PVPMC · 2026

How spectral effects impact capacity testing — a case study

PV Lighthouse:

Keith McIntosh

Solomon Freer

Malcolm Abbott

Ben Sudbury

Kiewit Engineering:

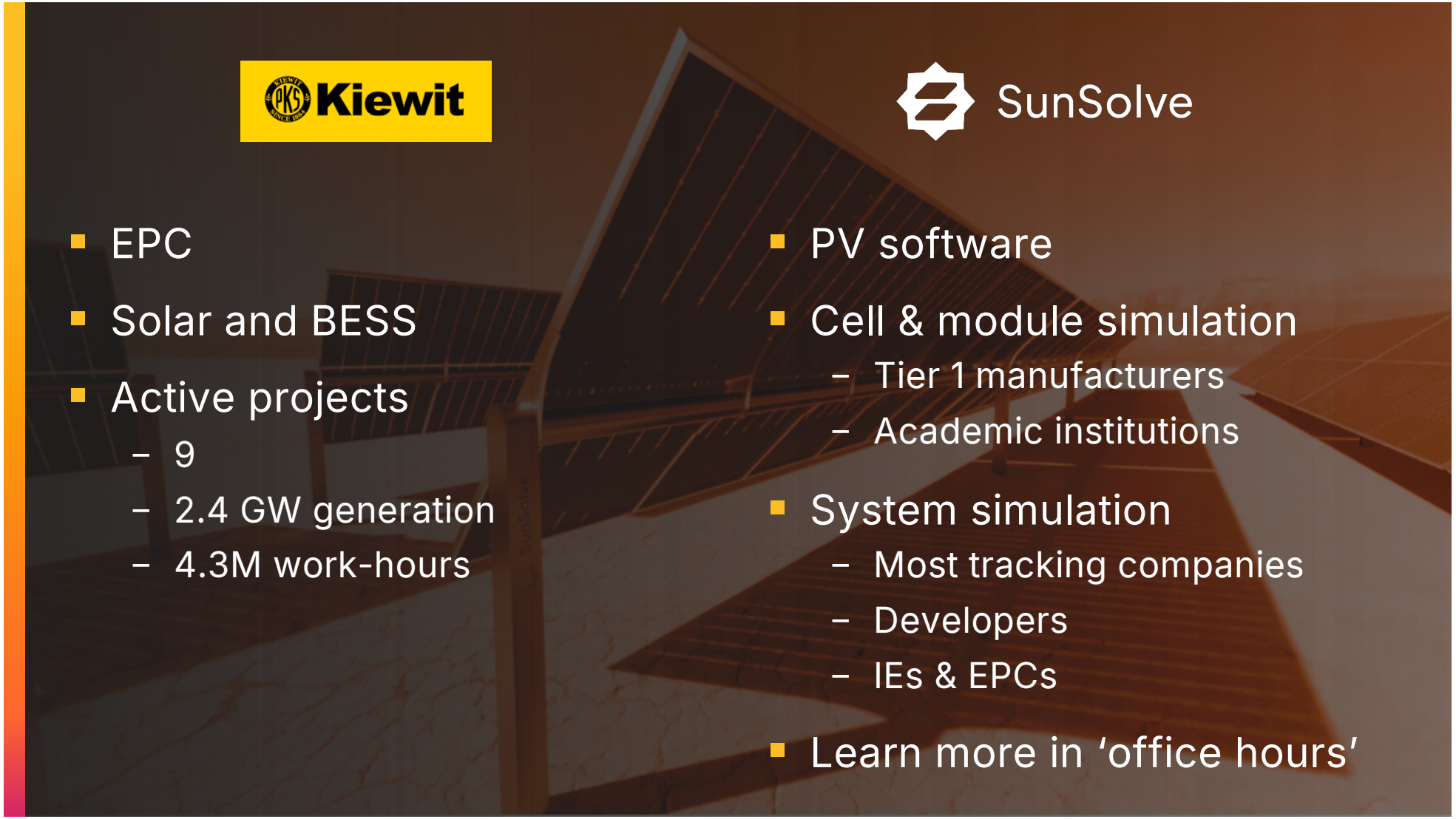
Chris Stelzer

Andrew Loveall

Samuel Vielman

Thank you

This project received funding from the Australian Renewable Energy Agency (ARENA) as part of ARENA's Advancing Renewables Program.



Kiewit

- EPC
- Solar and BESS
- Active projects
  - 9
  - 2.4 GW generation
  - 4.3M work-hours

SunSolve

- PV software
- Cell & module simulation
  - Tier 1 manufacturers
  - Academic institutions
- System simulation
  - Most tracking companies
  - Developers
  - IEs & EPCs
- Learn more in ‘office hours’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PART ONE
Background

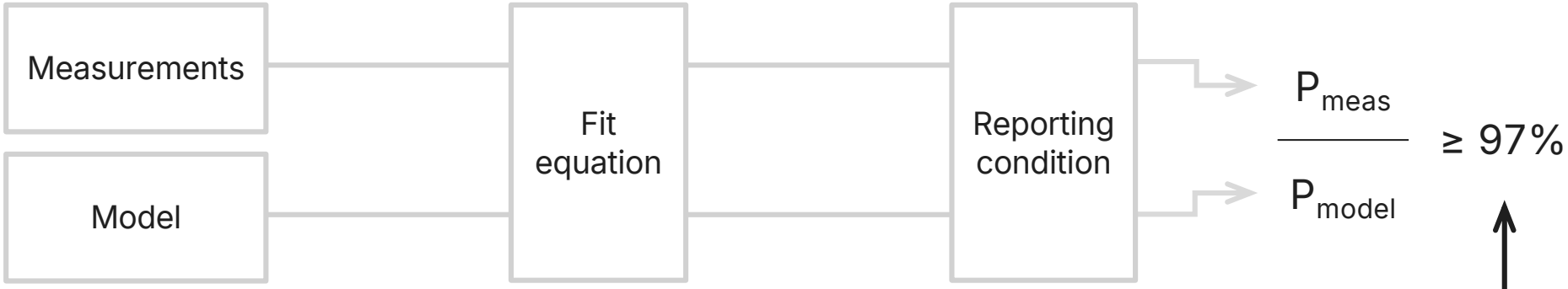
Capacity test

Does the new plant operate as expected?

Capacity test

Measured power = Modelled power

Capacity test



ASTM E2848

$$P = E_{POA} \times (a + b \times E_{POA} + c \times T_{amb} + d \times WS)$$

E.g.
E_{POA} = 850 W/m²
T_{amb} = 25 °C
WS = 2.5 m/s

MCTC

$$P_{corr} = a + b \cdot E_{POA}$$

E.g.
E_{POA} = 850 W/m²
T_m = 40 °C

Example test — ASTM

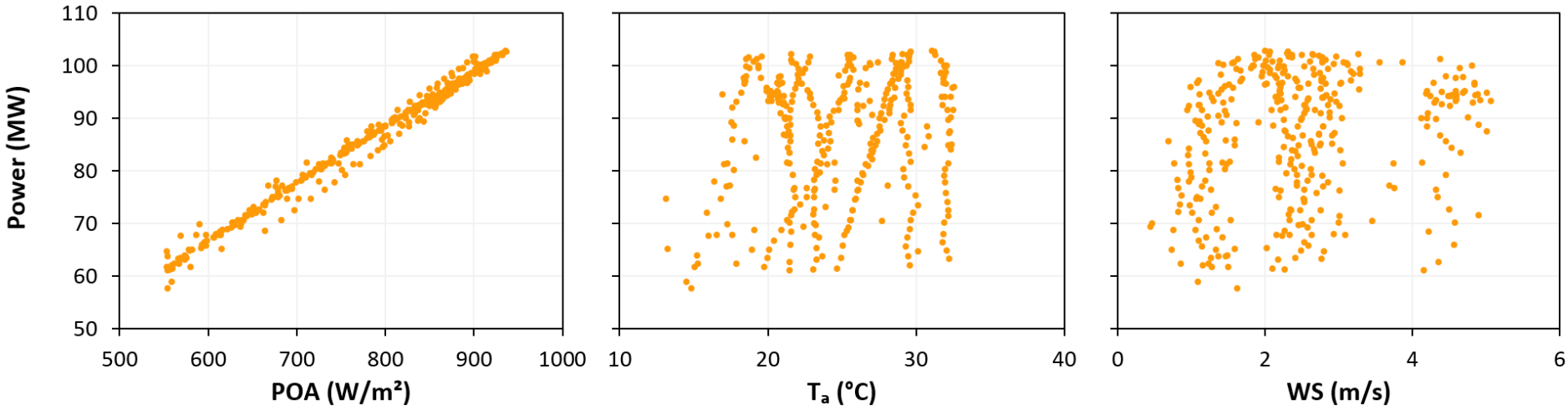
Measurements

Model

Fit equation

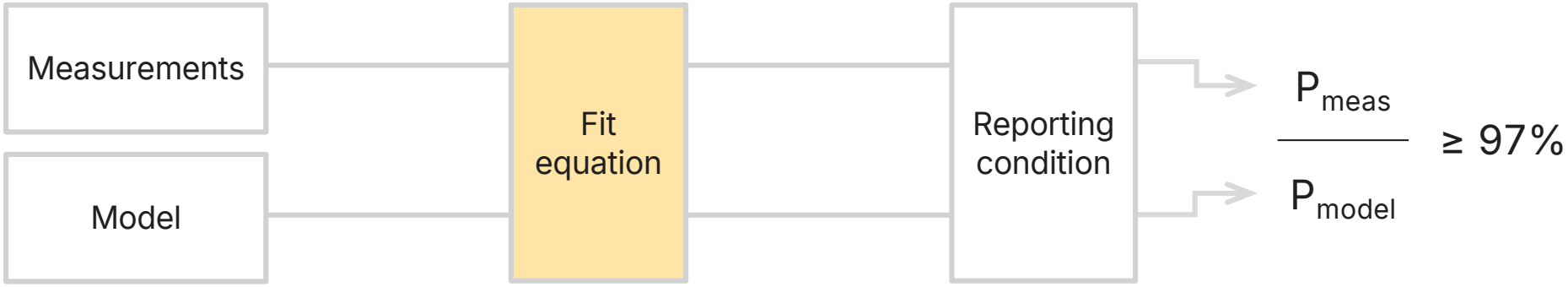
Reporting condition

$$\frac{P_{meas}}{P_{model}} \geq 97\%$$

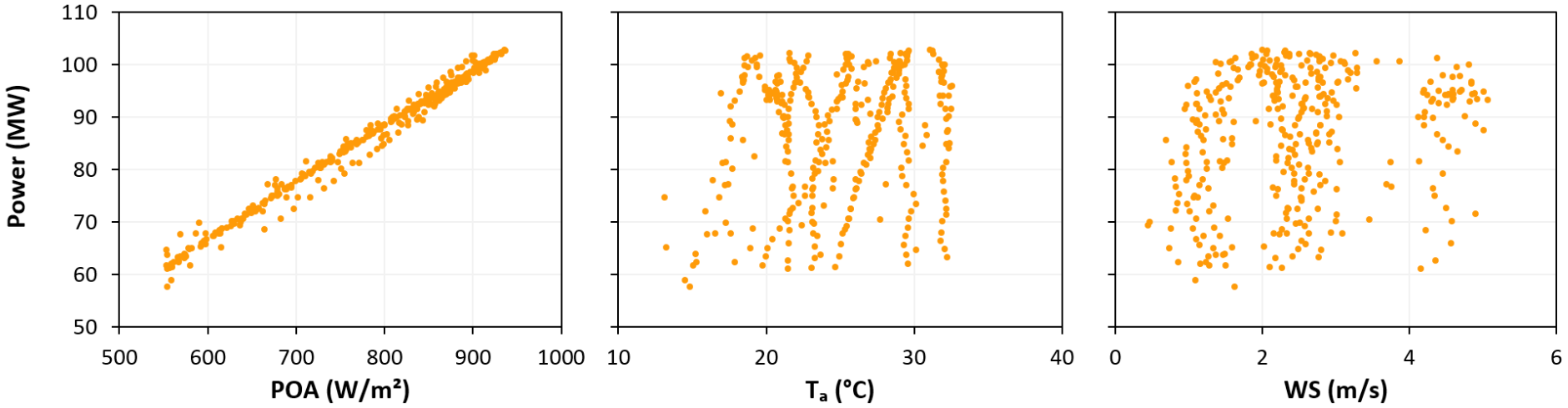


Example test — ASTM

Kiewit SunSolve

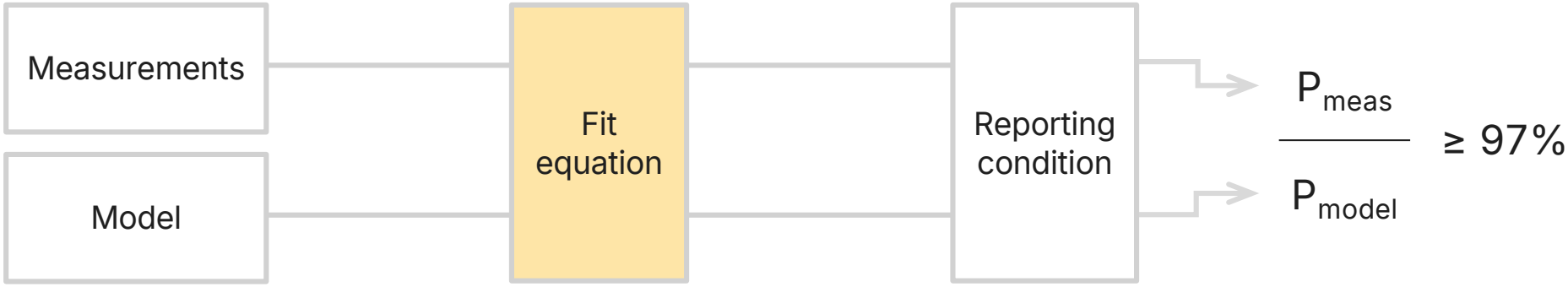


$$P = E_{POA} \times (a + b \times E_{POA} + c \times T_{amb} + d \times WS)$$

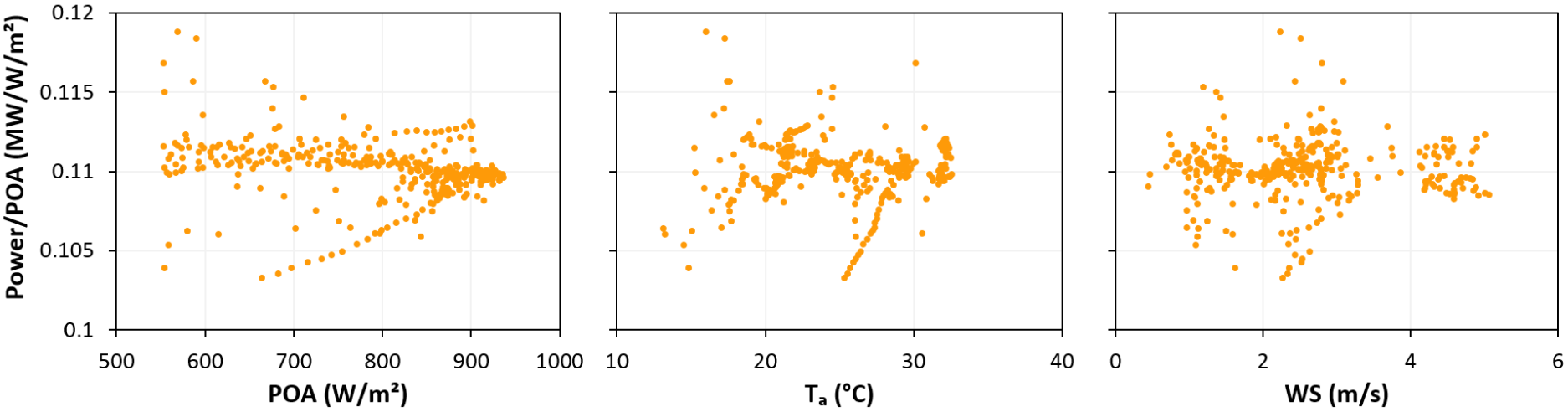


Example test — ASTM

Kiewit SunSolve

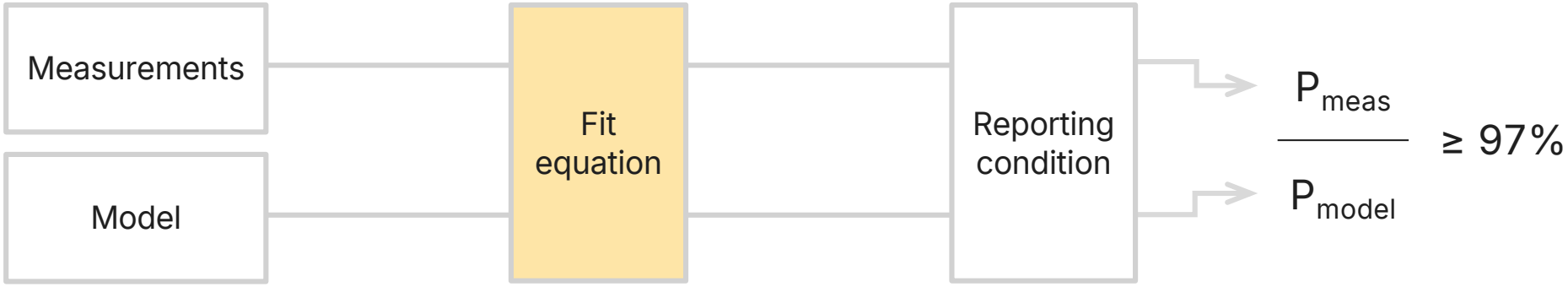


$$P / E_{POA} = a + b \times E_{POA} + c \times T_{amb} + d \times WS$$

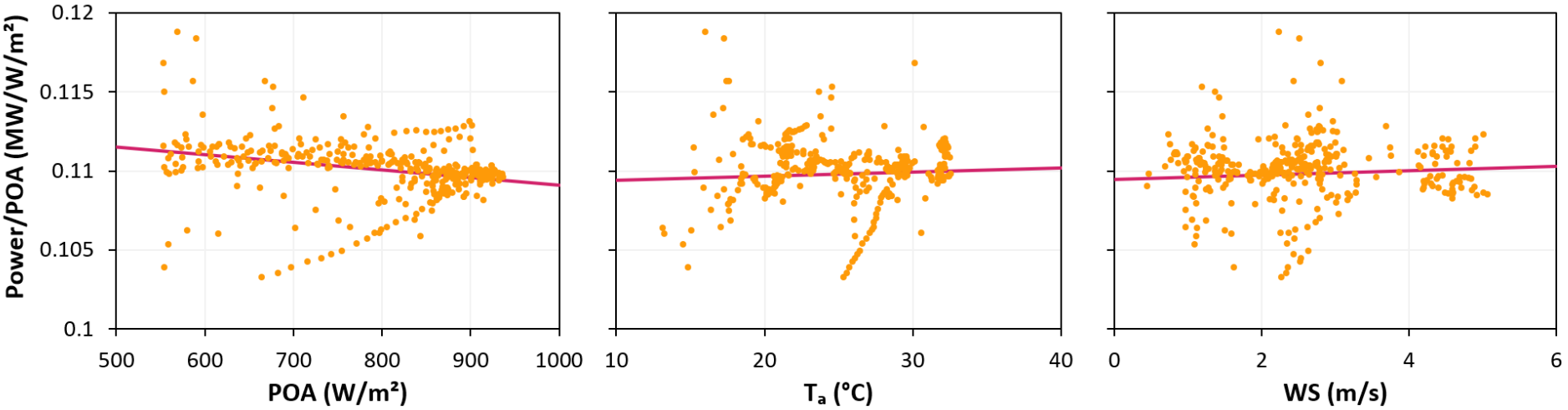


Example test — ASTM

Kiewit SunSolve



$P / E_{POA} = 1.1e\text{-}1 + -4.8e\text{-}6 \times E_{POA} + 2.6e\text{-}5 \times T_{amb} + 1.4e\text{-}4 \times WS$ $R^2 = 0.987$



Example test — ASTM

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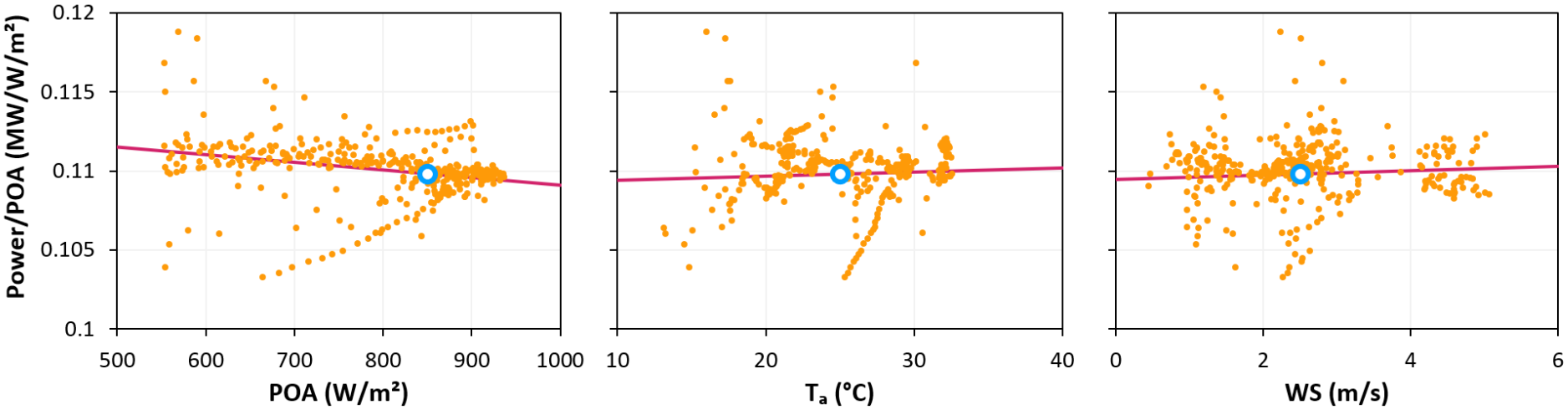
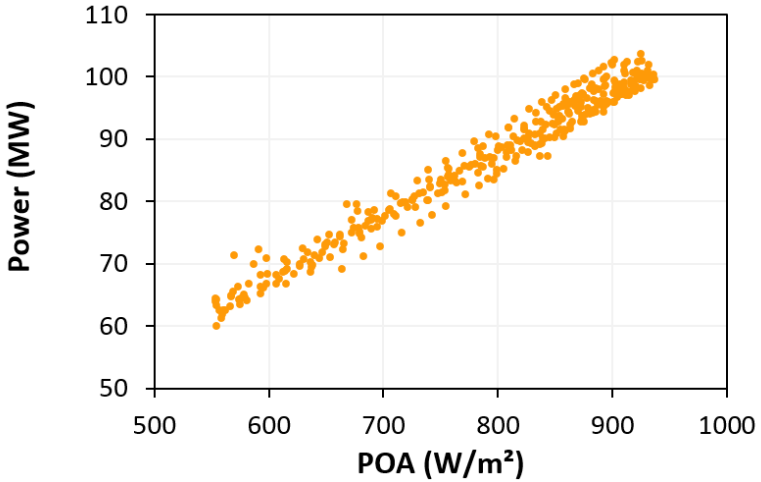
$P / 850 = 1.1e\text{-}1 + -4.8e\text{-}6 \times 850 + 2.6e\text{-}5 \times 25 + 1.4e\text{-}4 \times 2.5$

P_{meas} = 93.3 MW

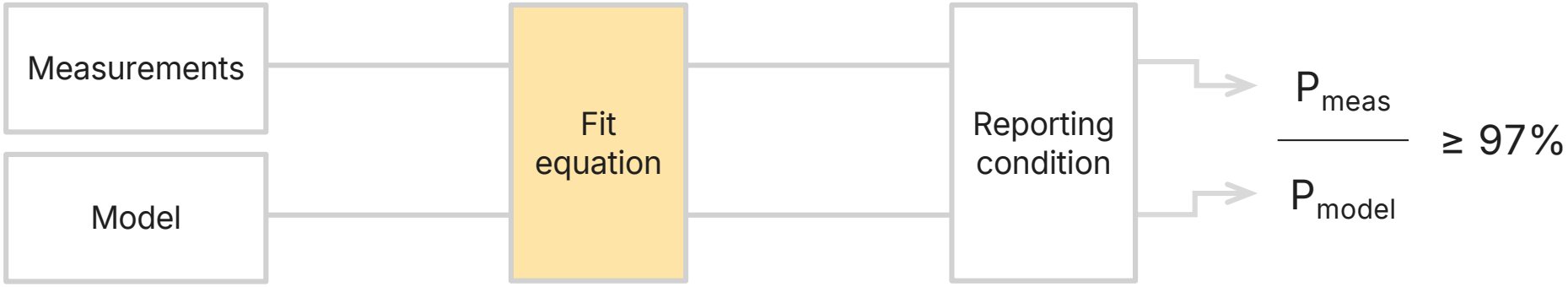


Example test — MCTC

T_m = 40 °C

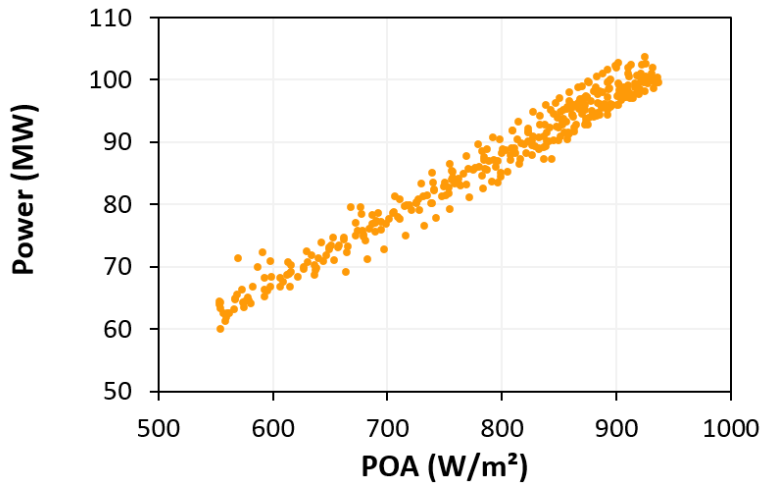


Example test — MCTC



$P_{corr} = a + b \times E_{POA}$

$T_m = 40\ ^oC$

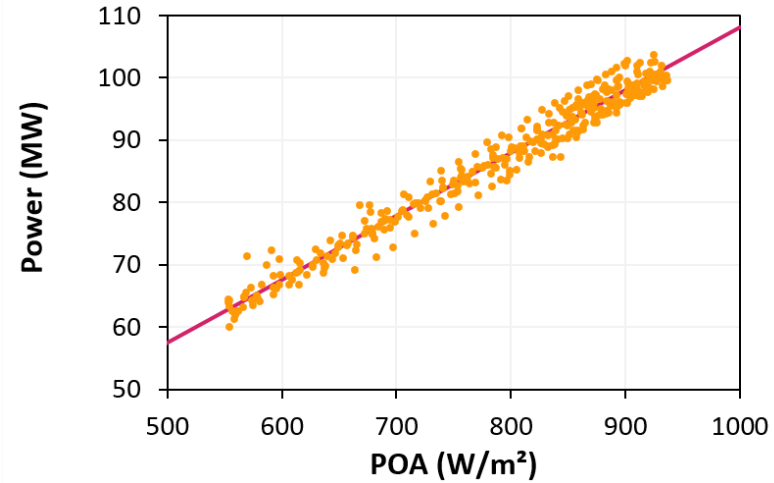


Example test — MCTC

$P_{corr} = 6.84 + 0.101 \times E_{POA}$

$R^2 = 0.968$

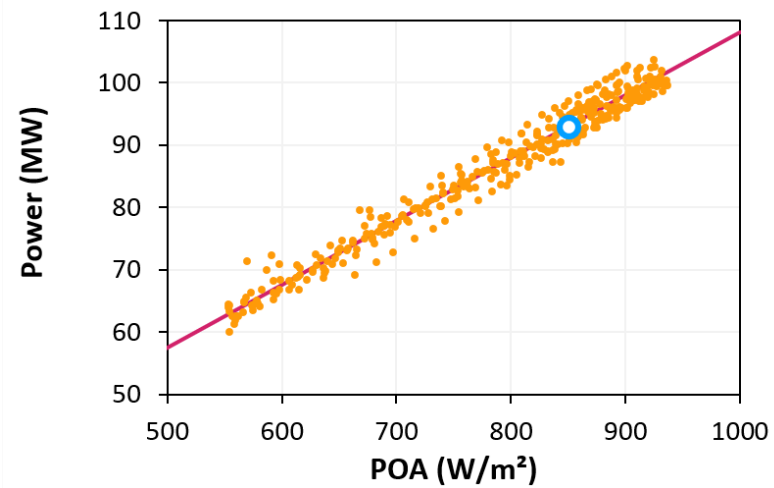
$T_m = 40\ ^oC$



Example test — MCTC

$P_{corr} = 6.84 + 0.101 \times 850$

$P_{meas} = 93.0$ MW



Capacity test

E.g., if model matches measurements:

$$\frac{P_{meas} = 100\ MW}{P_{model} = 100\ MW} = 100\% \geq 97\%$$ PASS

Capacity test

What if

- POA meas 1% high

$$\frac{P_{meas} = 99\ MW}{P_{model} = 100\ MW} = 99\% \geq 97\%$$ PASS

Capacity test

What if

- POA meas 1% high
- P meas 1% low

$$\frac{P_{meas} = 98\ MW}{P_{model} = 100\ MW} = 98\% \geq 97\%$$ PASS

Capacity test

What if

- POA meas 1% high
- P meas 1% low
- T model 3 ˚C low

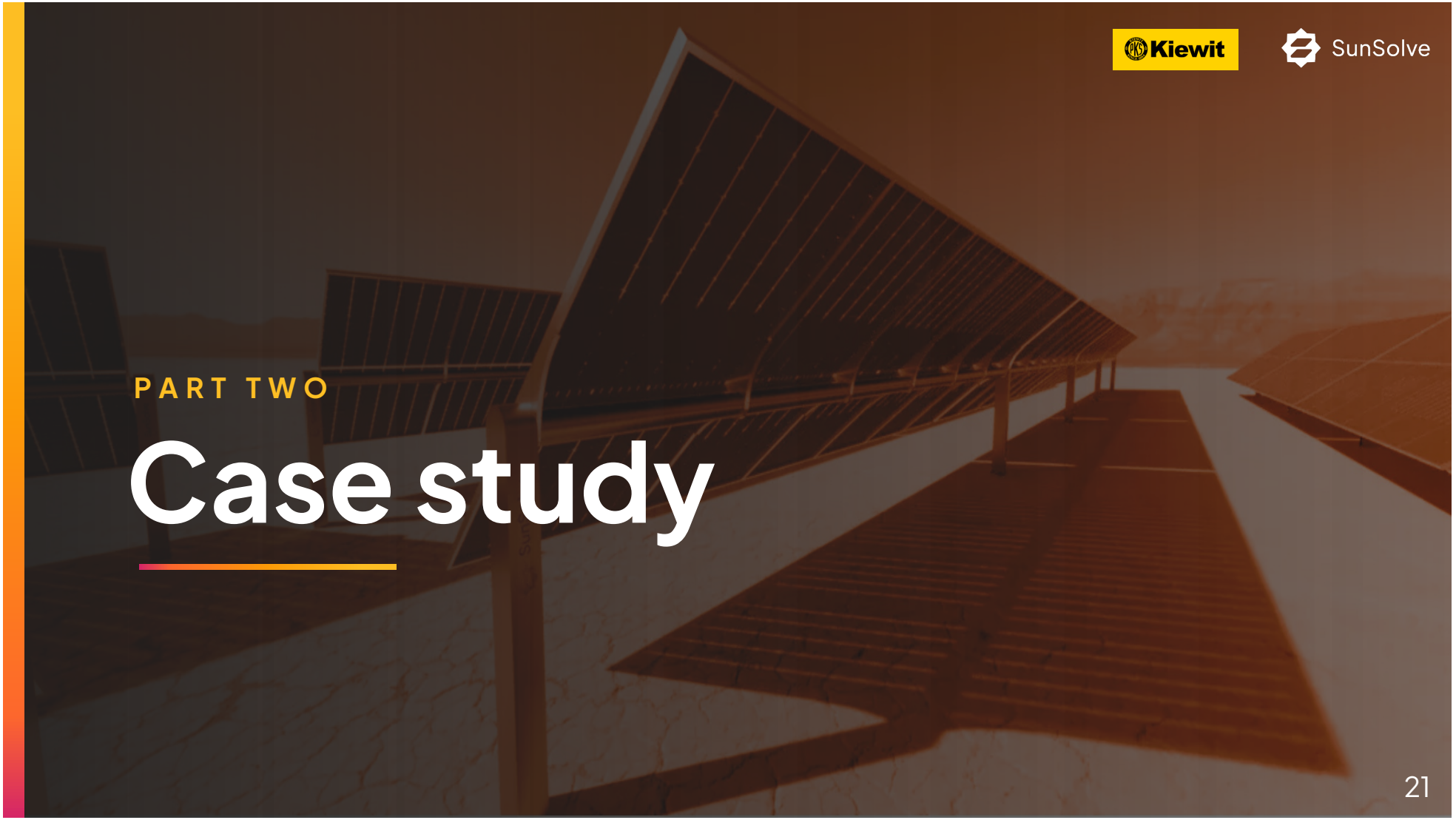
$$\frac{P_{meas} = 98\ MW}{P_{model} = 101\ MW} = 97\% \geq 97\%$$ PASS

Capacity test

What if

- POA meas 1% high
- P meas 1% low
- T model 3 ˚C low
- Spectral model 1% high

$$\frac{P_{meas} = 98\ MW}{P_{model} = 102\ MW} = 96\% < 97\%$$ FAIL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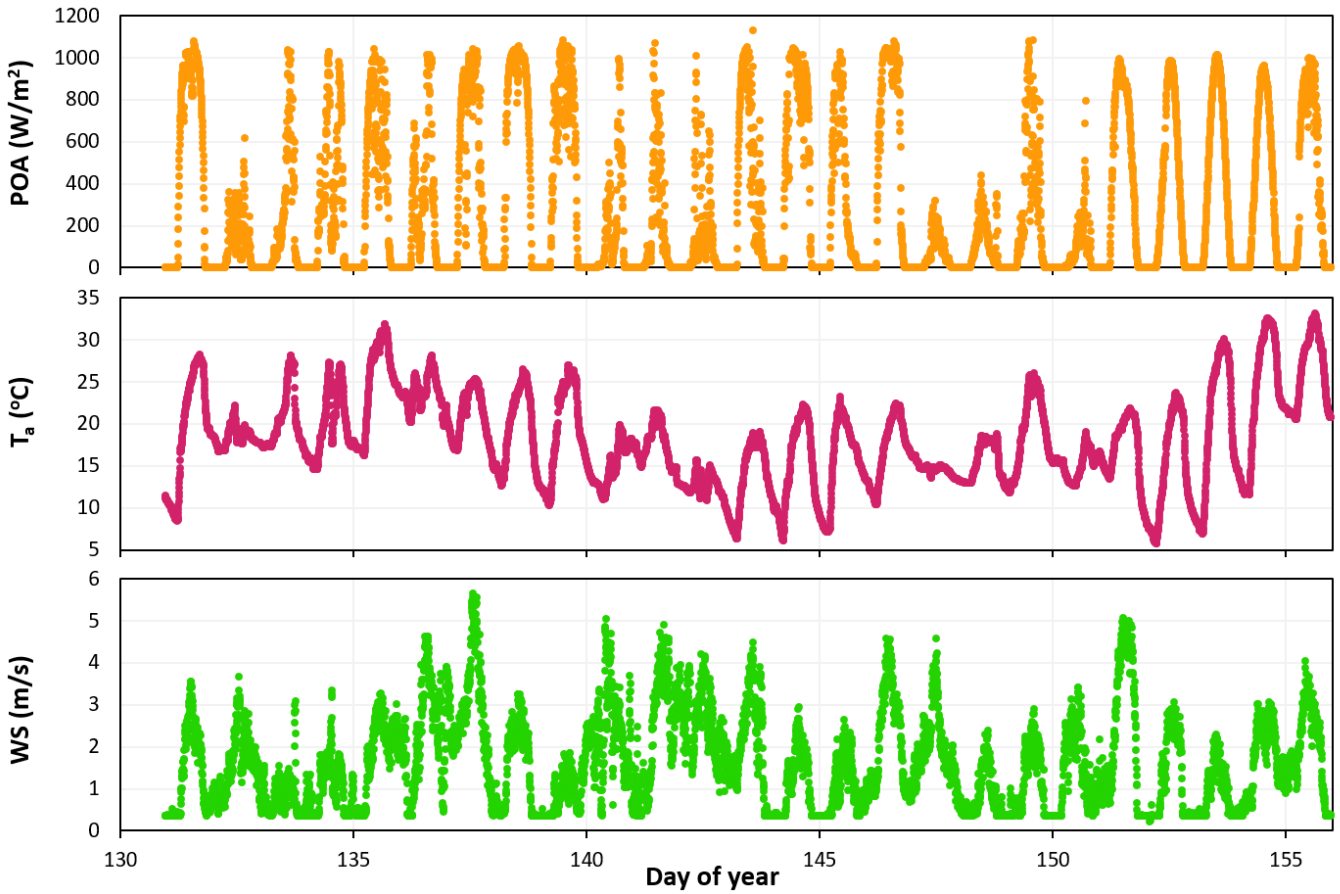
PART TWO
Case study

Site details

- Site
  - Midwest
  - > 100 MW
  - Single-axis tracker
  - True tracking (no back tracking)
  - First Solar modules (CdTe)
  - Monofacial
- Capacity test
  - 25-day monitoring period
  - ASTM and MCTC

Site conditions — weather

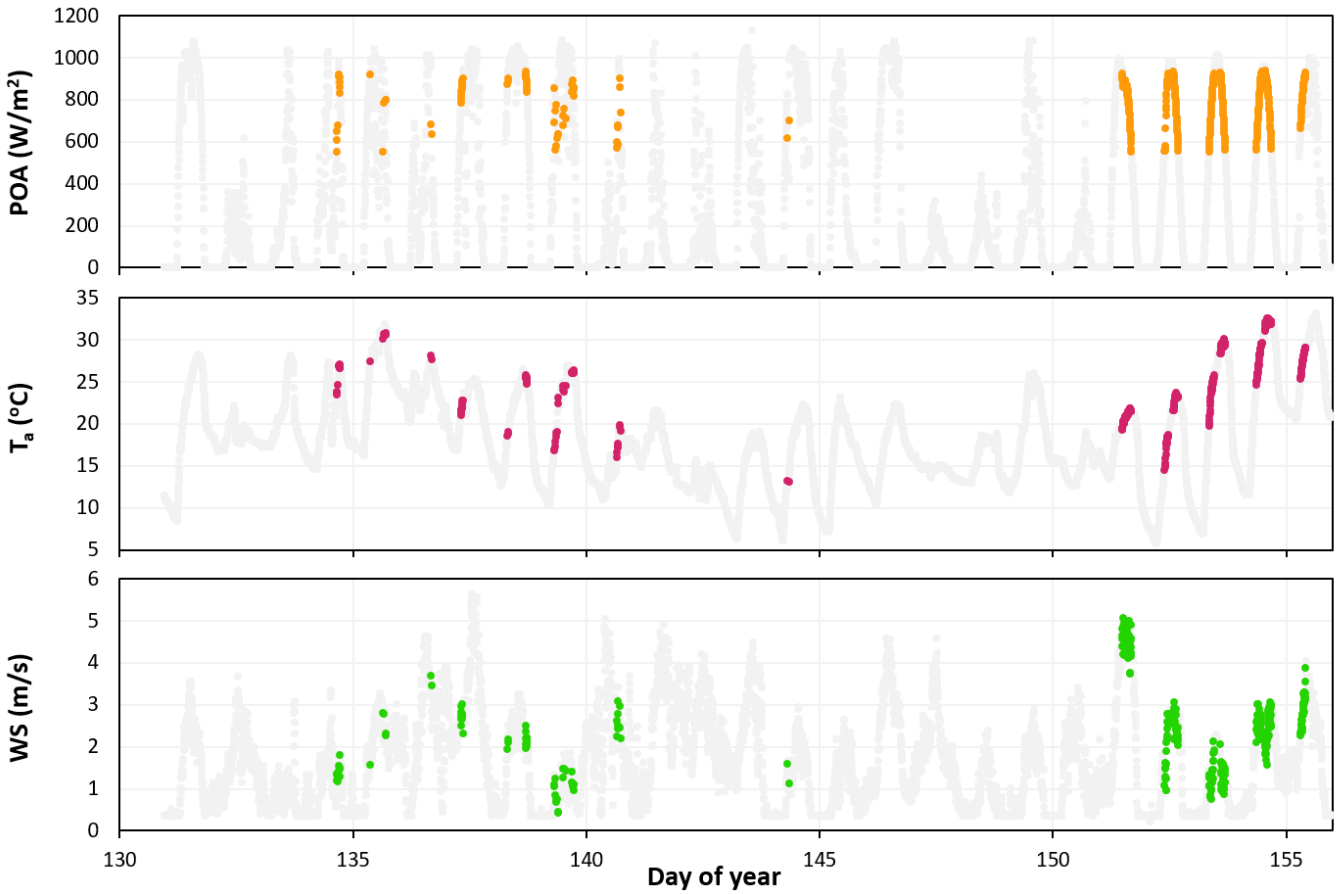


POA: 0–1130 W/m^2

T_{amb}: 6–33 °C

WS: 0.2–5.6 m/s

Site conditions — weather



- Filtering
  - Clipping, curtailment
  - Spatially varying GHI
  - Direct shading
  - POA > 950 W/m²
  - POA < 550 W/m²

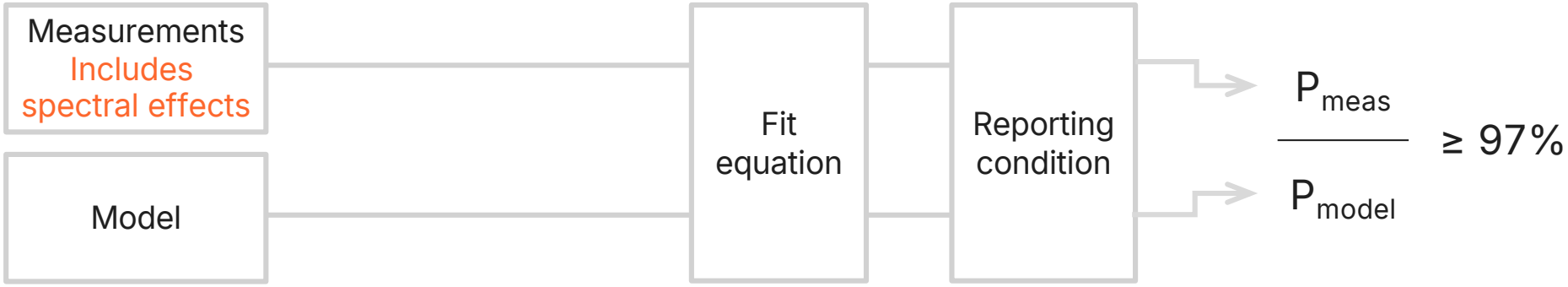
→ 355 data points (5-min steps)

POA: 550–940 W/m²

T_{amb}: 13–33 °C

WS: 0.4–5.1 m/s

Capacity test



Capacity test

Kiewit SunSolve

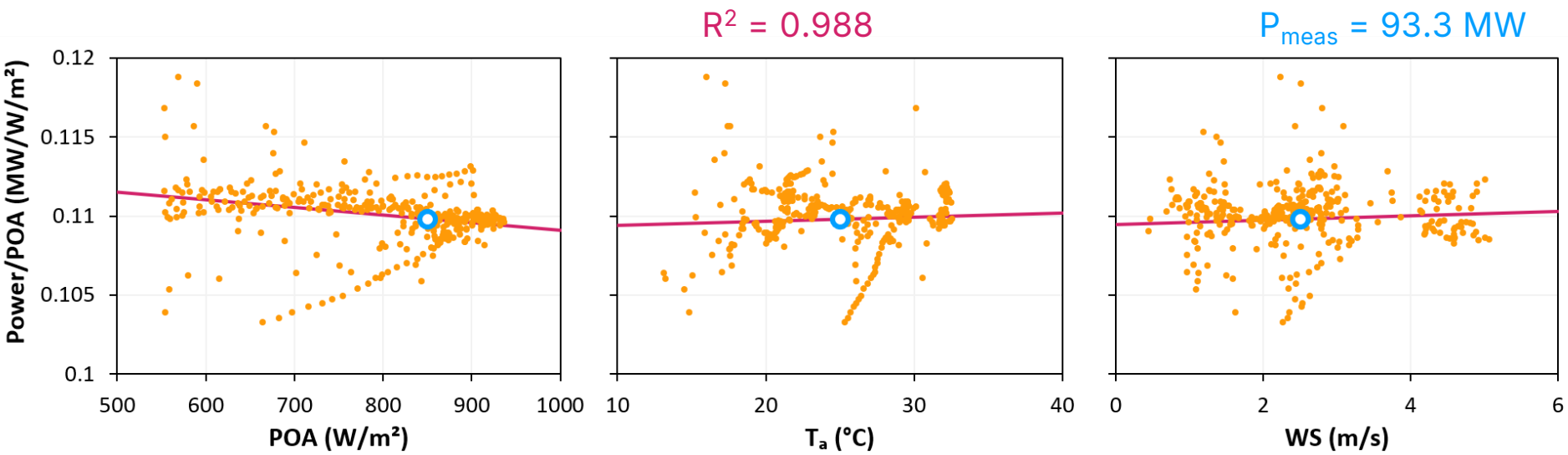
Measurements
Includes spectral effects

Model

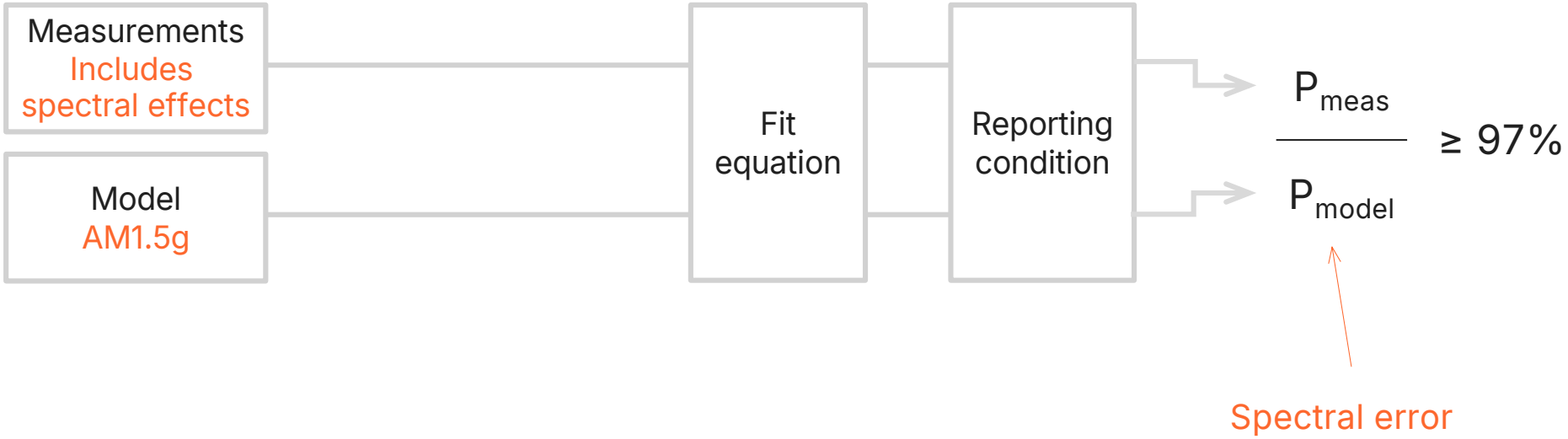
Fit equation

Reporting condition

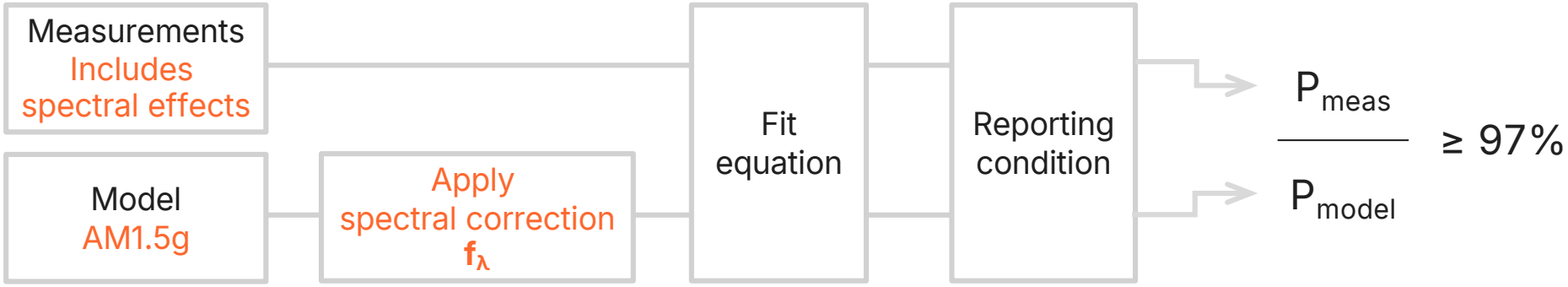
$$\frac{P_{meas}}{P_{model}} \geq 97\%$$



Capacity test



Correction with First Solar model



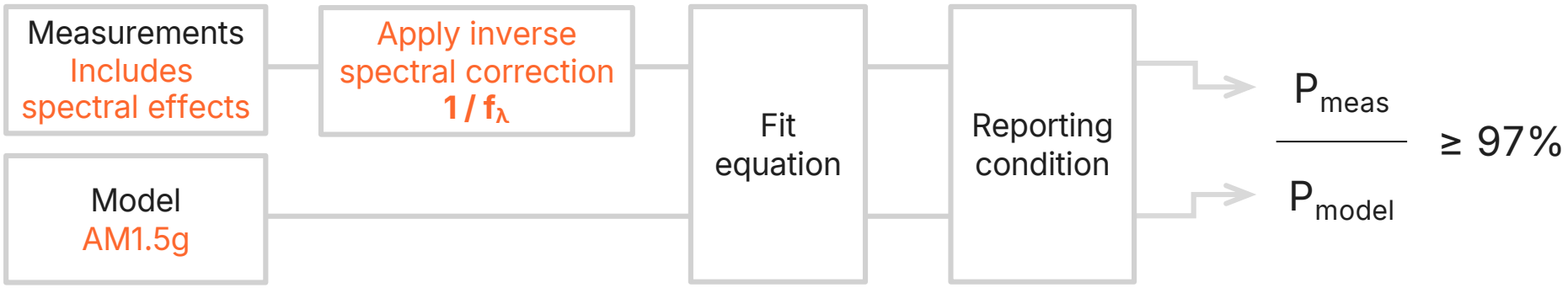
- E.g., PVsyst, Plant Predict, Solar Farmer, Duet, etc.
  - Solve optics at AM1.5g.
  - Correct with First Solar model.

Airmass

PWV

$$f_\lambda = c_1 + c_2 AM_a + c_3 P_w + c_4 \sqrt{AM_a} + c_5 \sqrt{P_w} + c_6 \frac{AM_a}{\sqrt{P_w}}$$

Correction with First Solar model



- E.g., PVsyst, Plant Predict, Solar Farmer
  - Solve optics at AM1.5g.
  - Correct with First Solar model. $f_\lambda = c_1 + c_2 AM_a + c_3 P_w + c_4 \sqrt{AM_a} + c_5 \sqrt{P_w} + c_6 \frac{AM_a}{\sqrt{P_w}}$

Correction with First Solar model

Kiewit SunSolve

Measurements
Includes spectral effects

Model
AM1.5g

Apply inverse spectral correction
$1 / f_\lambda$

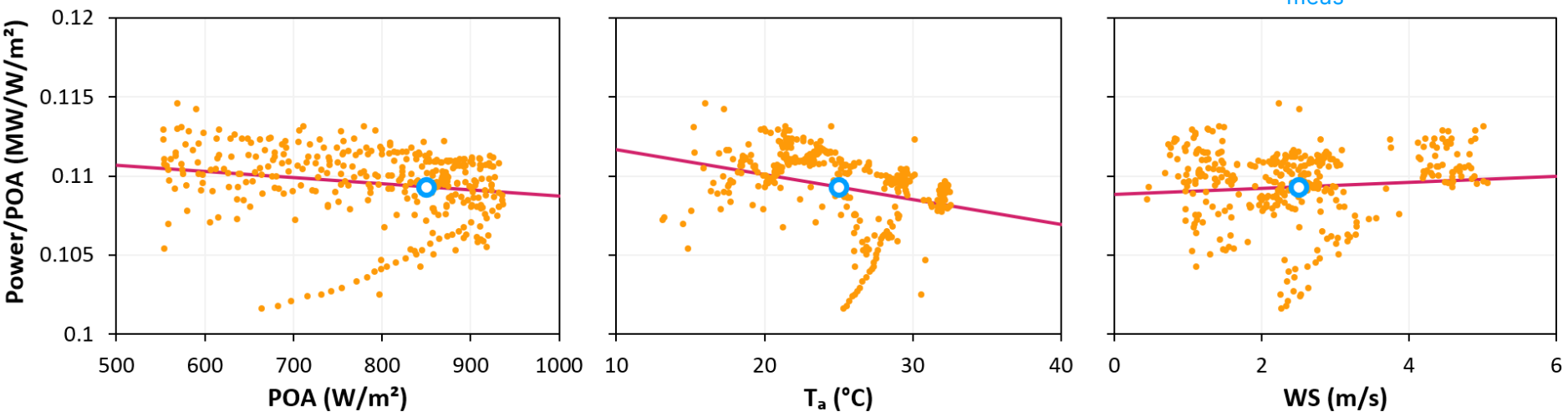
Fit equation

Reporting condition

$\frac{P_{meas}}{P_{model}}$ ↓0.5%

$R^2 = 0.980$

$P_{meas} = 92.1\ MW$



Correction with reference modules

Measurements
Includes spectral effects

Apply inverse spectral correction
1 / f_λ

Model
AM1.5g

Fit equation

Reporting condition

$\frac{P_{meas}}{P_{model}}$

Thermopile
- QE ~ 100% all λ

Reference modules
- I_{sc} calibrated at AM1.5g
- T and IAM corrected
- Cleaned every day

$\frac{E_{POA}}{E_{POA\ AM1.5g}} = f_\lambda$

Correction with reference modules

Kiewit SunSolve

Measurements
Includes spectral effects

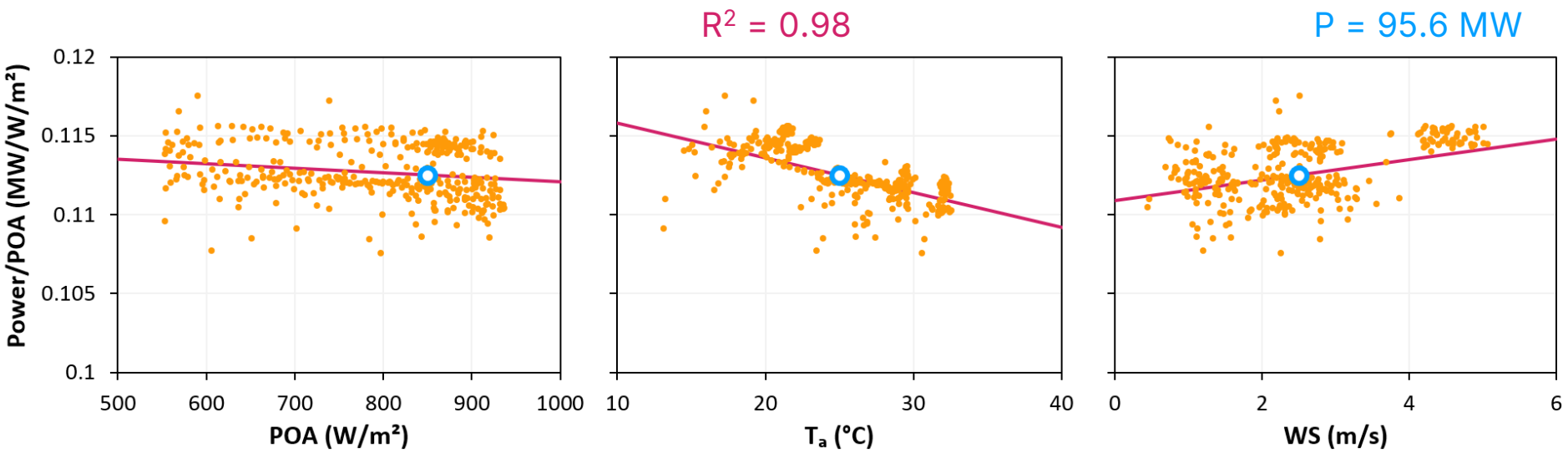
Model
AM1.5g

Apply inverse spectral correction
$1 / f_\lambda$

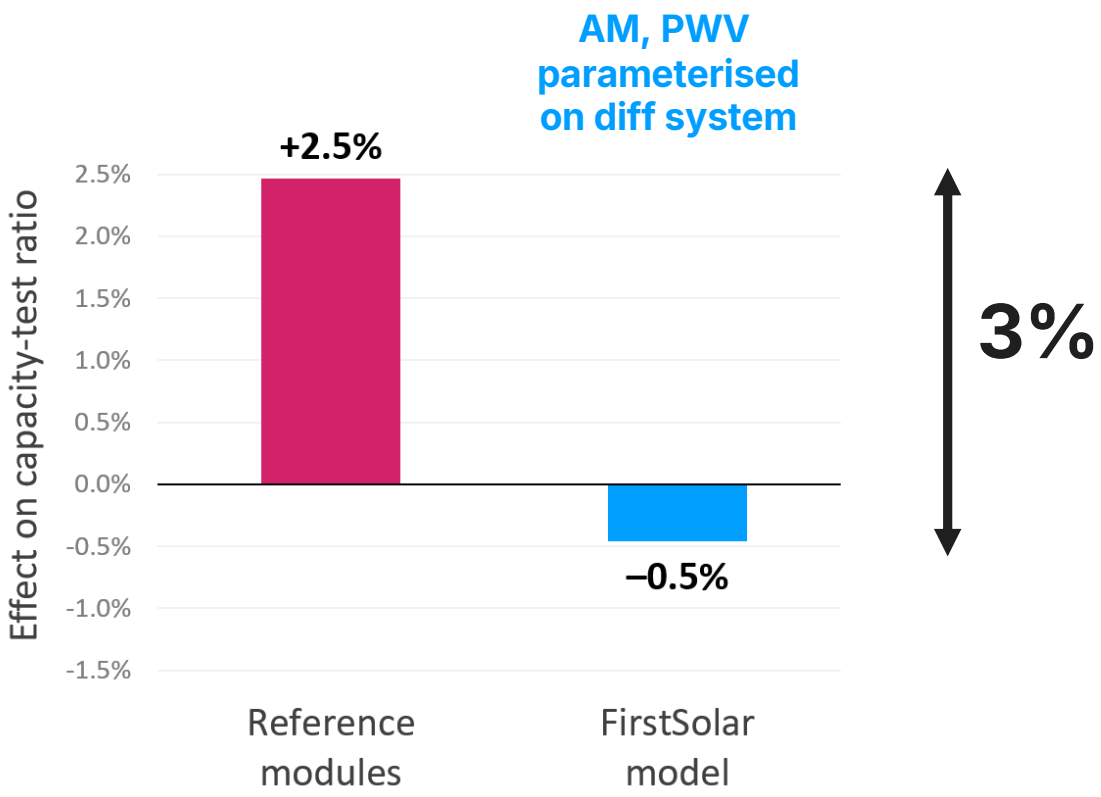
Fit equation

Reporting condition

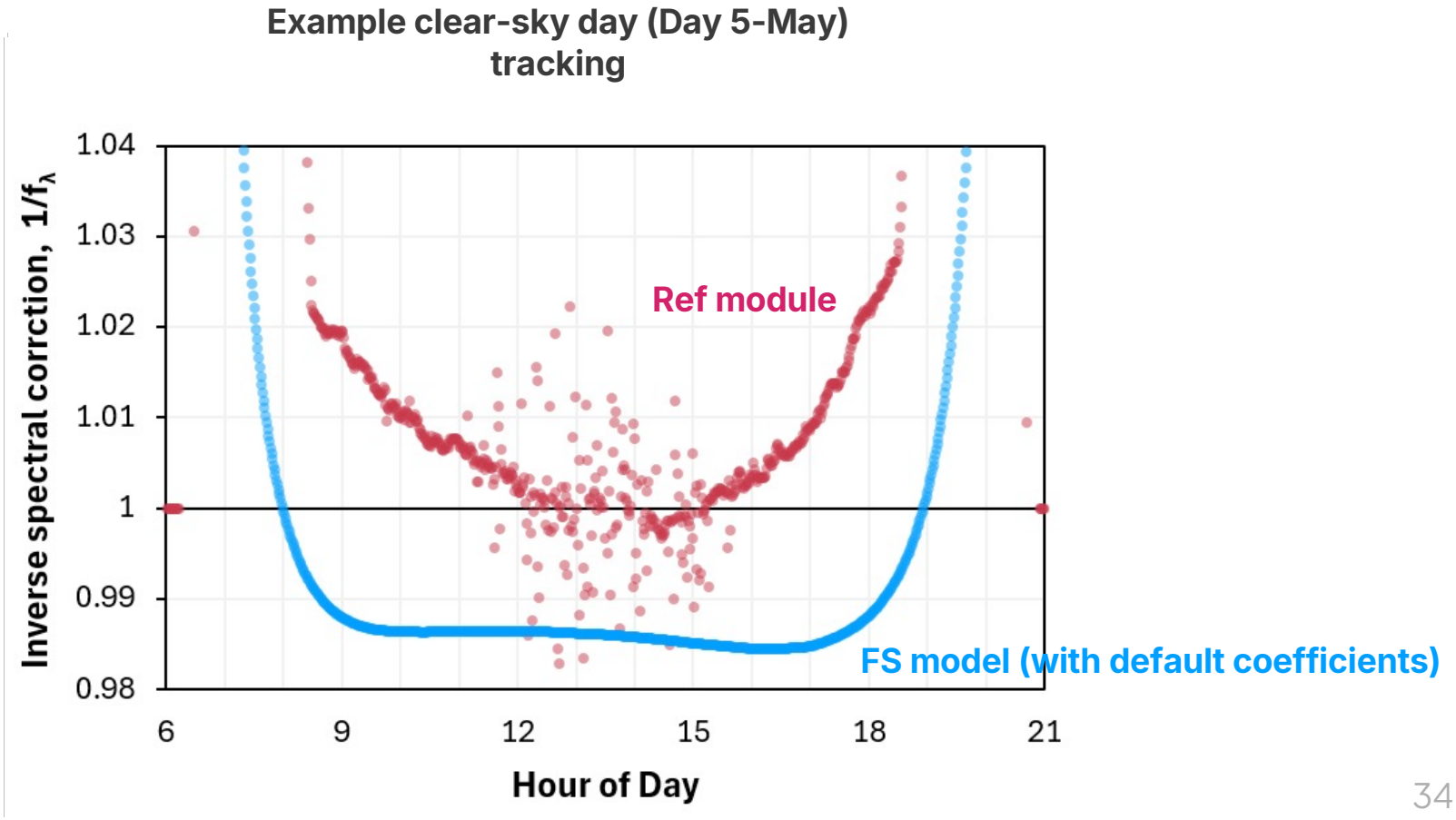
$\frac{P_{meas}}{P_{model}}$ ↑2.5%



Impact on capacity test — ASTM

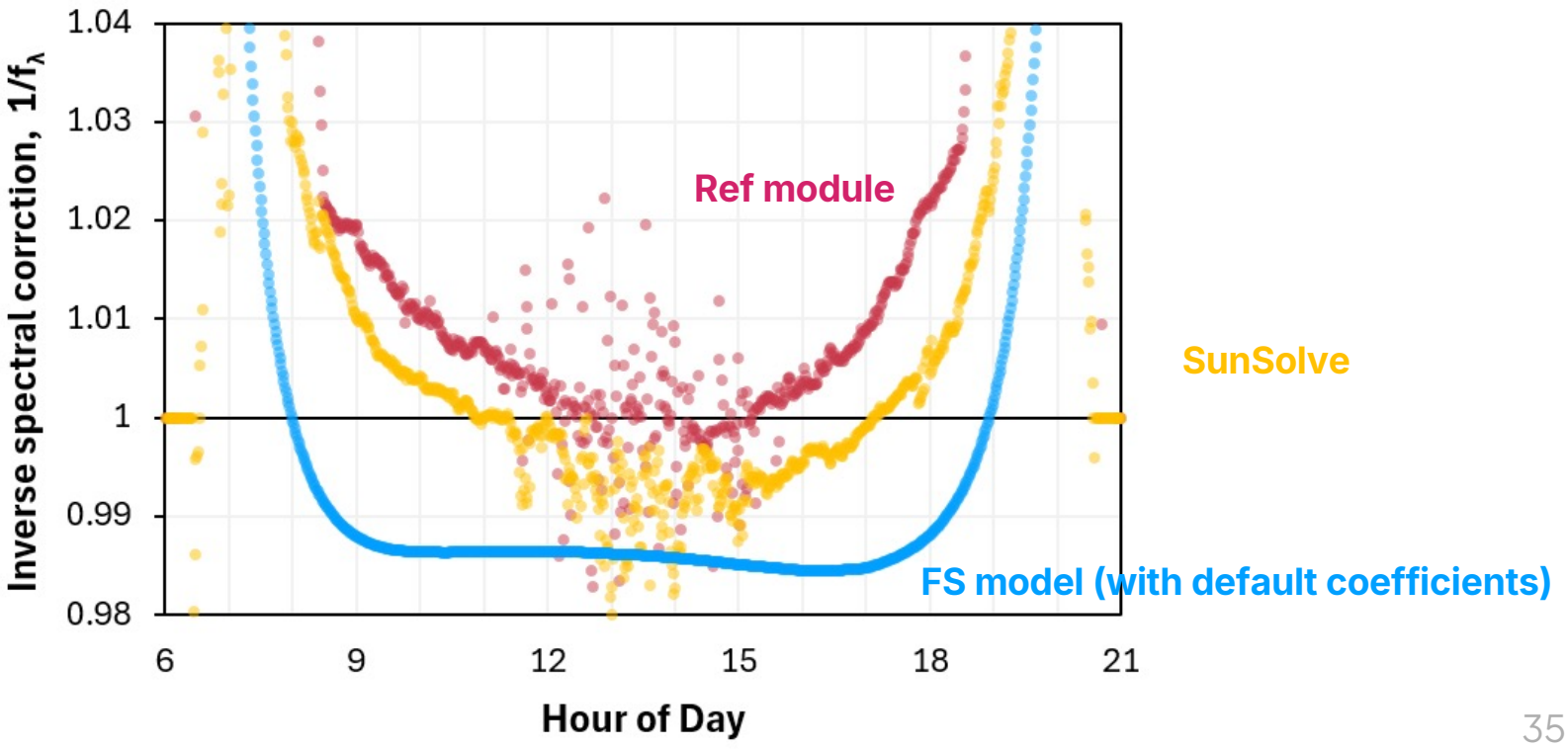


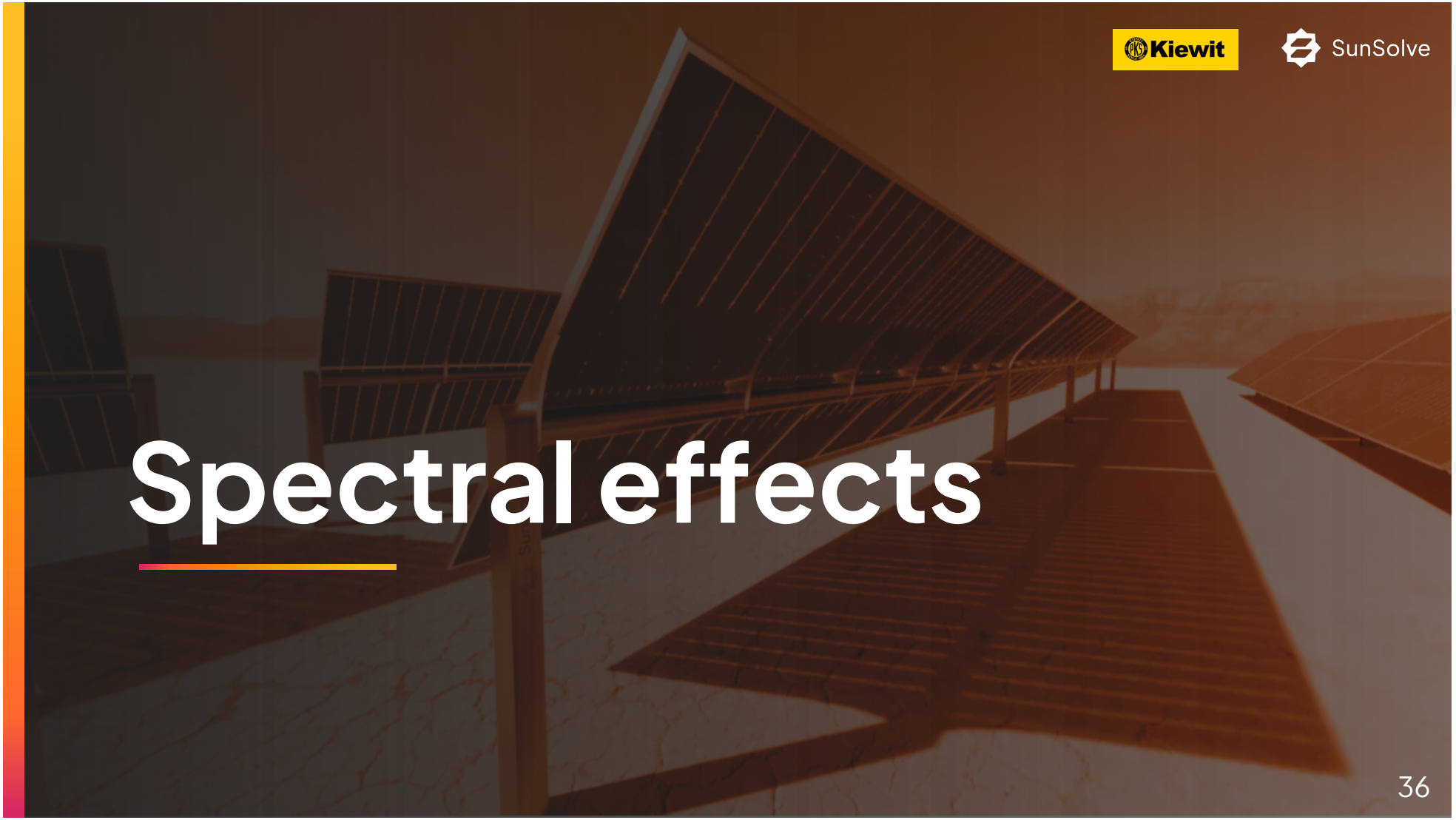
Impact on capacity test — ASTM



Impact on capacity test — ASTM

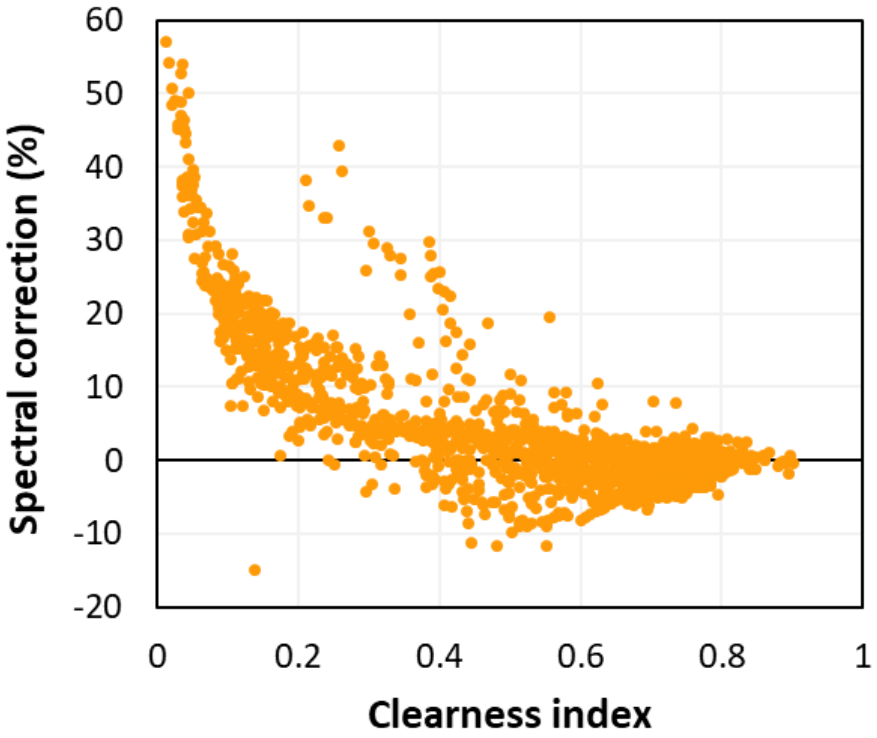
Example clear-sky day (Day 5-May) tracking





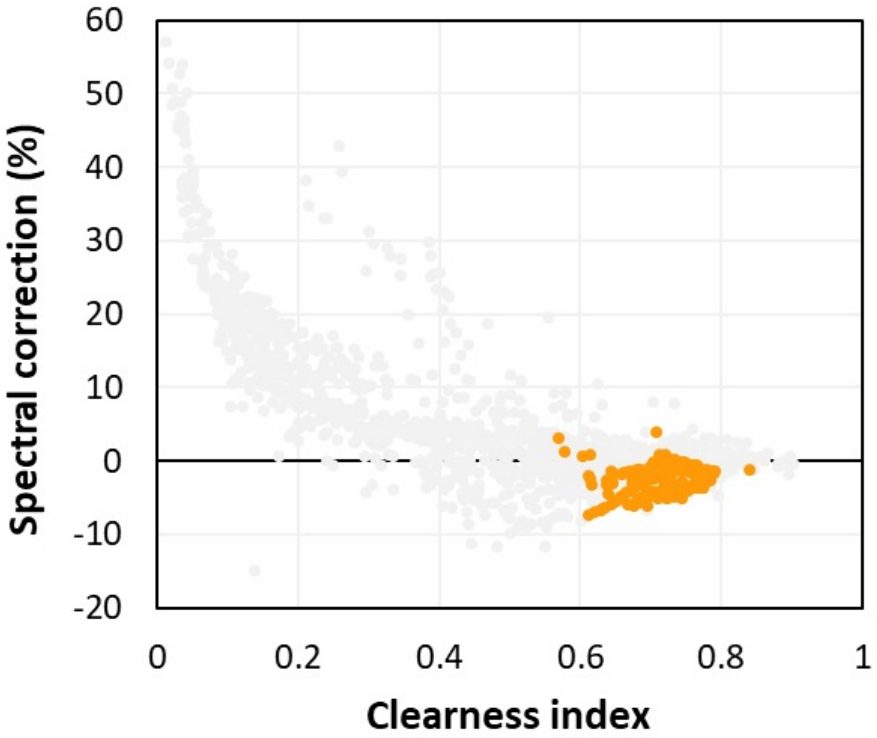
Spectral effects

Spectral correction — measurements



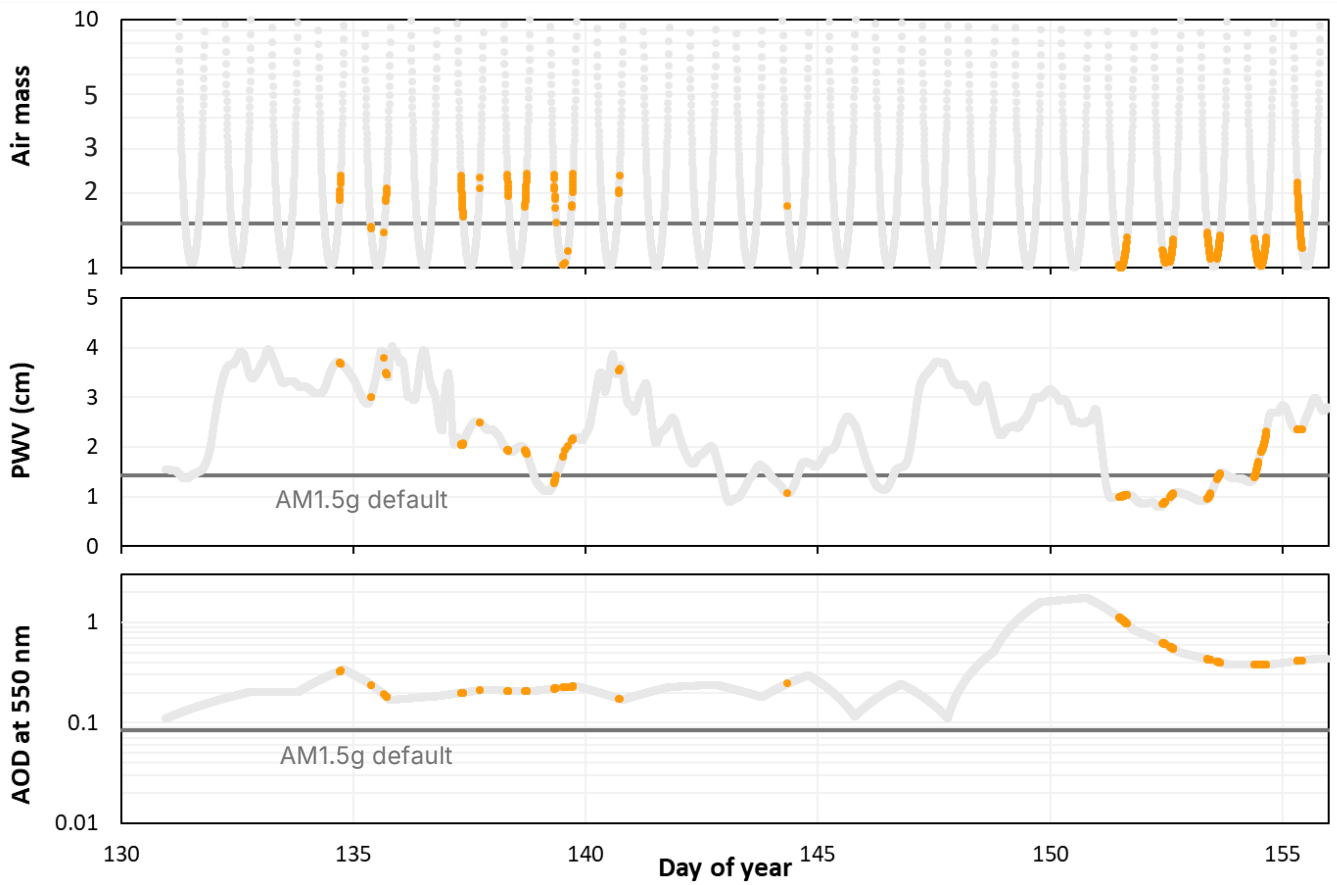
- Filtering
  - Clipping, curtailment
  - Spatially varying GHI
  - Direct shading
  - POA > 950 W/m^2

Spectral correction — measurements



- Filtering
  - Clipping, curtailment
  - Spatially varying GHI
  - Direct shading
  - POA > 950 W/m^2
  - POA < 550 W/m^2

Site conditions — atmosphere

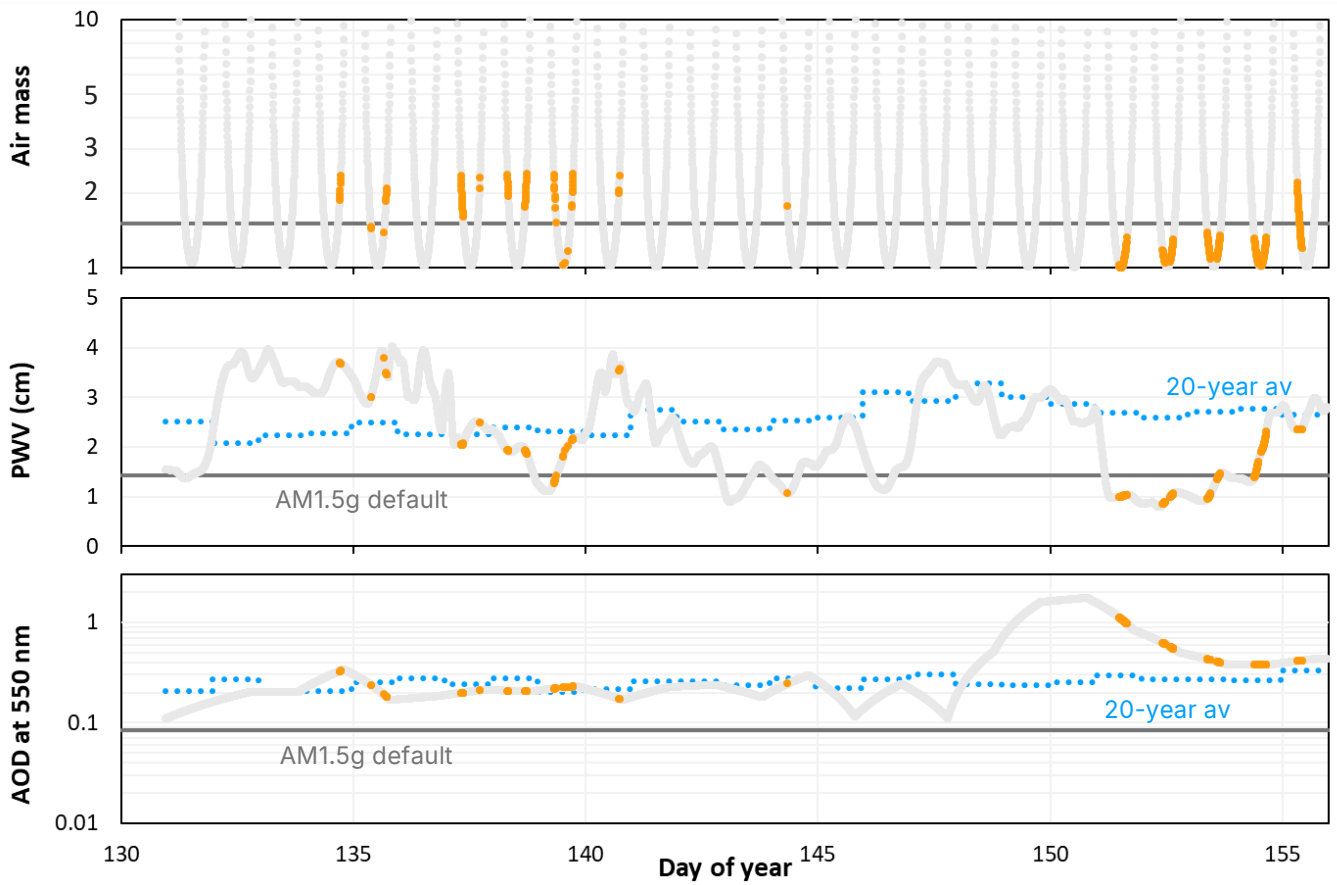


AM: 1.0–2.4

PWV: 0.8–3.9 cm
Satellite data

AOD: 0.17–1.33
Satellite data

Site conditions — atmosphere



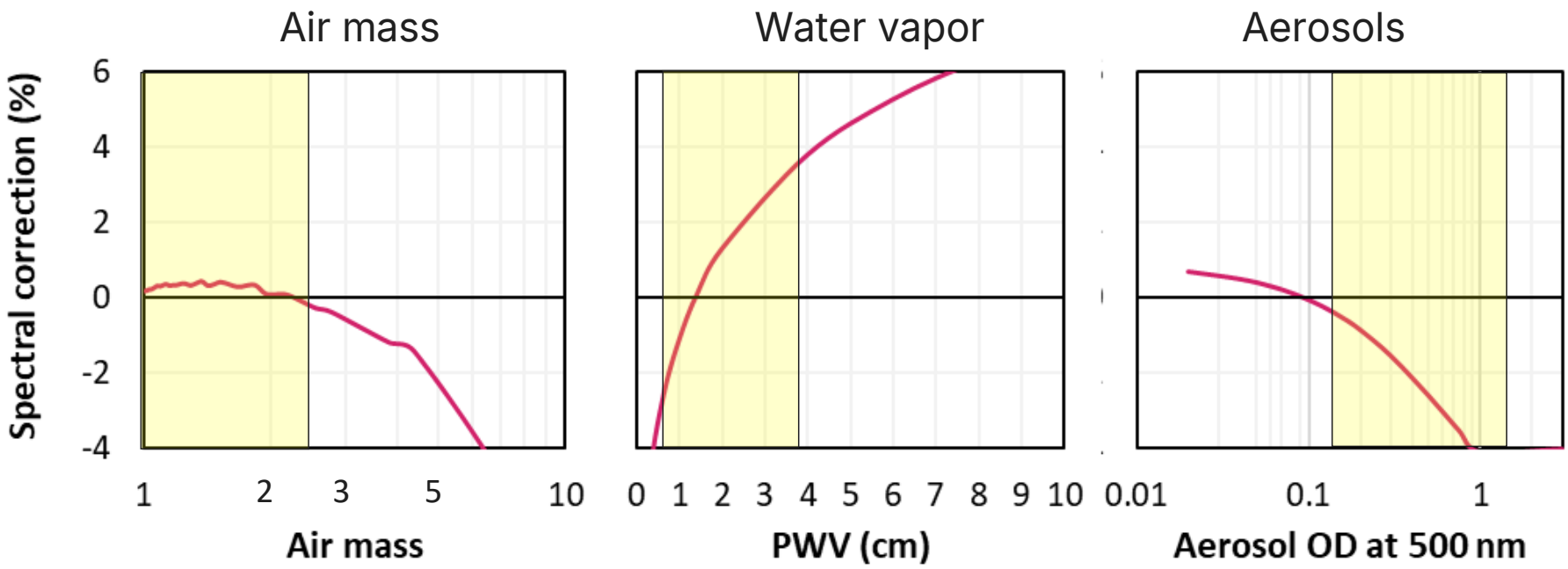
AM: 1.0–2.4

PWV: 0.8–3.9 cm
Satellite data

AOD: 0.17–1.33
Satellite data

Spectral impact

CdTe

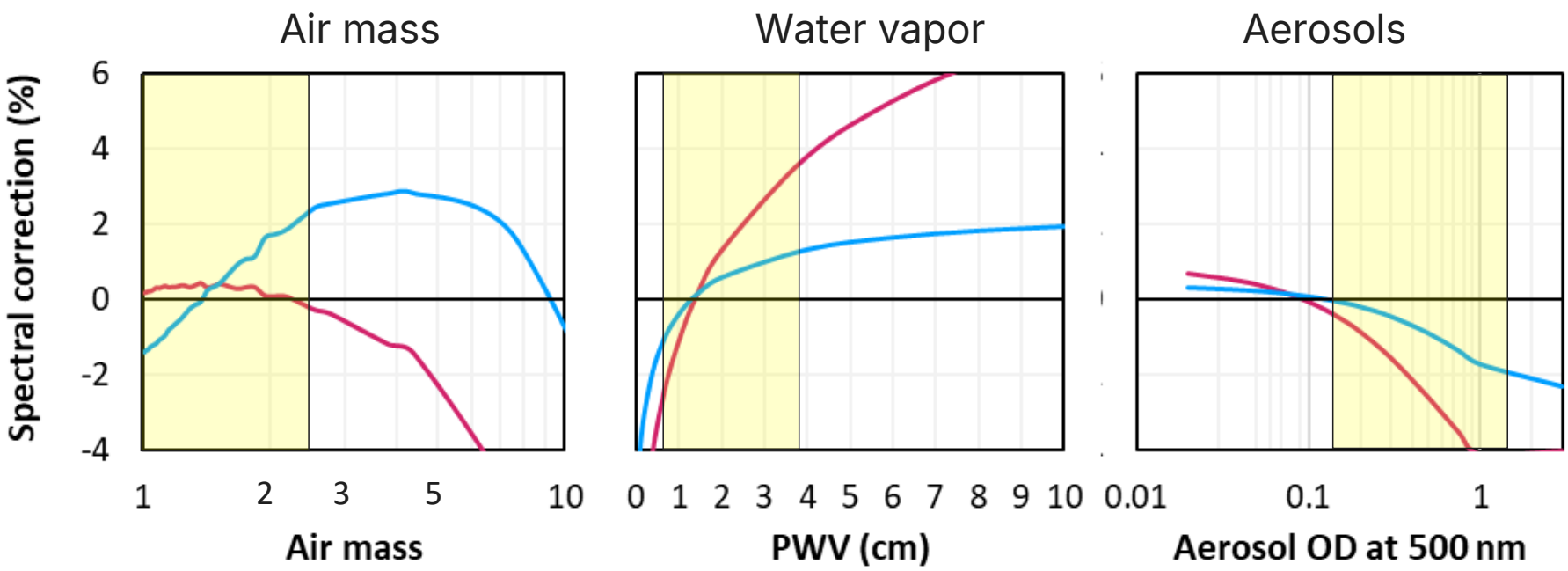


Calculations for clear skies:

- SMARTS 2.95
- Atmospheric values equal to AM1.5g defaults except swept value.
- QE of CdTe and C-Si in tutorial
- IAM = 1, no ground reflection
- Monofacial
- SAT, no BT, max tilt 60°
- Latitude ~40°
- Includes diffuse shading from neighbouring row

Spectral impact

CdTe
Silicon



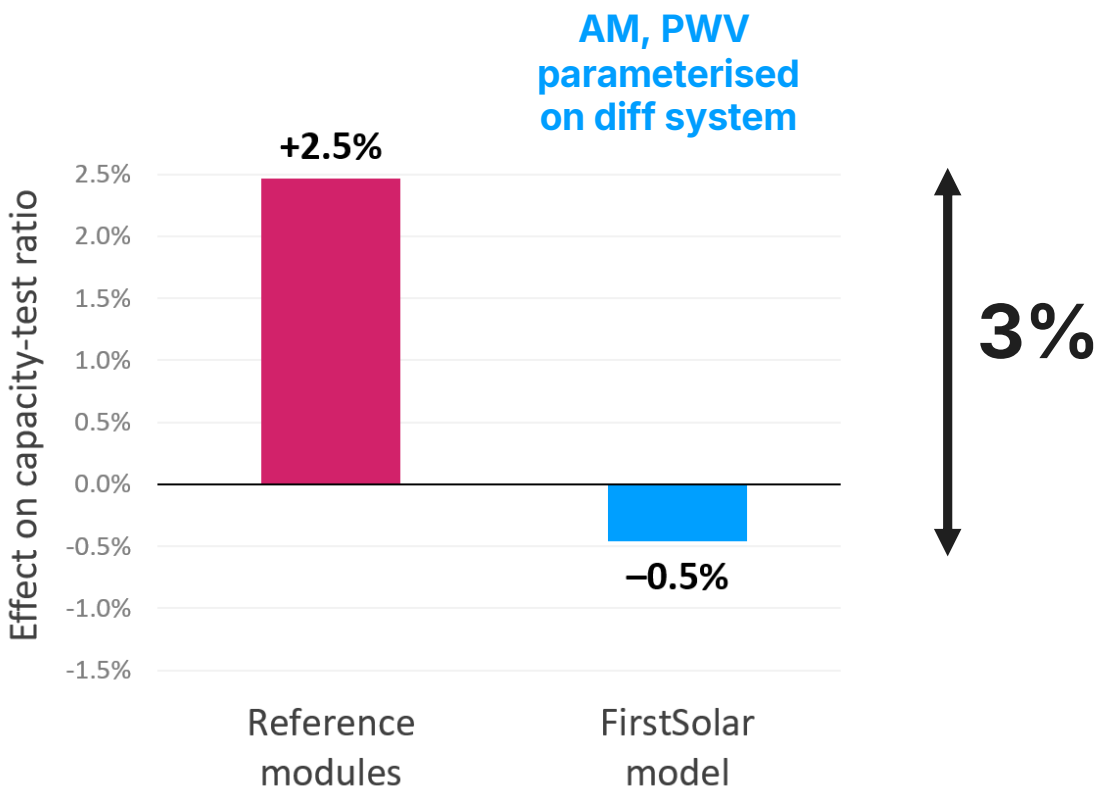
Calculations for clear skies:

- SMARTS 2.95
- Atmospheric values equal to AM1.5g defaults except swept value.
- QE of CdTe and C-Si in appendix
- IAM = 1, no ground reflection
- Monofacial
- SAT, no BT, max tilt 60°
- Latitude 38°
- Diffuse shading from neighbouring row

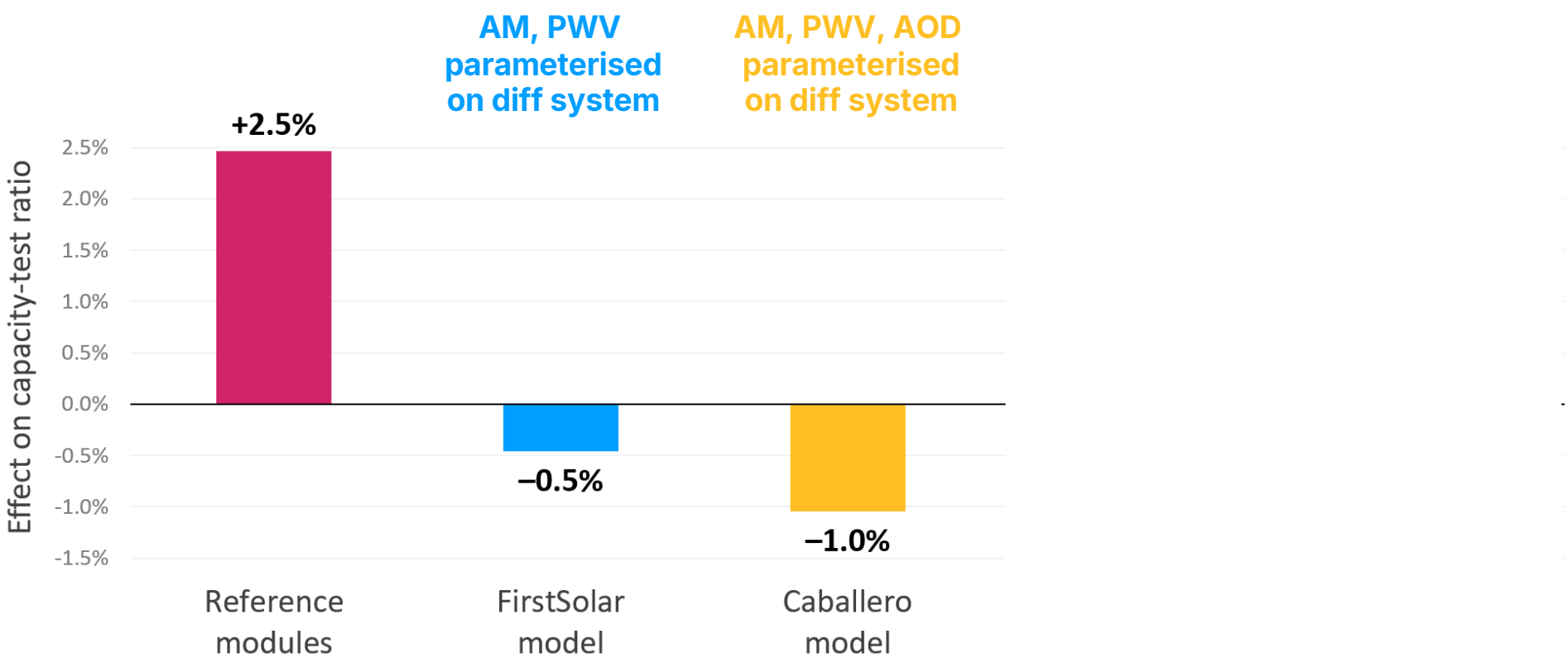
PART FOUR

Results

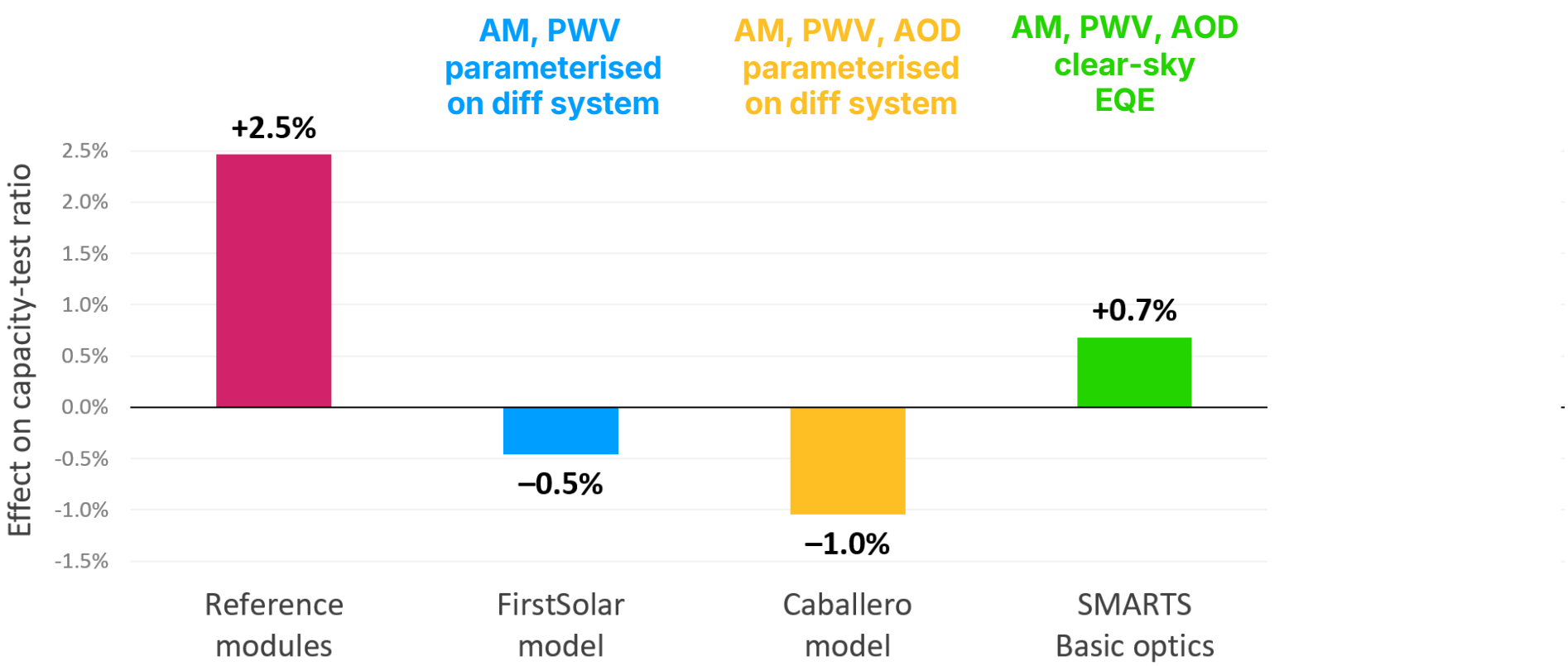
Impact on capacity test — ASTM



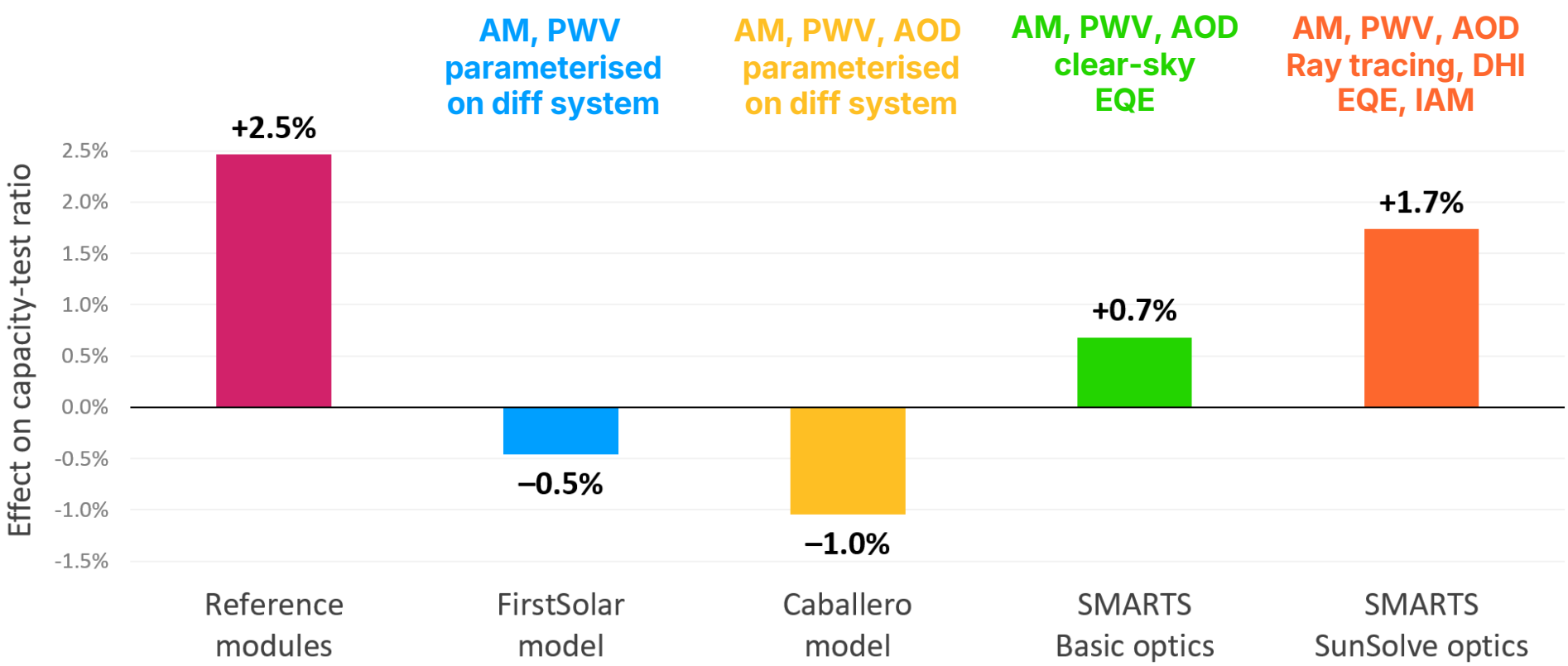
Impact on capacity test — ASTM



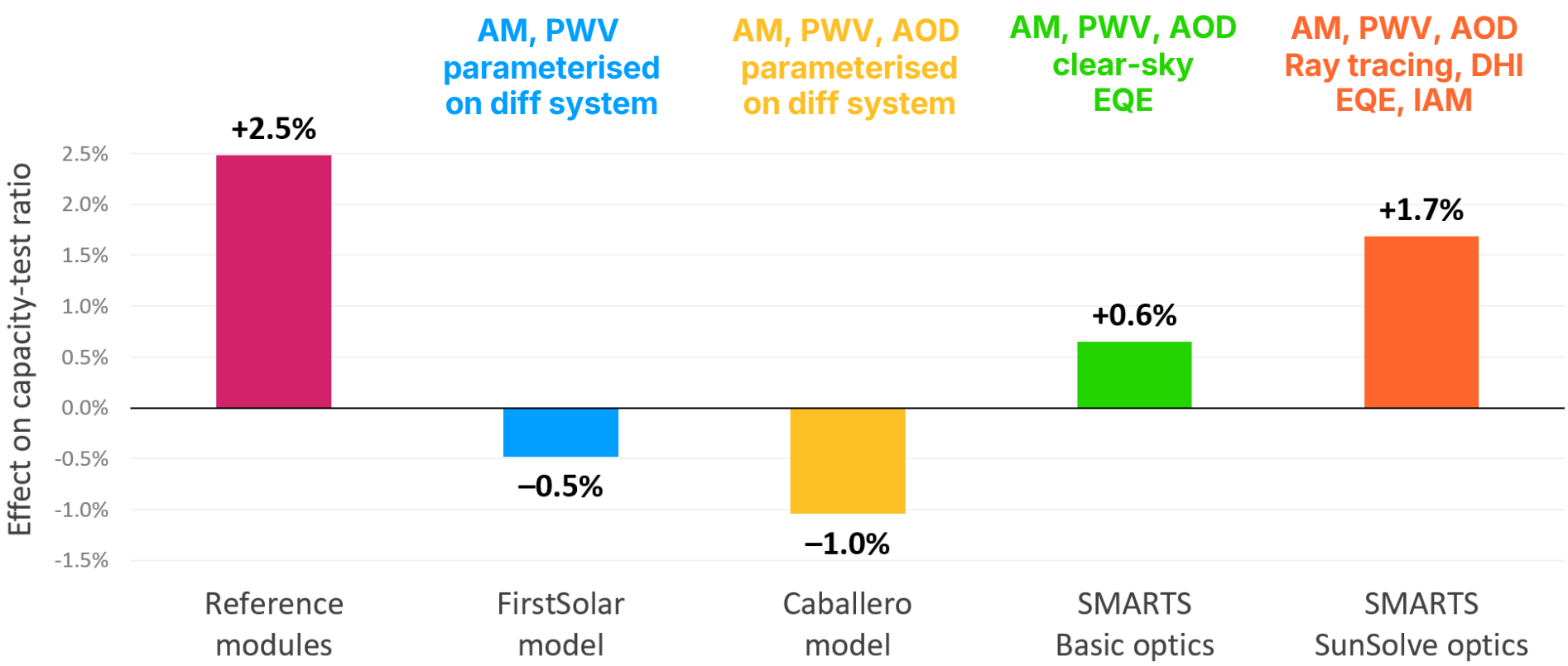
Impact on capacity test — ASTM



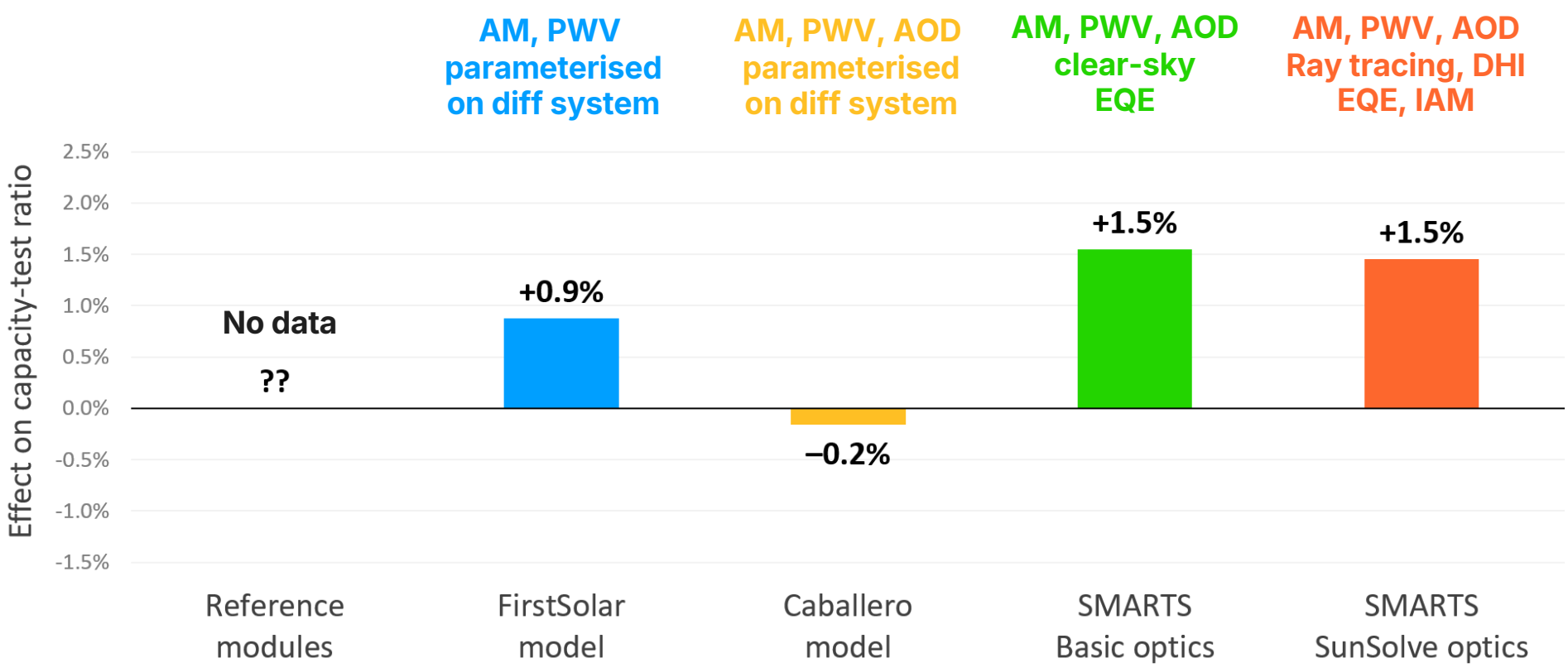
Impact on capacity test — ASTM



Impact on capacity test — MCTC



Impact on capacity test — ASTM — Si



Conclusion

- Modelling errors > 1% are of great concern to capacity tests.
- Spectral effects can easily introduce errors of > 1%.
- Case study on monofacial CdTe system:
  - Different approaches to spectral correction → vary over 3%.
  - FS model reduced capacity test ratio (neglected aerosols; diff config).
  - SunSolve, which applies more sophisticated spectral and optical models, gave trends closest to the reference module.

→ Tutorial on spectral correction — Thu 4:30 pm.