Checking the new IEC 61853.1-4 with high quality 3rd party data to benchmark its practical relevance in energy yield prediction

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PVSC-46 Chicago USA 20th Jun 2019

Checking IEC 61853 equations and methods vs. GI's OTF measured data and modelling

for standards tests, designers, modellers and measurements

IEC 61853- ***Photovoltaic module performance testing and energy rating***

-1 Ed 1.0 2011 :	Irradiance and temperature performance matrix
-2 Ed 1.0 2016 :	Spectral responsivity, incidence angle
-3 Ed 1.0 2018 :	Energy rating
-4 Ed 1.0 2018 :	Climatic profiles

Gantner Instruments' Outdoor Test Facility (OTF)

- High quality Meteorological and Electrical PV measurements
- Works with all module technologies and climates
- Good fitting and modelling with GI/SRCL's Loss factors model (2011) and Mechanistic performance model (2017) (LFM/MPM)

Comparing IEC 61853 vs. GI's OTF testing

	IEC 61853 energy rating *"Indoor and/or steady"*	OTF e.g. GI energy yield *"Real weather data"*
	Characterise modules → *Estimate expected energy rating at given climate by module type and technology*	Measure Energy yield → *Derive module characteristics to optimise and validate performance at test site*
# Samples	1-3 Specific modules for testing	Actual modules measured (may only be flash tested before use?)
Characterisation vs. input e.g. Gi, Tmod, AOI, SR …	Independent e.g. P vs Gi(Tmod=25) then P vs Tmod(Gi=1) etc.	Correlated weather params e.g. High insolation ~ Hot, Low AOI, Blue rich …
Steady/transient conditions?	Steady state (thermal equilibrium)	Includes transient weather (but can wait for steady)
Direct or Global irradiance?	All or mostly Direct	Direct+Diffuse+Reflected
Module status	New, clean, uniform	Aged, Soiling? Shading? Snow?

Gantner Instruments' OTF Tempe AZ measurements

For further information email: otf@gantner-instruments.com or authors.

Irradiance : Plane of array Gi from pyranometers, cSi and KG3 reference cells
Horizontal Gh, Dh; Beam normal Bn, spectral 350-1050nm …

Met data: WindSpeed and direction, Relative Humidity, Tambient…

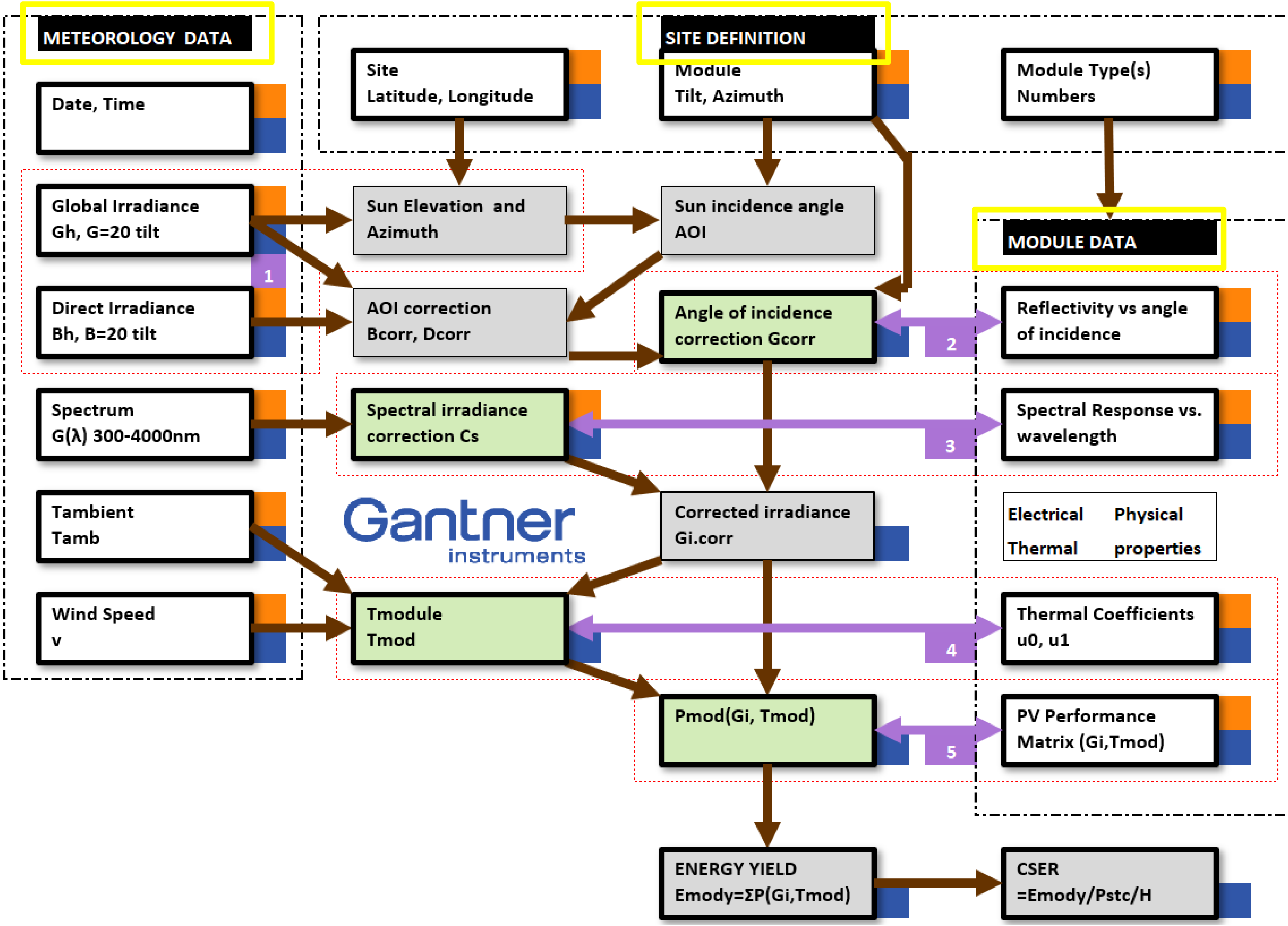
PV : Fixed and 2D track; IV curve every minute, Tmodule
Derive parameters using Loss Factors and Mechanistic Performance Models

Continuous measurements in Arizona since 2010; Other sites available around the world

Flow chart for DC Energy Yield and Energy Rating

IEC 61853

GI OTF

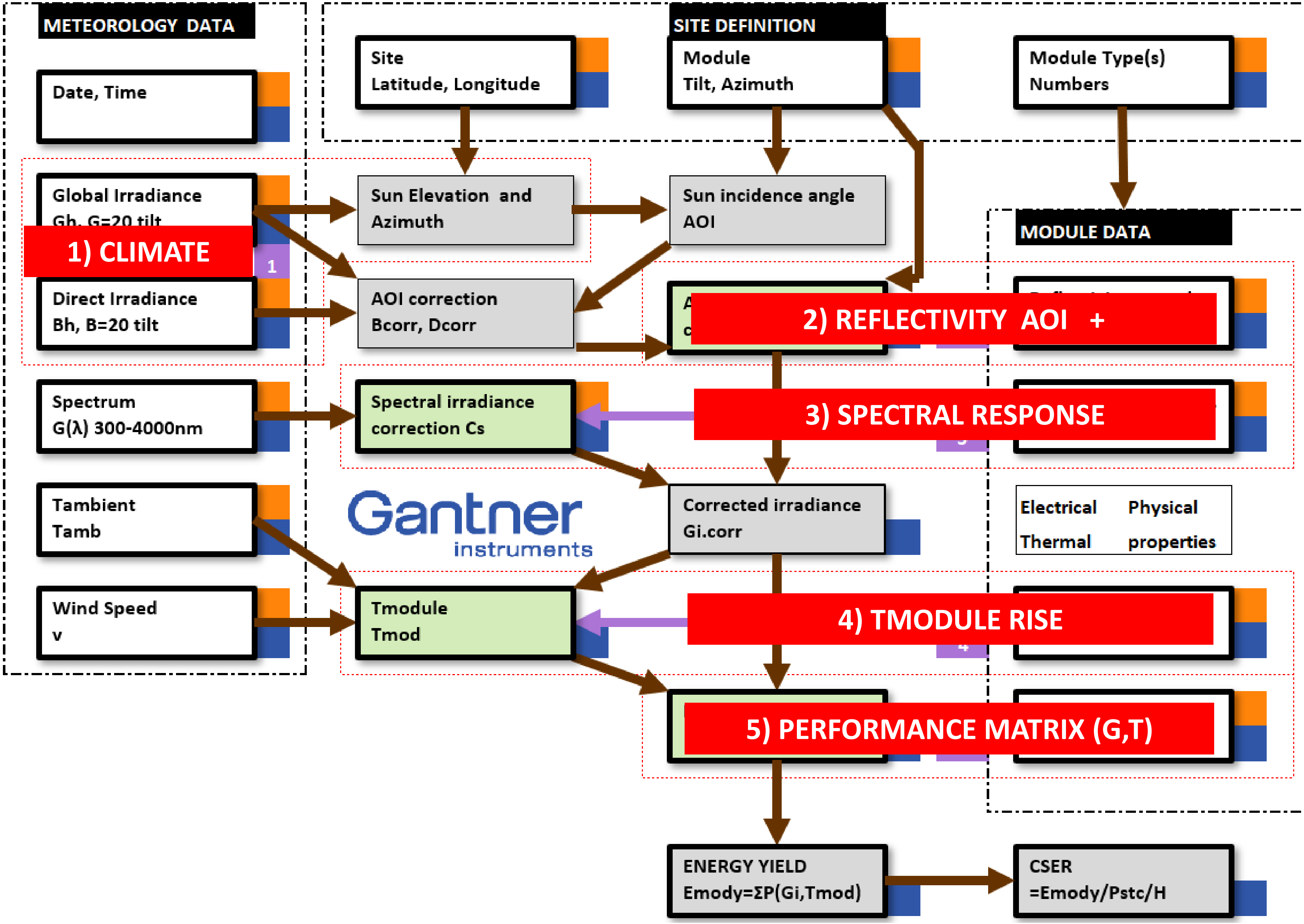


Flow chart for DC Energy Yield and Energy Rating

IEC 61853

GI OTF

calcs that can be checked

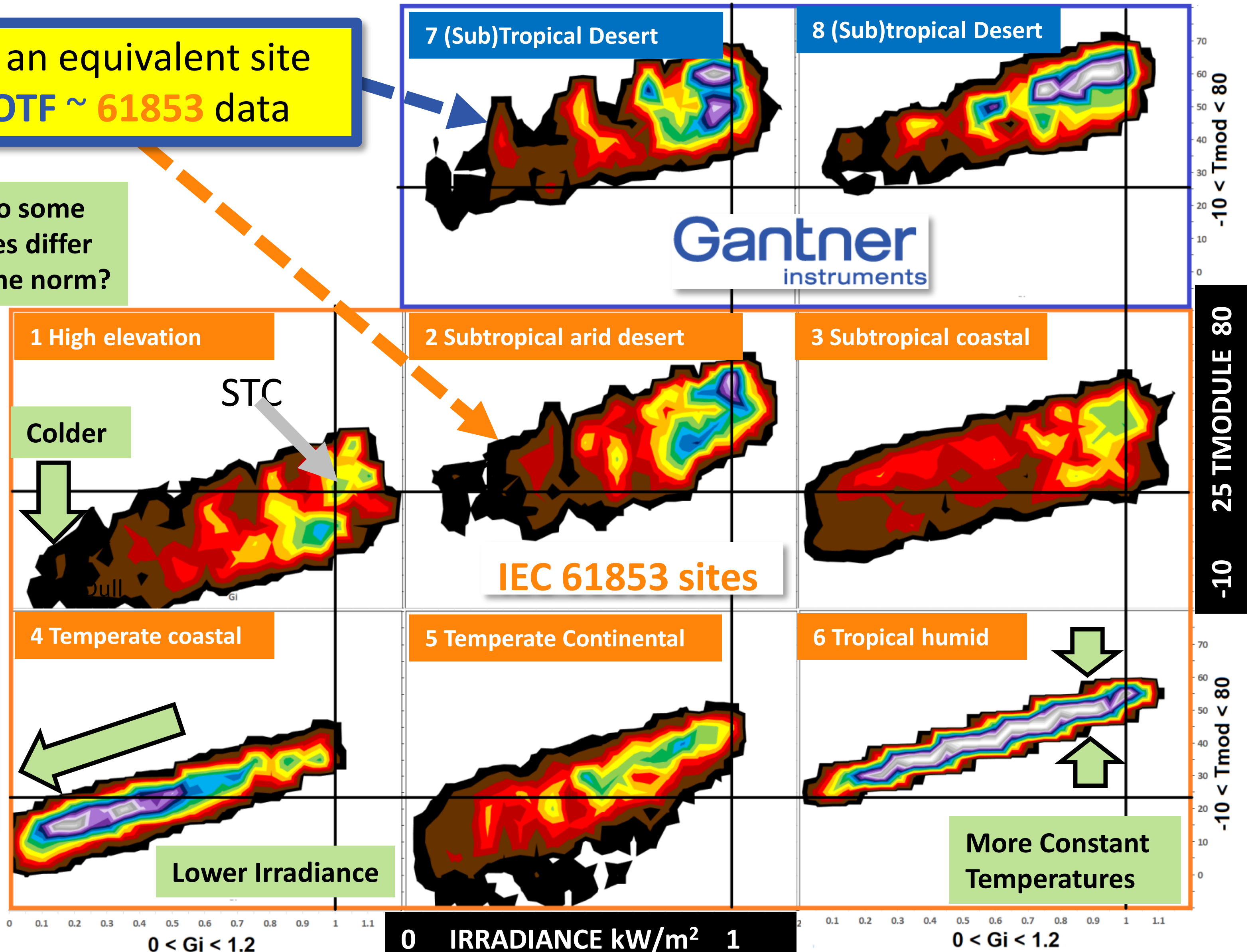


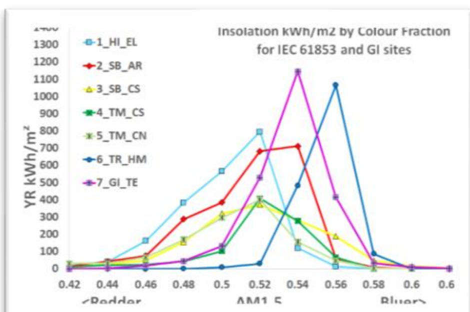
CLIMATE : %Insolation (colour) vs. Irradiance, Tamb→Tmodule (calc)

- 0.0%-0.2%
- 0.2%-0.4%
- 0.4%-0.6%
- 0.6%-0.8%
- 0.8%-1.0%
- 1.0%-1.2%
- 1.2%-1.4%
- 1.4%-1.6%
- 1.6%-1.8%
- 1.8%-2.0%

For an equivalent site GI OTF ~ 61853 data

How do some climates differ from the norm?



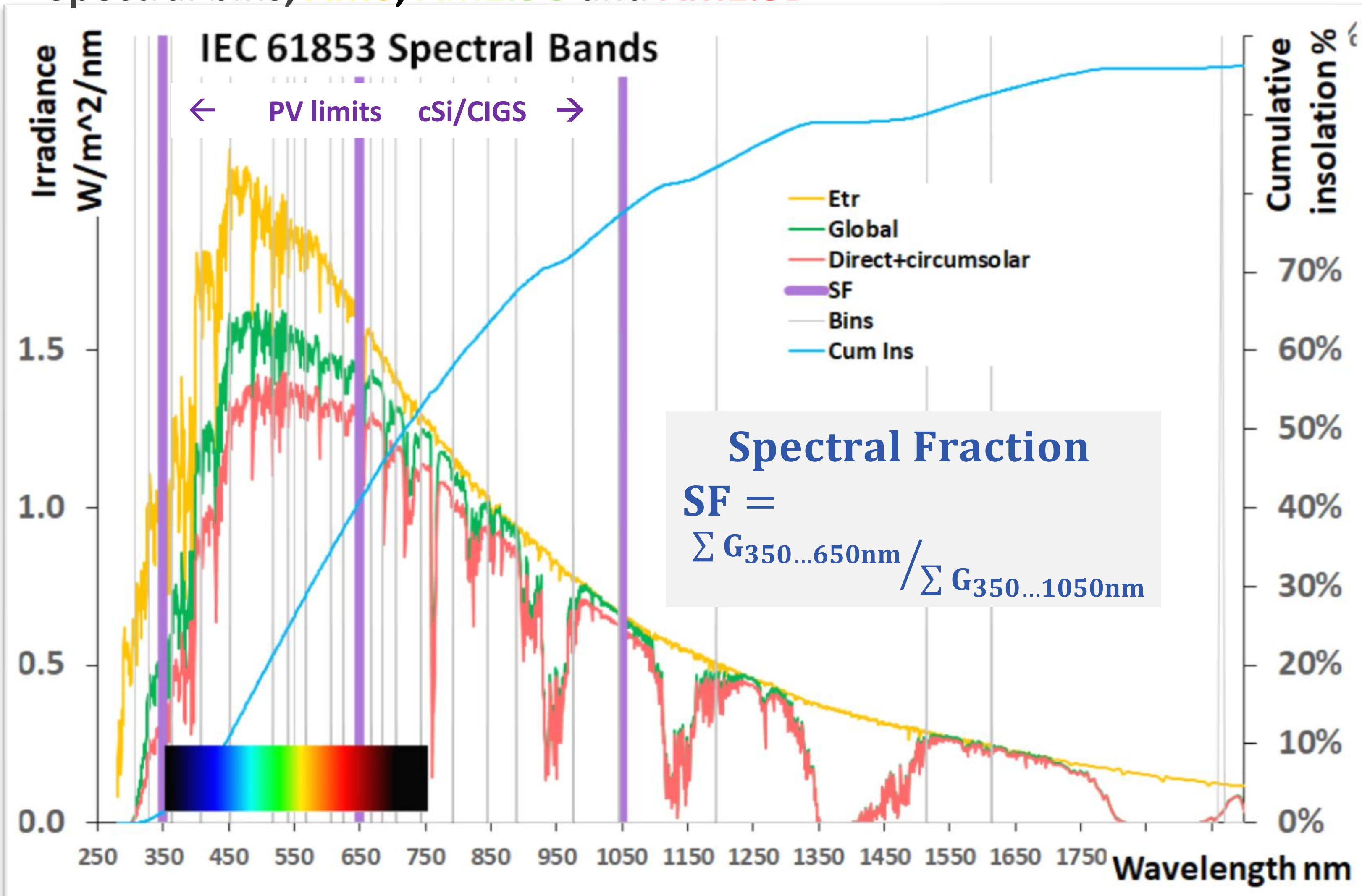


Fractional Insolation at spectral distributions also compared, not enough time to discuss

SPECTRAL : ASTM G-173-03

61853 Satellite spectra 306-4660nm of varying bin widths. GI 350-1050nm but can extend on new OTFs

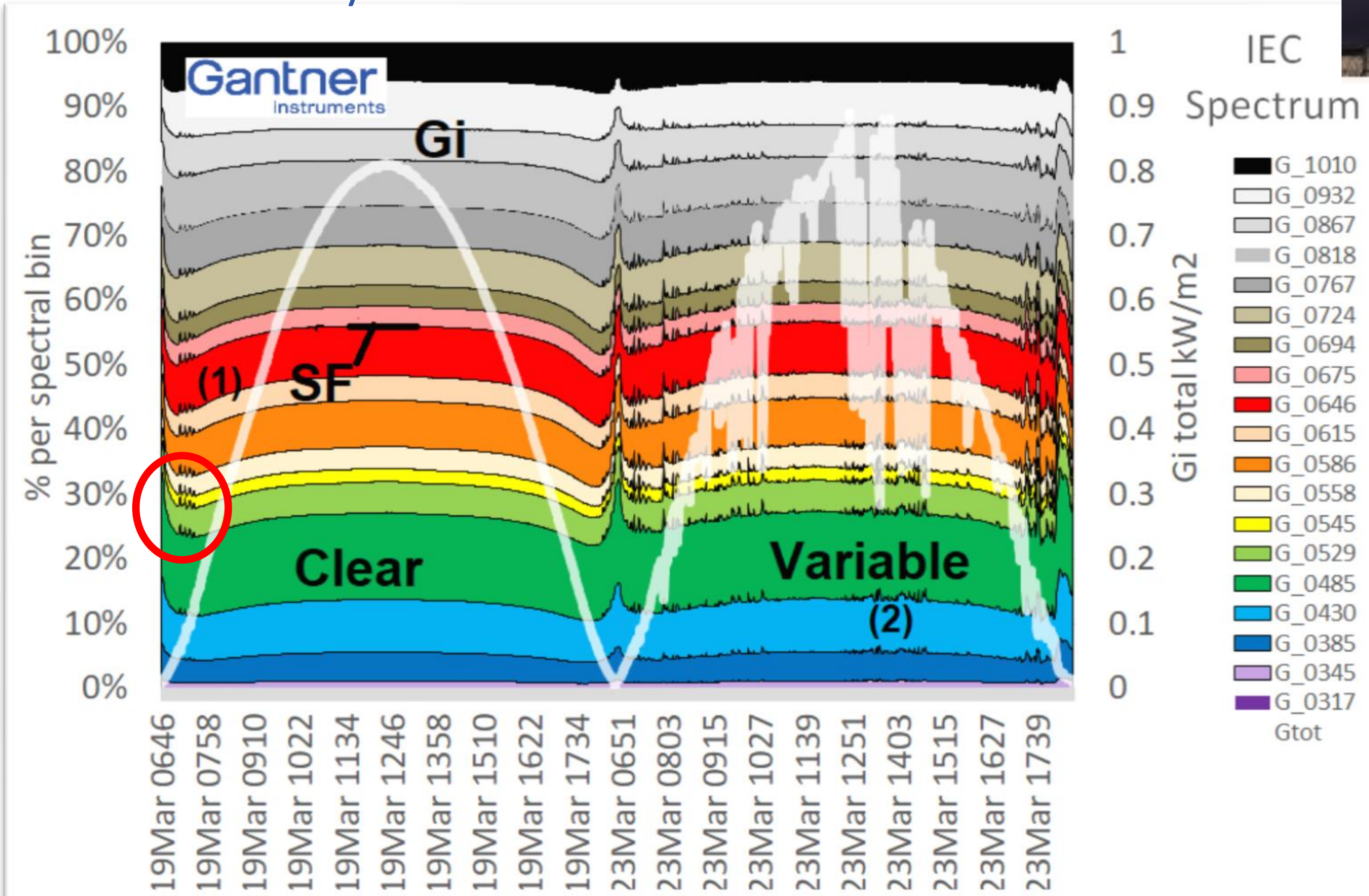
Spectral bins, AM0, AM1.5G and AM1.5D



SPECTRAL :

GI OTF 350-1050 every 3.3nm → 61853 bins

- Clear day and Variable days
- Most PV only sensitive ~350 to <=1050nm



Spots morning shading from transmission lines

GI OTF measurements are accurate and can be used 350-1050nm

REFLECTIVITY AOI and SPECTRAL :

- **IEC 61853** irradiance correction methods rely on knowing the spectral response and the reflectivity/AOI of a test device before using this for energy rating calculations.

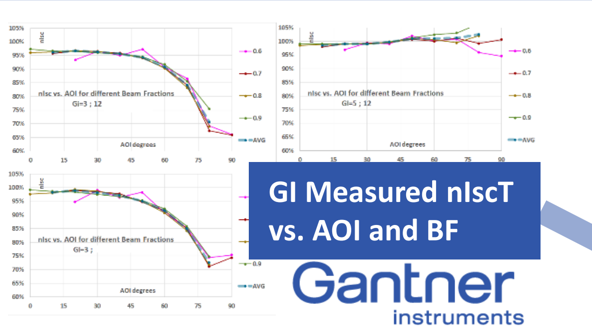
- Many test modules won't have had spectral response or reflectivity/AOI measurements

- Find AOI and spectral correction factors from standard **GI OTF** data 350-1050nm vs. pyranometer ~280-2800nm
  nI_{SC_T} vs. AOI and Spectral fraction

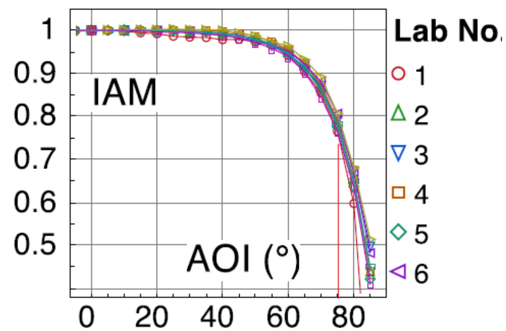
- (Not yet analysed 1D or 2D tracker data – for a future paper)

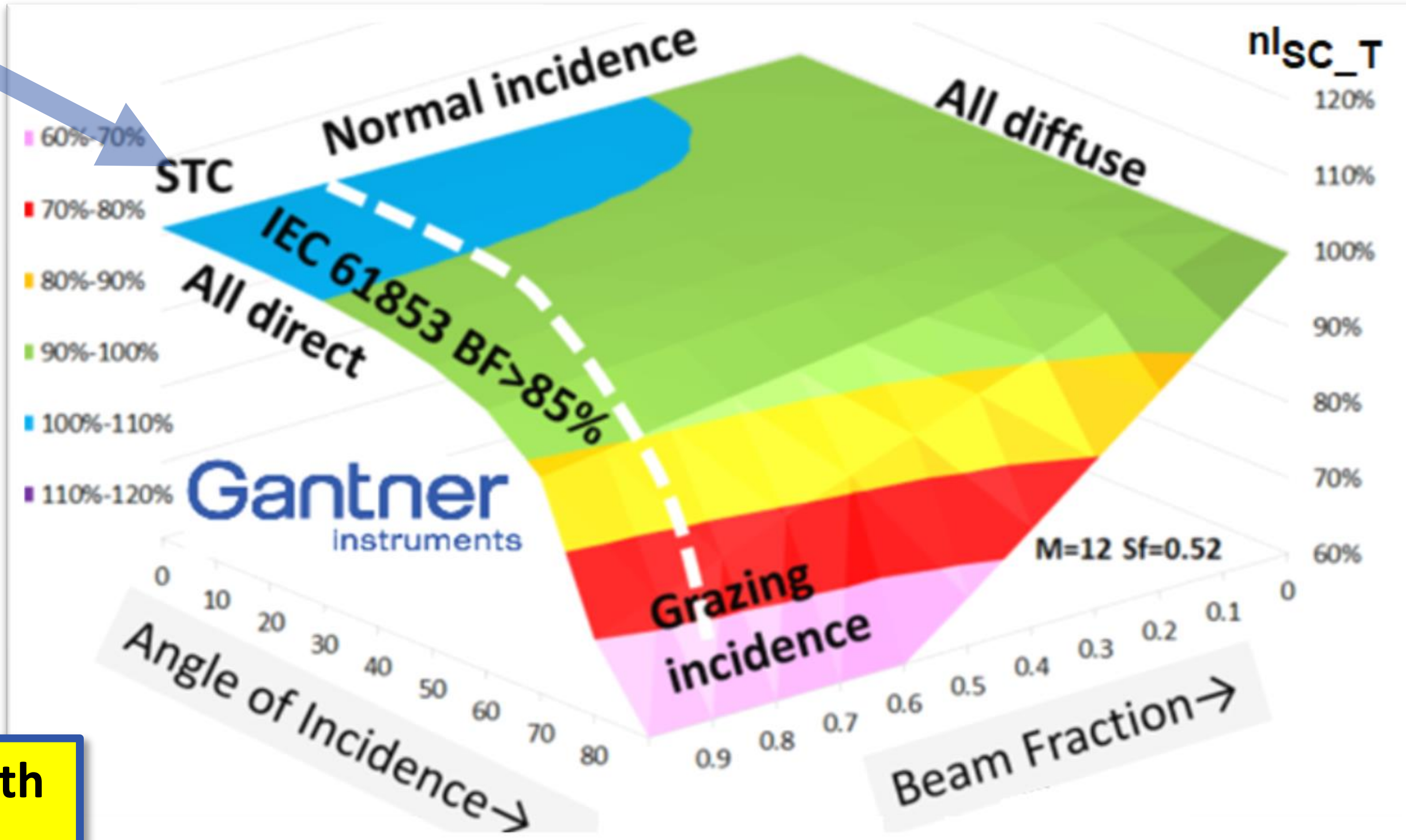
REFLECTIVITY vs. AOI (high beam fraction)

$$nI_{SC\_T} = \frac{meas.I_{SC}}{ref.I_{SC} * G_I} \times (1 - \alpha_{ISC} \times (T_{MOD} - 25)) \qquad (1)$$



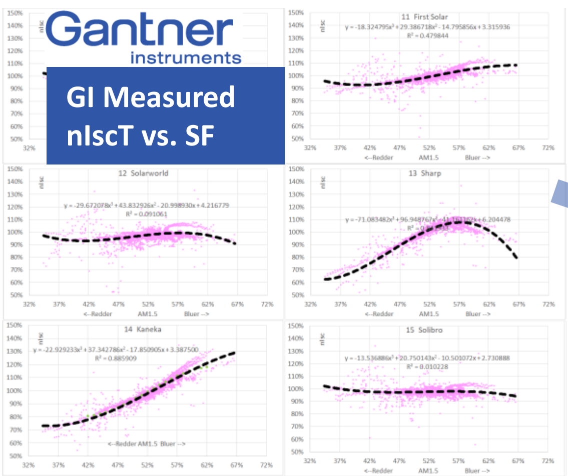
Compare with
Riedel et al 12th PVPMC 2019
"Incident Angle Modifier
(IAM) Round Robin Updates"





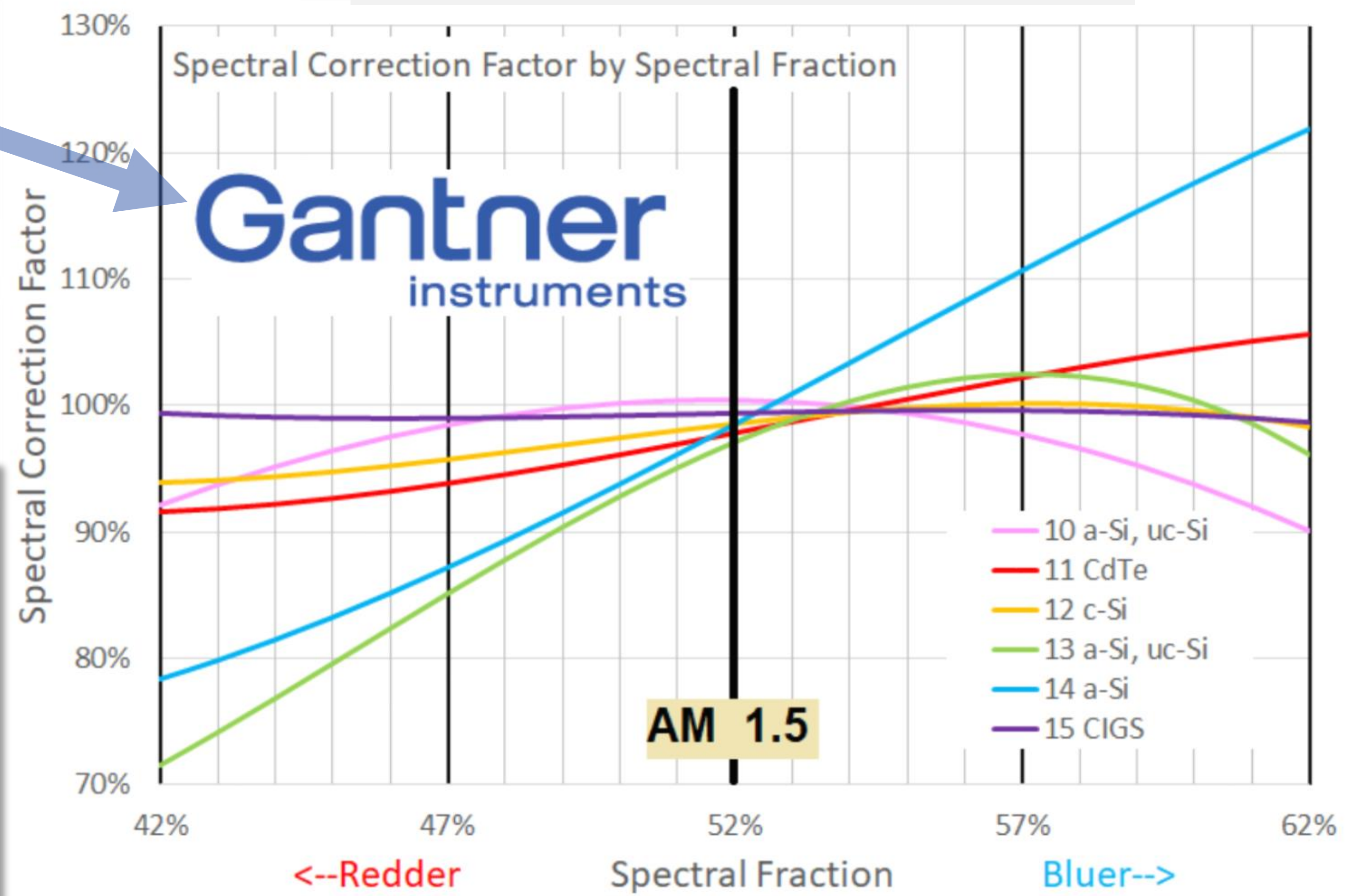
GI OTF agrees well with round robin

Spectral correction factor SCF vs. Spectral fraction SF



Spectral Fraction

$$SF = \sum G_{350...650nm} / \sum G_{350...1050nm}$$



simple fits SCF vs. SF

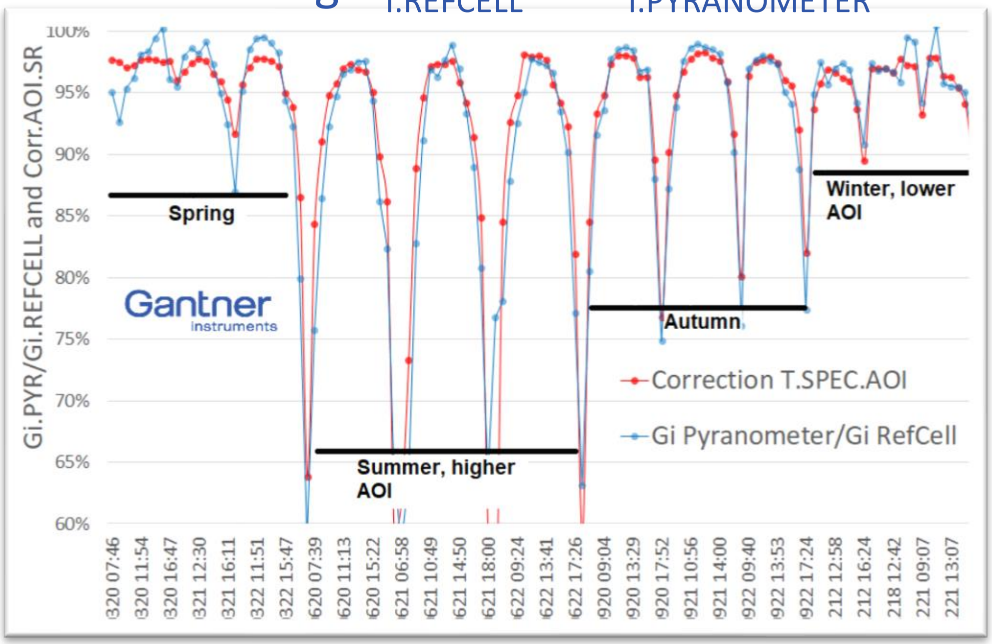
1 Junction = Linear fit
a-Si, CdTe, c-Si
2 Junction = Concave down
a-Si:uc-Si a-Si:uc-Si

Spectral correction factor vs. SF and AOI/Beam fraction

for a 1 junction device (2+ Junction equation to come later)

- **SF** = Spectral fraction
- **BF** = Beam fraction
- **AOI** = Angle of incidence
- **cXXX** = Fitted Mechanistic coefficients

Correcting $G_{I.REFCELL} \rightarrow G_{I.PYRANOMETER}$



$Corr_{T.SPEC.AOI}$ and Gi.pyr/Gi.refcell vs. time

- $nISC_{T,SPEC,AOI} = nI_{SC\_T} *$
  $(1 + cSF_M * (SF - cSF)) *$
  $((1 - BF * cAOI * (1/Cos(AOI)-1)) + cBF * BF)$

nIsc

Spectral

AOI (ASHRAE)
or other …

MODULE TEMPERATURE RISE vs. Irradiance and Windspeed

IEC 61853 formula

- $$T_{RISE} = T_{MOD} - T_{AMB} = \frac{G_{CORR.AOI}}{U_0 + U_1.W_S} \quad (2)$$

Coefficient	Example value from Gi meas	Unit
U_0	0.0322	$C/(kW/m^2)$
U_1	0.0018	$C/(kW/ms^{-1})$

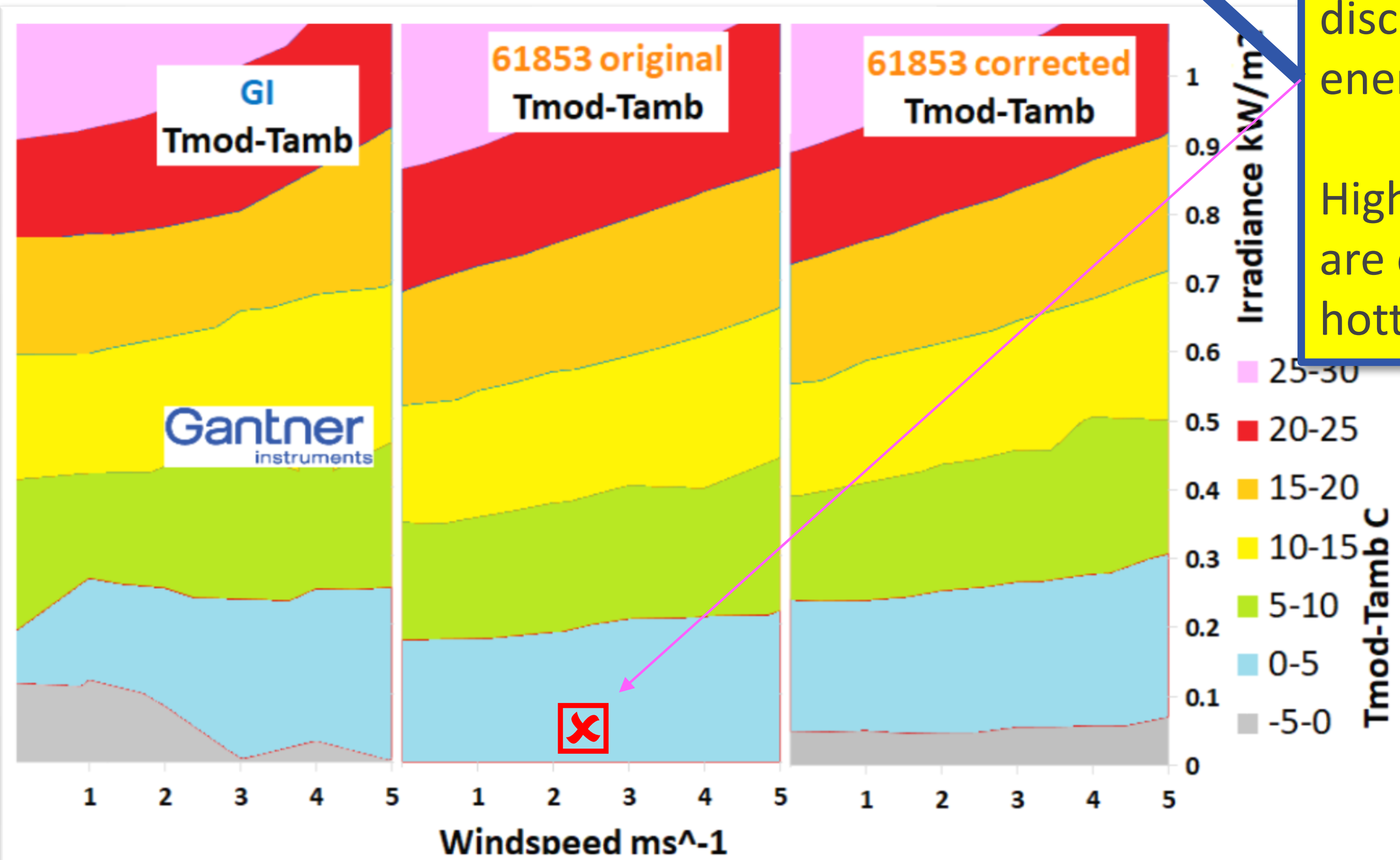
MODULE TEMPERATURE RISE vs. Irradiance and Windspeed

Best fit to GI measurements in AZ (1 measurement/h for 4000 pts, 1 year)

$$T_{RISE} = T_{MOD} - T_{AMB} = \frac{G_{CORR.AOI}}{U_0 + U_1.W_S} + U_2$$

New temperature coefficient **U_2 ~-2.0C** fixes low irradiance T_{RISE} discrepancy but won't alter energy yield much.

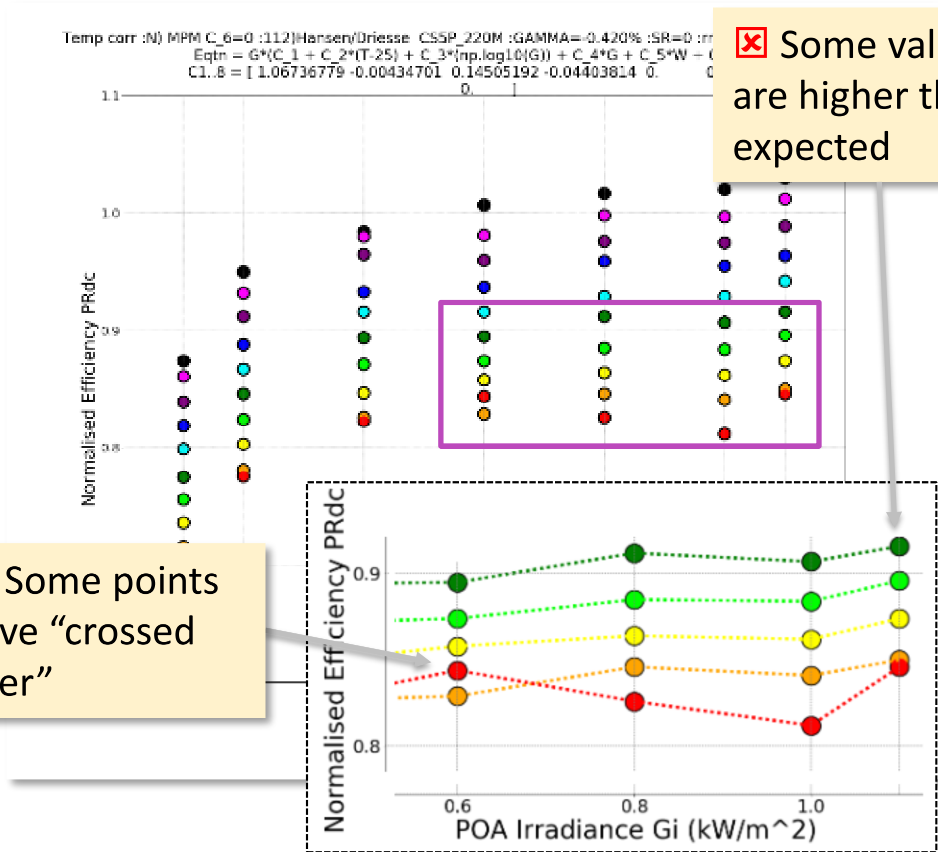
Higher efficiency modules are cooler, and glass-glass hotter



Matrix Performance Measurements "Raw data"

PR_{DC}↑ vs. Irradiance kW/m^2→ and Tmodule C (colours), not 23 points

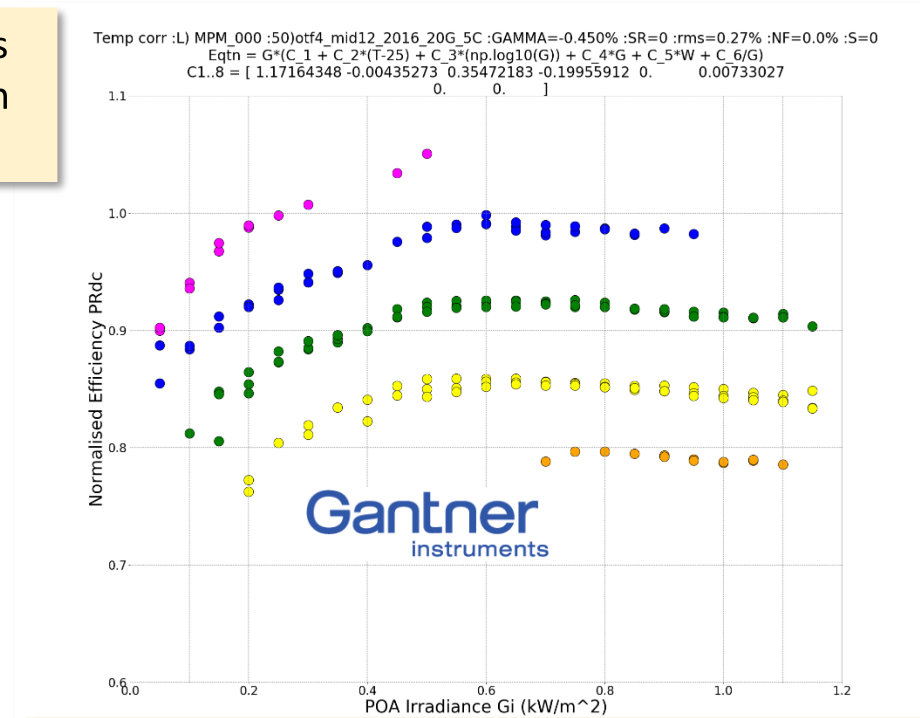
61853-1 : c-Si indoor
Old, <u>poor quality, temp sensor problems</u> (zoomed in)



☒ Some values are higher than expected

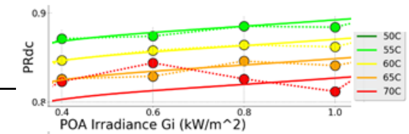
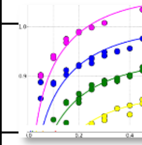
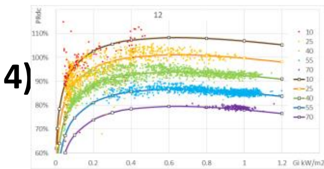
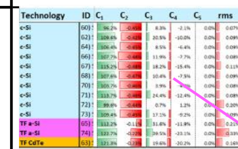
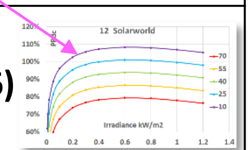
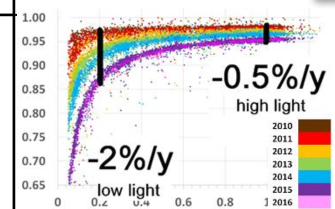
☒ Some points have "crossed over"

GI OTF :
4000 points 1 year, 1/h, Avg PR_{DC} per Irradiance bin, corrected to T



Real weather = "Non rectangular" (G,T) distribution. Dull+Cold↖ to Bright+hot↘

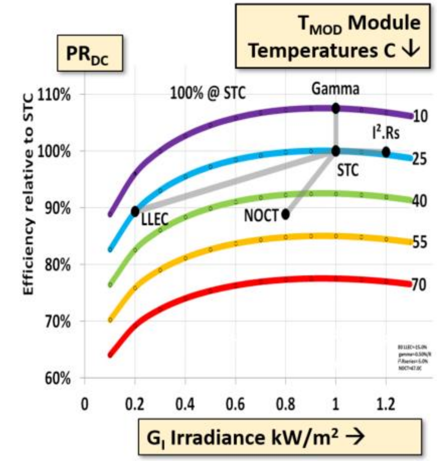
Matrix Performance Measurements fitting

Effect	Linear Interpolation 61853	Mechanistic model GI MPM	Examples
1) Points with wrong values?	☒ Nearby interpolated and extrapolated values badly affected	☑ "Sanity check" easily finds them Erase, correct or remeasure!	1,2 
2) Noisy Data?	☒ No noise reduction	☑ Robust fit, noise averages out	
3) Missing Points?	☒ Affects extrapolations	☑ Can still can get good fits	 3)
4) Reduced or outdoor data (points<>23)	☒ Can't easily interpolate too few or too many points	☑ Can fit any number of points, weighted if needed	4) 
5) Useful Coefficients to analyse ?	☒ No coefficients from analysis	☑ Yes, useful normalised orthogonal coefficients for a database	 5)
6) Data storage	☒ Every point needs to be stored	☑ Only 5-6 coefficients stored +rmse	6) 
7) Module variability or degradation Binning	☒ Hard to compare datasets without coefficients	☑ Normalised coefficients can determine rates and causes ☑ Pmax binning → C1?	 7)

MPM "Mechanistic Performance Model"

meaningful, orthogonal, robust, normalised

(see 7th PVPMC, 44th PVSC, 33rd EUPVSEC, PVSEC-27 for more details www.steveransome.com)

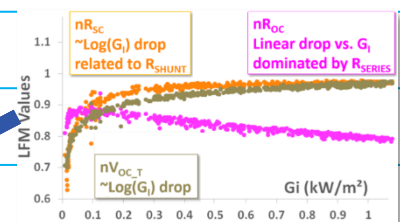


Where G_I in kW/m², $dT_{MOD} = T_{MOD}$-25C

$$PR_{DC} = C_1 + C_2 \times dT_{MOD} + C_3 \times Log_{10}(G_I) + C_4 \times G_I + C_5 \times WS + {*}C_6/G_I$$

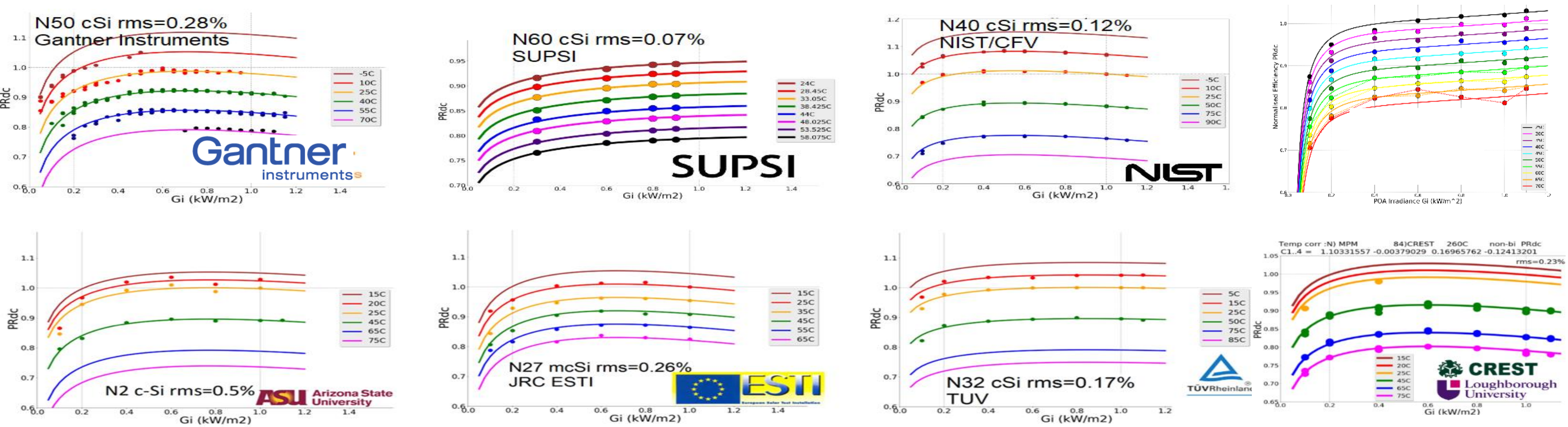
	Dependency	Comment	Normalised Unit
C_1	Tolerance	Actual/Nominal value ~100%	%
C_2	Tmodule-25C	Temperature coefficient ~ -0.25 to -0.50%/K	%/K
C_3	$Log_{10}(G_I)$	Low light fall due to V_{OC} (and R_{SHUNT}?)	%
C_4	G_I	High light fall – R_{OC} due to R_{SERIES}	%
C_5	Wind speed	Small correction	%/(ms^{-1})
C_6	$1/G_I$	*Only some modules (depends on how their R_{SHUNT} behaves)	%/(kW/m²)

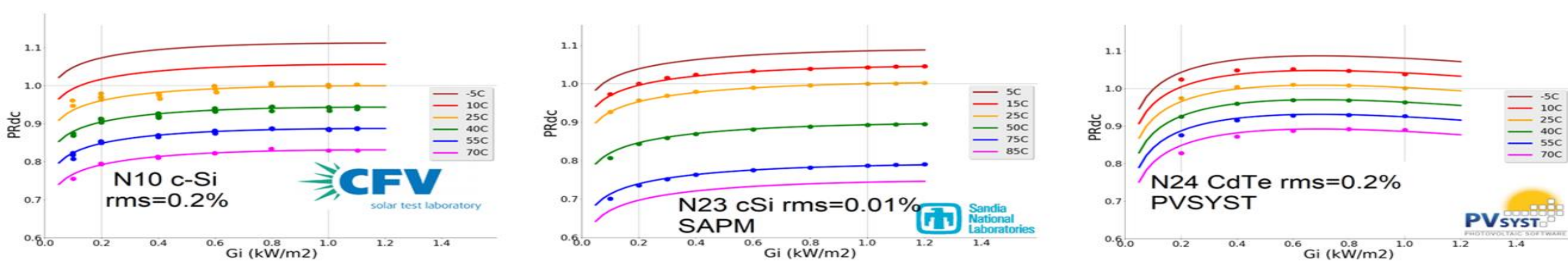
Loss factors Model (2011)



MPM validation on different PV technologies from

SUPSI, NIST, ASU, ESTI, TÜV Rheinland, CFV, SANDIA, CREST, SAPM, PVSYST, Gantner instruments and many more …



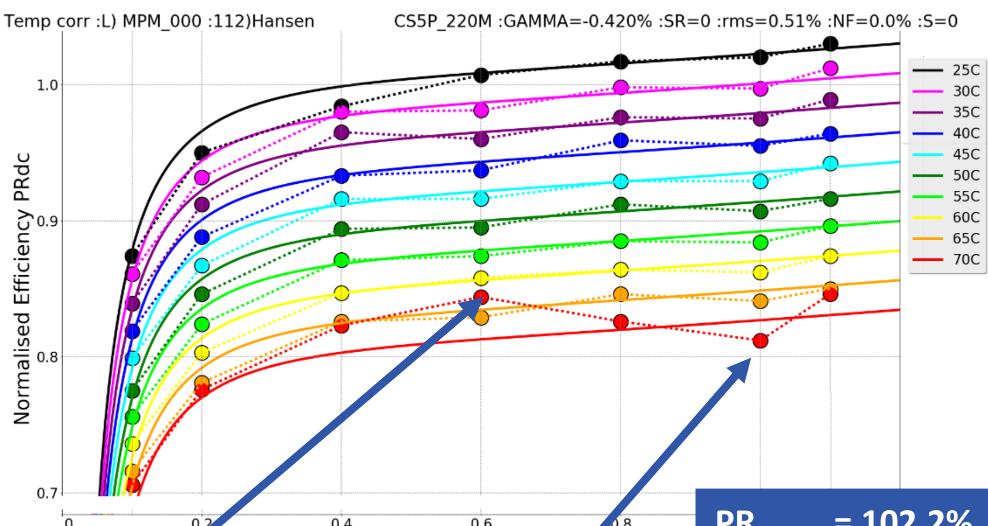


Please share your data!

MATRIX Performance Measurements fitted with MPM

61853-1 : c-Si (Indoor)

Known bad measurements thermal sensors etc.



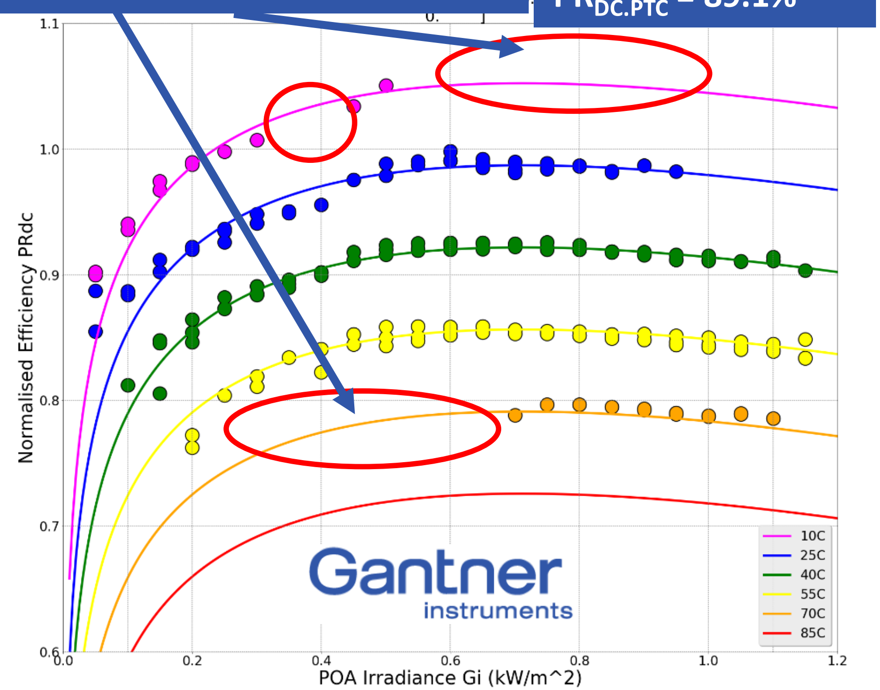
MPM RMSE good 0.55%
even with bad data points indoors

$PR_{DC.STC}$ = 102.2%
Gamma = -0.43%/K
$PR_{DC.LIC}$ = 96.6%
$PR_{DC.PTC}$ = 92.0%

GI OTF Avg PR_{DC} corrected Tmod

MPM RMSE very good 0.28%
even with "missing data" outdoors

$PR_{DC.STC}$ = 97.9%
Gamma = -0.43%/K
$PR_{DC.LIC}$ = 92.1%
$PR_{DC.PTC}$ = 89.1%

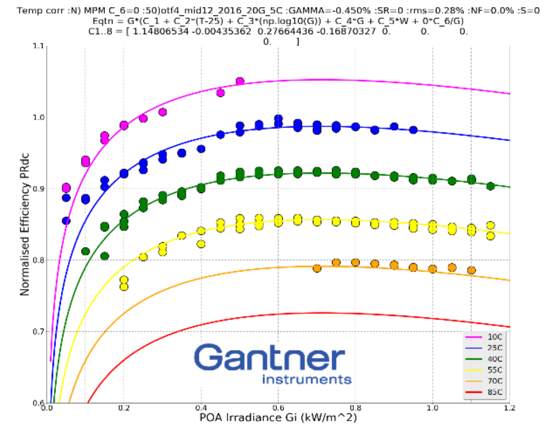


Current status on energy yield/energy rating predictions

- Simulation programs have been predicting energy yields vs. technology, climate, temperature coefficients, spectral effects etc. well enough for manufacturers, investors etc. for many years
- Binning of module P_{MAX} (±2.5%?), manufacturing variability and irradiance sensor tolerance may limit the accuracy of any energy rating validation
- A “Cookie cutter approach” is often used to guarantee performance by making similar new sites to old ones that are known to work
- How useful is this IEC 61853 method?
- Will it duplicate existing predictions/measurements or differ?

Summary

- **Hourly climate** – **GI OTF good results**
- **Reflectivity vs. AOI** – **GI OTF good results**
- **Spectral response**
  - if **61853 SR** not available, simpler **GI OTF method** presented (can extend nm range)
- **T_{MOD} (vs. T_{AMB}, Gi and WS)**
  - **GI OTF** suggests a small correction at low irradiance
- **Matrix performance fitting (vs. Gi, T_{MOD})**
  - **61853 - bilinear fit**
    - ☒ Poor choice, particularly for noisy or missing data
  - **GI OTF - MPM**
    - ☑ meaningful, orthogonal, robust, normalised
    - ☑ validated on data from many test institutes
    - ☑ technology and site independent



$$PR_{DC} = C_1 + C_2 \times dT_{MOD} + C_3 \times Log_{10}(G_I) + C_4 \times G_I + C_5 \times WS + {}^{*}C_6/G_I$$

- **Check 61853 energy rating vs. existing working methods (e.g. simulation programs)**

Thank you for your attention !

More data analysis will be presented in PVSEC Marseille

Spare

Other advantages available from using the MPM

$$PR_{DC} = C_1 + C_2 \times dT_{MOD} + C_3 \times \mathrm{Log}_{10}(G_I) + C_4 \times G_I + C_5 \times WS + {}^{*}C_6/G_I$$

- **Tolerance** – Gives expected performance at STC, LIC etc.
- **Degradation studies** – quantify changes with coefficients over time
- **Temperature coefficients** – C_2 = gamma
- **Loss characterisation** and identification e.g. V_{OC} loss is due to C_3, R_{SERIES} loss is low C_4
- **Fault finding** – coefficients that glitch or aren't expected values
- **Database comparison** – normalised values should be similar by technologies but differ c-Si vs. thin film (e.g. TempCoeff=C_2, low light=C_3 , high light=C_4)
- **It's a proven, optimised and validated model**