How accurate can PV energy yield simulations be?

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Introduction to Sizing programs

- Sizing programs
  - contain component databases
  - have many user defined inputs
  - use complicated algorithms

  estimate AC energy yield YF (kWh/kWp)

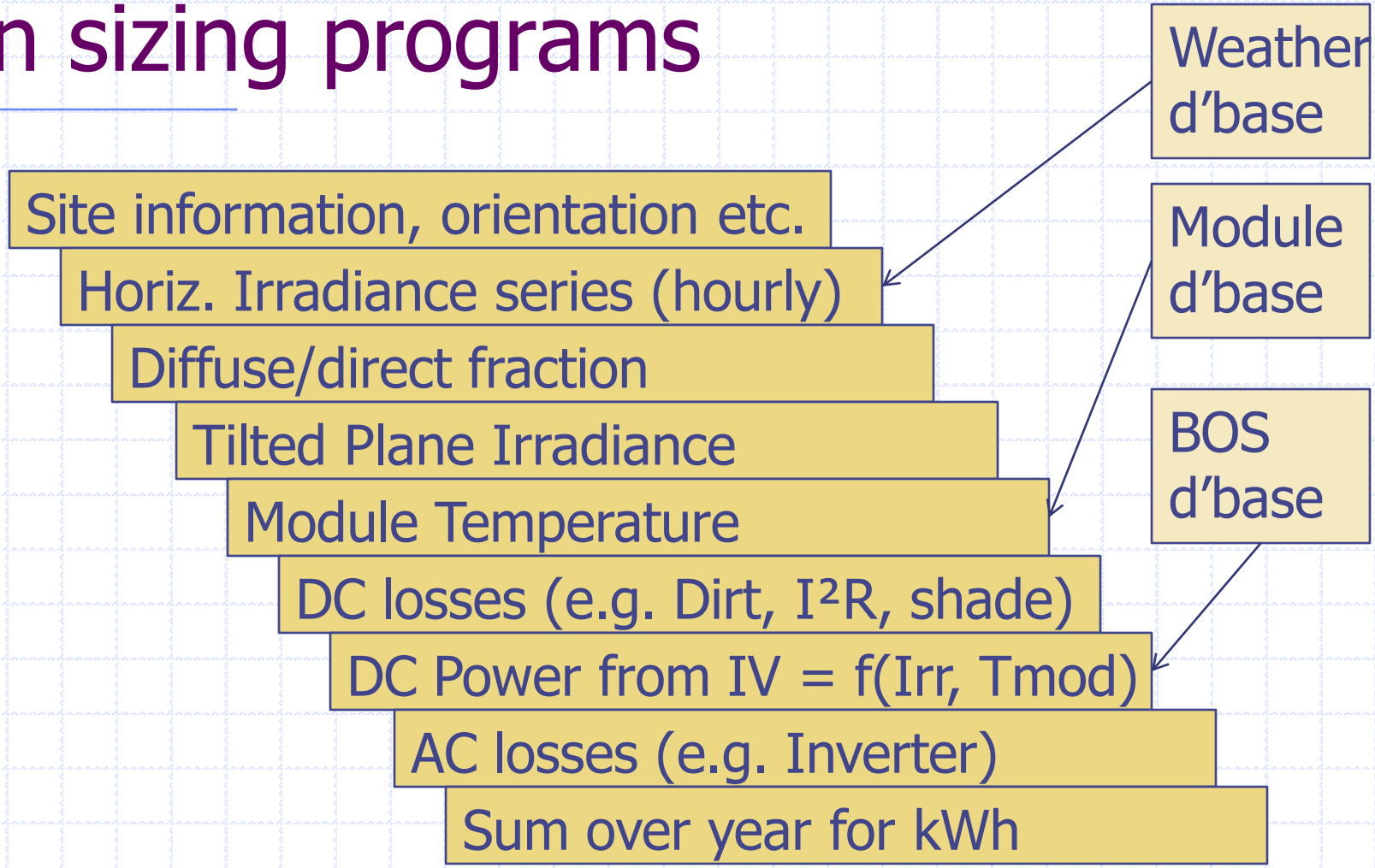
- Performance Ratio PR = measured/expected energy yield
- Measured PR can be ~ predicted values of 75-80%

- Do the programs model everything correctly?
- Are there so many unknowns that the predictions and output happen by chance to coincide to within a few %?

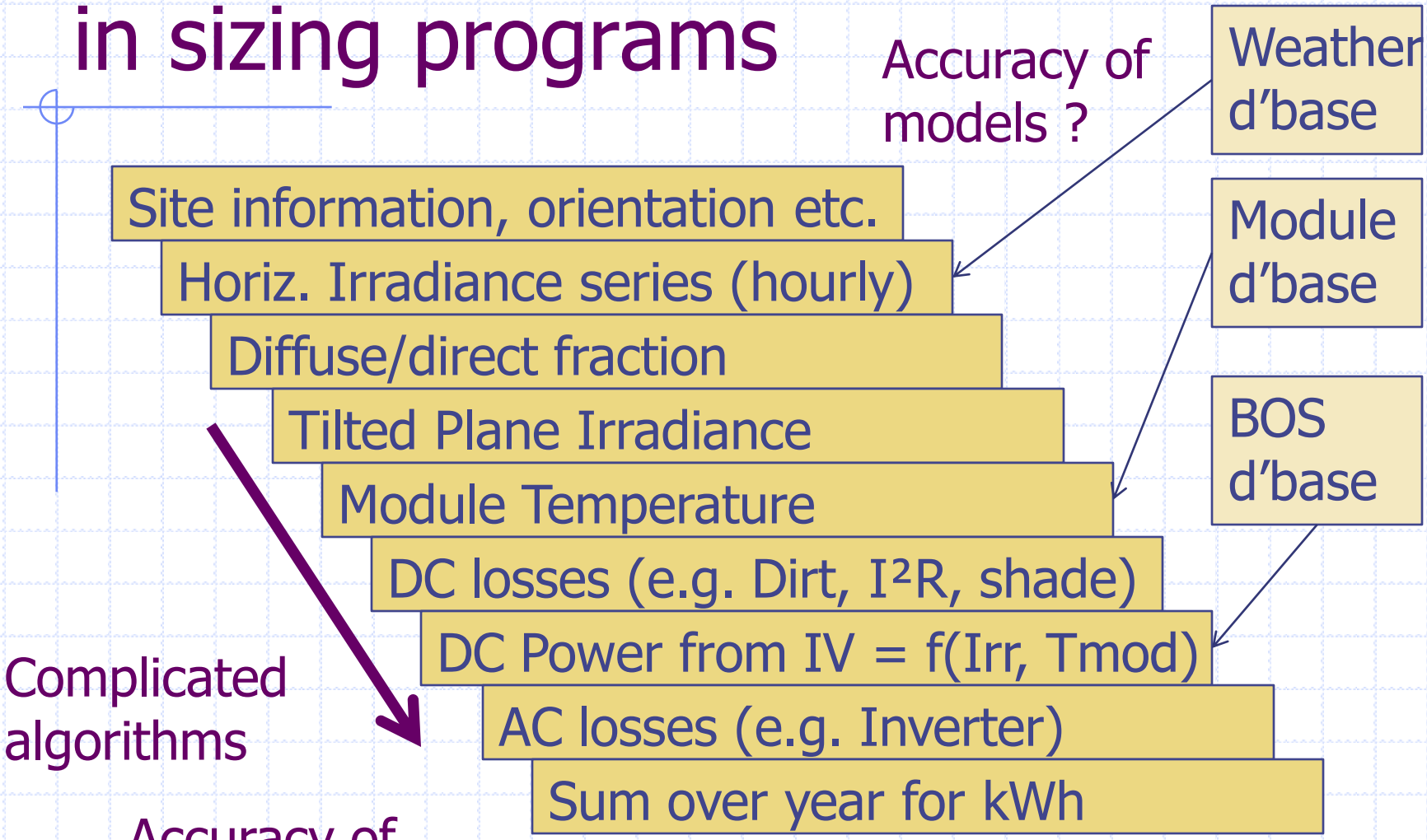
Weather and electrical measurements

- Irradiance (preferably plane of irradiance kW/m²)
  - pyranometers (flatter spectrally than cells and different angle of incidence)
  - reference cells (usually c-Si filtered for Thin Films response)
- Temperatures
  - shaded thermocouples (Tambient)
  - fixed to the back of the module (Tmodule)
- Wind speed
- MPP tracking – useful to monitor dc voltage
- AC power
  - instantaneous power
  - cumulative energy value
- Other – diffuse fraction, horizontal irradiance, precipitation

Common calculation steps in sizing programs

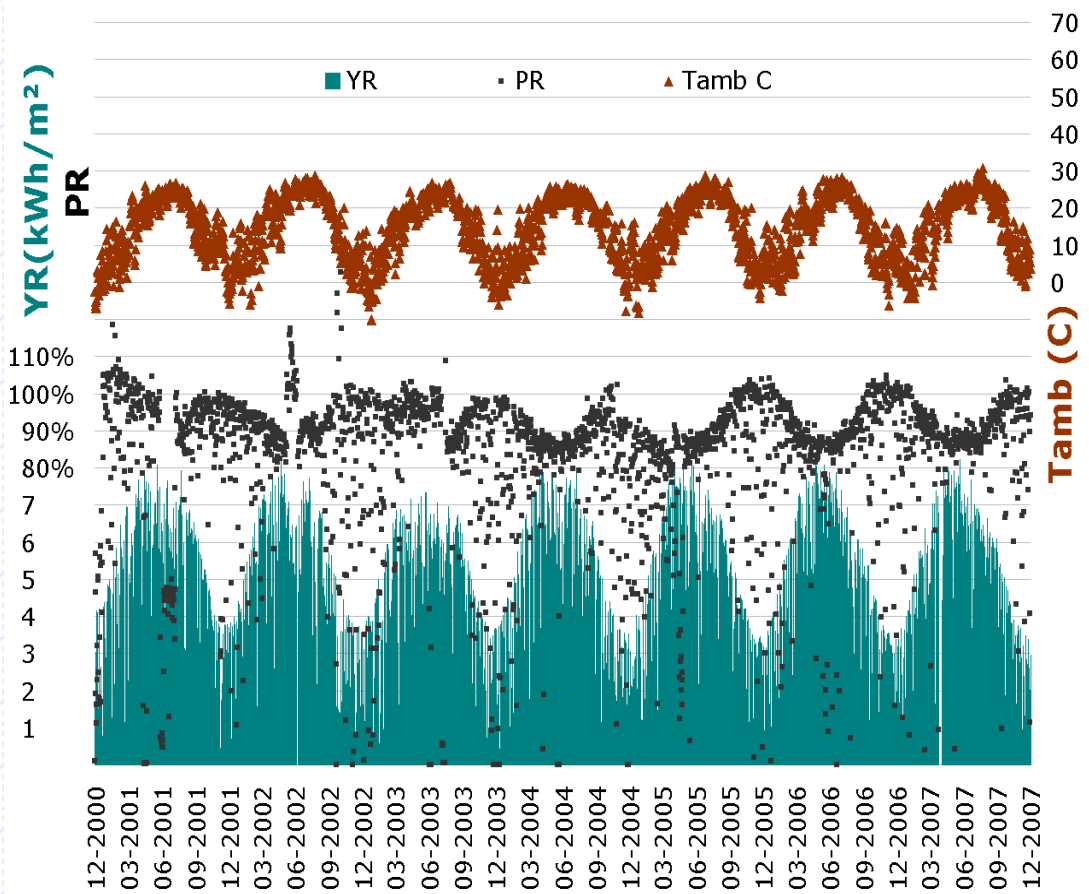


Common calculation steps in sizing programs



- Sizing programs predict one value for kWh/kWp
- How does this compare with real outdoor measurements ?

Typical 3rd party data - 7 years daily Thin Film array in USA



- Repeatable Tambient and Insolation each year
- Slight decline in PR 1st year then becomes more seasonal
- Lowest PR in summer

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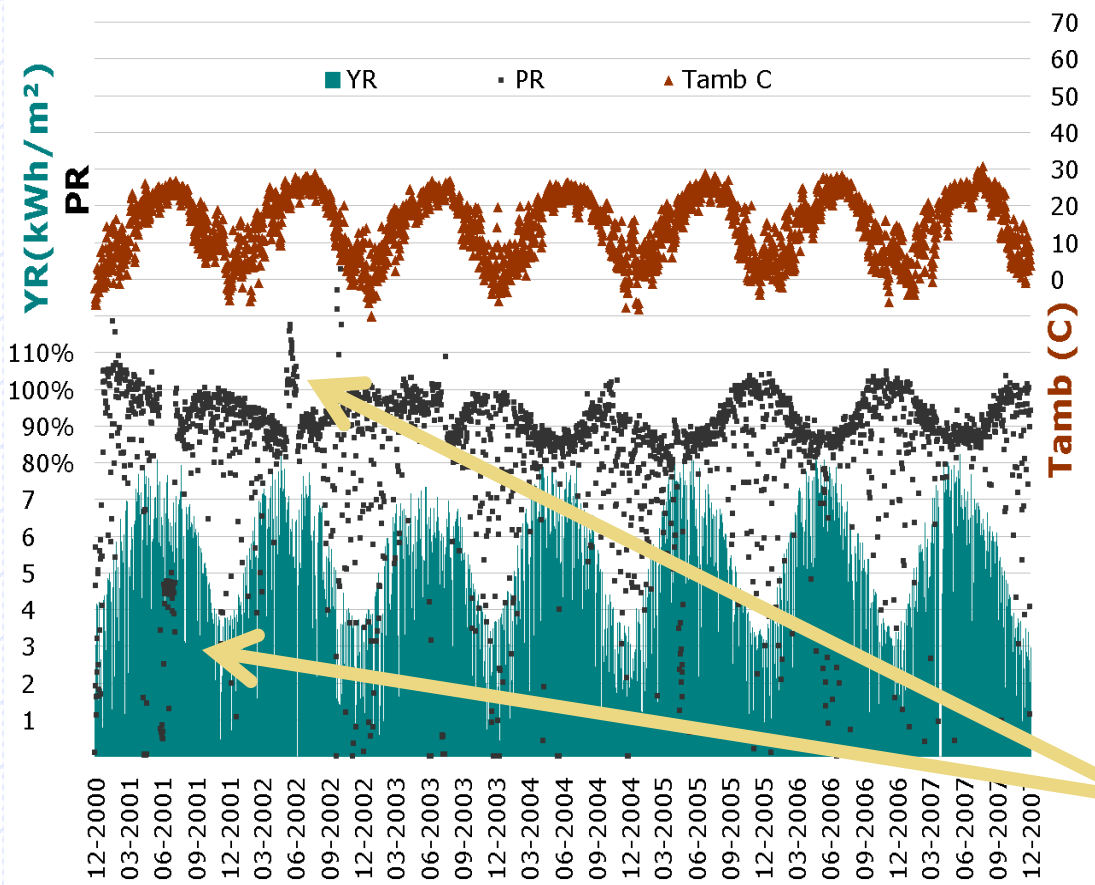
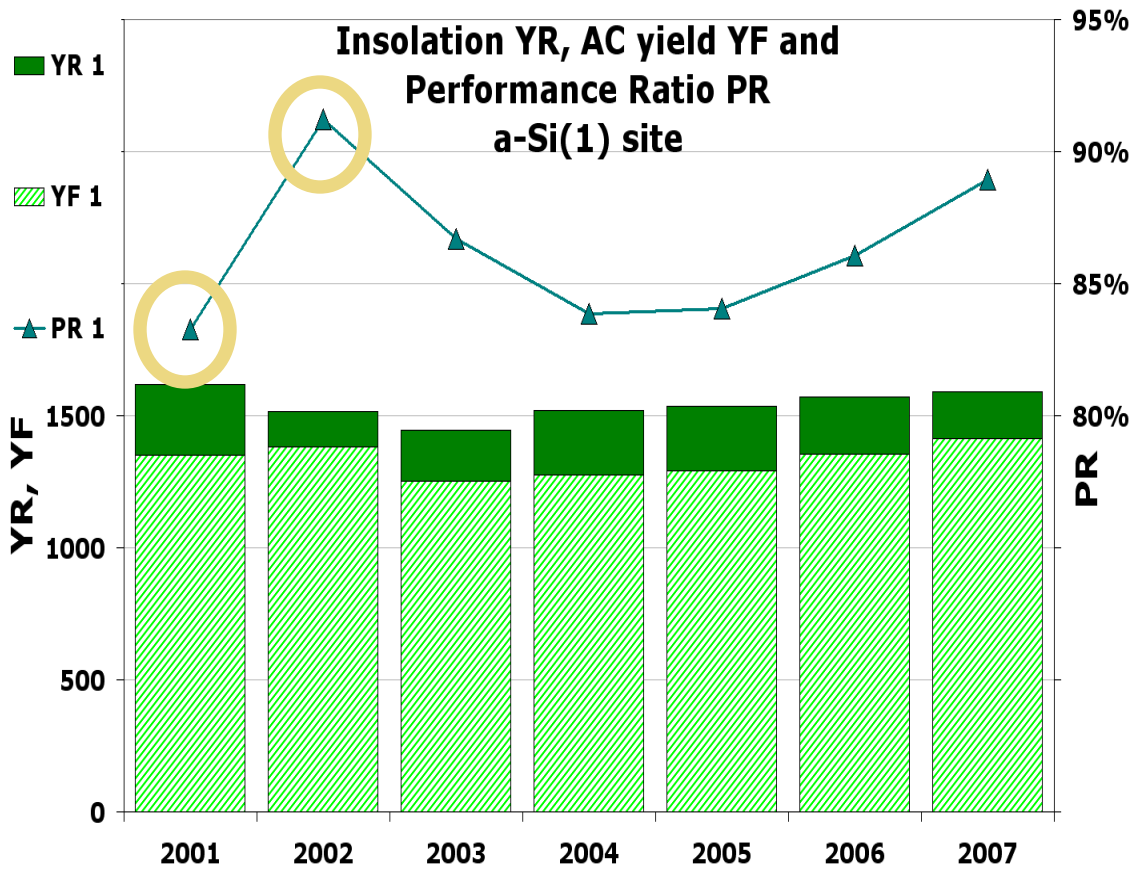


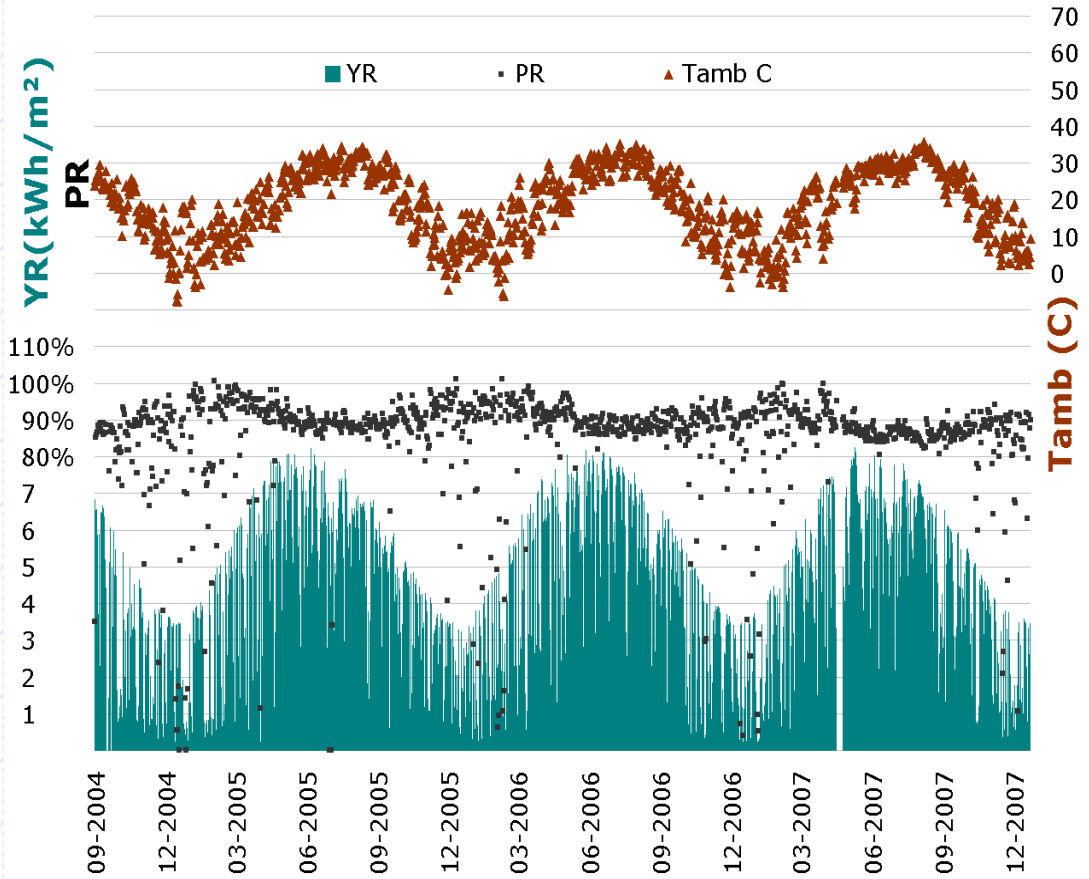
- Repeatable Tambient and Insolation each year
- Slight decline in PR 1st year then becomes more seasonal
- Lowest PR in summer
- Some clumps of too high or low PR

Performance of the thin film array yearly sum 2001-2007



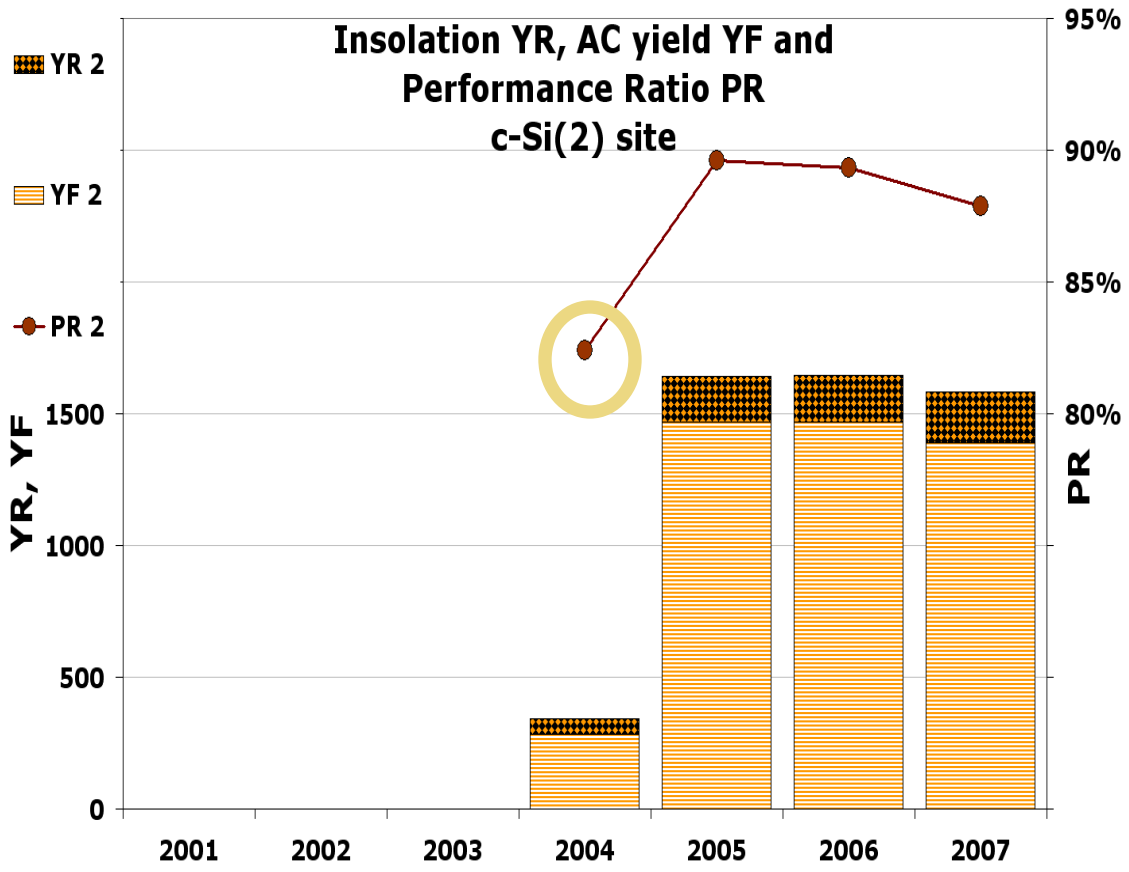
- Note variability in PR each year >5%)
- 2001 PR system downtime?
- 2002 PR low Irradiance measure-ments ?

Typical 3rd party data
3+ years daily c-Si array in USA



- Repeatable Tambient and Insolation each year
- Slightly lower PR in summer
- Some PR data too low in winter

Performance of crystalline array yearly sum 2004-2007



- Note variability in PR each year (>2%) full years
- 2004 start up, not full year

Summary of both typical sites

- Even though the Temperature and Insolation appeared steady each year there were still changes in the PR values, some due to measurement error, other may have been due to changes in the modules and/or bos components

Estimating variabilities in kWh/kWp produced

$$PR = \frac{YF}{YR} = \frac{\text{AC yield}}{\text{POA insolation}} = \frac{(kWh/kWp)}{(kWh/m^2)}$$

Rearrange to find kWh

$$kWh = PR * (YR) * (kWp)$$

Performance Ratio

Insolation kWh/m²

Pmax Wp array

Estimating variabilities in kWh - at different test sites

		Different sites	
PR	Downtime Vmax tracking Inverter loss Rshunt eff at low light Dirt etc.	? ? ? ? ± 1%	
YR	Pyranometer calibration Yearly Insolation	± 2% ± 4%	
kWp	Reference Module Module in Band degradation seasonal/annealing	± 2% ± 2.5% <-1%/y ?	
Sum		± 6-12%	

Estimating variabilities in kWh - side by side comparisons

		Different sites	Side by Side
PR	Downtime Vmax tracking Inverter loss Rshunt eff at low light Dirt etc.	? ? ? ? ± 1%	? ? ? ? same
YR	Pyranometer calibration Yearly Insolation	± 2% ± 4%	same same
kWp	Reference Module Module in Band degradation seasonal/annealing	± 2% ± 2.5% <-1%/y ?	± 2% ± 2.5% 0 to -1%/y ? ?
Sum		± 6-12%	± 6%

Conclusions

- Several large unknowns explain some variabilities in array performance (different sites and side by side comparisons).
- ac logged data shows random variations year by year
- Sizing programs can never be better more accurate than the unknown input variables.
- Sizing programs should be used mostly to design and check monitored systems to not have large avoidable losses.
- Comparisons shouldn't just show kWh/kWp sums but attempt to find reasons for any variations such as low light, high temperature, downtime or module rating

Thank you for your attention

The presentation paper and slides will soon be available at

http://www.steveransome.com