Applications of and Model Post-processing of JMA-NHM

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Training Workshop on the Latest Developments on the Use and Interpretation of NWP Models

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JMA

Purposes of this lecture

- To understand the necessity and the technique of making the “Guidance”.
- To understand the methods of making the “Guidance”.
- To introduce the guidance actually used in JMA.

Contents

- 1 Purpose for introducing “Guidance” (post process of NWP model output)
- 2 Methods to make guidance
- 3 Example and Use of guidance in JMA

Flow of forcasting

Observation

↓

Analysis

↓

* NWP : Numerical Weather Prediction

NWP* model

↓

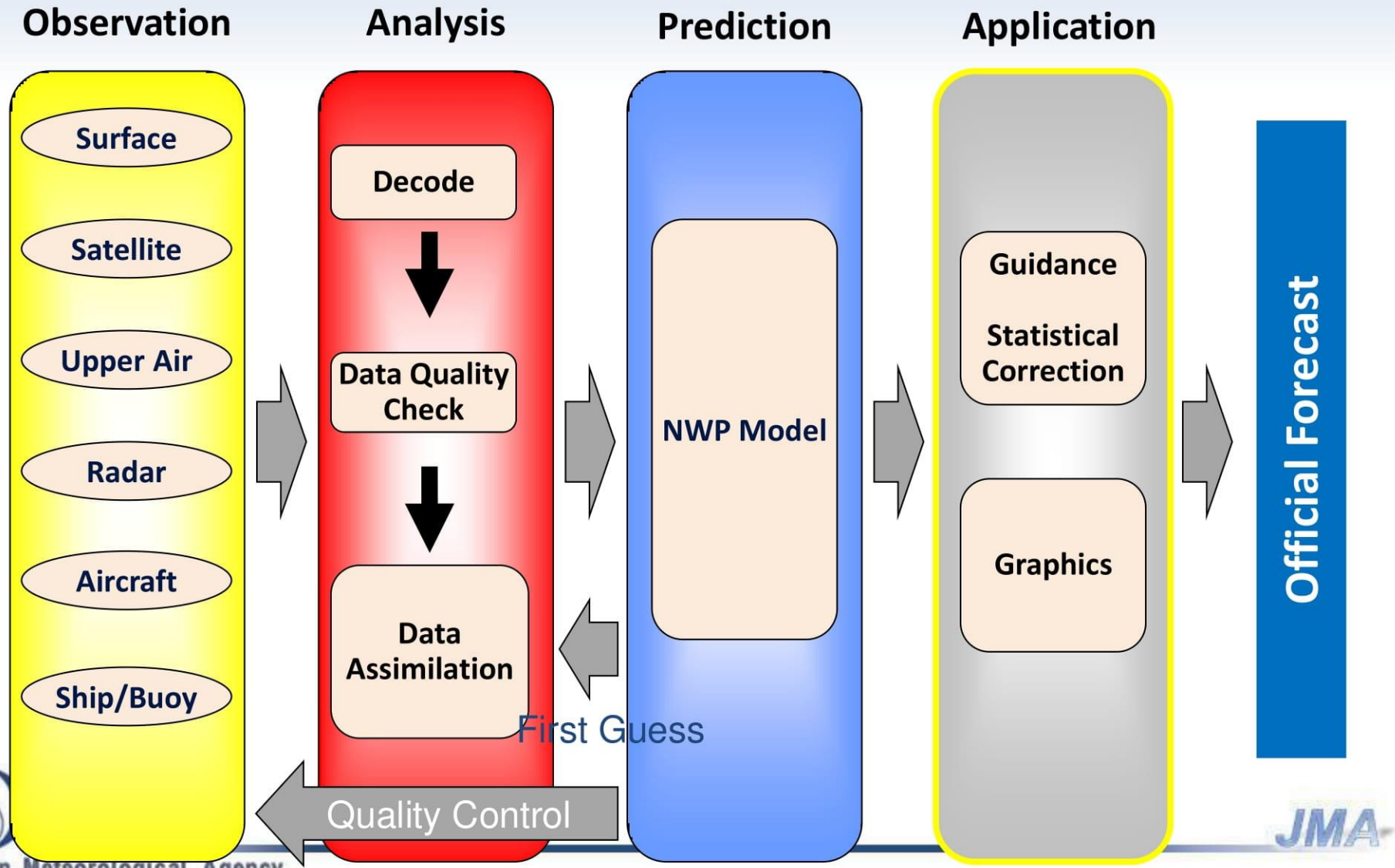
?

Can we use always NWP model output directly?

↓

Forecaster

Numerical Analysis and Prediction System (NAPS)



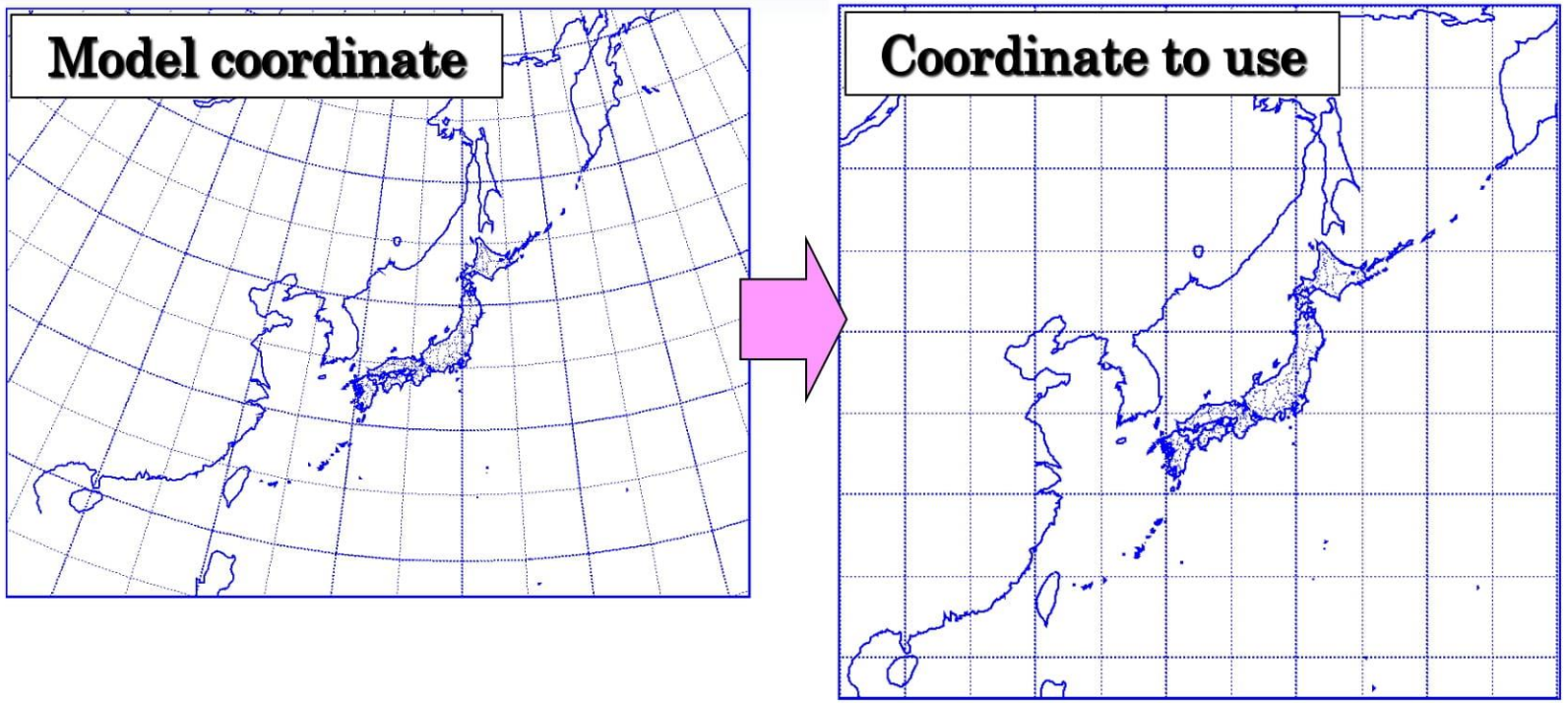
Purpose and kind application

- **Conversion into the form to be needed for forecast**
  - Conversion procedures of model output
    - Ex.) Model coordinate
    - Ex.) Air temperature and mixing ratio
  - Visualization of model outputs
    - Ex.) Facsimile charts, graphics for WEB

- **Improvement of accuracy with statistical methods, and translation of model outputs into other weather elements**
  - Guidance

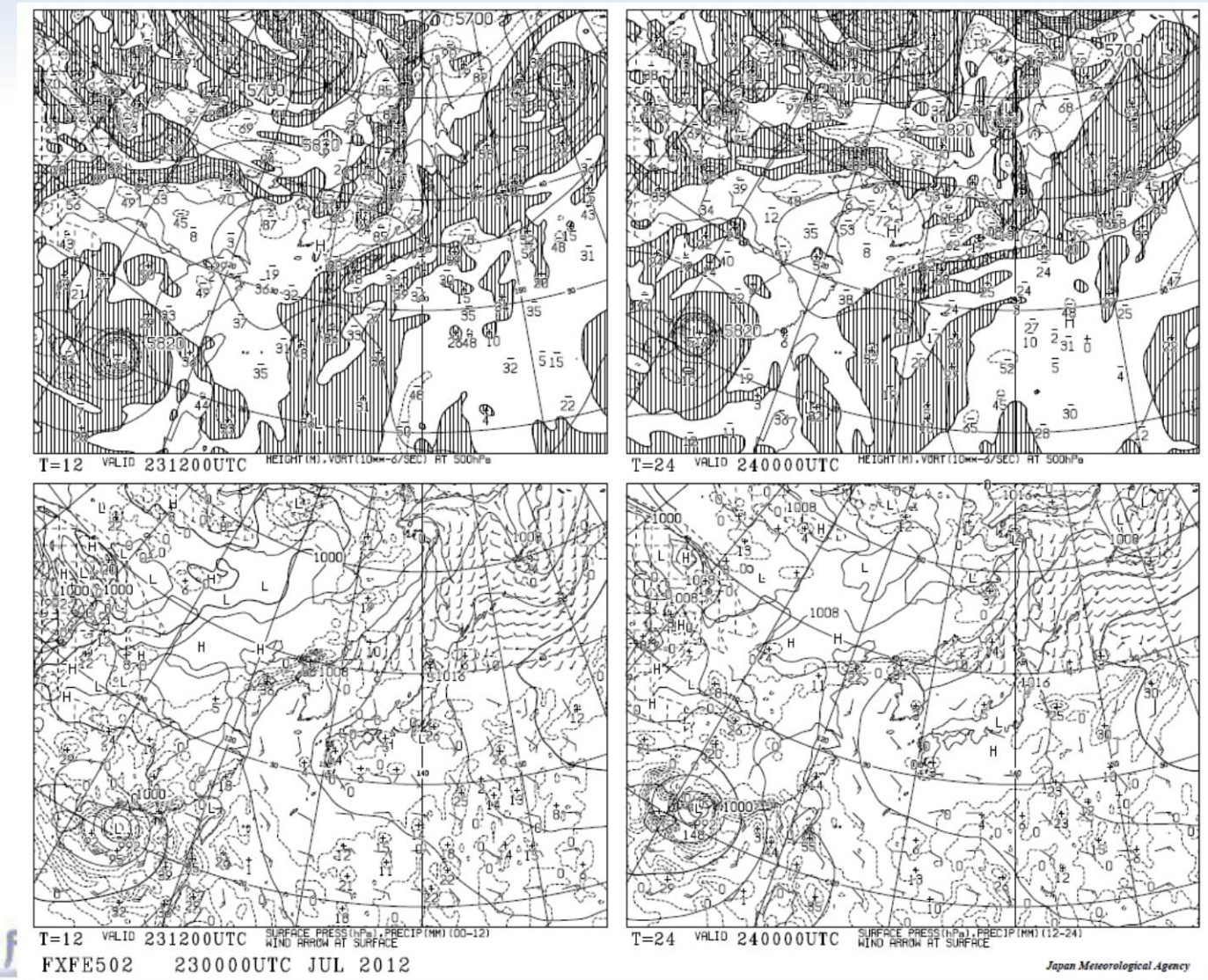
Example of processing of NWP model output

Conversion of coordinate



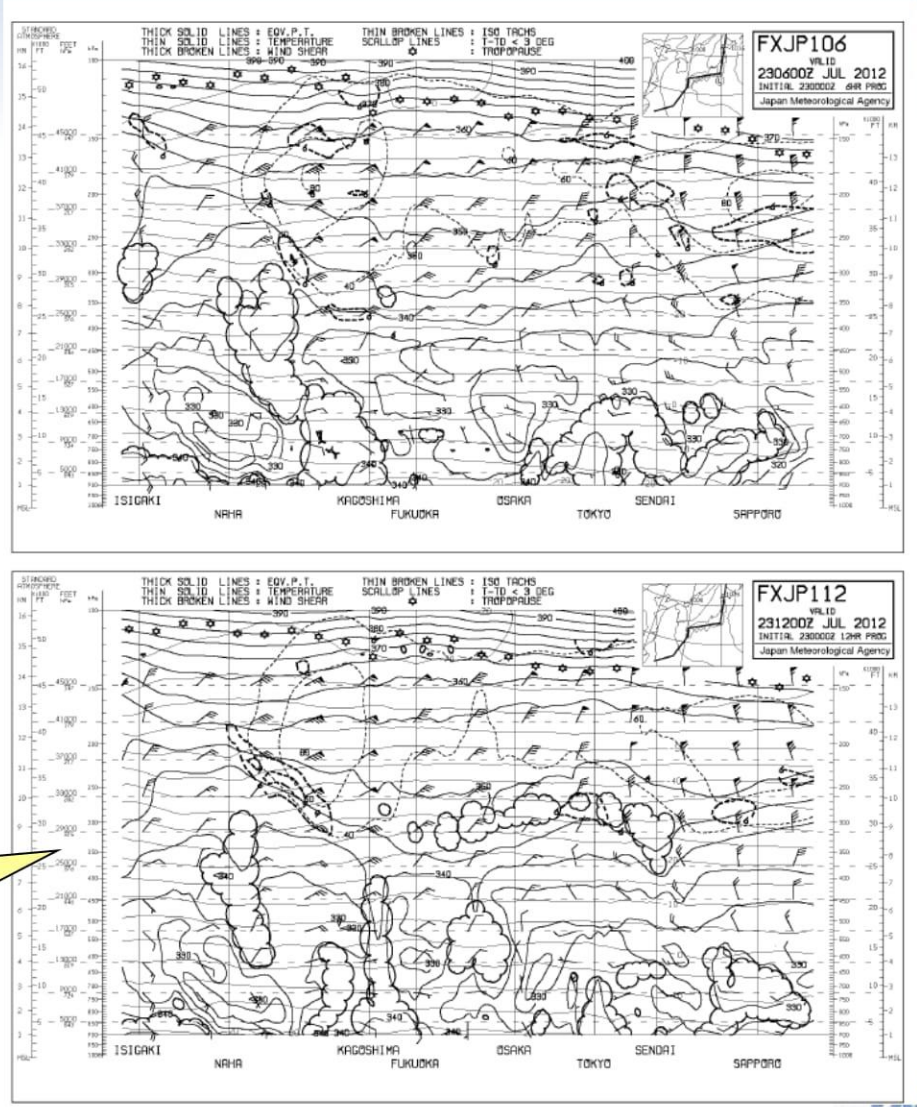
- The model coordinate is converted into the form to be needed by users. For example, rectangular coordinate of latitude and longitude is used in the maps for disaster prevention.

Visualization — Facsimile chart of NWP model



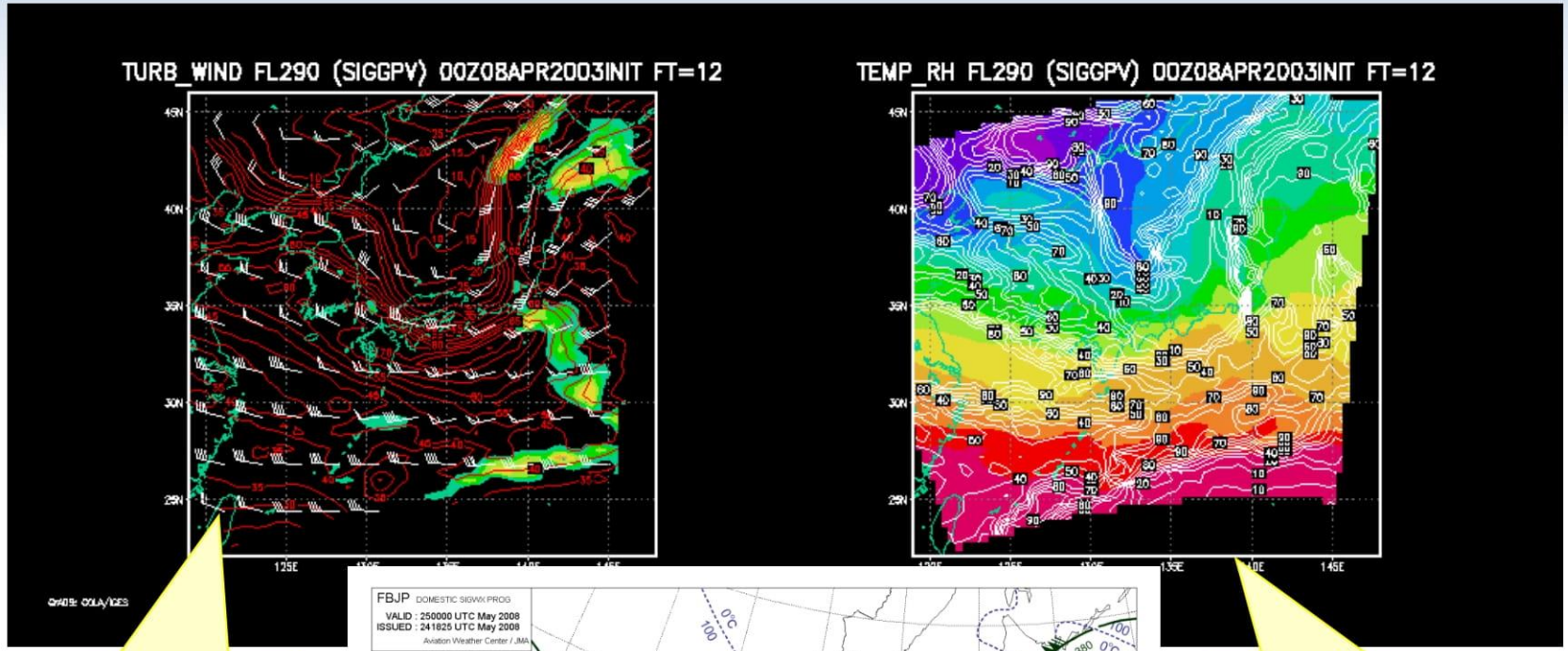
Facsimile Charts for flight operation

- Cross section chart of forecast along en-route for domestic flight (FT=06, 12)
- temperature, equivalent potential temperature, T-Td, wind, vertical wind shear, isotachs, and tropopause



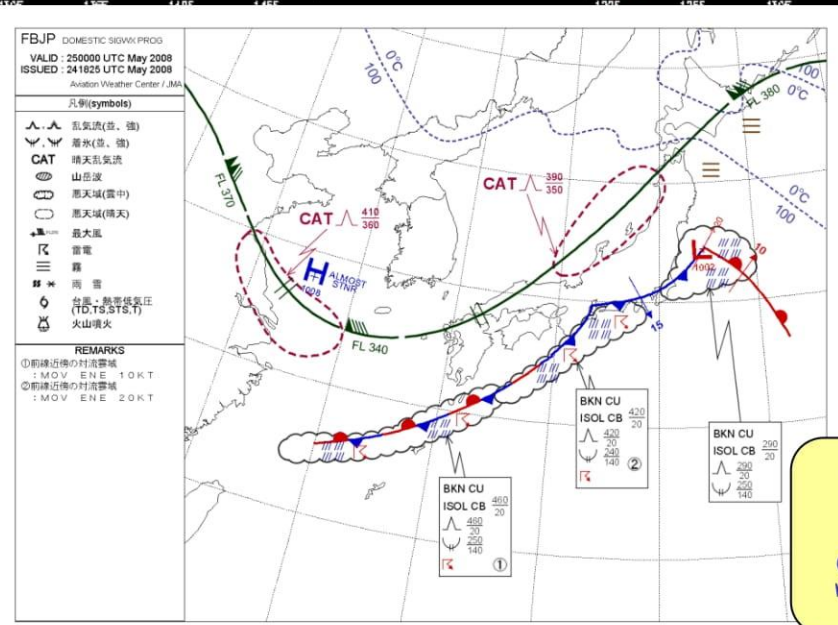
Used by forecasters and operators

GPV of Significant Weather



turbulence, wind

relative humidity, temperature



Used by domestic SIGWX Prog chart

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Why is the Guidance needed?

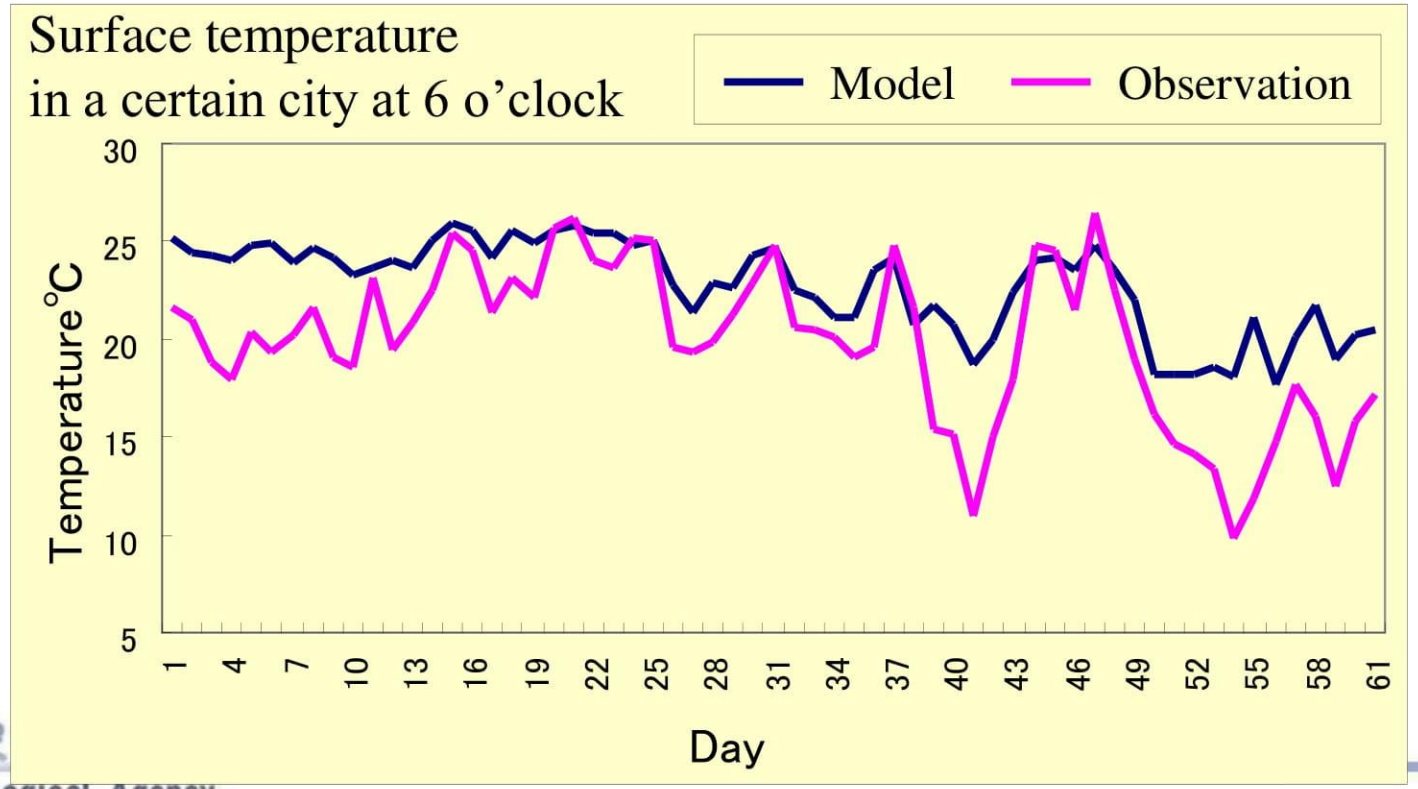
- **(1) Some elements that the model does not predict will be needed.**
  - Objective translation makes a Product to meet a demand for forecast
    - Categorized weather (fine, cloudy, rainy…)
    - Probability of precipitation
    - Probability of thunderstorms
    - Visibility, and so on

Why is the Guidance needed?

- **(2) Some errors are included in the model output.**
  - NWP models have **systematic biases** caused by **Errors in initial field**, **limit of resolution**, and **approximation in dynamical and physical process** … etc.
  - **The guidance** is a technology that appropriately **removes the systematic error** of the NWP models' output.
  - To correct model's error leads improvement of the accuracy of forecasting products.
    - Precipitation amount
    - Wind (speed, direction)
    - Temperature (max., min.), and so on

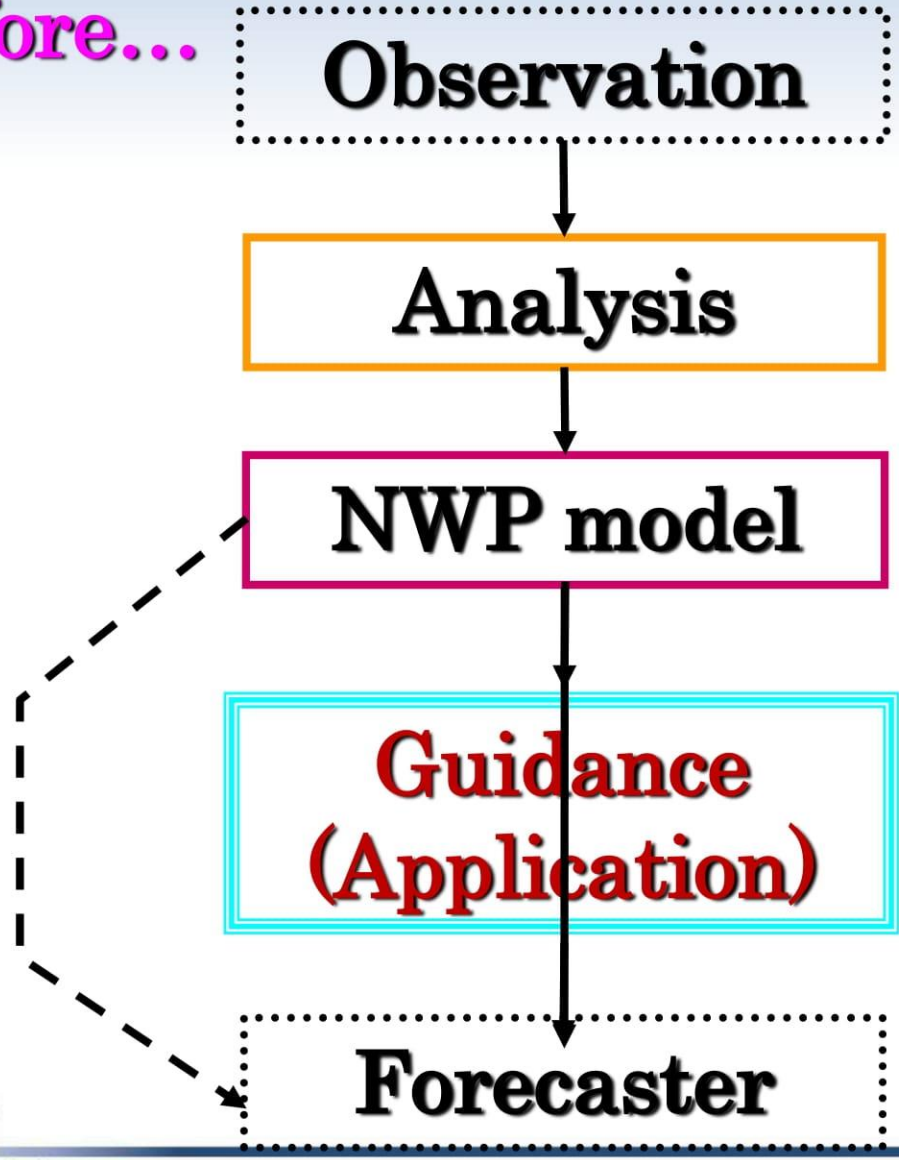
Why is the Guidance needed?

- If we can use the NWP model output directly, there is no need to use the Guidance.
- However, we cannot use it directly, because…



Flow of forecasting

Therefore…



Correction of the errors of model outputs, and translation of model outputs into weather elements.

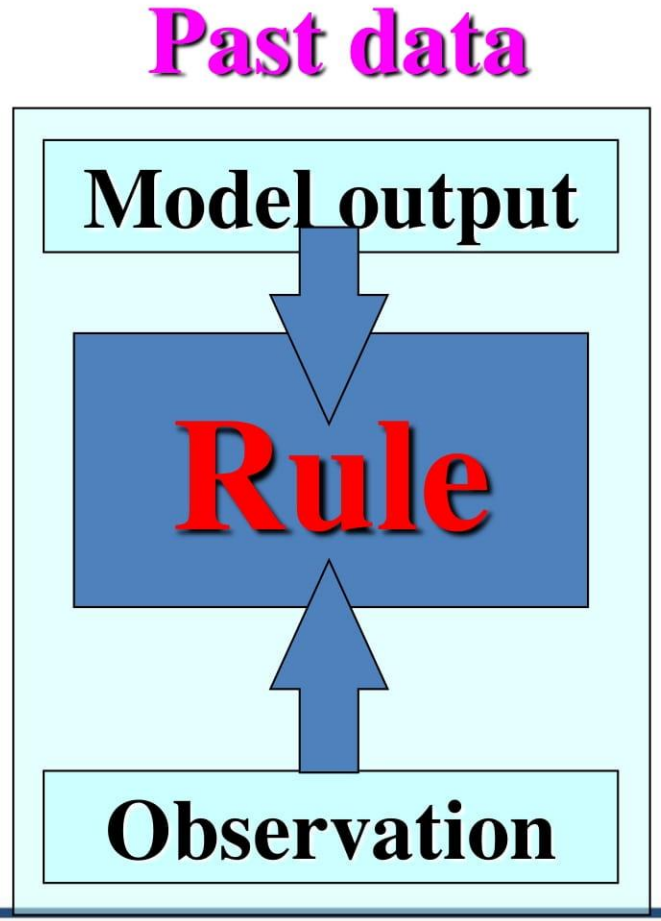
Difference of data used for the rule making

- **To make the guidance products is to make *"Rules of translation"***

- **The *"Rule of translation"* is made with the predicted weather of NWP model and the actual weather (observation).**

Rule of translation

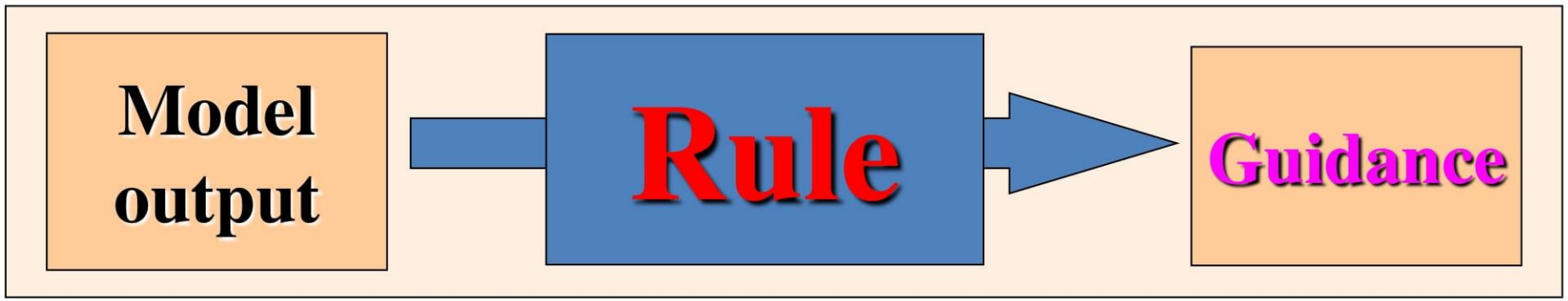
1. Make the rule with the past data of model output and observation.



Rule of translation

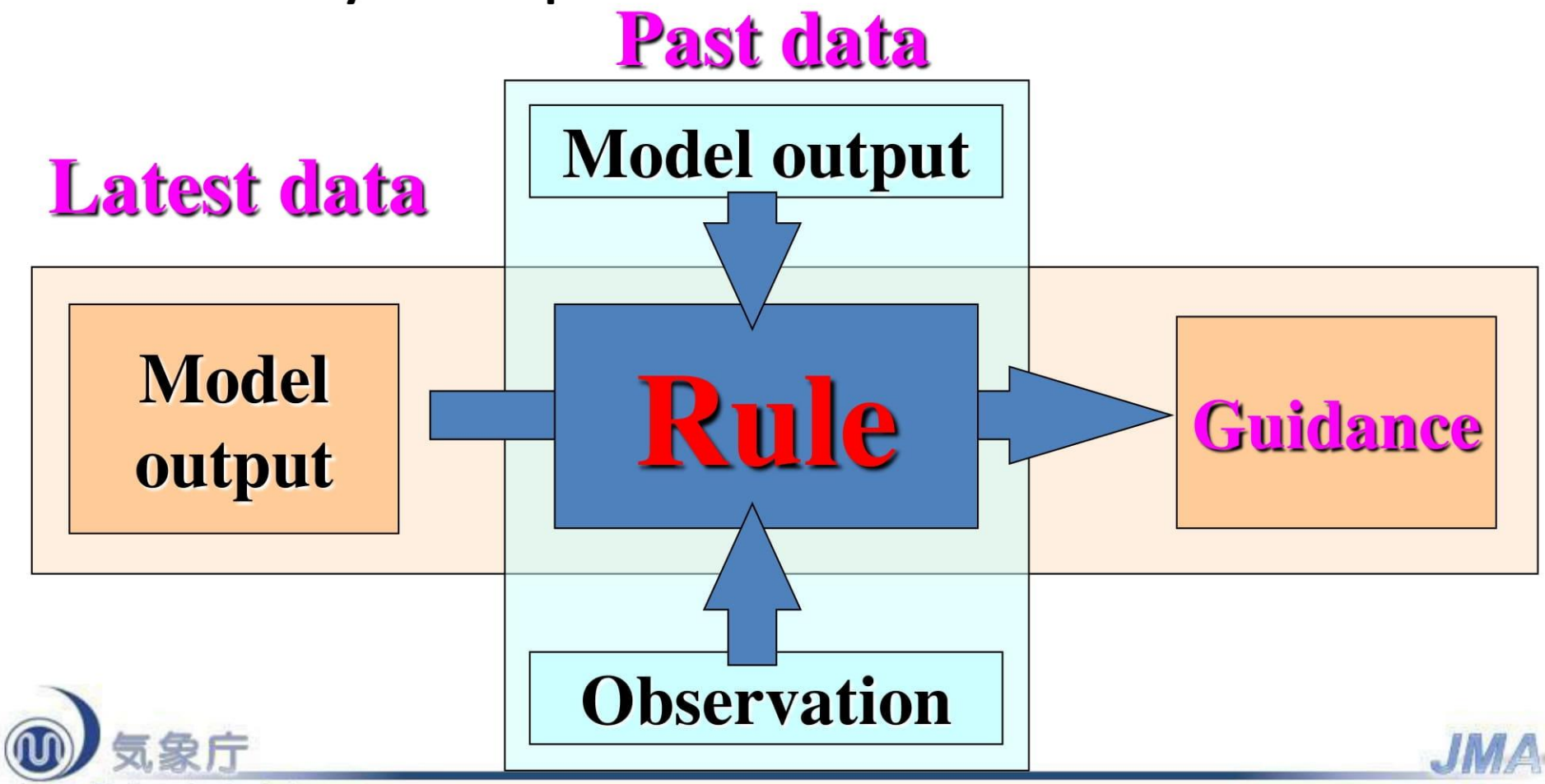
2. Forecast with the rule applying the latest model output.

Latest data



Rule of translation

1. Make the rule with the past NWP model output and observation data.
2. Modify the output with the rule.



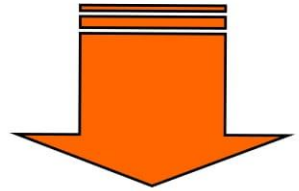
Correct model's error

Systematic errors in NWP model

【Examples of the situation】

- The surface temperature predicted by NWP model is **always lower by 5 degrees** compared with the observation.
- **Precipitation** of forecast by the model is **less** compared with that of observation, **whenever surface wind direction is southwest.**

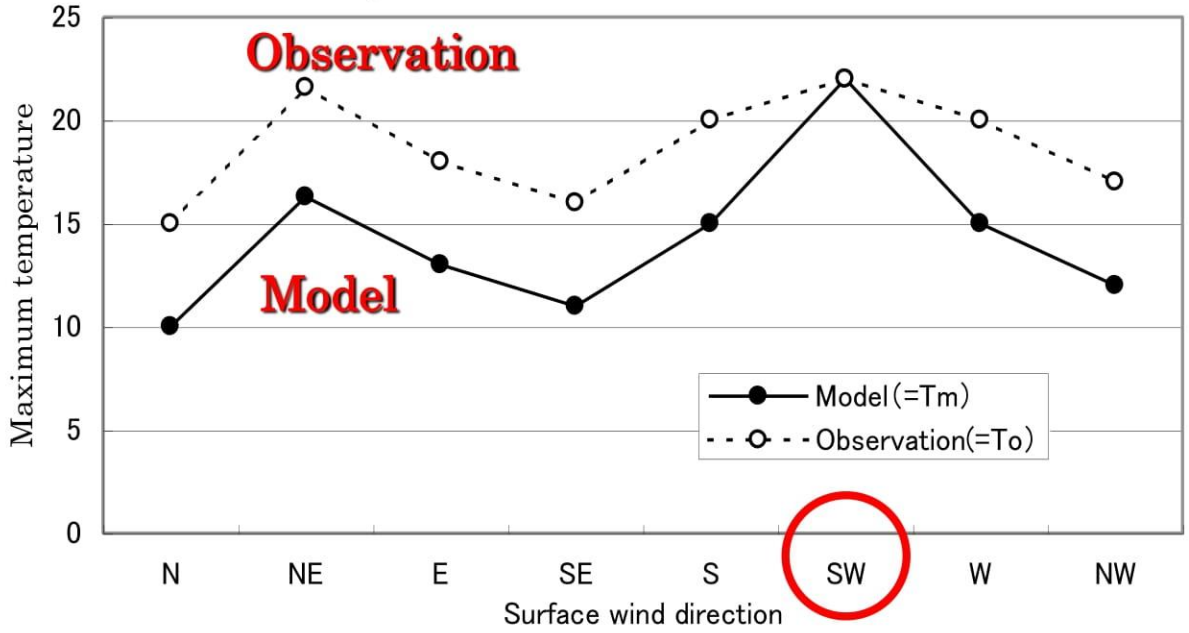
If these characteristics are found, then ...



These errors can be corrected.

Correct model's error

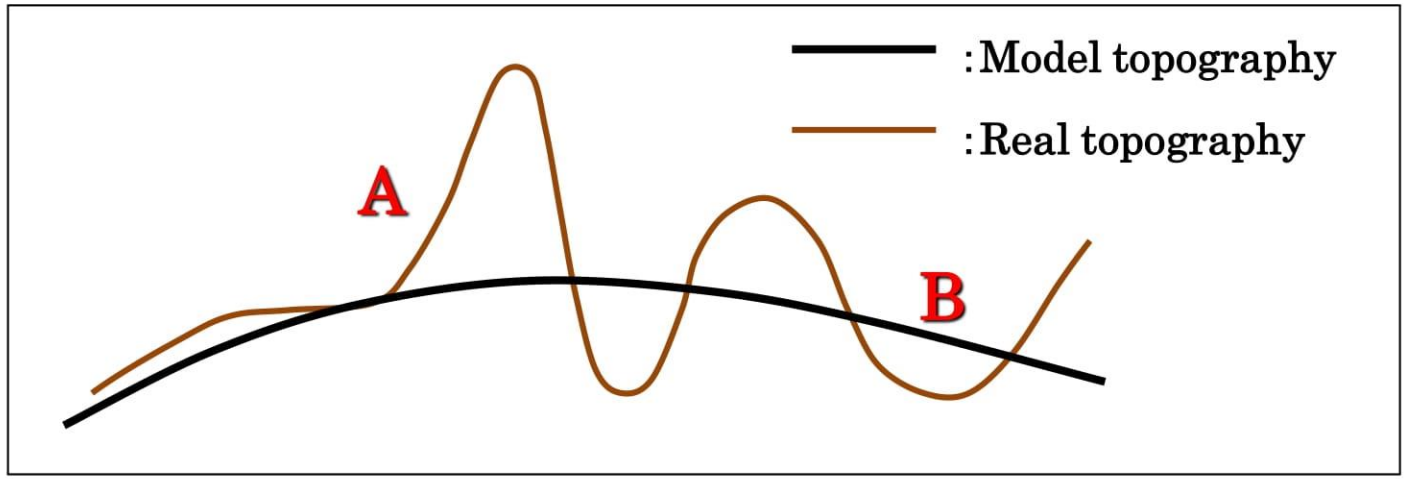
Fig. Relationship between maximum temperature and surface wind direction at an observatory.



- Systematic errors are found in the upper figure, i.e.
- Generally, temperatures of the model (T_m) are lower than that of observations (T_o) by 5 degrees.
- $T_m = T_o$ when the surface wind direction is southwest (SW).

Correct model's error

Difference of the effects of topography due to the model resolution.

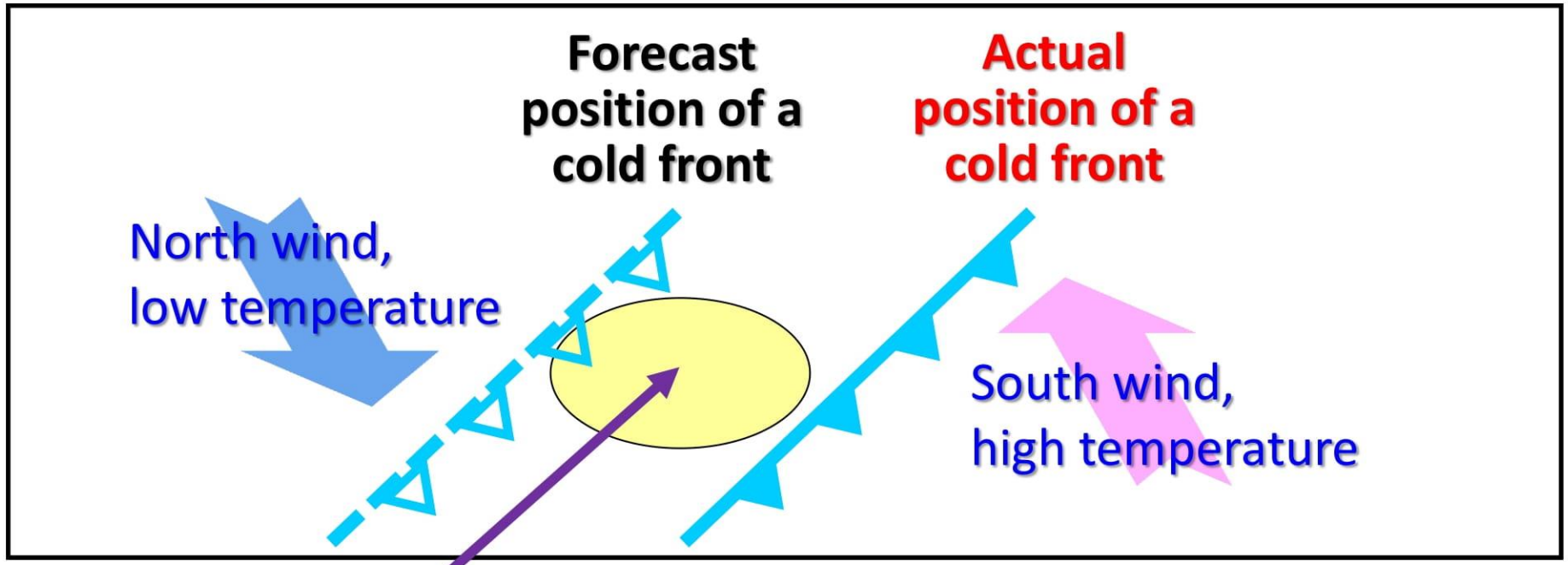


Point A : actual hilside is steeper than model's
→ rain is heavier than that of model output
Point B : valley (in real terrain) and slope (in the model)
→ higher temperature and weaker wind
(than those of model output)

Random errors in NWP model

The errors of the forecast field of the model affects the accuracy of the guidance.

Ex.) Forecast error in the position of cold front



Forecast : South wind, Warm
Actual : North wind, Cold

It is impossible to correct this error with the guidance.

Translation of model output

Variables in NWP model output
(Grid Point Value [GPV])

Pressure, height, wind, temperature, humidity,…
on surface, 925hPa, 850hPa, 700hPa, 500hPa,…

Translation

Variables (not calculated in NWP model directly)

- Categorized weather (fine, cloudy, rainy…)
- Probability of precipitation
- Probability of thunderstorms
- Snowfall amount
- Visibility, …

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- 1 Purpose for introducing “Guidance” (post process of NWP model output)
- **2 Methods to make guidance**
- 3 Example and Use of guidance in JMA

Methods to make Guidance

- **Methods to make "Rules"…**
  - **Multiple Regrassion Analysis**
  - **Kalman Filter**
  - **Neural Network**
  - **Logistic Regression**

Multiple Regression Analysis

as one of the method for the guidance.

$$Y = X_{\mathrm{o}} + \Sigma X_{\mathrm{i}} \times C_{\mathrm{i}} \ (i = 1,\ 2,\ 3,\ \ldots)$$

Y: Predictand (temperature, probability of precipitation, …)

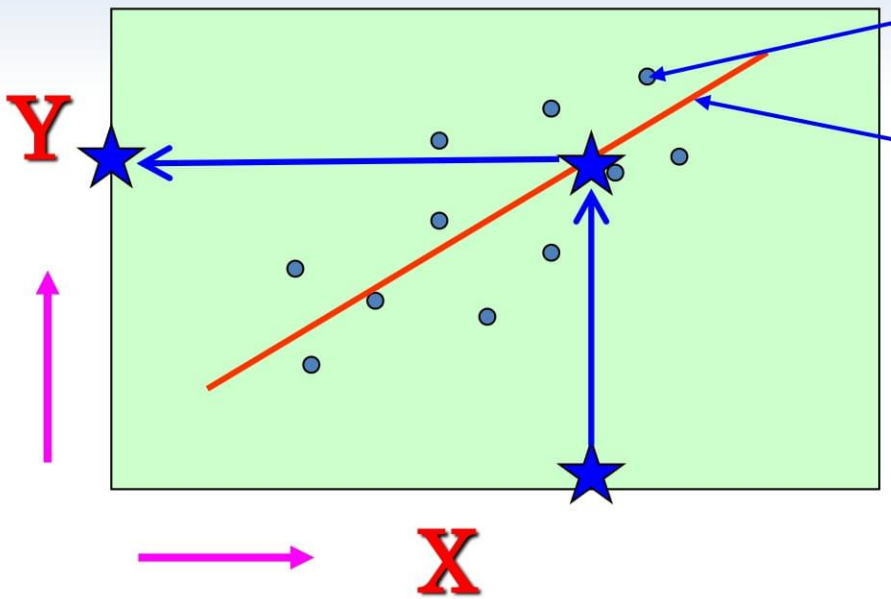
X_i: Predictors (NWP model output)

C_i: Regression coefficients

Sufficient data (of 2 or 3 years) are needed for deciding values of C_i.

How can we decide C_i values?

Example of regression analysis with 2 variables.



Given data set

$$Y = C_0 + C_1 X$$

(regression equation)

means a line fitting best the given data set.

- When a new X value is given,
  "Y of the point on the line corresponding to X" is the most suitable.
- Presumption of "method of least squares"

Characteristics of multiple regression

- **Merit:**
  - 1. Easy to make.
  - 2. Backgrounds of the forecast value are comprehensible.
  - 3. Selection of the predictors is objective.

- **Demerit:**
  - 1. Not possible to apply to the change of numerical prediction model.
  - 2. A large amount of data is necessary to make.

- **Usage:**
  - Almost not used as a method to make guidance in JMA recently.

Characteristics of multiple regression

- When the NWP model is replaced,
  "Translation rule" should be also remade.

- To grasp the characteristics of the new model, there will be sufficient period (2 or 3 years).

- The guidance of **successive study** is applicable to the model changes and is used mainly in the recent operations of JMA.

Kalman Filter (outline)

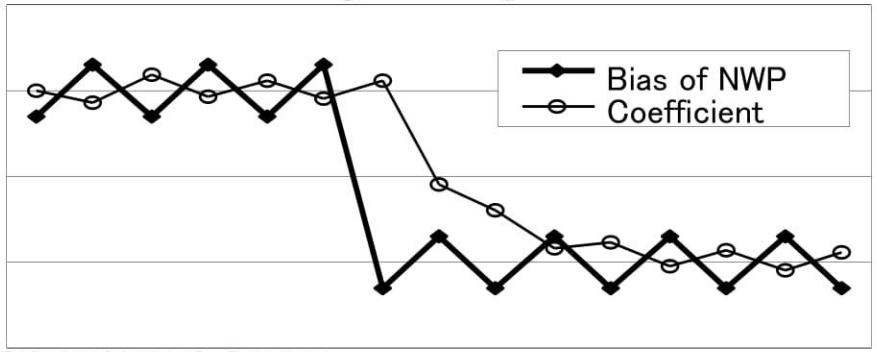
as one of the methods for the guidance.

$$Y = C_0(t) + \Sigma(C_i(t)X_i) \ (i = 1,\ 2,\ 3,\ \ldots)$$

Y: Predictand (temperature, probability of precipitation, …)
Xi : Predictors (NWP model output)
Ci(t) : Regression coefficients

Coefficients are estimated in each step.
— The error of the prediction fomula is evaluated.
— The coefficients are estimated to decrease the error.
— This operation is repeated in each step (initial time of the model).

Coefficient's change of "Temperature Guidance"



In the case of only C_0 is used for the coefficient of the prediction fomula, C_0 changes according to the bias of the model.

Estimation of the coefficients

$$C_{\mathrm{i}}(t) = C_{\mathrm{i}}^{\mathrm{old}} + \delta(t)(Y_{\mathrm{obs}} - Y_{\mathrm{fct}})$$

$\mathbf{C_i(t)}$: Estimated coefficient

$\mathbf{C_i^{old}}$: Used coefficient in forecast eq.

$\mathbf{Y_{fct}}$: Predicted value using $\mathbf{C^{old}}$ ($Y_{\mathrm{fct}} = C_0^{\mathrm{old}}(t) + \Sigma(C_{\mathrm{i}}^{\mathrm{old}}(t)X_{\mathrm{i}})$)

$\mathbf{Y_{obs}}$: Observed value

$\mathbf{Y_{obs} - Y_{fct}}$: Error of the prediction fomula

$\boldsymbol{\delta(t)}$: Rate of change : Kalman gain

Characteristic of Kalman Filter

- **Merit:**
  - 1. Follows automatically to the change of NWP model.
  - 2. Backgrounds of the result of a forecast are comprehensible.
  - 3. Possible to make with a small amount of data.

- **Demerit:**
  - 1. Change of the coefficients makes it difficult to understand the result immediately.
  - 2. Systems such as predictors are set subjectively.

- **Usage**
  - Precipitation amount, Probability of precipitation, Temperature, Wind, Visibility … etc

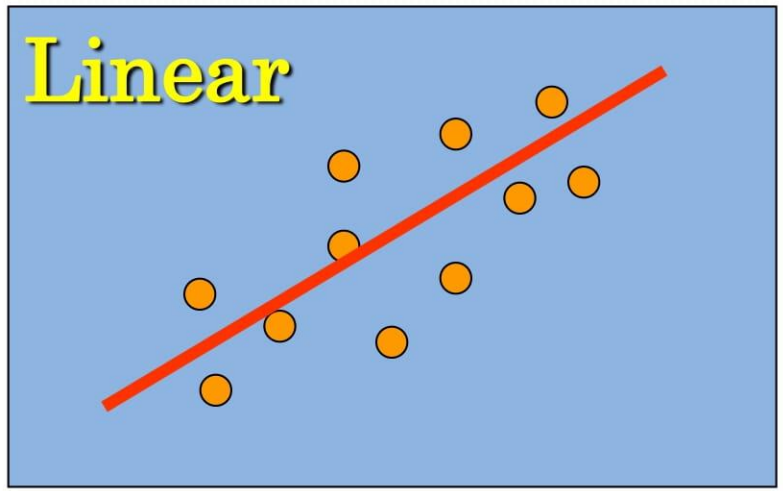
Neural Network (outline)

as one of the method for the guidance.

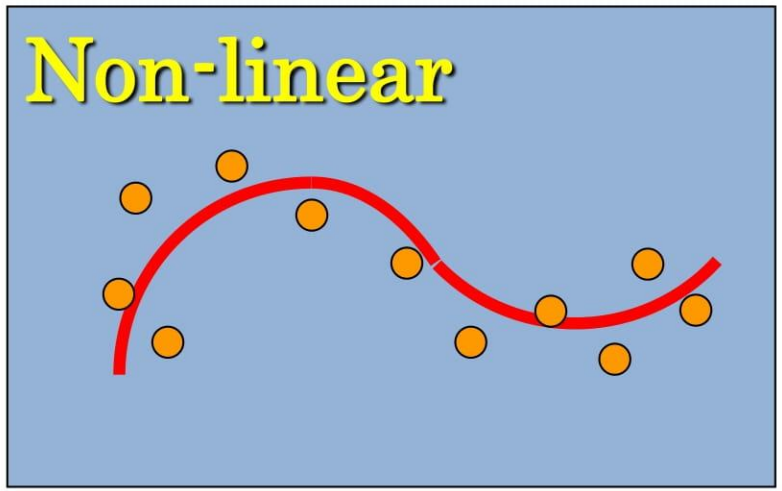
The Neural Network (NRN) is one of the artificial intelligence methods and is an effective technique to analyze non-linear phenomena.

— A non-linear relation can be forecasted.

— prediction fomula can be optimized in each step.



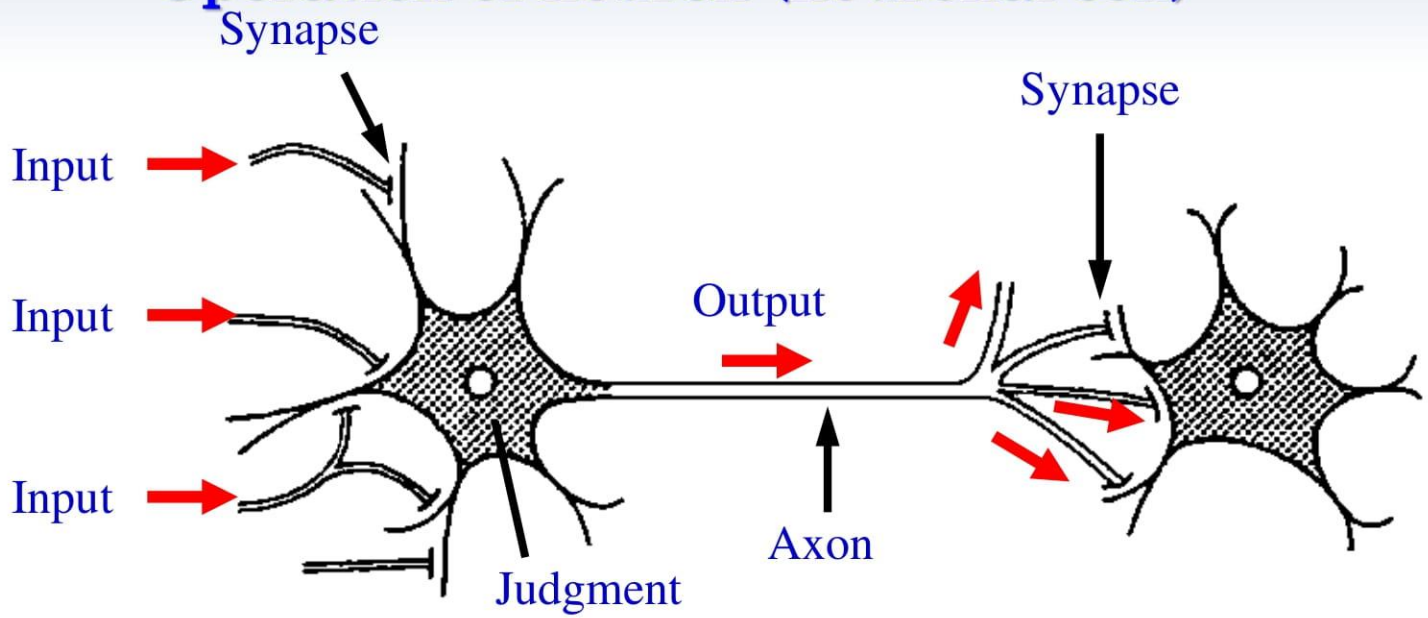
The relation of data is expressed by a straight line.



The relation of data is expressed by a curve.

Neural Network (Image)

Operation of neuron (neuronal cell)



- Electric potential in the neuron rises when the input signal reaches to the neuron.
- The electric potential in the neuron exceeds the threshold.
  - The output pulse is generated.
- The electric potential does not exceed the threshold.
  - The output pulse is not generated.

Characteristic of Neural Network

- **Merit:**
  - 1. Nonlinear relation can be dealt with.
  - 2. Follows automatically to the change of NWP model.

- **Demerit:**
  - 1. The backgrounds of the forecast are incomprehensible due to its complexity.
  - 2. Variance of relation (weights) makes difficult to understand the characteristics.
  - 3. The selection of the predictor is subjective.

- **Usage:**
  - One of the methods that JMA uses for guidance.
    - Weather (distinction between fine and cloudy),
    - Humidity (daily minimum),
    - Maximum precipitation amount…

Logistic regression (outline)

as one of the method for the guidance.

- Logistic regression is used to make guidance of probability whose **outputs (observation data) is binomial (0/1, occur or not occur).**

- **p** as probability is provided by the equation as follows :

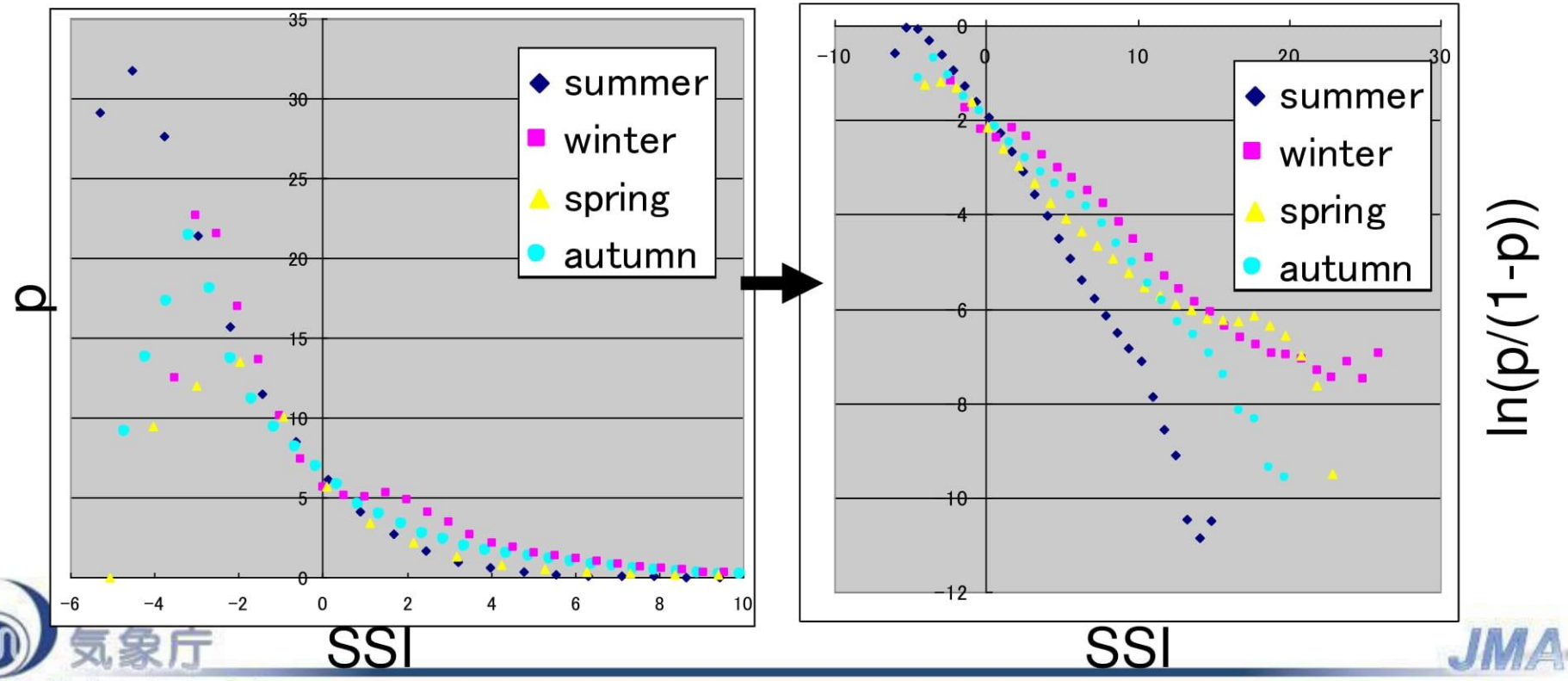
$$\ln\left(\frac{p}{1-p}\right) = C_0 + C_1X_1 + C_2X_2 + \ldots$$

$$p = \frac{1}{1+\exp[-(C_0 + \Sigma(C_iX_i))]} \quad (i = 1,\ 2,\ 3,\ \ldots)$$

sigmoid function

Logistic regression

- Guidance with Logistic regression can **deal with the nonlinear relation** between predictand and predictors.
  - e.g. relation between SSI (predictor) and p (predictand; probability of thunderstorm)



Characteristic of Logistic regression

- **Merit:**
  - 1. Nonlinear relation can be dealt with.
  - 2. The selection of the predictors is objective.
  - 3. Backgrounds of the forecast are comprehensible.

- **Demerit:**
  - 1. Can not follow to the change of NWP model.
  - 2. A large amount of data is necessary to make guidance.

- **Usage:**
  - One of the methods that JMA uses for guidance.
    - Probability of thunderstorms

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Example of guidance in JMA

- **Let's see what kinds of guidance based on the result of JMA-NHM in JMA.**
  - **For disaster prevention**
  - **For aviation forecast**

For Disaster Prevention

Maximum Precipitation	maximum precipitation during 1, 3, 24 hours (5km mesh)
Maximum Wind Speed	maximum wind speed/direction during 3 hours (at observation site)
Maximum Snowfall	maximum snowfall during 3, 6, 12, 24 hours (5km mesh)
Probability of Thunderstorms	probability of thunderstorms during 3 hours (20km mesh)

Method of making Guidance (For Disaster Prevention)

- **Kalman Filter**
  - Probability of precipitation
  - Mean precipitation amount
  - Temperature
  - Mean & maximum wind speed/direction
- **Neural Network**
  - Categorized weather (ratio of sunshine duration)
  - Daily minimum humidity
  - Snowfall amount
- **Logistic regression**
  - Probability of thunderstorms
  - Maximum Snowfall
  - Composition of Kalman Filter & Neural Network
  - Maximum precipitation amount

For Aviation Forecast

Visibility	minimum visibility during 1 hour
	mean visibility during 1 hour
	probability of visibility less than 5km during 3hours
	probability of visibility less than 1.6km during 3hours
Cloud	cloud amount and height of 3 layers (at minimum ceiling during 1 hour)
Wind	maximum wind speed/direction during 1 hour
	mean wind speed/direction during 1 hour
Weather	categorized weather during 1 hour
Probability of Thunderstorms	probability of thunderstorms during 3 hours (around airport)
Probability of ceiling blow	Probability of ceiling blow 600and1000ft during 3 hours (around airport)
Temperature	time series
	maximum, minimum temperature (03, 09, 15, 21UTC)

Method of making Guidance (For Aviation Forecast)

- **Kalman Filter**
  - Temperature
  - Mean & maximum wind speed/direction
  - Mean & minimum visibility
  - Probability of minimum visibility
- **Neural Network**
  - Cloud amount & height of 3 layers at minimum ceiling
- **Logistic regression**
  - Probability of thunderstorms
  - Probability of ceiling blow 600and1000ft
- **Another method (Flow chart)**
  - Categorized weather

Some examples of the Guidance used in JMA

- Temperature
- Probability of Thunderstorms
- TB index

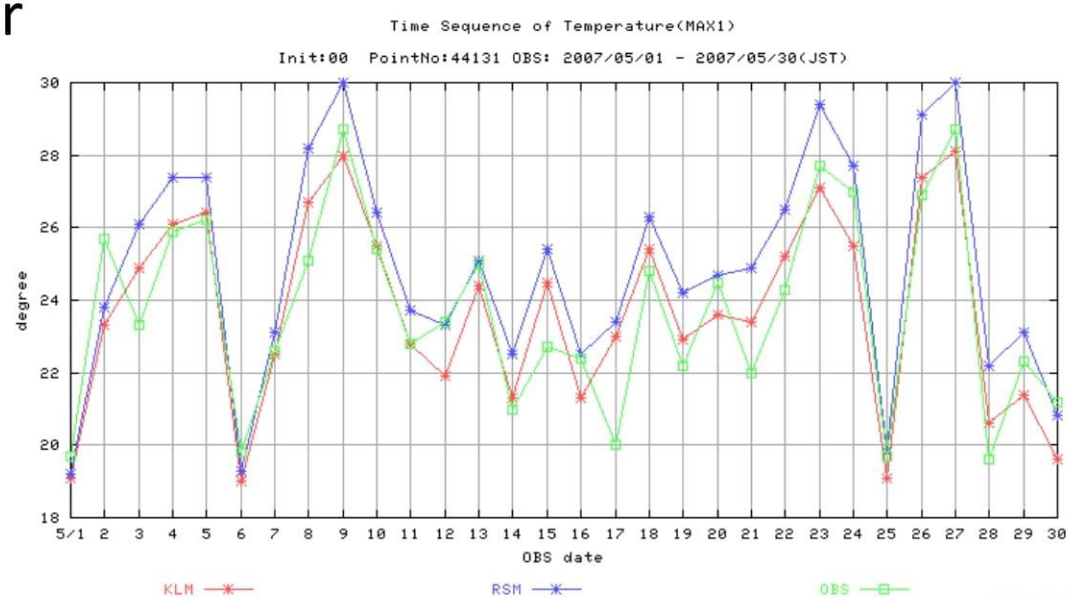
Temperature

- **Output :**
  - **Time-series temperature** every 1, 3 and 6 hours.
  - **Maximum/minimum temperature**.
- **925 stations** (including Meteorological Observatories)
  - Predictand : **Error margin** of the surface temperature by model **[Observation value - Model value]**
- Method : Kalman Filter

NWP model output

Guidance

Observation



Probability of thunderstorms

- Probability of thunderstorms **during 3 hours**.
- Every **20km** square grids
- Method : Logistic regression

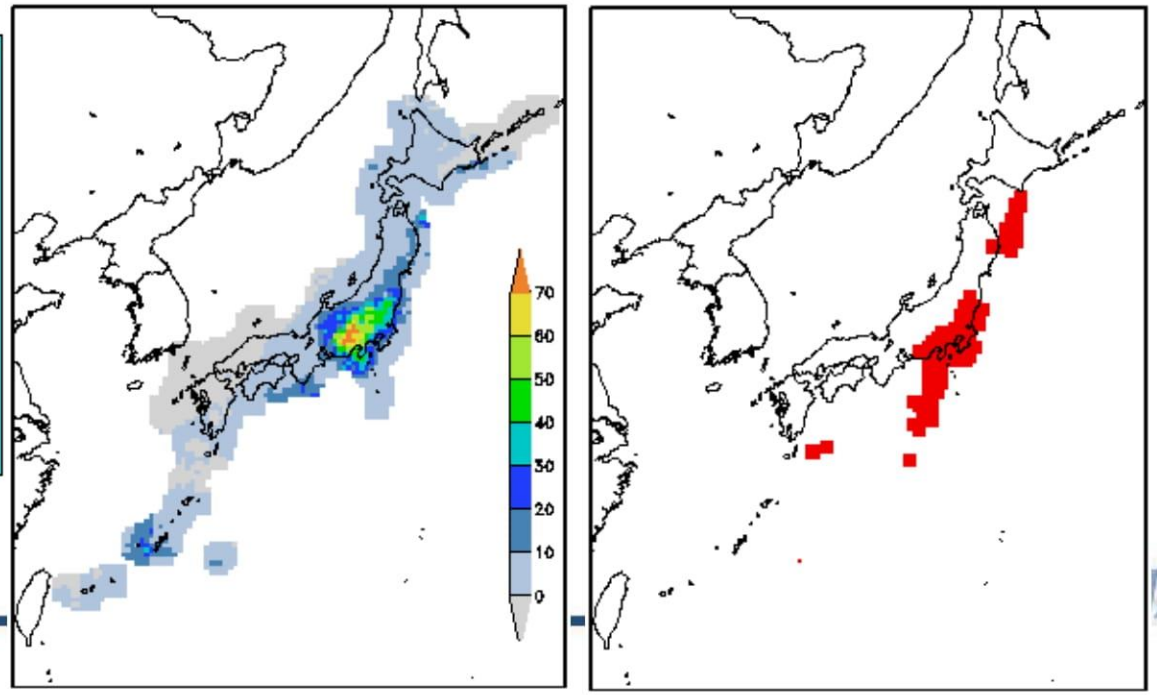
MSM **Observed**

Initial time :

12UTC, 09 Sep. 2007

Valid time :

03UTC, 10 Sep. 2007



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TB index

- **Existing indices** and **newly-developed indices** are combined by logistic regression method.
- By using only independent indices for explanatory variables, operators can easily understand which indices contribute to Tbindex.
- TBindex improves forecast accuracy significantly compared to VWS.

6 newly-developed indices

- Skew wind shear
- Convective cloud index
- Lee wave index
- Vertically propagating mountain wave index
- Mid-level cloud-base index
- Transverse band index

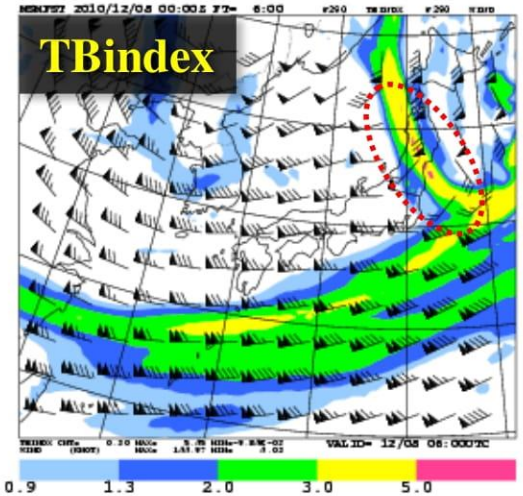
9 existing indices

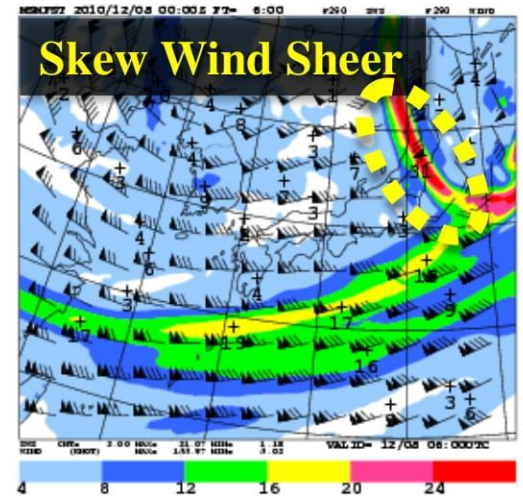
- Richardson number
- Temperature gradient
- Miyakoshi's Index (TPI, TSI)
- VWS
- HWS
- TI1
- TI2
- Dutton

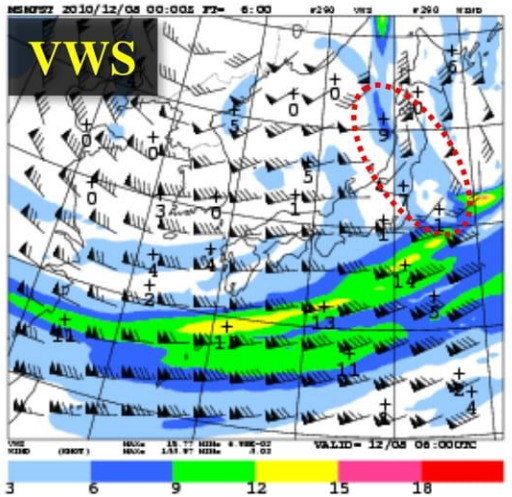
Case Study

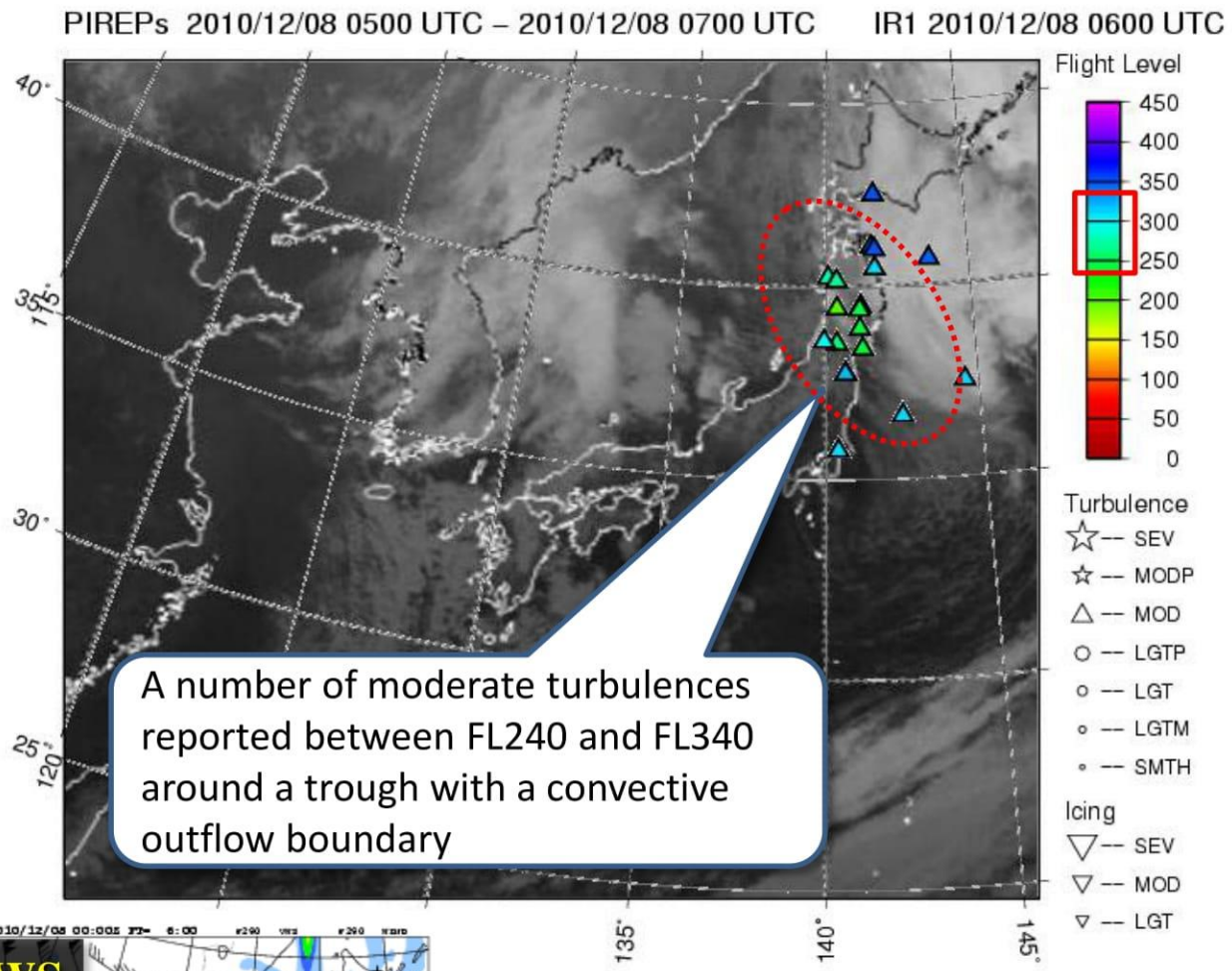
Clear Air Turbulence

↓6-hour forecast at FL290
Initial time : 00Z, 8 Dec, 2010









↑ IR imagery at 06 UTC 8th Dec 2010 and turbulences observed between 05 and 07 UTC

← VWS is small (3～6 kt/1000ft) in the area of turbulence, but TBindex is large because of large skew wind shear

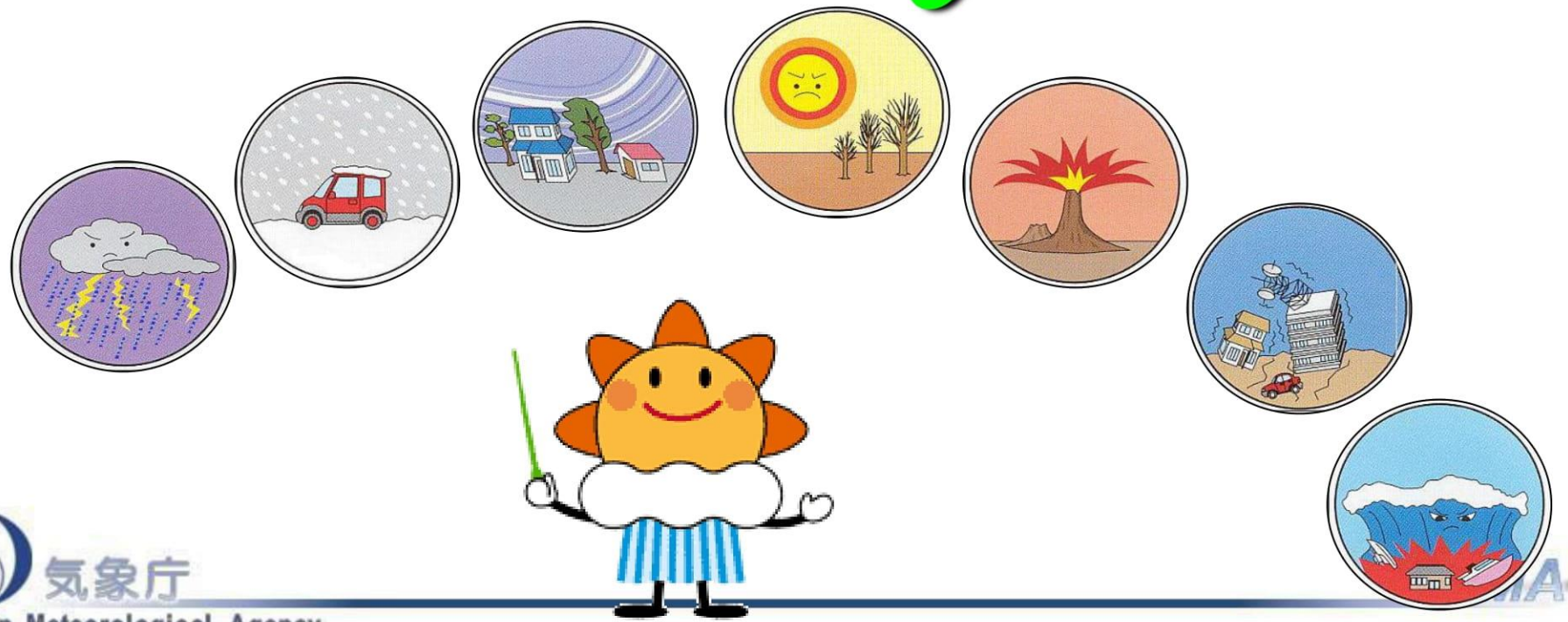
Conclusion of this lecture

- Guidance as statistical procedure of NWP model output gives the reliable forecast.
  - Correct model's errors
  - Translation of model output

- However, random errors cannot be corrected by the guidance. Forecasters must carefully watch the difference between model output, guidance and actual phenomena.

END

Thank you



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