INSTITUT POLYTECHNIQUE DE PARIS

Outdoor performance analysis of five different technologies in Palaiseau,France

PEARL PV Online Parallel Workshop ***23/09/2021***

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Outline

- *Motivation*
- *Experimental setup & Methodology*
- *Results & Discussion*
- *Summary & Conclusions*

Motivation

Photovoltaic production depends on many factors starting from the choice of the PV technology and the conditions to which PV modules will be exposed in terms of exposure to sunlight, temperature, dirt, shading, atmospheric water (humidity, rain, snow, dew, frost) and the surrounding environment.

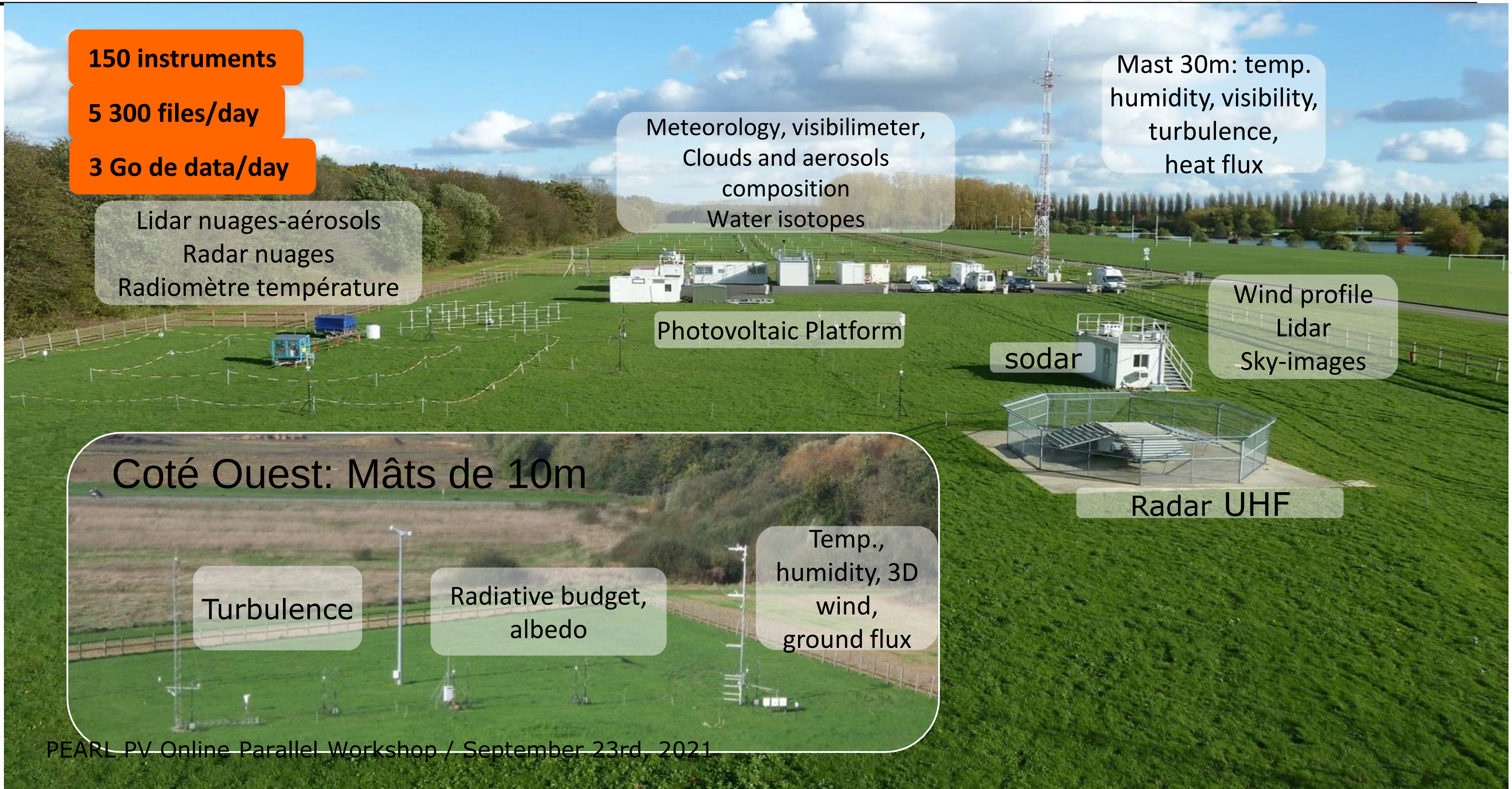
PV modules are usually qualified by the manufacturers under controlled laboratory conditions (known as the Standard Test Conditions, STC, and Normal Operating Conditions), which are useful to assess and compare the performance in a standardized way, but which might radically differ from real-life conditions.

How do different environmental factors affect the production of a PV module?

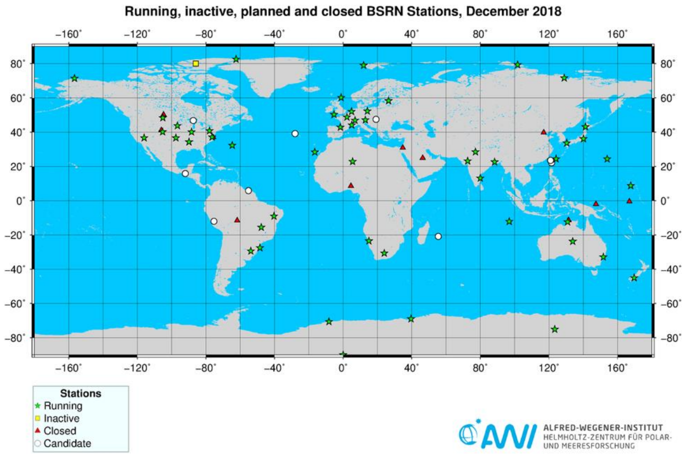
Experimental Setup & Methodology

- *Experimental Platform*
- *Data Treatment*
- *Performance Indicators*

A multi-parameter site (www.sirta.fr)



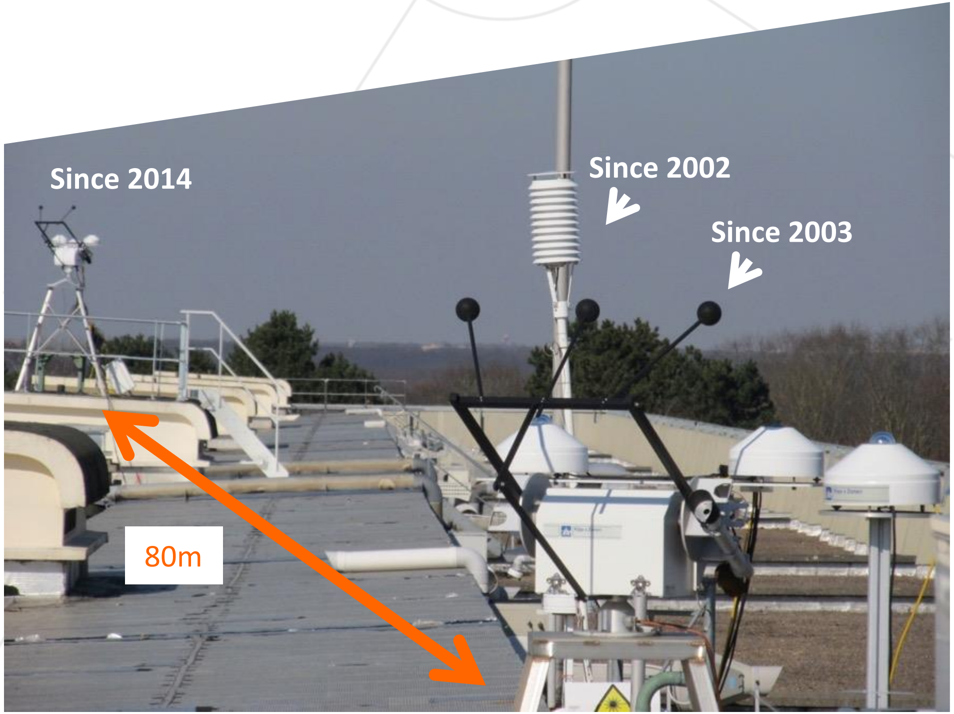
SIRTA (Site Instrumental de recherche par télédétection atmosphérique)



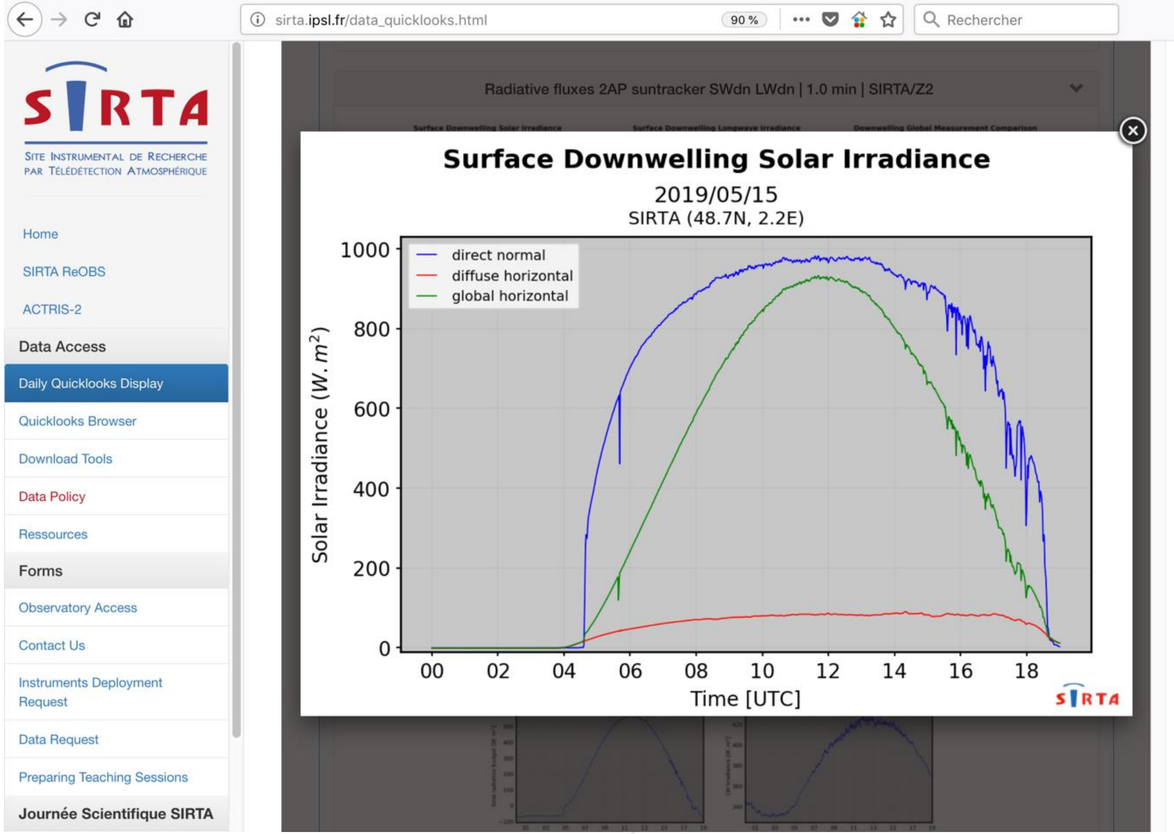
BSRN member since 2003 (site: PAL)
https://bsrn.awi.de/

Current available parameters in BSRN archive :

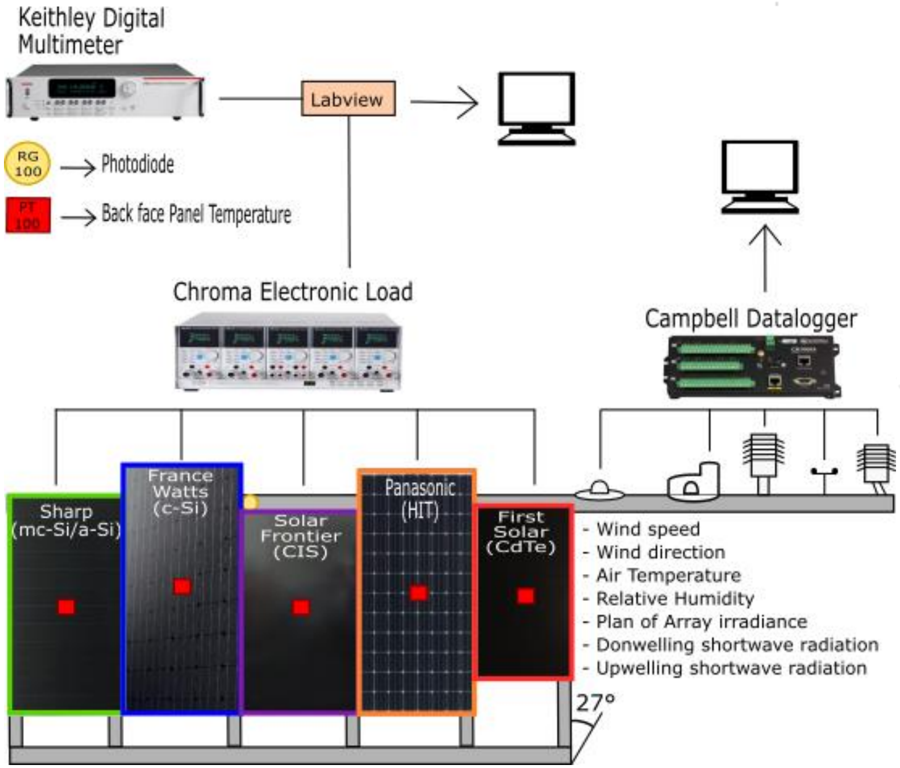
- SWDn (DIF, DIR, GLO), LWDn
- Air temperature, RH, pressure



http://sirta.ipsl.fr/data_quicklooks.html



Experimental Platform



- 10-min data (resampling due to different time resolutions)
- Installed in 2014 but data used is from 2018-2020

STC specifications

1000 W/m^2
25ºC (cell temperature)
AM 1.5

Characteristics	Module technology				
	Micromorphous (Sharp)	Mono-Si (FranceWatts)	HIT (Panasonic)	CIS (SolarFrontier)	CdTe (FirstSolar)
Short circuit current $I_{SC}(A)$	3.45	8.64	5.85	2.20	1.94
Open circuit voltage $V_{OC}(V)$	59.80	37.67	52.40	108.00	60.80
Current at maximum power $I_M(A)$	2.82	8.21	5.51	1.85	1.71
Voltage at maximum power $V_M(V)$	45.40	30.52	43.60	81.50	48.30
Maximum power $P_M(Wp)$	128	250	240	150	82.5
Efficiency (%)	9.5	15.0	19.0	12.2	11.4
I_{SC} temperature coefficient α (%/°C)	+0.07	+0.02	+1.76	+0.01	+0.04
V_{OC} temperature coefficient β (%/°C)	-0.30	-0.36	-0.131	-0.30	-0.25
P_M temperature coefficient γ (%/°C)	-0.24	-0.40	-0.29	-0.31	-0.25
Area (m^2)	1.42	1.64	1.26	1.23	0.72

Data Filtering

Geometric Filters

- AM[1,5]
- AOI < 60°

Quality control Filters

- DF < 1.05
- Global Solar Flux > 0

Stability Filters

- ΔKc < 0.5
- Abs(POA_calc – POA) < 0.1*POA_calc

Weather Filters

- Pmpp > 1% of max power otuput

Statistical Filters

- η > 50%
- PR quantile 0.01, 0.99

Resampling

Atmospheric & Performance Indicators

- *Clear-Sky Index (Kc)*
- *Average Photon Energy (APE)*
- *Spectral Mismatch (M)* → Spectral Impact Factor (SIF)

- *Reference Yield (RY)*
- *Array Yield (AY)*
- *Efficiency (η)*
- *Capacity Factor (CF)*

Reference Yield (RY) and Array Yield (AY) → Performace Ratio (PR)

$$RY = \frac{\sum G_i}{1000} \qquad K_c = \frac{GHI}{GHI_{clear\,sky}}$$

$$AY = \frac{\sum Pmpp}{P_{STC}} \qquad APE = \frac{\int_{\lambda_1}^{\lambda_2} E(\lambda)d\lambda}{q\int_{\lambda_1}^{\lambda_2} \phi(\lambda)d\lambda}$$

$$PR = \frac{AY}{RY}$$

$$M = \frac{\int_a^b (1)\, E_{ref}(\lambda)d\lambda}{\int_a^b S_T(\lambda)\, E_{ref}(\lambda)d\lambda} \cdot \frac{\int_a^b S_T(\lambda)\, E_{meas}(\lambda)d\lambda}{\int_a^b S_R(\lambda) E_{meas}(\lambda)d\lambda}$$

$$\eta = \frac{\sum P_{mpp}}{size \times \sum G_i} \qquad CF = \frac{\sum P_{mpp}}{P_{STC} \times hours \times days} \qquad SIF = \frac{\sum MG_i}{\sum G_i}$$

GHI: global horizontal irradiance

P_{mpp}: Maximum power point
P_{STC}: power output at standard conditions

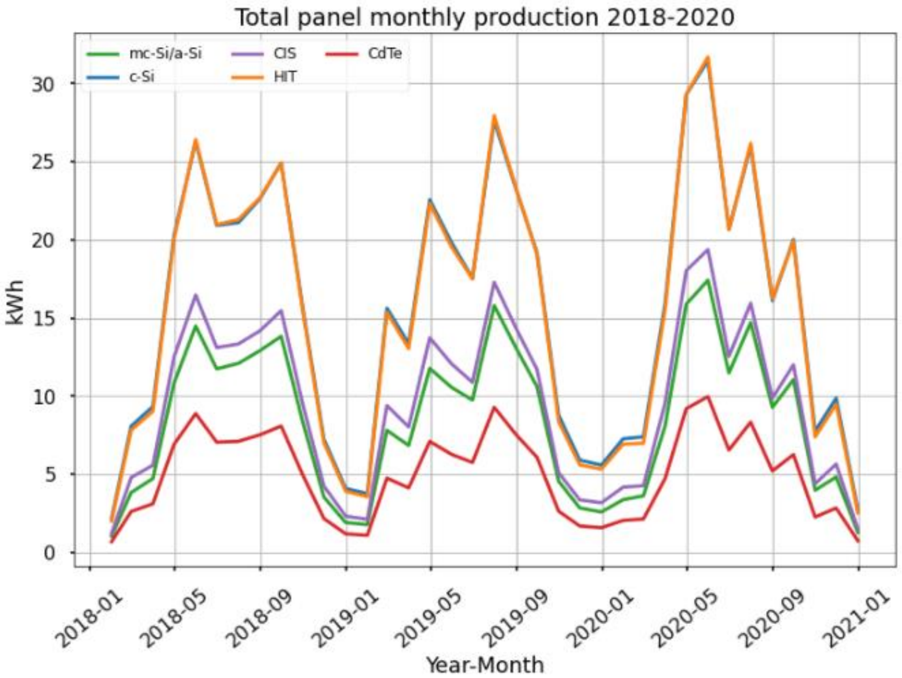
E: solar spectrum
Φ: photon flux
q: charge of electron

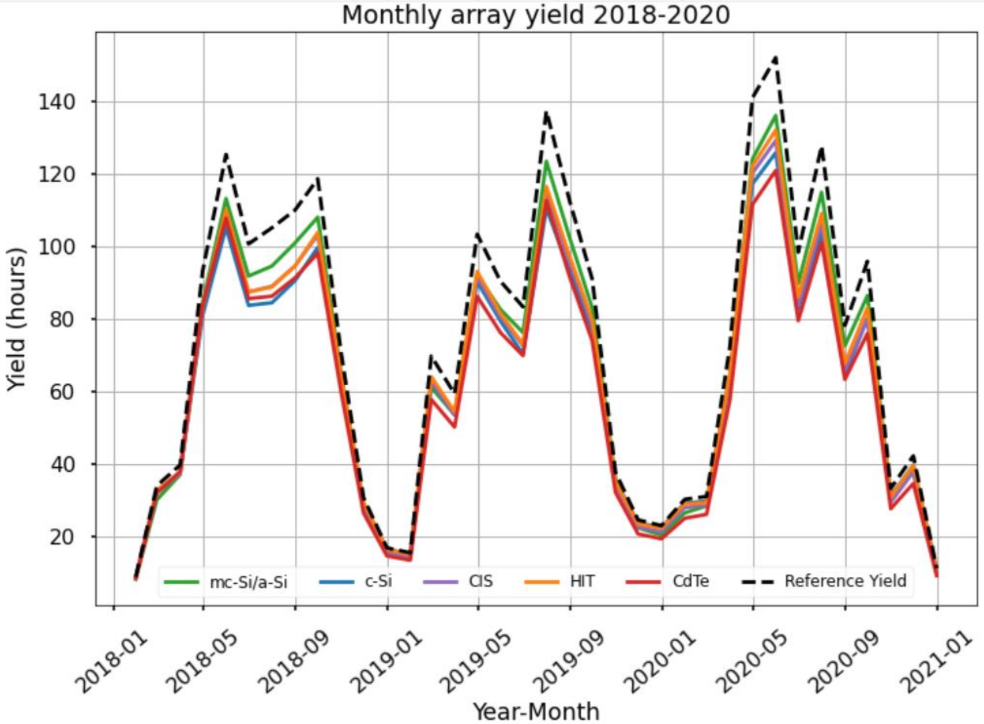
E_{ref}: reference solar
E_{meas}: measured solar spectrum
S_T : spectral response of module
S_R : spectral response of pyranometer (assumed to be 1)

G_i: measured in-plane irradiance

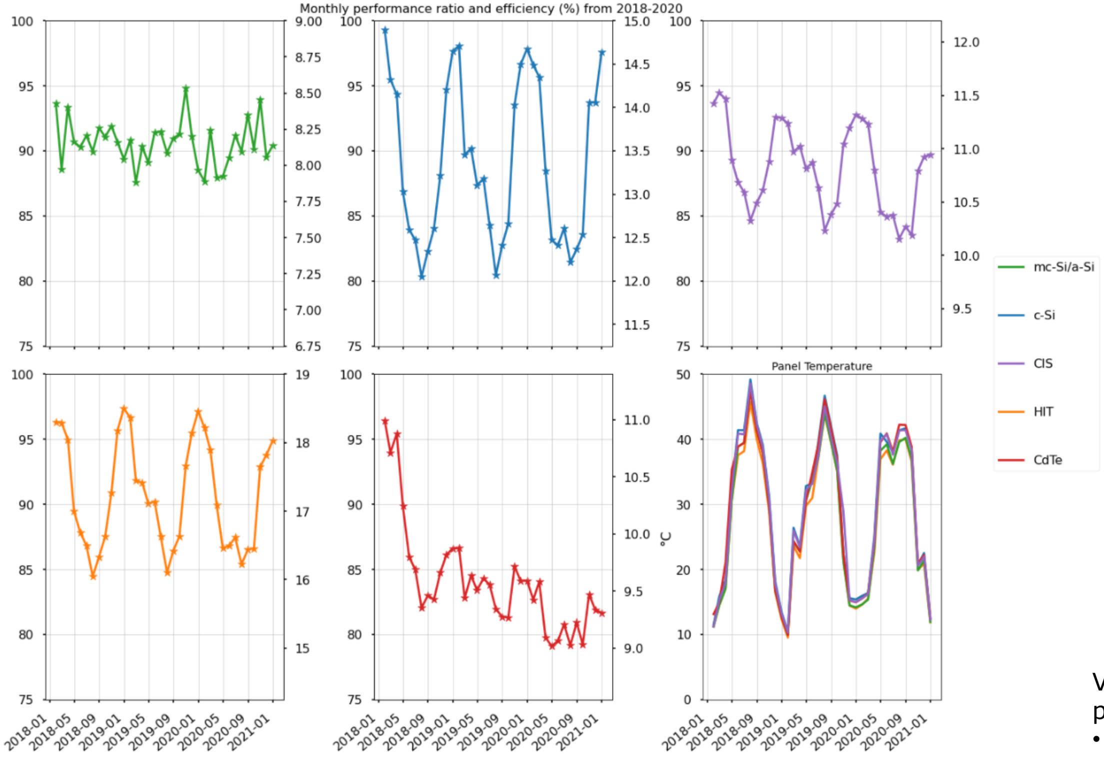
Results & Discussion

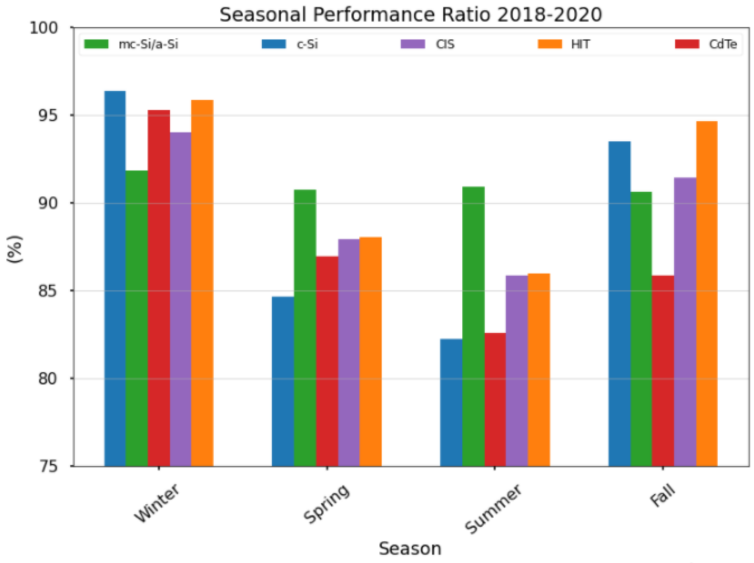
Results: Yield





Results: Performance Ratio, Efficiency

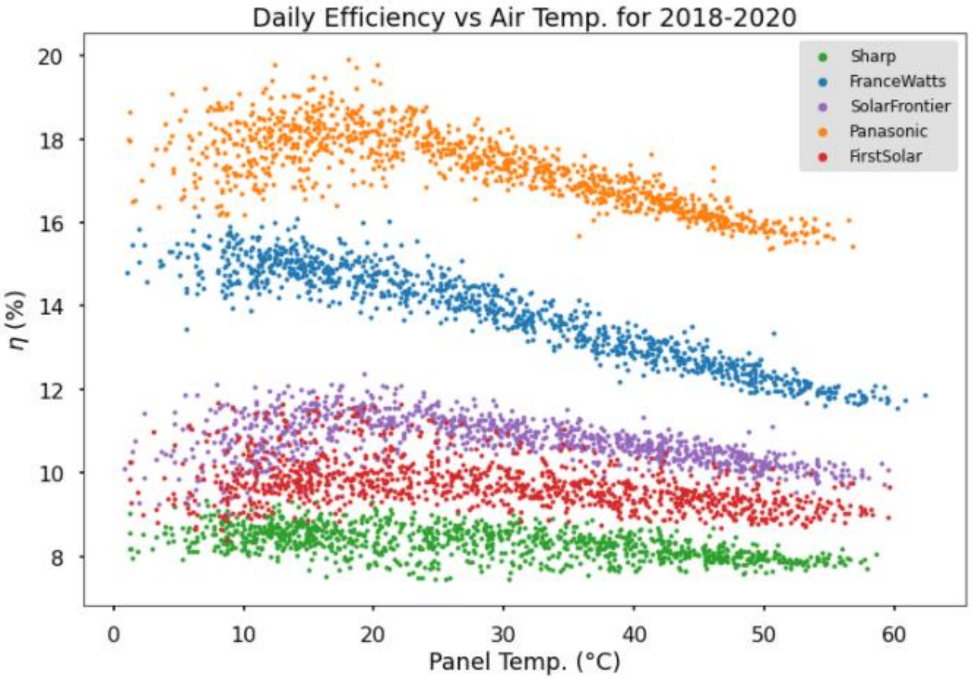


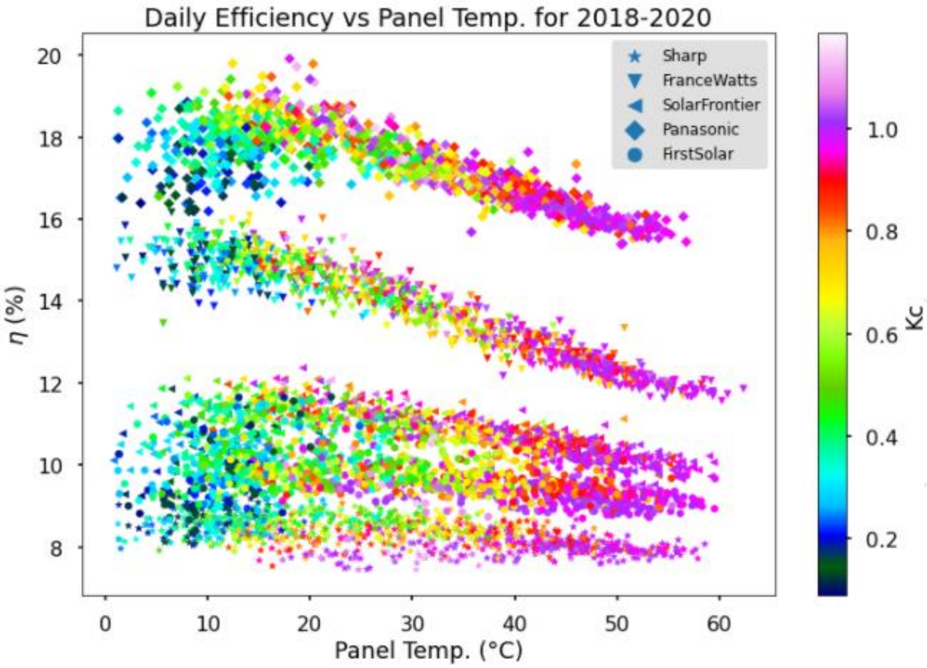


Variations in performance ratio:

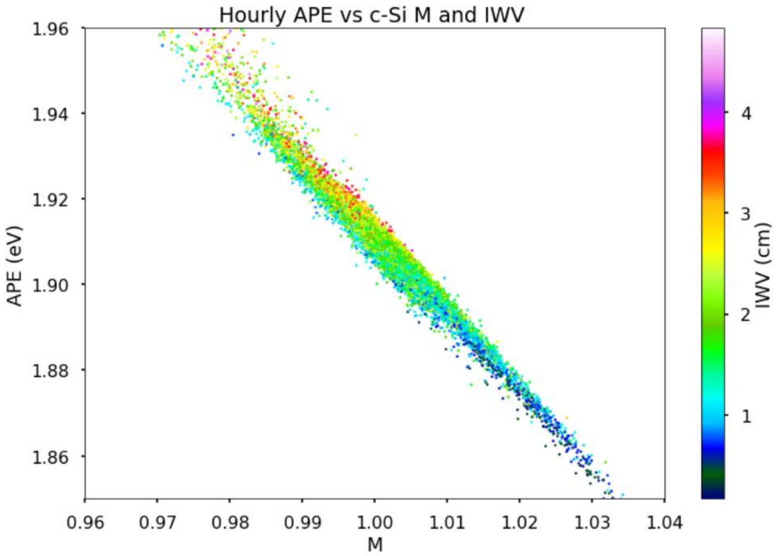
- mc-Si/a-Si → 8%
- c-Si → 20%
- CIS → 15%
- HIT → 15%
- CdTe → 10%

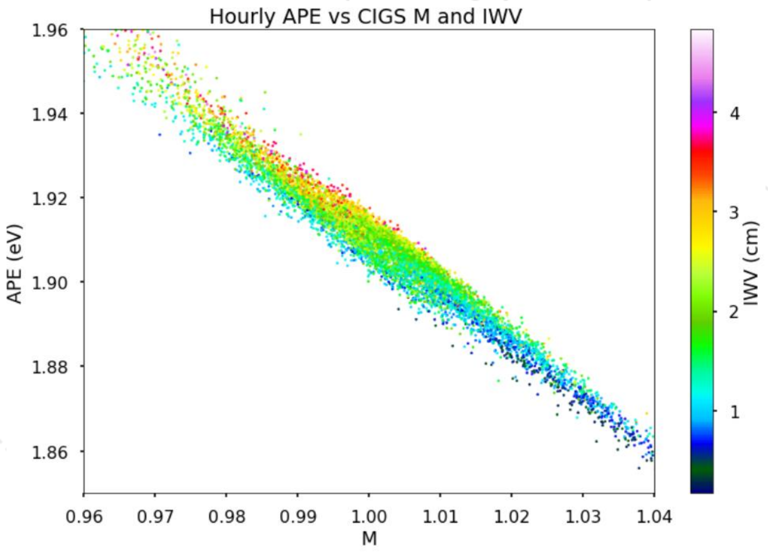
Results: Temperature, Kc effect

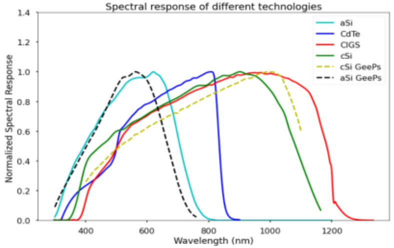




Results: APE


Hourly APE vs c-Si M and IWV
APE (eV)
M
IWV (cm)
1.96
1.94
1.92
1.90
1.88
1.86
0.96
0.97
0.98
0.99
1.00
1.01
1.02
1.03
1.04
1
2
3
4


Hourly APE vs CIGS M and IWV
APE (eV)
M
IWV (cm)
1.96
1.94
1.92
1.90
1.88
1.86
0.96
0.97
0.98
0.99
1.00
1.01
1.02
1.03
1.04
1
2
3
4


Spectral response of different technologies
Normalized Spectral Response
Wavelength (nm)
aSi
CdTe
CIGS
cSi
cSi GeePs
aSi GeePs
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
400
600
800
1000
1200

Summary & Conclusions

Summary

- *Thin-films give better performance ratio results in the midlatitude typical climate of the study, where there is variable weather as they remain more stable through different conditions and are less affected by high temperatures.*
- *c-Si based technologies will achieve higher performance and efficiency during cold weather but significantly lower values during warm ones due to their high temperature coefficient.*
- *The spectral mismatch factor effect is small when compared to the effect of temperature or irradiance but should be considered nonetheless as it is non-negligible.*

Acknowledgements

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Thank you !

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