Modelling inaccuracies of PV energy yield simulations

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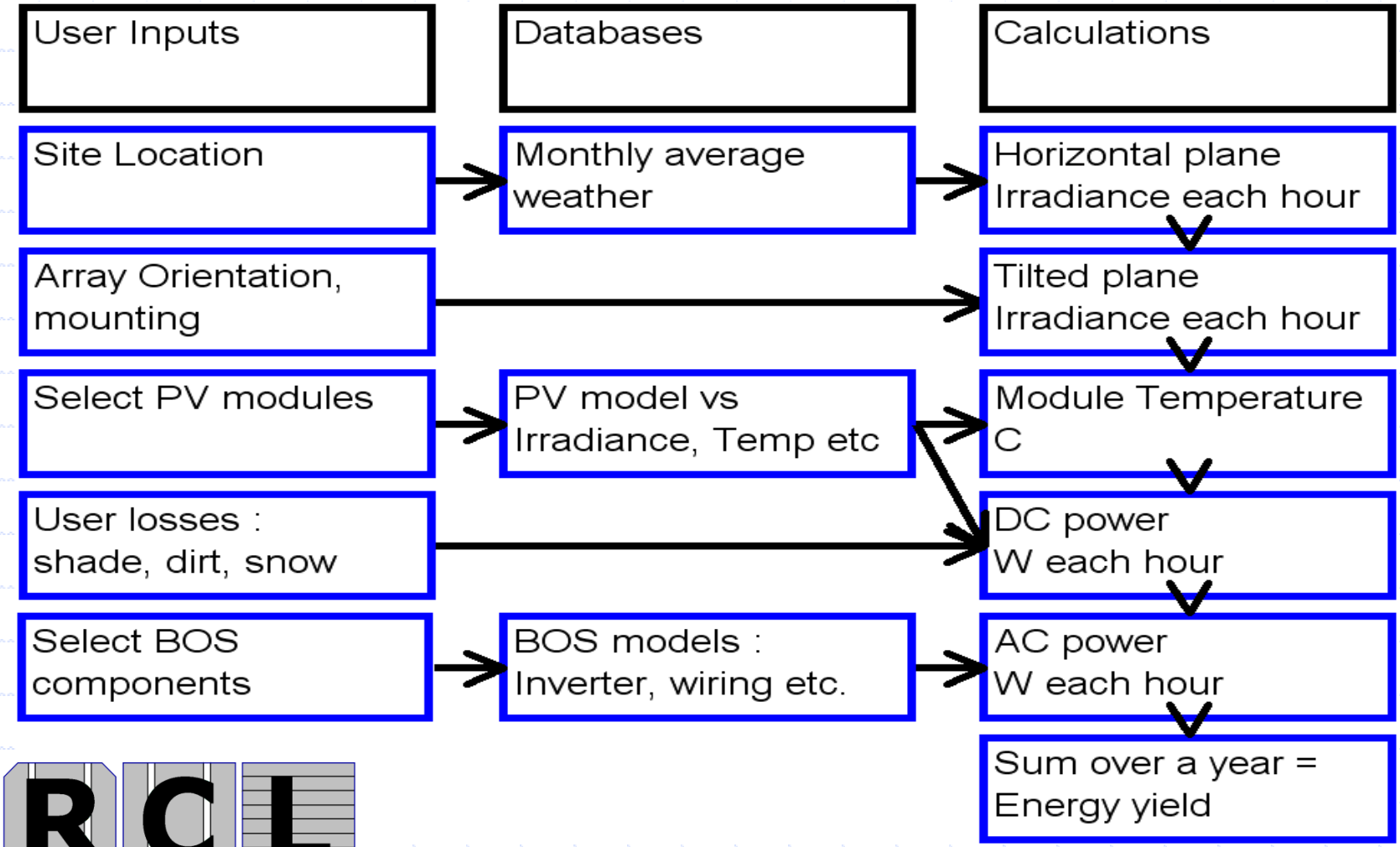
Introduction

- 19 years experience with BP Solar UK
- Responsible for sizing programs, kWh/kWp studies, indoor+outdoor testing and modelling of crystalline modules and thin film (a-Si and CdTe)
- Published at international conferences since 2000
- Left BP in Jan 2008 to form a PV consultancy SRCL

- This paper follows 23rd PVSEC in Milan Sep 2007 "4EP1.1 HOW WELL DO PV MODELLING ALGORITHMS REALLY PREDICT PERFORMANCE?" written while at BP Solar

Simple Sizing program flow chart



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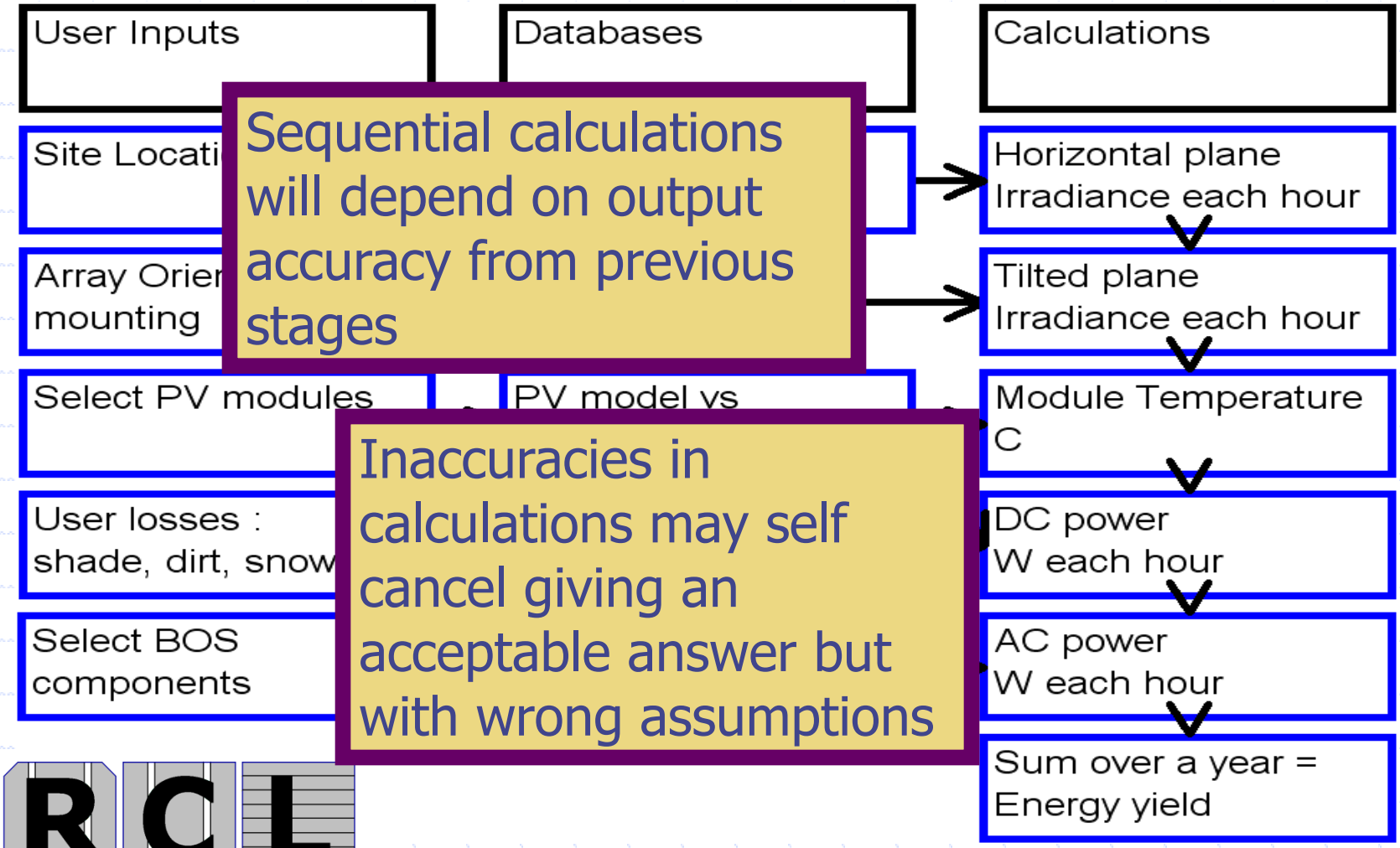
Simple Sizing program flow chart



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Estimating uncertainties in kWh/kWp

Insolation kWh/m²

$$\frac{kWh}{kWp_{NOM}} = (PR) * (YR) * \frac{(kWp_{ACTUAL})}{(kWp_{NOMINAL})}$$

Gaussian uncertainties combine as

$$U^2 = u_1^2 + u_2^2 + \ldots + u_n^2$$

kWh/kWp uncertainties

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

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%

kWh/kWp uncertainties

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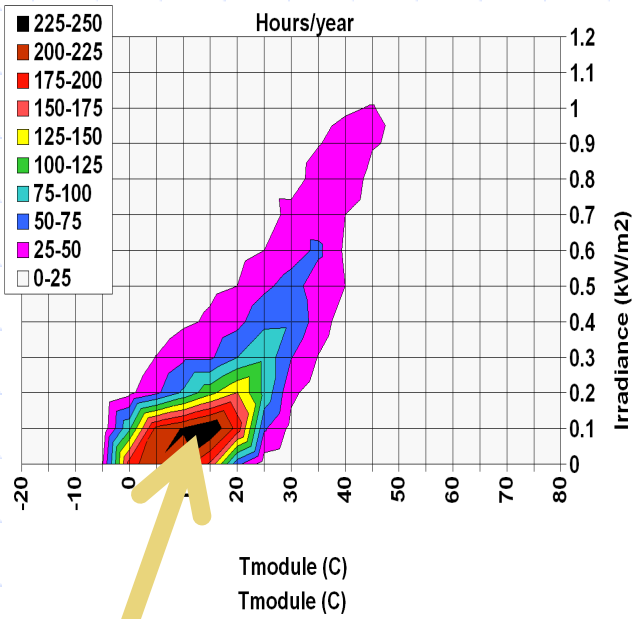
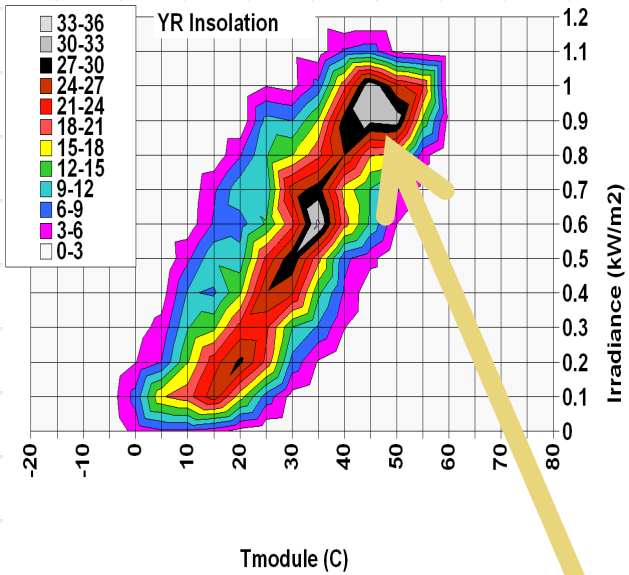
YR	Irradiance sensor Yearly Insolation	2% 4%	0% 0%
kWp/ Nom-inal	Ref. Module Calib. Module variability Degradation	2% 2.5% 1%/y	2% 2.5% 1%/y
	Uncertainty **PR range (nom 75%)**	**~6%** **71–79%**	**~3%** **73–77%**

ISET Germany 10minute measured Hours and POA Insolation





Most <u>time</u>
cool + low light

Most <u>insolation</u>
hot + high light

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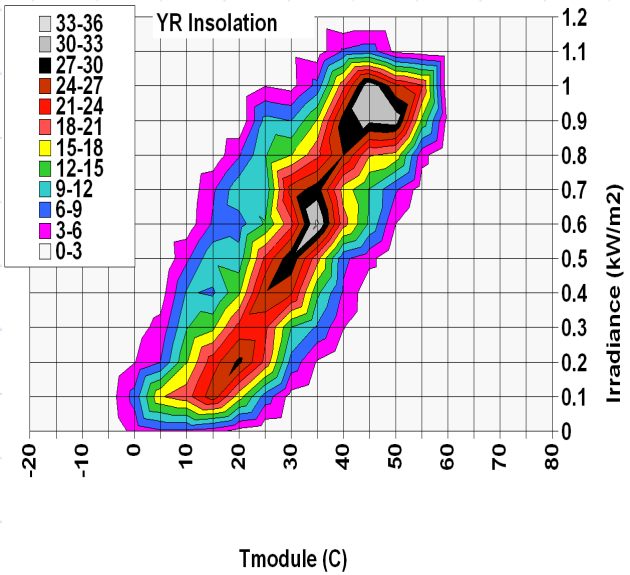
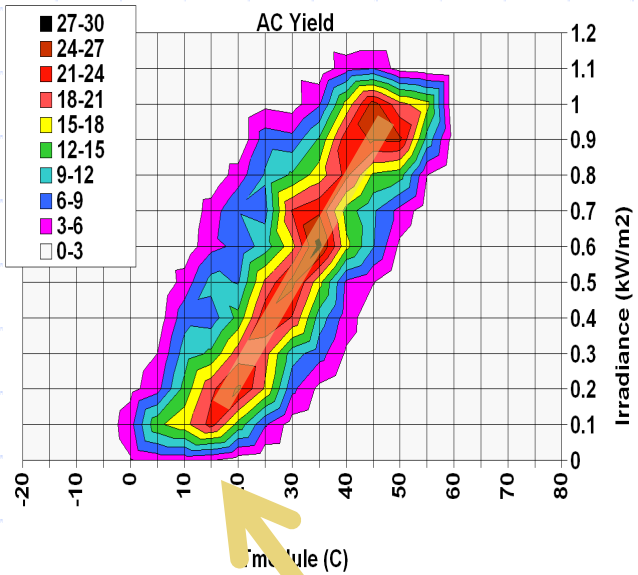
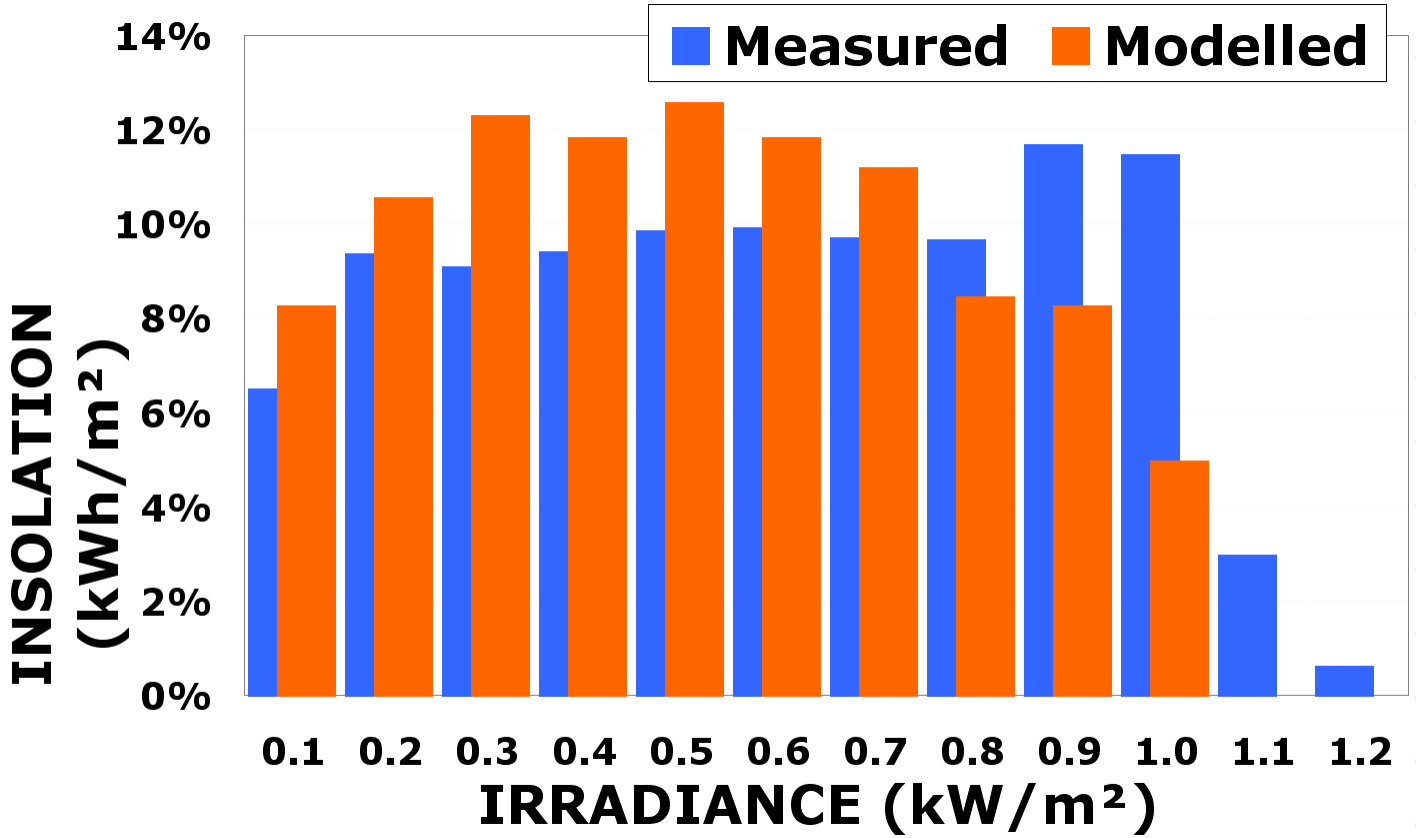
ISET Germany 10minute data Insolation and AC Yield



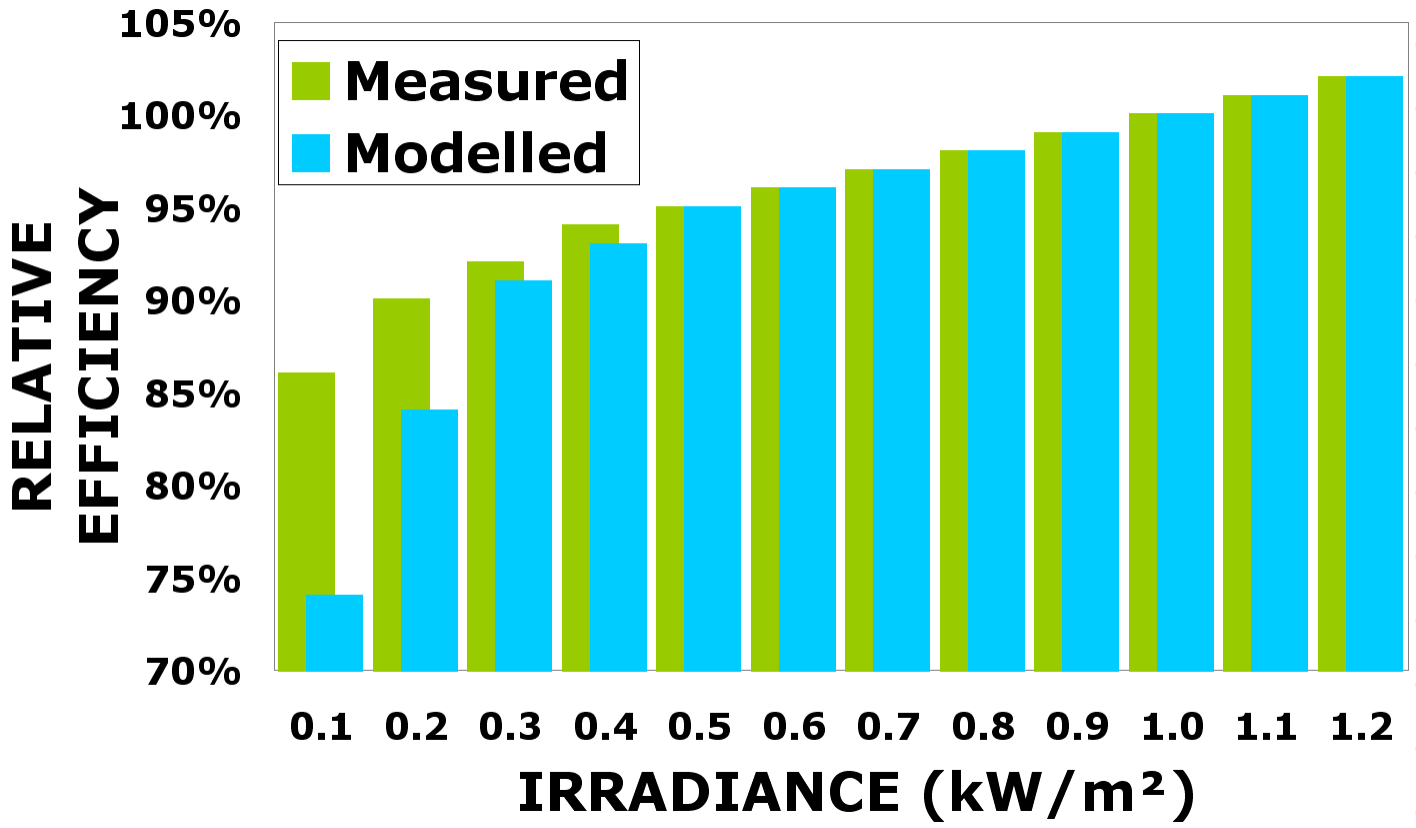


Most energy production on narrow band from cool/dull to warm/bright

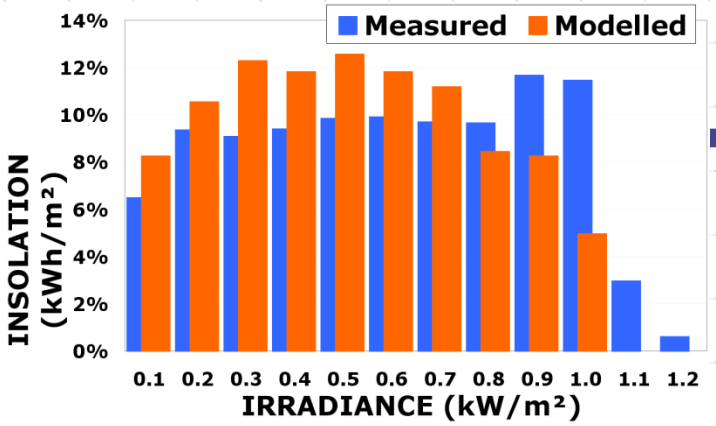
DC Energy Yield = Σ(Insolation(Gi)*Efficiency(Gi))



DC Energy Yield = Σ(Insolation(Gi)*Efficiency(Gi))



Modelled vs measured DC energy yield



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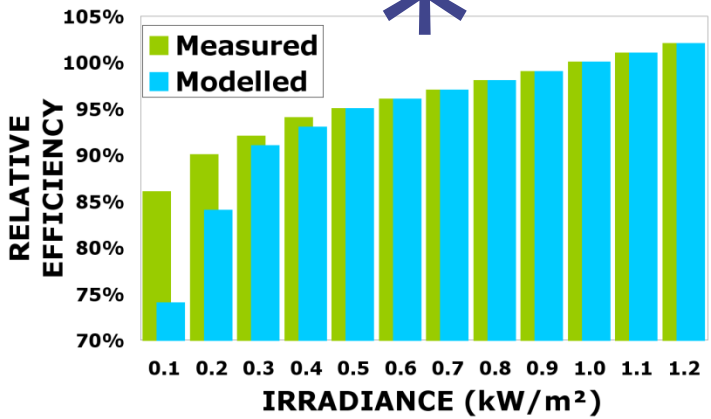

	Modelled Insolation	Measured Insolation
Measured Efficiency	98.9 %	100 %
Modelled Efficiency	97.0 %	98.4 %

Modelling program written to simulate losses vs climate

SIMULATE

STATUS STOPPED ver: 080502

Customer	Test	Site	Mumbai
Quote number	33PVSC - Mumbai, Sydney and Kassel	Lat	19N
Date and Time	2May08	Lon	73E
Comments	Standard sizing	Tilt	0
		Azimuth	0S

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SELECT MODULE >>> 12) P=200Wp

SELECT INVERTER >>> 33)

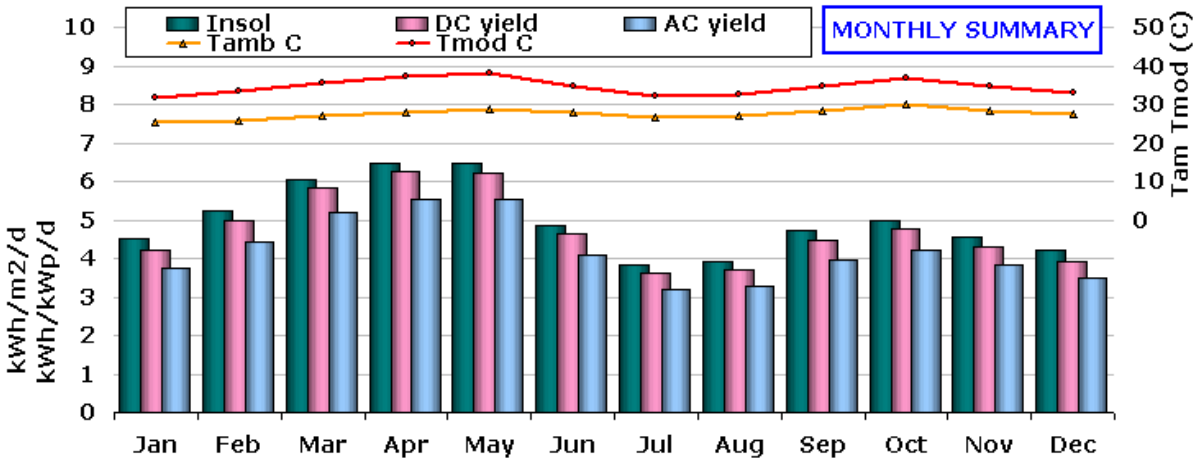
		limits	Check	low	high
Series Modules	13	(8 to 14)	OK	8 #	14 #
Parallel Modules	3	(1 to 3)	OK	1 #	3 #
Qty Modules	39	[26 to 38] Pmax Array 7806 Wp	HIGH	26 #	38 #

Inverter Eff. vs Vin >>> 4) At Max Vin

Parallel Inverters 1 #

MONTHLY PERFORMANCE

	Dust /month %	Ground Reflect #	Shadow /month %	Glob Horiz kWh/m2/d	Glob Tilt kWh/m2/d	Temp Amb C	Wind Speed ms^-1	Temp Mod C	DC Yield	Perf Fact %	AC Yield Yield Wh/kWp/	Perf Rat %	
Jan	2%	0.26	2%	4.51	4.51	25.49	3.28	31.82	4.22	93.7%	3.74	83.0%	Jan
Feb	2%	0.25	1%	5.24	5.24	25.92	3.77	33.29	4.98	95.1%	4.42	84.5%	Feb
Mar	2%	0.26	0%	6.06	6.06	26.95	3.76	35.48	5.83	96.3%	5.18	85.5%	Mar
Apr	2%	0.28	0%	6.47	6.47	28.04	3.77	37.15	6.24	96.3%	5.54	85.6%	Apr
May	2%	0.31	0%	6.45	6.45	28.81	3.32	37.89	6.21	96.2%	5.52	85.5%	May
Jun	2%	0.3	0%	4.85	4.85	27.68	3.81	34.50	4.62	95.2%	4.09	84.4%	Jun
Jul	2%	0.27	0%	3.84	3.84	26.73	4.24	32.13	3.63	94.4%	3.20	83.3%	Jul
Aug	2%	0.26	0%	3.92	3.92	26.91	3.79	32.42	3.70	94.4%	3.27	83.4%	Aug
Sep	2%	0.27	0%	4.70	4.70	28.25	2.83	34.87	4.48	95.3%	3.97	84.4%	Sep
Oct	2%	0.26	0%	4.98	4.98	29.97	2.81	36.97	4.77	95.8%	4.23	85.0%	Oct
Nov	2%	0.25	1%	4.55	4.55	28.49	2.82	34.89	4.31	94.6%	3.82	83.8%	Nov
Dec	2%	0.24	2%	4.21	4.21	27.27	2.81	33.18	3.93	93.4%	3.47	82.6%	Dec
kWh/kWp									1730	95.2%	**1534**	84.4%	kWh/kWp
kWh/y				1817	1817				13504		**11972**		kWh/y



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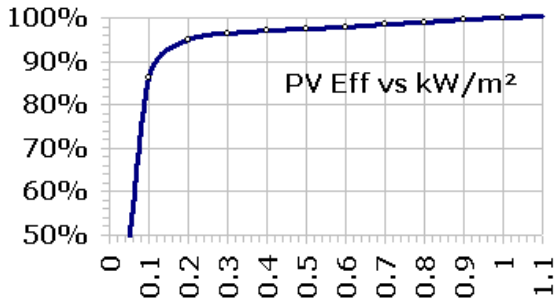
Modelling PV efficiency vs light level and Inverter efficiency vs %Pin

PV MODULE

Manuf		
Module Name		
Type	mc Si	#
Tolerance	-2	%
Isc	8.21	A
Voc	32.9	V
Imax	7.61	A
Vmax	26.3	V
NOCT	47	C
Alpha (%dIsc/dT)	0.04%	%/C
Beta (%dVoc/dT)	-0.37%	%/C
Gamma (%dPmax/dT)	0.00%	%/C
Length	1.425	m
Width	0.99	m
Max Sys V	0	V

Area	1.41	m²
FillFactor	74.1%	#

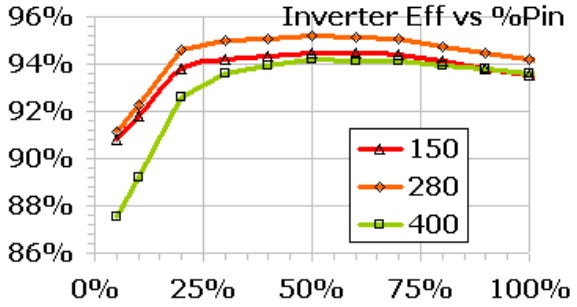
Pmax	200	Wp
Mod Eff	14.2%	%



Eff @ kW/m²	
0.0	0.0%
0.1	86.2%
0.2	95.1%
0.3	96.4%
0.4	97.0%
0.5	97.5%
0.6	98.0%
0.7	98.5%
0.8	99.0%
0.9	99.5%
1.0	100.0%
1.1	100.5%

INVERTER

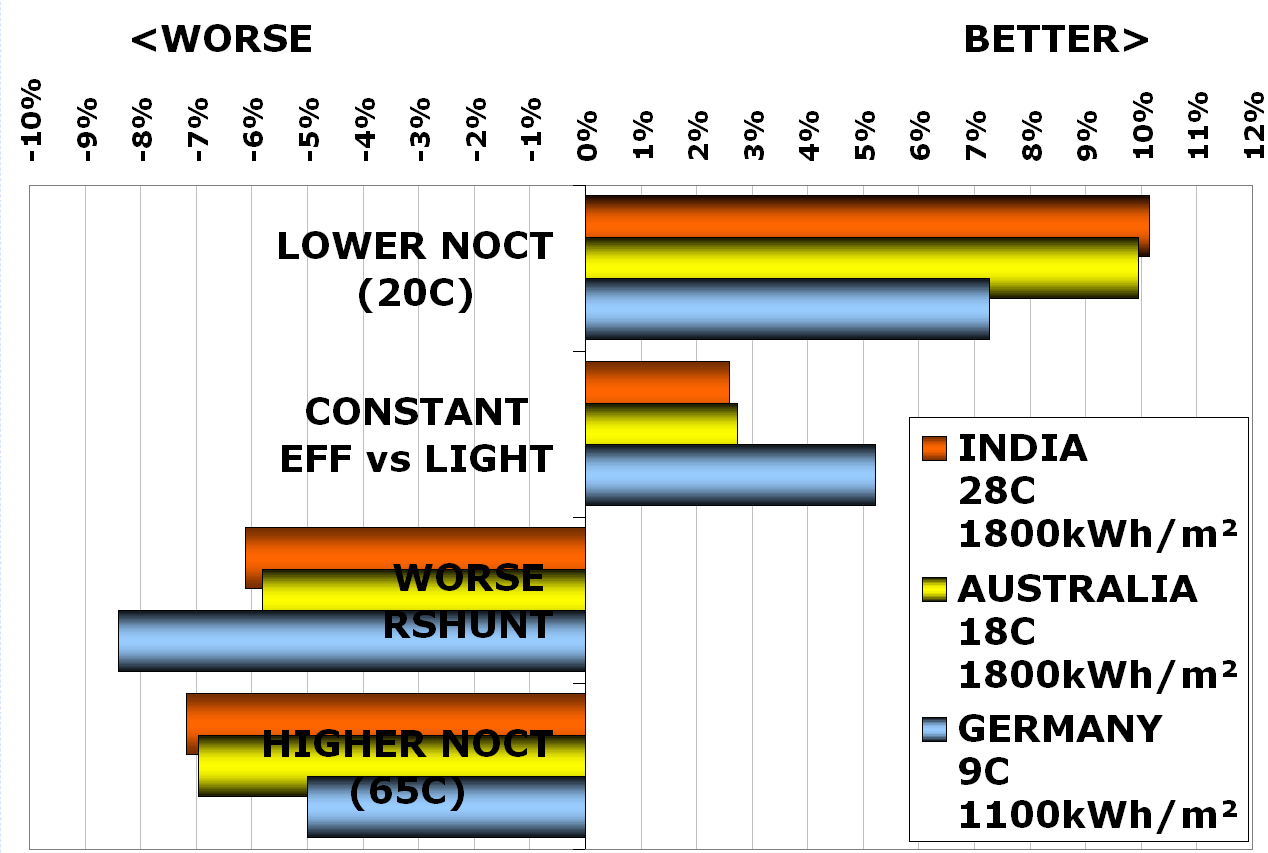
Manufacturer		
Name		
Max DC Input power	6300	W
Max DC Voltage	500	V
Max Input Current	33.2	A
Num MPP trackers	1	#
Max Strings	1	#
Max Output Power	5100	W
Max Output Current	21.3	A
Max Eff	94%	%
Euro ETA	94.50%	%
Toperating low	-20	C
Toperating high	50	C



Inverter Efficiency at Low, Mid and High MPPV

	Low V	Mid V	High V
Vmpp	150	280	400
Eff @ %Pin			
5%	90.8%	91.2%	87.5%
10%	91.8%	92.3%	89.2%
20%	93.8%	94.6%	92.6%
30%	94.2%	95.0%	93.6%
40%	94.4%	95.1%	93.9%
50%	94.5%	95.2%	94.2%
60%	94.5%	95.1%	94.2%
70%	94.4%	95.0%	94.1%
80%	94.1%	94.8%	93.9%
90%	93.8%	94.5%	93.8%
100%	93.5%	94.2%	93.6%
110%	93.2%	93.9%	93.4%

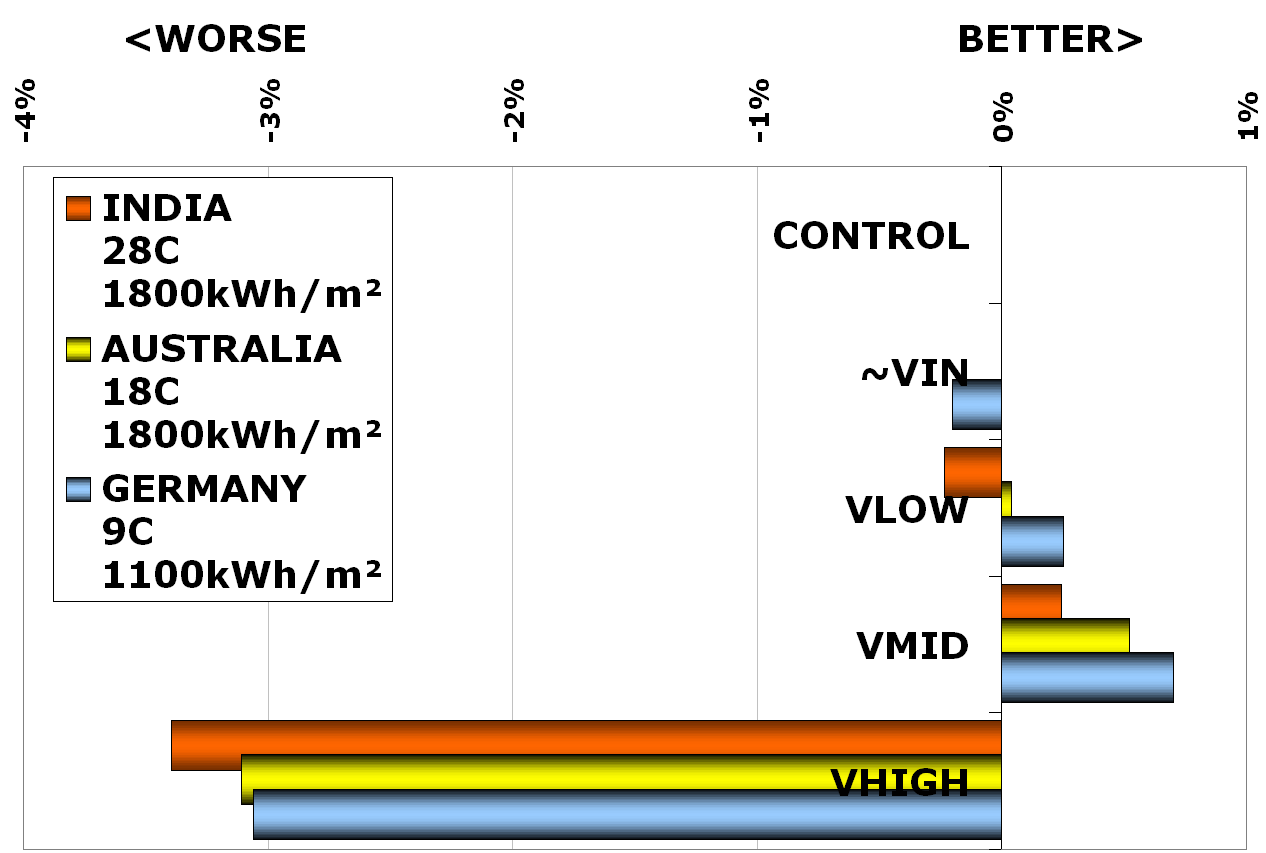
PV losses vs climate
India, Australia and Germany



India (highest T) most sensitive to NOCT changes

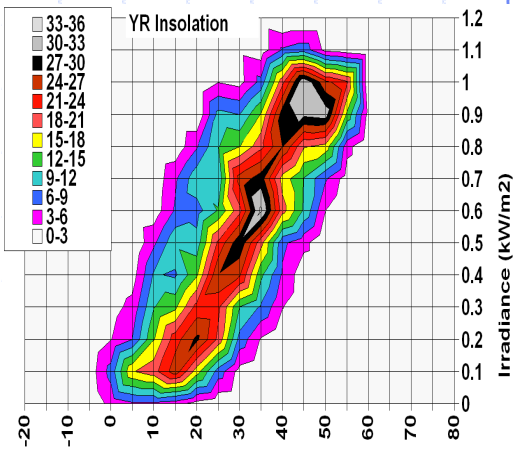
Germany (lowest YR) most sensitive to low light and shunt resistance

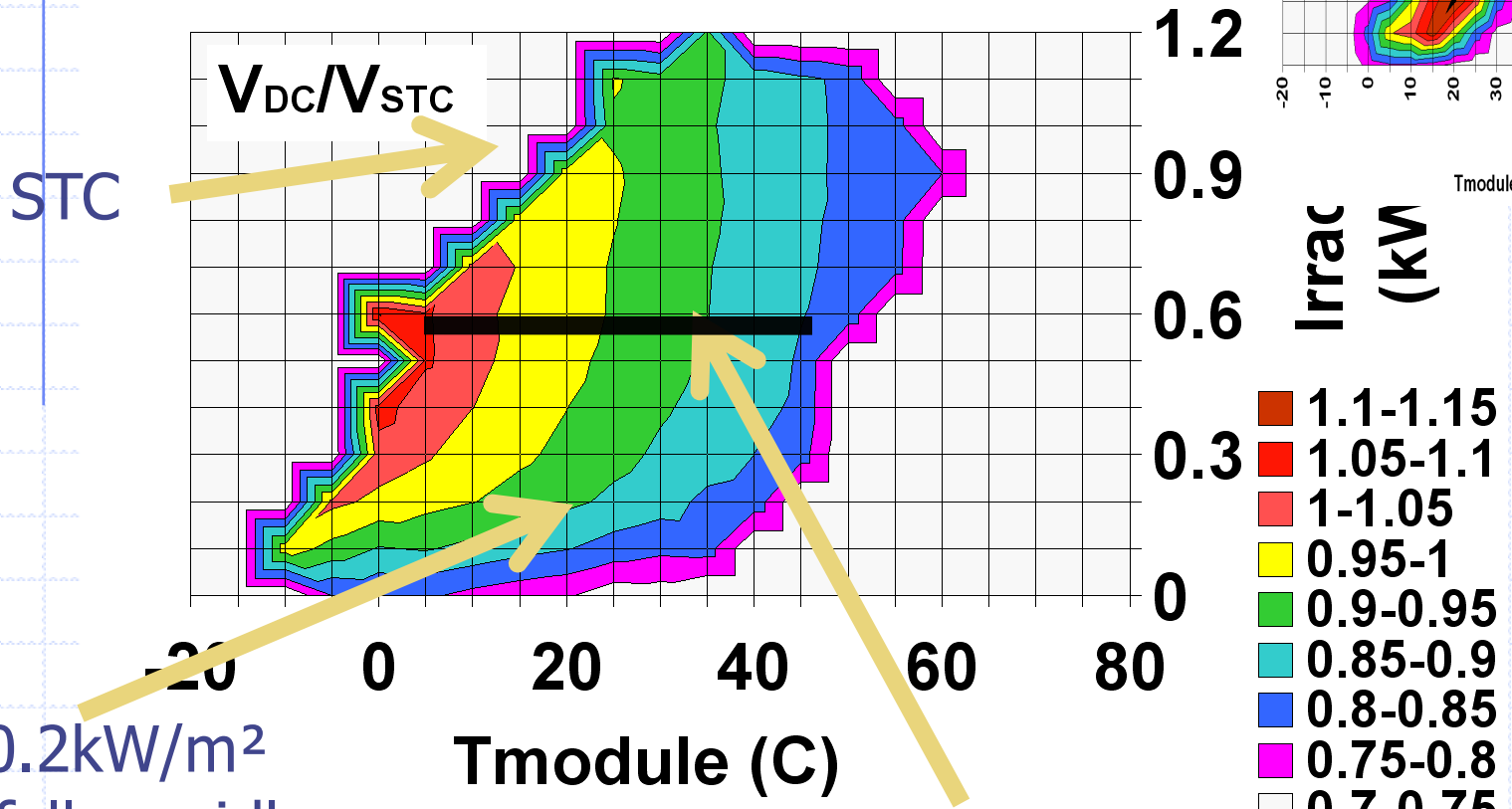
Inverter losses vs climate India, Australia and Germany



highest efficiency for this inverter at mid voltages, worst at high voltages, not very site specific.

Inverter Efficiency can depend on Vmax





<0.2kW/m²
V falls rapidly

>0.3kW/m²
V falls ~0.4%/C

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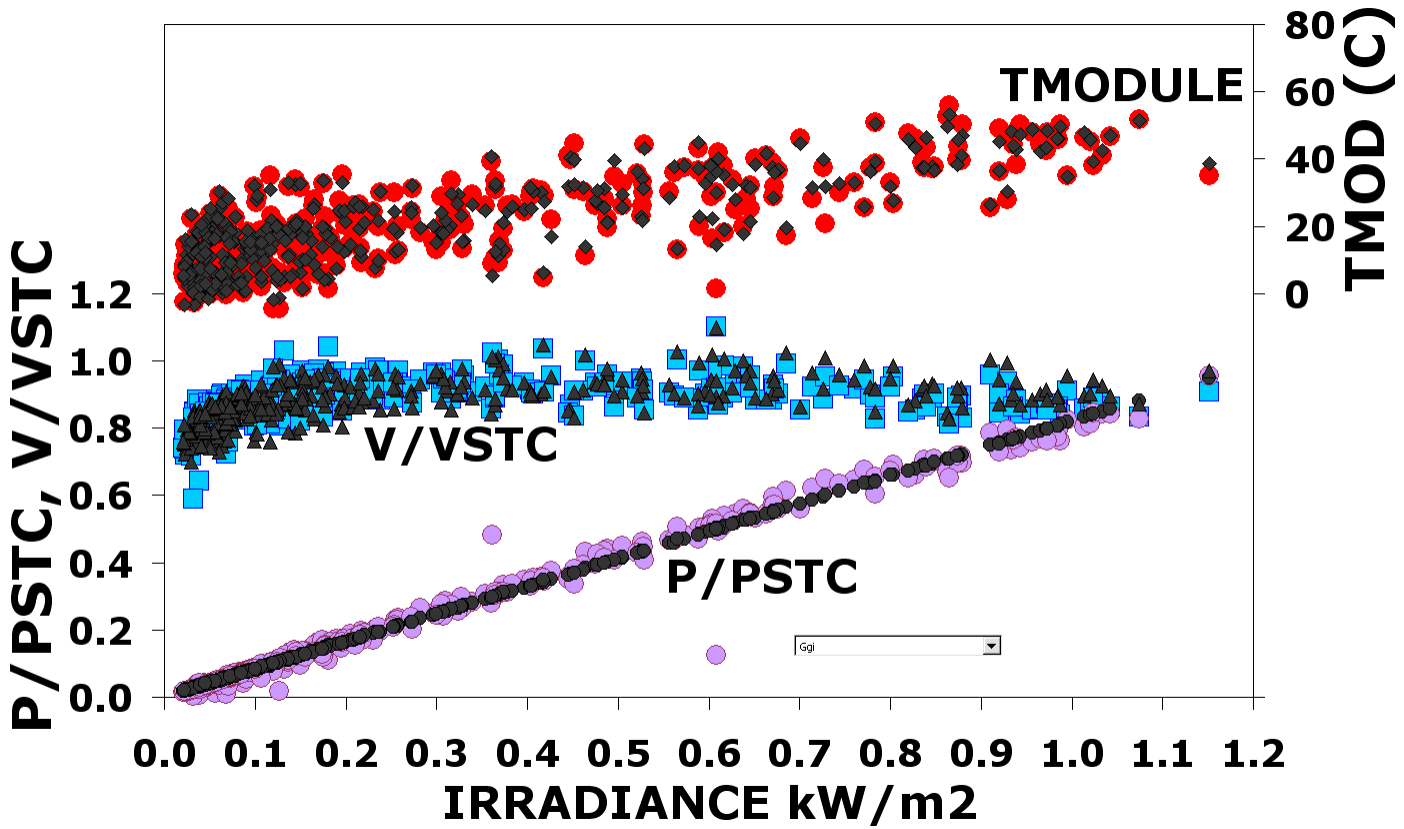
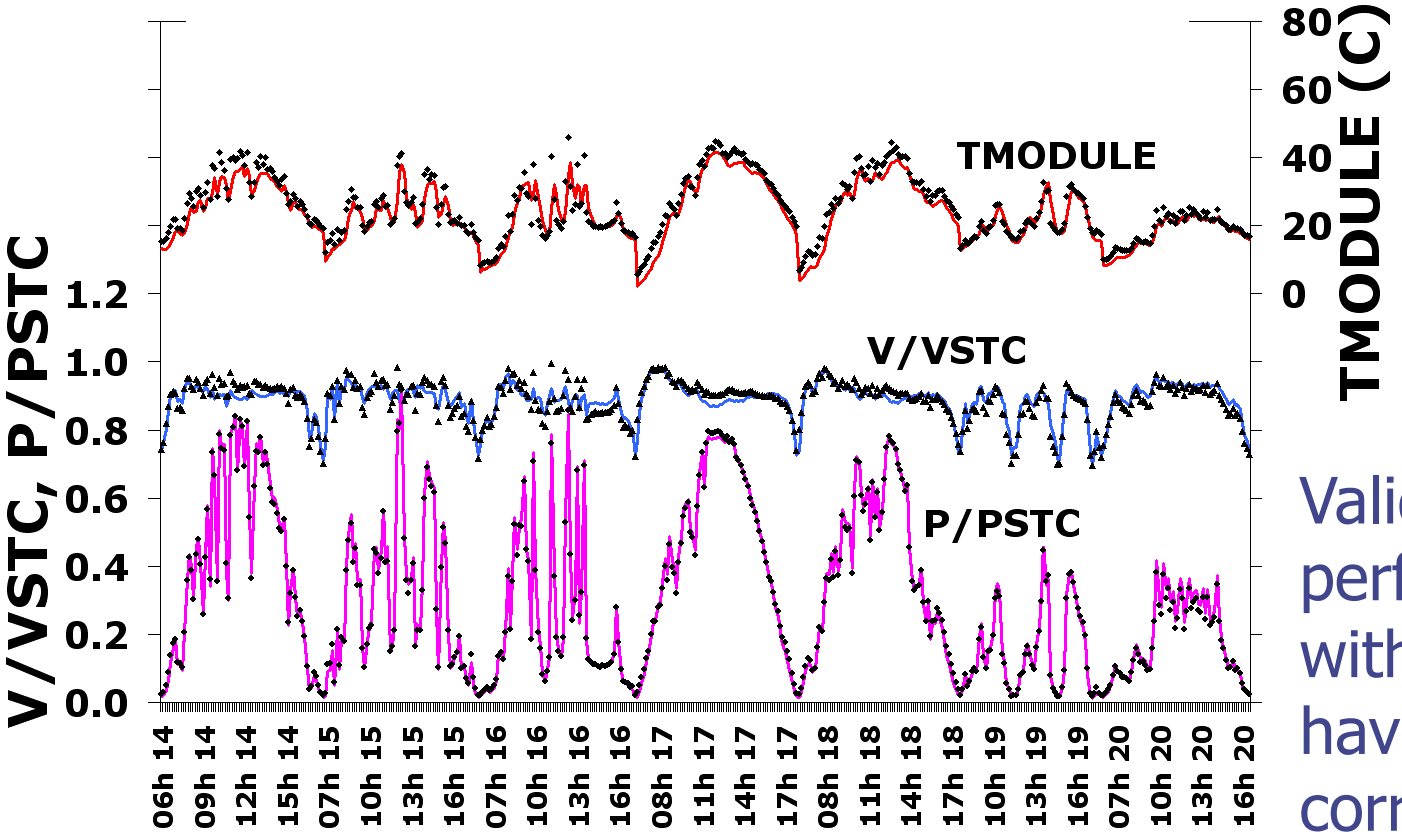
Empirical modelling – fitting Tmodule, Vmax and dc Yield



Empirical modelling – validating Tmodule, Vmax and dc Yield



Validates performance without having to correct to STC

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Conclusions

- Some DC and AC outdoor measurements can be very different from modelling algorithms
- Sizing programs are essential to design systems not to have avoidable losses
- kWh predictions can't be more precise than the input variable uncertainties
- Empirical equations can characterise performance and validate the correct operation of arrays.
- Errors in yield of several percent can be found from low light level and inverter voltage modelling

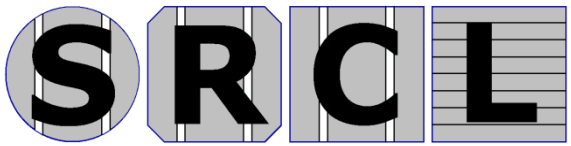
Thank you for your attention

Acknowledgements : ISET for dc data

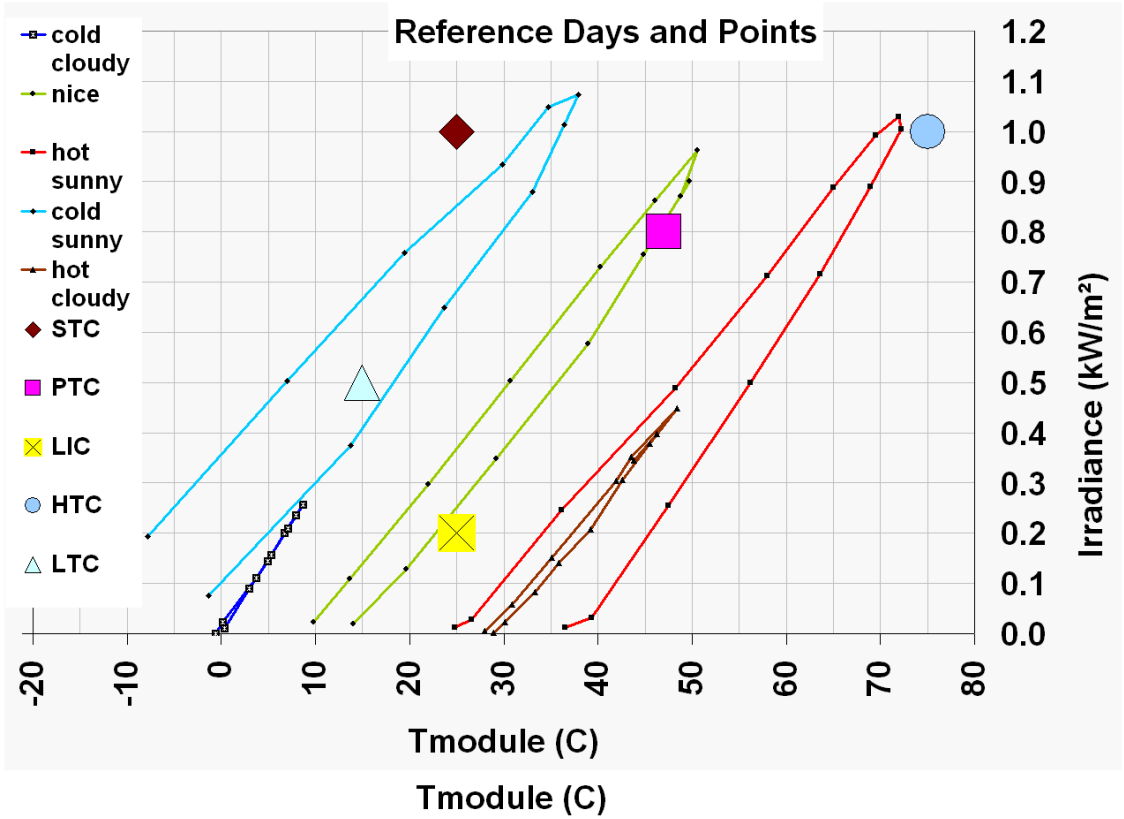
This presentation paper and slides will soon be available at

http://www.steveransome.com

Spare slides

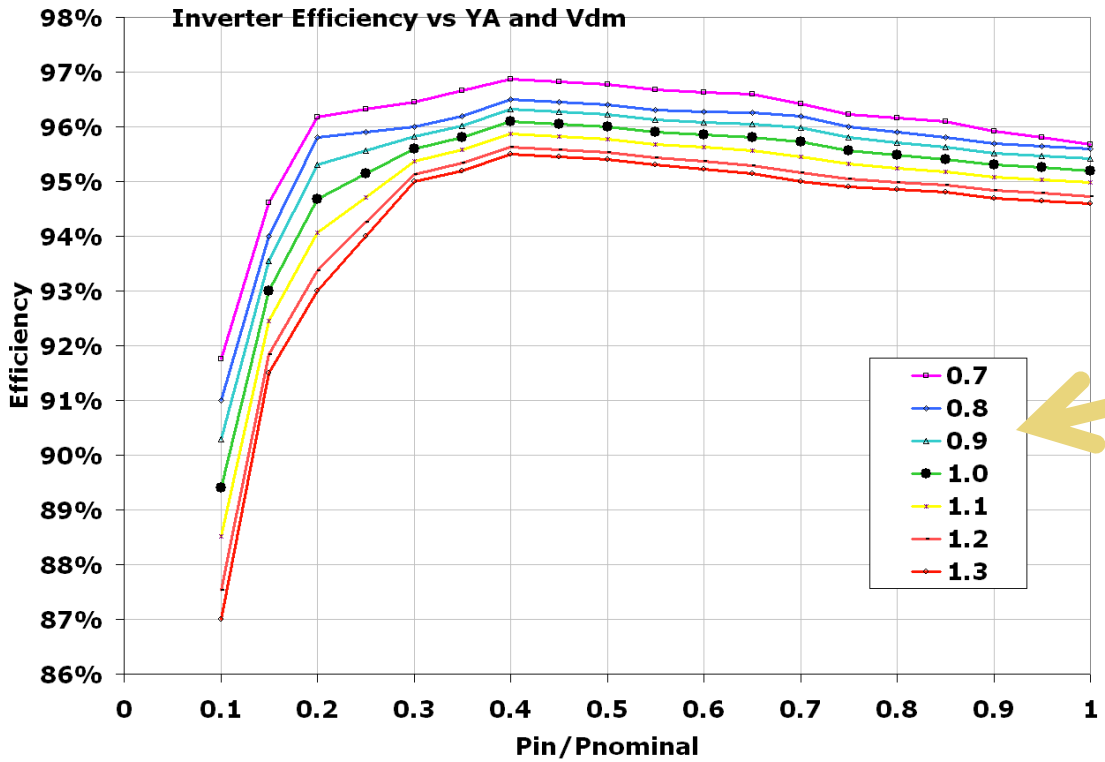


Reference days and points



Tmodule (C)

Inverter efficiency vs P_{IN} and V_{IN}



VIN depends on TMODULE

PIN depends on Irradiance

mcSi Efficiency vs Irradiance Diffuse and Direct radiation