Solar Irradiance Forecast Methods using Meteorological Data for Photovoltaic Generation Prediction

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Photovoltaic (PV) Installation status in JAPAN

Daytime maximum demand on holiday (Low demand season (e.g. May) in Japan)

Government target in 2030

- [GW]
- 100
- 75
- 50
- 25
- 0

Non Roof top (scheduled & authorized)

Non Roof top (installed)

Roof top (installed)

Roof top (scheduled & authorized)

Mar, 2016

Expected in future

JAPAN

Nagoya

Hong Kong

source：NASA

Reference : http://www.fit.go.jp/statistics/public_sp.html (Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry) (in Japanese)

Electric Power Supply – Demand Balance

Difficult to predict and control
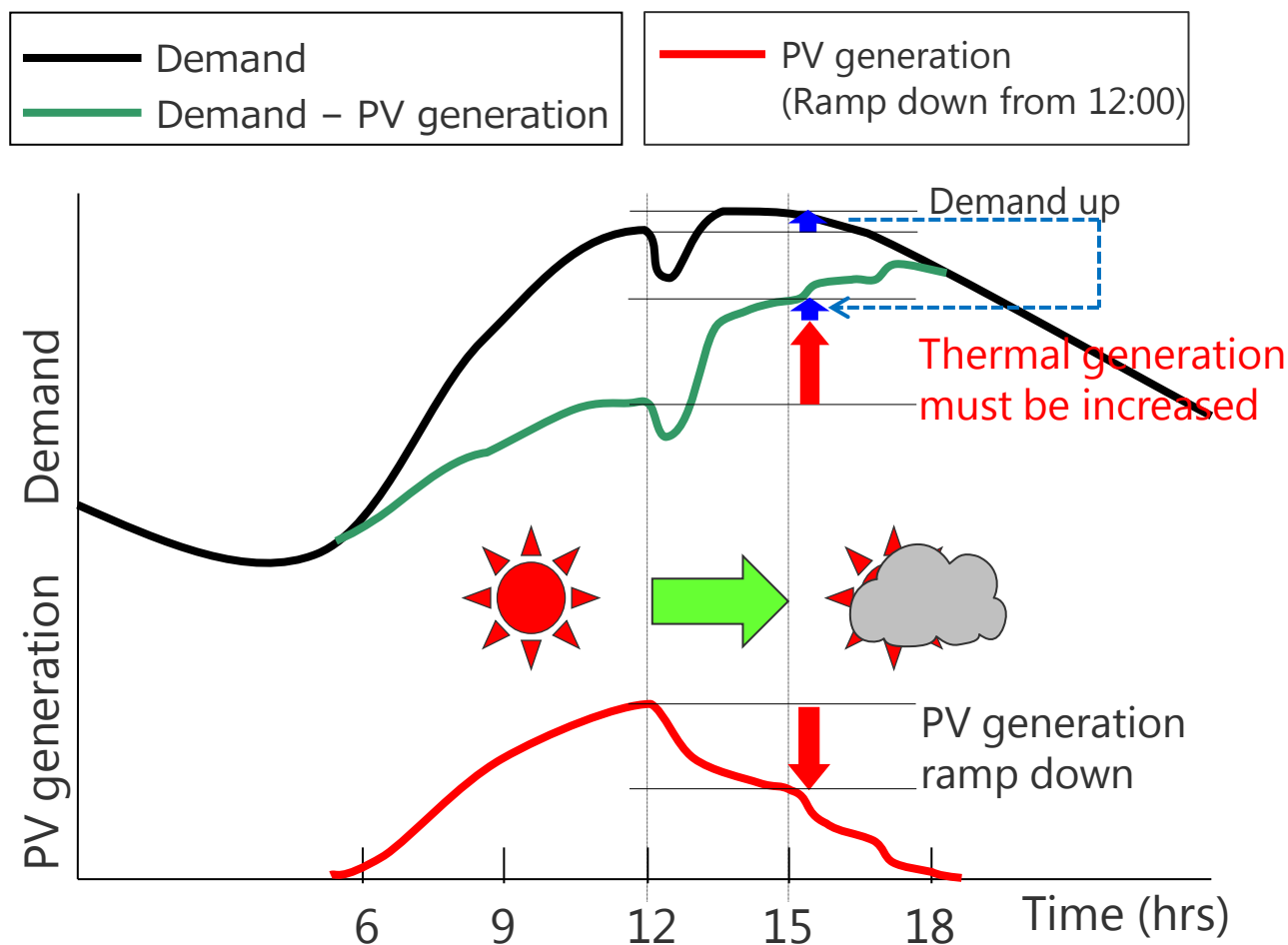
PV

Frequency

60
61   59
(Hz)

Possible to control

Possible to predict
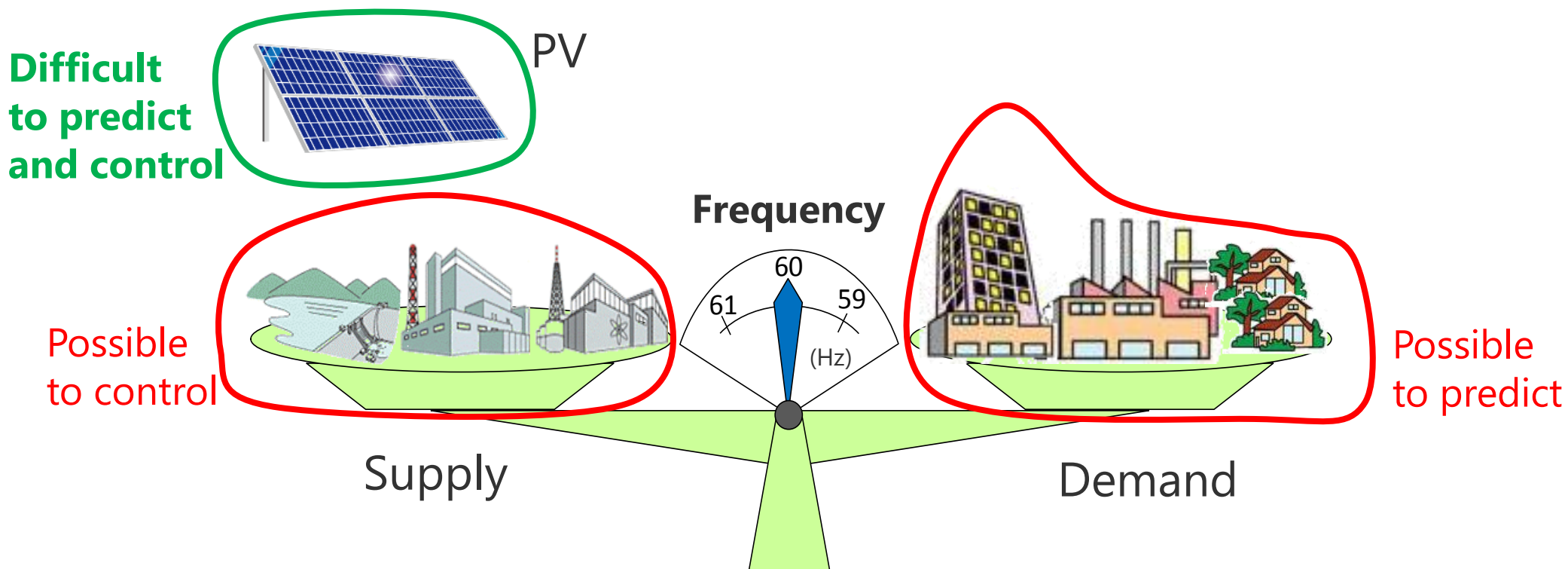
Supply

Demand

If the balance of demand and supply is lost, system frequency fluctuates, resulting in problems such as unstable operation of generation plants and electrical devices.

Necessity of PV Generation Prediction

Legend:
- ── Demand
- ── Demand – PV generation
- ── PV generation (Ramp down from 12:00)

Demand up

Thermal generation must be increased

PV generation ramp down

Time (hrs): 6 9 12 15 18

Ex. Area-wide PV Generation Decrease (Ramp down) from 12:00

If area-wide generation of the PV systems decreases, the generation from other sources like thermal power plants must be increased.

but,

When a power company starts to operate a reserved thermal power plant, it may take ten or more hours to start delivering power from its cold start depending on the type of thermal plant.

therefore,

Accurate predictions of area-wide generation of the PV systems are required.

Necessity of Solar Irradiance Forecast

As the power variation of PV systems heavily depends on the solar irradiance, accurate forecasts of the area-wide solar irradiance are highly important.
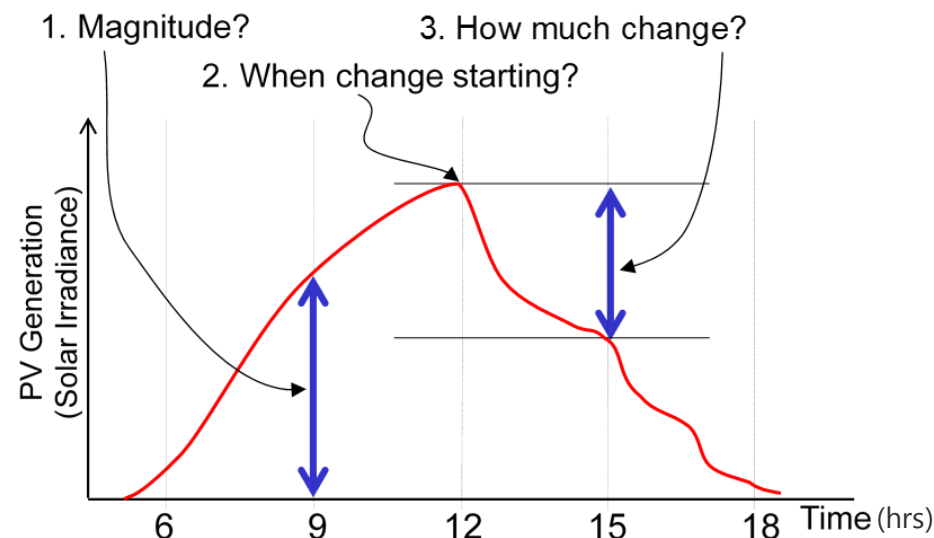
Data Input
- ✓ Meteorological data
- ✓ Pyranometer data
  ,etc.

➡️

Solar Irradiance Forecast
Several hours ~ a week ahead forecasting

➡️

PV Generation Prediction
Several hours ~ a week ahead prediction

A day ahead forecast is significant for planning of thermal power plant operation.

Theme of this paper

A day ahead forecast

1. Magnitude?   3. How much change?
2. When change starting?

PV Generation (Solar Irradiance)

6   9   12   15   18   Time (hrs)

Method 1

Developed by **Japan Weather Association (JWA)**

GSM, MSM Initial Time	12 UTC (21:00 at local time)
Providing Time	05:00 (at local time)
Forecast Range	The next day 00:00 ~ 24:00 (at local time)
Forecast Solar Irradiance	Every 30 minutes (average)
Grid Spacing	1km
Calculation Time	4 hours from the reception of GSM & MSM data
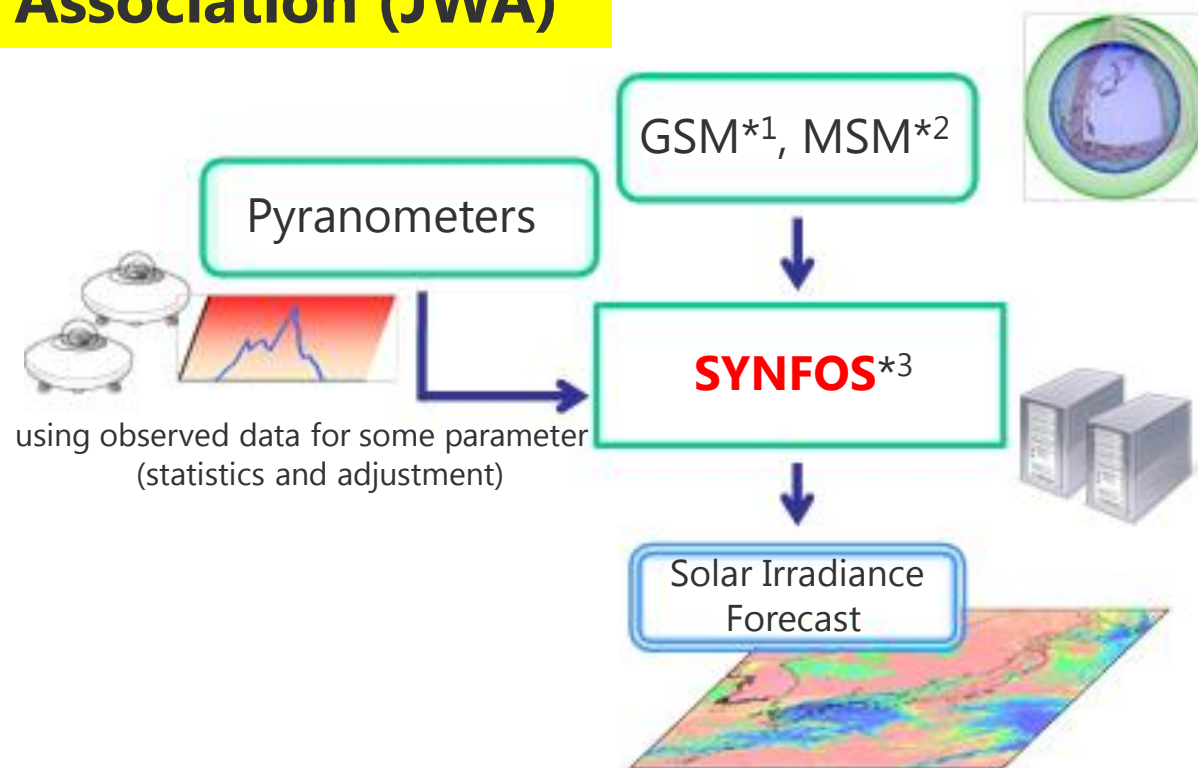
GSM[1], MSM[2]

Pyranometers

using observed data for some parameter (statistics and adjustment)

SYNFOS[3]

Solar Irradiance Forecast

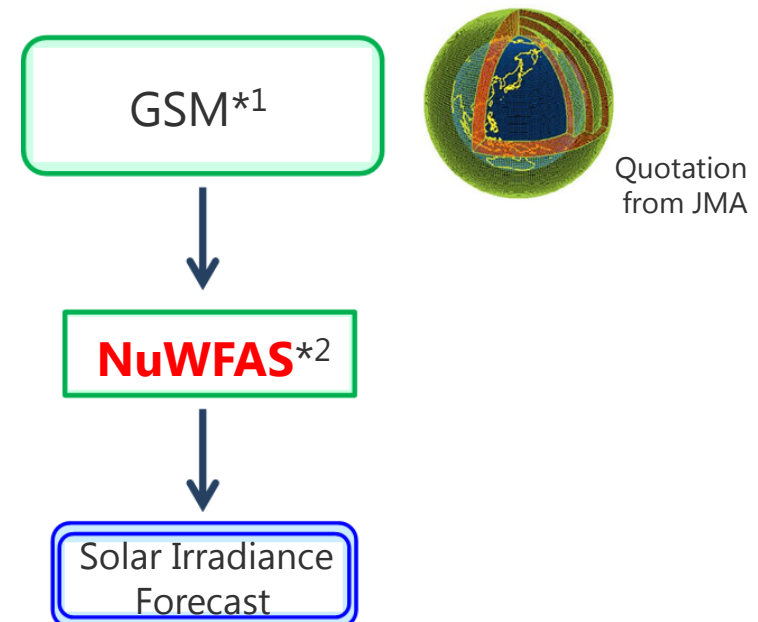[1] GSM : Global Spectral Model provided by Japan Meteorological Agency (JMA)
[2] MSM : Meso-Scale Model provided by JMA
[3] **SYNFOS** : JWA's Synnefo[4] Numerical Forecasting System ([4]: "Cloud" in Greek)

Method 2

Developed by Central Research Institute of Electric Industry (CRIEPI)

GSM Initial Time	12 UTC (21:00 at local time)
Providing Time	05:30 (at local time)
Forecast Range	The next day 00:00 ~ 21:00 (at local time)
Forecast Solar Irradiance	Every 30 minutes (average)
Grid Spacing	5km
Calculation Time	4 hours from the reception of GSM data

GSM*1

↓

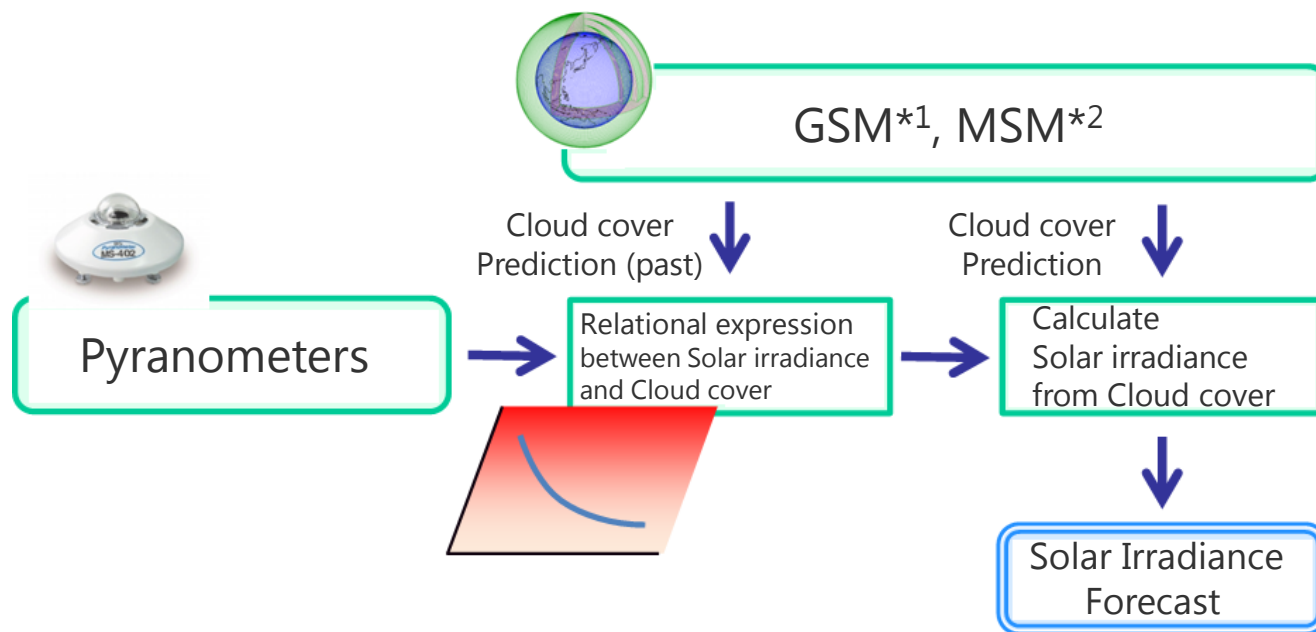**NuWFAS***2

↓

Solar Irradiance Forecast

Quotation from JMA

*1 GSM : Global Spectral Model provided by Japan Meteorological Agency (JMA)
*2 **NuWFAS** : CRIEPI's Numerical Weather Forecasting and Analysis System

Method 3

Developed by ITOCHU Techno-Solutions Corporation (CTC)

GSM Initial Time	18 UTC (03:00 at local time)
MSM Initial Time	21 UTC (06:00 at local time)
Providing Time	09:30 (at local time)
Forecast Range	The next day 00:00 ~ 24:00 (at local time)
Forecast Solar Irradiance	Every 30 minutes (average)
Grid Spacing	5km
Calculation Time	20 minutes from the reception of GSM & MSM data

GSM*1, MSM*2

Cloud cover Prediction (past)

Cloud cover Prediction

Pyranometers → Relational expression between Solar irradiance and Cloud cover → Calculate Solar irradiance from Cloud cover → Solar Irradiance Forecast

*1 GSM : Global Spectral Model provided by Japan Meteorological Agency (JMA)
*2 MSM : Meso-Scale Model provided by JMA

RMSE (Root Mean Squared Error)

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(FORE_i - OBS_i)^2}$$
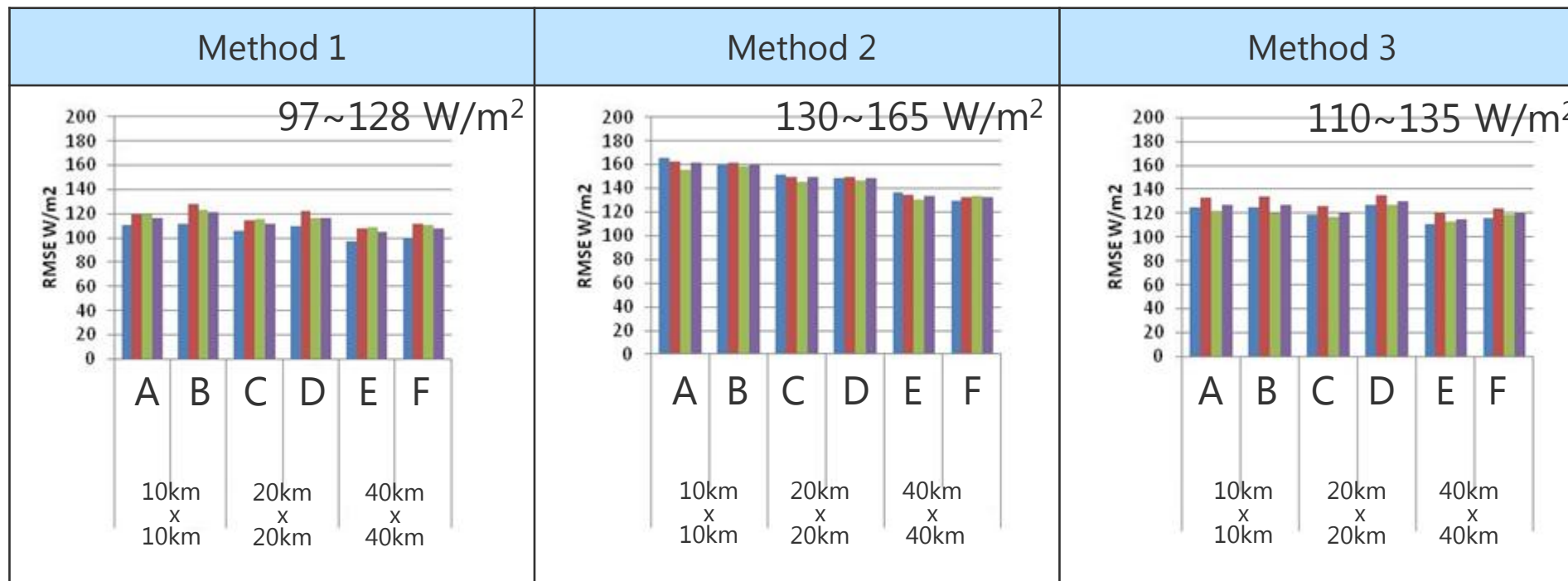
FORE : Forecast
OBS : Observed
N: Data Number

Area A, C, E

Area D, F

Area B

130km   260km
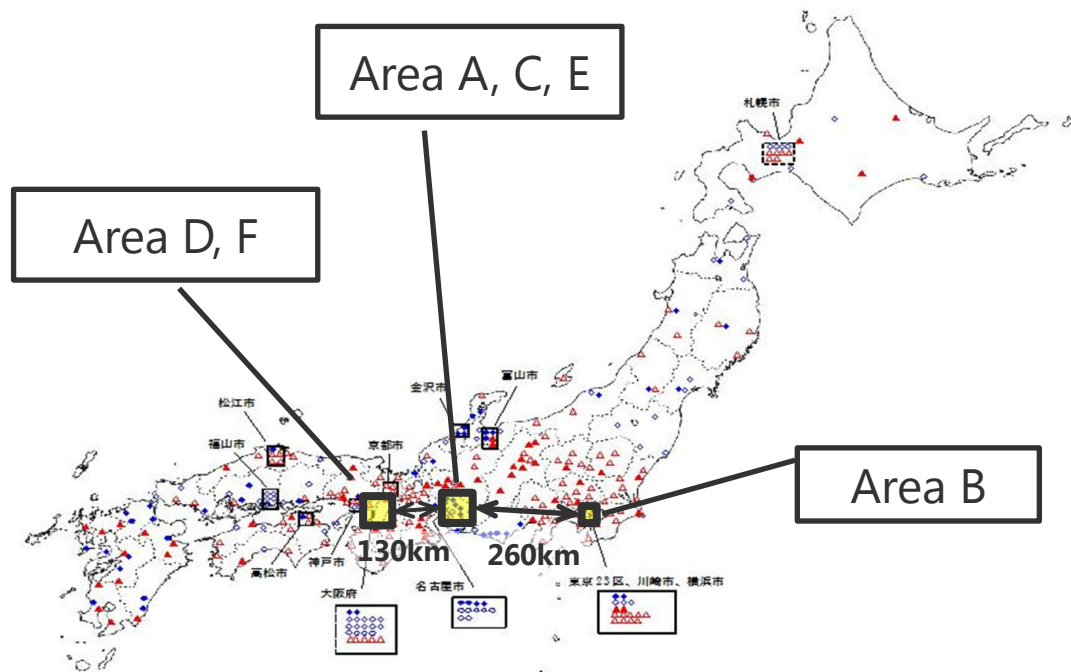
Evaluation condition	
Period	Nov, 2010 ~ Oct, 2013
Time	06:00 ~ 18:00 (at local time) (Sunrise to sunset only)
Observed	Average of all pyranometers in evaluation area

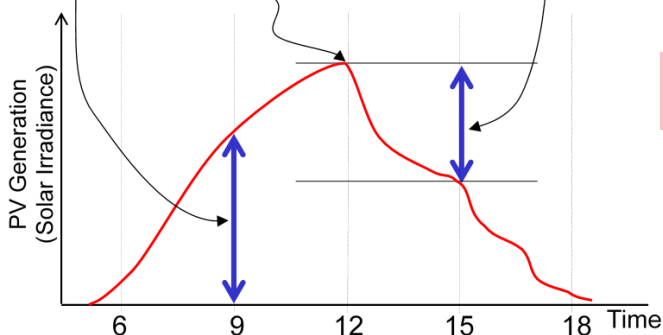| Area size		Area name	Number of pyranometers
10km x 10km	A	Central of Nagoya city	5
	B	Surrounding of Yokohama city	5
20km x 20km	C	Nagoya city	10
	D	Osaka city	9
40km x 40km	E	West of Aichi prefecture	14
	F	Surrounding of Osaka city	20

The yearly RMSE of a day ahead forecast : 100~160[*1] W/m^2

RMSE (Root Mean Squared Error)

*1 : Extraterrestrial solar radiation 1,370 W/m^2

Method 1	Method 2	Method 3
97~128 W/m^2	130~165 W/m^2	110~135 W/m^2

1. Magnitude?
2. When change starting?
3. How much change?

PV Generation (Solar Irradiance)

6 9 12 15 18 Time

However,
We confirm the daily error,
there are large forecast errors
by the weather condition.

Legend
- Nov, 2010 ~ Oct, 2011
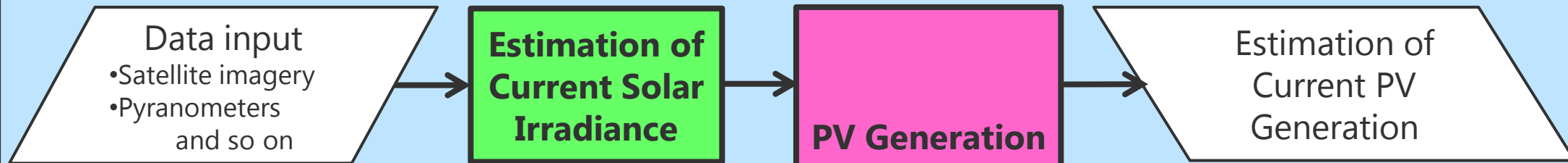- Nov, 2011 ~ Oct, 2012
- Nov, 2012 ~ Oct, 2013
- TOTAL

✓ We have developed solar irradiance forecast methods using meteorological data.

✓ The yearly RMSE of a day ahead forecast of the developed methods was found to be 100~160 Watt/m^2.

✓ We continue improving the forecast methods to reduce the error.

✓ The developed methods have been adopted by several electric power companies in Japan.

✓ The development results are serving as a benchmark for the solar irradiance forecast field.

CHUBU Electric Power

This work is carried out as a part of the demonstration project of forecast technology for photovoltaic generation subsidized by Ministry of Economy, Trade, and Industry, Japan.
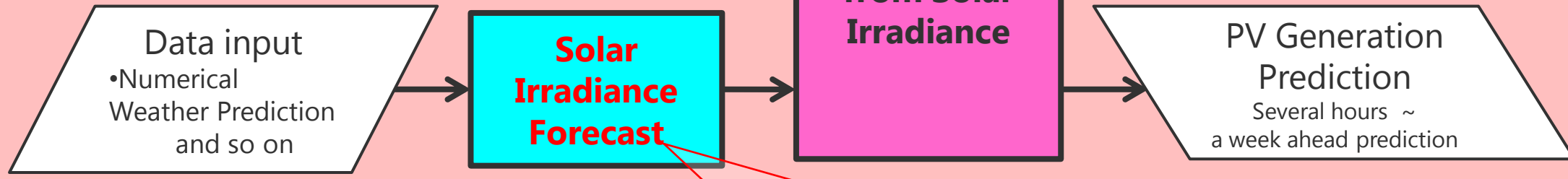
(From Aug, 2011 to Mar, 2014)

Research & Development Contents

1. Estimation of Current PV Generation

| Data input · Satellite imagery · Pyranometers and so on | → | **Estimation of Current Solar Irradiance** | → | | → | Estimation of Current PV Generation |

PV Generation Calculation from Solar Irradiance

2. Prediction of PV Generation

| Data input · Numerical Weather Prediction and so on | → | **Solar Irradiance Forecast** | → | | → | PV Generation Prediction Several hours ~ a week ahead prediction |

In this paper, a day ahead forecast is presented.

Demonstration Project Members

- The University of Tokyo

  Prof. Kazuhiko OGIMOTO (Project Leader)

- ITOCHU Techno-Solutions Corporation
- Solar Frontier K.K
- Japan Weather Association
- Hitachi, Ltd.
- Mitsubishi Electric Corporation
- Central Research Institute of Electric Industry

- Hokkaido Electric Power Co., Inc.
- Tohoku Electric Power Co., Inc.
- Tokyo Electric Power Company Holdings, Incorporated
- TEPCO Power Grid, Incorporated
- CHUBU Electric Power Co., Inc.
- Hokuriku Electric Power Company
- The Kansai Electric Power Company, Incorporated
- The Chugoku Electric Power Co., Inc.
- Shikoku Electric Power Company, Incorporated
- KYUSHU ELECTRIC POWER CO. INC.
- The Okinawa Electric Power Company, Incorporated

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