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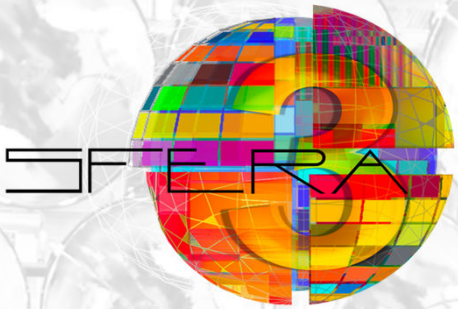
Sensor calibrations and performance measurements



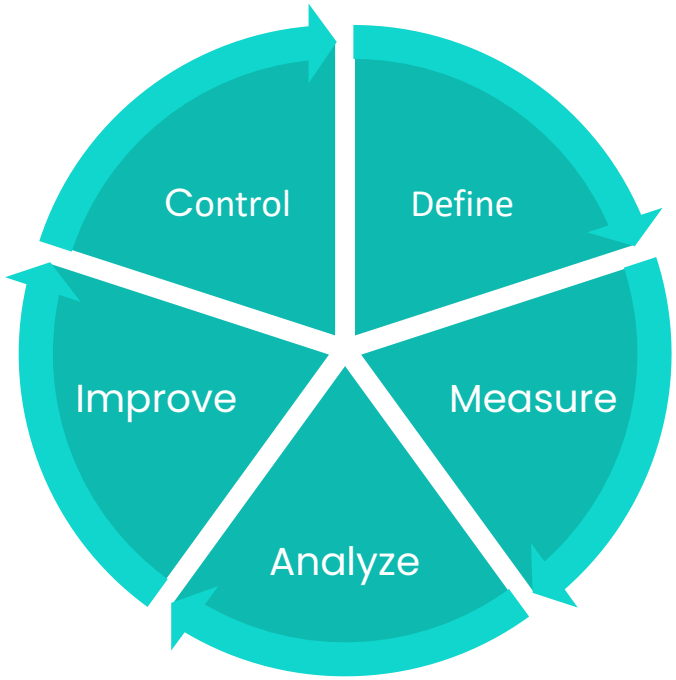
SFERA-III
Final Event
December 13, 2023 | Madrid, Spain

Marc Röger, DLR

THIS PROJECT HAS RECEIVED FUNDING FROM THE EUROPEAN UNION'S HORIZON 2020 RESEARCH AND INNOVATION PROGRAMME UNDER GRANT AGREEMENT NO 823802

Performance measurements – why?

- "Only when you know what you have, you can improve it."
- DMAIC-cycle (**D**efine – **M**easure – **A**nalyze – **I**mprove – **C**ontrol)



For example: New collector prototype with higher optical efficiency

- **D**efine design, efficiency and build first unit
- **M**easure performance parameters ⇦
- **A**nalyze the measurement results ⇦ Measurement Technologies
- **I**mprove the design
- **C**ontrol by remeasuring it ⇦

Sensor calibrations – why?

Practical problems remain in metrology, e.g.

- not properly working sensors,
- lack of specific calibration data banks.

In CSP technology metrology, we have the additional challenges, e.g.

- Cloud transients and thermal inertia during on-sun tests
- Large extension of mirror surfaces
- Outdoor measurements
- Rough temperature and pressure conditions

This increases uncertainties and makes accurate testing and characterization of prototypes a difficult task

→ This JRA increases the sector's capabilities to overcome these problems.

Metrology Topics in SFERA-III

Sensors (Lab/Field)

Eliminate practical problems related with **sensors** and **laboratory test benches**

- Reflectometers for soiled mirrors (RR)
- Load cells on REPAs
- Round robin heat loss parabolic trough rec.

Intermittence (Field)

Investigate and solve the **problems caused by intermittence of solar radiation** during in-field tests in research infrastructures and during evaluation of performance parameters

- Skyimager/ Nowcasting
- Dynamic Testing of Line Focusing Collectors

Optical Characterization (Lab/Field)

Increase the quality of services for **optical characterization** of line- and point-focusing concentrators

- Shape heliostats
- Shape trough mirror panel (Round Robin)
- Heliostat aiming

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Increase the quality of services for **optical characterization** of line- and point-focusing concentrators

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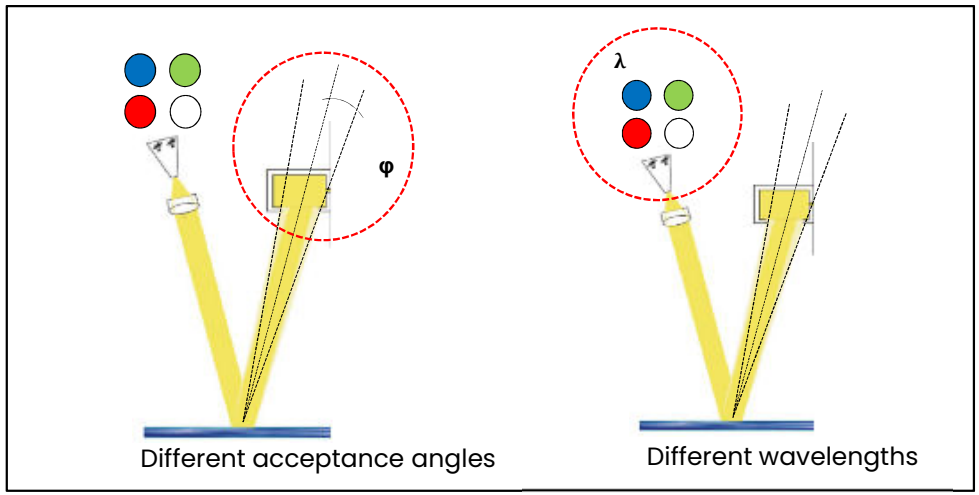
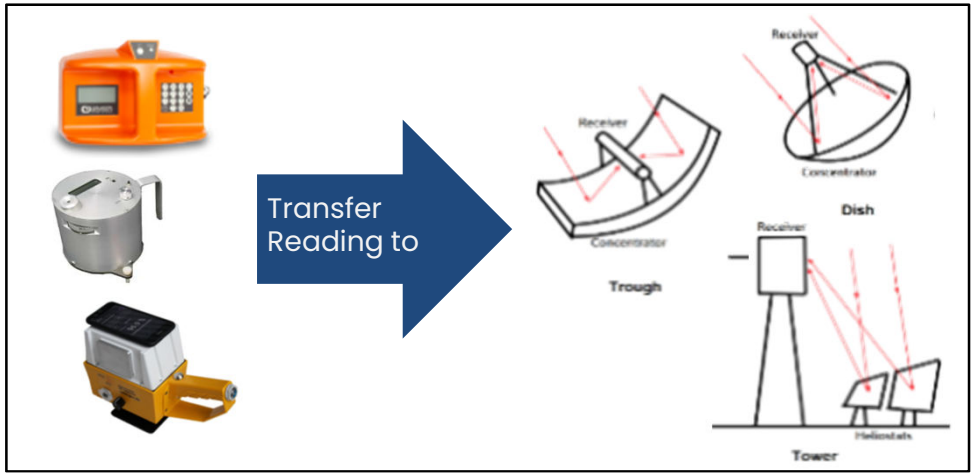
5. Shape trough mirror panel (Round Robin)
- Heliostat aiming

1 Reflectometer on soiled mirrors

Challenge: Specially on soiled reflective surfaces, the readings of different reflectometers systematically deviate due to different acceptance angles.

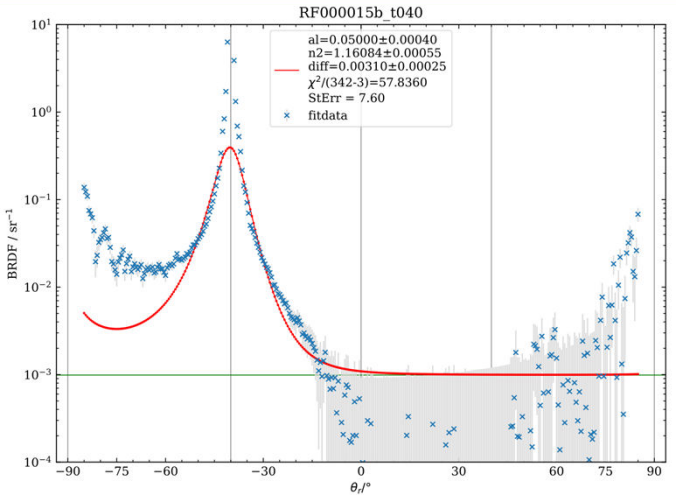


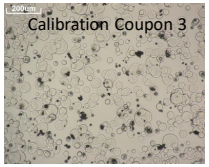


1 Reflectometer on soiled mirrors

Outcome:

- Scientific understanding of the different reflectometer readings for different instruments on soiled mirrors (varying acceptance angles and wavelengths).
- Models for spectrally resolved reflectance were developed.
- An international intercomparison campaign was performed.
- Techniques to decrease uncertainty of reflectance readings were developed .
- The calibration routines were improved by using newly designed calibration coupons

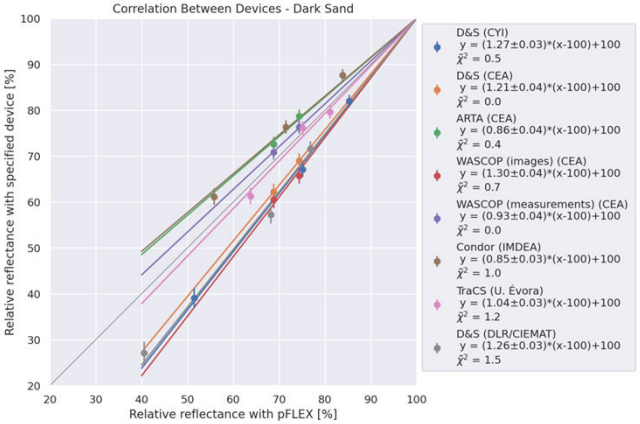




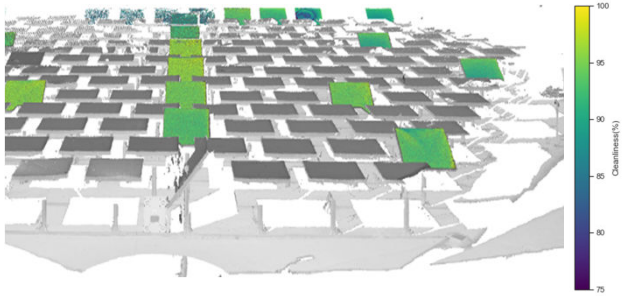
Sample name	"soiling" technique	Reflectance D&S @12.5 mrad	TraCS reflectance, Solar weighted, 15°	S2R solar weightedrefl @ 12.5 mrad, 15°incid.	S.W. Hemisph. Reflect.
SB1	Sand blast	91%	91%	89%	93%
SB2	Sand blast	81%	84%	80%	92%
SB3	Sand blast	89%	89%	87%	92%
P1	Black paint	86%	87%	86%	89%
P2	Black paint	77%	83%	79%	83%
HS1	Hair spray	76%	86%	81%	93%
HS2	Hair spray	83%	85%	84%	93%

1 Reflectometer on soiled mirrors

- Transfer functions to homogenize readings of different instruments were developed.
- Research on new contactless measurement techniques was conducted.
- A world-wide international cooperation led to a first-version SolarPACES Guideline (Task III) for reflectance measurements on soiled mirrors.



Transfer functions between reflectometers


Scanner based soiling measurement


SolarPACES

Guidelines

Recommendations for reflectance measurements on soiled solar mirrors

Version 0.1

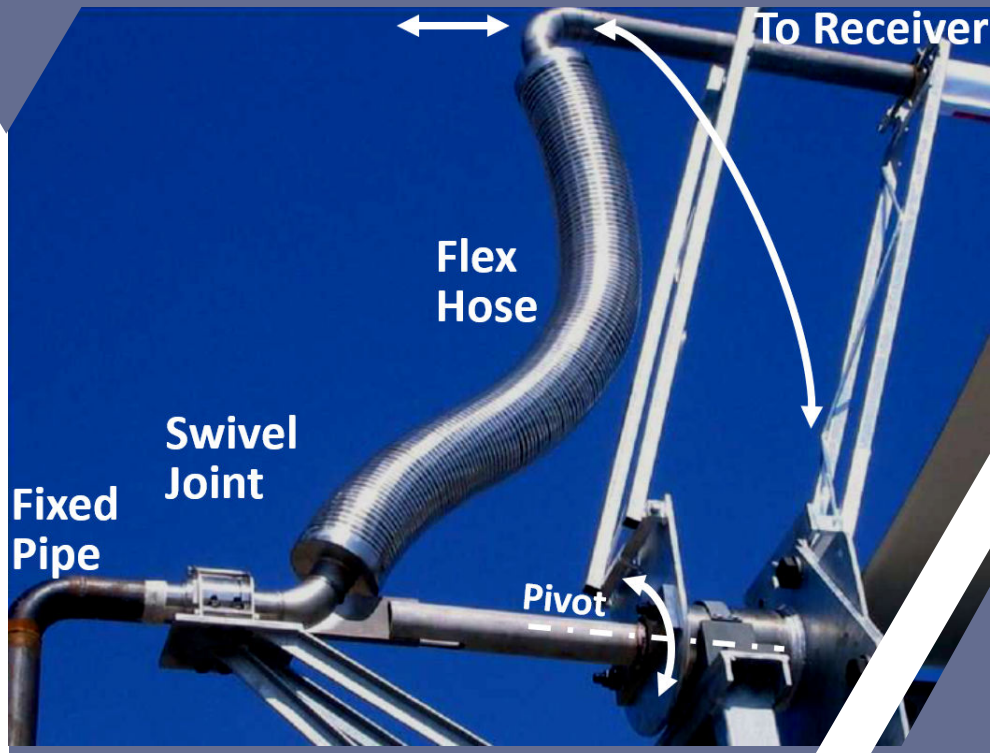
March 2022

Authors: F. Wolfertstetter (DLR), F. Sutter (DLR), E. Lüpfert (DLR), M. Montecchi (ENEA), C. Pelayo (UNIZAR), C. Heras (UNIZAR), G. Bern (Fraunhofer ISE), M. Bitterling (Fraunhofer ISE), A. Heimsath (Fraunhofer ISE), C.-A. Asselineau (IMDEA Energy, ANU), A. Fernández-García (CIEMAT), Guangdong Zhu (NREL)

2 Load cells on REPAs

Challenge:

- Flexible interconnections between collectors (REPAs) are sensible to external forces and moments.
- REPA testing needs an accurate knowledge of these forces and moments, measured by load cells.
- Load cells have to be calibrated and monitored and their uncertainty must be decreased under harsh ambient and temperature conditions.



REPA = Rotary Expansion Performing Assemblies
for Solar Parabolic Trough Plants (Ball joints, flex hoses)

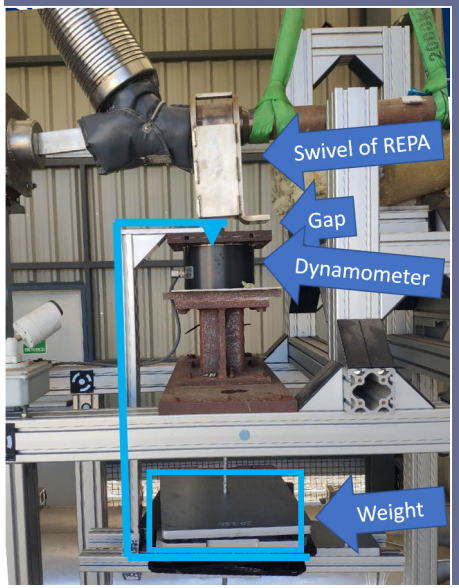
2 Load cells on REPAs

Outcome:

REPA test rig:

- Forces and moments on REPAs in the REPA test bench during a 10,000-cycle aging testing simulating field operation conditions have been measured and load cells monitored.
- Condition monitoring of flexible pipe connectors (REPA) through vibration analysis.

CIEMAT– DLR test rig for REPA tests on PSA



DLR calibration adapter for load cells (dynamometer) on REPA test rig

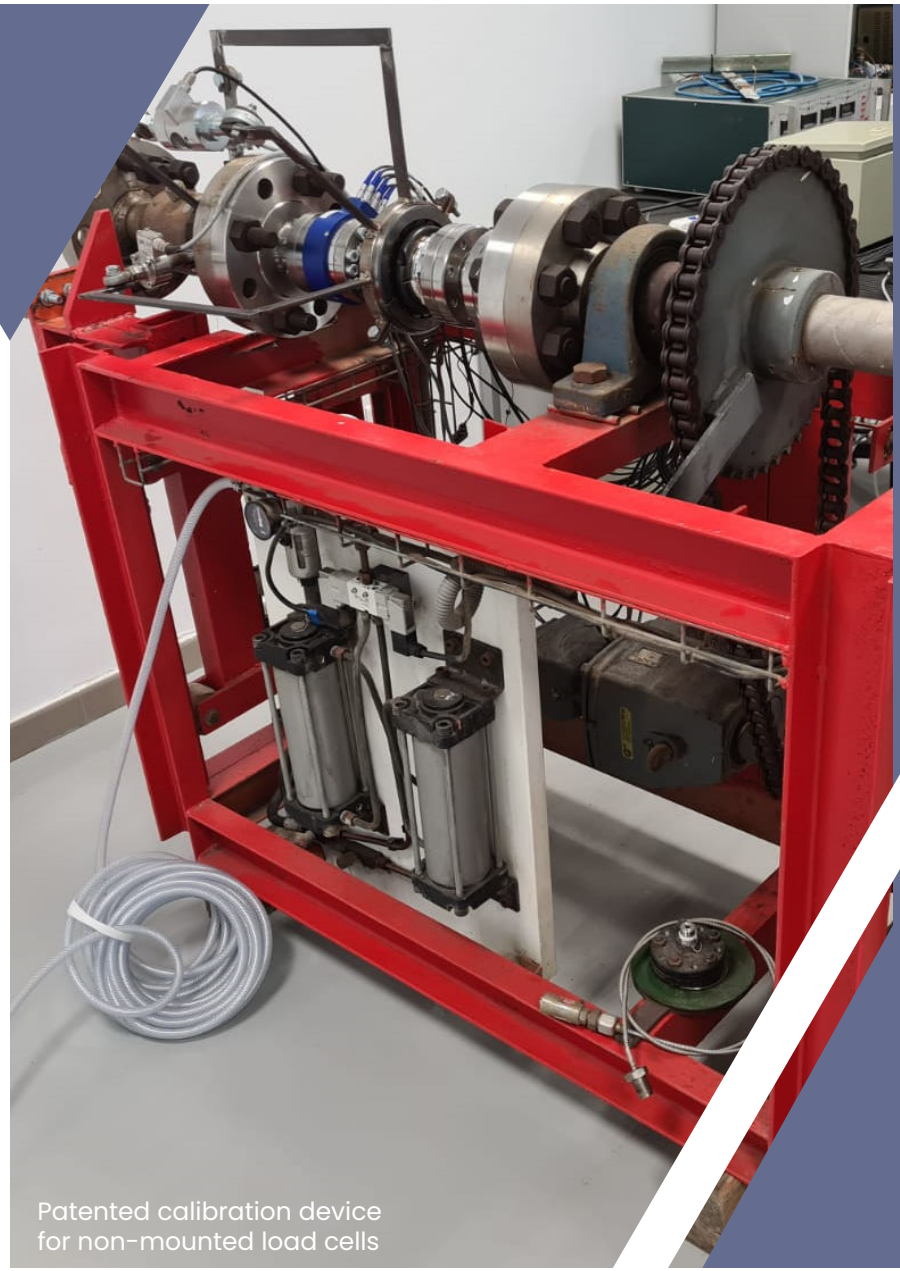
2 Load cells on REPAs

Outcome:

In-Field:

- Forces and moments on an in-field collector was measured.
- A calibration device and routine was developed for not mounted load cells (patent).
- A monitoring routine was developed to check mounted load cells.

Mounted load cells on URSSA-trough at PSA



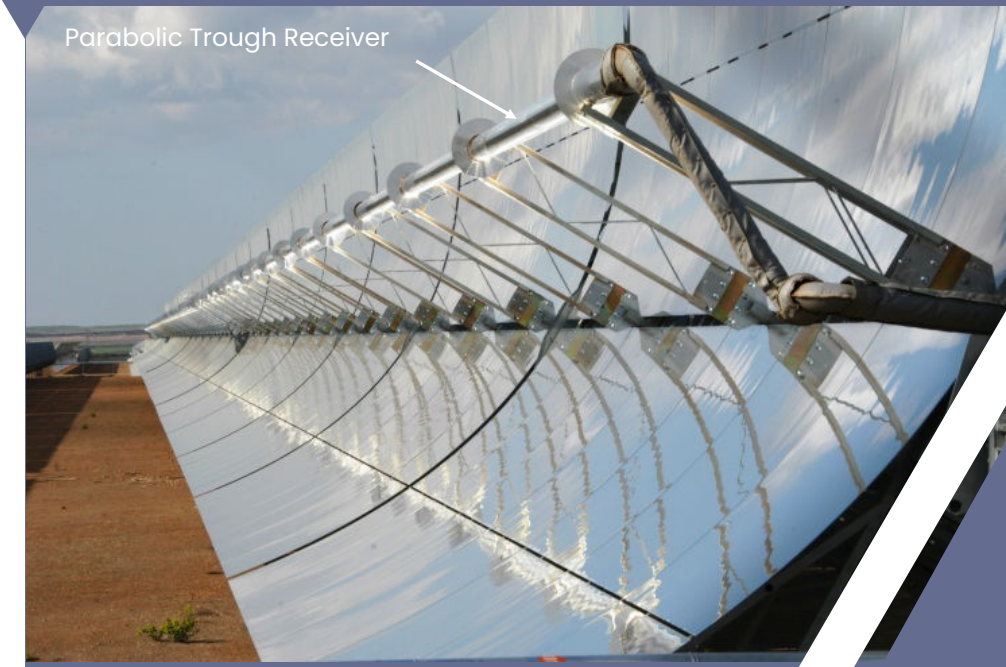
Patented calibration device
for non-mounted load cells

3 Round robin heat loss parabolic trough receiver

Problem:

- Comparability of heat loss measurements on parabolic trough receivers of different laboratories was not satisfactory.
- STAGE-STE PTR heat loss Round Robin test(2015): Typical standard deviation of 7%...10%
- Heat losses in the solar field are between 7% and 10%

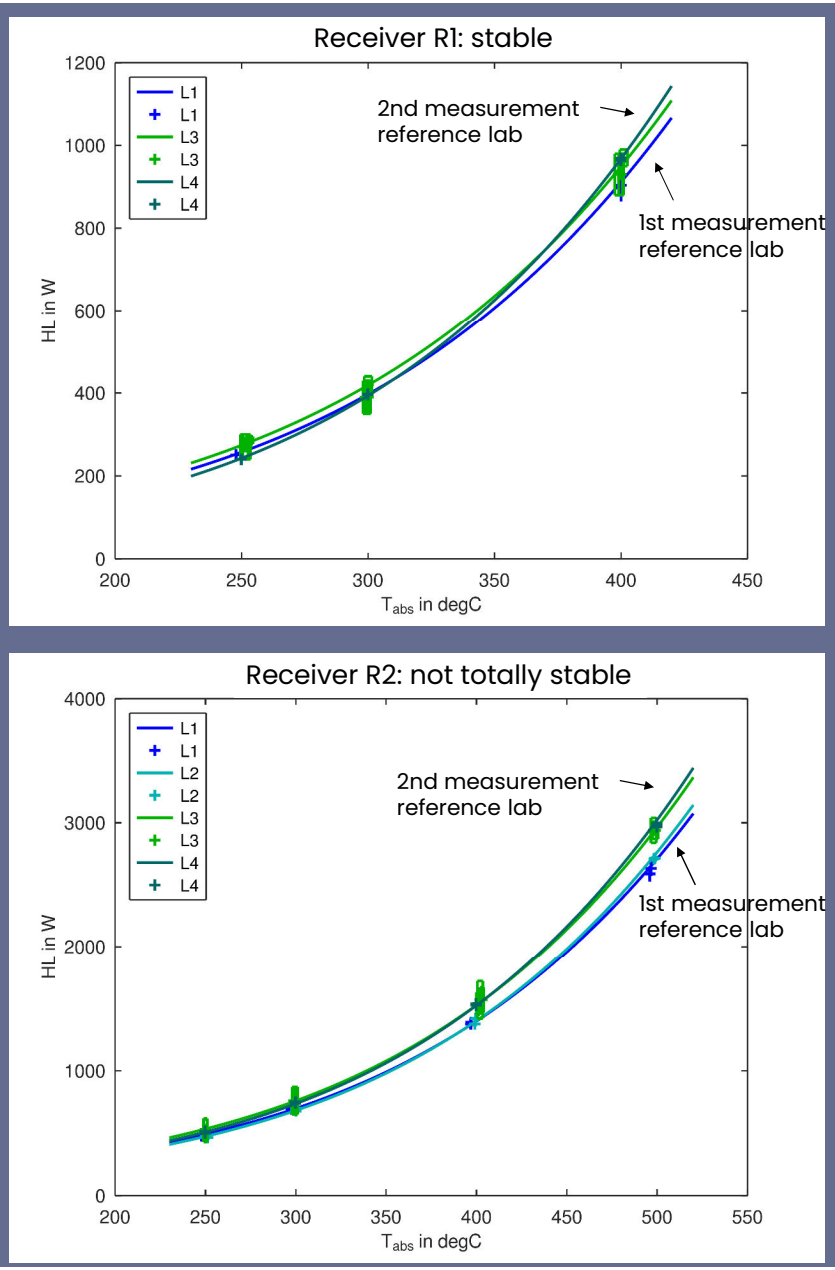
Parabolic Trough Receiver being prepared with a heater in a heat loss test rig



3 Round robin heat loss parabolic trough receiver

Outcome:

- A new measurement protocol, which modifies the IEC TS 62862-3-3:2020 for better accordance between laboratories was defined:
  - Specifications for heater geometry
  - Change in definition of absorber temperature
  - Clarification of steady state criteria
- A round robin test with 3 receivers including ENEA, CIEMAT, DLR, and CENER (as external partner) was defined.
- The agreement between PTR heat loss measurements at laboratories was improved: from STD 7% to 10% (STAGE-STE 2015/16) to STD 3% to 5% (SFERA-III 2023)

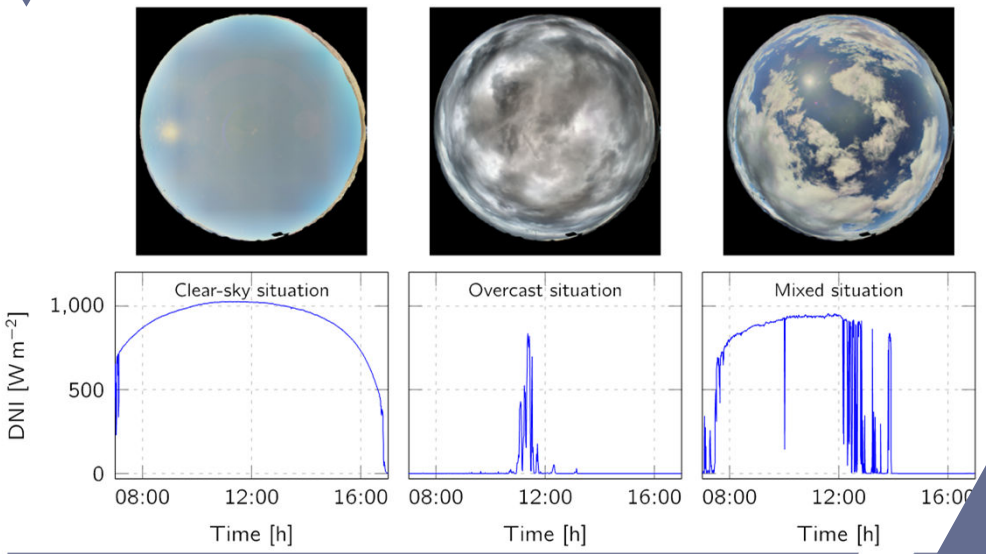


Round robin results. Heat Loss over Temperature

4 Skyimager/ Nowcasting

Challenge:

- Testing hours of solar facilities at research infrastructures are limited and solar energy is inherently intermittent.
- Increase testing hours by intelligent operation of a test facility also under variations of solar radiation using a skyimager to provide accurate intrahour DNI forecasts.

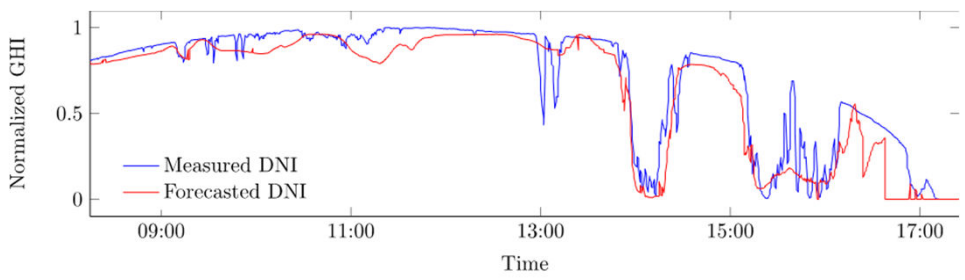


Different overcast situations as need by the skyimager and DNI sensors.

4 Skyimager/ Nowcasting

Outcome:

- A hybrid forecasting model for real-time usage based on high-quality, HDR images of a skyimager and DNI measurements was developed.
- A real-time DNI forecasting was implemented in Odeillo, providing critical information to infrastructure users.
- A model predictive control of a solar reactor using very short-term forecasts of 30 to 150 seconds was demonstrated with superior performance compared to classic control (see WP8.3), increasing testing hours of the facility.



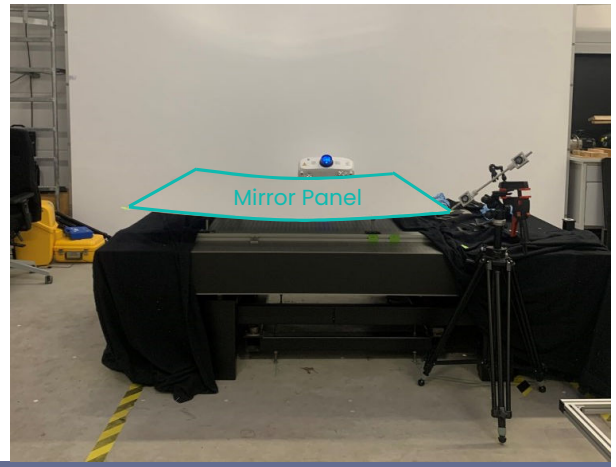
Example of a 15-minutes forecast using one of the models

Experiment in Odeillo
using real-time forecasting system

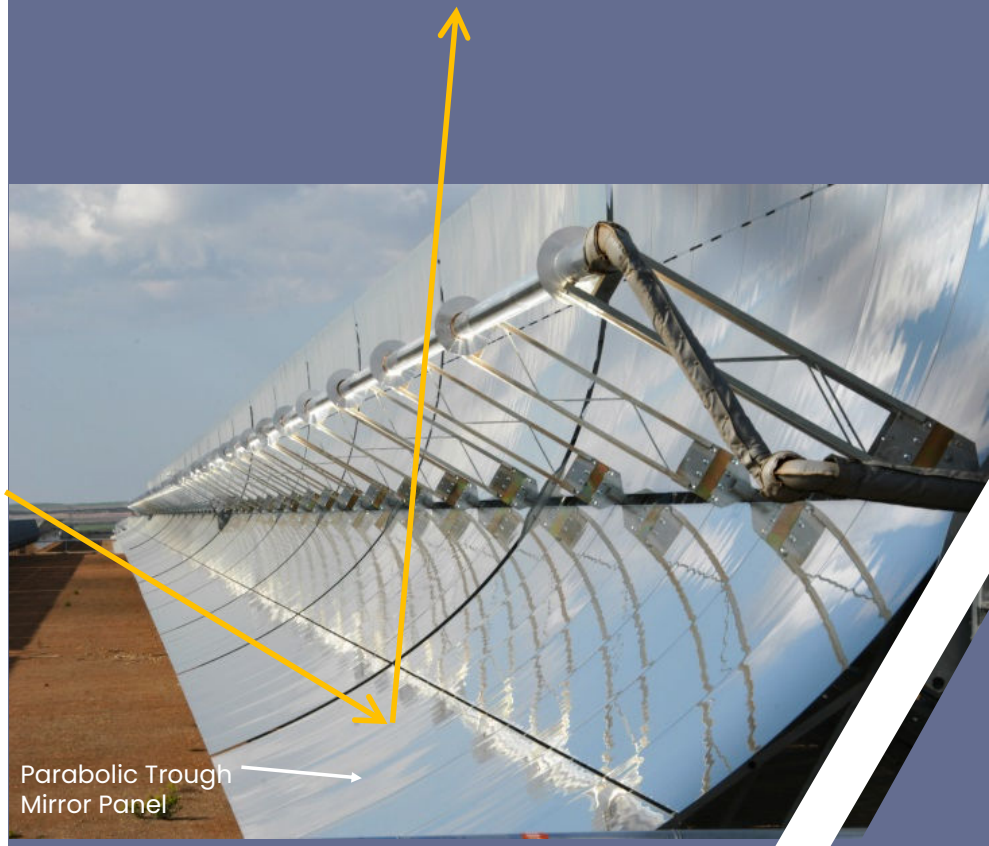
5 Round robin shape trough mirror panel

Problem:

- Comparability of shape measurements on parabolic trough mirror panels of different laboratories was not satisfactory.
- Non-ideal shape causes ray to not hit receiver.



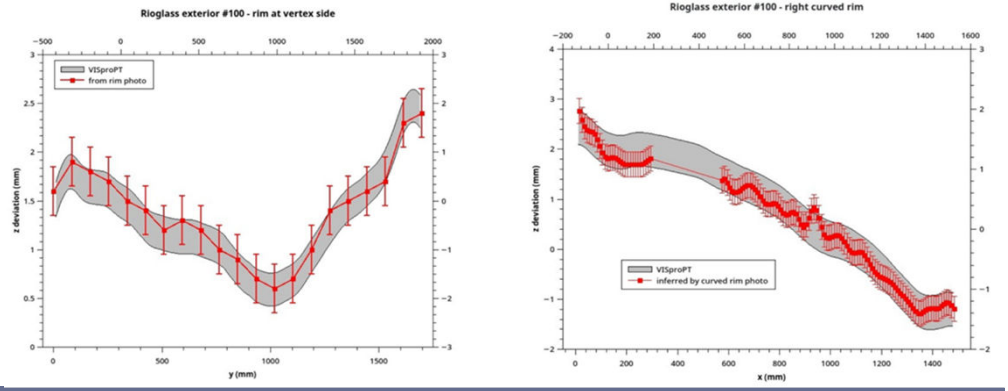
Parabolic Trough Mirror Panel being prepared for the round robin deflectometric measurement of DLR



5 Round robin shape trough mirror panel

Outcome:

- The service of optical characterization of parabolic trough panels was improved.
- A new shape measurement device (VISpro/ENEA) was developed, commissioned, validated and compared to the existing devices of other partners.



Validation of the VISproPT (ENEA) results with an independent technique using a photograph

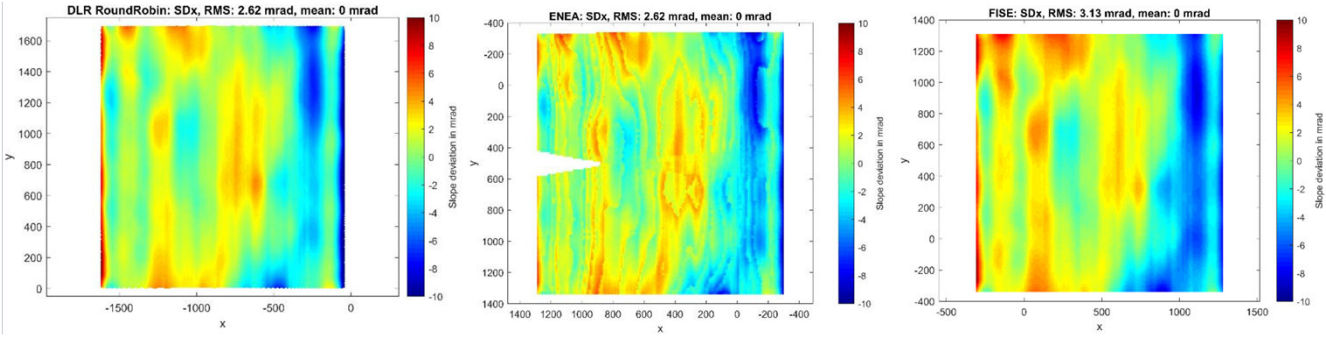
Developed ENEA test bench VISproPT

5 Round robin shape trough mirror panel

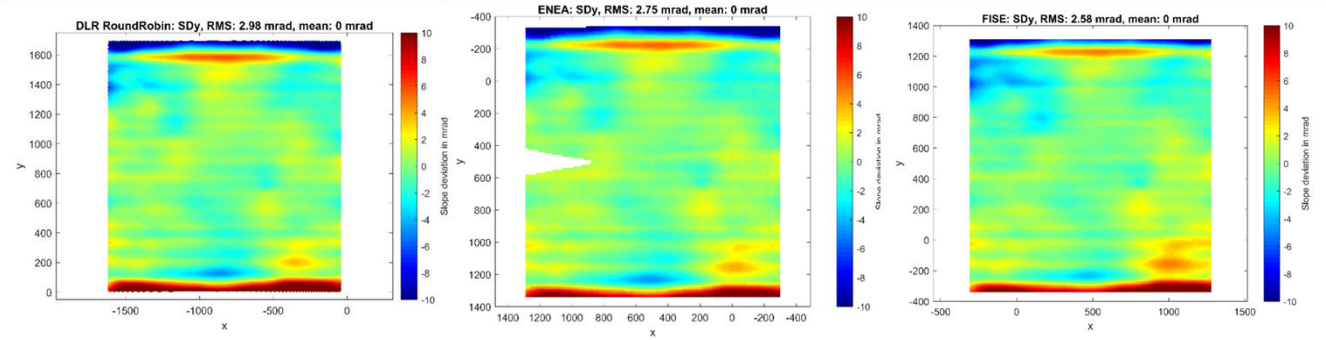
Outcome:

- A round robin test including ENEA, DLR, FRA, and NREL & SANDIA (as external partners) was performed.
- The results show a reasonable agreement between labs.

Preliminary results SD*x*

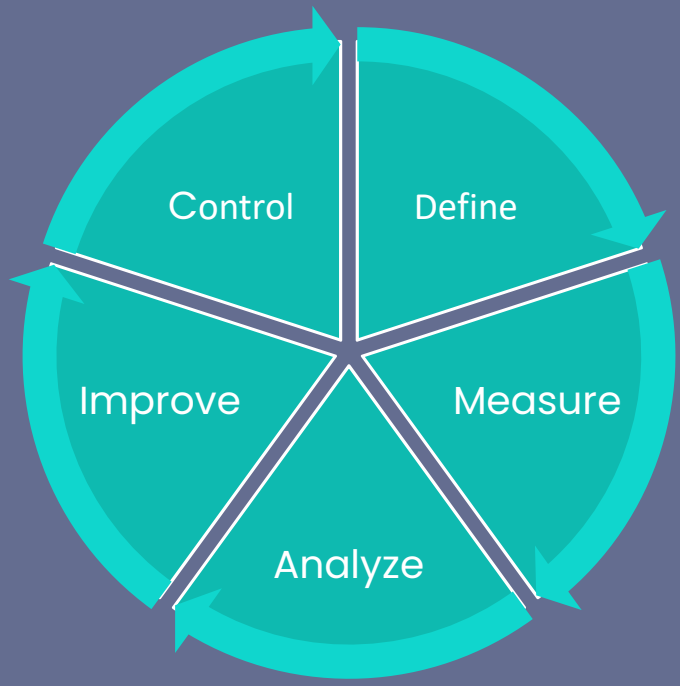


Preliminary results SD*y*



Future investigations

- Metrology for test infrastructures and development of better techniques are ongoing processes.
- Continued possibilities of round-robin tests between laboratories are needed to maintain and increase quality.
- Continued further development of measurement methods, using AI and new image processing techniques is needed.
- Further standardization of techniques between measurement laboratories via SolarPACES guidelines and standardization activities (e.g. IEC) is necessary.

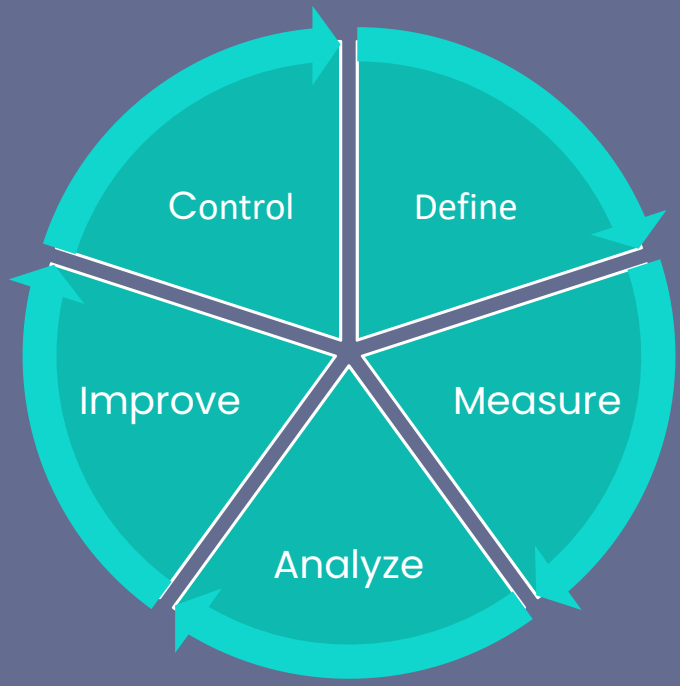


"The DMAIC-cycle (Define – Measure – Analyze – Improve – Control) should never stop. It is a continuous process."

Future investigations

Examples:

- Further develop guideline "Recommendation for reflectance measurements on soiled mirrors“.
- Further develop guideline “Heliostat performance testing and heliostat field testing“.
- Further cooperation and harmonization in evaluation and result presentation
  - E.g. in heliostat beam characterization systems, slope deviation measurement systems, etc.
- Further develop measuring the REPA behavior in the solar field and on the test rig.
- Fast and accurate 3D irradiance mapping in solar receivers/reactor.
- Development of open data bases for model testing and validation.



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Thank You

For Your Attention

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