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Plane of Array (POA) Irradiance Modeling

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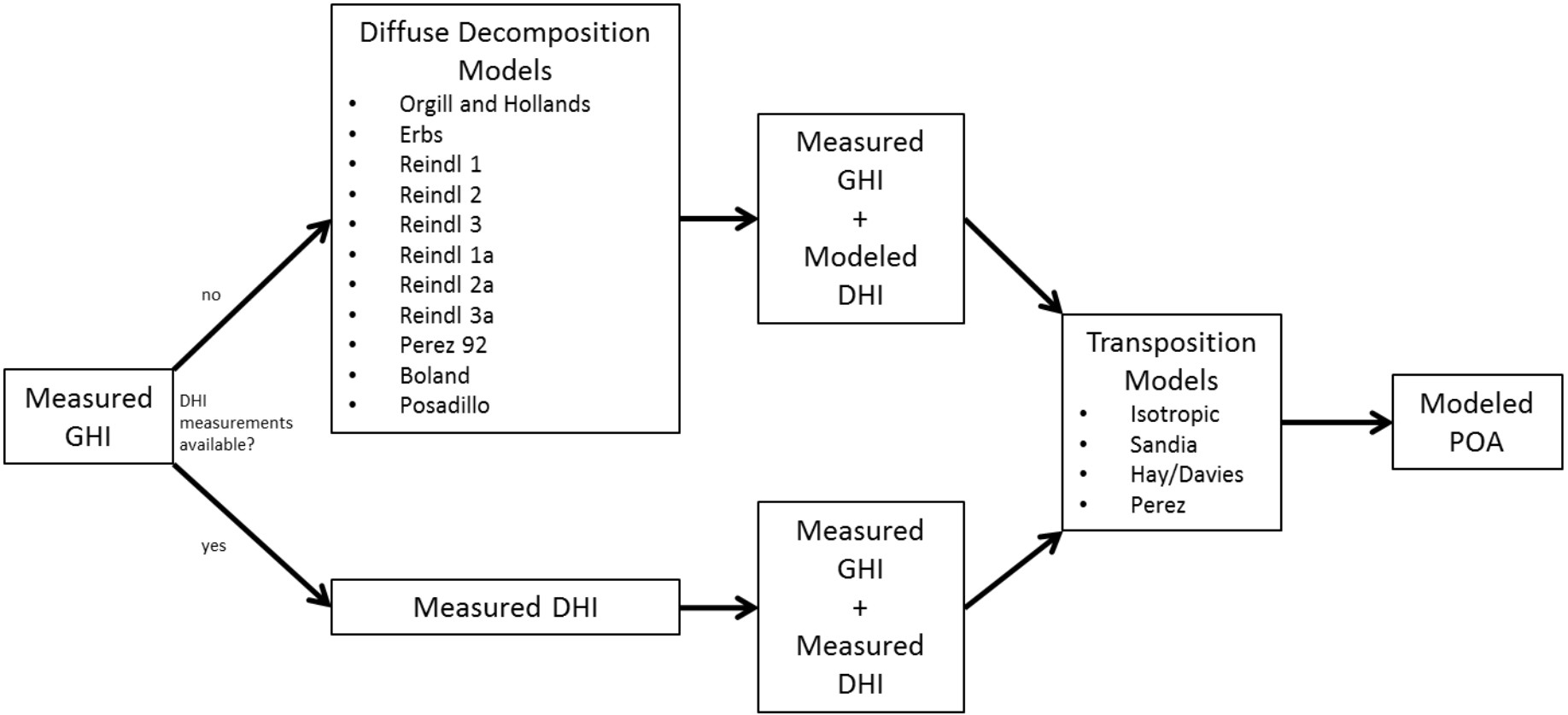
- This is a preview of work of forthcoming publications (PVSC 40 oral presentation and paper, Sandia technical report)
- Estimating plane of array (POA) irradiance often requires a sequence of models:
  - Decomposition: GHI to direct normal irradiance (DNI) and diffuse horizontal irradiance (DHI)
  - Transposition: GHI, DNI and DHI to total irradiance in POA
- Many choices are available for each step
  - E.g., Erbs decomposition + Hay/Davies or Perez 92 in Pvsyst
- First Solar and Southern Co. provided data for a representative set of different climates
- Sandia and First Solar evaluated numerous models, individually and in combination
- Which models should be used?
  - Performance Guarantees
  - Energy Predictions
  - Are there ways to help mitigate risk?



- Decomposition Models

Model	Input variables
Orgill and Hollands	Kt, GHI
Erbs	Kt, GHI
Boland	Kt, GHI
DISC	Kt, GHI, SunEl
Reindl 1	Kt, GHI
Reindl 1 adj	Kt, GHI
Reindl 2	Kt, GHI, SunEl
Reindl 2 adj	Kt, GHI, SunEl
Reindl 3	Kt, GHI, SunEl, AmbT, RH
Reindl 3 adj	Kt, GHI, SunEl, AmbT, RH
Perez 92	Kt, GHI, SunEl
Posadillo	Kt, GHI, SunEl, MF

- Transposition Models

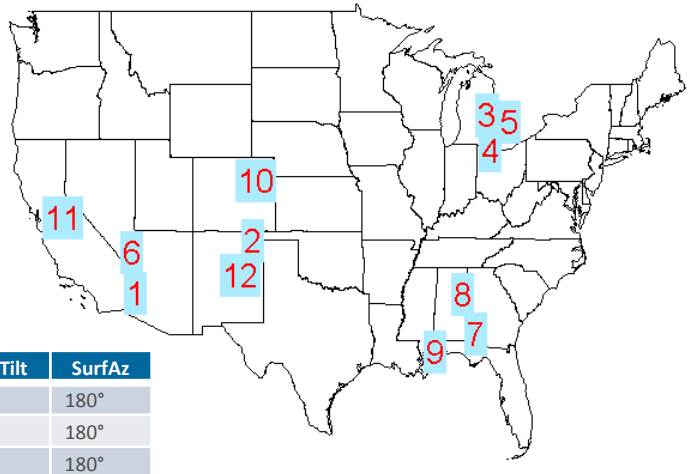
Model	Input variables
Isotropic	DHI, SurfTilt
Sandia	DHI, SurfTilt, GHI, SunZen
Hay and Davies	DNI, DHI, HExtra, SunZen, SurfTilt, AOI
Perez	DNI, DHI, HExtra, SunZen, SurfTilt, AOI, AM

All models of either type are:

1. (stationary) empirical (piecewise) correlations;
2. between measured DHI, DNI, or POA and input variables;
3. using some historical hourly data set.

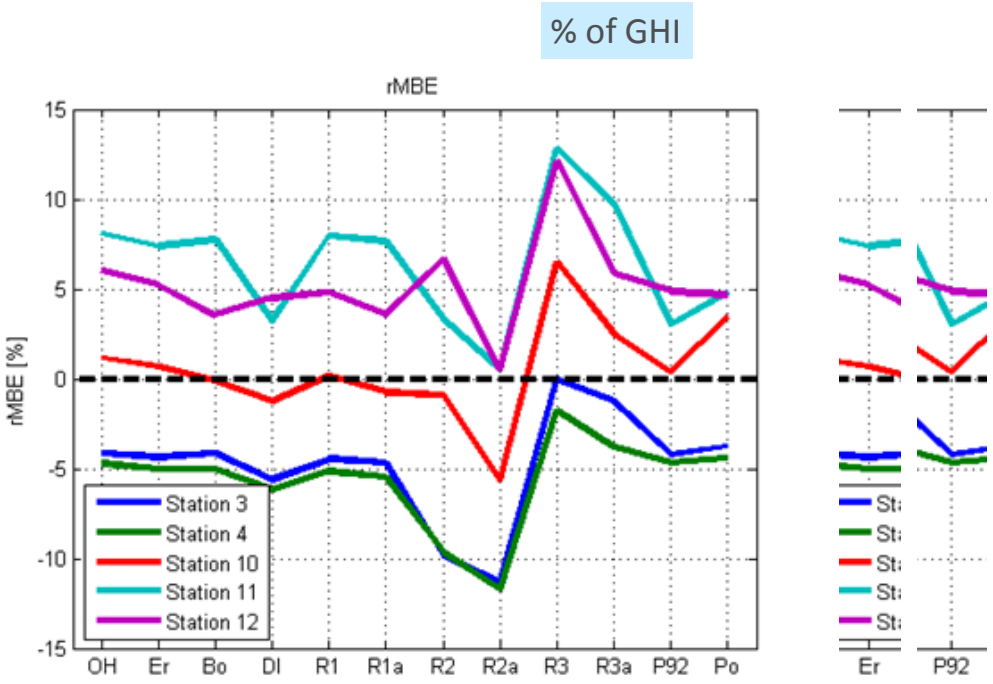
Several previous evaluations have found that models perform similarly at shorter time intervals.

- Twelve locations representing a range of climates
- GHI, POA for a southward tilted instrument
  - CMP-11, CM22, Eppley PSP, some Licor-200
  - Multiple instruments at several locations
  - DHI (RSR) at several locations (single instrument)

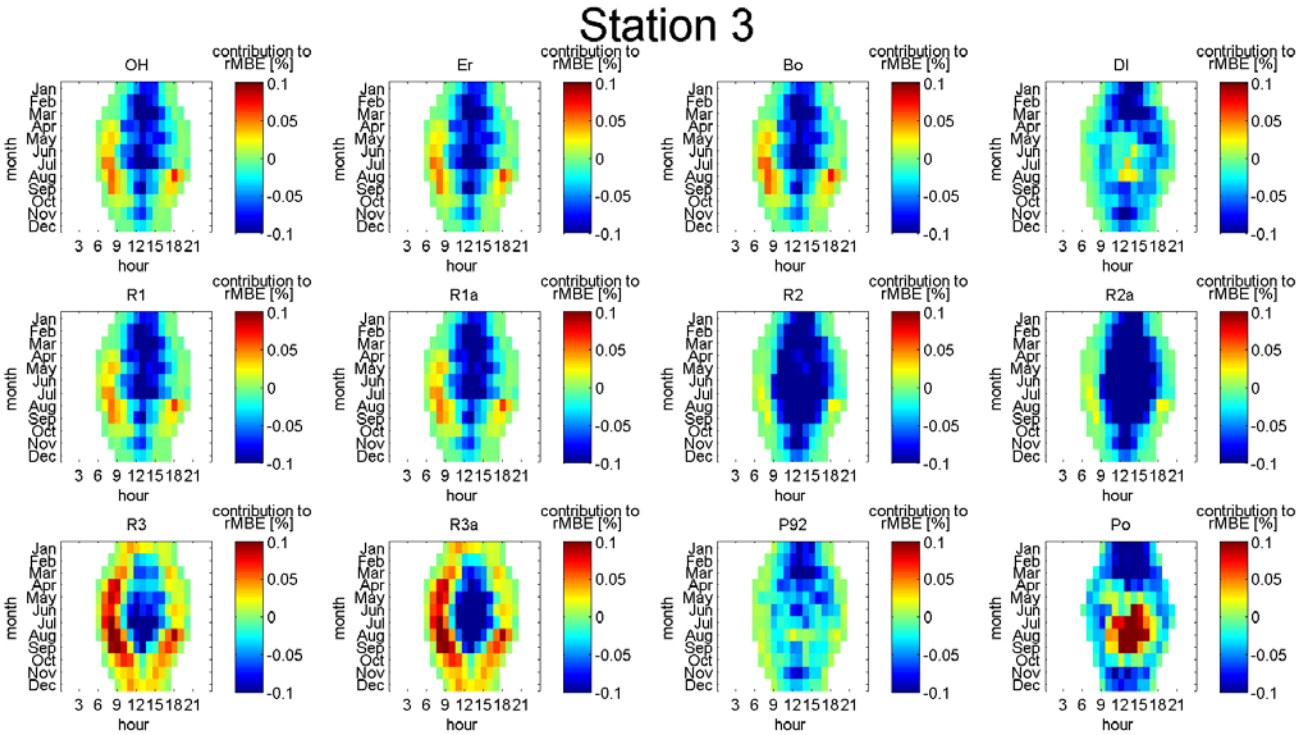


Station	Location	Elevation [m]	Climate Zone	Measured Data	Time Period	SurfTilt	SurfAz
1	Southeast CA	120	Arid Desert Hot (BWh)	GHI, POA	12/2009 - 8/2013	25°	180°
2	Northeast NM	100	Arid Steppe Cold (BSk)	GHI, POA	12/2010 - 8/2013	25°	180°
3	East MI	188	Snow; Fully humid; Warm summer (Dfb)	GHI, DHI, POA	2/2012 - 7/2013	25°	180°
4	East MI	181	Dfb	GHI, DHI, POA	2/2012 - 7/2013	25°	180°
5	East MI	193	Dfb	GHI, POA	10/2010 - 9/2013	25°	180°
6	Southern NV	572	BWh	GHI, POA	1/2011 - 12/2012	25°	180°
7	Southeast AL	97	Warm temperate; Fully humid; Hot summer (Cfa)	GHI, POA	8/2013 - 11/2013	26°	180°
8	Central AL	226	Cfa	GHI, POA	7/2013 - 11/2013	40°	180°
9	Coastal MS	6	Cfa	GHI, POA	2/2013 - 11/2013	15°	180°
10	Central CO	1829	BSk	GHI, DHI, POA	1/2013 -12/2013	40°	180°
11	Central CA	200	Warm temperate; dry, hot summer (CSa)	GHI, DHI	1/2013 -12/2013	N/A	N/A
12	Central NM	1657	BSk	GHI, GHI, POA	1/2011 – 12/2011	35°	180°

- Examined hourly data
- MBE : annual average deviation (model – measured) relates to annual energy
- RMSE : relates to hourly deviation
- Many models show similar deviation
- Perez 92 had lowest rMBE, rMAE and rRMSE at all locations, but
- Not significantly less than other models
  - E.g., compare Erbs and Perez 92
- Deviation in decomposition model depends on location
  - Partially reflects variation in sensor calibration
- Note that Erbs rMBE -5% at Station 4 (MI), +4% at Station 12 (NM)



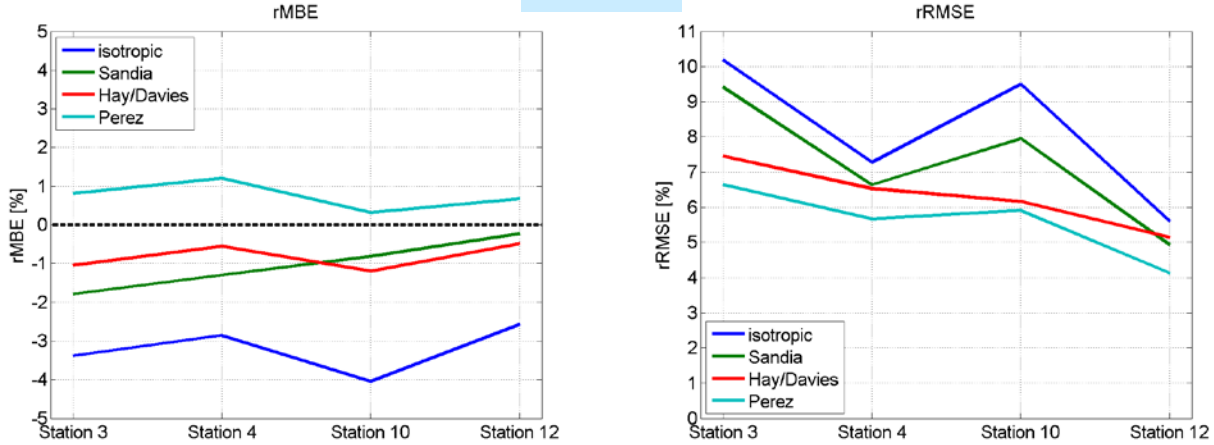
- Seasonal/time-of-day biases are evident for most decomposition models



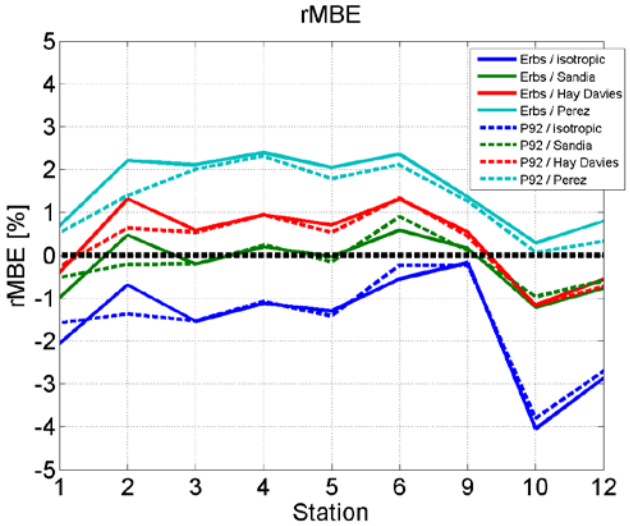
% of GHI

- Hay/Davies and Perez show lower deviation than other models; similar to each other.
- Systematic difference in bias: Perez > Hay/Davies
  - E.g., Hay/Davies rMBE -1% at Station 4, where Perez +1%
- Some dependence on location but does not appear to be significant for these sites

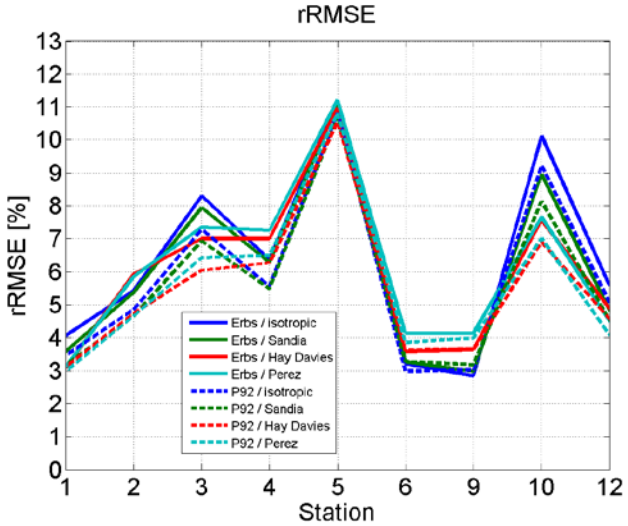
% of POA



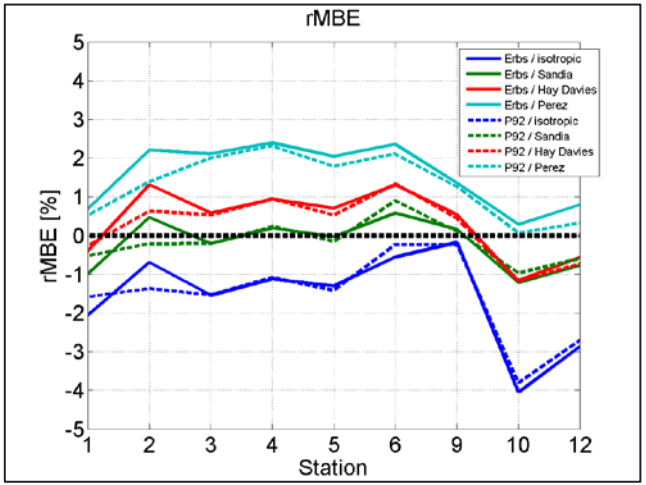
- Perez 92 (lowest deviation) and Erbs (default in PVsyst) with each of the transposition models
- POA deviation is NOT the sum of deviation from individual models
  - Diffuse deviation can be offset by transposition deviation
  - Perez > Hay/Davies but H/D>0 at Station 4 (where Erbs<0 and H/D<0 separately)



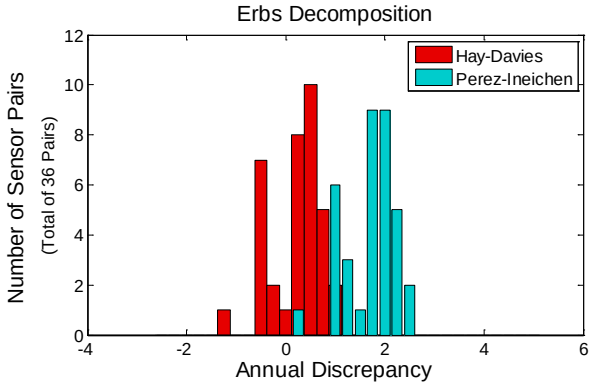
% of POA



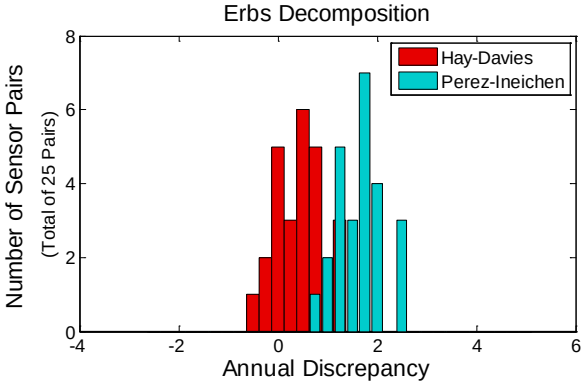
- Random uncertainty and bias error can be (and typically is) present in measurements which creates challenges when determining the level of *accuracy* of a given model.
- Looking at a larger population of sensors is needed in order to highlight random errors.



Multiple measurements points exist for GHI and POA at stations 1-6.

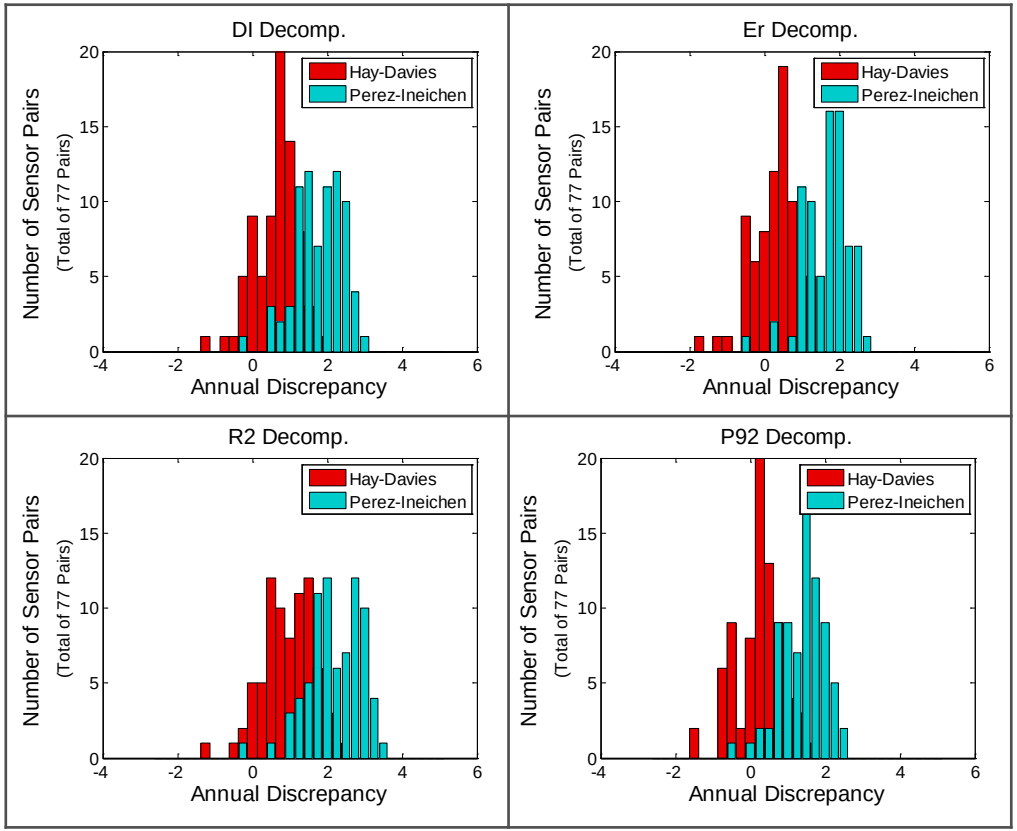


Plant 5



Plant 6

- Inputs to the model generally includes a number of secondary standard GHI measurements which should limit bias errors.
- From this study it has been found that Perez has a positive bias compared to Hay for ALL sensor pairs in ALL locations.
- PVsyst as the de-facto standard for performance modeling limits the focus to the differences between Hay and Perez using the Erbs decomposition.
- Furthermore, the distribution of errors for the Hay transposition model is more closely centered around 0%.



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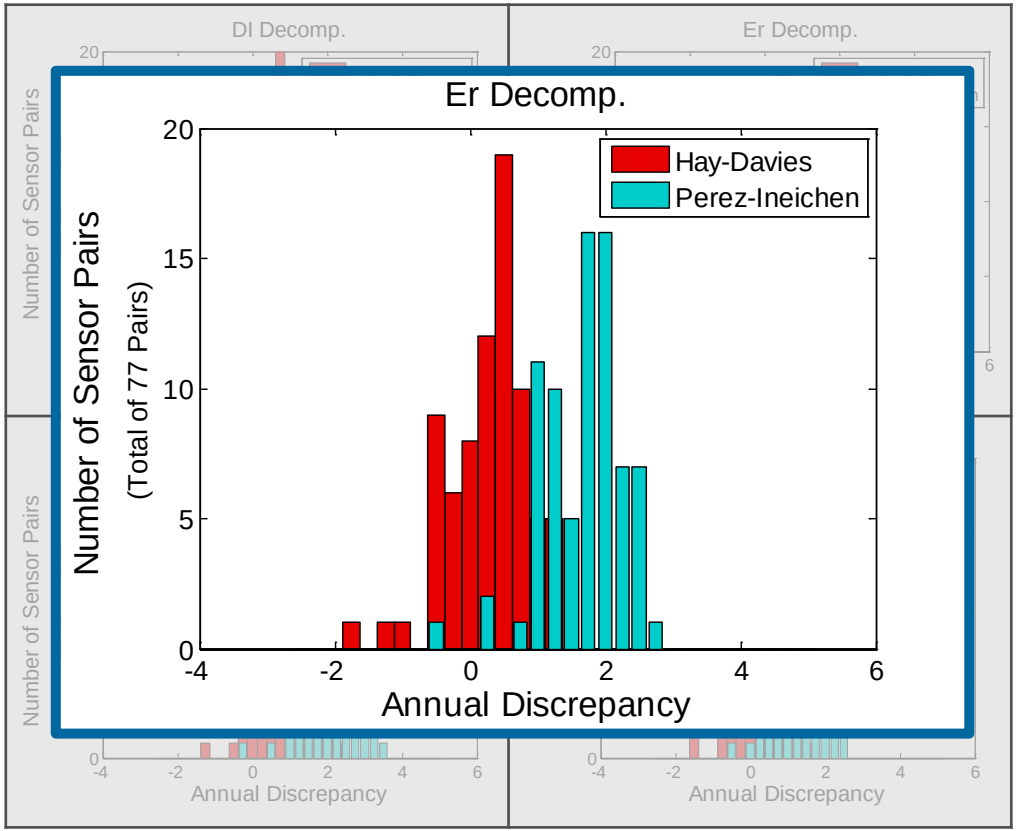
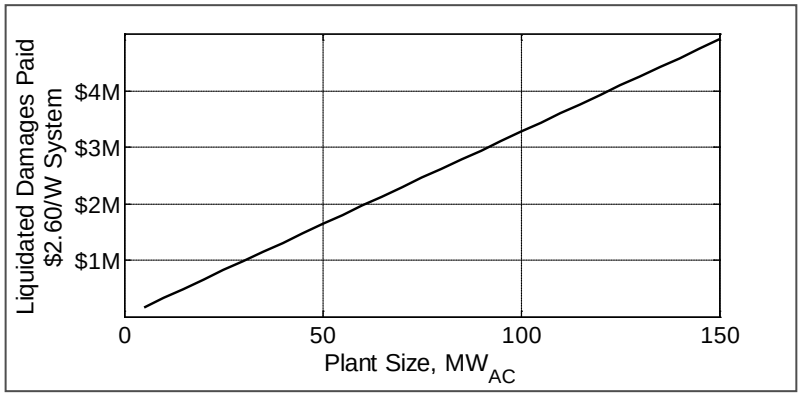
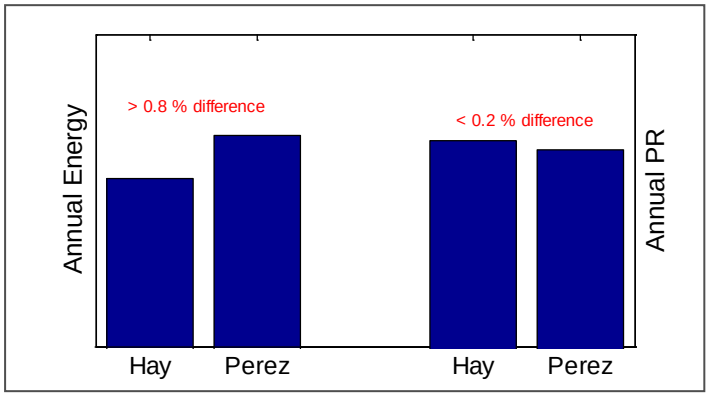


- How does the bias between the different transposition models influence the financial risk associated with a performance guarantee?
- In the event that the EPC fails the performance guarantee by 1% it is common that the terms of the guarantee require the EPC to pay liquidated damages of 1% of the contract price*.



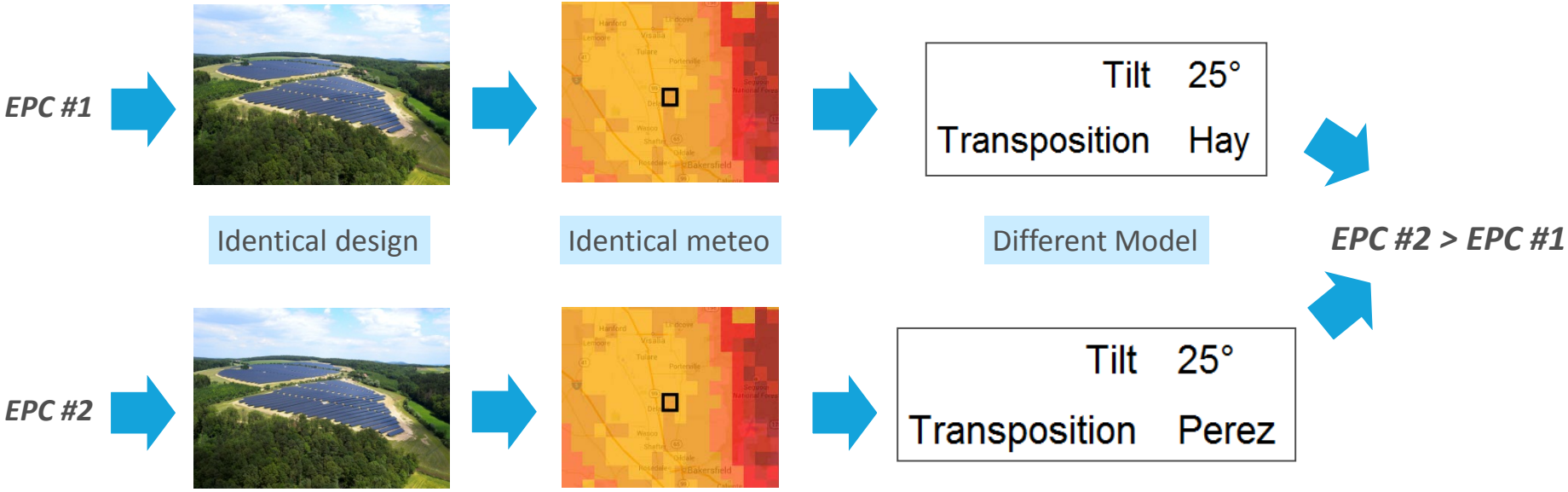


- Under-performance of a 40 MW$_{AC}$ system can cost an EPC/developer over $1M in LDs!
- This under-performance would not be observed if looking at the performance ratio.

*Common practice, but may differ.

System cost estimated at $2.60/W from GTM U.S. Solar Market Insight Report (2013)

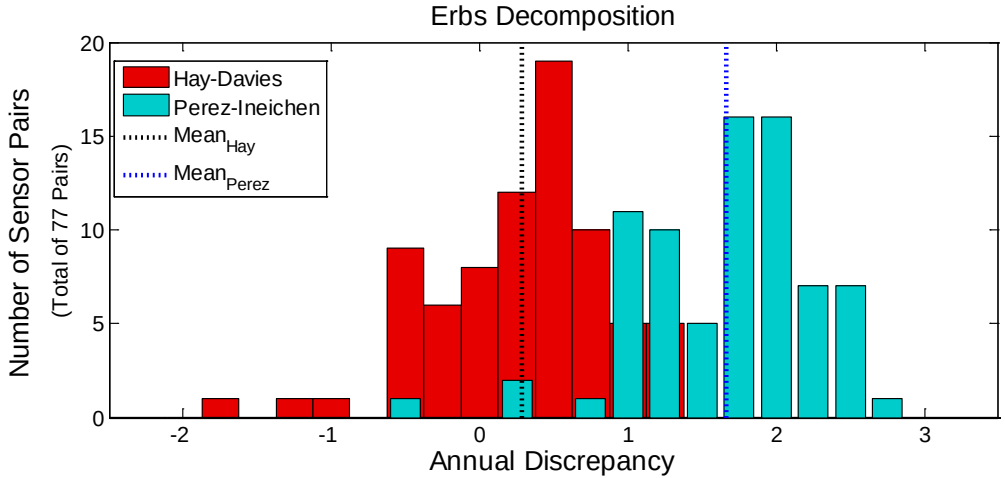
- This study has highlighted the bias difference that can be introduced in performance modeling at the point of the plane of array irradiance.
- This will have a direct impact on the financial metrics that are used to evaluate a project.



*http://maps.nrel.gov/prospector

- To help mitigate risk for energy predictions the RFP solicitor can define both the meteo file to be used as well as the transposition model to be implemented.
- There are ways to help mitigate risk in performance guarantees include:

Multiple sensor pairs will provide better accuracy (> 5-6 pairs won't tighten accuracy beyond +/- 1%)



- Use the Hay model when measurements of DHI are not available to avoid 1-1.5% bias.
- Use the Perez model when DHI measurements are available to achieve higher precision.

- We cannot comment on the uncertainty introduced by transposition models when the input data source is satellite data but it is recommended that this be studied to lower the risk for system owners/financers.