

# A Day-ahead Forecasting of Photovoltaic Power Generation Using Neural Network and Meteorological Data

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- ✓ We have proposed about a day-ahead forecasting of PV power generation and solar irradiance applying a neural network and Meteorological Data.
- ✓ The feature of the proposed method is simple to handle because it only uses temperature data, which can be easily obtained from Japan Meteorological Agency.
- ✓ Forecasted results by the proposed method are relatively accurate compared to the measured ones.

# Contents

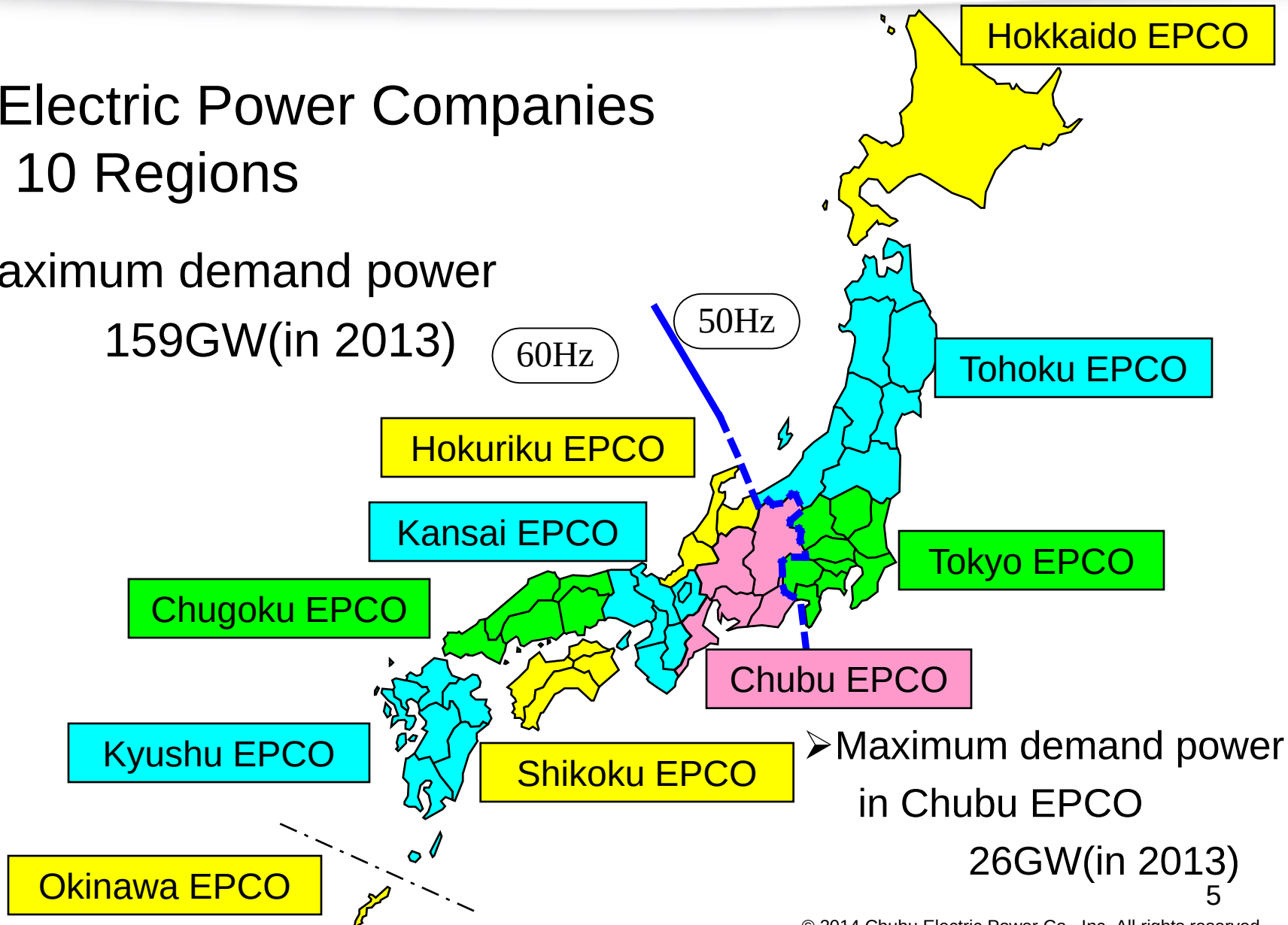
- Back ground of forecasting of Photovoltaic power generation
- Proposed method of forecasting solar irradiance and Photovoltaic power generation
- Results of forecasting
- Conclusions

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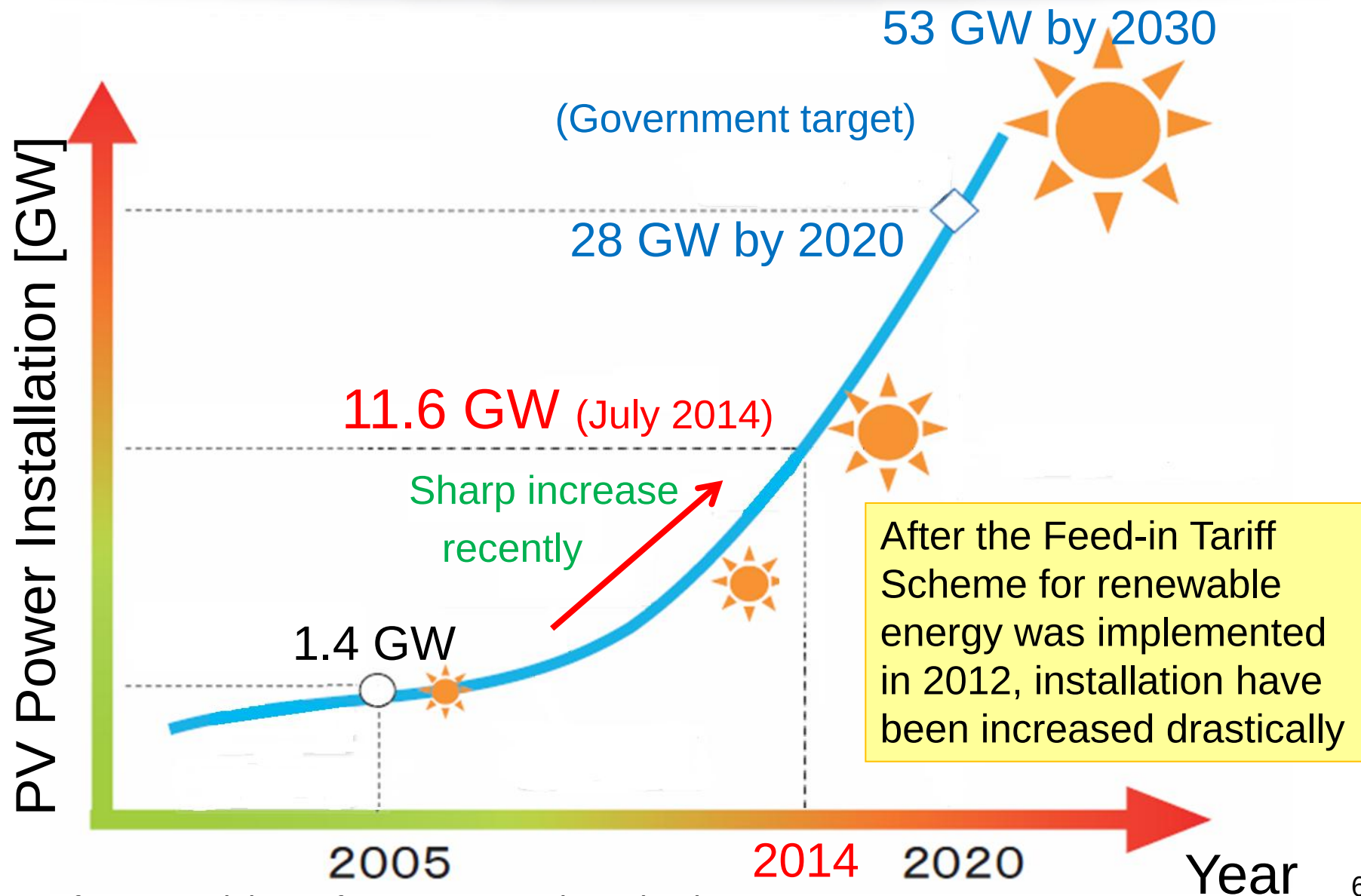
# Electric Power Companies in Japan

## 10 Electric Power Companies for 10 Regions

- Maximum demand power  
159GW(in 2013)

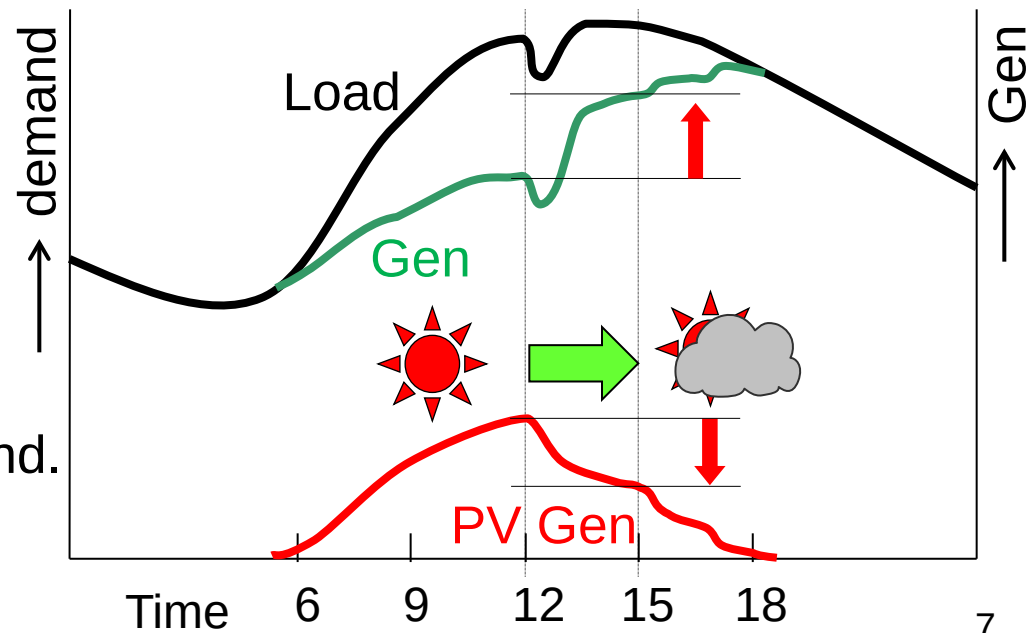
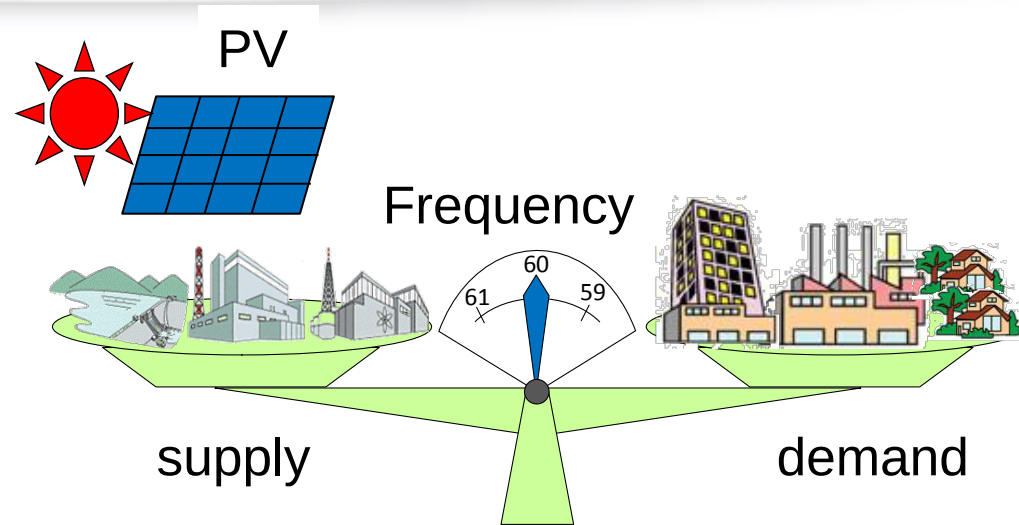


# PV Power Installation in Japan



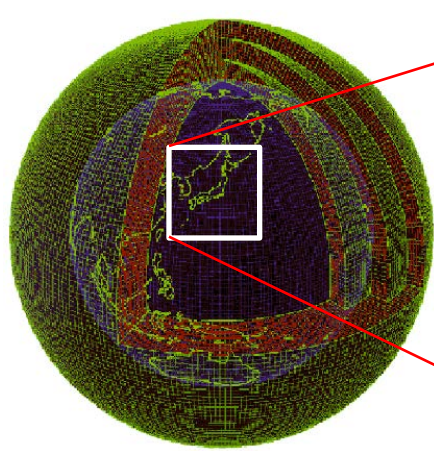
# Needs for forecasting of PV power generation

- ◆ For maintaining appropriate frequency, utility must supply electric power matching with its demand.
- ◆ However, PV power generation is influenced by the weather conditions.
- ◆ It is necessary that the forecasting of PV power generation is as accurate as possible, in order to reduce the gap between supply and demand.



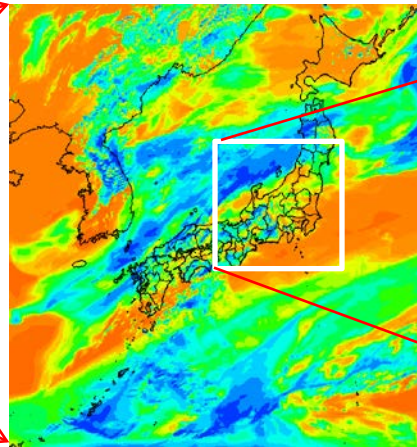
# Forecasting method developed in other studies

## Day-ahead solar irradiance forecast using weather forecasting model



GSM data from  
JMA

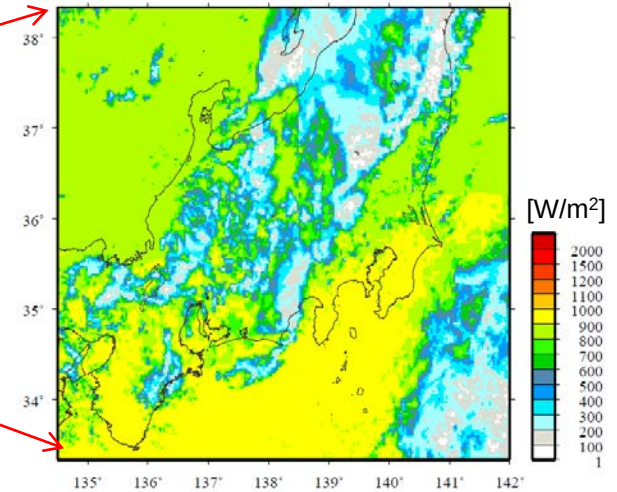
GSM : Global numerical  
weather prediction model  
JMA: Japan Meteorological  
Agency



Improvement of weather forecasting model to  
estimate solar irradiance

Reference: Demonstration project of forecast  
technologies for photovoltaic generation

Caution : These figures  
are for different day

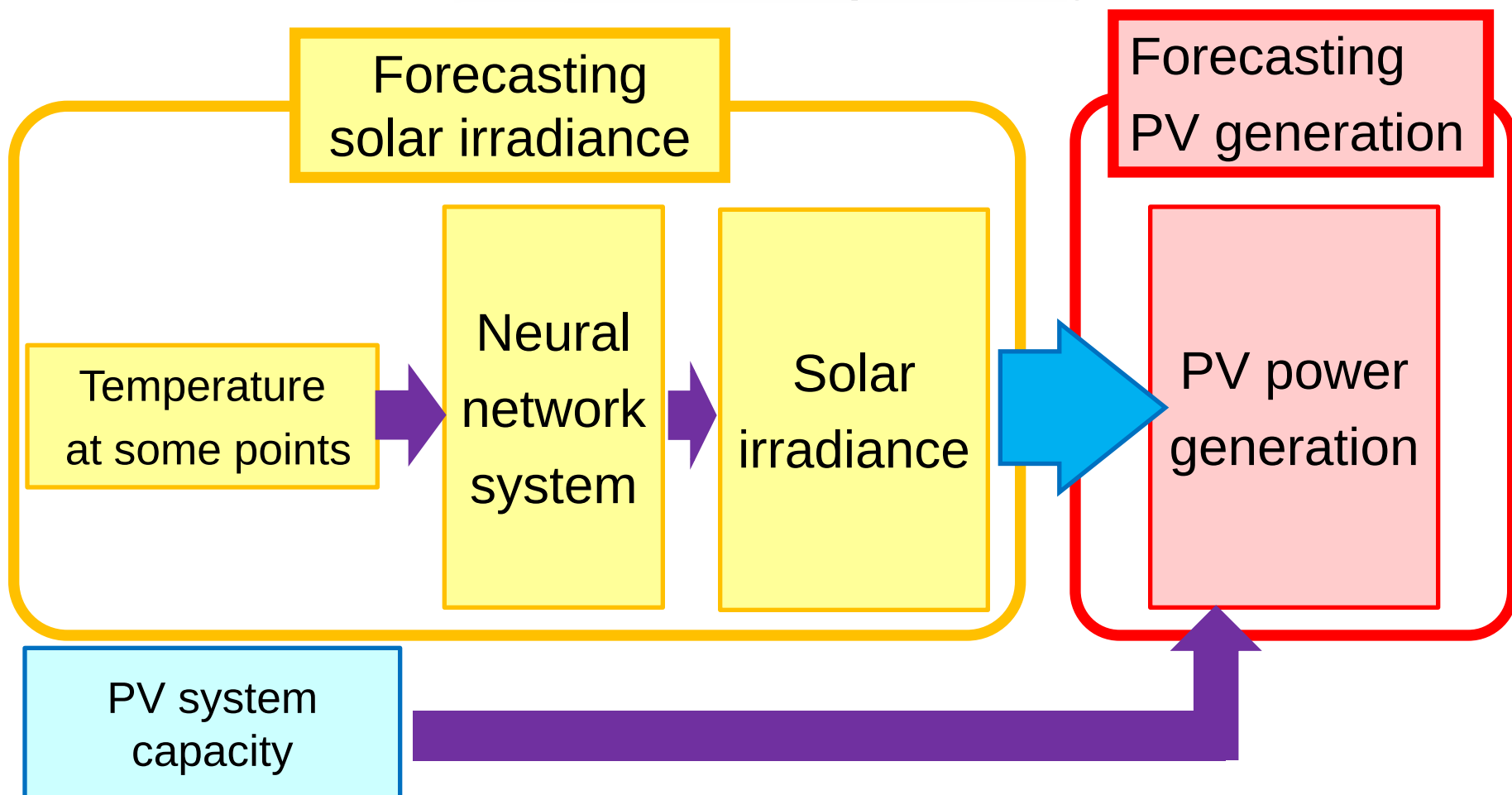


**It is accurate but highly complicated**

**Relatively simple and easy to handle method is expected**

- Back ground of forecasting of Photovoltaic power generation
- **Proposed method of forecasting solar irradiance and Photovoltaic power generation**
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# Outline of proposed method forecasting solar irradiance and PV power generation



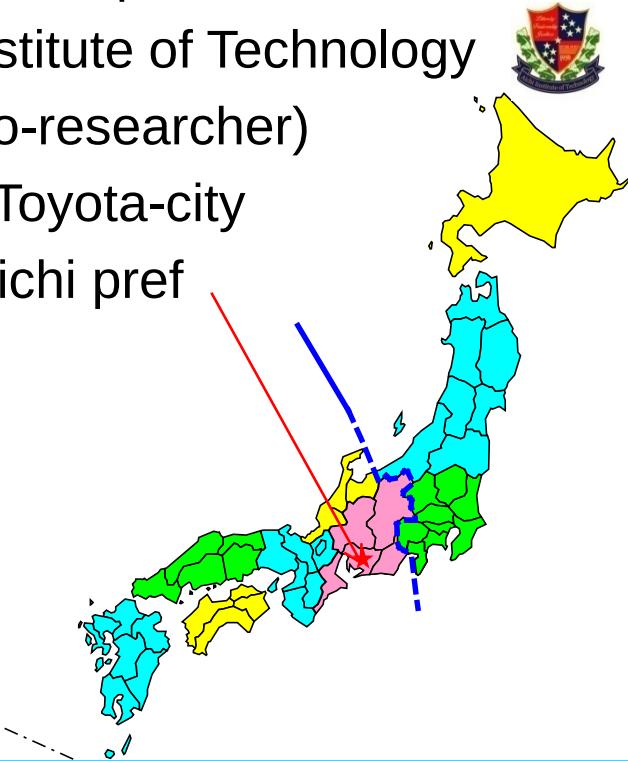
➤ Solar irradiance      ➡ Forecast by neural network

➤ PV power generation      ➡ Estimated from solar irradiance

# Measurement system used in the proposed forecasting method

## Measurement point

Aichi Institute of Technology  
(AIT ; co-researcher)  
located Toyota-city  
in Aichi pref



## PV power generation

- Panel type : Polycrystalline silicon  
(Made by Kyocera)
- Capacity: 10kW
- Measurement point : Output of PCS

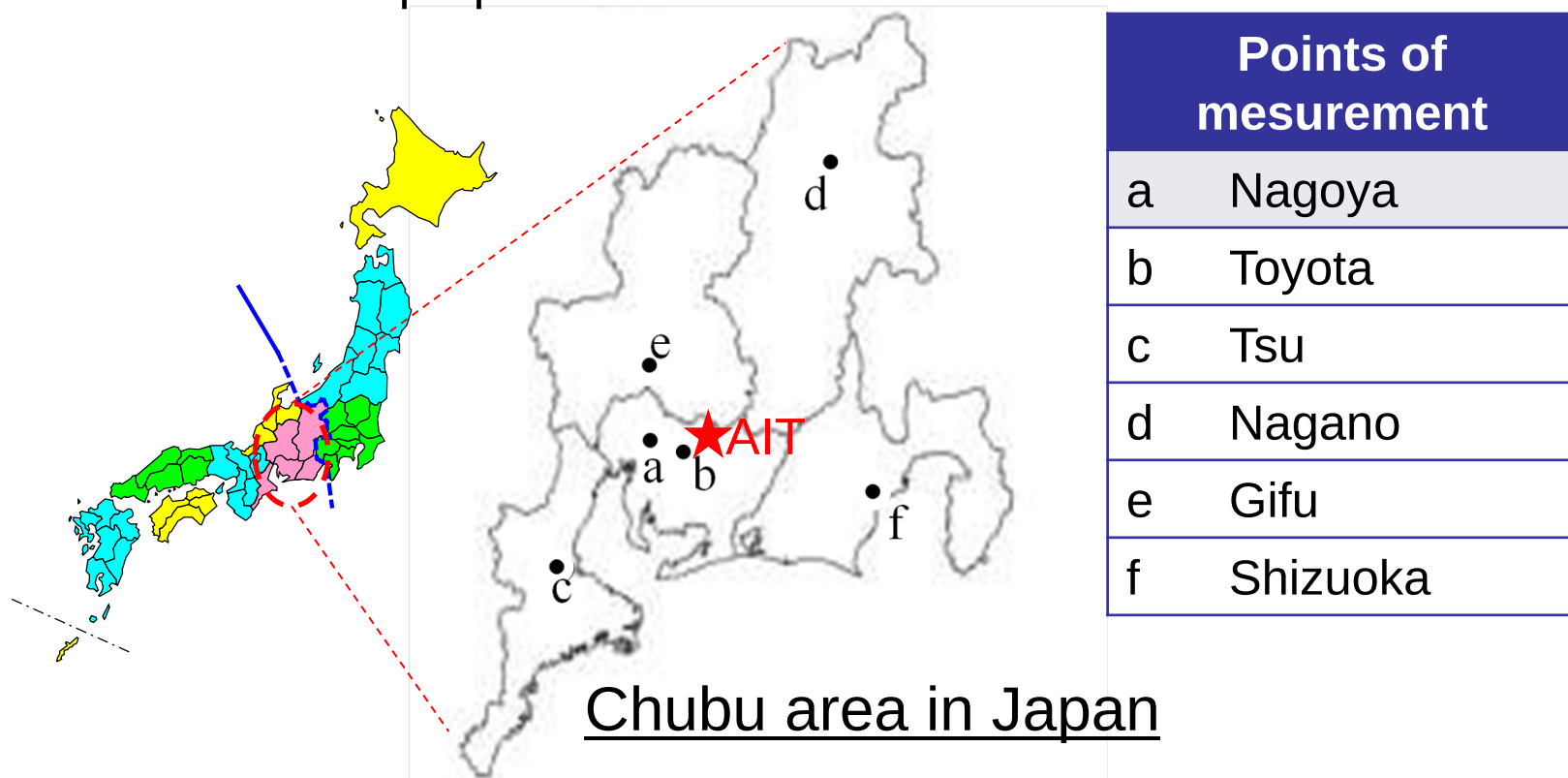
## Solar irradiance

- Measured by Pyranometer
- Type of solar irradiance  
Horizontal, inclined, vertical and direct



# Temperature data for proposed forecasting method

The temperature data of 6 points in be around AIT (so called Chubu area) were selected in the proposed method.



A day-ahead temperature is forecasted and made available on the internet by Japan Meteorological Agency at a day-before, we can obtain the data easily.

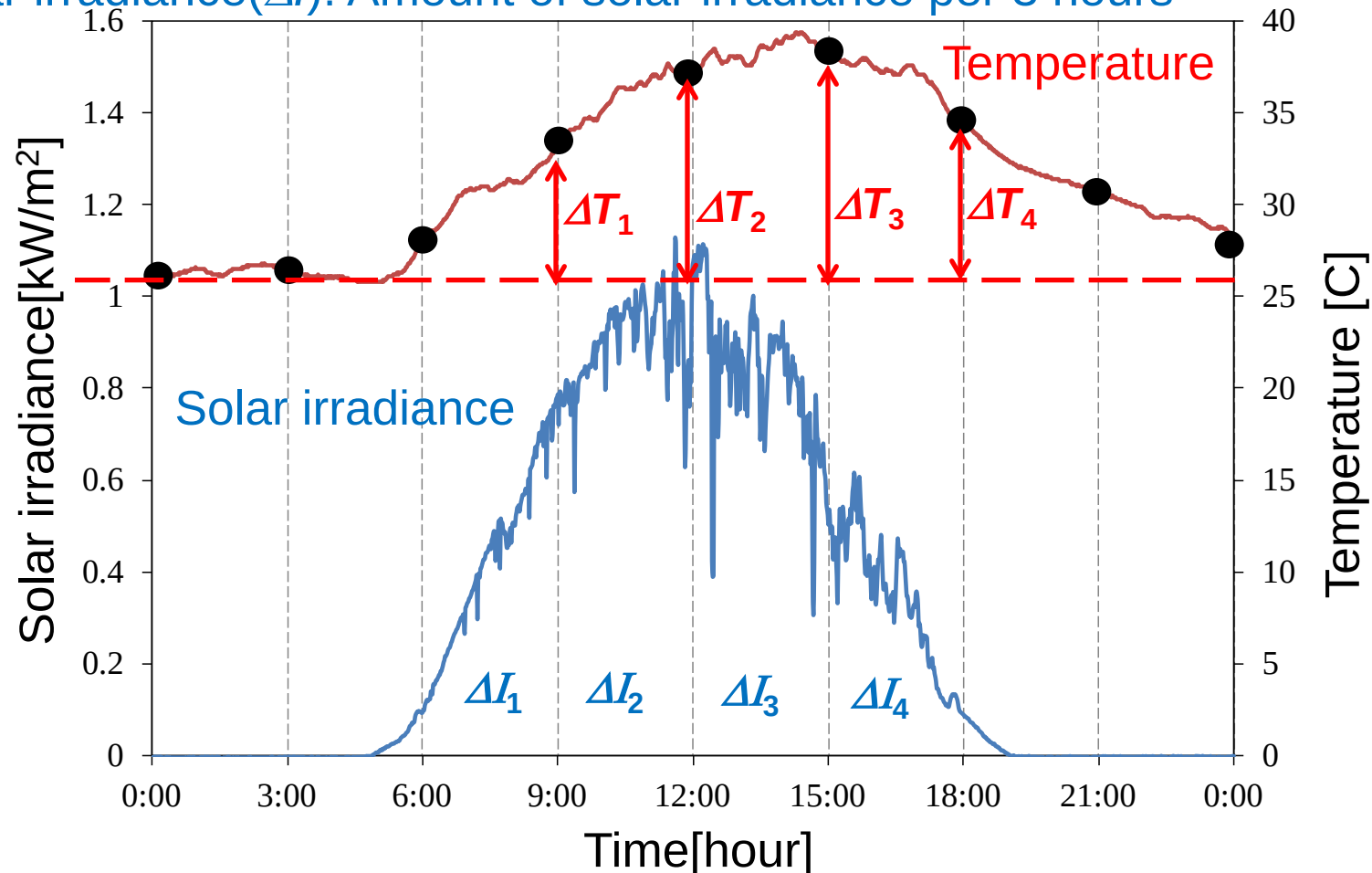
Checking correlation temperature and solar irradiance

# Correlation of temperature and solar irradiance (per 3 hours)

Temperature data ( $\Delta T$ ): Difference temperature and minimum temperature over a day


Close correlation

Solar irradiance ( $\Delta I$ ): Amount of solar irradiance per 3 hours

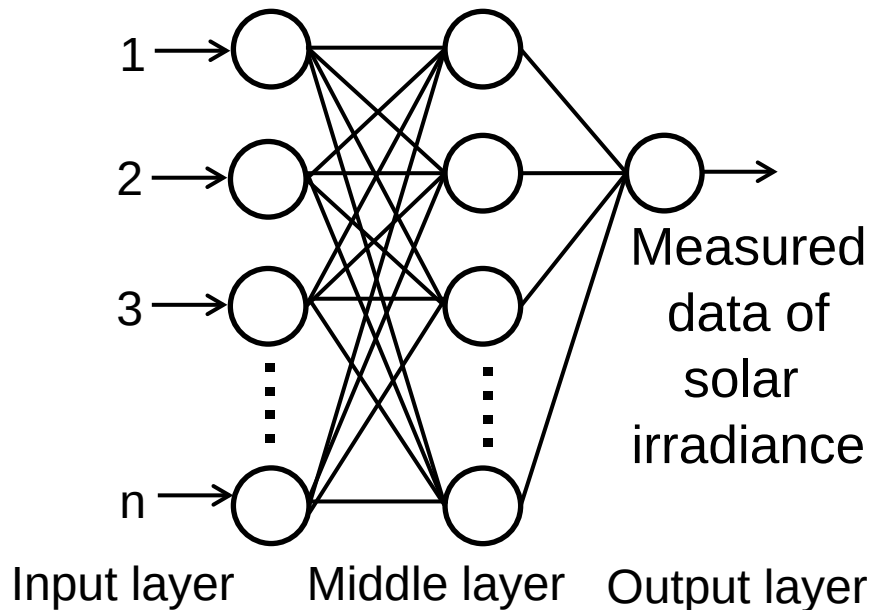


# Proposed method of forecasting solar irradiance

## ~ Applying neural network~

### Learning process

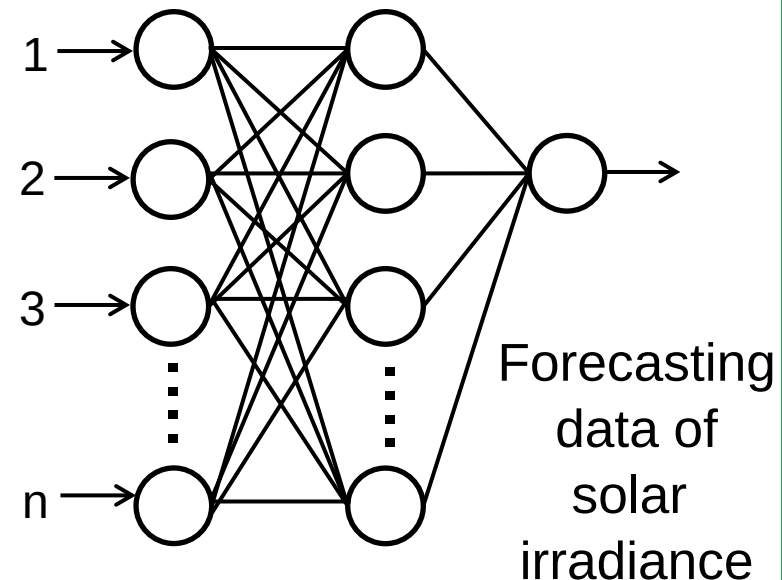
Previous  
Temperature



Using the previous temperature data the learning process was carried out.

### Forecasting process

Forecasted  
Temperature



The neural network can forecast solar irradiance at a point using temperature data at some points.

# Proposed method of forecasting PV power generation

Solar irradiance has a close correlation with PV power generation

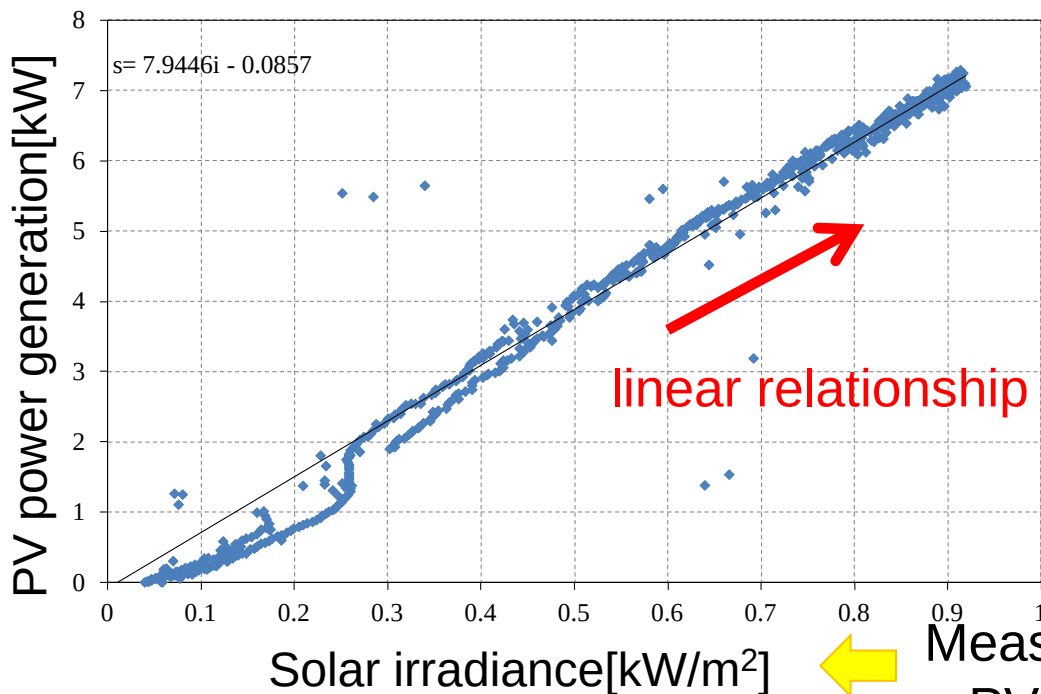
PV power generation is estimated from solar irradiance

$$\underline{S = aI + b}$$

(a[m<sup>2</sup>], b[kW] : Factor)

S: PV power generation[kW]  
I: Solar irradiance[kW/m<sup>2</sup>]

Measured at  
a PV system



Measured close to  
a PV system



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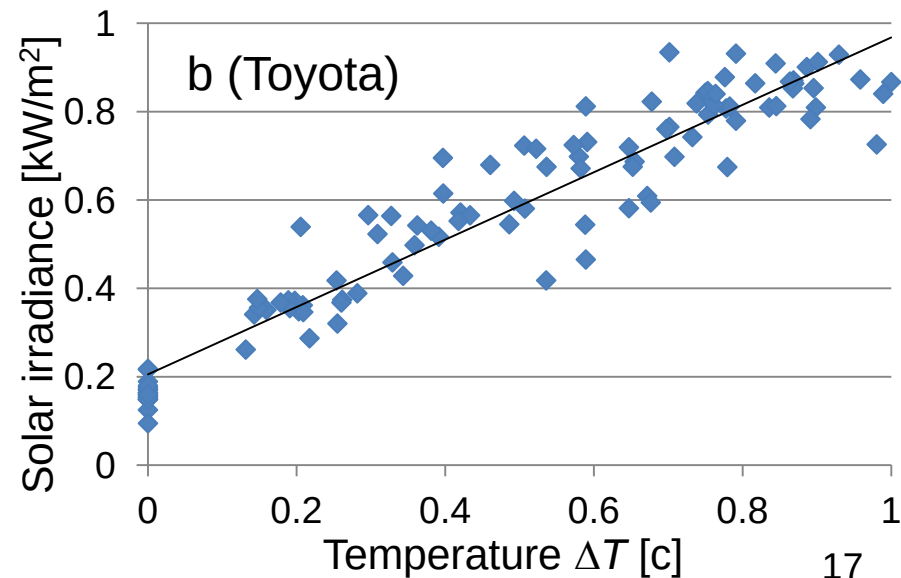
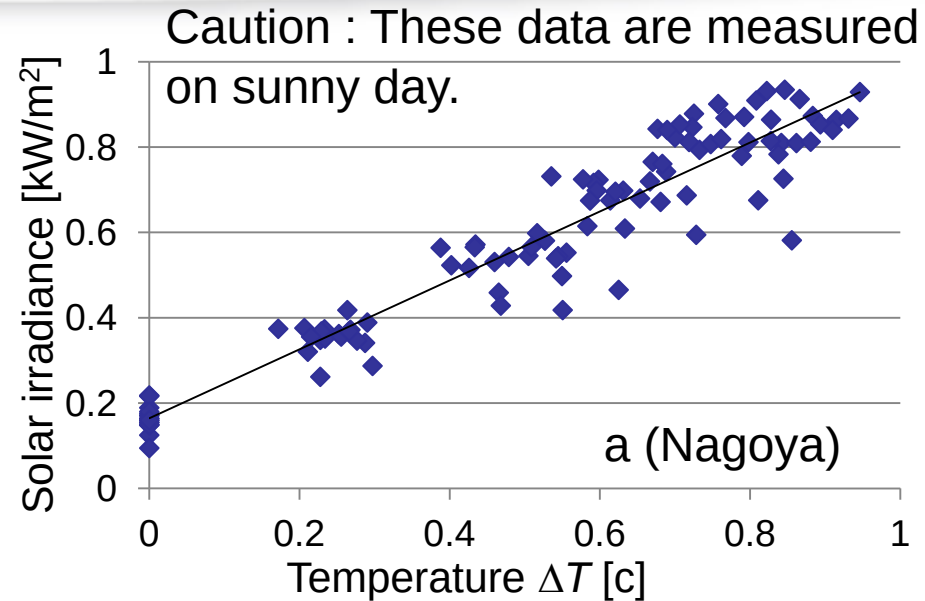
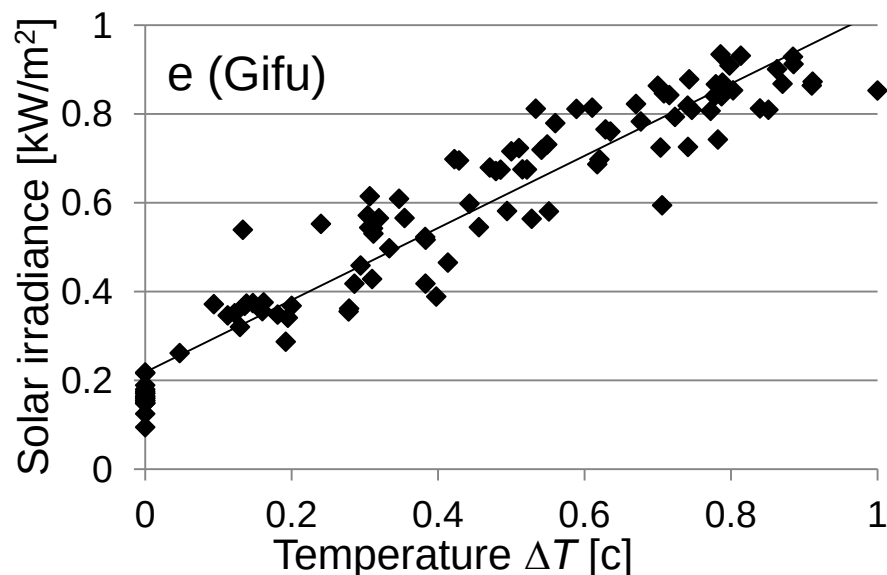
# Checking the correlation between temperature and solar irradiance

Checking the correlation between temperature at some points and solar irradiance at AIT



Temperature and solar irradiance has close correlation

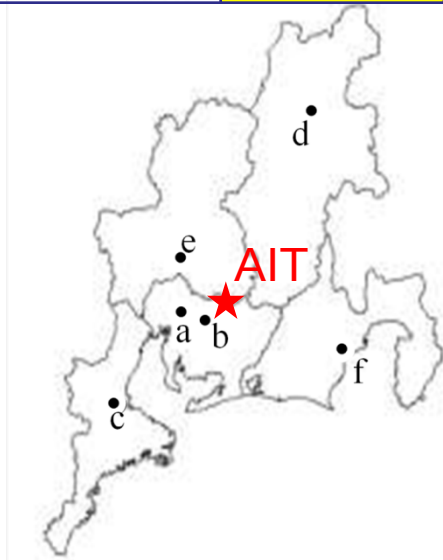
$\Delta T$  : Temperature difference and minimum temperature over a day



# Selection of temperature data-points

Correlation coefficient between temperature and solar irradiance

| Month   | Measurement points of temperature |       |       |       |       |       | Average |
|---------|-----------------------------------|-------|-------|-------|-------|-------|---------|
|         | a                                 | b     | c     | d     | e     | f     |         |
| 2011.09 | 0.882                             | 0.931 | 0.794 | 0.775 | 0.829 | 0.569 | 0.797   |
| ⋮       |                                   |       |       |       |       |       |         |
| 2012.07 | 0.895                             | 0.946 | 0.791 | 0.554 | 0.899 | 0.489 | 0.762   |
| 2012.08 | 0.394                             | 0.660 | 0.288 | 0.351 | 0.627 | 0.425 | 0.457   |
| Average | 0.760                             | 0.799 | 0.555 | 0.406 | 0.742 | 0.491 | 0.626   |



Checking monthly correlation coefficient between temperature and solar irradiance in 2011-2012

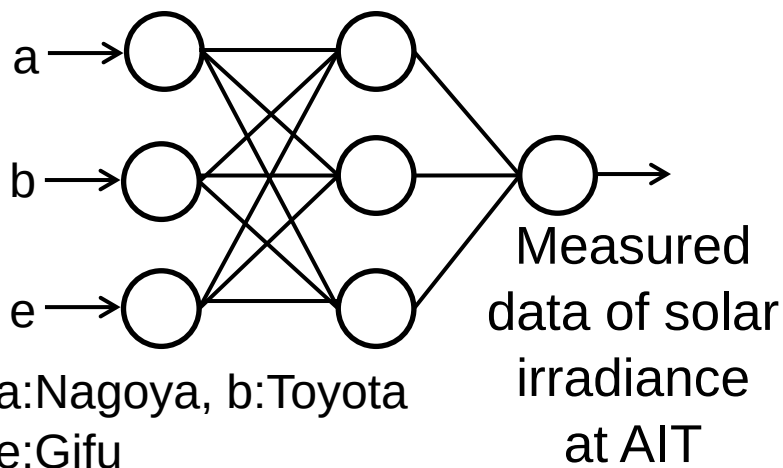


Points a, b and e for measuring temperature data are selected because temperature data at there has close correlation with solar irradiance data at AIT .

# Forecasting solar irradiance and PV power generation by neural network

## Learning process

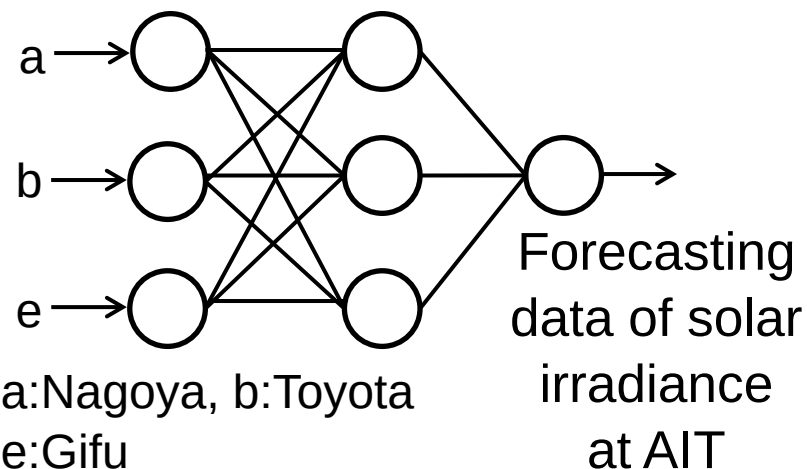
Temperature data in past



Number of learning iteration: 15,000

## Forecasting process

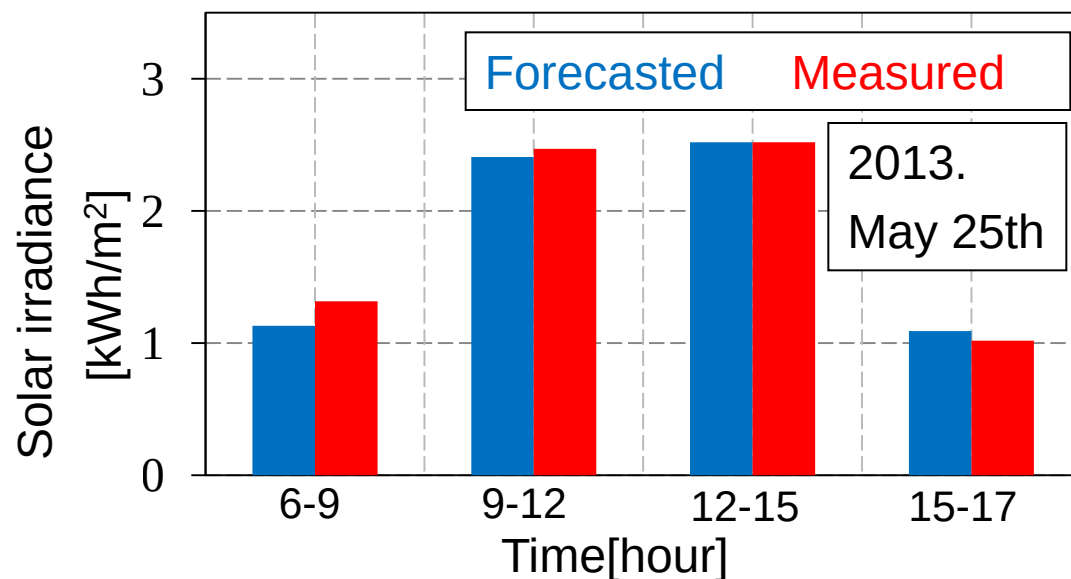
Forecasting Temperature



Using temperature data at points a, b and e, solar irradiance data at AIT is forecasted by neural network.

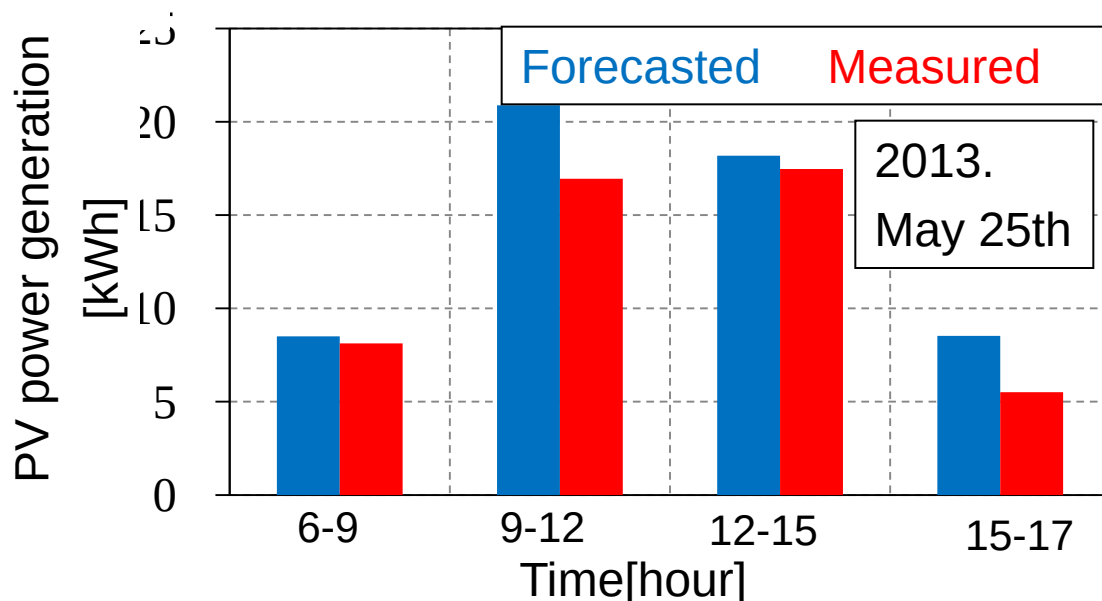
PV power generation is estimated by solar irradiance, applying the correlation.

# Forecasted results of solar irradiance and PV power generation -on sunny day-



## Solar irradiance

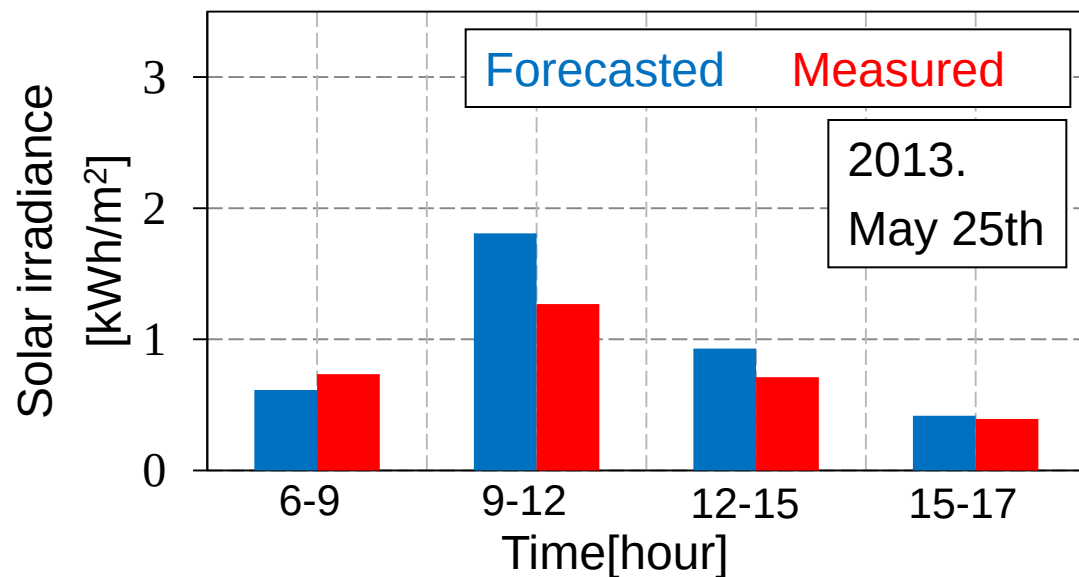
On sunny day, the forecasting results have similar trend compared to measured data



## PV power generation

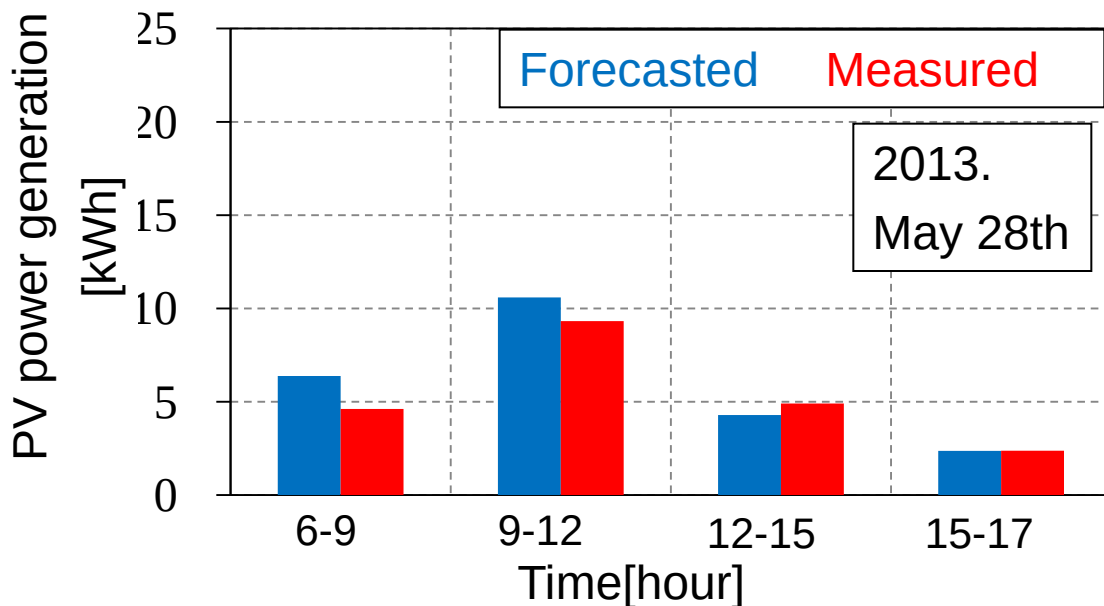
Forecasted PV power generation, estimated from solar irradiance has almost close correlation with measured data

# Forecasted results of solar irradiance and PV power generation -on cloudy day-



## Solar irradiance

On cloudy day, forecasted results have almost similar trend compared to measured data, although there are some out view points



## PV power generation

Forecasted PV power generation, estimated from solar irradiance has almost close correlation with measured data

# Forecasted error of solar irradiance

| time \ day<br>[h] | Forecasted error [%] |          |          |          |           |
|-------------------|----------------------|----------|----------|----------|-----------|
|                   | May 25th             | May 26th | May 31th | June 2nd | June 29th |
| 6:00-9:00         | 14.1                 | 15.4     | 4.1      | 48.9     | 64.1      |
| 9:00-12:00        | 2.5                  | 5.0      | 5.6      | 60.0     | 0.6       |
| 12:00-15:00       | 0.0                  | 6.8      | 73.7     | 35.5     | 17.0      |
| 15:00-18:00       | 7.1                  | 86.6     | 21.8     | 20.0     | 14.8      |
| Average           | 5.9                  | 28.4     | 26.3     | 41.1     | 24.2      |

## The sunny day

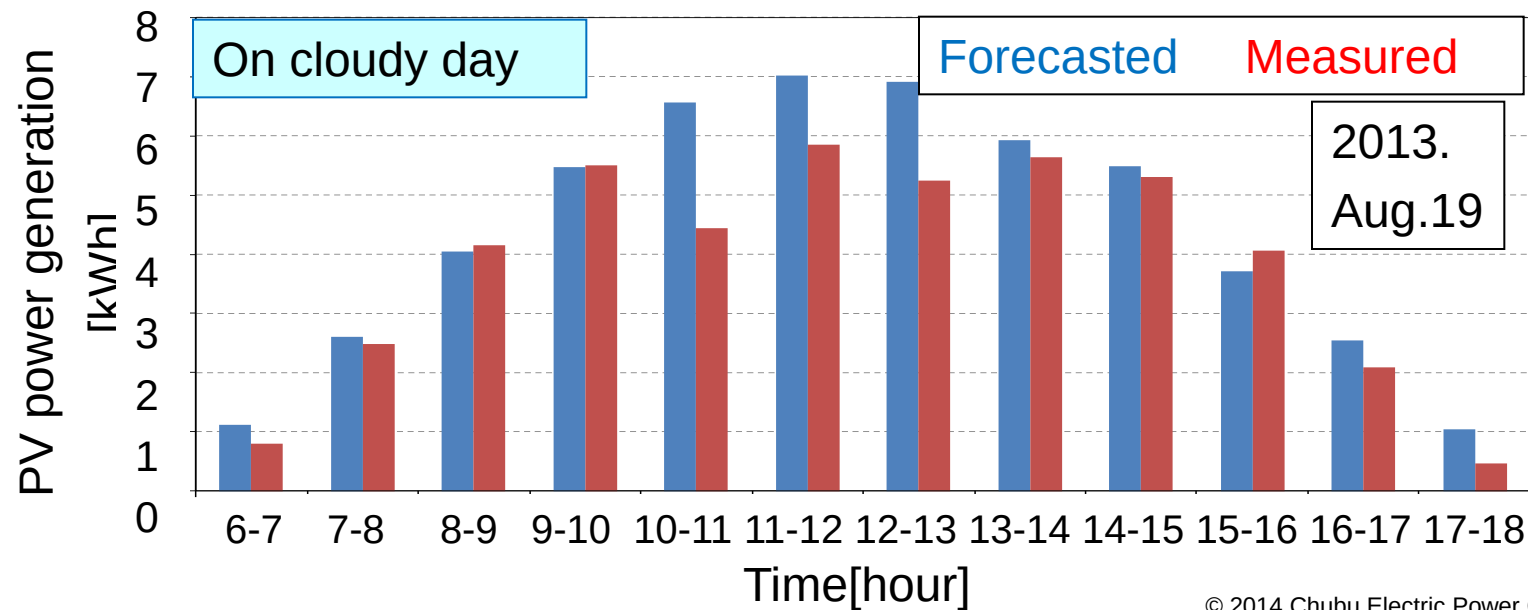
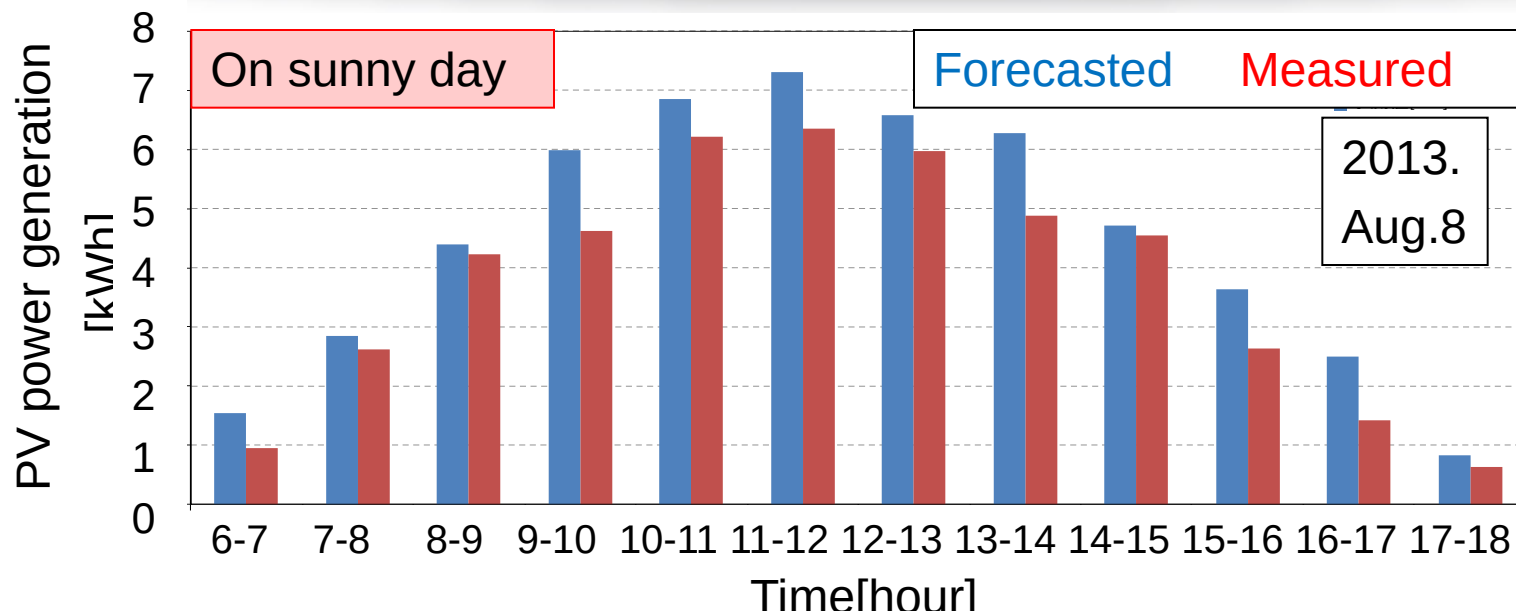
The range of forecasted error is found to be 5.9-41.1%  
(5days-average: 25.2%)

| time \ day  | Forecasted error[%] |          |           |           |         |
|-------------|---------------------|----------|-----------|-----------|---------|
|             | May 28th            | June 1st | June 24th | July 25th | Sep 1st |
| 6:00-9:00   | 16.5                | 60.6     | 1.5       | 87.0      | 61.9    |
| 9:00-12:00  | 42.6                | 125.4    | 80.6      | 10.9      | 3.0     |
| 12:00-15:00 | 30.6                | 176.1    | 74.4      | 44.2      | 66.5    |
| 15:00-18:00 | 6.5                 | 141.9    | 85.2      | 17.2      | 58.8    |
| Average     | 24.0                | 126.0    | 60.4      | 39.8      | 47.6    |

## The cloudy day

The range of forecasted error is found to be 24.0-126.0%  
(5days-average:59.6%)

# Forecasted result of hourly PV power generation



# Hourly forecasted error of PV power generation

| <div> <div>time</div> <div>h</div> </div> <div>day</div> | Forecasted error [%] |          |            |
|----------------------------------------------------------|----------------------|----------|------------|
|                                                          | Sunny day            |          | Cloudy day |
|                                                          | Aug.8th              | Aug.13th | Aug.19th   |
| 6:00-7:00                                                | 62.4                 | 79.9     | 38.0       |
| 7:00-8:00                                                | 8.71                 | 75.6     | 4.4        |
| 8:00-9:00                                                | 3.75                 | 20.4     | 2.6        |
| 9:00-10:00                                               | 29.7                 | 40.1     | 0.5        |
| 10:00-11:00                                              | 10.2                 | 1.4      | 47.7       |
| 11:00-12:00                                              | 15.2                 | 2.0      | 20.1       |
| 12:00-13:00                                              | 10.1                 | 2.0      | 31.9       |
| 13:00-14:00                                              | 28.4                 | 2.3      | 5.1        |
| 14:00-15:00                                              | 4.0                  | 2.5      | 3.5        |
| 15:00-16:00                                              | 37.6                 | 15.5     | 8.7        |
| 16:00-17:00                                              | 75.2                 | 25.3     | 21.6       |
| 17:00-18:00                                              | 31.9                 | 66.6     | 125.1      |
| Average                                                  | 26.4                 | 27.8     | 25.8       |

Hourly forecasted data and measured data on the sunny day have almost close trends.

Due to shortage of data, it is expected that some times the forecasting results may differ largely

We are going to collect more forecasting data and checking its difference with the measured data.

# Contents

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# Conclusions

- ◆ We have proposed a method for a day-ahead forecasting of PV power generation and solar irradiance applying neural network and temperature.
- ◆ Proposed method is simple to handle because it only uses temperature data only during forecasted.
- ◆ The forecasted results by the proposed method are found to be relatively accuracy. And yet, they have sometimes large error particularly on cloudy day.
- ◆ Further, the studies are being carried out to improve the accuracy of the proposed forecasting method.

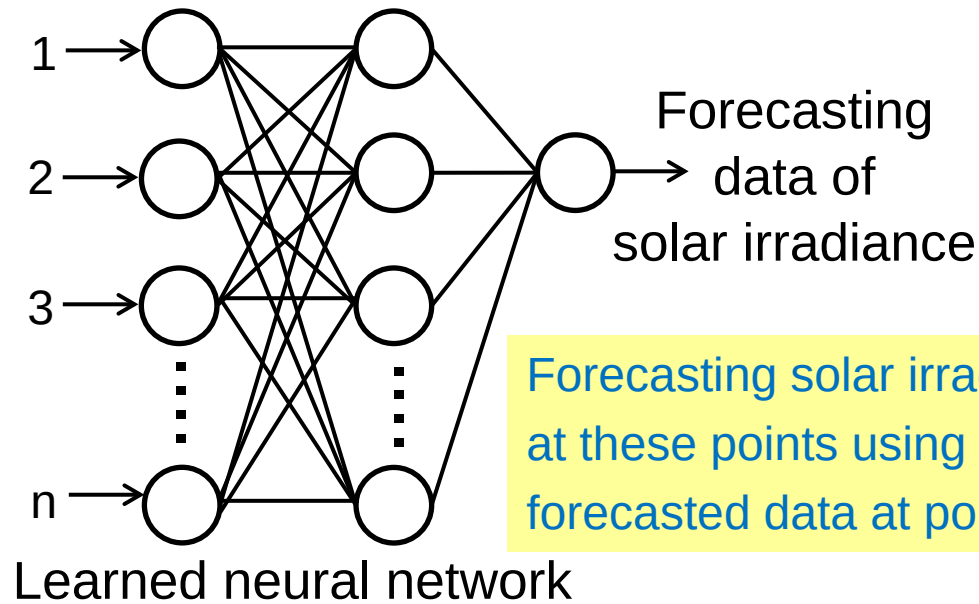
*Thank you for  
your attention!!*



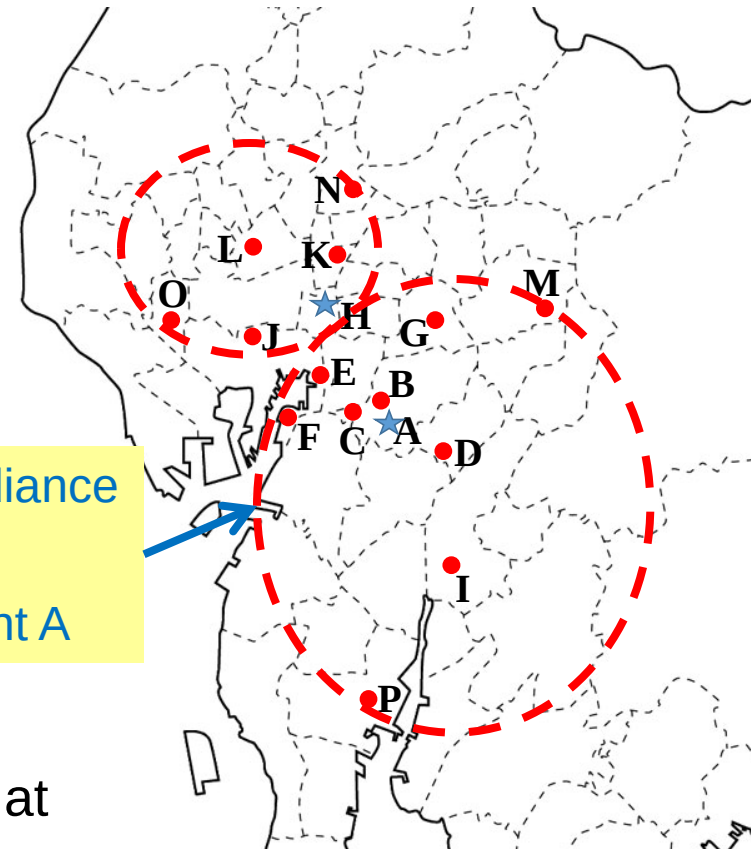
# Additional slides

# Forecasting solar irradiance at many points in Chubu area applying the proposed method

Forecasting  
Temperature



Forecasting solar irradiance  
at these points using  
forecasted data at point A



Western part  
of Aichi prefecture

- ◆ We have tried to forecast solar irradiance at many points applying neural network with temperature at a point.
- ◆ By searching the range which can forecasting at a point, we try to forecasting at wide-area .

# Correlation of temperature and solar irradiance (per 1 hour)

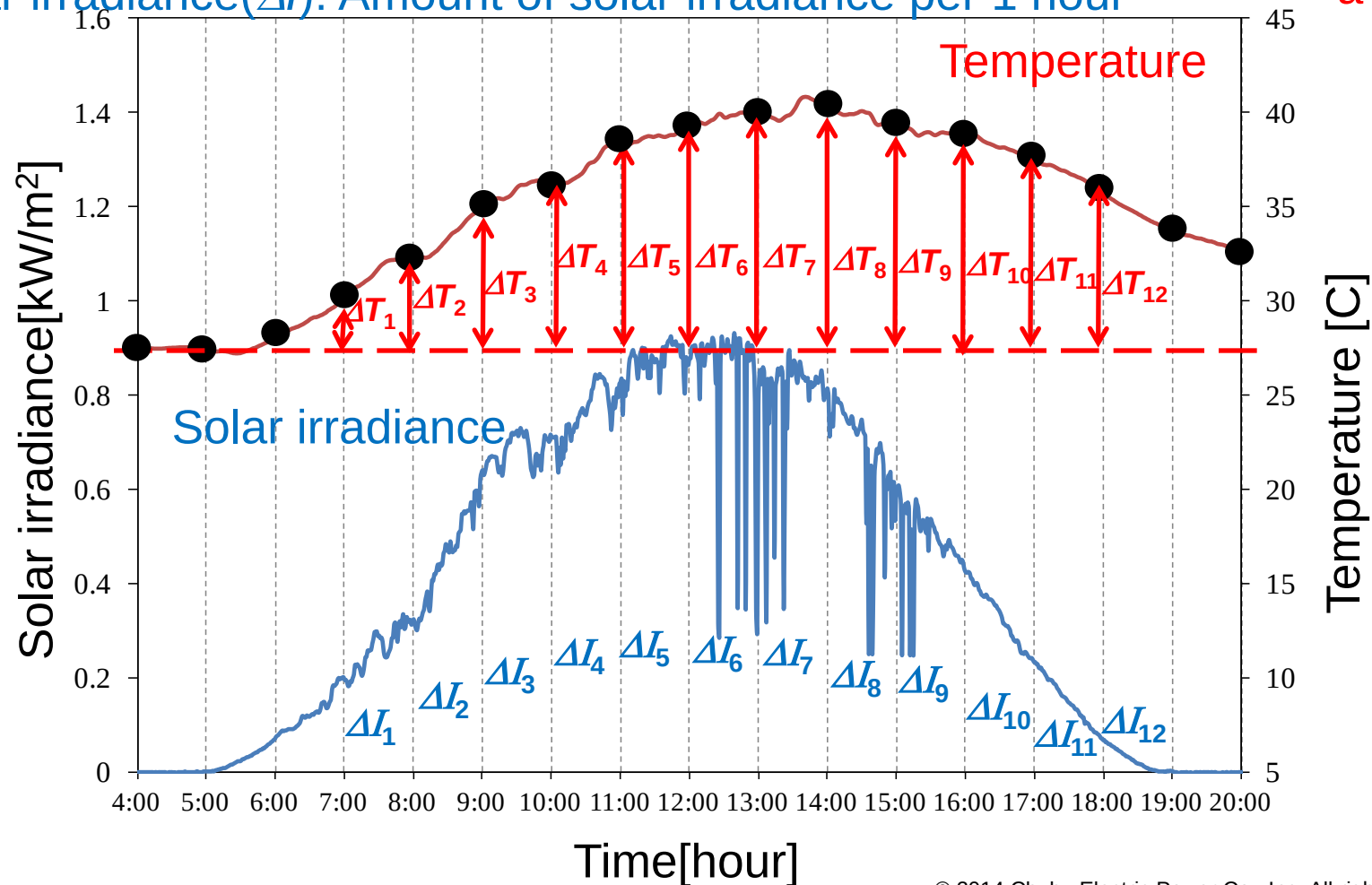
Temperature data ( $\Delta T$ ): Difference between temperature and minimum



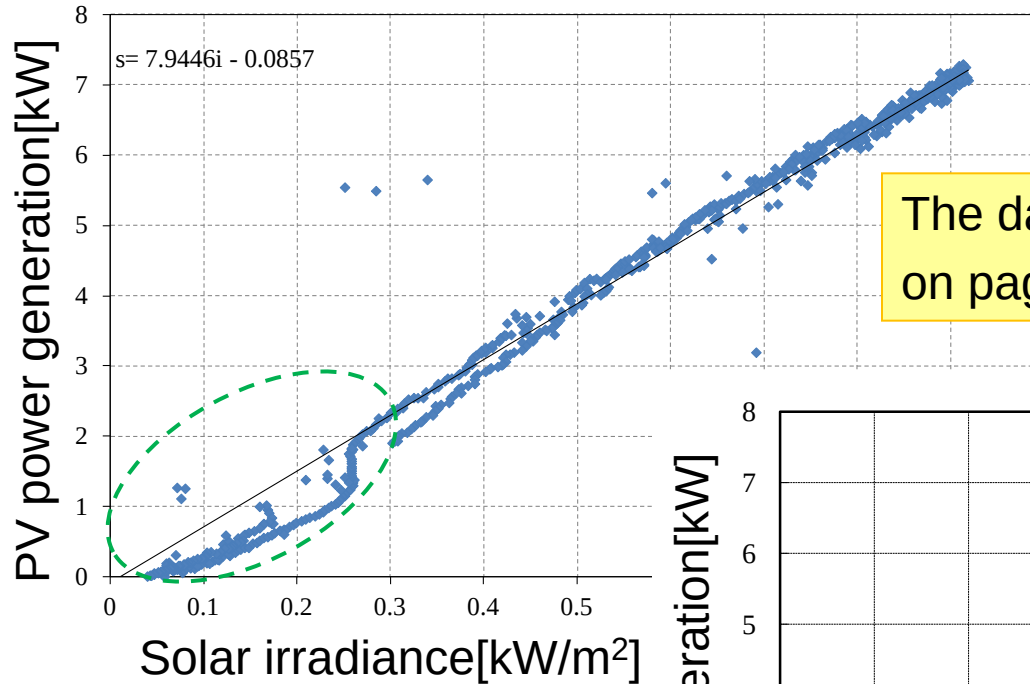
Close correlation temperature over

Solar irradiance( $\Delta I$ ): Amount of solar irradiance per 1 hour

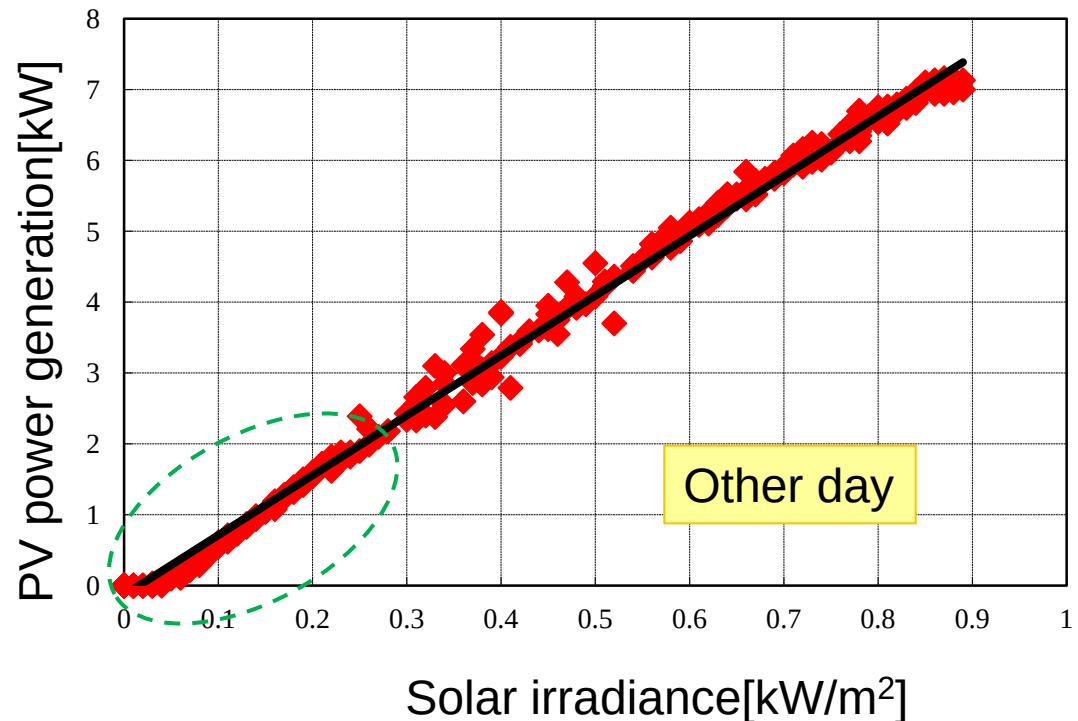
a day



# Relationship between PV power generation and solar irradiance

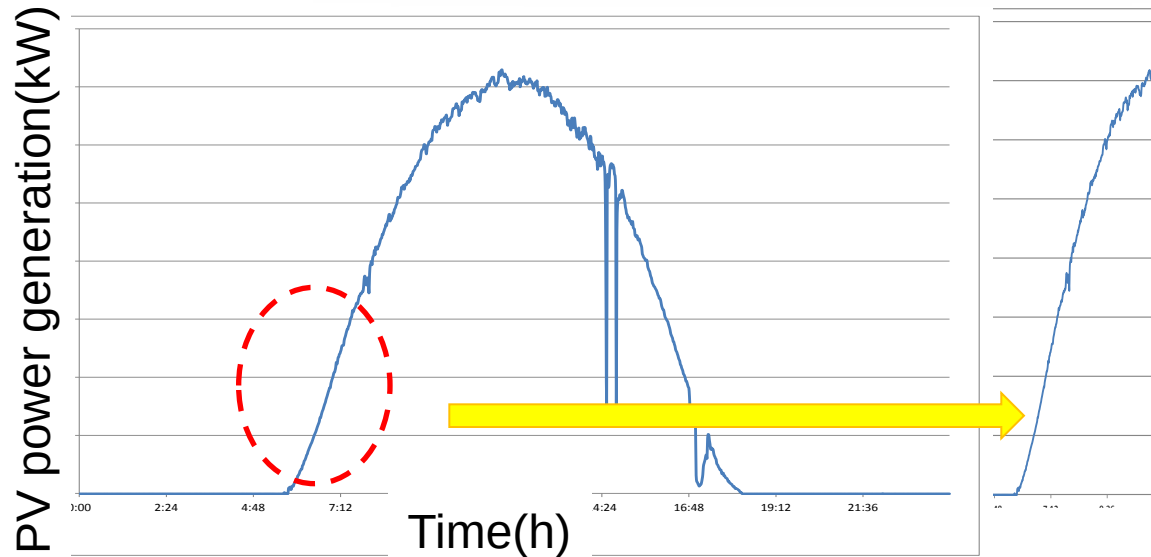


The day shown  
on page15



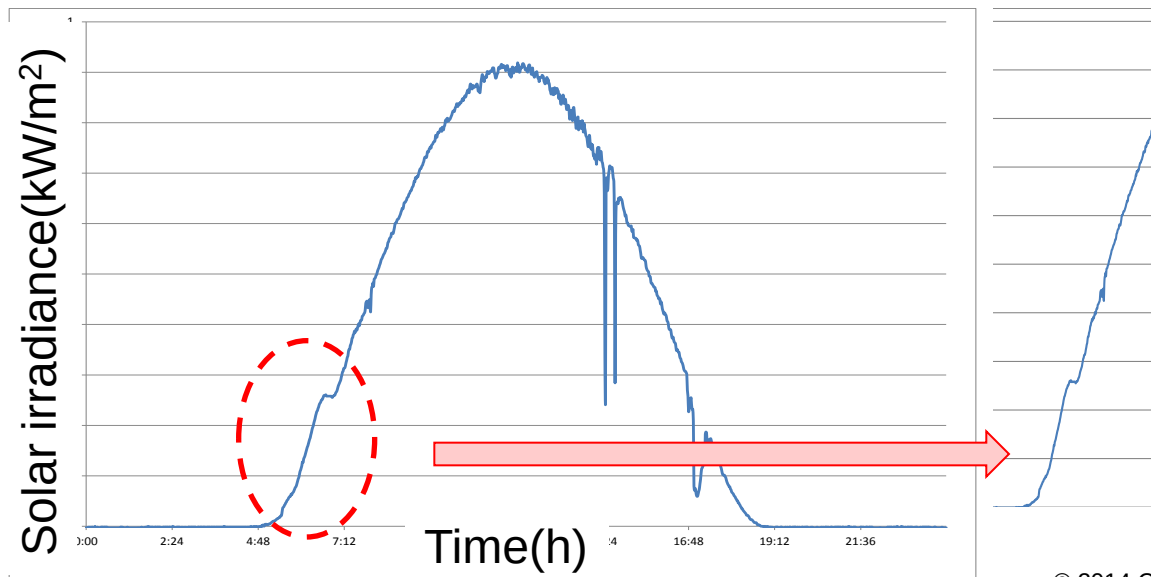
Other day

# Comparison of PV power generation and solar irradiance



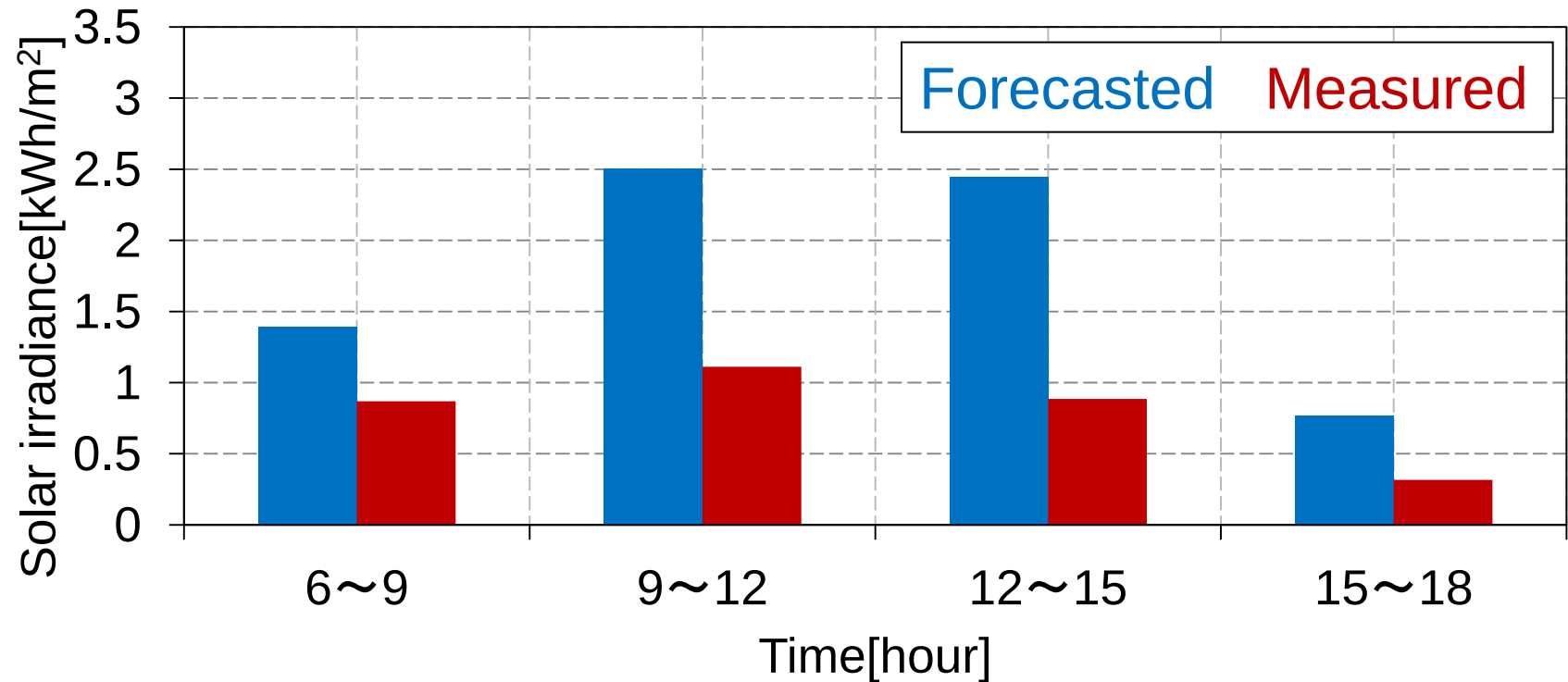
PV power  
generation

In the situation of  
small value, PV  
power generation  
is increased more  
sharply than solar  
irradiance

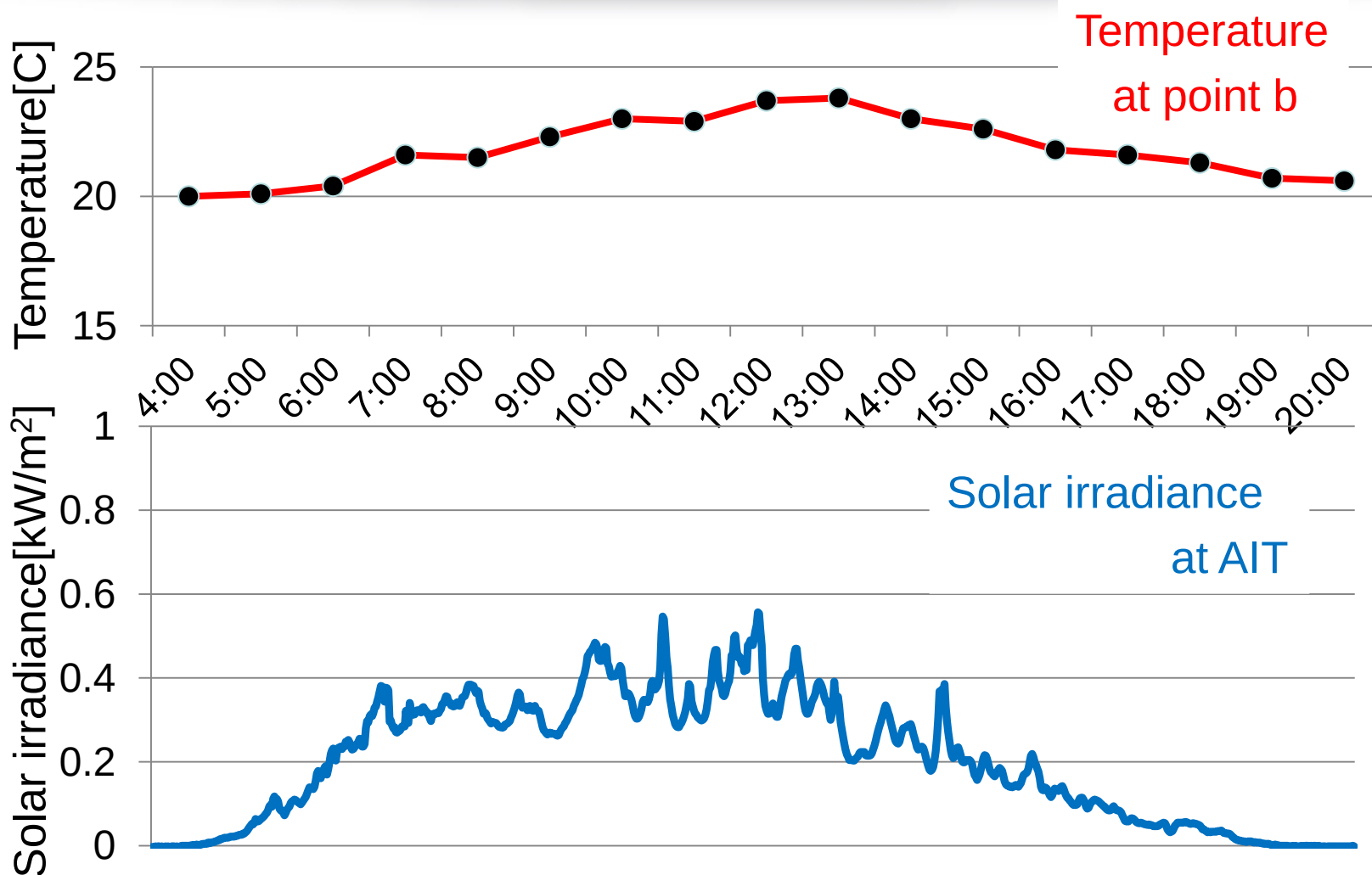


Solar irradiance

# Forecasted results of solar irradiance in 1st June



# Temperature and solar irradiance in 1st June



Temperature at point b is not similar to solar irradiance at AIT