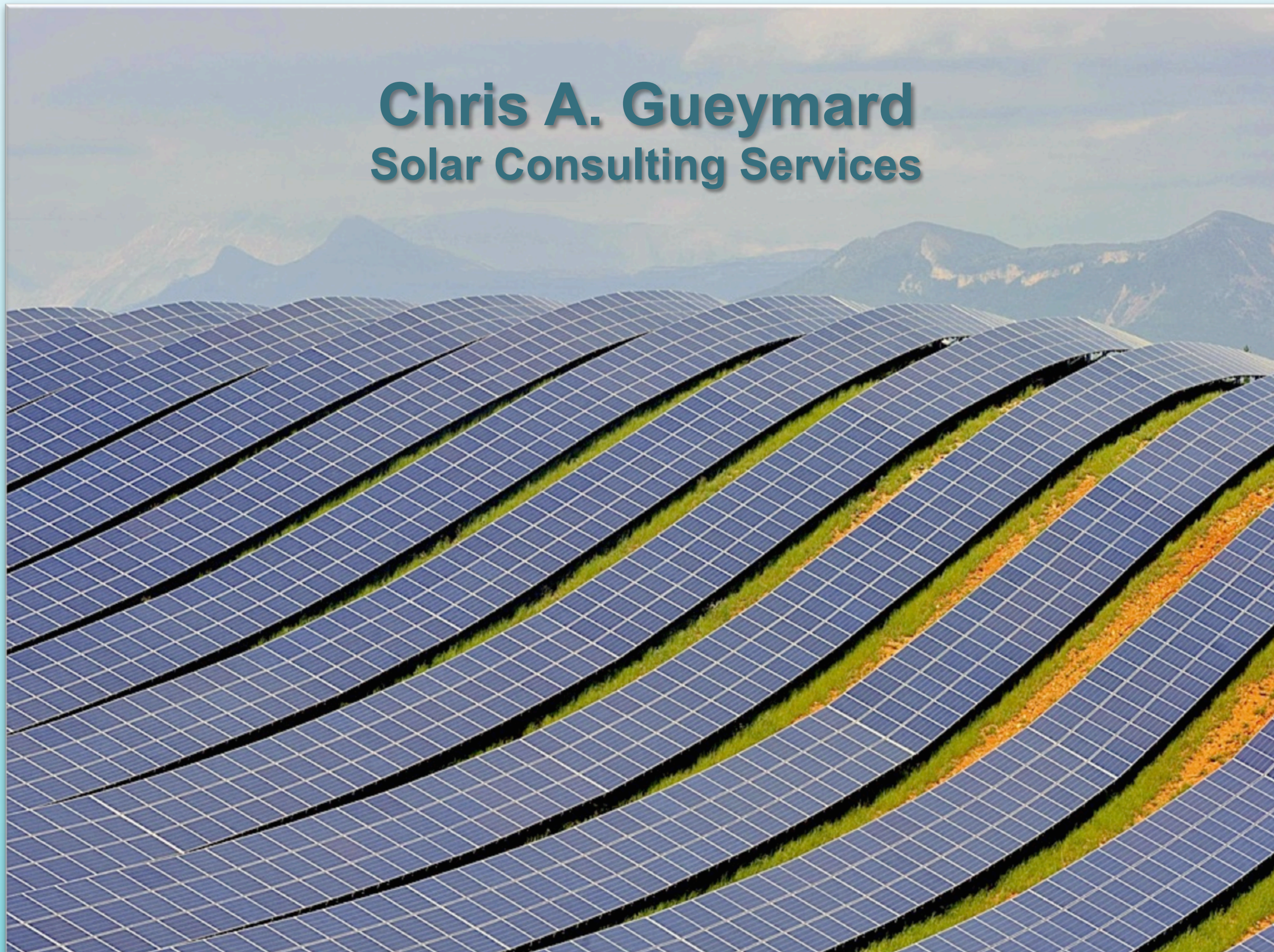
Uncertainties in Transposition and Decomposition Models: Lessons Learned



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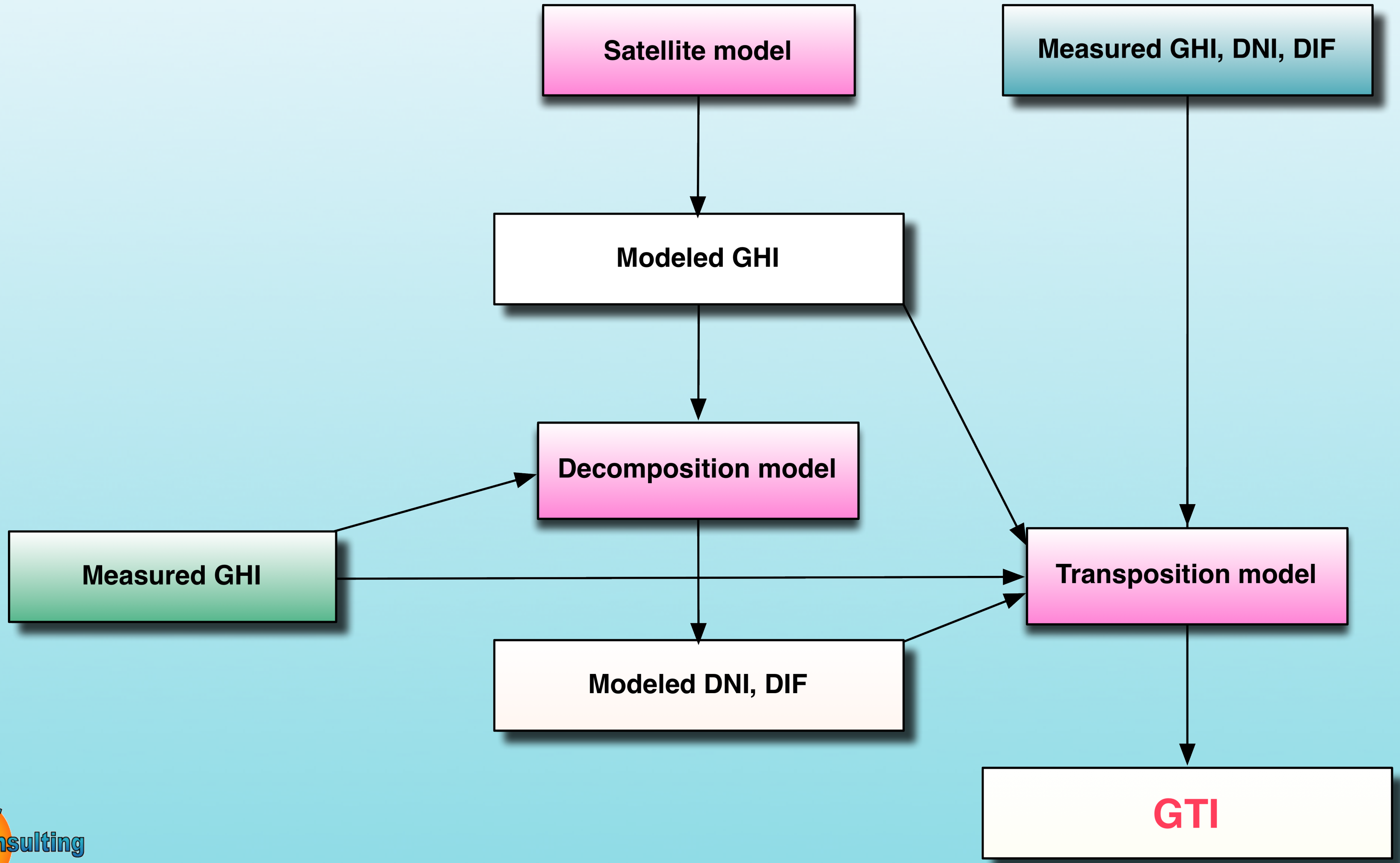
Overview

- How to obtain GTI (Global tilted irradiance on POA) if not measured?
- Three possible ways



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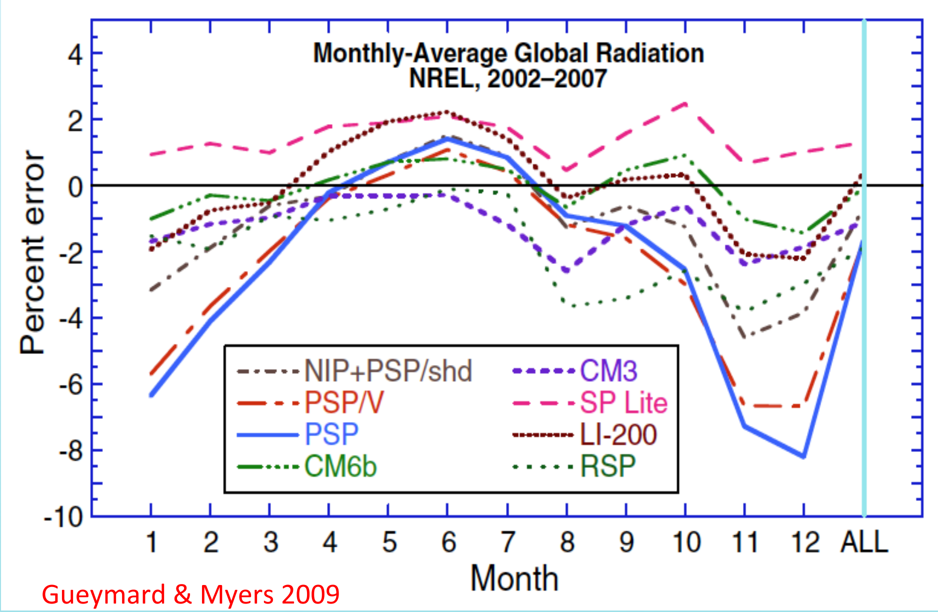
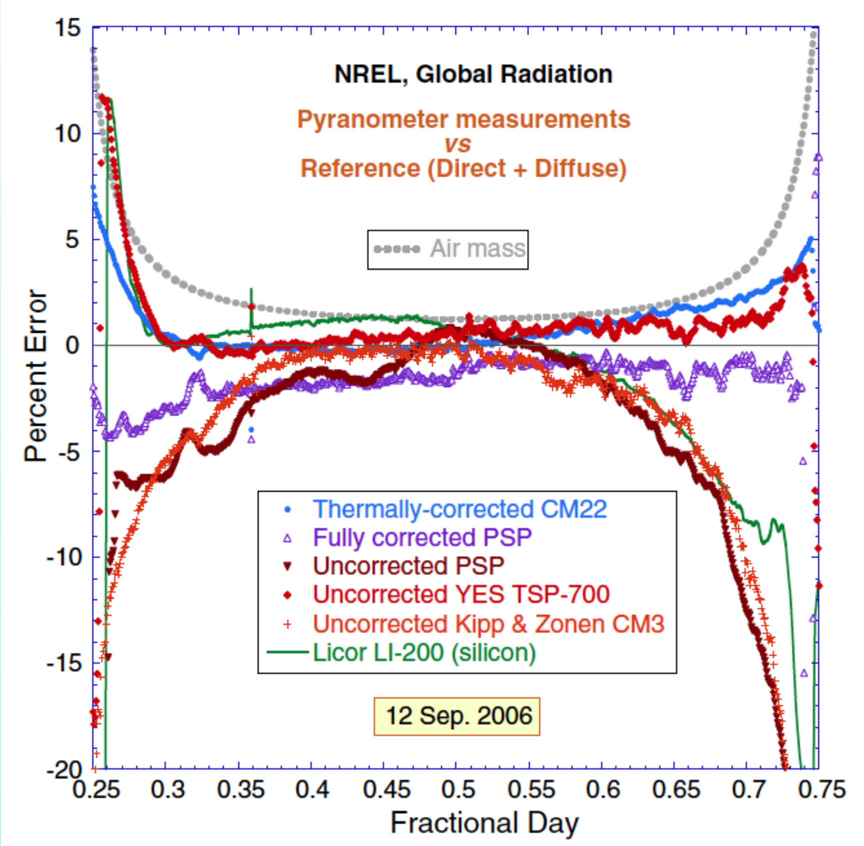
- Measuring GHI with a pyranometer is simplest but suboptimal
- A seasonal bias is likely, except with selected instruments
- Beware of thermal offset (e.g., PSP); requires appropriate correction





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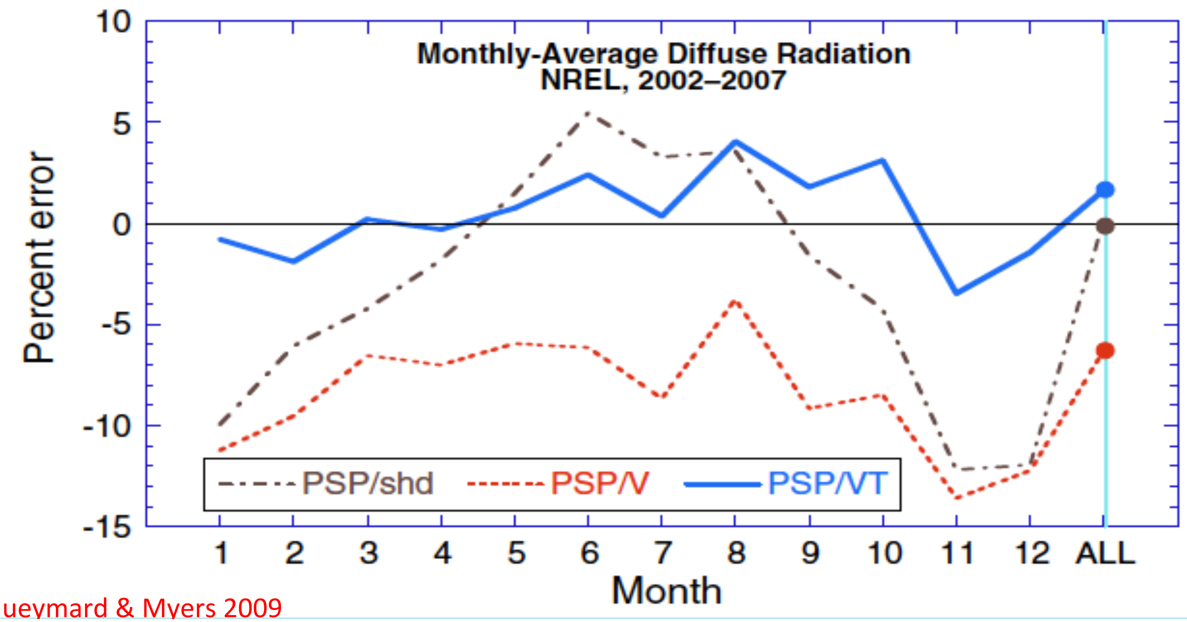
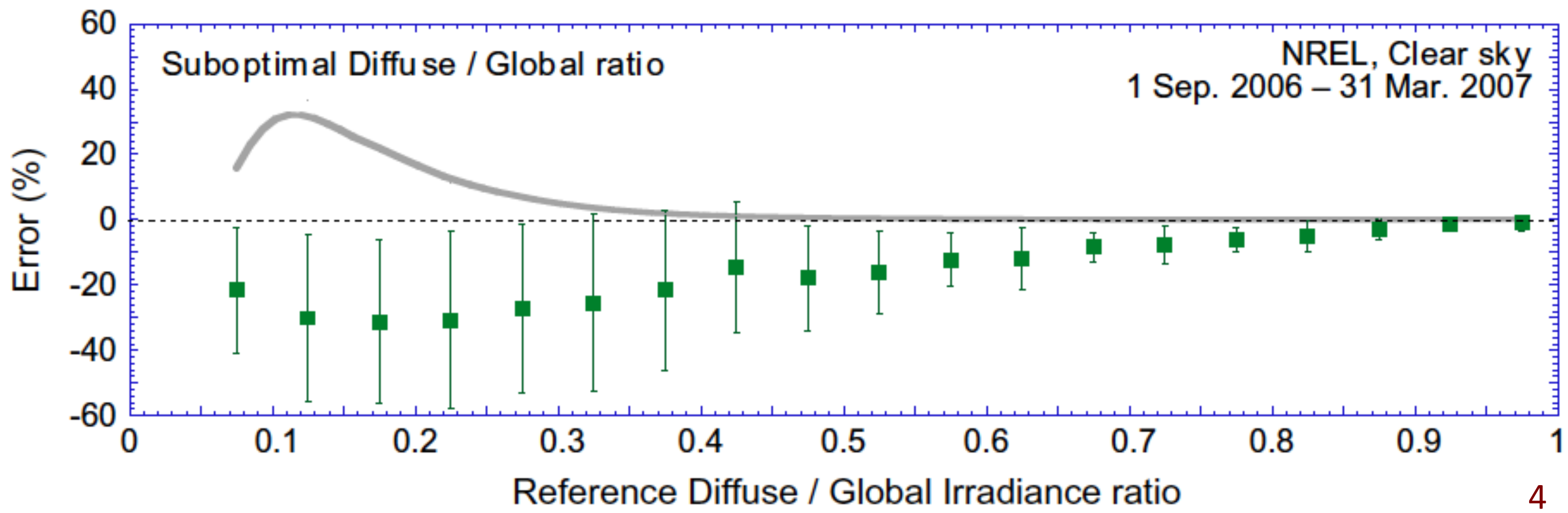
- Beware of thermal offset; may induce large bias
- Avoid shadowband



Gueymard & Myers 2009



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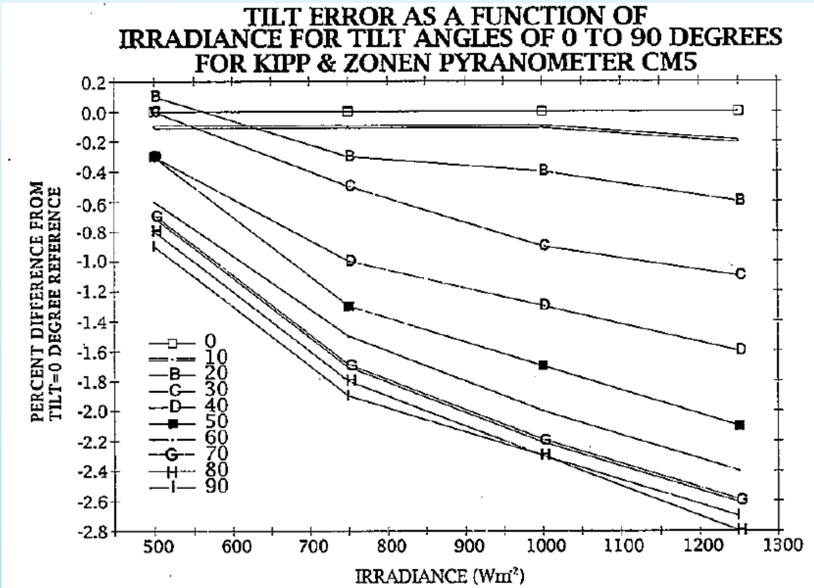
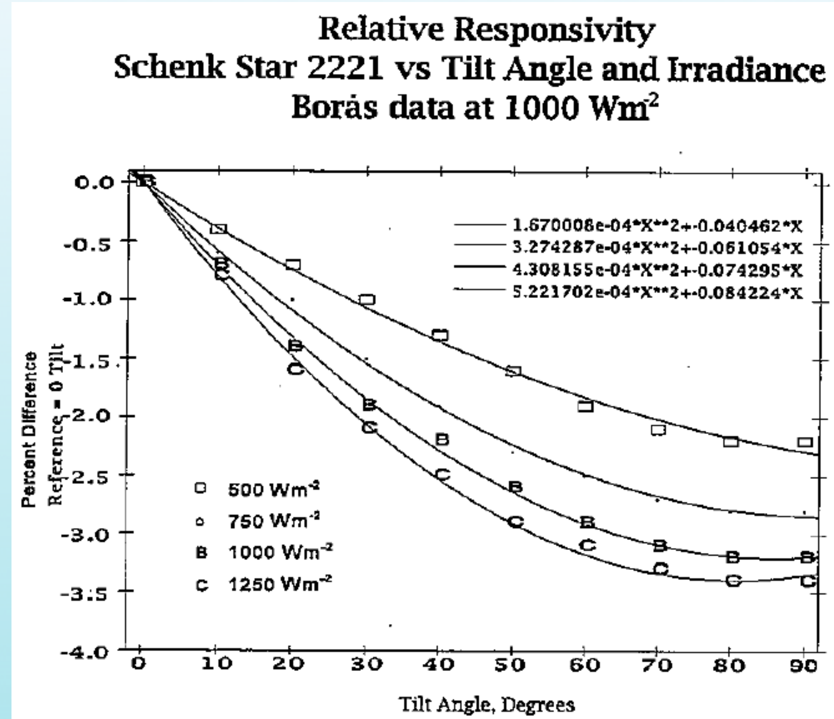
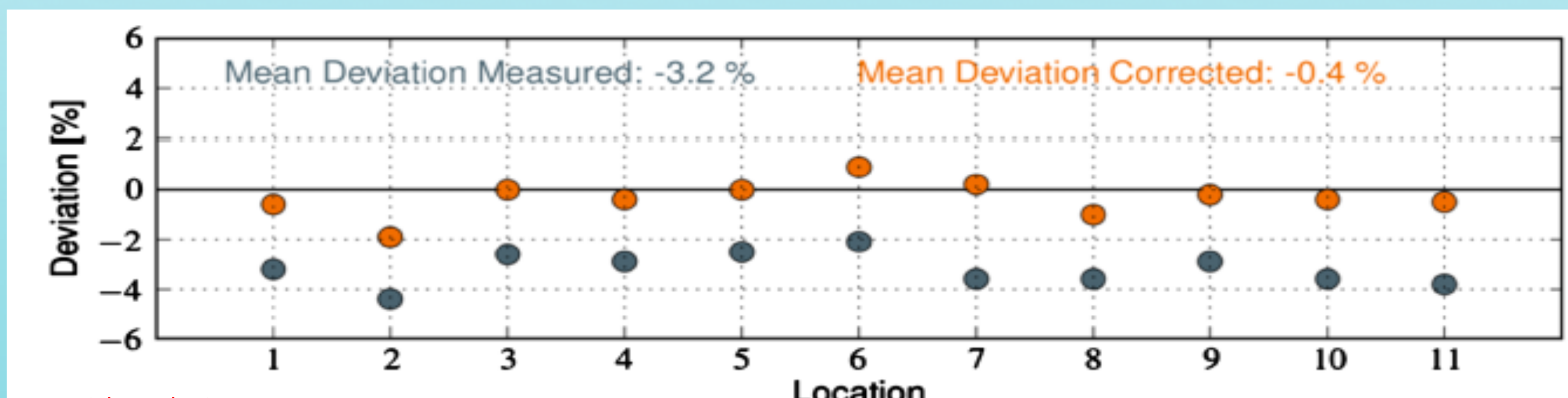
Experimental Issues—GTI

- Tilted pyranometers and photodiode sensors may require specific calibration
- Reference cells are convenient but induce bias (2–5% typical)







Reich et al, PiP 2012

- Modeling **GTI**:

$$\text{GTI} = \text{DNI}\cos\theta + R_d\,\text{DIF} + f_s\,\rho\,R_r\,\text{GHI}$$

f_s Shading factor

ρ Surface albedo

R_r Ground view factor

- **21 models** tested for IEA-SHC Task 9 study (Hay, 1988) for hourly or sub-hourly data. This remains the most comprehensive study ever undertaken on this topic.
- **27 stations** were classified depending on setup:
  A. Artificial horizon, measured DNI (6)
  B. Measured albedo, measured DNI (6)
  C. Estimated albedo, measured DNI (3)
  D. Artificial horizon, measured DIF (6)
  E. Measured or estimated albedo, measured DIF (6)
- Study found 3 models with consistently best performance overall, but with varying ranking depending on station and geometry:

  Perez (1983), Gueymard (1983), Hay (1979)

Transposition Models Performance

Results for U.S. sites

ATLANTA

SLOPE	GUEYMARD MAD	GUEYMARD RMSD	HAY MAD	HAY RMSD	PEREZ 1 MAD	PEREZ 1 RMSD	PEREZ 2 MAD	PEREZ 2 RMSD
34S	33	48	31	45	33	48	36	51
Rank.1	2=	2=	1	1	2=	2=	4	4
Rank.2	2=	2=	1	1	2=	2=	4	4

SAN ANTONIO

SLOPE	GUEYMARD MAD	GUEYMARD RMSD	HAY MAD	HAY RMSD	PEREZ 1 MAD	PEREZ 1 RMSD	PEREZ 2 MAD	PEREZ 2 RMSD
20S	27	42	27	40	22	32	22	33
30S	35	53	37	54	25	37	26	39
40S	45	68	49	70	34	48	36	52
90N	51	72	88	120	49	69	53	74
90E	78	113	100	138	62	90	65	94
90S	75	106	99	136	64	87	68	93
90W	75	113	103	146	65	97	67	100
All	55	85	72	109	46	70	48	74
Rank.1	3	3	4	4	1	1	2	2
Rank.2	3	3	4	4	1	1	2	2

GOLDEN

SLOPE	GUEYMARD MAD	GUEYMARD RMSD	HAY MAD	HAY RMSD	PEREZ 1 MAD	PEREZ 1 RMSD	PEREZ 2 MAD	PEREZ 2 RMSD
40S	48	73	47	73	55	86	56	86
90S	43	71	49	75	50	72	48	72
All	46	72	48	74	53	79	52	79
Rank.1	1	1	2	2	4	3=	3	3=
Rank.2	1	1	2	2=	4	2=	3	2=

ALL LOCATIONS

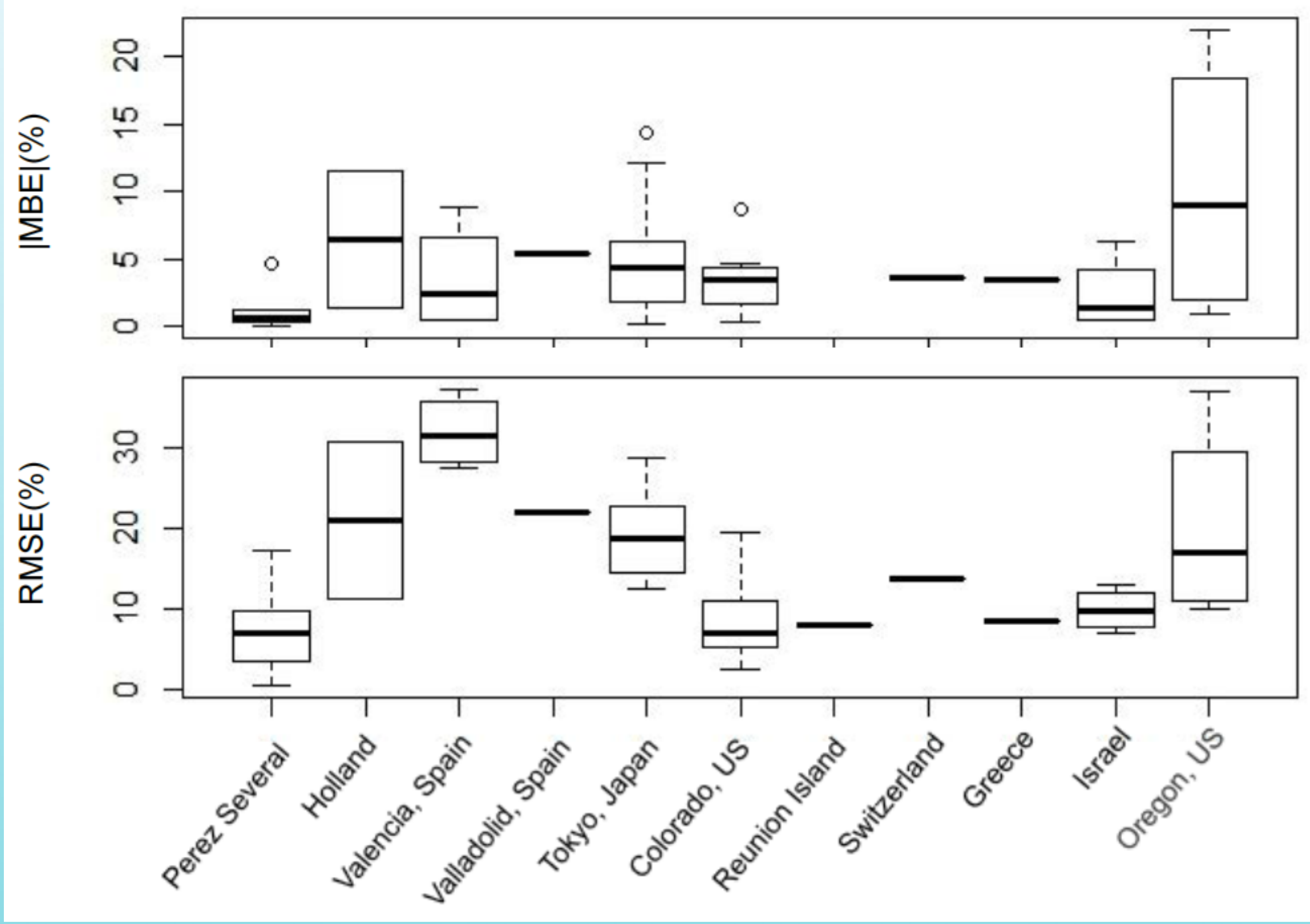
SLOPE	GUEYMARD MAD	GUEYMARD RMSD	HAY MAD	HAY RMSD	PEREZ 1 MAD	PEREZ 1 RMSD	PEREZ 2 MAD	PEREZ 2 RMSD
All	55	97	63	103	54	92	53	91
Rank.1	3	3	4	4	2	2	1	1
Rank.2	3	3	4	4	2	2	1	1
Equatorward	56	99	60	101	54	94	54	93
Rank.1	3	3	4	4	1	2	2	1
Rank.2	3	3	4	4	1	1	2	2
Poleward	53	94	67	106	53	89	51	87
Rank.1	3	3	4	4	2	2	1	1
Rank.2	2	3	4	4	3	2	1	1

LOS ALAMOS

SLOPE	GUEYMARD MAD	GUEYMARD RMSD	HAY MAD	HAY RMSD	PEREZ 1 MAD	PEREZ 1 RMSD	PEREZ 2 MAD	PEREZ 2 RMSD
45ESE	145	289	139	279	141	272	141	274
90S	136	285	123	265	127	247	126	249
All	141	287	131	272	134	260	134	262
Rank.1	4	4	1	3	3	1	2	2
Rank.2	4	4	1	3	3	1	2	2

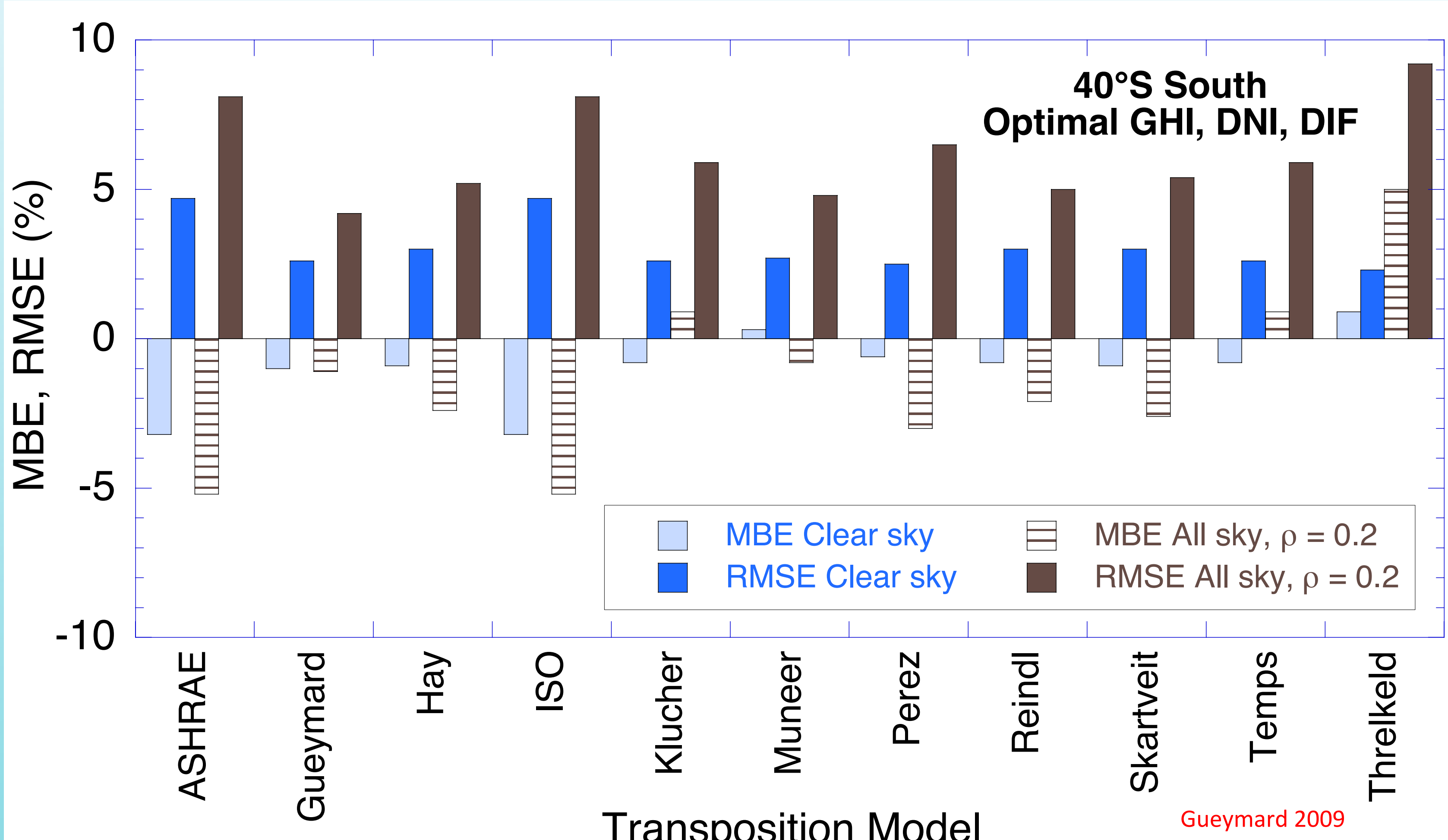
Transposition Models Performance

- Many more (but much more limited) studies followed
- Sun et al. (2014) showed variable bias and RMS for Perez model depending on site



Transposition Models Performance

- For Golden (NREL) and *optimally measured 1-min irradiances*, the lowest bias is obtained with the Muneer, Klucher, Temps and Gueymard models
- Best models under both clear-sky and all-sky conditions have low bias (<2%) and low RMS (<7%), even if albedo is assumed constant (0.2)

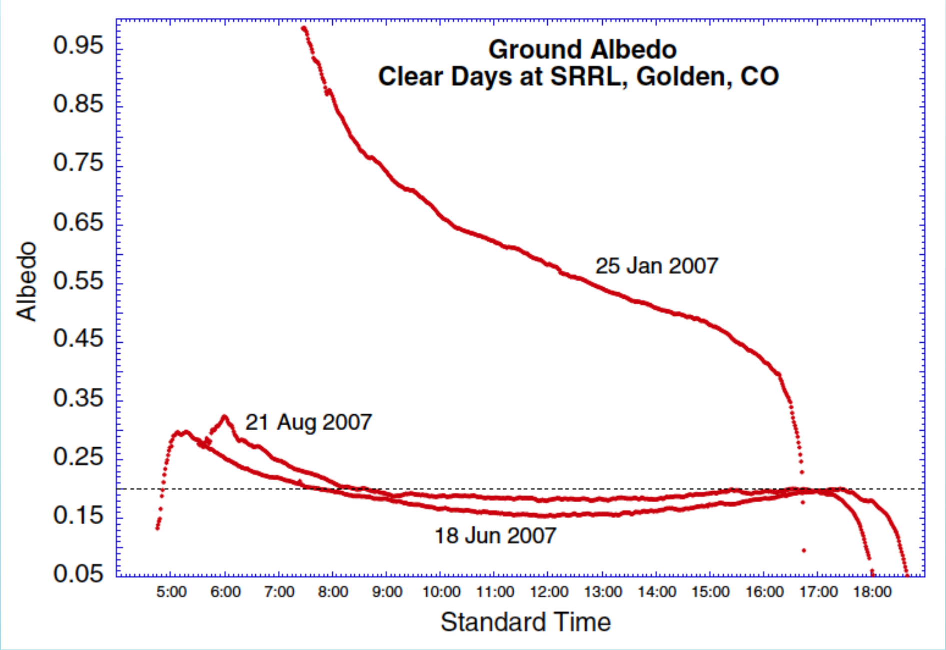


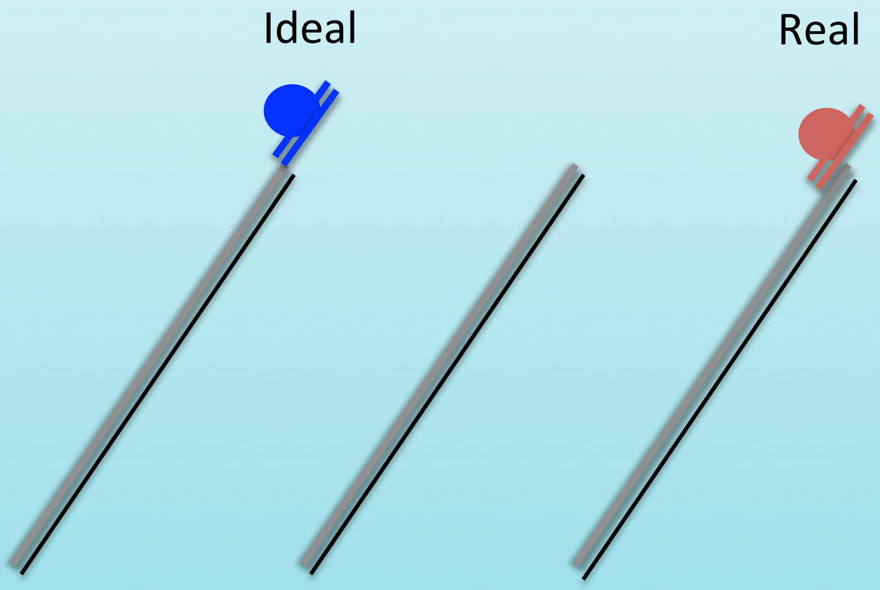
Gueymard 2009

Validation Issues

Sources of error:

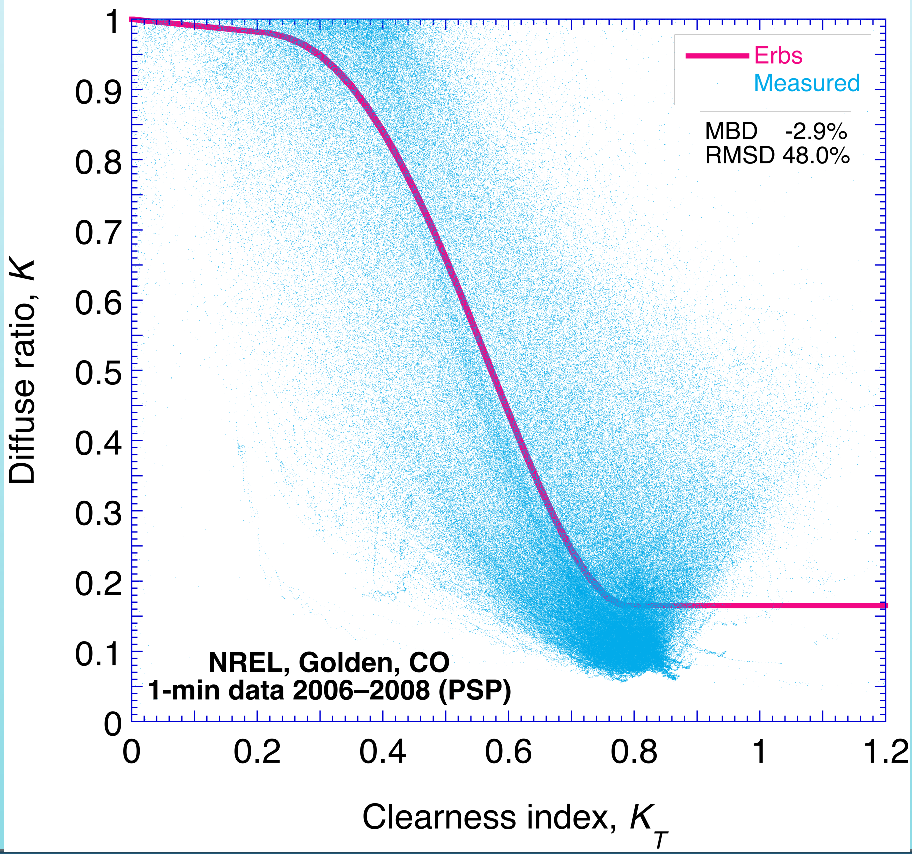
- Measured irradiances (DNI, GHI, DIF) may not be optimal
- Measured GTI may not be optimal (tilt-specific calibration?)
- Foreground may not be infinitely extended (R_r less than ideal value)
- Foreground may be shaded by e.g. back-panels (f_s less than 1)
- Surface albedo ρ is usually unknown; often assumed constant (0.2)





Decomposition

- Also referred to as *Separation*
- Many empirical models exist (>100), so which one should be used?
- Most are of the "diffuse fraction" type
- Many validation studies exist, usually just for some models at a few sites
- Random errors increase when time step decreases
- No known truly "universal" model
- 1-min DNI and DIF are desirable



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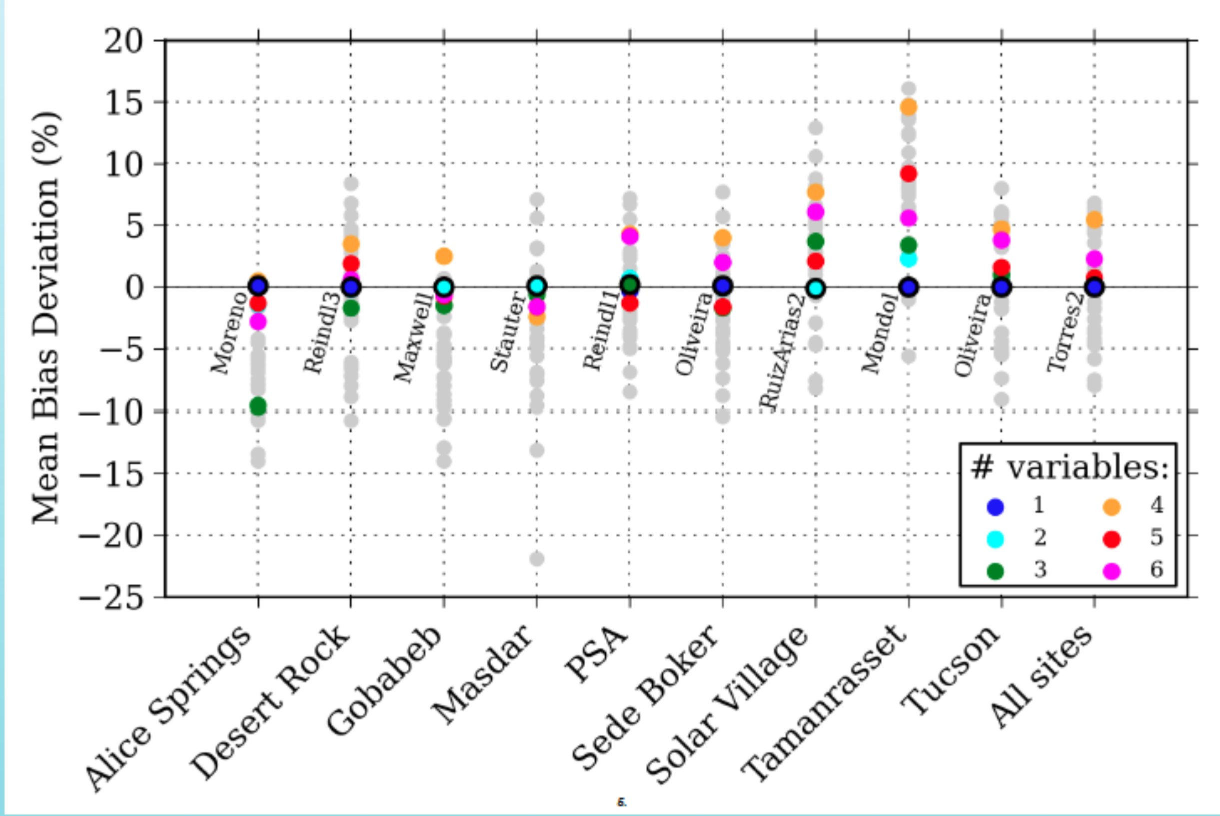
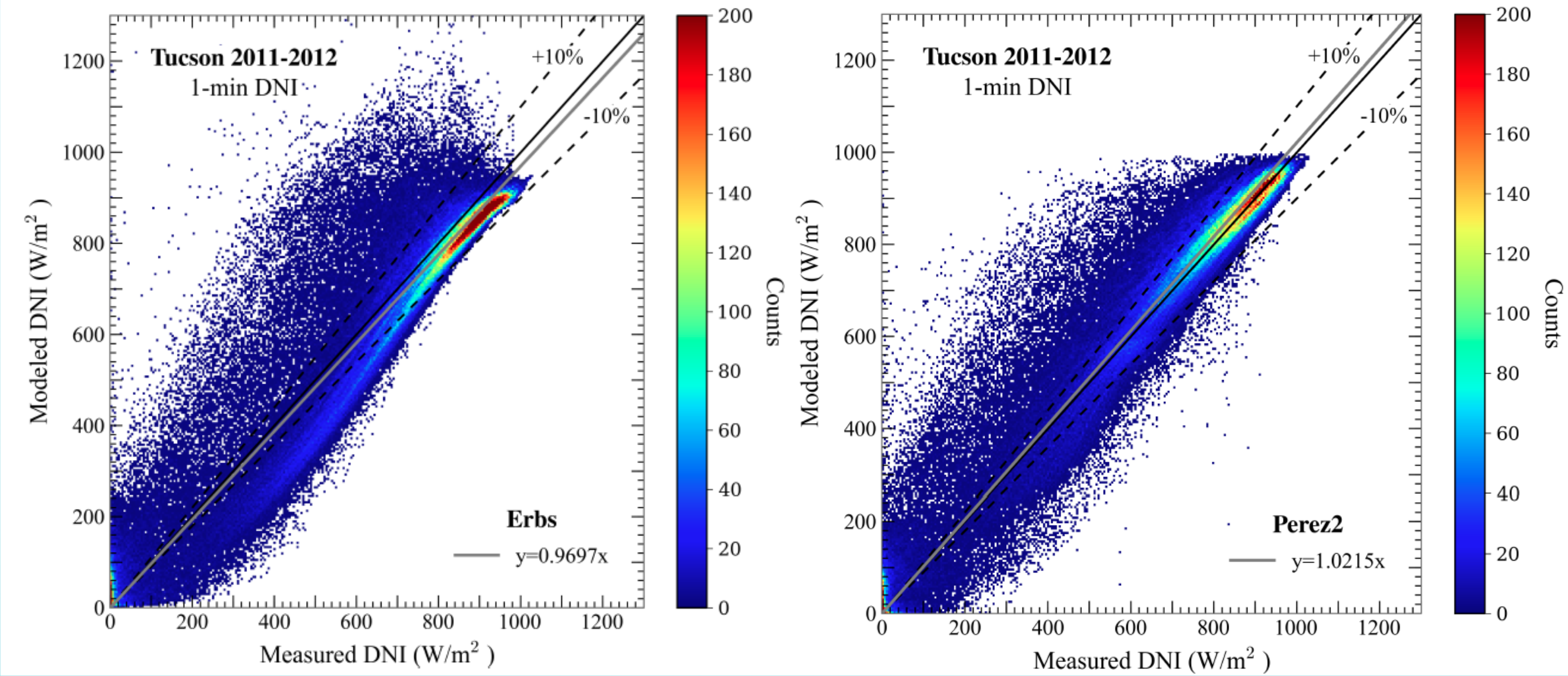
- Recent study by Gueymard & Ruiz-Arias (2014): 36 models tested at 9 arid sites, using 1-min data
- Models in 6 categories, based on number of predictors (*Kt, m*, etc.)
- Bias varies depending on model and site; significant impact of aerosols
- Adding predictors does not necessarily improve performance



- Issues found with Erbs, Louche and Perez
- Perez has lowest RMS most often, but systematic high bias (2–5% on average)



Decomposition + Transposition

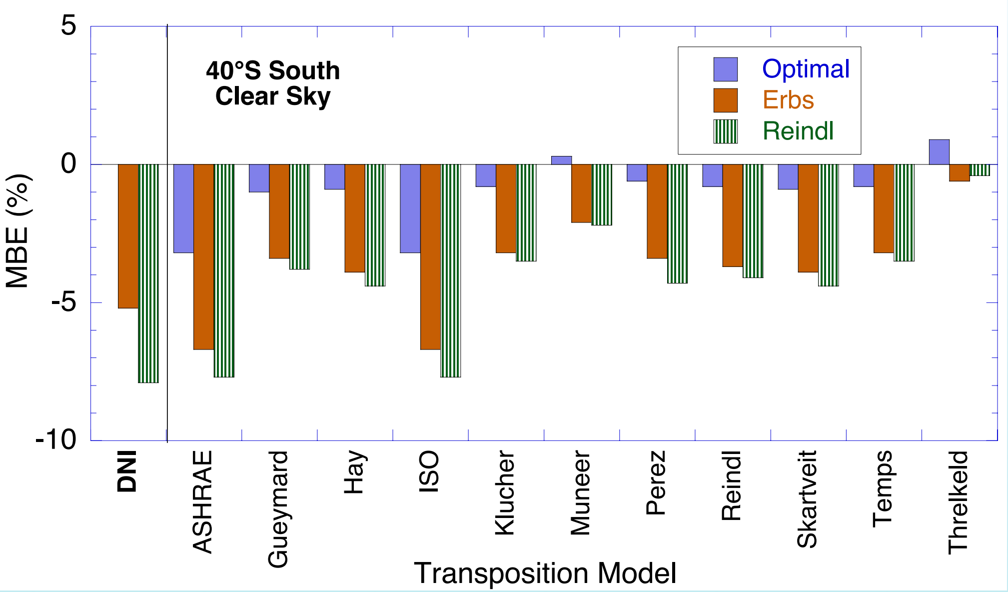
- Only a few studies have considered the overall process

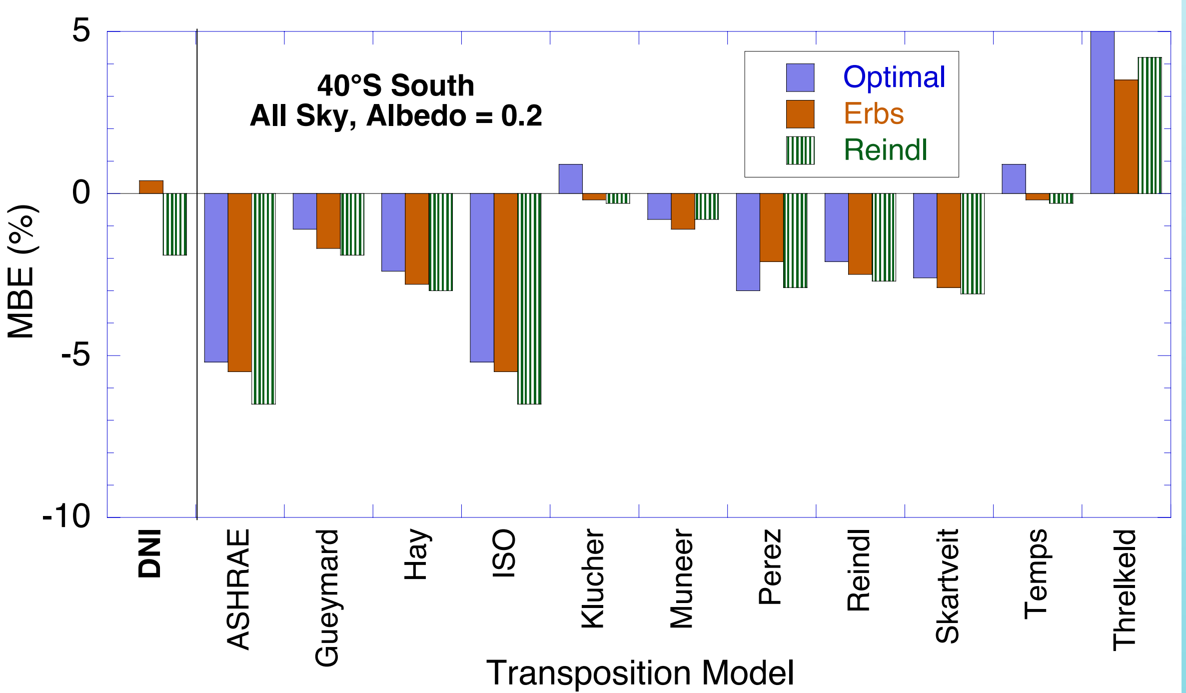
Author	Year	Decomposition	Transposition	Study Sites	Geometries
Gueymard	2009	4	10	1 (NREL)	40°, 90° S, 2AT
Orehounig et al.	2014	2	1	1 (Austria)	90° N, E, S, W
Prada et al.	2015	22	12	5 (Europe)	90° N, E, S, W
Lave et al.	2015	12	4	10 (USA)	15°, 25°, 35°, 40°

Decomposition + Transposition

Results from Gueymard (2009):

- Significant increase in bias due to using decomposition, mostly under clear skies
- Bias in GTI increases depending on the bias in estimated DNI
- Klucher, Muneer, Temps perform best with any decomposition





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Conclusions

- Transposition is relatively accurate
- Surprisingly few transposition models have been considered by the industry (Perez, Hay). Lesser known models may perform as well or better (Gueymard, Klucher, Muneer, Temps…), depending on climate (cloudiness?)
- Decomposition may play a major role, depending on the generated bias in DNI, local conditions, associated transposition, etc.
- Best model combination still need to be found empirically (trial and error)
- Results by Gueymard (2009) and Lave et al. (2015) do not agree well about the bias resulting from model combinations at their common location (NREL)
- Combination studies need to be expanded to more sites, using better instrumentation, and more rigorously controlled conditions (sky shade; ground shade)
- Differences between ideal and realistic conditions must now be emphasized and better modeled (albedo, shading, limited foreground…), so that validation results can be correctly interpreted in the practice of PV performance simulations.