Prediction of the solar spectrum for accurate prediction of energy yield of the high-performance PV system using multi-junction cells and solar-driven cars

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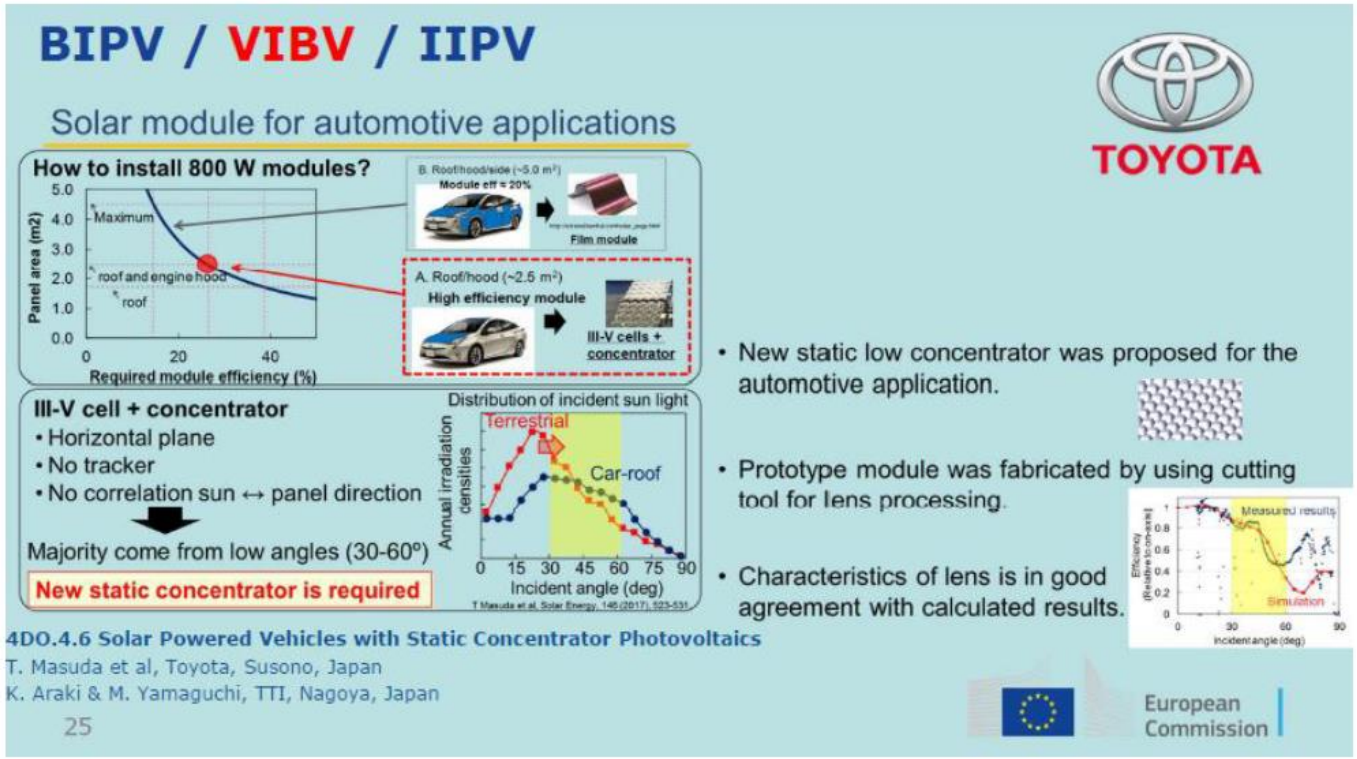
New market of the super-high-efficiency solar cells



A highlighted topic of the most-recent world conference of PV (EV-PVSEC in September, 2017)

Innovation: High-efficiency PV on the car-roof → Solar-driven car

Merit: 70 % of the car (< 30 km/day) will be replaced → 8 % cut of GHG emission

Requirement: More than 30 % of efficiency

Simply multiplying 70 % to the annual sales of the car, the market size will be 50 GW/yr

Solar-driven car will create a new industry and change our society.

Solar-driven cars

70 % of the cars, 50 GW/yr of the new creation of the market, 8 % reduction of GHG emission.

Market of the car-roof PV, now and future

180 W Si module

1 kW high-efficiency module

Saving cycles of electricity charge

Driven by the solar energy

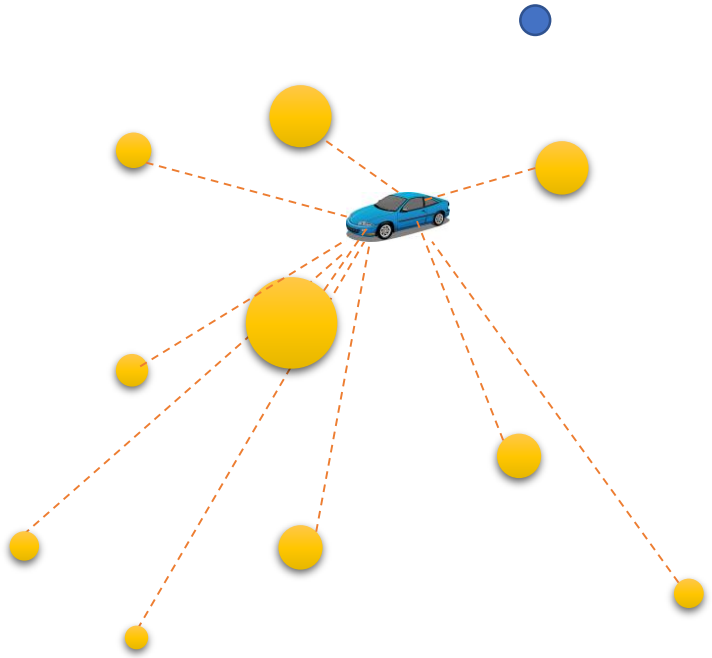
Efficiency and energy is not critical.
Driver will be satisfied if the PV fills the battery during parking.

Both efficiency and energy yield are critical.

Beside the panel performance, smart control and accurate prediction of the energy yield will be required

Data from stations

GHI, DNI
Atmospheric parameters (fitted from spectrum data)
Position of the station
Local weather forecasts

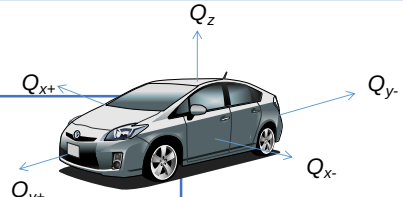


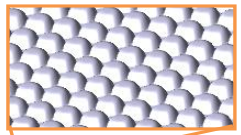
Data acquisition by the car

GPS/Gyro (Position, direction, and speed)
Map data (position and shading prediction)
Drive recorder (Shading prediction)
Battery status

Energy prediction

Removal of outliners and NaN
Auto-correlation & cross-correlation
Weighting factors by relative position
Spectrum prediction
Irradiance prediction





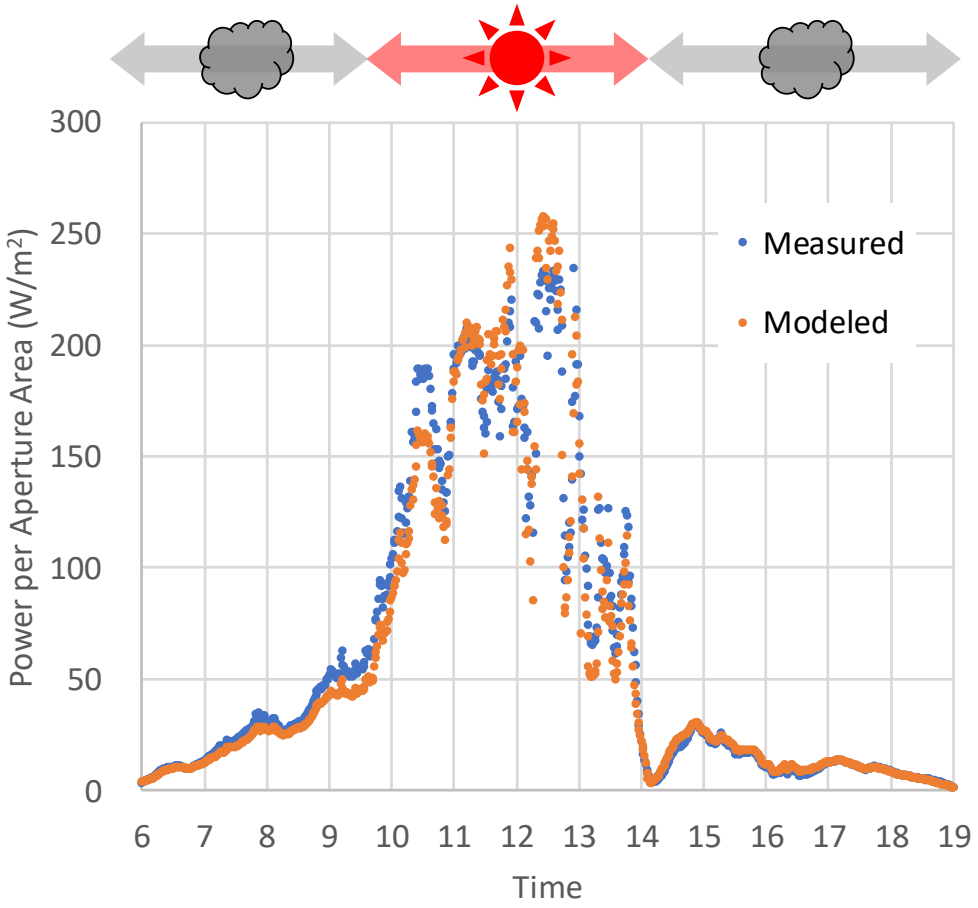
Energy info. management

Smart advice to the driver
(necessity of stopping to the station etc.,)

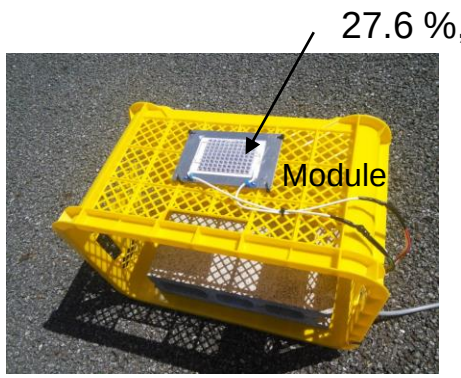
Required technology relevant to this workshop.

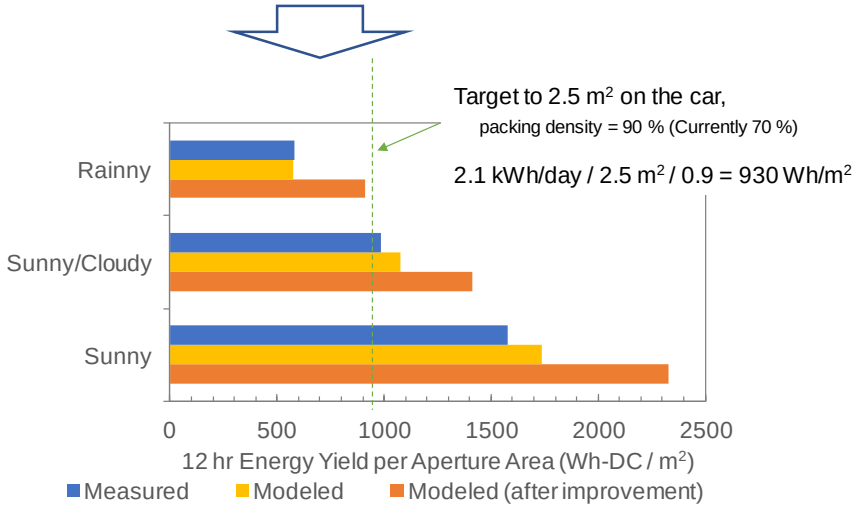
1. Irradiation on the car-roof as well as car-sides
    1. Modeling GHI relative to the GHI on the roof-top
    2. Dynamic modeling incl. shading and reflection by surrounding buildings and roads
    3. Direct measurement and its comparison to the roof-top irradiation
    4. Shading prediction by the image from the drive recorder
2. Spectrum prediction of the spectrum (to MJ cells)
3. Power output prediction from the car-roof array.
    1. Correction by the partial shading
    2. Correction by the curved surface (incl. mismatching)
    3. Power generation modeling and its measurement proof
    4. Modeling of unwanted days (not clear sky)
4. Interpolation and autocorrelation using multiple observation points
5. LCO –km
    1. Definition and measurement proof
    2. World database
6. Standardization
    1. DOT
    2. IEC standards

Development of the energy model is on the way, but it is in the good shape.



Outdoor validation of the model by a **prototyped** high-efficiency module

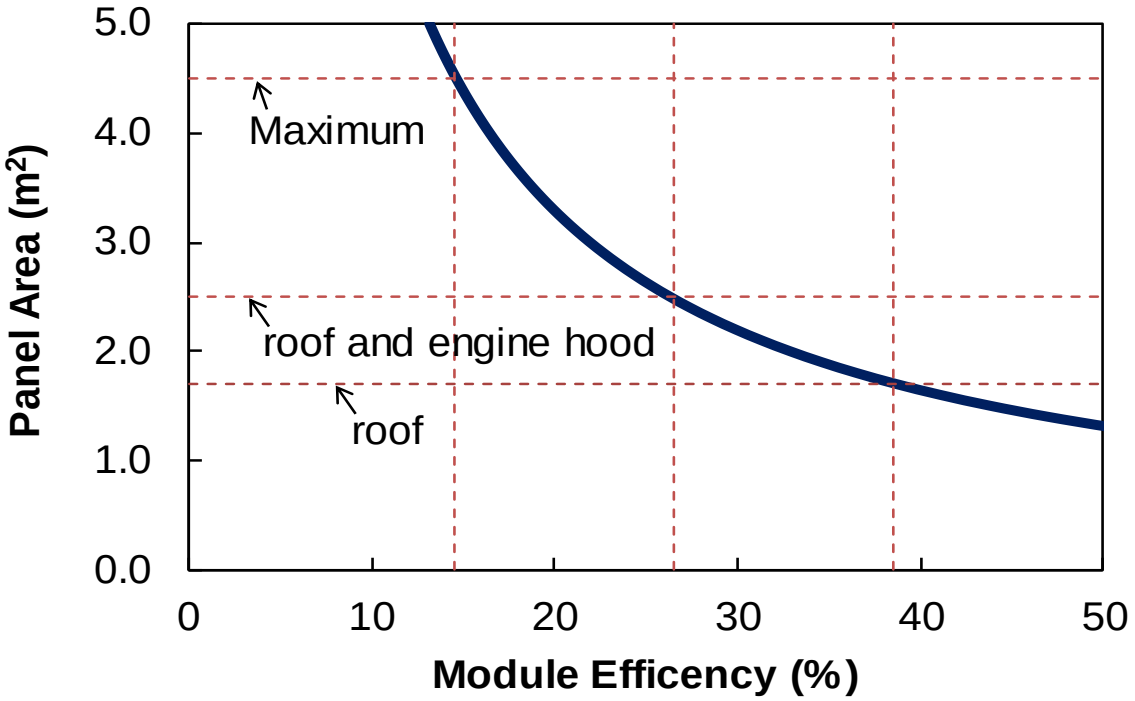




Presented at the 27th PVSEC in three weeks ago.

Most of the solar cells have reached almost the potential limit. Most of the solar cells do not meet the requirements.

Minimum requirement = 30 % considering real-estate, irradiation and car-design.

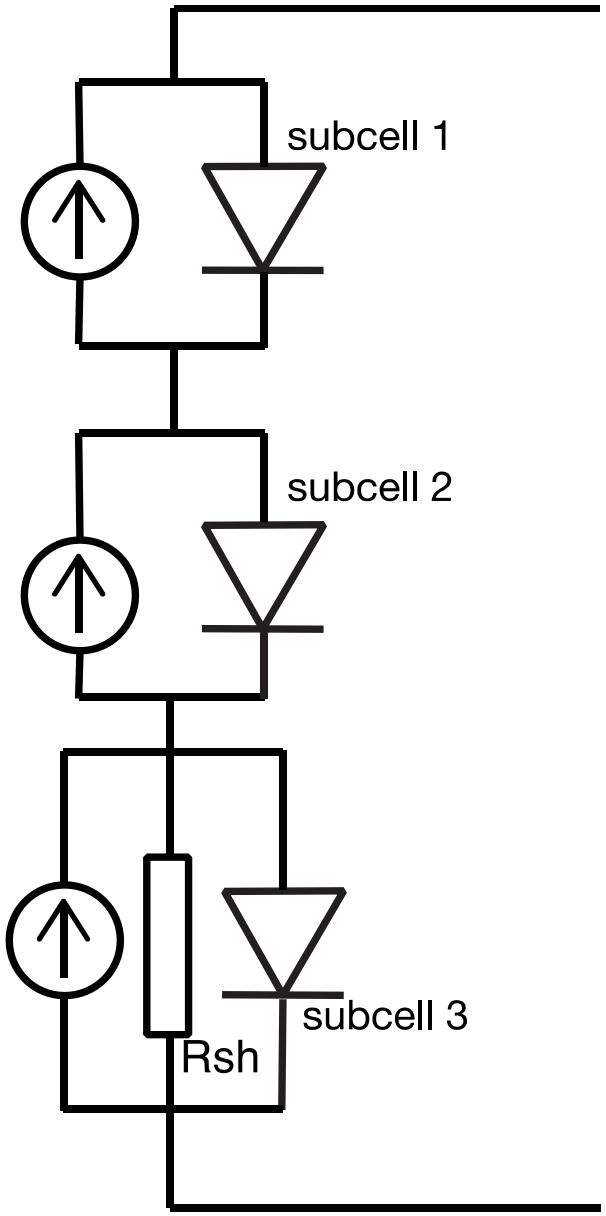


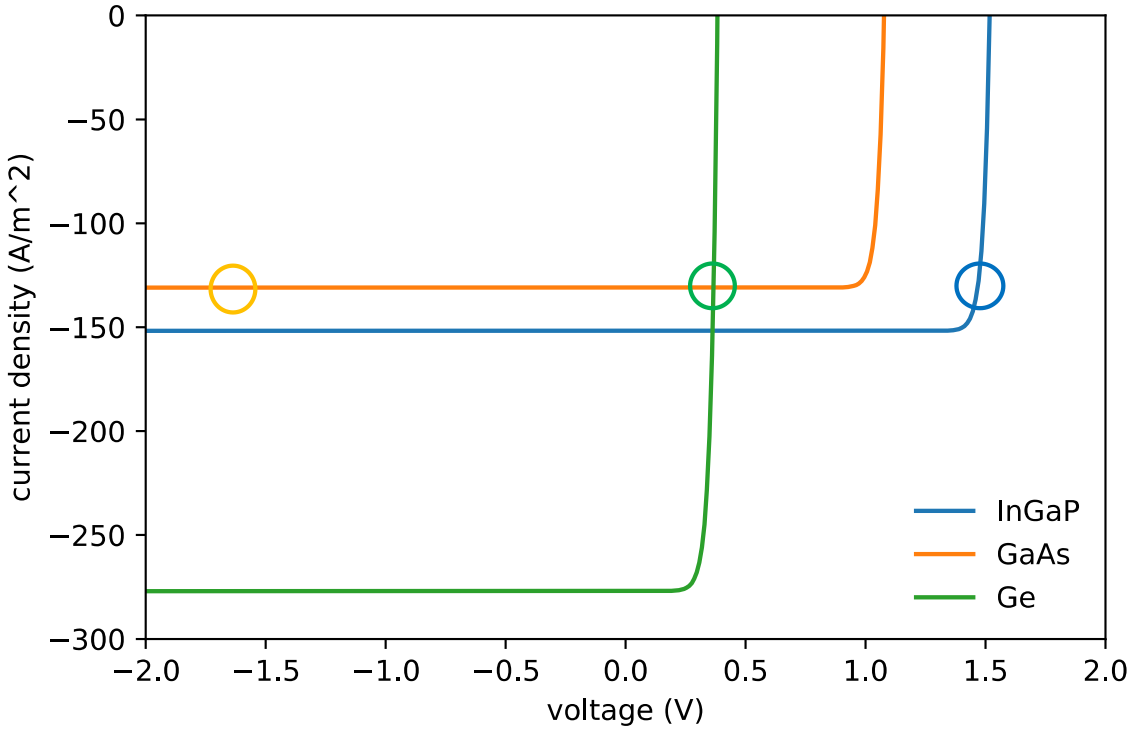
	Potential	Achieved
Si	28.5 %	26.7 % (94 %)
III-V (GaAs)	29.7 %	28.8 % (97 %)
III-V (3J)*	42 %	37.9 % (90 %)
III-V (5J)*	43 %	38.8 % (90 %)
III-V on Si	38.0 %	35.9 % (94 %)
CIGSe	26.5 %	22.6 % (85 %)
CdTe	26.5 %	22.1 % (83 %)
QD	25.8 %	13.4 % (52 %)
Perovskite	24.9 %	**22.1 % (89 %)

* Non-concentrator
** Not stabilized

Only MJ cell can meet the requirement.

Output current is constrained by the “bottle-necked” junction





What is Jsc of this multi-junction cell?

Hint: Can you find a solution that satisfies $V_1(J_1)+V_2(J_2)+V_3(J_3)=0$ and $J_1=J_2=J_3$?

Spectrum issue

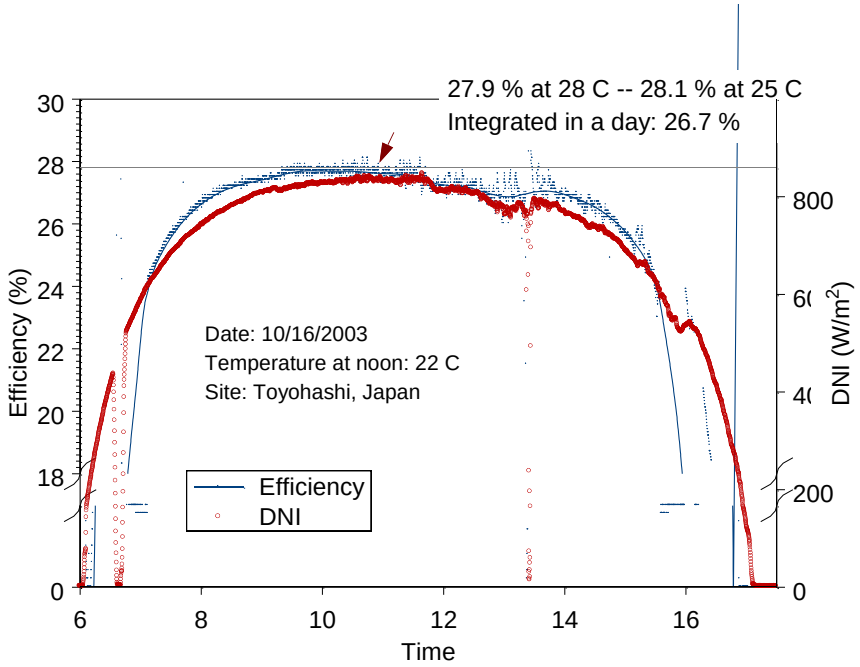
Rating or Prediction?

History of the spectrum recognition to high-efficiency MJ cells

1997 Low concentration of 2-J III-V cells were tested outside in USA. Kurts and her group recognized the CA of the optics induced the spectrum mismatching loss.

2002 It was calculated that the increase of the number of junctions will not promise to increase the annual energy yield.

2003 28 %, 400 X and 150 W module was demonstrated and significant spectrum mismatching loss was reported.



This module is still monitored and generating power in Tsuyama National Institute of technology, Japan and possibly the oldest living CPV III-V module.

History of the spectrum recognition to high-efficiency MJ cells

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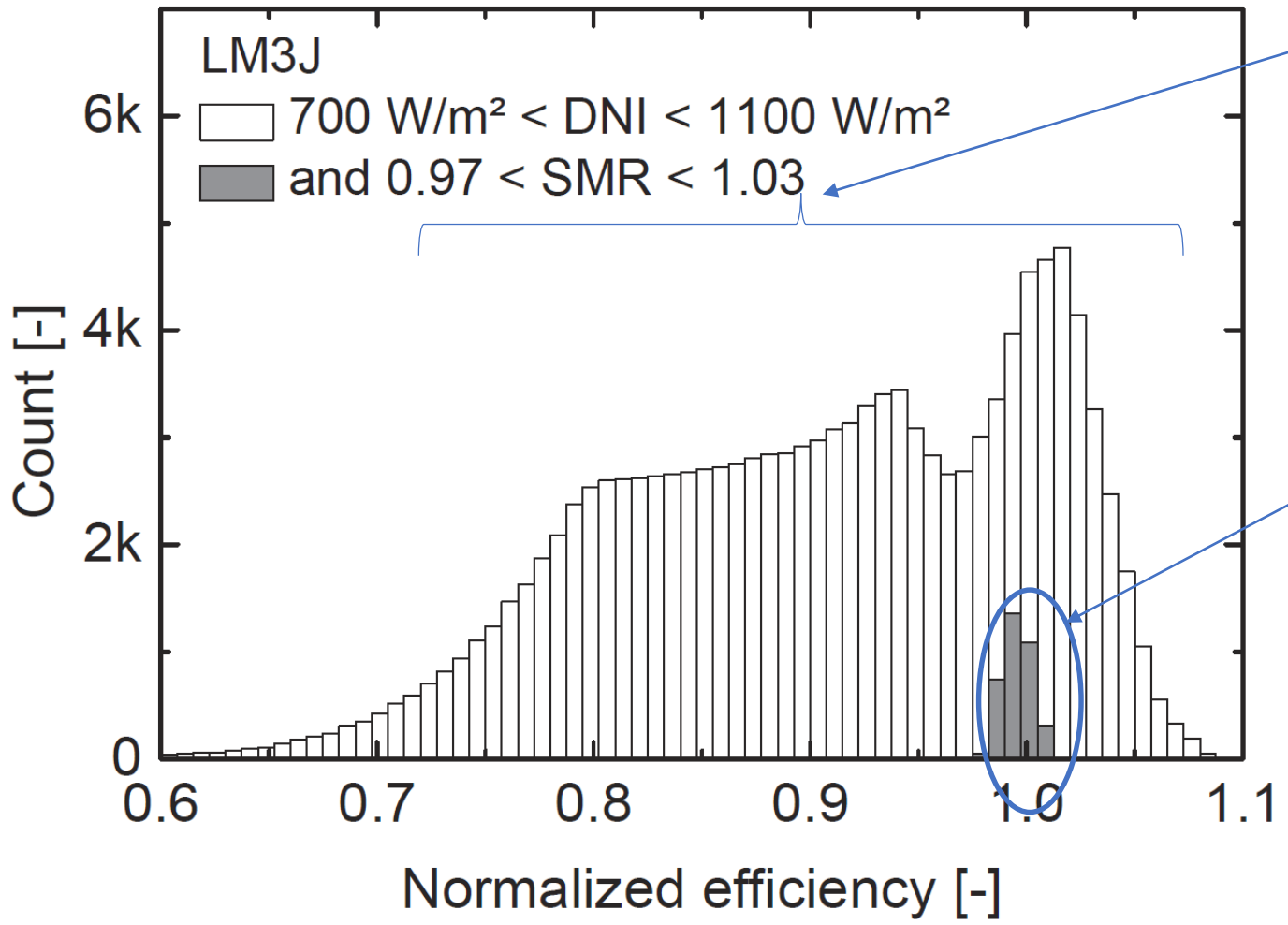
2002 It was calculated that the increase of the number of junctions will not promise to increase the annual energy yield.

2003 28 %, 400 X, 3J and 150 W module was demonstrated and significant spectrum mismatching loss was reported.

3J cell rather than 4J cells in research phase → Quick deployment of CPV

After field experiences of CPV power plant, the spectrum issue became the common knowledge. But the most of the studies was done only considering AM using a standard air conditions, except for the work of Chen in Imperial College.



Our new approach

(Energy prediction)

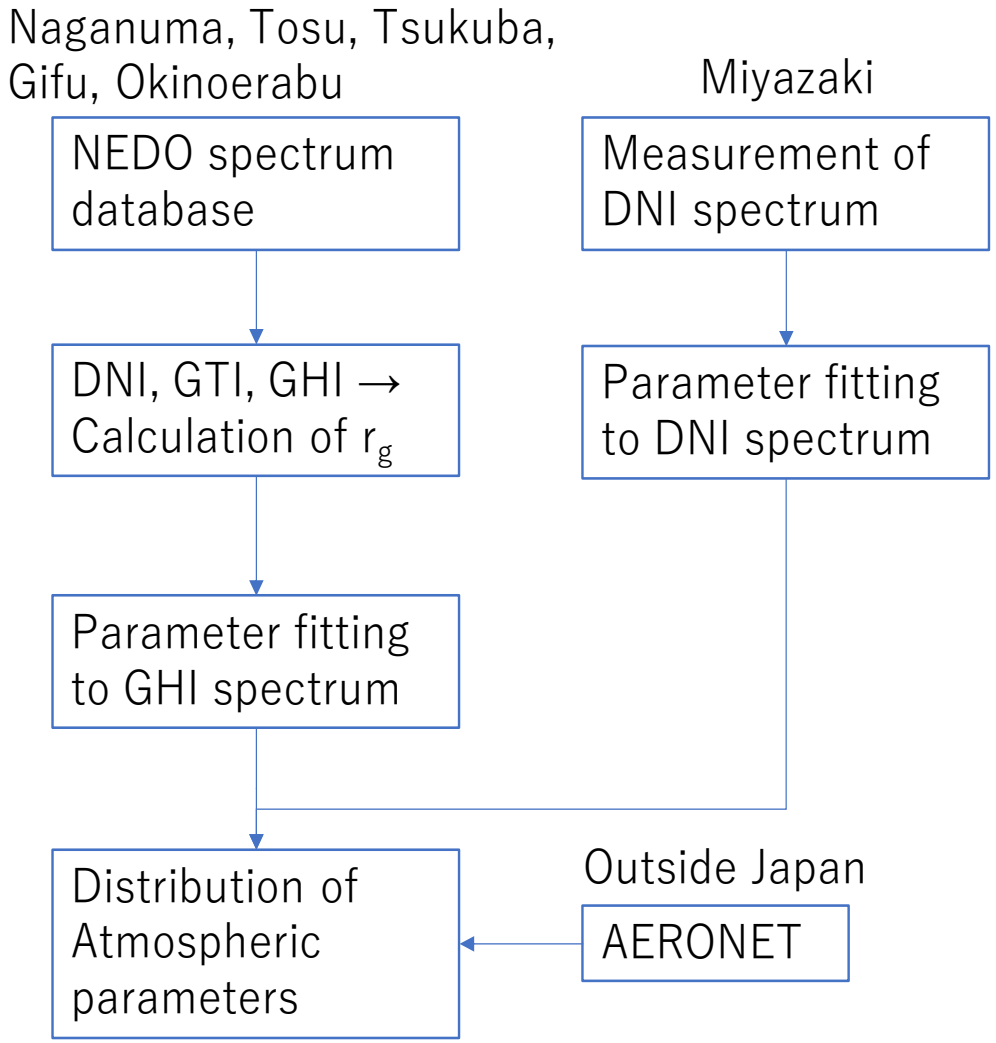
Integration of the predicted power in every time, regardless it is an unwanted spectrum for measurement

Previous interests

(Performance rating)

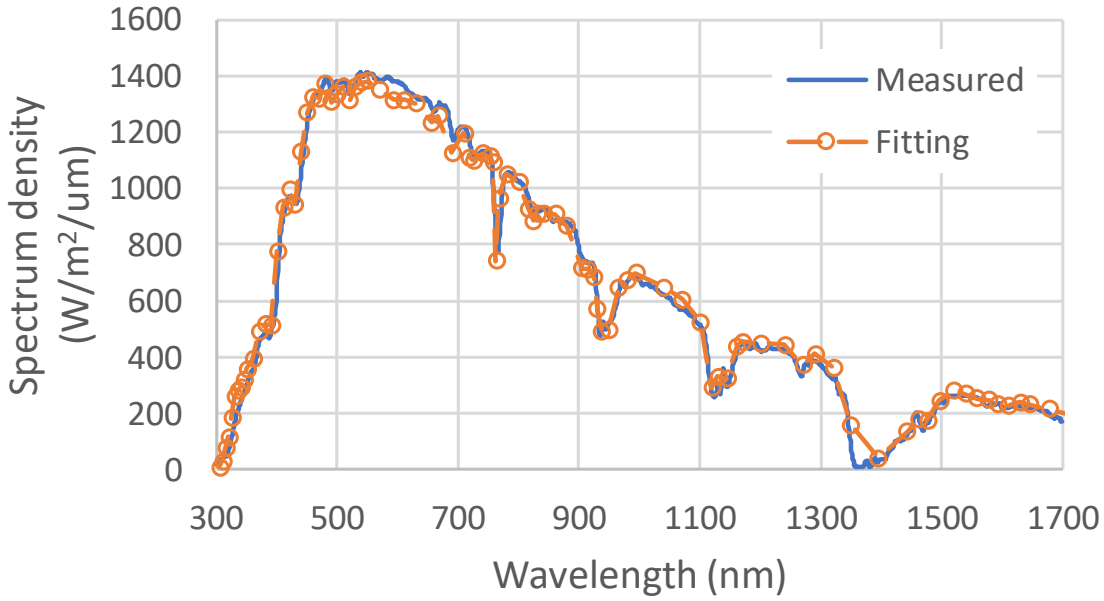
Trying to find a good “shape parameter” of the spectrum for removing uncertainty of the power measurement

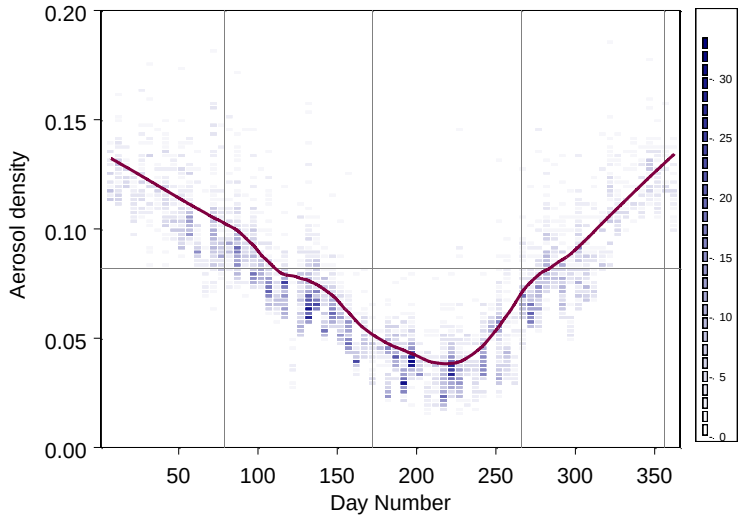
Our approach – Identification of parameters



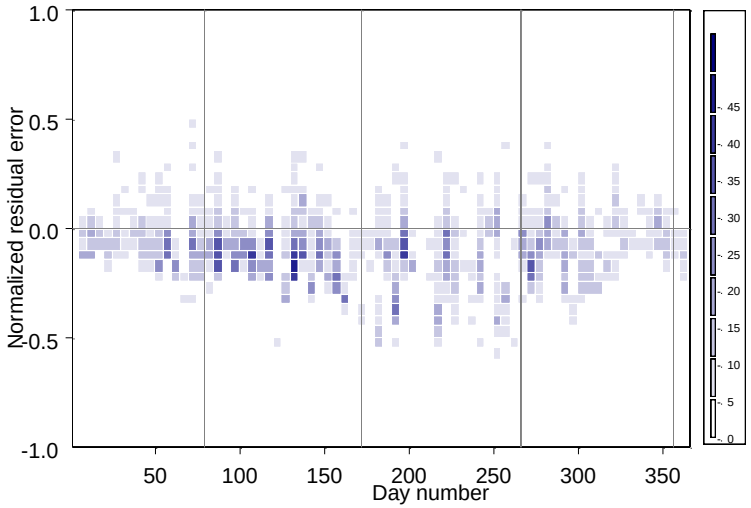
Target:

Not by the “Shape parameters”
But by the “meteorological and reproducible parameters”.



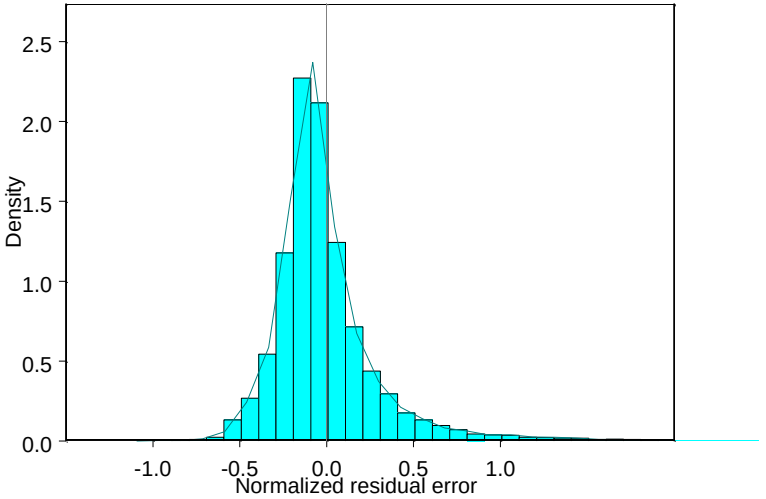


Fitting and smoothing by segmented polynomials using the local least square error method

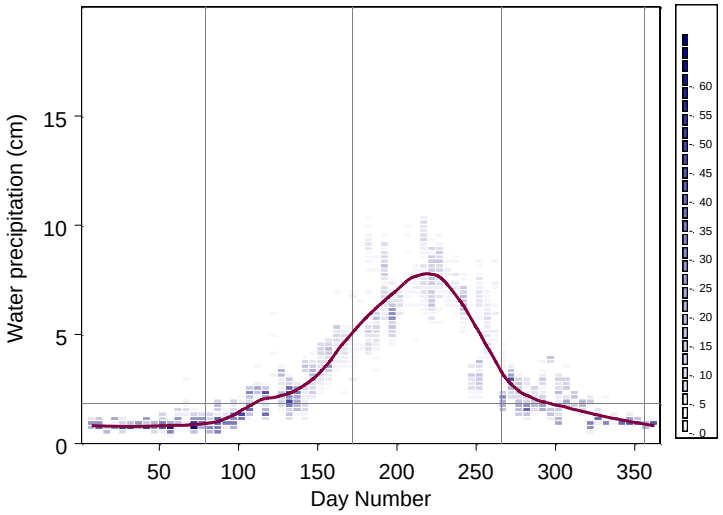


Time-series trend of the normalized residual errors

Although, slight skewness and biasness remain, the fluctuation of the air optical parameters can be modeled by a random number distributed by the normal distribution around the seasonal trend.



Histogram of the normalized residual errors



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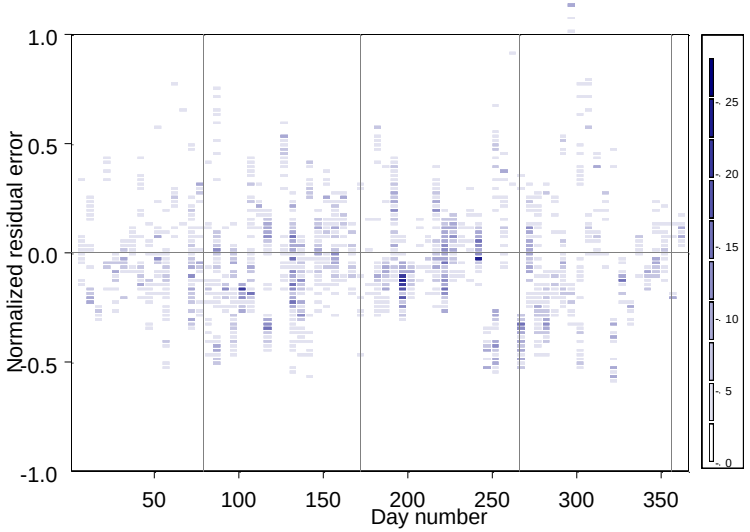

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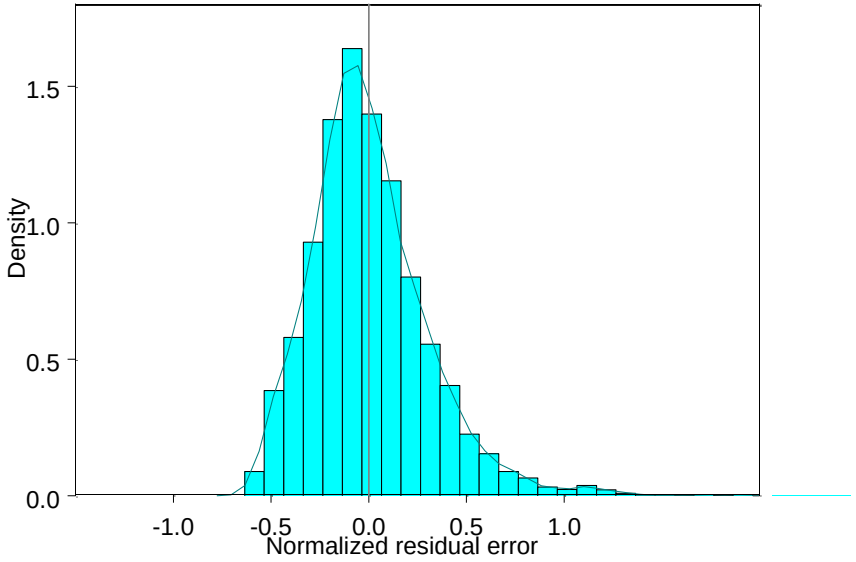
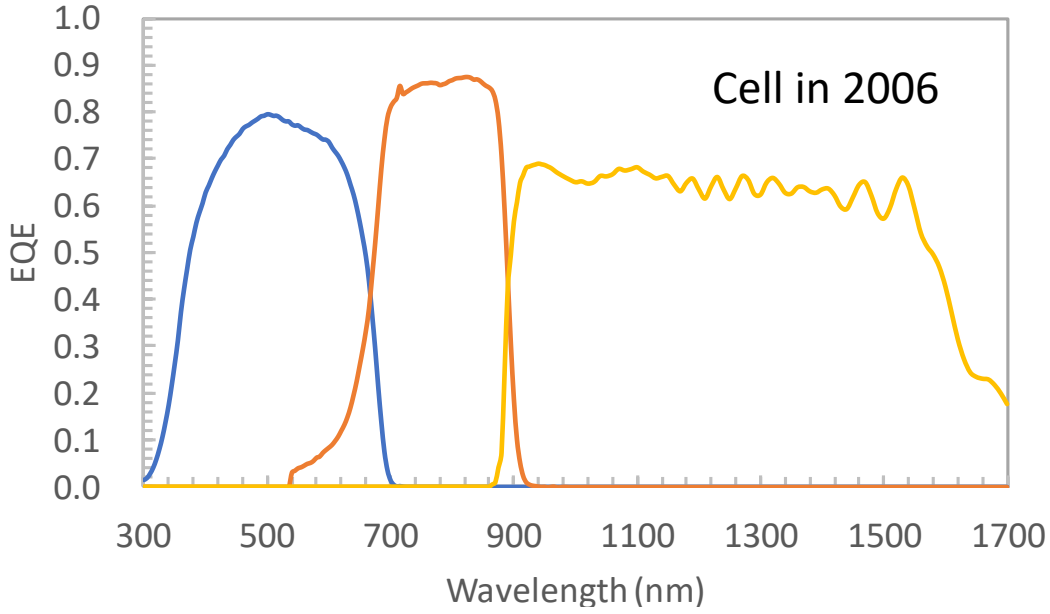
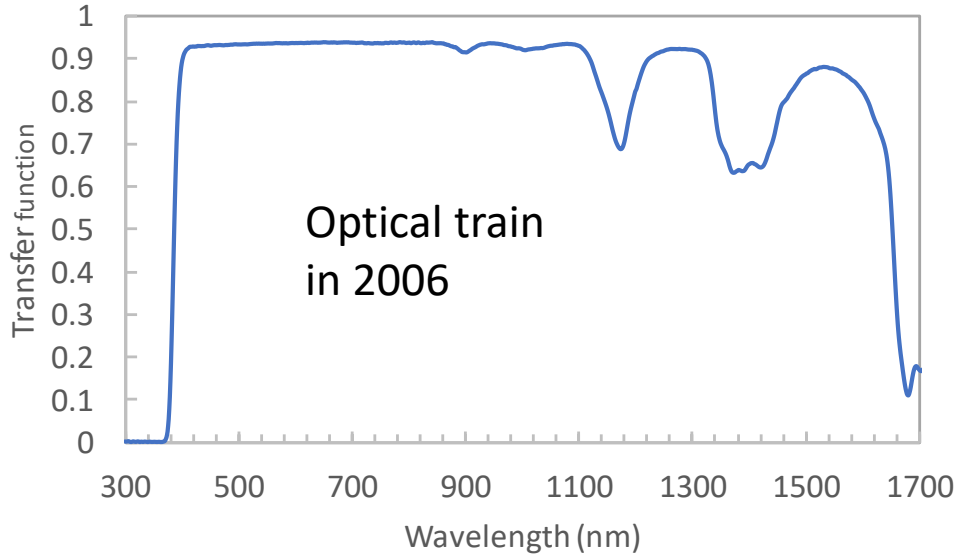
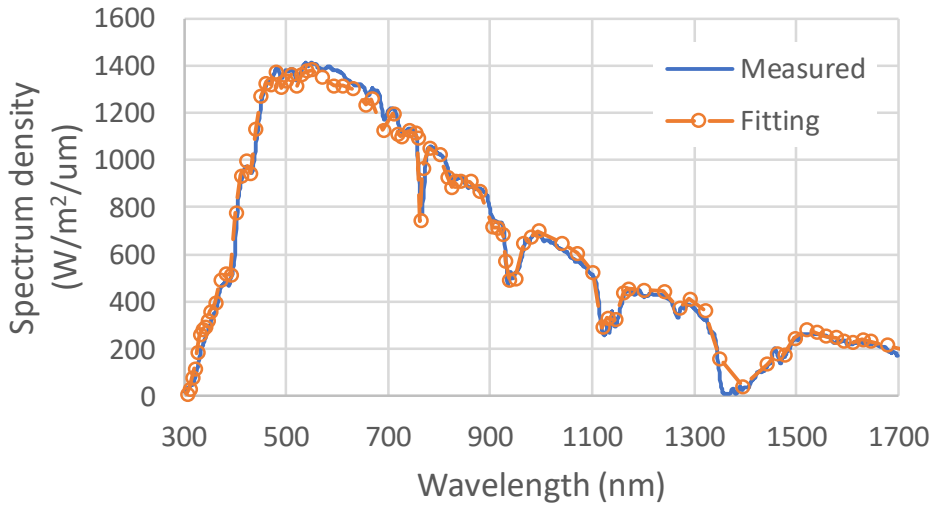


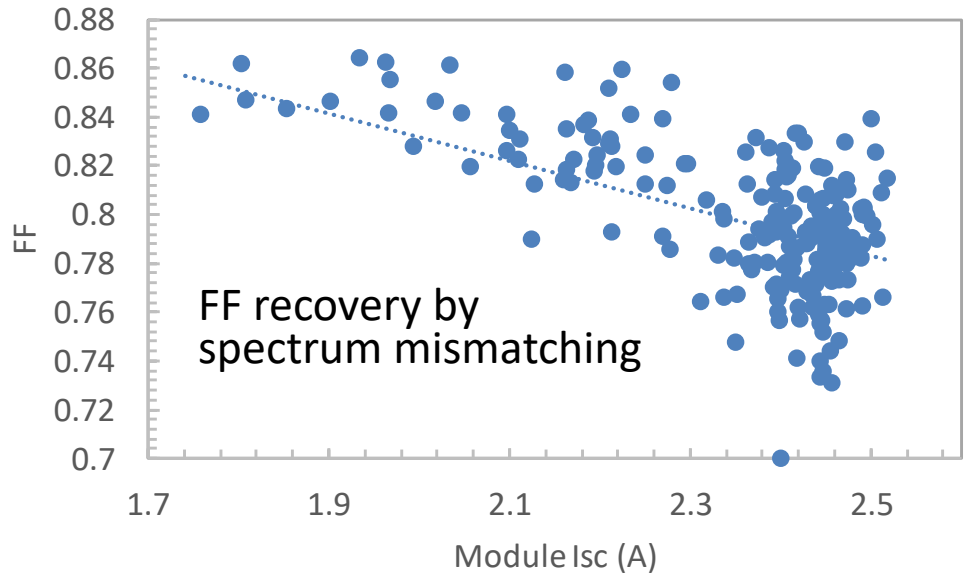
Histogram of the normalized residual errors

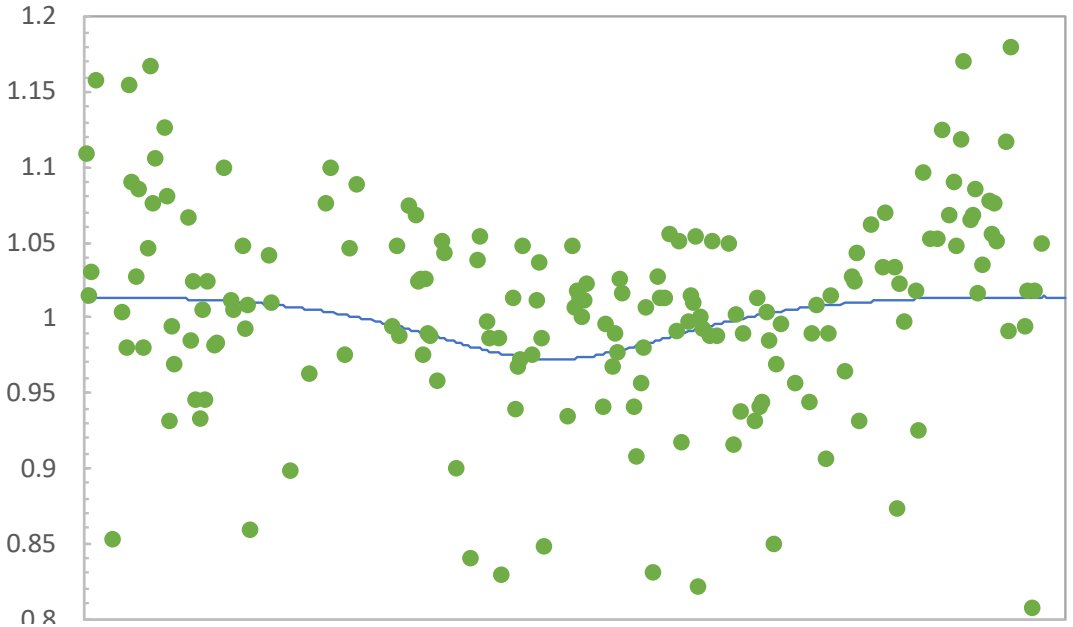
Other information for examining uncertainty of the energy generation influenced by spectrum fluctuation

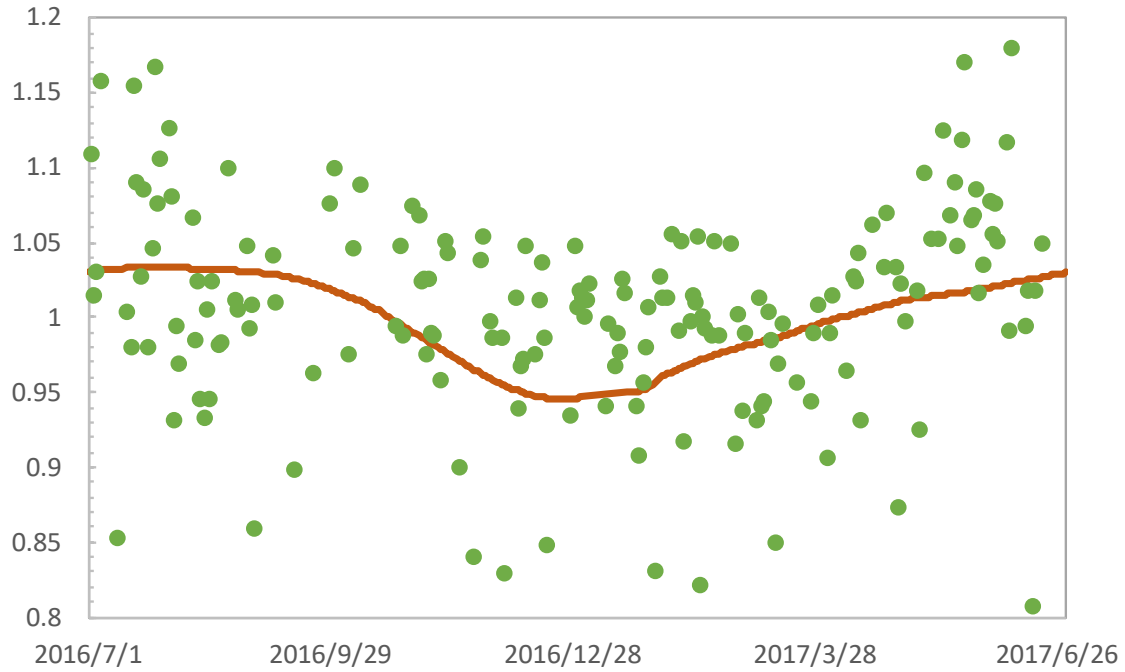


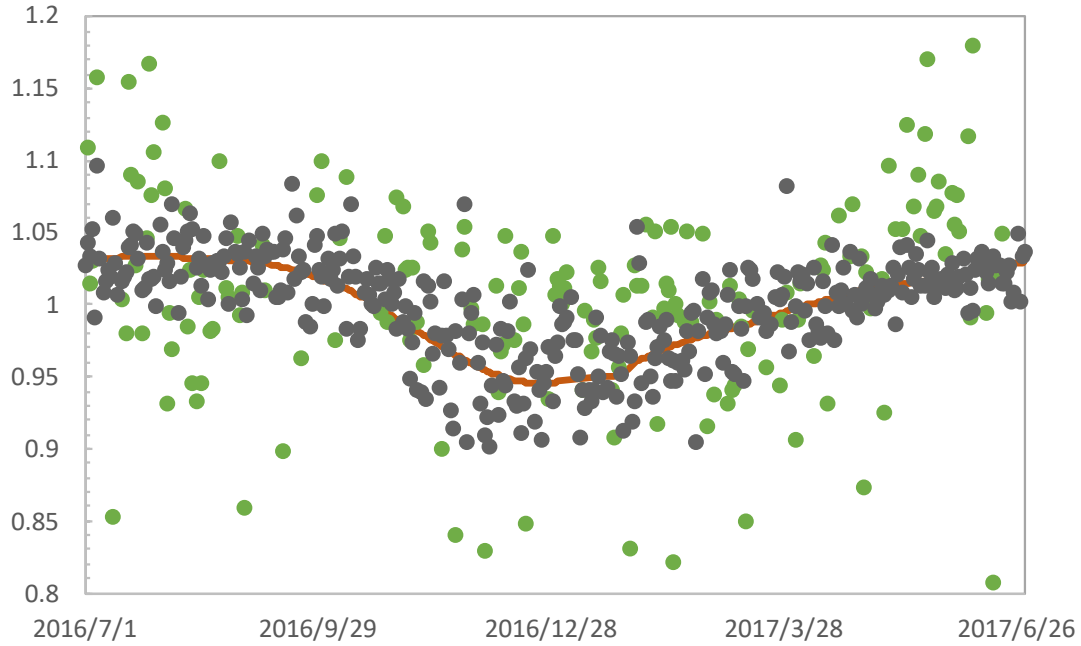








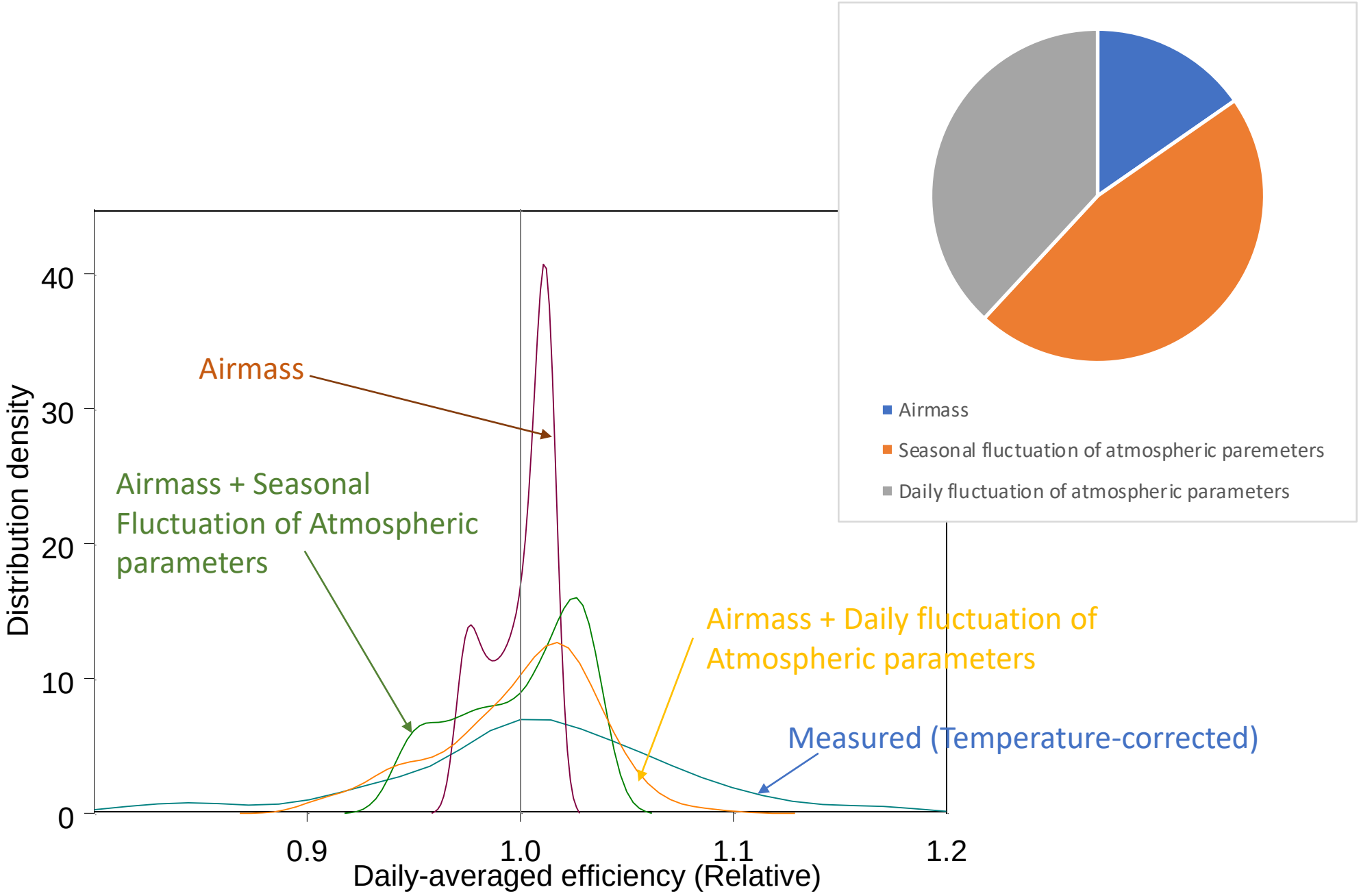




Only Airmass

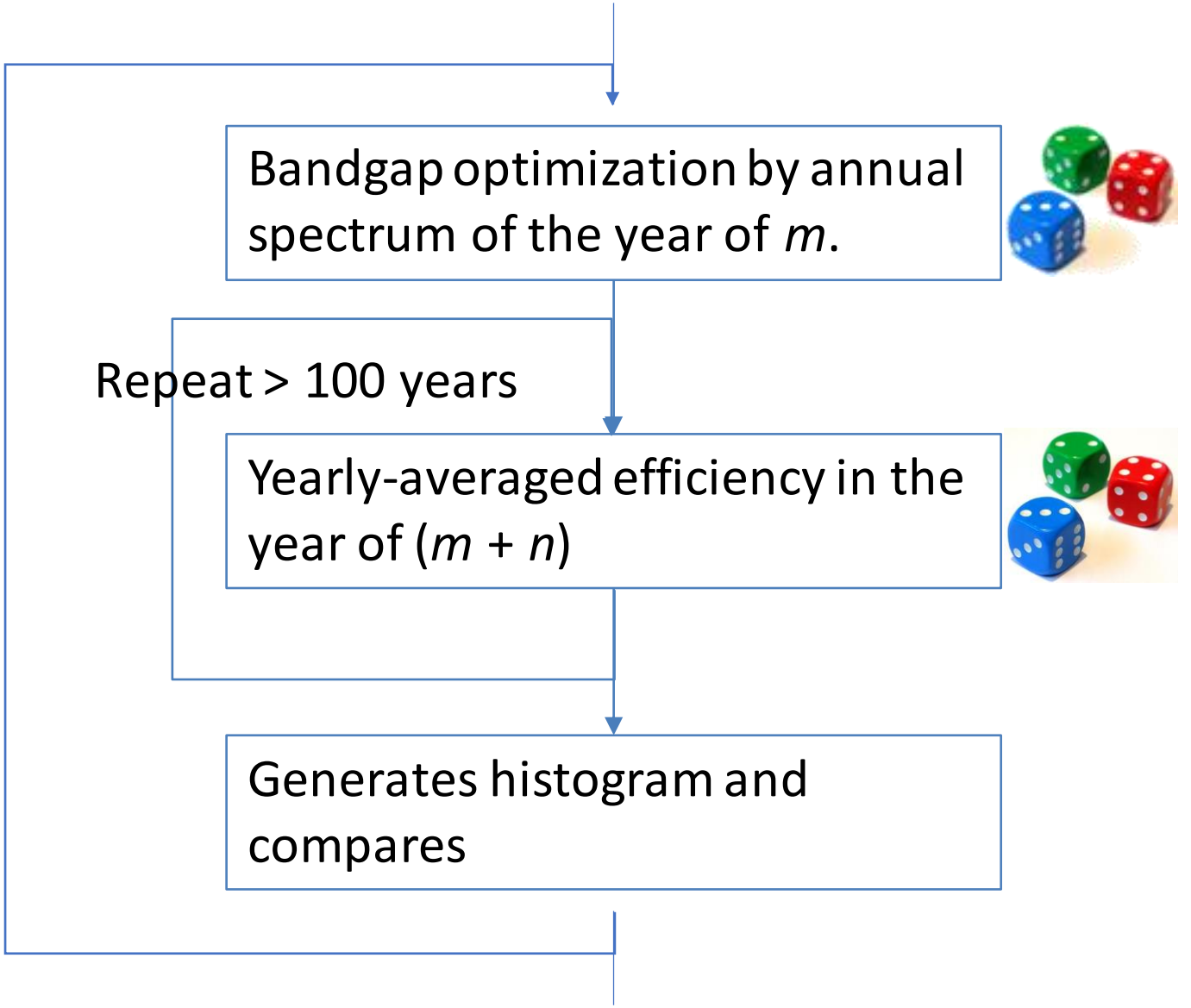
Airmass + Seasonal fluctuation

Airmass + Daily fluctuation

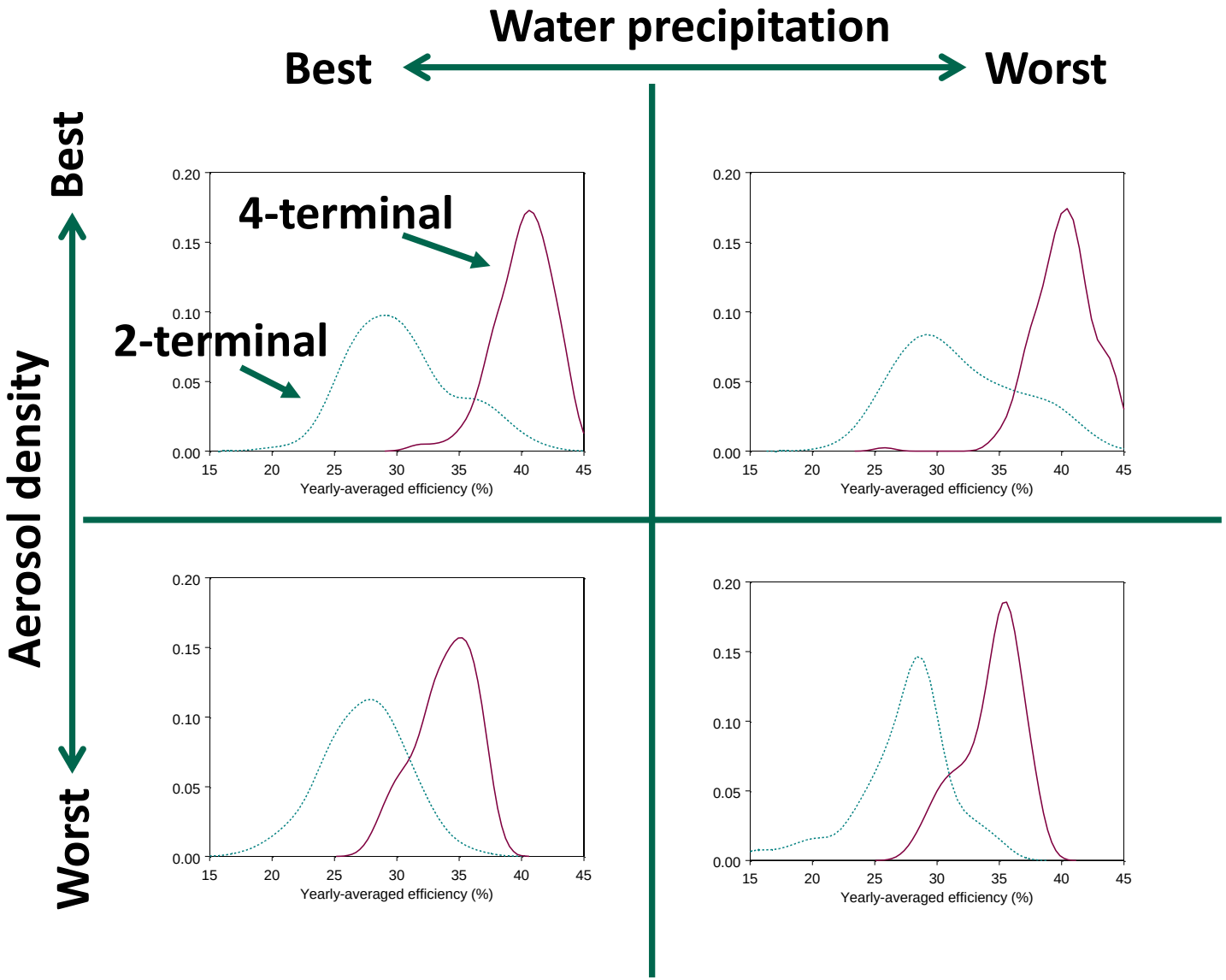

Airmass
Seasonal fluctuation of atmospheric paremeters
Daily fluctuation of atmospheric parameters
Airmass
Airmass + Seasonal Fluctuation of Atmospheric parameters
Airmass + Daily fluctuation of Atmospheric parameters
Measured (Temperature-corrected)
Distribution density
0
10
20
30
40
0.9
1.0
1.1
1.2
Daily-averaged efficiency (Relative)

Application of the spectrum prediction.

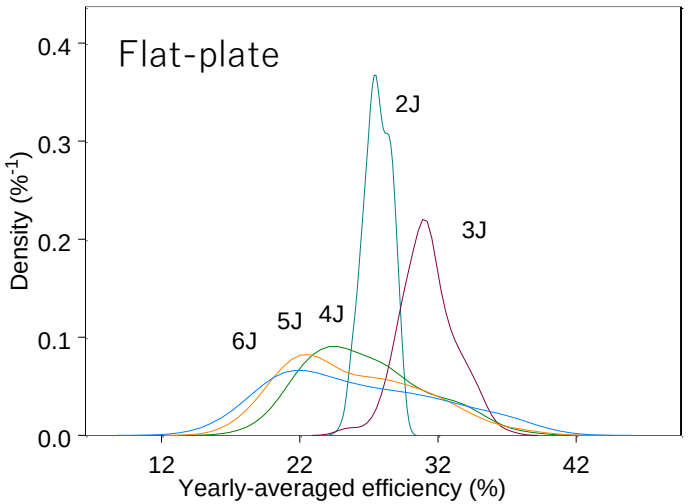
Monte-Carlo method to predict spectrum influence

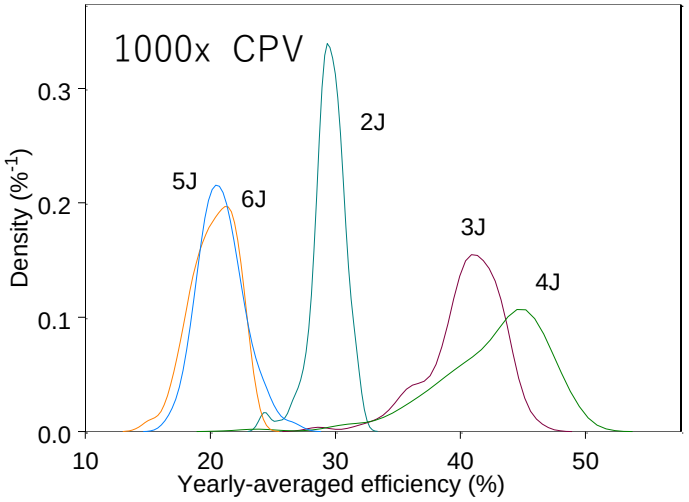


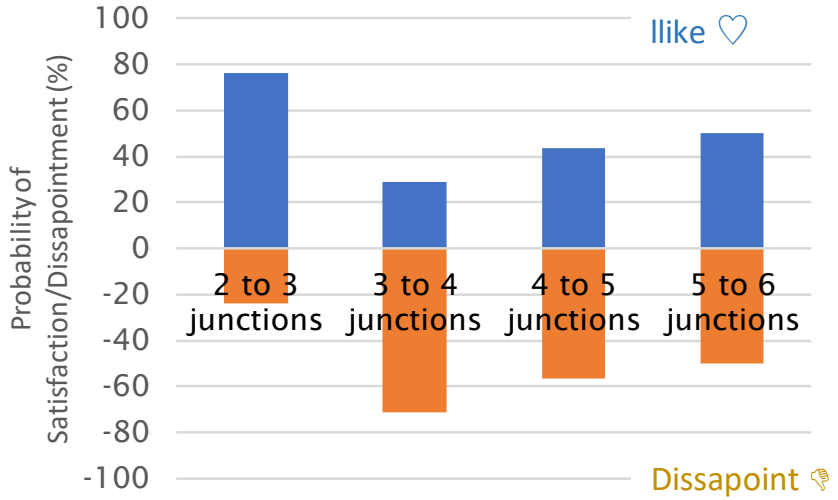
On-Si tandem, 2-terminal or 4-terminal

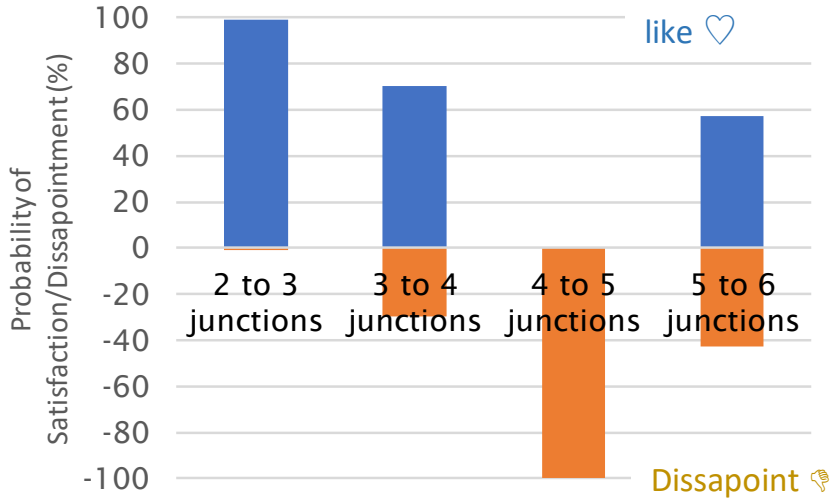


Which is the best number of junctions?





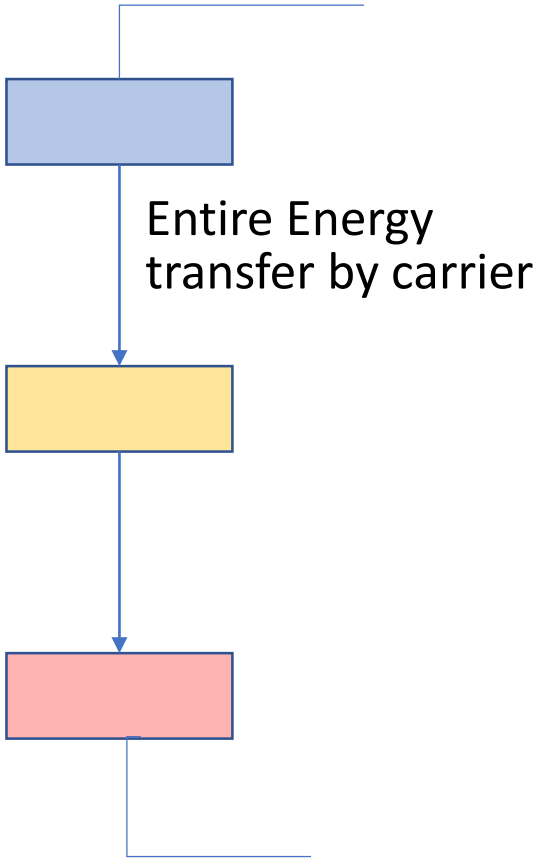




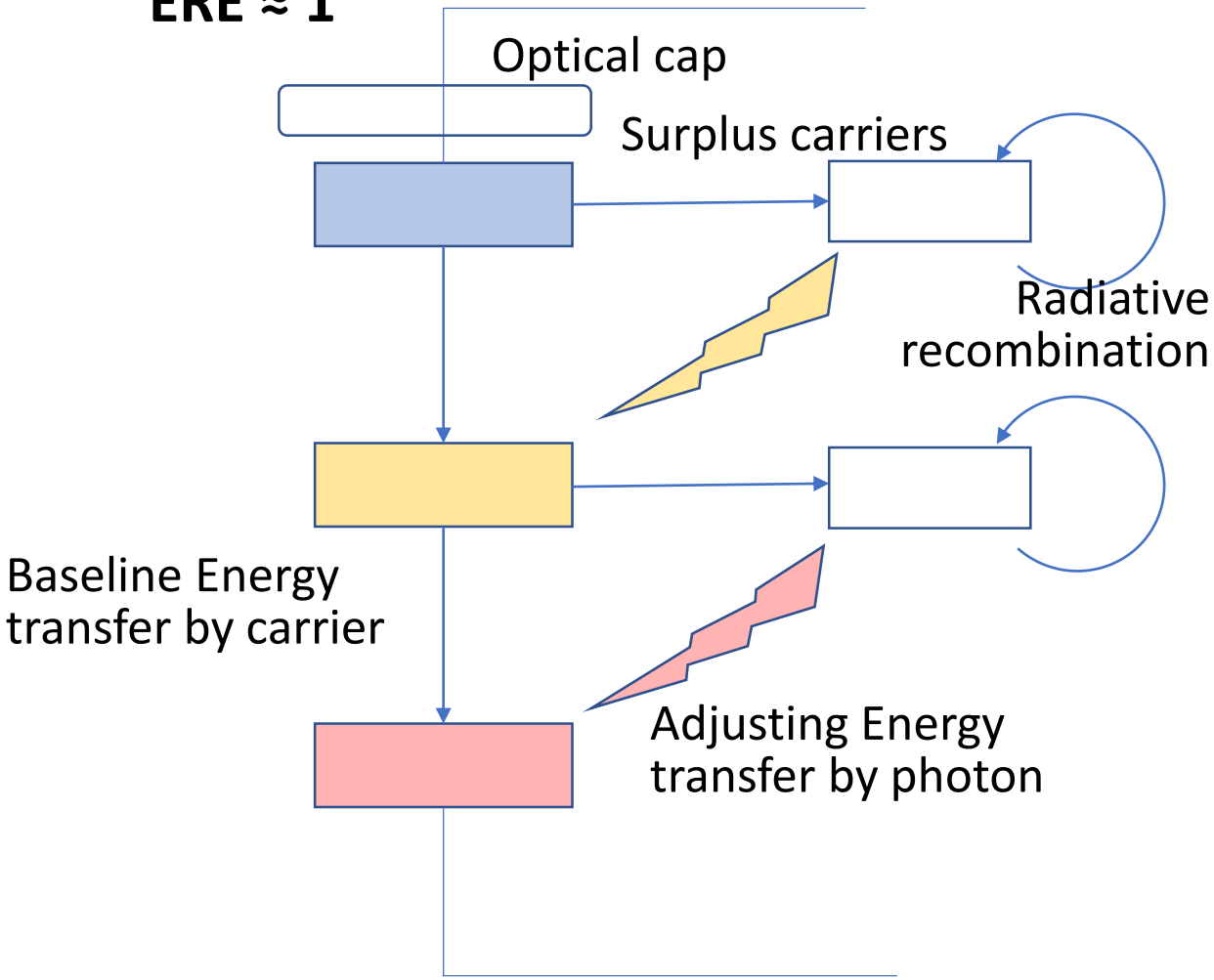
Improved ERE material will lessen the spectrum impact

MJ → Super-MJ

ERE ≪1



ERE ≈ 1



Invitation to the international collaboration of R&D to the game-changing car-roof PV technologies.

Highlights

PV for Transport: a logical evolution

The decrease of PV system prices is now becoming so visible that it starts to influence decisions in the energy sector. With the cost of PV electricity going below 0,02 USD/kWh in extremely sunny locations, PV will become in the coming years the cheapest energy (and not only electricity) source of electricity for new plants. This already starts to influence energy consumption sectors such as the building and transport sector. The shift towards electricity for heating and transport materializes already the need for cleaner energy but it hasn't yet incorporated the PV-effect. With cheap PV electricity available at mid-day (or later thanks to cheaper-than-ever storage), the pressure to use that available energy will grow in the coming years. It can be expected that the shift to electricity will be at least accelerated and most probably

What We Do

The **IEA Photovoltaic Power Systems Programme (PVPS)** is one of the collaborative R&D Agreements established within the IEA and, since its establishment in 1993, the PVPS participants have been conducting a variety of joint projects in the application of photovoltaic conversion of solar energy into electricity.

Invitation to the international web meeting for standardization of the car-roof PV

Background: IEC TC82 seriously considers the standardization of the car-roof PV. Before official organization is consolidated, I will call for the preliminary web meeting inviting academic, PV and car industries.

Purpose: Establishment of the common language between car and PV industiries for standardization of the car-roof PV technology, like the standardization of BIPV (PV and architecture industries).

Questions: Rating of the curved PV, Definition of aperture, Definition of the acceptance angle, Qualification and safety, Effective irradiation on the car-roof, Irradiation on the car-surface (Local coordinates), and etc.,

If you are interested in and eager to contribute

Send me the mail for the invitation letter.

cpvkenjiaraki@toyota-ti.ac.jp

取法乎上 得乎其中
取法乎中 得乎其下

Thank you for your attention.

Acknowledgments

Part of this work was supported by the Incorporated Administrative Agency New Energy and Industrial Technology Development Organization (NEDO) under the Ministry of Economy, Trade and Industry (METI).

I think we still have a large room of innovation.