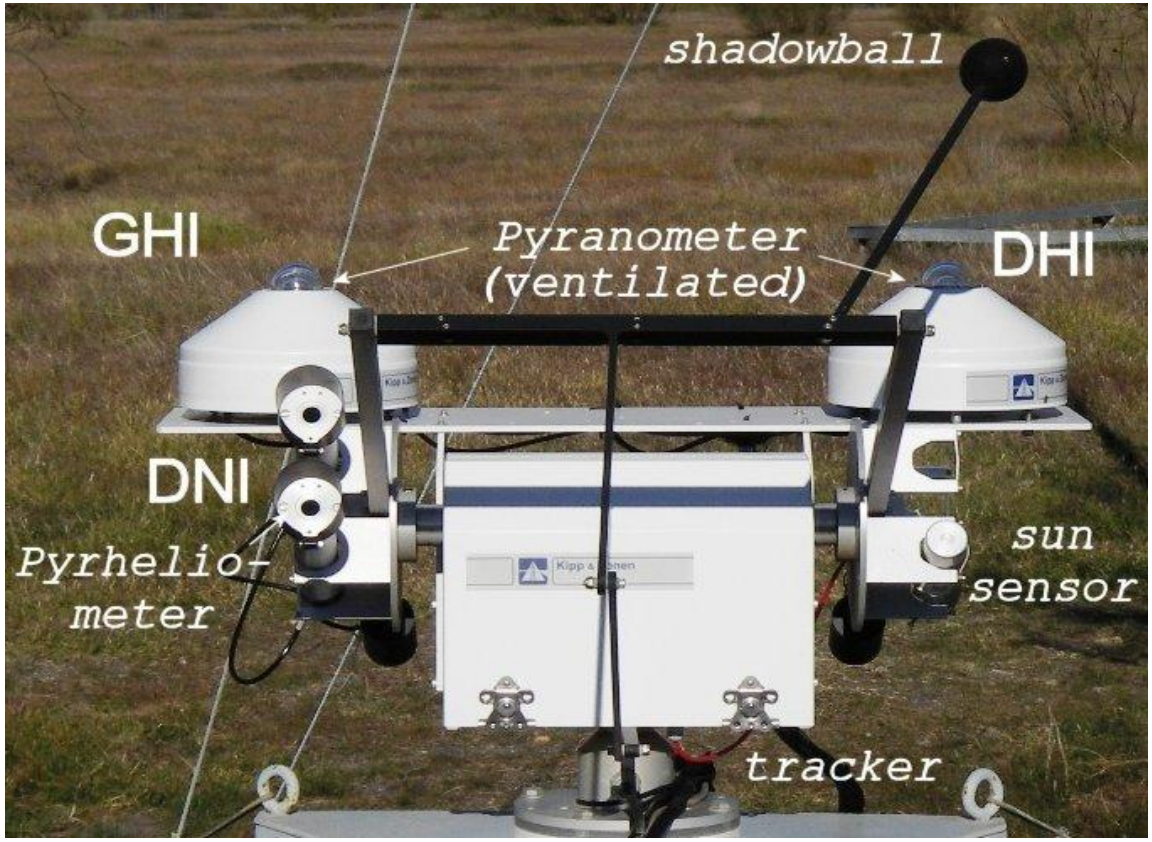


Simplified sensor signal during shadow band rotation:
once per minute, rotation lasts about 1.5 seconds



Source: Solar Millennium AG

PRECISE THERMAL SENSORS:
PYRHELIOMETER AND PYRANOMETER ON A TRACKER



Advantages:

+ high accuracy (1 to 2%)
+ separate sensors for GHI, DNI and DHI
  (cross-check through redundancy)

Disadvantages:

- High acquisition costs
- High maintenance costs
- High soiling sensitivity
- High power demand
  (grid connection required)

ROTATING SHADOWBAND IRRADIOMETER: RSI
SENSOR WITH PHOTODIODE

Advantages:

+ fair acquisition costs
+ low maintenance
+ low soiling sensitivity
+ low power demand *(PV panel)*

Disadvantages:

- systematic deviations of the measurement signal

+ corrigible!!

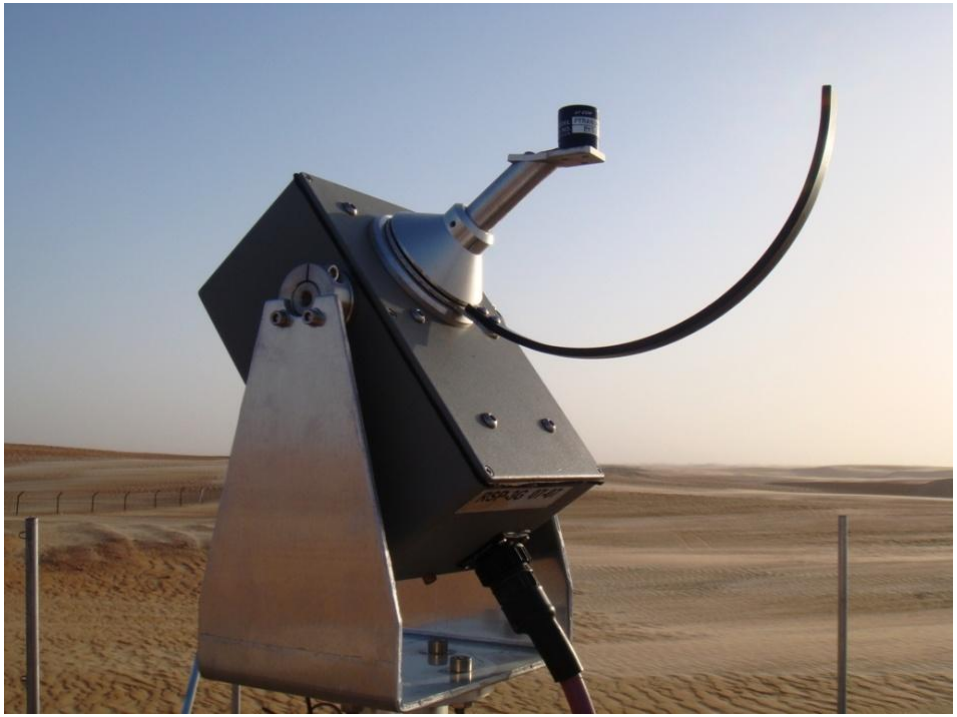
Reachable accuracy:

- uncorrected: ~ 6 %
- with corrections: ~ 2 - 3 %

CHOICE OF MEASUREMENT EQUIPMENT

Which equipment is suitable for measurements in Solar Resource Assessment?

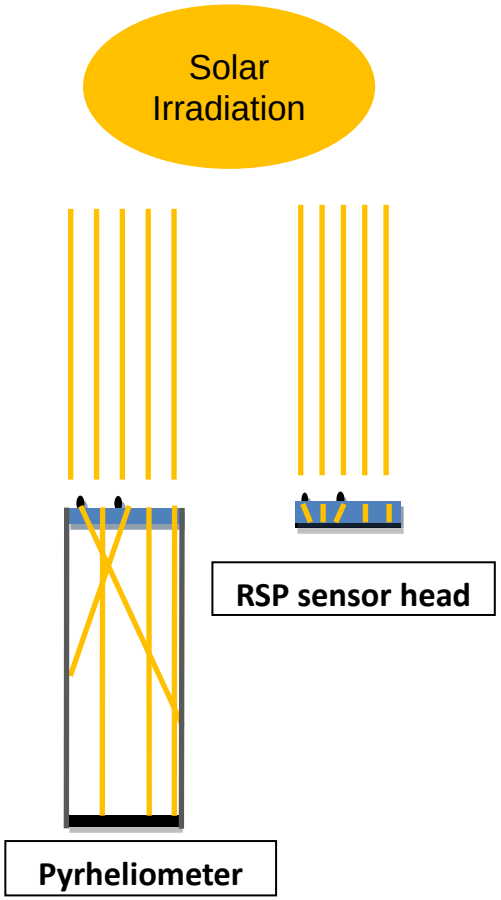
?

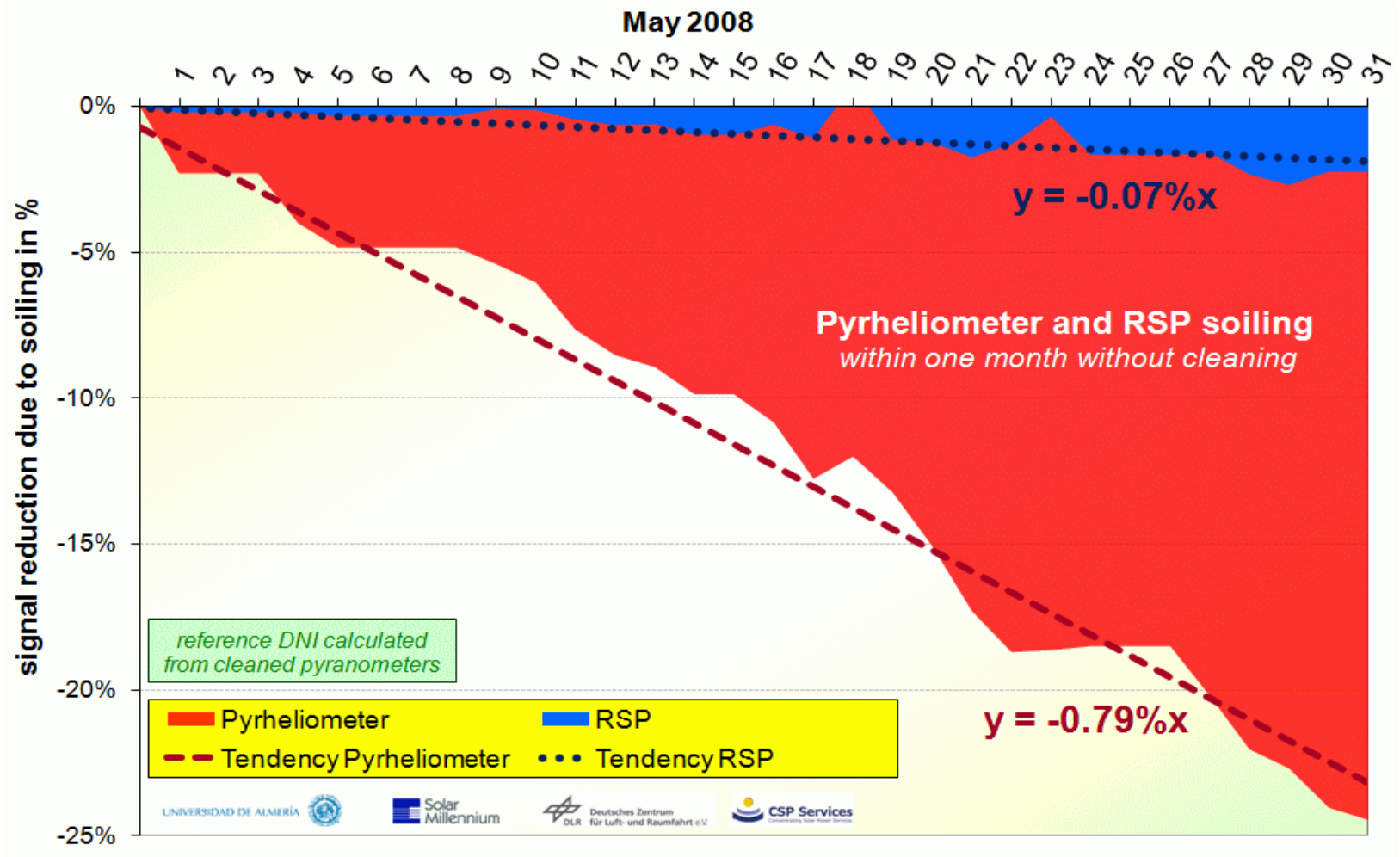


High Precision sensors (thermopiles)

Rotating Shadowband Irradiometer: RSI

SOILING CHARACTERISTICS OF PYRHELIOMETERS AND RSI‘S

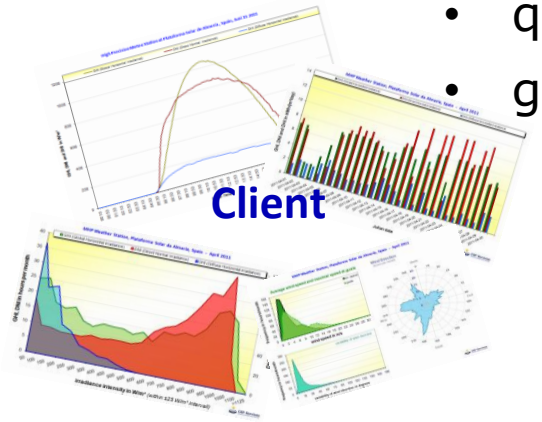




USUAL EXPERT SERVICE FOR SOLAR RESOURCE ASSESSMENT

Daily data retrieval via modem *(GSM/GPRS)*

- Delivery of hardware
- Installation & commissioning
- Operational supervision and control
- Equipment monitoring with inspection visits on site



Data collection and processing:

- accuracy enhancement (correction)
- quality and functionality check
- graphical visualization

Daily, monthly, annual report with good quality data to client (via e-mail)

Thank you very much for your attention!