Guidelines for Procurement, Calibration and Installation of Meteorological Stations

EEP Workshop, Windhoek, Namibia

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CSP Services

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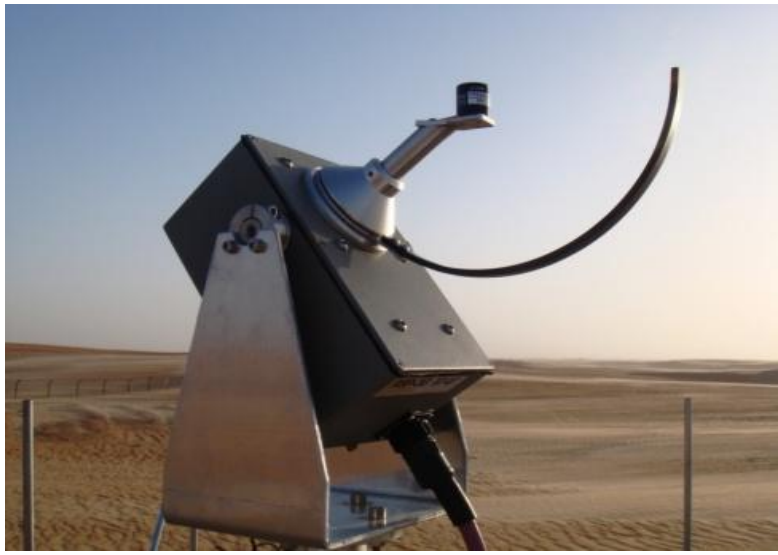
INSTRUMENTS FOR MEASUREMENT OF IRRADIANCE

- <u>Silicon photodiode:</u>
  Rotating **S**hadowband **I**rradiometer (RSI)

  Station costs: 13‘000 – 25‘000 USD



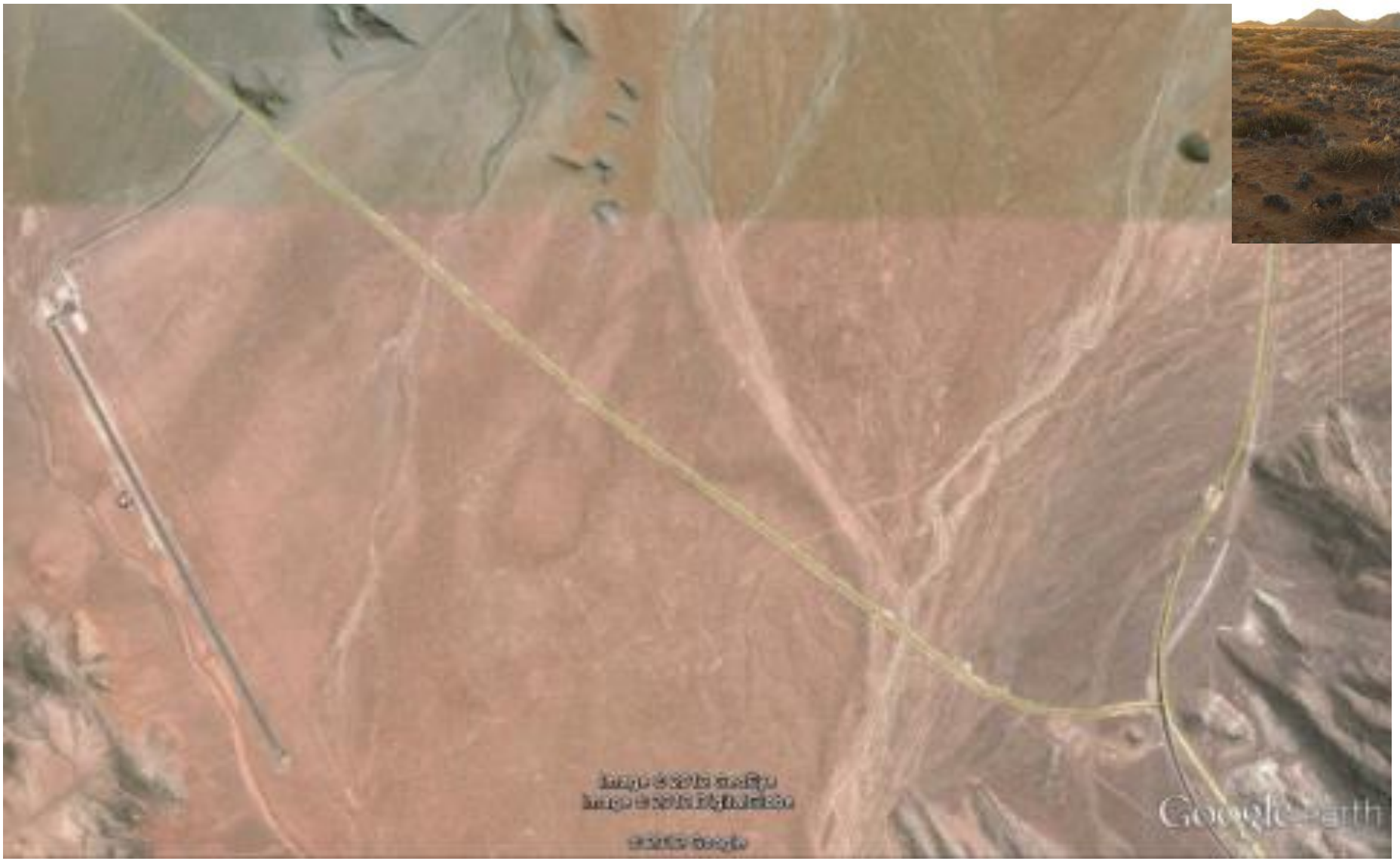
- <u>Thermopile Sensors:</u>
  pyrheliometer and
  pyranometer,
  solar tracker with shading assembly,
  ventilation

  Station costs: 35‘000 – 55‘000 USD

PROCEDURE TO FOLLOW FOR PROPER SOLAR RESOURCE ASSESSMENT

- Find a good location: close to site, safe, suitable for collocation of Weather Station
- Clarify the ground property conditions
- Check/define the budget for:
  instrumentation, maintenance and measurement related services
- Select the appropriate measurement equipment and provider
  (based on budget considerations, local conditions on site and maintenance possibilities)
- Find local maintenance personnel
- Prepare the measurement site according to the supplier's specifications
  (foundations, fencing, etc.)
- Installation and commissioning of the measurement equipment
- Steady monitoring of the measurement data,
  duration minimum 1 year

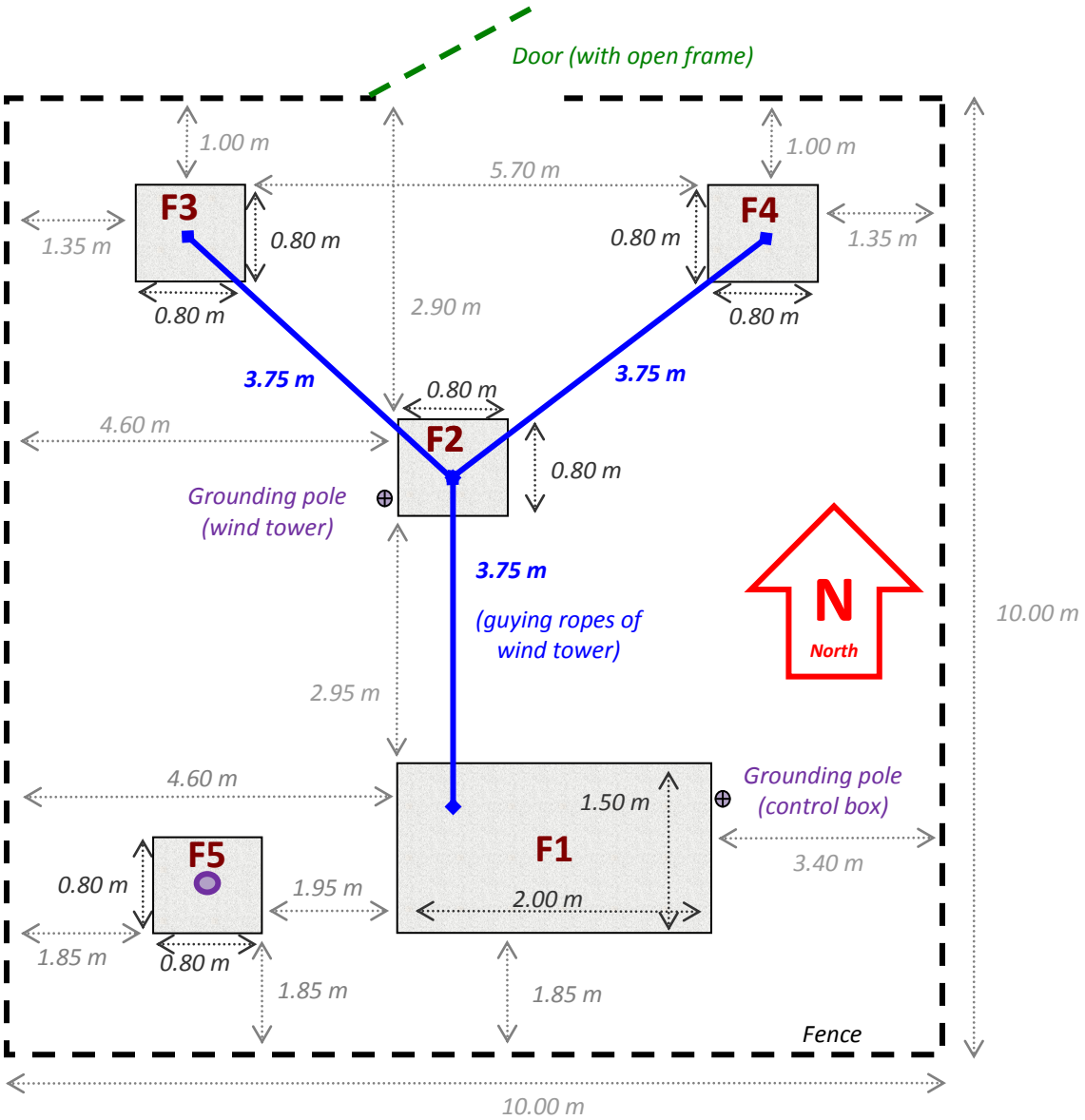
EXEMPLARY SITE SELECTION



PROCEDURE TO FOLLOW FOR PROPER SOLAR RESOURCE ASSESSMENT

- Documenting the selection of instruments
- Choosing a renowned company or institution to conduct or assist the measurement campaign
- Documenting sensor calibration with proper calibration certificates
- Meticolously documenting the instrument installation and alignment
- Performing and documenting regular sensor cleaning, maintenance and verification of alignment
- Cautiously and continuously checking data for errors and outliers
- Flagging suspect data, and applying corrections if possible, during and after the measurement campaign
- Stating and justifying the uncertainty estimate in a detailed report after the measurement campaign.

GENERAL REQUIREMENTS FOR THE LOCATION OF A WEATHER STATION



- Dimensions at least 10×10 m², firm and horizontally leveled ground
- No obstructions (buildings, vegetation) in the environment
- No hollows, steep slopes, swamps
- No power lines
- No industrial or dusty areas, no close-by street
- No quickly growing vegetation
- Accessibility by car
- GSM data connection available
- Secured by a fence
- Local staff available for maintenance available

SITE PREPARED FOR INSTALLATION OF A METEOROLOGICAL STATION

EQUIPMENT AND SPECIFICATIONS

	Measured value	Unit	Accuracy	Range
DNI	Direct Normal Irradiation	W/m²	instantaneous values: < ± 3.5 %, annual sum: < ± 2 %	0 to 1500 W/m²
GHI	Global Horizontal Irradiation	W/m²	instantaneous values: < ± 4 %, annual sum: < ± 3 %	0 to 1500 W/m²
DHI	Diffuse Horizontal Irradiation	W/m²	instantaneous values: < ± 10 %, annual sum: < ± 5 %	0 to 800 W/m²
Measured value		**Unit**	**Accuracy**	**Range**
Ambient Temperature		°C	± 0.4 °C (range: + 5 to 40°C) ± 0.9 °C (range: - 40 to 70°C)	-40 to + 70°C
Relative humidity		%	± 2 % (range: 10 to 90%) ± 4 % (range: 0 to 95%)	0 to 100 %
Wind speed		m/s	0.1 m/s (range: 5 to 25 m/s)	1 to 96 m/s
Wind direction		°N	<5° installed	0 to 360°N
Barometric pressure		hPa	1.0 hPa (range: 0°C to 40°C)	600 to 1100 hPa
Precipitation		mm	2 % (< 50 mm hr^{-1})	0 to 700 mm/hr, (-40°) 0°C to 70°C

RECOMMENDATIONS FOR THE EQUIPMENT

Measurement equipment

- Mounted locked and safely in a weather-proof box, safe against animal bites, easily accessible for maintenance and inspection purposes.
- Made of stainless steel and/or UV resistant material
- Data logging at 1 Hz sampling rate, data storing at 10 min resolution for at least one year.

Power supply

Weather Stations for unattended remote sites via a solar panel and backup battery

Grounding and shielding

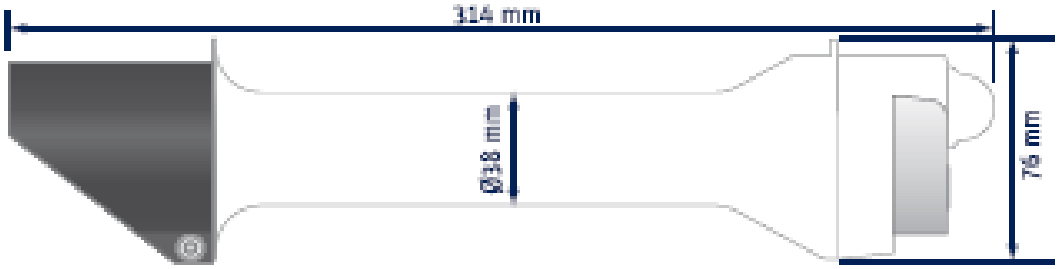
properly grounded and shielded

Communication and data transfer

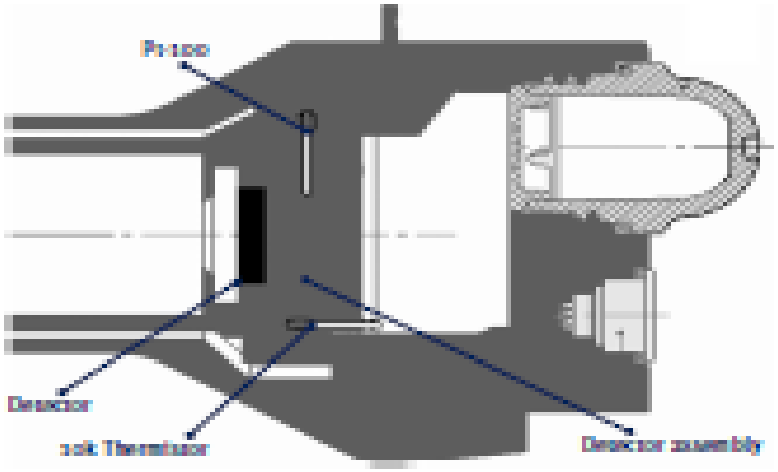
GSM/GPRS or 3G data transfer, optionally via satellite connection

THERMOPILE SENSORS – PYRHELIOMETER

Principle of Measurement:



- Pyrheliometer = radiometer suitable to measure Direct Normal Irradiance (DNI)
- Highly transparent window 97 – 98 % transmission of solar radiation
- Housing geometry with 200 mm absorber tube restricting acceptance angle to 5°
- Sensing element with black coating and built-in termopile
- Pt-100 temperature sensor for temperature corrections



www.kippzonen.com/?product/18172/CHP+1.aspx

PYRHELIOMETER SPECIFICATIONS

Kipp&Zonen CHP1 Specifications:

Spectral range: 200 to 4000 nm

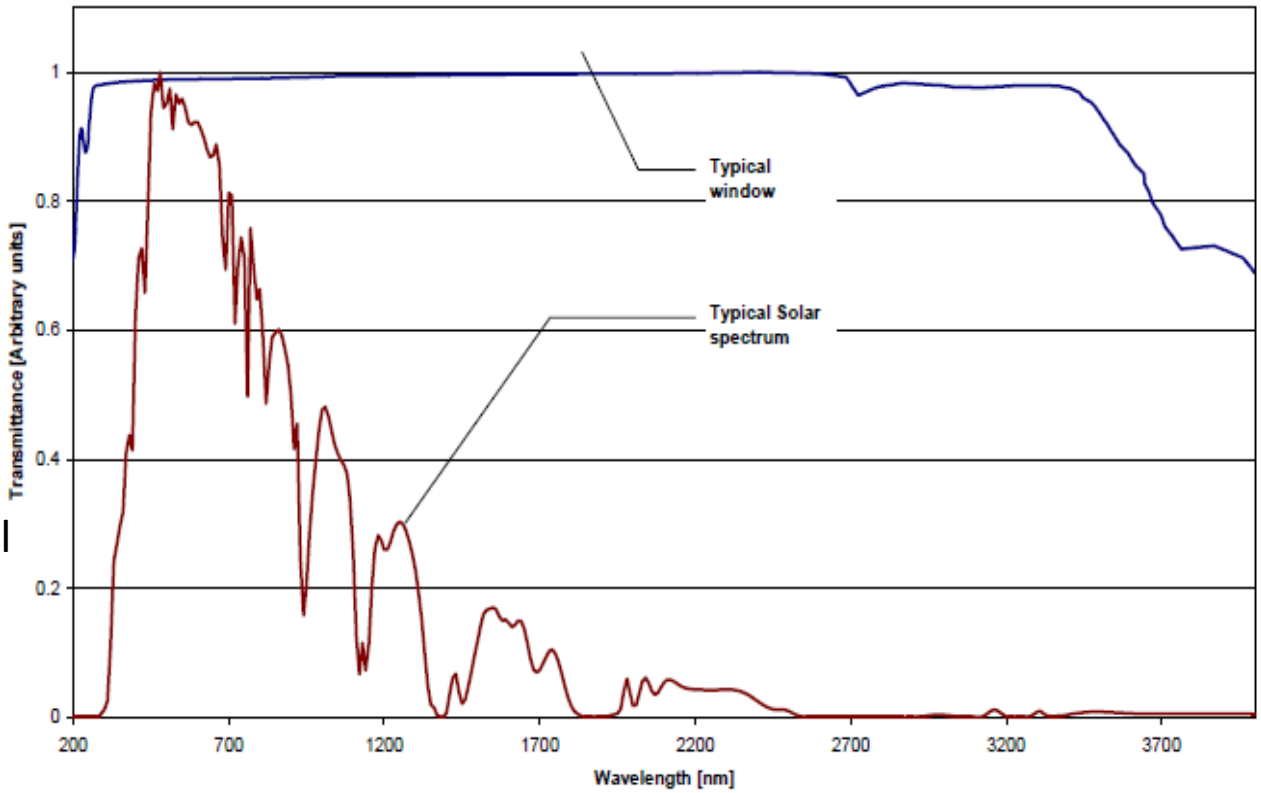
Sensitivity: 7 to 14 µV/W/m² (mV/kW/m²)

Response time: < 5 s

Expected daily uncertainty: ± 1 %
(when proper calibrated and clean)

Full opening view angle: 5° ± 0.2°

Required tracking accuracy: ± 0.5° from ideal

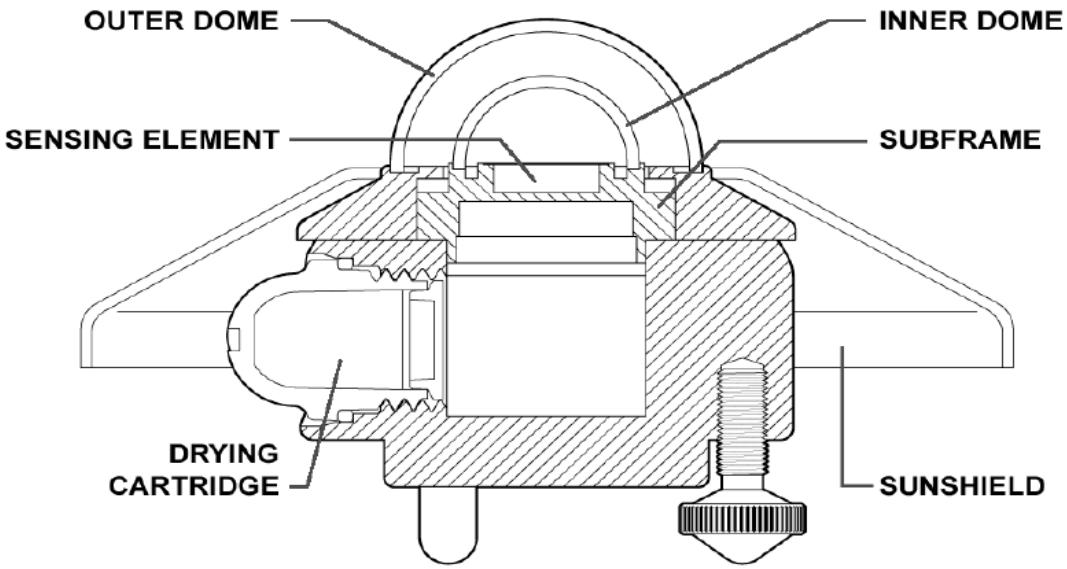


www.kippzonen.com/?product/18172/CHP+1.aspx

THERMOPILE SENSORS – PYRANOMETER

Principle of Measurement:

- Pyranometer = radiometer suitable to measure short-wave irradiance (0.2 - 4 µm): global or diffuse
- Highly transparent glass dome 97 – 98 % transmission of solar radiation
- Full view on 2π hemisphere (horizontal levelling required)
- Sensing element with black coating and built-in termopile
- Pt-100 temperature sensor for temperature corrections



www.kippzonen.com/?product/18172/CHP+1.aspx

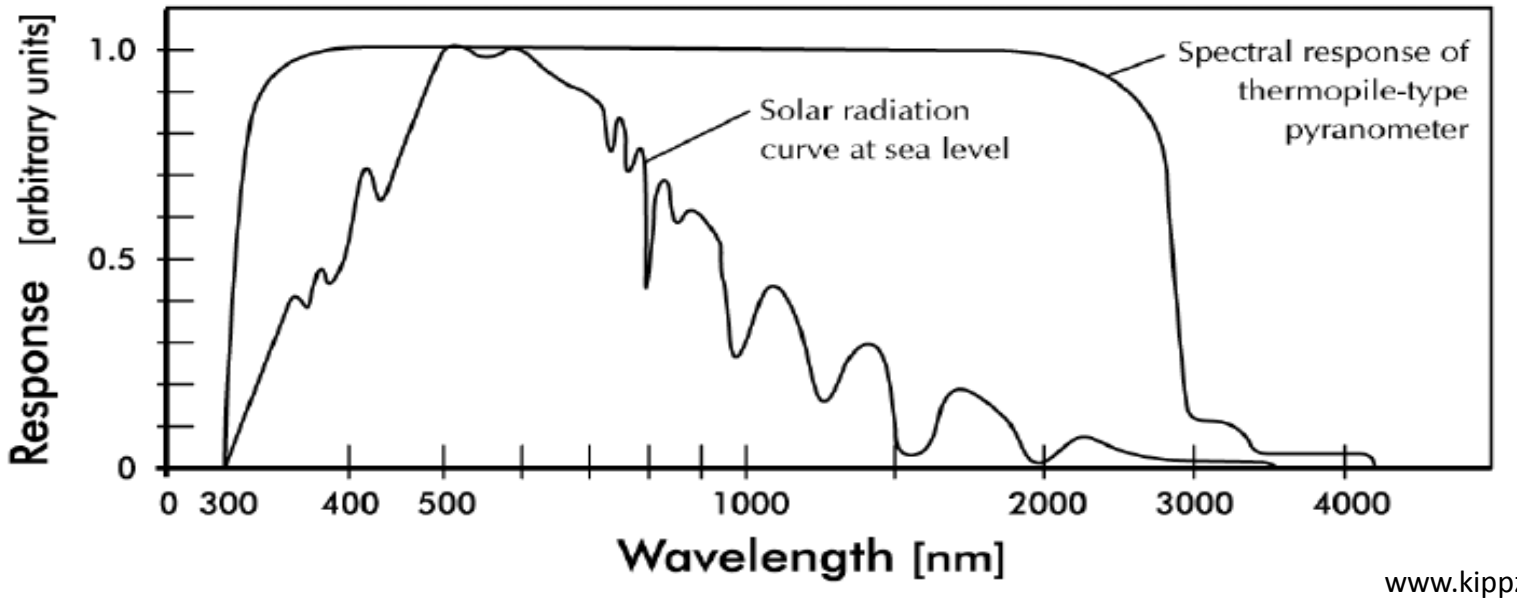
THERMOPILE SENSORS – PYRANOMETER

Kipp&Zonen CMP21 Specifications:

Spectral range: 285 to 2800 nm

Sensitivity: 7 to 14 µV/W/m² (mV/kW/m²)

Response time: 5 s



www.kippzonen.com/?product/1491/CMP+21.aspx

LICOR LI-200 PYRANOMETER SENSOR

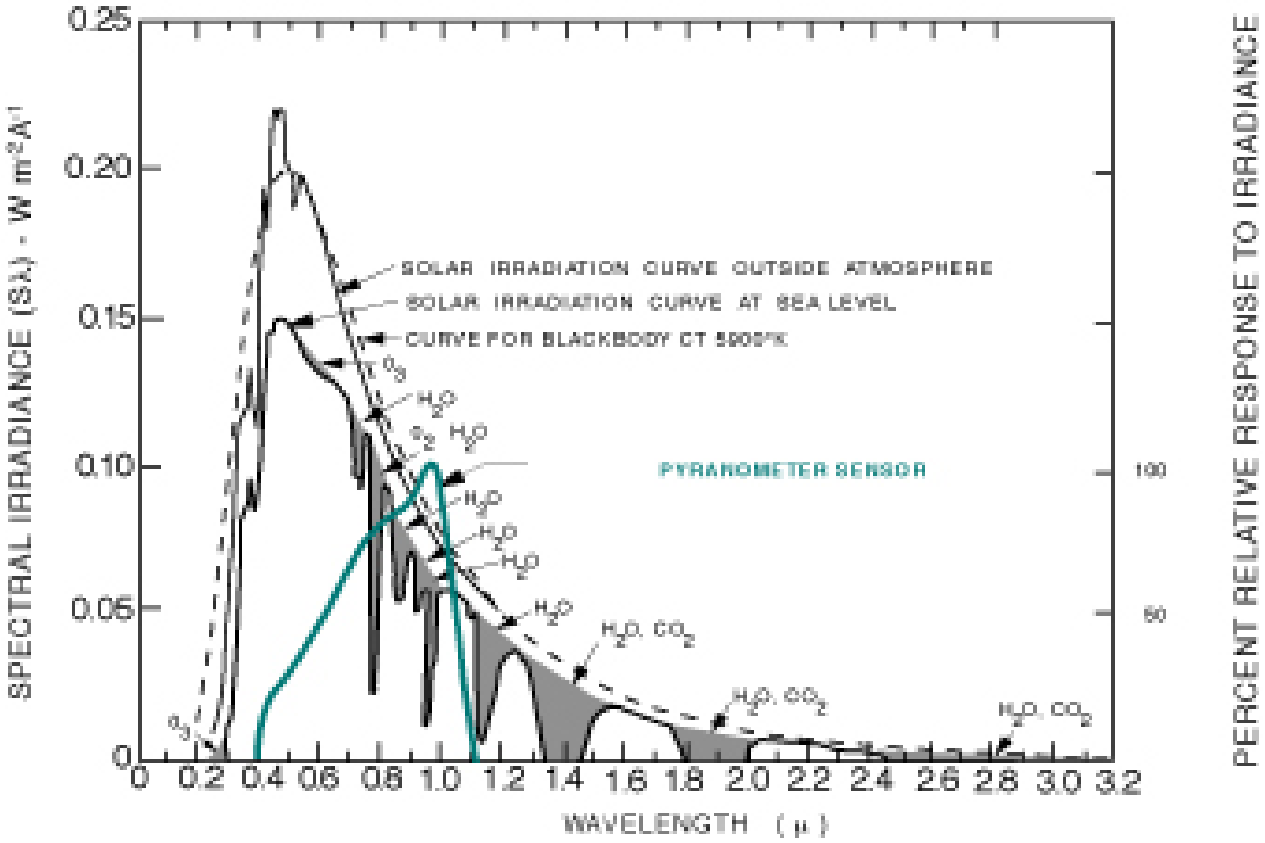
LI-COR Photodiode Specifications:

Sensitivity: Typically 90 µA per 1000 W/m²

Response time: 10 µs.

Spectral range: 0.4 – 1.1 µm

Pre-Calibration at manufacturer:
Calibrated against an Eppley Precision Spectral Pyranometer under natural daylight conditions. Typical error under these conditions is ± 5%.



www.licor.com/env/Products/Sensors/200/li200_description.jsp

ABSOLUTE CAVITY RADIOMETER

Principle of Measurements:

- Possibility to measure absolute irradiance values. All other irradiance measurement devices need to be calibrated using an absolute cavity radiometer

- Its principle of operation is based on the substitution of radiative power by electrical (heating) power

- Measurement in intervals with minimal length of 45 s. Constant irradiation required for measurement campain

- Tracking device required

- No continuous measurement (!)

ftp.pmodwrc.ch/pub/pmo6-cc/user_guide_11.pdf

Valid for calibration purposes

WORLD RADIOMETRIC REFERENCE (WRR)

- The World Standard Group (WSG) is an assembly of highly precise Absolute Cavity Radiometers.

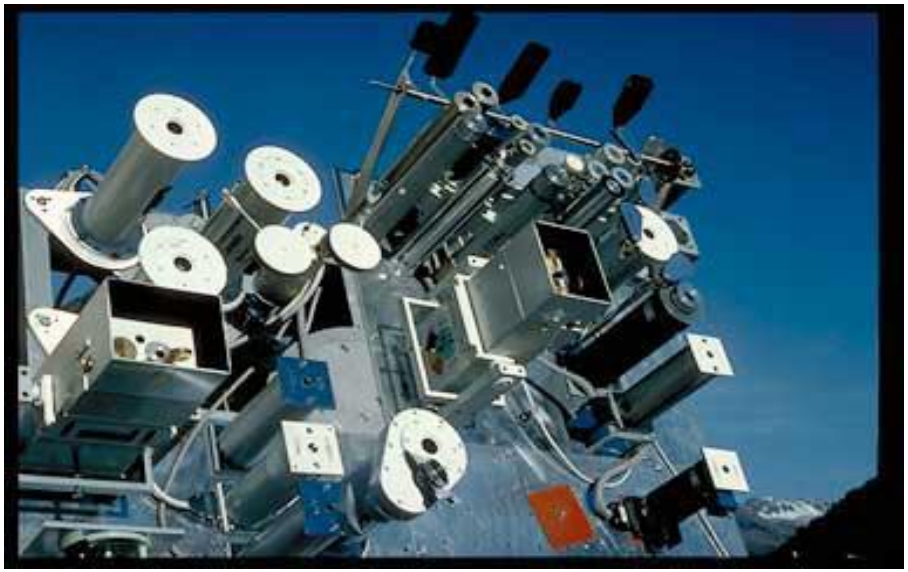
- The mean value of WSG is the measurement standard WRR (World Radiometric Reference), representing the SI unit of radiance with an estimated accuracy of 0.3 %.

- All other short wave irradiation measurement systems are compared against WRR value, calibration chain needs to be retraceable to the WRR.

- Calibration accuracy of field pyrheliometer : ~ 1.1 %

  (due to calibration chain)

www.pmodwrc.ch/pmod.php?topic=wrc

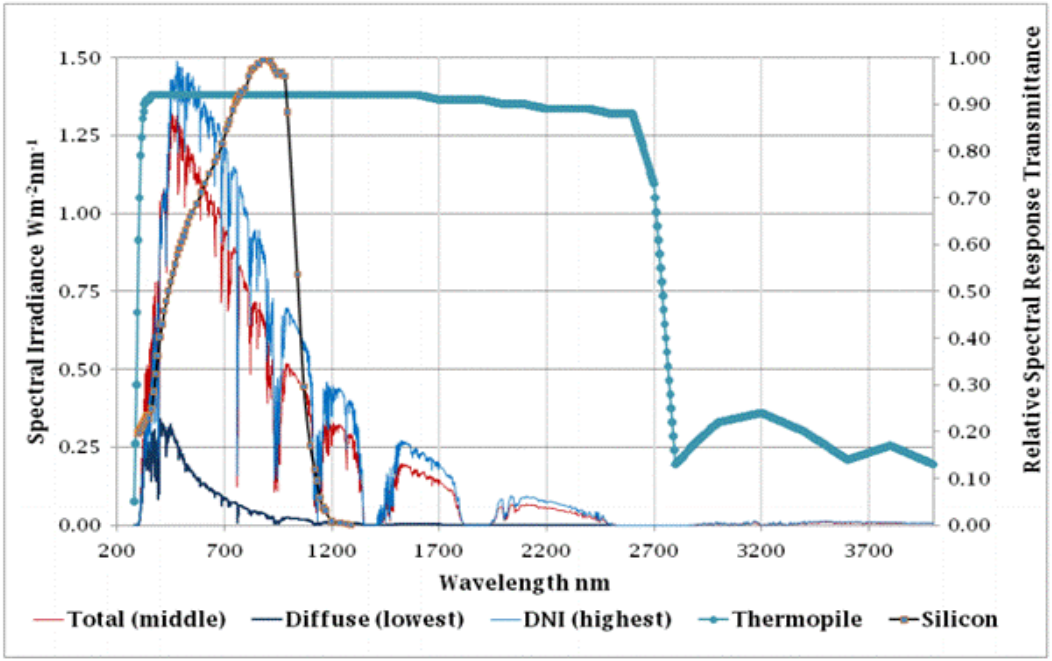


Definition of WRR, the radiance SI unit, with the World Standard Group (WSG) at the World Radiation Center (WRC) in Davos, Switzerland

GENERAL SENSOR CALIBRATION FUNDAMENTALS

- Thermopile sensors are usually calibrated against national reference standards, which are calibrated against WRR at WRC
- Due to the usually uniform spectral sensitivity of thermopile sensors, one constant Calibration Factor is sufficient

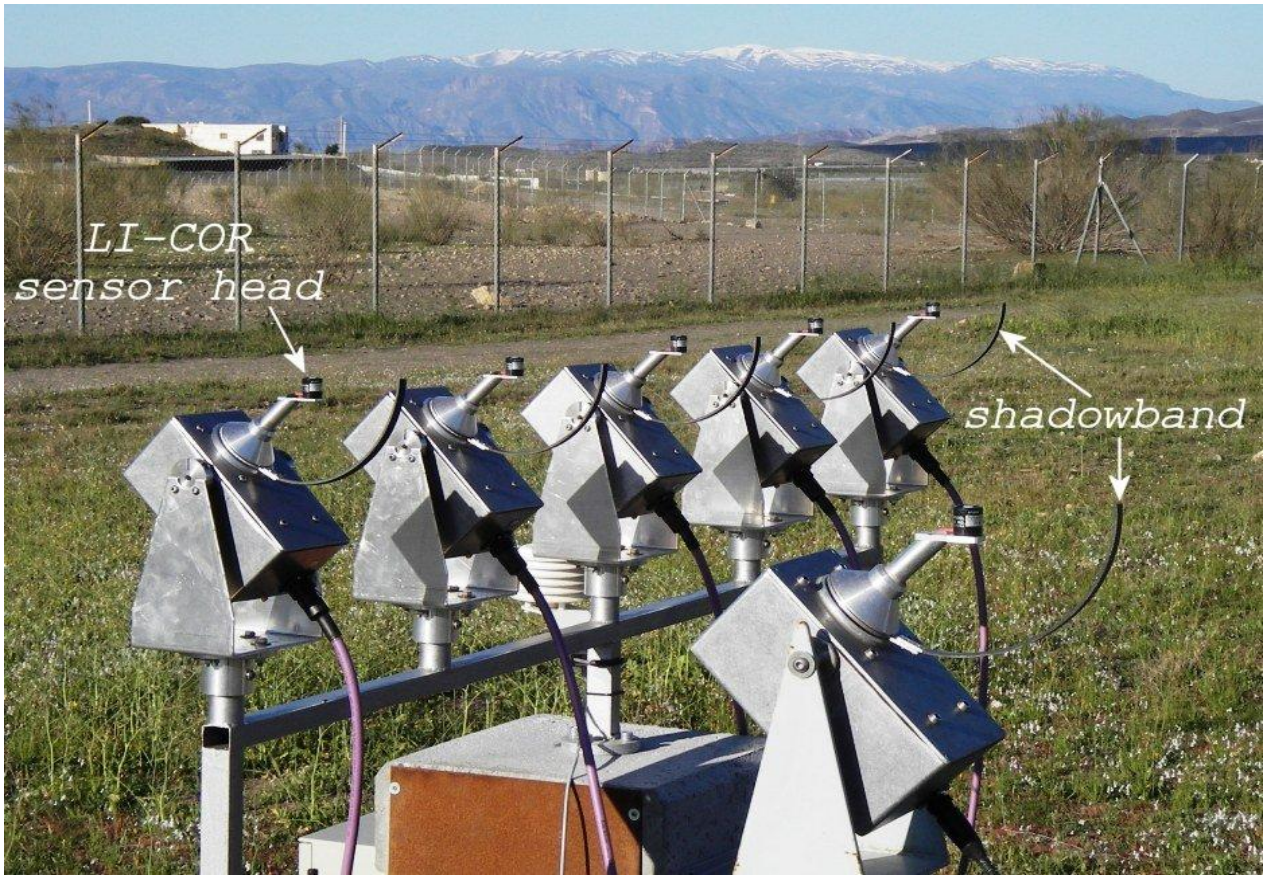
- Photodiode sensors are usually compared to high-precision reference instruments like thermopile sensors
- Due to their non uniform sensitivity (spectrum, temperature, intensity, etc.), more complicated corrections need to be applied



RADIOMETER CHARACTERISTICS

- **Calibration Stability**
  can it maintain a calibration over a long period of time?
- **Cosine response**
  are the optics of a quality that the signal output is independent of solar elevation?
- **Temperature stability**
  will a given input provide the same output voltage independent of temperature?
- **Spectral Quality**
  is the instrument spectrally flat across the solar spectrum so that it responds linearly to changes in the solar spectrum?
- **Tilt**
  does the instrument behave the same when tilted?

CALIBRATION OF RSI INSTRUMENTS

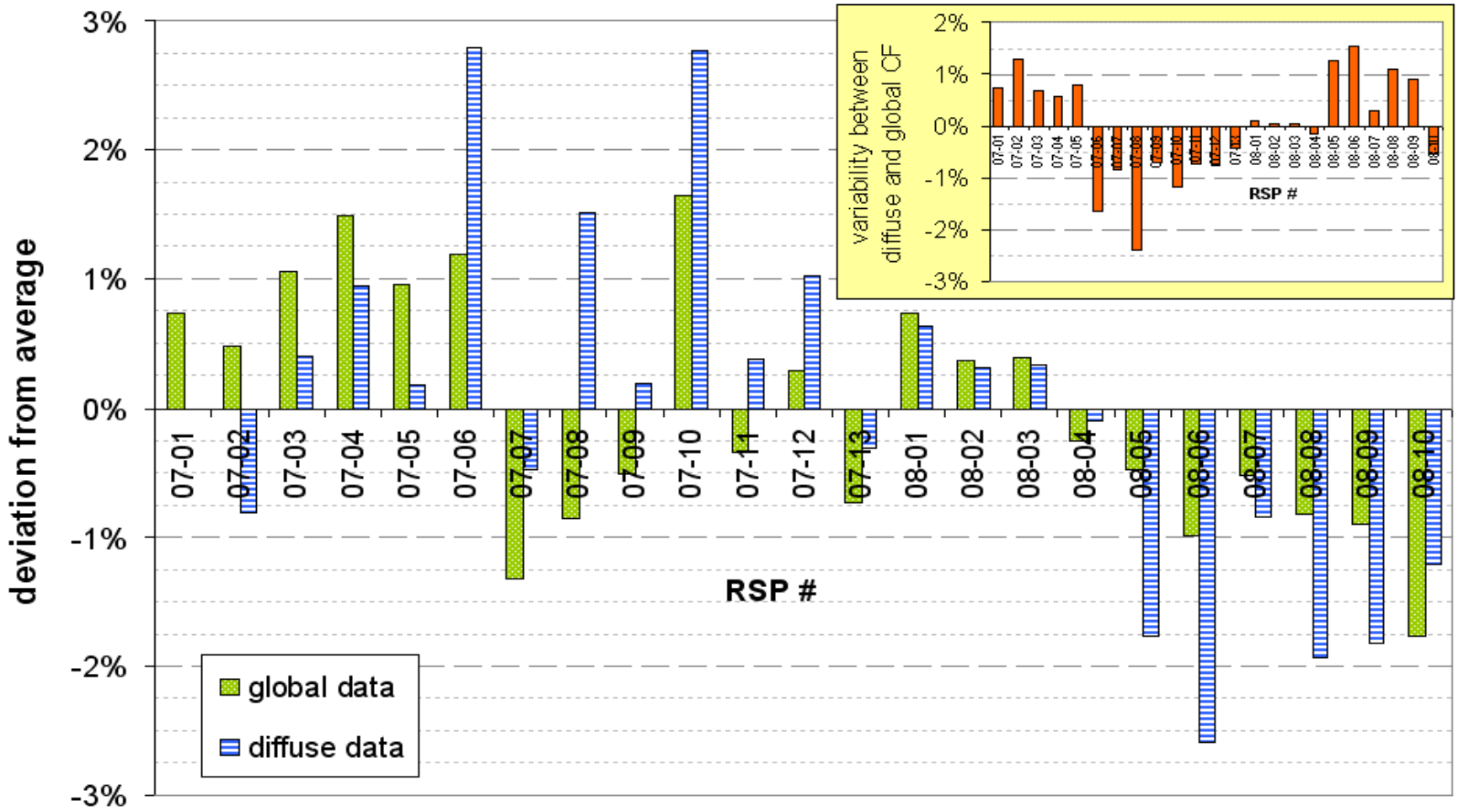


Calibration of the RSIs:
for example by
German Aerospace Center (DLR)
during 2 months against
High-Precision instruments
on Plataforma Solar de Almería

(recommended frequency:
every 2 years)

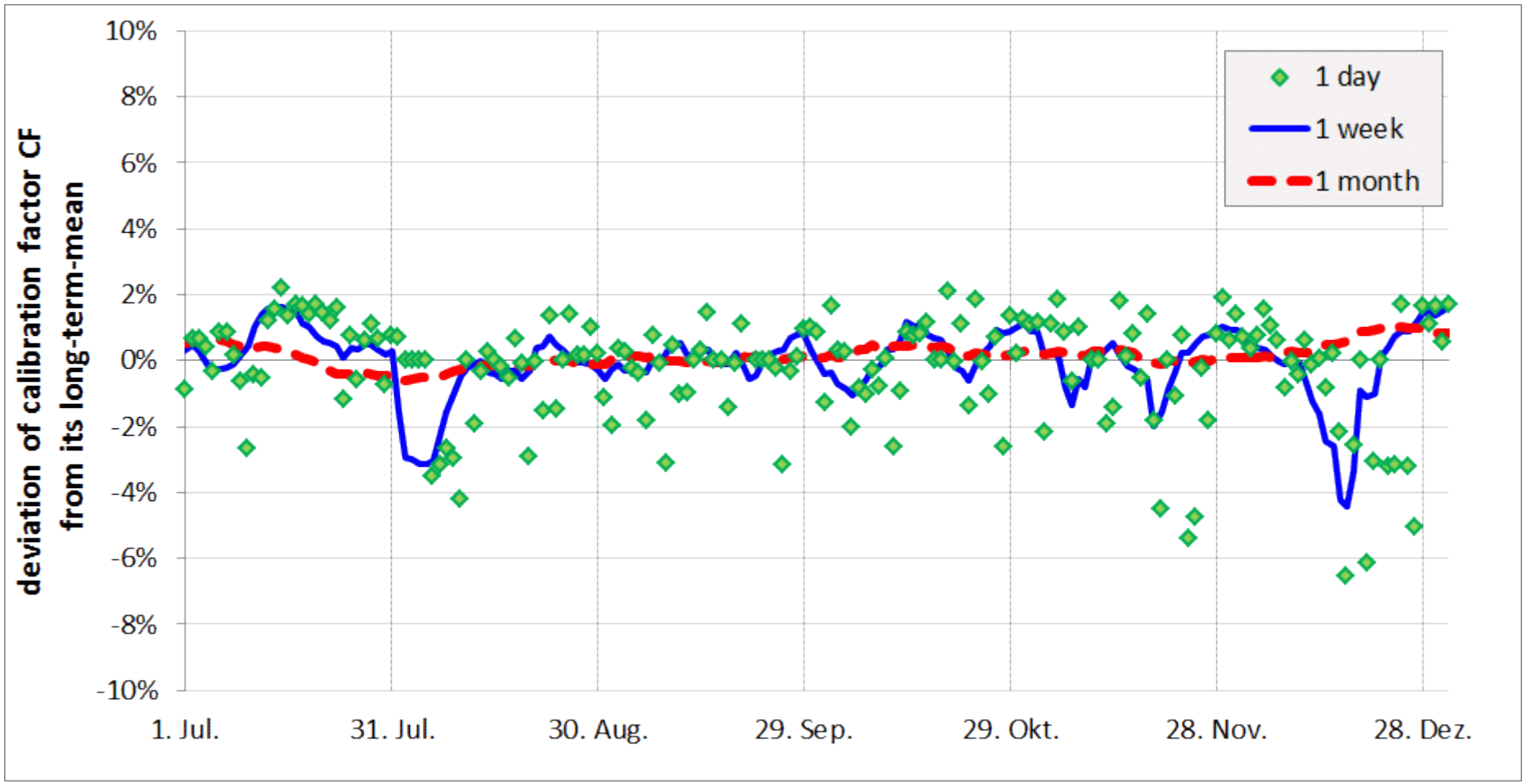
DLR High-Precision instruments are calibrated regularly with ACR

CARACTERISTICS OF THE RSI CALIBRATION FACTOR



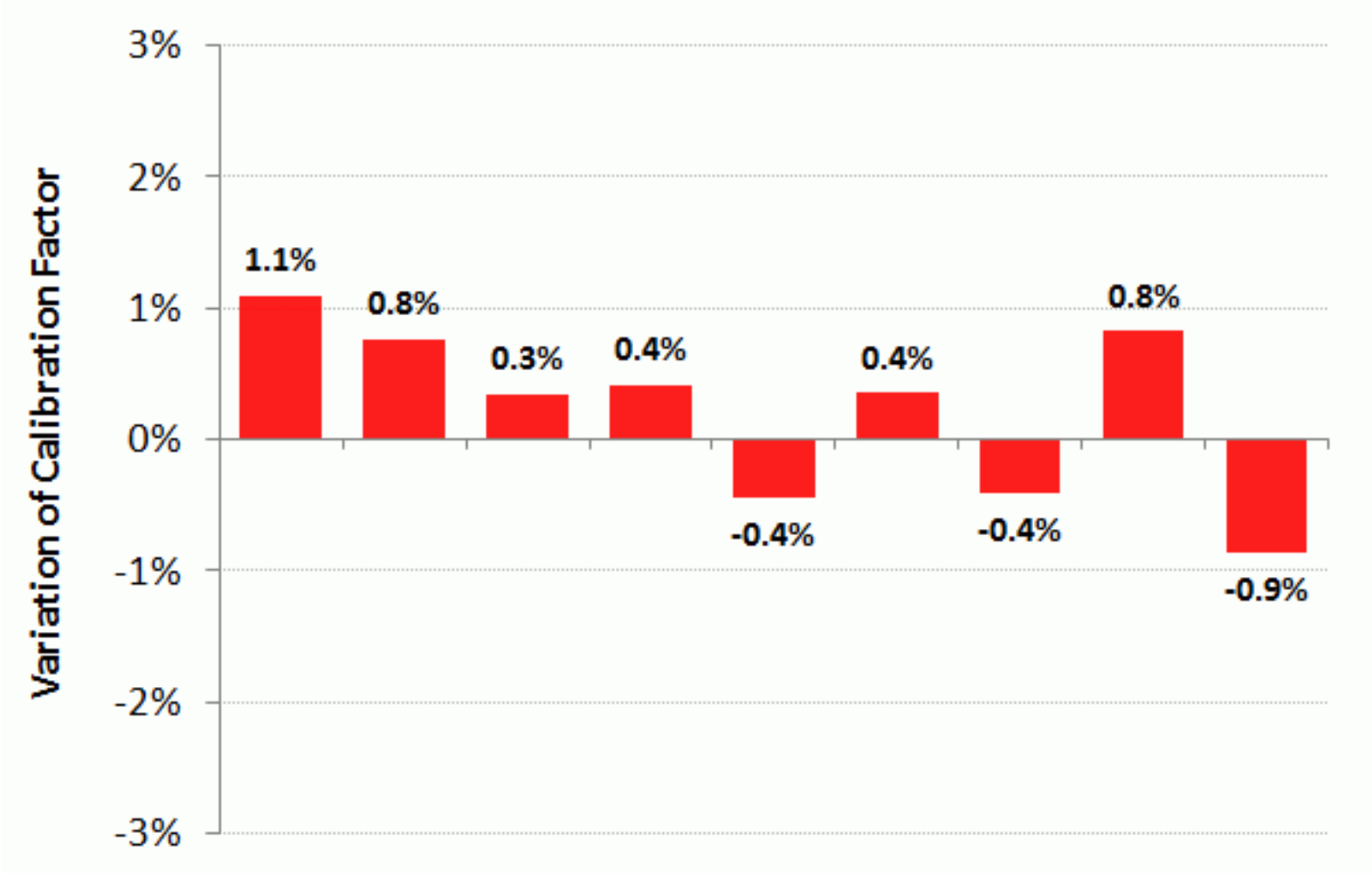
Differing Calibration Factor for Diffuse and Global Irradiance

NECESSARY DURATION OF RSI CALIBRATION

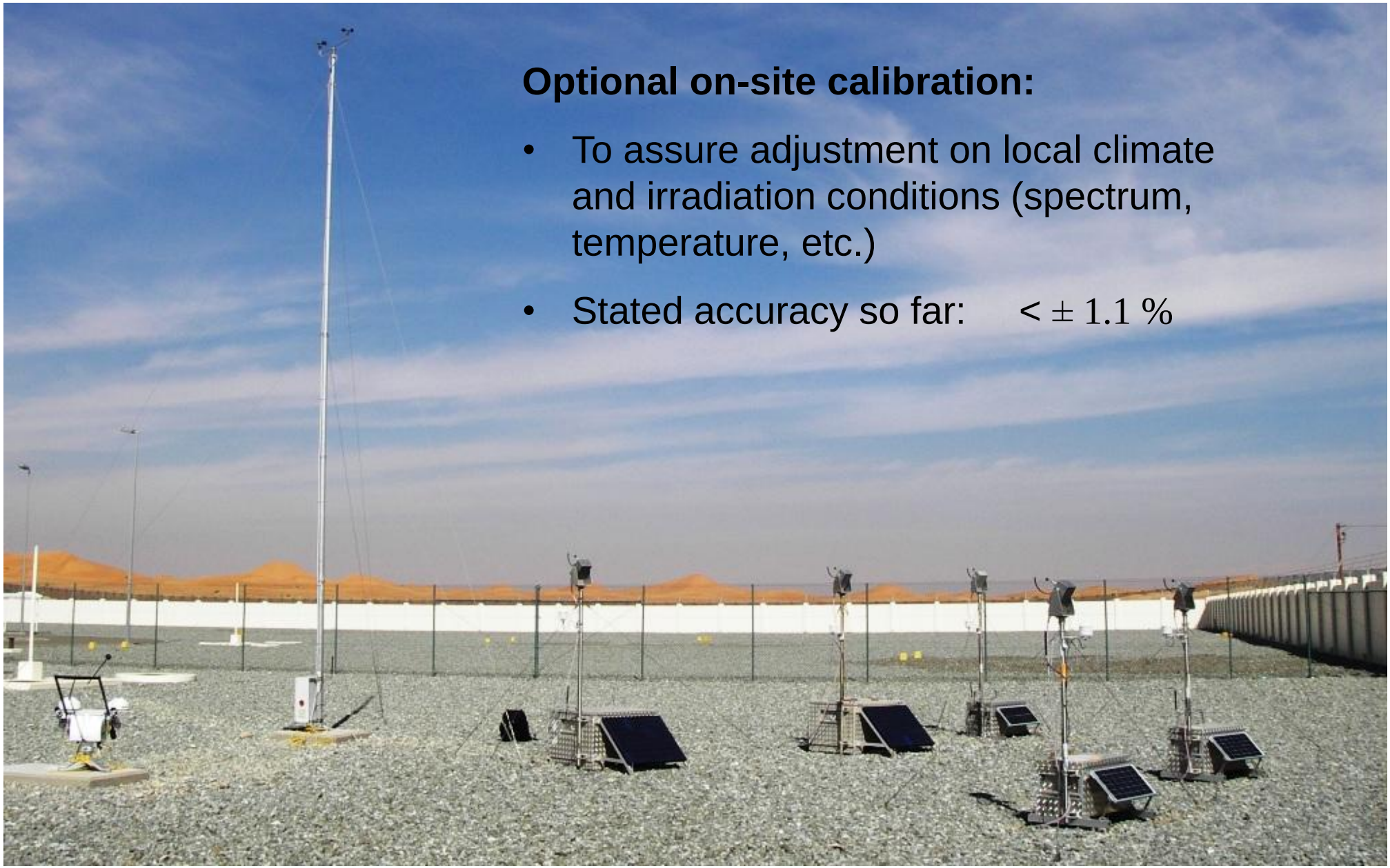


Duration of RSI field calibration >4 weeks

LI-COR SENSOR DRIFT (FROM RECALIBRATION)



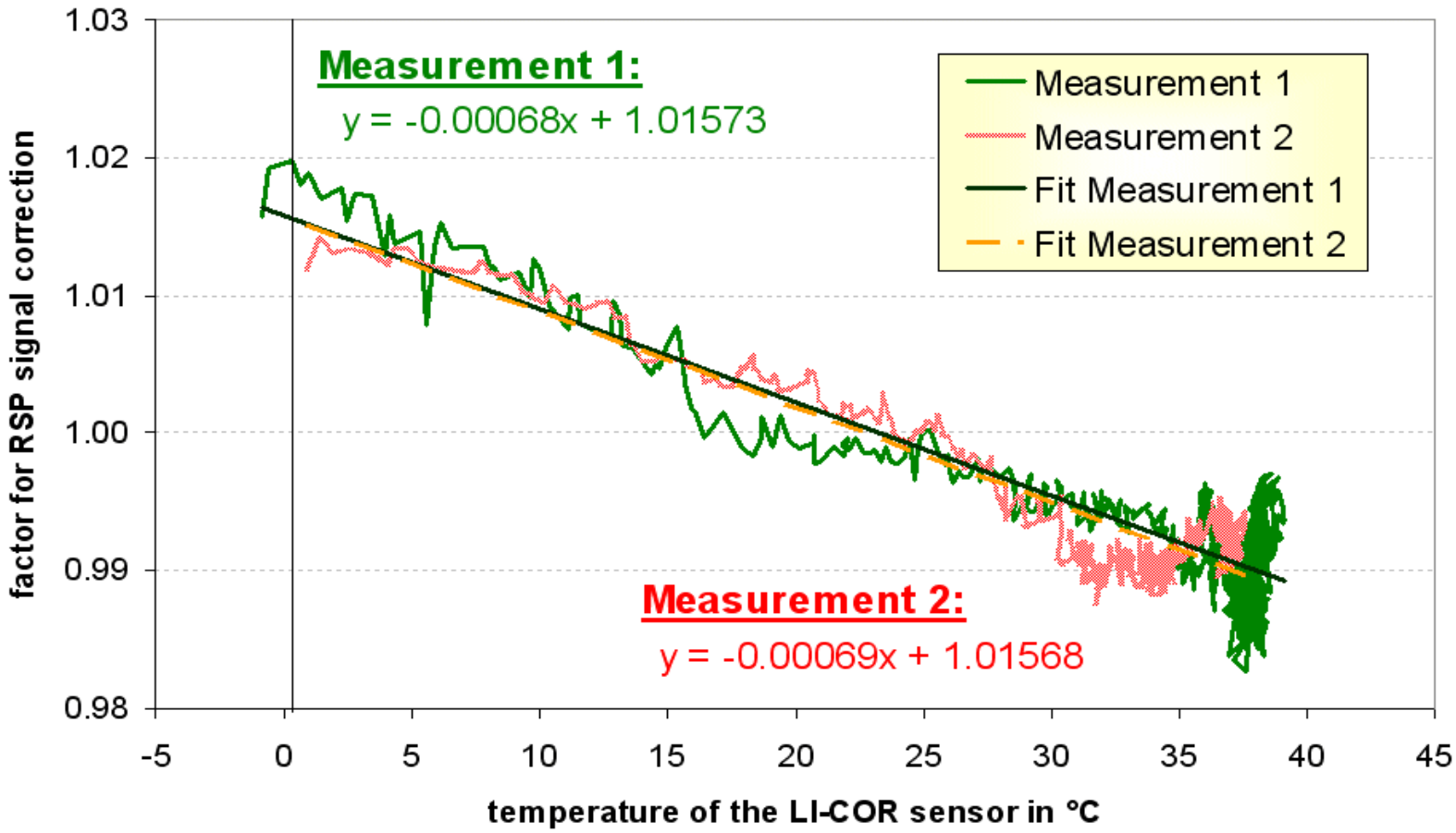
RSI ON-SITE CALIBRATION (AGAINST HIGH-PRECISION EQUIPMENT)



Optional on-site calibration:

- To assure adjustment on local climate and irradiation conditions (spectrum, temperature, etc.)
- Stated accuracy so far: < ± 1.1 %

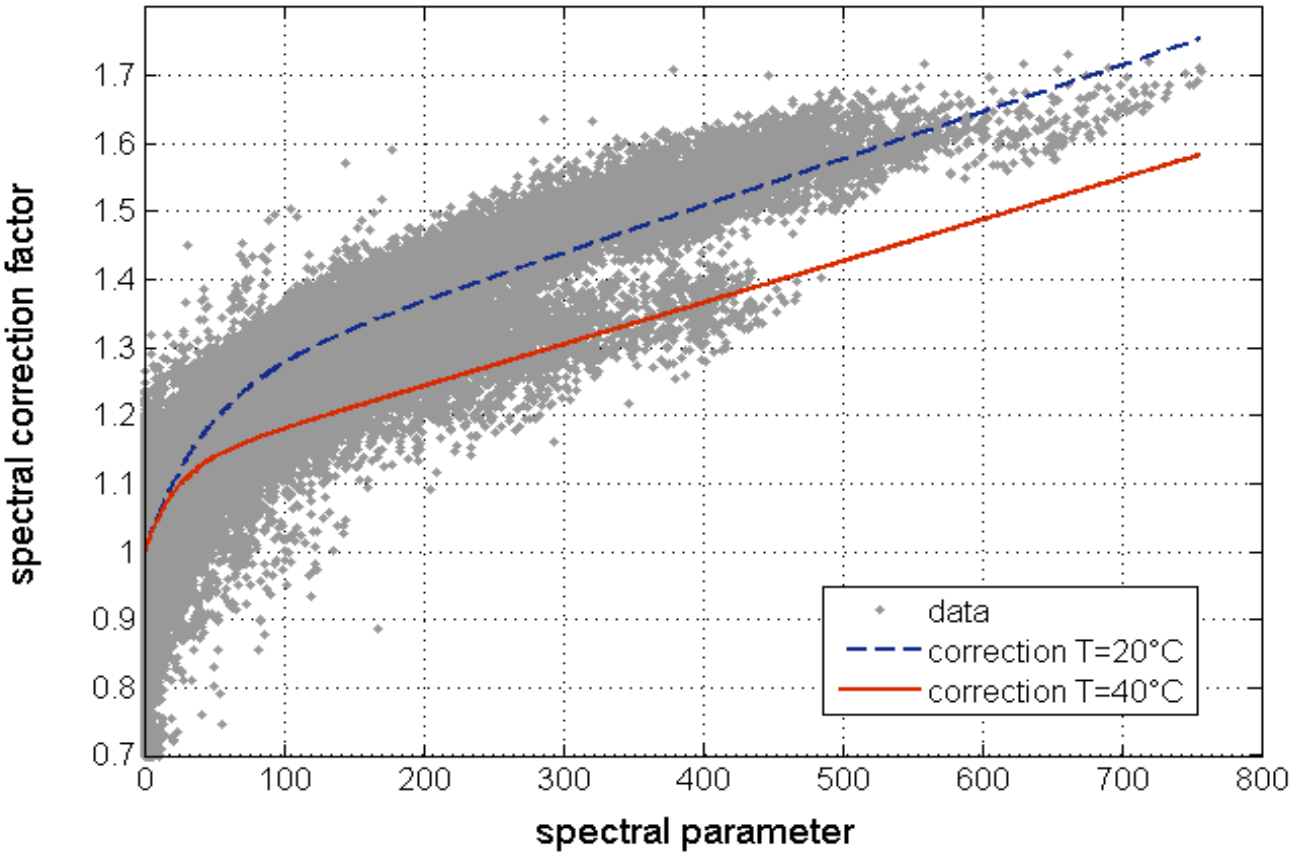
CORRECTIONS OF RSI MEASUREMENT DATA



$$CF_{temp} = (1 - 0.0007 \cdot (T_{LI-COR} - 25°C))$$

Linear correction of the temperature dependence of the LI-COR sensor

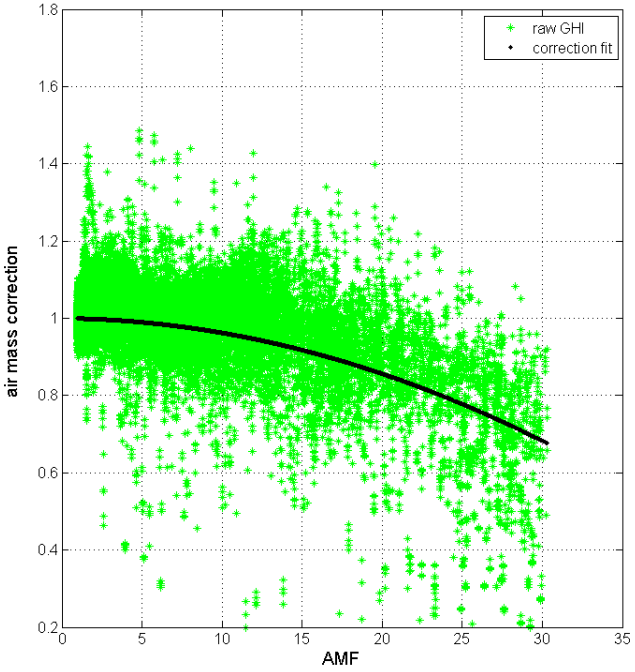
CORRECTIONS OF RSI MEASUREMENT DATA

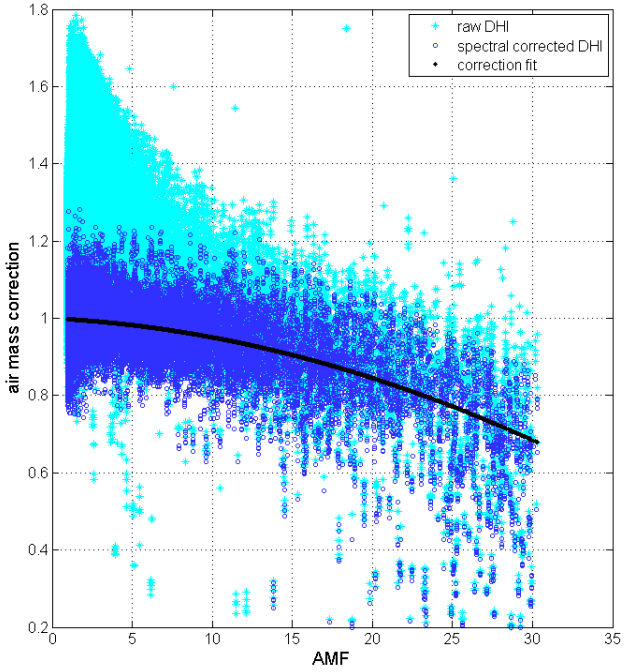


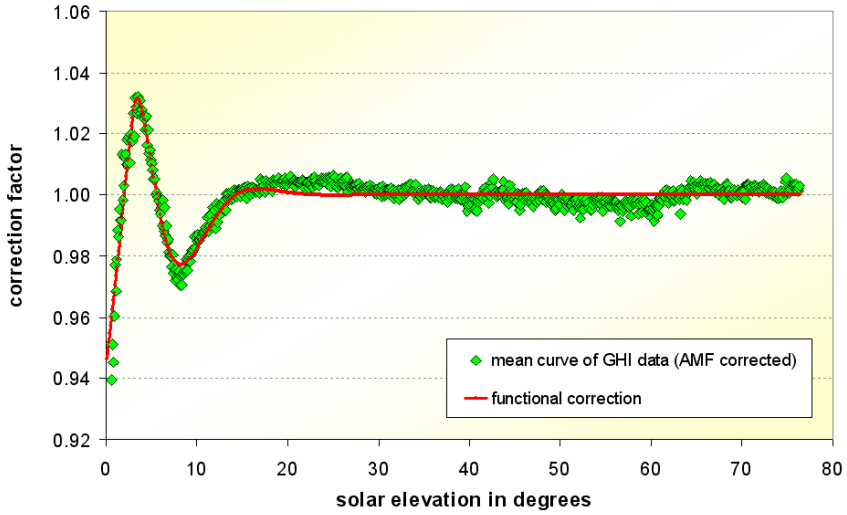
Further corrections in dependence on:

- Spectral Parameter *(depending on atmospheric conditions)*
- Air Mass Factor
- Solar elevation

CORRECTIONS OF RSI MEASUREMENT DATA



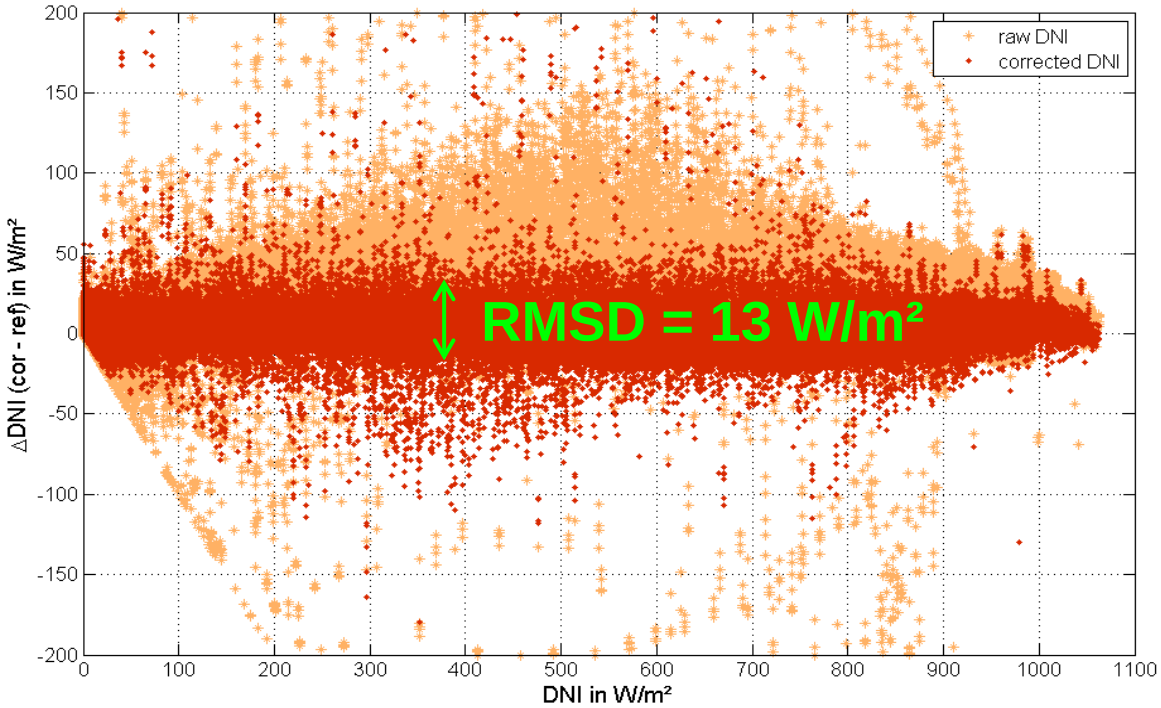




Further corrections in dependence on:

- Spectral Parameter *(depending on atmospheric conditions)*
- Air Mass Factor
- Solar elevation

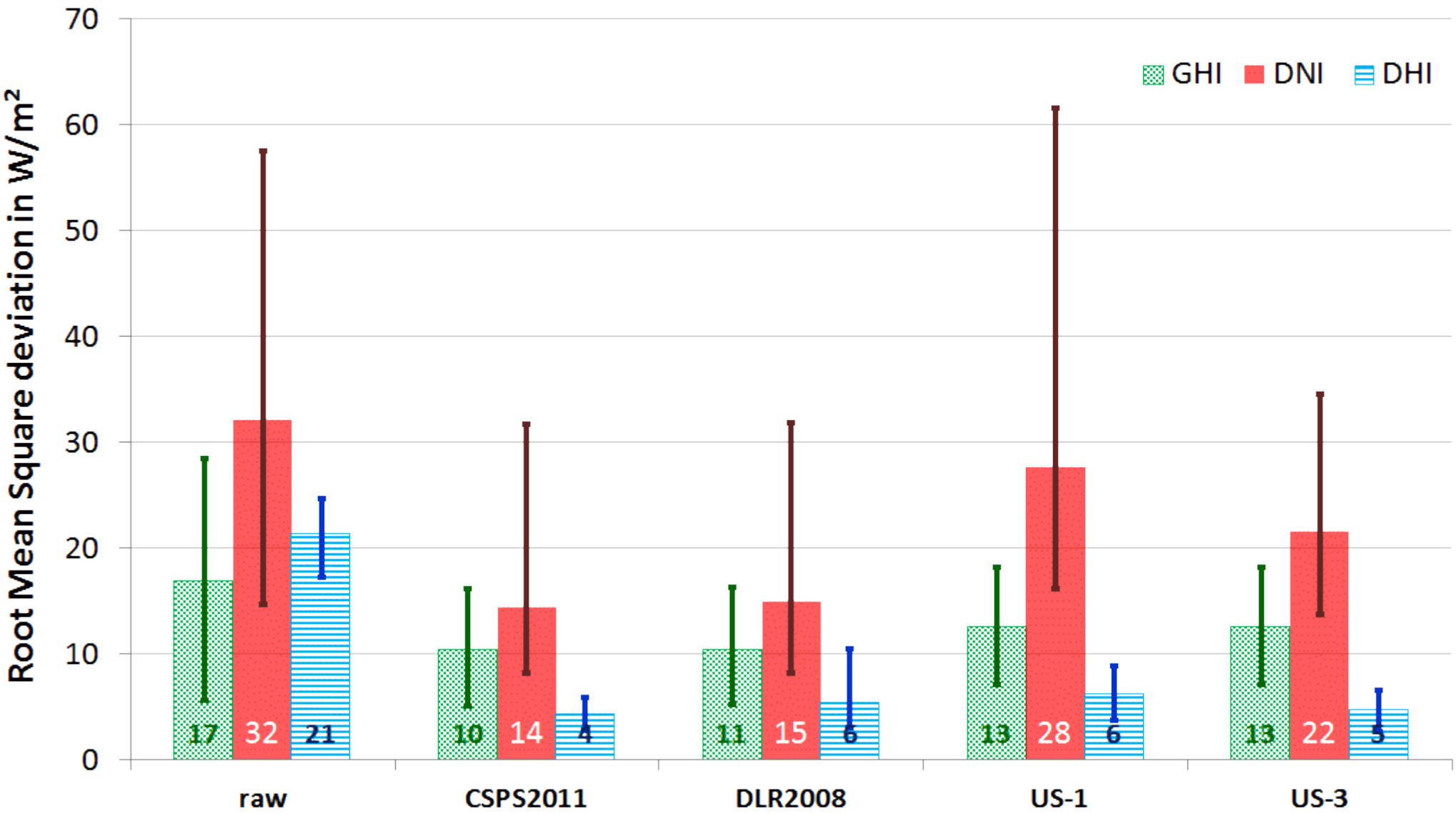
REACHABLE ACCURACY FROM RSI MEASUREMENTS



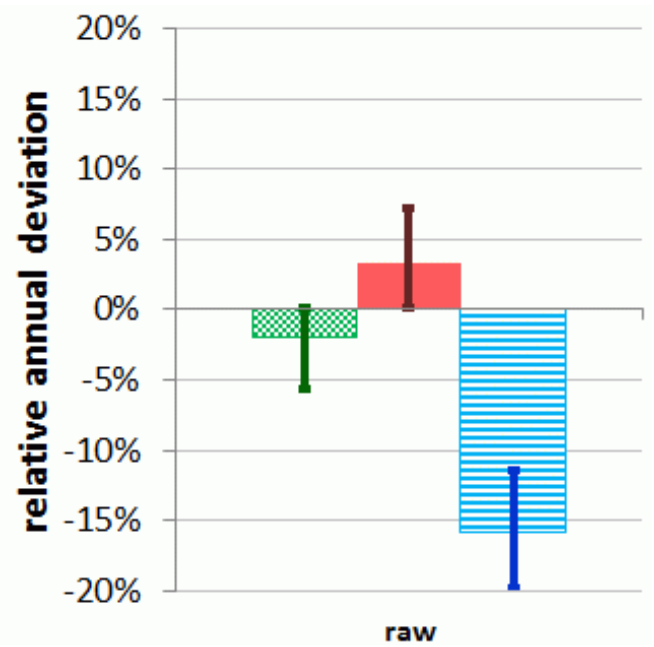
derived from data comparison of 23 RSIs with High-Precision Instruments within the course of a whole year

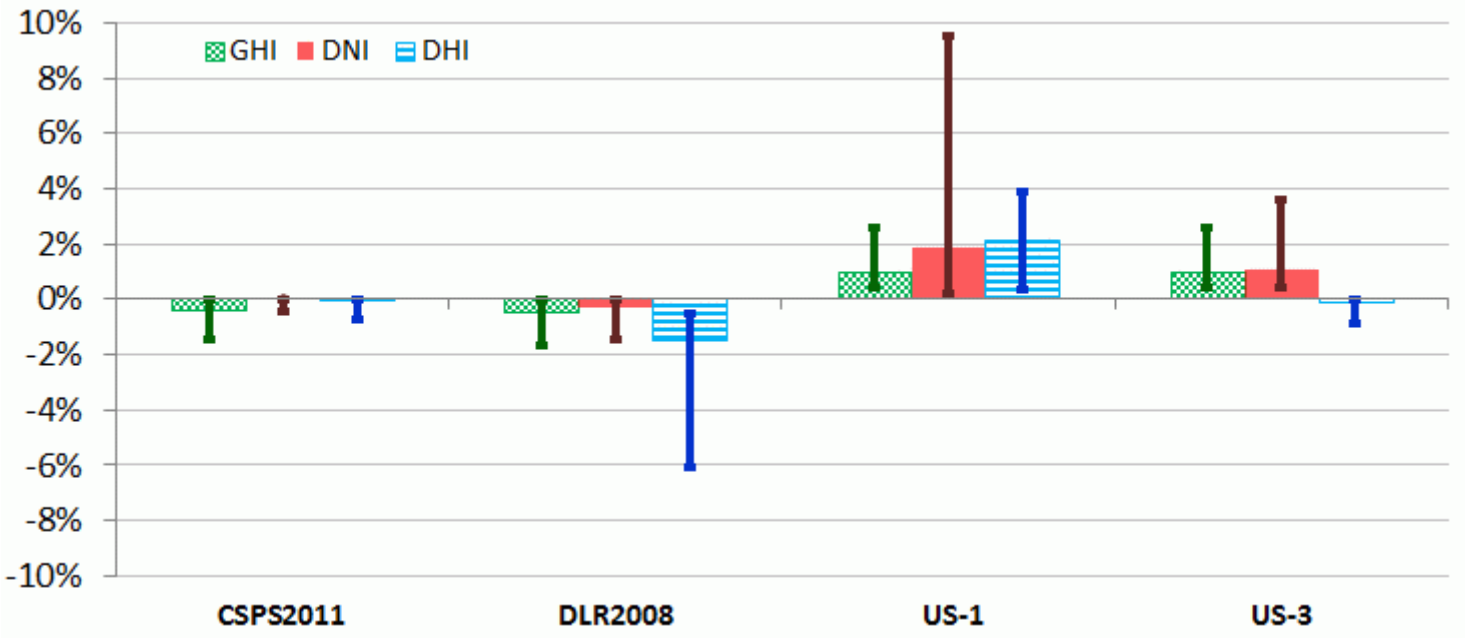
RSP	GHI		DHI		DNI		reference pyrheliometer	unit
	uncor	***cor***	*uncor*	***cor***	*uncor*	***cor***		
Mean bias	-10.3 *±4.0*	**0.3** ***±1.3***	-17.3 *±1.6*	**-0.4** ***±0.7***	24.6 *±10.5*	**1.0** ***±0.5***	1.0 *±3.9*	*W/m²*
RMSD	14.2	**7.6**	18.9	**4.5**	33.3	**13.0**	5.3	*W/m²*
Annual sum	< -2.5%	< **±1%**	< -15%	< **3.5%**	< +7%	< **±1%**	0,2% - 1,3%	

COMPARISON OF DIFFERENT CORRECTIONS: ROOT MEAN SQUARE DEVIATION



COMPARISON OF DIFFERENT CORRECTIONS: DEVIATION OF ANNUAL SUM





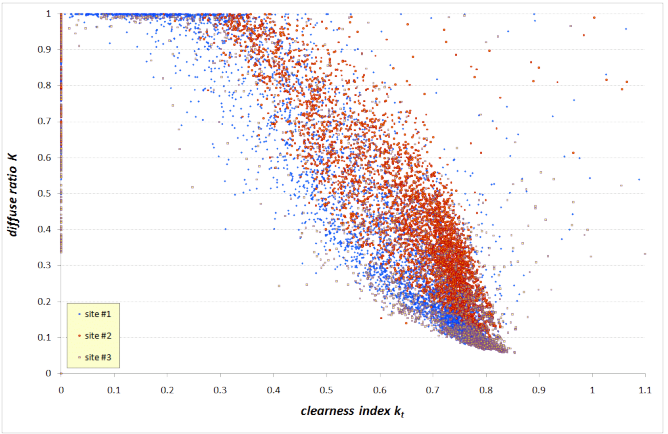
QUALITY CONTROL OF MEASUREMENT DATA

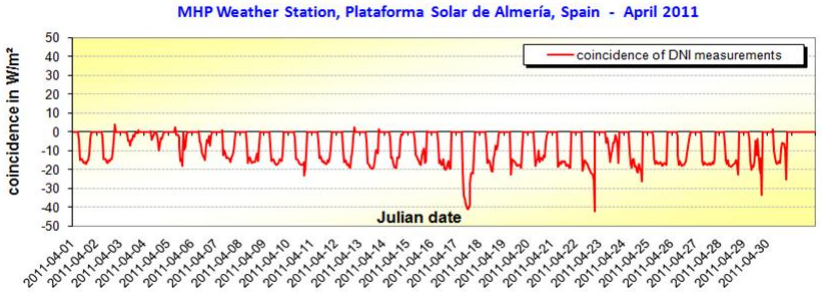
- Are values physically possible ?
  Measurement values must met physical limits

- Are they reasonable?
  e.g. comparison to a clear sky model (Bird)
  or in k_d-k_t-space

- Are they consistent?
  Comparison of redundant information

- Visual inspection by an expert

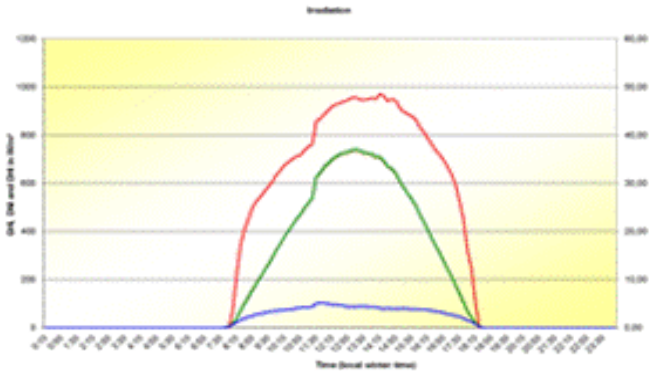




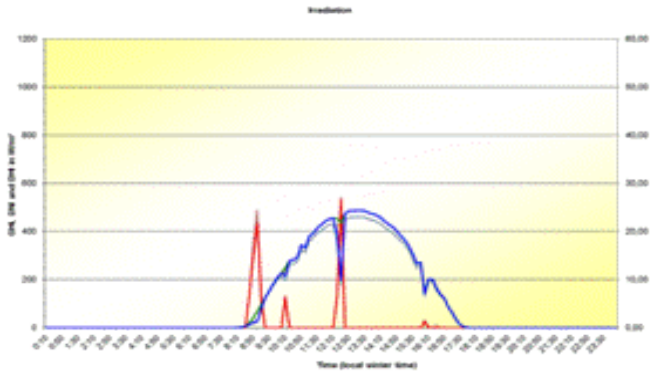
CAUSES FOR MEASUREMENT ERRORS

- Bad sensor alignment (sun tracking and horizontal leveling)
- Rotation error (RSI)
- Insufficient sensor cleaning *(frequent error!!)*
- Unstable electric power supply
- Instrument deterioration :
  leaks, corrosion, brittle seals, unstable electronics, ...
- Long-term effects of high temperatures and/or high humidity
- Bad cables or connections
- Parasitic electromagnetic fields (e.g. from power lines crossing the site)
- Local effects (e.g., shading)

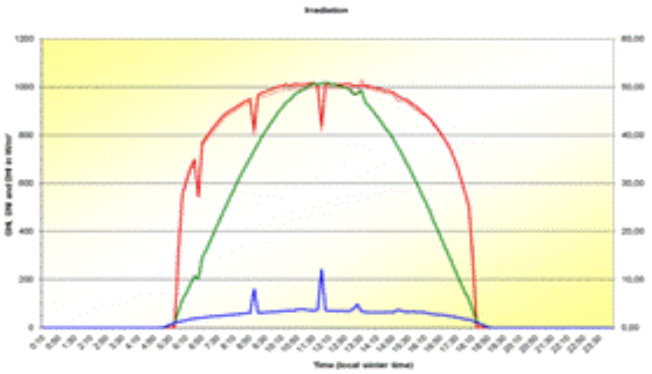
DATA QUALITY CONTROL: EXAMPLES FOR MEASUREMENT ERRORS



Soiling detection at cleaning



Tracking / Rotation error



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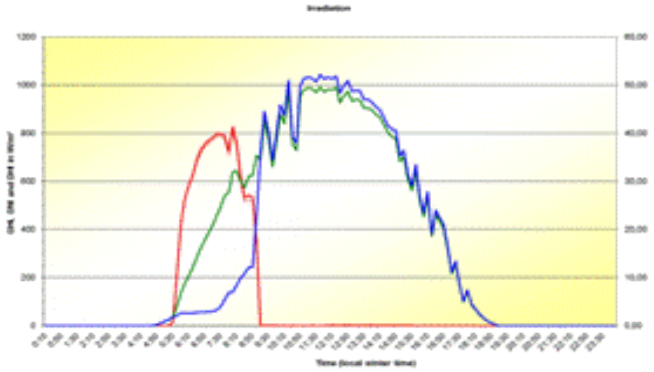

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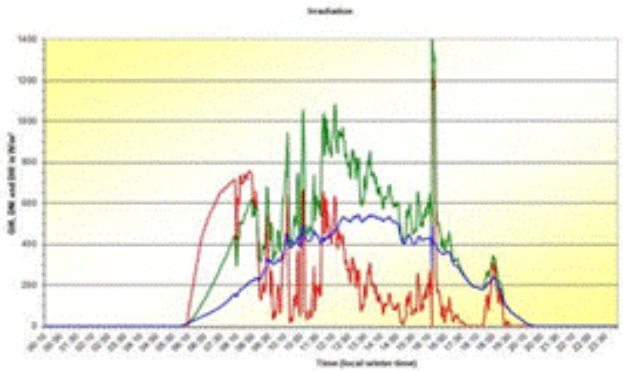
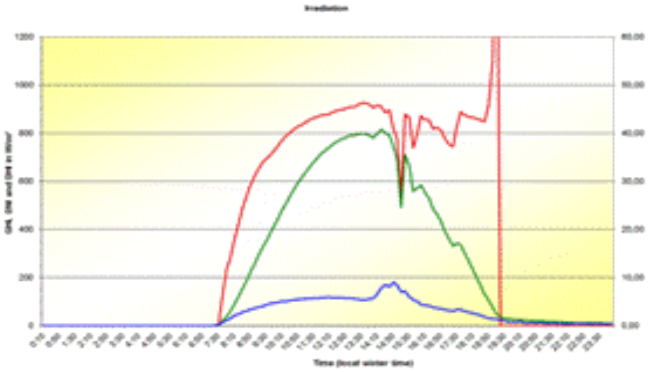
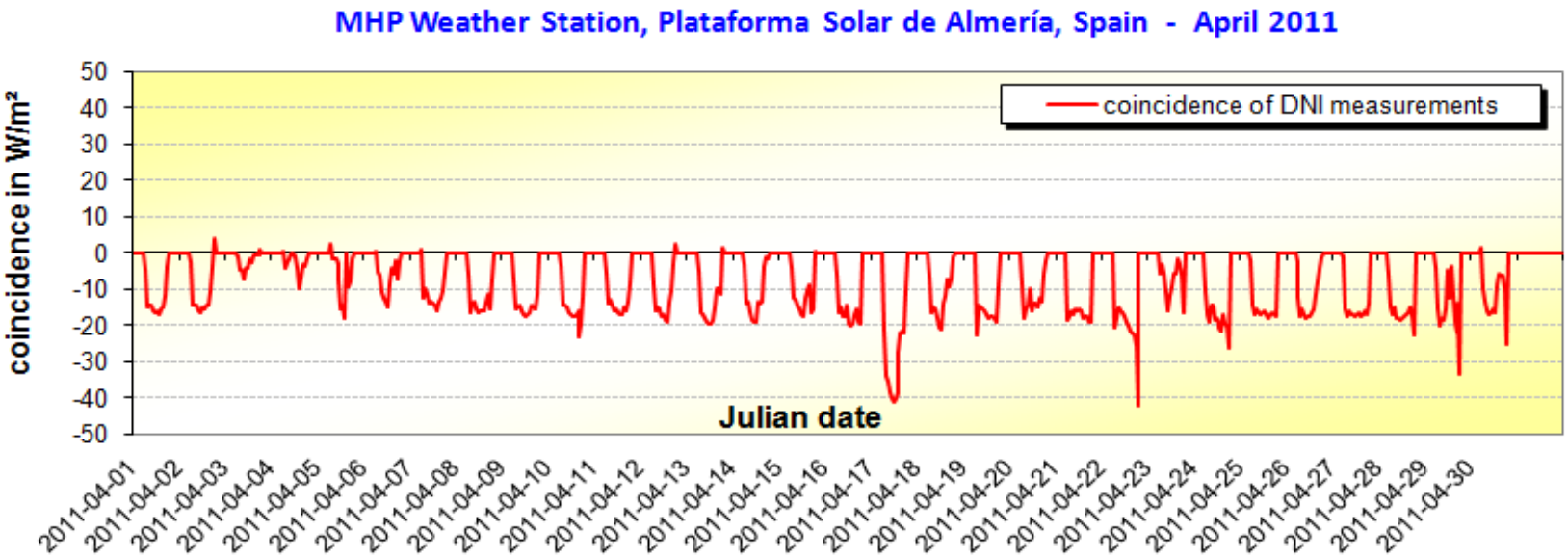


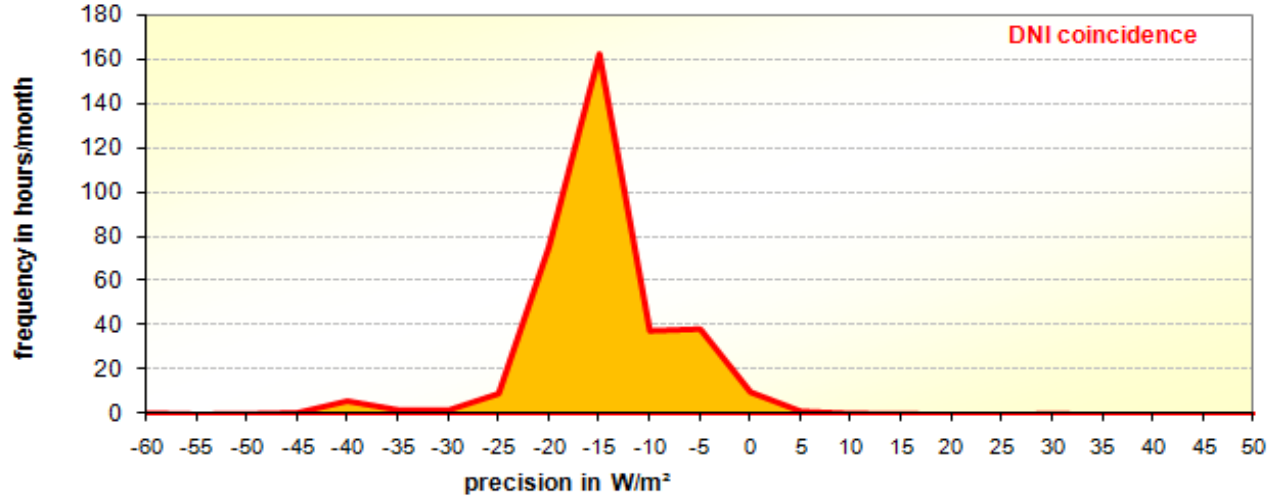
Values out of physical limits



Time/Coordinates error

DATA QUALITY CONTROL FOR HIGH-PRECISION STATIONS: REDUNDANCY CHECK





Precision of DNI measurements from coincidence of measured and calculated DNI values.

(Calculated DNI from global and diffuse irradiadion and solar angle.)

Full service for site-specific Solar Resource Assessment:

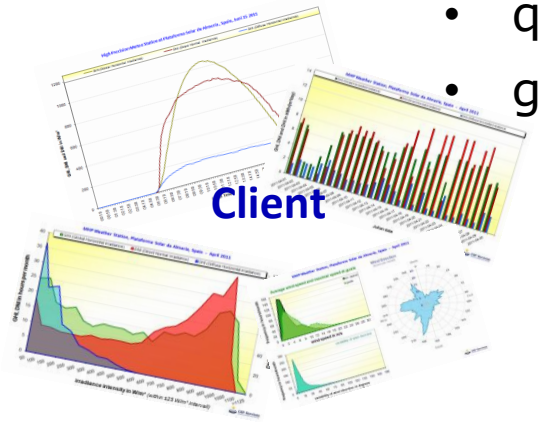
- Selection of adequate and high quality sensors from selected manufacturers for a complete, fully automatic and highly accurate weather station
- Thorough calibration of the sensors required
- Installation and commissioning of the station on site
- Data retrieval and data processing:
  - Operability monitoring and supervision to minimize data gaps
  - Data corrections for utmost accuracy
    (depending on equipment and required accuracy)
  - Check on data consistency and data quality checks
  - Data error corrections and gap filling (where possible)
- Regular maintenance inspections on site
  (depending on equipment and local supervision)

CSP SERVICES SOLAR IRRADIATION DATA SERVICE

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

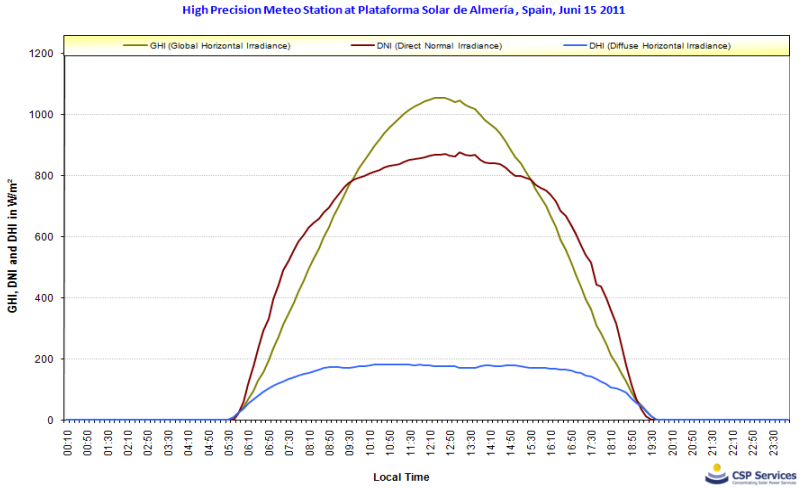
Daily data retrieval via modem *(GSM/GPRS)*

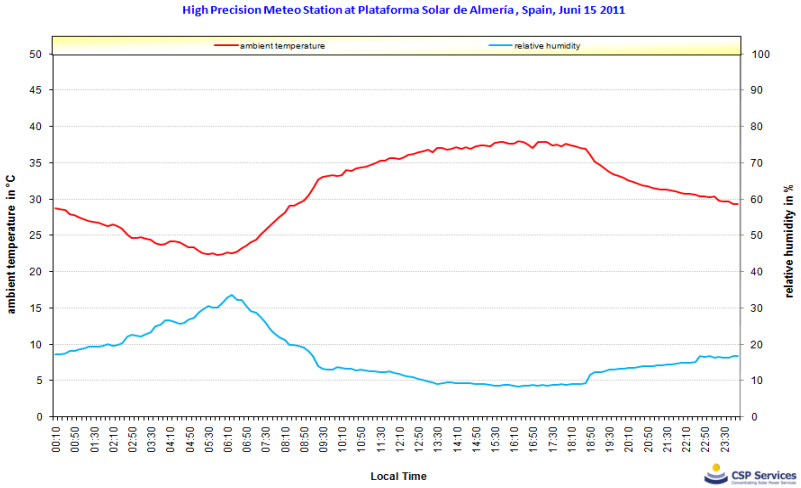
- Data collection and processing,
- accuracy enhancement (correction),
- quality and functionality check,
- graphical visualization

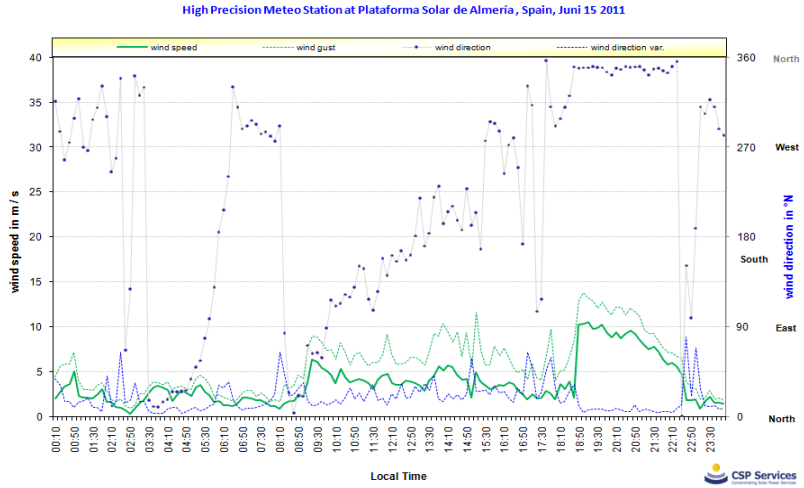


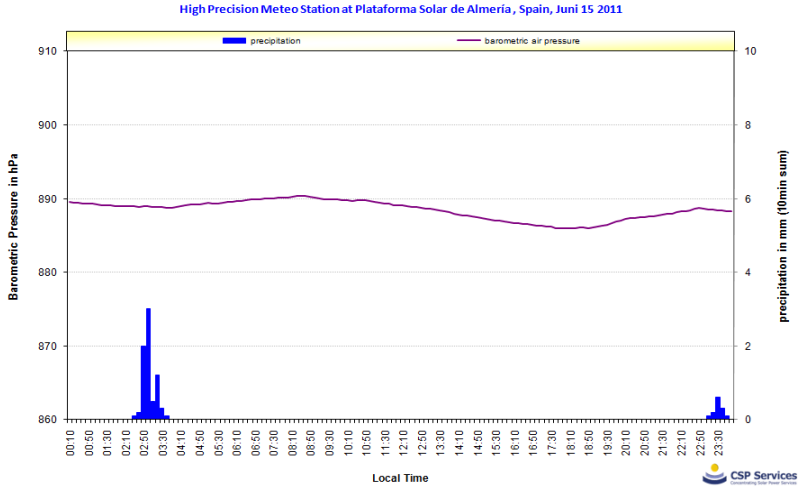
Daily, monthly, annual report to client via e-mail

DAILY REPORT ON METEOROLOGICAL DATA

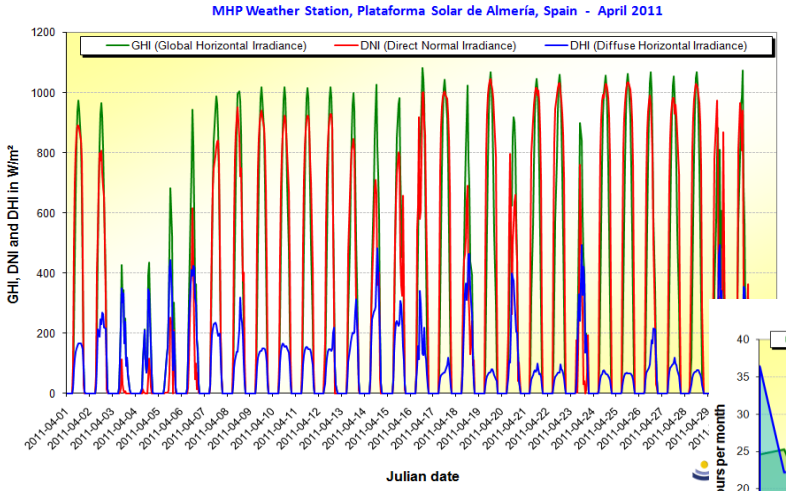


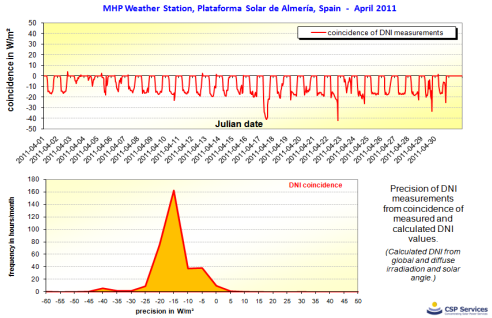


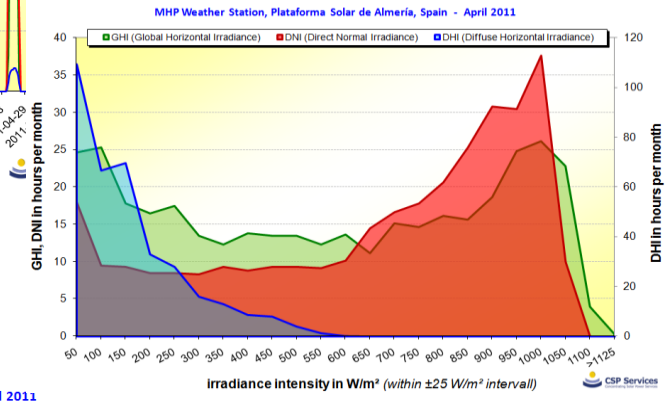


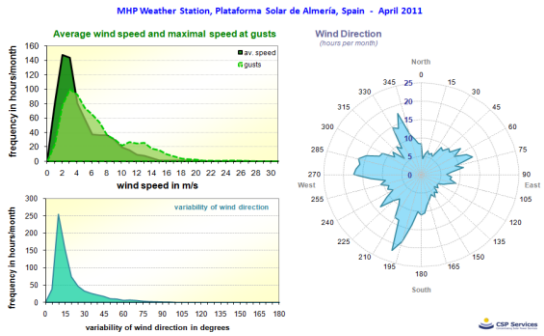


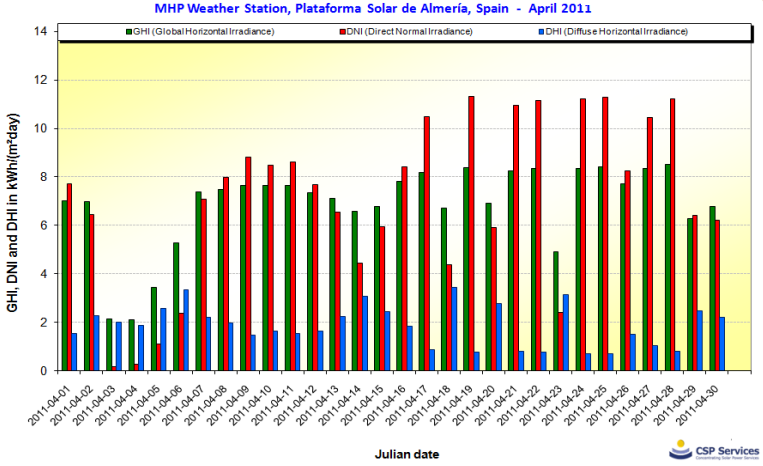
MONTHLY METEOROLOGICAL REPORT

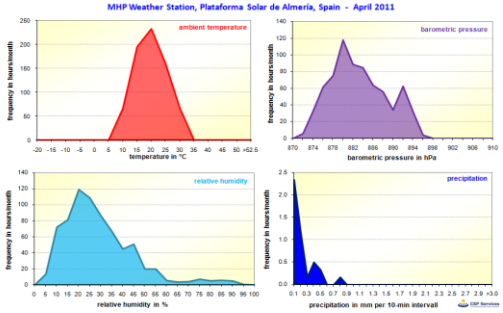












Thank you very much for your attention!