Simulation of POA front irradiance sensor mounting position

Marc Korevaar and Damon Nitzel

European PVPMC 8-9 November 2023, Mendrisio

OTT HYDROMET GROUP

KIPP & ZONEN
an OTT HydroMet brand

OTT HydroMet

APPLICATIONS

HYDROLOGY

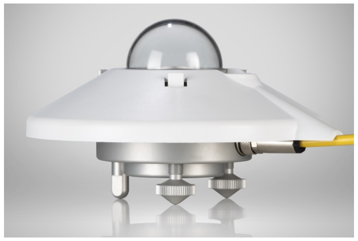
Water Resource Management,
Flood Warning

METEOROLOGY

Atmospheric Meteorology, Solar and Wind Energy,
Traffic Weather, Agriculture

BRANDS

OTT | SUTRON | HYDROLAB | Lufft | KIPP & ZONEN | ADCON | METEOSTAR



WHERE TO PLACE FRONT POA PYRANOMETER?

- Where across the module?
- Where in the park?
- bifacial rearside irradiance sensor position previous work: [1],[2],[3],[4],[5]….

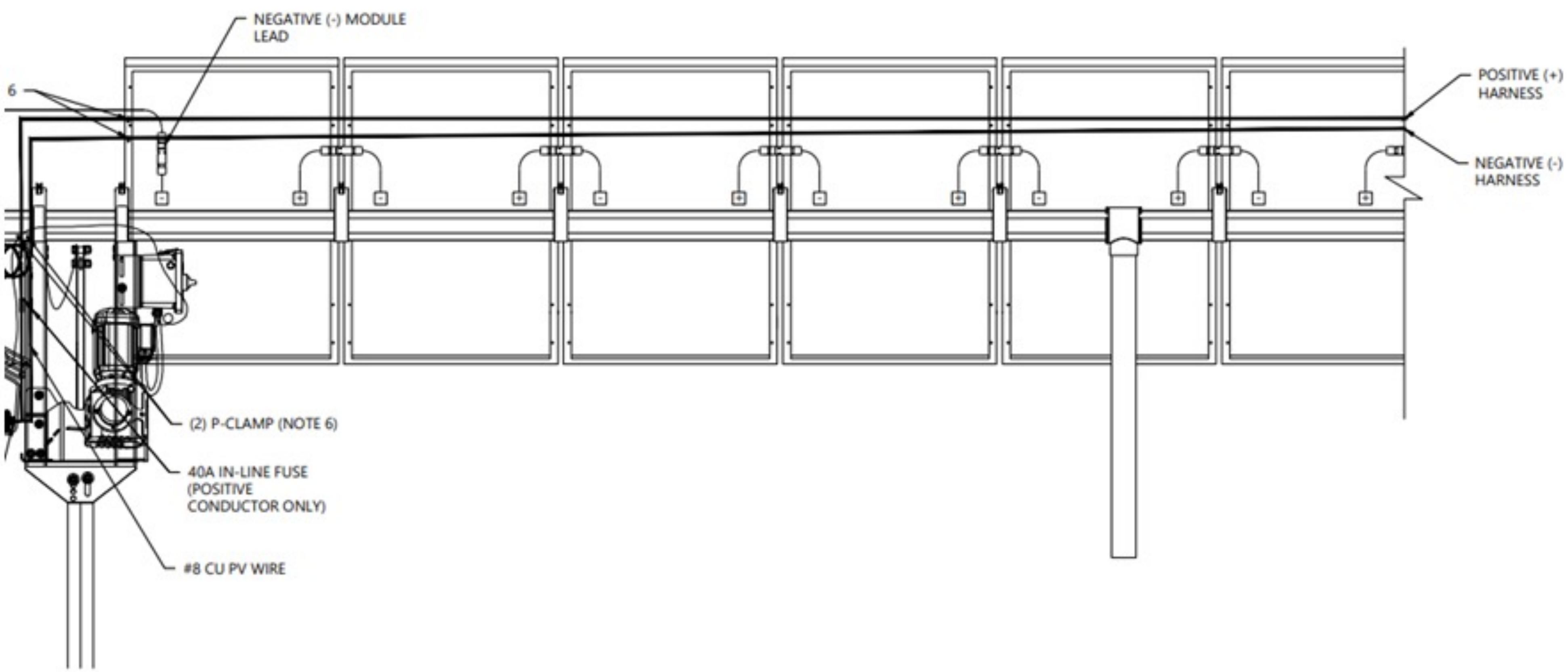
[1] "A Spatial Irradiance Map Measured on the Rear Side of a Utility-Scale Horizontal Single Axis Tracker with Validation using Open Source Tools" Riedel-Lyngskæret al. Proceedings of 2020 IEEE PSC
[2] "Measuring Irradiance for Bifacial PV Systems", Gostein et al. IEEE PVSC, 2021.
[3] "Simulation and Validation of Bifacial Irradiance Sensor Mounting Position", Korevaar et al. EU PVSEC 2020
[4] "Strategies for Rear Irradiance Monitoring", Riedel et al., PVPMC 2023
[5] "Bifacial photovoltaic Technology: recent advancements, simulation and Performance measurement", M. Aghaei et al., 2022, ISBN:978-1-83968-858-4

WHY IS THIS RELEVANT?

- Performance ratio can be calculated using the POA front irradiance measurement.
- The PV customers like an as low as possible uncertainty on the measurement instrument.
- Calibration uncertainty of pyranometers can be ±1%
- Field measurement uncertainty can be ±1.3-1.7% in economic relevant hours of the day.[6]
- Therefore, quantification of the influence of sensor position is relevant

[6] Kipp & Zonen Suncertainty (google app store)

PV PLANT DESIGN



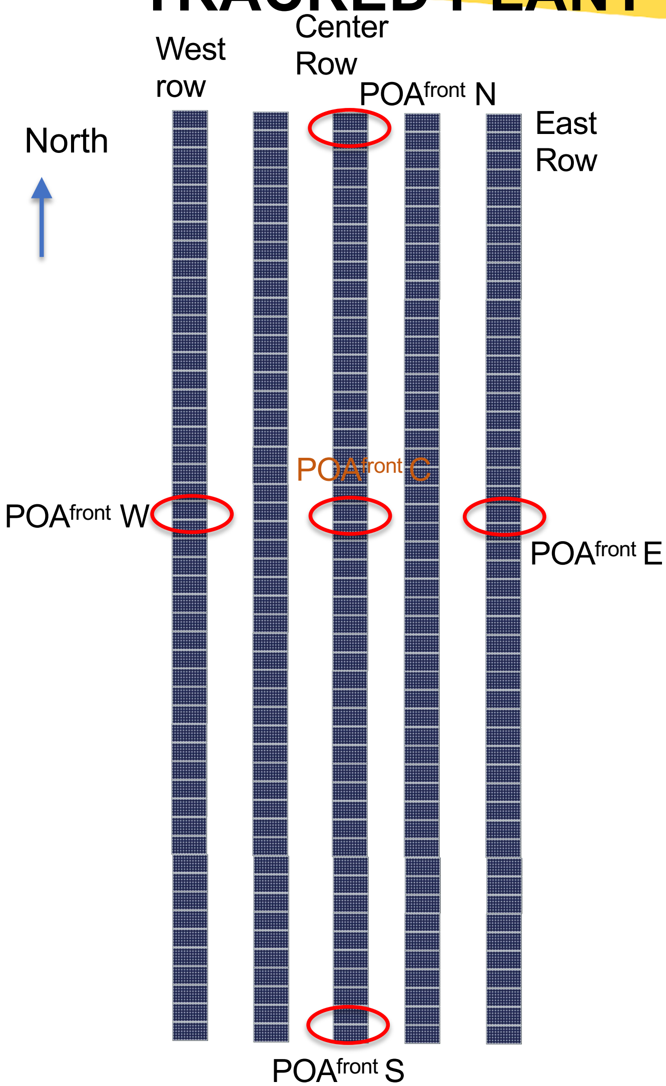
SIMULATION PARAMETERS SINGLE-AXIS TRACKED PLANT

KIPP & ZONEN

Parameter	Value	Parameter	Value
Hub Height	1.3 m	Module rows	5
Tilt	Backtracking on	Modules per row	80
Azimuth	N-S axis	Number of sensors	20
Ground Coverage Ratio (GCR)	0.48	Location	Near Lemoore CA, USA
Albedo	0.35	Weather data	Energyplus.net
Module orientation	Portrait	Module dimensions	1.98 m x 0.98 m
Nr. Modules above each other	1	Torque tube	yes
Type of plant	Tracked	Type of simulation	Cumulative sky yearly
Software version: Bifacial radiance V0.4.2 (2023-03-11)[7]			

[7] Ayala Pelaez and Deline, (2020). bifacial_radiance: a python package for modeling bifacial solar photovoltaic systems. Journal of Open Source Software, 5(50), 1865, https://doi.org/10.21105/joss.01865

TRACKED PLANT TOP VIEW

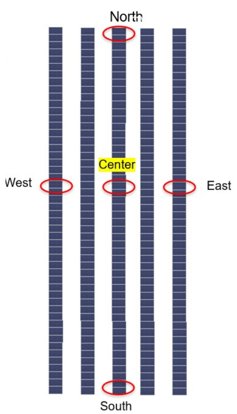


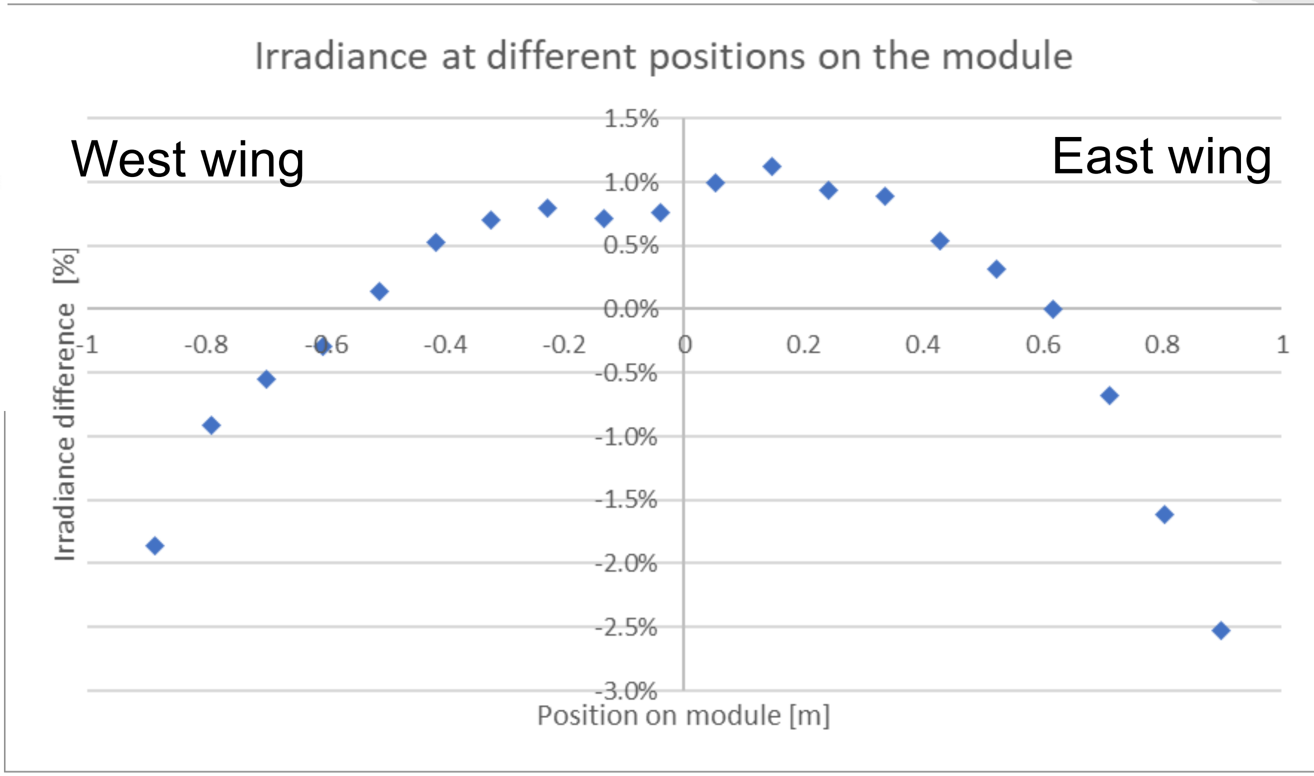
- Yearly average measurement compared to POA front C (center)
- Averaged over all measurement positions across the module

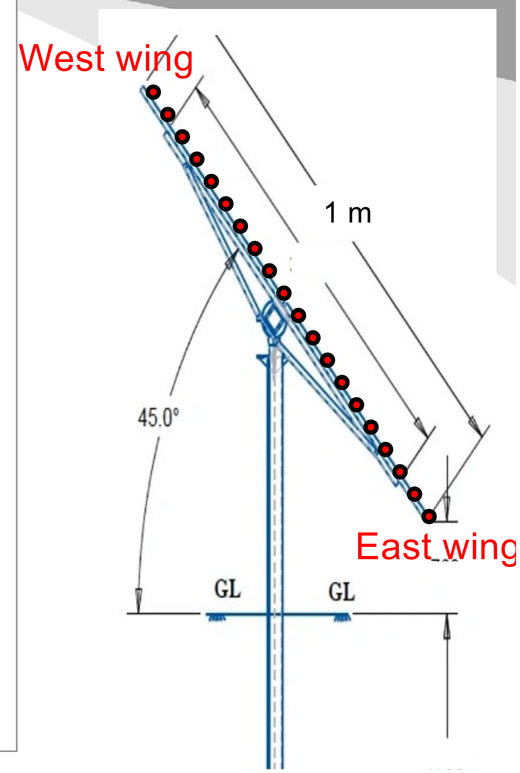
	POA front N	POA front S	POA front W	POA front E
POA_{front}	+2.0%	+2.2%	+2.3%	+2.1%

- Advise: placement in center area away from edges

TOTAL YEARLY RESULTS CENTER

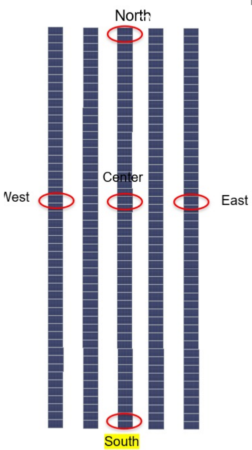


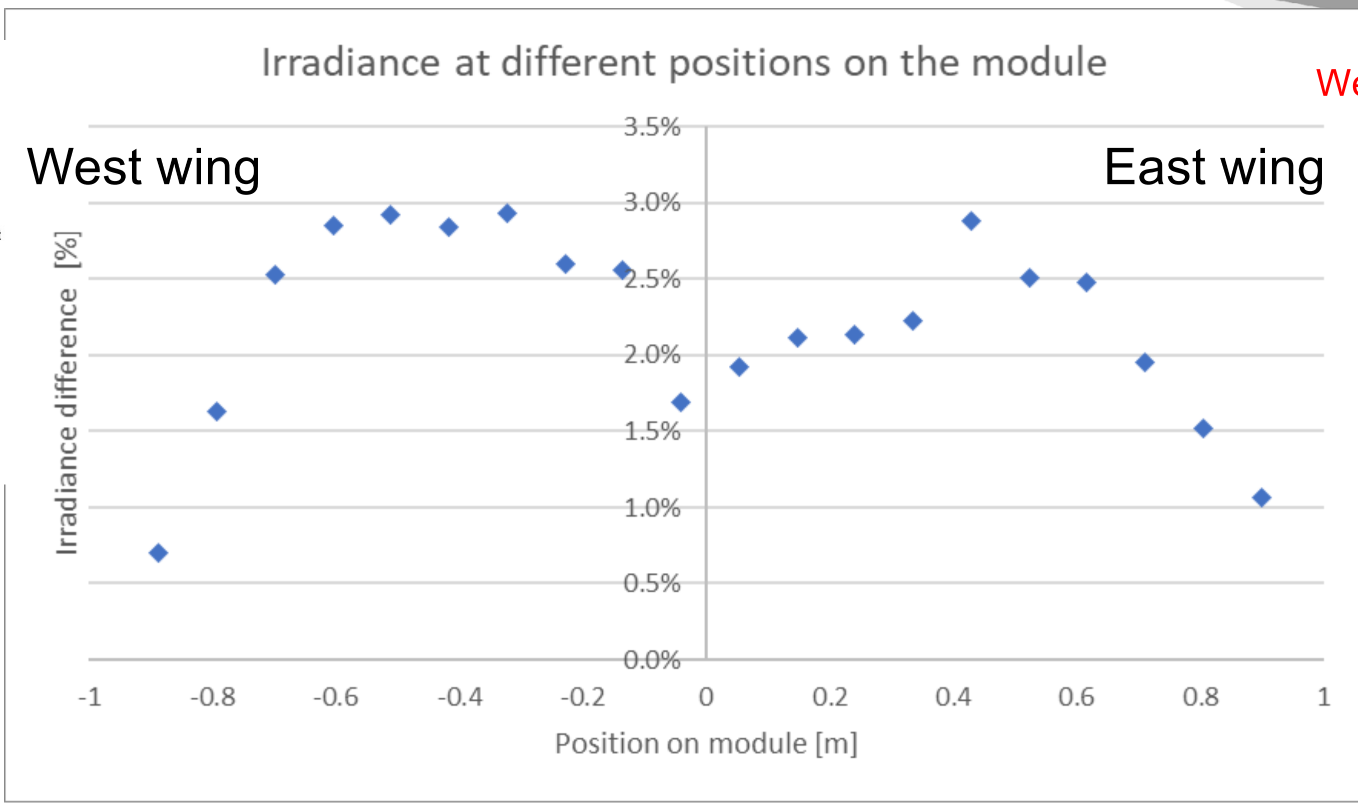


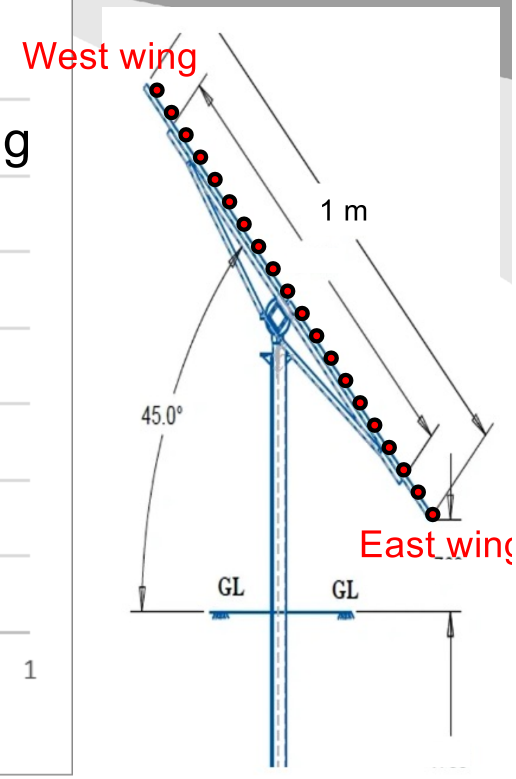


- Average of 5 center modules
- +2.5% at “tips of the wings”, +1% in center

TOTAL YEARLY RESULTS SOUTH

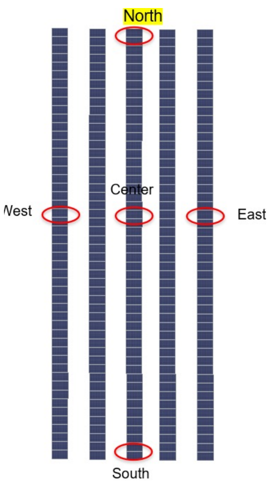


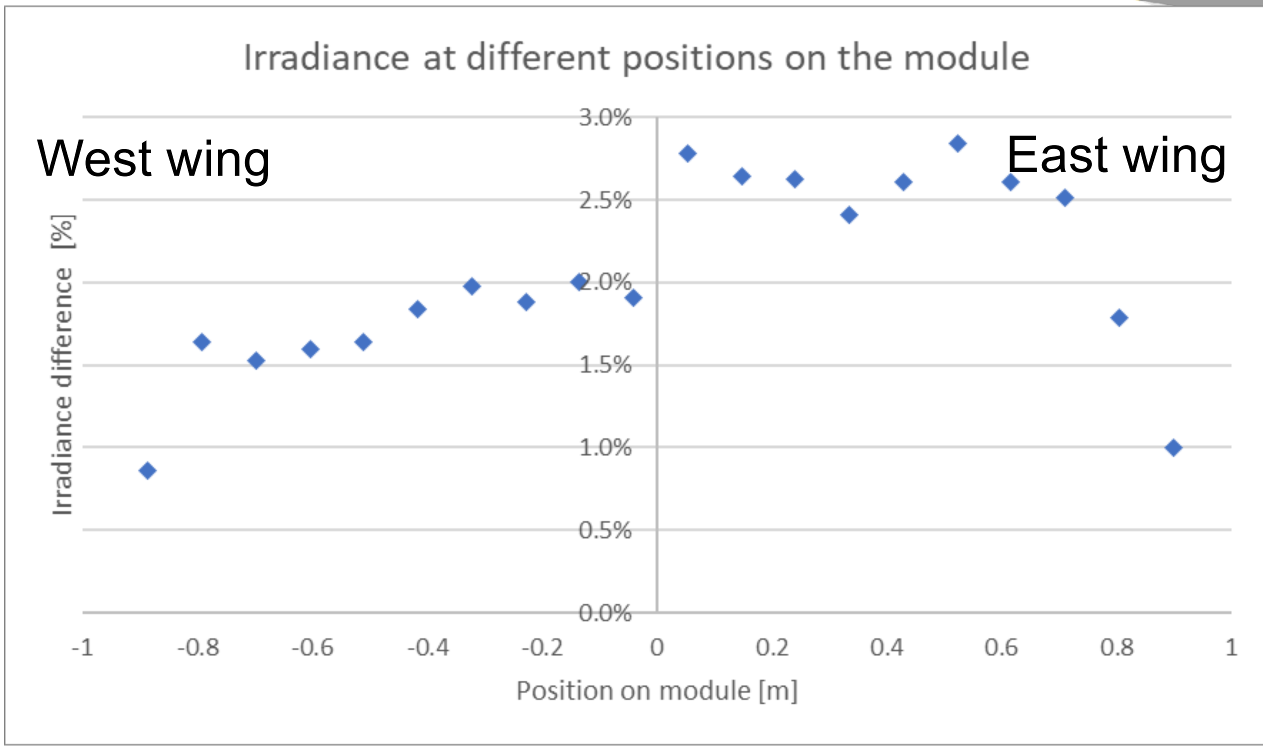


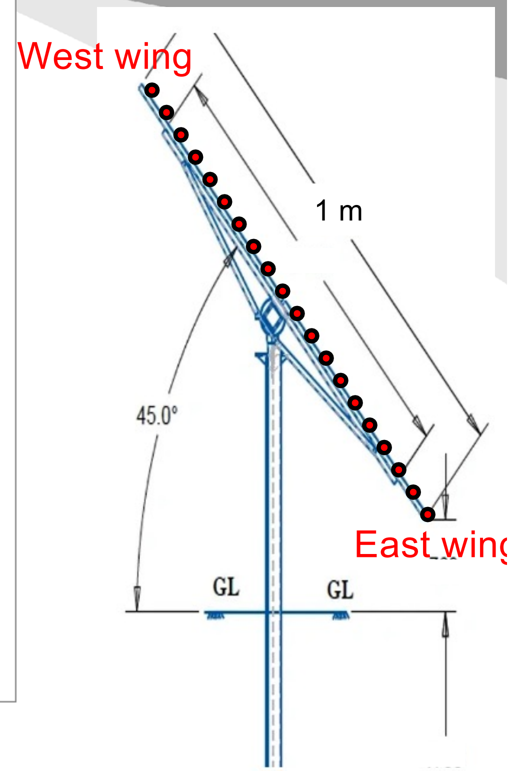


- +3% at “middle west wing”, and +1% at wing edges

TOTAL YEARLY RESULTS NORTH

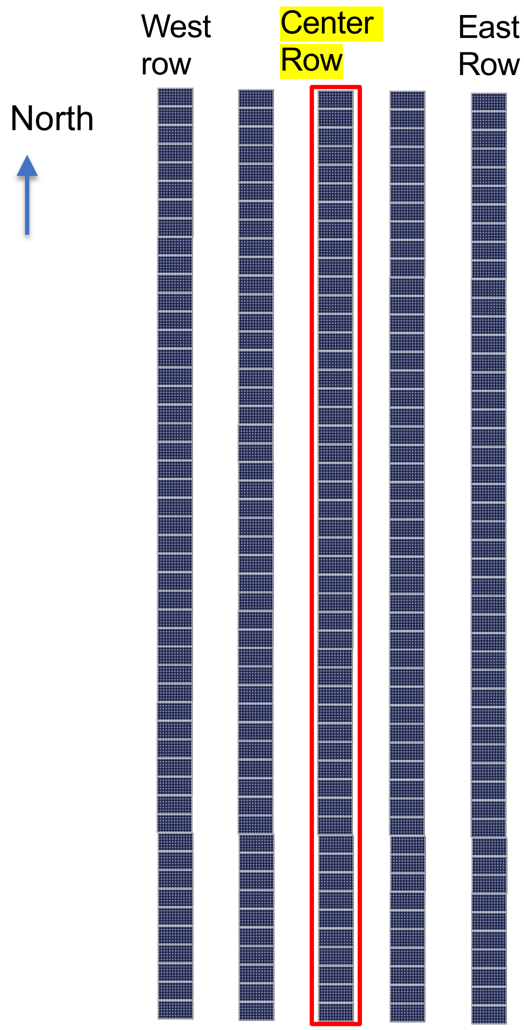


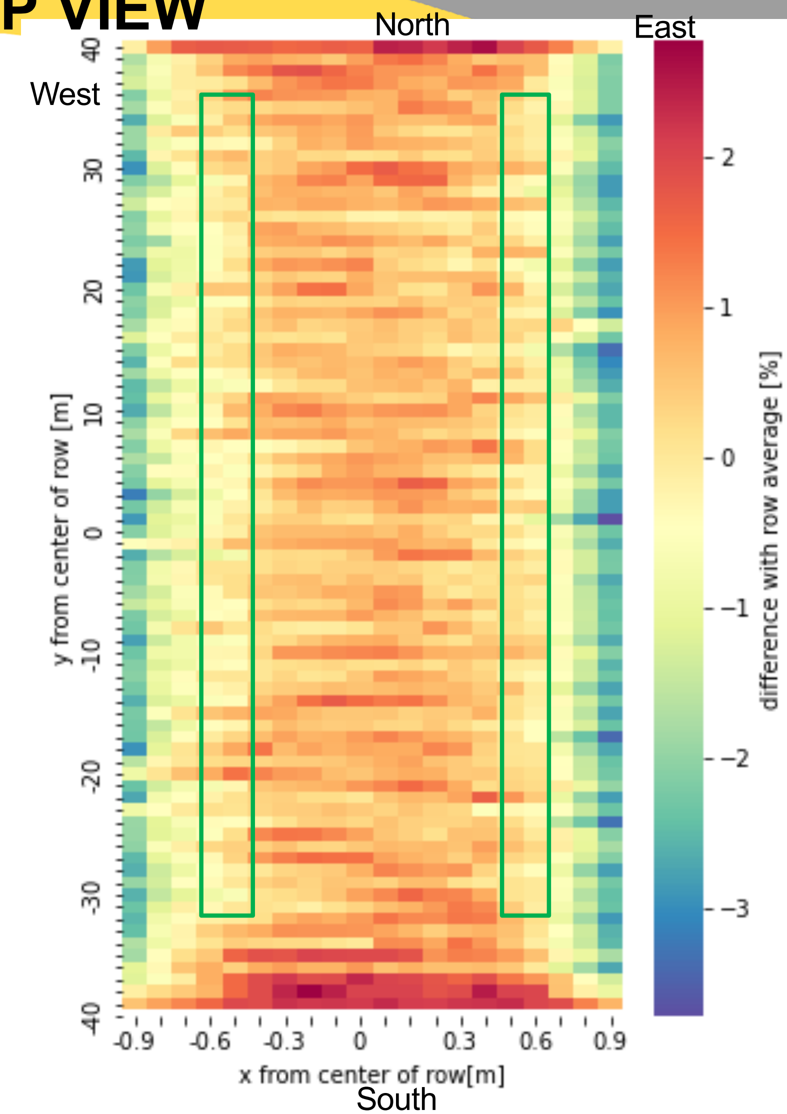




- From ±3% overestimation to ±1% overestimation at the wing tips

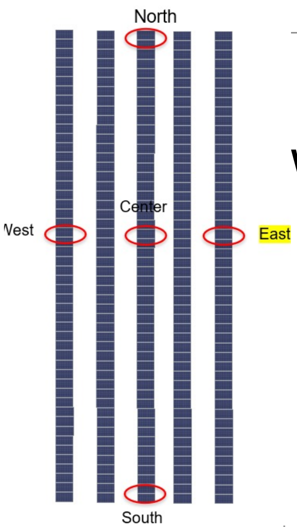
TRACKED PLANT TOP VIEW

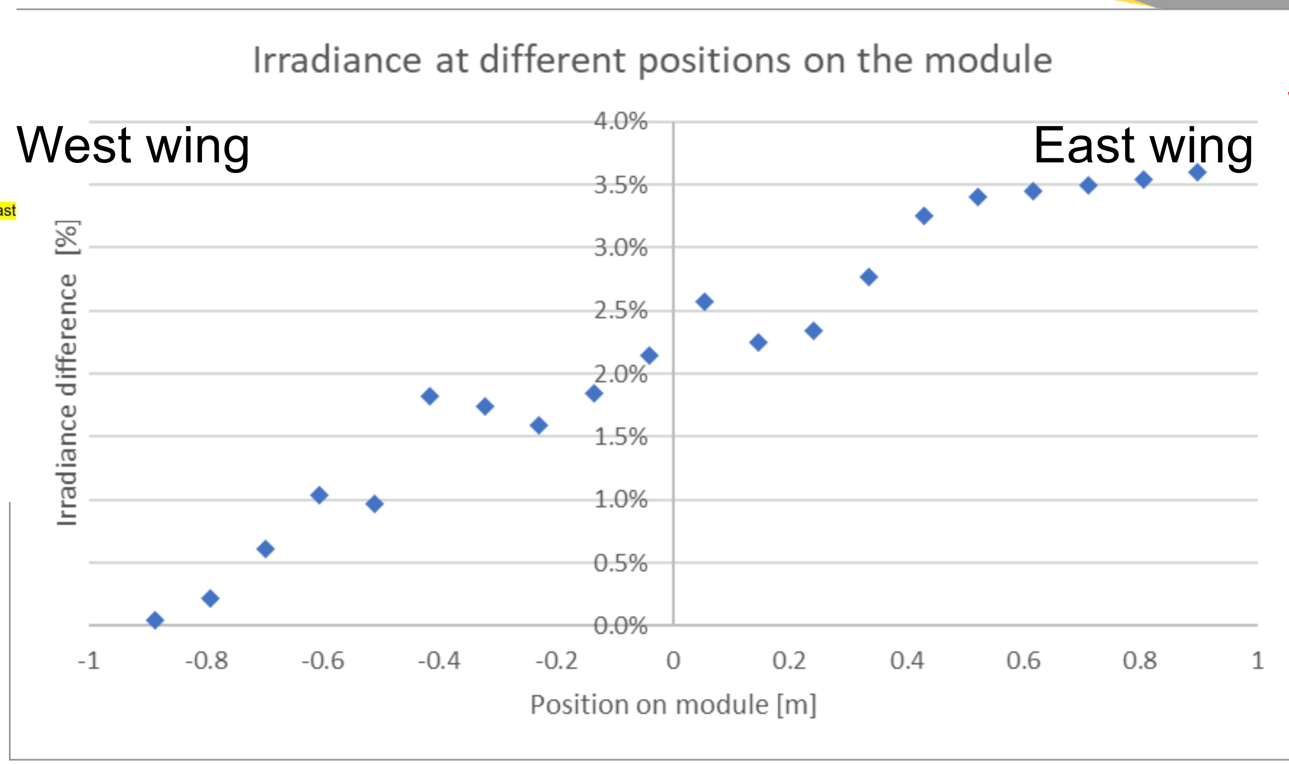


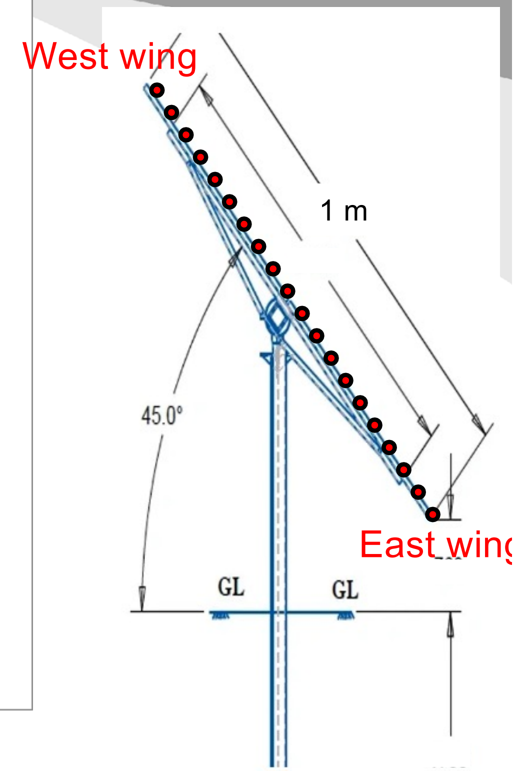


- Center row map of yearly average POA^{front} difference with average
- Differences from +2.8 % to -3.7%
- optional sensor positions
- > 5 modules away from row edge

TOTAL YEARLY RESULTS EASTERNMOST ROW

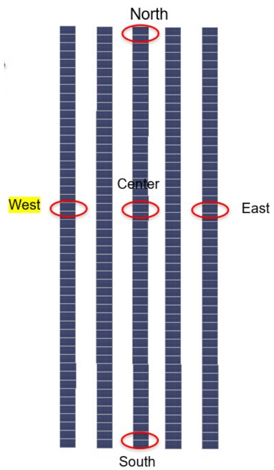


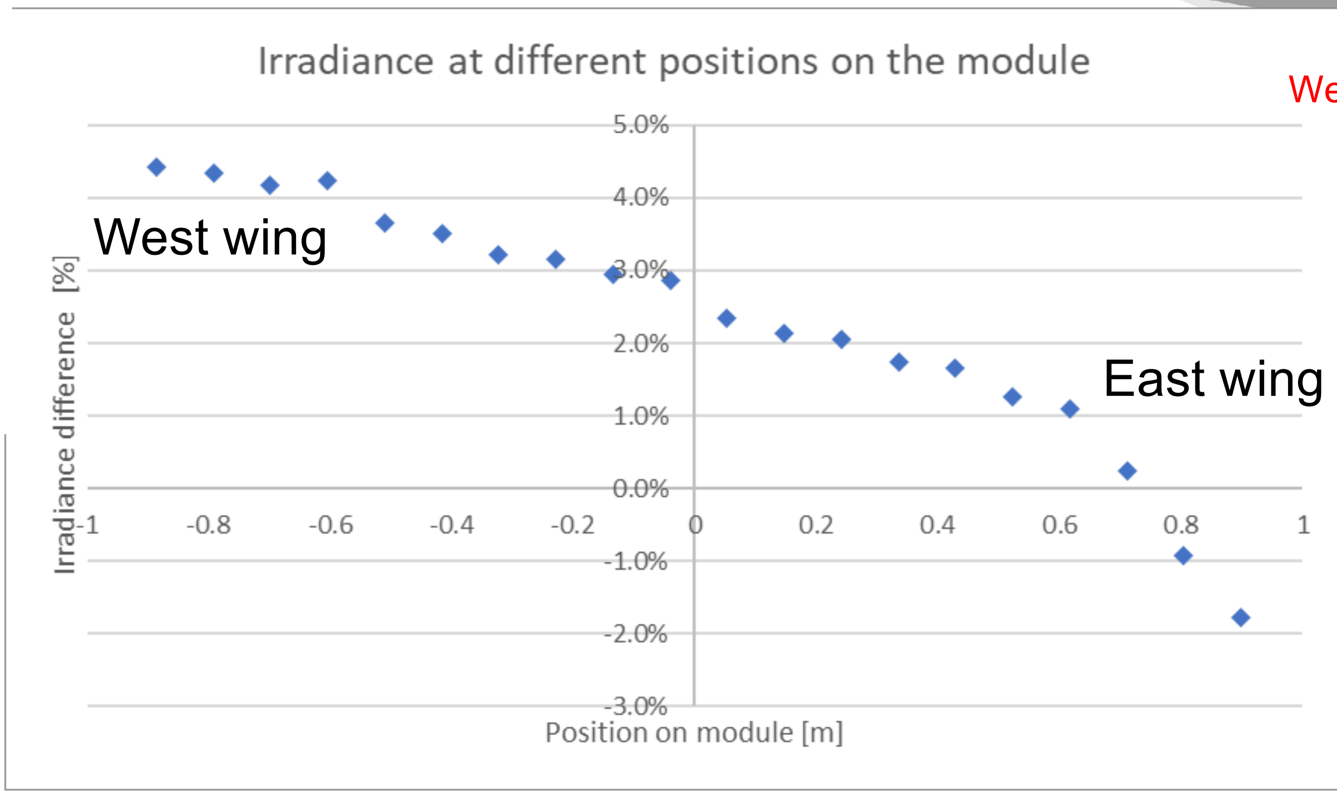


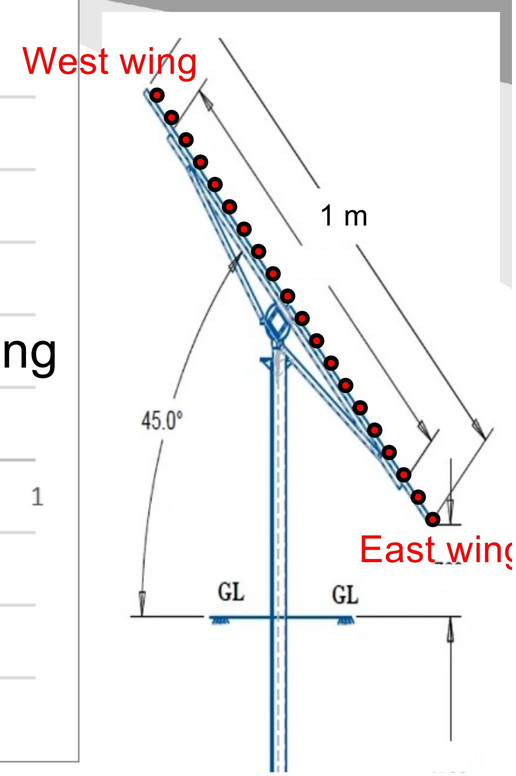


- 0% at west wing to +3.5% at east wing
- asymmetric result

TOTAL YEARLY RESULTS WESTERNMOST ROW

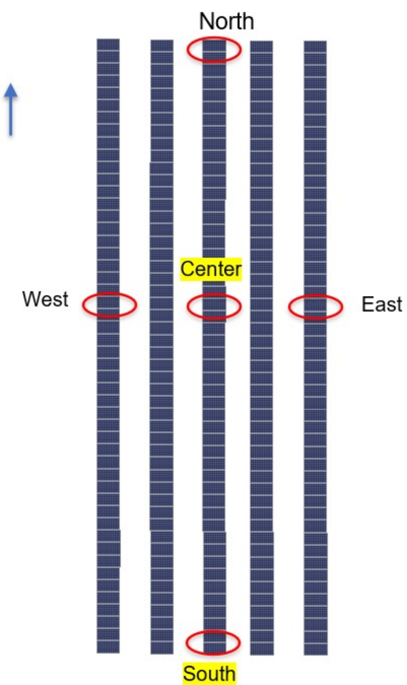


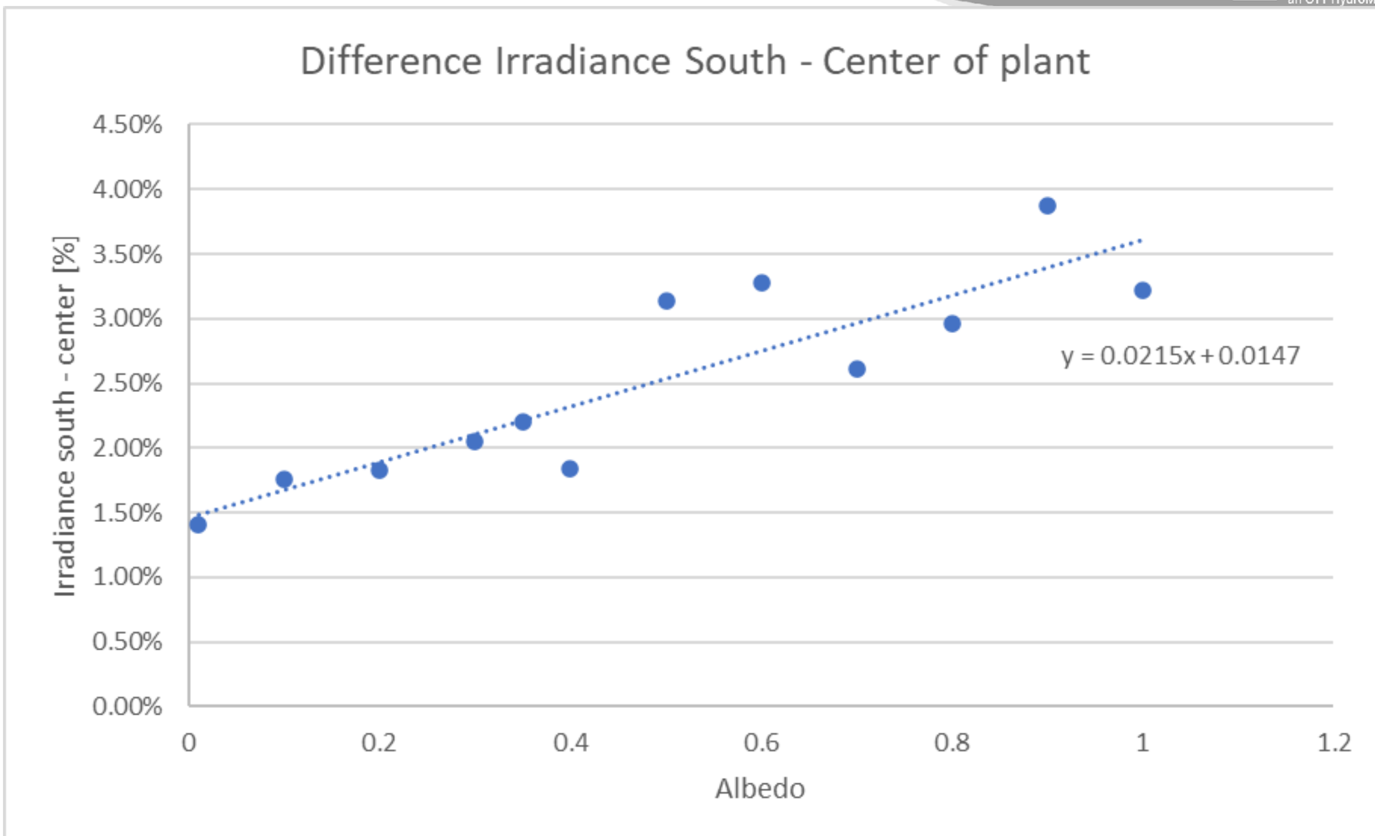




- > +4% at west wing to - 2% at east wing
- asymmetric result

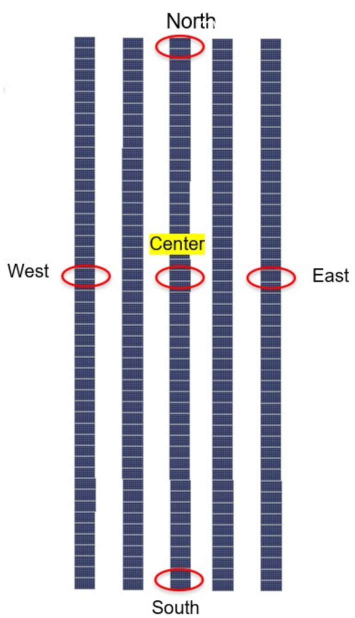
EFFECT ALBEDO YEARLY CENTER-SOUTH DIFFERENCE

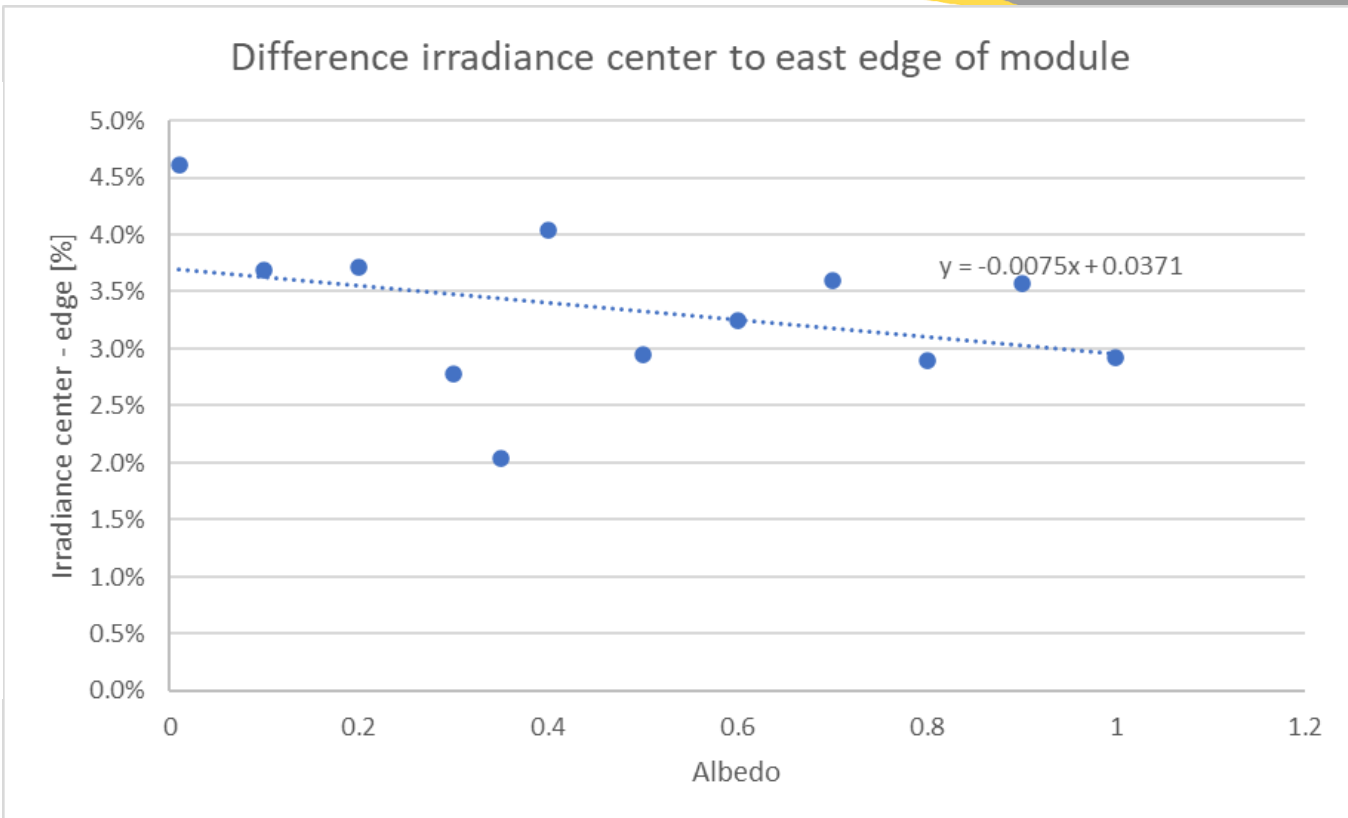


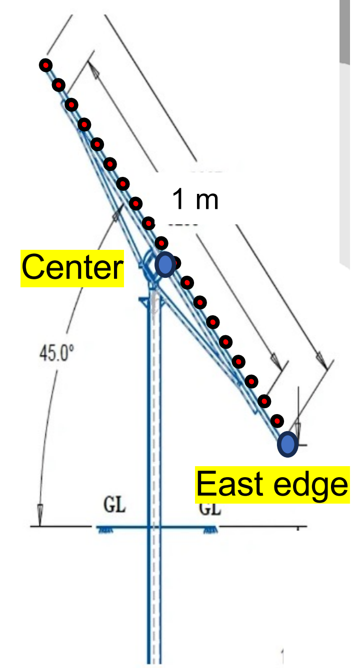


- Effect of albedo is quite linear
- 0 albedo value +1.5% likely due to difference in diffuse / visible part of sky

EFFECT ALBEDO ON CENTER MODULE YEARLY

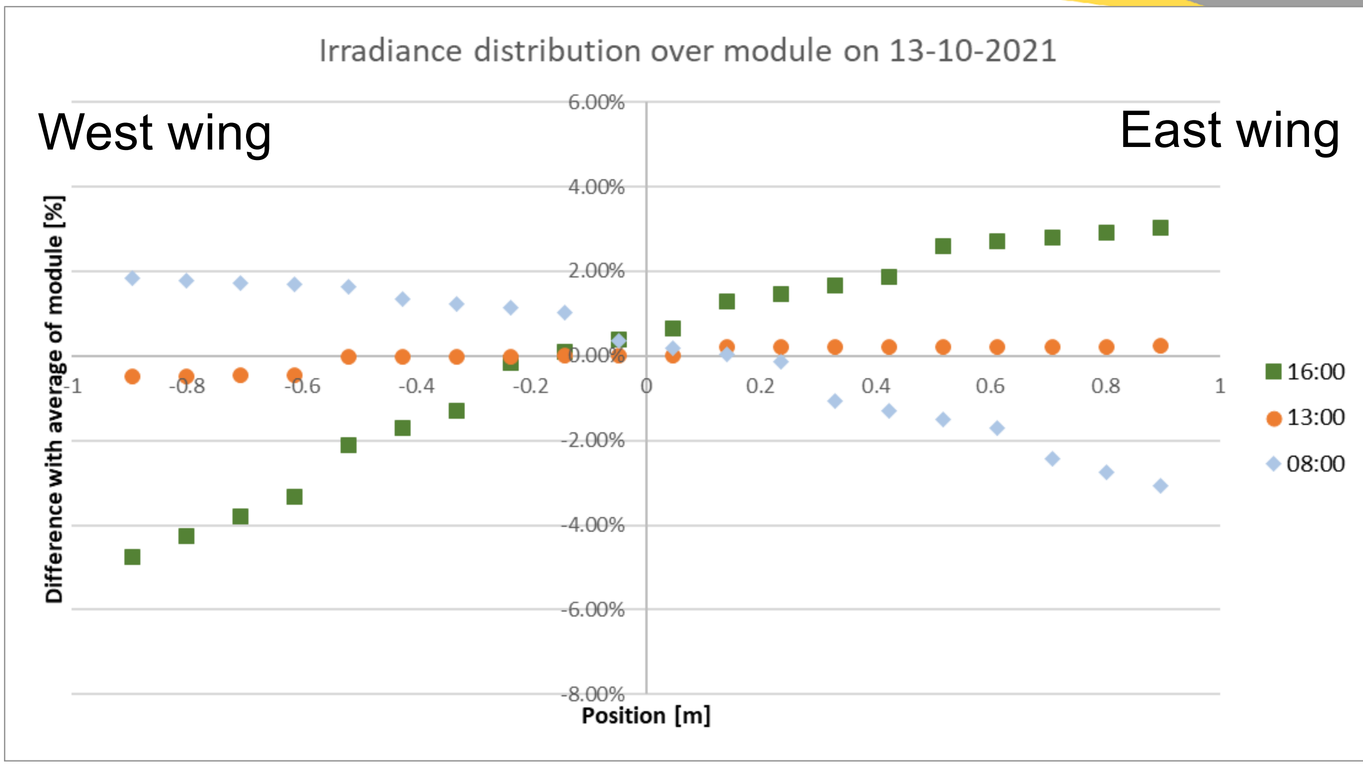


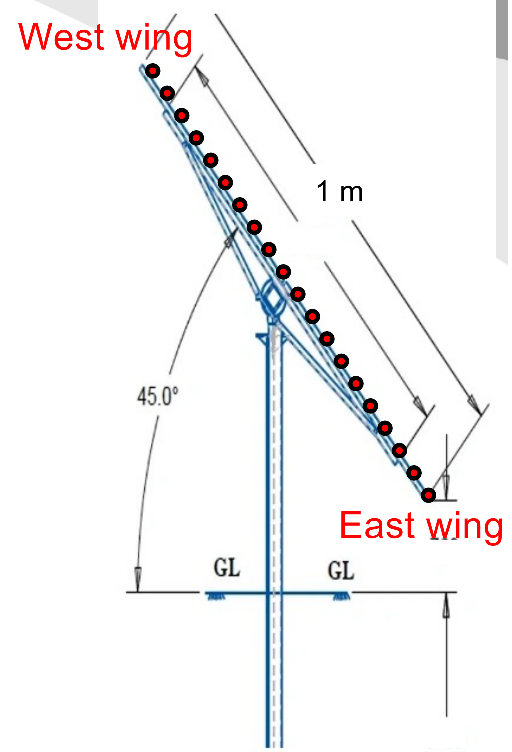




- Larger albedo → less difference center to edge of module
- 0 albedo value + 4% likely due to difference in diffuse / visible part of sky

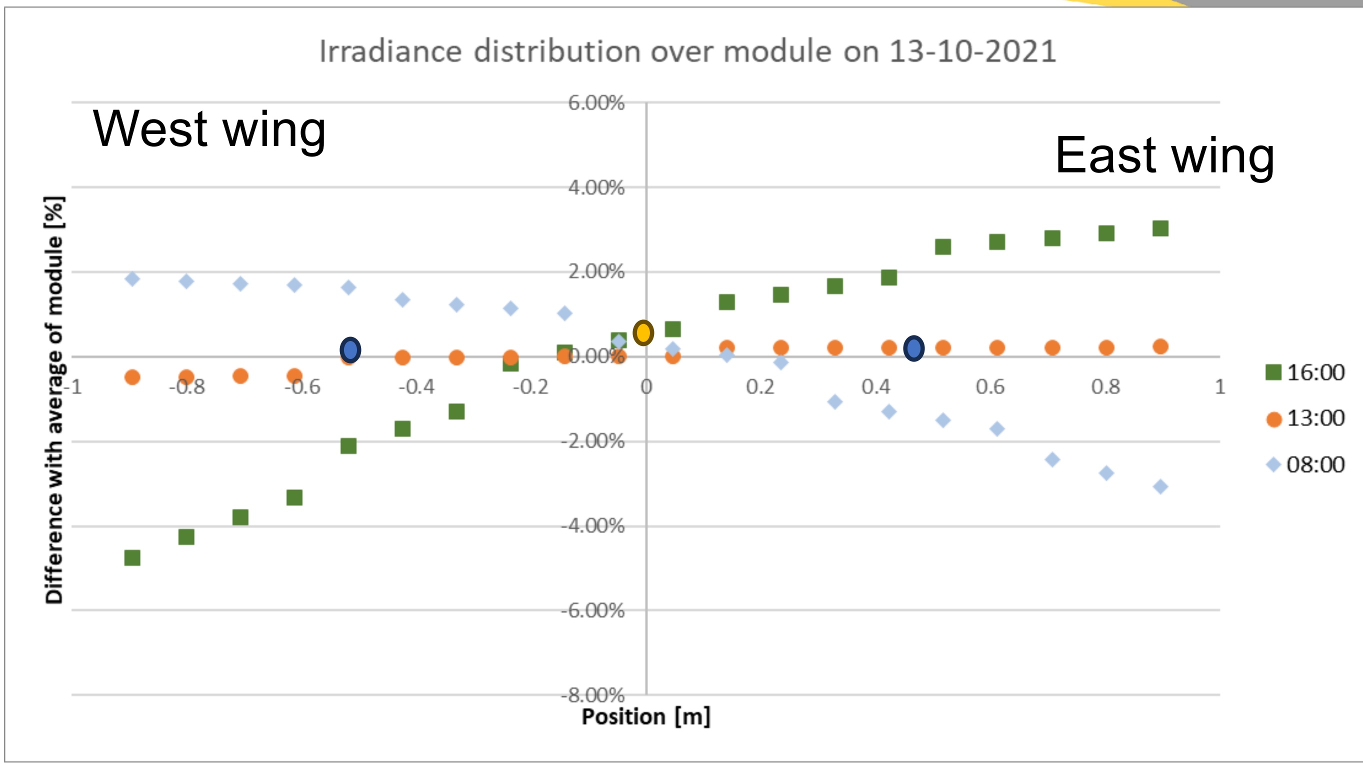
INTRADAY RESULTS – FALL (CLEAR DAY) CENTER

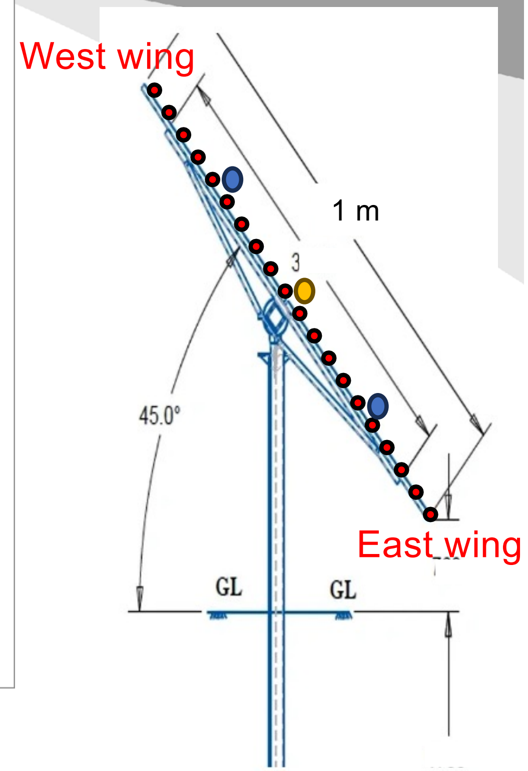




- Morning: more light west and less on east (Δ 5%)
- solar noon: more uniform light distribution
- Afternoon: more light east and less on west wing (Δ 8%)

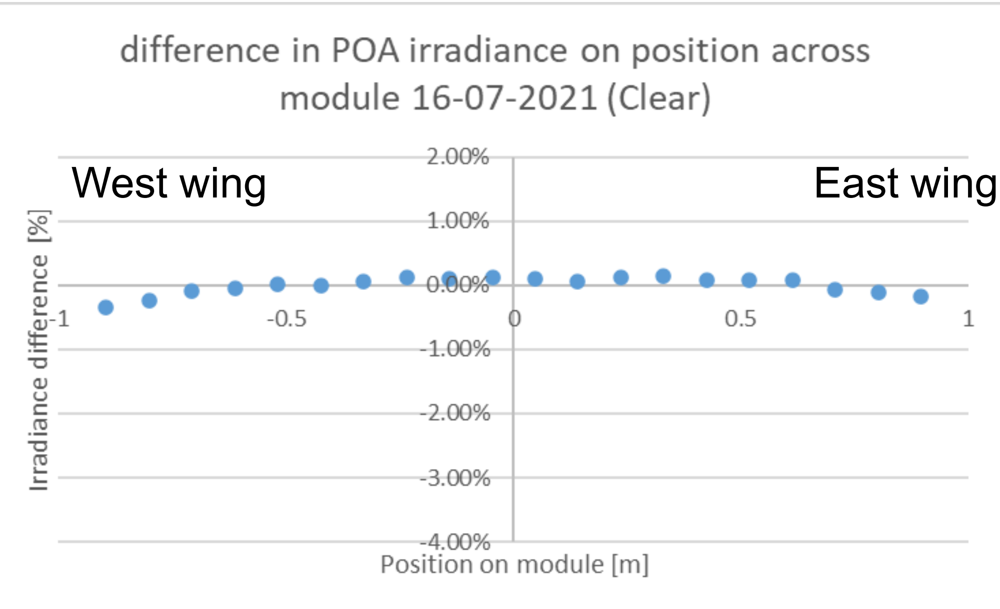
INTRADAY RESULTS CENTER – SENSOR PLACEMENT



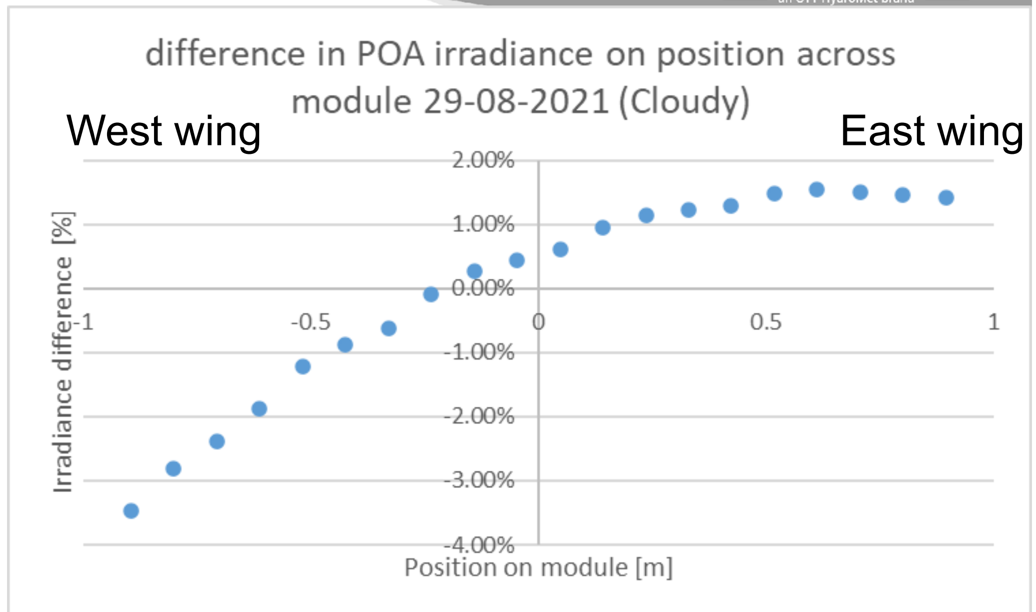


- 1 sensor in center (center position +0.7% yearly)
- 2 sensors at -0.5 m and +0.5 m (25% and 75%) representative whole module intraday and yearly
- Small hourly effect found for seasonal, clear/cloudy conditions

WEATHER CONDITIONS: 1 DAY AVERAGE RESULTS



Clear



Cloudy/Semi-cloudy

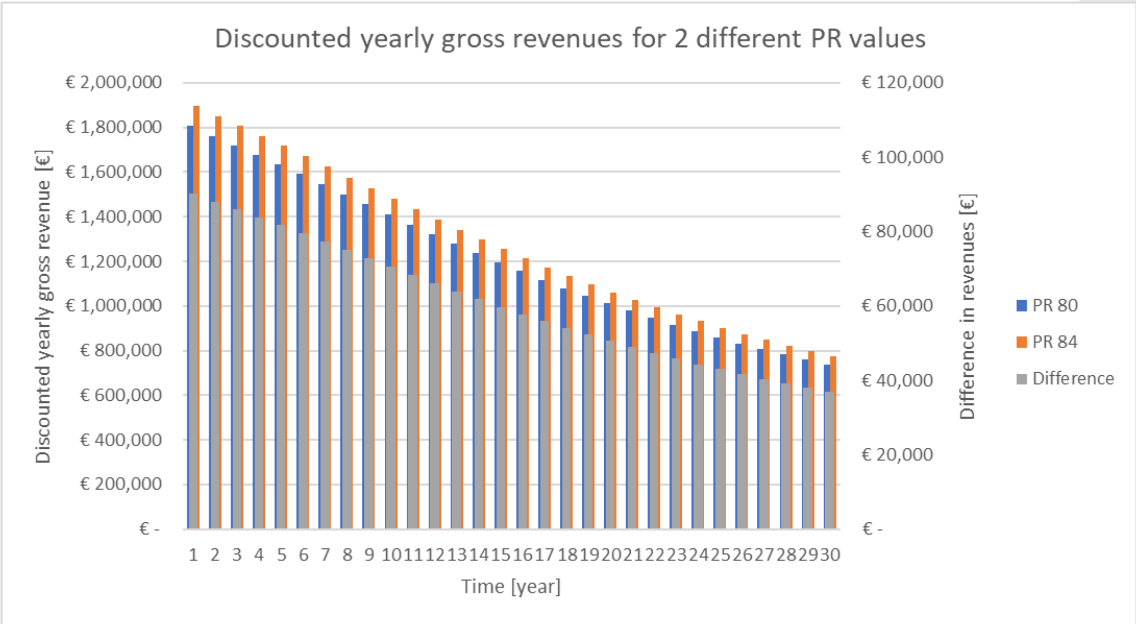
- clear: day average small variation (±0.3%)
- (semi) cloudy:, day average large variance (±5%)
- Likely due to some non or semi-cloudy hours of the day

FINANCIAL IMPACT CALCULATION

- 4% irradiance difference → 4% Performance ratio difference
- gross revenue: equivalent sun hours x days x MW x $/MWh x PR/100
- Assuming PV park in California of 64 MW (=average park size):
  - 5 hours [8] x 365 days x 64 MW x 20 $/MWh [7] x 0.8
  - yield curve discounting

- 30 year future gross revenues (discounted): $ 36 Million for PR 80
- 4% difference PR → **$ 1.8 Million** difference present value of PV park

- Potential incorrect valuation



[7] https://emp.lbl.gov/sites/default/files/utility-scale_solar_2022_technical_brief.pdf
[8] Smets A, Jäger K, Isabella O, van Swaaij R, Zeman M. Solar Energy: The physics and engineering of photovoltaic conversion, technologies and systems. Cambridge: UIT Cambridge Limited, 2016. 462 p.

SIMULATION CONCLUSIONS

- Accurate pyranometers as well as correct placement of these sensors is very relevant.
- Potential large impact on PR and therefore valuation PV park

- Simulations max. cumulative **yearly** error: 4 %
- More optimal sensor placement → options away from the edges
  - In the plant:
    - not east/west row
    - > 5 modules away from north/south end
  - Across the module: at roughly 25% and/or 75% points

- Simulations predict a maximum **intraday** error: ± 5 %
- More optimal sensor placement options:
  - 1 center of module sensor
  - 2 sensors across the module at roughly 25% and 75% points

- Causes: sky fraction and albedo fraction differences across the plant and module.

FUTURE WORK

- The plan is to do a validation of this in a single-axis tracked plant
  - Simulate non-uniform irradiance on the generated power
  - Simulate different locations/racking/rear of module
  - Simulate effect of different classes of instruments on uncertainty

- What is interesting to you?

- Contact: marc.Korevaar@otthydromet.com, Damon.Nitzel@otthydromet.com

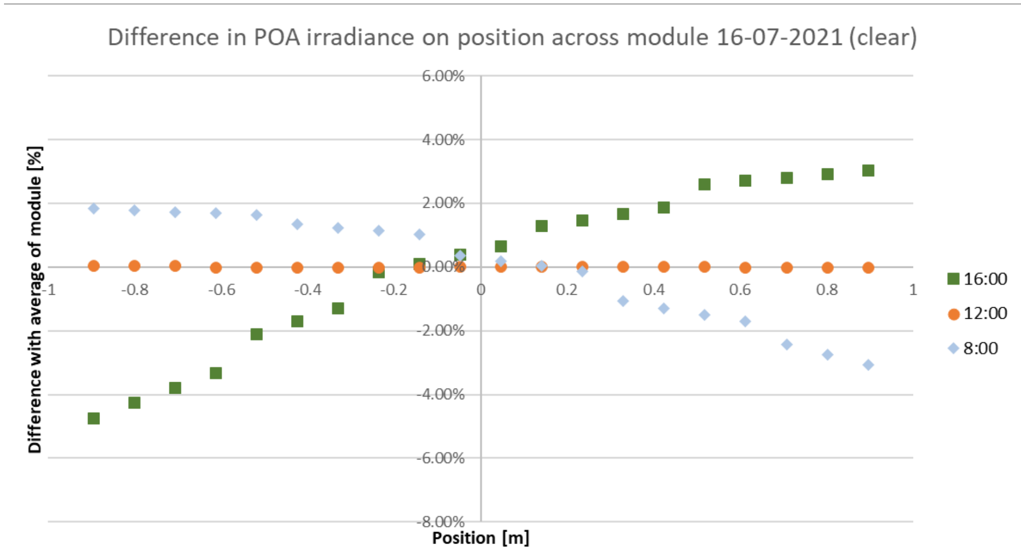
ACKNOWLEDGEMENTS

Thanks to Joop Mes, Keith Wilson and Thijs Bergmans and the team for valuable comments and tips!

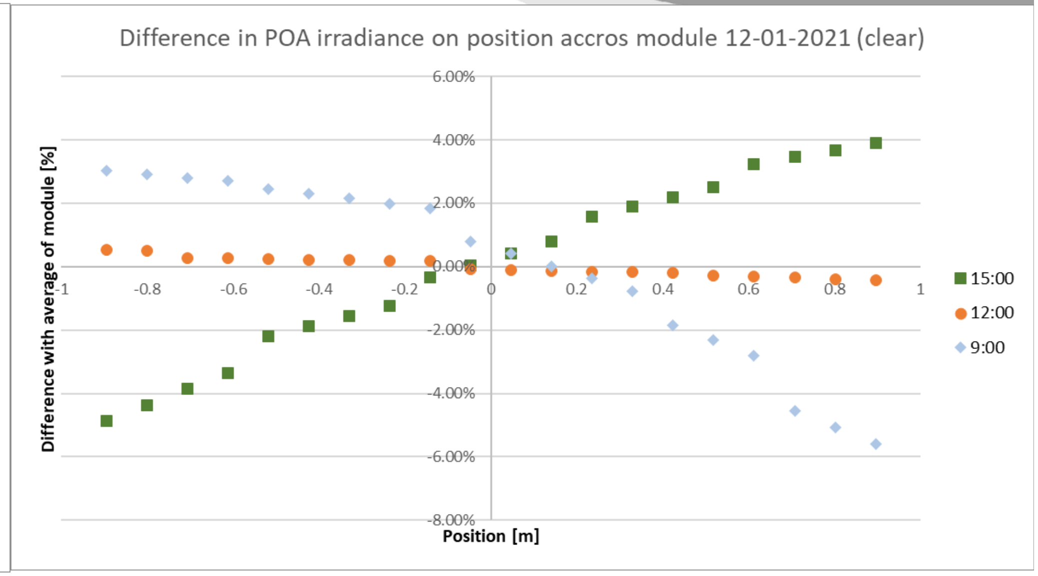
Thank you for your attention!

BACKUP SLIDES

INTRADAY RESULTS CENTER: SEASONS



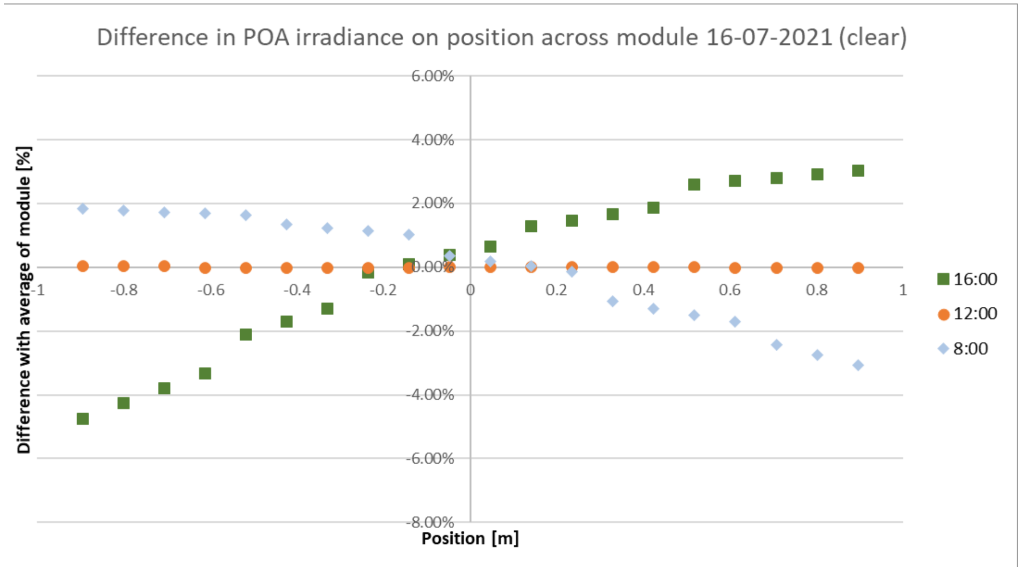
Summer



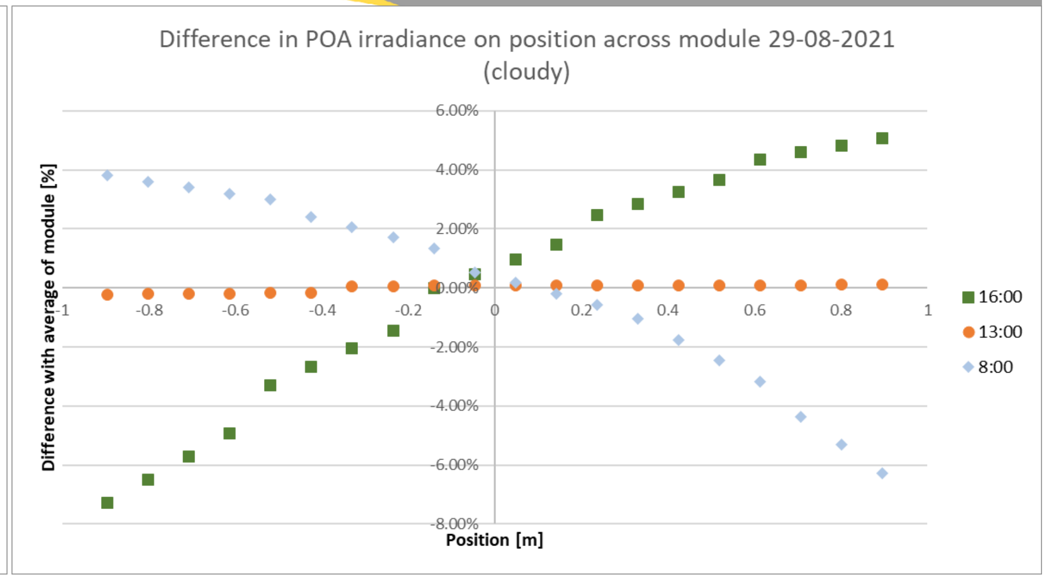
Winter

- Winter: up to 9% differences, summer: up to 8 % differences.
- clear days → no intraday seasonal effect

WEATHER CONDITIONS ON HOURLY INTRA DAY RESULTS



Clear 16-07-2021



Cloudy 29-08-2021

- clear weather: up to 8% difference,
  cloudy wather: up to 12% difference.
- larger differences for cloudy due to:
  - larger diffuse fraction of the irradiance
  - Different sky fraction visible for different positions across the module