CanadianSolar

A comparison of bifacial PV system energy yield modeling tools applied to 1P single-axis tracker system

Yuanjie.Yu, Jn.Jaubert, Baohua.He
System technology center
Canadian Solar Inc.

Dec 4th , 2018

CSIQ NASDAQ Listed

CanadianSolar

CONTENTS

Bifacial module with leading half-cut cell technology

2010 | Double glass | Worldwide leading double glass module manufacturer

2010 | Ku (Half -cell) | Worldwide No. 1 Ku module manufacturer Capacity>5GW, Shipment>3GW

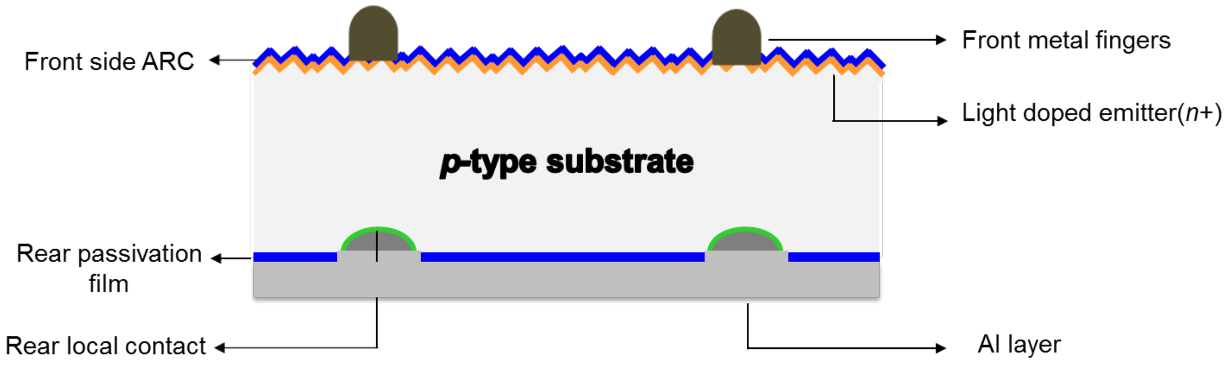
2017 | BiKu | Worldwide NO.1 manufacturer to offer bifacial Ku poly module , shipment>300MW

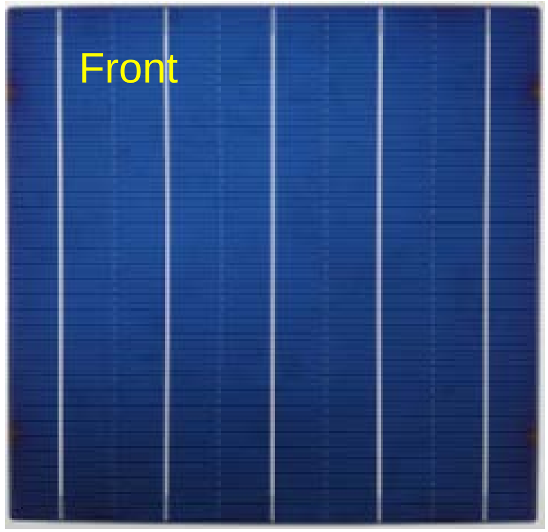
Canadian Solar's BiKu : Based on Eight years' track record

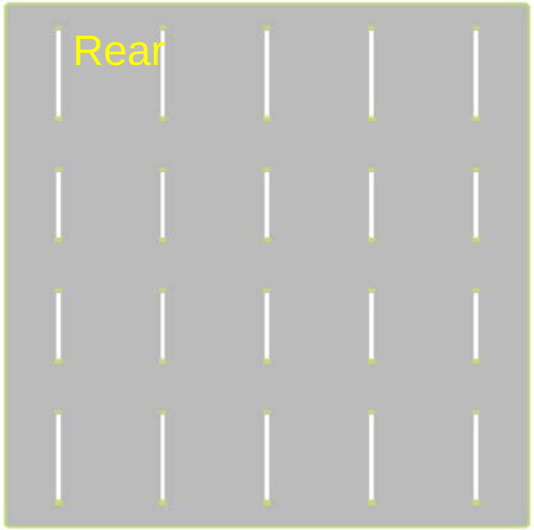
Canadian Solar Poly PERC technology introduction

Main Characteristics

- State of the art MCCE (Metal Catalyzed Chemical Etching)
- PERC structure using ALD Al2 O3 passivation
- 5 busbar design / MBB multi-busbar (9)
- Controlled LID/LeTiD
- Excellent low light response
- Lower temperature coefficient
- Enables Bifacial cells





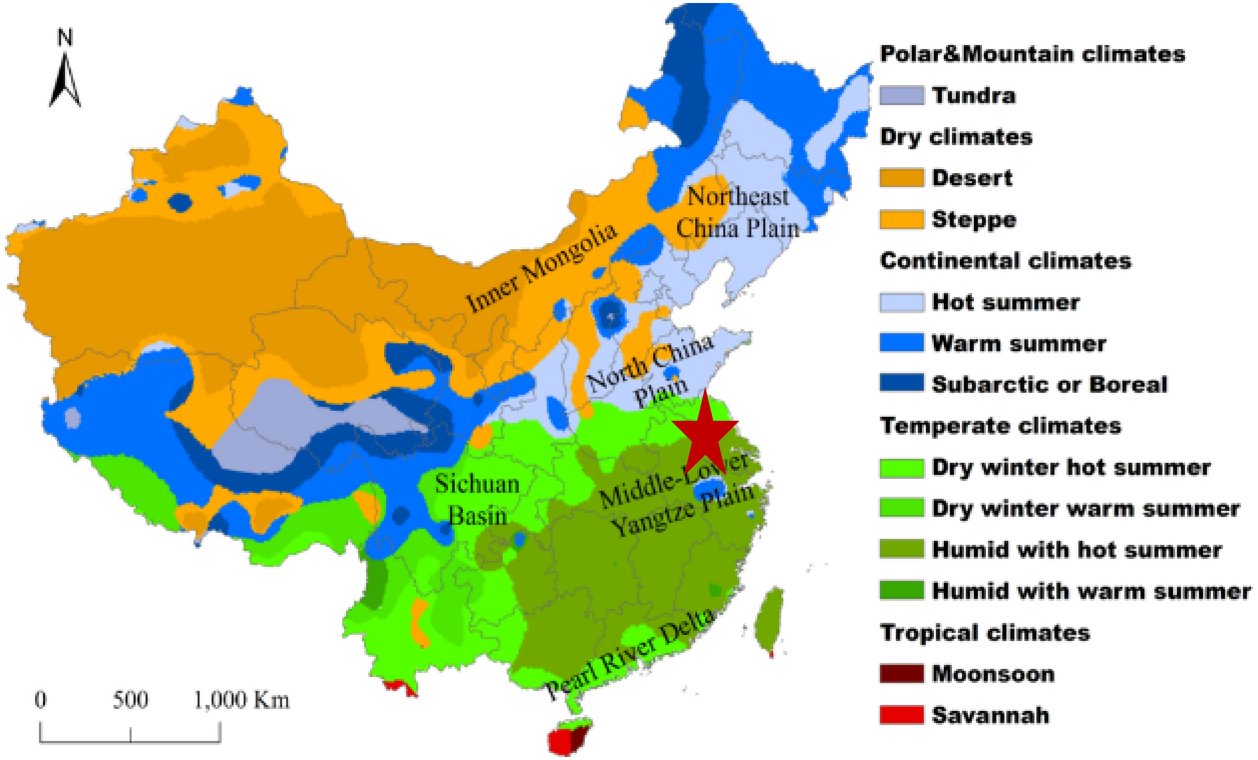


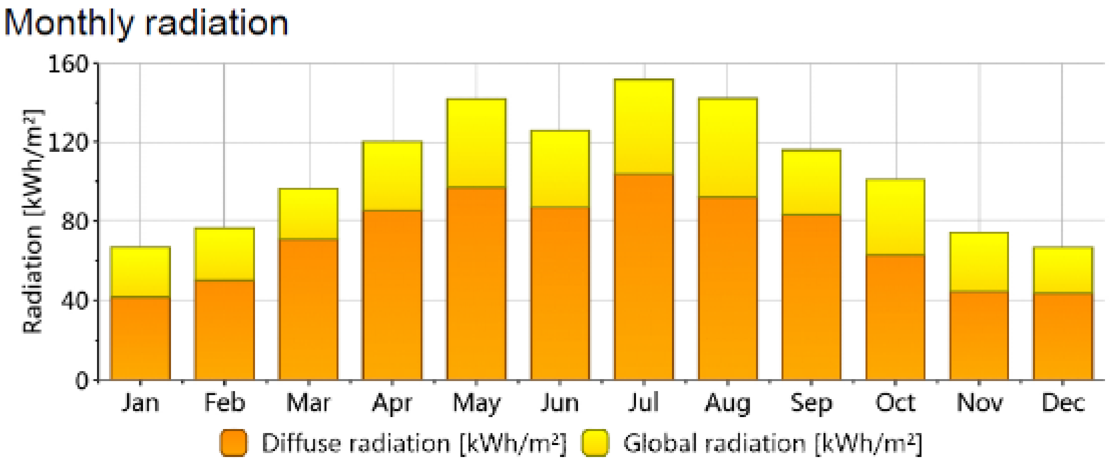
Canadian Solar Inc.

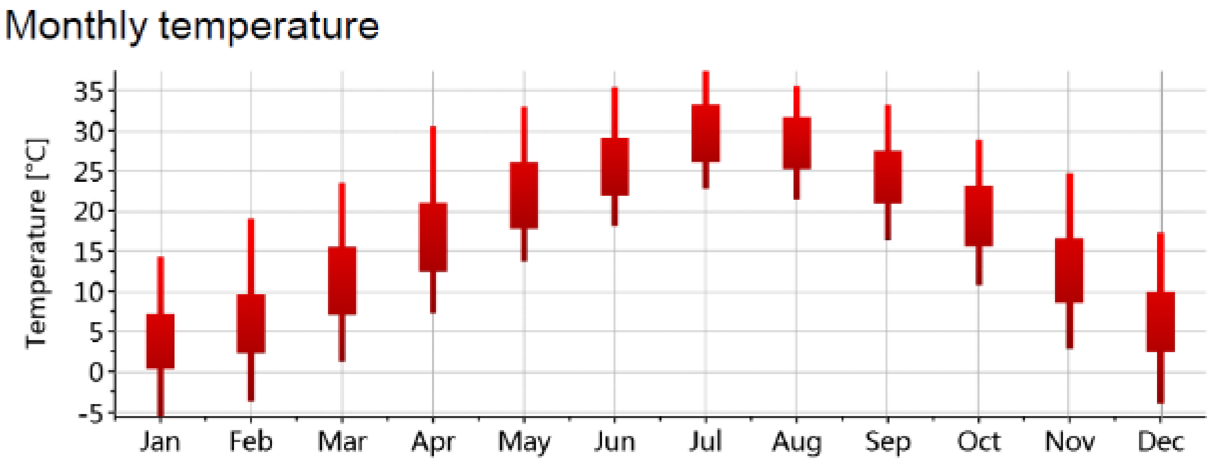
Changshu bifacial field trial overview

Changshu project located in Suzhou, Jiangsu Province, East China, total system size is 28 kWdc. Climate type is typical Humid with hot summer.

Latitude :39.7°
Longitude :106.8°



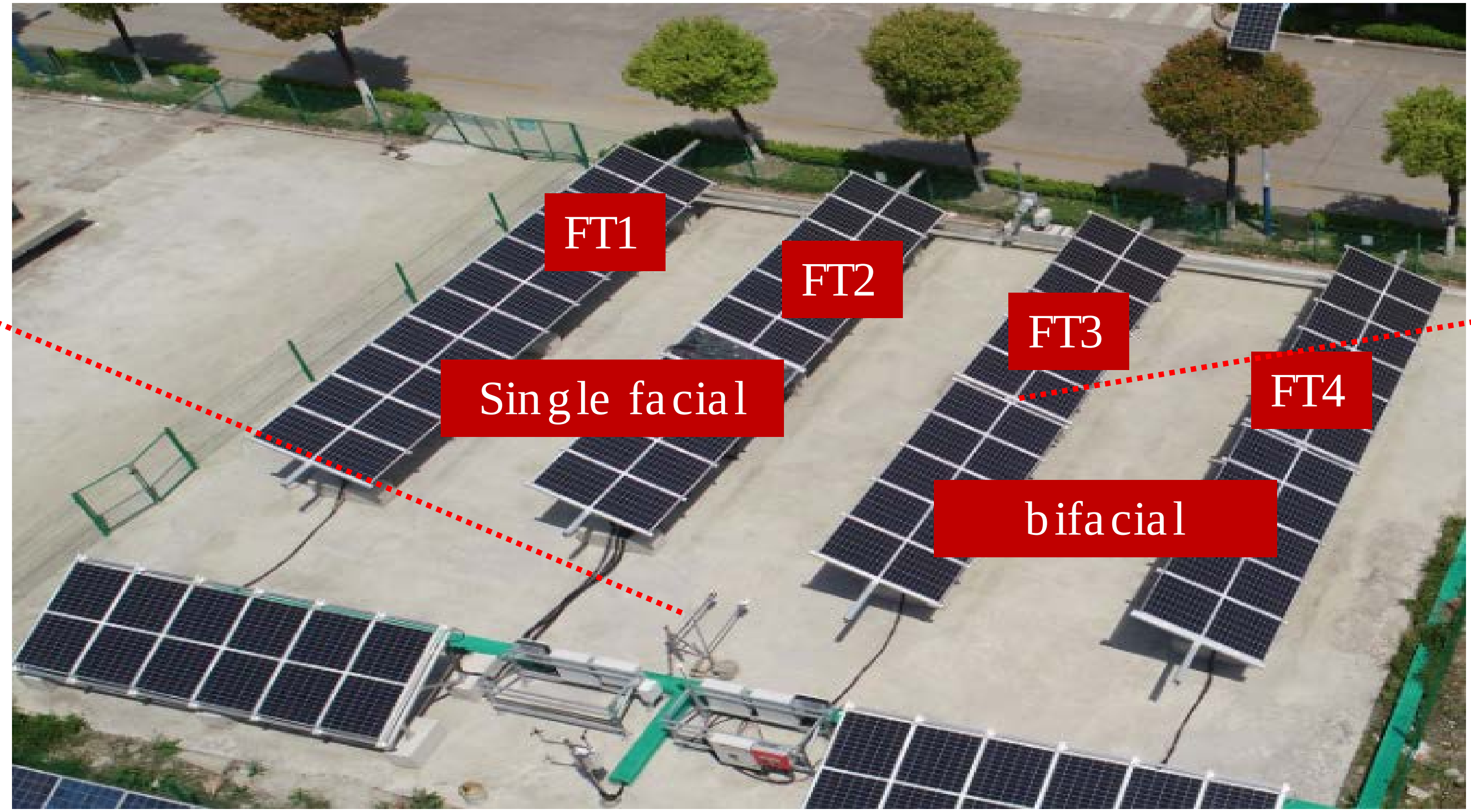




Changshu bifacial field trial basic information

Item	Mounting type	Module type	Module quantity	DC capacity (Kw)	Inverter			
					Product type	Nominal power	MPPT number	Max input current
FT1	Single axis tracker(1*10)	3U-MS-FG (single facial)	10	3.71	GROWATT 1000TL3-S	10kW	2	13A
FT2			10	3.70				
FT3		3U-MB-FG (bifacial)	10	3.67		10kW	2	13A
FT4			10	3.69				

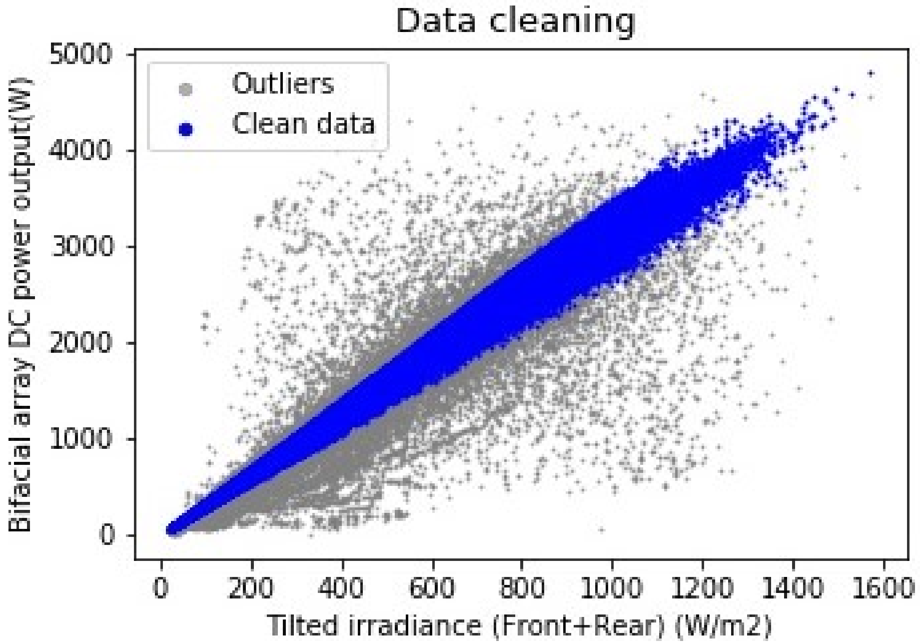

Albedo meters




Silicon sensor on back side

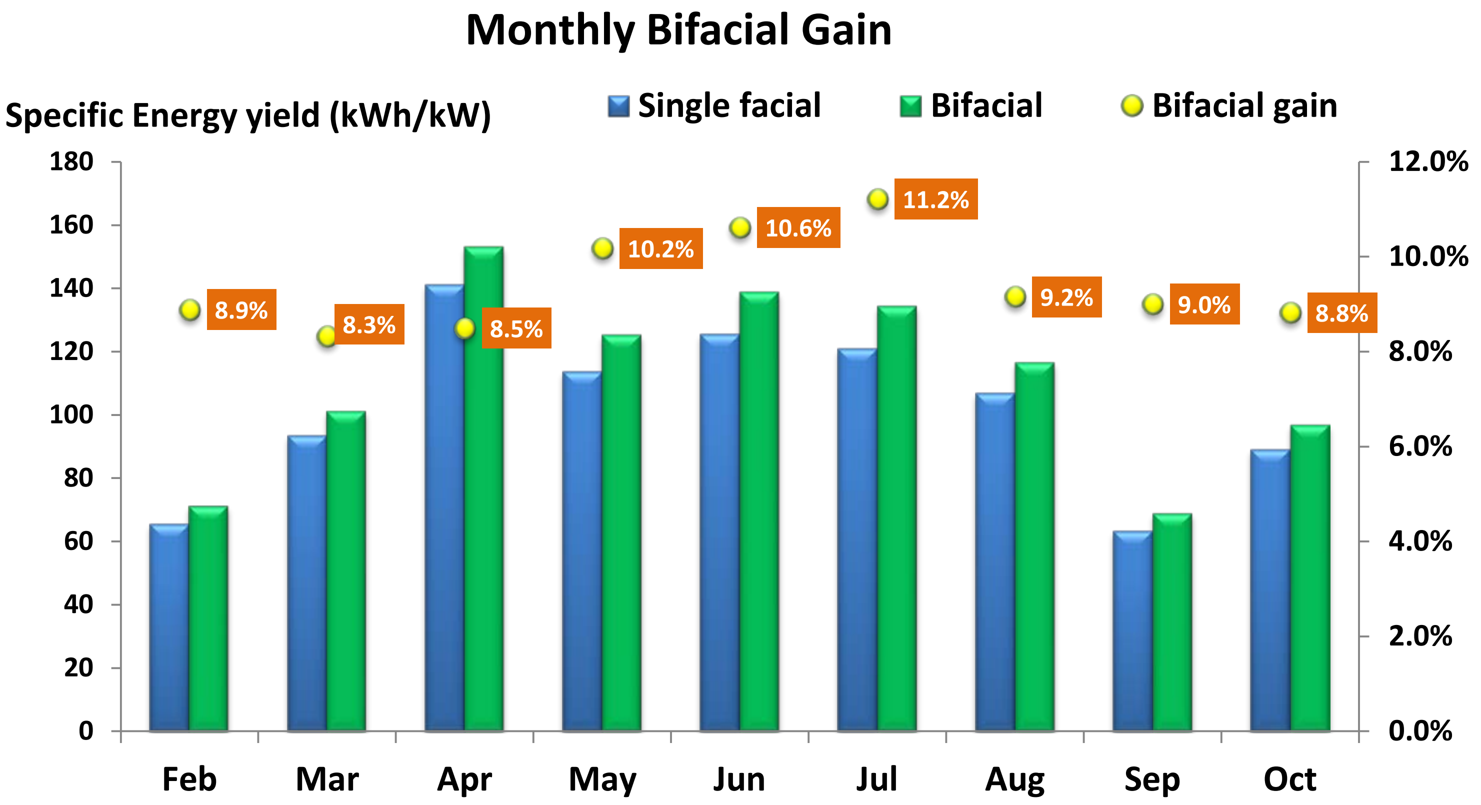
Field trial data cleaning methodology

Data processing item	Description
Data source	DC related parameters and climate data with 1min interval
Basic outlier filter	✓ $P_{Array\text{-}DC} < 5W$; ✓ $POA < 20W/m^2$; ✓ Events and missing data ✓ Box plot extreme and mild outliers for Power/irradiance
Comparison criterion	Specific energy yield calculation (kWh/kW) with front side power
Bifacial gain definition	$100\% \times \left(\frac{E_{bifacial} / Pmp_{bifacial}}{E_{monofacial} / Pmp_{monofacial}} - 1\right)$



Bifacial field trial testing results- *Energy yield*

During normal operation 231 days, accumulated bifacial gain for the tracker system is 9.5% under average albedo 26%.



Monthly albedo

Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.
25.8%	28.2%	28.9%	26.5%	26.5%	25.5%	26%	26.8%	26.8%

Data source: DC side on field trial platform in Changshu, China. **Testing period** : Feb-Oct, 2018

Canadian Solar Inc.

CanadianSolar

CONTENTS

Energy modeling methodology -*software introduction*

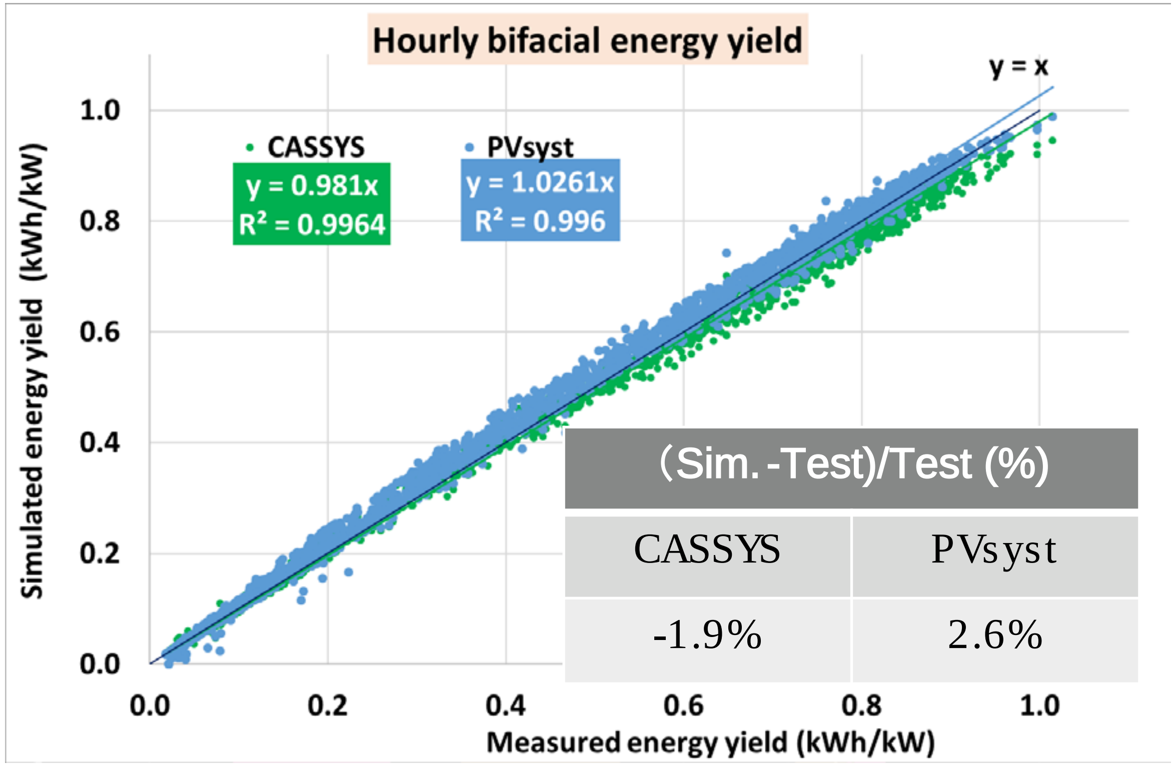
- ✓ NREL's Python code named **BifacialVF** . (Only used for irradiance simulation)
- ✓ Freeware and open-source: https://github.com/NREL/bifacialvf

- ✓ One of the most popular commercial simulation software tools, **PVsyst.**

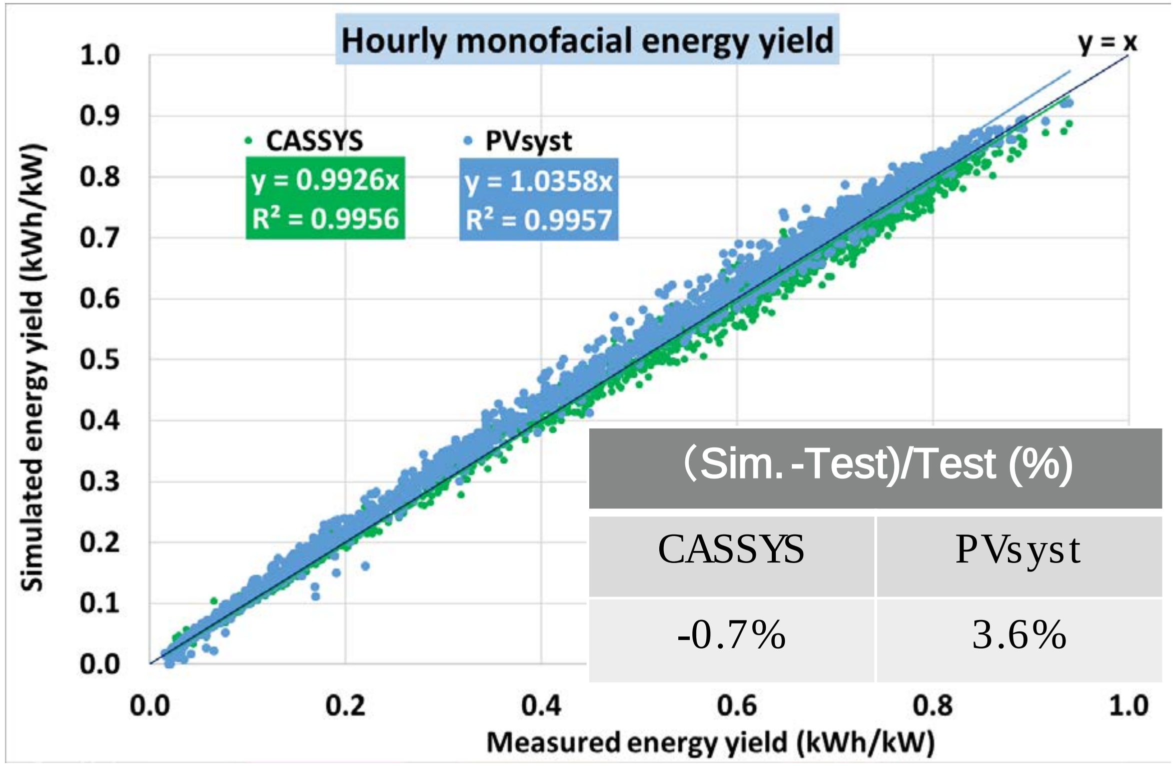
- ✓ Canadian Solar's own simulation tool, **CASSYS**
- ✓ Freeware and open-source: http://canadiansolar.github.io/CASSYS/
- ✓ Inputs and underlying model are very similar to PVsyst
  - ❖ Some alternate models are available like spectral correction.
  - ❖ Can be run with any time step and in batch mode

Simulation VS measurement - *Energy yield*

Bifacial energy yield difference between simulation and measurement can match well within reasonable uncertainty range .



(Sim.-Test)/Test (%)	
CASSYS	PVsyst
-1.9%	2.6%



(Sim.-Test)/Test (%)	
CASSYS	PVsyst
-0.7%	3.6%

Different simulation approach on backside irradiance and energy yield

Simulation A (DNI+GHI)

Measured DNI, GHI .

NREL Transforming ENERGY

BifacialVF

PVSYST

CASSYS

Irradiance

Simulation B(POA)

Measured F ront POA,
Monthly Albedo
Ambient temperature

PVSYST

CASSYS

Irradiance and Power simulation

Simulation A (DNI+GHI) comparison

Simulation A VS **Measurement**

Measured DNI, GHI ，（Using Changshu Ambient temperature and Albedo ）

↓

NREL Transforming ENERGY | PVSYST | CASSYS

↓

Irradiance

Measured Front POA, Rear POA, Albedo, Ambient temperature ， DC power

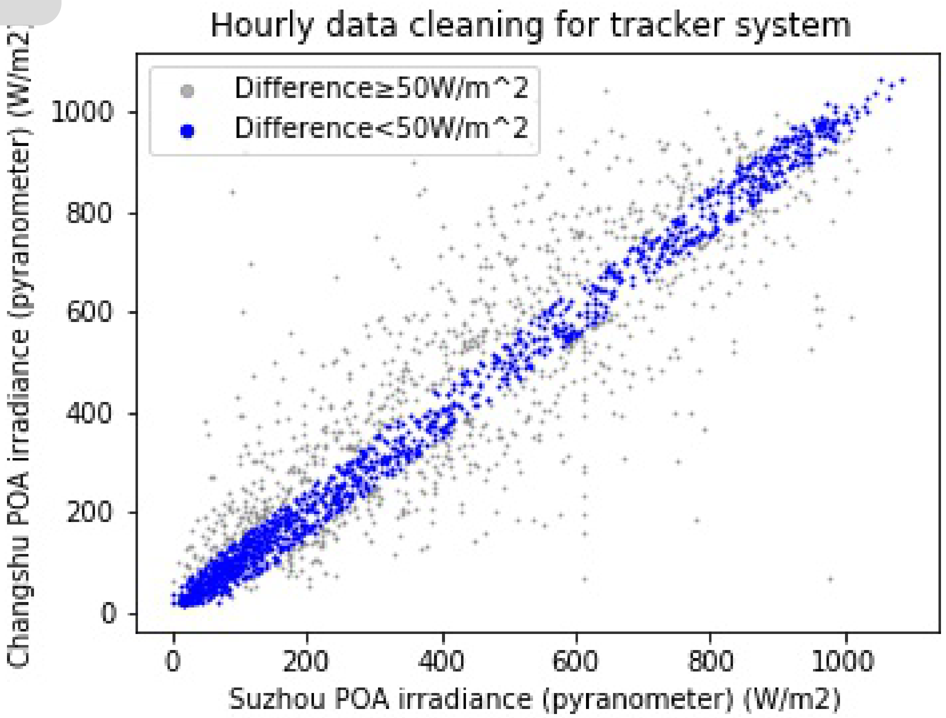
↓

↓

Irradiance

$$\mathrm{MBE/AV} = \frac{\sum_{i=1}^{N}(y_i - x_i)}{N\bar{x}},$$

$$\mathrm{RMSE/AV} = \left[\left\{\frac{\sum_{i=1}^{N}(y_i - x_i)^2}{N}\right\}^{1/2}\right] \Big/ \bar{x}$$



Limitation :

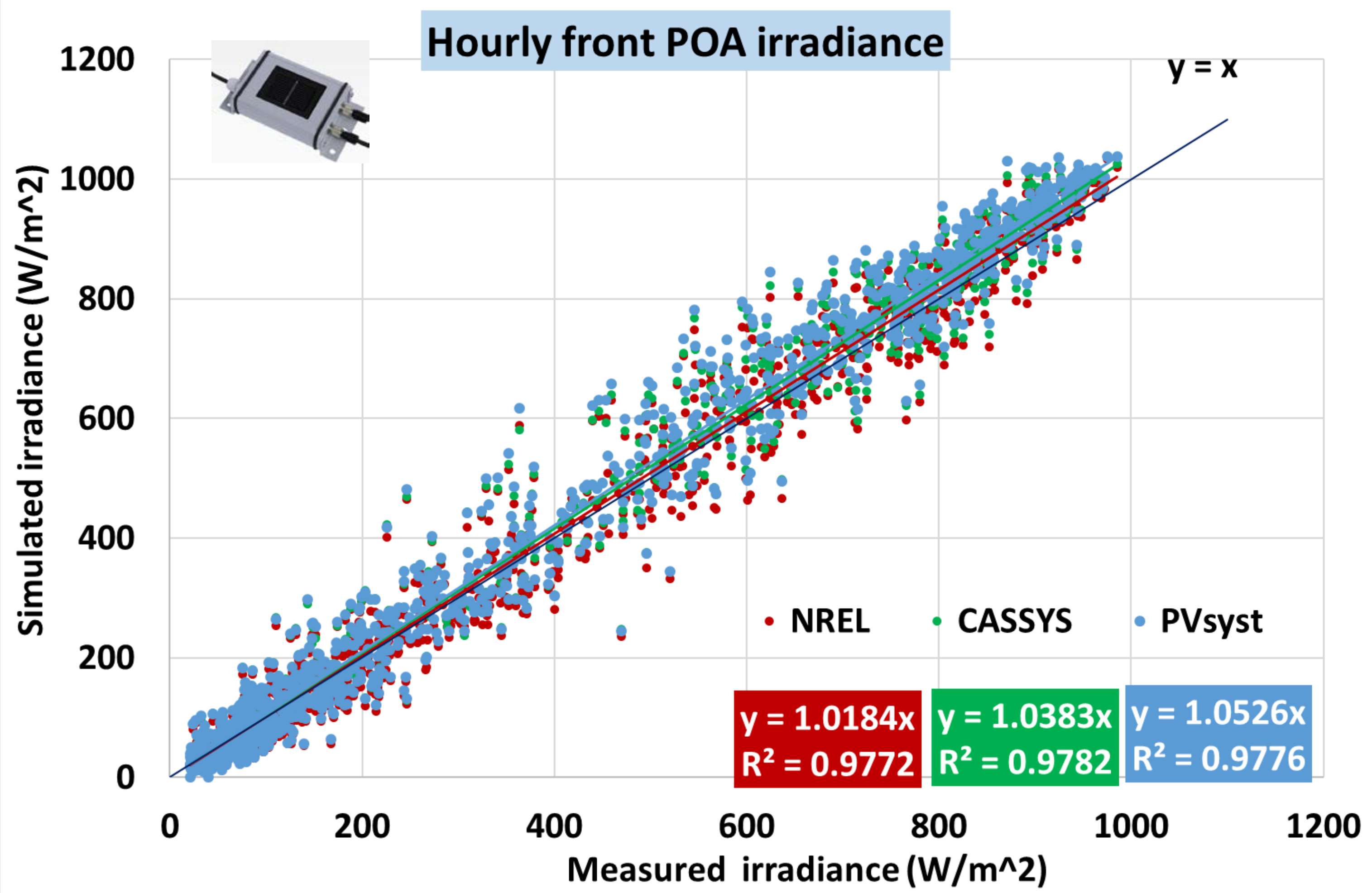
The irradiance data in two neighboring places were adopted.

Remark:

Filter the measured POA irradiance difference more than $50W/m^2$

Simulation A (DNI+GHI) VS measurement- *Front POA irradiance*

Three approaches showed reasonable uncertainty expectation on front irradiance simulation.

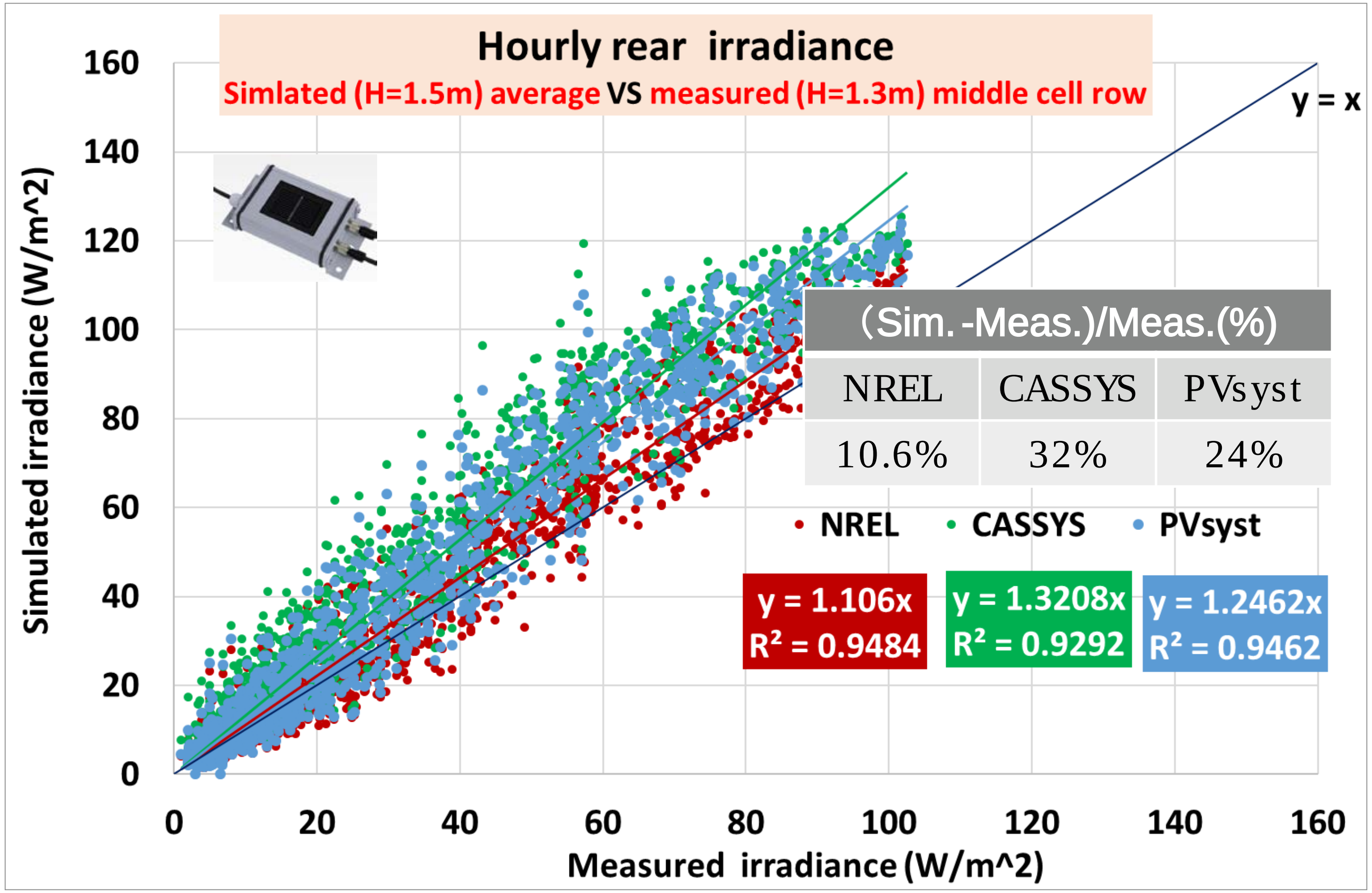


(Sim. -Meas.)/Meas.(%)		
NREL	CASSYS	PVsyst
1.8%	3.8%	5.2%

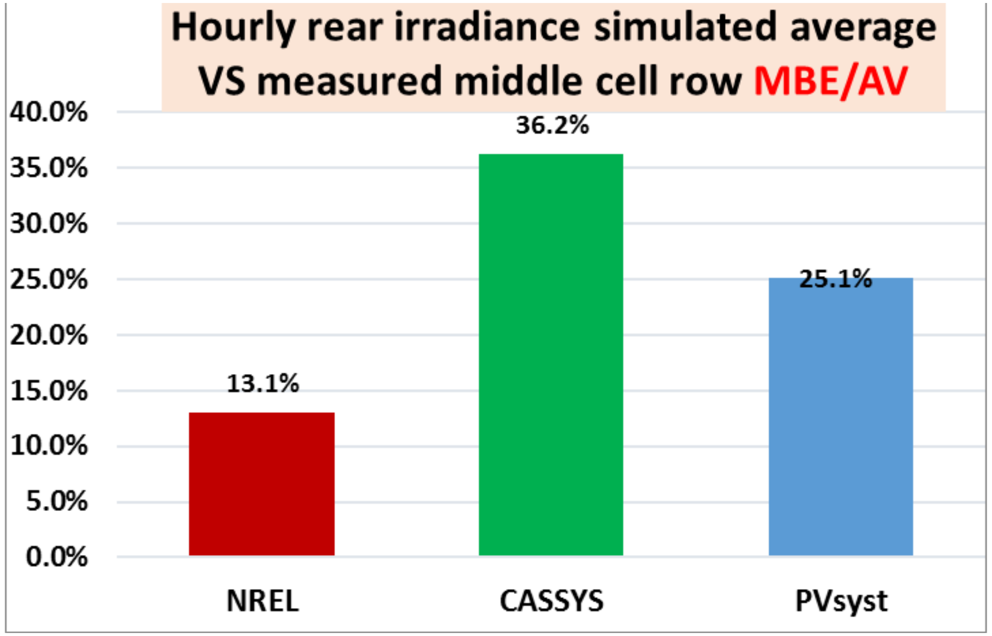
Note: Model transposition uncertainty(2-3%) and measured difference between sensor difference between the pyranometer and Si sensor(1-3%) should be considered,

Simulation A (DNI+GHI) VS measurement-*Rear POA irradiance*

Three approaches showed **aggressive** results on rear irradiance simulation ?



(Sim.-Meas.)/Meas.(%)		
NREL	CASSYS	PVsyst
10.6%	32%	24%

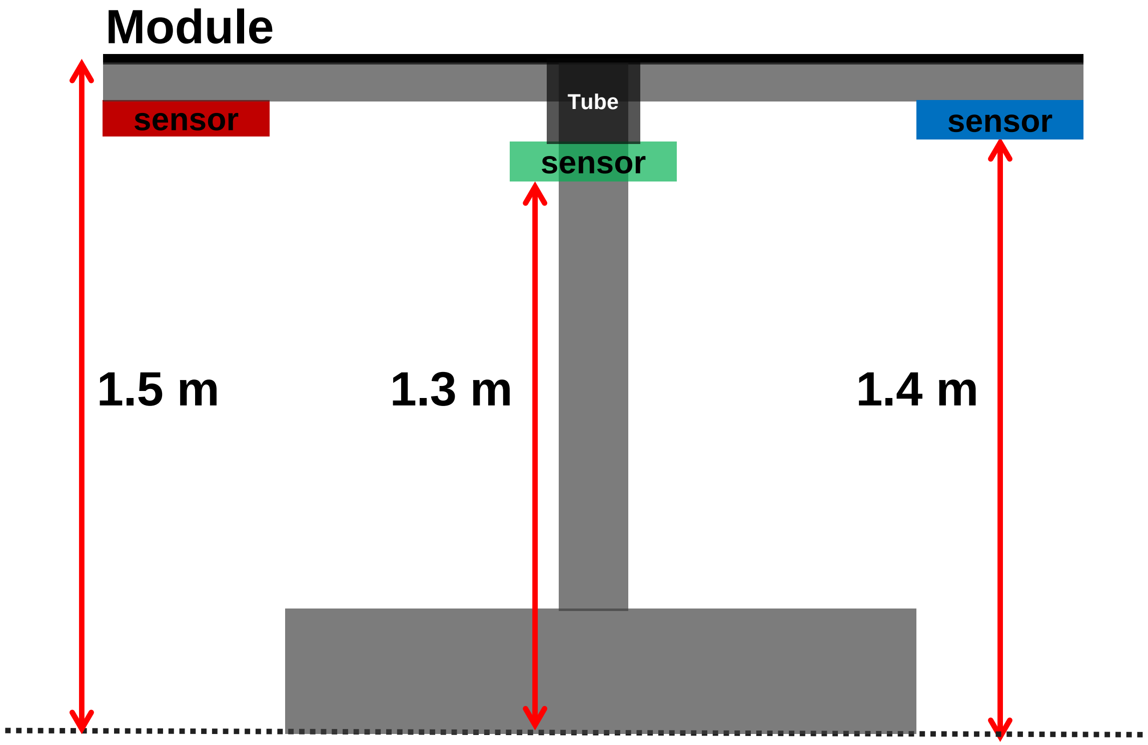


MBE: Sim.-Meas.

Additional factors that influence the results need to be studied.

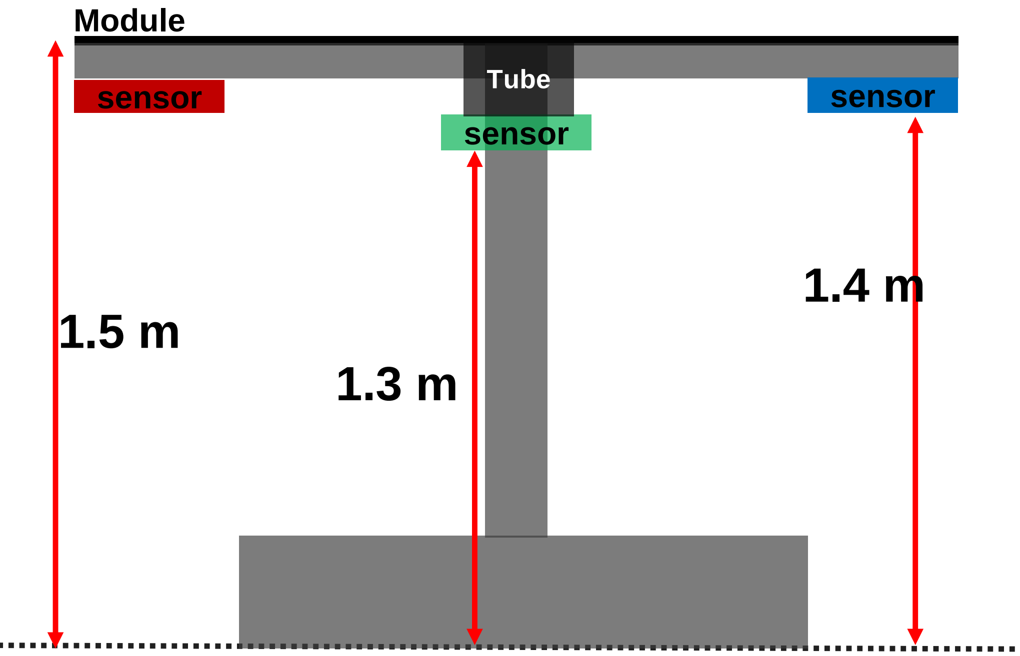
Simulation limitation *– Backside irradiance sensor height*

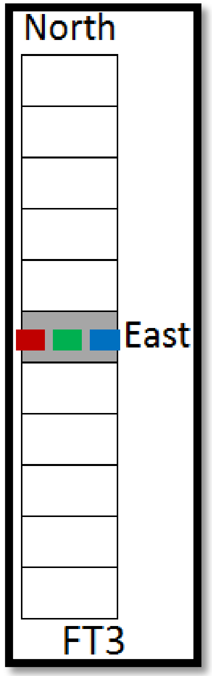
Sensor height difference is one of simulation deviation sources.

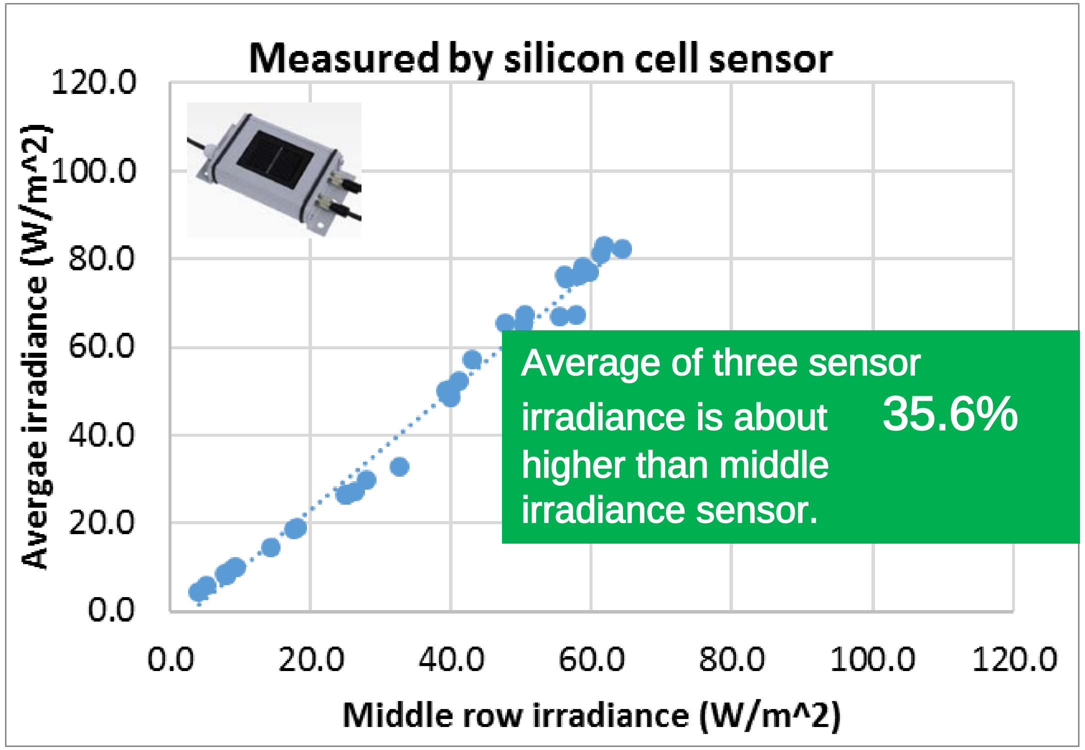


Simulation A (DNI+GHI) VS measurement- *Corrected Rear POA irradiance*

After correction, the simulation results become conservative. It is not very easy to match very well.





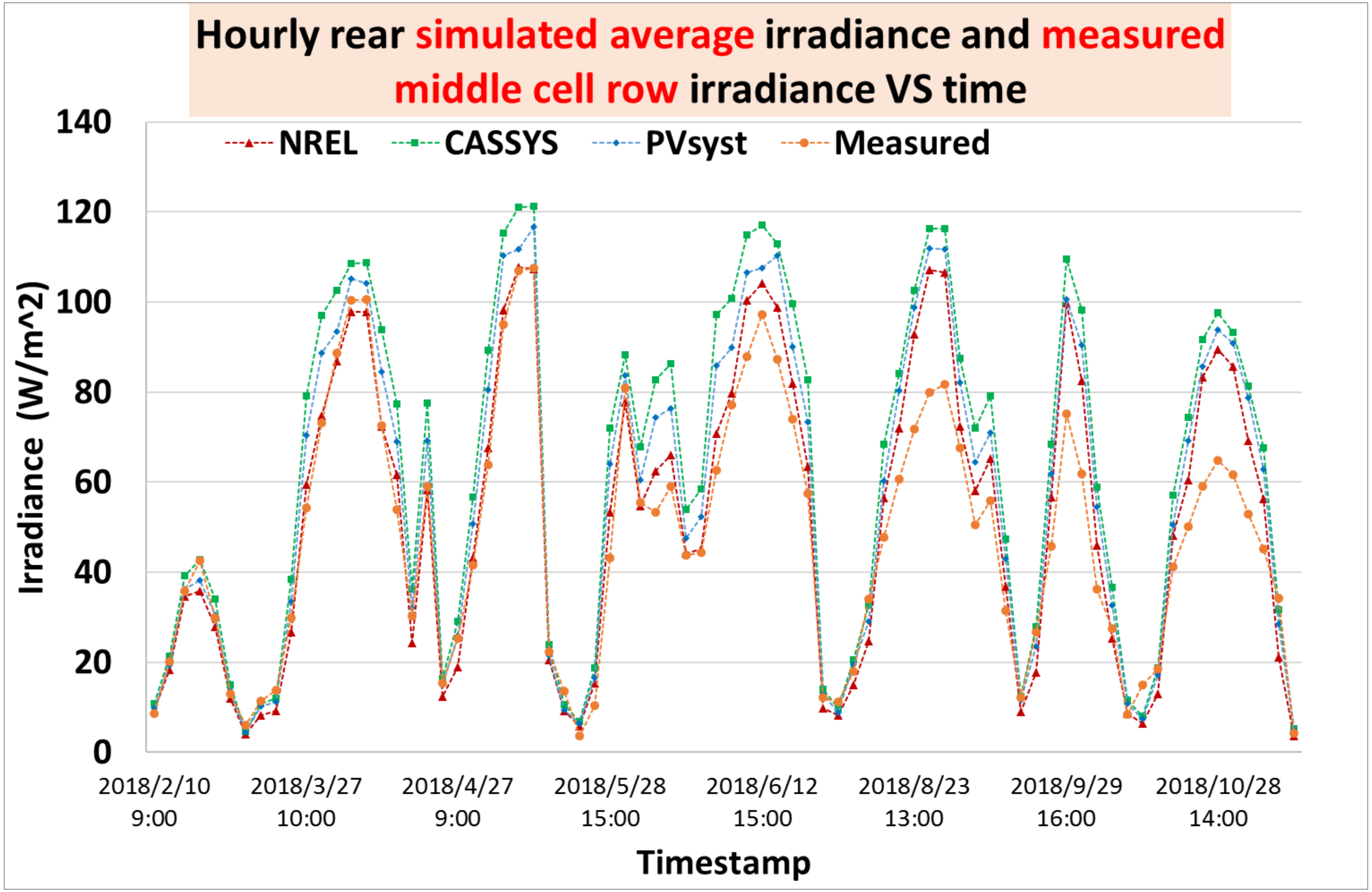


Remark:

- ✓ Module installation height 1.5m used as simulation input.
- ✓ Measured rear side irradiance heights are 1.4m and 1.3m for edges and middle positons respectively.

(Sim. -Meas.)/Meas.(%)			
Approach	NREL	CASSYS	PVsyst
Before correction	10.6%	32%	24%
After correction	-25%	-3.6%	-11.6%

Simulation A (DNI+GHI) VS measurement -*Rear POA irradiance*



Simulation B (POA) approach comparison

Simulation B VS **Measurement**

Measured Front POA, Albedo, Ambient temperature, DC power

PVsyst / CASSYS

Irradiance and Power

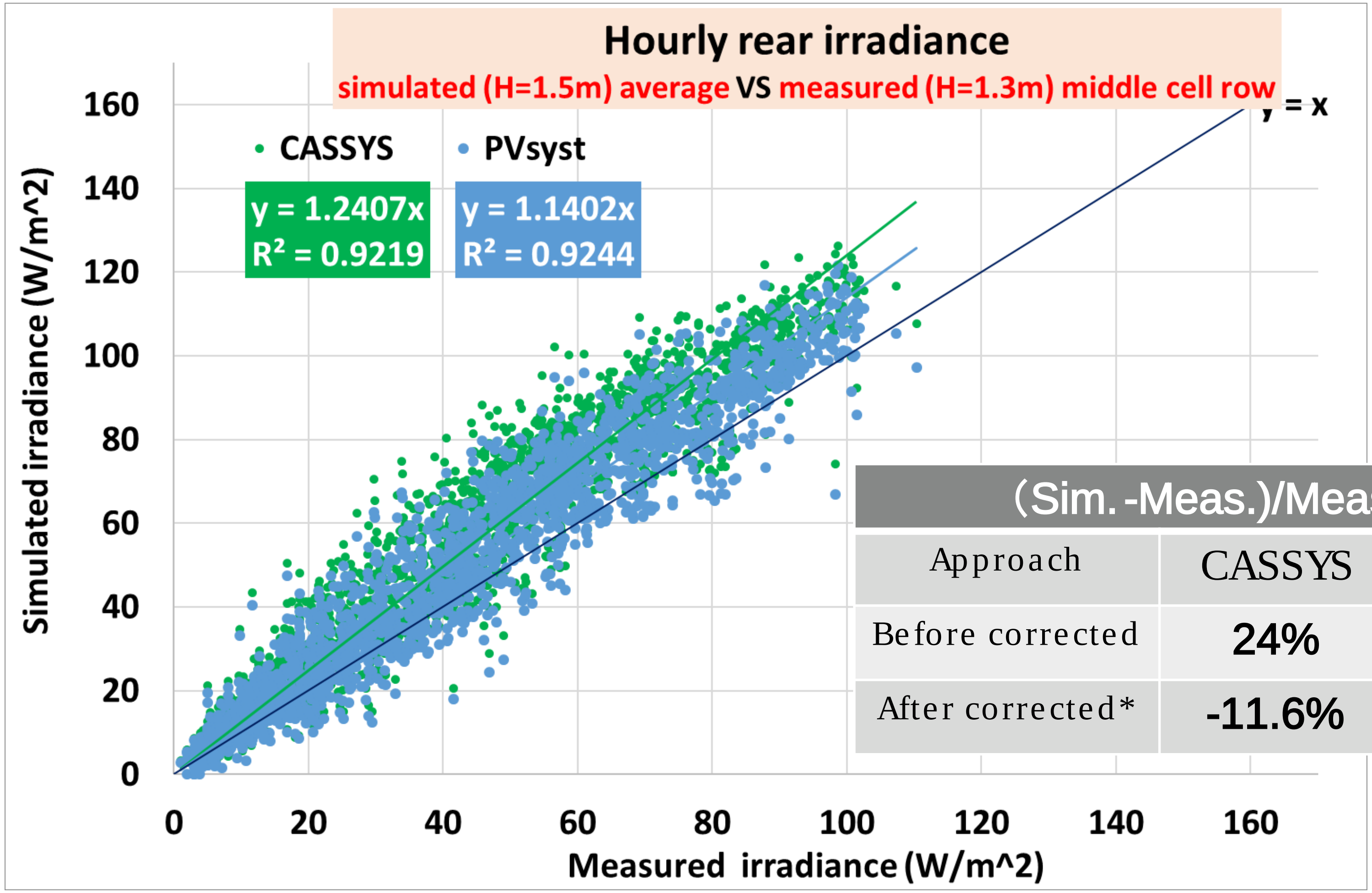
Measured Front POA, Monthly Albedo Ambient temperature

Irradiance and Power

$$\mathrm{MBE/AV} = \frac{\sum_{i=1}^{N}(y_i - x_i)}{N\bar{x}}, \quad \mathrm{RMSE/AV} = \left[\left\{\frac{\sum_{i=1}^{N}(y_i - x_i)^2}{N}\right\}^{1/2}\right] \Big/ \bar{x}$$

Simulation B (POA) *approach* VS measurement - *Rear POA irradiance*

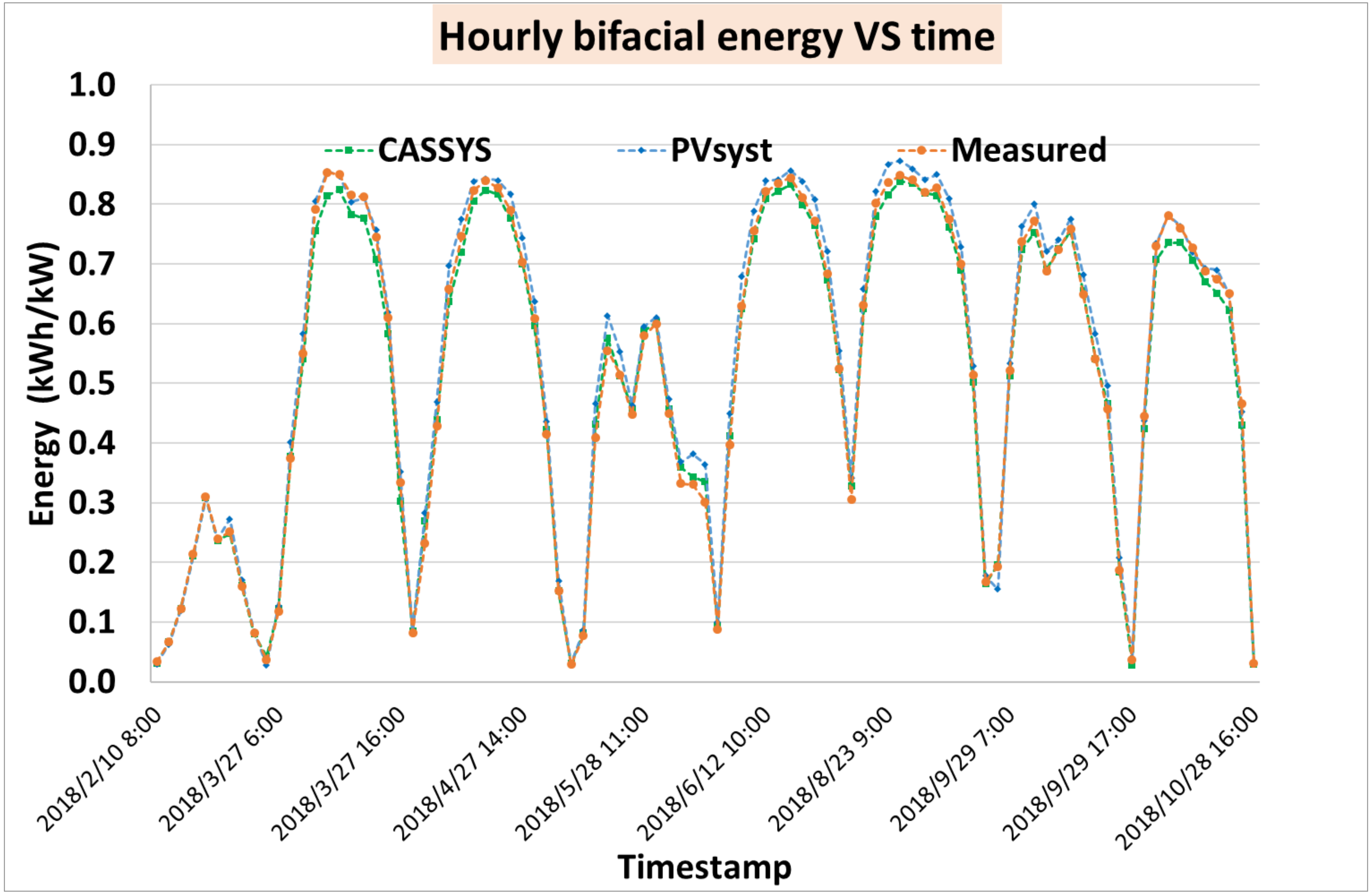
For rear side irradiance: CASSYS and PVsyst are still **aggressive** ?



(Sim. -Meas.)/Meas.(%)		
Approach	CASSYS	PVsyst
Before corrected	24%	14%
After corrected*	-11.6%	-21.6%

Remark : Average of three sensor irradiance is about 35.6% higher than middle irradiance sensor. Height brings additional uncertainty.

Simulation B (POA) VS measurement - *Energy yield*



Different simulation time intervals comparison

CASSYS can provide alternative time step from 1min to hourly for key parameter input.

Simulation

VS

Measurement

Measured Front POA, Albedo
Ambient temperature

One minute measured **minutely albedo**	One hour measured **hourly albedo**	One hour measured **monthly albedo**

CASSYS

Irradiance and Power

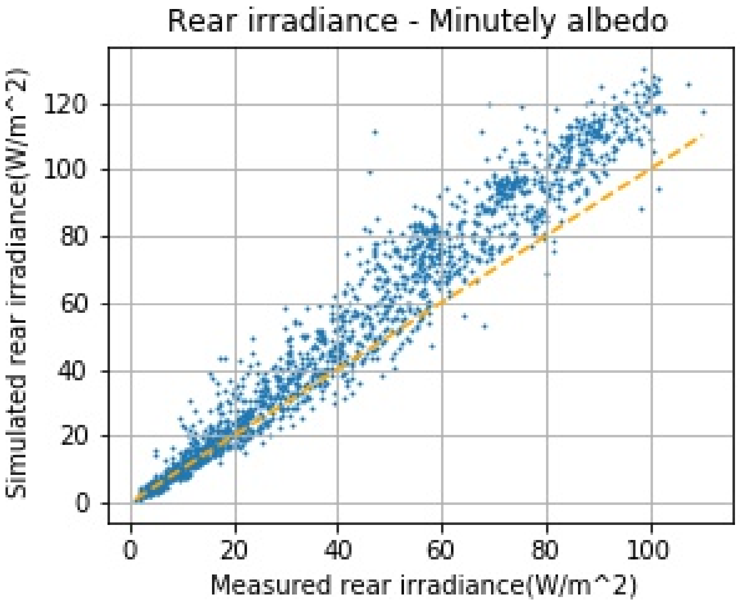
$$\mathrm{MBE/AV} = \frac{\sum_{i}^{N}{}_{1}(y_i - x_i)}{N\bar{x}}, \quad \mathrm{RMSE/AV} = \left[\left\{\frac{\sum_{i}^{N}{}_{1}(y_i - x_i)^2}{N}\right\}^{1/2}\right] \Big/ \bar{x}$$

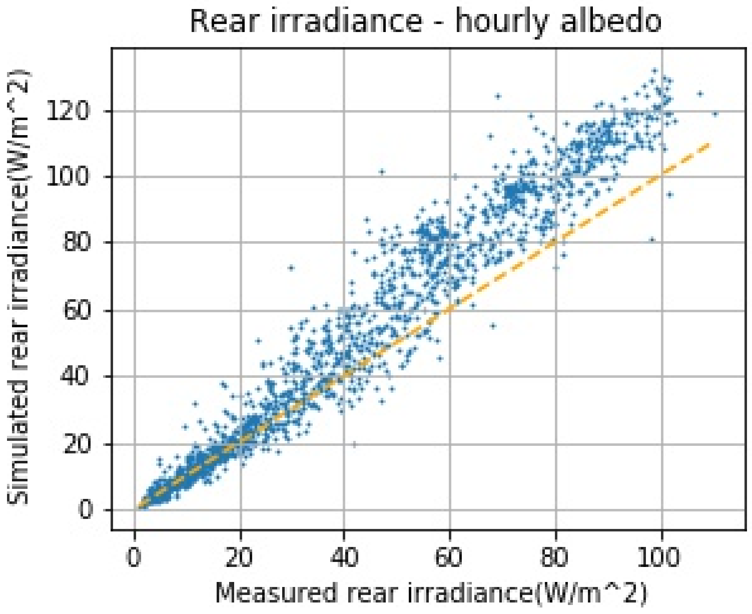
Measured Front POA, Rear POA, Albedo, Ambient temperature, DC power

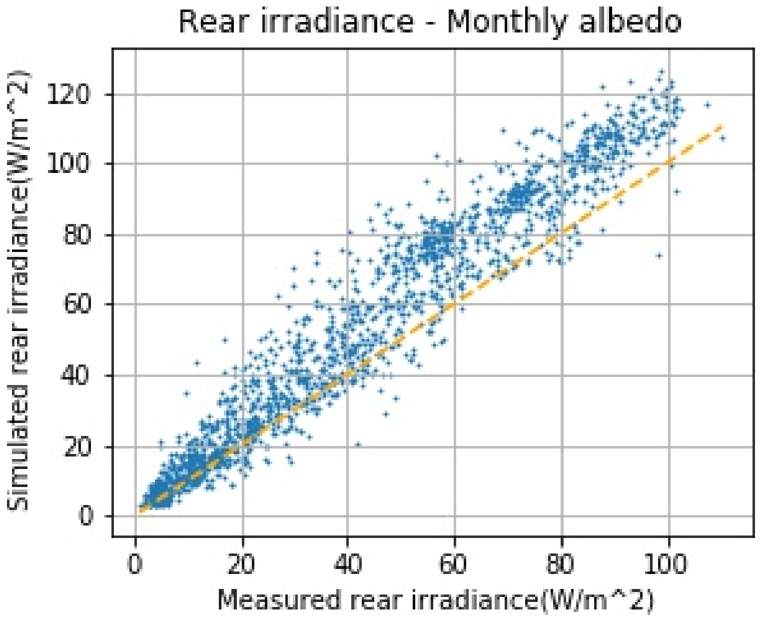
Irradiance and Power

Different time intervals - *Rear POA*

Minutely simulation results is a little better than hourly and monthly on back irradiance level.



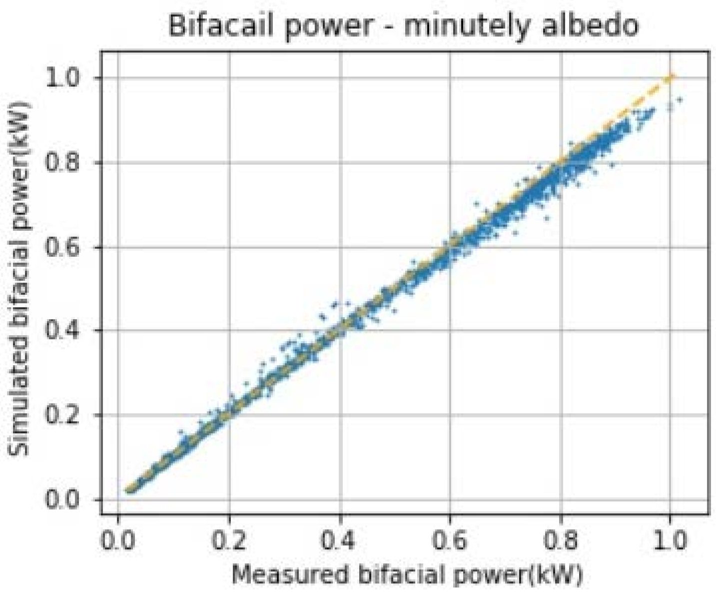


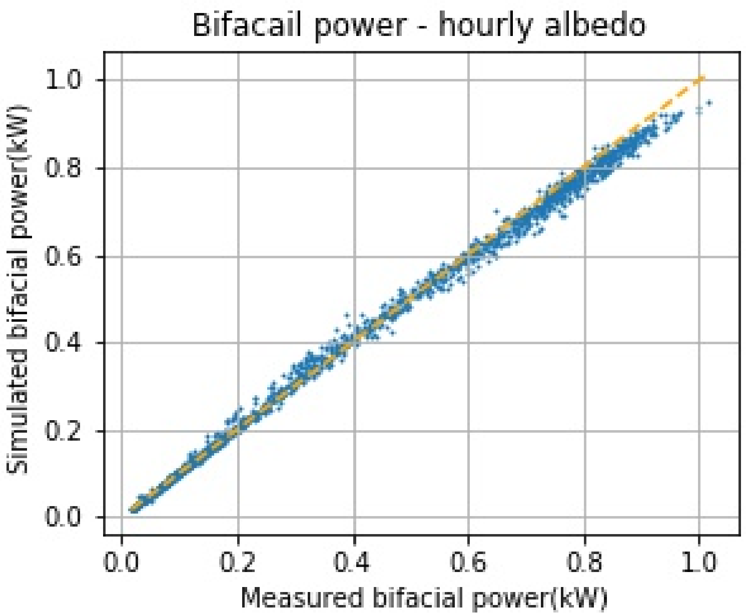


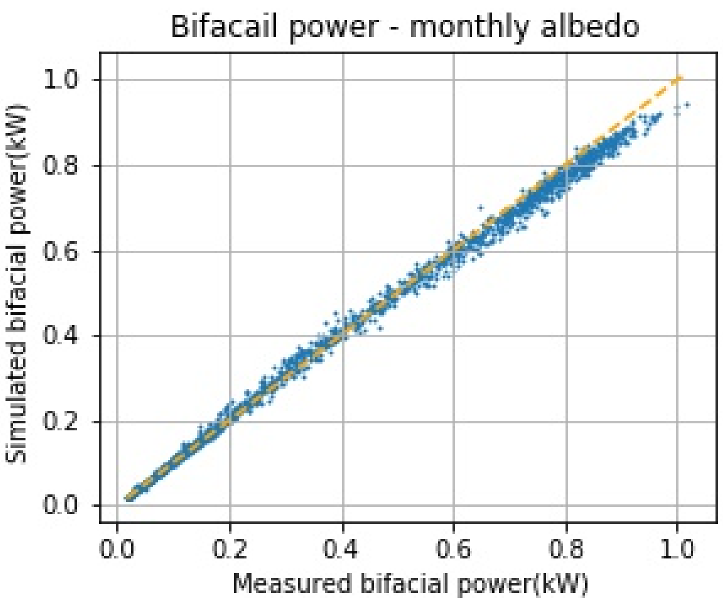
(Sim. -Meas.)/Meas.(%)			
Time step	Minutely albedo	Hourly albedo	Monthly albedo
MBE/AV	22.1%	22.7%	23.6%

Different time intervals *– Energy yield*

Simulation results with different time steps show the same level in energy yield side. Current monthly albedo should be enough for bifacial energy yield simulation.







(Sim.-Meas.)/Meas.(%)			
Time step	Minutely albedo	Hourly albedo	Monthly albedo
MBE/AV	**-1.5 %**	**-0.8%**	**-1.1%**

Canadian Solar Inc.

CanadianSolar

CONTENTS

Conclusion

- Three simulation approaches (NREL,PVsyst,CASSYS)seem relatively conservative considering the limitation of sensor type, height, position, etc.
- Energy yield simulation and measurement in Changshu field match well within reasonable uncertainty range. Rear side simulation under low albedo is not sensitive to energy yield impact.
- Different time intervals for albedo input are not sensitive under low albedo for bifacial energy yield simulation.

Next step

In order to simulate more accurately next step, we will

- ✓ Set up more accurate irradiance sensor testing system with more reasonable position
- ✓ Simulate through stronger irradiance simulation software(like Rhinoceros +DIVA)
- ✓ Albedo testing method and calculation needs to align the same.
- ✓ Special modules can be made to monitor and verify irradiance non-uniformity on back side.
- ✓ ……

Thanks for continuous contribution to bifacial energy modeling from PVsyst, NREL,SANDIA,CASSYS,...

Canadian Solar will share learnings about simulation experience based on more field test data!

New Field trial testing in Wuhai

Total 24 strings

Location	Mounting type	Module type	Module Qty	String Qty	Invert	Remark
1-17 Red zone	Landscape 3*6	CS3U-355PB-FG	216	12	Sungrow SG80KTL-M	The same BOM for bifacial and monofacial module
		CS3U-355P-FG	216	12		

Single facial module

bifacial module

Back side irradiance monitoring

Ground Albedo monitoring

Key parameter	Value
Tilt	35°
Height above the ground	0.5m(fixed)
pitch	8m(fixed)
Ground albedo	0.3
Mounting structure	Triangle steel structure
Foundation	Screw steel tube
Cable connection	Up and down string connection


Thank you for your attention
2018/12