Short term PhD Exchange
Brasil/Australia 2016

PV SYSTEMS IN WARM AND SUNNY CLIMATES: RESULTS FROM PV INSTALLATIONS IN BRAZIL AND SYNERGIES WITH AUSTRALIA

UNIVERSIDADE FEDERAL DE SANTA CATARINA

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UNSW AUSTRALIA

Australian Government
Department of Education

Australian Academy of Science

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Fotovoltaica - UFSC

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Prof. Ricardo Ruther
Director

Distributed Generation: ANEEL RN482/2012

- Microgenerators: up to 75kWp
- Minigenerator: 75kWp to 5MWp

Net Metering (energy credits valid for 60 months)

Competes with tariff @ 0.20 AUD/kWh

Installed until now: 11MWp

Up to 2024: Expected 1.3 GWp

Dedicated solar PV auctions organised by governament

- Dec 2014: 1st Solar Auction = 1GWp -> (**to come online until 2017**)
- Aug 2015: 2nd solar Auction = 1GWp -> (**to come online until 2016**)
- Nov 2015: 3rd solar Auction= 1GWp -> (**to come online until 2018**)

Up to 2024: Expected 7 GWp

PV MARKET IN AUSTRALIA
PERFORMANCE ASSESSMENT

Australia reaches 4.8 GW of rooftop PV capacity

Post date: 02/05/2016 - 08:45

Australia had 1,527,684 rooftop PV systems, representing 4,809 MW of installed PV capacity, as of March 31, 2016, according to new figures provided by Australia's Clean Energy Regulator. In March, the newly installed PV power was 23.1 MW, down from 44.5 MW in the previous month and 62.3 MW in March 2015. Last month's numbers, however, are provisional and will be updated and likely increased in the statistics for April.

In the first quarter of 2016, the country registered new rooftop PV systems with a combined capacity of 104.9 MW. In the same period of 2015, the newly installed PV power was 176.6 MW

In 2015, Australia added over 642.64 MW through the RET scheme. Australia had around 3.9 GW of cumulative installed rooftop PV power at the end of 2014, 3.1 GW at the end of 2013, 2.4 GW at the end of 2012 and 1.3 GW at the end of 2011.

http://www.cleanenergyregulator.gov.au

http://www.cleanenergyregulator.gov.au/RET/Forms-and-resources/postcode-data-for...

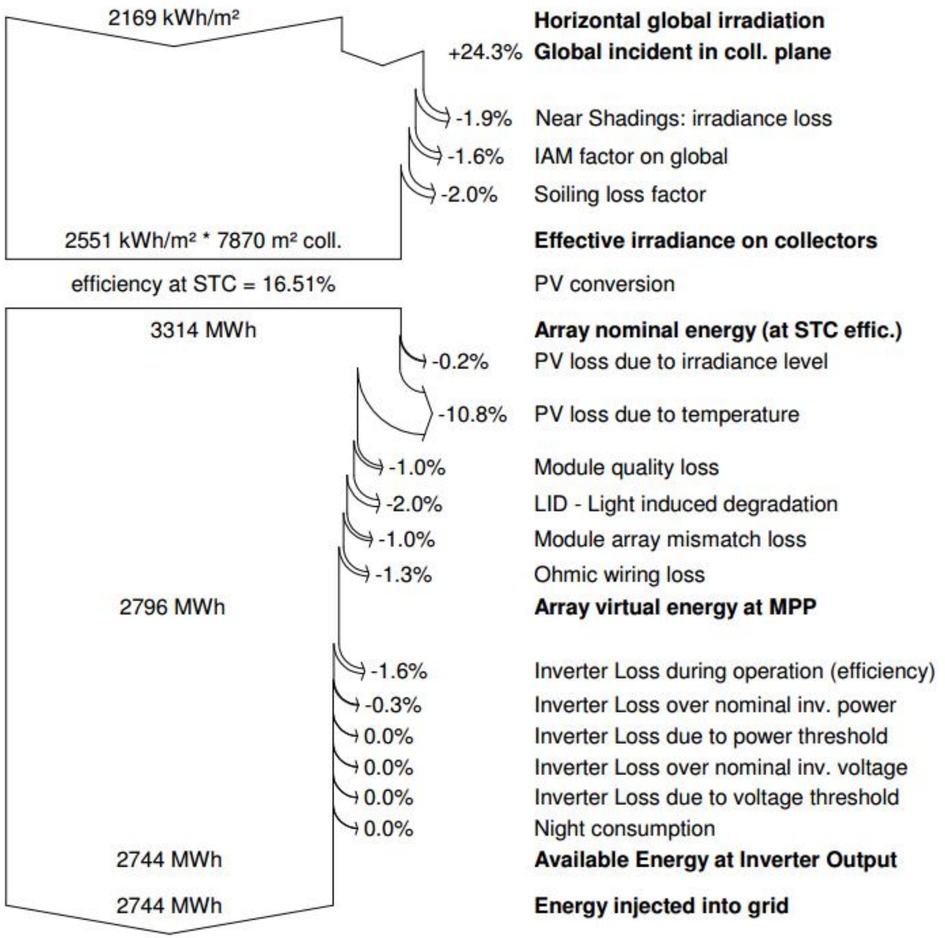
Source: http://www.photon.info/en/news/australia-reaches-48-gw-rooftop-pv-capacity

Japonese Solar Neighborhood

Performance Ratio (PR)

- Ratio between real and theoretical performance
- Allows direct comparison between PV systems (independent from system configuration and location)

PVSYST LOSS DIAGRAM OVER THE WHOLE YEAR



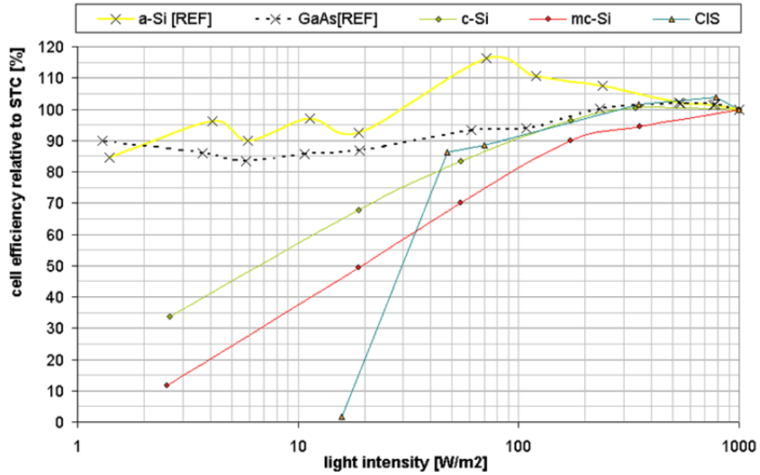
PR: 76,3%

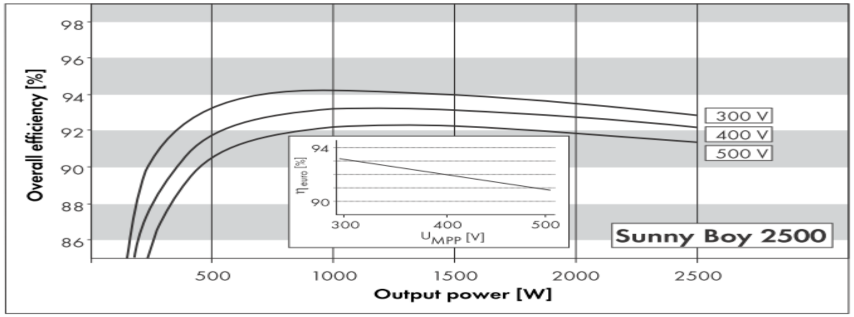
- Long term variability
- Soiling
- Modelling inaccuracies

LONG TERM PERFORMANCE

FLORIANOPOLIS – BRAZIL (1997-2012)
IRRADIANCE DISTRIBUTION OVER 15 YEARS

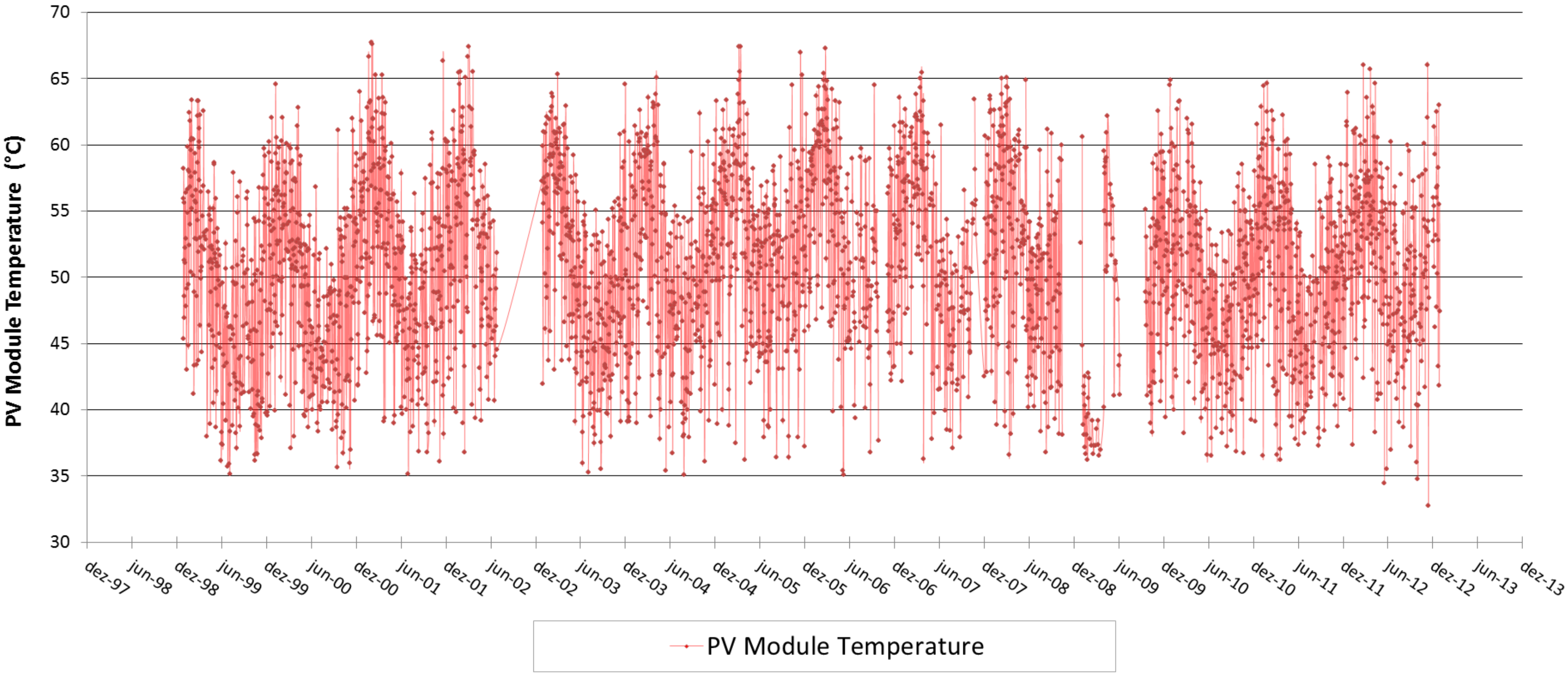
	0	50	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000	1050	1100	1150	1200	1250	1300
1997	3,5%	6,7%	8,1%	7,6%	6,7%	5,5%	5,1%	4,7%	4,4%	4,0%	4,1%	4,0%	3,9%	3,8%	4,1%	4,4%	4,4%	5,4%	6,3%	1,9%	1,3%	0,2%	0,1%	0,0%	0,0%	0,0%	0,0%
1998	2,8%	5,7%	5,9%	5,5%	5,6%	5,0%	4,9%	4,4%	4,4%	4,2%	4,4%	4,1%	4,4%	4,5%	5,0%	5,4%	6,9%	6,2%	5,7%	2,9%	1,9%	0,5%	0,2%	0,0%	0,0%	0,0%	0,0%
1999	2,8%	5,8%	6,0%	5,7%	5,6%	5,1%	4,6%	4,5%	4,4%	4,1%	3,8%	4,2%	4,6%	4,6%	5,0%	5,3%	6,1%	6,0%	5,6%	3,3%	1,6%	0,8%	0,3%	0,1%	0,0%	0,0%	0,0%
2000	2,1%	4,2%	4,9%	5,0%	4,6%	4,3%	4,1%	4,1%	4,1%	4,1%	4,3%	4,6%	4,9%	5,4%	6,0%	6,9%	7,5%	7,3%	6,6%	2,9%	1,2%	0,5%	0,2%	0,1%	0,0%	0,0%	0,0%
2001	2,5%	4,8%	5,0%	5,1%	5,2%	5,0%	4,7%	4,4%	4,2%	4,1%	4,5%	4,5%	4,5%	5,1%	5,7%	6,9%	7,4%	5,8%	5,9%	2,8%	1,1%	0,5%	0,2%	0,1%	0,0%	0,0%	0,0%
2002	1,9%	3,8%	4,6%	5,0%	5,2%	4,9%	5,1%	5,4%	5,1%	5,8%	5,9%	5,6%	5,2%	4,9%	5,2%	5,6%	5,7%	5,8%	5,8%	2,5%	0,6%	0,2%	0,1%	0,0%	0,0%	0,0%	0,0%
2003	2,3%	4,1%	4,5%	4,9%	5,3%	4,9%	4,9%	4,5%	4,3%	4,4%	4,6%	4,6%	4,9%	5,1%	5,5%	6,4%	6,5%	6,7%	7,3%	2,8%	0,8%	0,4%	0,2%	0,0%	0,0%	0,0%	0,0%
2004	3,0%	5,5%	5,8%	5,5%	4,9%	4,9%	4,6%	4,3%	4,2%	4,1%	4,2%	4,2%	4,5%	4,8%	5,6%	6,5%	6,7%	5,7%	5,5%	3,2%	1,3%	0,6%	0,3%	0,1%	0,0%	0,0%	0,0%
2005	2,8%	5,0%	5,0%	4,7%	4,8%	4,9%	4,6%	4,5%	4,2%	4,2%	4,3%	4,5%	4,9%	5,2%	6,1%	7,1%	7,4%	5,8%	5,8%	2,5%	1,0%	0,4%	0,1%	0,1%	0,0%	0,0%	0,0%
2006	2,3%	4,3%	5,3%	5,1%	4,9%	4,9%	4,9%	4,6%	4,7%	4,8%	4,7%	5,0%	5,1%	5,5%	6,4%	7,6%	6,4%	6,0%	4,4%	1,7%	0,8%	0,3%	0,1%	0,0%	0,0%	0,0%	0,1%
2007	3,0%	5,2%	5,6%	5,7%	5,4%	5,1%	4,8%	4,9%	4,9%	5,0%	5,4%	5,5%	5,5%	5,6%	6,5%	7,0%	6,9%	5,2%	1,8%	0,7%	0,2%	0,1%	0,0%	0,0%	0,0%	0,0%	0,0%
2008	2,8%	4,7%	5,1%	4,9%	5,1%	5,0%	5,1%	5,0%	5,3%	5,2%	5,4%	5,4%	5,8%	6,5%	7,5%	8,0%	6,0%	4,5%	1,6%	0,6%	0,3%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
2009	2,8%	5,8%	5,8%	5,6%	5,5%	5,4%	4,9%	4,5%	4,5%	4,3%	4,4%	4,6%	4,9%	5,4%	6,7%	7,2%	6,6%	6,4%	3,5%	0,9%	0,4%	0,1%	0,0%	0,0%	0,0%	0,0%	0,0%
2010	4,0%	6,2%	6,3%	5,9%	5,4%	4,9%	5,0%	4,7%	4,9%	4,9%	4,8%	5,0%	5,1%	5,4%	5,8%	6,1%	6,4%	5,2%	2,5%	0,8%	0,3%	0,2%	0,0%	0,0%	0,0%	0,0%	0,0%
2011	3,7%	6,4%	6,2%	6,0%	5,8%	5,5%	5,0%	4,7%	4,7%	4,5%	4,9%	5,0%	5,4%	6,3%	7,3%	7,3%	6,0%	3,3%	1,4%	0,5%	0,2%	0,1%	0,0%	0,0%	0,0%	0,0%	0,0%
2012	4,8%	5,1%	4,7%	4,5%	4,4%	4,1%	4,1%	4,2%	4,2%	4,1%	4,3%	4,3%	4,8%	5,0%	5,6%	6,8%	6,9%	5,9%	5,5%	4,2%	1,0%	0,4%	0,1%	0,1%	0,0%	0,0%	0,0%
Média	**2,9%**	**5,2%**	**5,5%**	**5,4%**	**5,3%**	**5,0%**	**4,8%**	**4,6%**	**4,5%**	**4,5%**	**4,6%**	**4,7%**	**4,9%**	**5,2%**	**5,9%**	**6,5%**	**6,5%**	**5,7%**	**4,7%**	**2,1%**	**0,9%**	**0,3%**	**0,1%**	**0,0%**	**0,0%**	**0,0%**	**0,0%**





N. REICH; W. VAN SARK; E. ALSEMA; S. KAN, S. S.; DER, A. V.; HEIDE, R. L., AND R. SCHROPP. Weak light performance and spectral response of different solar cell types. In: 20th European Photovoltaic Solar Energy Conference, 2005. **Anais.** Spain, 2005.v.p.

FLORIANOPOLIS – BRAZIL (1997-2012)
TEMPERATURE DISTRIBUTION OVER 15 YEARS



LONG TERM PERFORMANCE ASSESSMENT

Performance Ratio (PR)

Max: 79%

Min: 73%

Est. Average:76%

Yield (kWh/kWp)

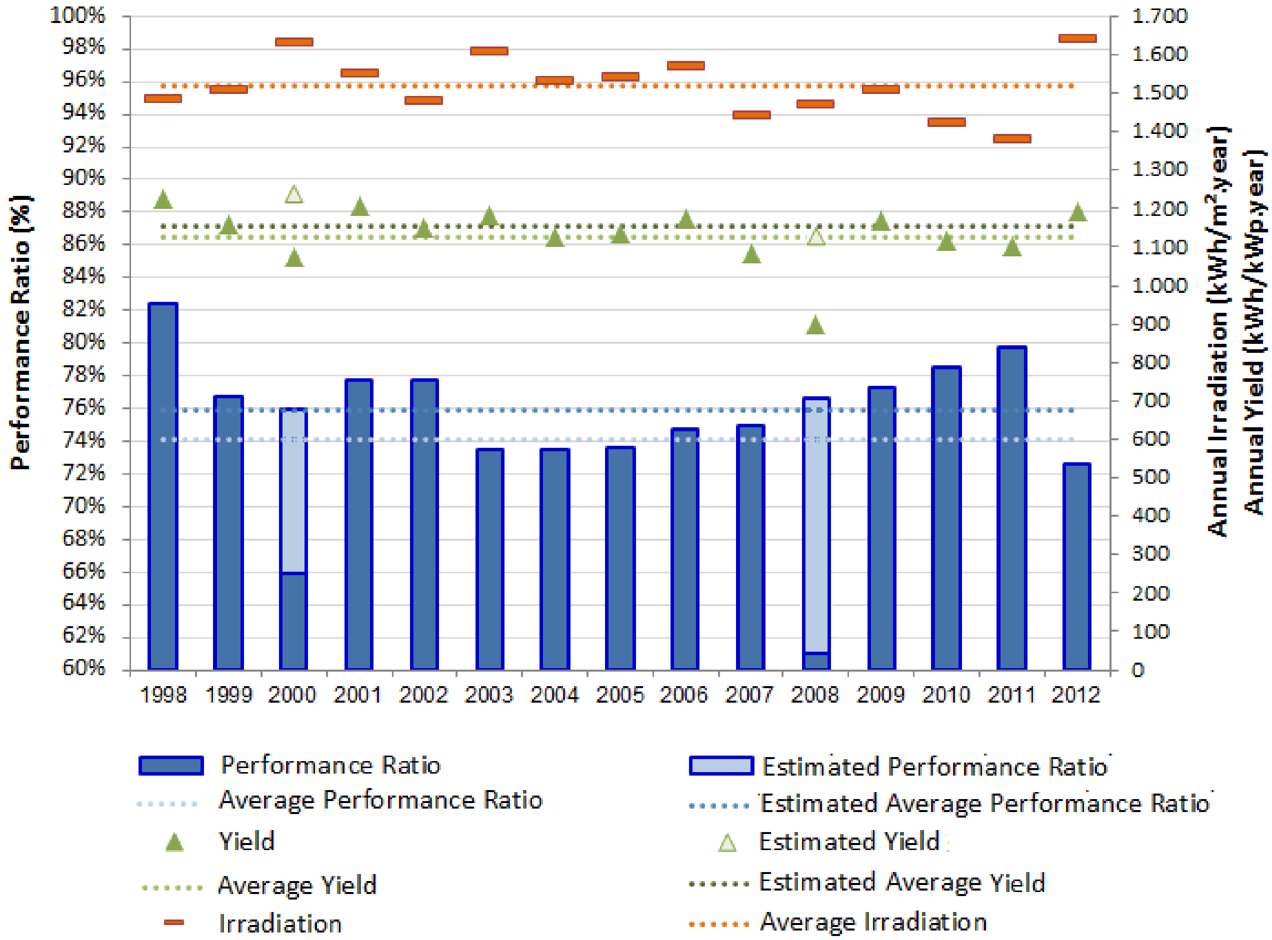
Max: 1205

Min: 1072

Est. Average :1159

Irradiation

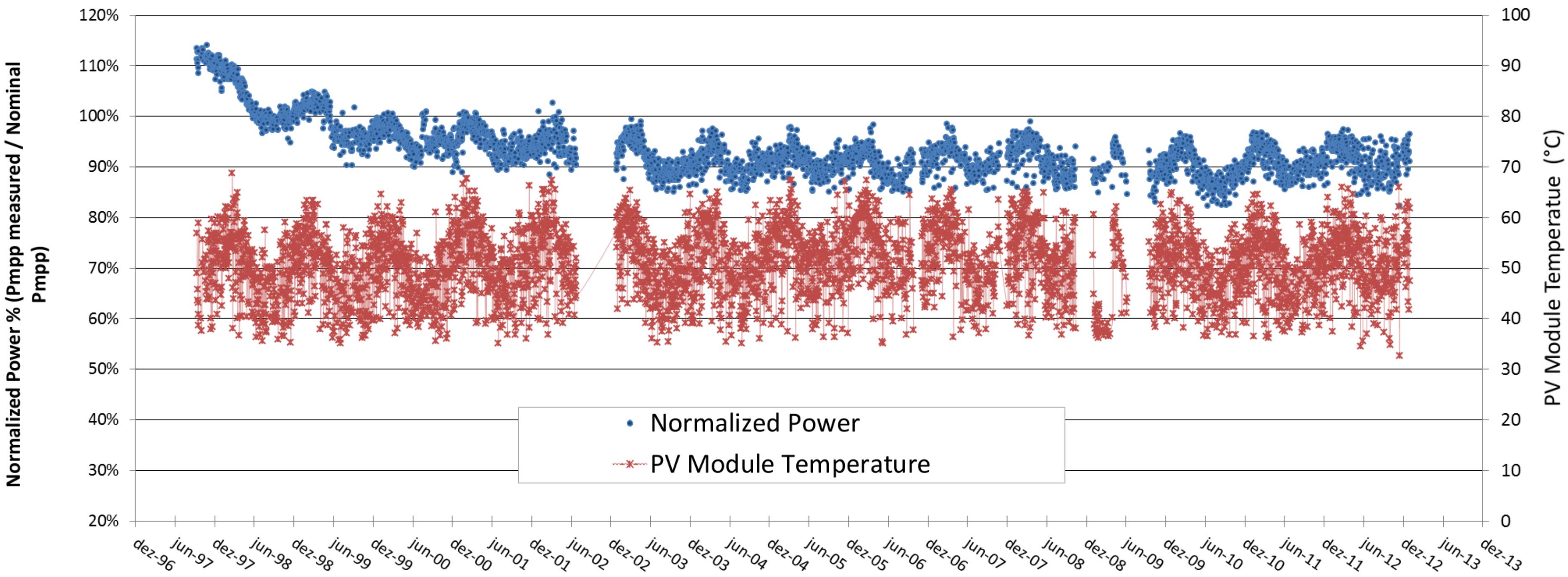
1527 kWh/m².year



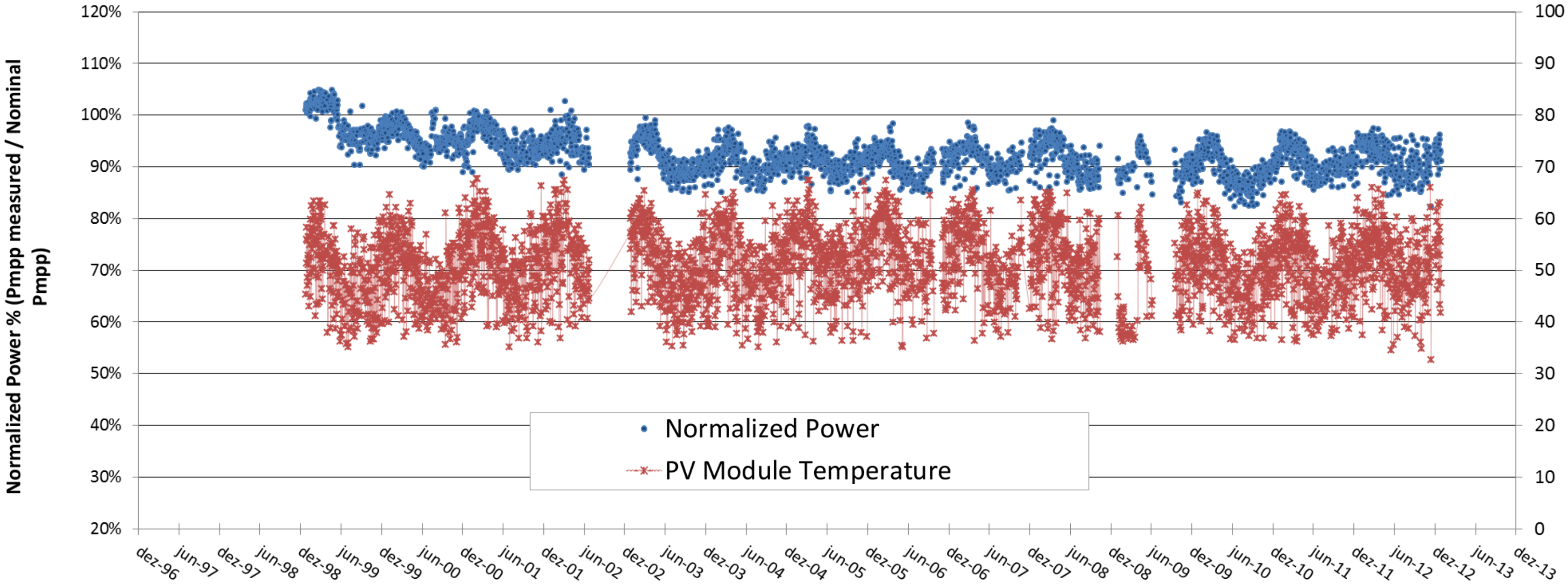
NASCIMENTO, L.; RUTHER, R. Fifteen years and counting: The reliable long-term performance of the first grid-connected, building-integrated, thin-film photovoltaic installation in Brazil. In: 2014 IEEE 40th Photovoltaic Specialist Conference (PVSC), 2014. **Anais.**, 2014.v.p. 3372-3377.

DIERAUF, T.; GROWITZ, A.; KURTZ, S. R.; CRUZ, J. L. B.; RILEY, E.; HANSEN, C. **Weather-Corrected Performance Ratio**. National Renewable Energy Laboratory, 2013.

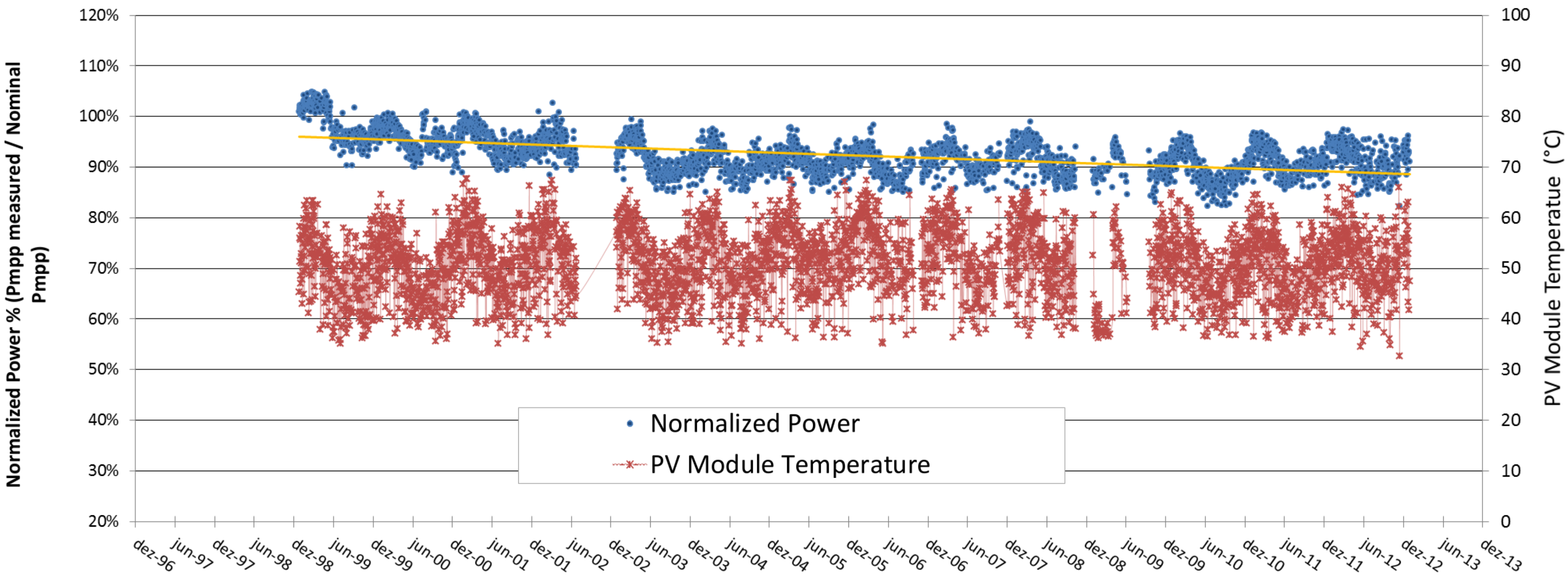
RESULTS - PV ARRAY DEGRADATION



RESULTS - PV ARRAY DEGRADATION



RESULTS - PV ARRAY DEGRADATION



- Degradation of about 0.55% p.a.
- Degradation specsheet ~ 1% p.a.
- Literature thin films (1.5% p.a. on average)
- Literature Si (0.7% p.a. on average)

NASCIMENTO, L.; RUTHER, R. Fifteen years and counting: The reliable long-term performance of the first grid-connected, building-integrated, thin-film photovoltaic installation in Brazil. In: 2014 IEEE 40th Photovoltaic Specialist Conference (PVSC), 2014. **Anais.**, 2014.v.p. 3372-3377.

SOILING

SEASONAL IMPACT HOMOGENEOUS SOILING

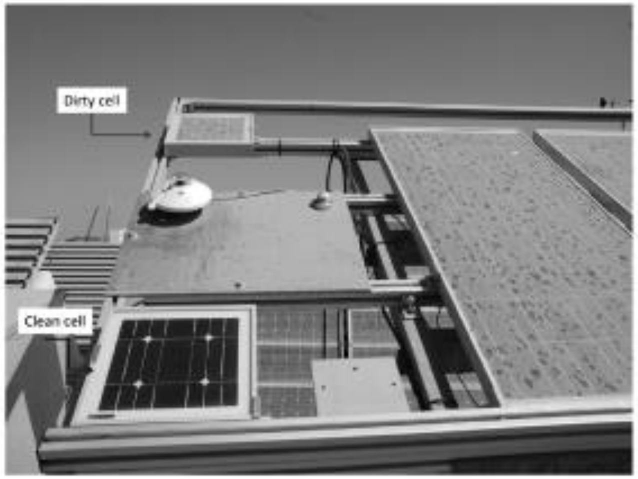
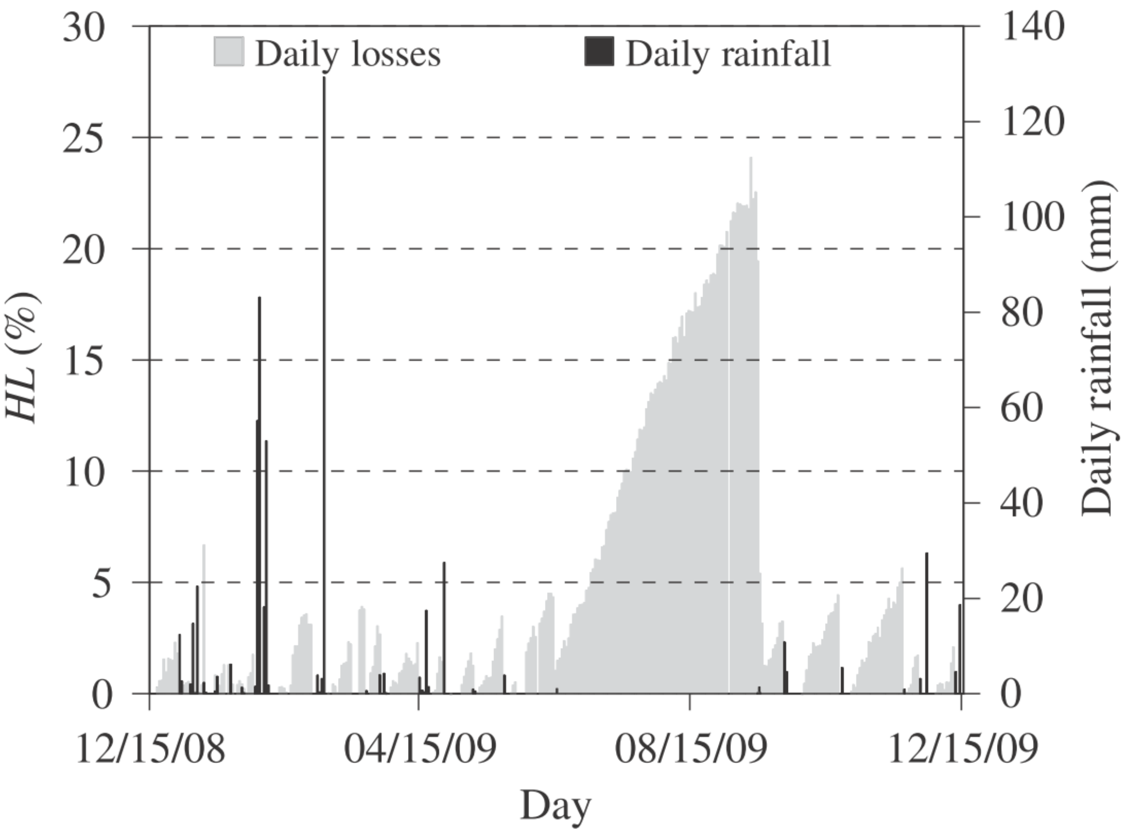


Table I. Monthly mean values of daily irradiation and daily irradiation losses, monthly values of rainfall and days with available data.

Month/year	$\bar{H}_D$ (kWh m^{-2})	$\bar{HL}$ (%)	Rain (mm)	Days
December 2008	3.9	0.8	15.0	15
January 2009	3.8	0.5	54.9	31
February 2009	4.8	1.4	217.0	28
March 2009	5.3	1.1	141.5	28
April 2009	6.6	0.6	50.7	30
May 2009	7.1	0.8	5.2	29
June 2009	6.8	3.2	0.0	28
July 2009	7.4	9.6	0.0	31
August 2009	7.4	17.3	0.0	31
September 2009	5.7	10.8	15.7	26
October 2009	5.8	1.5	5.4	31
November 2009	4.5	2.2	33.5	30
December 2009	4.2	0.4	23.2	14
Average	*5.8*	*4.3*	*46.8*	



ZORRILLA-CASANOVA, J.; PILIOUGINE, M.; CARRETERO, J.; BERNAOLA-GALVÁN, P.; CARPENA, P.; MORA-LÓPEZ, L.; SIDRACH-DE-CARDONA, M. Losses produced by soiling in the incoming radiation to photovoltaic modules. **Progress in Photovoltaics: Research and Applications.** Issue 4, v.21, p.790-796, 2013.

SEASONAL IMPACT HOMOGENEOUS SOILING

SEASONAL IMPACT HOMOGENEOUS SOILING

Slime mould?

Need manual cleaning!

Annual rainfall in Florianópolis 1600mm/year

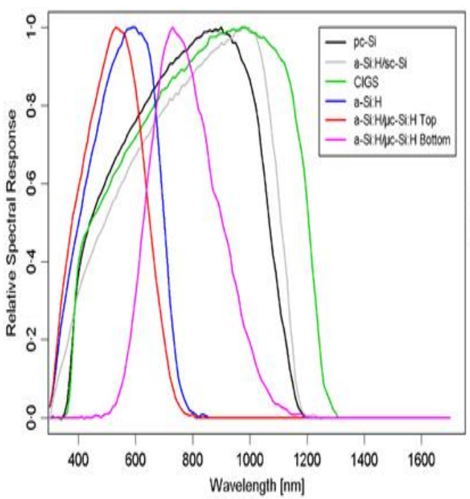
RESULTS - SOILING

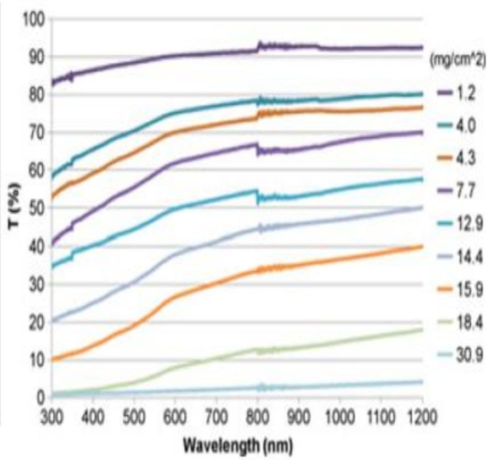
	T mod °C	E eff W/m2	Isc STC (A)		Uoc STC (V)		Impp STC (A)		Vmpp STC (V)		Pmpp STC (W)		Fill factor (%)	
String 1 - Clean	61	1001	1,15	**5,7%**	611,44	**0,7%**	0,88	**5,7%**	404,84	**0,7%**	354,4	**6,5%**	50,2	**0,0%**
String 1 - Dirty	57	991	1,09		607,10		0,83		401,85		332,9		50,3	
String 2 - Clean	60	986	1,14	**5,8%**	609,30	**1,0%**	0,86	**6,1%**	401,50	**0,4%**	344,9	**6,6%**	49,7	**-0,3%**
String 2 - Dirty	57	997	1,07		603,36		0,81		399,80		323,5		49,9	
String 3 - Clean	60	1003	1,14	**4,9%**	615,28	**0,0%**	0,86	**4,9%**	410,81	**0,1%**	351,6	**5,1%**	50,3	**0,2%**
String 3 - Dirty	58	1001	1,08		615,54		0,82		410,23		334,7		50,2	
String 4 - Clean	60	991	1,11	**5,7%**	614,62	**-3,2%**	0,82	**5,6%**	405,13	**-1,6%**	330,7	**3,9%**	48,7	**1,6%**
String 4 - Dirty	58	951	1,05		635,14		0,77		411,68		318,2		47,9	
String 5 - Clean	60	1014	0,97	**4,9%**	604,96	**-2,0%**	0,73	**5,9%**	404,54	**-1,5%**	295,6	**4,3%**	50,5	**1,4%**
String 5 - Dirty	57	984	0,92		617,26		0,69		410,66		283,5		49,8	
Average				**5,4%**		**-0,7%**		**5,6%**		**-0,4%**		**5,3%**		**0,6%**

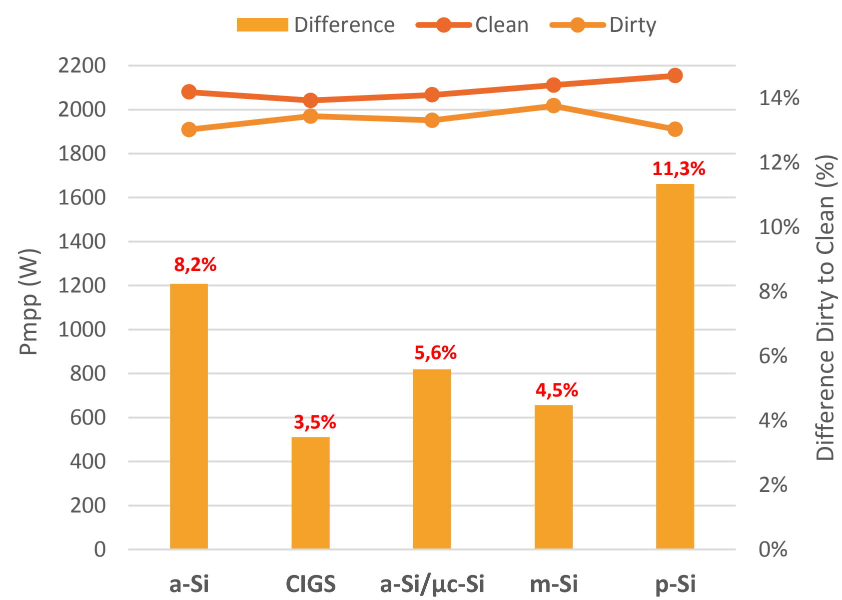
- ~ 5% losses ~ 0.2$/kWh - Would result in $48.00 over the 2-years

SEASONAL IMPACT HOMOGENEOUS SOILING

ELETRICAL IMPACT NON-HOMOGENEOUS SOILING







Soiling acts as a filter for short wavelengths (blue light)
Good for CIGS; bad for CdTe and a-Si

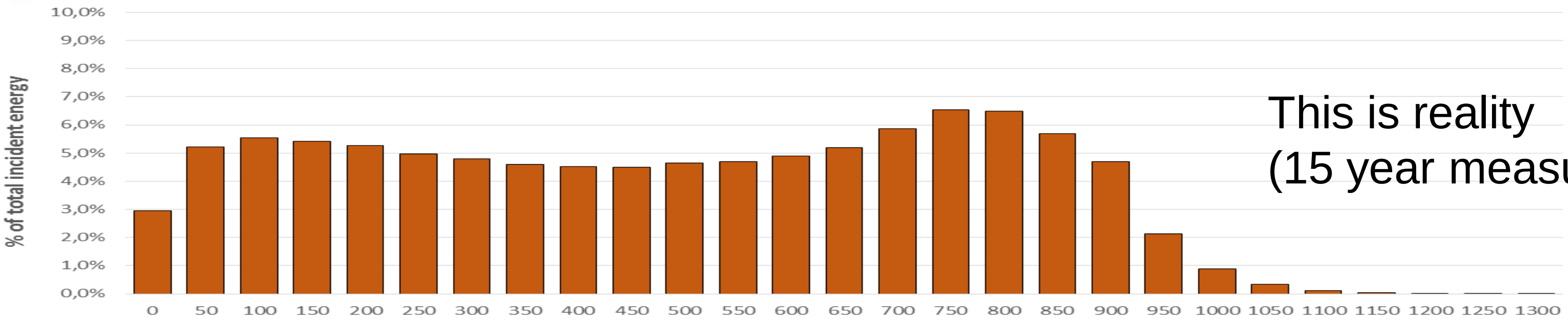
QASEM, H.; BETTS, T. R.; MÜLLEJANS, H.; ALBUSAIRI, H.; GOTTSCHALG, R. Dust-induced shading on photovoltaic modules. **Progress in Photovoltaics: Research and Applications.** p.n/a-n/a, 2012.

NASCIMENTO, L.; CAMPOS, R.; RUTHER, R.; SIMÕES, G. AVALIAÇÃO DE DESEMPENHO DE DIFERENTES TECNOLOGIAS FOTOVOLTAICAS NO NORDESTE BRASILEIRO. In: VI Congresso Brasileiro de Energia Solar 2016. **Anais.** Belo Horizonte - Brasil, 2016.v.p.

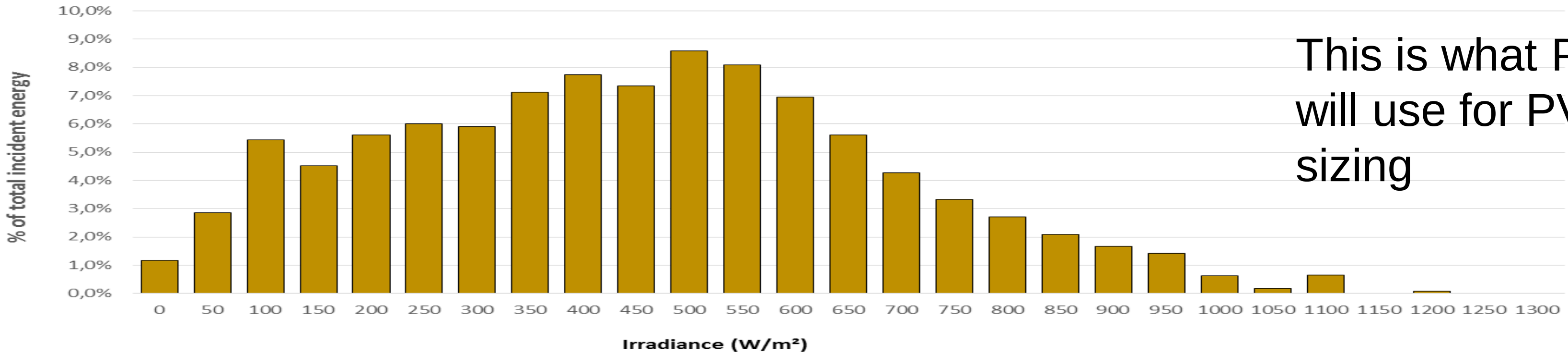
HICKEL, B.; DESCHAMPS, E. M.; NASCIMENTO, L.; RUTHER, R.; SIMOES, G. ANÁLISE DA INFLUÊNCIA DO ACÚMULO DE SUJEIRA SOBRE DIFERENTES TECNOLOGIAS DE MÓDULOS FV: REVISÃO E MEDIÇÕES DE CAMPO. In: VI Congresso Brasileiro de Energia Solar, 2016. **Anais.**

MODELLING INACCURACIES

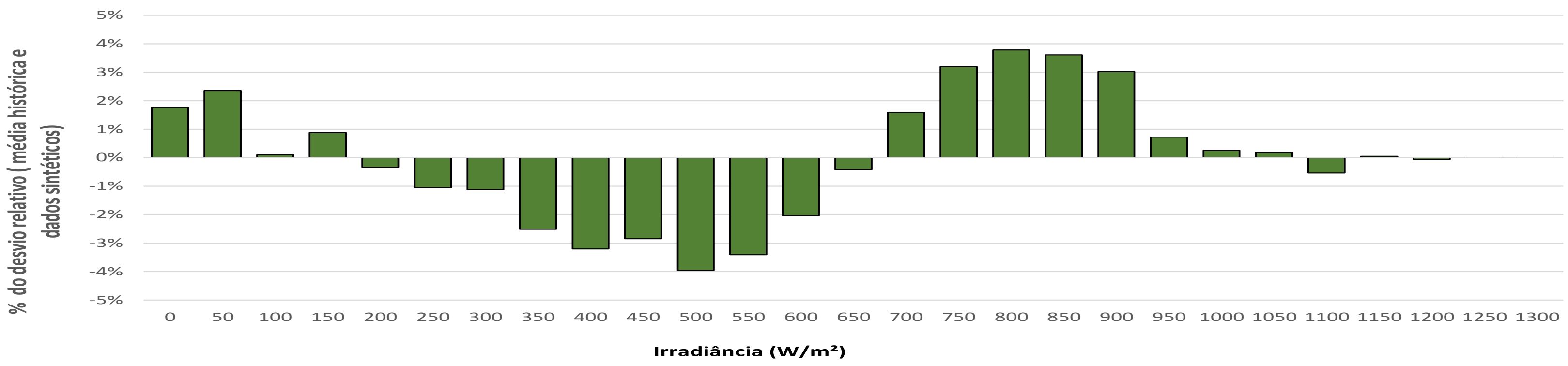
IRRADIANCE DISTRIBUTION - BRAZIL



This is reality
(15 year measurements)



This is what PVSyst will use for PV system sizing

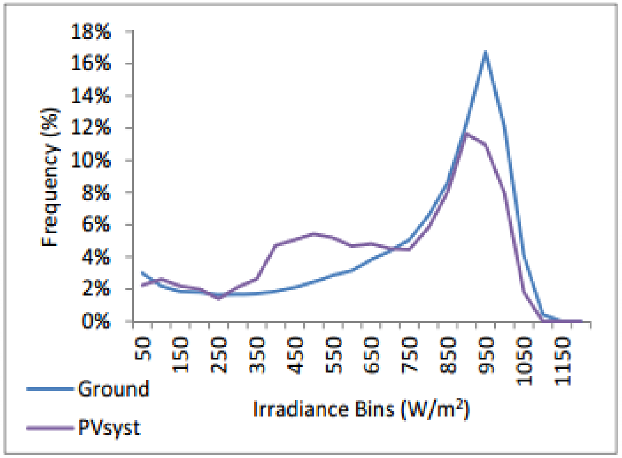


fotovoltaicaufsc

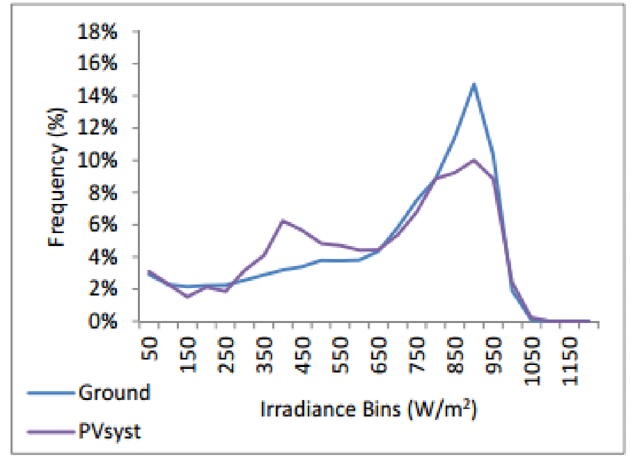
IRRADIANCE DISTRIBUTION - AUSTRALIA

PVsyst

Alice Springs

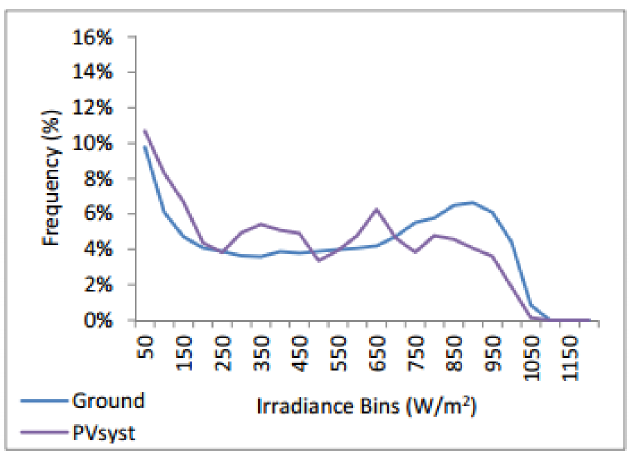


Broome

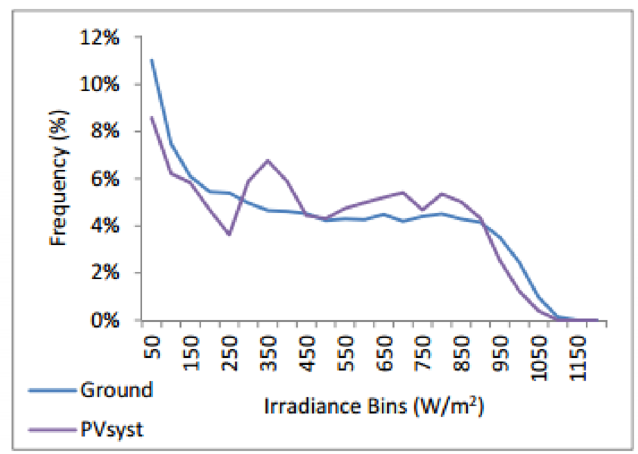


PVsyst

Melbourne



Cape Grim



COPPER, J. K.; BRUCE, A. G. **Assessment of the Australian Bureau of Meteorology hourly gridded solar data**: ASIA-PACIFIC SOLAR RESEARCH CONFERENCE. Brisbane - Australia, 2015.

SOLAR FARMS – LAST BRAZILIAN ENERGY AUCTION INVERTER LOADING RATIOS

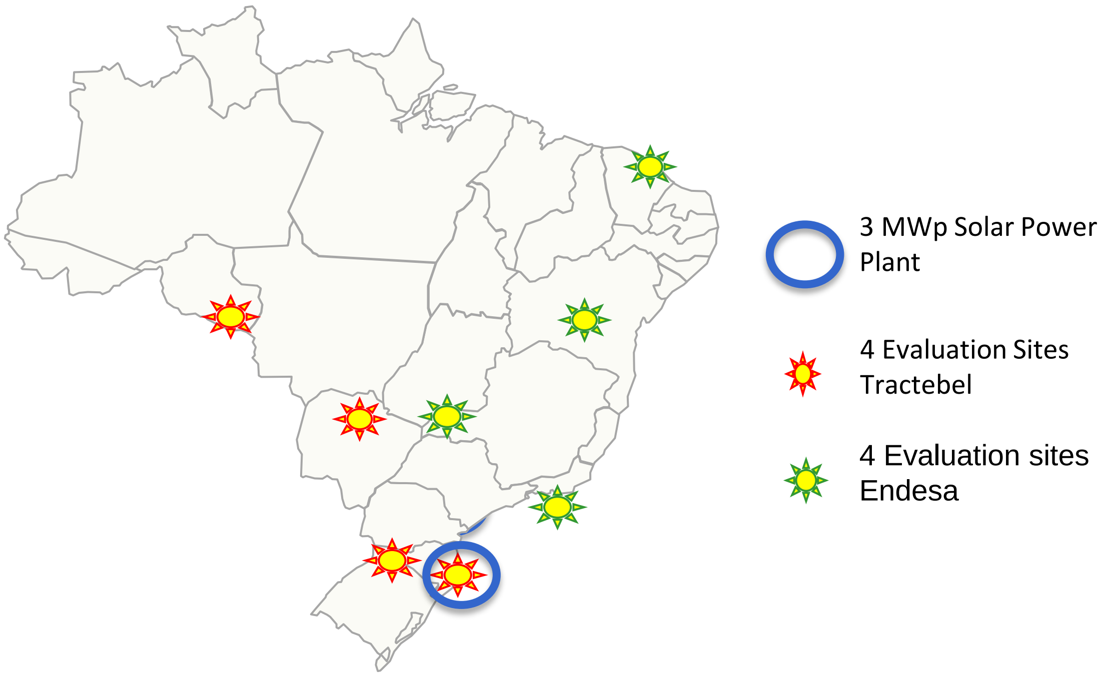
APPENDIX I – Contracted projects in the 2nd LER/2015: main technical features

PV Project	State	DC Power (MWp)	AC Power (MW)	Qualified Power (MW)	Physical Guarantee (MWa)	Capacity Factor (%)		Mounting system	Connection	Contracted Energy (MWa)	Inverter Sizing Factor (%)
						ref.: Qual.Pow	**ref.: DC.Pow**				
Sol Steelcons Miracema 1	TO	33.3	30.0	30.0	5.4	18.0%	16.2%	Fixed	Basic Grid	5.4	90.2%
Sol Steelcons Miracema 2	TO	33.3	30.0	30.0	5.4	18.0%	16.2%	Fixed	Basic Grid	5.4	90.2%
Sol Steelcons Miracema 3	TO	33.3	30.0	30.0	5.4	18.0%	16.2%	Fixed	Basic Grid	5.4	90.2%
Fazenda Esmeralda	PE	40.1	30.0	30.0	6.2	20.7%	15.4%	Fixed	Distribution	6.2	74.7%
Boa Hora 1	PE	30.0	25.0	25.0	5.3	21.2%	17.7%	Fixed	OTF	5.3	83.3%
Boa Hora 2	PE	30.0	25.0	25.0	5.3	21.2%	17.7%	Fixed	OTF	5.3	83.3%
Boa Hora 3	PE	30.0	25.0	25.0	5.3	21.2%	17.7%	Fixed	OTF	5.3	83.3%
NOVA CRUZ	RN	34.0	30.0	30.0	7.0	23.3%	20.6%	1 axis tracking	Distribution	6.3	88.2%
COREMAS III	PB	36.8	30.0	30.0	7.1	23.7%	19.3%	Fixed	Basic Grid	7.1	81.6%
BJL 4	BA	25.5	20.0	20.0	5.0	25.0%	19.6%	Fixed	Basic Grid	5.0	78.4%
Sobrado1	BA	34.2	30.0	30.0	7.8	26.0%	22.8%	1 axis tracking	Distribution	7.8	87.7%
BRISAS SUAVES	SP	6.0	5.0	5.0	1.3	26.0%	21.8%	1 axis tracking	Distribution	1.3	84.0%
GUIMARANIA 1	MG	36.8	30.0	30.0	8.2	27.3%	22.3%	1 axis tracking	Distribution	8.2	81.5%
GUIMARANIA 2	MG	36.8	30.0	30.0	8.2	27.3%	22.3%	1 axis tracking	Distribution	8.2	81.5%
PIRAPORA 2	MG	36.8	30.0	30.0	8.4	28.0%	22.8%	1 axis tracking	Basic Grid	8.4	81.5%
PIRAPORA 3	MG	36.8	30.0	30.0	8.4	28.0%	22.8%	1 axis tracking	Basic Grid	8.4	81.5%
PIRAPORA 4	MG	36.8	30.0	30.0	8.4	28.0%	22.8%	1 axis tracking	Basic Grid	8.4	81.5%
PARACATU 1	MG	36.8	30.0	30.0	8.5	28.3%	23.1%	1 axis tracking	Basic Grid	8.5	81.5%
PARACATU 2	MG	36.8	30.0	30.0	8.5	28.3%	23.1%	1 axis tracking	Basic Grid	8.5	81.5%
PARACATU 3	MG	36.8	30.0	30.0	8.5	28.3%	23.1%	1 axis tracking	Basic Grid	8.5	81.5%
PARACATU 4	MG	36.8	30.0	30.0	8.5	28.3%	23.1%	1 axis tracking	Basic Grid	8.5	81.5%
APODI I	CE	36.5	30.0	30.0	8.7	29.0%	23.9%	1 axis tracking	Basic Grid	8.7	82.3%
APODI II	CE	36.5	30.0	30.0	8.7	29.0%	23.9%	1 axis tracking	Basic Grid	8.7	82.3%
APODI III	CE	36.5	30.0	30.0	8.7	29.0%	23.9%	1 axis tracking	Basic Grid	8.7	82.3%
APODI IV	CE	36.5	30.0	30.0	8.7	29.0%	23.9%	1 axis tracking	Basic Grid	8.7	82.3%
JUAZEIRO SOLAR II	BA	34.4	29.8	29.8	8.7	29.2%	25.3%	1 axis tracking	Basic Grid	8.7	86.7%
JUAZEIRO SOLAR I	BA	34.4	29.8	29.8	8.7	29.2%	25.3%	1 axis tracking	Basic Grid	8.7	86.7%
JUAZEIRO SOLAR III	BA	34.4	29.8	29.8	8.7	29.2%	25.3%	1 axis tracking	Basic Grid	8.7	86.7%
JUAZEIRO SOLAR IV	BA	34.4	29.8	29.8	8.7	29.2%	25.3%	1 axis tracking	Basic Grid	8.7	86.7%
Assú V	RN	36.7	30.0	30.0	9.2	30.7%	25.1%	1 axis tracking	Basic Grid	9.2	81.7%
Floresta I	RN	36.7	30.0	30.0	9.4	31.3%	25.6%	1 axis tracking	Basic Grid	9.4	81.7%
Floresta II	RN	36.7	30.0	30.0	9.4	31.3%	25.6%	1 axis tracking	Basic Grid	9.4	81.7%
Floresta III	RN	24.5	20.0	20.0	6.3	31.5%	25.7%	1 axis tracking	Basic Grid	6.3	81.7%
Total		**1,115.9**	**929.3**	**929.3**	**246.0**					**245.3**	

83,4% -> 120% Overload

ANEEL R&D project: 3 MWp PV power plant 8 evaluation sites

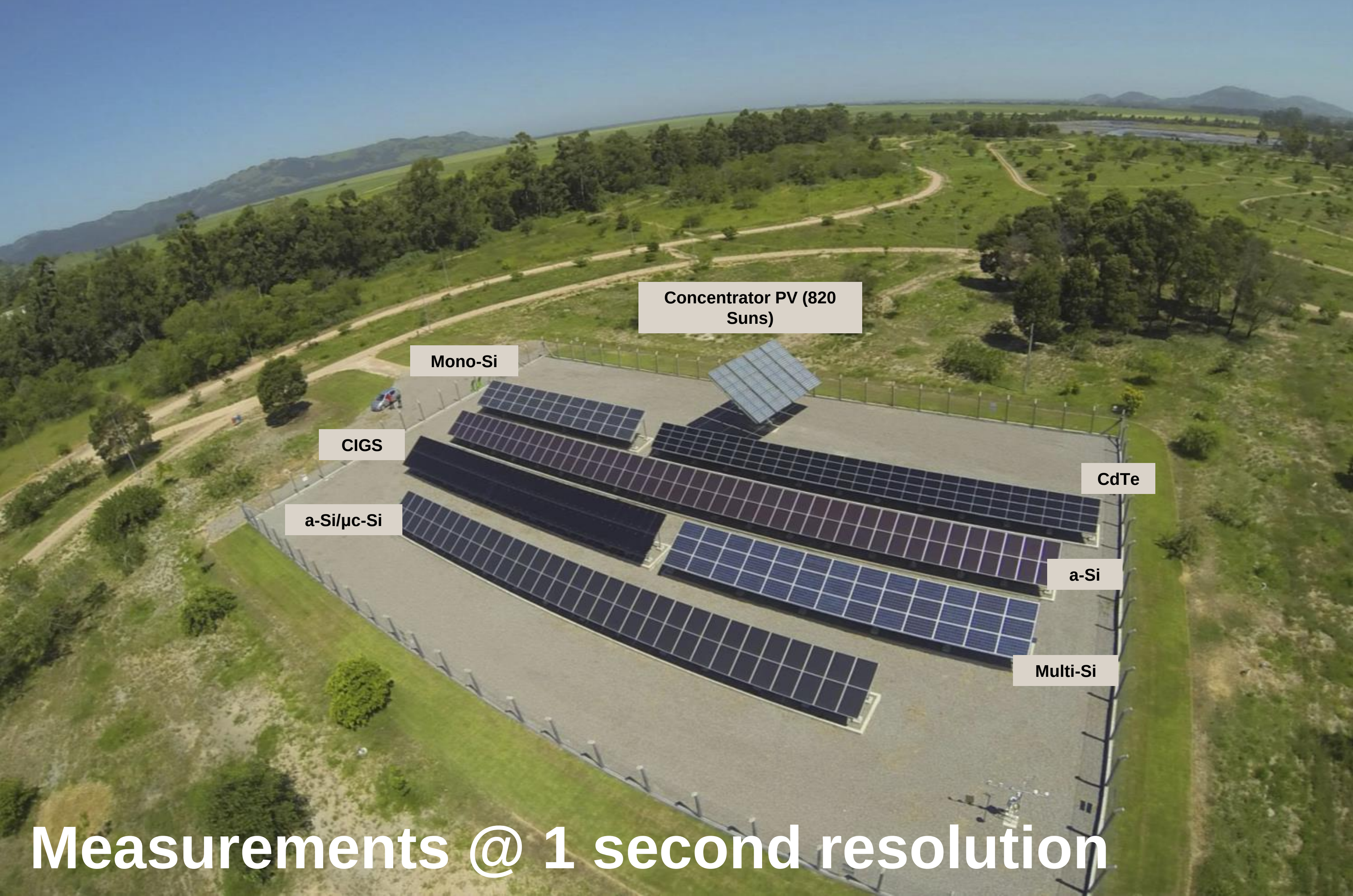
30 million US$ (single project)



Evaluation Sites(MAs):

- **Inverters: Power One (ABB)**
- **PV Modules (7 technologies):**
  - Multi/c-Si (Hanwha)
  - Mono/c-Si (Yingli);
  - a-Si (Dupont Apollo)
  - a-Si/µc-Si (Dupont Apollo)
  - CdTe (First Solar)
  - CIGS (Saint Gobain)
  - CPV – InGaP/GaAs/Ge (Daido Steel)
- **Tracker:** BSQ Solar

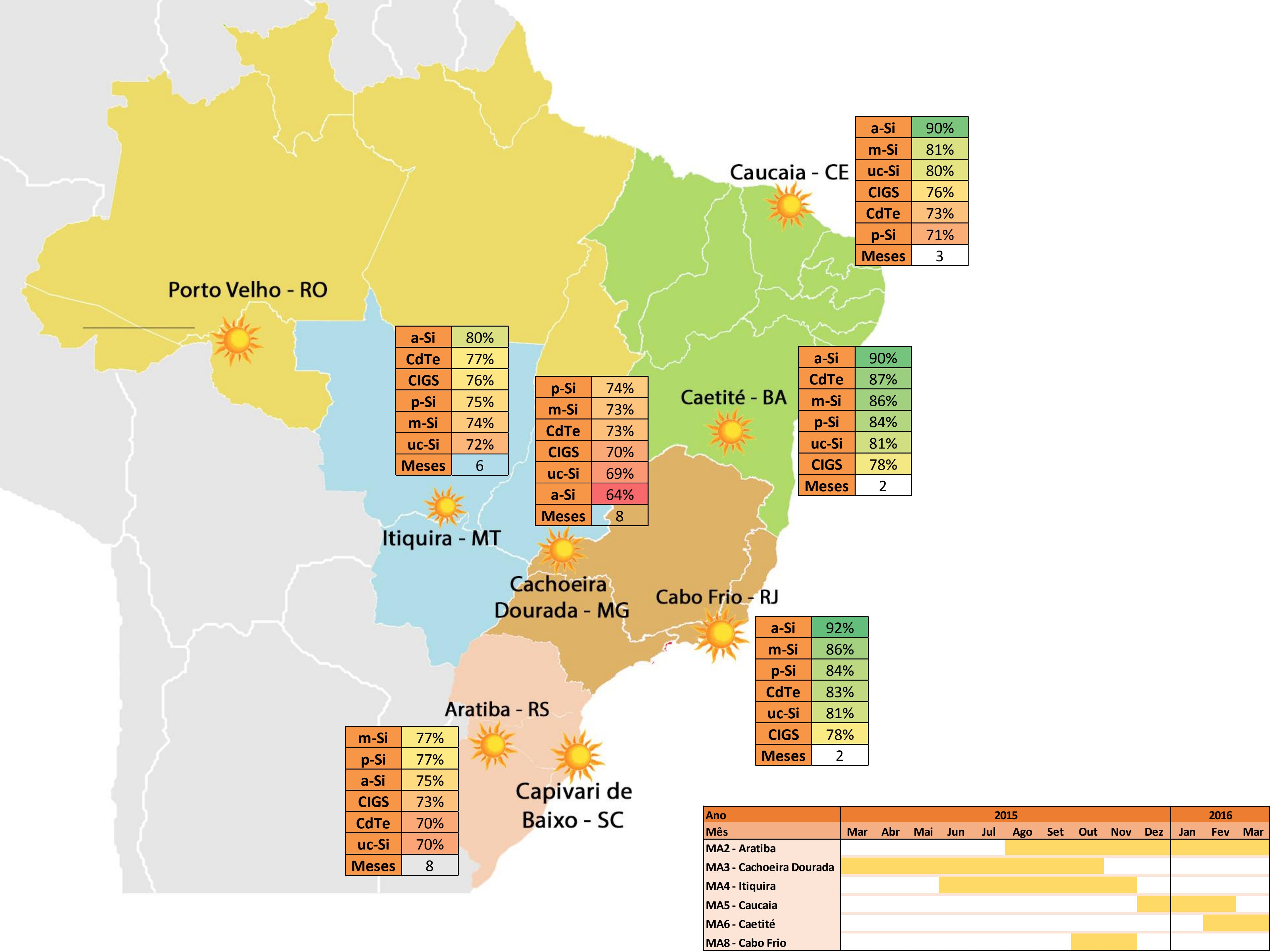
Choice of PV Technologies: What is (are) the best technology(ies) for PV projects in Brazil?



Measurements @ 1 second resolution

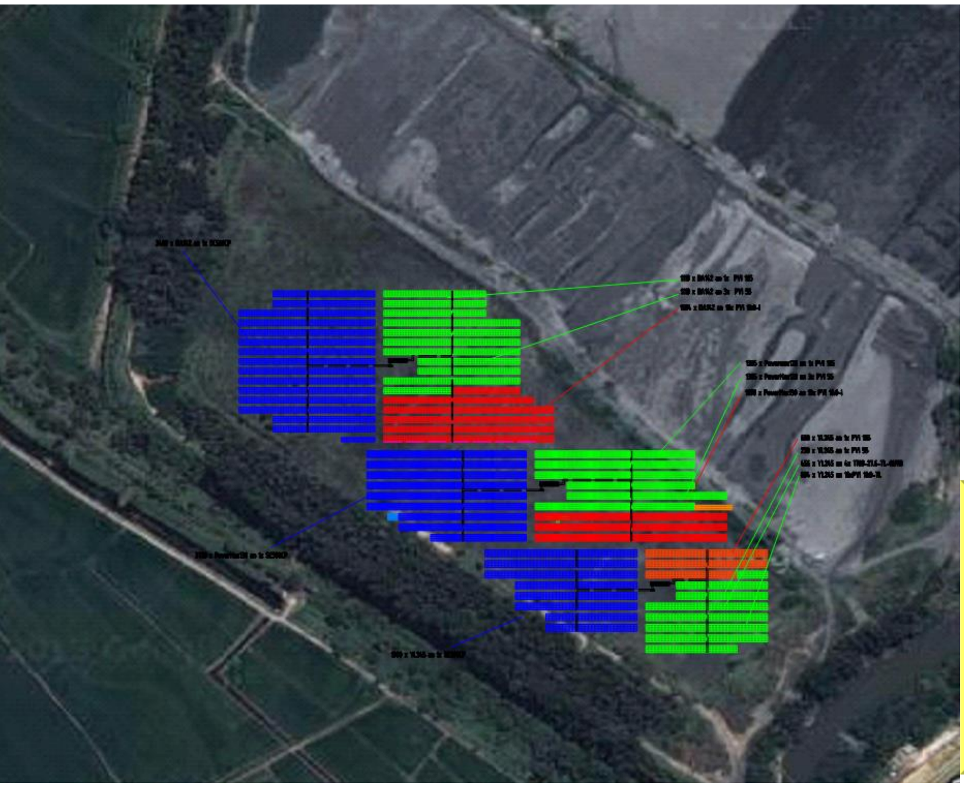
EVALUATION SITES

EVALUATION SITES


Porto Velho - RO
Caucaia - CE
a-Si 90%
m-Si 81%
uc-Si 80%
CIGS 76%
CdTe 73%
p-Si 71%
Meses 3
Itiquira - MT
a-Si 80%
CdTe 77%
CIGS 76%
p-Si 75%
m-Si 74%
uc-Si 72%
Meses 6
Cachoeira Dourada - MG
p-Si 74%
m-Si 73%
CdTe 73%
CIGS 70%
uc-Si 69%
a-Si 64%
Meses 8
Caetité - BA
a-Si 90%
CdTe 87%
m-Si 86%
p-Si 84%
uc-Si 81%
CIGS 78%
Meses 2
Cabo Frio - RJ
a-Si 92%
m-Si 86%
p-Si 84%
CdTe 83%
uc-Si 81%
CIGS 78%
Meses 2
Aratiba - RS
m-Si 77%
p-Si 77%
a-Si 75%
CIGS 73%
CdTe 70%
uc-Si 70%
Meses 8
Capivari de Baixo - SC
Ano
2015
2016
Mês
Mar Abr Mai Jun Jul Ago Set Out Nov Dez Jan Fev Mar
MA2 - Aratiba
MA3 - Cachoeira Dourada
MA4 - Itiquira
MA5 - Caucaia
MA6 - Caetité
MA8 - Cabo Frio


3 MWp R&D PV power plant
Measurements @ 1 second resolution

3 MWP R&D PV POWER PLANT
INVERTER TOPOLOGY & INVERTER LOADING RATIO



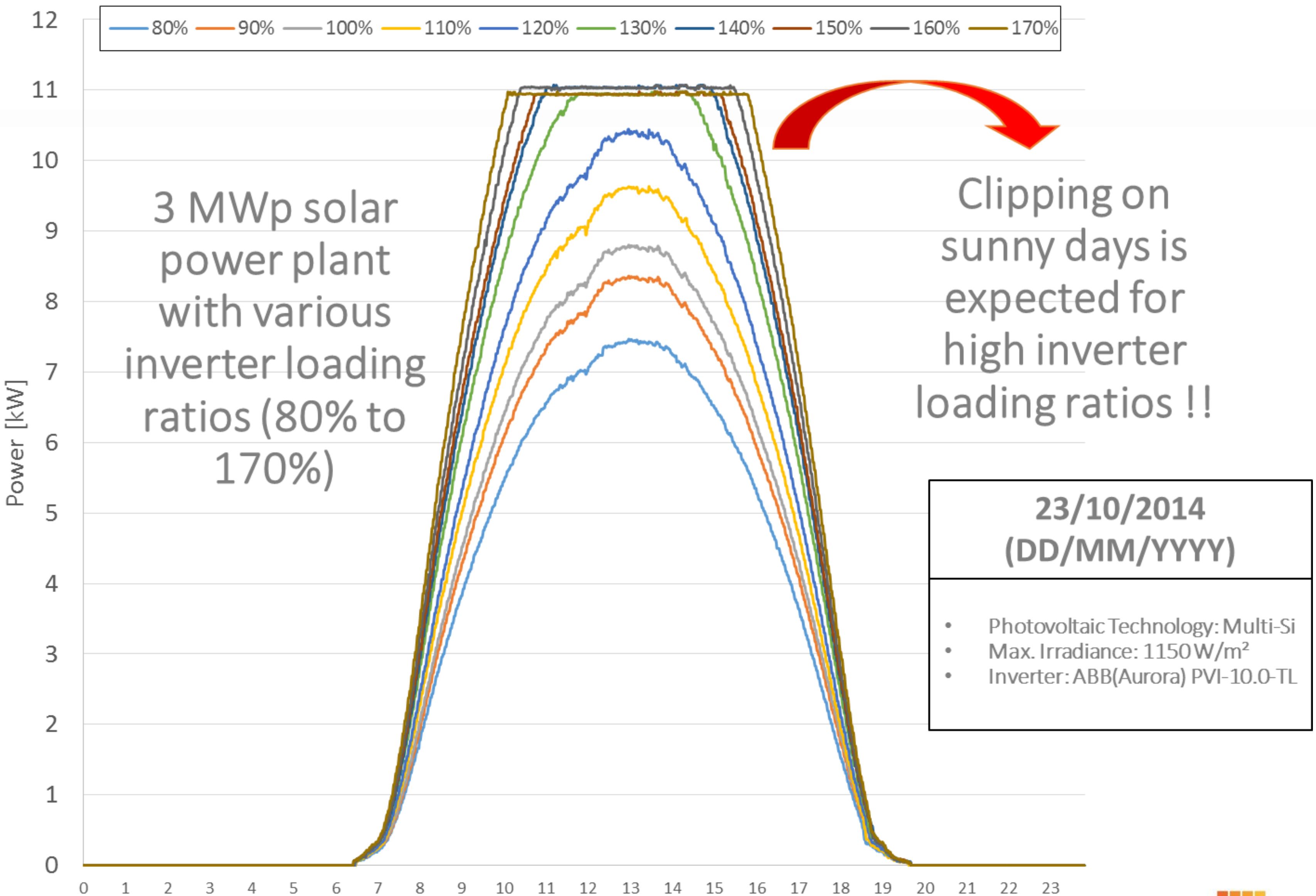
PV

c-Si a-Si/μc-Si CIGS

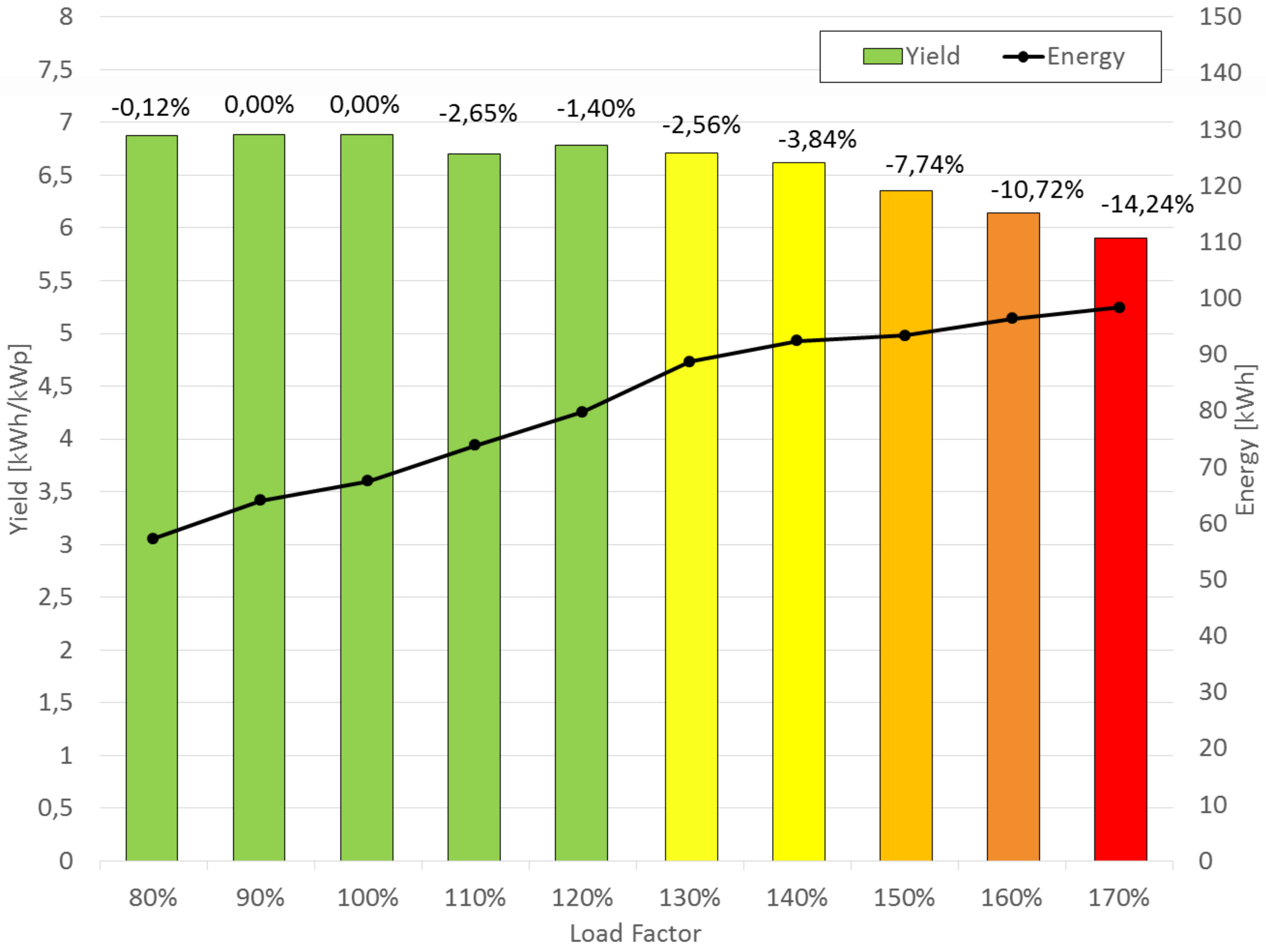
Inverter

500kW 165kW 55kW 27,5kW 10kW

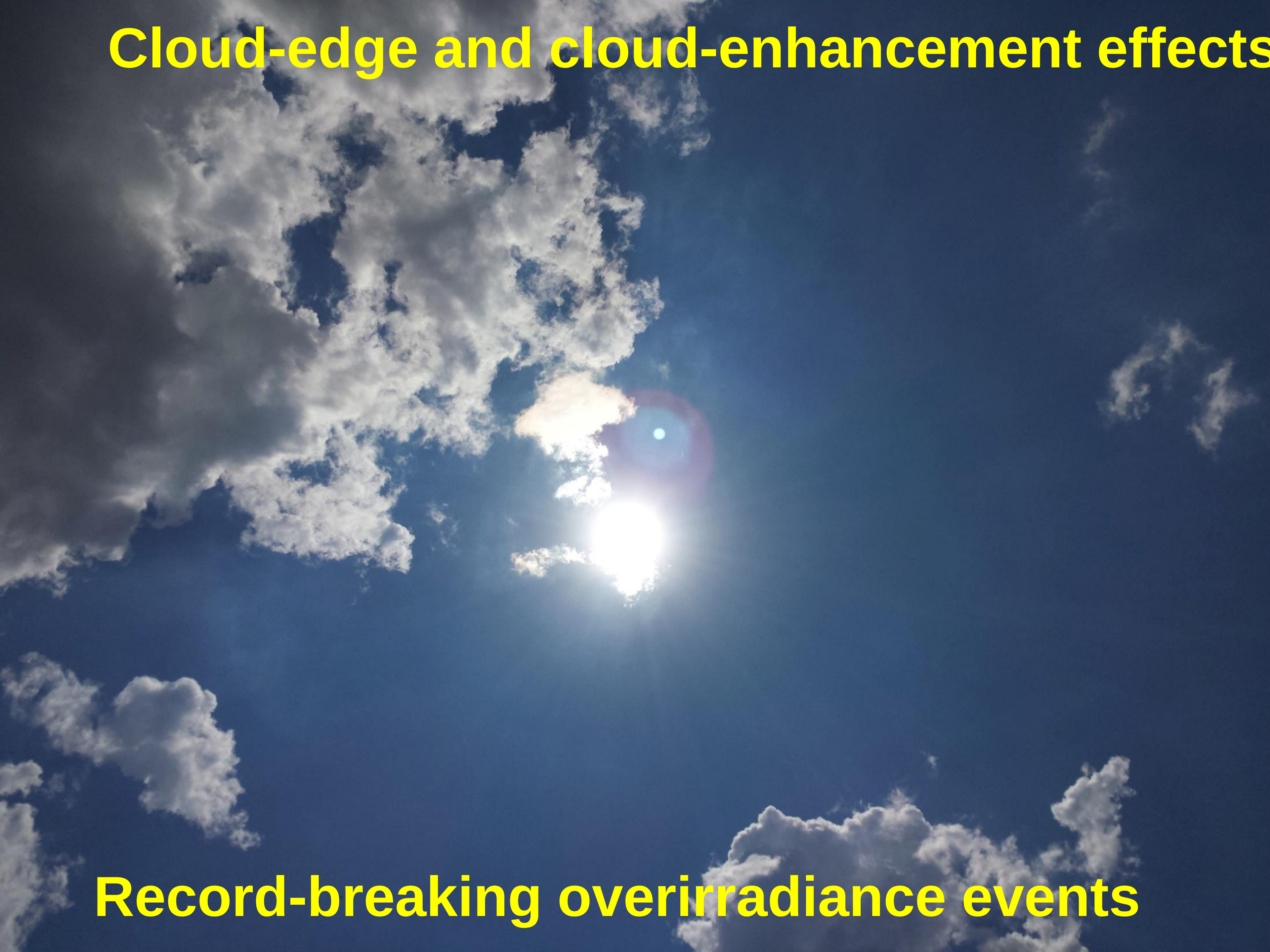
INVERTER LOADING RATIO



INVERTER LOADING RATIO



BUT THE EFFECT NEEDS TO BE QUANTIFIED ON AN ANNUAL BASIS


Cloud-edge and cloud-enhancement effects
Record-breaking overirradiance events

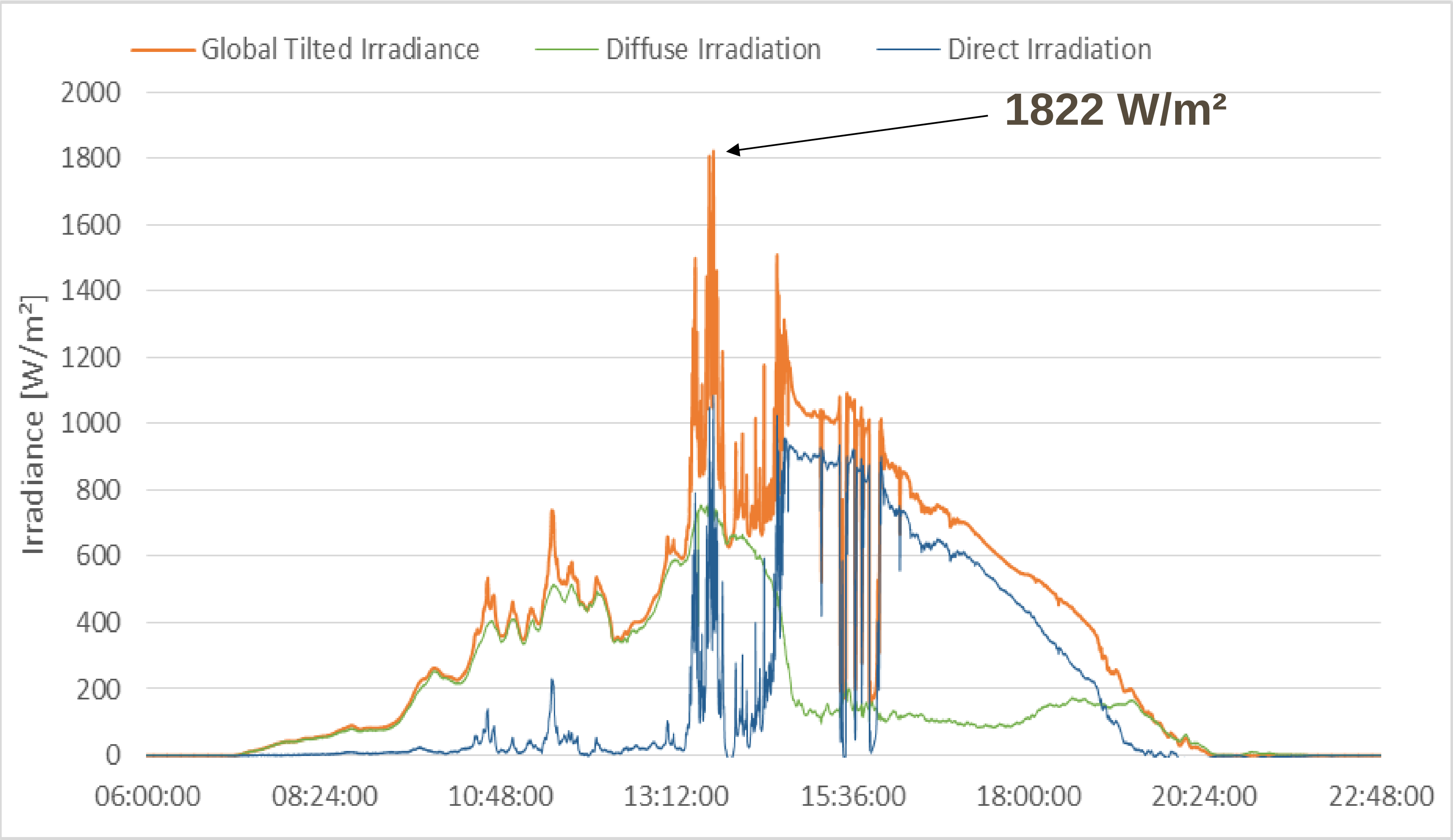
RECORD-BREAKING OVERIRRADIANCE EVENTS

Table 1
Maximum irradiance registered during cloud enhancement events around the World.

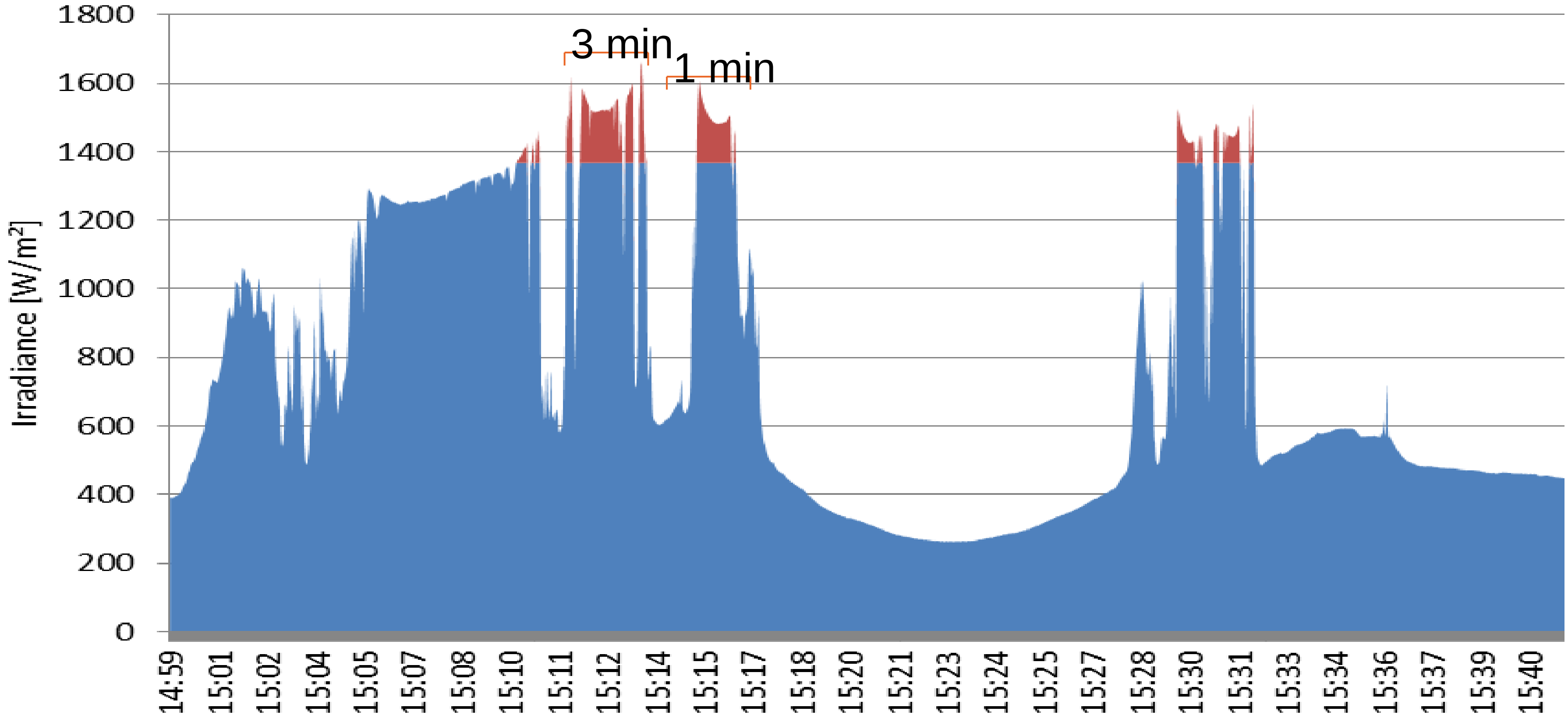
References	Maximum irradiance (W/m^2)	Altitude (m)	Location	Plan of measurement	Duration of measurement	Instrument of measurement	Resolution of measurements (s)	Response time of instrument, 95% of final value (s)
Emck and Ritcher (2008)	1832	3400	Ecuador (Andes)	Horizontal	4 years	Pyranometer (CM3)	300	⩽18
Yordanov et al. (2013a)	>1800	1131	Kenya (Kisumu)	–	–	–	–	–
Present paper	1590	760	Brazil (São Paulo)	Horizontal	<1 year	PV module (MSX-10)	1	$\leqslant 10^{-5}$
Tapakis and Charalambides (2014)	1533	360	Cyprus	Horizontal	1 year	Pyranometer (MS-802)	<60	⩽5
Piacentini et al. (2003)	1528	3900	Argentina (Puna of Atacama)	Horizontal	<1 year	Pyranometer (PSP Eppley)	5	⩽15
Yordanov et al. (2013a)	1528	60	Norway (Grimstad)	Tilted (39°)	<1 year	mc-Si PV Cell (Soldata 80spc)	10^{-2}	⩽0.025*
Weigl et al. (2012)	>1500	<10	USA (Oahu)	Horizontal	–	Pyranometer (LICOR LI-200)	1	$\leqslant 10^{-5}$
Piacentini et al. (2011)	1477	4	Brazil (Recife)	Horizontal	1 year	Pyranometer (PSP Eppley)	⩽60	⩽15
Hansen et al. (2010)	>1400	1620	USA (Albuquerque)	Horizontal	<1 year	Pyranometer (CM-21)	60 (average)	⩽5
Gu et al. (2001)	>1400	<400	Brazil (Rondônia)	Horizontal	<1 year	Pyranometer (PSP Eppley)	60 (average)	⩽15
Luoma et al. (2012)	>1300	22	USA (San Diego)	Horizontal	–	Pyranometer (LICOR LI-200)	1	$\leqslant 10^{-5}$
Piedehierro et al. (2014)	1244	680	Spain (Granada)	Horizontal	5 years	Pyranometer (CM-11)	60	⩽15

ALMEIDA, M. P.; ZILLES, R.; LORENZO, E. Extreme overirradiance events in São Paulo, Brazil. **Solar Energy.** v.110, p.168-173, 2014.

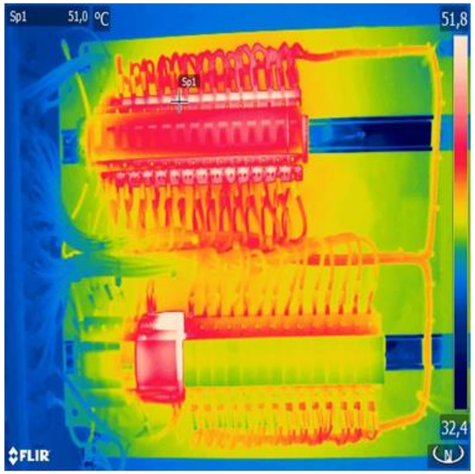
Itiquira-MT evaluation site (one of the eight sites)
500 meters above sea level



Cachoeira Dourada-GO evaluation site (another one of the eight sites)

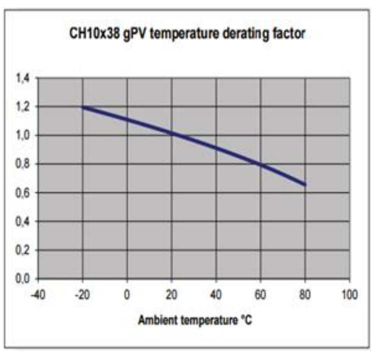


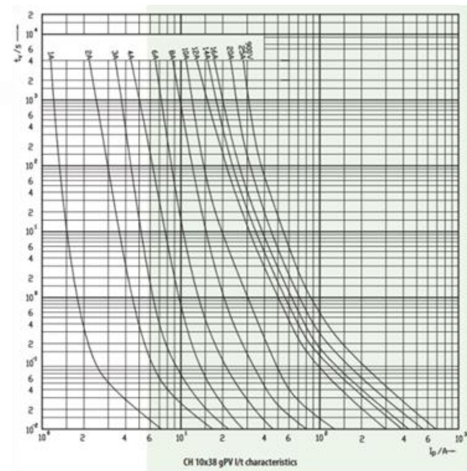
POSSIBLE REVISION OF MAXIMUM FUSE RATING BY PV MODULE MANUFACTURER

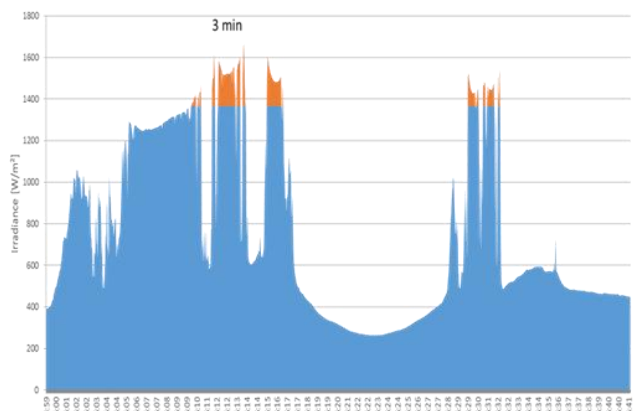


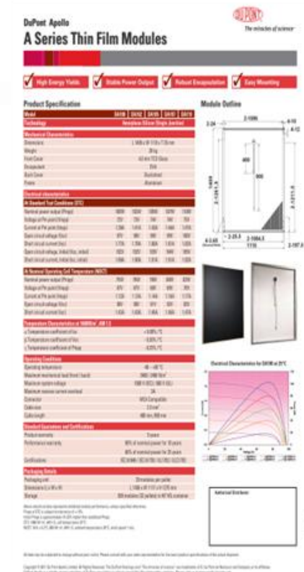
Fuse estimated temperature of 70 °C

Tamb (°C)	A1
-20	1,196
-10	1,153
0	1,109
10	1,063
20	1,015
30	0,964
40	0,911
50	0,854
60	0,794
70	0,728
80	0,656



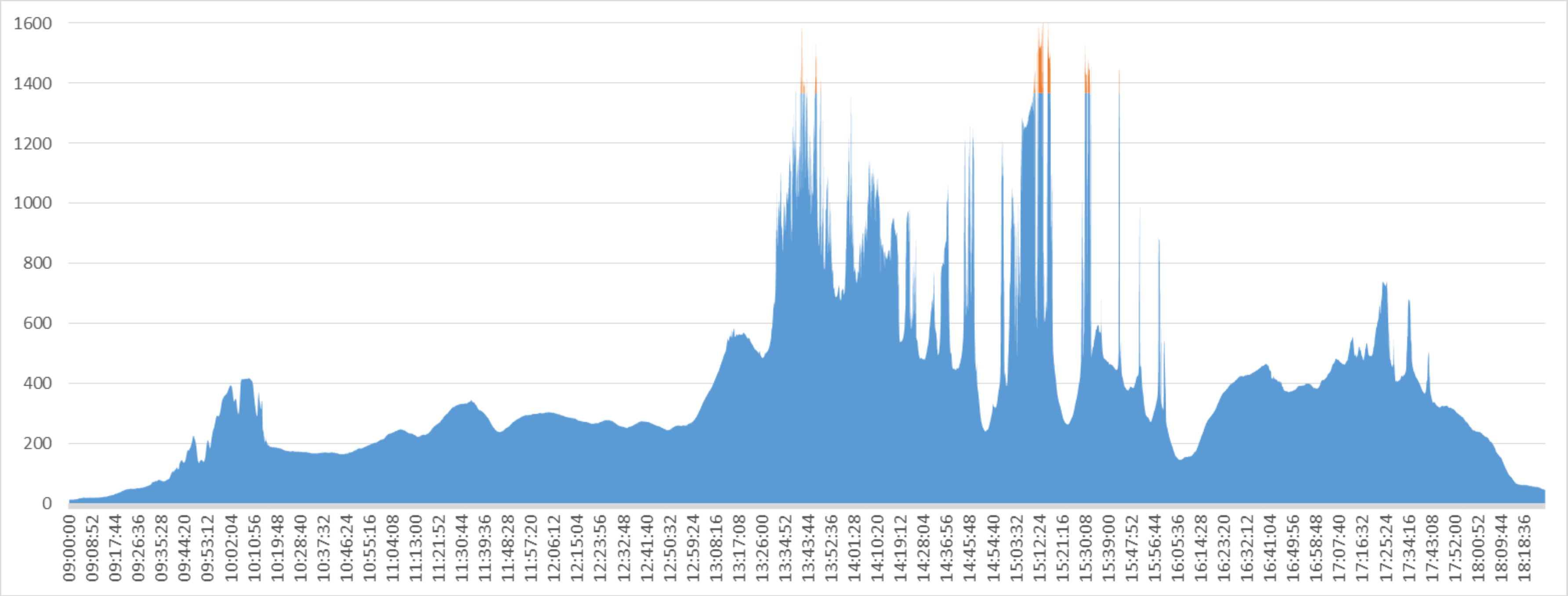




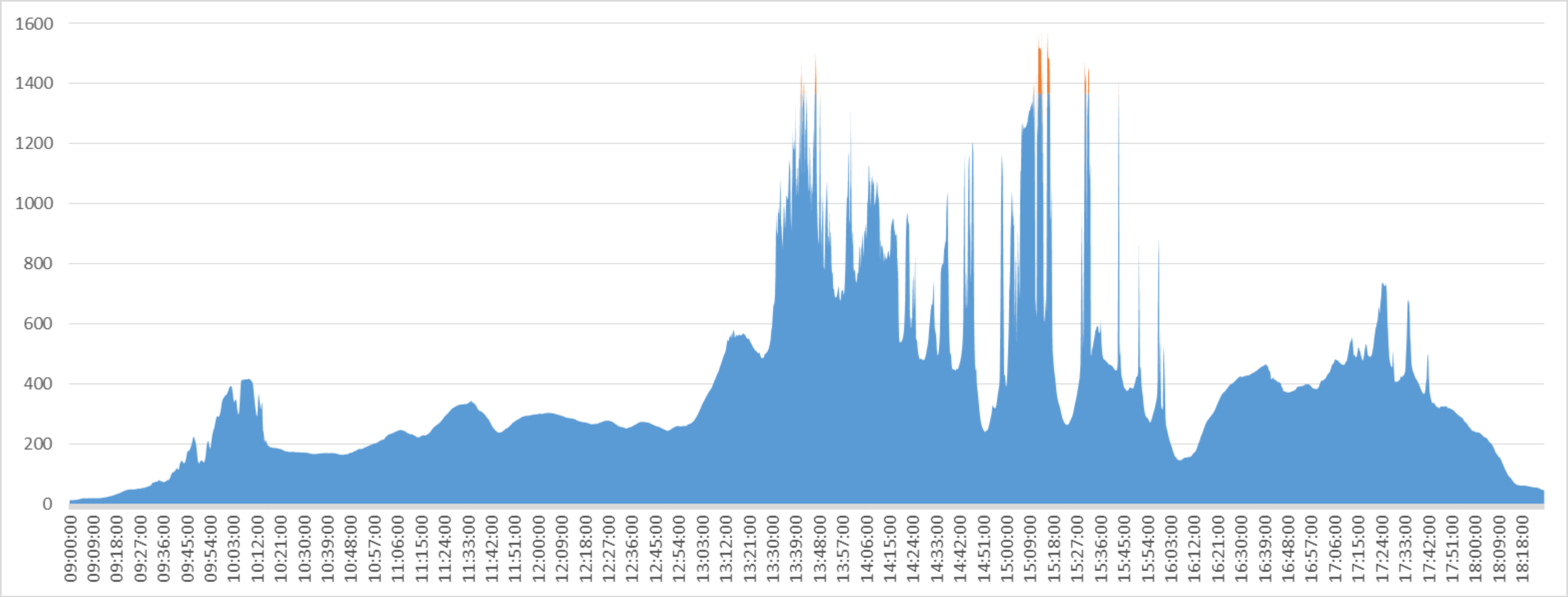


Derating factor due to high fuse temperature + **Long over irradiance events** → **Manufacturer specified fuse blows**

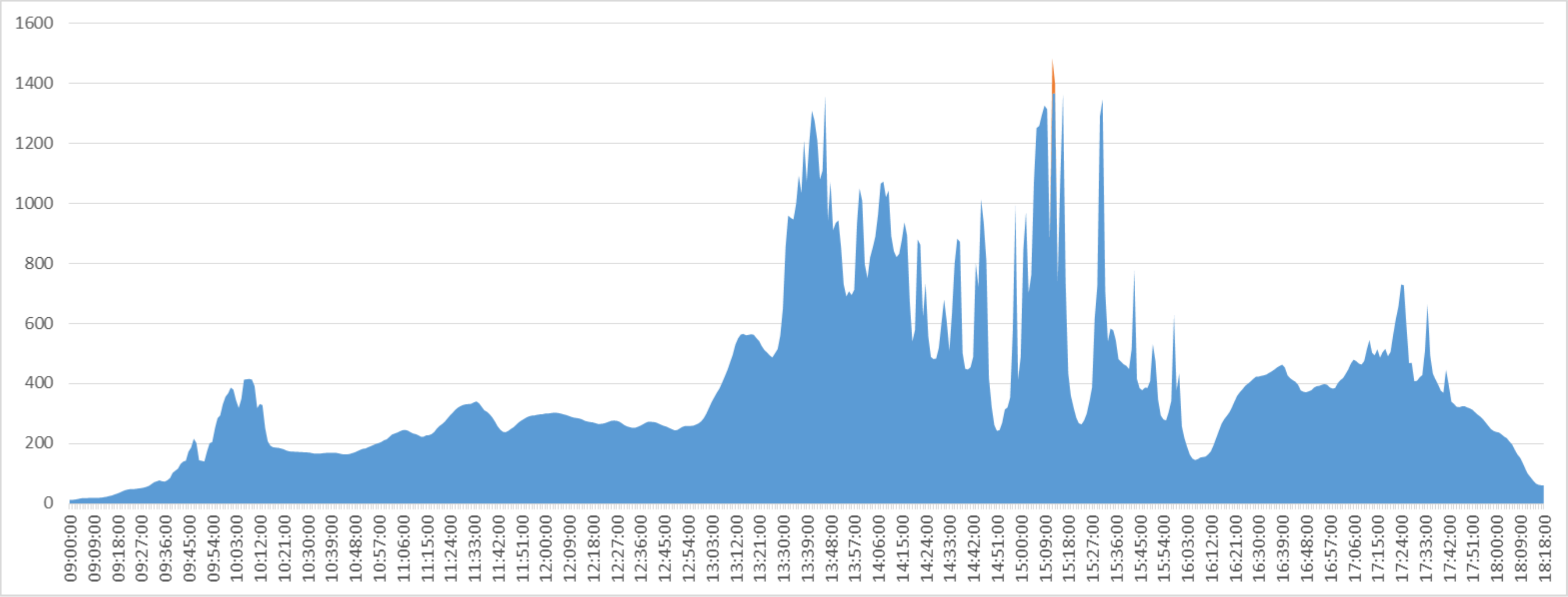
TIME RESOLUTION OF SOLAR RADIATION INTEGRATION TIME (1 SEC)



TIME RESOLUTION OF SOLAR RADIATION INTEGRATION TIME (10 SEC)

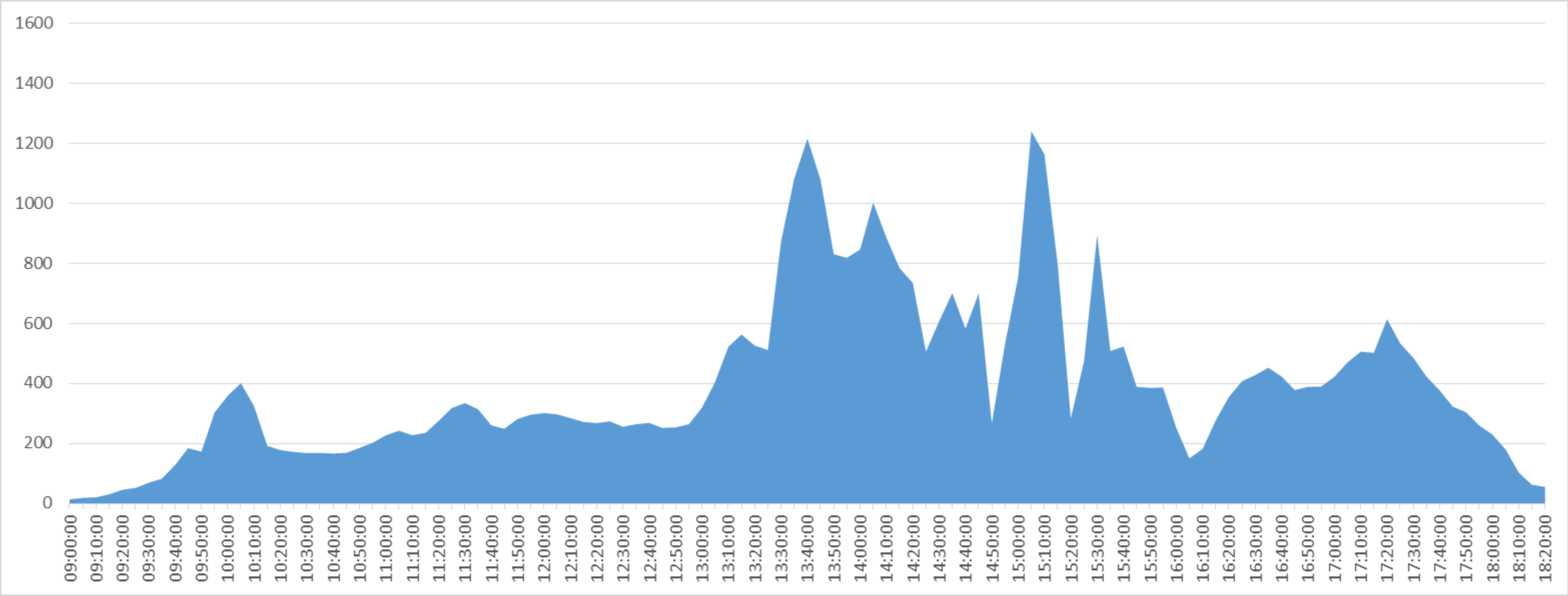


TIME RESOLUTION OF SOLAR RADIATION INTEGRATION TIME (1 MIN)

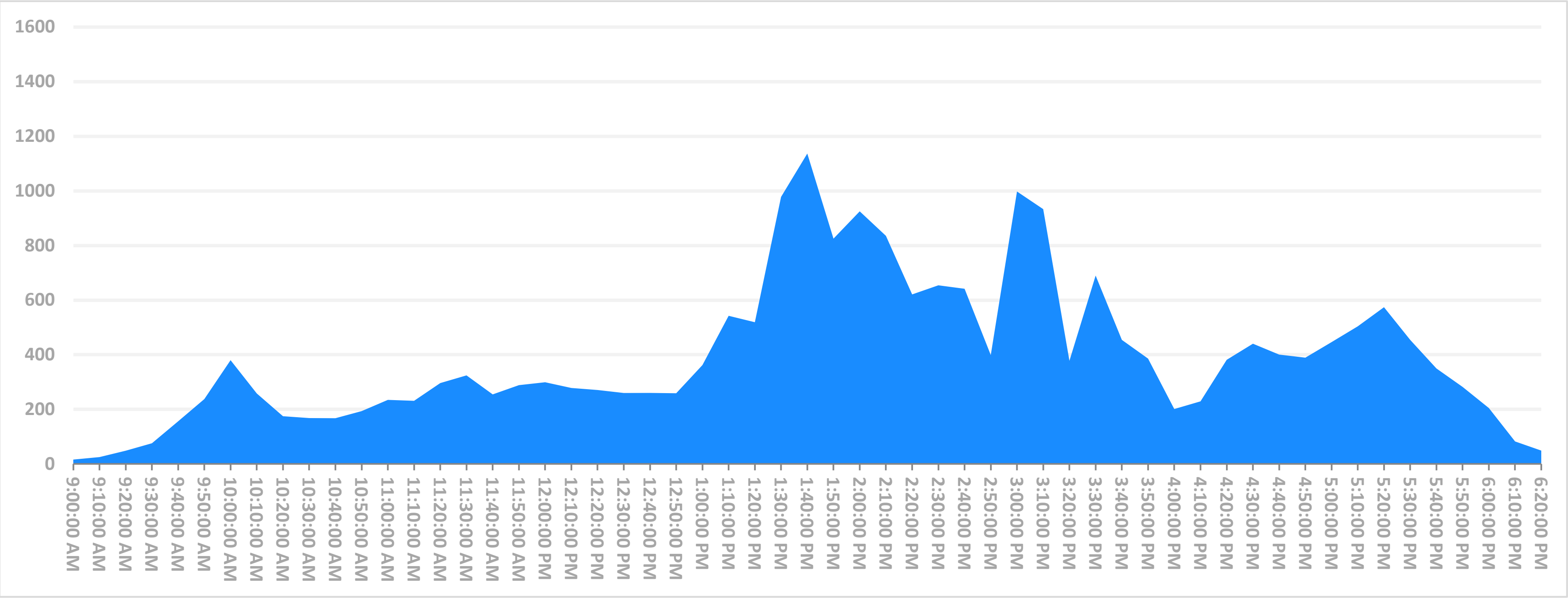


fotovoltaica ufsc

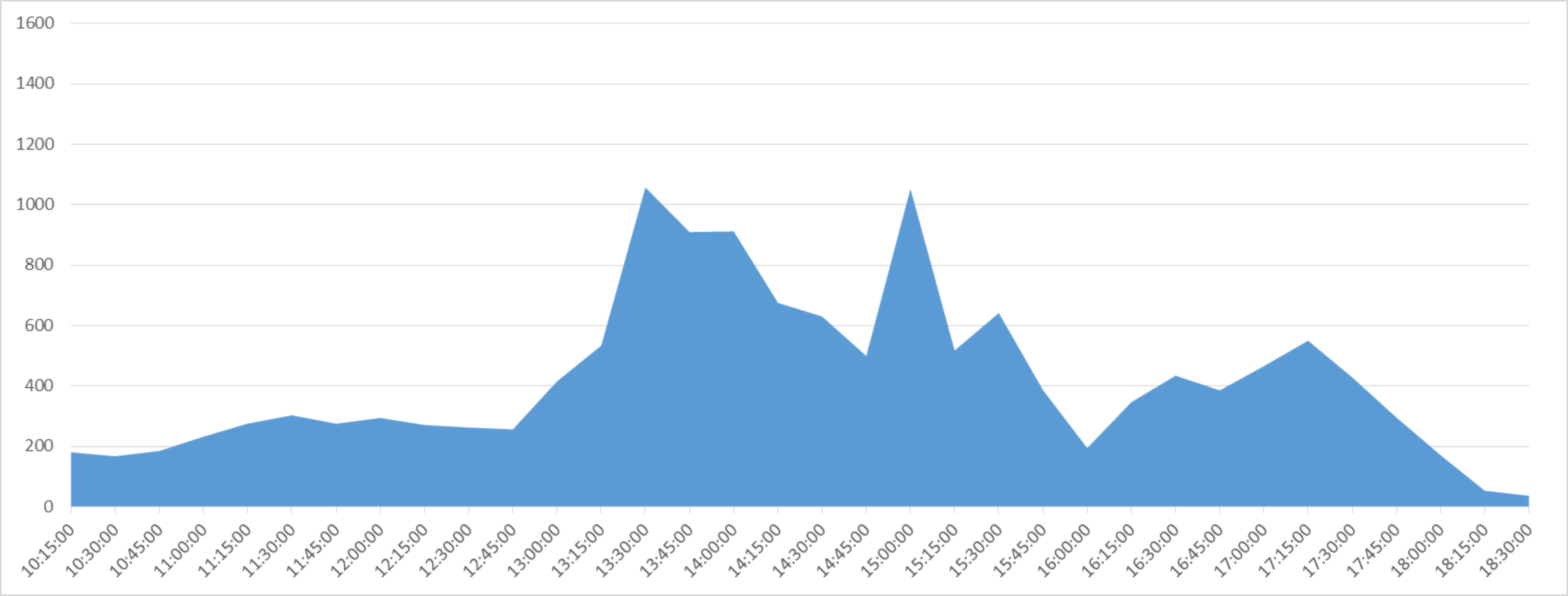
TIME RESOLUTION OF SOLAR RADIATION INTEGRATION TIME (5 MIN)



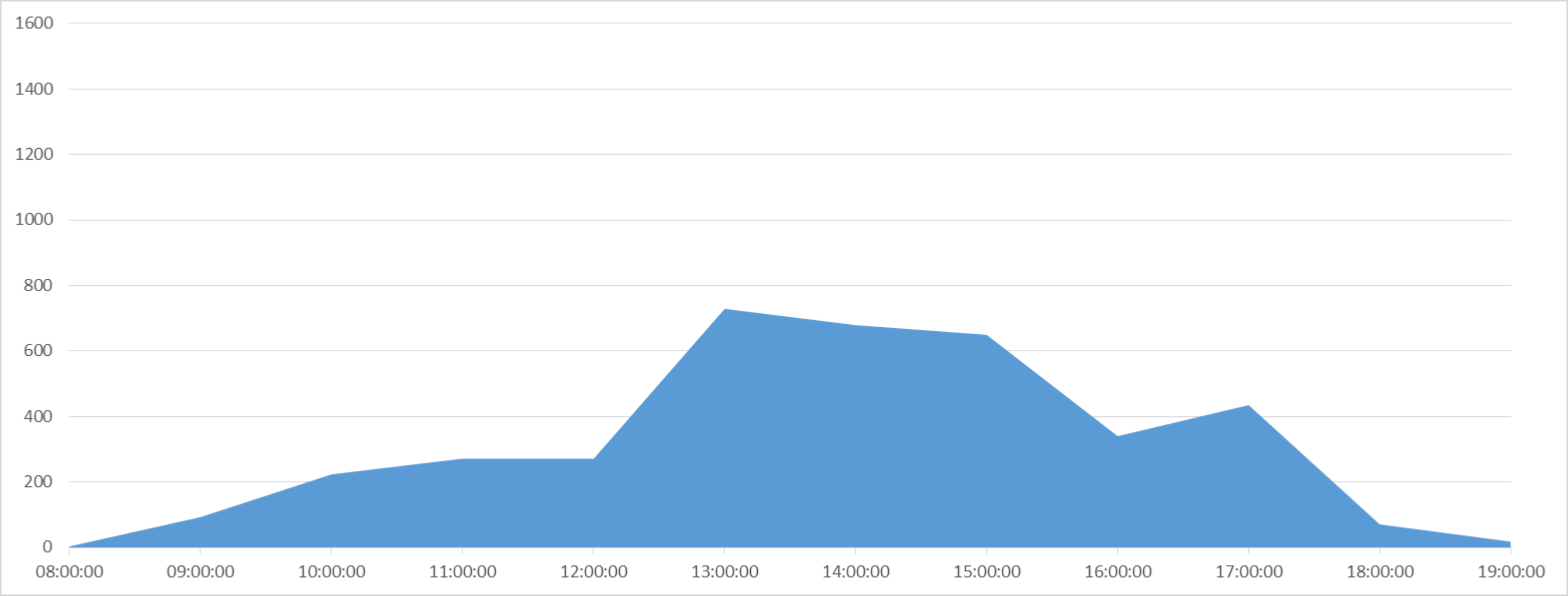
TIME RESOLUTION OF SOLAR RADIATION INTEGRATION TIME (10 MIN)



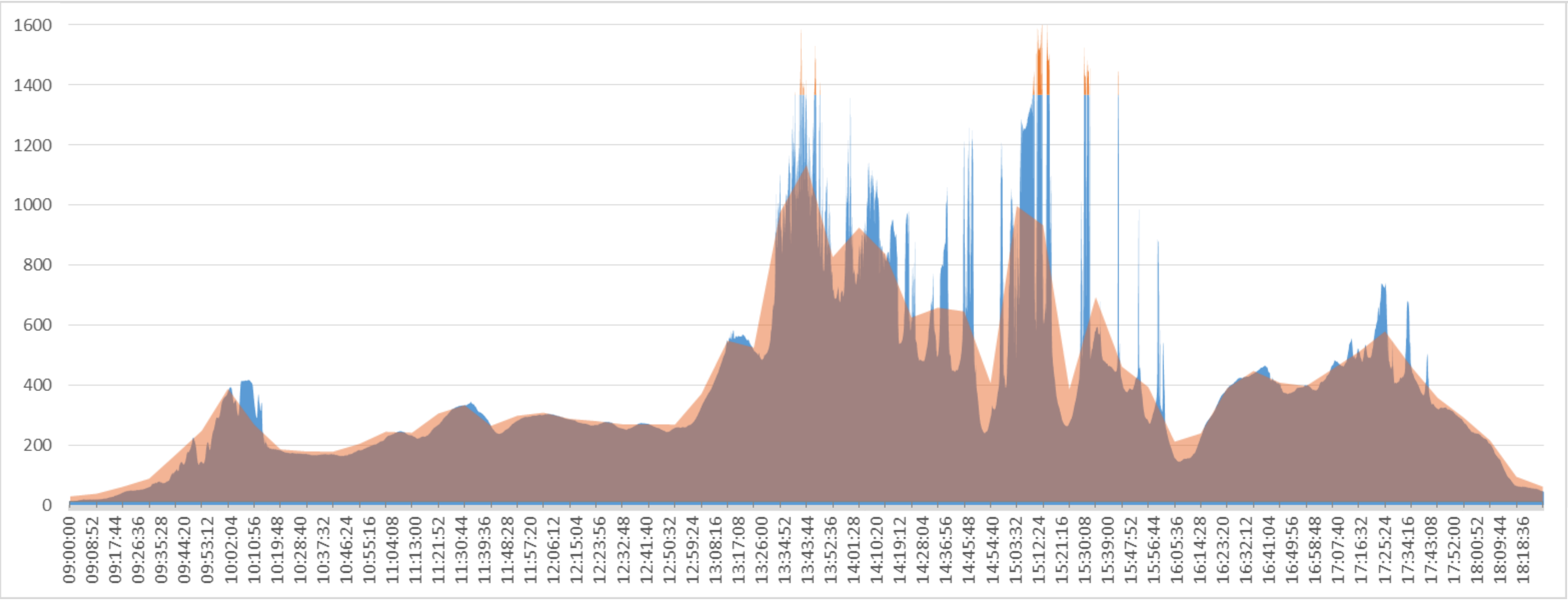
TIME RESOLUTION OF SOLAR RADIATION INTEGRATION TIME (15 MIN)



TIME RESOLUTION OF SOLAR RADIATION INTEGRATION TIME (1 HOUR)

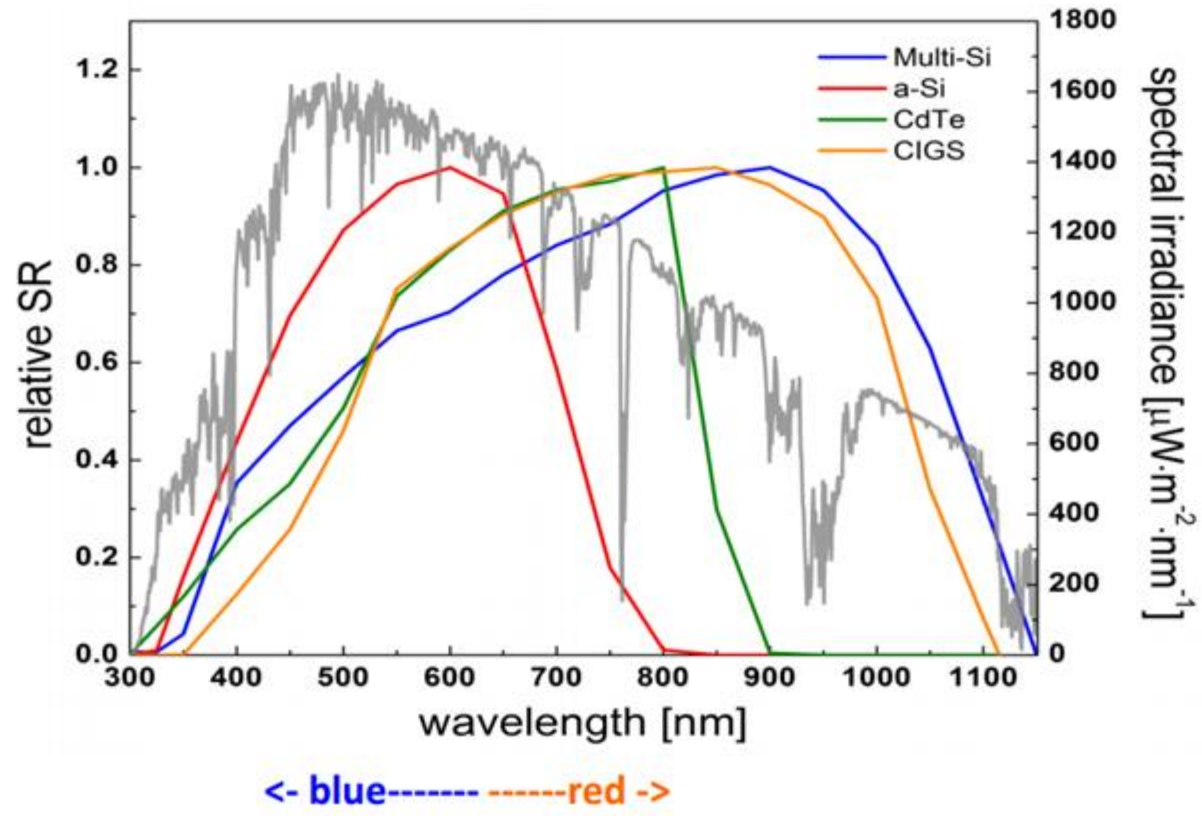


TIME RESOLUTION OF SOLAR RADIATION INTEGRATION TIME (1O MIN vs 1 SEC.)



SOLAR ENERGY (IRRADIATION) DISTRIBUTION IN TERMS OF PERCENTAGE OF ENERGY CONTENT

	G<= 300	300<G<=700	700<G<1000	1000<G<=1200	G>=1200
1s	25%	42%	15%	8%	10%
10s	25%	42%	16%	8%	9%
1min	24%	41%	18%	7%	9%
5min	24%	41%	21%	9%	5%
10min	26%	42%	27%	5%	0%
15min	25%	49%	12%	14%	0%
30min	29%	37%	34%	0%	0%
1h	26%	55%	19%	0%	0%



Normalised spectral response for seven PV technologies and the standard ASTM G173-03 spectrum

Relative spectral response of various PV technologies (multicrystalline Si, amorphous Si, CdTe and CIGS), measured under STC temperature (25° C), with the AM1.5G spectrum (grey) also shown as reference (LIU *et al.*, 2014b).

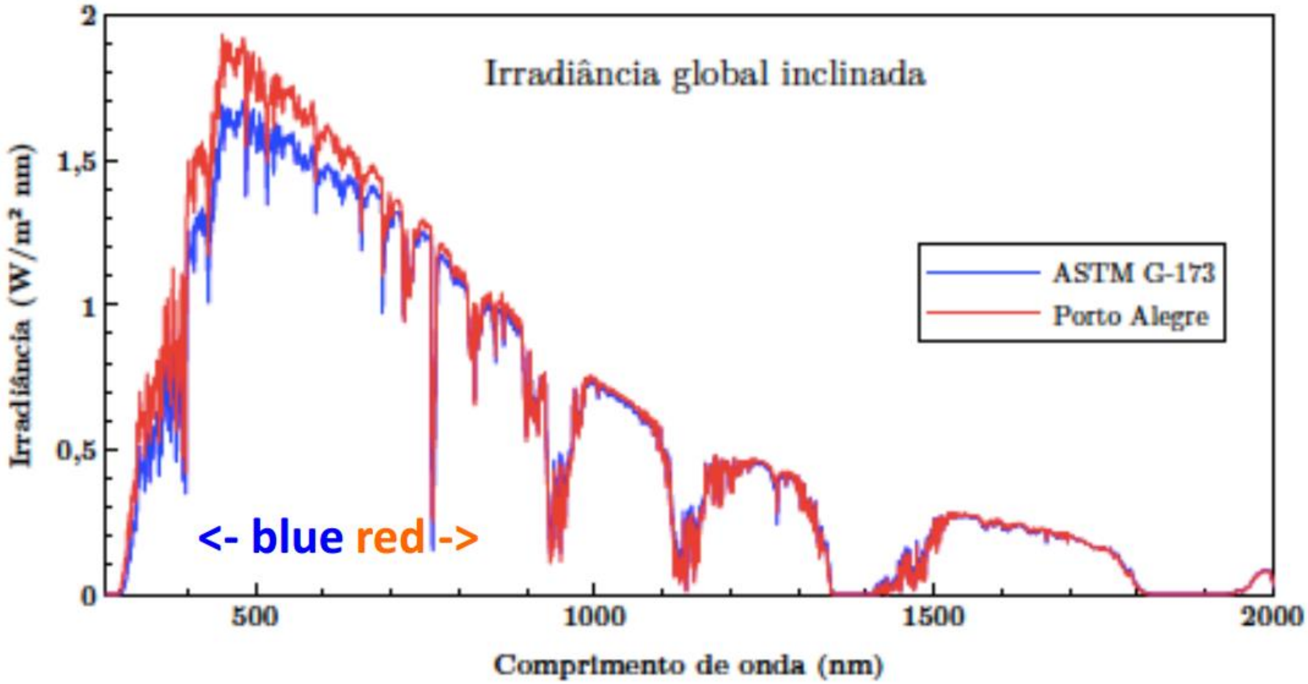
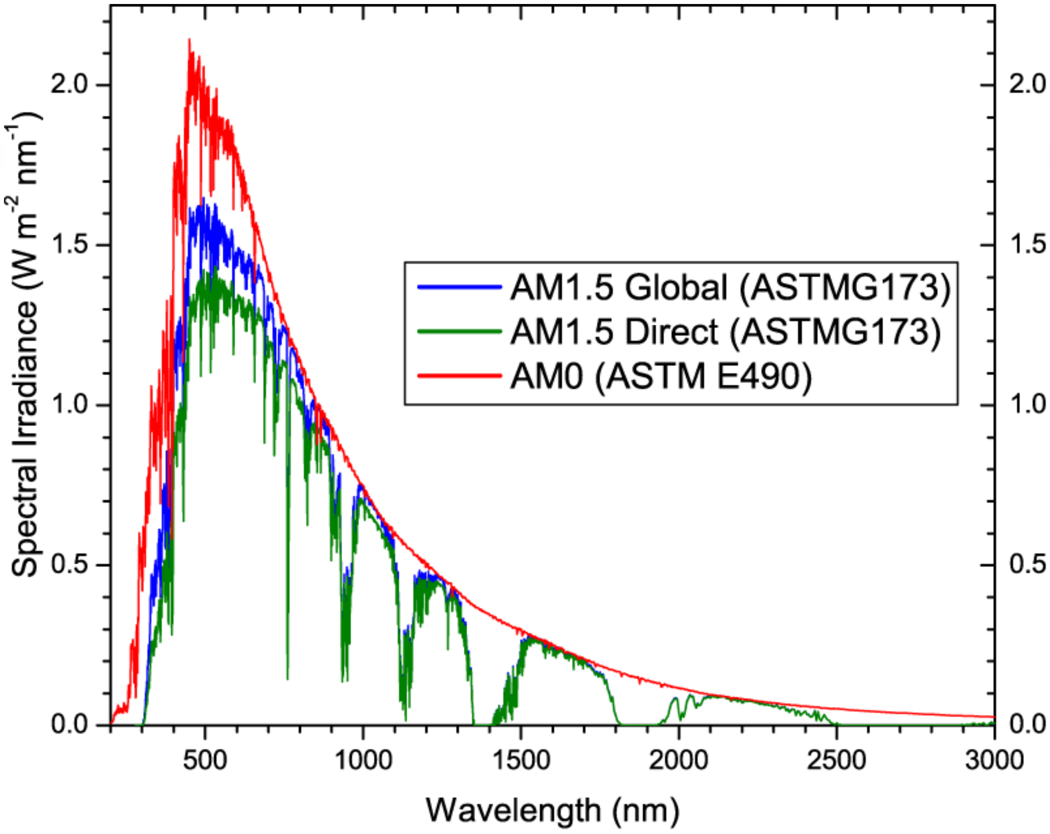


Figura 6.3: Espectro característico para uma superfície voltada para o norte e com inclinação de 30º na cidade de Porto Alegre, RS (vermelho) e o espectro definido pela norma ASTM G-173 (azul).

"Estimativa da distribuição espectral da radiação solar sobre o território brasileiro através de análise multiinstrumental"
Ph.D. Thesis - Rafael Haag – 2012 – Universidade Federal do Rio Grande do Sul, orientador: Prof. Arno Krenzinger

SOLAR SPECTRAL IRRADIANCE: ASTM G-173



INPUT DATA

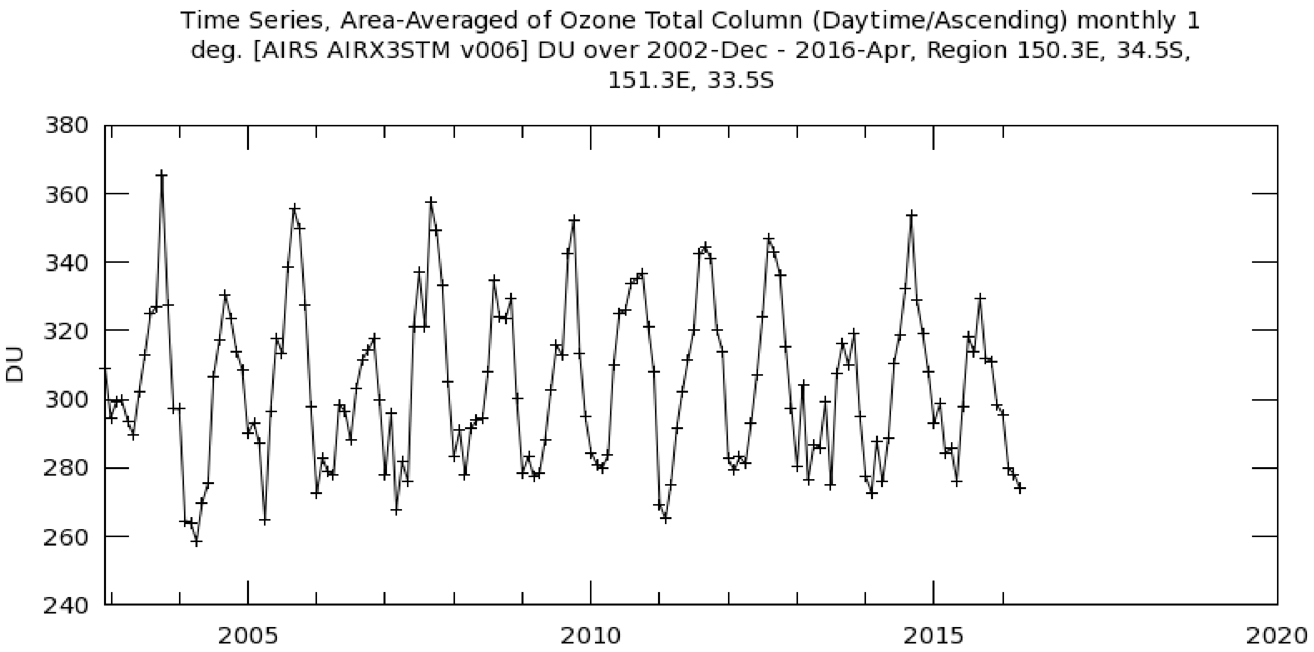
- Total column ozone equivalent
- Total column water vapor equivalent
- Aerosol optical depth
- carbon dioxide concentration
- Air Mass

GUEYMARD, C. **SMARTS2, A Simple Model of the Atmospheric Radiative Transfer of Sunshine: Algorithms and performance assessment** Florida Solar Energy Center. Cocoa, Florida, p.84, 1995.

ASTM INTERNATIONAL
Helping our world work better

ASTM G173 - 03(2012) Standard Tables for Reference Solar Spectral Irradiances: Direct Normal and Hemispherical on 37° Tilted Surface

ESPECTRAL DATA SYDNEY
TOTAL COLUMN OZONE EQUIVALENT



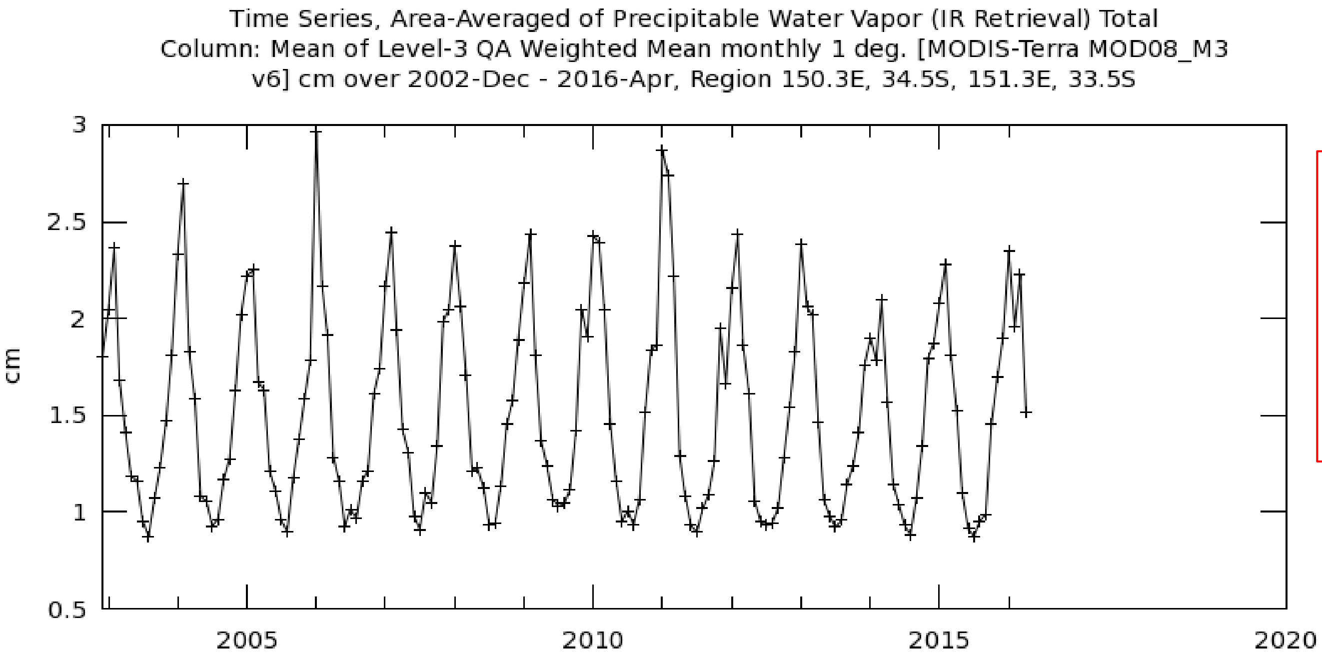
Average Value Sydney:
304 DU

Average Value G-173:
340 DU

Data sets from NASA Giovanni Web Portal

GUEYMARD, C. A.; MYERS, D.; EMERY, K. Proposed reference irradiance spectra for solar energy systems testing. **Solar Energy.** Issue 6, v.73, p.443-467, 2002.

ESPECTRAL DATA SYDNEY
TOTAL COLUMN WATER VAPOR EQUIVALENT



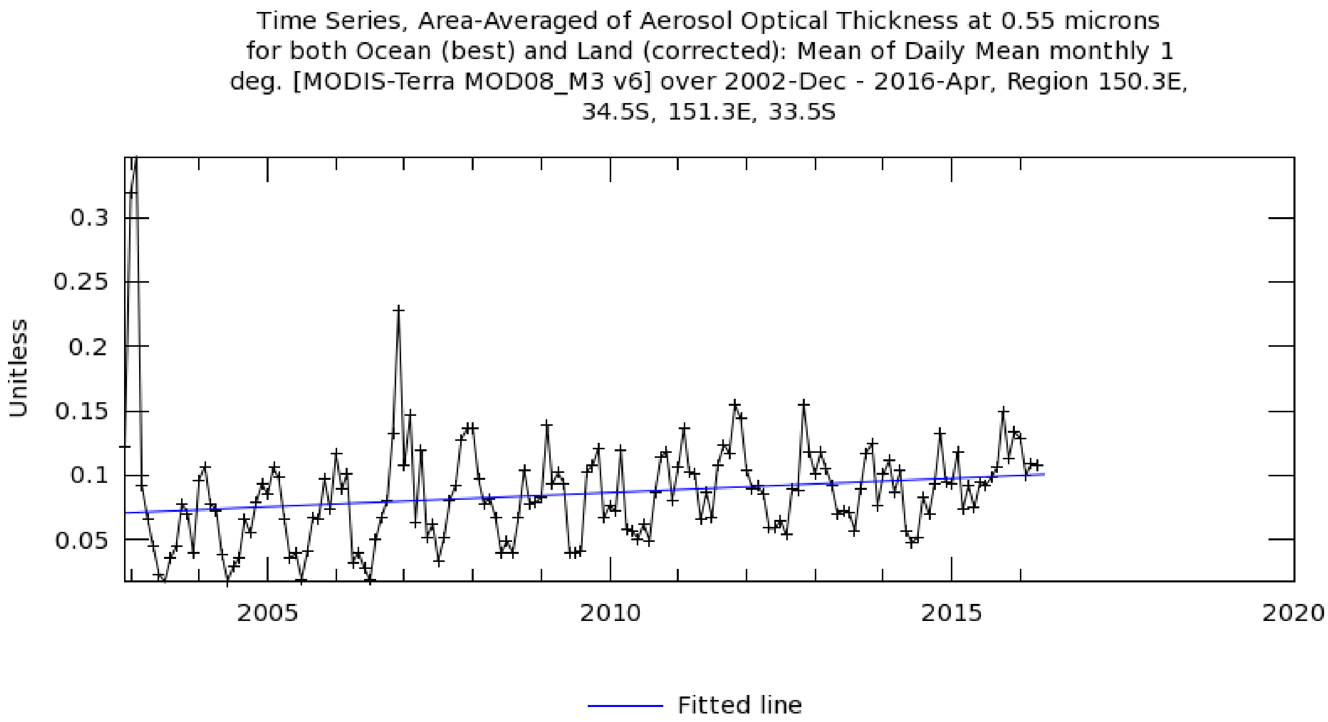
Average Value Sydney:
1.52 cm

Average Value G-173:
1.42 cm

Data sets from NASA Giovanni Web Portal

GUEYMARD, C. A.; MYERS, D.; EMERY, K. Proposed reference irradiance spectra for solar energy systems testing. **Solar Energy.** Issue 6, v.73, p.443-467, 2002.

ESPECTRAL DATA SYDNEY
AEROSOL OPTICAL DEPTH



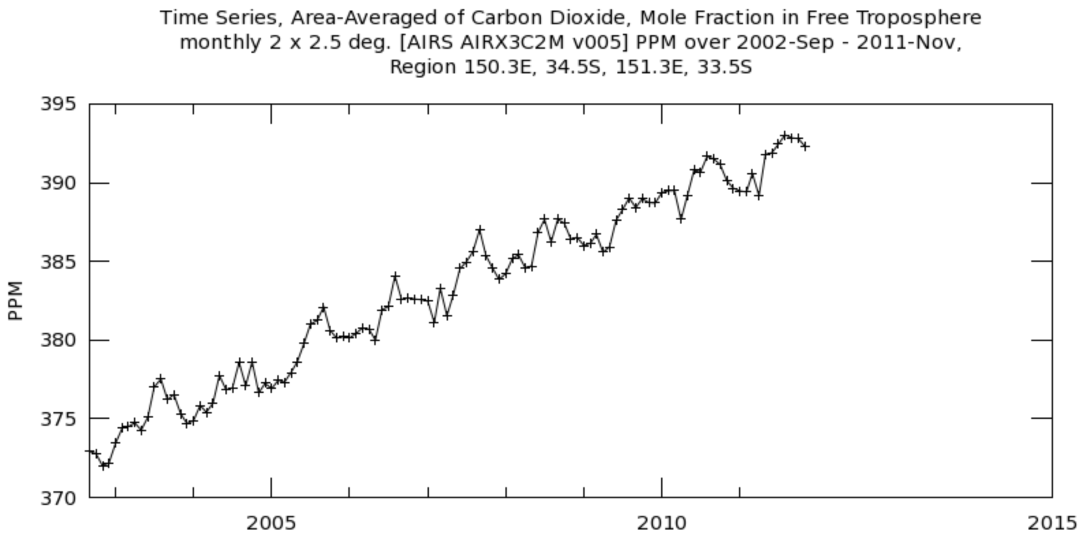
Trend Sydney: **0.1**

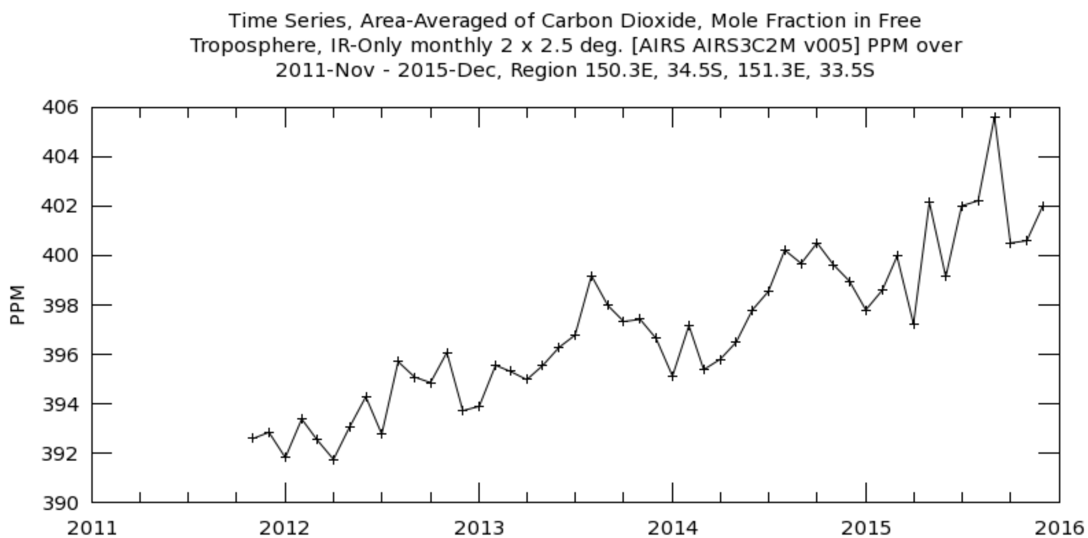
Average Value G-173: **0.084**

Data sets from NASA Giovanni Web Portal

GUEYMARD, C. A.; MYERS, D.; EMERY, K. Proposed reference irradiance spectra for solar energy systems testing. **Solar Energy.** Issue 6, v.73, p.443-467, 2002.

ESPECTRAL DATA SYDNEY
CARBON DIOXIDE CONCENTRATION





Trend Sydney: **402 PPM**

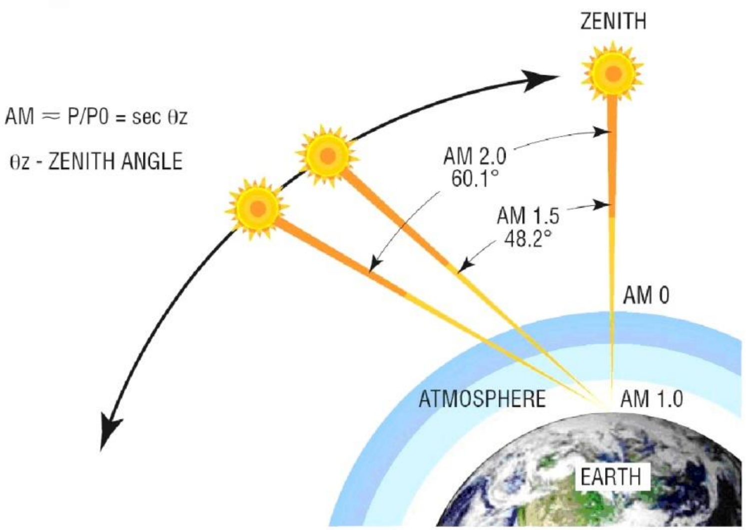
Average Value G-173: **370 PPM**

Data sets from NASA Giovanni Web Portal

Giovanni - The Bridge Between Data and Science

GUEYMARD, C. A.; MYERS, D.; EMERY, K. Proposed reference irradiance spectra for solar energy systems testing. **Solar Energy.** Issue 6, v.73, p.443-467, 2002.

ESPECTRAL DATA SYDNEY AIR MASS



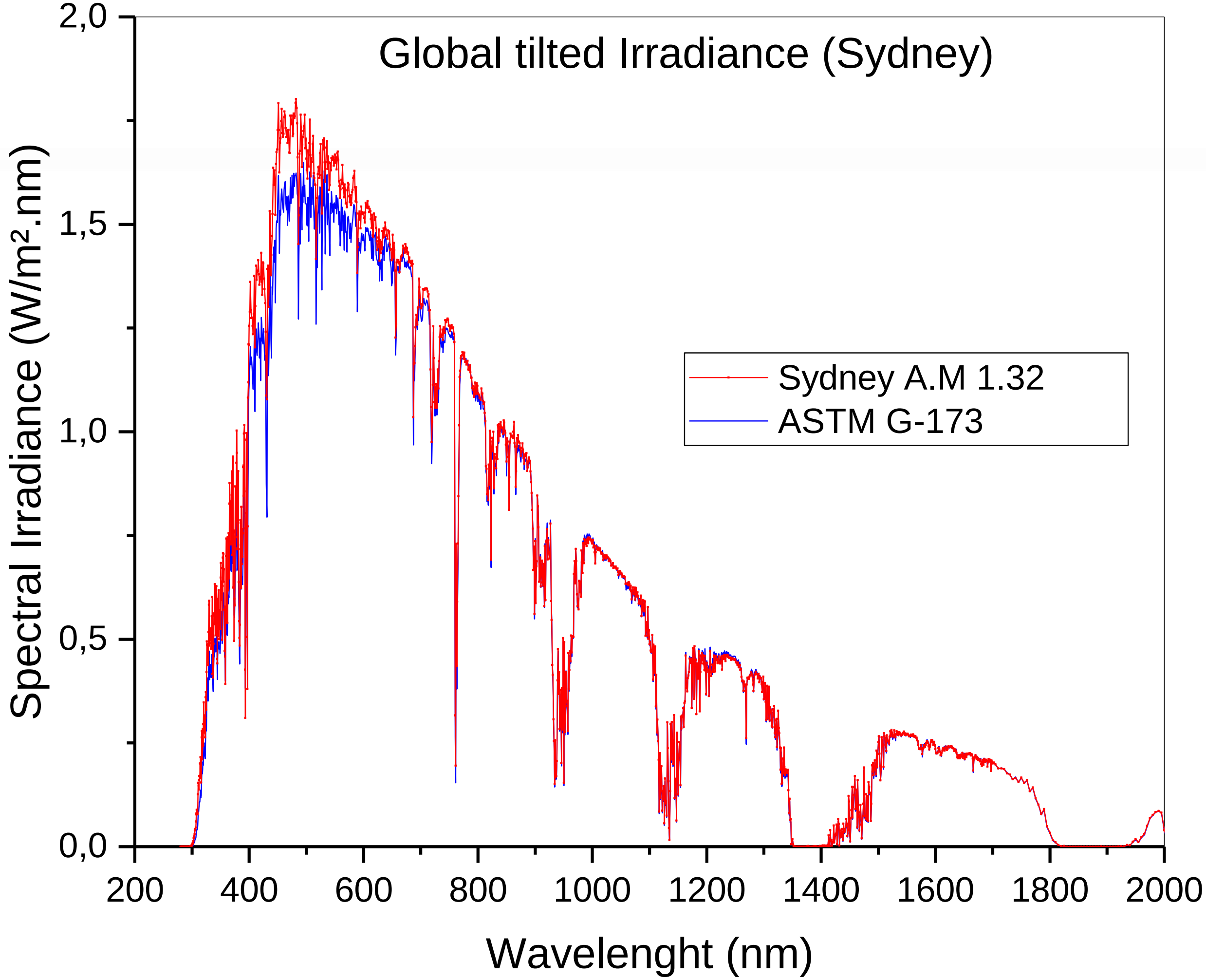
Average Value Sydney at Noon - Optical Air Mass: **1.32**

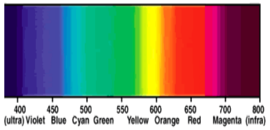
Average Value G-173: **1.5**

GUEYMARD, C. A.; MYERS, D.; EMERY, K. Proposed reference irradiance spectra for solar energy systems testing. **Solar Energy.** Issue 6, v.73, p.443-467, 2002.

KASTEN, F.; YOUNG, A. T. Revised optical air mass tables and approximation formula. **Applied Optics.** Issue 22, v.28, p.4735-4738, 1989.

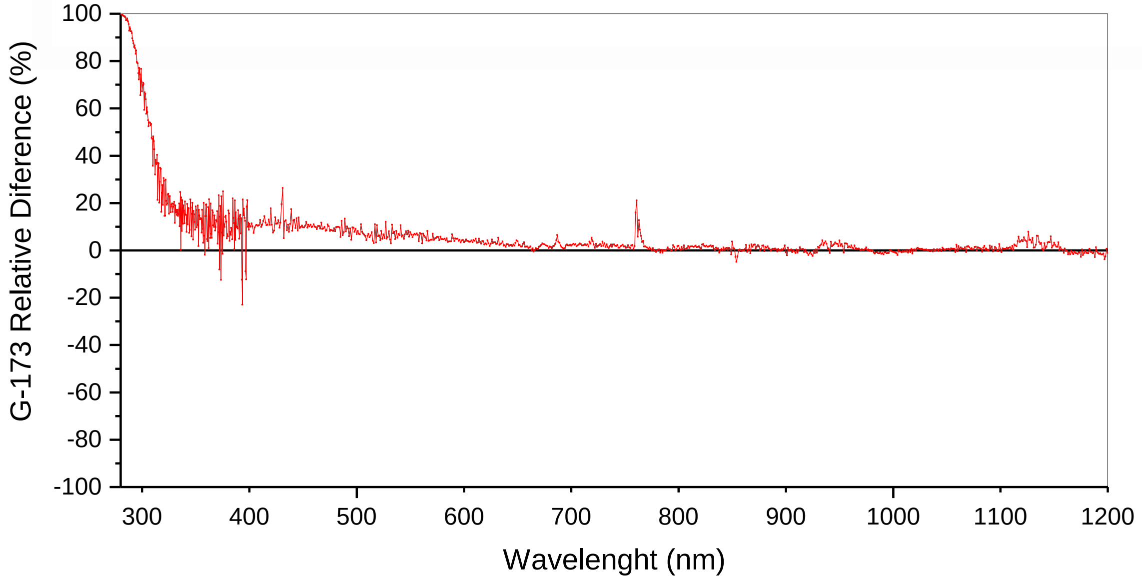
ESPECTRAL DATA SYDNEY

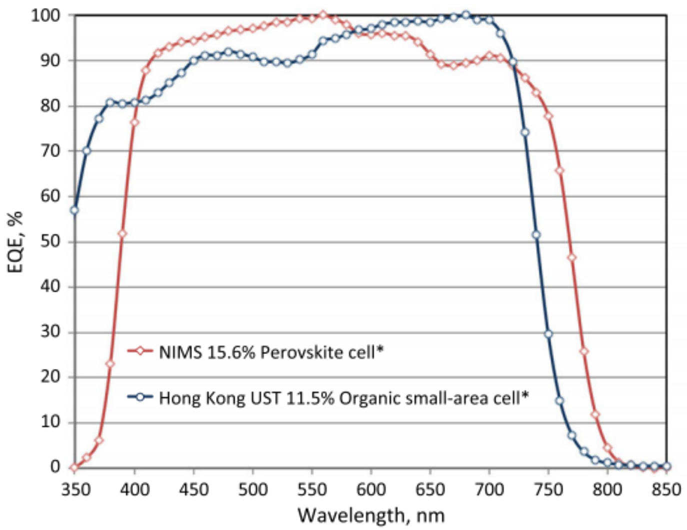




SIMULATED DATA NEED FIELD VALIDATION

ESPECTRAL DATA SYDNEY





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Short term PhD Exchange
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PV SYSTEMS IN WARM AND SUNNY CLIMATES: RESULTS FROM PV INSTALLATIONS IN BRAZIL AND SYNERGIES WITH AUSTRALIA

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