Modeling on Unconventional PVs and Their Standardization – Curved Surface, Vehicle-Integration, Multi-Junction Cells, and Static Concentrators

Kenji Araki[1], Yasuyuki Ota[2], Kan-Hua Lee[1], Kensuke Nishioka[2], and Masafumi Yamaguchi[1]

1Toyota Technological Institute, cpvkenjiaraki@toyota-ti.ac.jp, Nagoya, Japan

2University of Miyazaki, Miyazaki, Japan

PV needs to grow diversity

VIPV
(Car-roof PV)

BIPV

Tracking PV

Low cost III-V
& tandem

PV modeling needs diversity

	Spectrum Prediction	3-D Curved Surface	Unwanted Orientation	Partial shading Loss
VIPV (Car-roof PV)	✓	✓	✓	✓
BIPV	✓	✓	✓	✓
Tracking PV				✓
Low cost III-V & tandem	✓		✓	✓

Can we rely on the golden procedure?

(irradiance with correction of temperature and IAM)

Yes, for the conventional installation, but …

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Possibly, NO for diversified new PV installation

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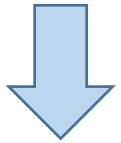
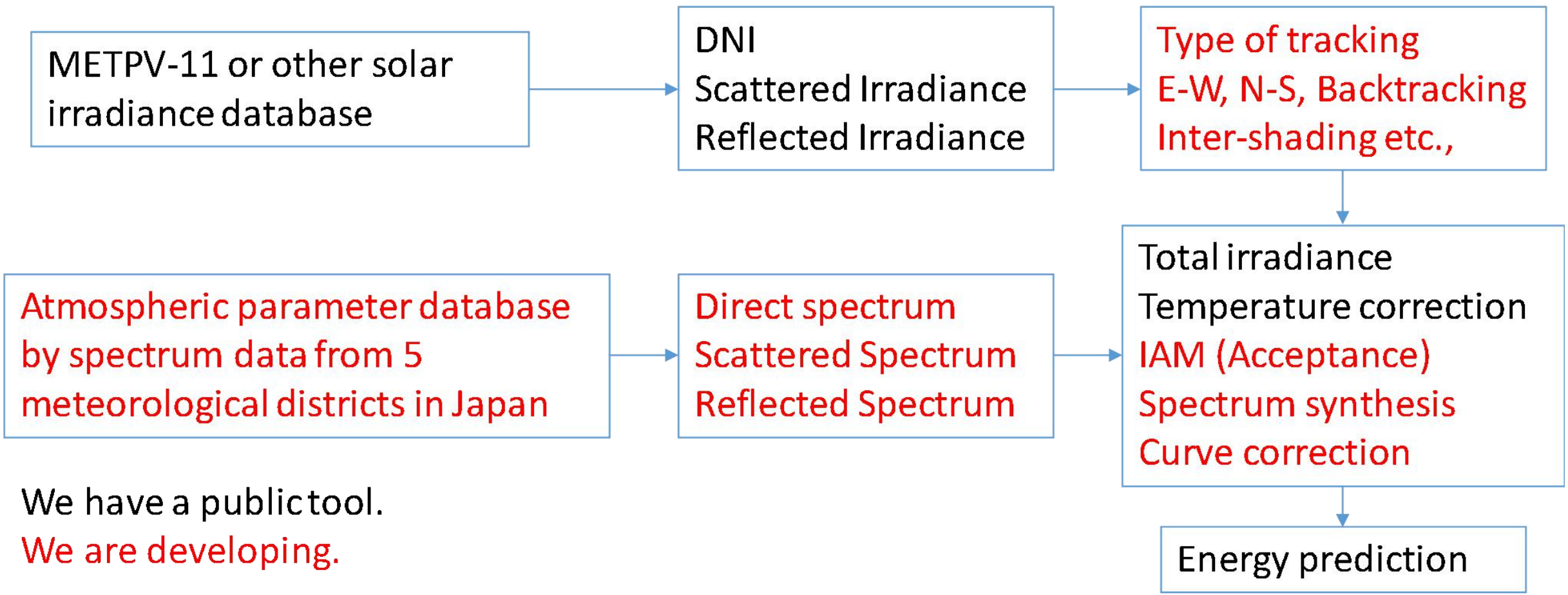


R&D of the new integrated model that can applied to every type of installation, including tandem cells.

VIPV and BIPV for ZEB require high energy yield under the unwanted operation and installation conditions (orientation, partial shading, colored PV and etc.), thus **tandem cells** will be preferred when the cost and other technological issues are solved.

Key parameters are dependent each other. For example, different IAM, different orientation means different mixture of the direct and diffused sunlight, and thus varies spectrum. This impact was unexpectedly huge in our observation (not in this presentation).

Basic model construction

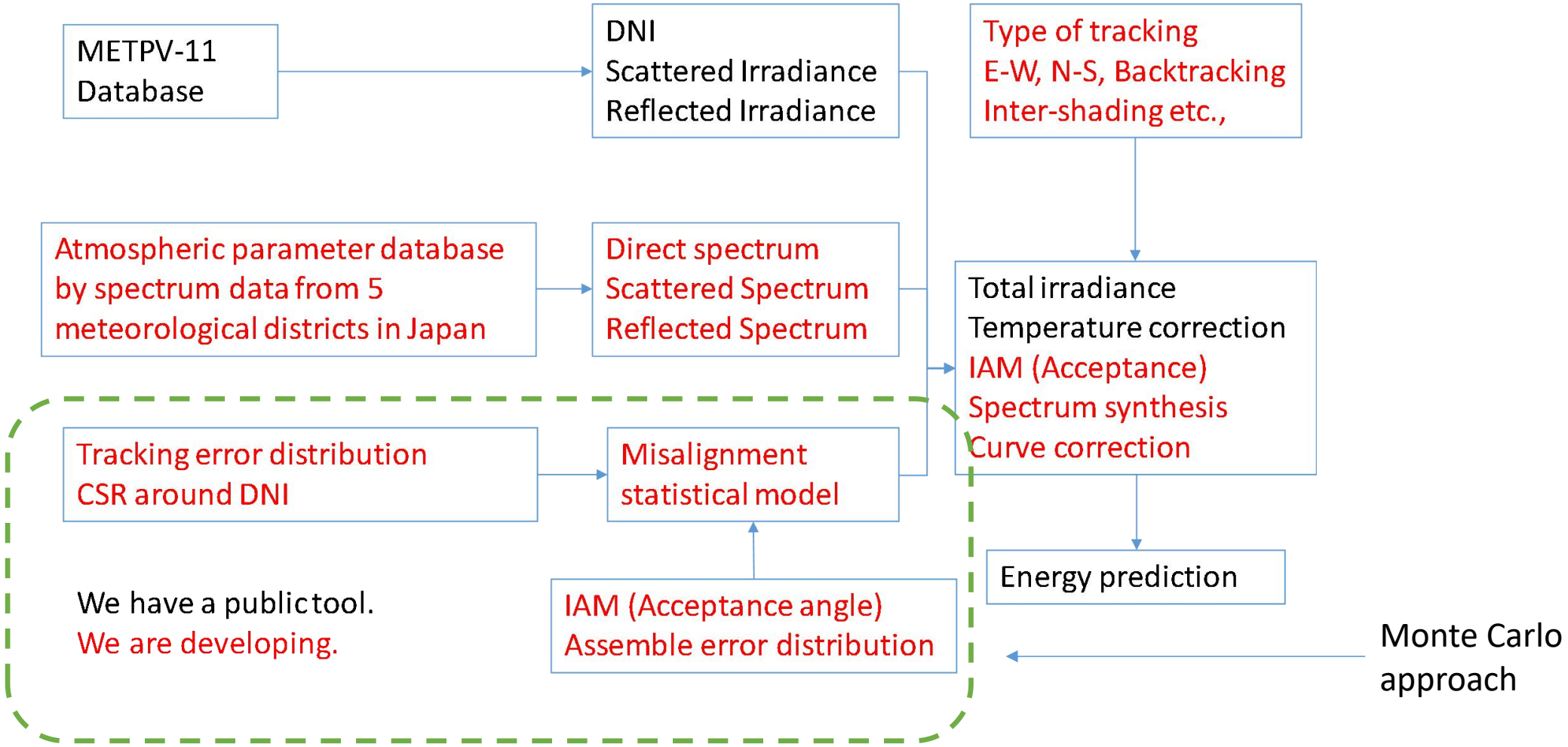


We have a public tool.

We are developing.

Option with unexpected and unwanted disturber (like CPV)

Modulation factor by Monte Carlo calculation

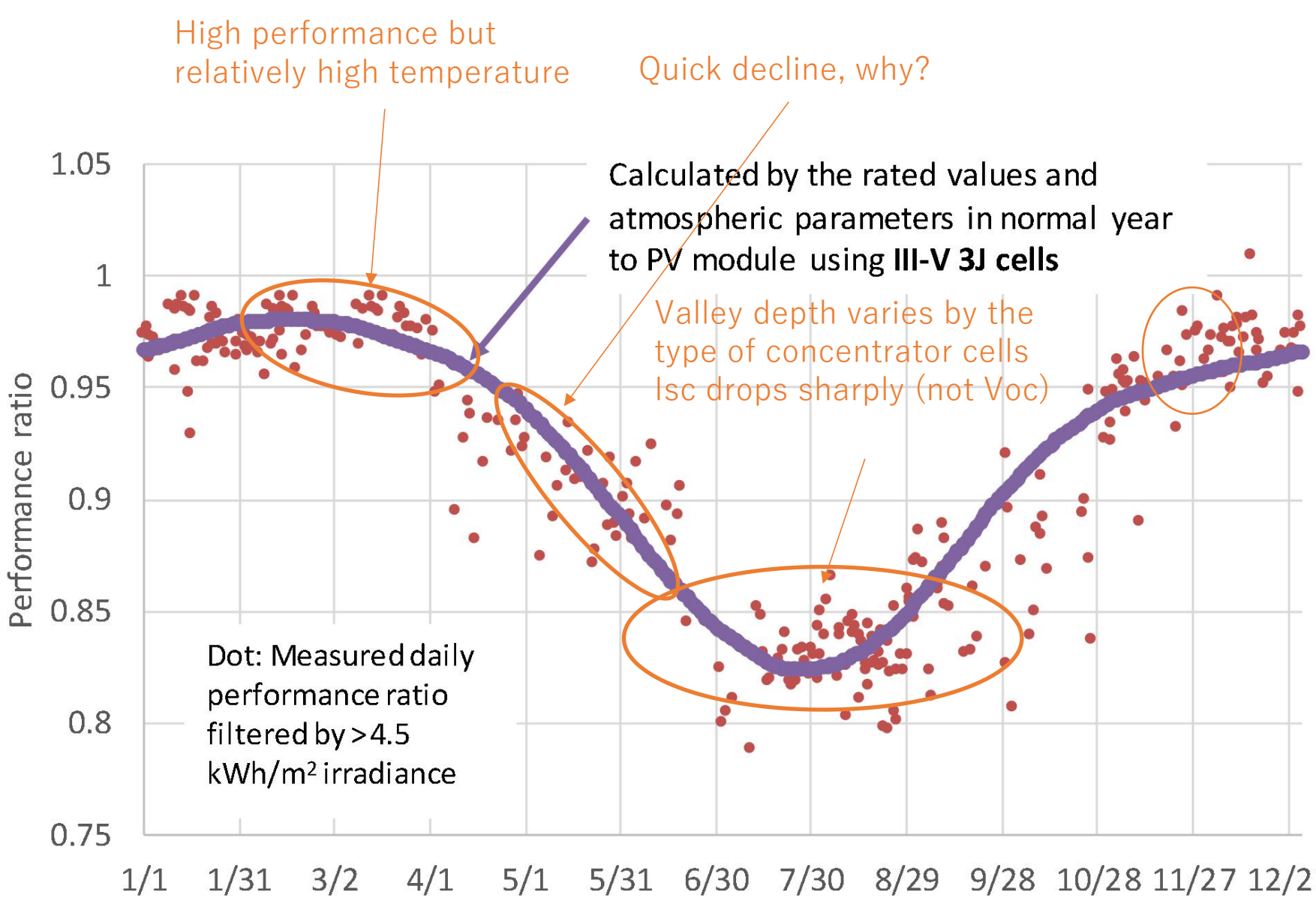


Achievement

Consideration on spectrum (water and turbidity-dependent) and IAM successfully, explained strange behavior of III-V multi-junction cells

PV module using 3J tandem cell

Area: 983 cm2
STC: 30.7 %
2016/08 – up to now



Selected topics around our integrated model challenging new type of installations and new cells

1. Challenge to the curved surface
2. Challenge to the mismatching loss by partial shading

1,000 cuts to the car-roof PV

Car-roof PV may be killed by 1,000 small cuts, not by a sharp cut.

- Curved correction factor (local cosine loss)
- Higher incident angle
- Frequently shaded
- Car side is typically less than 50 % of the car-roof
- Mismatching loss by uneven illumination
- Partial shading by frequent drop of the small shadows (including mismatching loss associated by the partial shading)

It is essential to acknowledge the impact of each damage.

Give him
1,100 life points.

But, not 3,000 life points…

Issues of the curved module

Local cosine loss

Significance of the local loss varies by the incident angles

Self-shading loss

If the curve is a simple convex body, it may be the extension of the cosine loss with Front Only

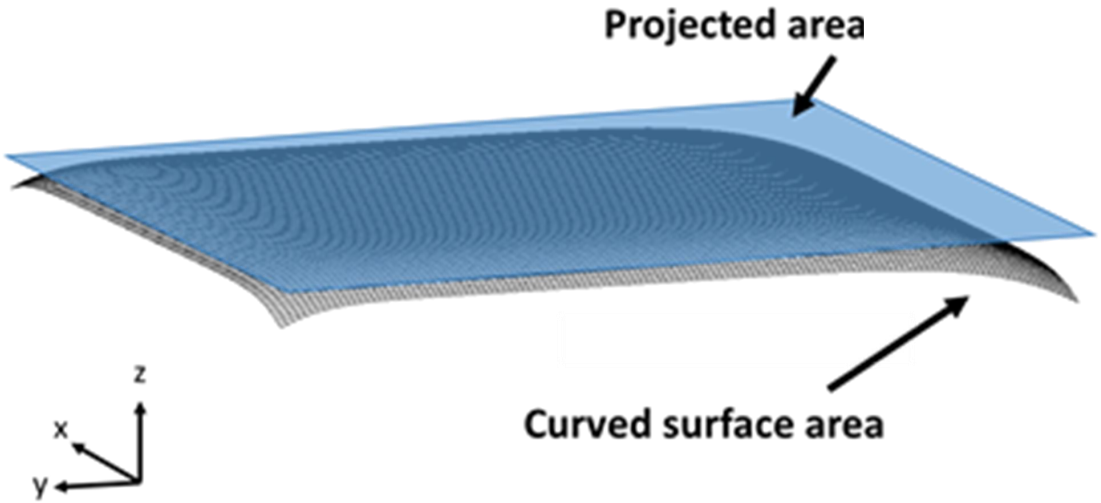
Definition of aperture

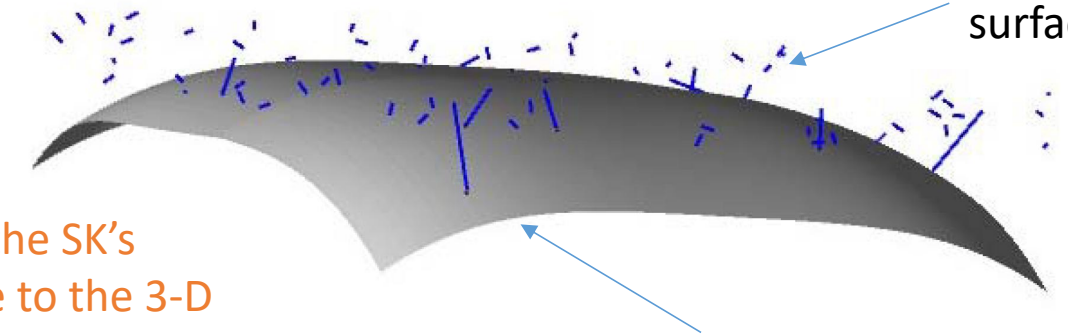
Aperture mask or Collimated solar simulator
Aperture mask: Side reflection? Height of the window? Specification of the mask itself?
Collimated solar simulator: Practical? Required collimation angle?

IAM (Incident Angle Modifier)

Varies by the curve shape
Varies by orientations
More weight on the response from the higher incident angles.

Definition of areas





Irradiance onto both projected and curve-surface were calculated by ray-tracing.

This explains how effective the SK's construction of the aperture to the 3-D curved object. The reflector inside the aperture volume help entire rays that passes aperture illuminate onto the 3-D curved surface.

Curve profile is made by connection of power functions symmetry to y-direction but asymmetry (front-back) to x-direction.

A proposal of the curve correction factor

$$P = AIf\eta$$

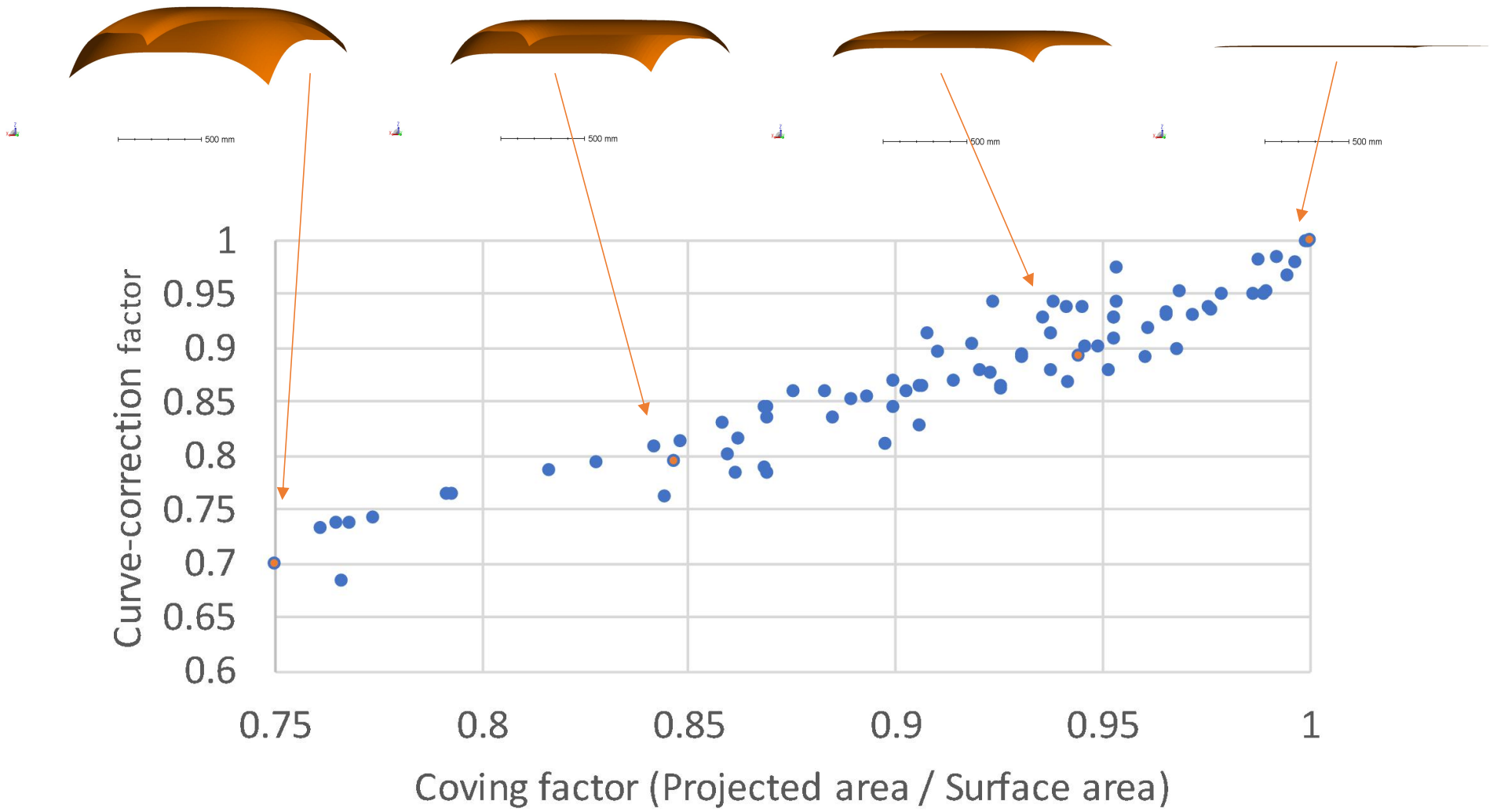
A:	Flattened area of the panel (Not projected area)
I:	Irradiance of the car-roof (Not GHI)
f:	Curve-correction factor
η:	Efficiency

What is *f*?

Unique value depending on the 3-D curve shape of the panel (affected by AOI of the panel and the standard car-roof irradiance model).

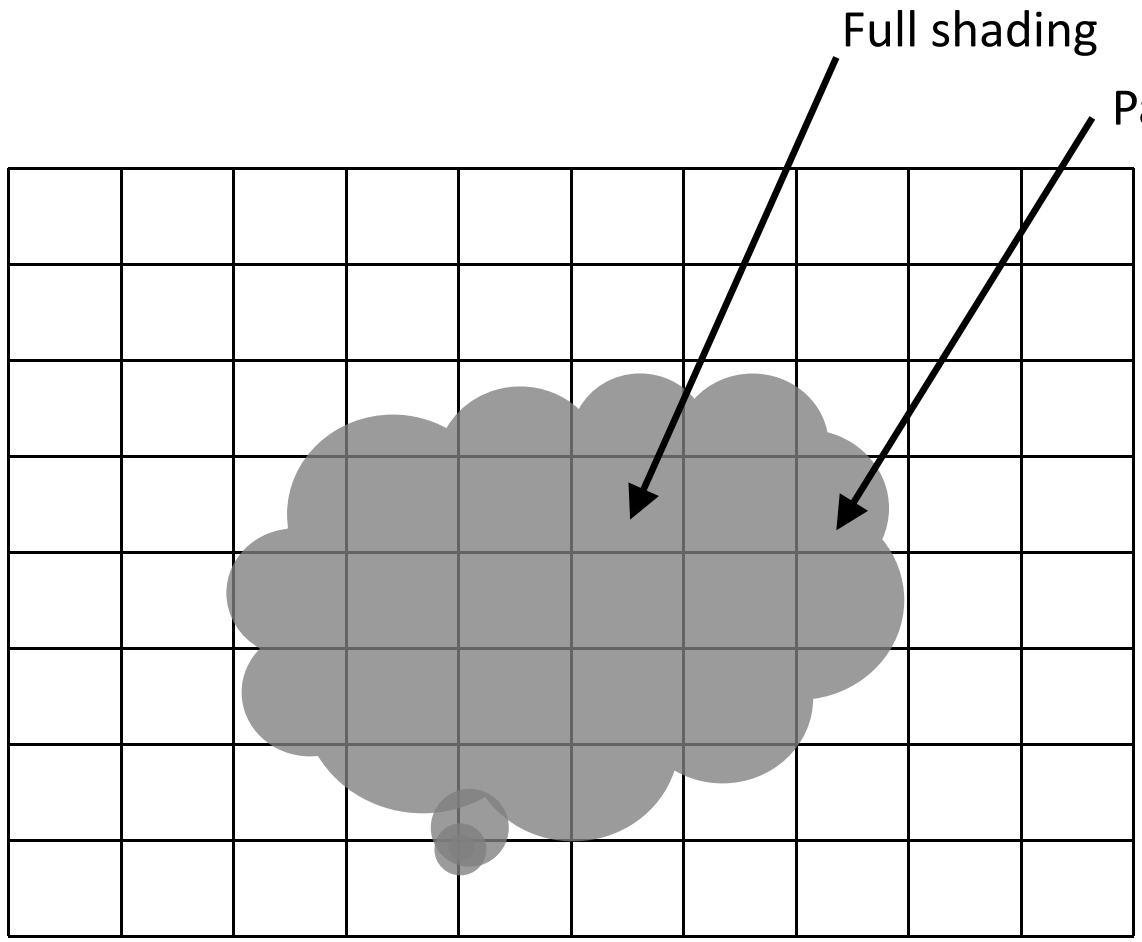
Calculated by numerical calculation (calculation algorithm should be open, transparent, and repeatable within some acceptable numerical errors, *ie.* use of Monte Carlo method).

Applicable to the 3-D CAD interface (Most of the car-roof 3-D shapes were not simple polynomials but segmented smooth functions like NURBS).



Parameters of the curves were given by random numbers. Curve correction factor was calculated by the ray-tracing simulation using 1E8 rays distributing by the direction weighted by the annual distribution of the incident angle on the horizontal plane.

Quantitative approach



Cells in a module may be categorized into 3 types.

1. In the sun
2. Full shaded
3. Partial shaded

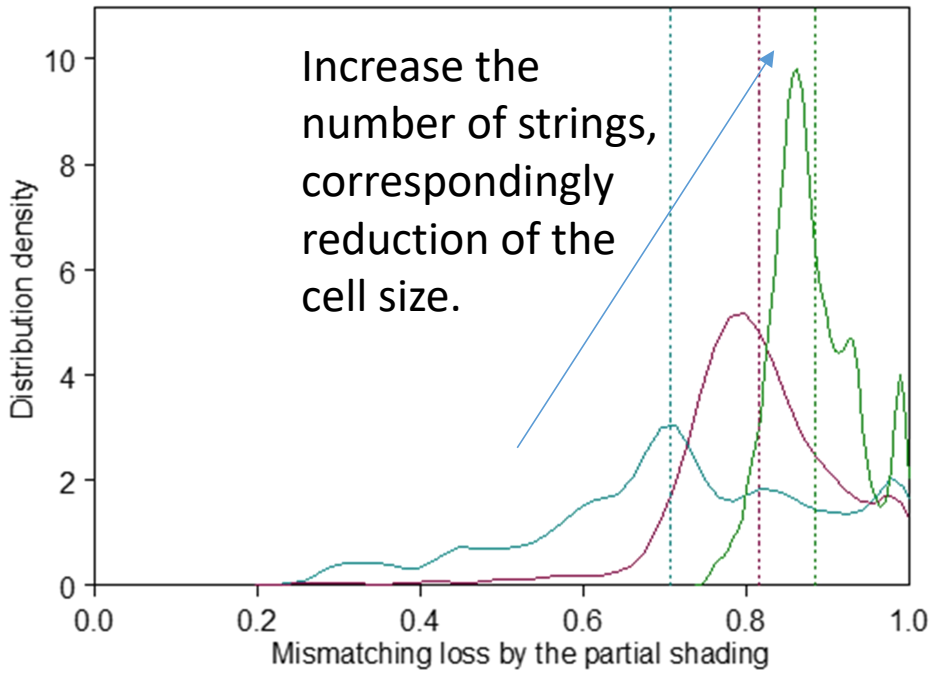
Shaded area:
(Diffused sunlight) + (Reflected sunlight)

Cells in the sun:
All the sunlight including direct sunlight

Modeling partial shading and its mismatching loss using random numbers

Parameter	Distribution	Range	Remarks
Date (Day number)	Uniform distribution	0 - 364	Repeat throwing a dice until the horizontal global sunlight given by the database is more than 1 Wh/m^2 to avoid inclusion of the trial in the night time. The bissextile day is removed.
Time	Uniform distribution	0 – 23 (1 hr)	
Number of cells partially shaded	Uniform distribution	0 – (Cells in the strings)	Random numbers are given to each string. The number of the partial and full shaded cells must be less than the number in the strings.
Number of cells fully shaded	Uniform distribution	0 – (Cells in the string)	
Shading ratio of each partially-shaded cell	Uniform distribution	0 - 1	Ratio of the partial shading (0 to 1)
Car orientation	Uniform distribution	0°- 360°	
Isc of each cell	Normal distribution		
Voc of each cell	Normal distribution		
Diode ideality of each cell	Normal distribution		Representing the shape of I-V curve

Typical result (Car-roof PV)



The ratio of the power output of the partially shaded module is less than the ratio of the area in the sun.

The reduction ratio corresponds to the mismatching loss.

The ratio of this mismatching loss decreases with increase of the number of the strings.

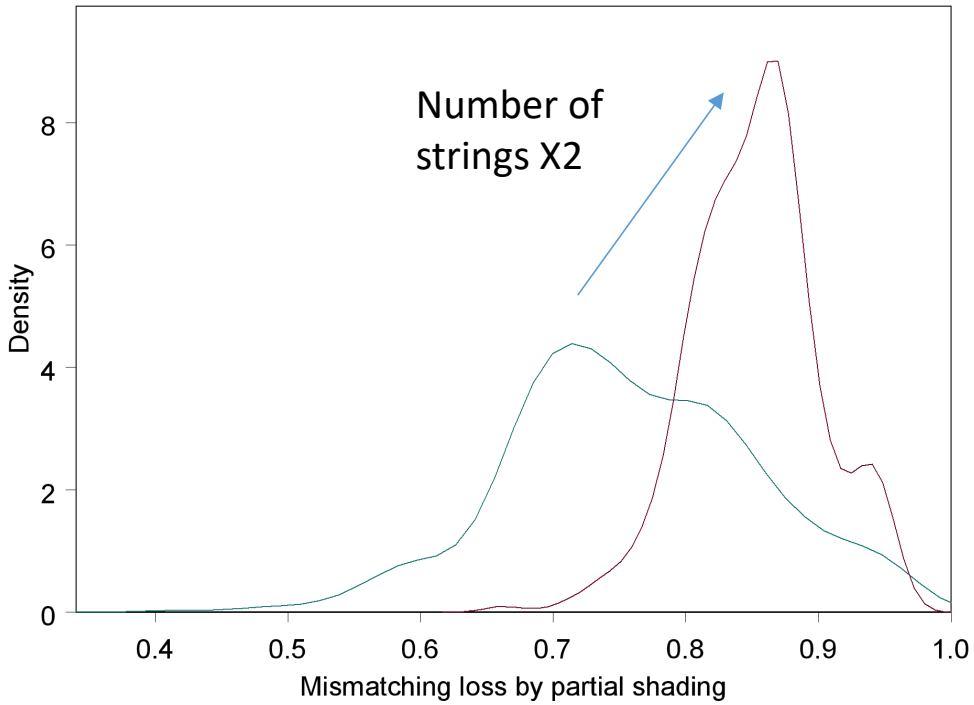
For Si cell in the normal size, it is difficult to construct with multiple strings considering the area of the individual cells per the area of the car-roof.

Cutting cells into triangle will be effective to increase the number of strings, thus reduction of the mismatching loss by the partial shading.

Triangle cut is also effective to coverage of the curved surface (less than 3000 mm of the radius of curvature).

The loss factor is a function of the number of strings, curvature of the car-roof and latitude.

Typical result (Urban CPV)



Urban CPV is a good application to the EV charging station by RE (high efficiency and white module face). The common problem is the frequency of the partial shading, especially shading by the power line.

CPV only utilize the DNI and the impact by the partial shading is large. However, high sensitivity implies it can be improved relatively easily.

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. Currently, 49 people from 14 countries are registered, including 8 from China, 11 from USA, and 3 from Germany.

cpvkenjiaraki@toyota-ti.ac.jp

- New-type installation may needs advanced model (preferably, unifying model, treating different type of installation fairly and with the same scale)
- Spectrum prediction, 3-D curved surface, unwanted orientation, partial shading loss, and etc.,
- These key parameters are dependent each other, small correction sometimes does not work.
- The unifying model was proposed.
- Some factors are difficult to predict, then Monte Carlo approach is effective.
- The new unifying model successfully explained strange behavior of these new PVs.
- 3-D curved issue may be convenient to treat by a curve correction factor.
- Partial shading can be treated by the Monte Carlo method.
- Invitation of the web meeting group.

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Thank you for your attention.

Acknowledgments

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I think we still have a large room of innovation.