Comparison of Simulated and Measured Flux Distributions at the Aperture of the Next-CSP Solar Receiver

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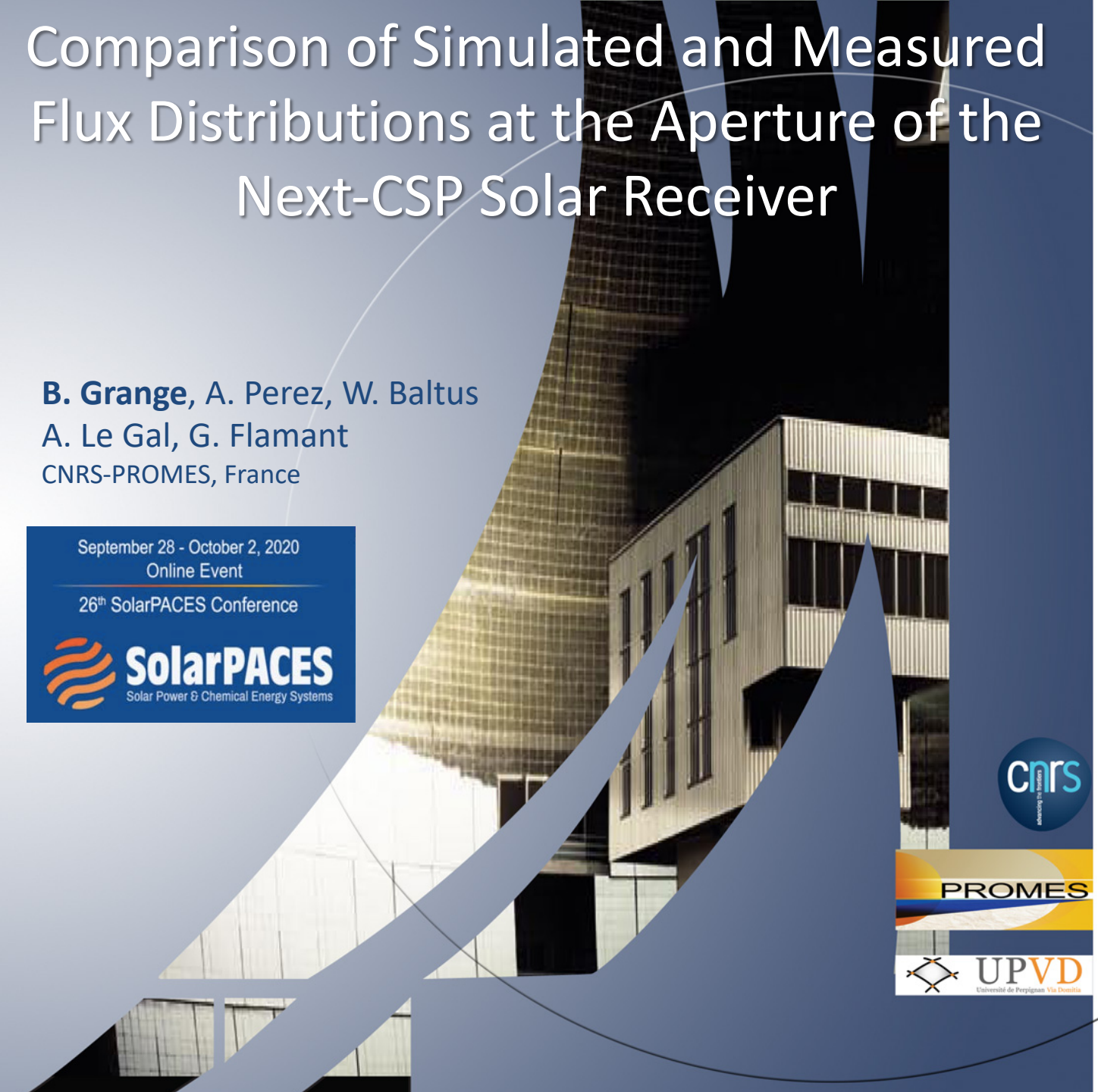
SolarPACES
Solar Power & Chemical Energy Systems



Horizon 2020
European Union Funding
for Research & Innovation

next-CSP

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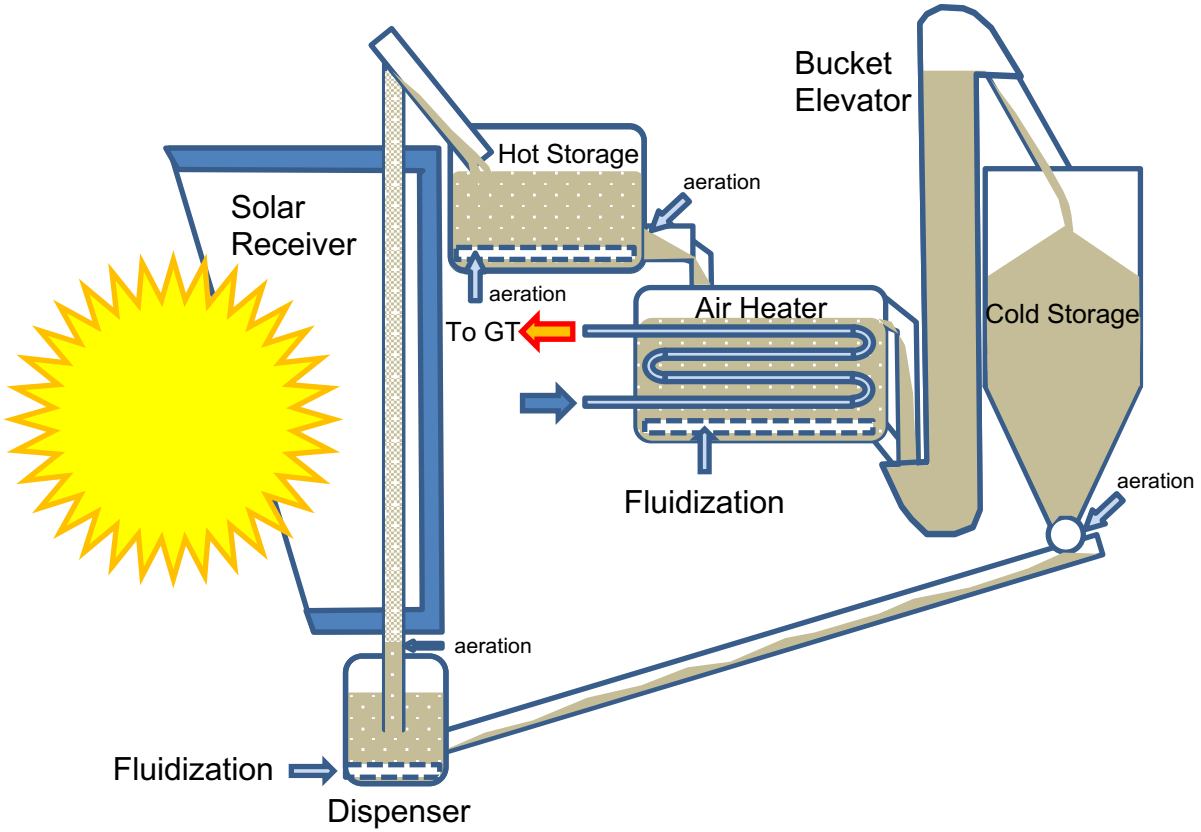
Outline

- Presentation of the Next-CSP Project
- Description of the Solar Receiver
- Methodology
  - TABU Search/*Solstice*
  - Heat Flux Measurement
- Results & Perspectives

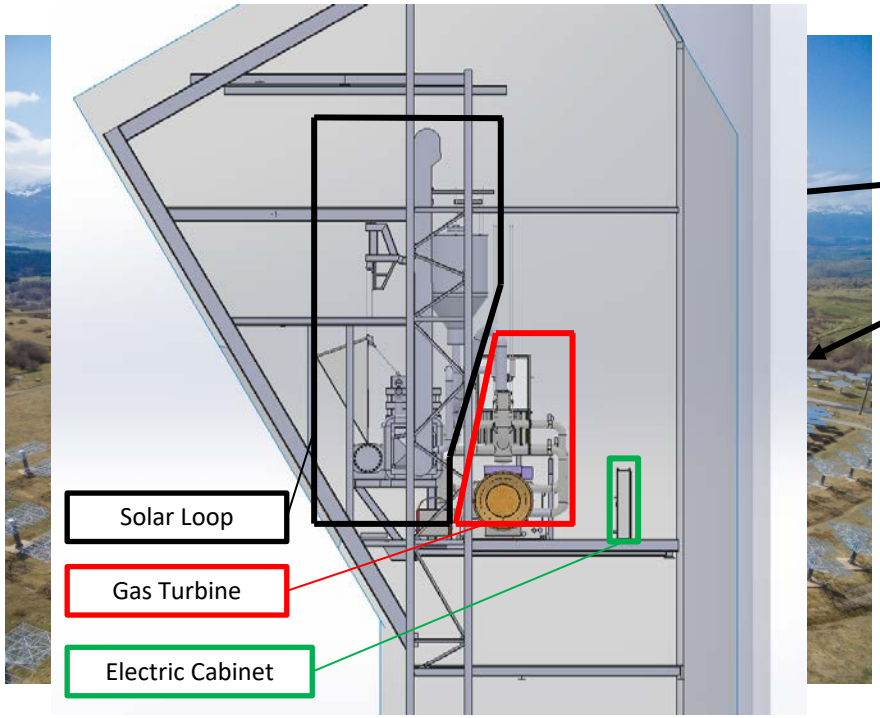
Next-CSP project

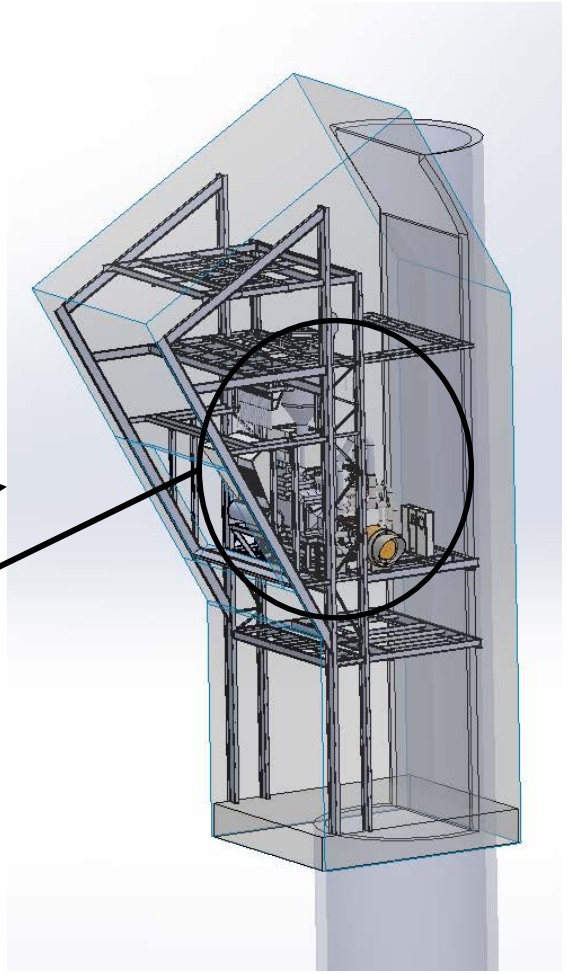
- Operation of the system
  - Dispenser
  - Tubular receiver
  - Hot and cold storage
  - Air heater
  - Bucket elevator
  - Hybrid gas turbine



Next-CSP project

- Installation at the Themis site
  - Tower of 104 m
  - 107 heliostats of 54 m² each
  - System between 83 m and 92 m height
  - ~70 tons





Next-CSP project

- Major challenges
  - **Develop a solar receiver able to heat particles up to 700°C**
  - Design and test a two-tank particle thermal energy storage and a particle-to-pressurized air heat exchanger.
  - Integrate a hybrid gas turbine with the solar loop.

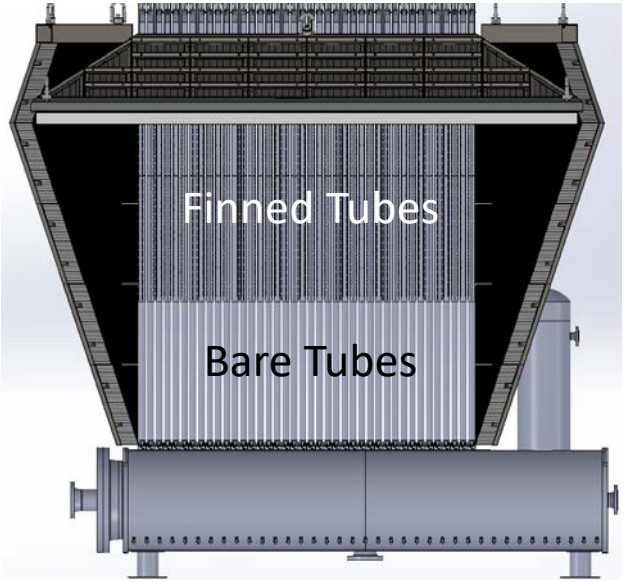
- Major barriers
  - Heat transfer limitation
  - **High temperature materials**
  - Particle conveying and circulation in a close loop
  - Control of the complete system

Aiming point strategy on the Next-CSP receiver

Description

- Tubular receiver (SS 310S) with back refractory panel
- 40 tubes - 1 m bare (lower part) and 2 m finned
- Divergent half cavity made of refractory panels
- Refractory panels → ALSIFLEX®-1260
- Angles of the cavity panels comes from position of most Eastern, Western and Northern heliostats

  → Complex geometry and optical paths

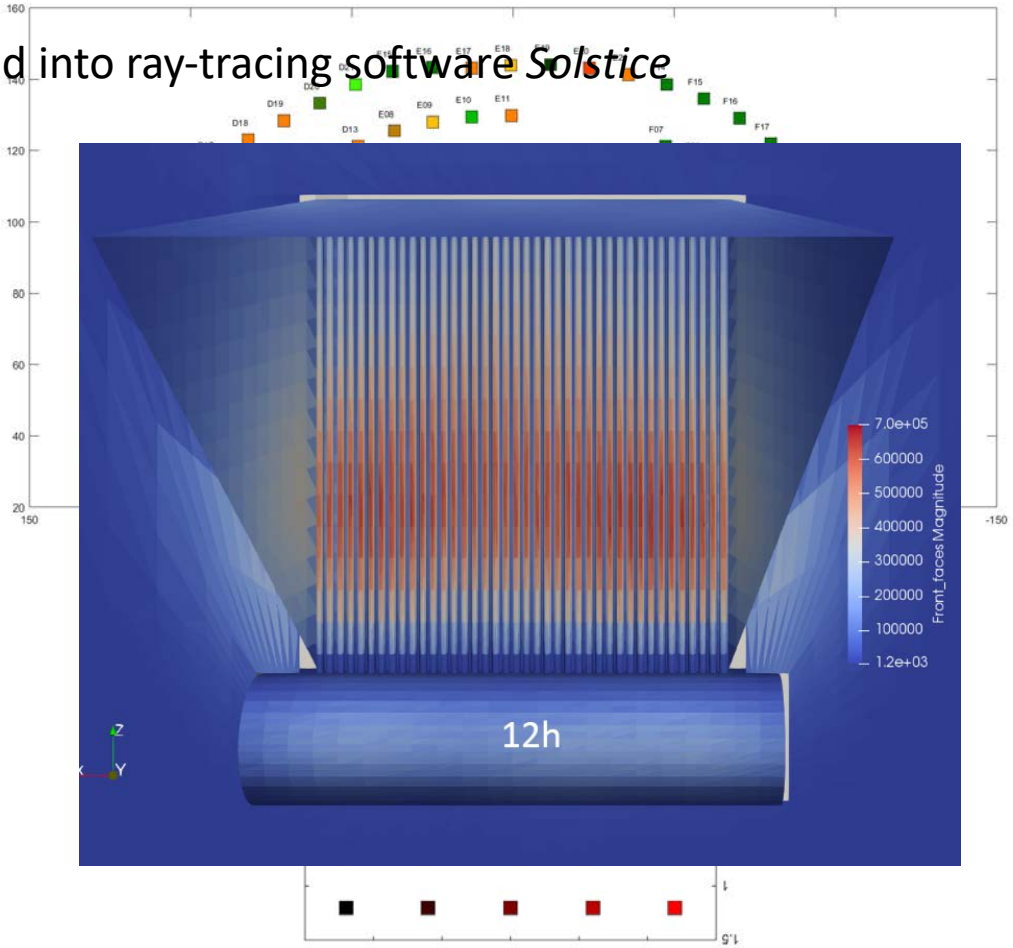


Aiming point strategy has to take into account the complex geometry

Methodology

Simulation Tools

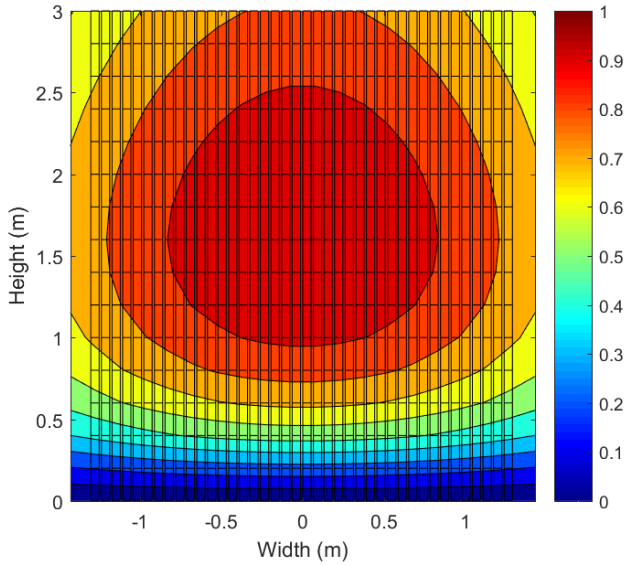
- TABU search coupled with convolution-projection optical model Unizar
- Results introduced into ray-tracing software *Solstice*



Methodology

TABU Search

- Definition of objective normalized flux distribution, # of aiming points, cost function and constraint



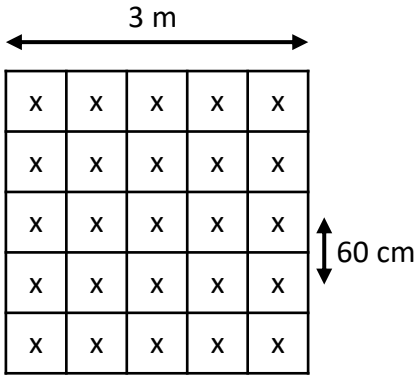
Objective normalized flux distribution

Horizontally → Gaussian distribution

Vertically → $y = \left(\frac{x}{x_{peak}}\right)^{x_{peak}.b} exp\left(b\left(x_{peak} - x\right)\right)$

→ $\varphi_{inc} \leq 500$ kW/m²

Number of aiming points = 25



Cost function

Root-Mean-Square Deviation

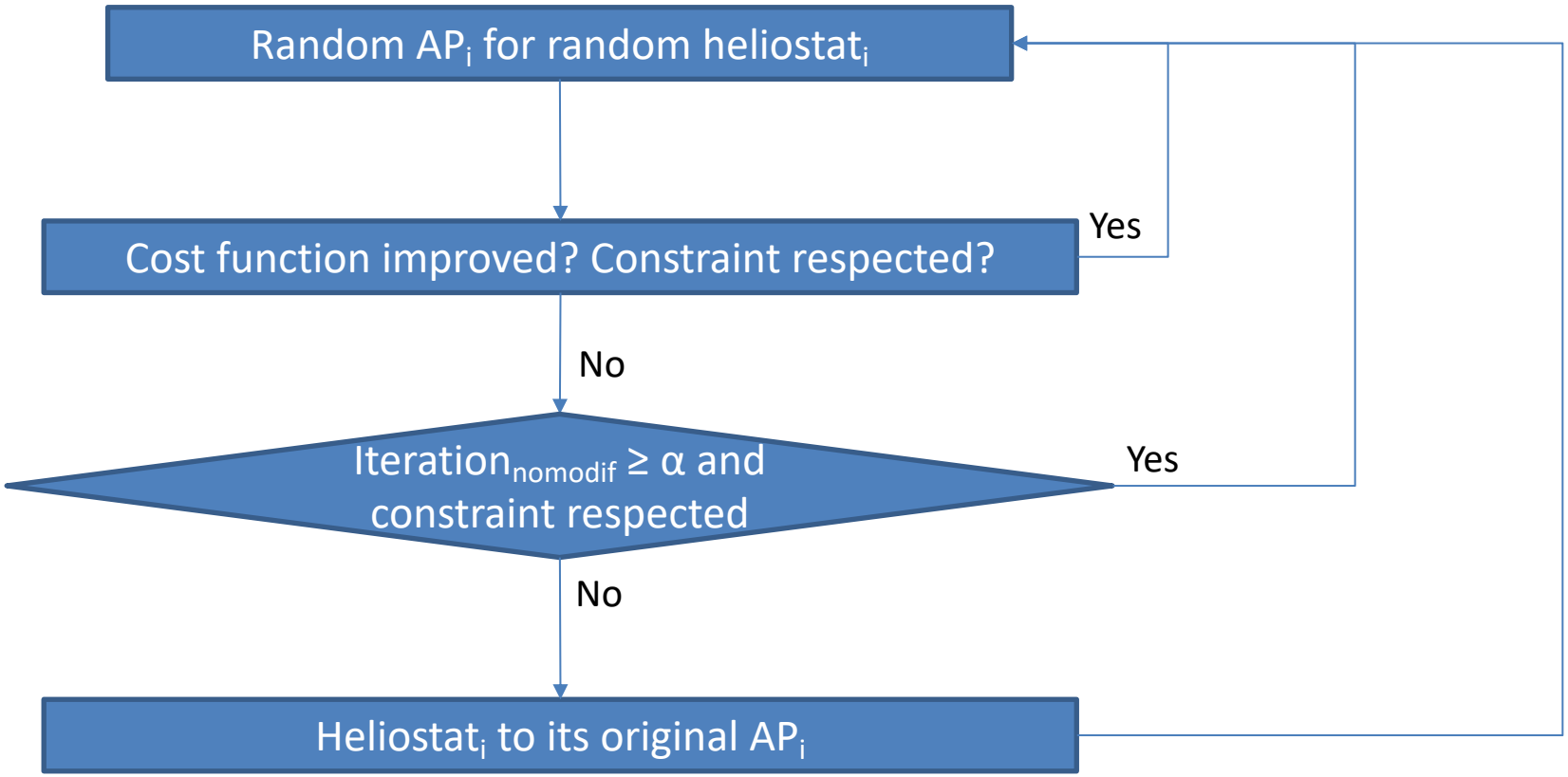
Constraint

Not more than 30% of flux loss relative to base case

Methodology

TABU Search

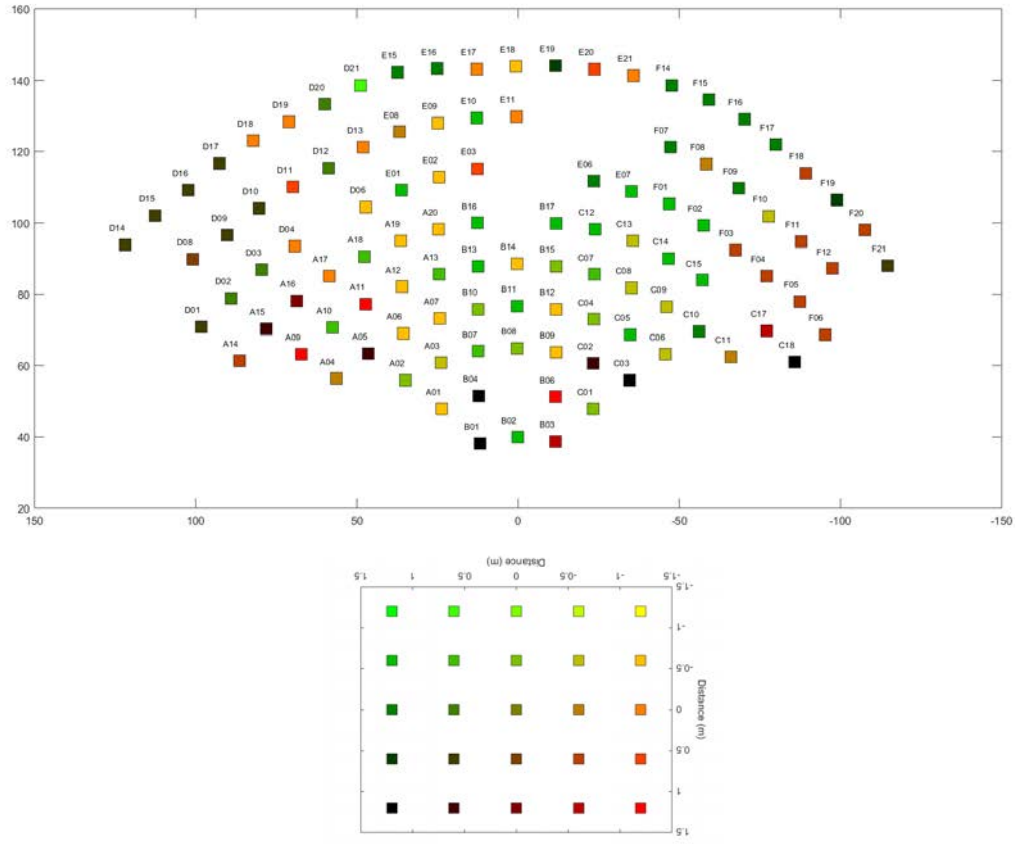
- Algorithm

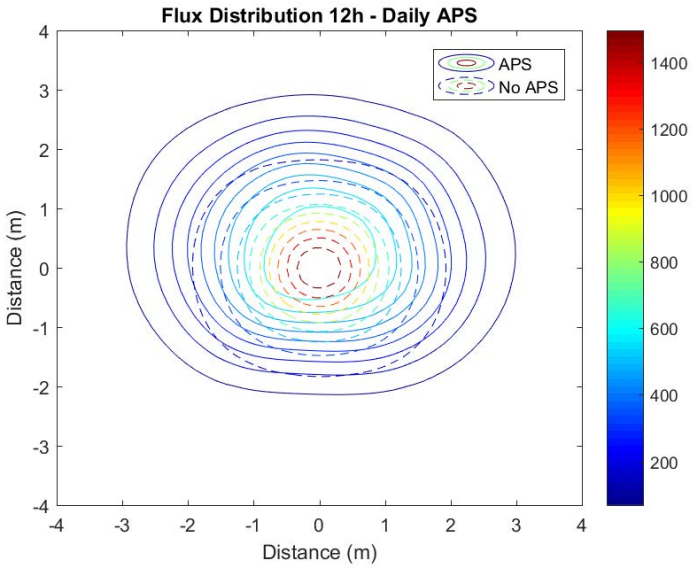


Methodology

TABU Search

- Typical results

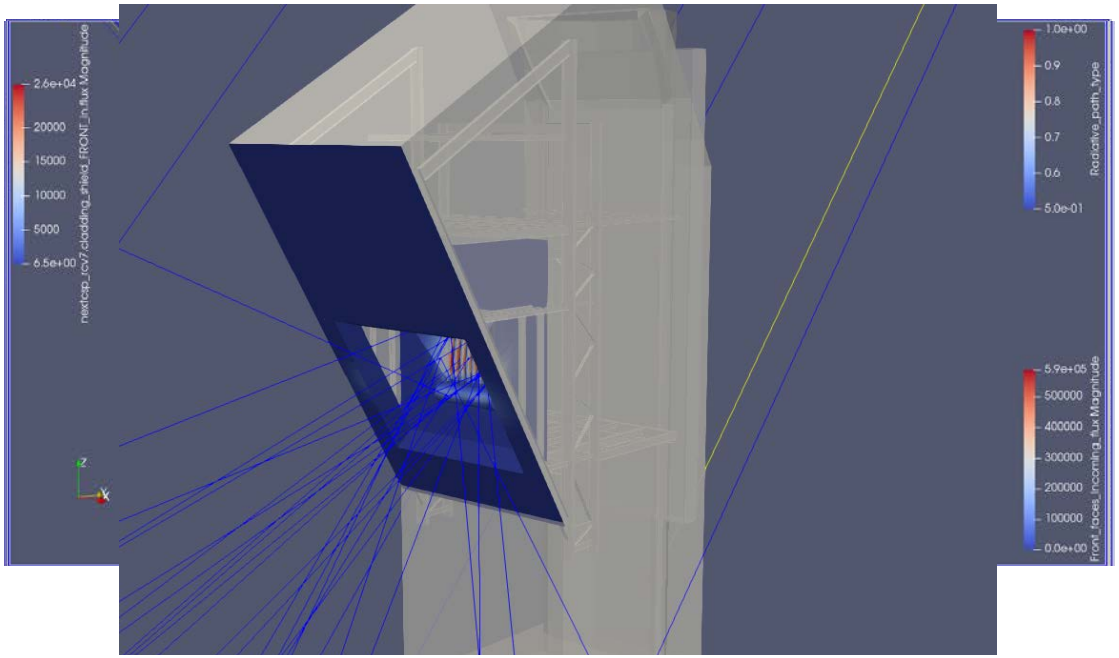




Methodology

Solstice

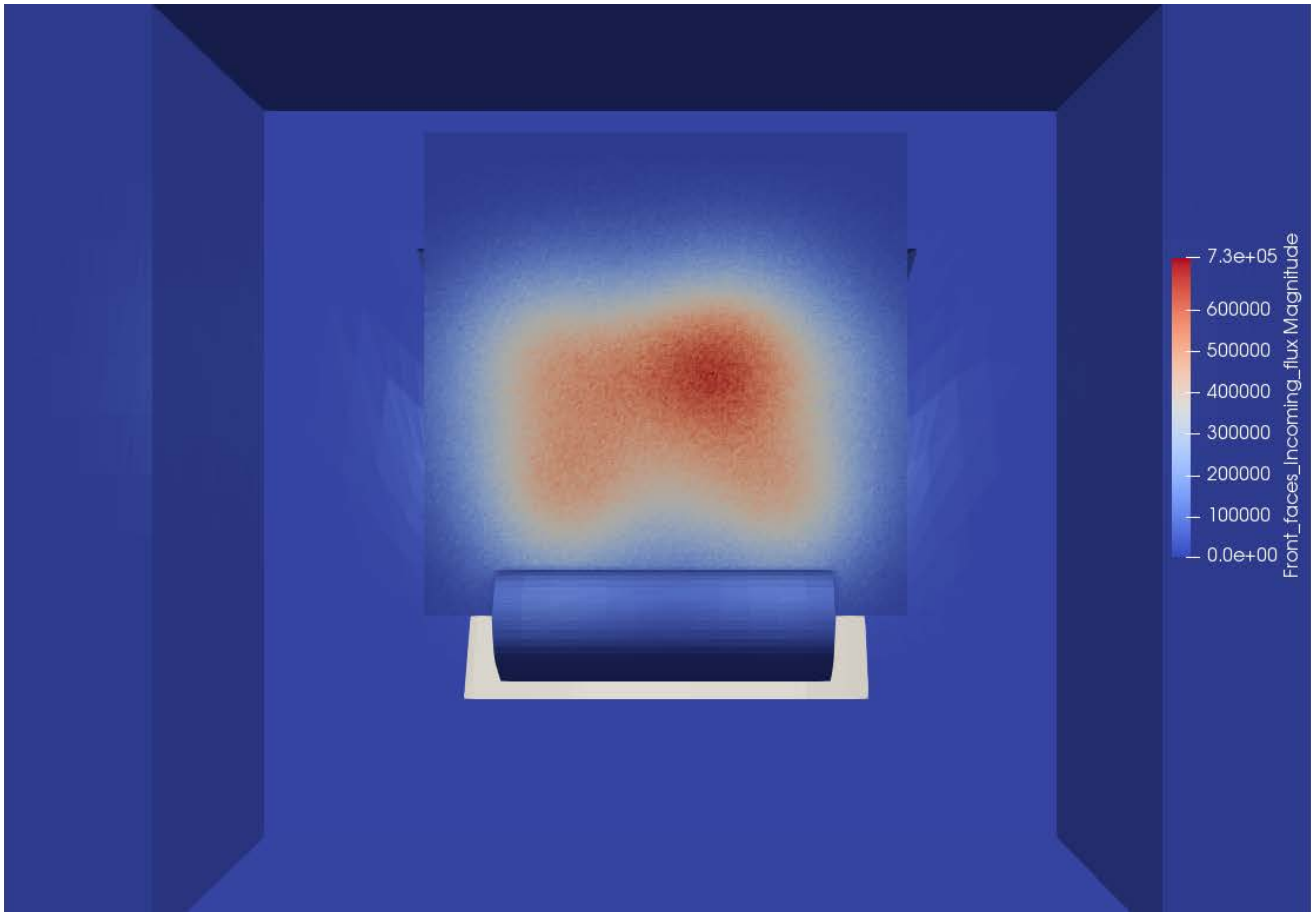
- Presentation of *Solstice*
  - New open-source ray-tracing software developed by the CNRS-PROMES laboratory and Meso-Star SAS
  - YAML (Yet Another Markup Language) language to create geometries
  - Import CAD model → Ray's path in complex geometry
  - Access to performance of the solar field



Methodology

Solstice

- Flux distribution on the receiver bar plane with a virtual target

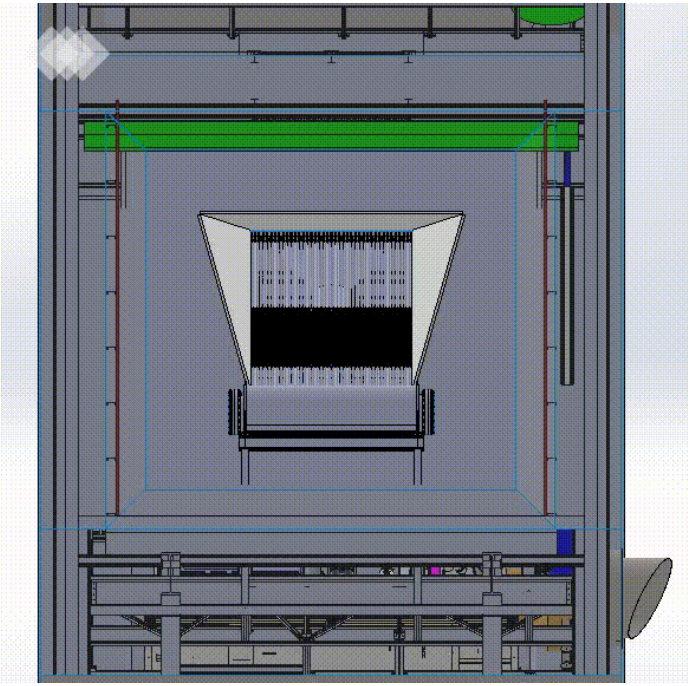


Methodology

Flux Measurement System

- Consists in:
  - CMOS camera
  - Heat flux sensor
  - Scanning bar

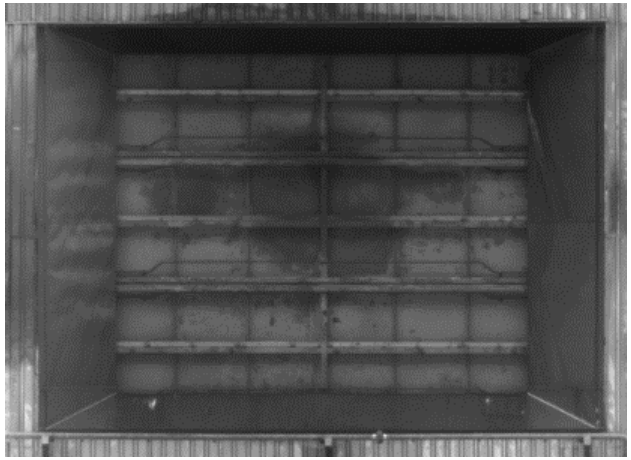
→ Measure the heat flux distribution at the aperture of the receiver



Methodology

Flux Measurement System

- CMOS camera installed in the solar field

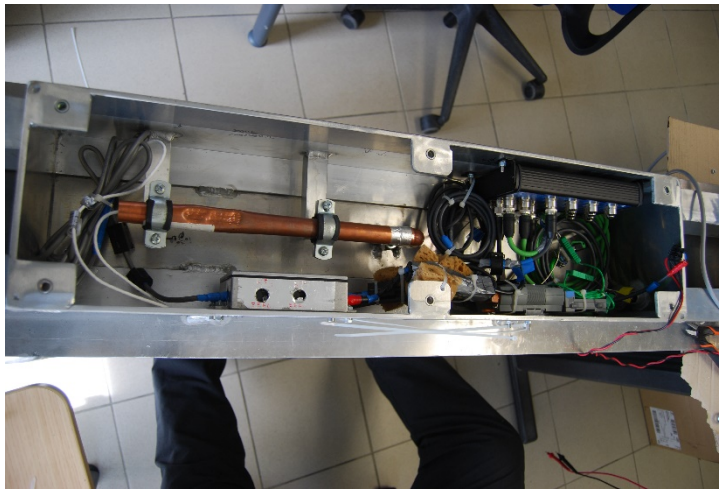


- Basler, sensor CMOS Sony IMX174, 1920*1200, monochrome
- High picture frame rate (up to 163 FPS)
- 16-bit dynamic
- Pixel of 2.34 x 2.34 mm

Methodology

Flux Measurement System

- Heat flux sensor installed on the scanning bar

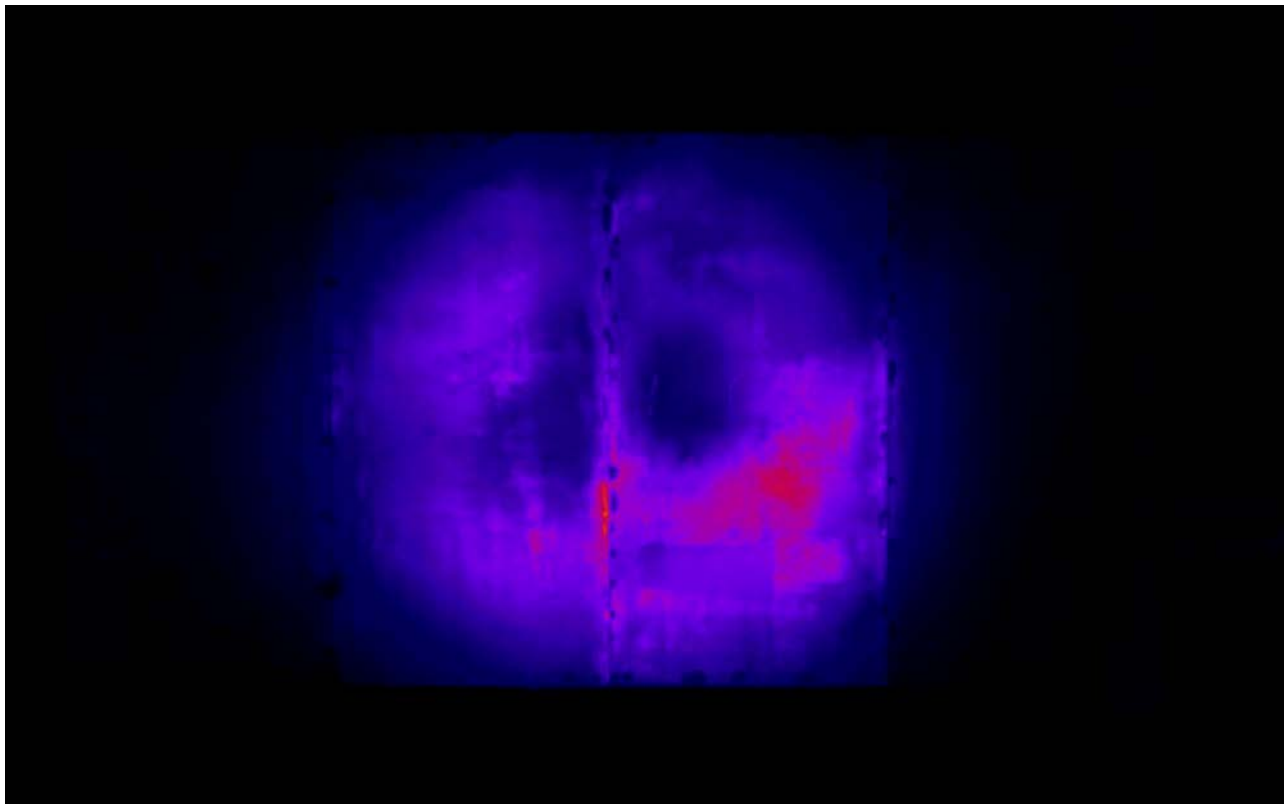


- Heat flux micro-sensor model HFM 6
- 17 to 300 μs response time
- Thermopile 4 mm in diameter, covered with Pyromark® film → α = 94%
- Accuracy of ± 3%
- High-speed A/D converter and data acquisition system ADDI DATA MSX-E3011

Methodology

Flux Measurement System

- View of the scanning bar from the CMOS camera



Methodology

Flux Measurement System

- Data processing
  - Flat-field correction

$$I_{net} = \frac{I_{raw} - I_{black}}{I_{flat} - I_{black}}$$

  - Peak Signal to Noise Ratio (PSNR)

$$PSNR = 10log_{10}\left(\frac{1}{rms(I_{raw} - I_{net})}\right)$$

  - Background subtracted from each “net” image

$$I_{corr} = I_{net} - I_{back}$$

Methodology

Flux Measurement System

- Data processing
  - Spatial derivative approach to detect the bar

$$I_{corr-n} = 2\frac{I_{corr} - Min_{pix-all}}{Max_{pix-all} - Min_{pix-all}} - 1$$

$$I_{grad-x} = grad(I_{corr-n})$$

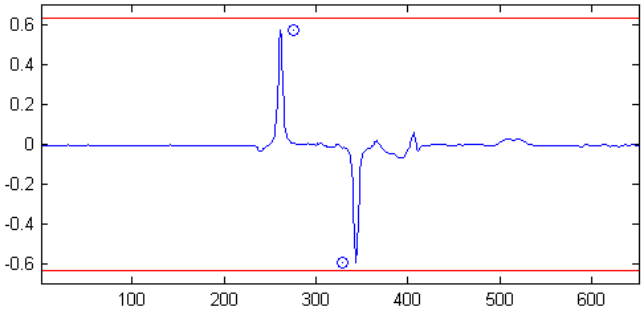
$$I_{grad-x-n} = 2\frac{I_{grad-x} - Min_{grad-x-all}}{Max_{grad-x-all} - Min_{grad-x-all}} - 1$$

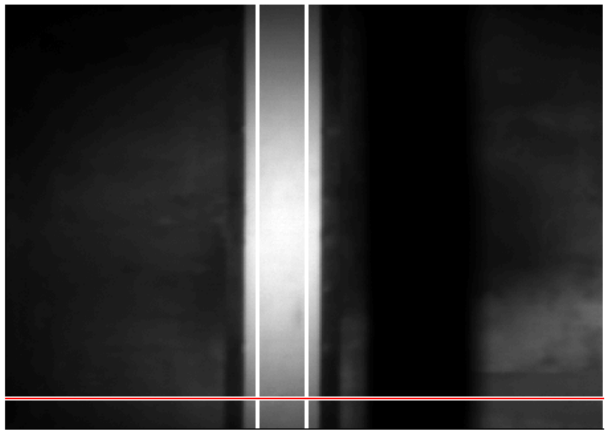
$$Mean_{grad-x-n} = mean_y\left(I_{grad-x-n}\right)$$

Methodology

Flux Measurement System

- Data processing
  - Spatial derivative approach to detect the bar





Methodology

Flux Measurement System

- Data processing
  - Mapping grey value

$$MeanValPixel(p) = \frac{1}{n}\sum_{i=1}^{n} ValPixel_p(i)$$

$$STD(p) = \frac{1}{n}\sqrt{\sum_{i=1}^{n}\left[ValPixel_p(i) - MeanValPixel(p)\right]^2}$$

  - *$ValPixel_p(i)$* that deviate from the average by more than twice the *STD(p)* are rejected

$$MeanValPixel(p) - 2 \times STD(p) < ValPixel_p(i) < MeanValPixel(p) + 2 \times STD(p)$$

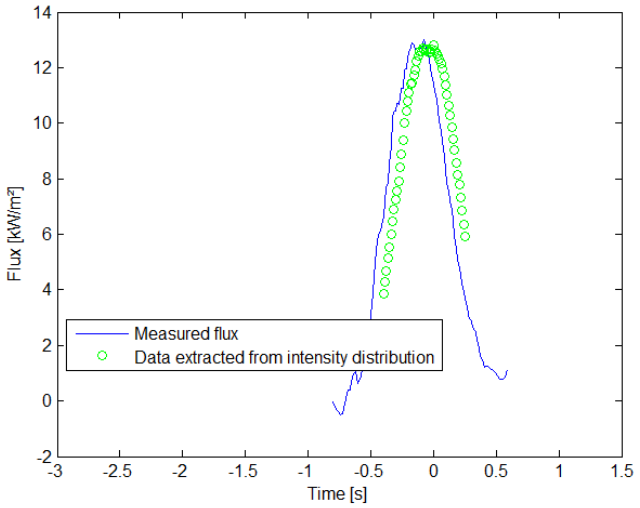
Methodology

Flux Measurement System

- Data processing
  - Calibration

$$\begin{cases} X_{flux}(n) = X_{max}(n) + dF_x \\ Y_{flux} = dF_y \end{cases}$$

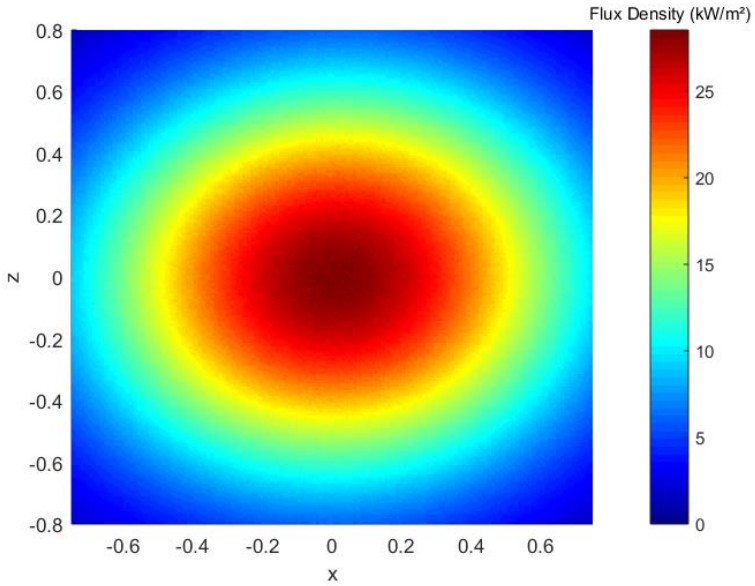
  - $ValPixel(x_n)=ValPixel(X_{flux}(n),Y_{flux})$



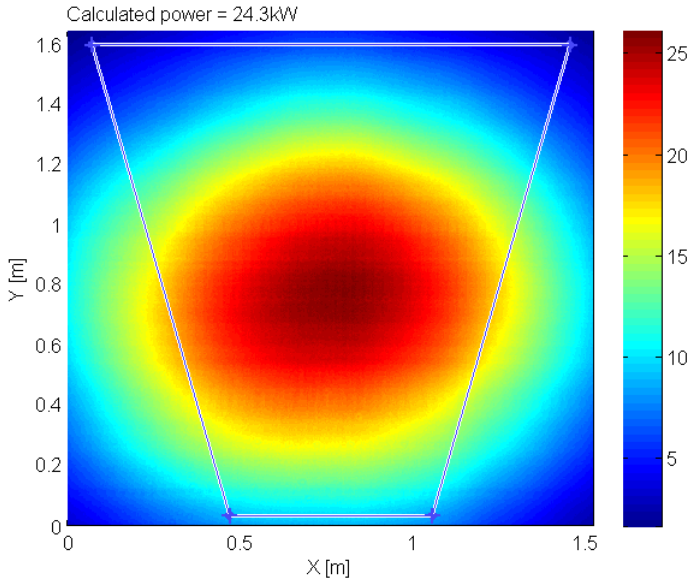
  - Power calculation: $P_{solar-in} = \sum_{cells} [Flux(cell_i) \times Area(cell_i)]$

Results & Perspectives

- Single Heliostat



Simulation



Experiment

- Comparison with an APS with more heliostats when operating the solar loop

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http://next-csp.eu/

Thank you for your attention

Any Questions?

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