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HOW WELL DO PV MODELLING ALGORITHMS REALLY PREDICT PERFORMANCE ?

S. J. Ransome, BP Solar UK

Performance Ratio definition

PR = (Measured)/(Theoretical Lossless) ac output

PR = (kWh_{AC}/kWp) / (POA Insolation)

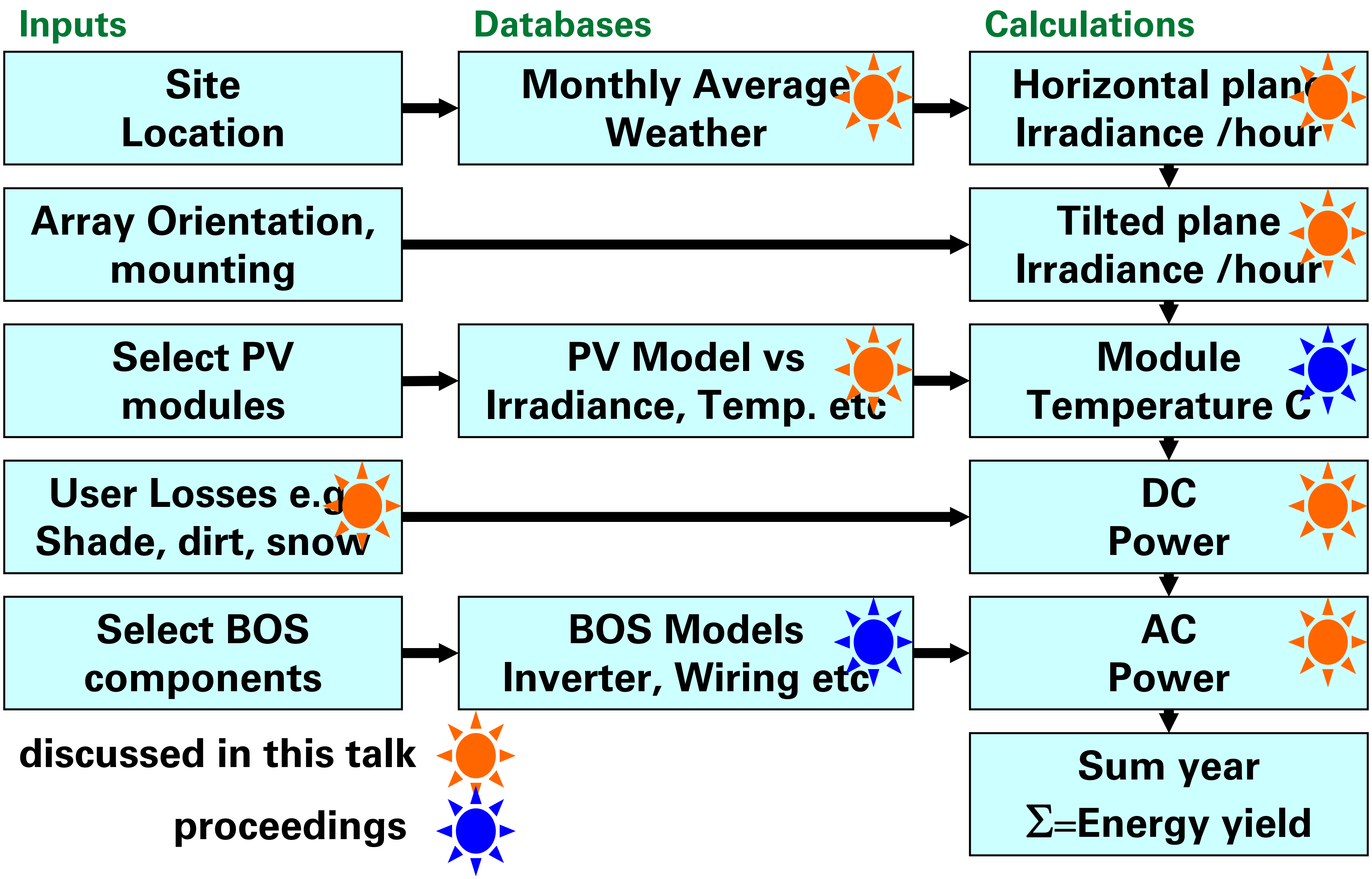
0.78 = 780 (kWh/kWp) / 1000 (kWh/m^2) e.g.

PR from Sizing Program predictions and measurements are often ~75-80%

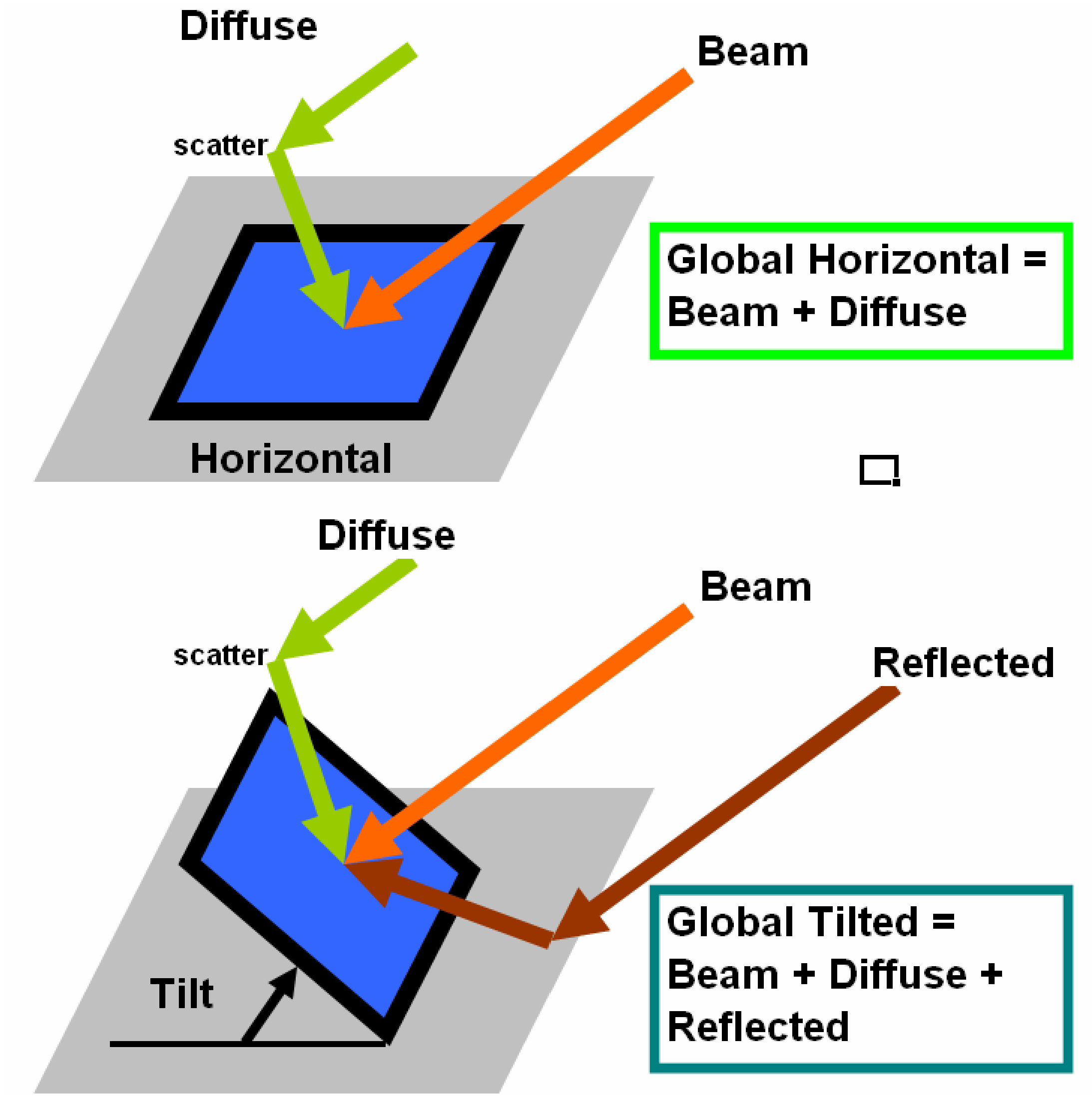
But

Do programs model everything correctly ?
Are there sufficient unknowns and user defined inputs to enable predictions to coincide with measurements ?

General Sizing program methodology

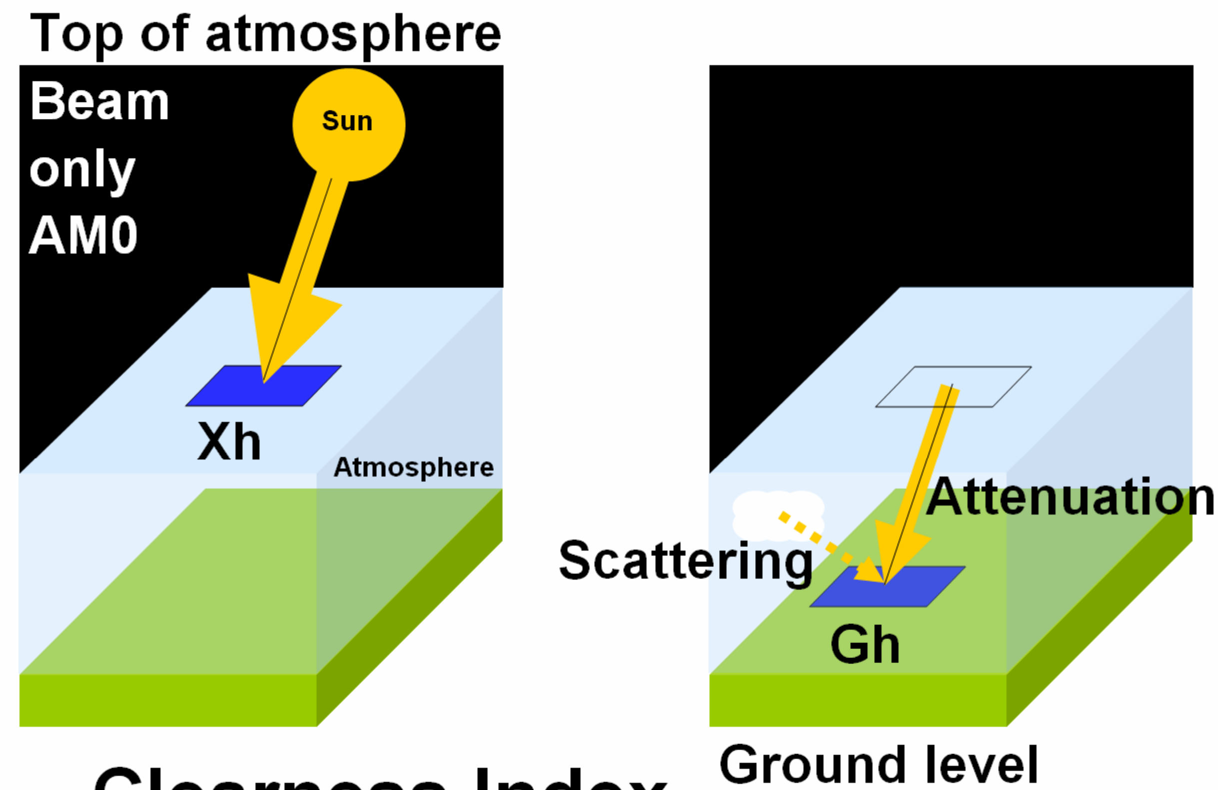


Calculating Tilted plane irradiance from horizontal plane measurements



How do we calculate the Diffuse:Beam ratio if it's not measured ?

Calculating kT (Clearness index) to find the beam:diffuse ratio



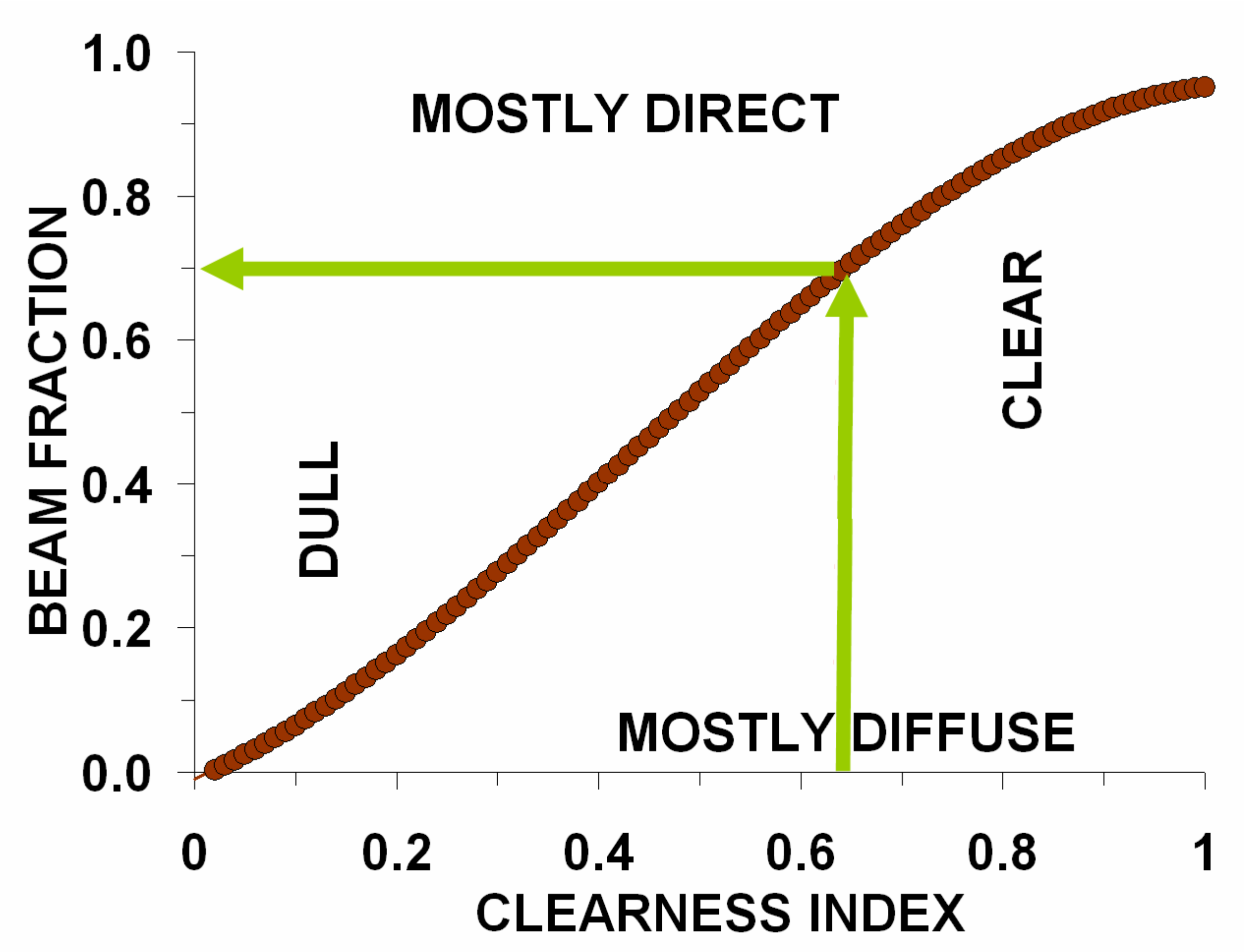
Clearness Index

$kT = Gh/Xh$

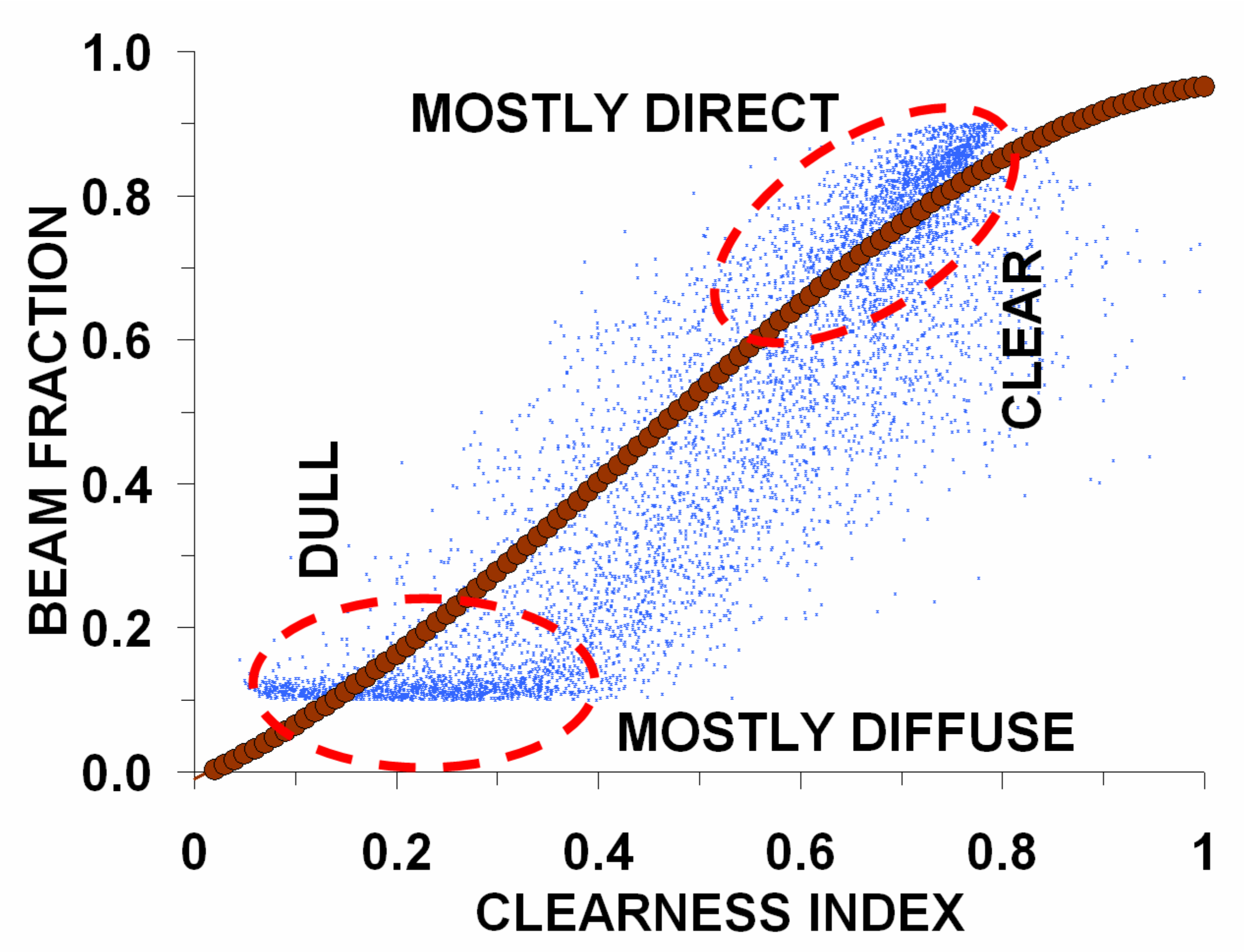
Cloudy kT = 0.1-0.3, Clear kT = 0.6-0.8

Calculating Beam:Diffuse fraction from Clearness Index (i)

Models use a curve fit for Beam Fraction from Clearness Index



Calculating Beam:Diffuse fraction from Clearness Index (ii)

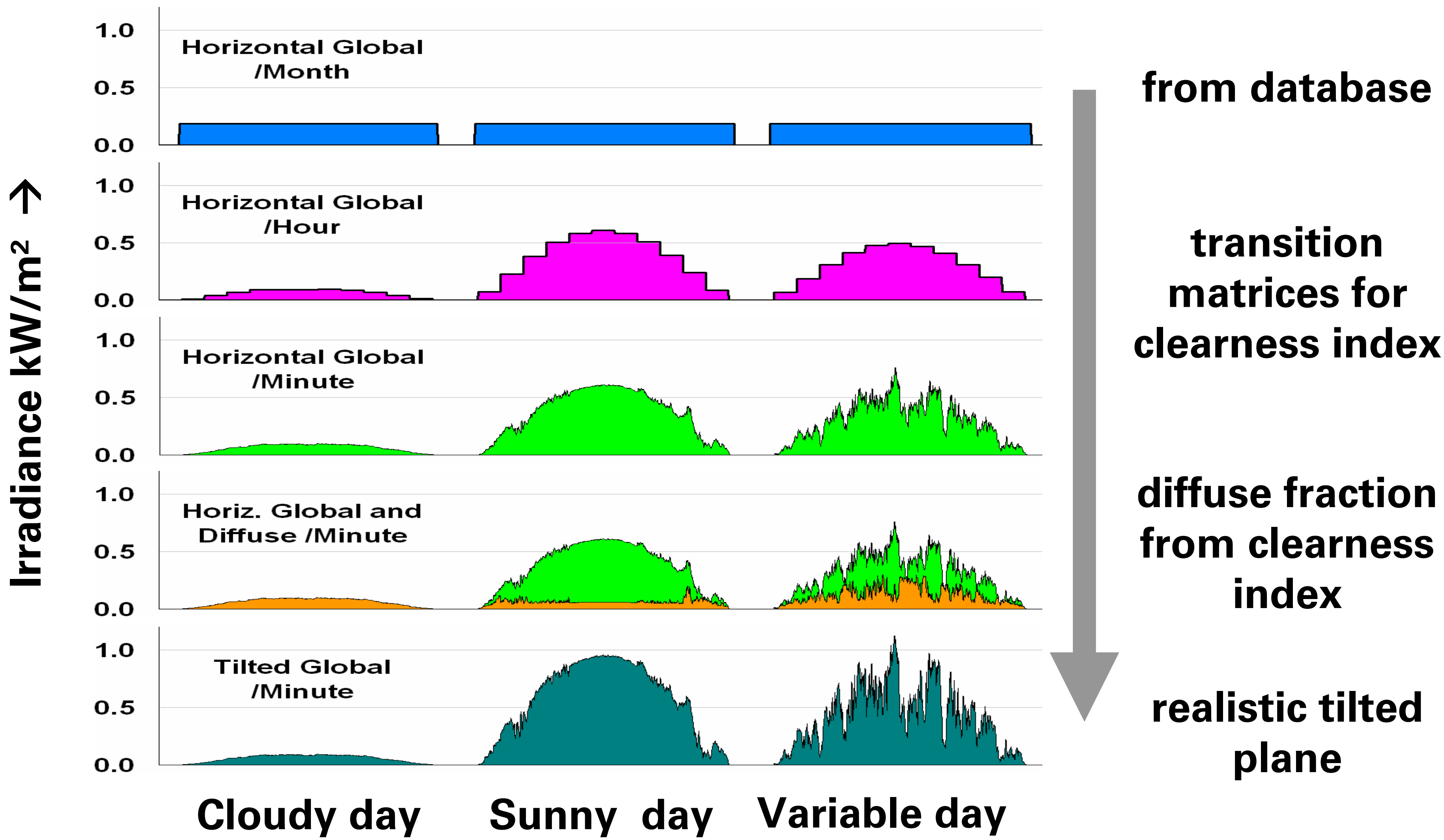


Models use a curve fit for Beam Fraction from Clearness Index

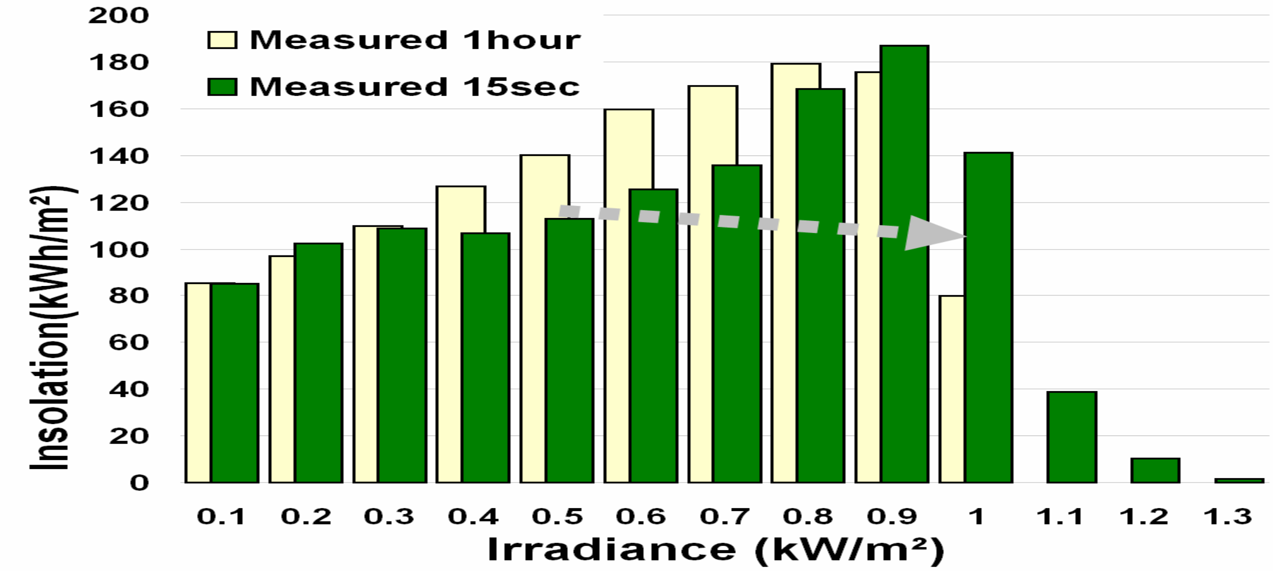
ISET data looks quite different

Large scatter but doesn't follow the model well

Calculating tilted plane irradiance from monthly horizontal average insolation

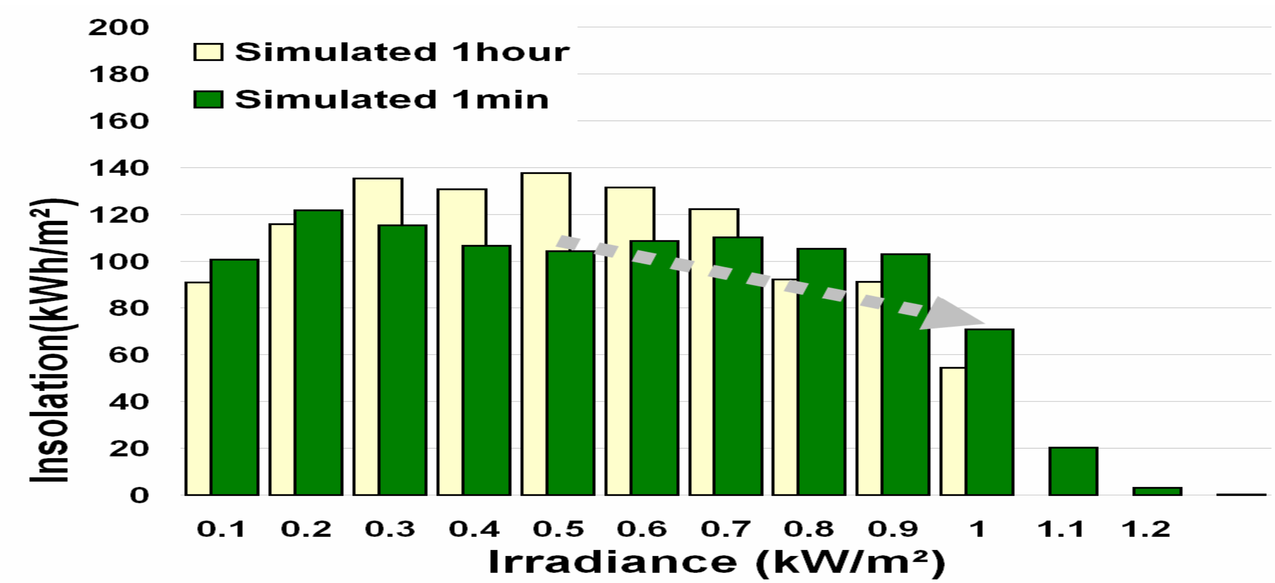


Measured vs Simulated Insolation vs Irradiance and frequency of measurement



Measured data

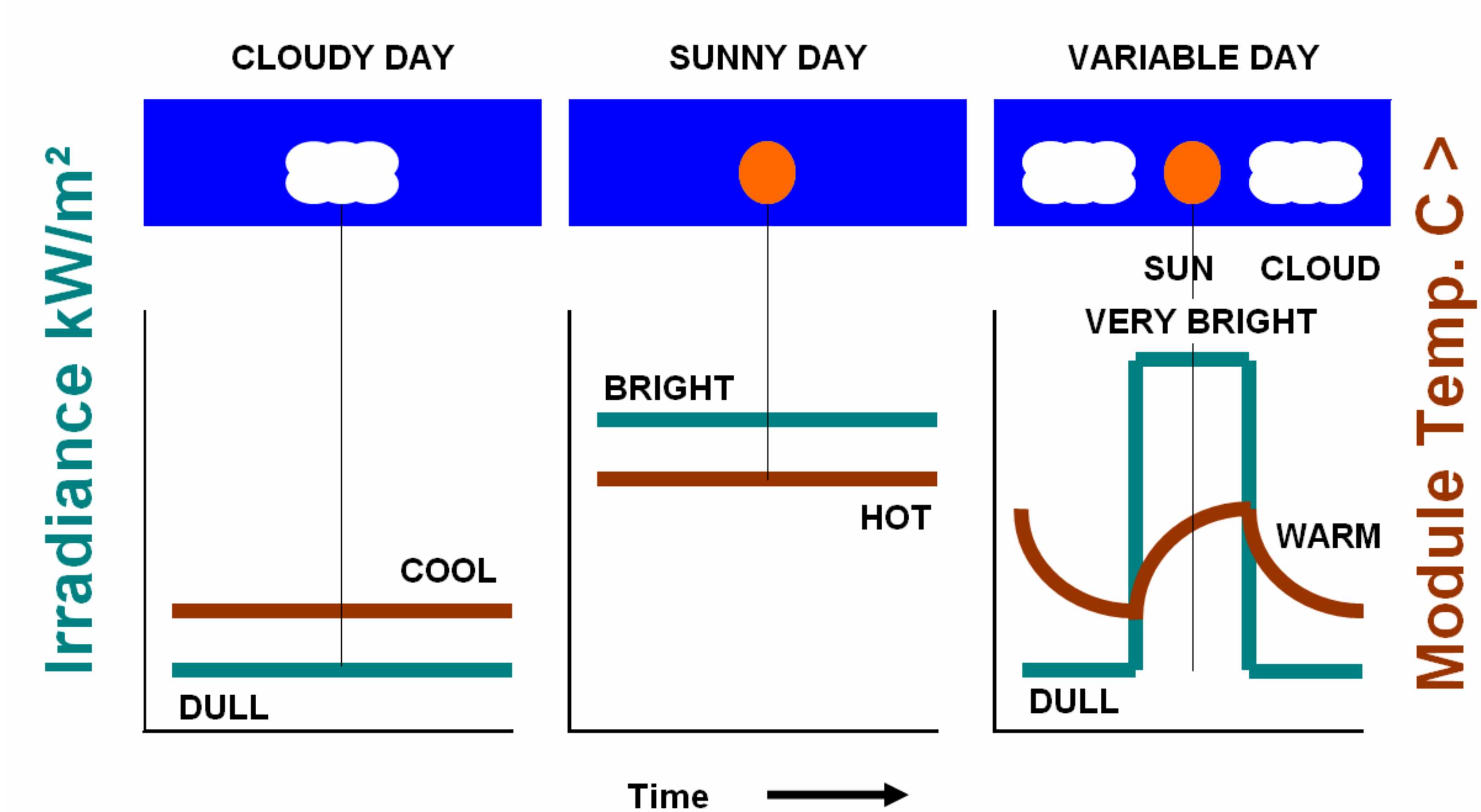
- Averaging overpredicts low light levels, loses high light



Modelled data

- also shows “averaging effect”
- has the wrong overall shape

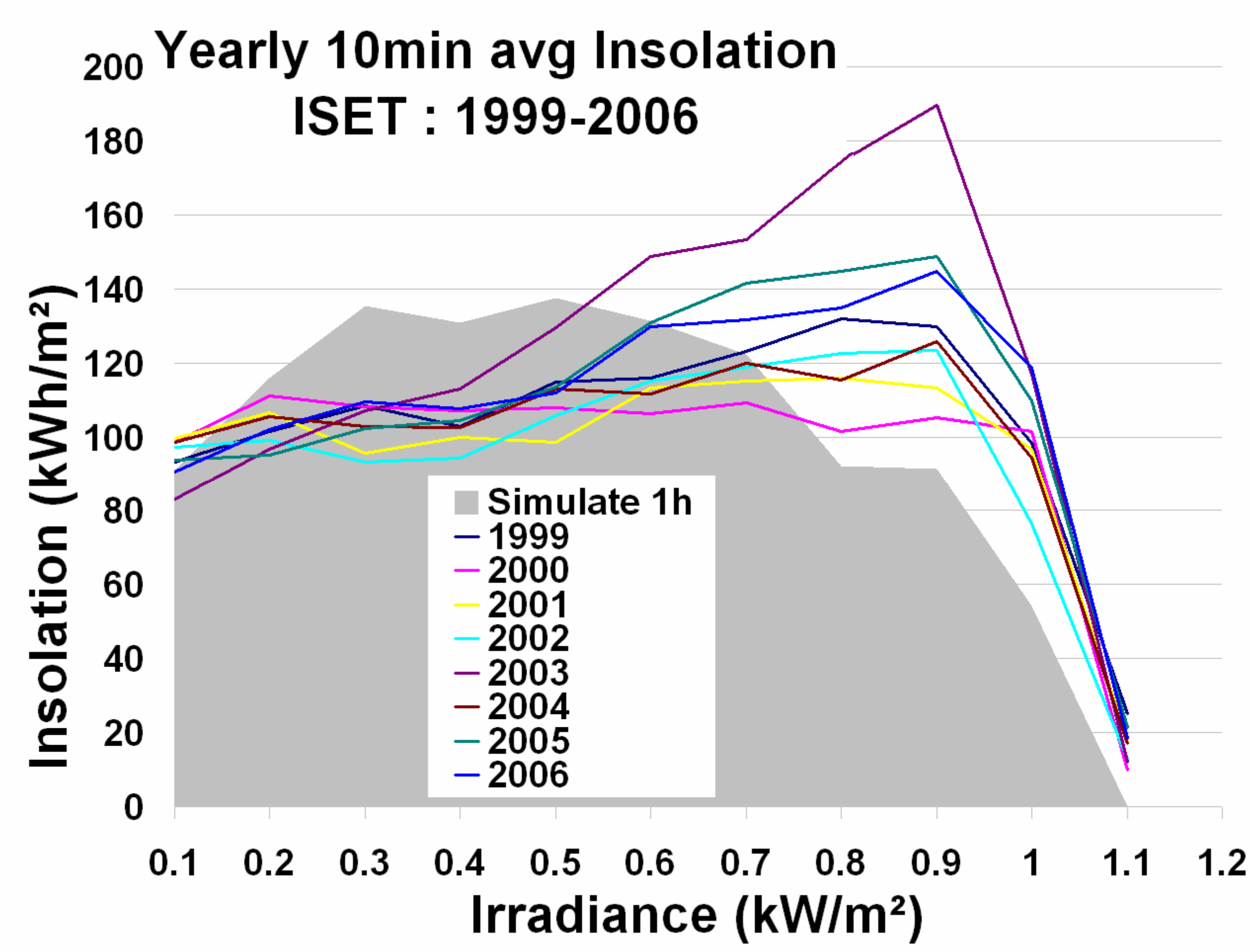
Module Temperature vs time and irradiance under variable weather



Variable weather :

brightness will be higher and temperatures cooler than averaging would suggest

Variability of weather ISET 1999-2006



- **Models predict most insolation at low irradiance**
- **Measurements show most insolation at high Irradiance (except for poor year 2000)**
- **yearly insolations have a stdev of ~ ± 4%**
- **Model has wrong shape**

Models for module efficiency vs irradiance and temperature

- <u>Lookup table</u>
  (EN 50380 200-1000W/m^2 @25C, AM1.5)

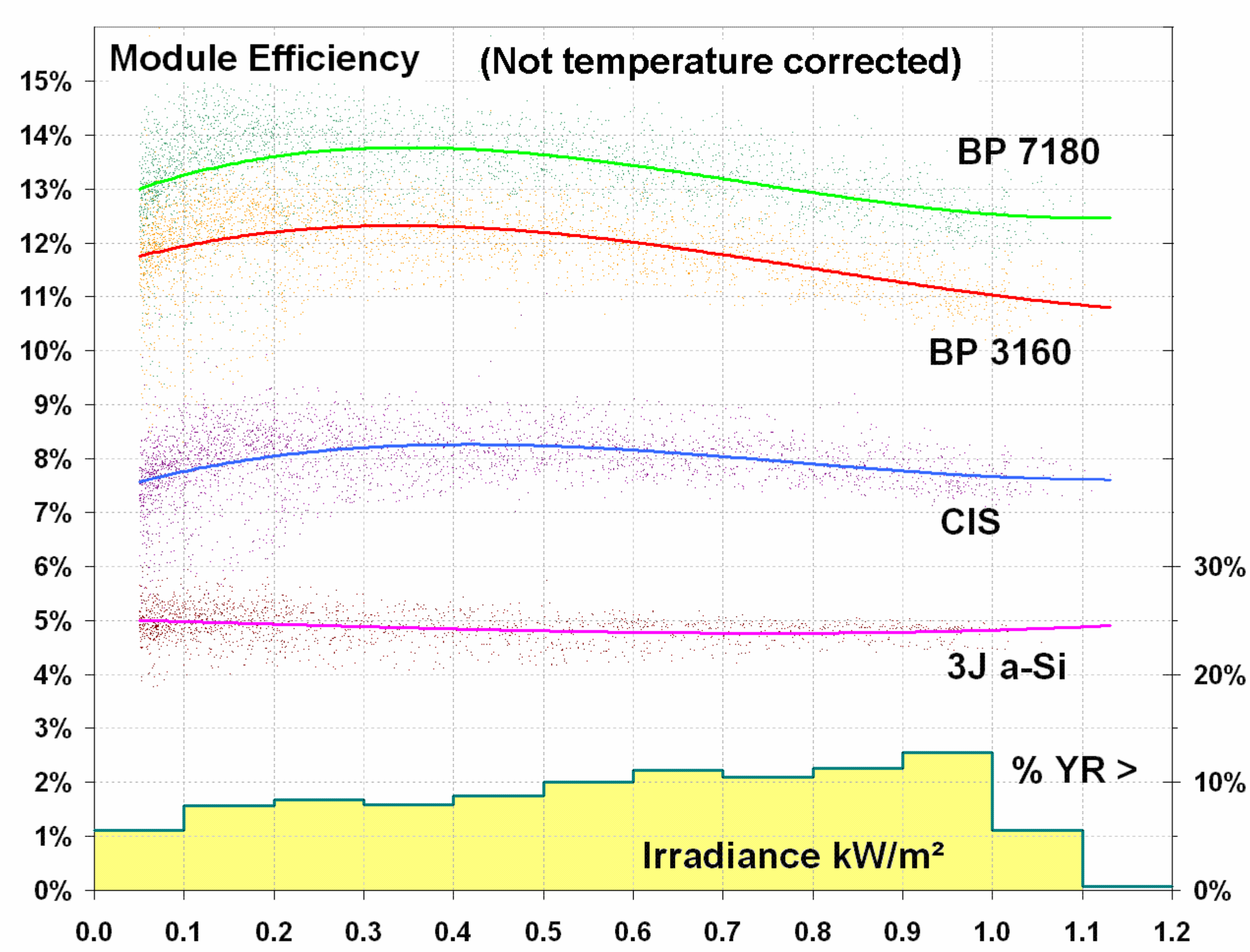
- <u>Pmax at "high" and "low" irradiances</u>
  Then interpolate a curve between two points
  (mathematically > 3 points are required for a curve)

- <u>Equivalent circuit 1-diode model (nf, Jo, Rs, Rsh, Jsc)</u>
  A 1-diode model does not fit IV curve near Pmax.
  Some parameters are temperature dependent

- <u>Spec sheet Data</u>
  Temperature dependency from α β γ coefficients.

- Characterisations usually on one module, but there is a spread in module parameters

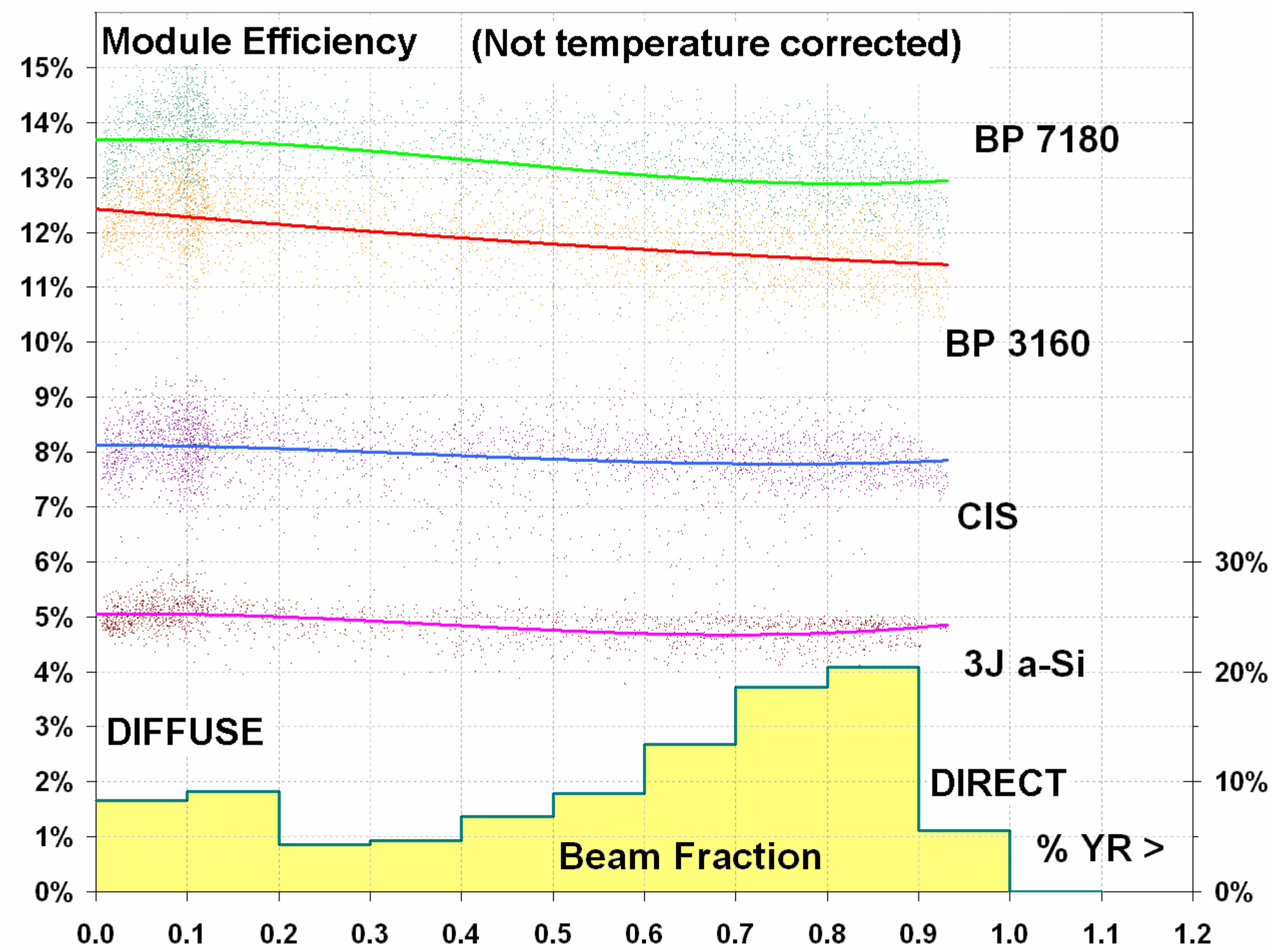
Outdoor Measured Efficiency
sc-Si, mc-Si, CIS, a-Si , ISET, Germany (i)



vs Irradiance

- **Similar relative efficiencies at low light level**
- **This looks <u>very different</u> to some models**

Outdoor Measured Efficiency
sc-Si, mc-Si, CIS, a-Si , ISET, Germany (ii)



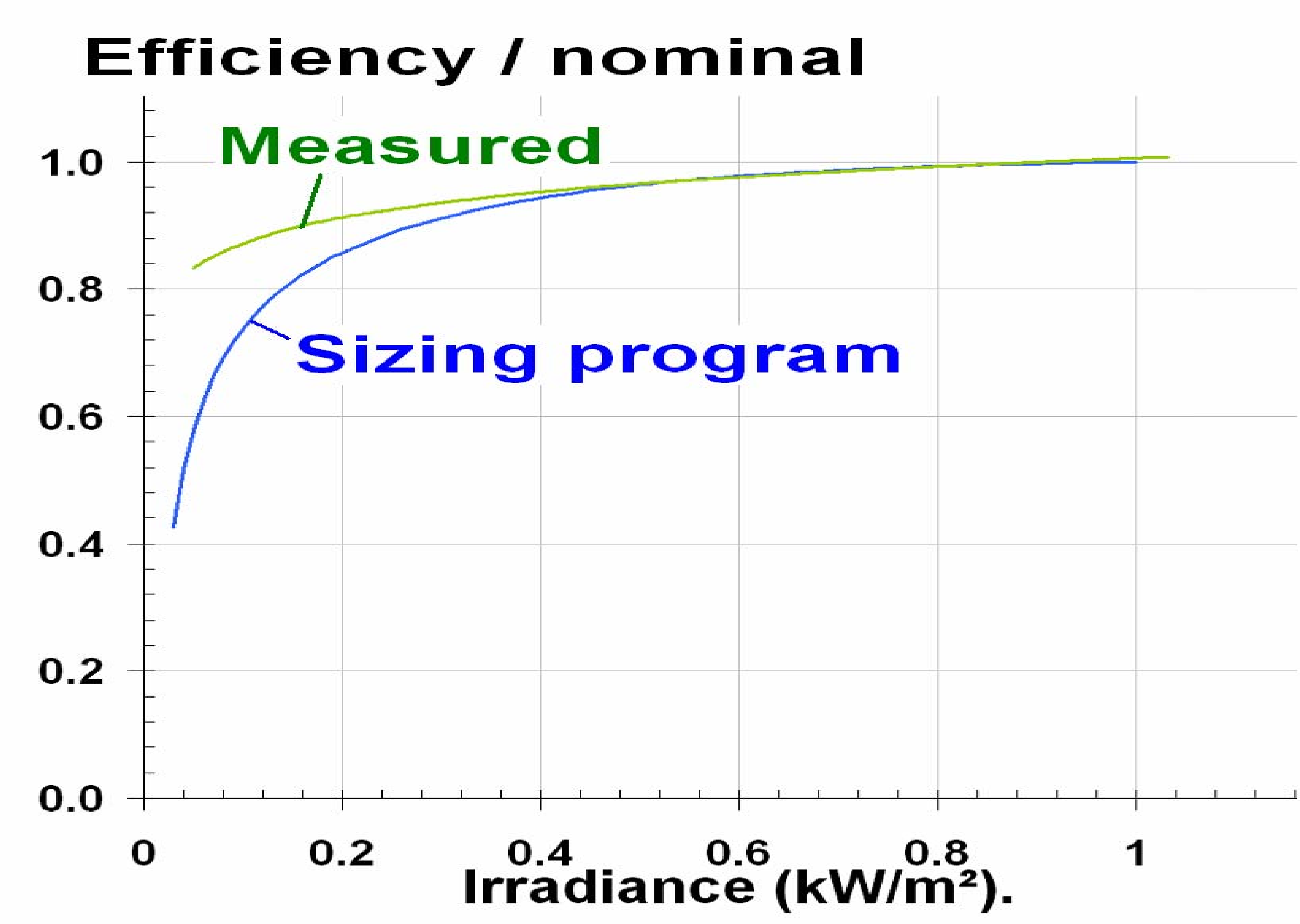
vs Irradiance

- Similar relative efficiencies at low light level
- This looks very different to some models

vs Diffuse:Beam

- **Similar relative efficiencies at Diffuse**
- **This looks very different to some claims**

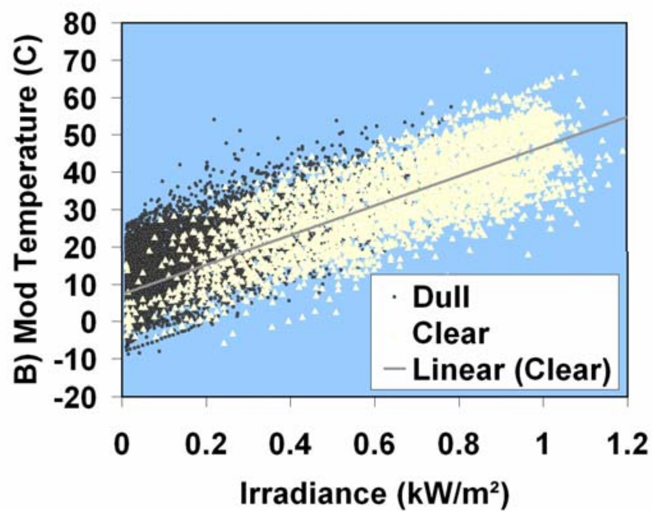
Outdoor Measured Efficiency
sc-Si, mc-Si, CIS, a-Si , ISET, Germany (iii)



All weather related parameters are correlated with irradiance

Weather Parameter	"Poor weather"	"Good Weather"
Irradiance (kW/m²)	Lower	Higher
Ambient Temp. (C)	Lower	Higher
Module Temp. (C)	Lower	Higher
Angle of incidence	~Parallel	~Normal
Solar height	Low (redder)	High (bluer)
Beam Fraction	~Diffuse	~Direct

Hotter module (y axis) with higher irradiance (x axis) →



Difficult to extract dependencies from outdoor measurements

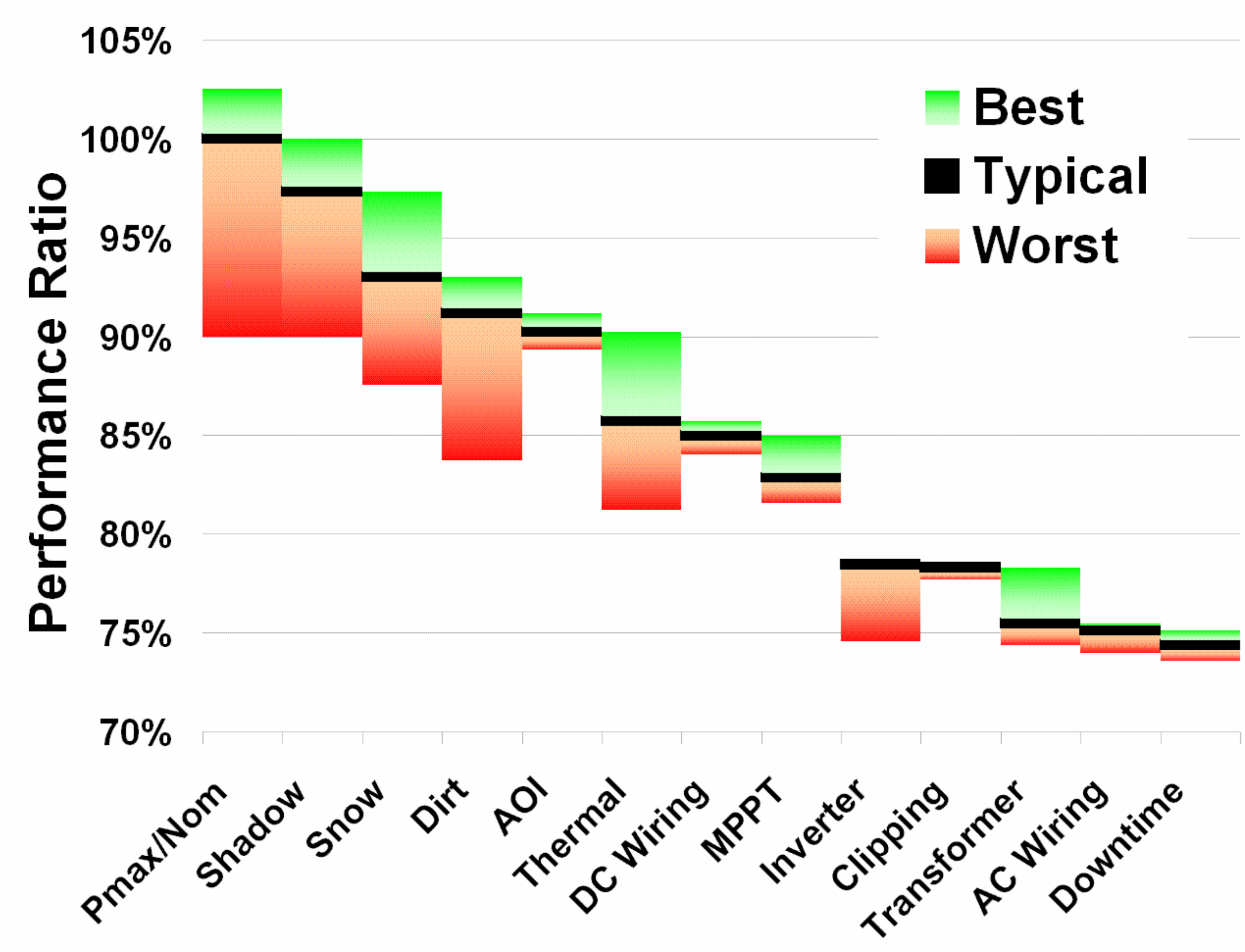
Inverter Modelling

How well are inverters modelled ?

Their efficiencies can depend on

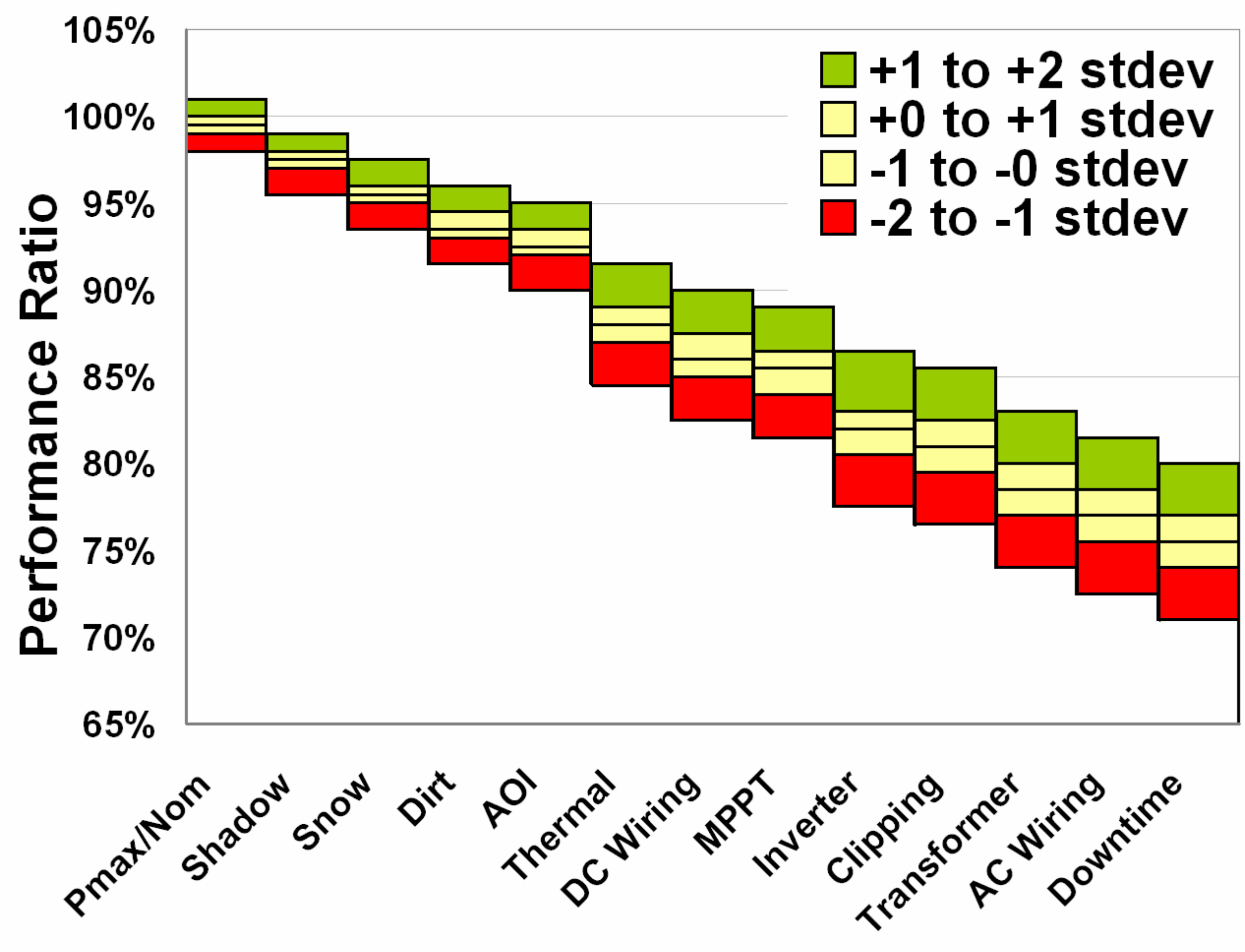
- **Input voltage (Baumgartner et al)**
- **Ambient temperature (ISET)**
- **Transient weather conditions**
- **Turn on**
- **Clipping**
- **Are all these considered ?**

PR vs loss stage with "best", "typical" and "worst loss" limits



- **High and low limits for loss in a typical PV System**
- **Final performance depends on the product of each of these**
- **A typical system is shown in black**
- **Just these losses result in a PR of ~75%**

PR vs loss stage showing ±1 and ±2σ spreads with uncertainties



- **Estimate 3sigma distribution from previous graph for loss in a PV System**
- **Final performance depends on the product of each of these**
- **Just the spread in these losses result in a PR of ~75±3% for 1stdev**

CONCLUSIONS

bp solar

- **Met Data programs can overestimate low light insolation**
- **There is a spread in performance of real modules not modelled in databases**
- **PV efficiency at low light/high diffuse is often better than Sizing databases**
- **Performance ratios ~75-80% can be obtained from both measurements and Sizing programs**
- **Unknown inputs can result in PR ± ~5% for a system**
- **Outdoor data gives better understanding of performance**
- **Sizing programs help minimise avoidable losses**

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This paper will soon join more than 70 of BP Solar's other technical papers at

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Thank you for your attention!