Frame Conditions for Thermography Inspections of Photovoltaic Plants

Sergiu Spataru
Technical University of Denmark
sersp@dtu.dk

Drone Inspection Context

Drone +RGB + LWIR

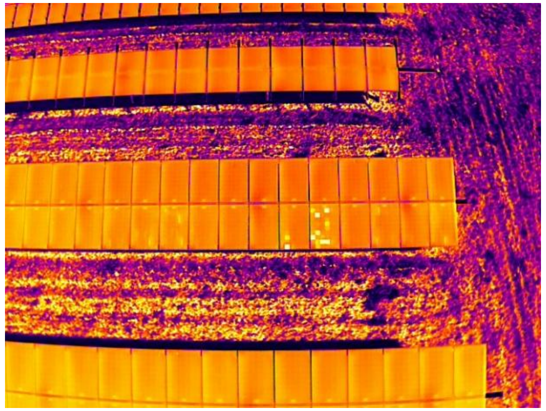
~ 6 k€

Drone + RGB ~**10-k€**

SWIR **~ 10-15 k€**

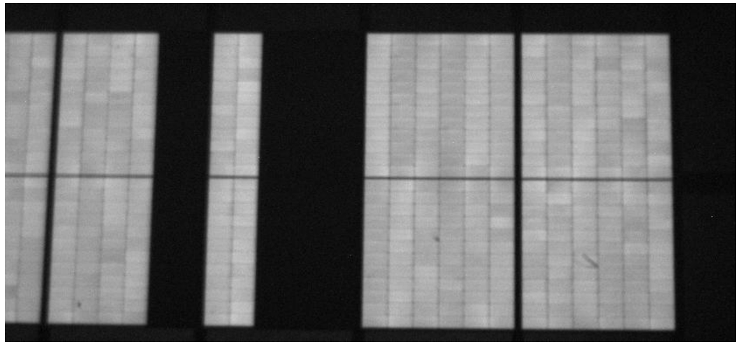
RBG

IRT



Daytime

EL



– Nighttime (requires back powering)

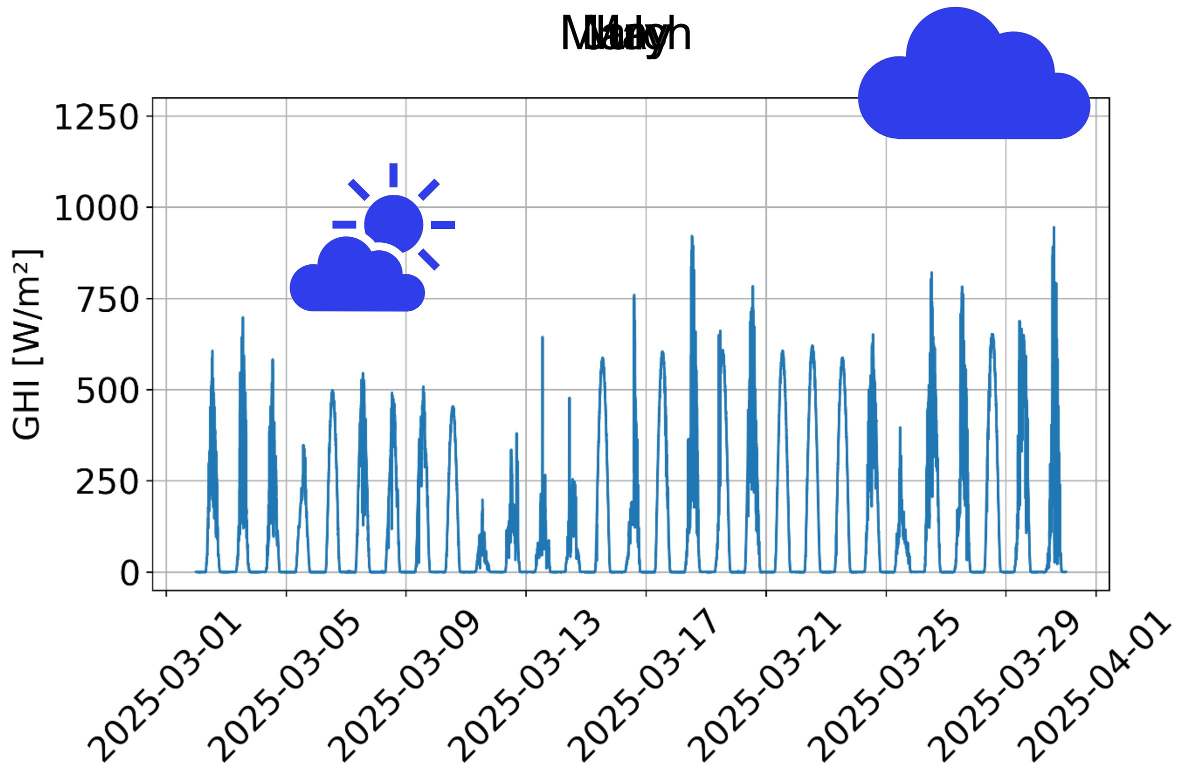
– Daytime (more complex, requires back powering or special inverter)

- **Cheaper**
- **Faster**
- **Less accurate in fault identification**

- **Very accurate in fault identification**
- **Slower**
- **More expensive**

How accurate is “less accurate”?

- Optimal conditions for IRT according do
- IEC TS 62446-3
  - > 600 W/m²
  - Windspeed < 28 km/h
  - Low cloud coverage

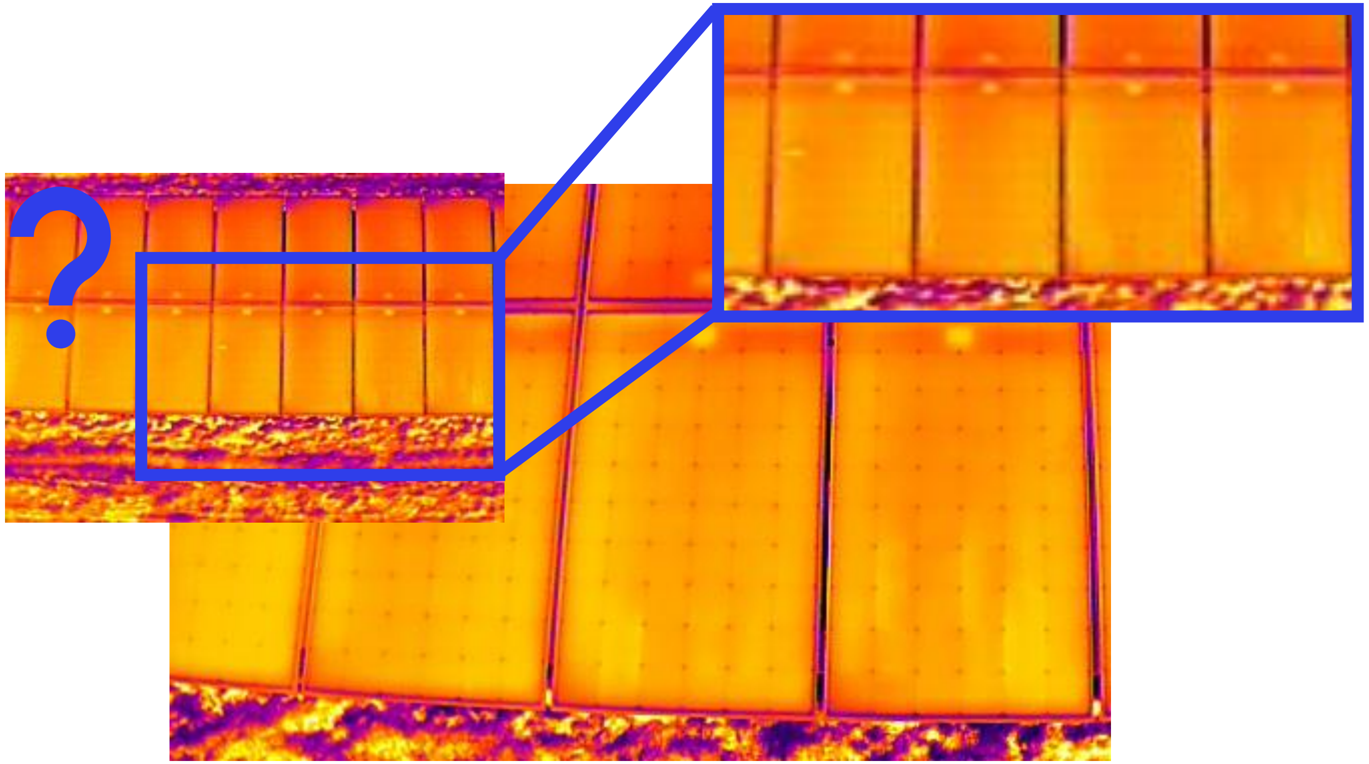


- Limits IRT inspections in certain locations
- We often see and use IRT images from optimal conditions

What is the influence of irradiance in hotspot identification?

What do hotspots mean? How are they influenced by imaging conditions?

- IRT is well stablished:
  - Optimal camera position *
  - Hotspot diagnosis **
  - How to automatize drone inspections ***
- IEC TS 62446-3
  - Spatial resolution **max. 3 cm/pixel**
- Hotspots can be hard to correlate with specific degradation



*S. Vergura, doi: 10.3390/en15145086
**J. Uma, doi: 10.1520/JTE20170653
*** Oliveira, doi: 10.3390/en15062055

Systematic overview of hotspots from different defects and operational conditions

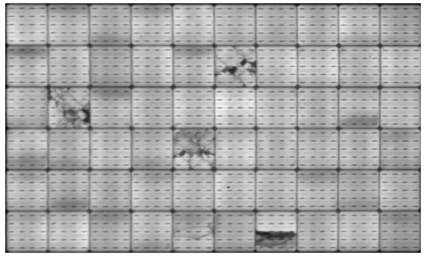
What is the influence of drone altitude in hotspot identification?

What defects were investigated?

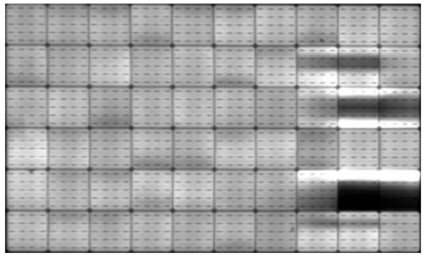
- **Soiling**
  - 12 modules
  - Power loss 66%

- **Shorted bypass diode**
  - 7 modules
  - Power loss 33-66%

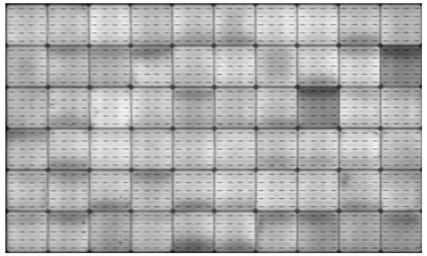
- **Cell cracks**
  - 8 modules (69 cracked cells)
  - Power loss 4-5%



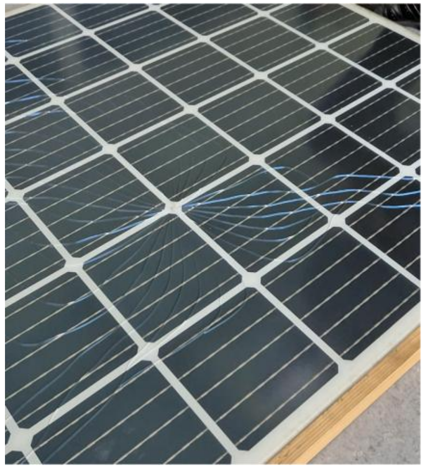
- **Broken cell interconnections**
  - 8 modules (98 cells affected)
  - Power loss 3-14%



- **PID**
  - 6 modules
  - Power loss 5%



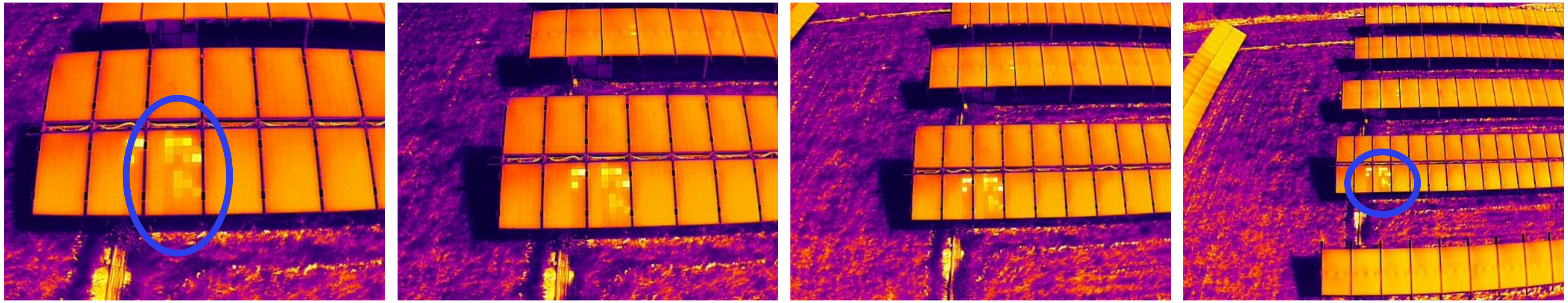
- **Glass cracks**
  - 2 modules
  - Power loss <1%



Inspection conditions

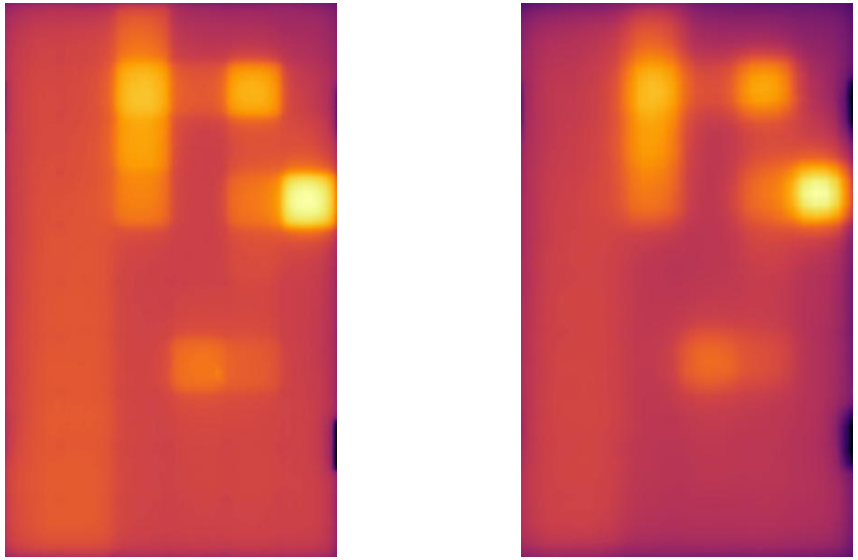
- **IRT drone altitude:**
  - 8 m
  - 10 m
  - 14 m
  - 20 m
- **Irradiance:**
  - > 800 W/m²
  - 800 W/m²
  - 600 W/m²
  - 200 W/m²

8m **10m** **14m** **20m**



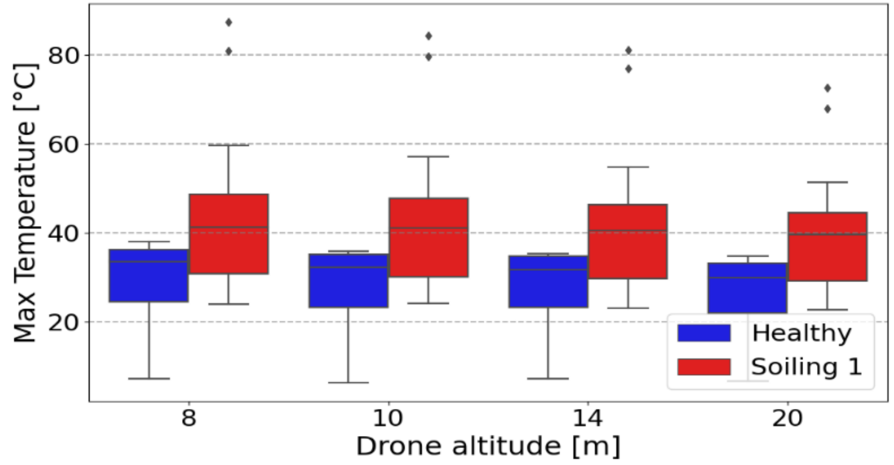
Spatial resolution

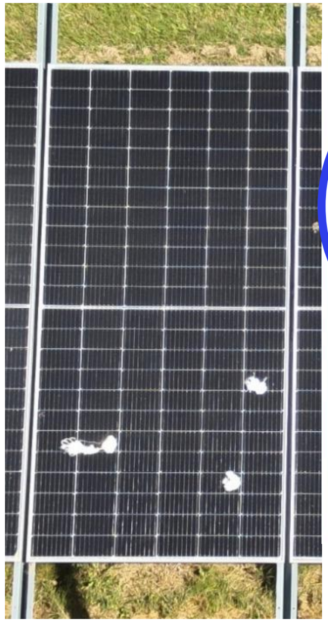
≈<1 cm/px ≈3 cm/px

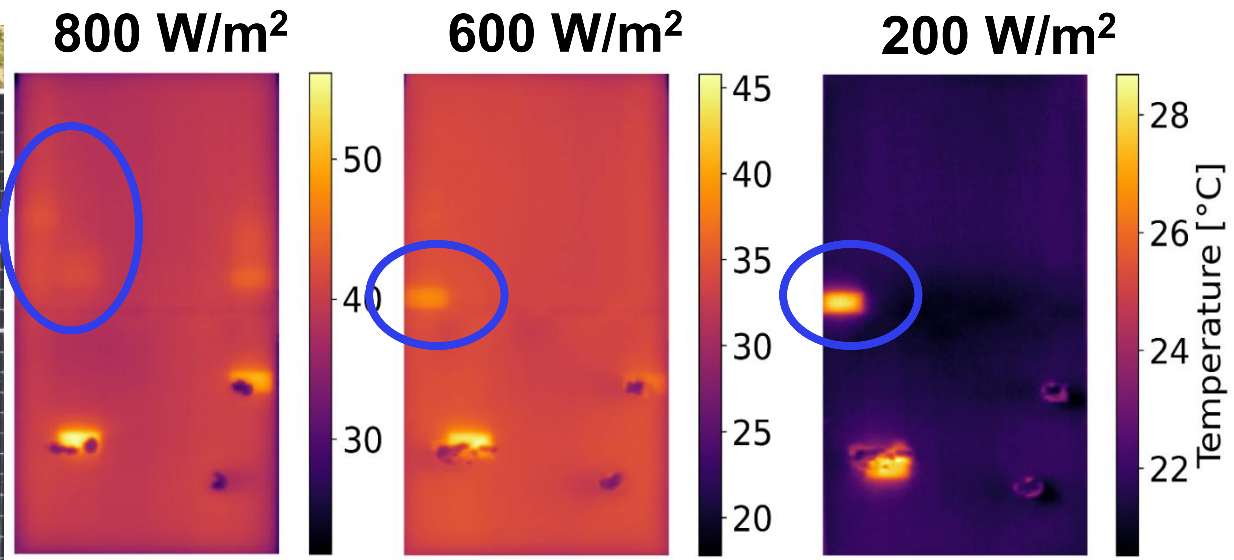


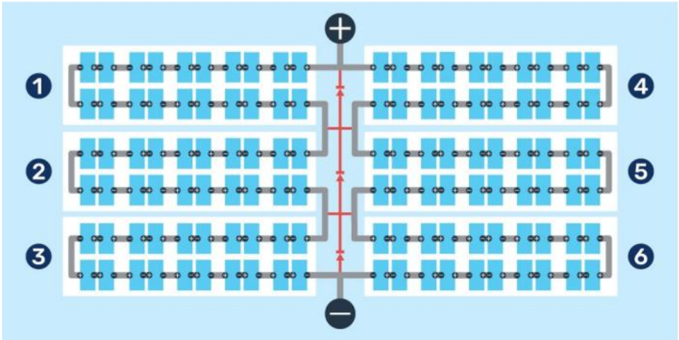
What is the impact of soiling in IRT?

- Soiling 1 - Punctual cell shading
  – Bird drops and small patches of dirt
- Non-homogeneous hotspot development
- Assessment is not conditioned by image spatial resolution
- Even at 200 W/m^2 the ΔT >10^{o}C



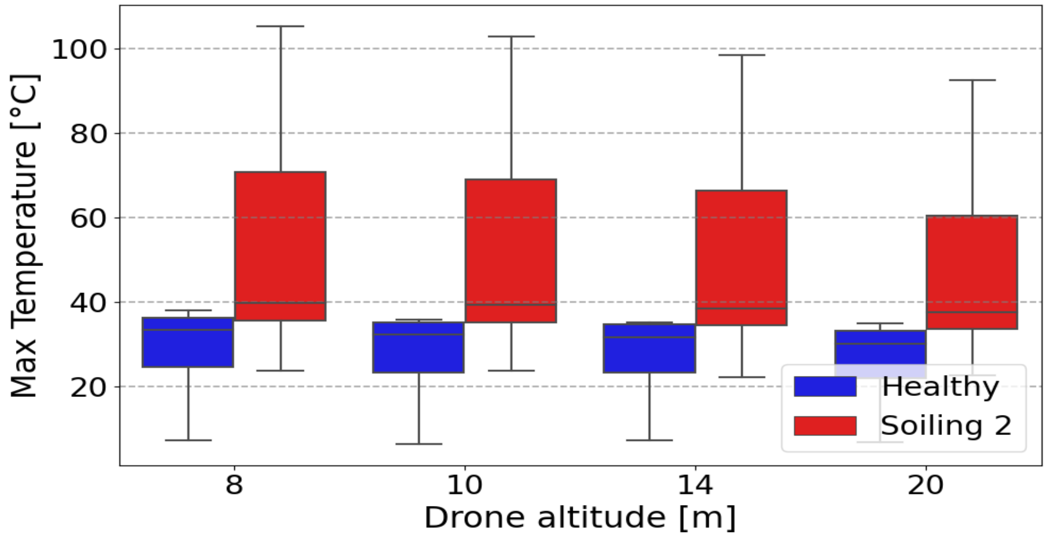


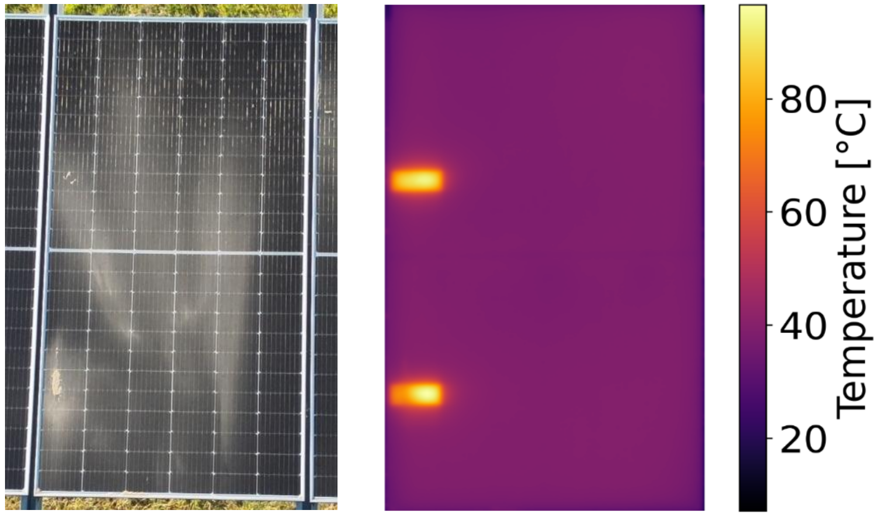


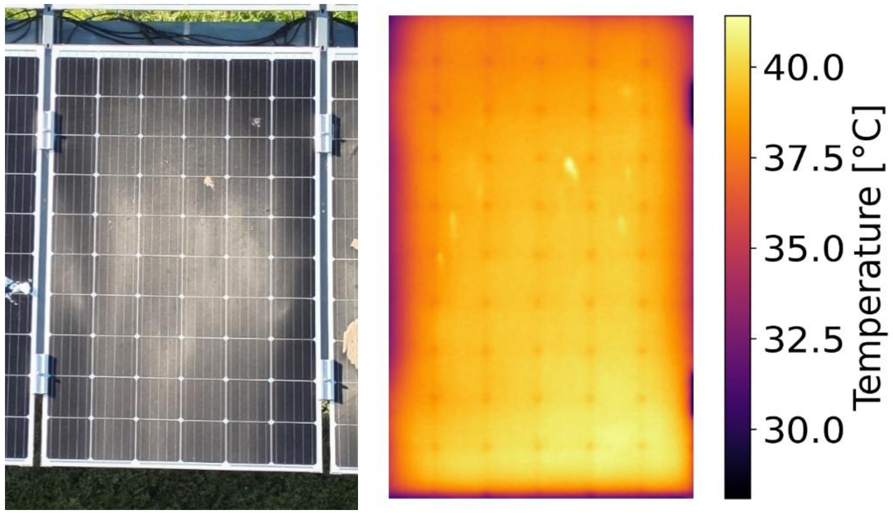


What is the impact of soiling in IRT?

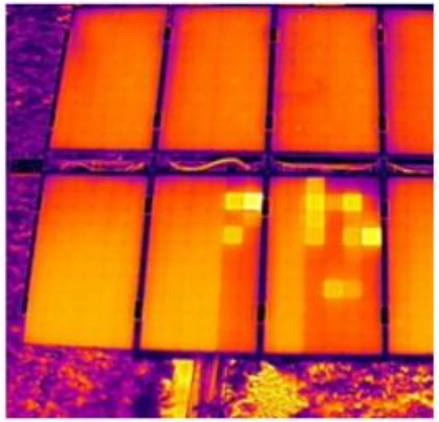
- Soiling 2 – Homogeneous dirt across the module surface
  – Desert soiling conditions
- Hotspots vs full module heating
- Assessment is not conditioned by image spatial resolution
- Even at 200 W/m^2 the ΔT >10^{o}C

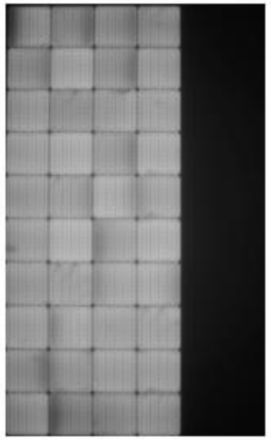


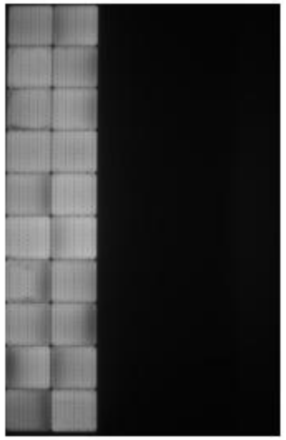




How do Shorted Bypass Diodes hotspots look like?

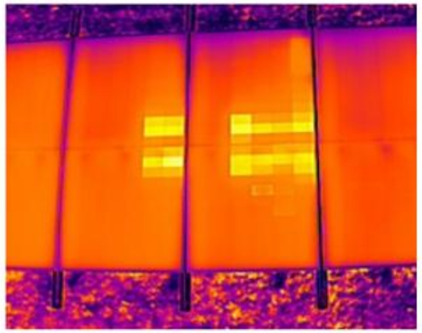


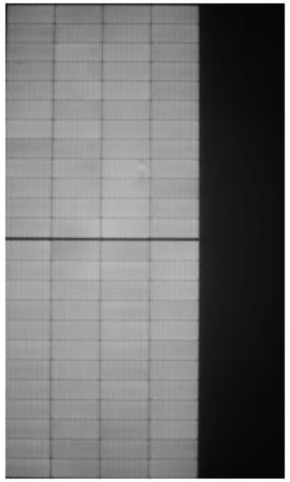


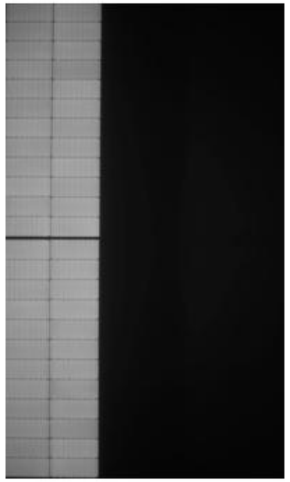


Hotspots of shorted bypass diodes can be significantly different

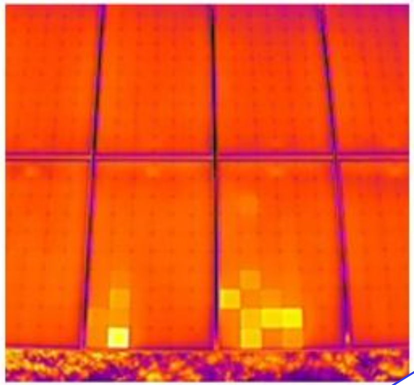
For bifacial and butterfly modules

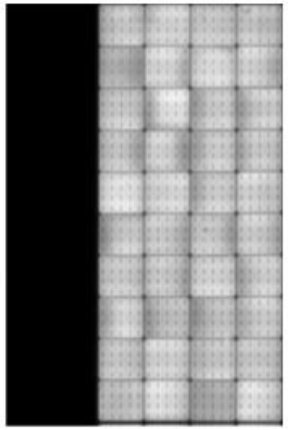


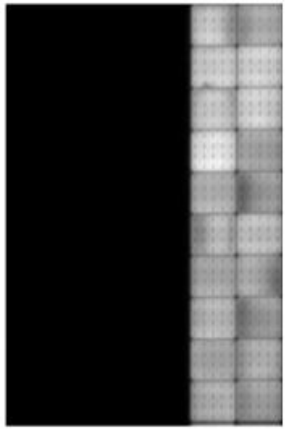




Hotspots caused by rear shading

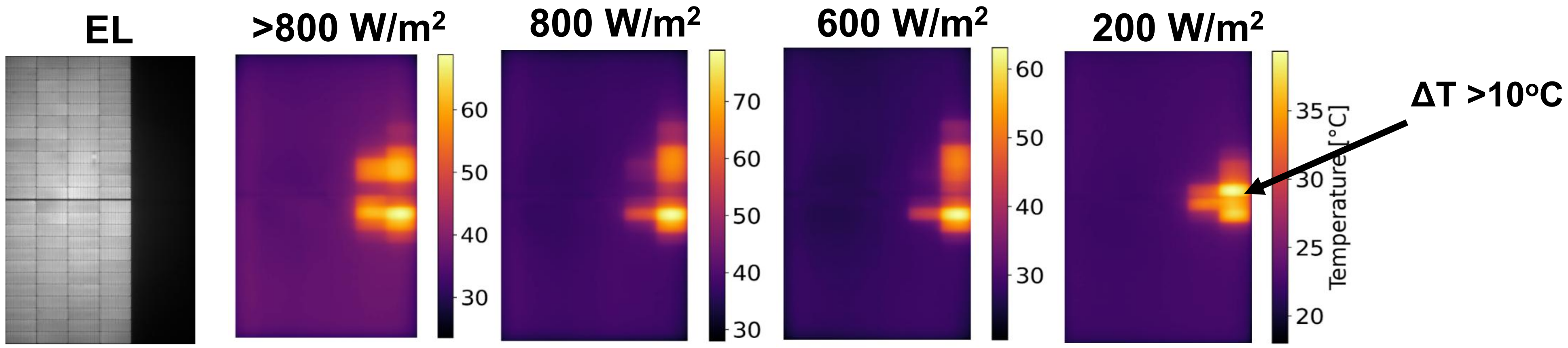


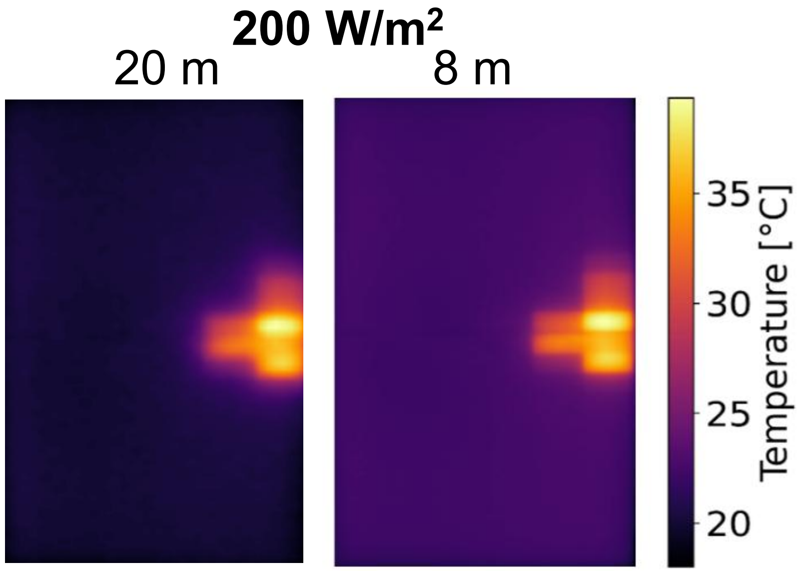




Hotspots caused by cell mismatch

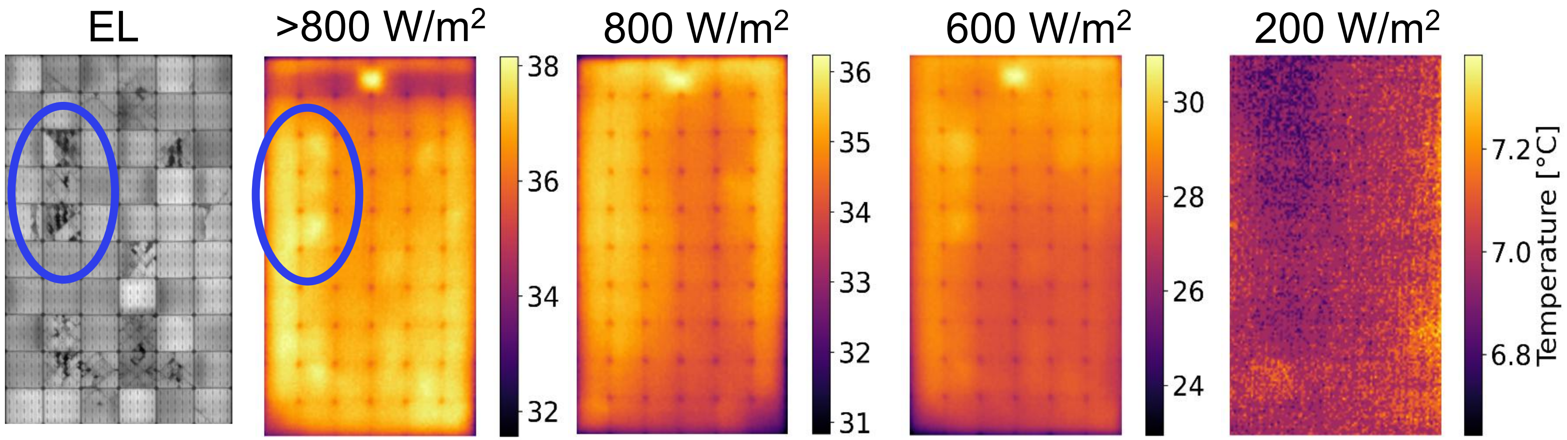
What is the impact of Shorted Bypass Diodes on IRT?



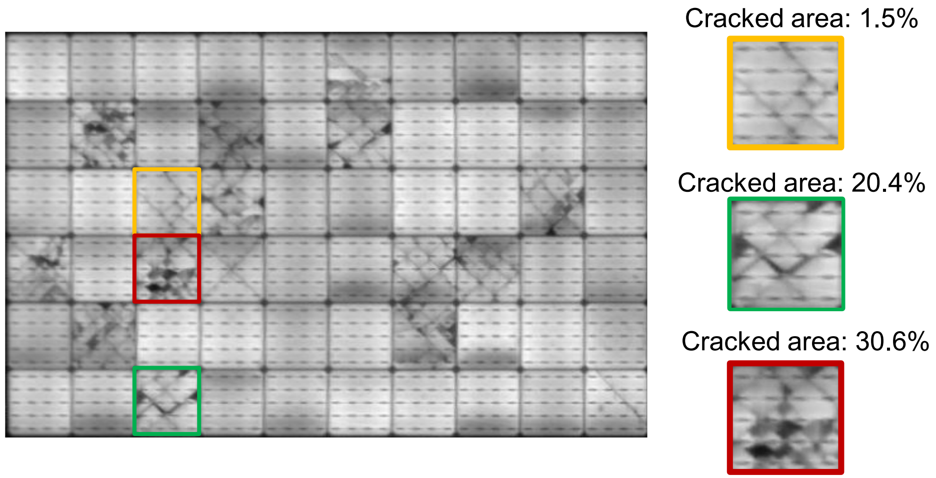


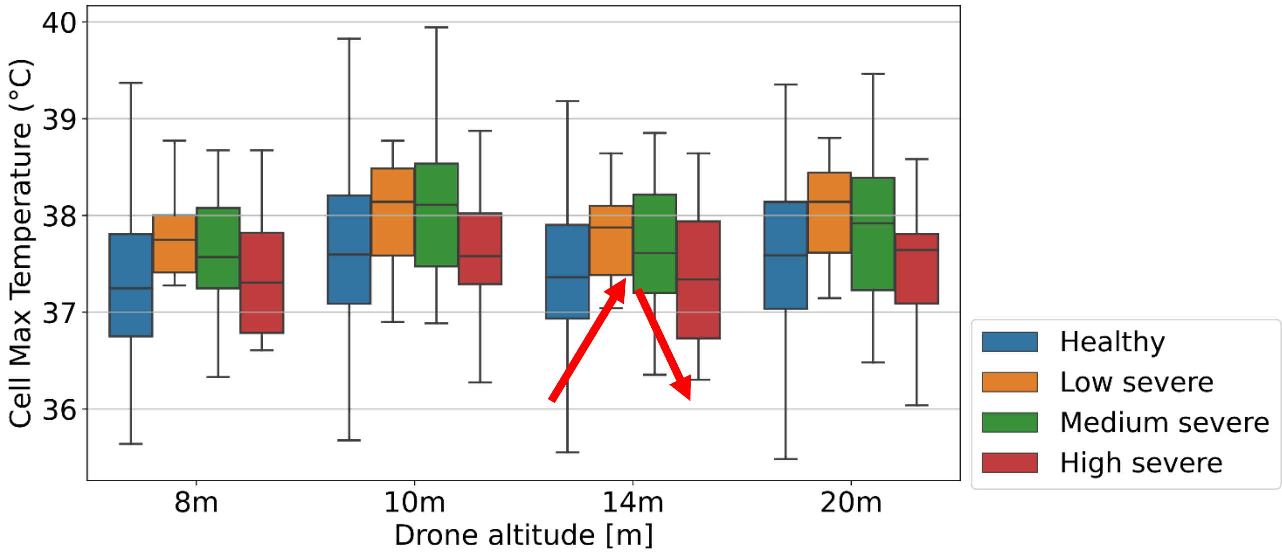
- Hotspots near the middle of the module
- The number of hotspots decrease with irradiance
- Even at 200 W/m^2 the ΔT >10^{o}C
- Identifiable reliably both under high altitude and low irradiance conditions

What is the impact of cell cracks on IRT?

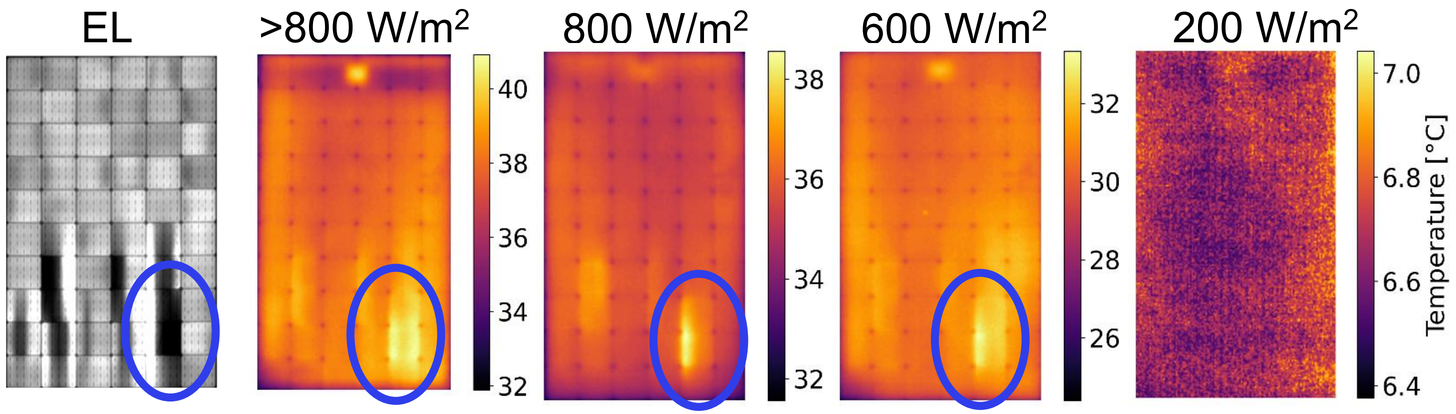


- Hotspots become hard to assess at **600 W/m²** and become unidentifiable below that
- ΔT are **max. 1°C**
- Low (<10%) and medium (<30%) cracked area cells show higher temperatures than highly cracked (>30%) cells.

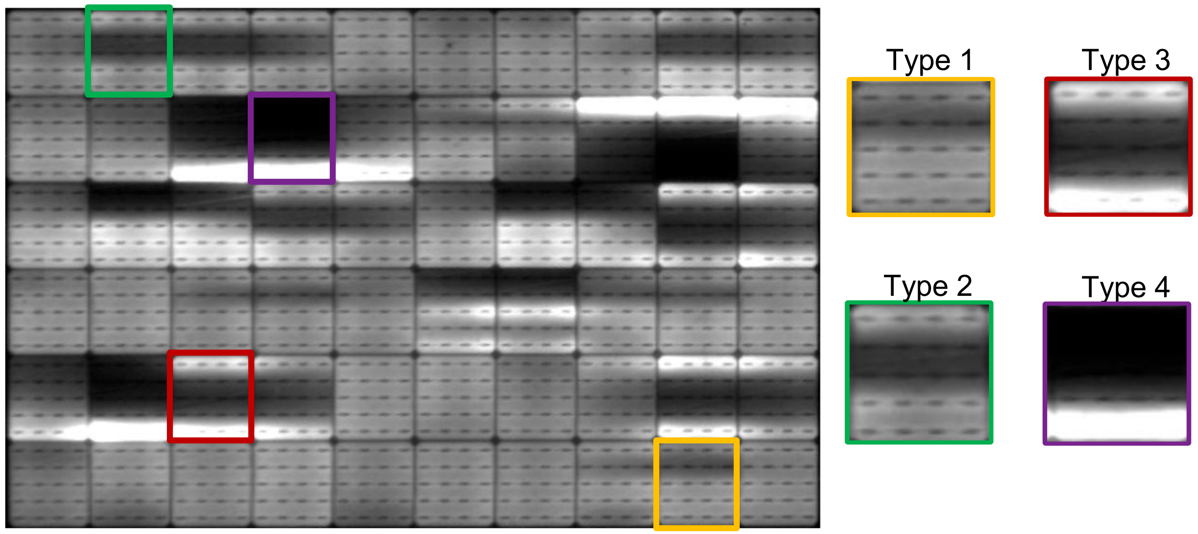


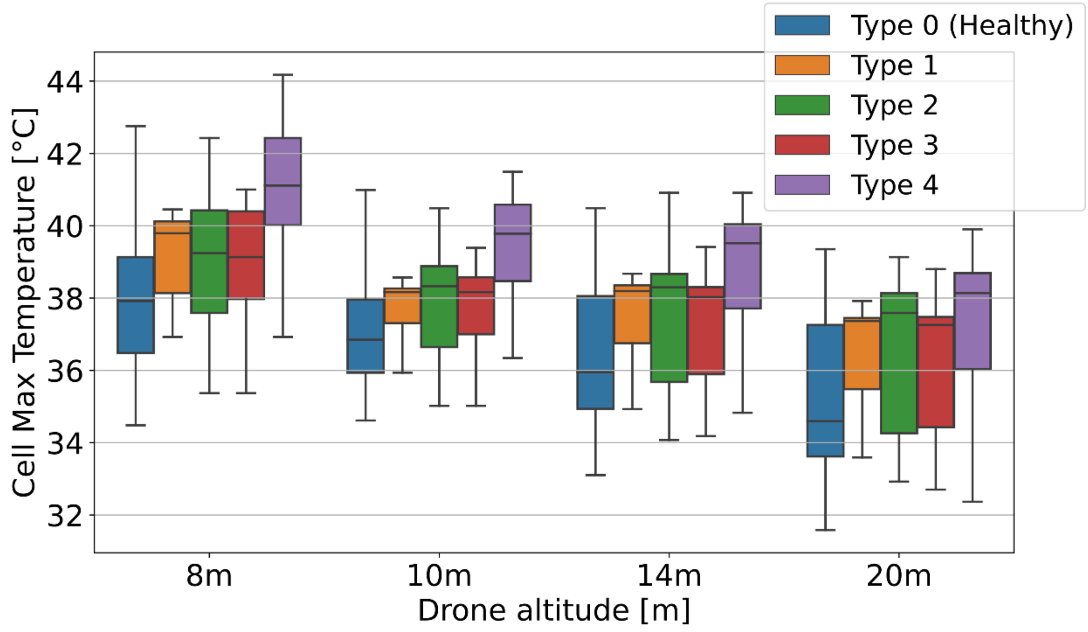


What is the impact broken cell interconnections on IRT?

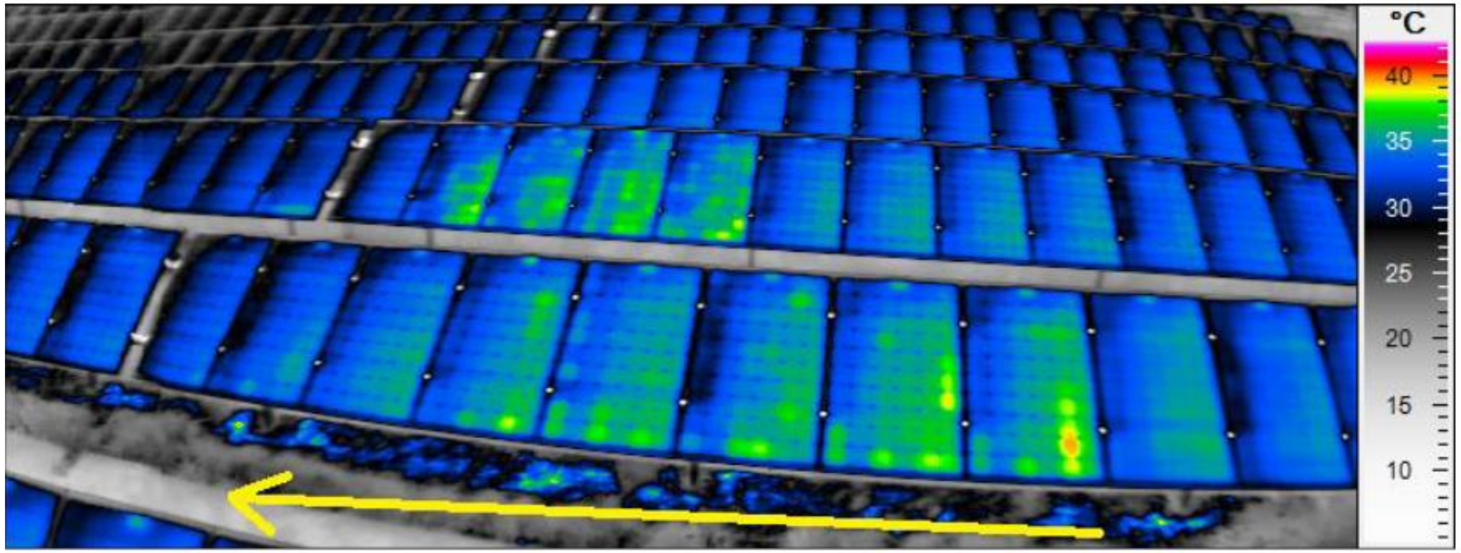


- Hotspots identifiable until **600 W/m²**
- Type 4 disconnections have temperature differences **over 3ºC**

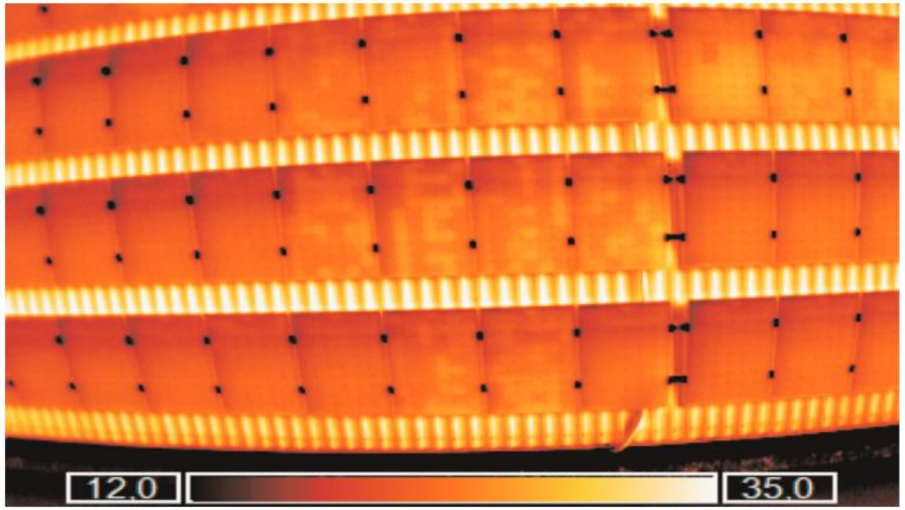


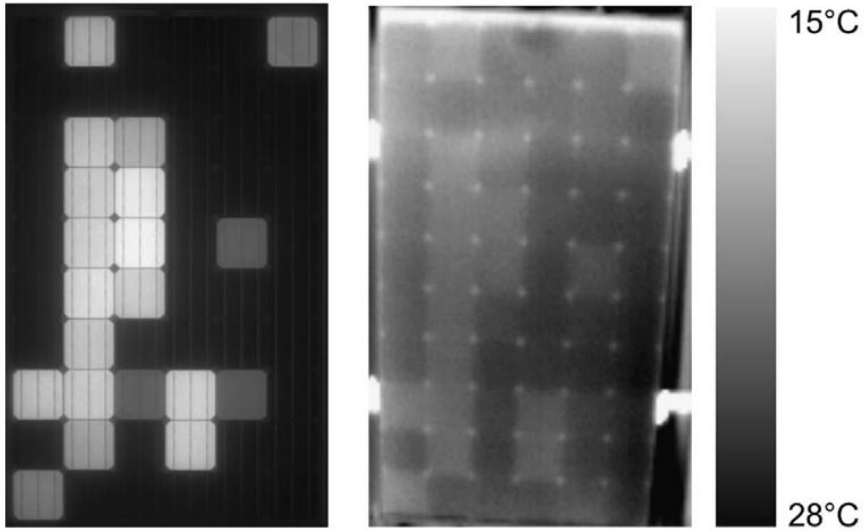


What is the impact of PID on IRT?



B. Weinreich, 2016

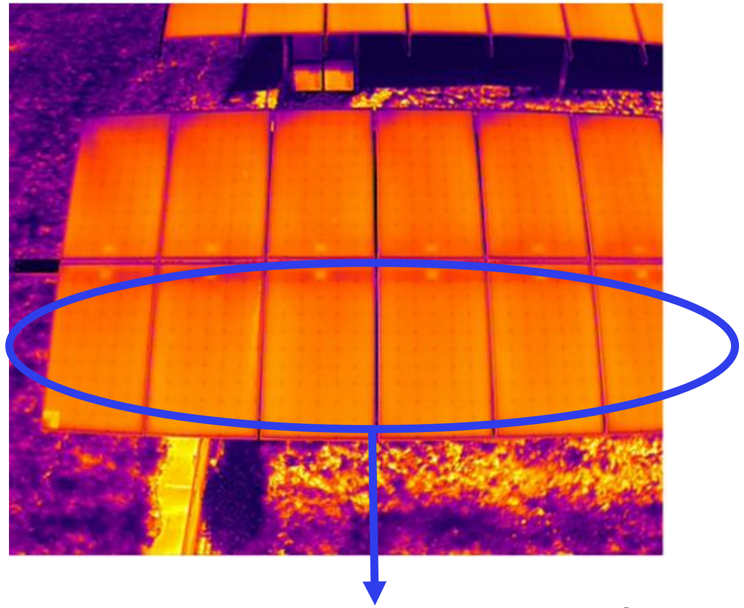




Thomas Kaden, 2015

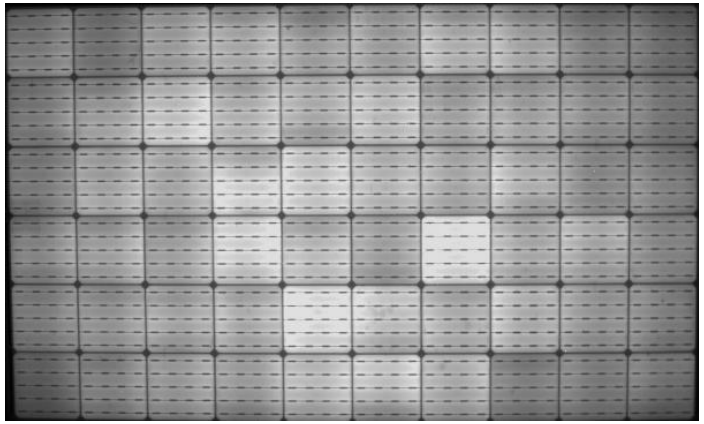
~40% Power loss

What is the impact of PID on IRT?

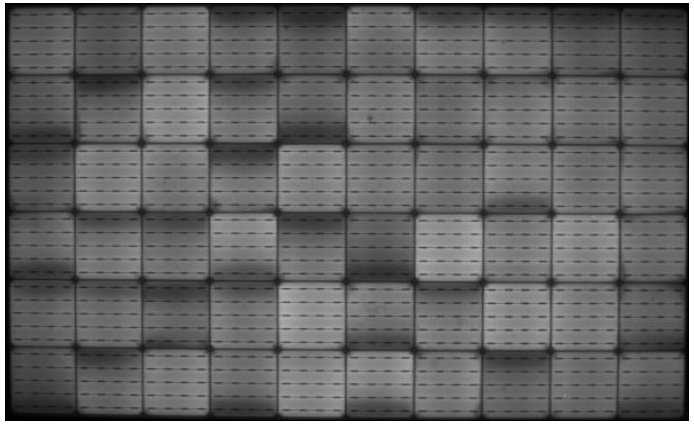


~5% Power loss

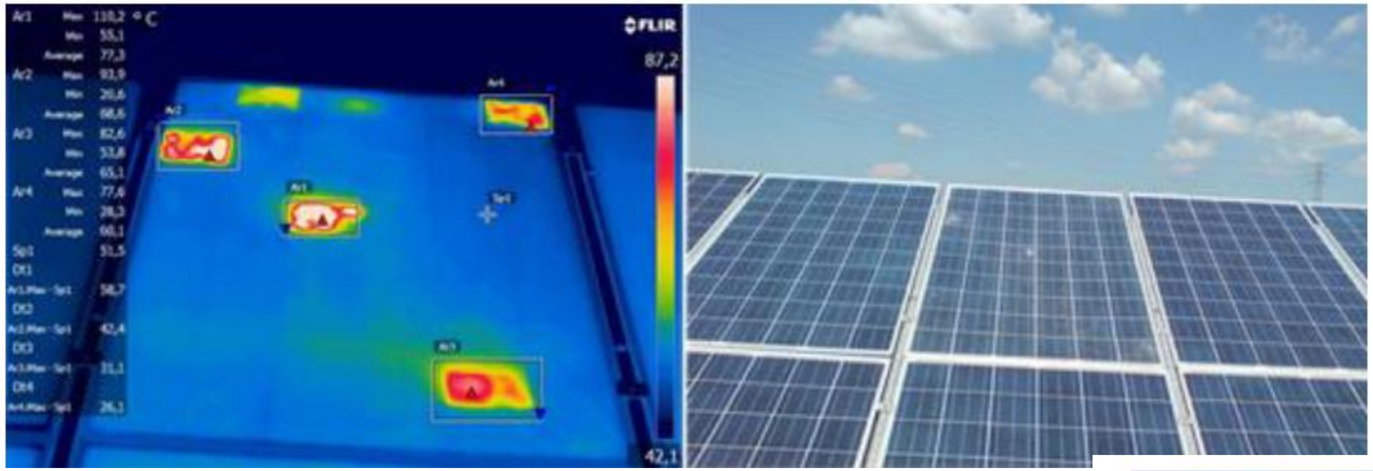
Before PID stress test



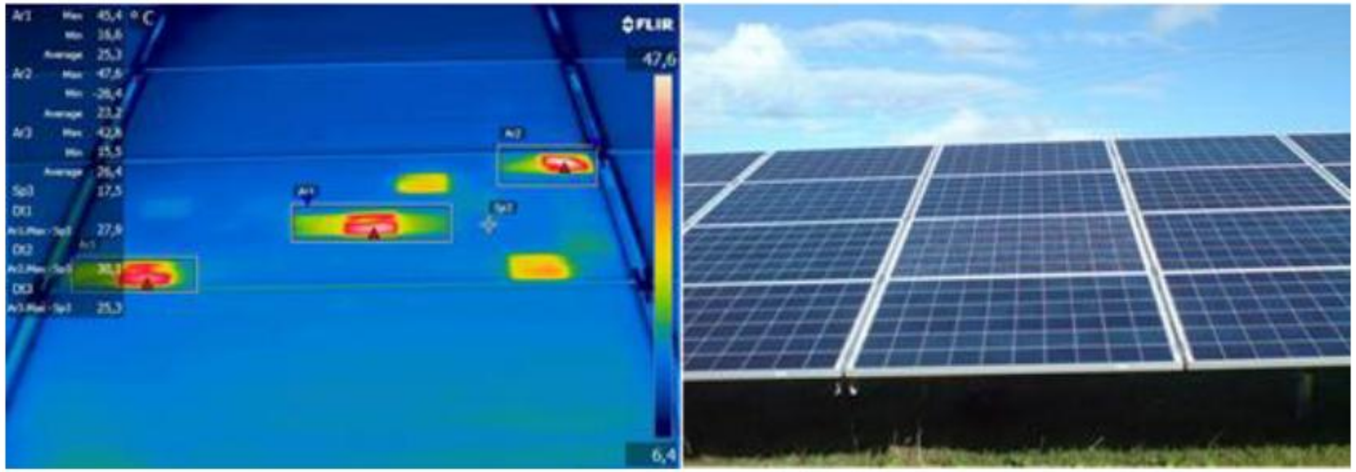
After PID stress test



What is the impact of Front Glass Cracks on IRT & RGB?



IEA-PVPS T13-10:2018



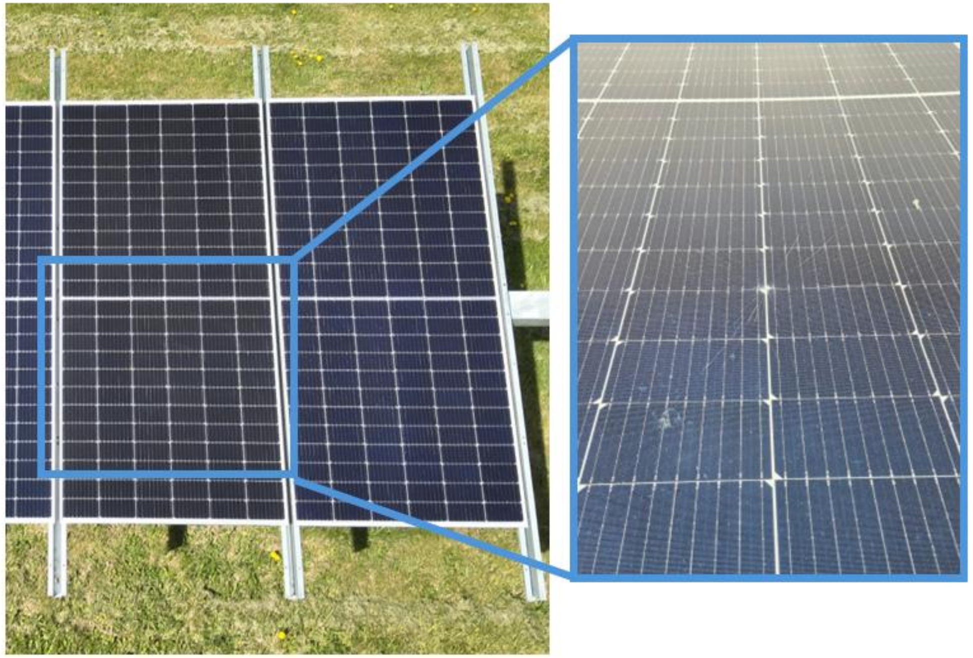
What is the impact of Front Glass Cracks on IRT & RGB?

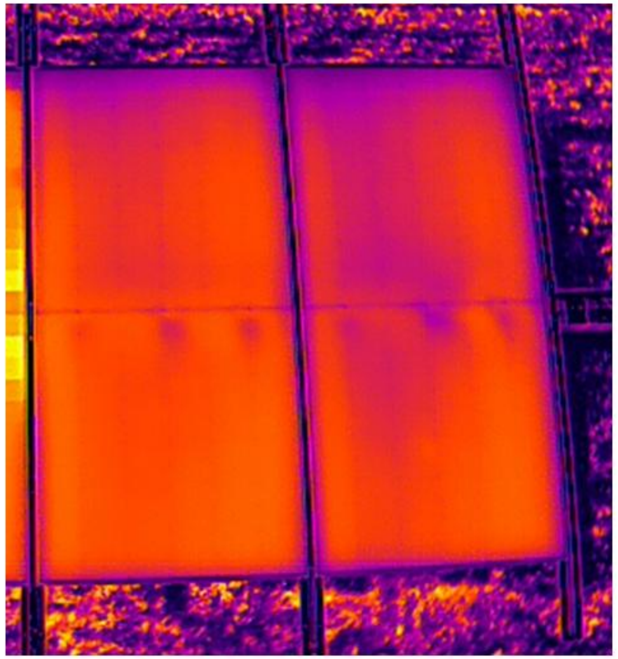
Low energy glass cracks

Drone RGB at 8 m altitude

RGB closeup

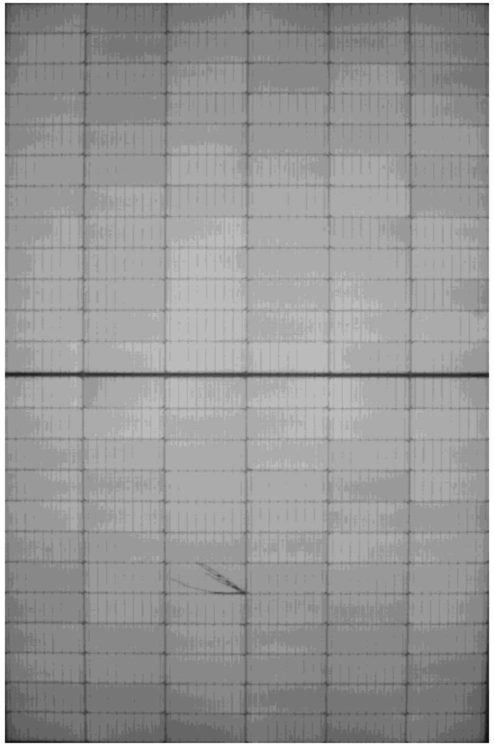
Drone IRT at 8 m altitude



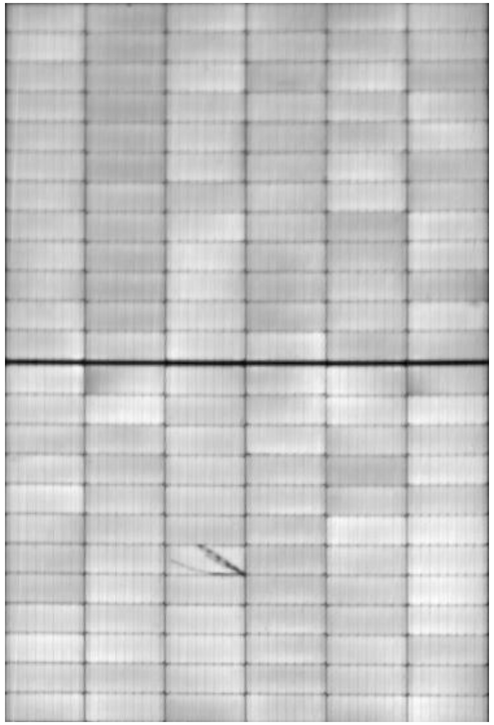


Detecting low-energy front glass cracks with EL

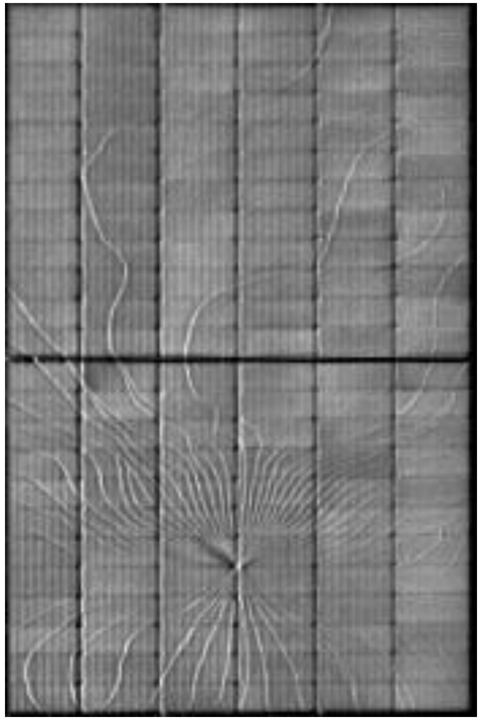
Indoor/nighttime EL



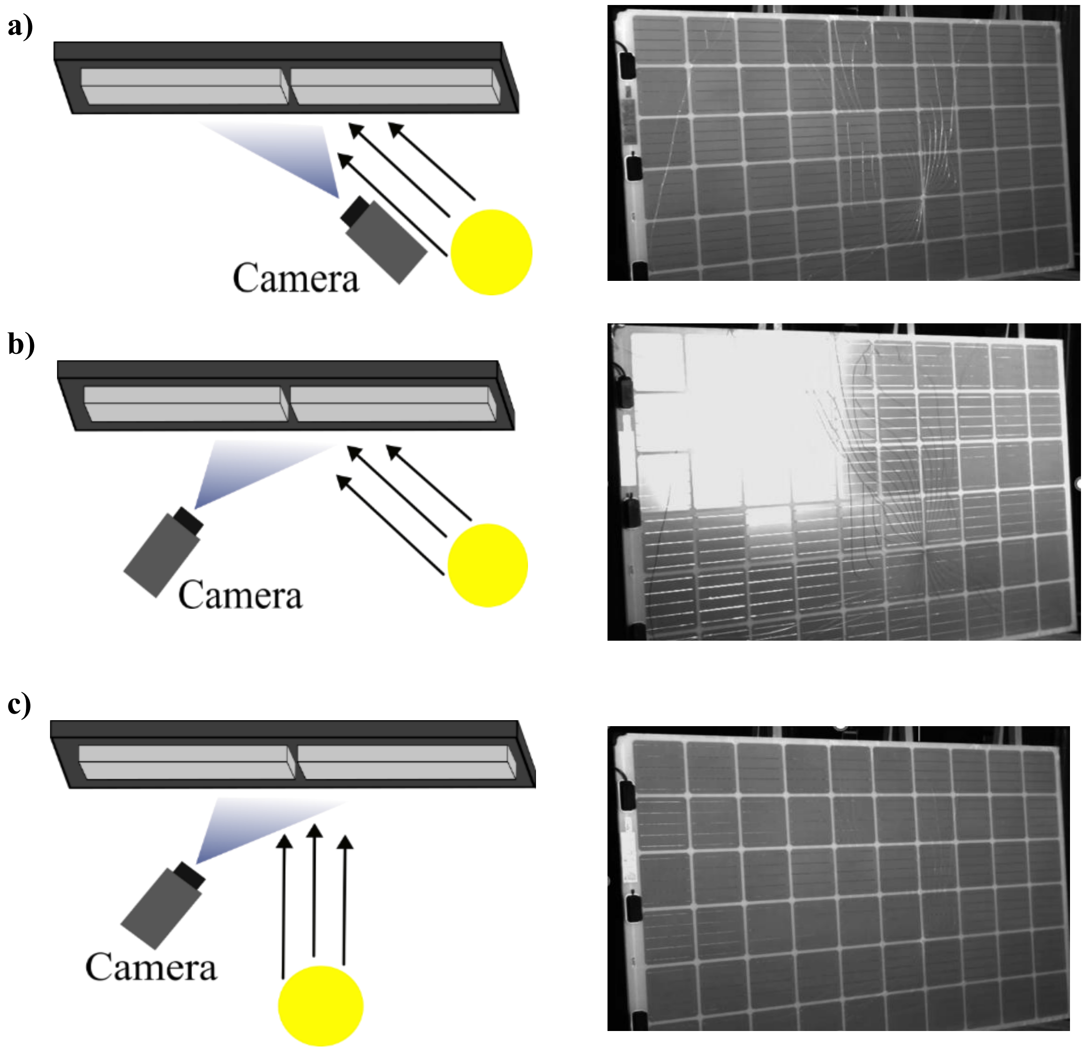
Daytime stationary EL



Daytime drone EL



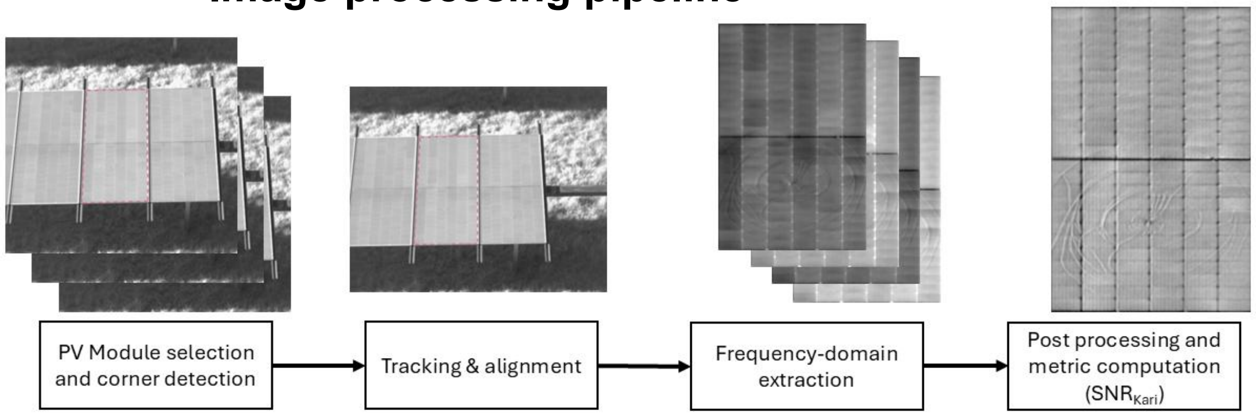
Principle of operation



R. Santamaria - A Novel Method for Detecting Low-Energy Front Glass Cracks in Photovoltaic Modules Using Daylight Electroluminescence Imaging

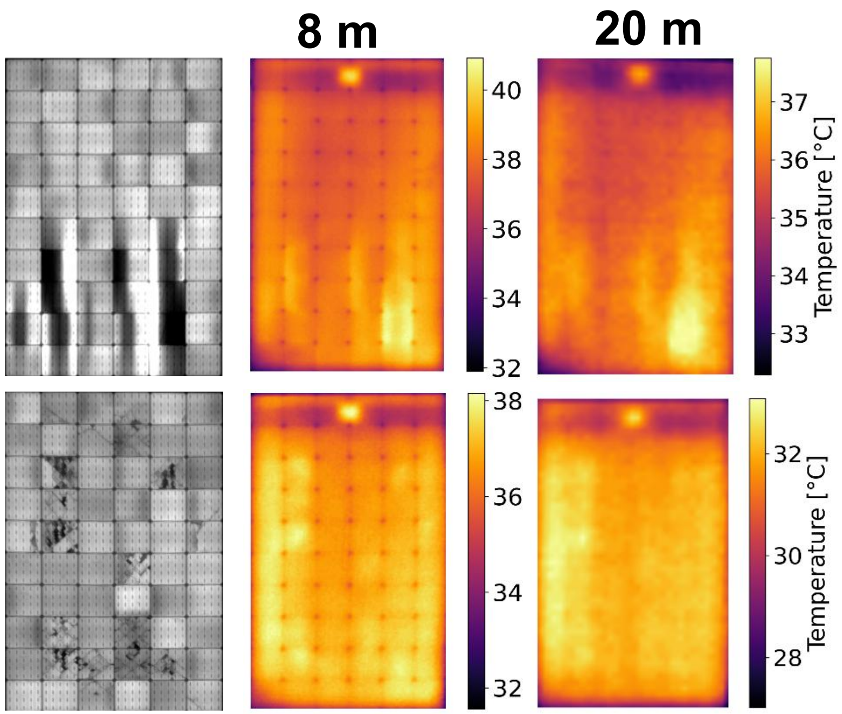
Acquiring images at different view angles

Image processing pipeline



Summary

- Altitude and lower image resolution blur hotspot patterns
- Some defects are hard to identify based on maximum temperature alone – especially “small” ones.

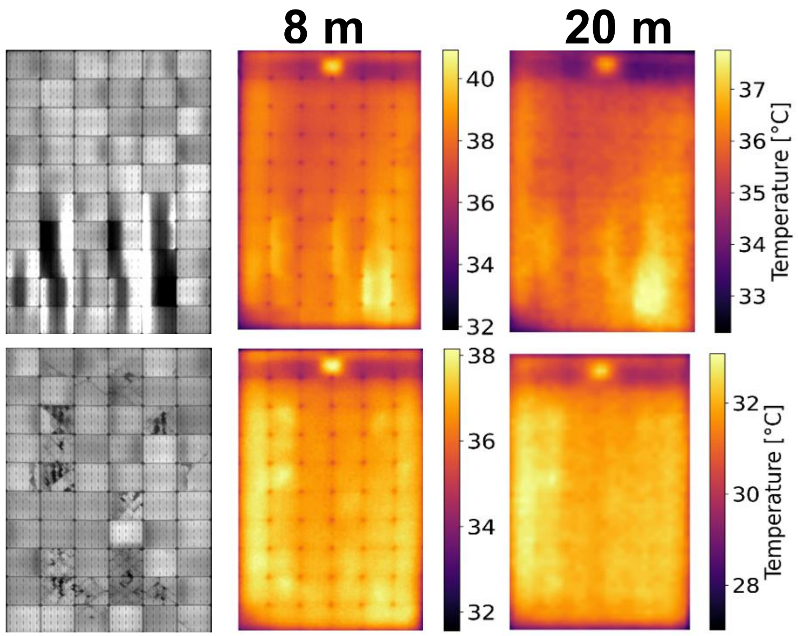


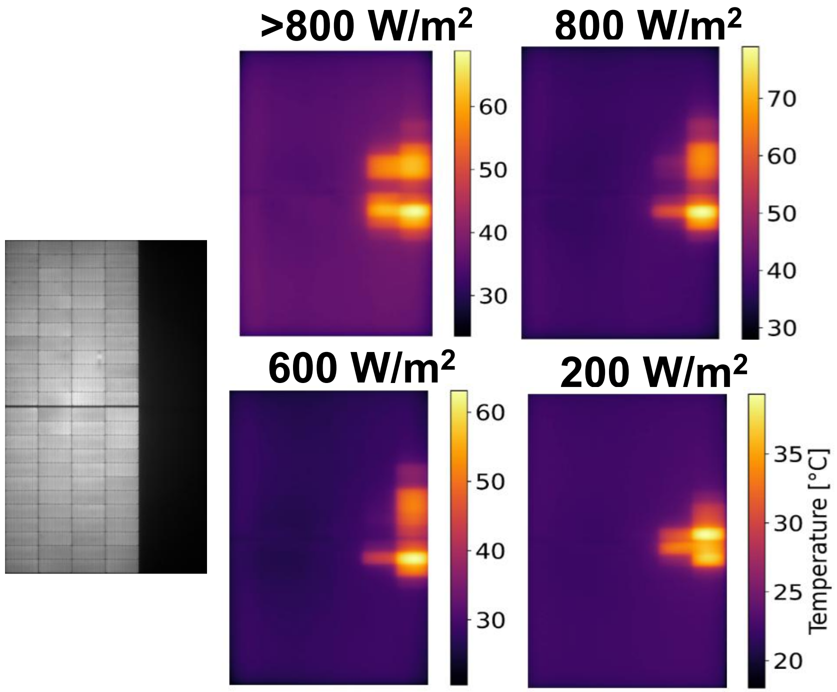
Module Type	Severity	Max. cell T [°C]	$\Delta T_{max\_healthy}$ [°C]
Healthy	-	38	1.5
Cell cracks	Low	38.7	1.5
	Medium	38.6	1.4
	High	38.6	1.4
Defective cell interconnects	Type 1	40.45	0.2
	Type 2	42.42	2.2
	Type 3	41	0.75
	Type 4	44.17	3.57
PID	-	38	2
Shorted bypass diodes	1	84.3	47.8
	2	81.7	45.2
Glass cracks	-	38	2.7
Soiling	Type 1	59.7	18.7
	Type 2	105.4	61

DTU

Summary

- Comprehensive analysis of 43 PV modules with defects
- Imaged under conditions 1000 to 200 W/m^2 and 8 to 20m drone altitude
- **Spatial resolution challenges some defect identification**
- **General condition monitoring** of soiling and large area defects can be done in **non-optimal conditions**
- Limitations of the study:
  - Inspection time costs
  - Optimal flight path and altitude
  - Wind conditions





Open dataset of module failures IVS, IRTs, ELs

- STC IVs
- High res ELs 100% and 10% Isc
- Dron IRTs (DJI Mavic M3T Drone)
- RGBs for soiling failures

Defect Type	# of modules	Range of Power Loss [%]	Module type	Details
Cell cracks	8	4 - 5%	• Monofacial PERC 305 W	Cells cracked by mechanical stress test. Total of 69 cells affected.
Cell interconnections	8	3 - 14%	• Monofacial PERC 305 W	Cell ribbon interconnection cut from the back sheet. Total of 98 cells affected.
PID	6	5%	• Monofacial PERC 305 W	PID stress tested according to standard
Short-circuited bypass diode	7	33 - 66%	• Monofacial PERC 305 W • Bifacial PERC 295 W • Bifacial PERC 540 W (Half-cut cells)	4 modules with 1 Shorted diode and 3 with 2 Shorted diodes
Glass crack	2	< 1%	• Bifacial PERC 540 W (Half-cut cells)	Glass cracked in front and rear side
Soiling 1	6	33%	• Monofacial PERC 305 W • Bifacial PERC 295 W • Bifacial PERC 540 W (Half-cut cells)	Punctual soiling - Bird drops
Soiling 2	6	66%	• Monofacial PERC 305 W • Bifacial PERC 295 W • Bifacial PERC 540 W (Half-cut cells)	Large area soiling - Sand

Interested in the data?

https://doi.org/10.11583/DTU.29665346.v1

Acknowledgement and Contact Information

This project has received funding from the European Union under grant agreement no. 101146377 as part of the SOLARIS project – *Solar Operational Lifecycle and Asset Reliability Intelligence System*.

This work has been supported by the Eurostars project MULTISPECTRAL – *Outdoor Luminescence and Infrared Imaging of Photovoltaic Systems*, funded by the national funding agencies and the European Union under the EUREKA Eurostars programme.

Rodrigo del Prado Santamaría

Mail: rdpsa@dtu.dk

Gisele A. dos Reis Benatto

Mahmoud Dhimish

Timurhan Koc,

Rizal Friansyah,

Thøger Kari

DTU