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Copernicus Institute of Sustainable Development

"Advanced performance assessment and fault detection techniques for residential PV fleets"

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Wilfried van Sark

Pearl PV Workshop, 11/1/2021

Differences of PV-Systems
PV plant vs Residential

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- Re
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  -
  -

Monitoring: Solar Park vs House

- **Weather Data**
  - Solar Park
    - ✓Almost Everything on site (GTI, GHI, Tamb, Tmod)
  - House
    - ❑Almost nothing on-site
    - ❑No IRRADIANCE FOR REFERENCE

- **Static Data**
  - Solar Park
    - ✓Under control due to installation from one installer
- House
  - Many individuals
    - ❑Owners may don't know some info, ie tilt-orientation-capacity

- **Power Data**
  - Connection errors in both
  - But many individuals are always more difficult to contact with

Fixing Static Data Errors

The production of the panel under STC (1000W/m^2, 25^{o}C, 1 atm)

- **Capacity**
  - Panel number * panel capacity (if both exist)
  - Inverter model?
  - Simply take the Max Power measurment (may add 5%)
    - But keep this value for all calculations and all the period of time

- **Tilt and orientation**
  - Orientation: maybe satelite view in case of a few systems
  - Use of algorithms[1] for calculation, in combination with the solar angles (from PVLIB)

1 "A quality control algorithm for distributed photovoltaic array power output", Killinger et all, 2017

What about no existing weather measurments?

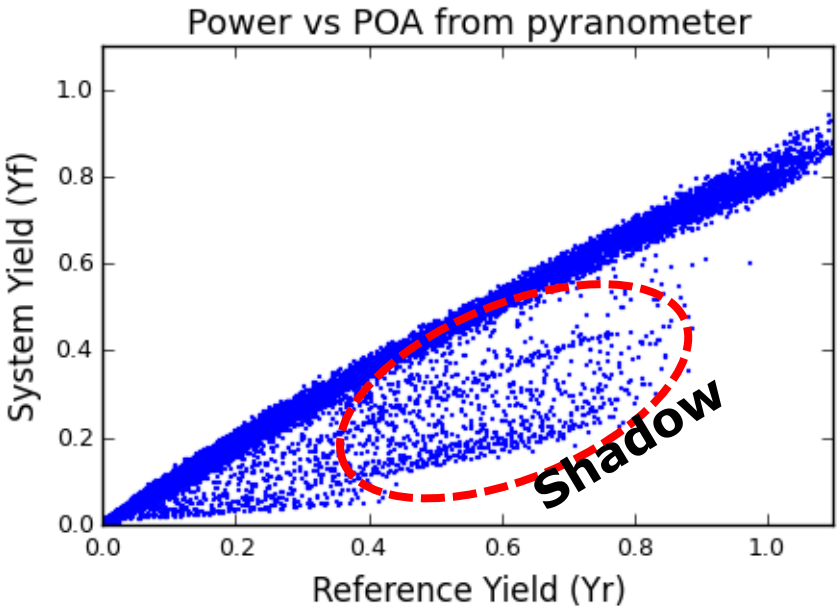
- **GHI (& maybe DHI) would be available somewhere**
  - Local weather stations
  - Satelite data (meteosat – GHI & DHI)
- **Solar Models**
  - Decomposition GHI -> DHI + DNI – empirical (DISC, ERBS, DIRINT)
  - Transpostion DHI -> Diffuse in POA – Perez, Hay/Davies etc
  - Effectiveness of models may differ per region. Better conduct a study!
- **Possible errors**
  - Geospatial errors – station far from PV – Satellite covers large area
  - GTI from solar models ⇒ More errors
- **Peer2peer – use neighboring PV systems**
- Either on large Regions (Jonathan is the best on that)
- In neigborhoods (my part)

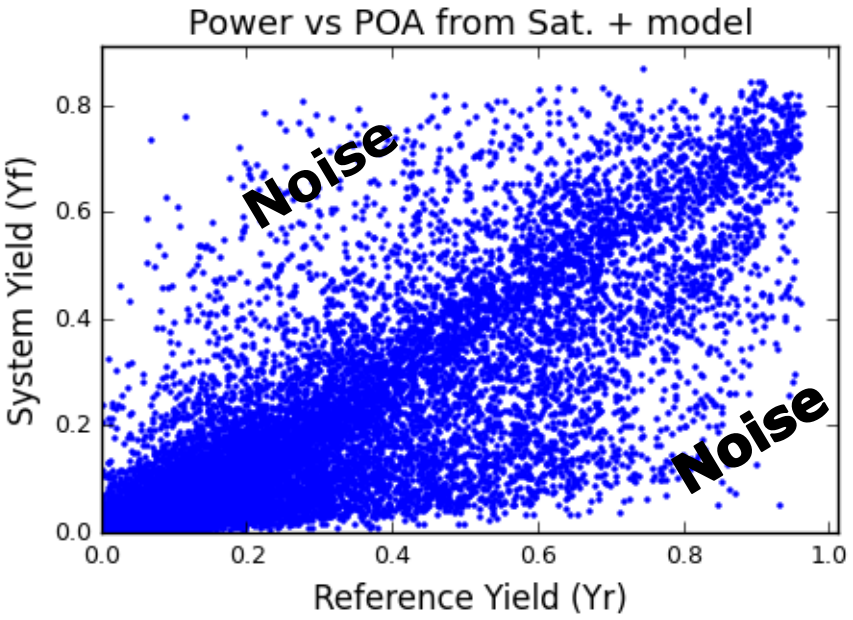
Plot of PR

$$System\ Yield\ (Y_f) = \frac{E_{AC}}{W_{peak}}\ [^{Wh}/_{W}]$$

$$Reference\ Yield\ (Y_r) = \frac{H_{poa}}{G_{STC}}\left[\frac{^{Wh}/_{m^2}}{1000\ ^{Wh}/_{m^2}}\right]$$

$$\boldsymbol{Performance\ Ratio(PR) = {}^{Y_f}/_{Y_r}}$$





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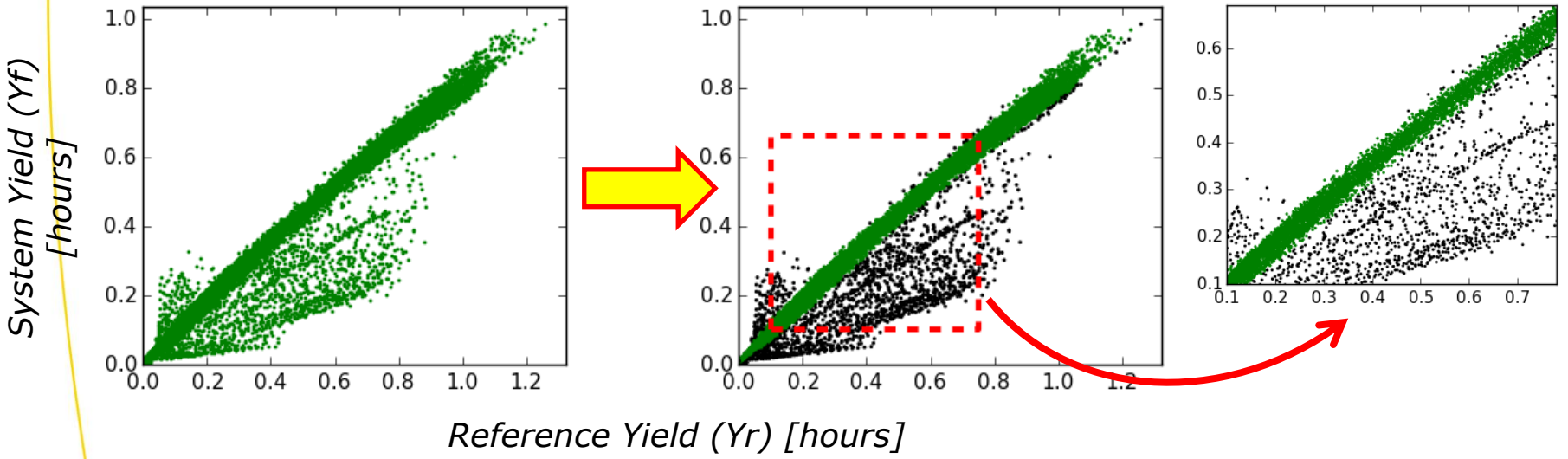
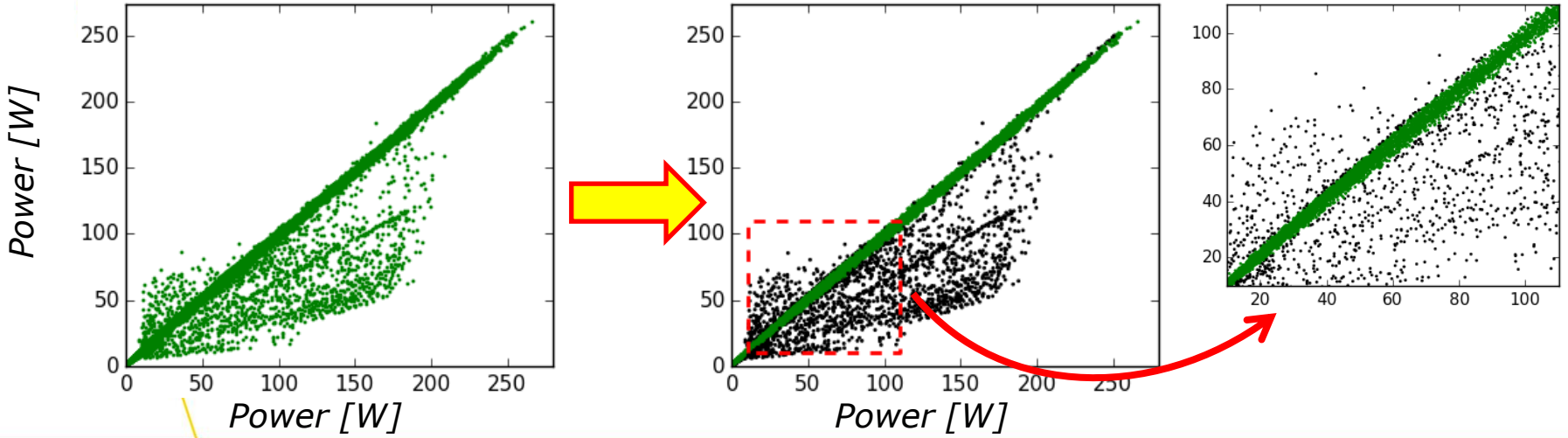
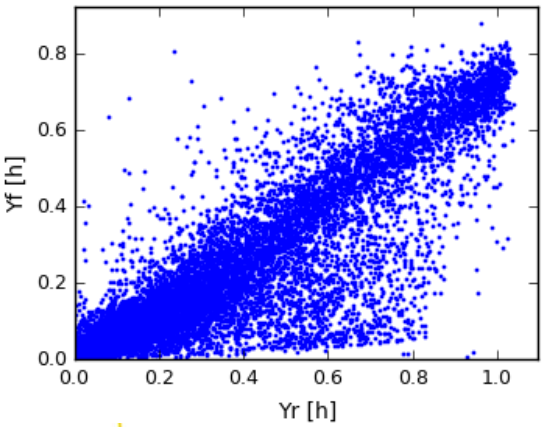
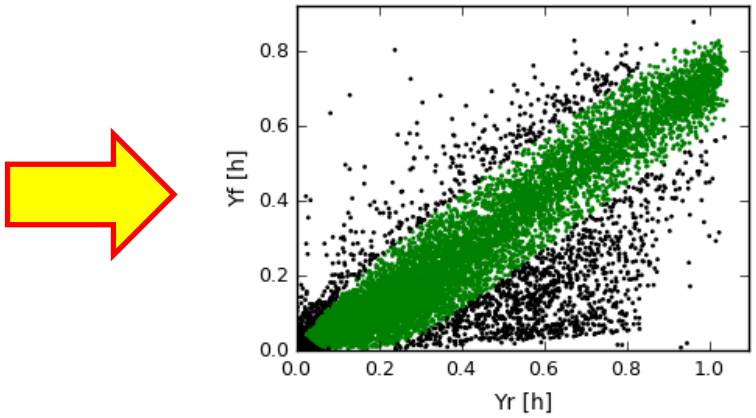
REAL PR algorithm

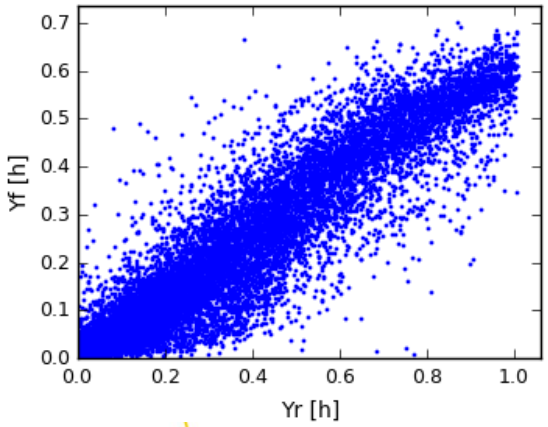


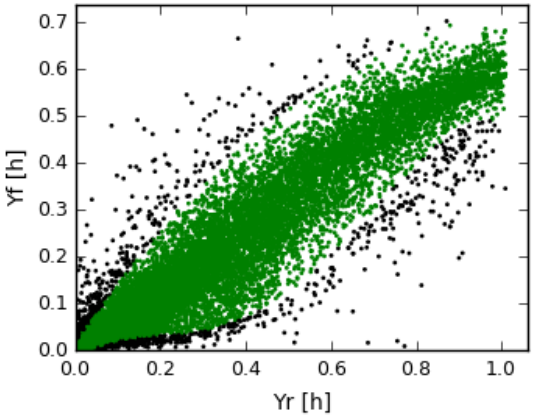




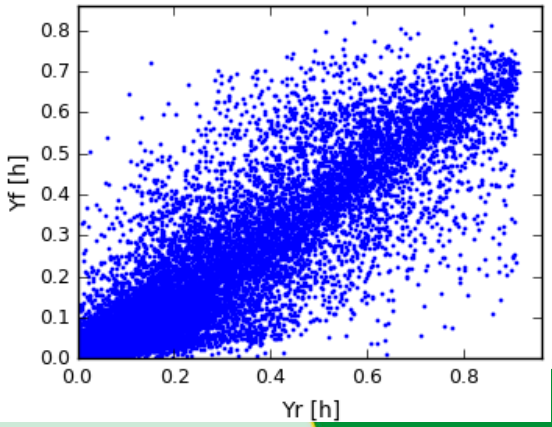


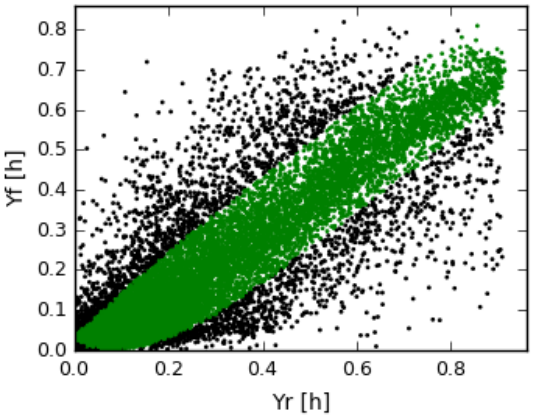
78% Inliers
21% Outliers
17% under
8% over
$PR_{inl} = 67.4\%$
$PR_{all} = 62.3\%$





87% Inliers
12% Outliers
7% under
5% over
$PR_{inl} = 61.8\%$
$PR_{all} = 62.2\%$





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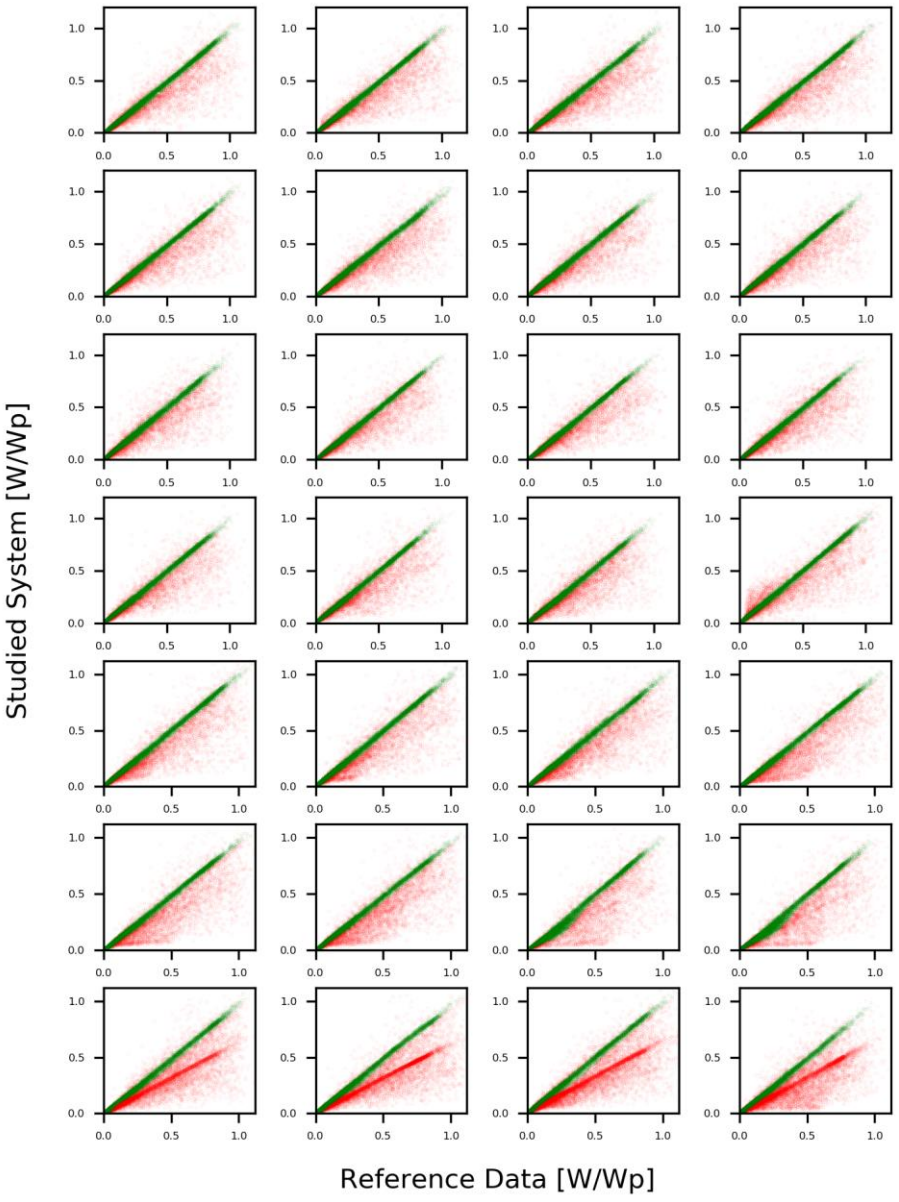
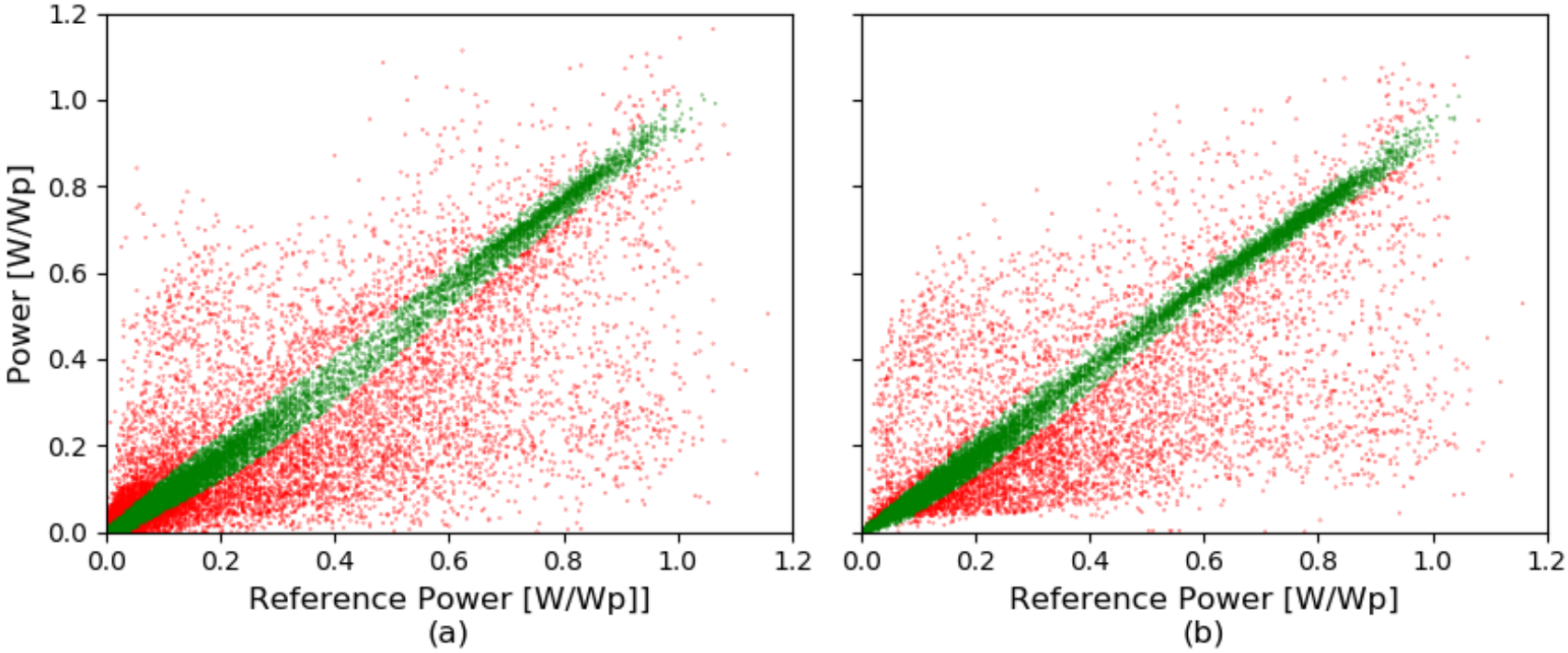
Application on panels of MLPE system with neighboring panels as reference



Reference data:

- The other panels of the MLPE system
- Each moment the panel with the max power

Application on houses with neighboring panels as reference (150m away)



Reference data:

- The panels of an MLPE PV system – 150 m away
- Each moment the panels with the max power

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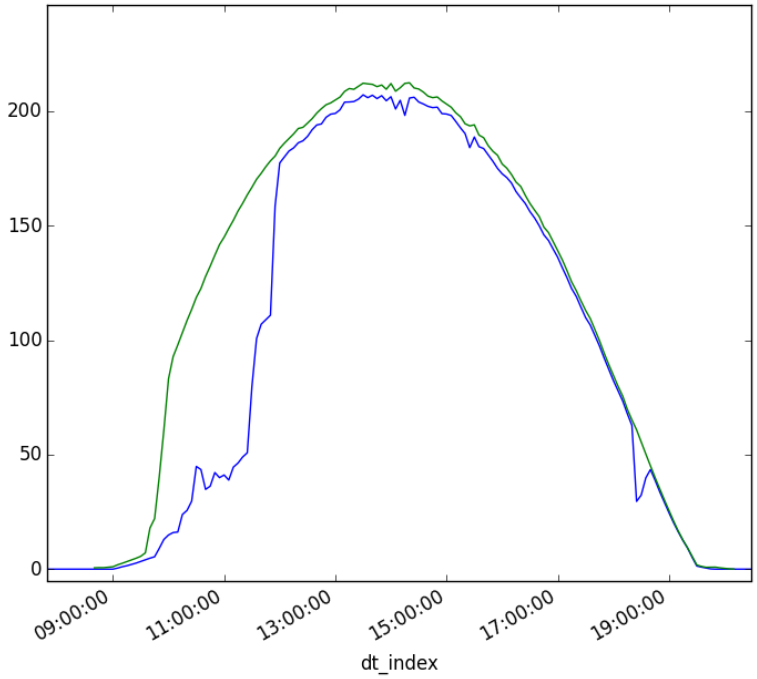
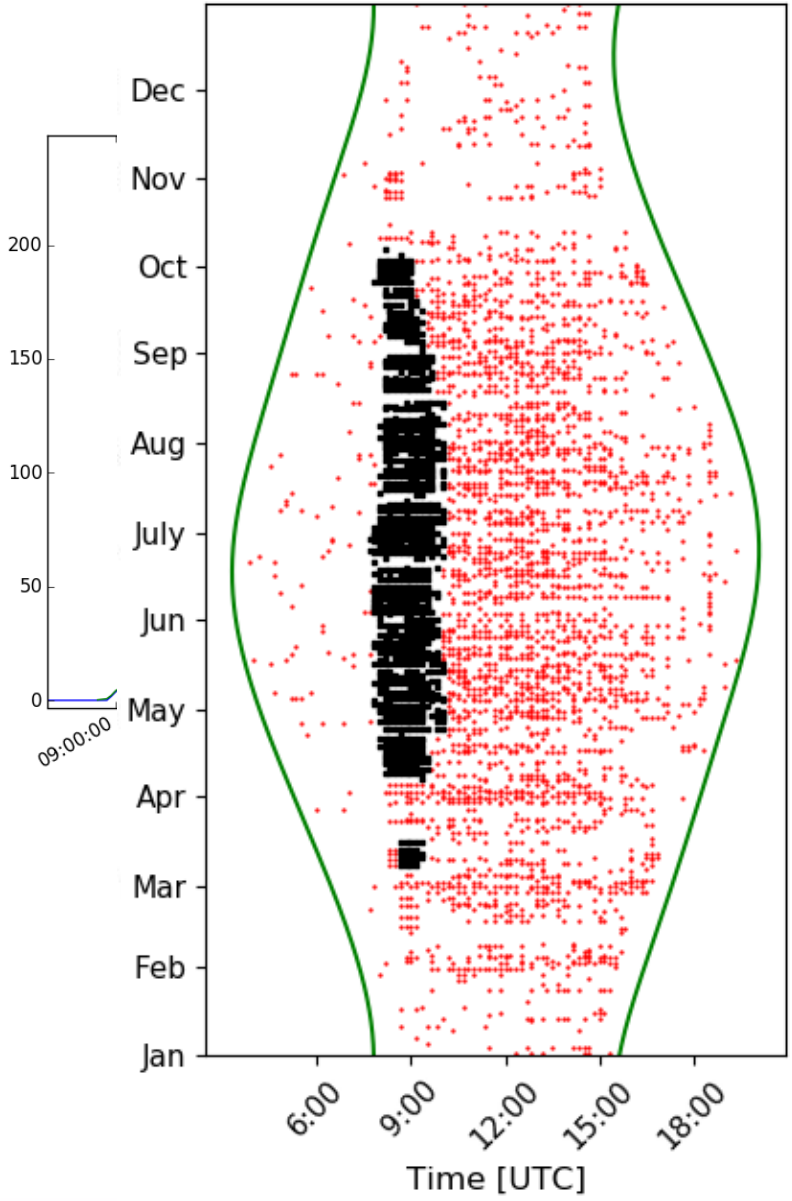
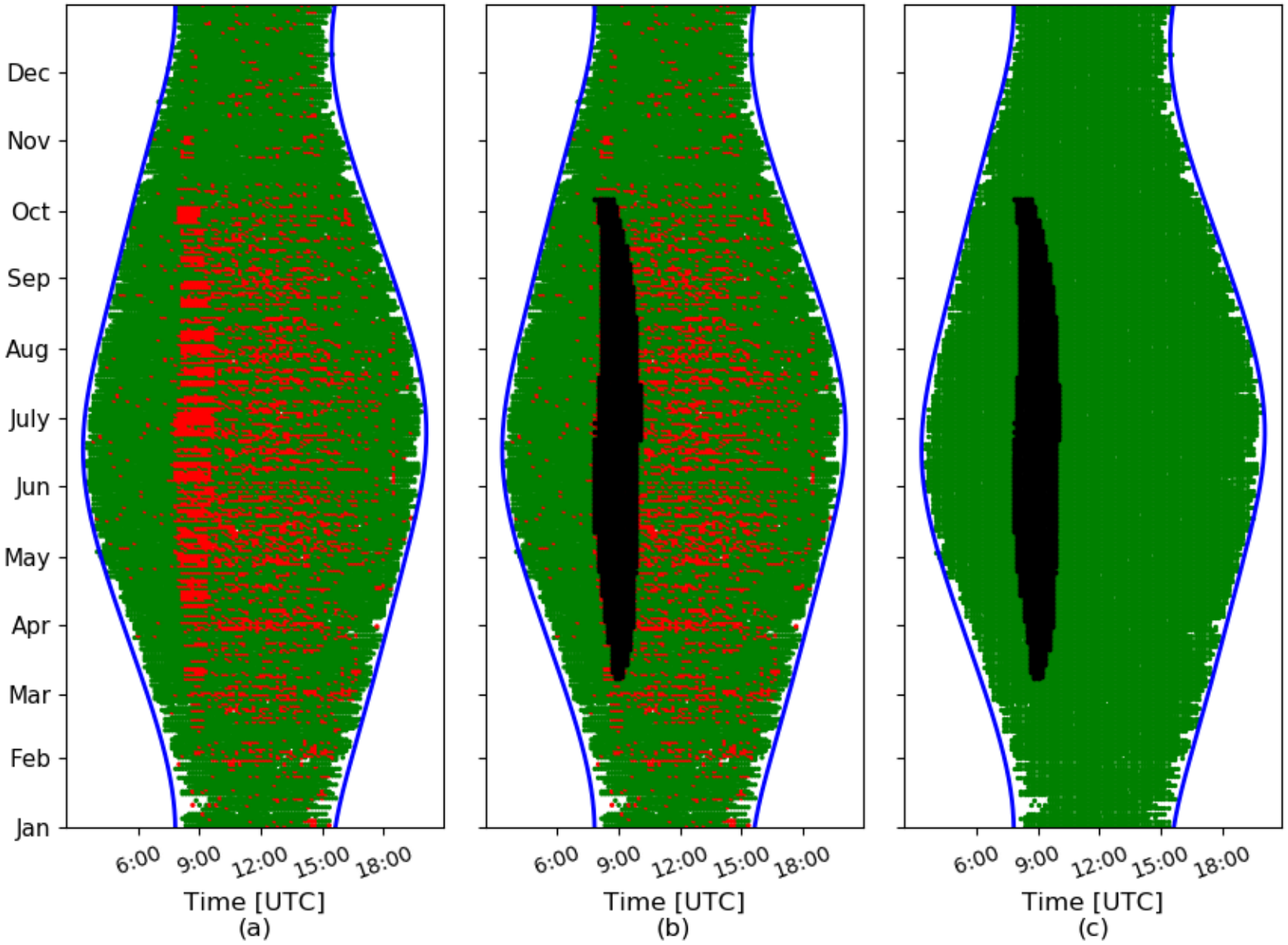
further use: shadow detection

PV1 vs PV3, Monday






Dec
Nov
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6:00
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15:00
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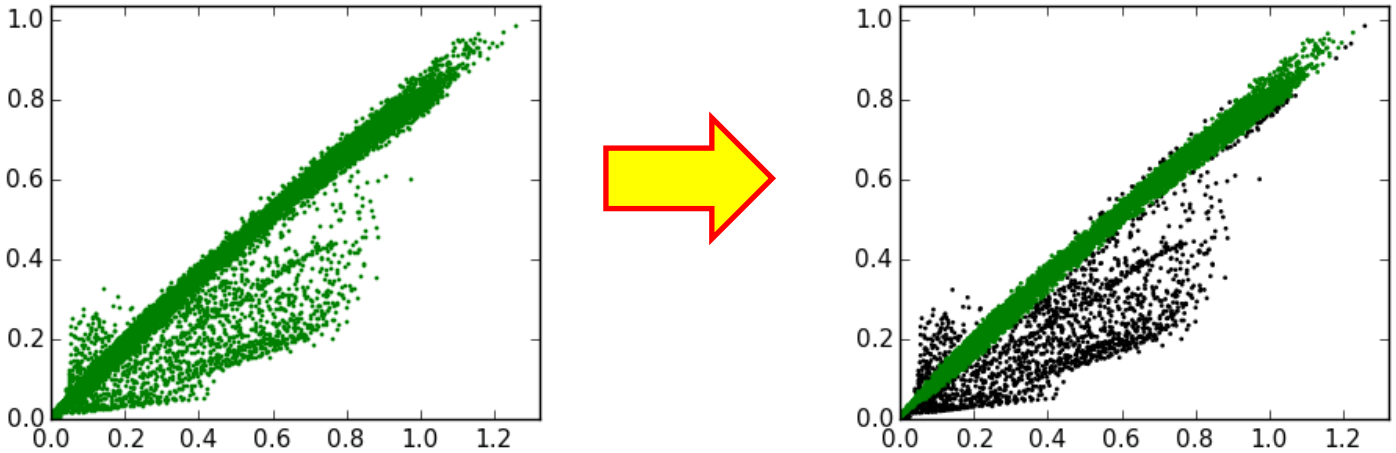
Time [UTC]
(a)
Time [UTC]
(b)
Time [UTC]
(c)

Moniroring of residential PV



- Not easy to find reference data: we have to be creative!!!
- Weather data are very useful but peer2peer is more acurate
- Per2peer in a neighborhood level is useful for shadow detection
- Shadow is more imprtant for the monitoring company, not that much for the owner
- But estimated loss of power due to shadow can be provided
- "Real PR" clusters to inliers and outliers – Then outliers should be continusly studied for any further malfunction. ML application for further fault categorization

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Thank you for your attention

Questions??

- More info:

  "PV System Performance Evaluation by Clustering Production Data to Normal and Non-Normal Operation"
- Odysseas Tsafarakis, Kostas Sinapis and Wilfried G. J. H. M. van Sark
- Energies 2018, 11, 977; doi:10.3390/en11040977
- New paper on shadow detection is coming soon!!!

A few more examples!!!

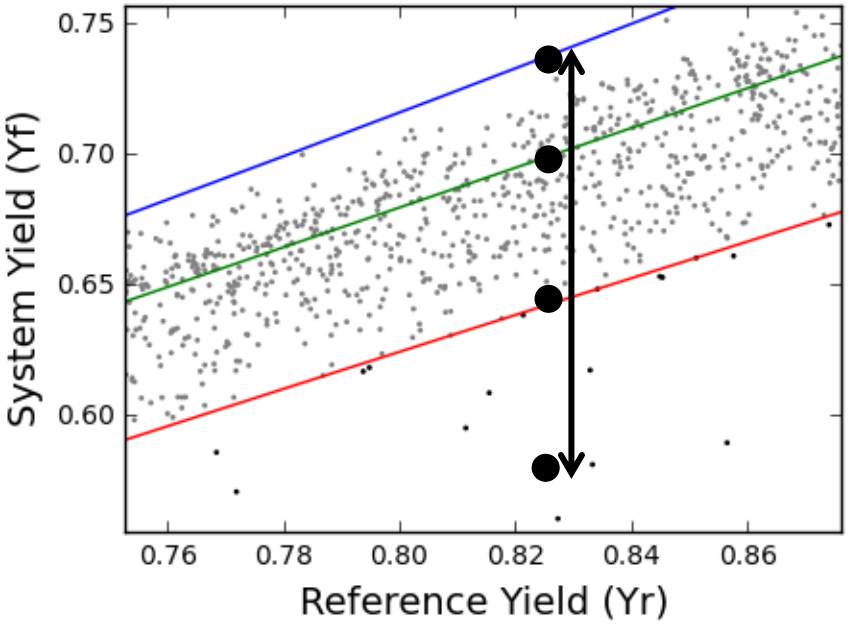
Energy loss

- $\varepsilon_i^{Poly}(Y_R) = Y_{f,i} - Y_R \Rightarrow$

$$\boldsymbol{Y_{f,i} = \varepsilon_i^{Poly}(Y_R) - Y_{r,i}}$$

$i \in [Upper, Lower, Max]$

- 3 scenarios for outliers:
  a) Error of outliers is 105% to the smaller threshold (ε_{left})
  b) Error is equal to the higher frequent error (global maximum)
  c) Error is 95% of the higher threshold (ε_{right})
- Energy Loss:
  - $E_{loss} = E_{studied\ PV}^{scenario} - E_{studied\ PV}^{real}$



Example 1

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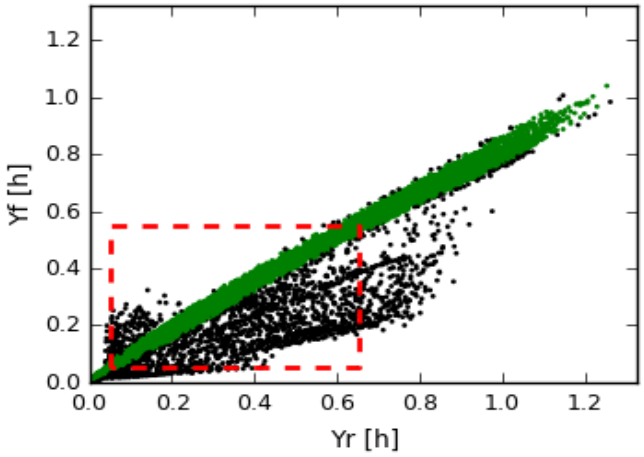
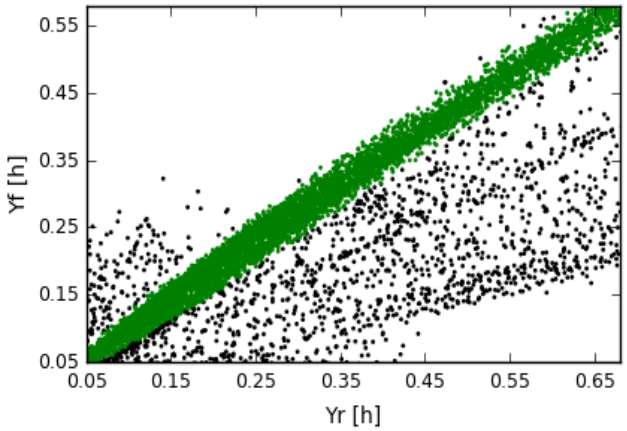
Studied (Y_f):shaded Panel with Power optimizer
Reference data (Y_r): Pyranometer and unshaded Panel with PO



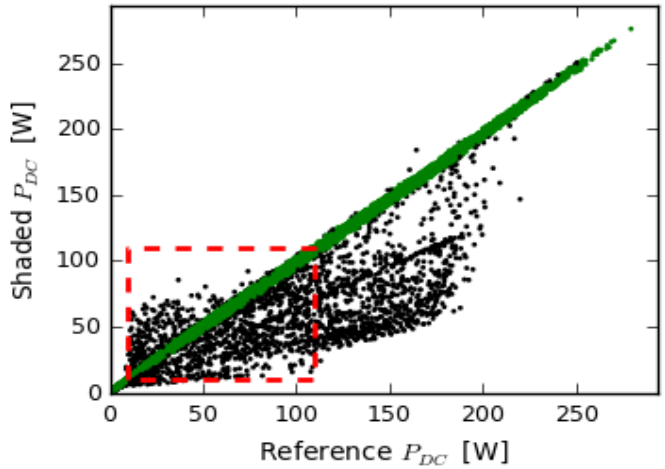


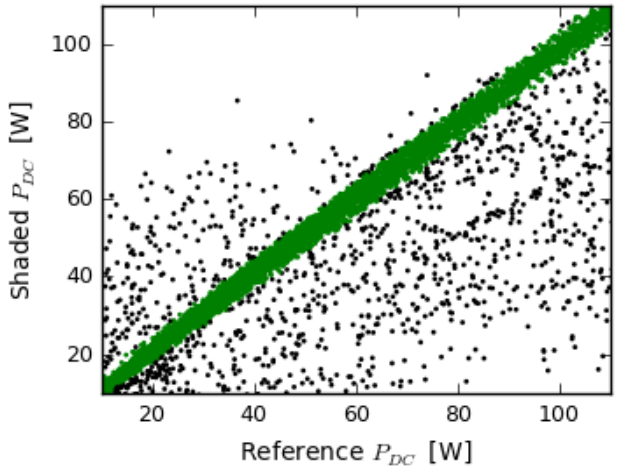
vs Pyranometer

$PR_{real} = 86.8\%$

$PR_{shadow} = 81.7$

E_{loss}	
Min	4.9%
frequent	6.7%
Max	8.1%



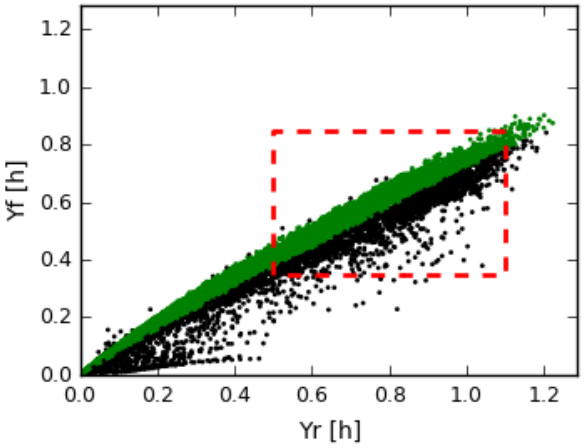


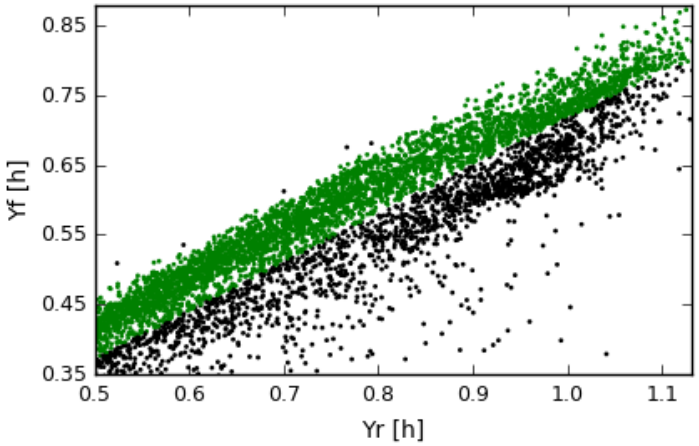
vs panel

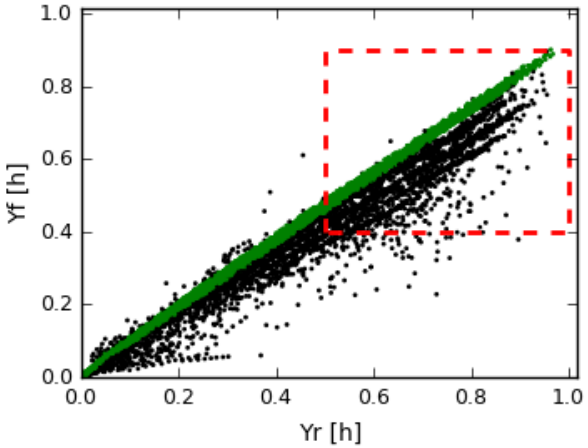
E_{loss}	
Min	5.5%
frequent	6.1%
Max	6.8%

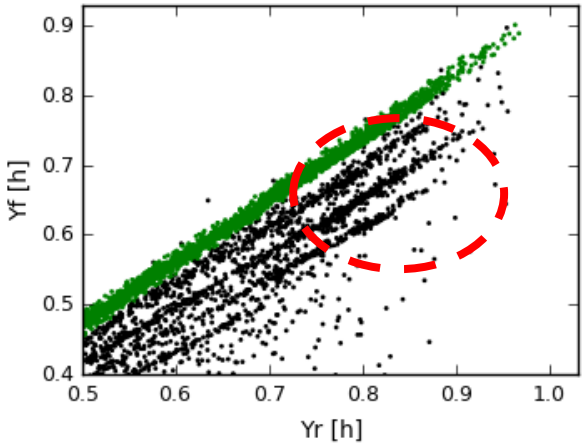
Example 2

Studied (Y_f):shaded PV system with string optimizer
Reference data (Y_r): Pyranometer and unshaded Panel with PO



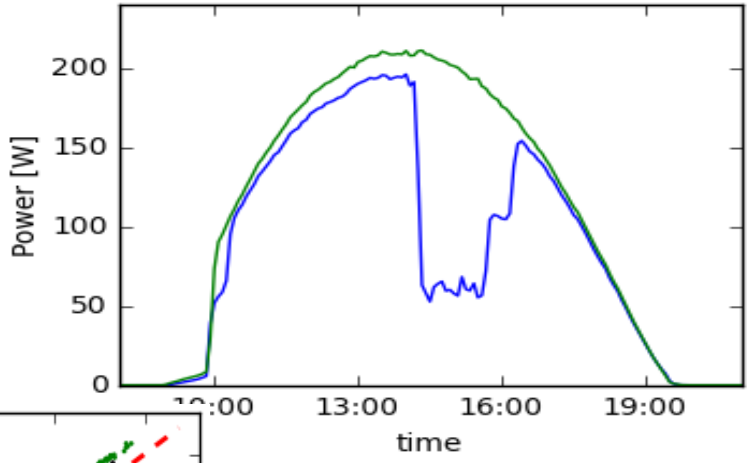


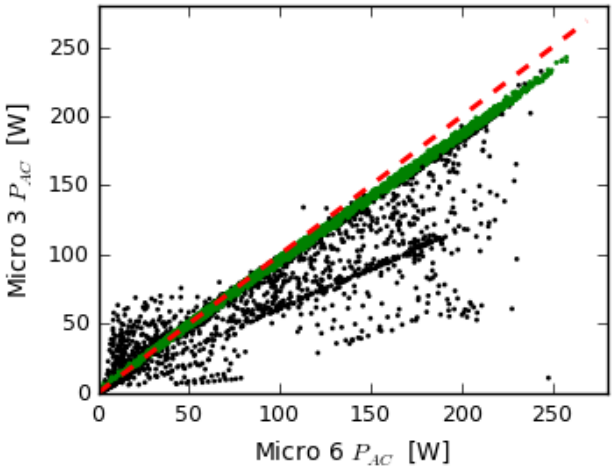


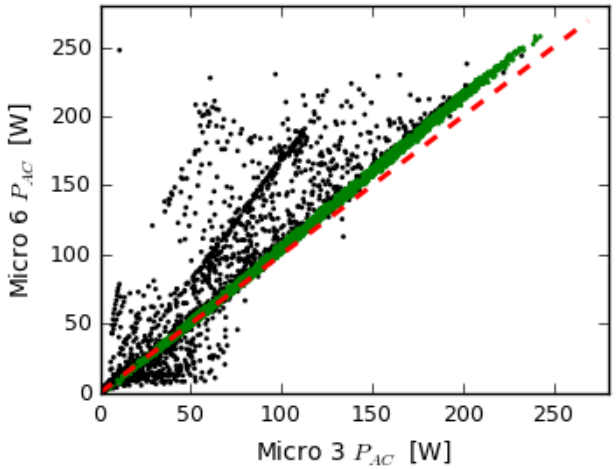


Example 3

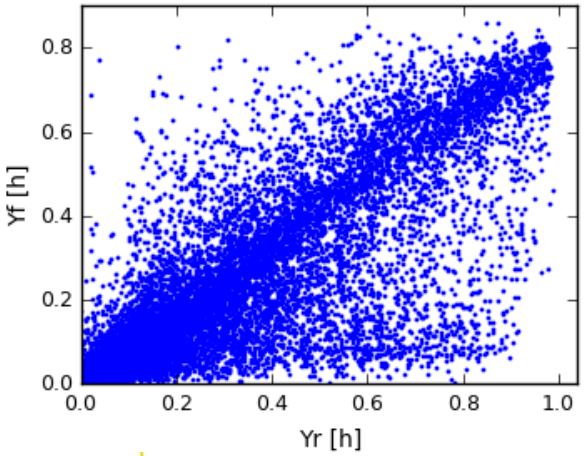
- Same panels with different inverter are monitoring each other
- 3 values for Energy loss:
  - Micro 3 due to shadow
  - Micro 6 due to shadow
  - Micro 3 due to bad inverter

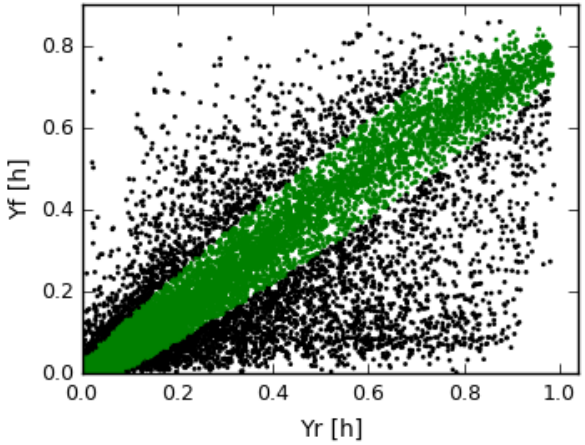




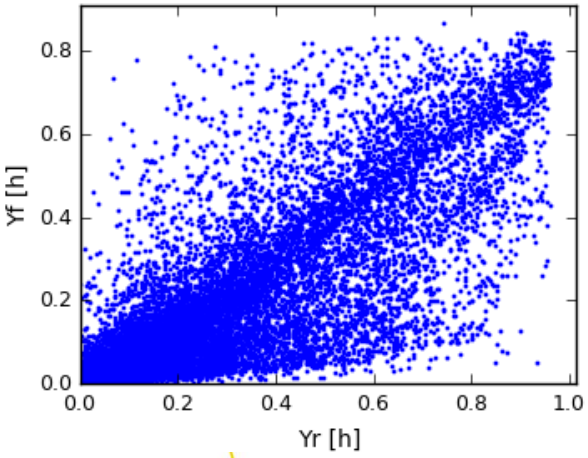


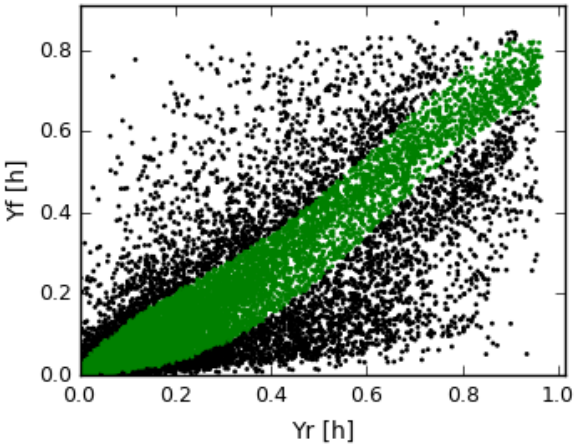
Example 4
Application on random houses



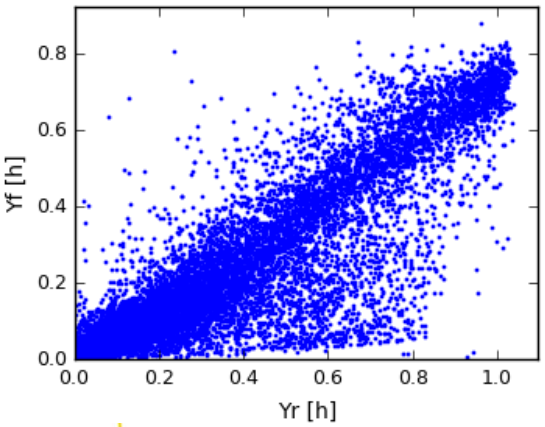


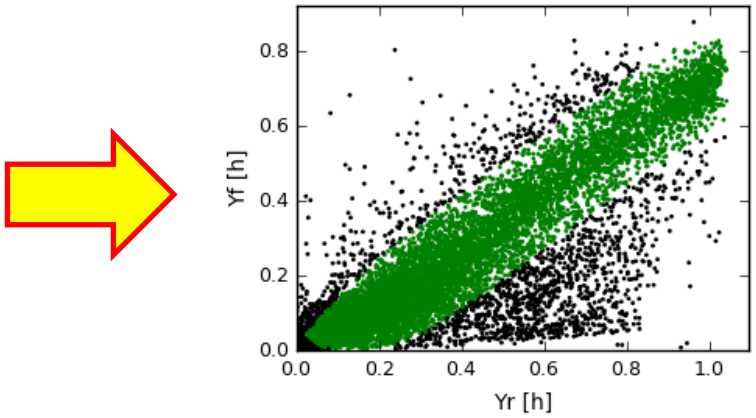
75% Inliers
25% Outliers
17% under
8% over
$PR_{inl} = 79.4\%$
$PR_{all} = 71.3\%$





67% Inliers
33% Outliers
21% under
12% over
$PR_{inl} = 67.2\%$
$PR_{all} = 64.9\%$





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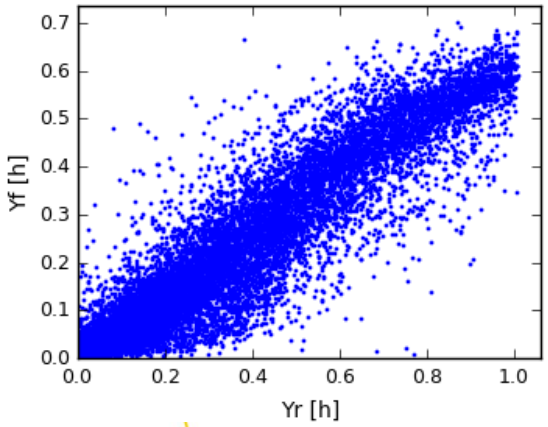

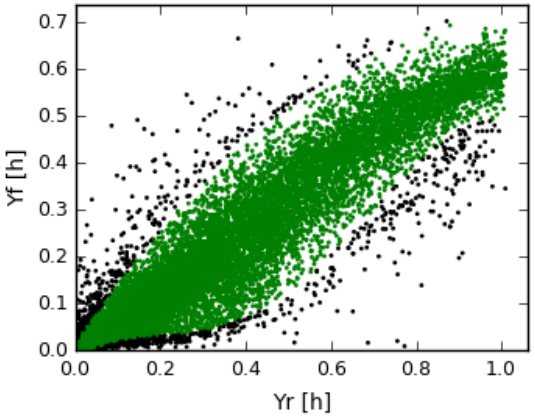

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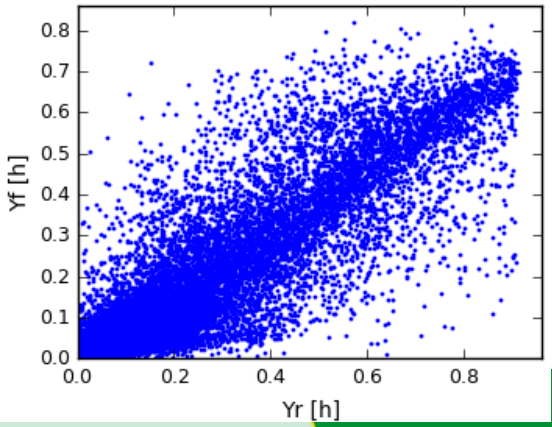

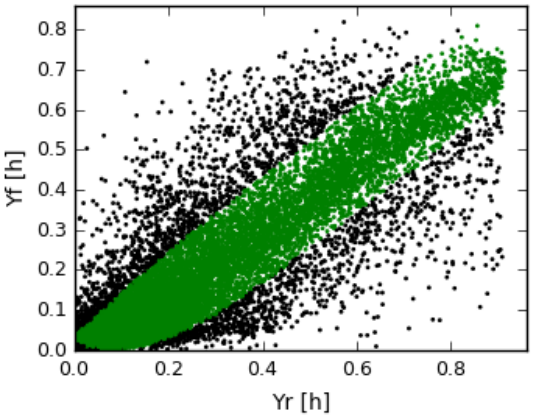

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