Applications of probabilistic forecasting at JMA

Expert Meeting on the Application of Probabilistic Forecast

Shanghai, China

24-28 Sep. 2007

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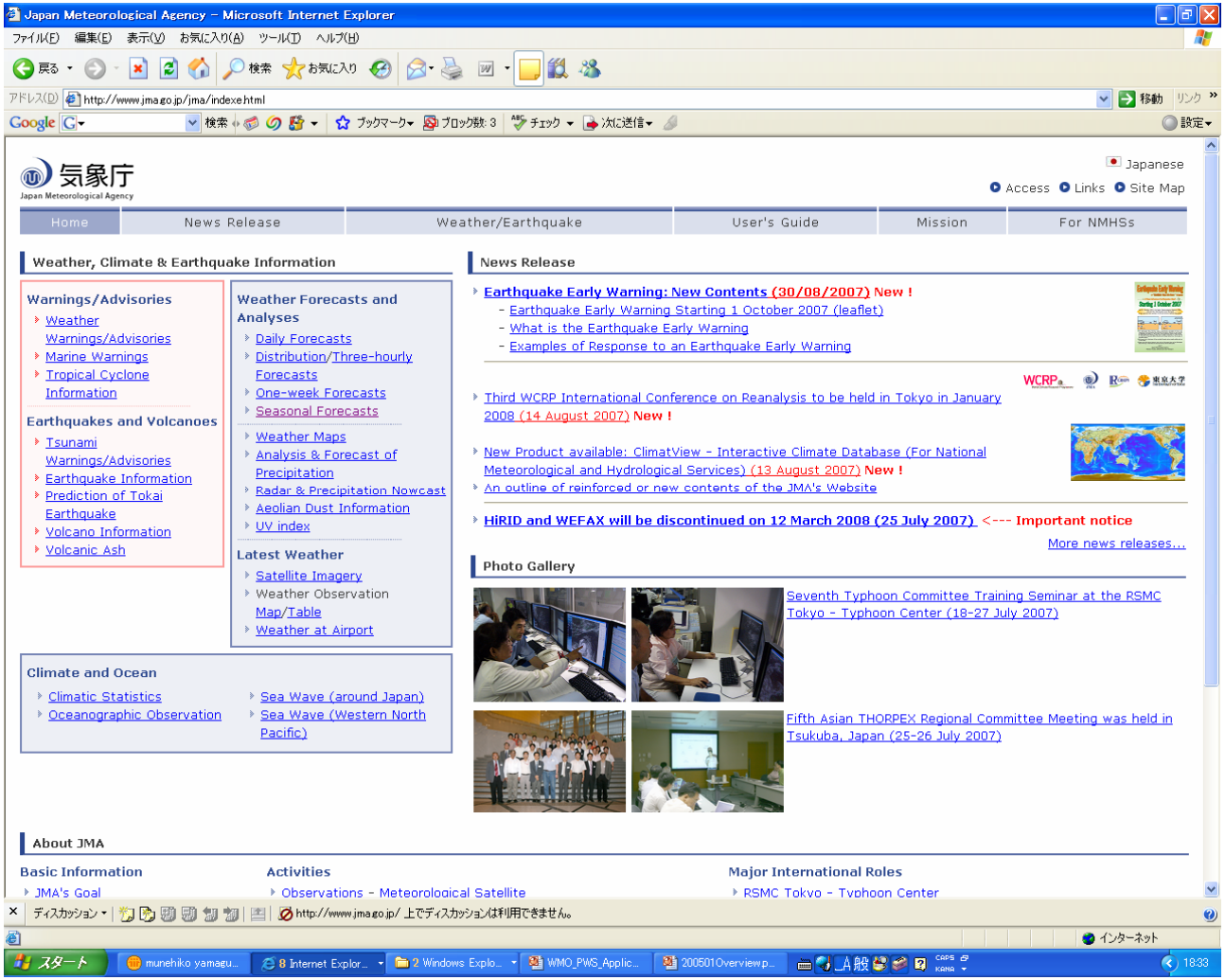
JMA Home Page

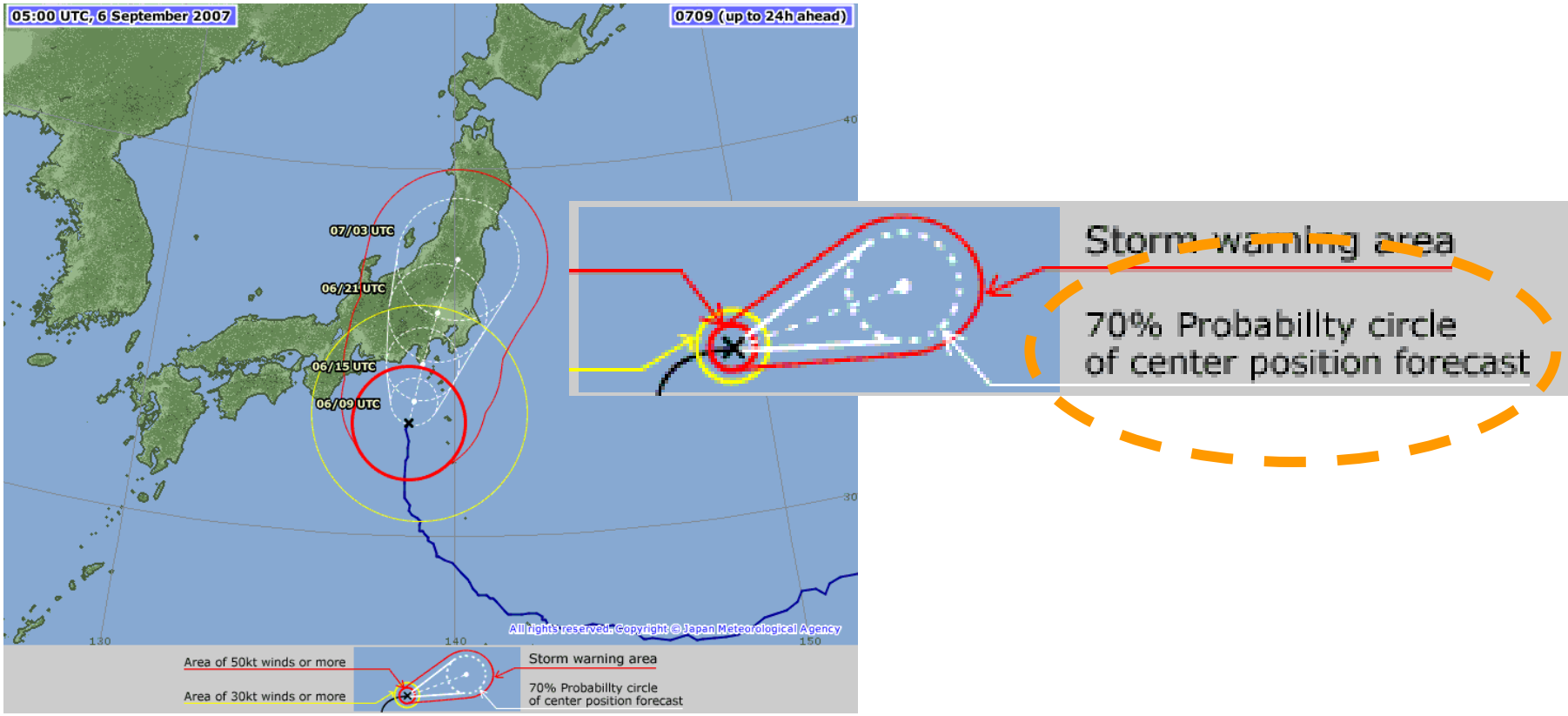
JMA Home Page

JMA provides applications of probabilistic forecasting through JMA homepage (http://www.jma.go.jp/jma/indexe.html)



Typhoon Track Forecast @ JMA Home Page

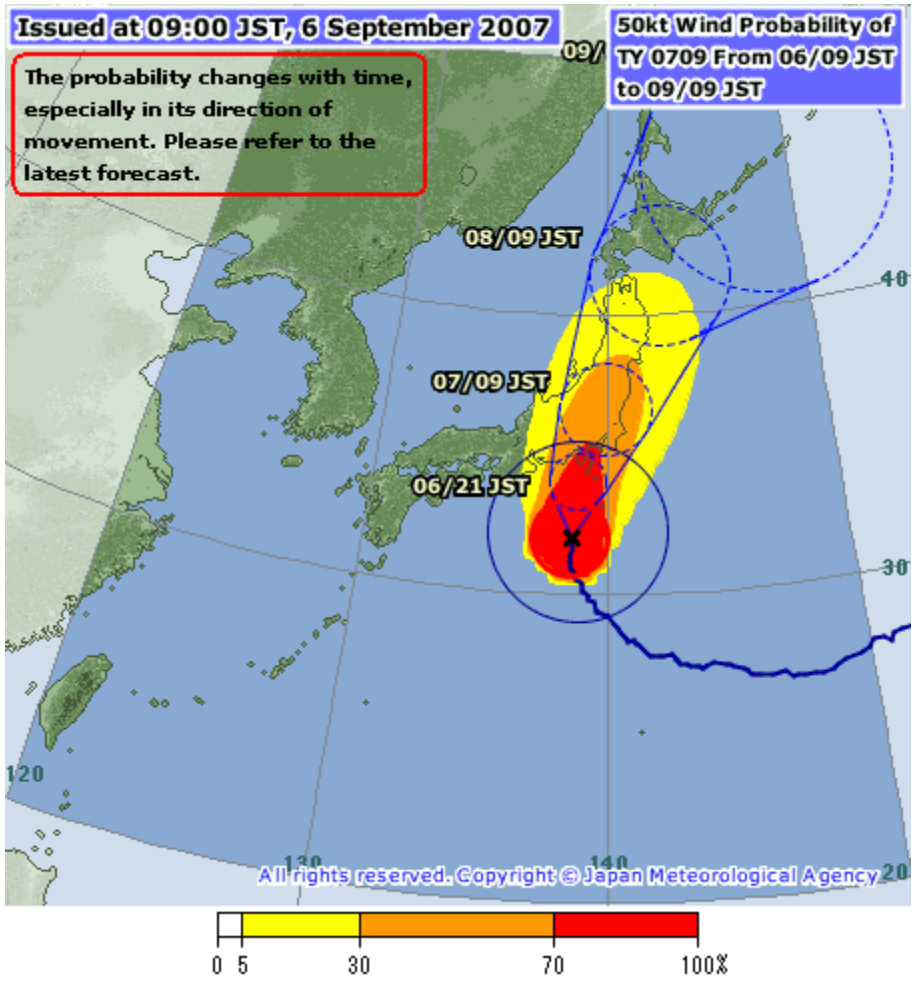
The forecast uncertainty on TC central position is described in a circle, whose radius is decided on a statistical method, using information about current TC position and intensity.



Issued at 05UTC 6 Sep. 2007

Typhoon FITOW

Typhoon Strike Probability @ JMA Home Page



Issued at 00UTC 6 Sep. 2007

Typhoon FITOW

Typhoon Strike Probability

Definition;

A probability with which sustained wind speed reaches 50kt over the next 3 days.

As of now (Sep. 2007), the areasize of the TC striking area is estimated using a statistical method, not EPS.

Future issue is optimizing the areasize using ensemble spread.

Probability Forecast of Rain @ JMA Home Page

JMA provides 6-hourly probability forecast of rain up to 2 days ahead, using kalman filter technique.

Multiple regression method

$$y = a_0 + a_1X_1 + a_2X_2 + \ldots$$

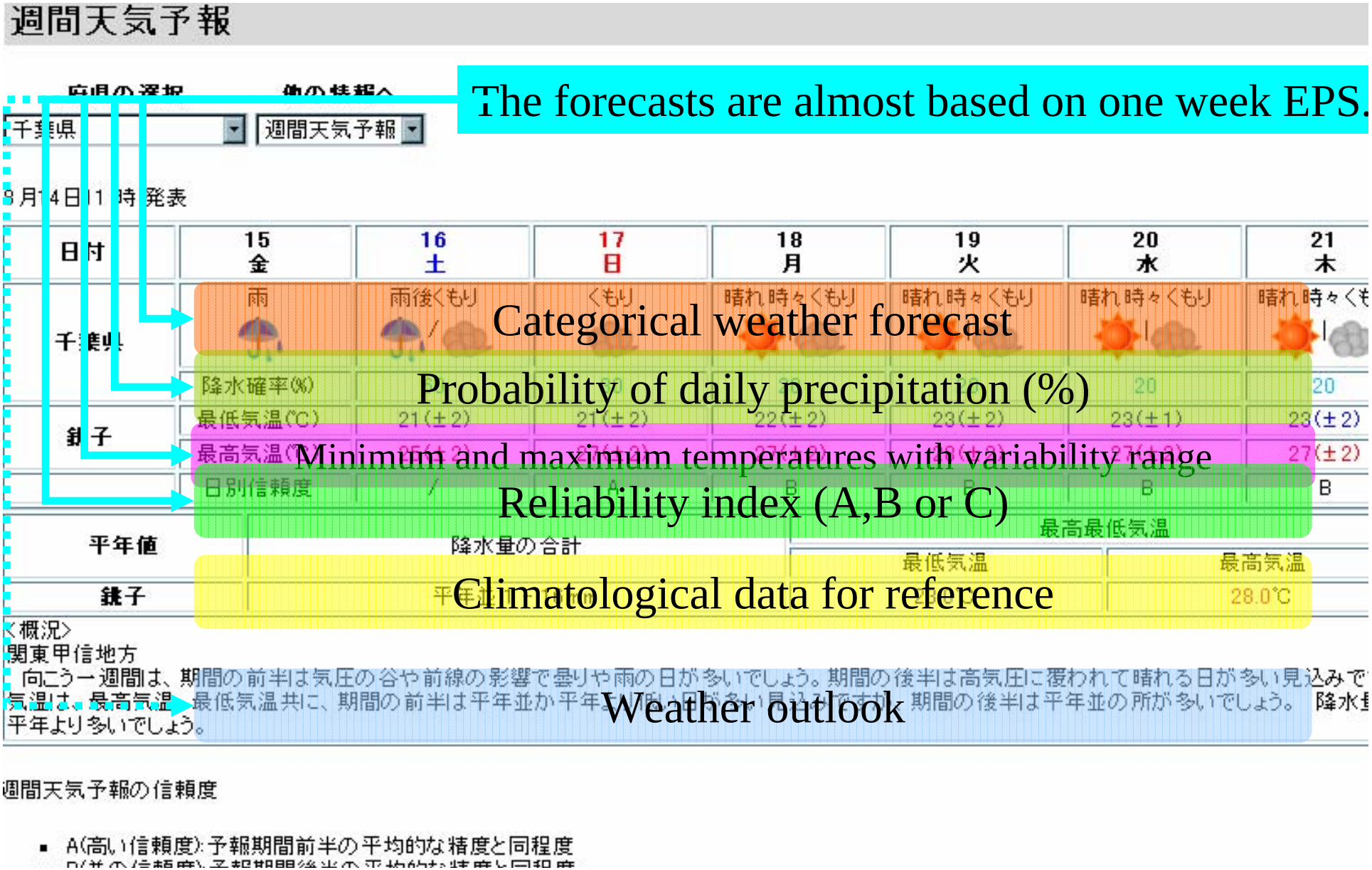
y : objective variable (ex. Probability of rain)
a : coefficients
x : explaining variable (model output)

(/: ☀, |: occasionally or partly)

Osaka-fu	Three-hourly Forecasts	Probability of Precipitation	Temperature Forecast
Today 13 September	FINE BECOMING CLOUDY	00-06 --% 06-12 --% 12-18 10% 18-00 30%	Daytime High Osaka 33° C
Tomorrow 14 September	RAIN AT TIMES	00-06 30% 06-12 40% 12-18 50% 18-24 30%	Morning Low / Daytime High Osaka 23° C / 32° C
Day after tomorrow 15 September	RAIN AT TIMES	One-week Forecasts	

JMA uses kalman filter method to update the coefficients and gets to the probability of 6-hourly precipitation forecast up to 2 days ahead.

One week forecast for end users



The forecasts are almost based on one week EPS.

Categorical weather forecast

Probability of daily precipitation (%)

Minimum and maximum temperatures with variability range

Reliability index (A,B or C)

Climatological data for reference

Weather outlook

One Week Forecast @ JMA Home Page

The forecast uncertainty on weather predictions is described in a “character”, A, most reliable, B and C, least reliable, using information of ensemble spread by medium-range EPS. The information is update every day.

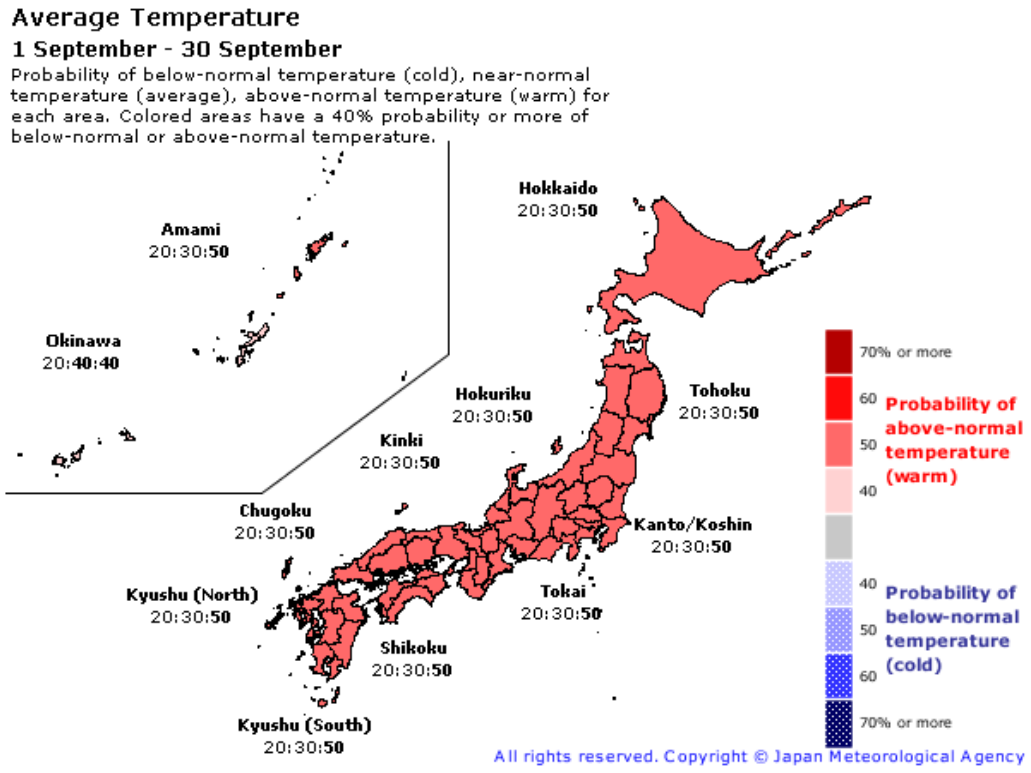
Date		21 Fri	22 Sat	23 Sun	24 Mon	25 Tue	26 Wed	27 Thu
Ishikari/Sorachi/Shiribeshi Chiho Daily Forecast		RAIN AT TIMES	PARTLY CLOUDY	PARTLY CLOUDY	PARTLY CLOUDY	RAIN AT TIMES	RAIN AT TIMES	MOSTLY CLOUDY
Probability of Precipitation (%)		20/20/30/50	10	10	20	50	50	30
Sapporo	Low (° C)	19	19 (±2)	13 (±3)	14 (±4)	15 (±4)	13 (±4)	13 (±4)
	High (° C)	27	23 (±3)	21 (±3)	22 (±2)	21 (±4)	20 (±4)	20 (±4)
Reliability		/	/	A	B	B	B	B
Normal		Precipitation			Low		High	
Sapporo		11 - 34mm			11.7 ° C		20.6 ° C	

Issued at 02UTC 20 Sep. 2007

One-Week Forecast

One Month Forecast @ JMA Home Page

JMA One month EPS provide probabilistic information on average temperature, precipitation, sunshine and snowfall over the next 4 weeks. The information is updated once a week.

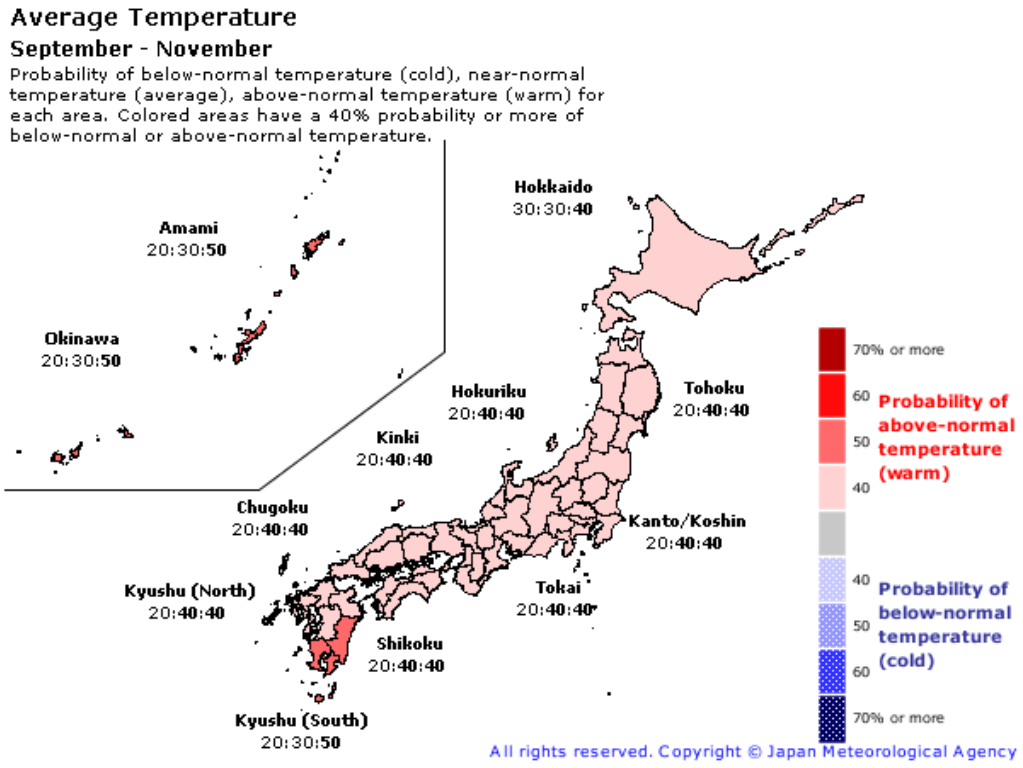


Issued at 02UTC 01 Sep. 2007

Probabilistic forecast of average temperature in Sep. 2007

Seasonal Forecast @ JMA Home Page

JMA seasonal EPS provide probabilistic information on average temperature, precipitation, sunshine and snowfall over the next three months. The information is updated once a month.



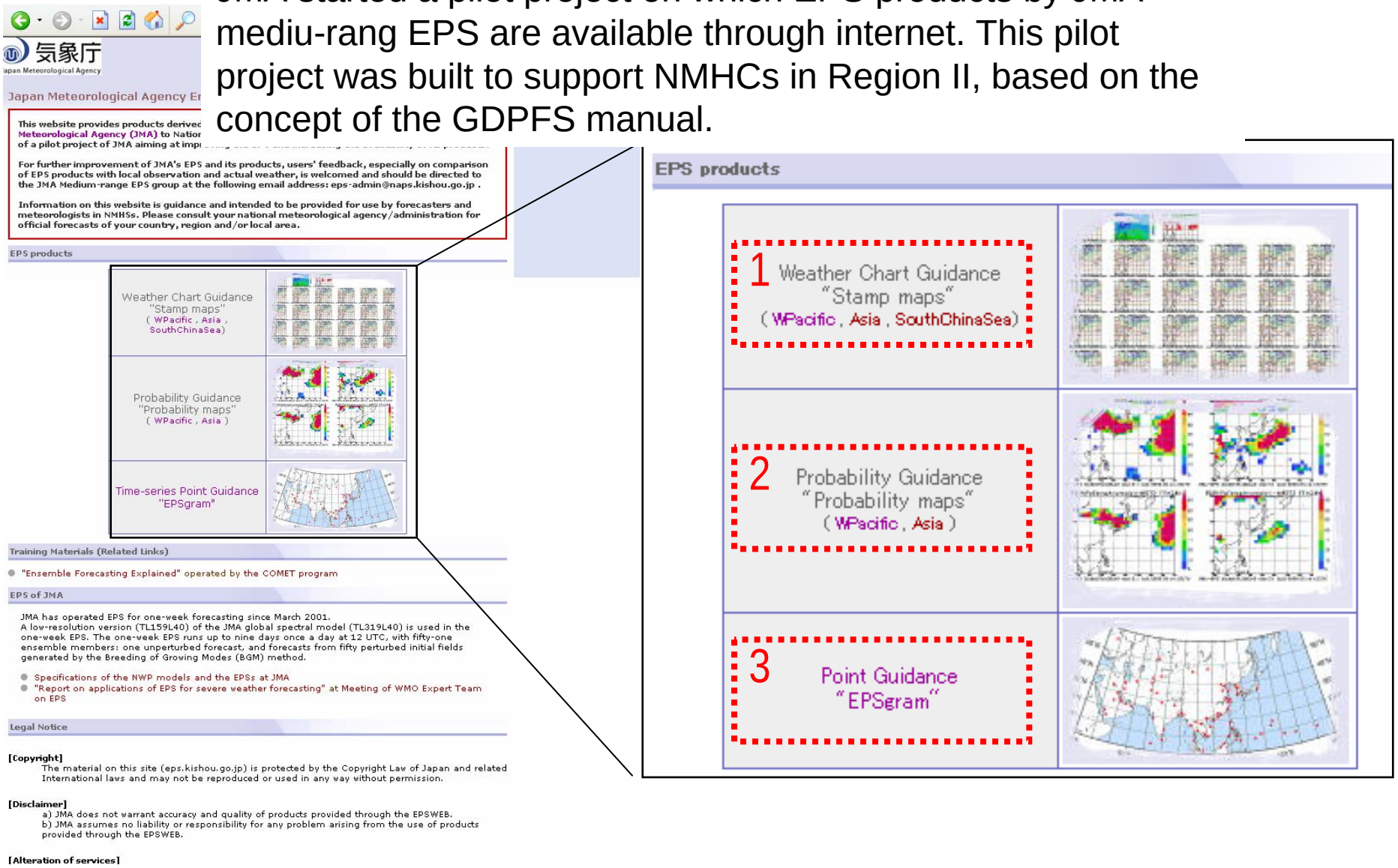
Issued at 02UTC 01 Sep. 2007

Probabilistic forecast of average temperature during Sep to Nov. 2007

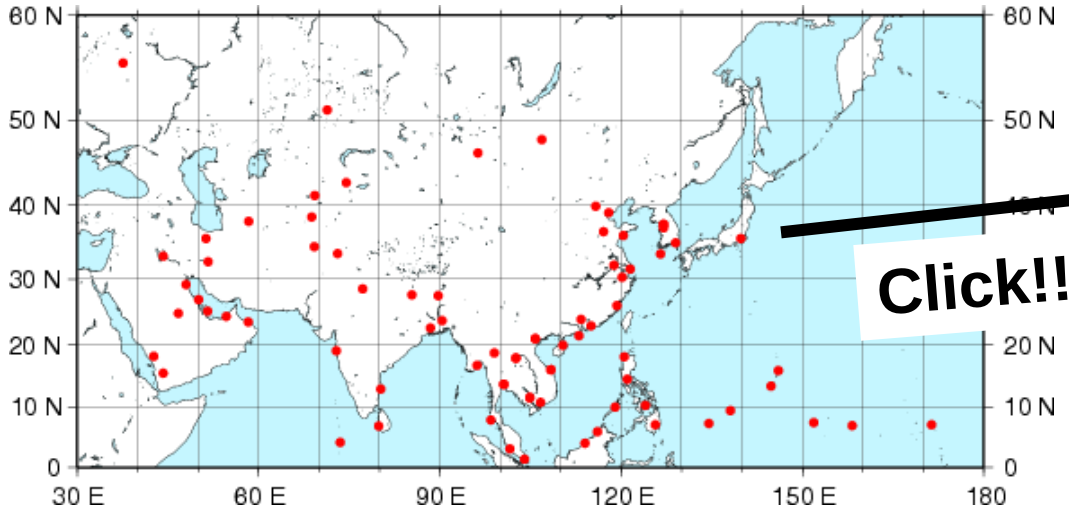
JMA’s Pilot Project for EPS products

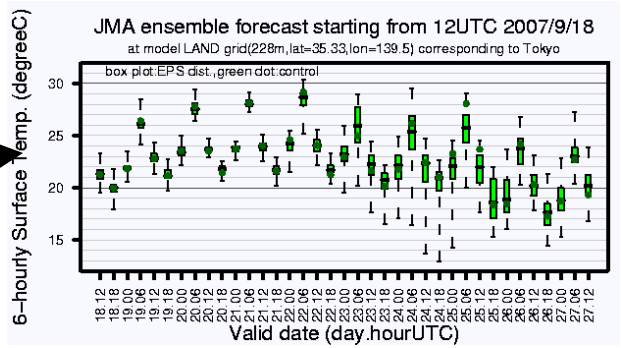
JMA's Pilot Project for EPS products

JMA started a pilot project on which EPS products by JMA mediu-rang EPS are available through internet. This pilot project was built to support NMHCs in Region II, based on the concept of the GDPFS manual.



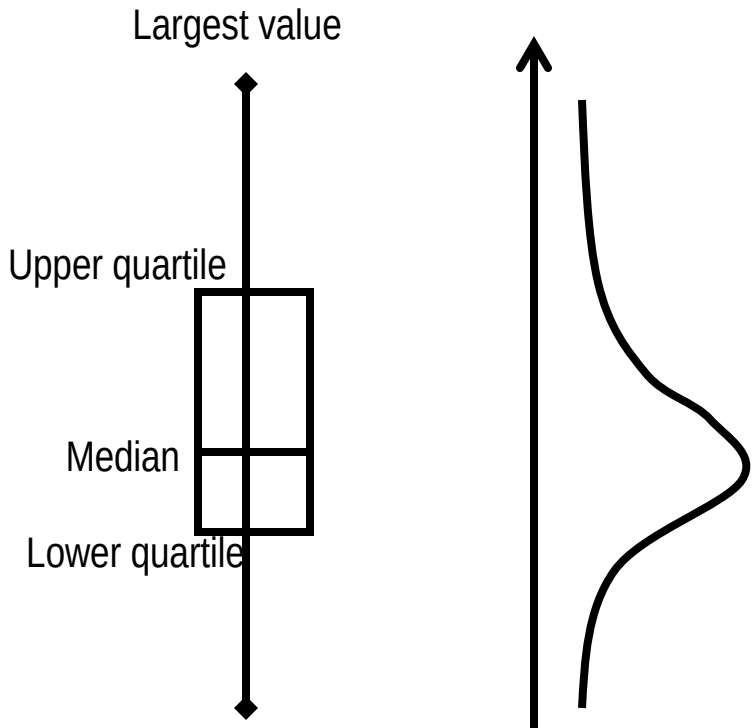
EPSgram for about 70 points in Region II





Moscow	ABHA	COLOMBO	CHIANG MAI	JINAN	MAJURO/MARSHALL IS.
ASTANA	BAHRAIN(INT. AIRPORT)	MALE	BANGKOK	QINGDAO	KOROR, PALAU WCI.
BISHKEK	DOHA INTERNATIONAL AIRPORT	ALTAI	PHUKET	NANJING	YAP, CAROLINE IS.
TASHKENT	ABU DHABI INTER. AIRPORT	ULAANBAATAR	KUALA LUMPUR/SUBANG	SHANGHAI	BRUNEI AIRPORT
DUSHANBE	SEEB, INTL AIRPORT	KATHMANDU AIRPORT	SINGAPORE CHANGI AIRPORT	HANGZHOU	KOTA KINABALU
ASHGBAT	SANA'A	KOWLOON	HANOI	FUZHOU	LAOAG
KING KHALED INT. AIR	ISLAMABAD	TAIPA GRANDE	DA NANG	GUANGZHOU	MANILA
KUWAIT INTERNATIONAL AIRPORT	DHAKA	SEOUL	TAN SON HOA (Ho Chi Minh)	HAIKOU	PUERTO PRINCESA
BAGHDAD	NEW DEHLI/SAFDARJUNG	BUSAN	VIENTIANE	NWSO AGANA, GUAM	MACTAN
TEHRAN-MEHRABAD	CALCUTTA/DUM DUM	JEJU	PHNOM-PENH/POCHEN TONG	SAIPAN (CG)	DAVAO AIRPORT
ESFAHAN	BOMBAY/SANTACRUZ	TOKYO	BEIJING	CHUUK, ECI	
KABUL AIRPORT	MADRAS/MINAMBAKKAM	YANGON	TIANJIN	POHNPEI, CAROLINE IS.	

Interpretation of box plot

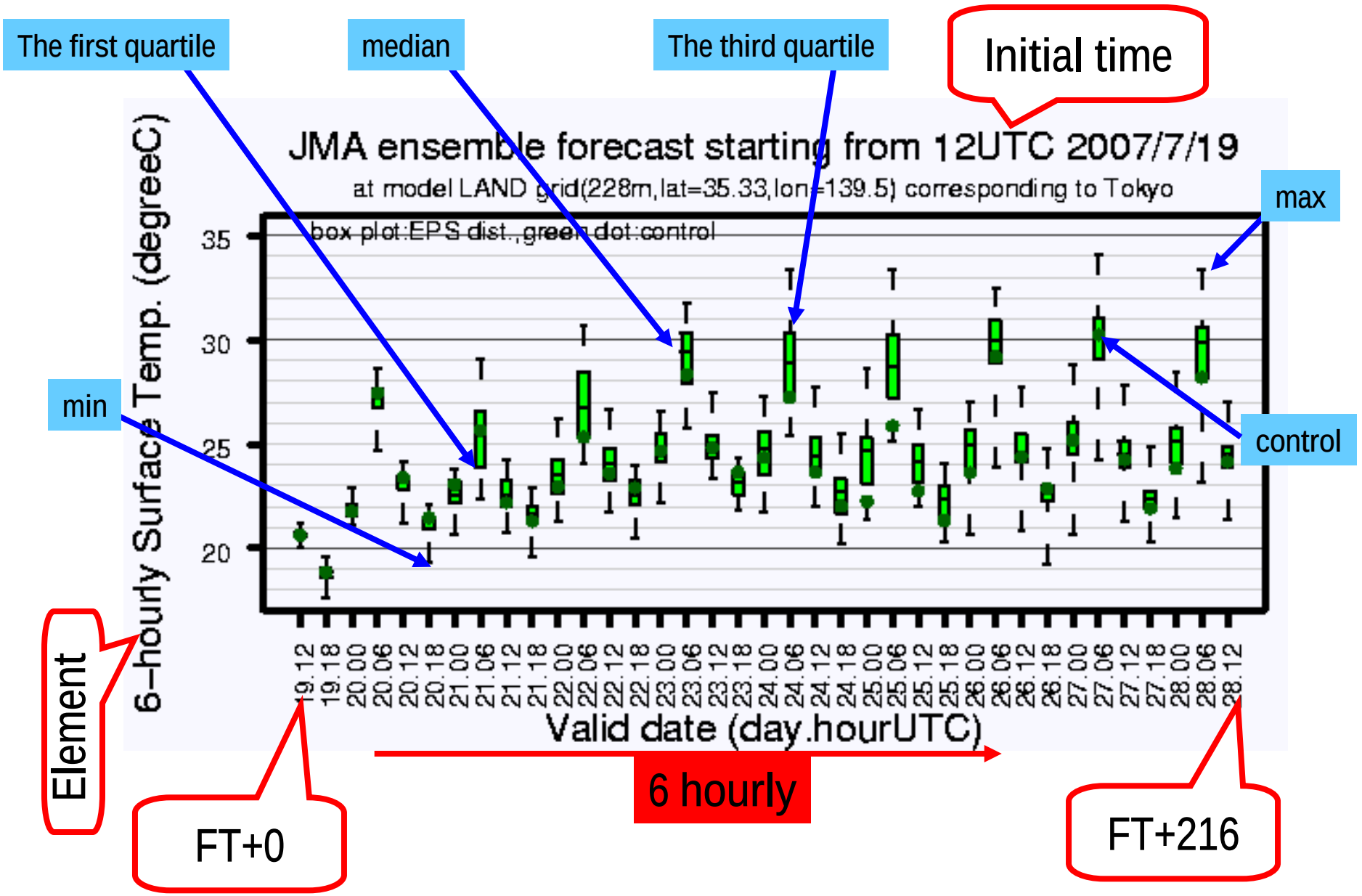


Interpretation of boxplots

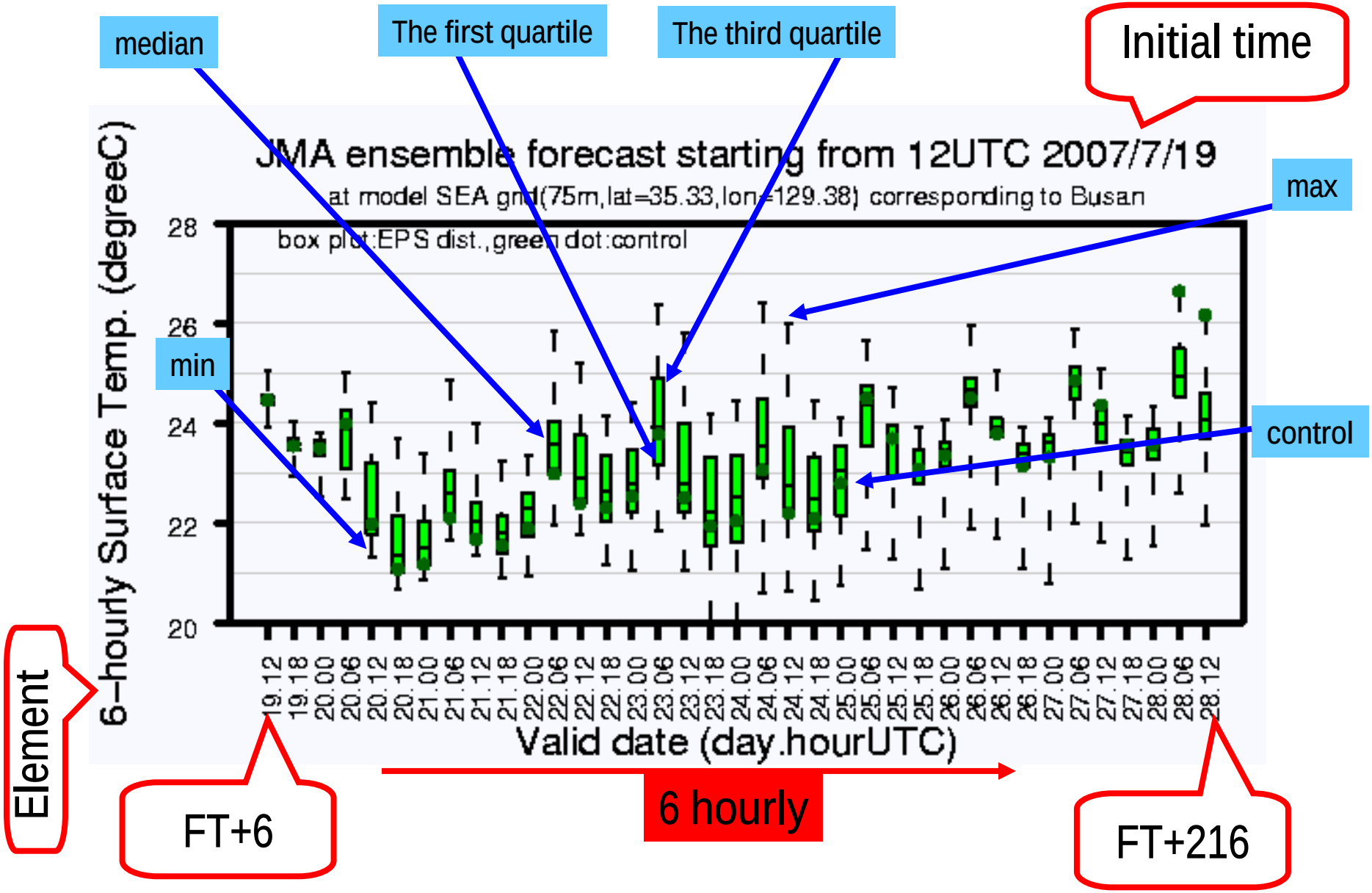
Image of PDF

"Box plot" represent the distribution of the forecast by ensemble prediction system.

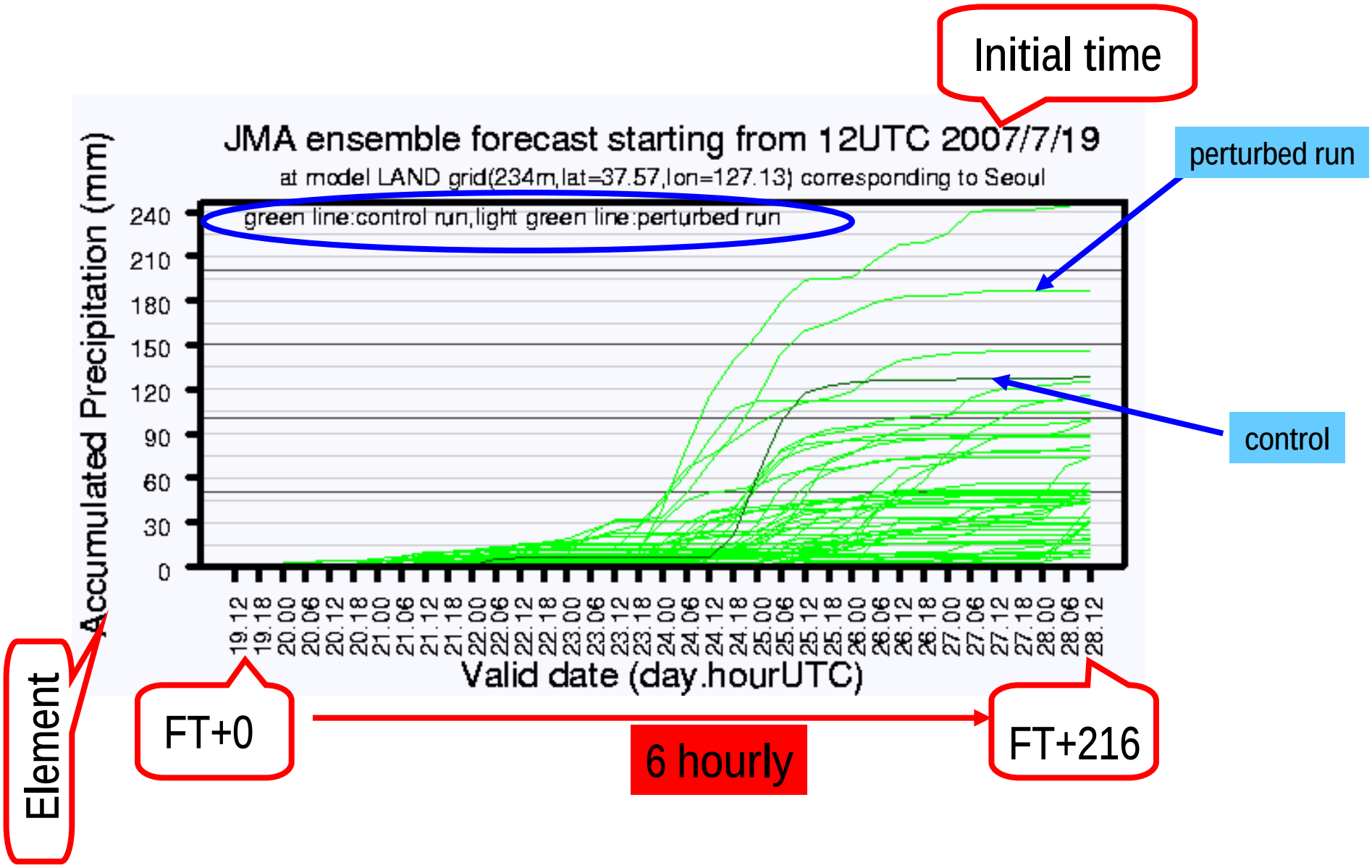
Surface temperature (degree C)



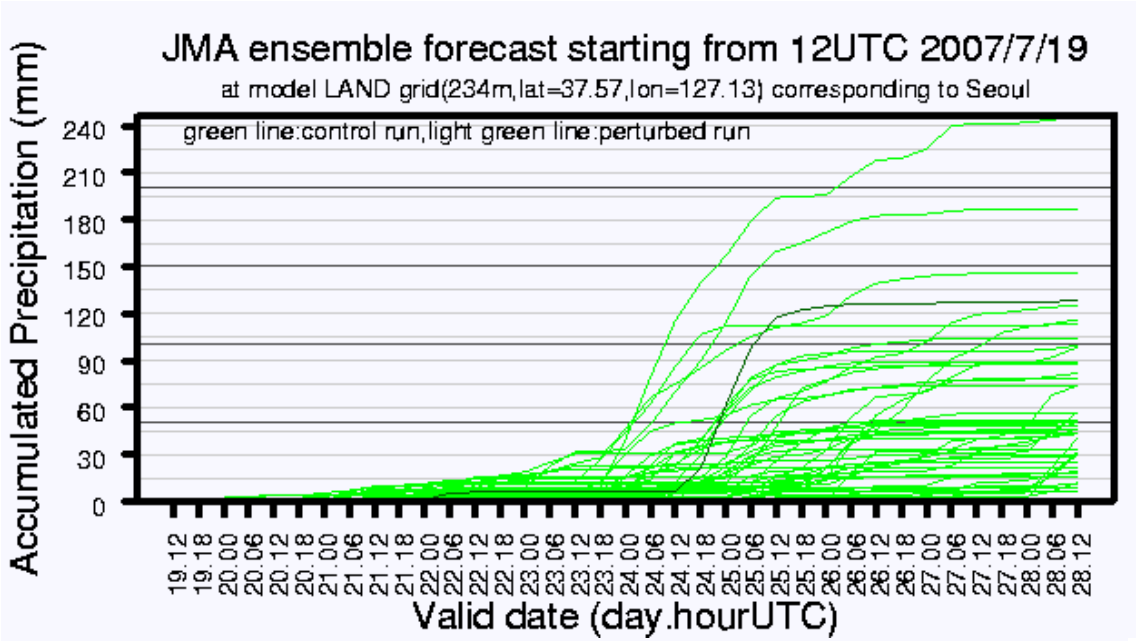
Precipitation rate (mm/6hr)



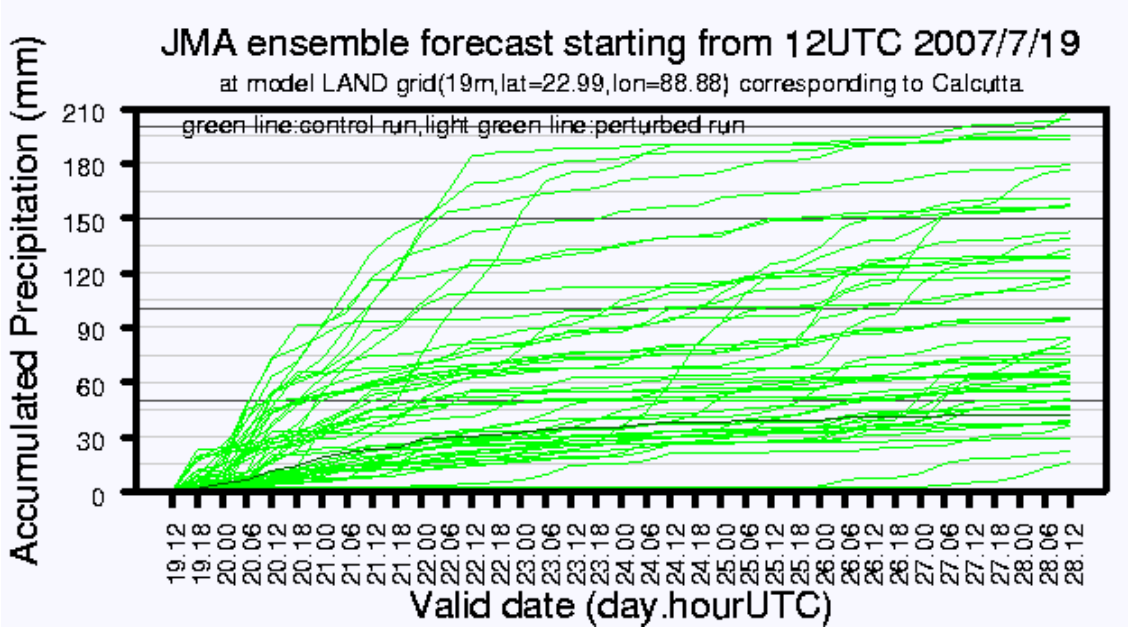
Accumulated precipitation (mm)



Accumulated precipitation (mm)

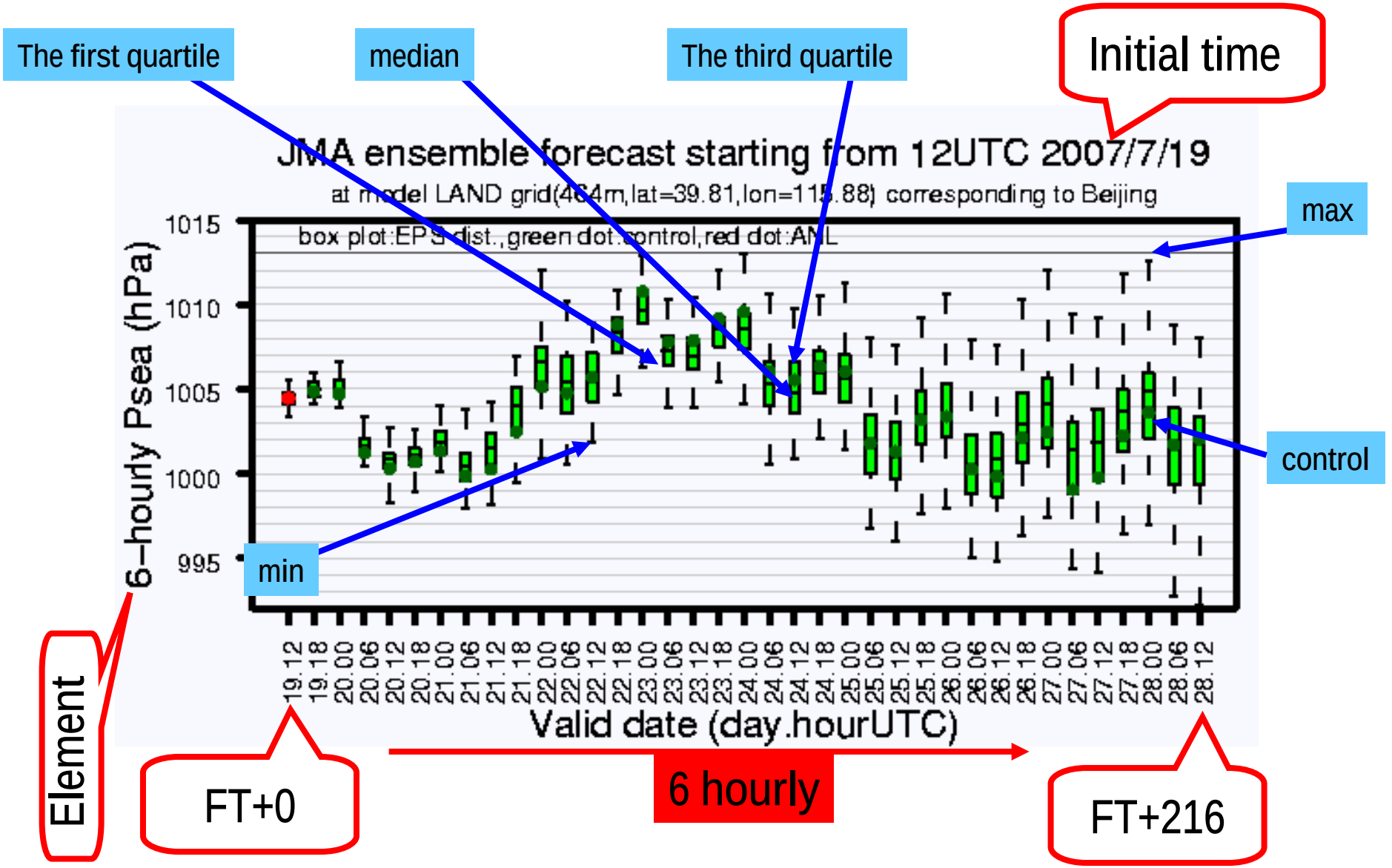


Heavy rain is predicted with some ensemble members at 24th July.

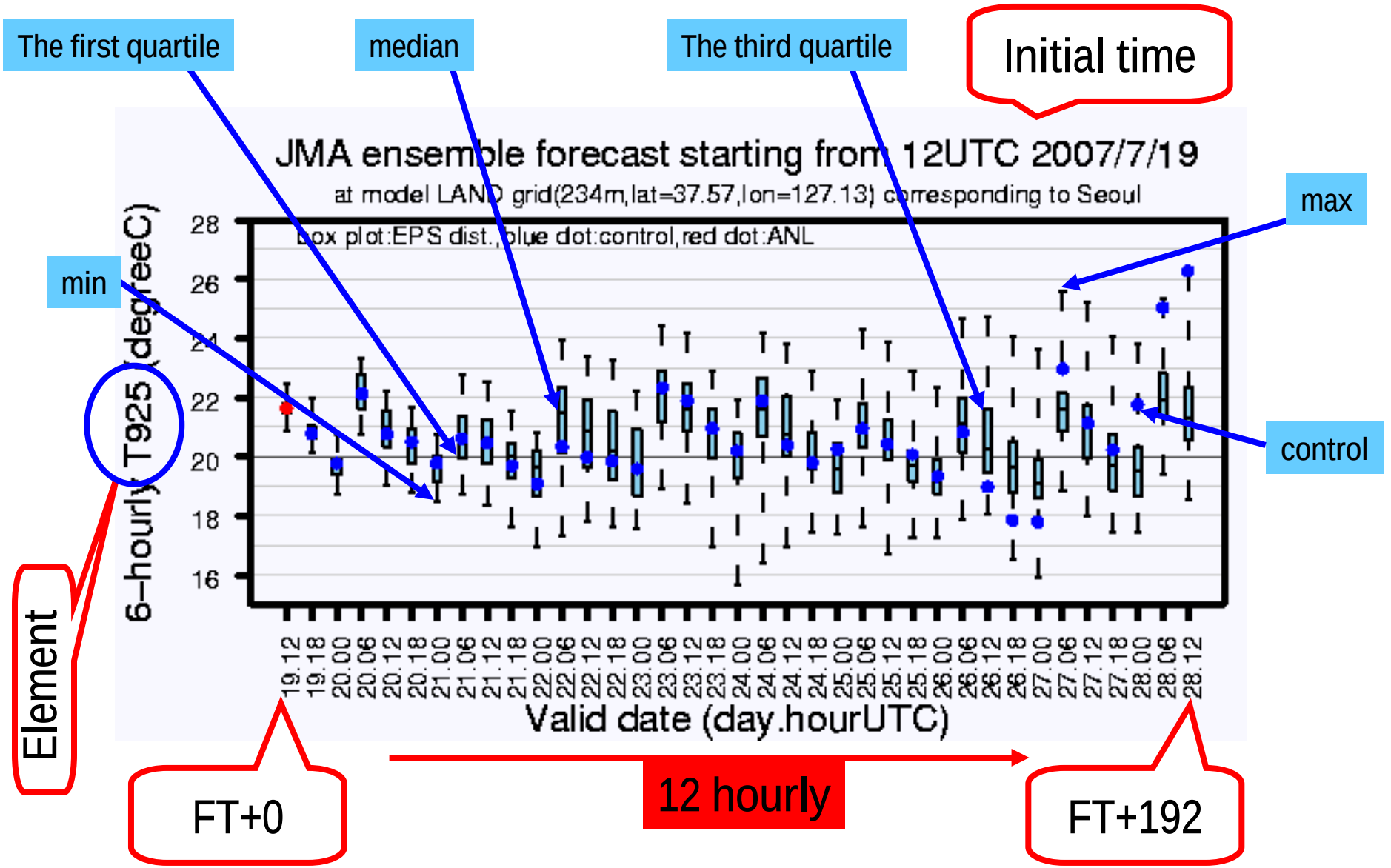


Heavy rain is predicted with many ensemble members.

Sea level pressure (hPa)

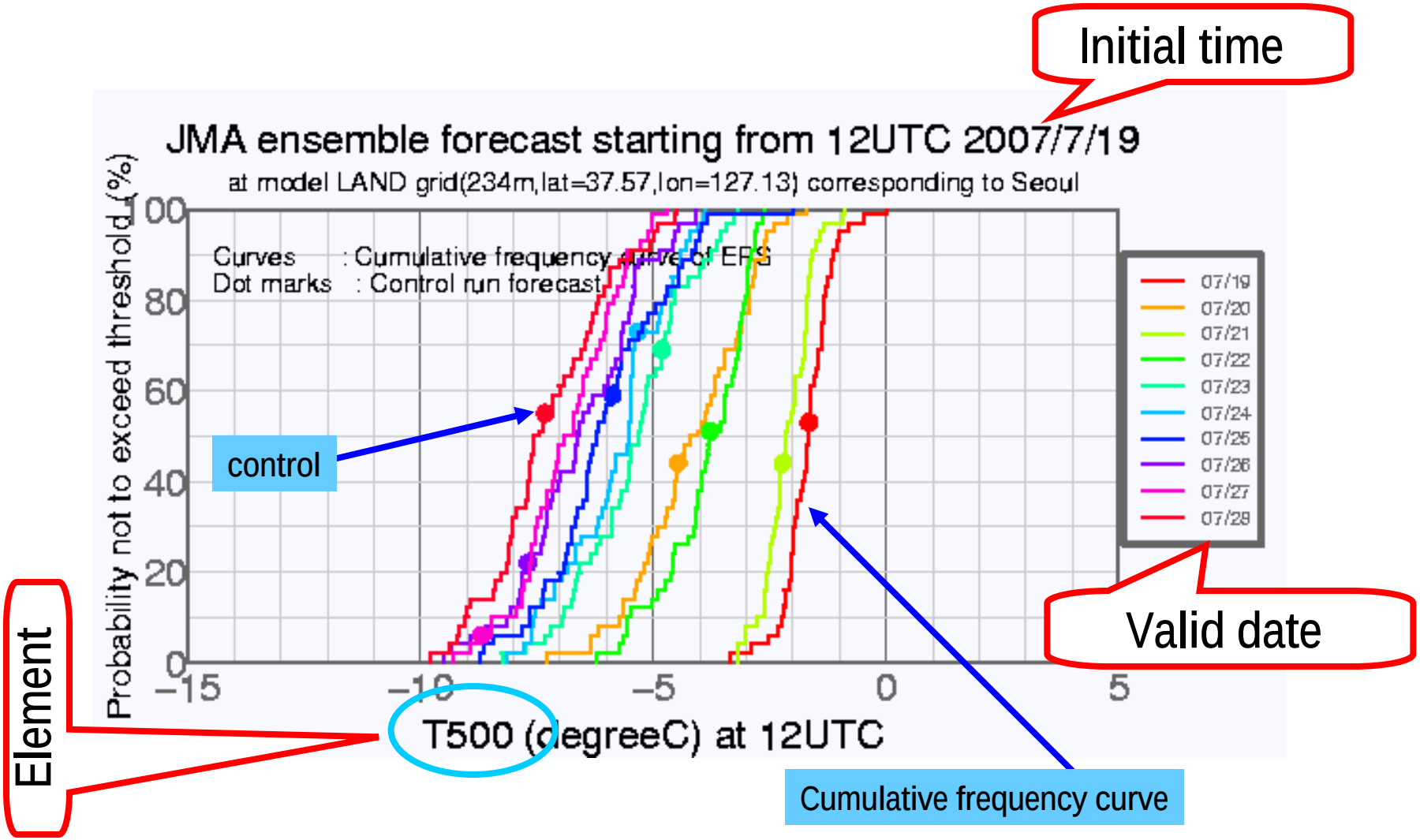


Upper air temperature (degree C)



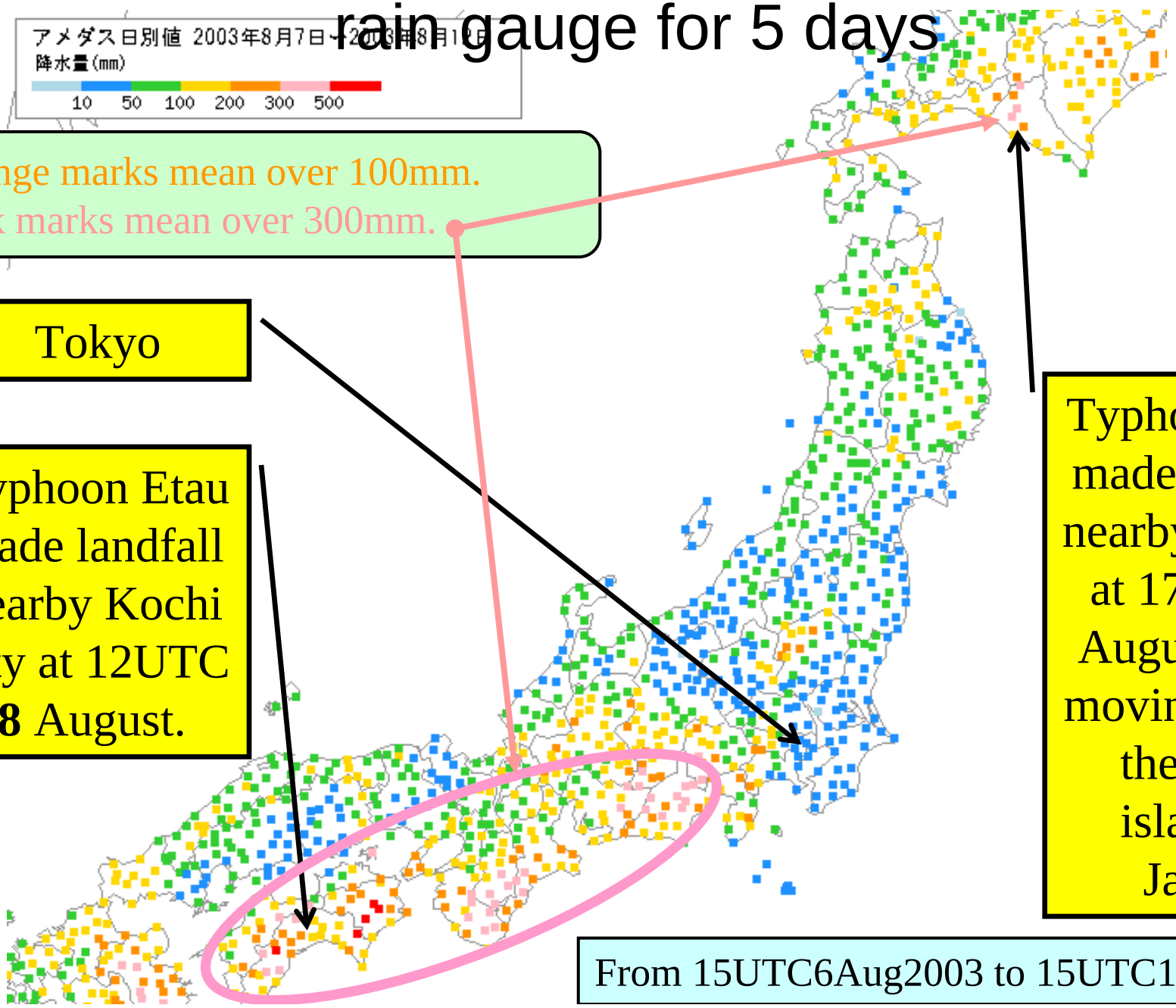
Upper air temperature (degree C)

Probability (%) not to exceed threshold



Application of One-week EPS for heavy rain forecast

Plots of the accumulated rain observed by the rain gauge for 5 days



Orange marks mean over 100mm.
Pink marks mean over 300mm.

Tokyo

Typhoon Etau made landfall nearby Kochi city at 12UTC **8** August.

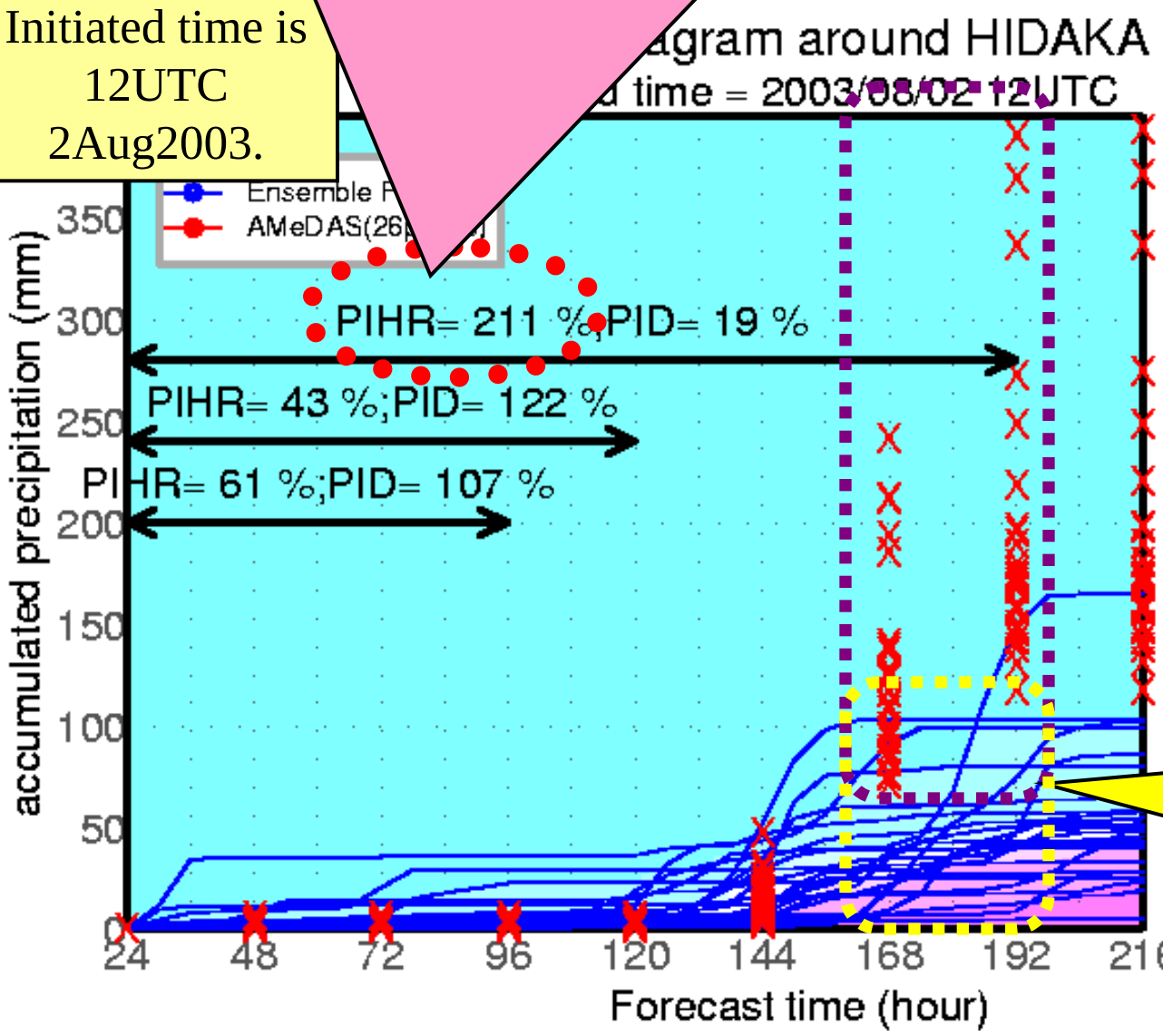
Typhoon Etau made landfall nearby Hidaka at 17UTC **9** August after moving across the main island of Japan.

From 15UTC6Aug2003 to 15UTC11Aug2003

Accumulated precipitation around Hidaka

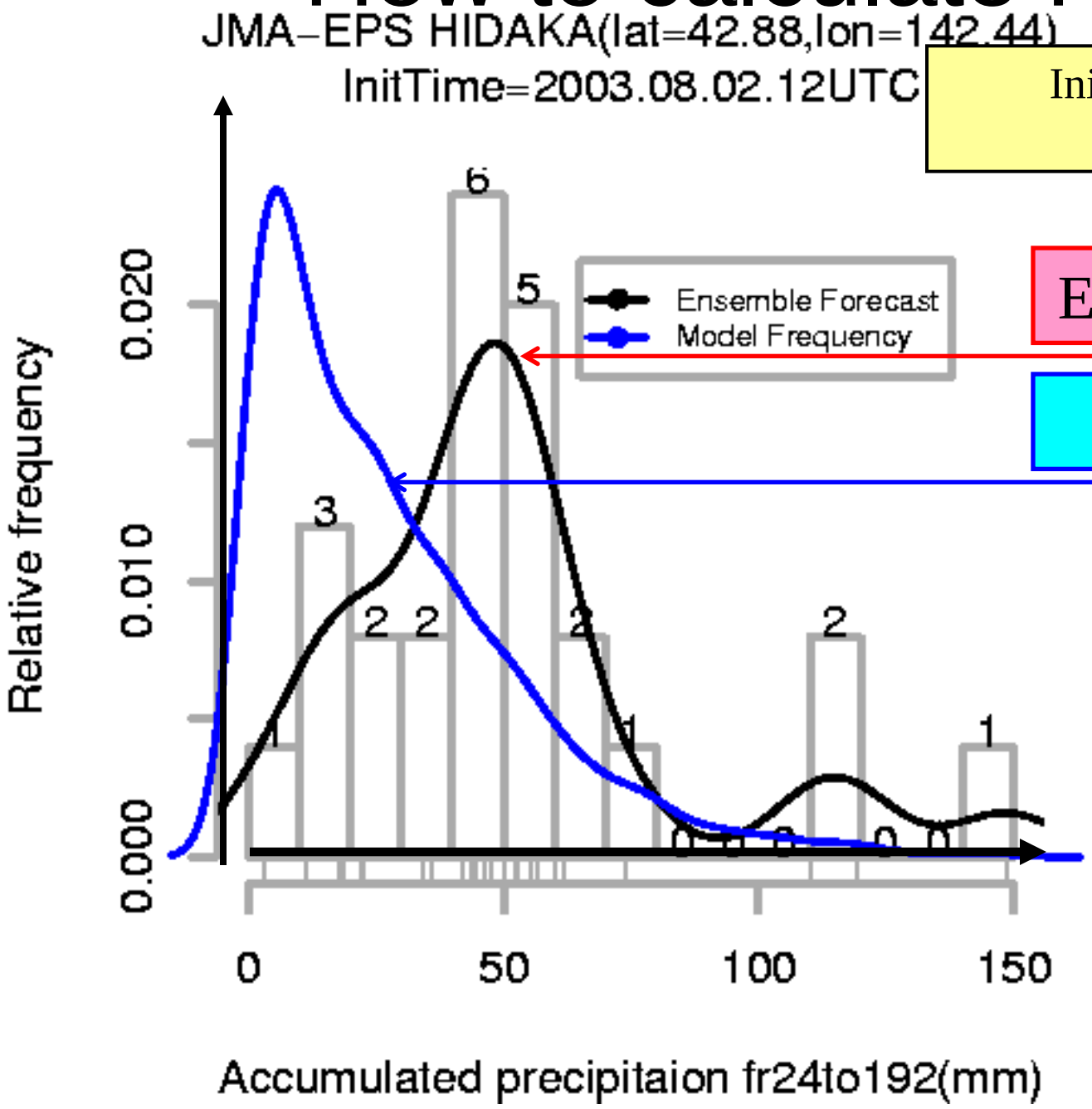
PIHR(Potential Index of a Heavy Rainfall) marks 211%,
saying a high possibility of an abnormal rainfall in this period shown as the arrow.

Initiated time is 12UTC 2Aug2003.



Any forecast was not enough to estimate the amount of the heavy rainfall.

How to calculate PI (1)



Initial time is 12UTC 2Aug2003.

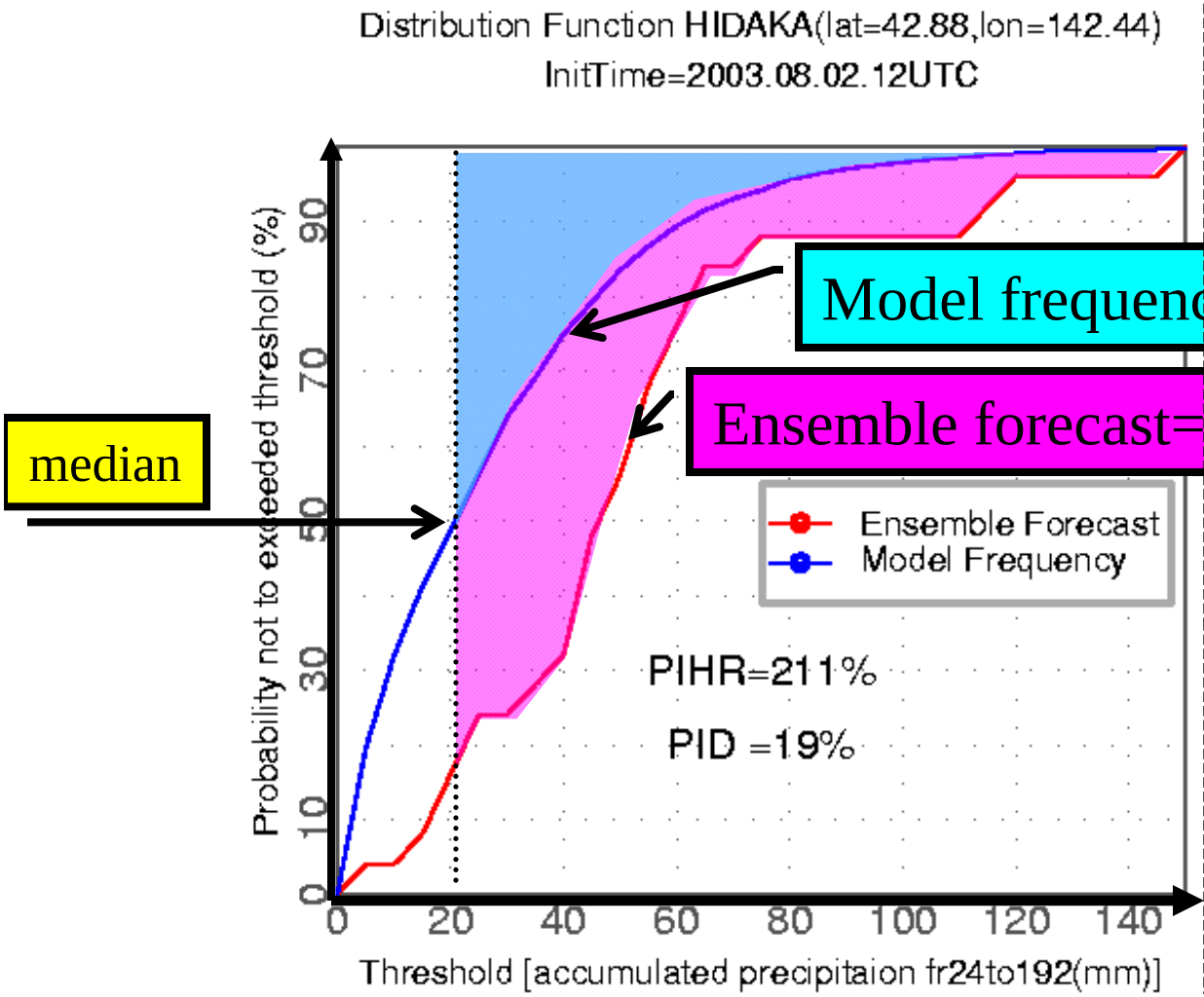
Ensemble forecast

Model climate

The EPS distribution is compared with the model climate, not observed distribution.

How to calculate PI (2)

The potential index is made from a difference between probability distribution function (PDF) of the EPS and that of the model climate.

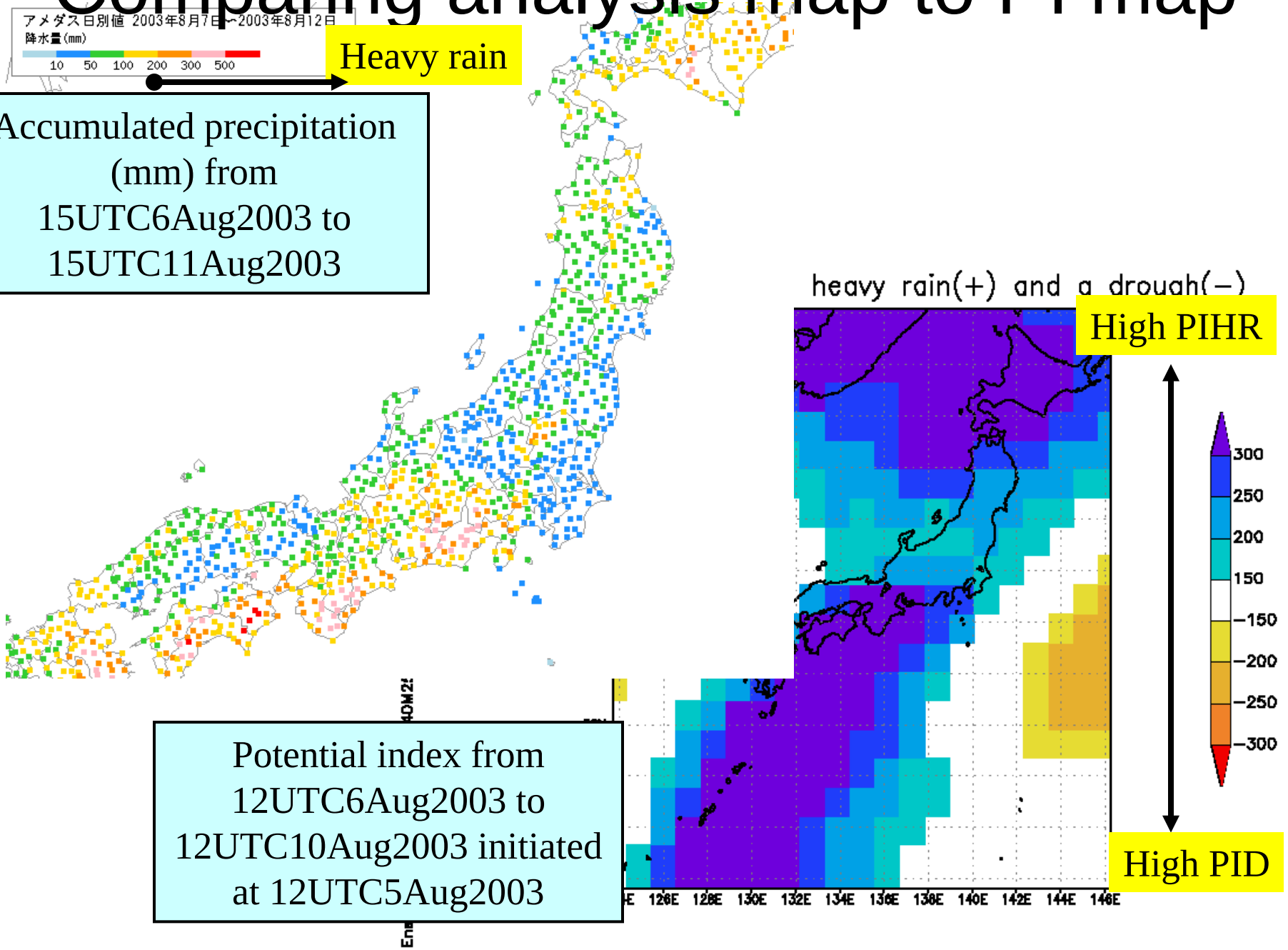


$$PIHR = \frac{\int_{1/2}^{1} (1 - F(p))dp}{\int_{1/2}^{1} (1 - p)dp}$$

$$= \frac{\text{(Red area)}}{\text{(Blue area)}}$$

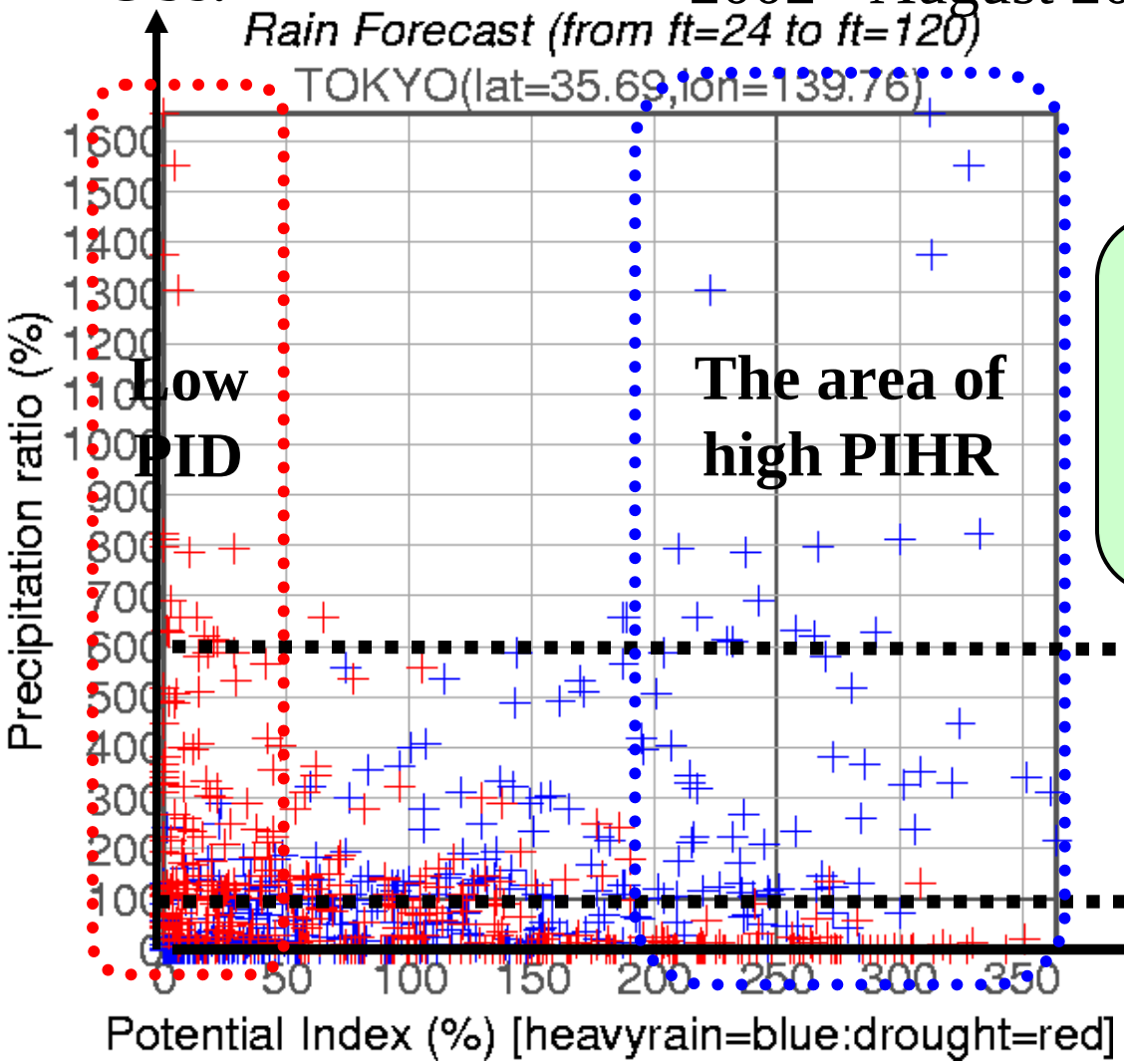
$$PID = \frac{\int_{0}^{1/2} F(p)dp}{\int_{0}^{1/2} pdp}$$

Comparing analysis map to PI map



Verification of PI

Scatter diagram for forecasts and the precipitation ratio (the rain gauge data) from 24hr to 120 hr at TOKYO for 365 cases for September 2002 - August 2003.



Red X =PID
Blue X =PIHR

PID is below 50% and PIHR is above 200% when heavy rainfall exceeding 600% of climate value occurs.

600% of climate value

Normal (100%)

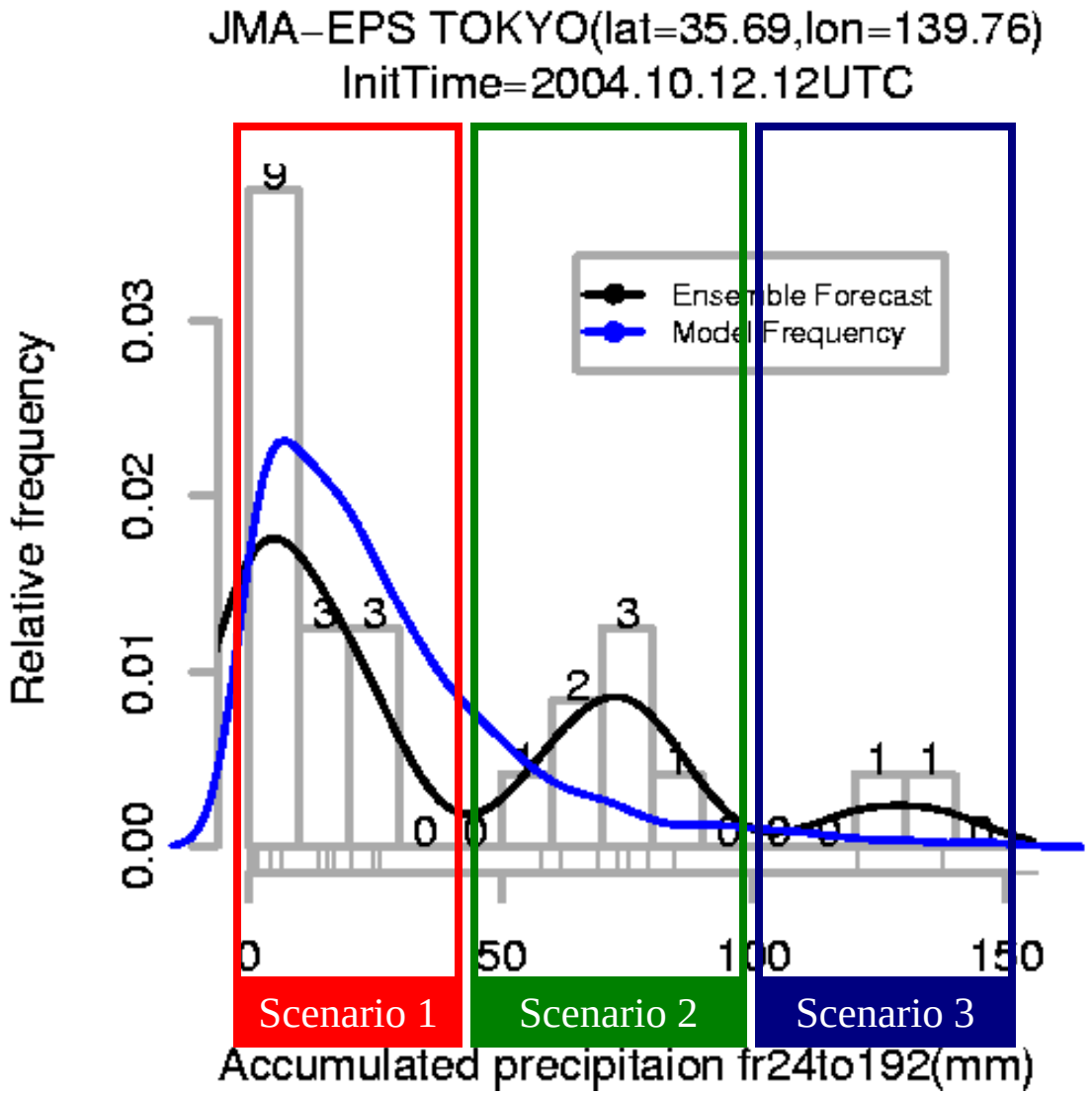
Forecast

How to get a forecast scenario

- Histogram
- Spaghetti / Plume diagram
- Cluster analysis

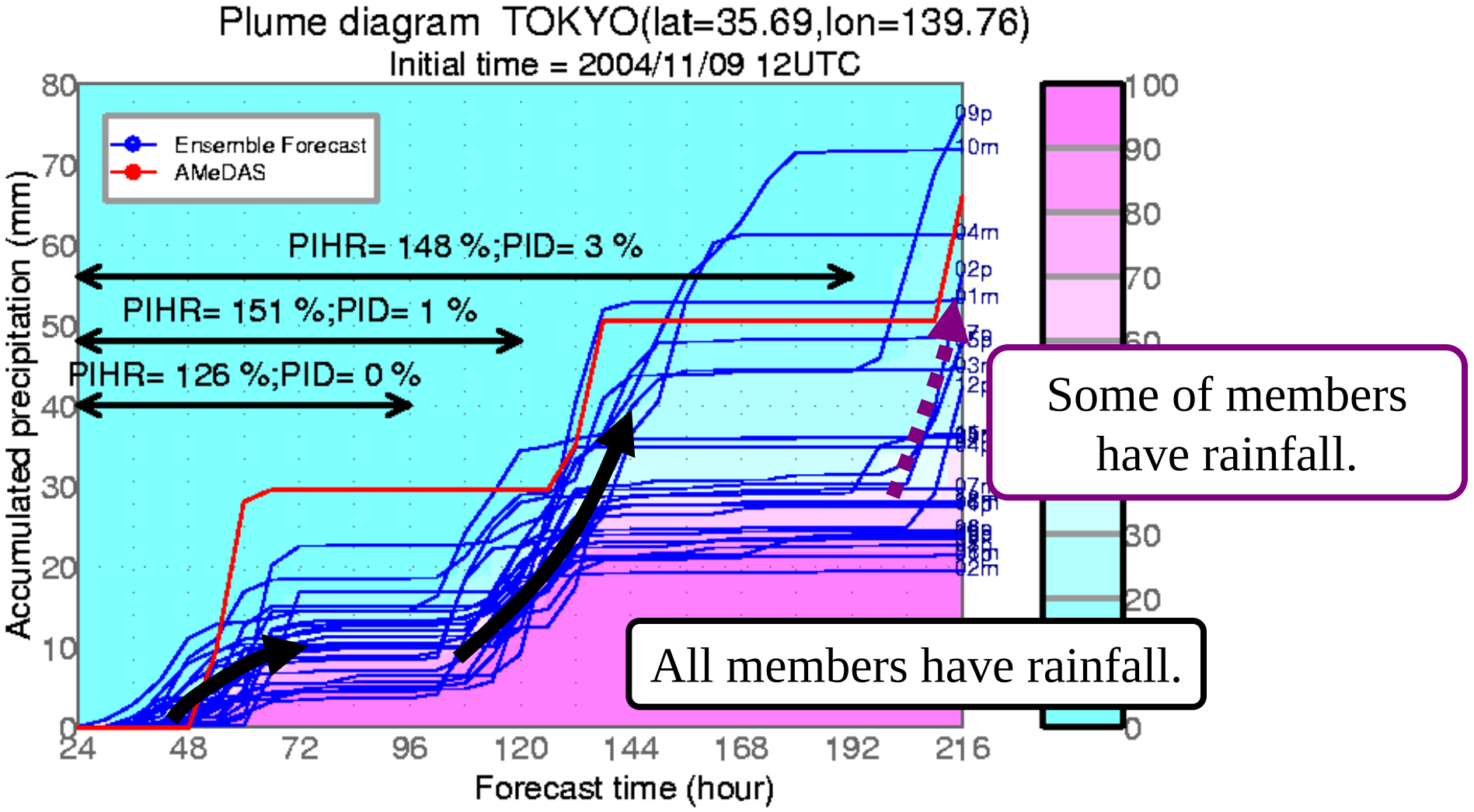
Rainfall PDF derived from JMA-EPS

Histogram of accumulated precipitation from 24hr to 216hr at T106 land grid-point closest to Tokyo predicted by the 25 ensemble members. The initial time is 12UTC on 12th October 2004. Black line indicates a density function of the histogram. Blue line indicates a density function of daily model climate.



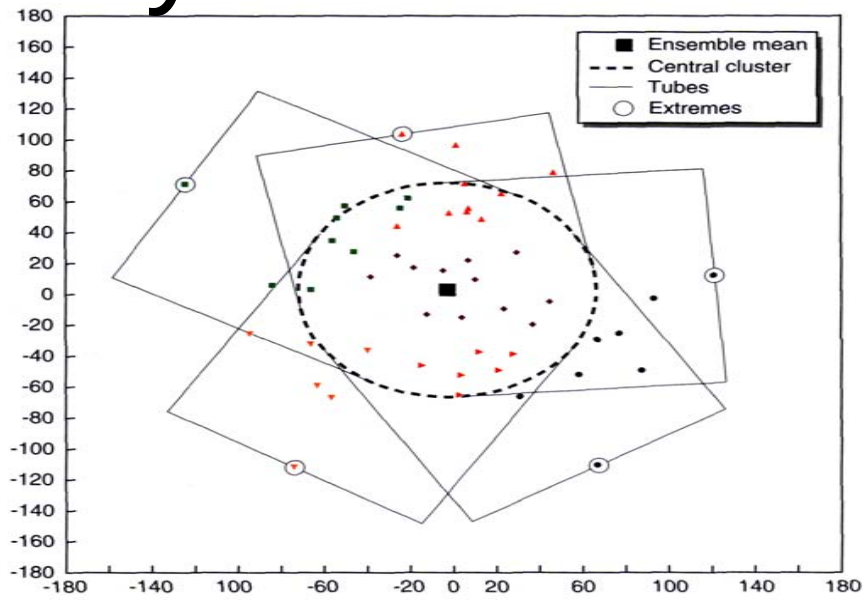
Accumulated precipitation at Tokyo

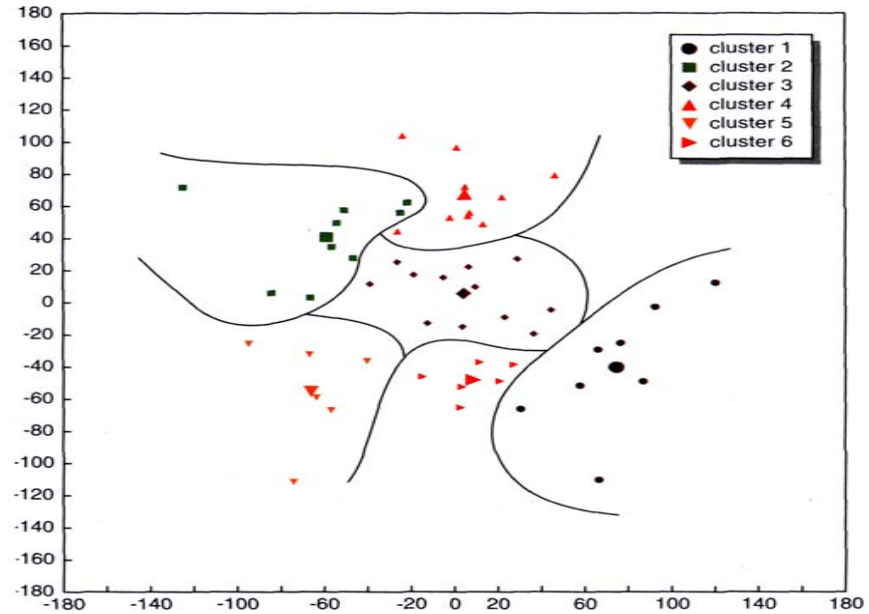
Plume diagram of accumulated precipitation at T106 land grid-point closest to Tokyo predicted by the 25 ensemble members (blue lines) as a function of forecast time from 24hr to 216hr. The initial time is 12UTC on 9th November 2004. Red line indicate the accumulated precipitation observed by the rain gauge at Tokyo. The shading shows a probability of accumulated precipitation defined as the occurrence ratio in EPS. Potential indices (PIHR and PID) are indicated for the period shown as arrows.



Cluster analysis

- Cluster analysis
  - JMA introduces Ward method.
- Tube method
  - developed by ECMWF
  - JMA also introduce a central cluster derived from a tube method.

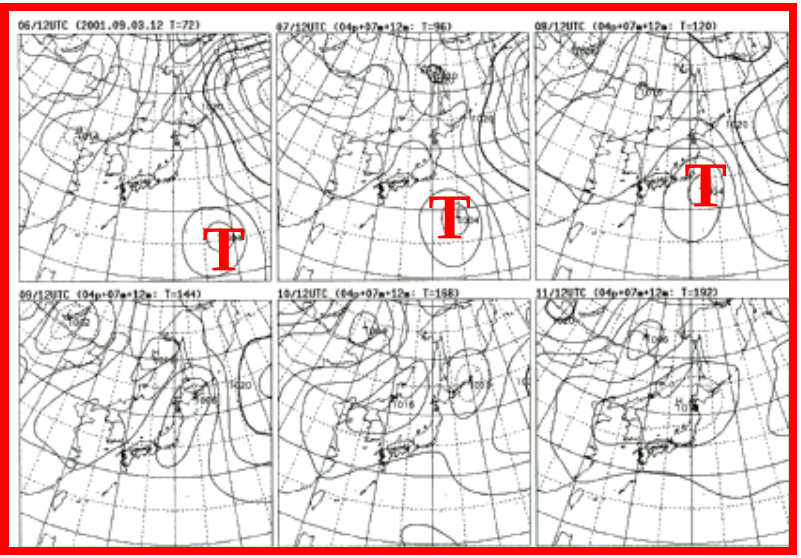




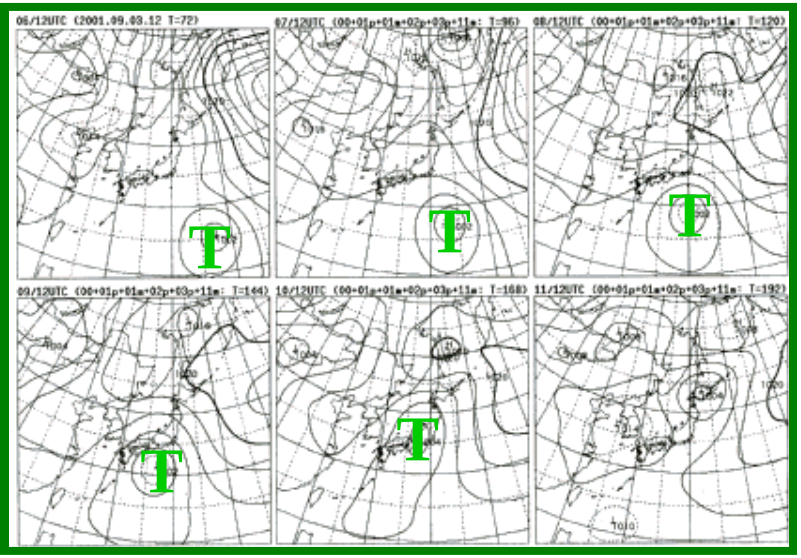
ECMWF News Letter No.79

JMA cluster analysis

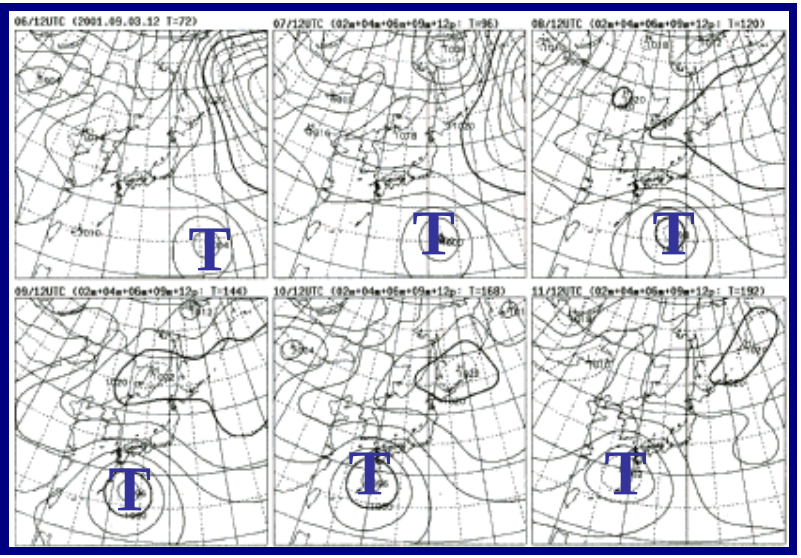
Cluster 1



Cluster 2



Cluster 3



Each panel has six maps, showing daily charts 72 to 192 hours ahead. Initial time is 12UTC on 3rd September 2001.

The typhoon moves toward the eastern part of Japan.

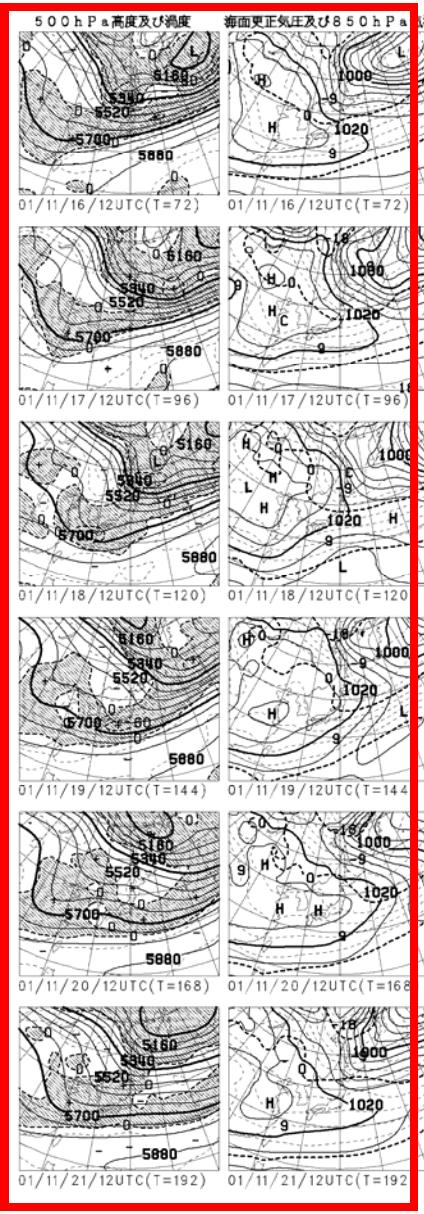
The typhoon moves toward central part of Japan

The typhoon moves toward south-western part of Japan.

A series of JMA EPS products

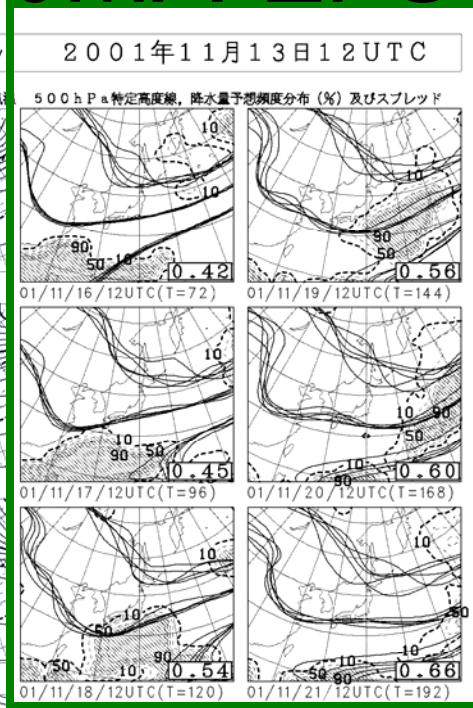
Central cluster charts

Left column is daily forecast maps of 500hPa geopotential height 72 to 192 hours ahead as an average of central cluster members of EPS. The next column is for 850hPa potential temperature



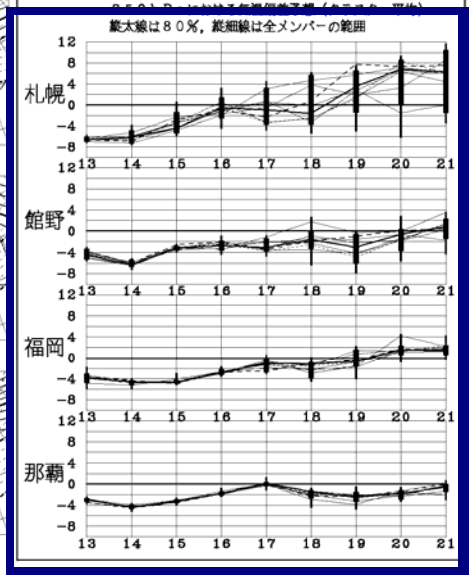
Cluster-analyzed spaghetti diagram

Six figures are daily spaghetti diagram 72 to 192 hours ahead. 25 members are grouped into 5 clusters. Average of members in each cluster for 500hPa geopotential height (solid line), PoP (dash line) and normalized spread (number) are shown.



Cluster-analyzed plume diagram

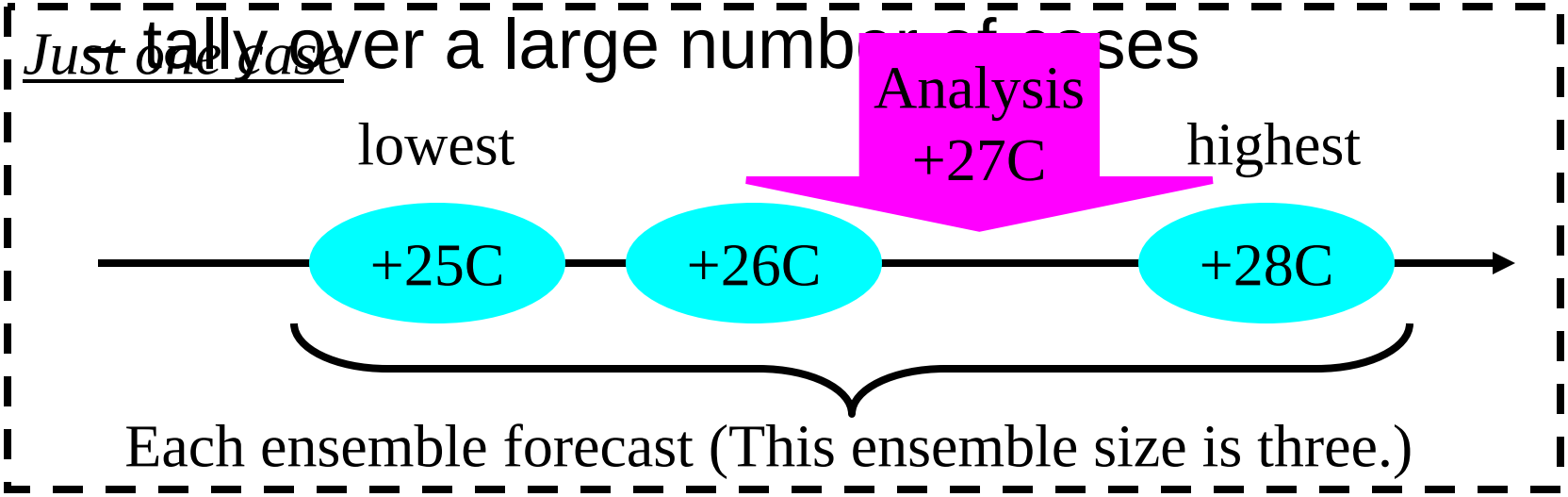
The figure shows 5 cluster averages, control forecast and high-resolution forecast of temperature anomaly at 850hPa for four cities of Japan



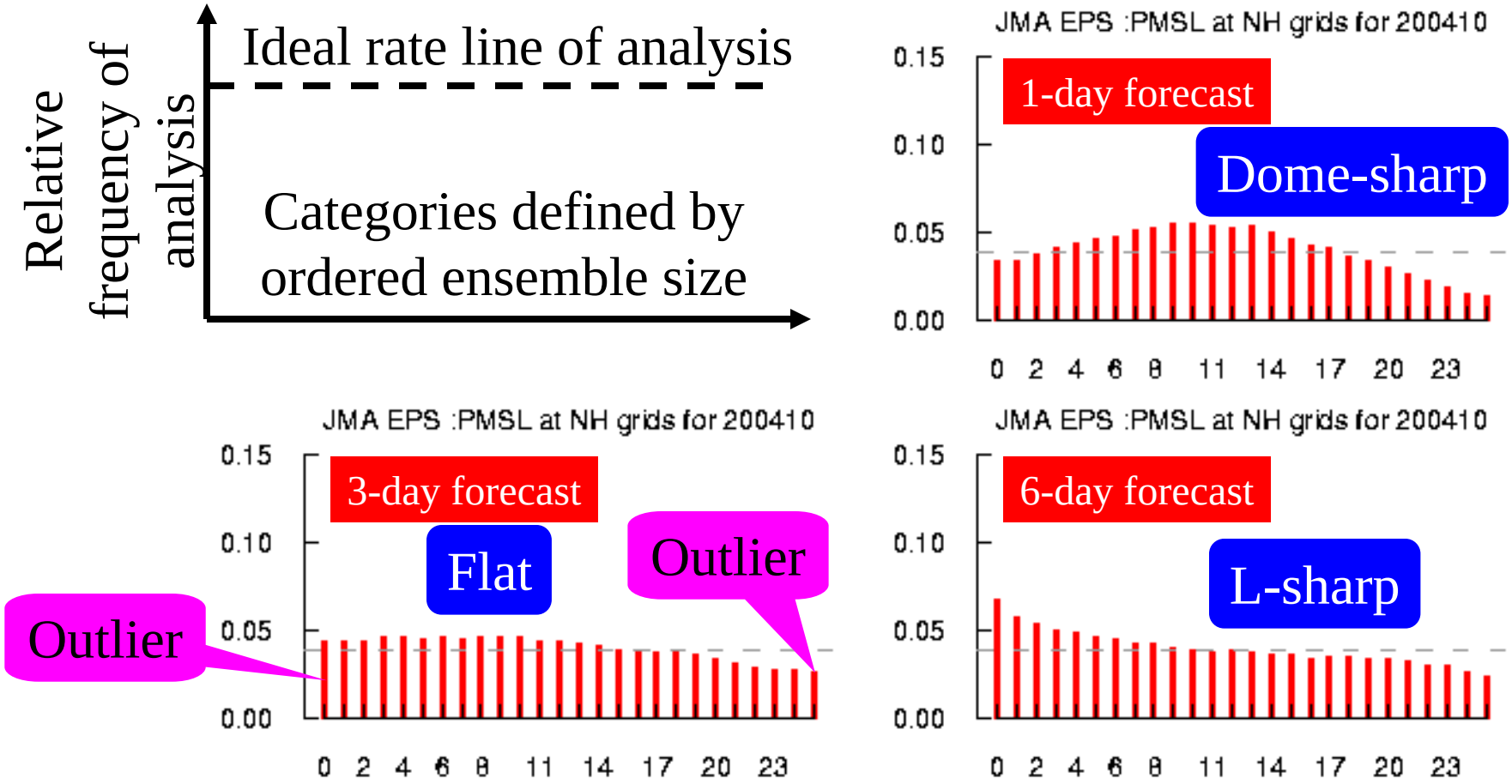
Whether the ensemble forecast captures the analysis or not?

Talagrand diagram (1)

- Preparation
  - order the members of the ensemble forecast from lowest to highest
  - identify n+1 ranges including the two extremes
  - identify the location of the observation
  - tally over a large number of cases



Talagrand diagram (2)



Three talagrand diagrams for 1-, 3- and 6-day ensemble forecasts of sea level pressure in the Northern Hemisphere extratropics.

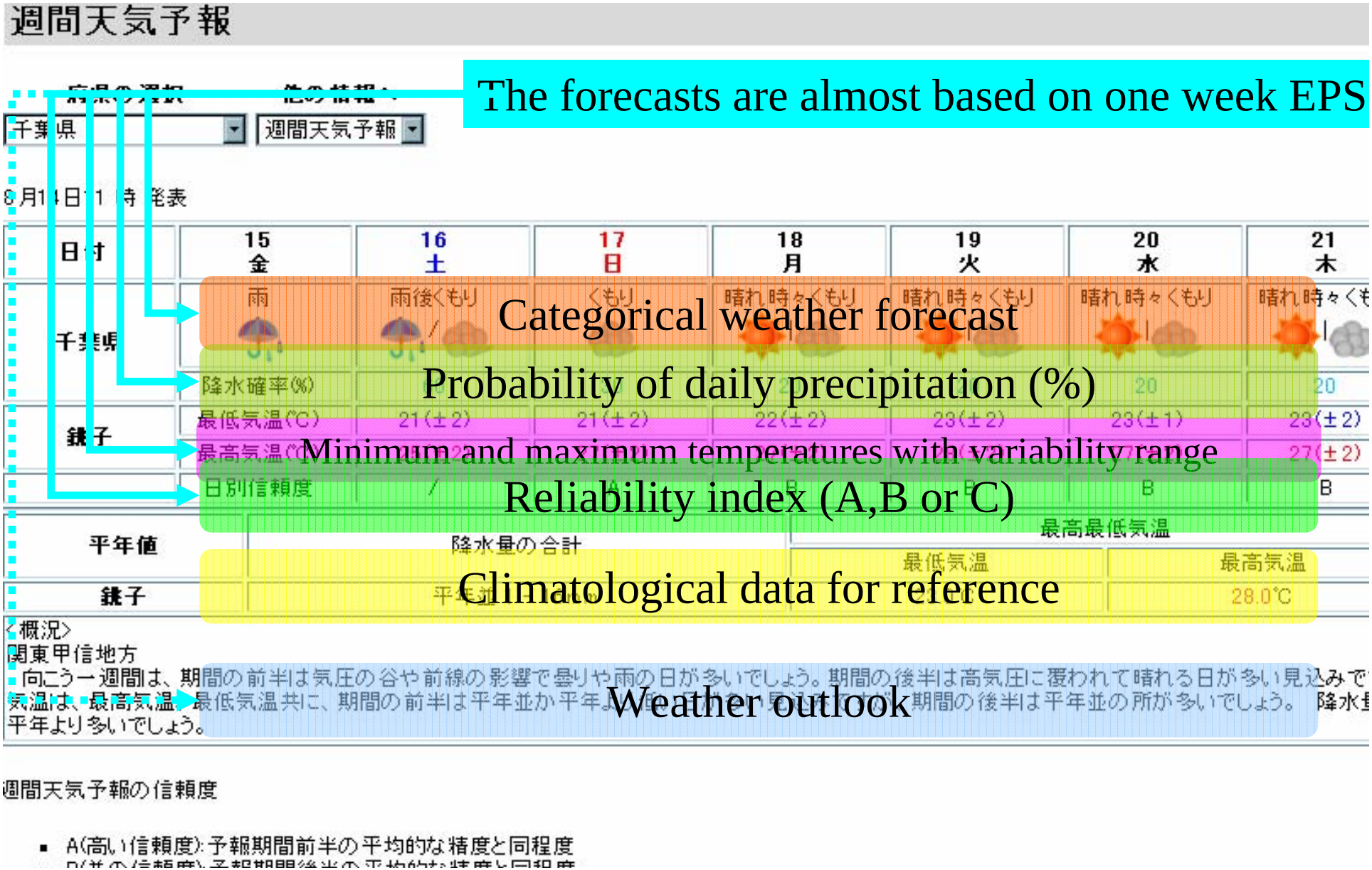
Talagrand diagram (3)

- Interpretation
  - Flat indicates the ensemble spread is suitable so that the ensemble forecast capture the analysis well.
  - A U-shaped distribution indicates the ensemble spread is not enough to capture the analysis.
  - A dome-shaped distribution indicates the ensemble spread is too large.
  - L-shaped and J-shaped distributions indicate the NWP model has over- and under-forecasting bias, respectively.

Operational use of One-week EPS

- **Stamp map**
- **The ensemble mean and spread**
- **Reliability Index**
- **Guidance of the maximum and minimum temperature**

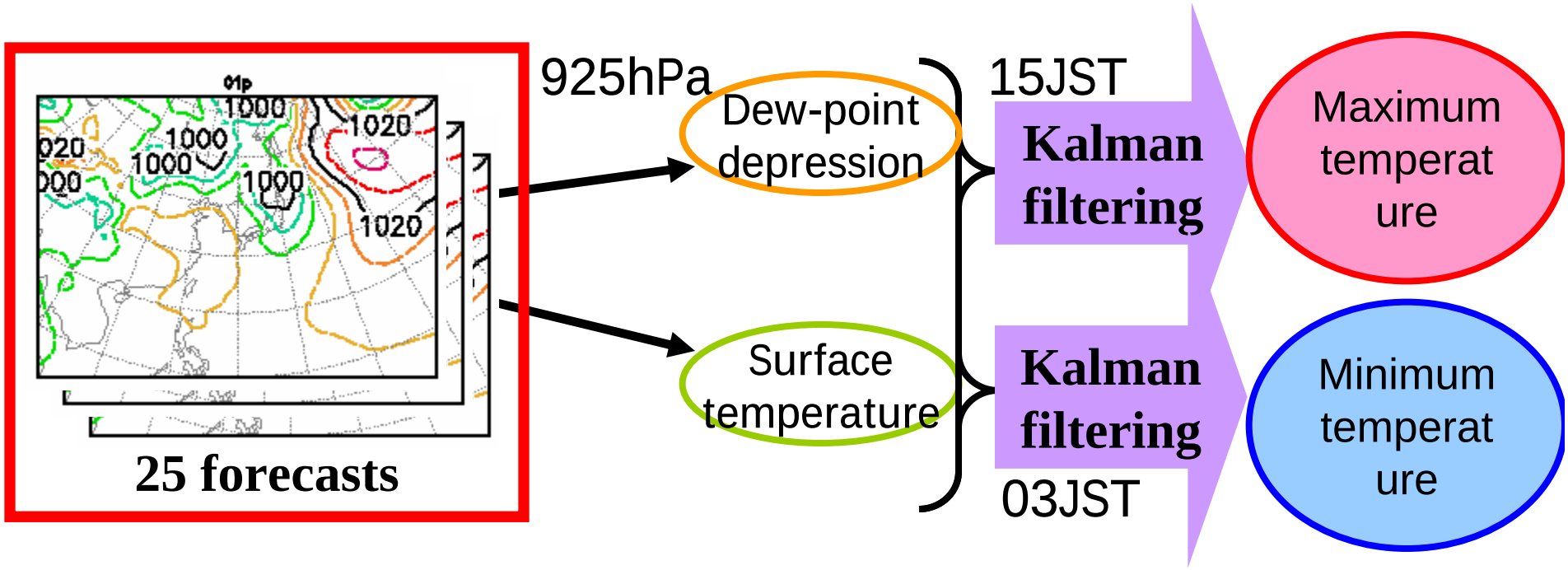
One week forecast for end users



Application of one-week EPS to temperature forecast

How to calculate the daily maximum and minimum surface temperature

•The daily maximum and minimum surface temperatures at about 180 cities of Japan are calculated for each member by using a Kalman filtering technique.
•Ensemble GPVs at target cites are calculated through interpolation.
•The maximum and minimum temperatures are calculated using the previous Kalman filtering coefficients and two predictors at 15JST and 03JST, respectively.

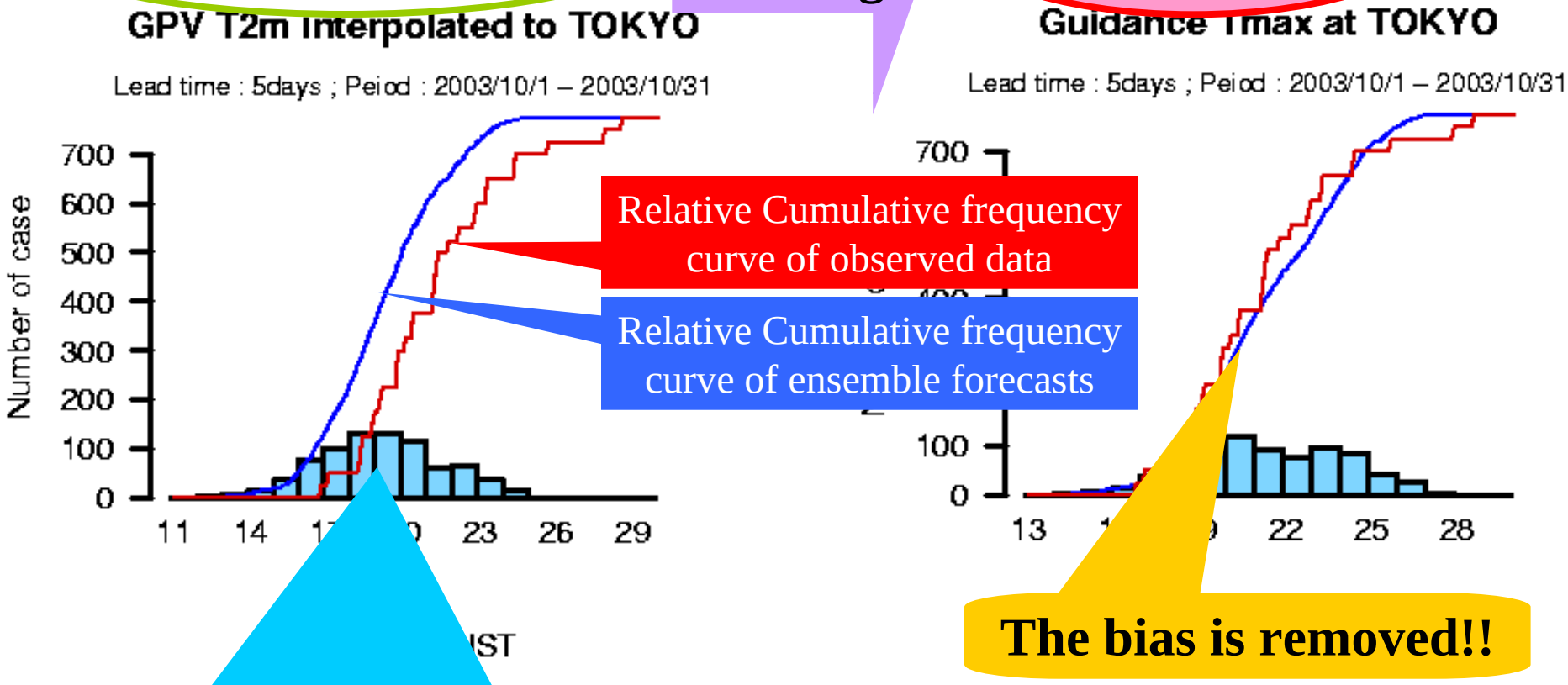


Probability Density Function of the daily maximum temperature

Surface temperature at 15JST derived from one-week EPS

Kalman filtering

Maximum temperature



Relative Cumulative frequency curve of observed data

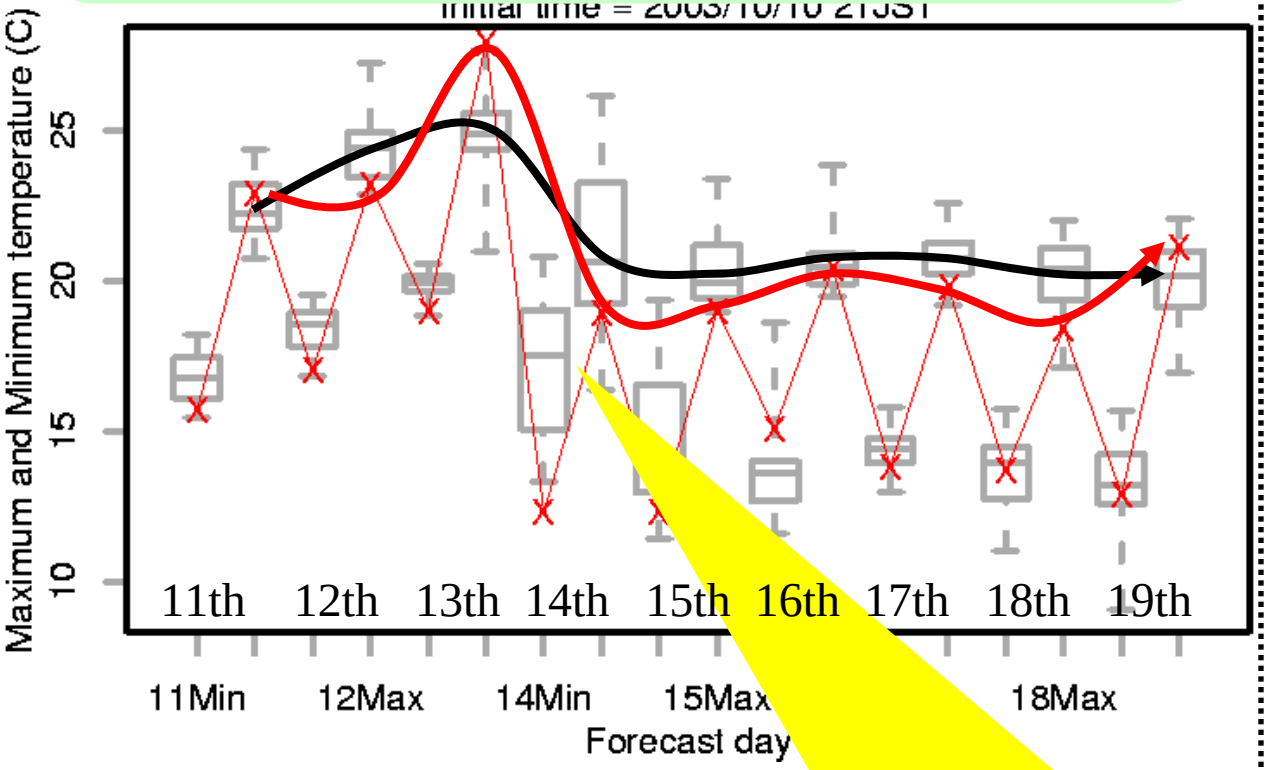
Relative Cumulative frequency curve of ensemble forecasts

The bias is removed!!

Frequency distribution of all ensemble 5-days forecasts at TOKYO for 1st-31th October 2003

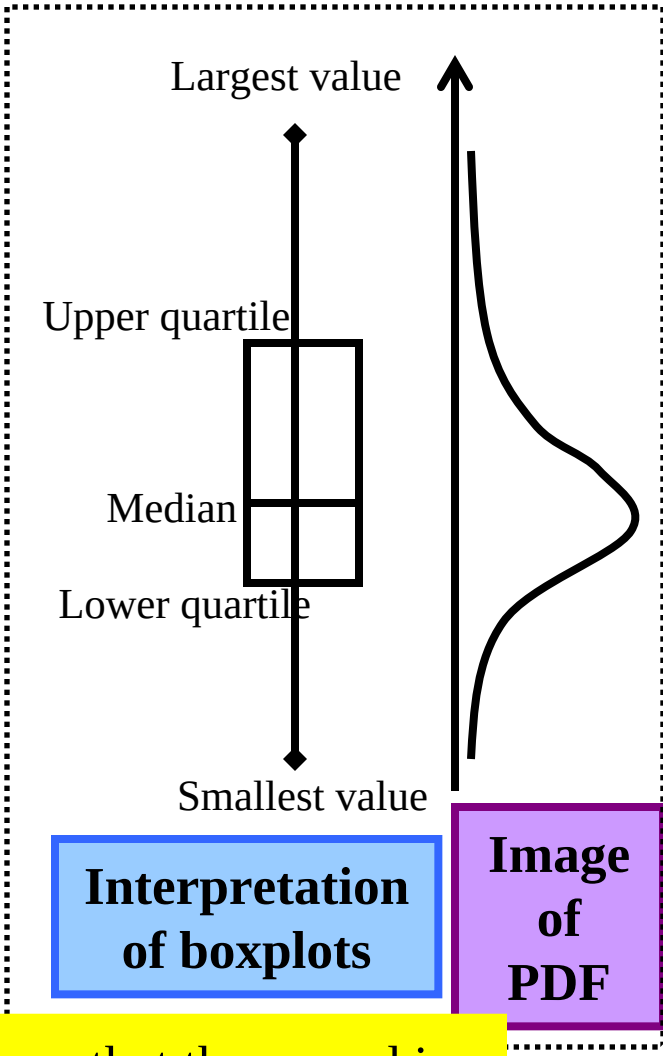
EPSgram of daily Max/Min guidance

Initial time : 12UTC10October2003
Valid day : 11,12,13,14,15,16,17,18,19
Target point : TOKYO



X marks : Observed value

Boxplots : Ensemble guidance



The ensemble guidance says that the spread is large when the trend of the max. temp. changes.

Product of extreme high temperature

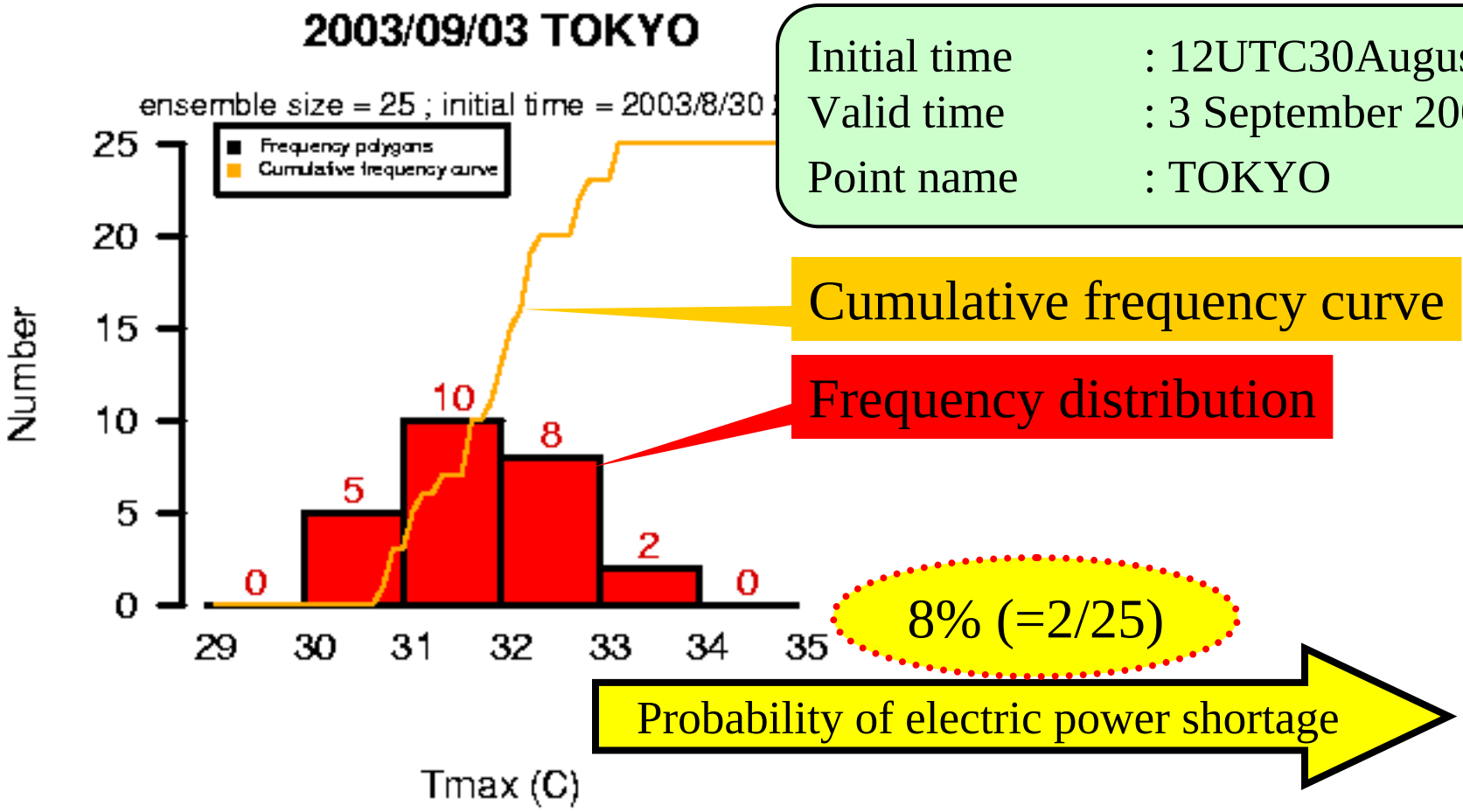
•Offered to forecasters and Electric Power Company

•They use as a probabilistic measure of the extreme high temperature.

•If the maximum temperature exceeds a certain level (33C at Tokyo), consumption of electric power increases rapidly to exceeds the limit of supply, resulting in power shortage.

PDF of daily maximum temperature

The maximum temperatures at about 180 cities of Japan are calculated for each member by using a Kalman filtering technique. The PDF is a frequency distribution of one week EPS members at 9 local sites in Tokyo metropolitan area. The lead time is 3day.



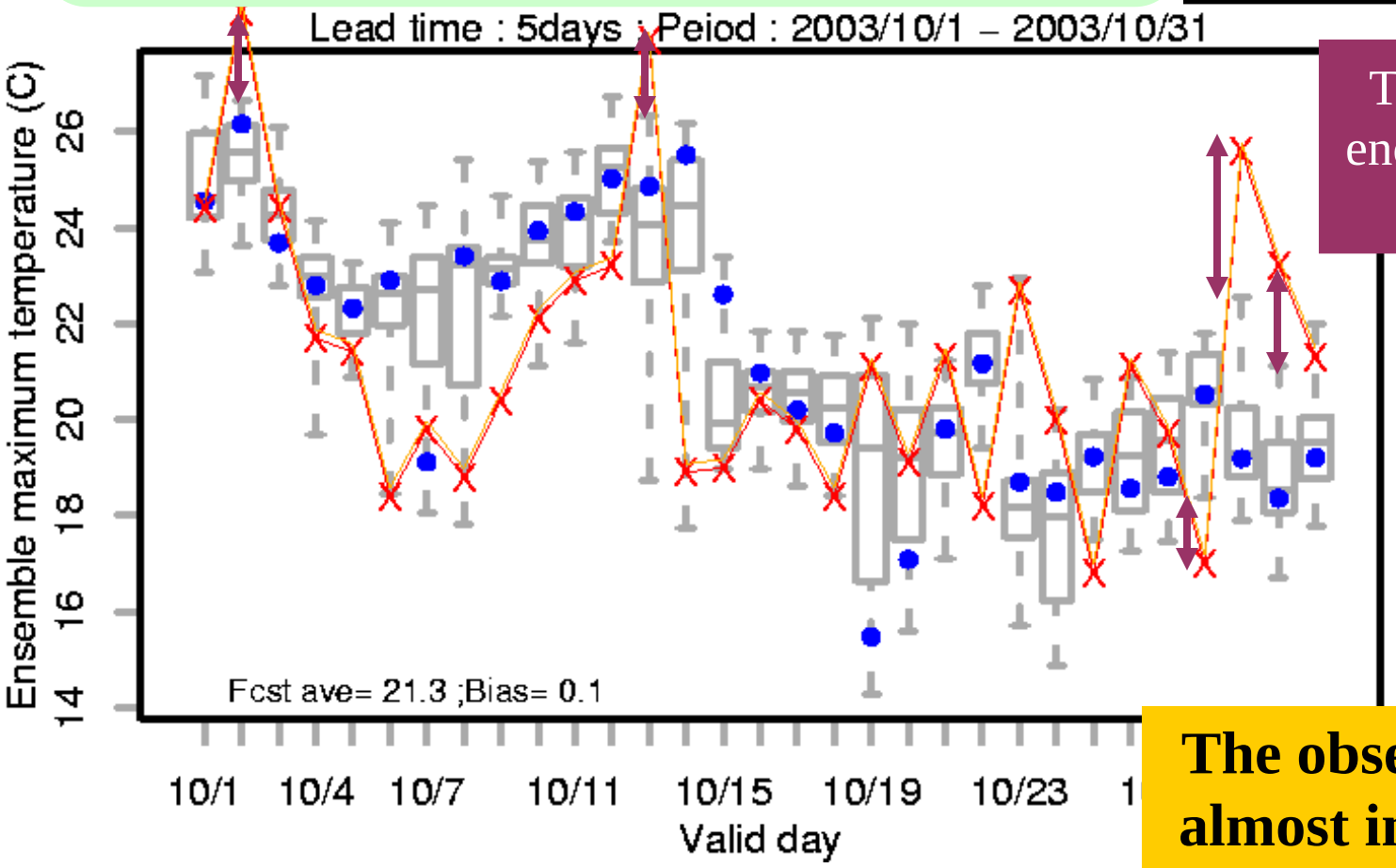
Verification of daily Maximum guidance

Valid day : from 1st to 31th of October 2003
Forecast day : 5 days
Target porint : TOKYO

X marks : Observed value

Boxplots : Ensemble guidance

Blue dots : Control guidance



The spread is not enough to catch the extreme cases.

The observed value is almost in the range of the ensemble guidance.

Conclusion of the application of One-week EPS to temperature forecast

- Temperatures derived from EPS represent the actual PDF very well.

- The Kalman filtering is effective to remove the systematic bias from the model results such as surface temperature derived from EPS.

- Extreme cases, especially surface variables, are not always caught up by all ensemble members.
  - Increase of the ensemble size
  - Introduction of a new guidance for expanding the spread
  - Introduction of another calibration technique (say later)

Typhoon EPS

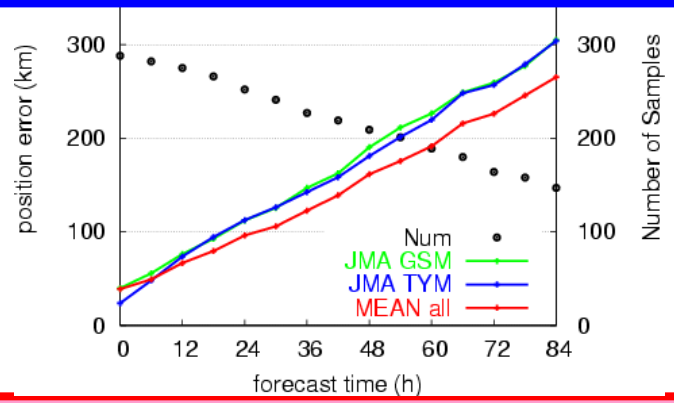
Motivation for developing Typhoon EPS

JMA plans to operate the Typhoon Ensemble Prediction System (EPS) from the TC season in 2008, following experimental operations in 2007.

Motivation 1

Expected error reduction of deterministic track forecasts by using statistical methods such as ensemble mean or cluster analysis.

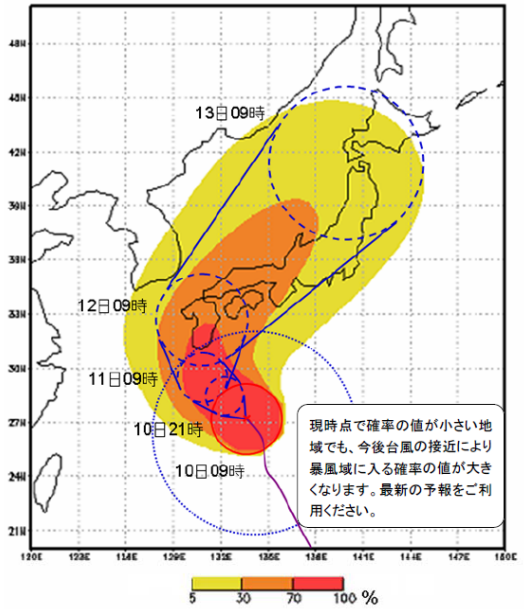
Mean distance error of ensemble mean track forecasts consisted of ECMWF, UKMO, JMA-GSM and JMA-TYM



Mean track forecasts error can be statistically improved. Error reduction is over 30km at +72h.

Motivation 2

Estimating track forecasts uncertainties which differ from day to day and applying to beneficial use of probabilistic track forecasts.



Specifications of the Typhoon EPS

The operation of TYM will stopped in this November when the Typhoon EPS starts its operation.

	Current TYM	**Typhoon EPS**
NWP model	regional model	global model
resolution	24(km) x 24(km) with 40 layers	60(km) x 60(km) with 60 layers
initial time	00, 06, 12, 18UTC	00, 06, 12, 18UTC
forecast time	84 hours	132 hours
number of targeted typhoons	2	3
member size	1 (deterministic forecast)	11 (1 non-perturbed run + 10 perturbed run)
initial condition	-	singular vector method
model ensumble technique	-	not considered

Intensity forecasts are supported by 20km GSM which will be operated from this November.

3 typhoons at the same time !!!

We sometimes have 3 or more TCs at the same time in the Western North Pacific

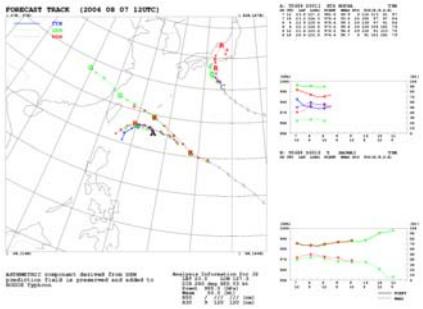
Typhoon track forecasts for typhoon MARIA, SAOMAI, BOPHA
initial time 2006.08.07.12 UTC

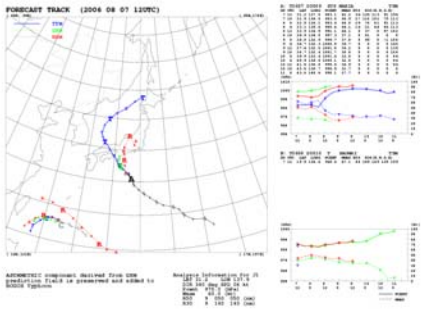
Current TYM

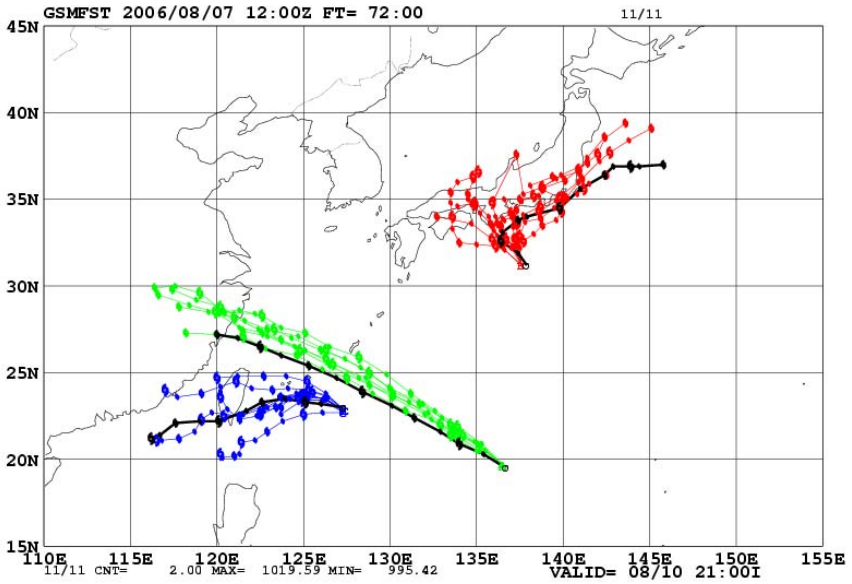
Typhoon EPS

J1

J2



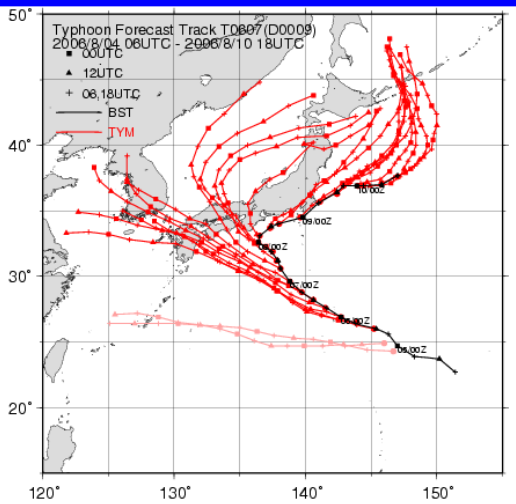




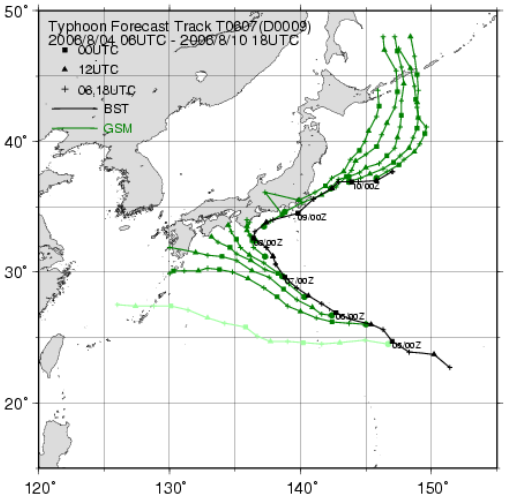
Case Study: Typhoon MARIA (T0607)

All track forecasts by TYM and GSM for MARIA.
Initail time is from 2006.08.05.00 to 2006.08.10.18 UTC.

TYM forecasts

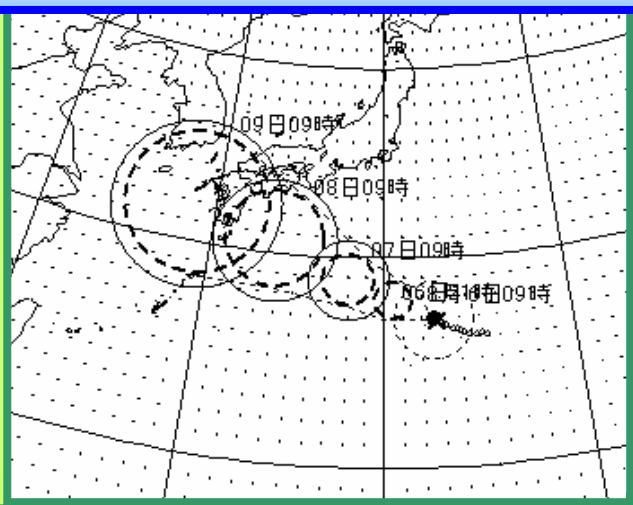


GSM forecasts

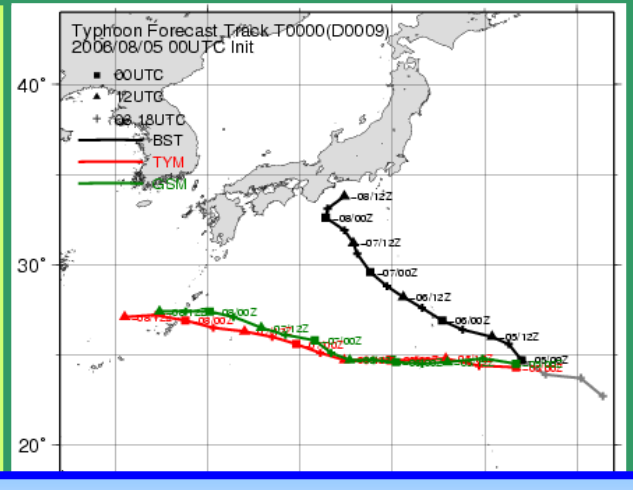


Initial time: 2006.08.05.00UTC

Current forecast



TYM and GSM



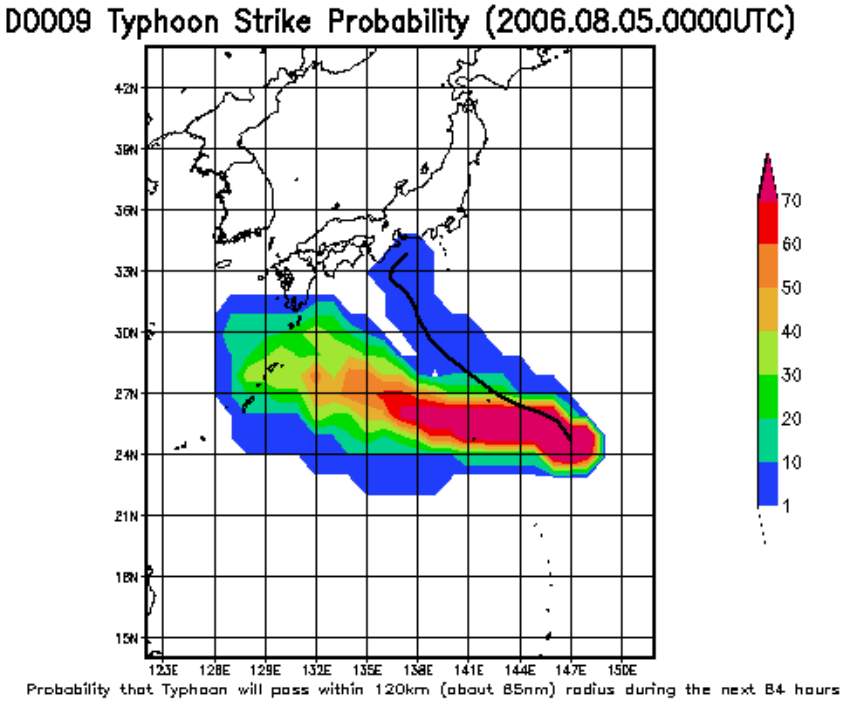
In the early stage of MARIA, TYM and GSM failed to express the recurvature.

Typhoon EPS for MARIA

Initial time: 00UTC 5Aug 2006

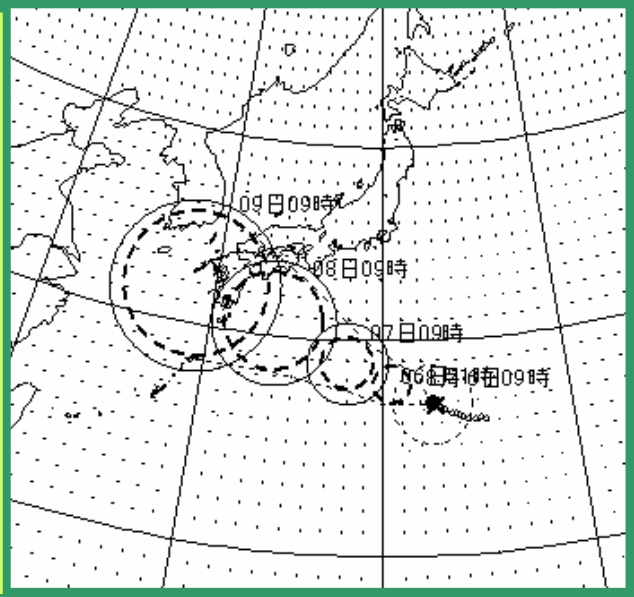
Typhoon ensemble forecast

(strike probability map)

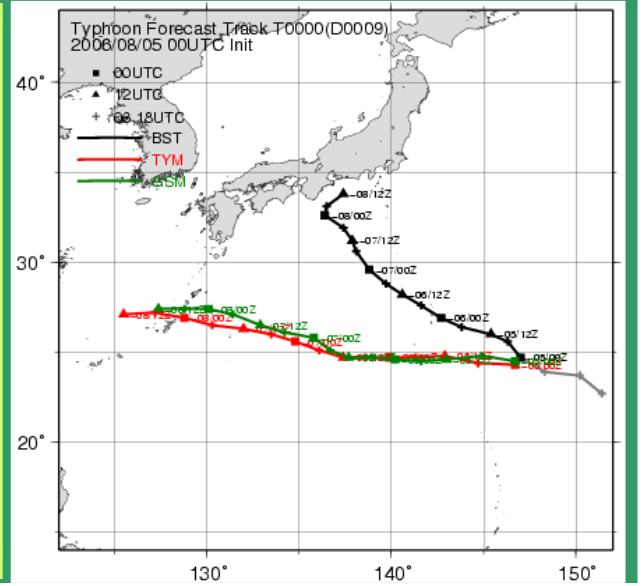


Typhoon EPS indicates the probability of landing around Tokai district.

Current forecast



TYM and GSM



Statistical verification results

We conducted a numerical experiment on the Typhoon EPS. The experiment period is Aug. and Sep. in 2004.

Deterministic forecasts

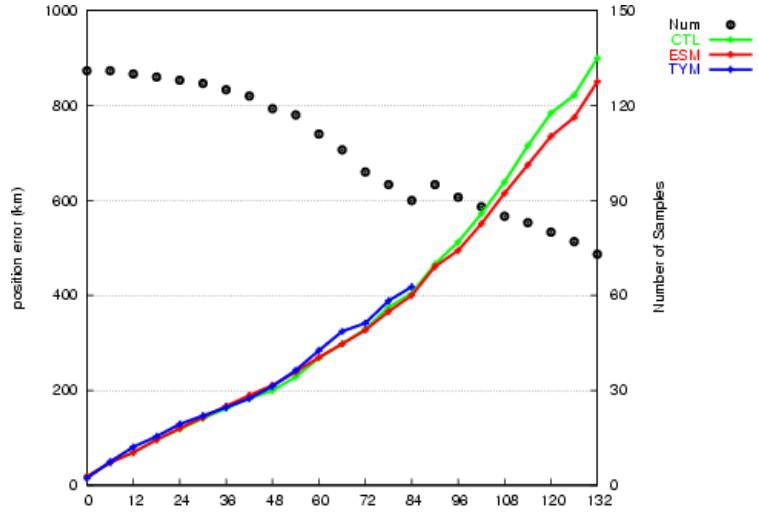
Mean distance error of TC track forecasts

Forecast range is 132hours (see X axis)

Blue line : JMA TYM

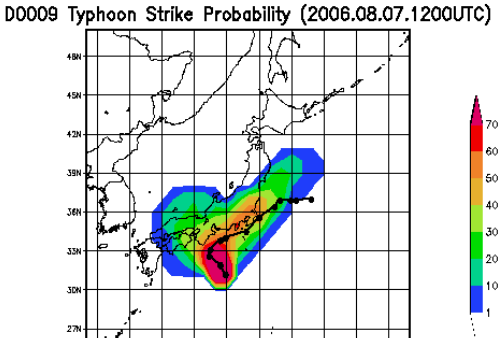
Green line : Control run (non-perturbed run)

Red line : Ensemble mean

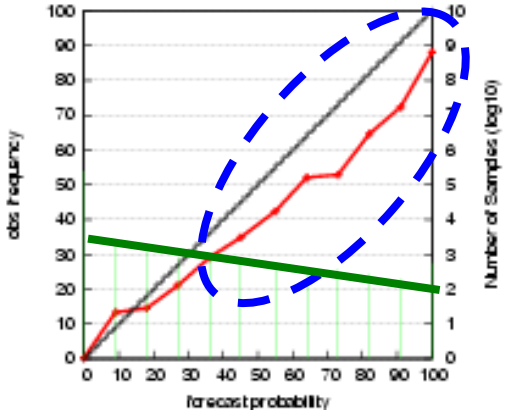


Mean track forecasts error is smaller than that of TYM. Error reduction is about 10km at +72h.

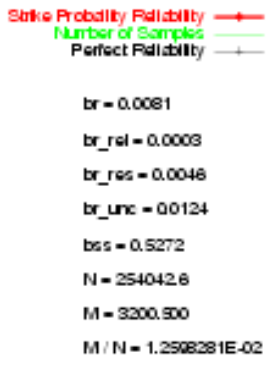
Probabilistic forecasts



Reliability Diagram



Brier Score

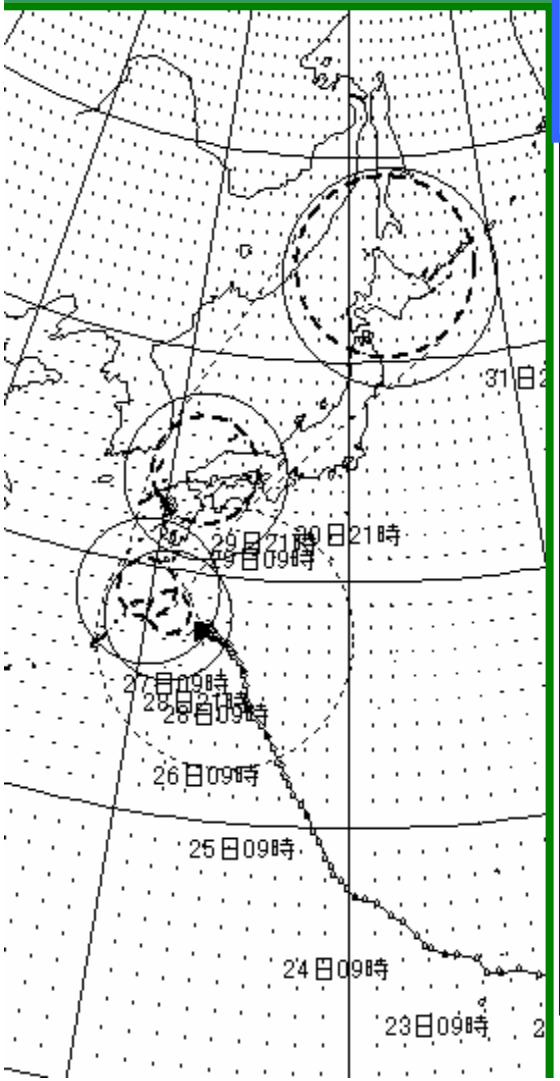


High reliability and plus brier skill score.

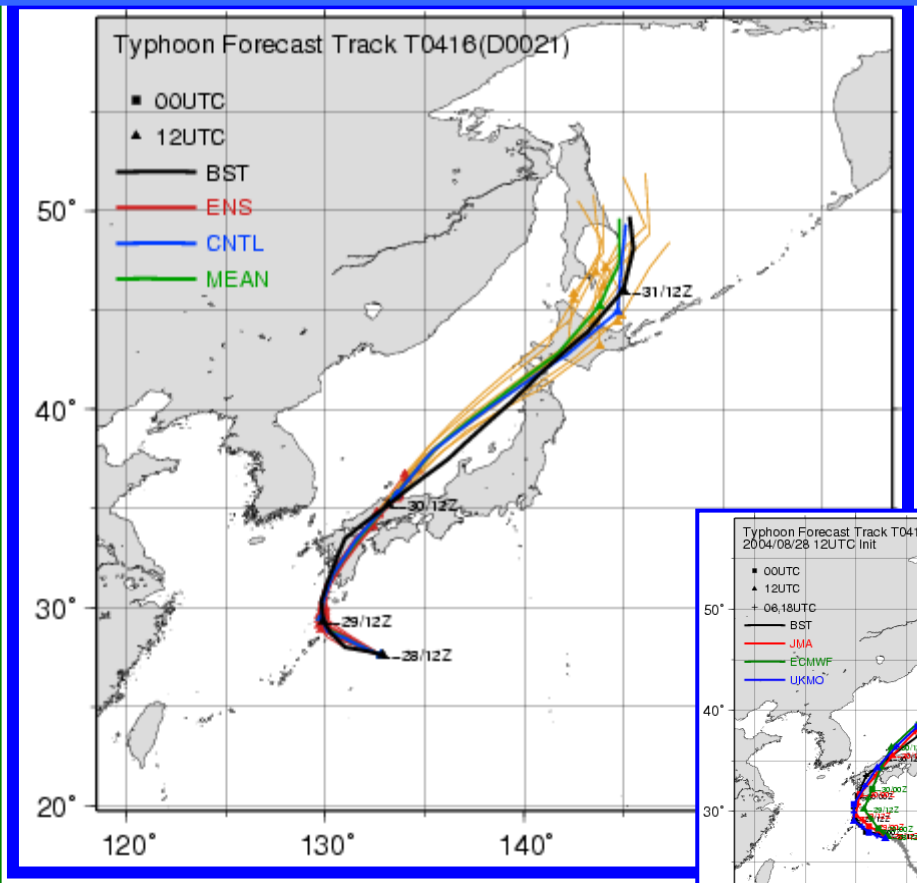
Preliminary research on the beneficial use of ensemble spreads

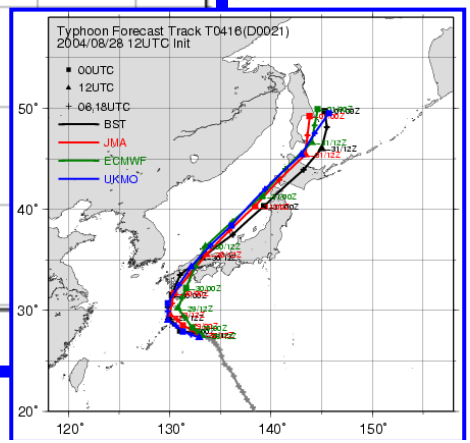
Initial time: 12UTC 28Aug 2004

Current forecast



Black: best track
Blue: unperturbed run (control run)
Red: perturbed run(s)
Mark is plotted every 24 hoursTEPS

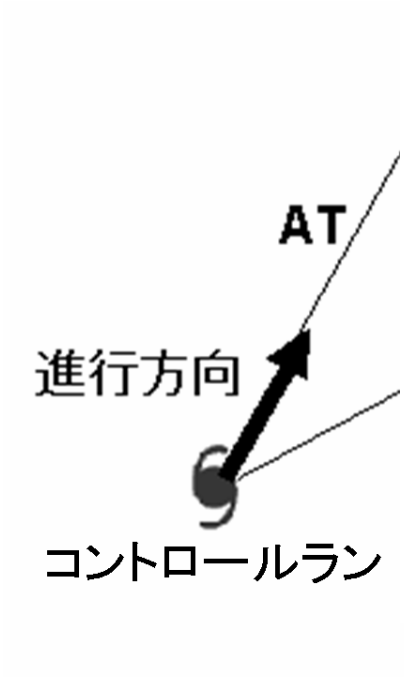


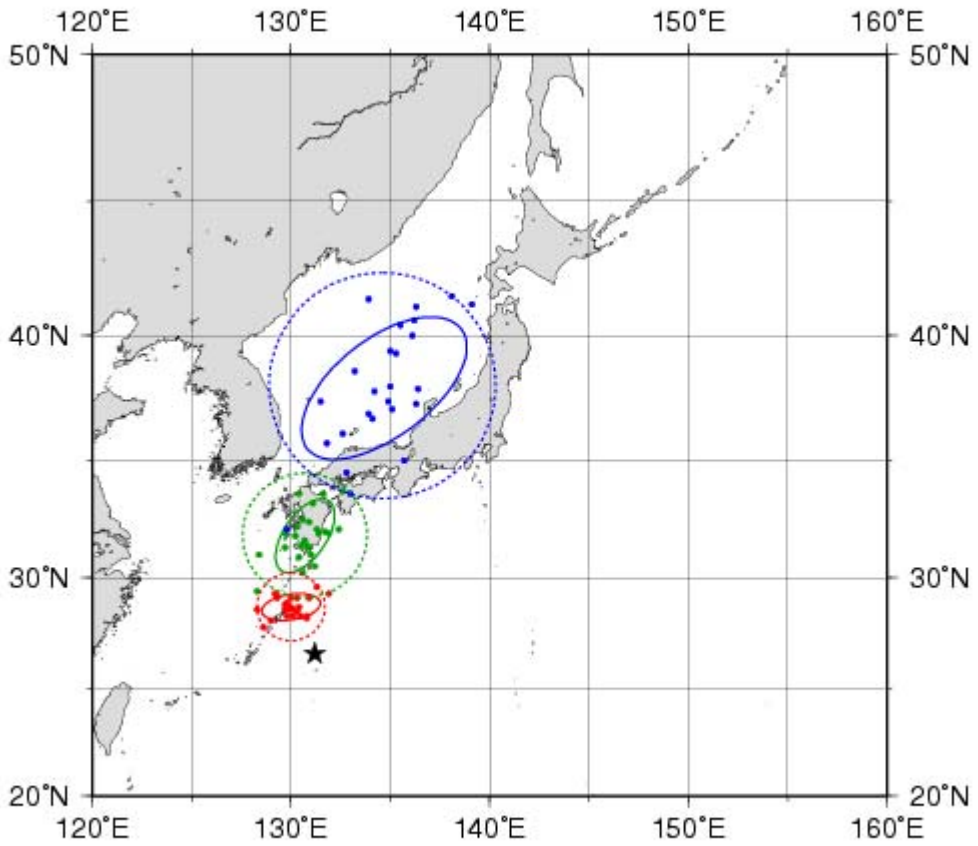


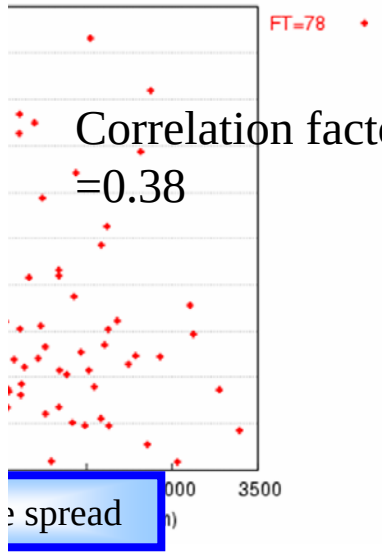
The spread of typhoon track forecasts enable to optimize the error circle's size, which is based on a statistical value in the current system.

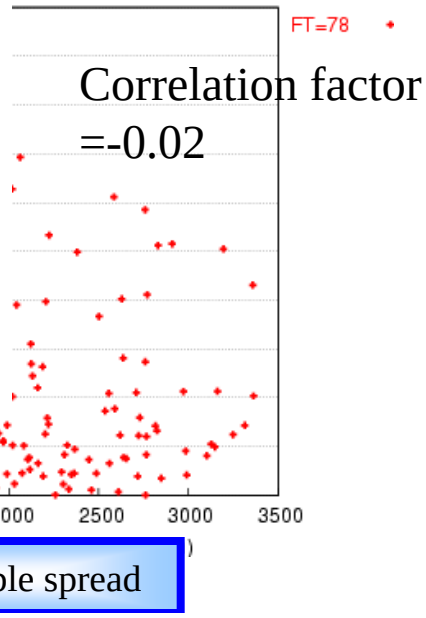
Preliminary research on the beneficial use of ensemble spreads

スプレッドをコントロ
沿った成分(AT)と直
て検証した。統計期
期間で、3日予報の





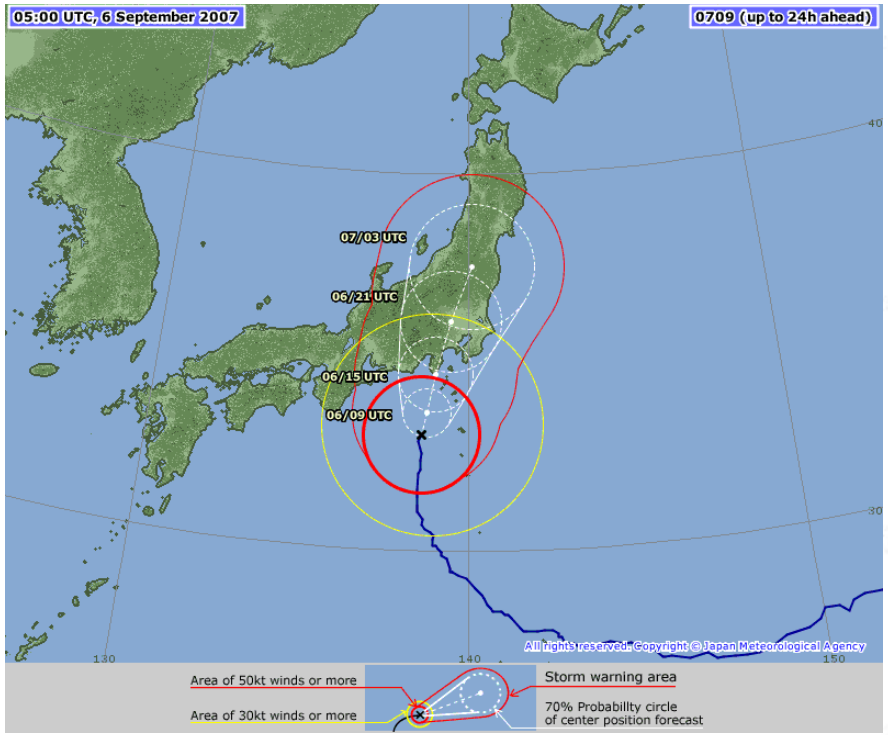




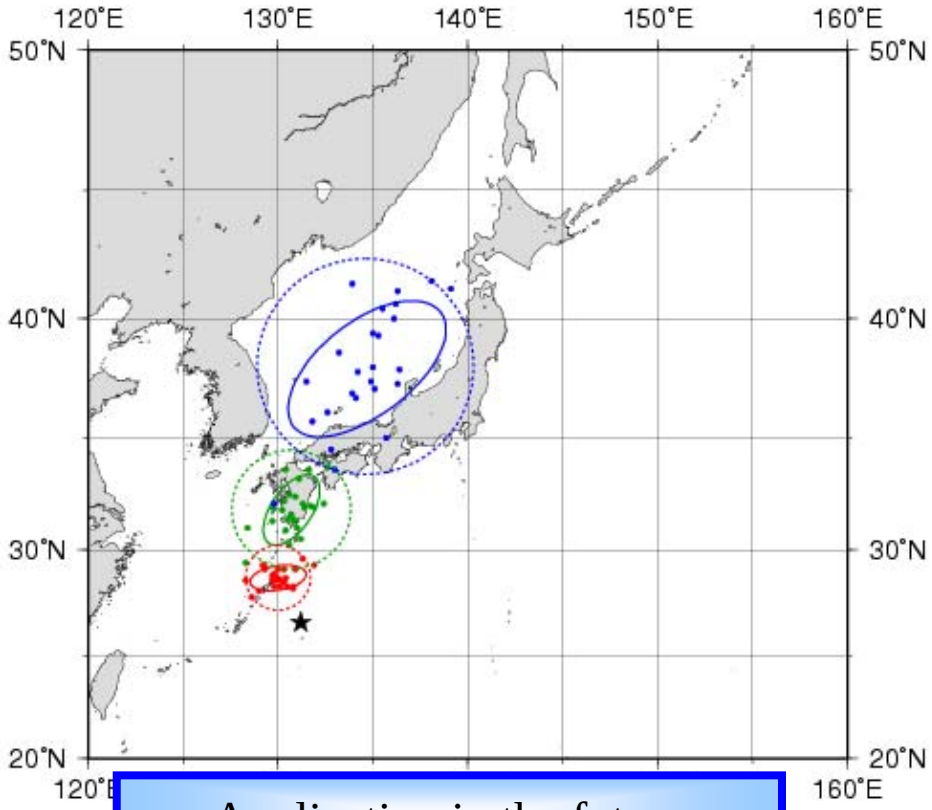
New application for typhoon track forecasts

The forecast uncertainty on TC central position is described in a circle, whose radius is decided on a **statistical method**, using information about current TC position and intensity.

The area which represents forecast uncertainty could be optimized by using **ensemble spread**, which changes day by day, typhoon by typhoon.



Current Application

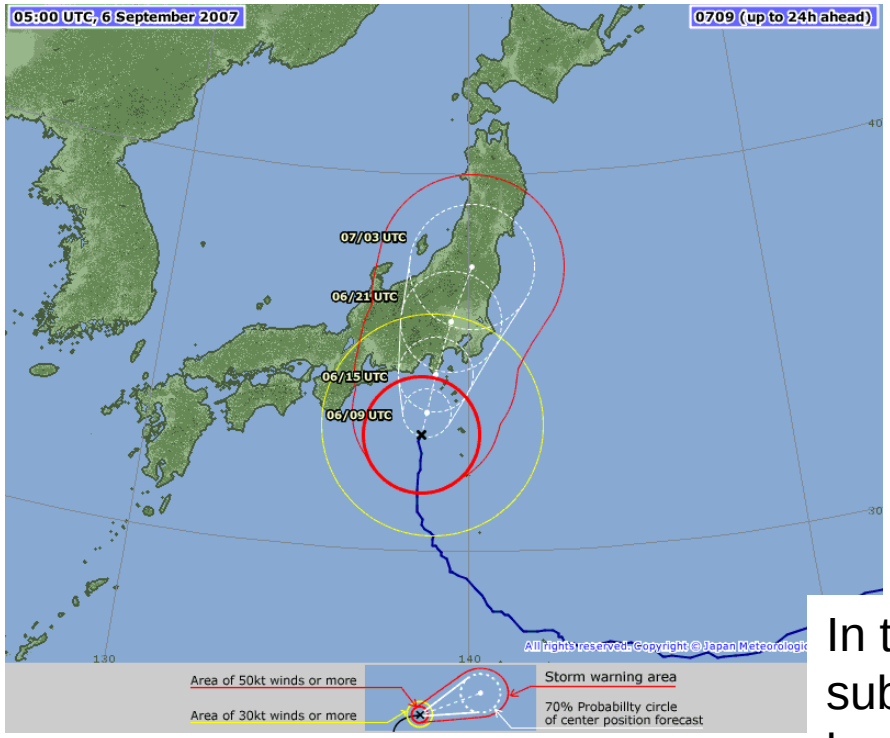


Application in the future

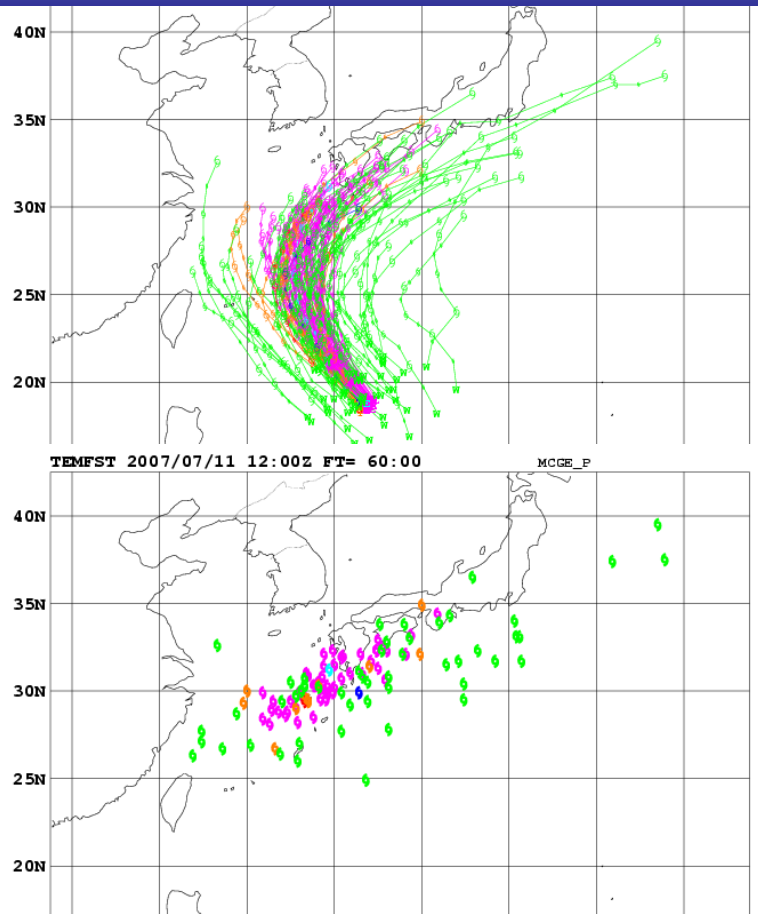
Circle is good ?

to express forecast uncertainty on typhoon track movements?

The forecast uncertainty on TC central position is described in a circle, whose radius is decided on a **statistical method**, using information about current TC position and intensity.

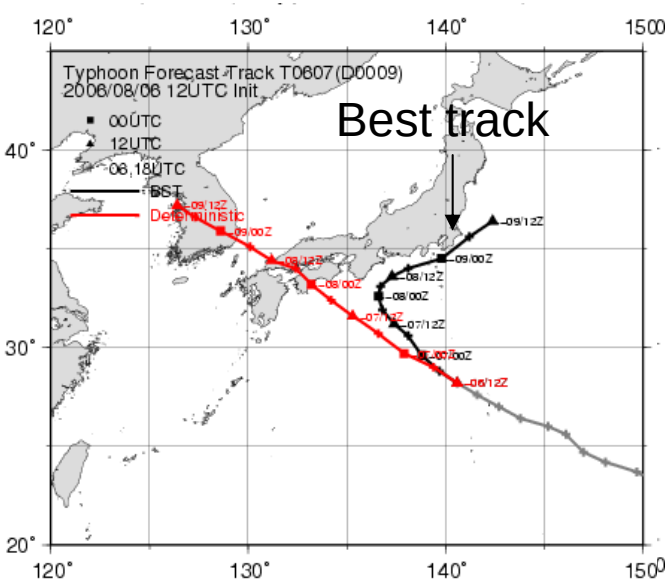


Current Application

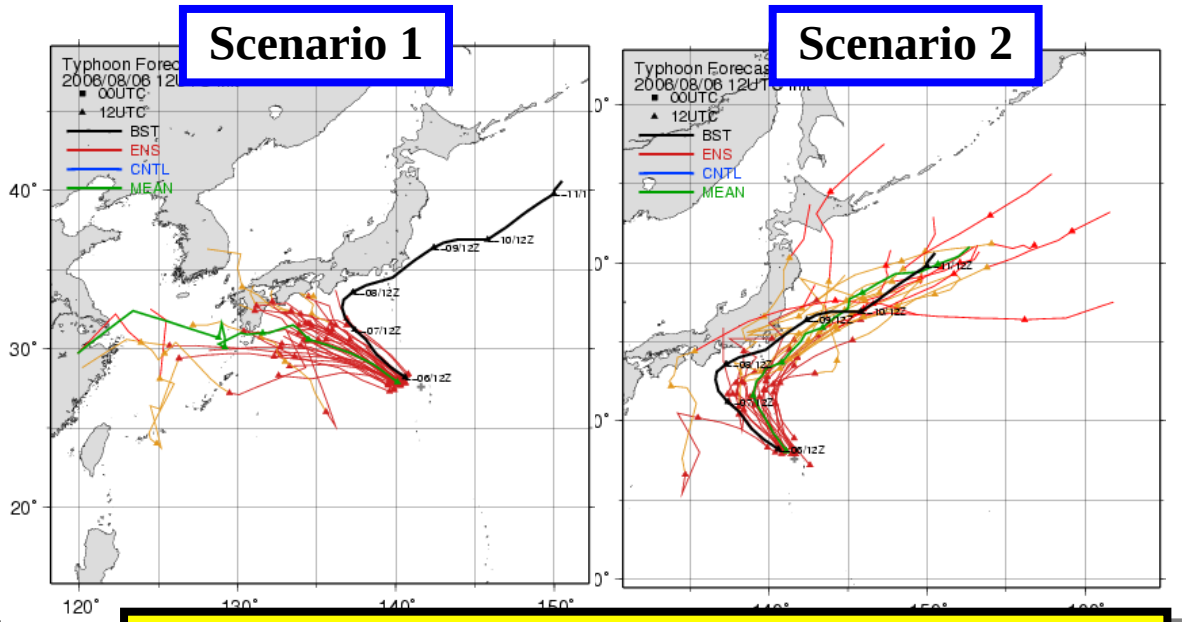


In the stage that typhoon is going along with subtropical jet, forecast uncertainty is relatively large in the direction of movement, compared with that in the crosswise direction.

Cluster Analysis
- case study : typhoon MARIA-



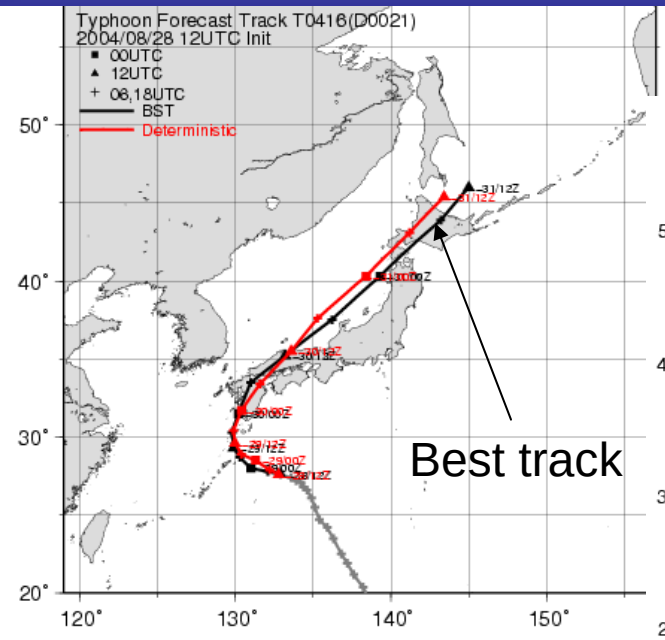
Deterministic forecast (red line)
Initial: 2006.08.06 12UTC

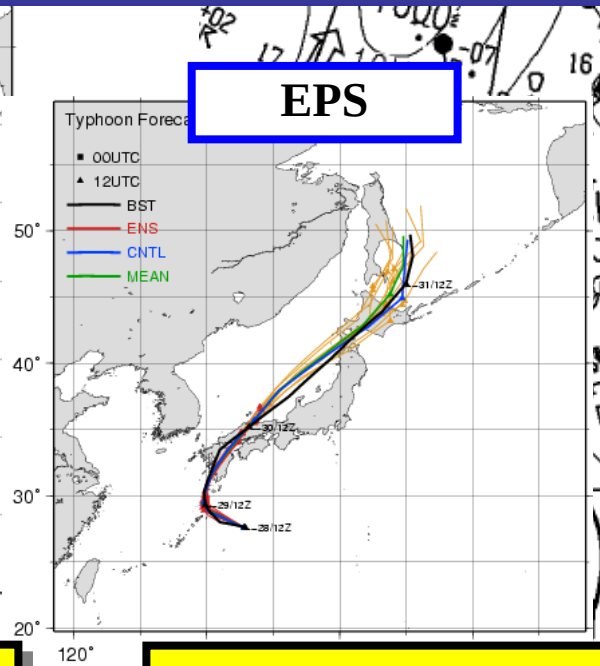


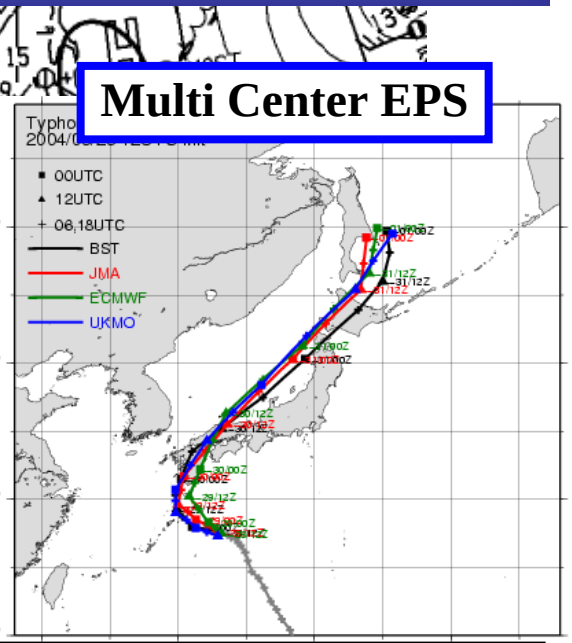
Example of probabilistic forecast
Two scenarios (see green line) suggested

Even if the best likely solution, or deterministic forecast, goes wrong, several other scenarios presented help people act accordingly, and in some cases they can prepare for the anticipated damage well in advance.

Cluster Analysis
- case study : typhoon CHABA-







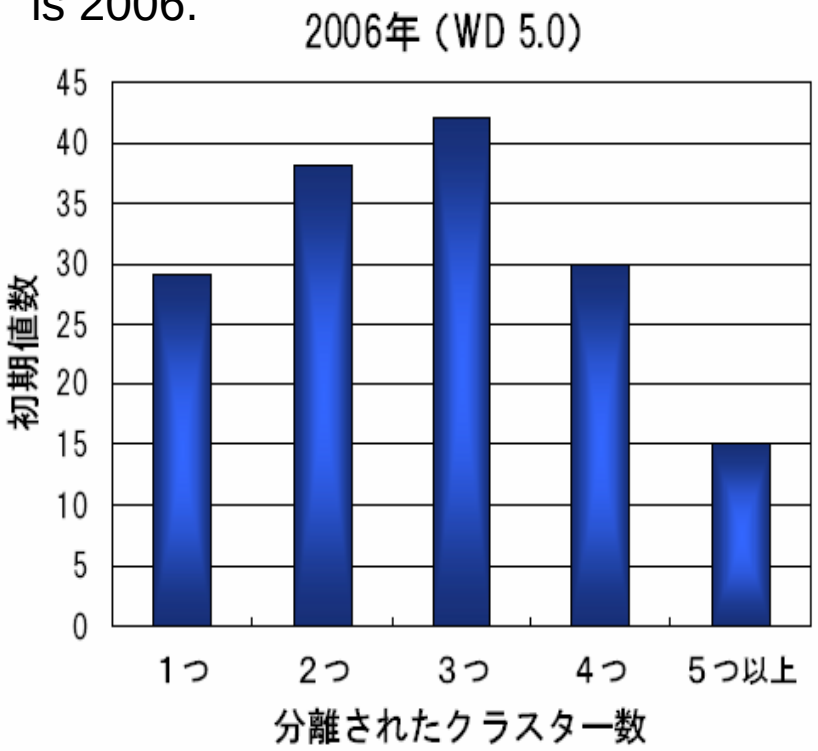
Deterministic forecast (red line)
Initial: 2004.08.28 12UTC

Example of probabilistic forecast.
Conceivable scenario is only one!

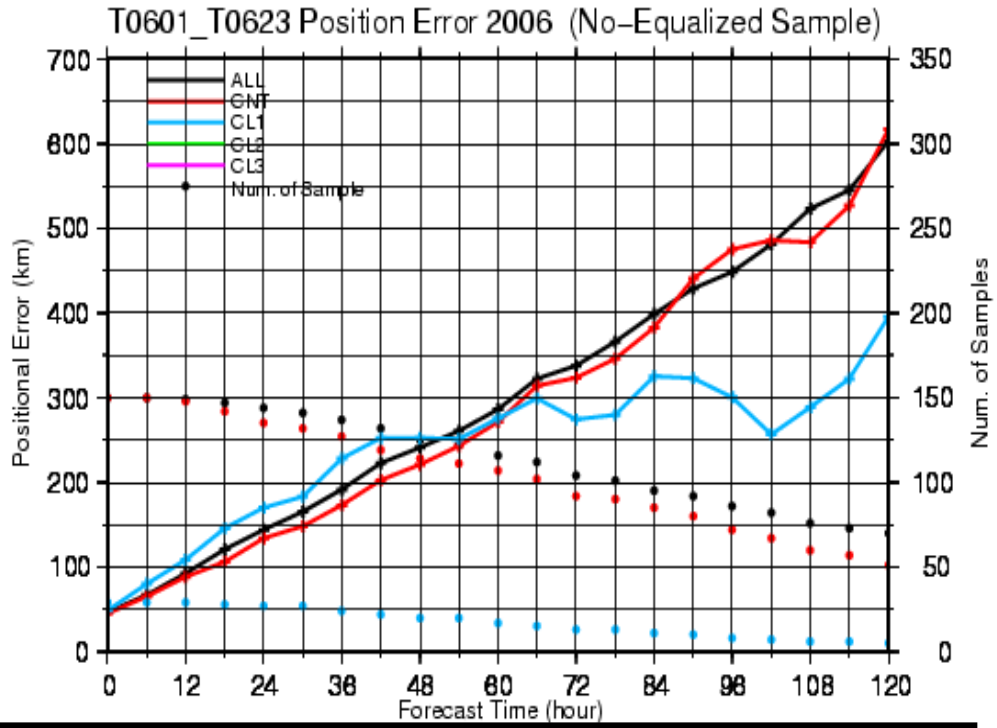
If the number of possible scenarios is only one, it means the scenario is a highly likely scenario. People can act accordingly and in areas where the possibility of the typhoon striking is estimated 0 they can avoid taking unnecessary actions against the typhoon approaching.

Uncertainty information derived from a cluster analysis - Typhoon track forecasting -

Frequency distribution of the analyzed number of cluster. Verification period is 2006.



ensemble mean of the only cluster vs control run vs ensemble mean



In the cases where the number of clusters is analyzed only one, a statistical verification shows the ensemble mean of the cluster have smaller error (light blue), compared with the average forecast error by control run or “simple” ensemble mean over a year(red or black).

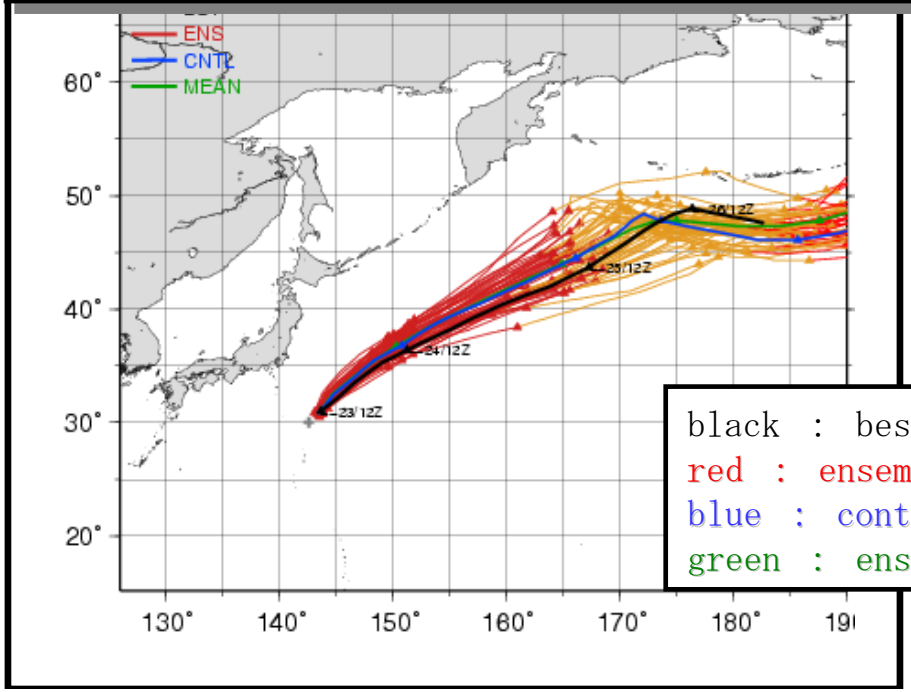
Case Study : The analyzed number of cluster is **1**

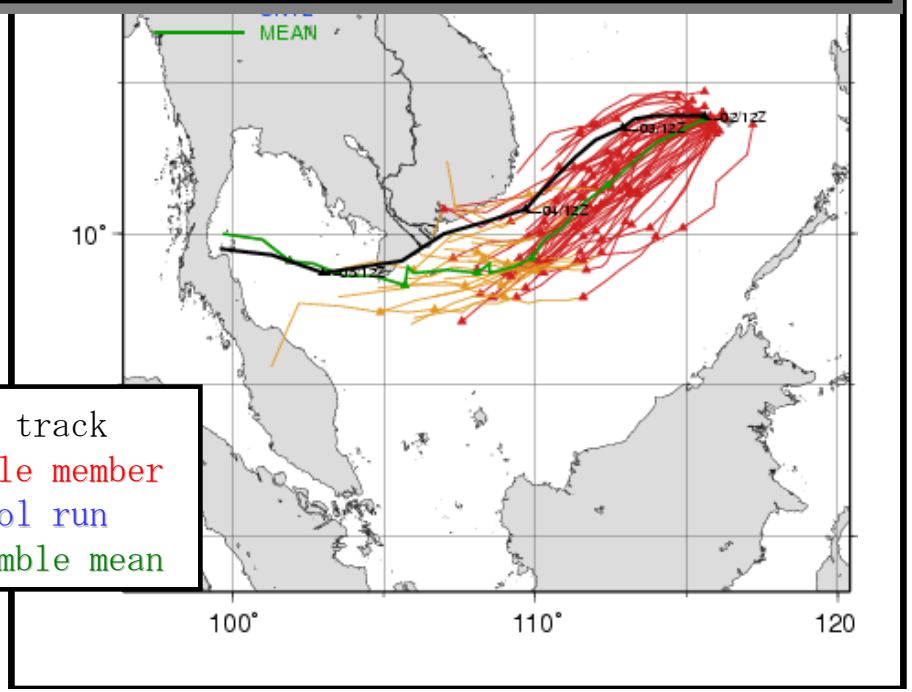
２００６年９月２３日　Ｔ０６１４ (left)

２００６年１２月２日　Ｔ０６２１(right)

In below cases the ensemble mean of the cluster have smaller error (light blue), compared with the average forecast error by control run or “simple” ensemble mean over a year(red or black).

We can say “the uncertainty of the track forecast is relatively small”



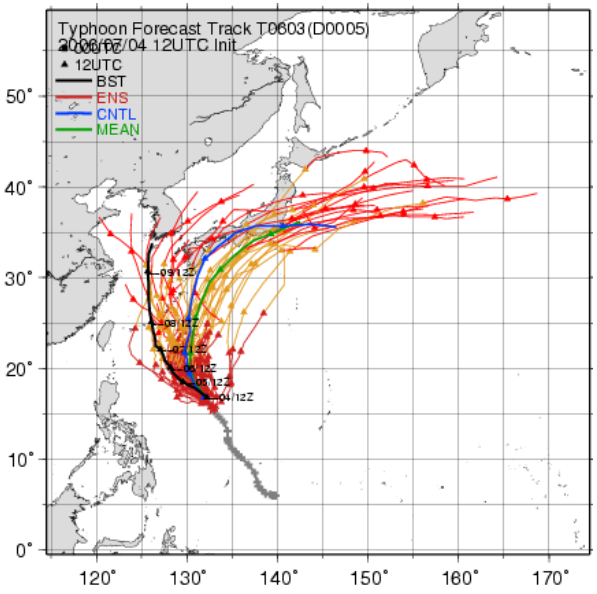


black : best track
red : ensemble member
blue : control run
green : ensemble mean

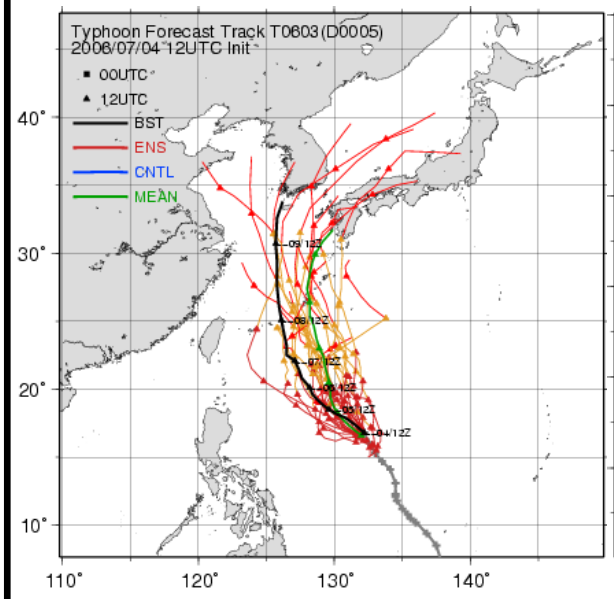
Case Study : The analyzed number of cluster is **2**

２００６年７月４日　Ｔ０６０３

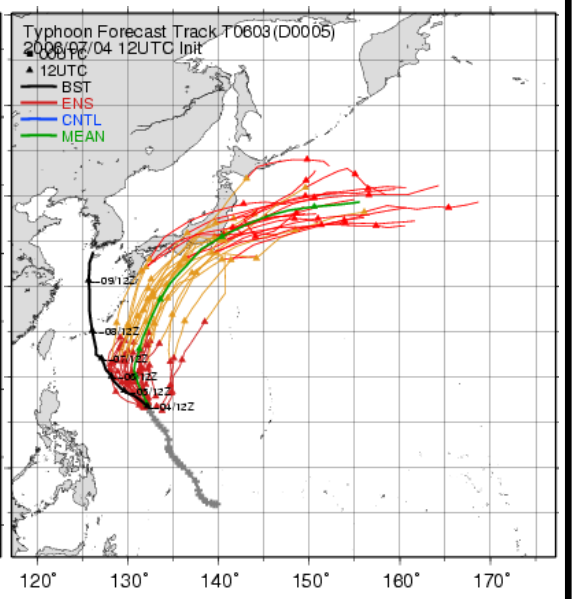
All ensemble members



1 s t **Cluster**



2nd cluseter



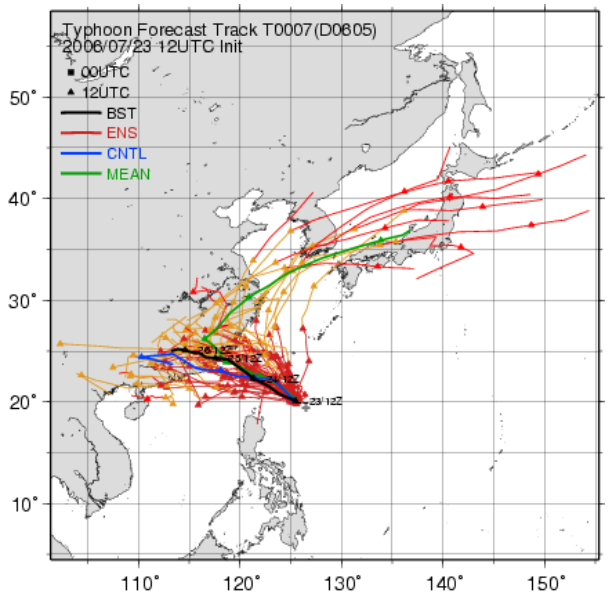
The 1st cluster was correct

By clustering, we can identify 2 scenarios, going into the Sea of Japan and going toward Tokyo area.

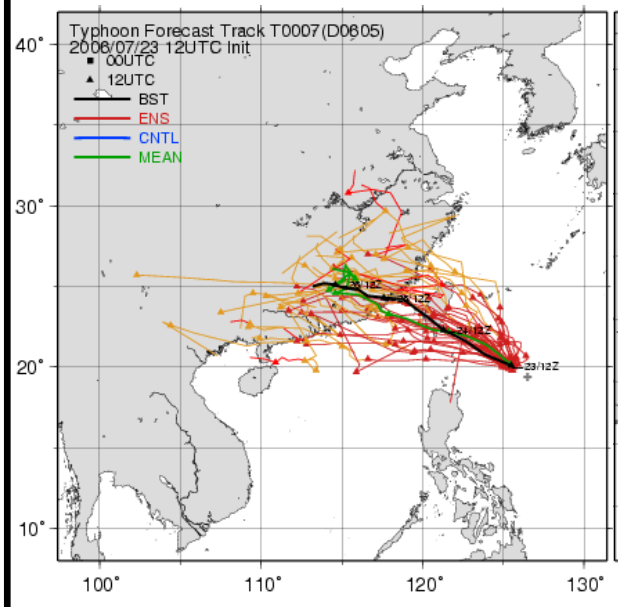
Case Study : The analyzed number of cluster is **2**

２００６年７月２３日　Ｔ０６０５

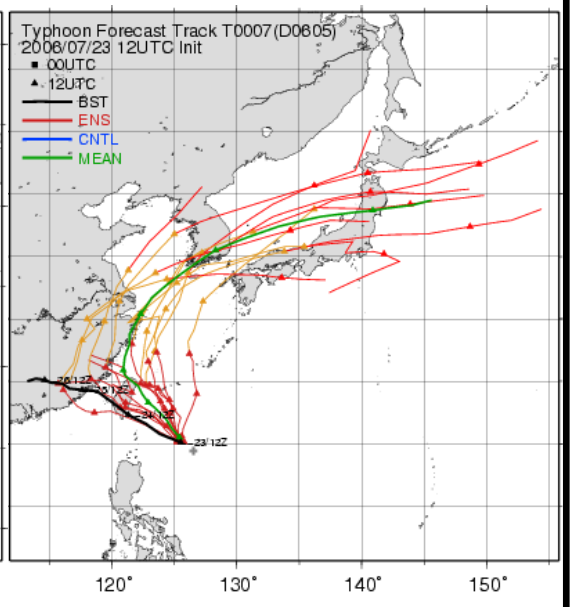
All ensemble members



1 s t **Cluster**



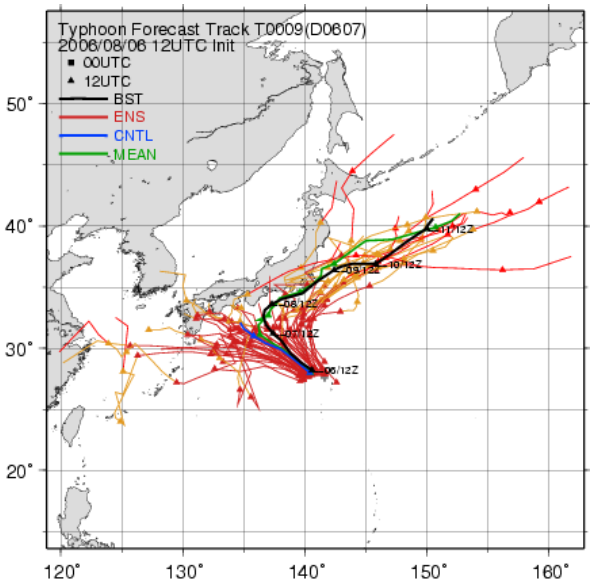
2nd cluseter



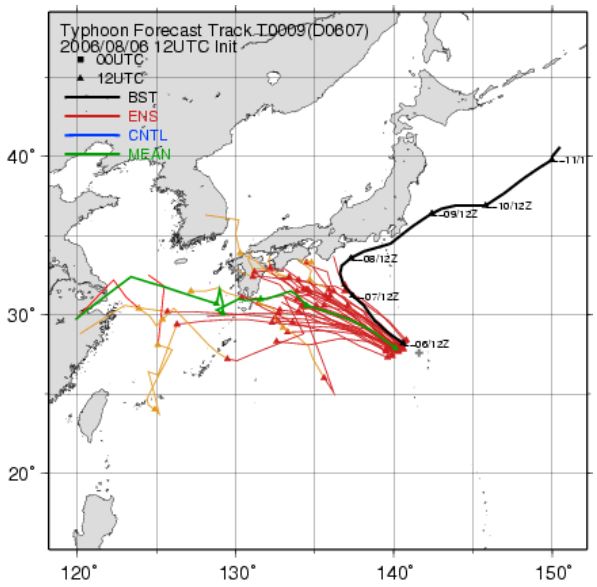
Case Study : The analyzed number of cluster is **2**

２００６年８月６日　Ｔ０６０７

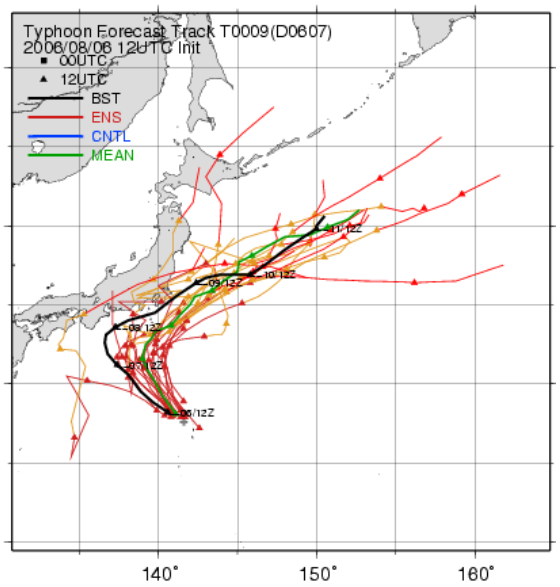
All ensemble members



1 s t **Cluster**



2nd cluseter



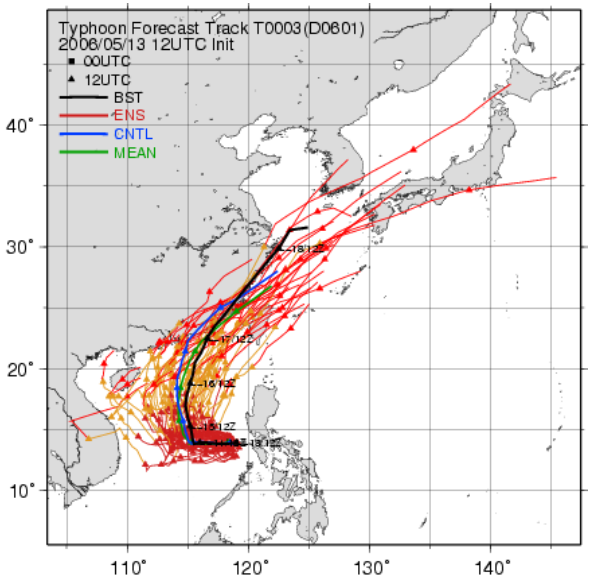
The 2nd cluster was correct

Even if the best likely solution, or deterministic forecast, goes wrong, several other scenarios presented help people act accordingly, and in some cases they can prepare for the anticipated damage well in advance.

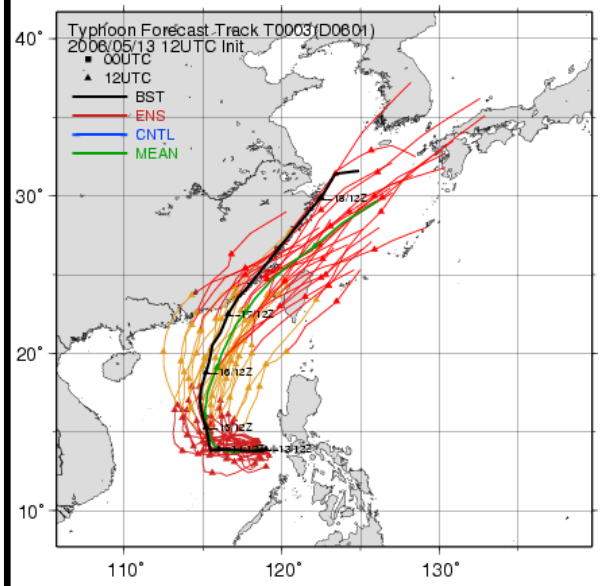
Case Study : The analyzed number of cluster is **3**

２００６年５月１３日　Ｔ０６０１

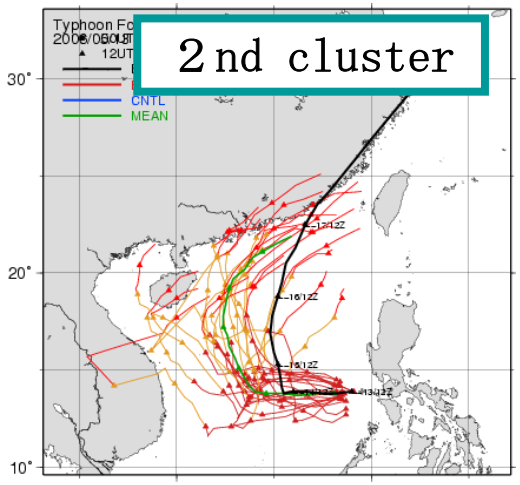
All ensemble members



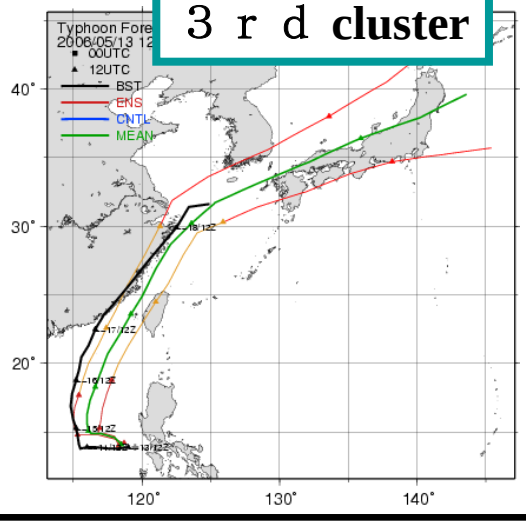
1 s t **cluster**



2nd cluster



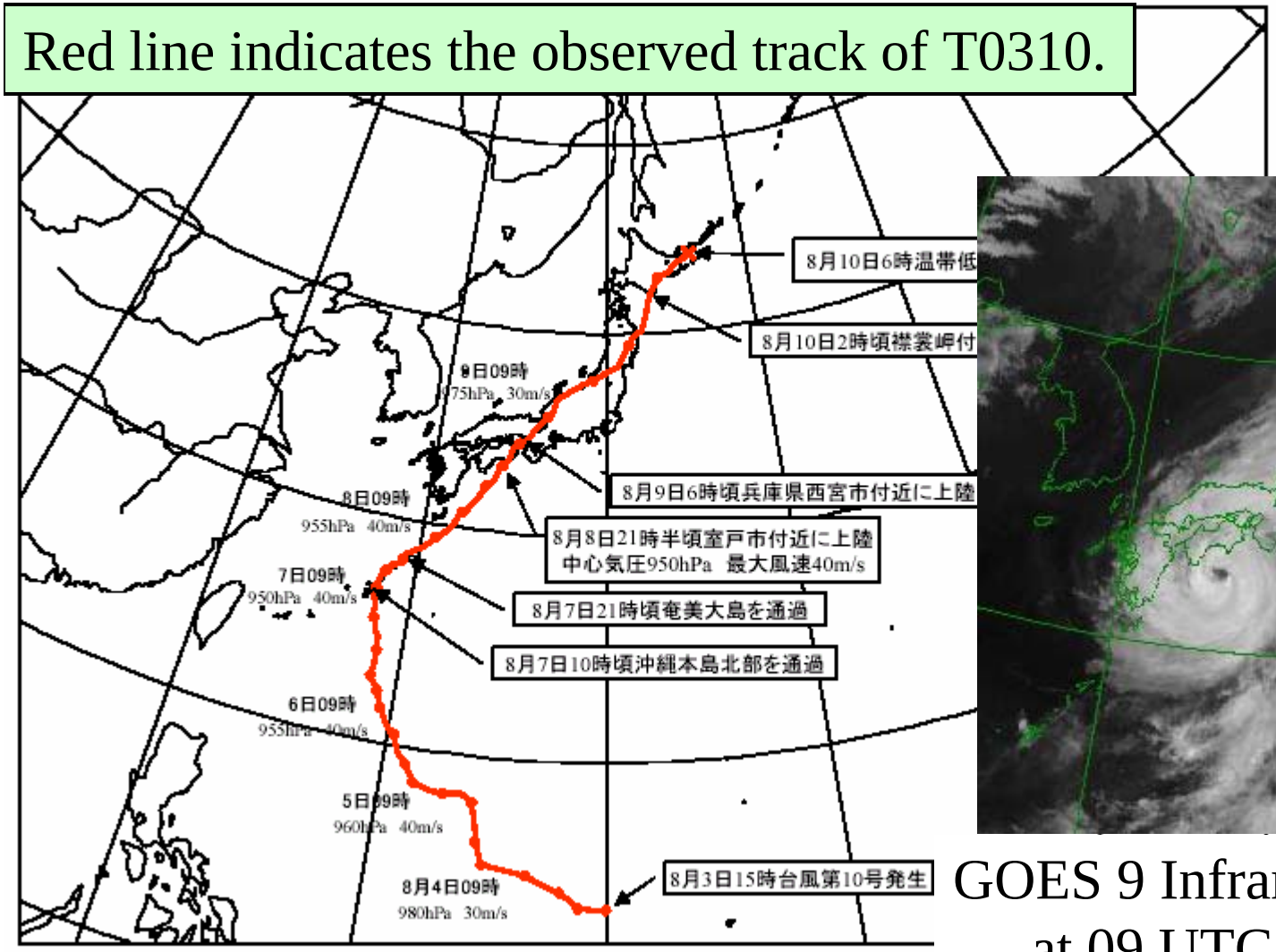
3 r d **cluster**

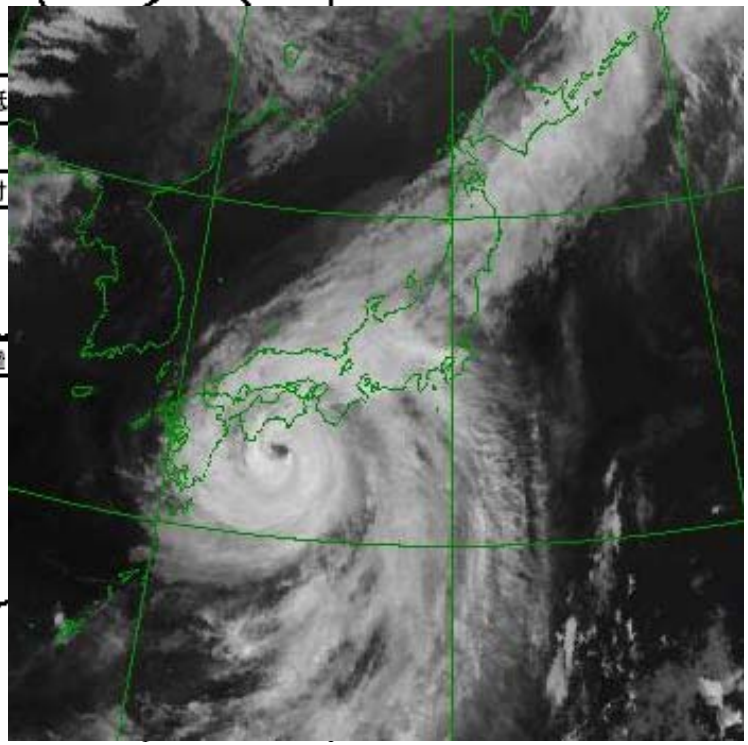


Considering not only the direction but also the speed, the cluster analysis method suggested 3 scenarios.

Case study - Typhoon Etau (T0310)

Red line indicates the observed track of T0310.

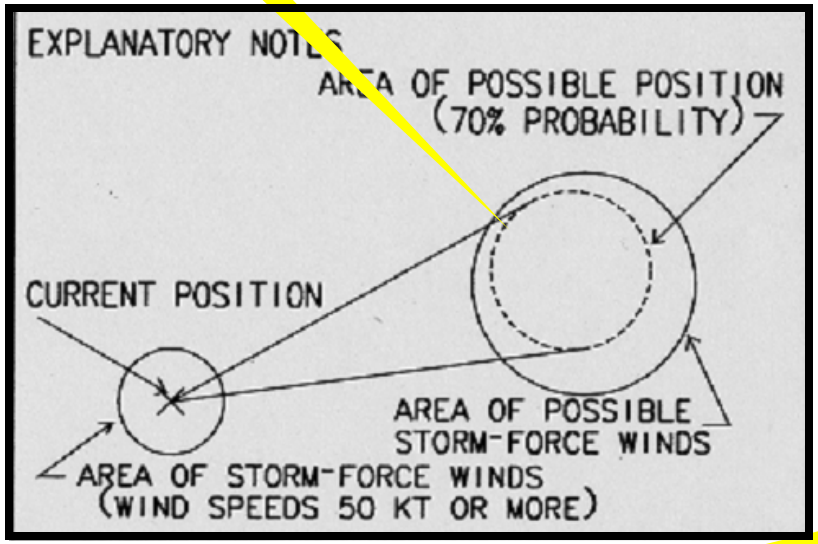


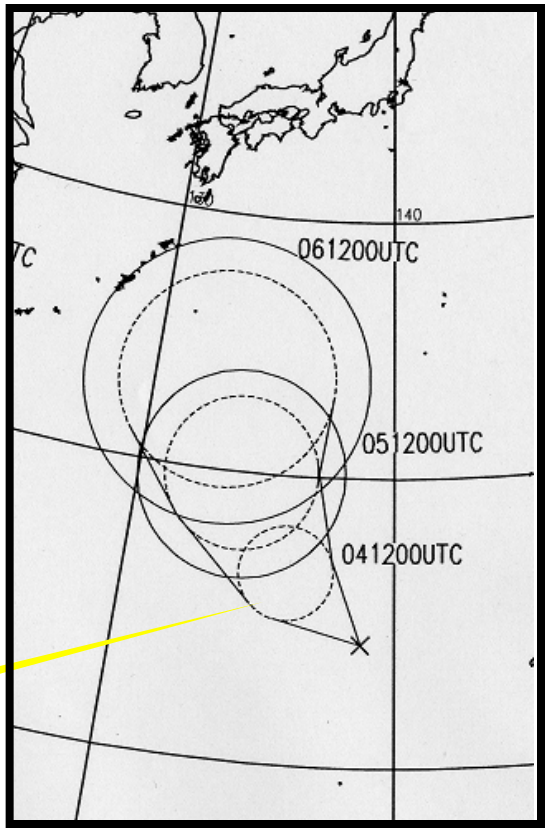


GOES 9 Infrared Satellite Image
at 09 UTC 8 August 2003

JMA issues the typhoon forecast

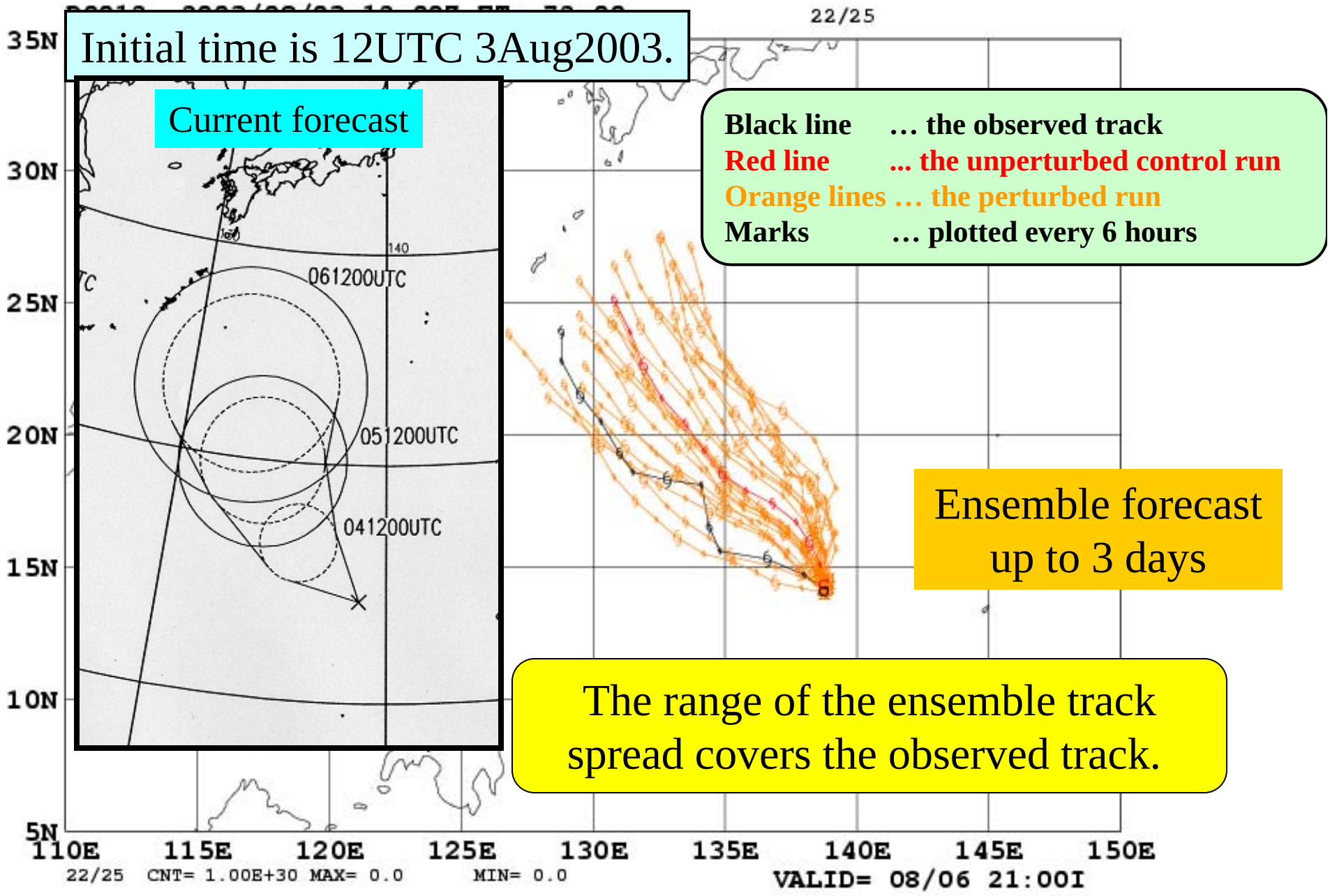
JMA currently issues the information on a geographical circle in which a typhoon center will reach with 70% probability.



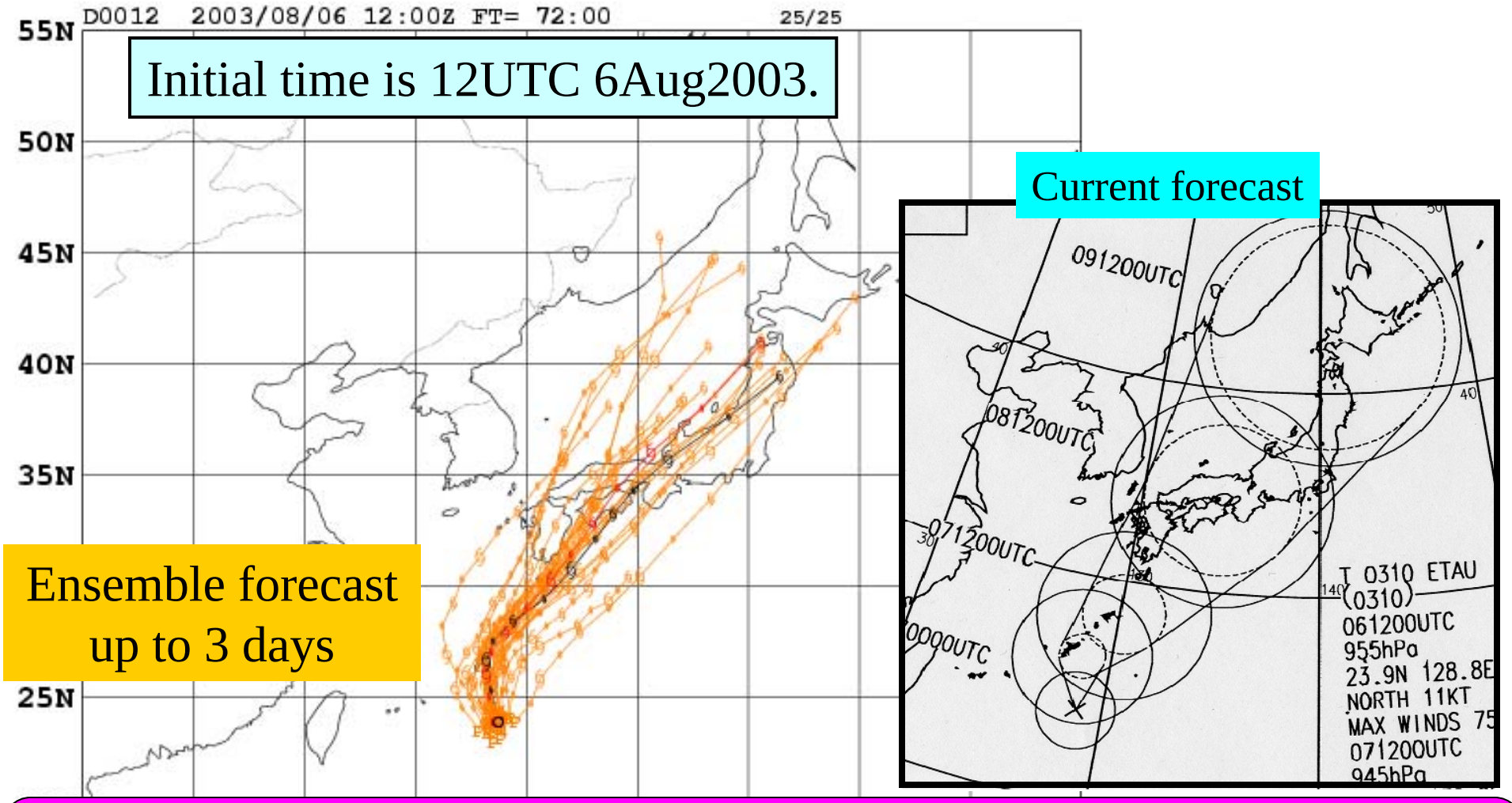


The radius of the forecast circle depends on the statistics of the past forecast results but **not on the characteristic of individual typhoon**.

yphoon track forecasts of Etau in the early stage



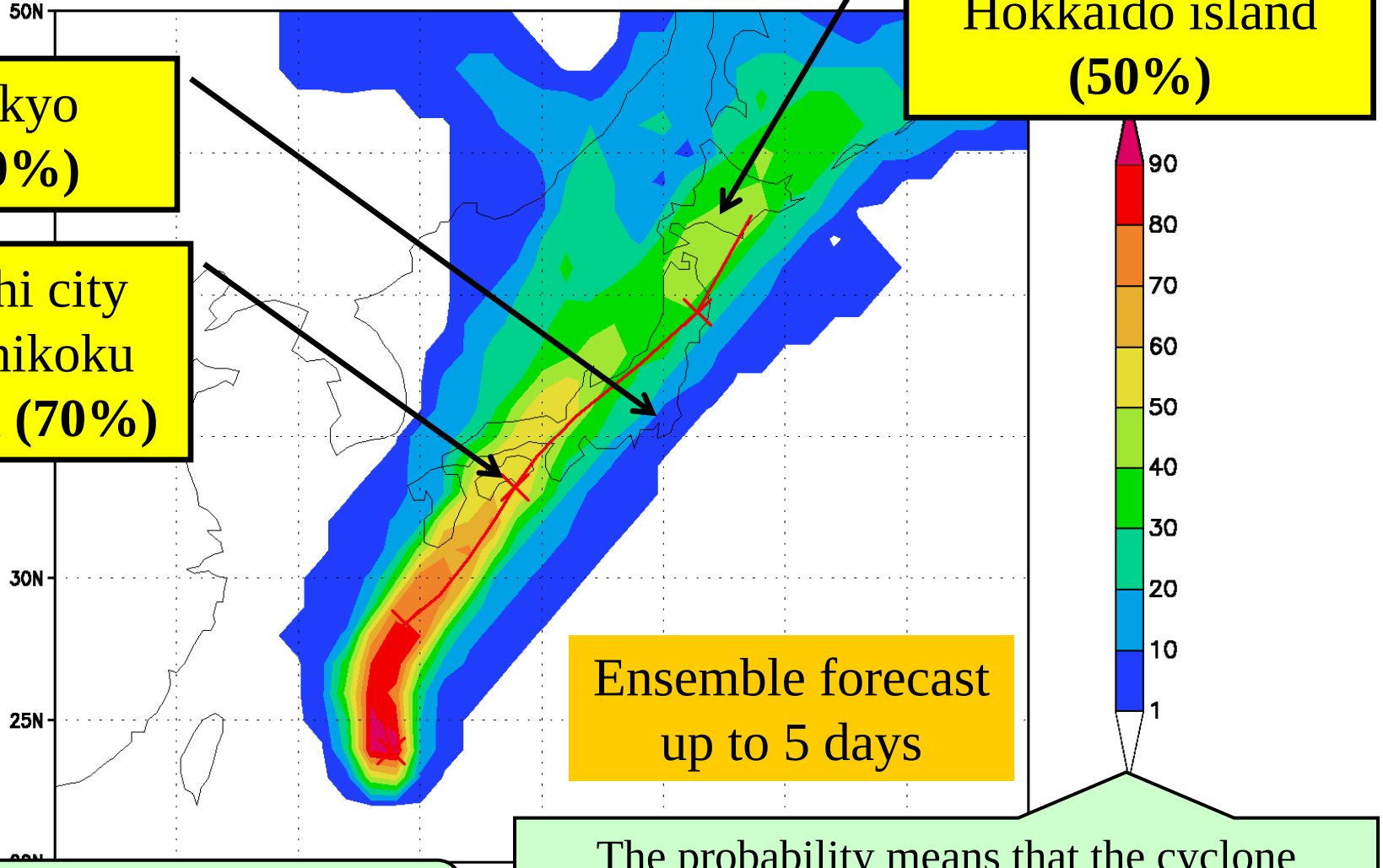
Typhoon track forecasts of Etau just before recurvature



The spread was small enough to indicate high reliability. The probability of landfall of the typhoon on western Japan was very high.

Strike probability of Etau

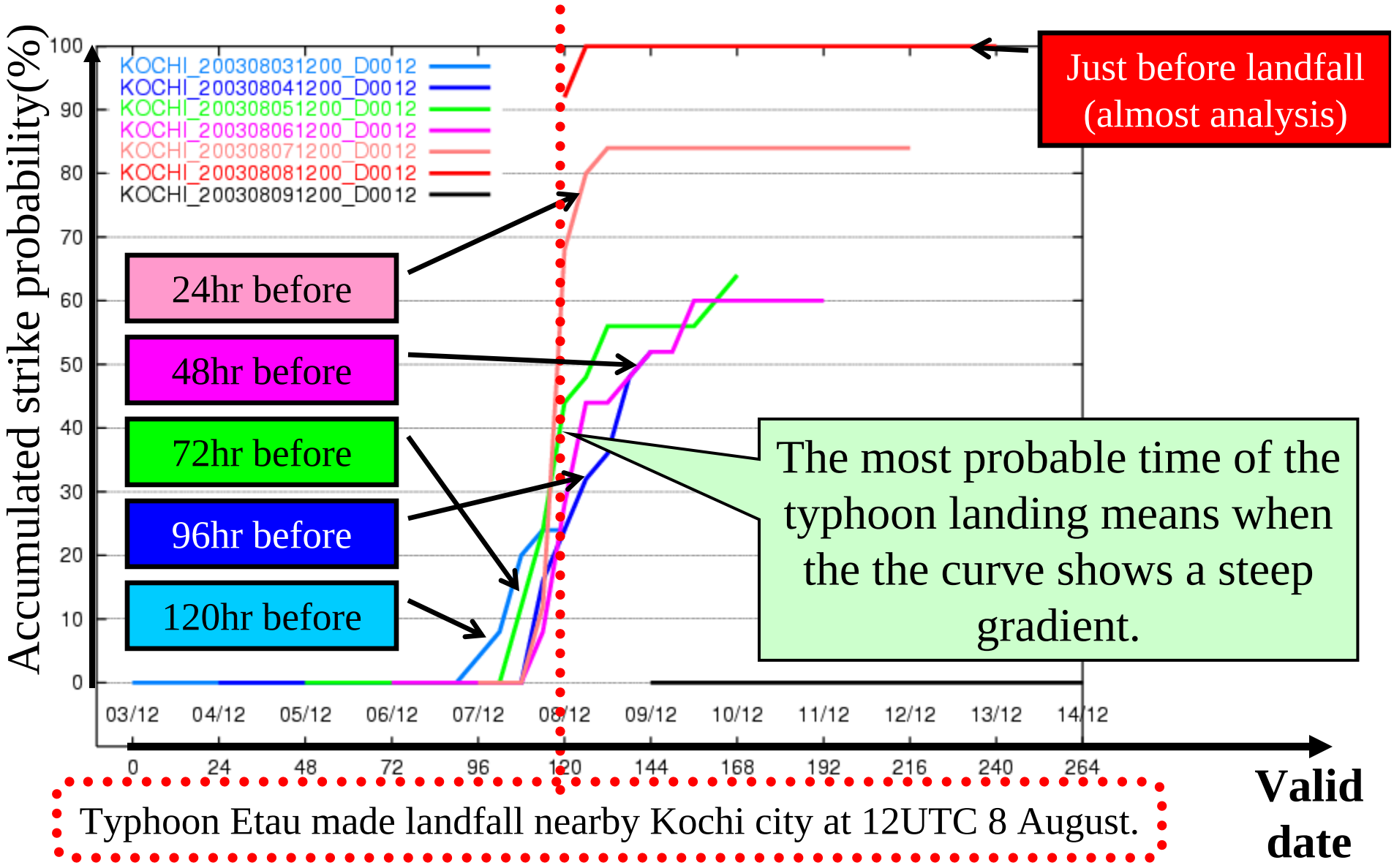
Initial time is 12UTC6Aug2003.



Red line ... the observed track
X marks … plotted every 24 hours

The probability means that the cyclone will pass within a 120km (about 65nm) radius during the next 120 hours.

Point strike probability at Kochi city



Verification of strike probability forecast

The reliability diagram for strike probability forecast that typhoon centers will pass within 120km from the verification points during the first 120 hours. The data used for verification are 174 forecasts for 37 Tropical cyclones over the responsible area of the RSMC Tokyo Typhoon Center in the year of 2002.

The strike probability has high reliability.