Analysing array performance

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International Workshop on PV System Monitoring and Performance Assessment

31st Oct 2008 : Nice, France

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- 19 years with BP Solar
- >10 years studying indoor and outdoor performance of modules
  c-Si, LGBC, 1-3J a-Si, CdTe, CIS etc
- Left BP Solar in Jan 2008
- Now an independent PV Consultant working with clients to improve their product, modelling and understanding of indoor and outdoor tests

Measuring kWh/kWp – view of ISET, Germany

Every few minutes measure :

In plane irradiance (specify sensor type)

module and ambient temperatures, wind speed,

V_{MAX}, I_{MAX} (DC)

P_{MAX} (AC)

Calculate kWh/kWp = $\Sigma(P_{MAX})/P_{NOM}$

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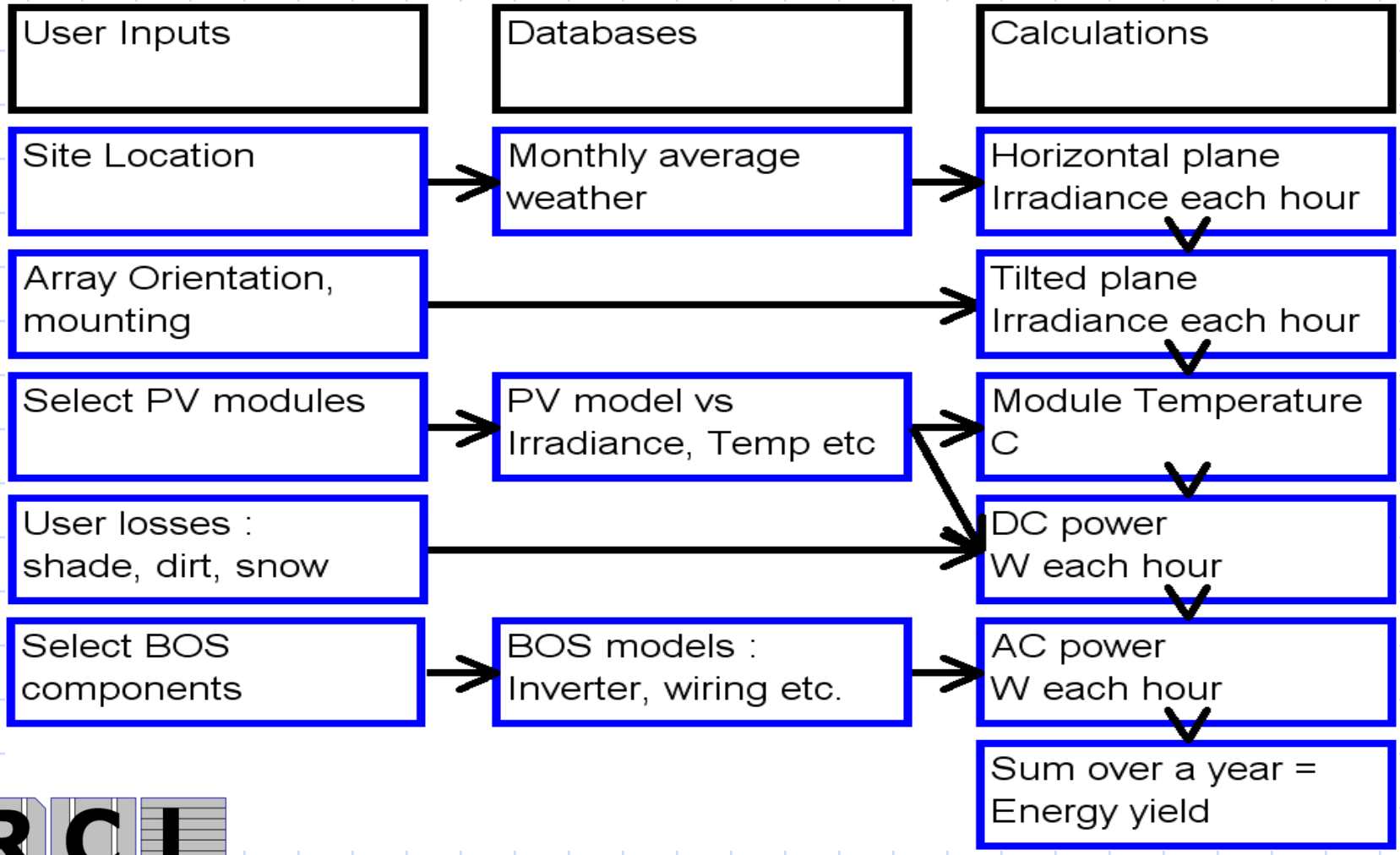
Simple Sizing program flow chart to model performance



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Some reasons found at other sites for wrong kWh/kWp module performance.

Possible Reason	Origin of Fault
Overrated Pmax	Module manufacturer calibration
Degradation	Module instability with time
Poor low light level performance	Module technology or fault (e.g. low Rshunt)
Poor high temperature performance	Module technology or mounting (e.g. rooftiles)
Downtime	Measurement setup
Dry joints	Module or measurement
Nearby shading (trees etc.)	Measurement location (each module may differ)
Inverter sizing	System design
Poor voltage tracking	Voltage tracker or system design
High horizon shading	Location
Spikes in data	Measurement, error, needs checking
Non coplanar array and sensor	Orientation of sensor, must be close to array
Poor quality irradiance sensor	Sensor choice

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kWh/kWp uncertainties

		Different sites	Side by side
PR	Dirt, Downtime etc.	1%	0%
YR	Irradiance sensor Yearly Insolation	2% 4%	0% 0%
kWp/ Nom-inal	Ref. Module Calib. Module variability Degradation	2% 2.5% 1%/y	2% 2.5% 1%/y
	Uncertainty	~6%	~3%

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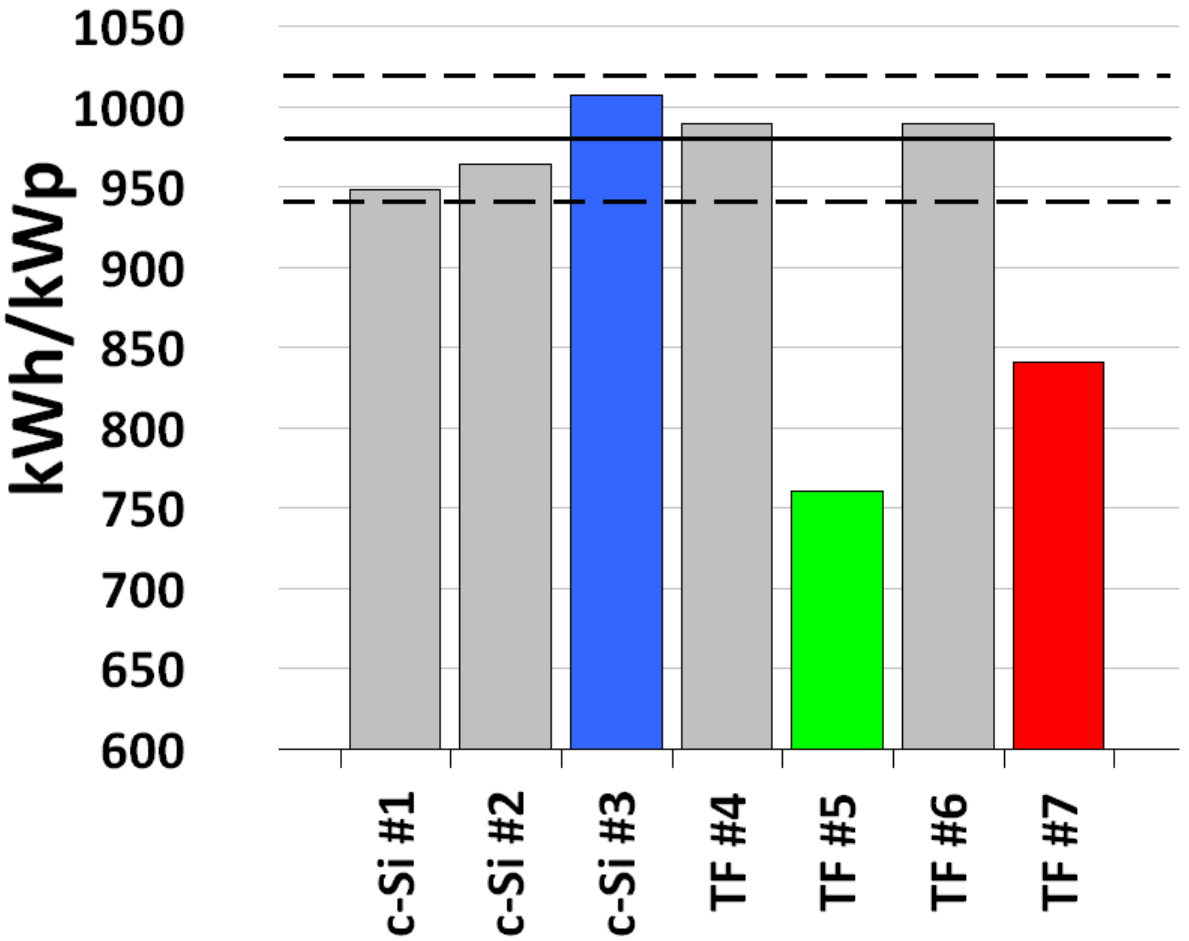
Measured kWh/kWp for 7 modules - 5 are within 4%, why are two lower ?



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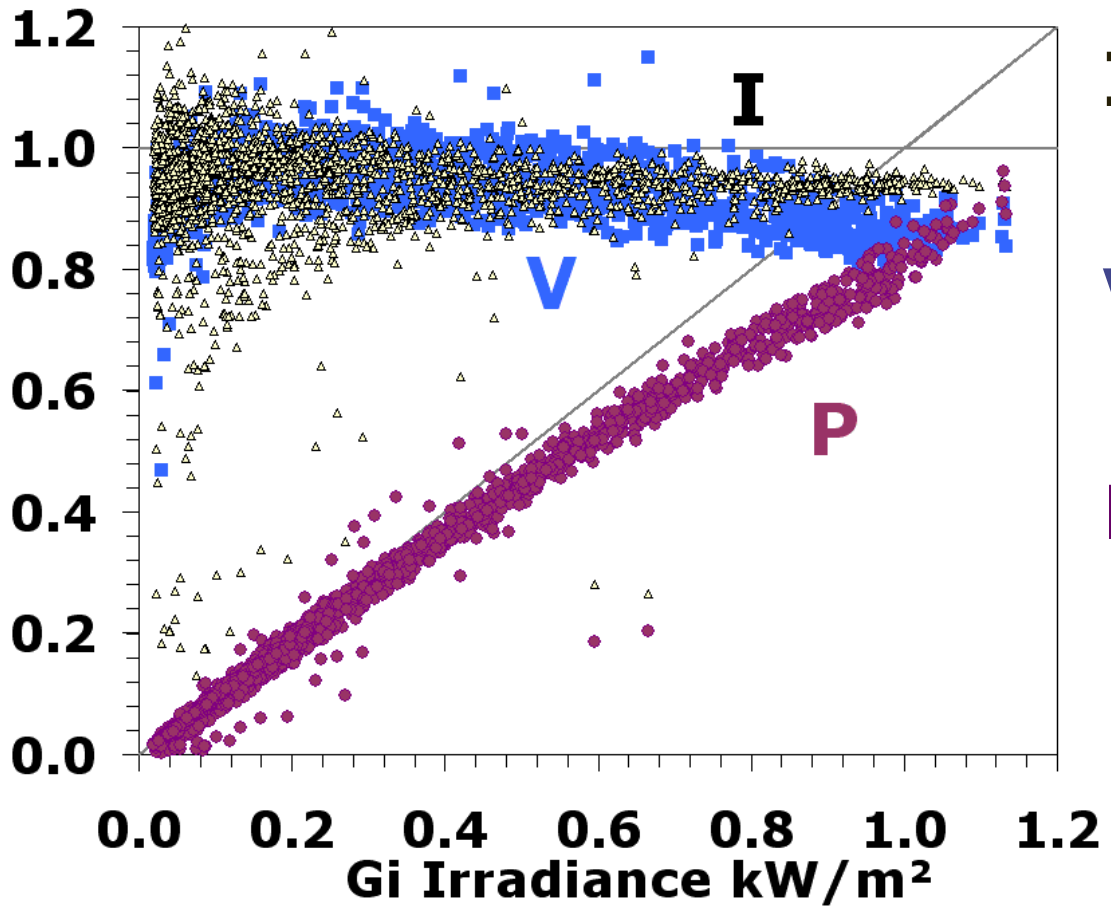
Normalised DC Performance Parameters vs Irradiance



I = Idc/Istc/Gi

V = Vdc/Vstc

P = Pdc/Pstc

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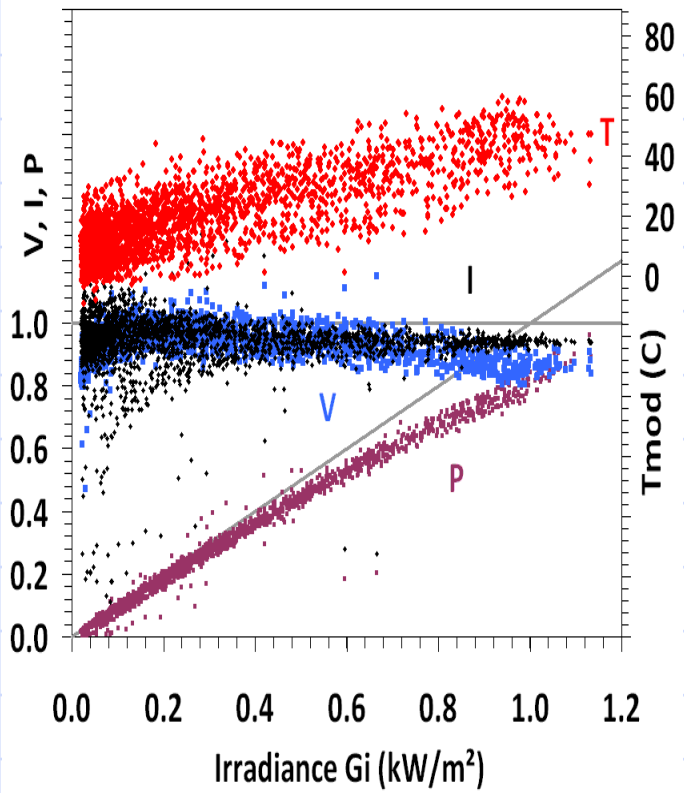
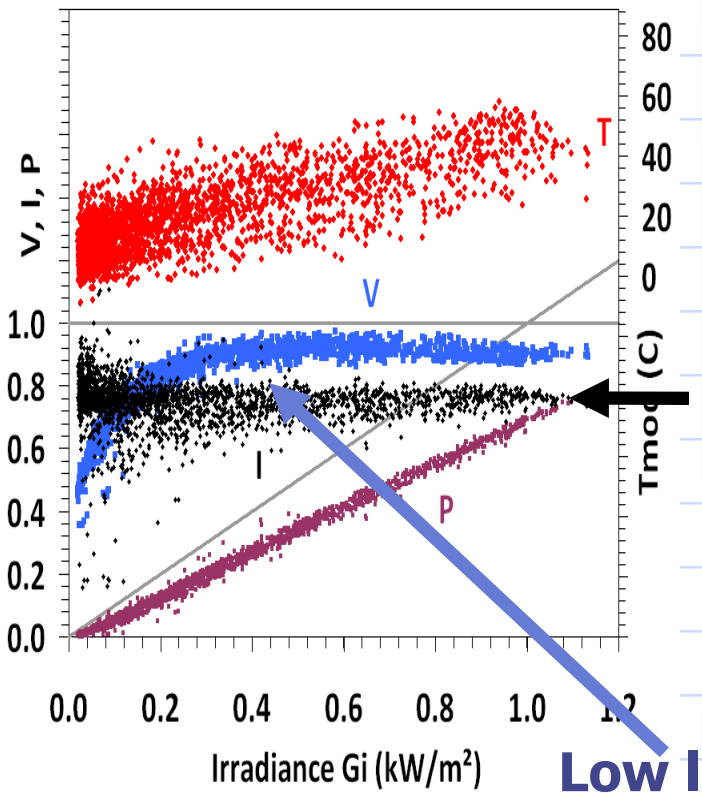
Module Temperature, Voltage, Current and Power vs Irradiance

Good #3



Poor #5



Lower Current

Low light Voltage Collapse

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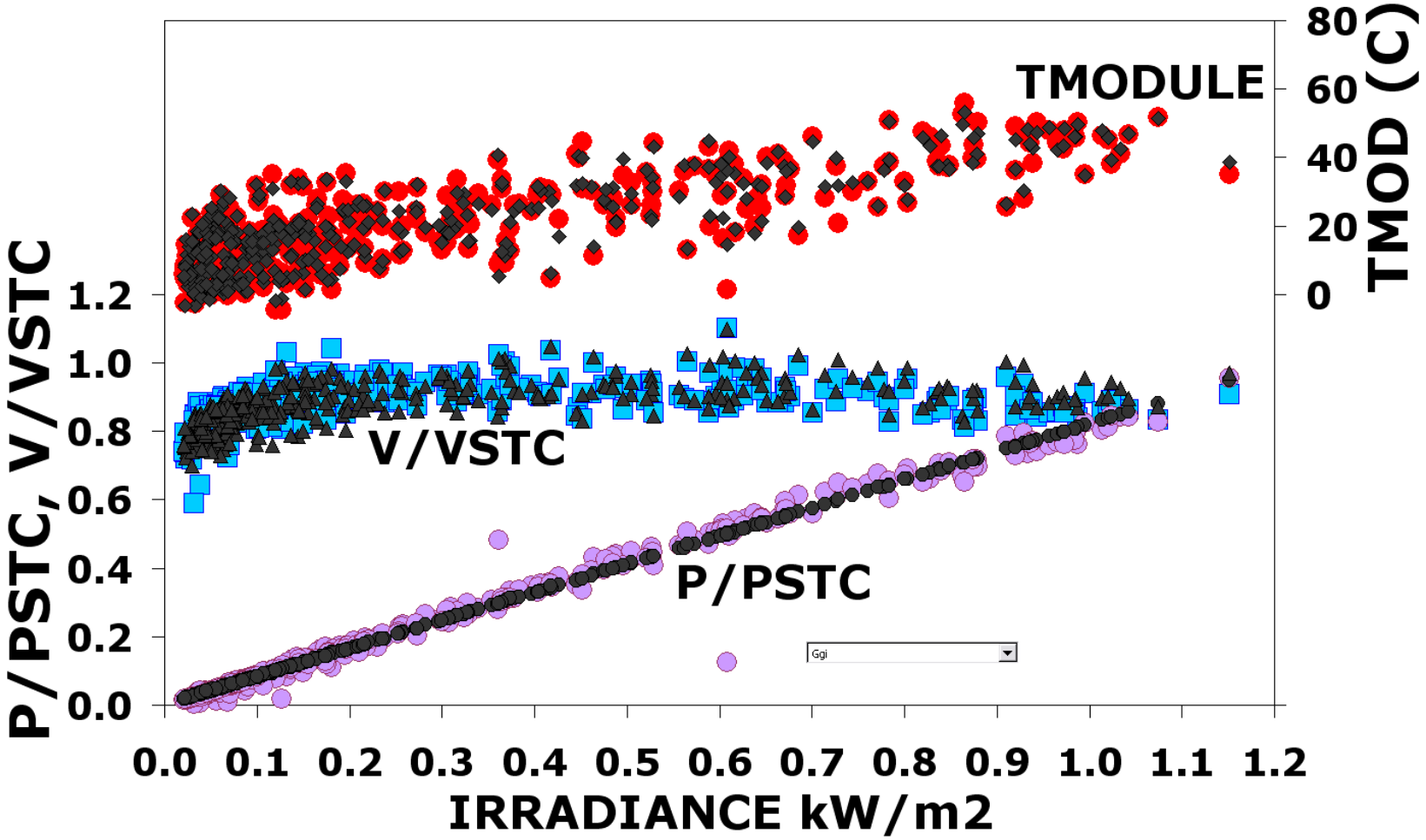
Empirical modelling – fitting Tmodule, Vmax and dc Yield



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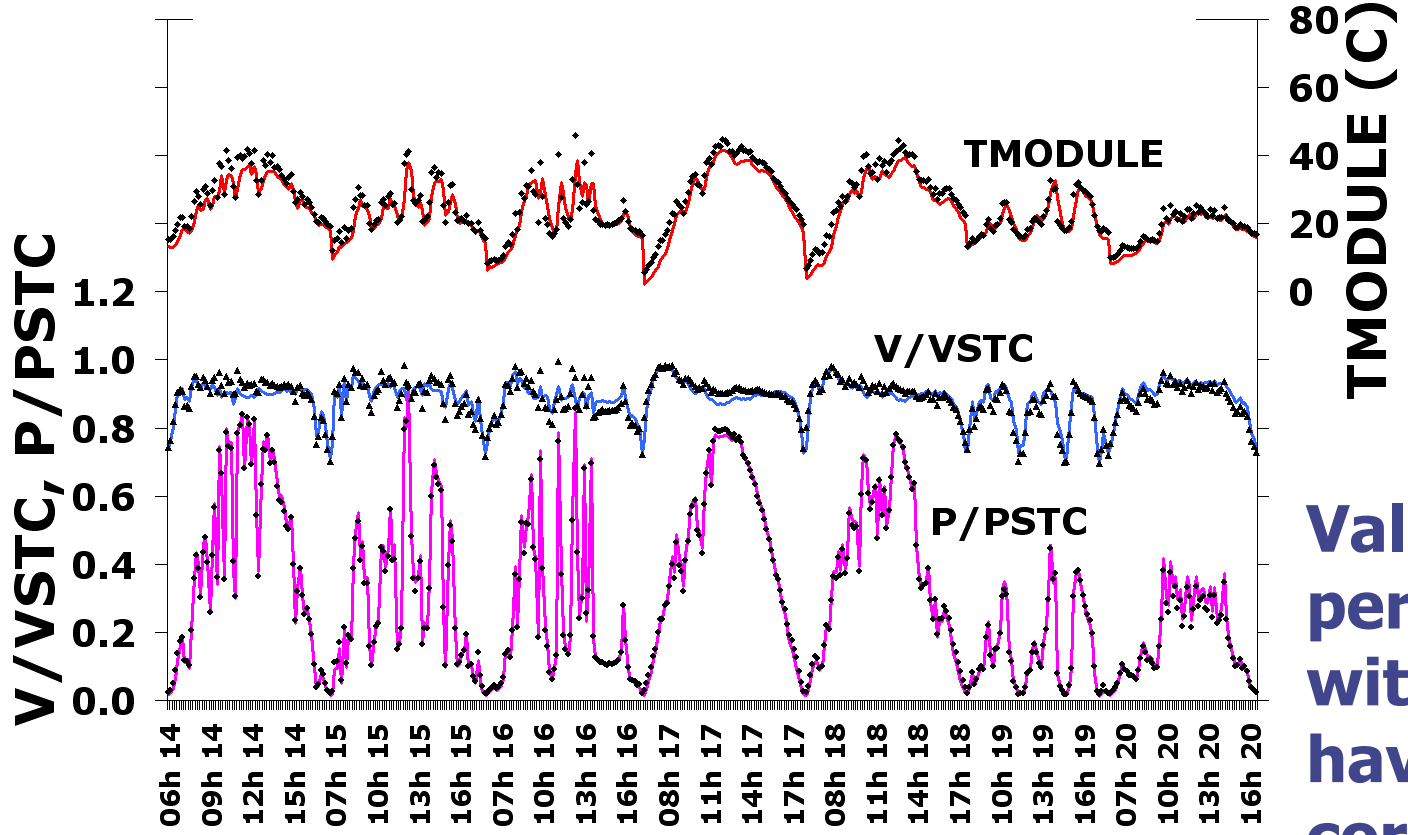
Empirical modelling – validating Tmodule, Vmax and dc Yield



Validates performance without having to correct to STC

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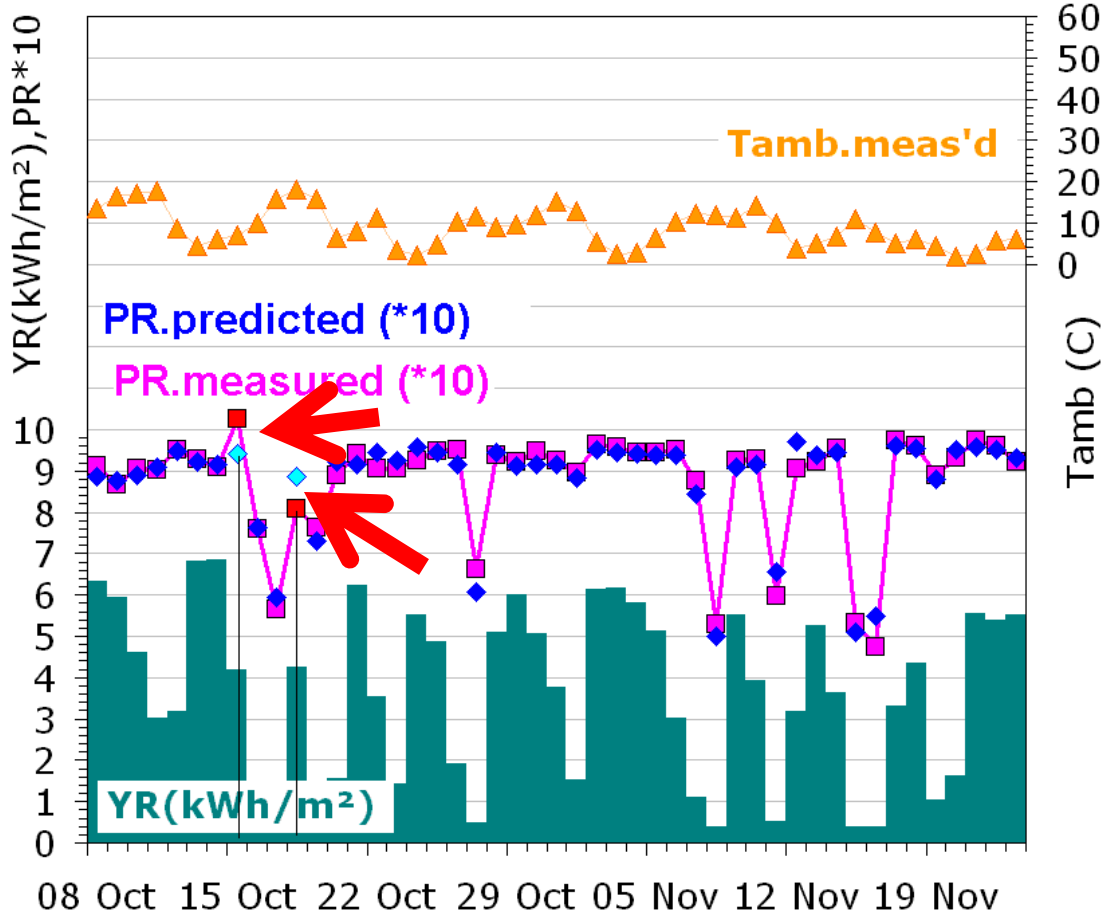
Predicted vs Measured
Daily Performance Ratio



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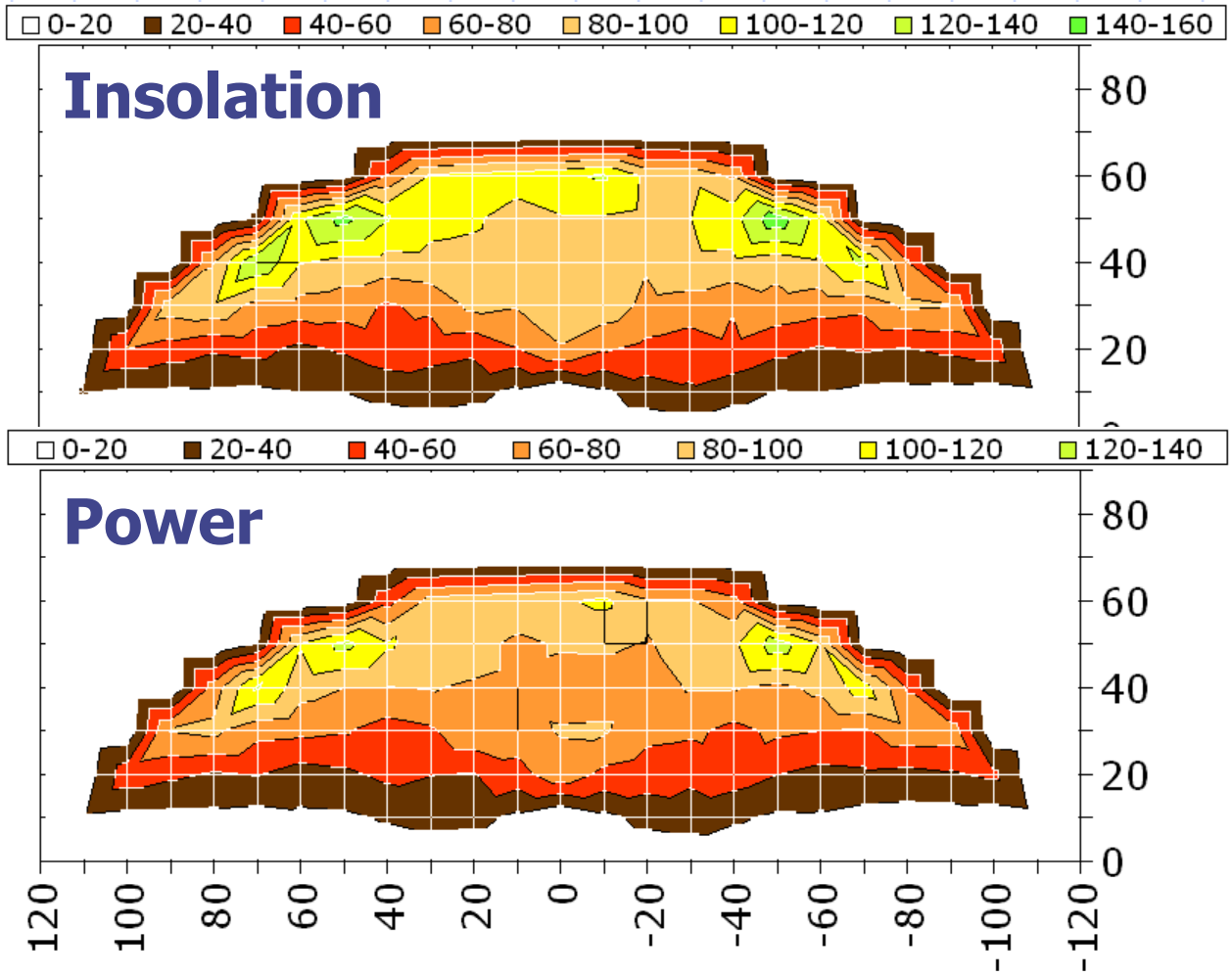
Detect Shading vs Solar Azimuth and Elevation



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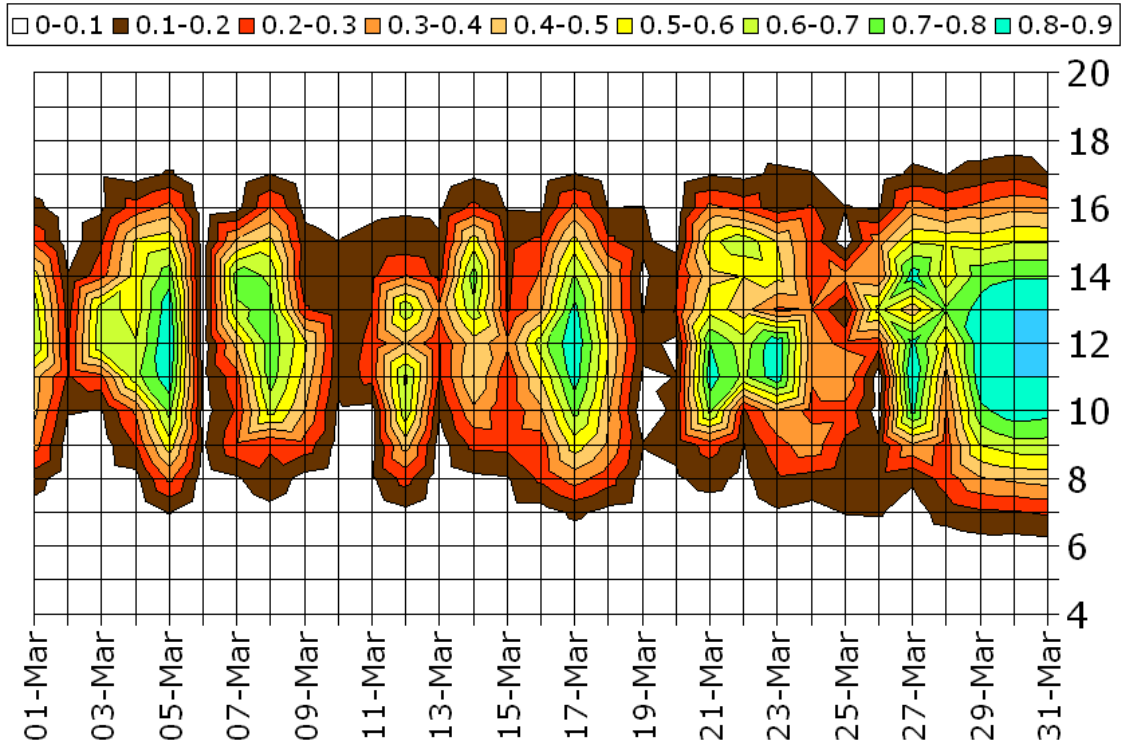
Irradiance Vs. Date and Time



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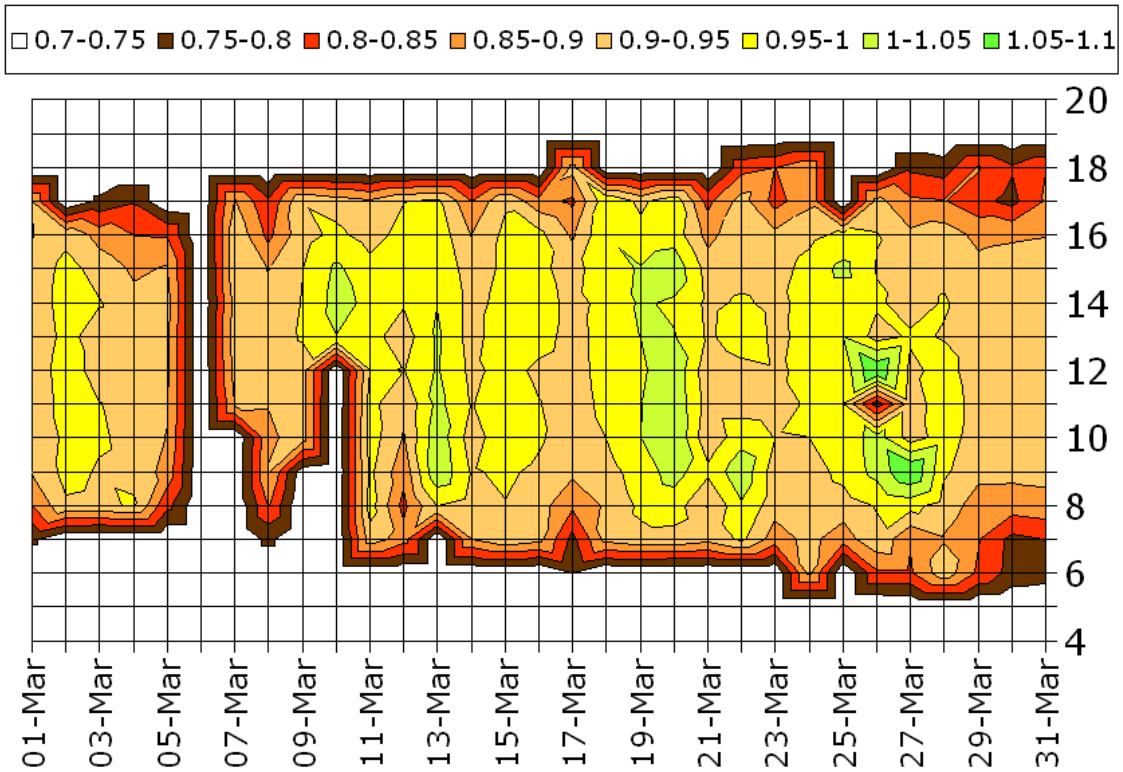
Look for downtime, poor behaviour
Performance vs Date and Time



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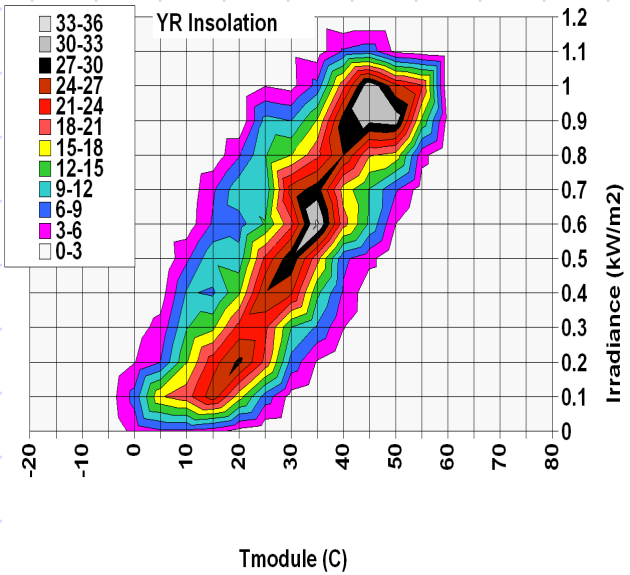
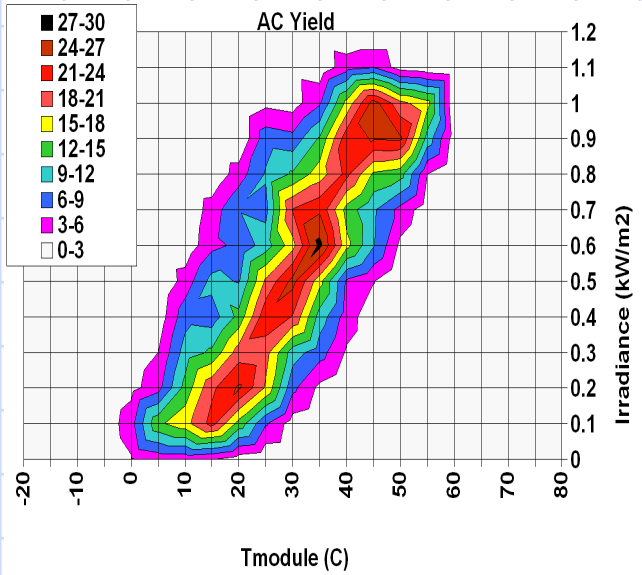
ISET Germany 10minute data Insolation and DC Yield





Irradiance →

Tmodule →

Most energy production on narrow band from cool/dull to warm/bright

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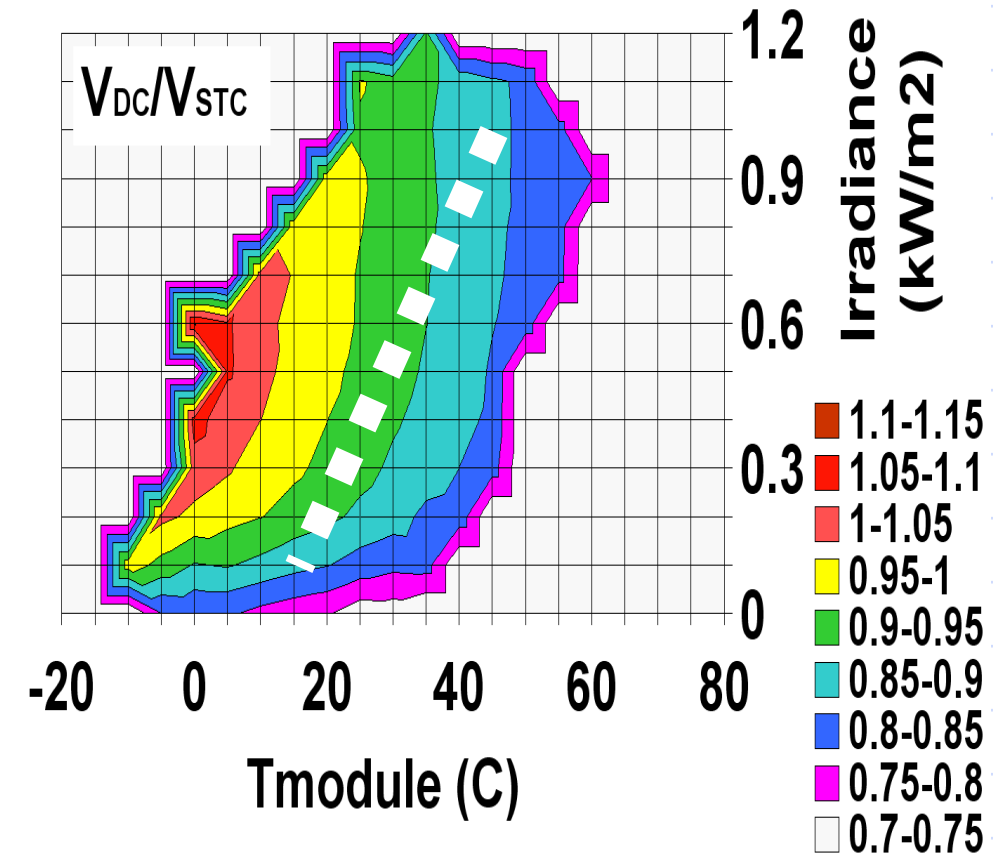
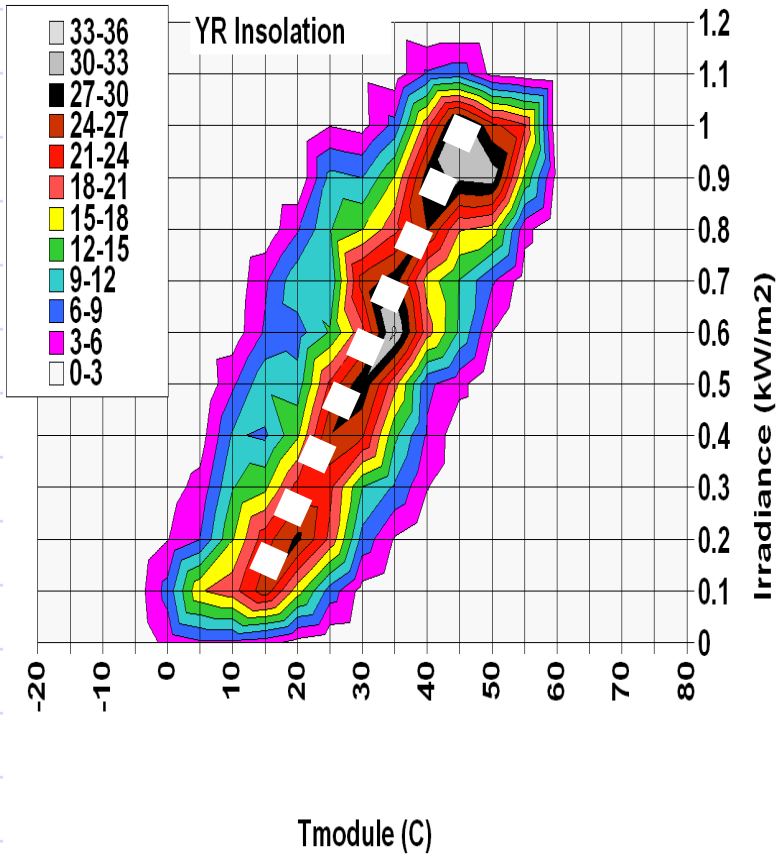
Inverter Efficiency can depend on Vmax





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Conclusions

- DC,AC outdoor measurements sometimes different from modelling algorithms
- Sizing programs minimise “avoidable losses“
- kWh predictions less precise than input uncertainties
- Empirical equations characterise/validate correct operation.
- Many channels within 4% kWh/kWp unknown
- kWh/kWp alone cannot identify reasons for losses
- Measuring one channel can’t differentiate atypical poor module, degradation or technology effects

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Thank you for your attention !

My publications are available
www.steveransome.com

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Acknowledgements :

Peter Funtan and ISET for the data

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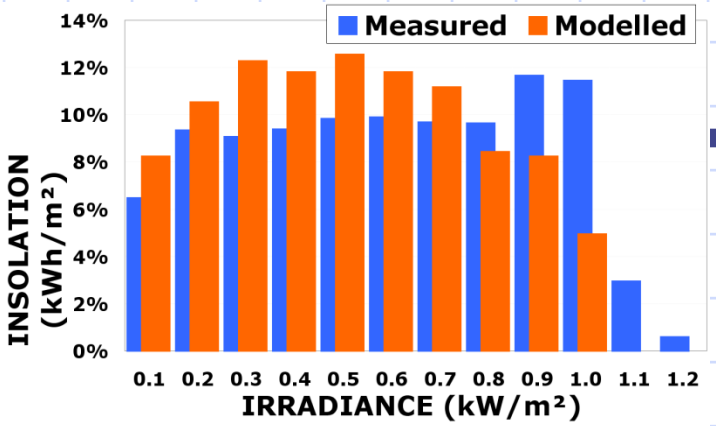
Spare slides

Modelled vs measured DC energy yield



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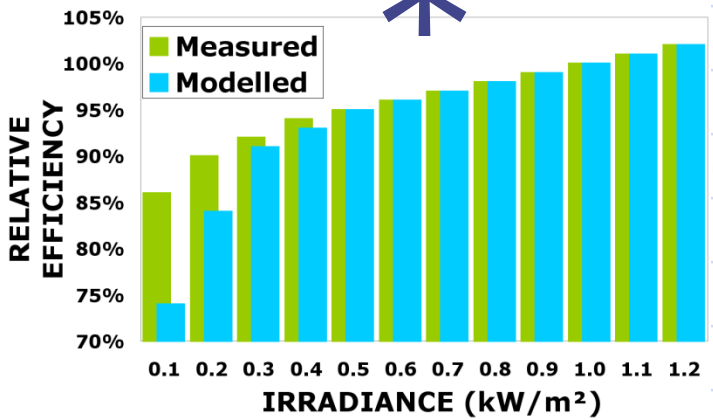
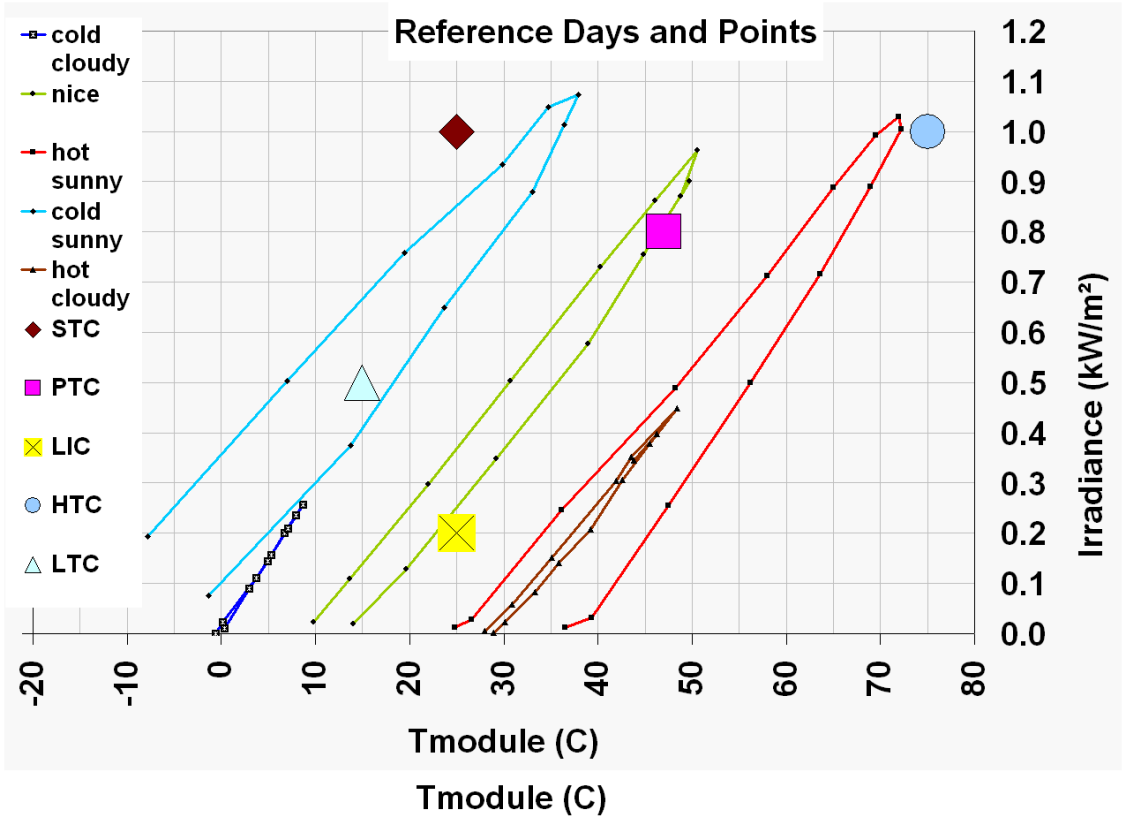


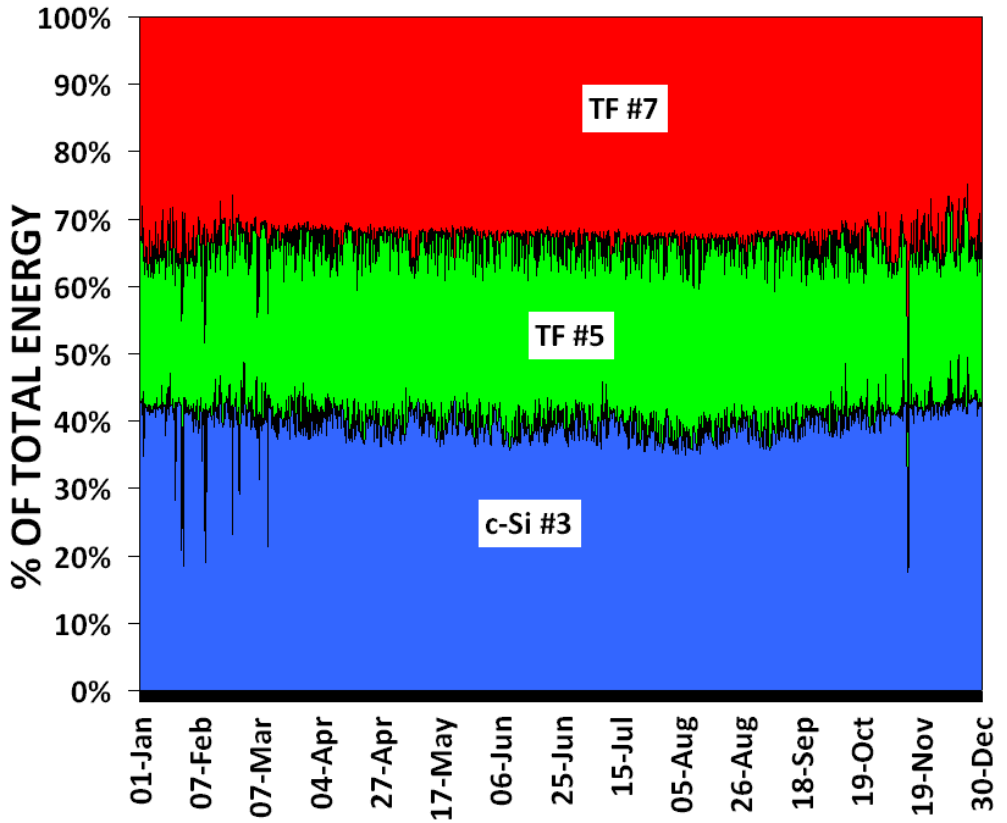
	Modelled Insolation	Measured Insolation
Measured Efficiency	98.9 %	100 %
Modelled Efficiency	97.0 %	98.4 %

Reference days and points



Tmodule (C)

Checking downtime and/or degradation for several modules : % of total power vs time



Effect	Appear-ance
Degradation	Loss over time for degrading module(s)
Downtime	Jumps to 0% for down module(s)
Seasonal effects	Cyclical reversible changes

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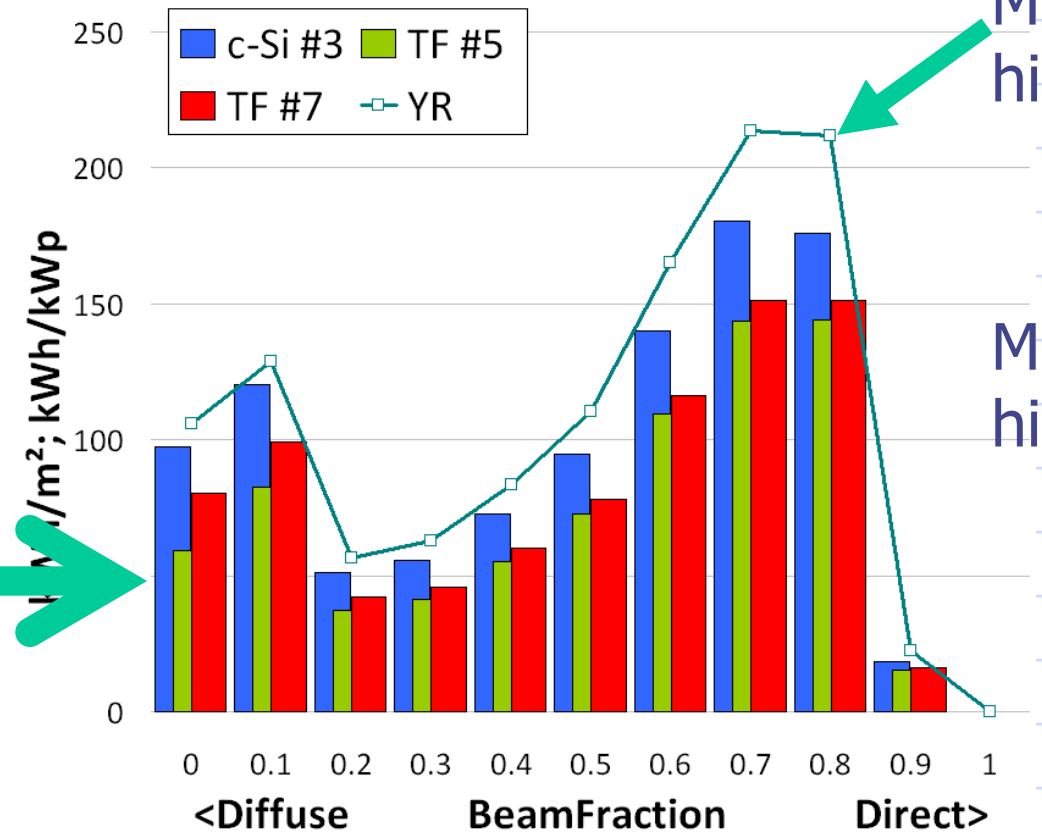
Insolation and Energy Yield vs Diffuse:Direct fraction in Germany



Most Irradiance is at high direct fraction

Most Energy yield is at high direct fraction

Poor TF #5 falls most under diffuse conditions

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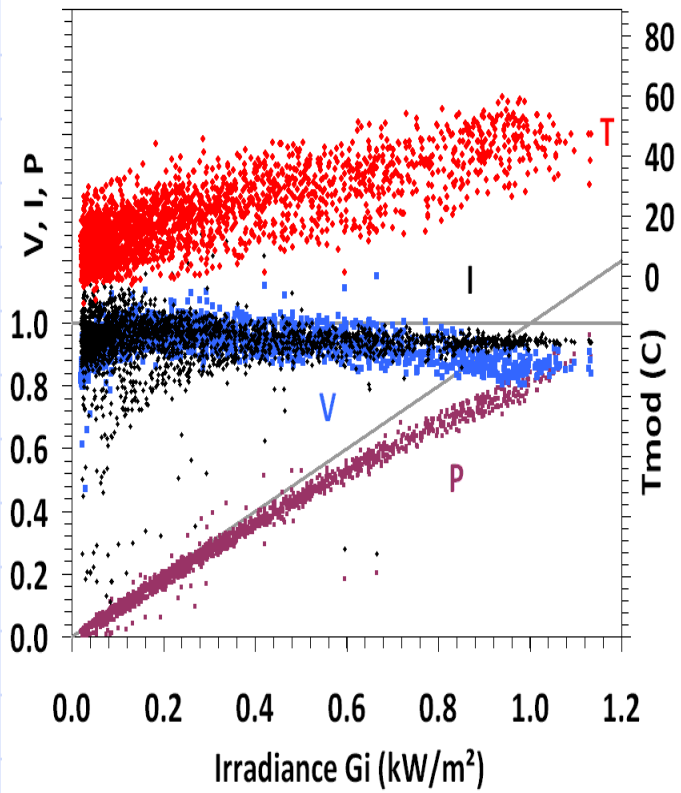
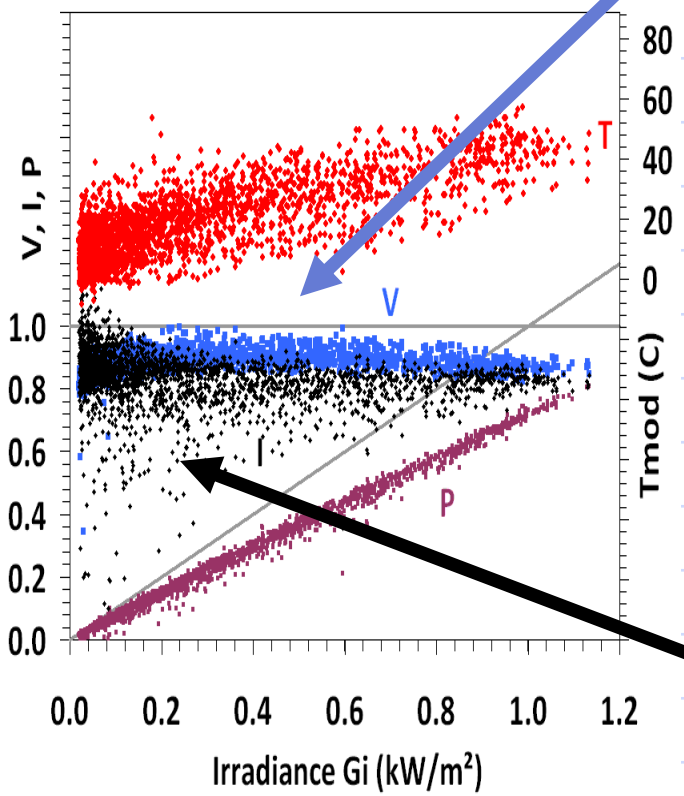
Module Temperature, Voltage, Current and Power vs Irradiance

Good #3



Poor #7



Lower Voltage

Lower and Variable Current

Predicted vs Measured Performance Ratio by time