Chapter 4

Application Products of NWP

4.1 Summary

The results of NWP are indispensable elements to weather forecasting both for general public and for special purposes, and therefore JMA disseminates them in real time to the local offices of JMA, private companies, and related organizations both in Japan and abroad. Although facsimile charts have been the primary means of distributing NWP output for a long time, at the present time dissemination in the form of Grid Point Values (GPV) is the essential method with the progress of telecommunication infrastructure and sophisticated visualization systems.

In addition to the raw NWP data, value-added products derived from NWP output are also disseminated. One example of such products is information on parameters not explicitly calculated in NWP models, such as probabilistic forecasts and turbulence potential for aviation. Another is error-reduced estimation of NWP output parameters, with statistics of the relationship between NWP output and the corresponding observation. JMA has been disseminating Very-short-range (6 hour) Forecast of Precipitation and the Hourly Analysis of horizontal wind and temperature field, a three-dimensional variational (3D-Var) method is utilized for Hourly Analysis. To support middle to long-range forecasting, JMA has been disseminating various kind of forecast charts and Grid Point Value for one-week forecast and one-month and seasonal forecast.

In the following sections, specification of Application Products of NWP and their utilization in the JMA offices are demonstrated.

4.2 Weather Chart Services

Facsimile chart is a conventional service to disseminate the result of NWP in a graphical form. The JMA's facsimile charts are sent to national meteorological services via the Global Telecommunication System (GTS) and to ships via the shortwave radio transmission (call sign JMH).

Table 4.2.1 and Figure 4.2.1 give summaries of weather charts easily accessible for international users, namely charts served through GTS and JMH.

The Web is emerging alternative to complement and innovate above services. A number of projects are running worldwide. JMA takes part in international projects such as Project on the Provision of City-Specific Numerical Weather Prediction (NWP) Products to Developing Countries via the Internet in the WMO Regional Association II (RA II) or the Severe Weather Forecast Demonstration Project (SWFDP) in WMO RAs II and V. There are also JMA's own projects, such as JMA Pilot Project on EPS Products or SATAID Services on the WMO Information System.

Table 4.2.1: List of facsimile charts provided through GTS and radio facsimile JMH. Symbols for vertical level: Surf: surface, Trop: tropopause, numbers (850, 700, ... 100): level of pressure in hPa; Symbols for contours: D: dewpoint depression ($T - T_d$), E: precipitation (over past 12h for 24h forecast, or past 24h for others), H: geopotential height, J: wave height, O: vertical velocity (ω), P: MSL pressure, T: temperature, W: wind speed (isotach), Z: vorticity, μ: time average, δ: time average and anomaly from climatology; Symbols for other drawings: a: wind arrow from GPV, b: observation plots, d: hatch for area $T - T_d < 3$K, g: arrow for prevailing wave direction, j: jet axis, m: wave period, t: temperature numbers, x: streamlines; Symbols for dissemination and temporal specialty: ': sent to GTS, *: sent to JMH, §: only for 12 UTC, †: average over pentad, sent only for 00 UTC five-daily, ‡: average over month, sent only for 00 UTC monthly.

Model	Area (see Figure 4.2.1)	Forecast Time: Analysis	12h	24h	36h	48h 72h	96h 120h	144h 168h 196h
GSM	A' (Far East)	500 (H, Z)' 850 (T; a)+700 (O)'		500 (T)+700 (D)'* 500 (H, Z)'* 850 (T, W)+700 (O)'* Surf(P, E; a)'*				
	C (East Asia)	300 (H, W; a, t, b)'* 500 (H, T; a, b)' 700 (H, T; b, d)' 850 (H, T; b, d)'*		Surf(P, E)'		500 (H, Z)' 850 (T, W)+700 (O)'§ Surf(P, E)'*	Surf(P, E)*§	
	O (Asia)						500 (H, Z)'§ Surf(P)+850 (T)'§	
	Q (Asia-Pacific)	200 (H, W; t, a, j)+Trop(H)' 250 (H, W; t, a)'		250 (H, W; t, a)' 500 (H, W; t, a)'				
	Q (NW Pacific)	200 (x)' 850 (x)'		200 (x)' 850 (x)'				
	D (N Hem.)	500 (H, T)'						
Ocean Wave	X (Japan)	Surf(J; b, g, m)'*						
	C'' (NW Pacific)	Surf(J; b, g, m)'*	Surf(J; g, m)*			Surf(J; g, m)*		
JCDAS	D' (N.Hem.)	100 (μH, δH)'† 500 (μH, δH)'† 500 (μH, δH)'‡ Surf(μP, δP)'‡						

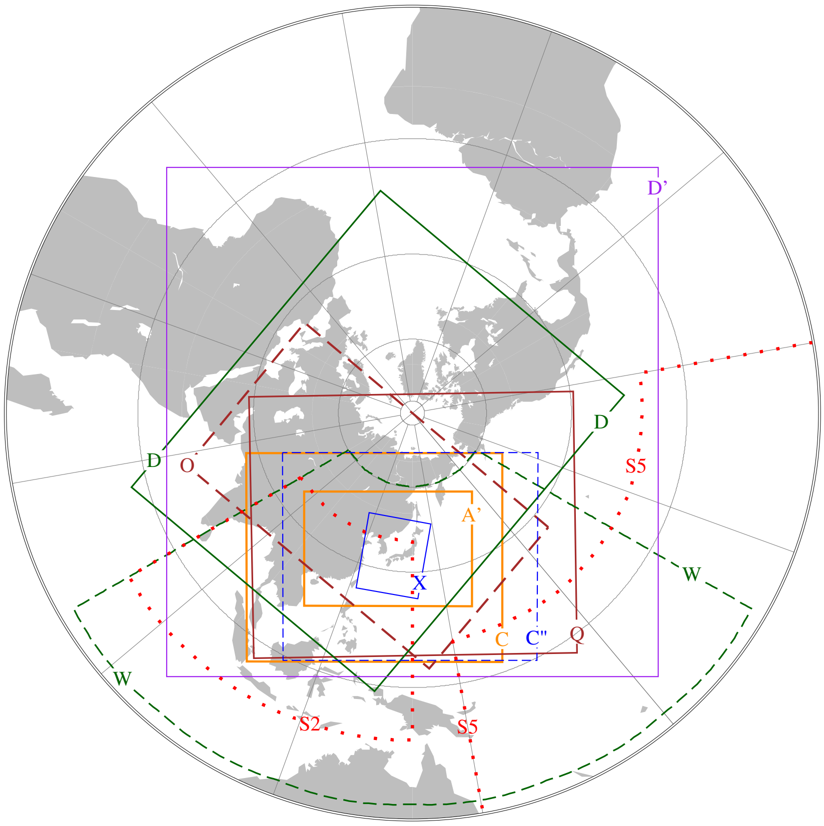

Figure 4.2.1: Areas for charts disseminated through GTS and radio facsimile JMH (symbols A', C, C", D, D', O, Q, W, and X). Dotted boxes labeled S2 and S5 are areas of SWFDP products for WMO Regional Associations II and V, respectively (for information).

4.3 GPV Products

As a part of JMA's general responsibility of meteorological information service, the grid point values (GPV) products are distributed to domestic and international users. In conformance to requirement of the WMO Information System (WIS), this data service utilizes both dedicated and public (i.e. the Internet) network infrastructure.

The dedicated infrastructure consists of an international part called GTS, together with domestic parts inside JMA (including the Meteorological Satellite Center and the Meteorological Research Institute) and toward government agencies and Meteorological Business Support Center, which is in charge of managed service for general users including the private sector.

The portal to JMA's international services over the Internet is the website of Global Information System Centre (GISC) Tokyo [1]. The WMO Distributed Data Bases (DDBs) and RSMC Data Serving System (RSMC DSS) are integrated into GISC Tokyo. Currently the international service of GPV products includes GSM, One-week EPS, and Ocean Wave Model, as listed in Table 4.3.1.

4.4 Very-short-range Forecasting of Precipitation

JMA has been routinely operating a fully automated system for semi-hourly analysis and very-short-range forecasting of precipitation since 1988 to provide products for monitoring and forecasting local severe weather. The products are :

1. Analysis of precipitation called the "Radar-Raingauge Analyzed Precipitation" (hereafter R/A) based on the radar observations operated by JMA and the other organization and the raingauge measurements operated by JMA(the Automated Meteorological Data Acquisition System, hereafter AMeDAS) and the other organizations,

2. Semi-hourly forecasts of 1-hour accumulated precipitation called the "Very-Short-Range-Forecasting of Precipitation" (hereafter VSRF) based on extrapolation and forecast by the Meso-scale Model (MSM, see Section 3.5). The forecast time of VSRF is from 1 to 6 hour.

The spatial resolution of these products are 1km. These products are made available in about 20 minutes after observation time every half hour. They are transmitted to local meteorological observatories, and the local governments and broadcasting stations which are responsible for disaster prevention.

4.4.1 Analysis of Precipitation (R/A)

R/A uses data of 46 radars (JMA 20, the other organization 26) and up to about 10,000 raingauges (AMeDAS 1,300, the other organizations 8,700). These data are combined to benefit from advantages of both facilities: the advantage of the radar is its high resolution in space and that of raingauge is its high accuracy of precipitation measurement.

The one-hour accumulated precipitation amounts estimated using radar observation are usually different from those observed with raingauges. The radar precipitation amounts are calibrated into more accurate precipitation using the raingauge precipitation data (Makihara 2000). First, calibration factors over the entire detection range of each radar are calculated by comparing the radar precipitation of the multiple radars and raingauge data. When comparing radar precipitation, the difference of radar beam height is taken into account. Then the estimated calibration factor is further modified using raingauge data to estimate local heavy precipitation more accurately at each grid which contains raingauges. For the grid has no raingauges, the modified calibration factors is calculated with weighted interpolation of the calibration factors of the surrounding grids that contain raingauges. Composition of all radar's calibrated precipitation into a nationwide chart is made by the maximum value method, in which the largest value is selected if a grid has several data observed by multiple radars. A schematic diagram of this procedure is shown in Figure 4.4.1.

[1] `http://www.wis-jma.go.jp`

Table 4.3.1: List of GPV products transmitted through GTS and GISC Tokyo website. Symbols for contents: C_L: low cloud amount, C_M: middle cloud amount, C_H: high cloud amount, D: dewpoint depression ($T - T_d$), E: precipitation (from initial time), G: prevailing wave direction, H: geopotential height, J: wave height, M: wave period, N: total cloudiness, O: vertical velocity (ω), P: MSL pressure, P_S: surface pressure, R: relative humidity, T: temperature, U: eastward wind speed, V: northward wind speed, X: stream function, Y: velocity potential, Z: vorticity, μ: average over ensemble, σ: standard deviation over ensemble. Symbols °, *, ¶, §, †, ‡are notes on availability, and are explained inside the table.

Model	GSM	GSM	GSM	GSM
Service Channel	GISC	GTS and GISC	GTS and GISC	GISC
Code form	GRIB Edition 1	GRIB Edition 1	GRIB Edition 1	GRIB Edition 2
Area	Whole Globe	20°S–60°N 60°E–160°W	Whole Globe	Whole Globe and also 5°S–90°N, 30°E–165°W
Resolution	1.25° × 1.25°	1.25° × 1.25°	2.5° × 2.5°	0.5° × 0.5° (0.25° × 0.25° for surface)
Contents 10, 20 hPa	H, U, V, T	H, U, V, T	H*, U*, V*, T*	H, U, V, T, R, O
30, 50, 70, 100 hPa	H, U, V, T	H, U, V, T	H°, U°, V°, T°	H, U, V, T, R, O
150 hPa	H, U, V, T	H, U, V, T	H*, U*, V*, T*	H, U, V, T, R, O
200 hPa	H, U, V, T, X, Y	H§, U§, V§, T§, X, Y	H, U, V, T	H, U, V, T, R, O, X, Y
250 hPa	H, U, V, T	H, U, V, T	H°, U°, V°, T°	H, U, V, T, R, O
300 hPa	H, U, V, T, R, O	H, U, V, T, D	H, U, V, T, D*‡	H, U, V, T, R, O
400 hPa	H, U, V, T, R, O	H, U, V, T, D	H*, U*, V*, T*, D*‡	H, U, V, T, R, O
500 hPa	H, U, V, T, R, O, Z	H§, U§, V§, T§, D§, Z	H, U, V, T, D*‡	H, U, V, T, R, O, Z
600 hPa	H, U, V, T, R, O			H, U, V, T, R, O
700 hPa	H, U, V, T, R, O	H§, U§, V§, T§, D§, O	H, U, V, T, D	H, U, V, T, R, O
800 hPa				H, U, V, T, R, O
850 hPa	H, U, V, T, R, O, X, Y	H§, U§, V§, T§, D§, O, X, Y	H, U, V, T, D	H, U, V, T, R, O
900 hPa				H, U, V, T, R, O
925 hPa	H, U, V, T, R, O	H, U, V, T, D, O		H, U, V, T, R, O
950, 975 hPa				H, U, V, T, R, O
1000 hPa	H, U, V, T, R, O	H, U, V, T, D	H, U*, V*, T*, D*‡	H, U, V, T, R, O
Surface	P, U, V, T, R, E†	P¶, U¶, V¶, T¶, D¶, E¶	P, U, V, T, D‡, E†	P, U, V, T, R, E†, P_S, N, C_L, C_M, C_H
Forecast time range (*from–until/interval*)	0–84h/6h †: except for analysis	0–84h/6h	0–72h/24h *: Analysis only	0–84h/3h
Extension on 12UTC	96–192h/12h	§: 96–192h/24h ¶: 90–192h/6h	96–192h/24h °: 96–120h/24h	90–216h/6h
Initial times	00UTC and 12UTC	00UTC and 12UTC	00UTC and 12UTC ‡: 00UTC only	00, 06, 12, 18UTC

Model	One-week EPS	Ocean Wave Model
Service Channel	GTS and GISC	GISC
Code form	GRIB Edition 1	GRIB Edition 1
Area	Whole Globe	75°S–75°N, 0°E–358.75°E
Resolution	2.5° × 2.5°	1.25° × 1.25°
Contents 250 hPa	μU, σU, μV, σV	
500 hPa	μH, σH	
850 hPa	μU, σU, μV, σV, μT, σT	
1000 hPa	μH, σH	
Surface	μP, σP	J, M, G
Forecast time range	0–192h/12h	0–84h/6h
Extension on 12UTC	(none)	96–192h/12h
Initial times	12UTC only	00UTC and 12UTC

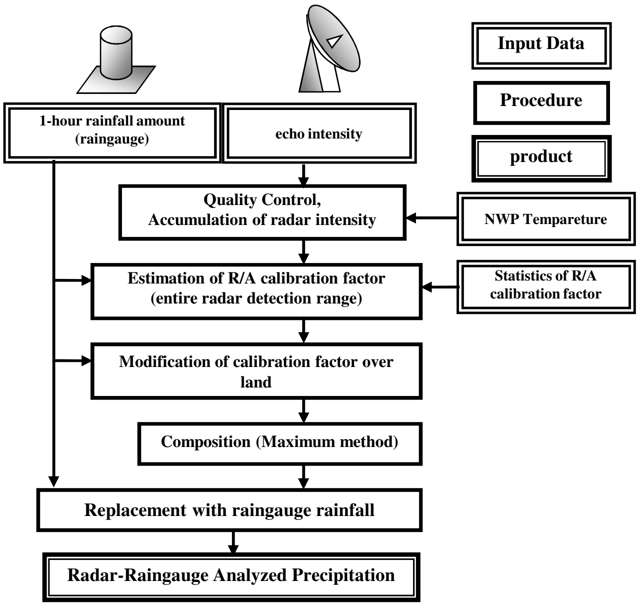

Figure 4.4.1: A flow chart of the “Radar- Raingauge Analyzed Precipitation”

4.4.2 Forecasting of Precipitation (VSRF)

Two methods are used for VSRF. One is the extrapolation of movements of the analyzed precipitation systems. In the course of extrapolation, development and decay of the precipitation systems due to the orographic effects and the echo intensity trends are taken into account. The other is the precipitation forecast of MSM, which is available in about two hours later from its initial time, eight times a day (every three hours). The extrapolation forecasts are more skillful than the MSM forecasts at first, but they rapidly lose skill. On the other hand, the skill of the MSM forecasts degrades gradually and becomes comparable with the extrapolation forecasts after a few forecasting hours. Therefore the so-called “merging technique” was introduced. It is essentially the weighted-averaging of those two precipitation forecasts. For the first one hour, the merging weights are set nearly zero for the MSM forecasts, so the products are almost the same as the extrapolation forecasts. After that, the merging weights for the MSM forecasts increase with forecast time. The merging weights are determined by comparing skills of the MSM forecasts and the extrapolation forecasts. A schematic diagram of this procedure is shown in Figure 4.4.2.

4.4.2.1 Extrapolation Forecasts

The calibrated precipitation intensity, which is obtained in the course of the precipitation analysis (Subsection 4.4.1), is used as the initial value of the forecast. A time step of the forecast is two or five minutes and the forecasted precipitations are accumulated to produce hourly forecasts up to six hours.

The extrapolation vectors (the movement vectors of precipitation systems) are evaluated by a generalized cross correlation method, comparing the location of the precipitation systems at the initial time with those at 0.5, 1, 2 and 3 hours before.

As the seeder-feeder mechanism is assumed to work in the regions of orographic updraft, the precipitation systems are allowed to develop in the course of extrapolation over such regions. Precipitation systems that have passed across mountains higher than its echo top height are decayed, when the following two conditions are satisfied:

1. orographic downslope motion of the rain system is expected from the low-level wind of MSM,

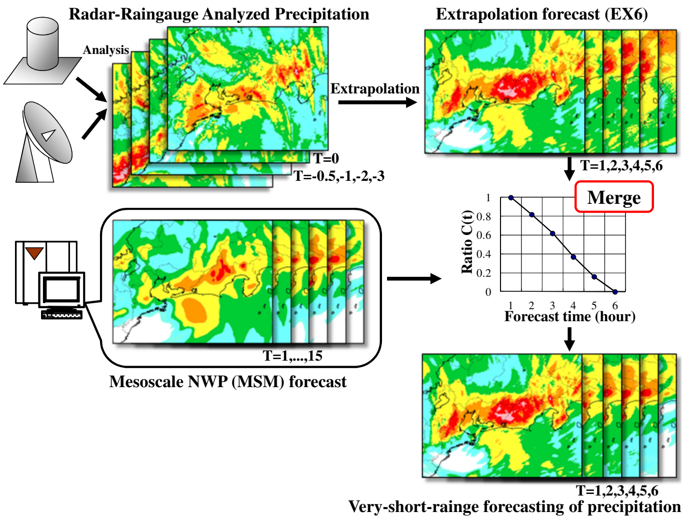

Figure 4.4.2: A schematic diagram of the very-short-range forecasting of precipitation

2. the direction of the rain system movement or that of 700hPa wind by MSM is nearly parallel to that of 900hPa wind by MSM.

And the echo intensity trends can be obtained by comparing the current area average of the echo intensity to the past one. The movement vectors for the intensity trends are calculated in addition to the extrapolation vectors. The vectors move the echo intensity trends and the trends change the forecasted precipitations.

4.4.2.2 Merging Technique

First, the relative skill of the extrapolation forecast and the MSM forecast are estimated. The extrapolation forecast from three hours before is verified against the current analysis. For the MSM forecast, the latest available forecast is verified with the current analysis. The relative reliability coefficient C_{RR} is defined as follows:

$$C_{RR} = \min\left(1, \frac{D_{EX}}{D_{MSM}}\right) \quad (4.4.1)$$

where D_{EX} is the 2-dimensional pattern distance, or 2-dimensionally extended Levenshtein distance, between the extrapolation forecast and the analysis, and D_{MSM} is the 2-dimensional pattern distance between the MSM forecast and the analysis.

Then, the relative weight of the extrapolation forecast $C_{EX}(T)$ is determined by C_{RR} and the statistically determined function $C(T)$ indicated at merge process in Figure 4.4.2, where T denotes the forecast time in hour:

$$C_{EX}(T) = 1 - C_{RR} \cdot (1 - C(T)) \quad (4.4.2)$$

Finally the merged forecast $R_{MRG}(T)$ is calculated with the following equation:

$$R_{MRG}(T) = C_{EX}(T) \cdot R_{EX}(T) + (1 - C_{EX}(T)) \cdot R_{MSM}(T) \quad (4.4.3)$$

where $R_{EX}(T)$ denotes the extrapolation forecasts of precipitation at the forecast time T, and $R_{MSM}(T)$ denotes the MSM forecasts of precipitation from the latest initial time at the same valid time T.

4.4.3 Example and Verification Score

An example of the R/A and VSRF is shown in Figure 4.4.3. The R/A in the Kyushu region, southwestern area of Japan at 20UTC 23 June 2012 is shown in the left panel (a), and the 3-hour forecast of VSRF at the same valid time, i.e. its initial time is at 17UTC 23 June 2012, is shown in the right panel (b). The intense rain band is well forecasted.

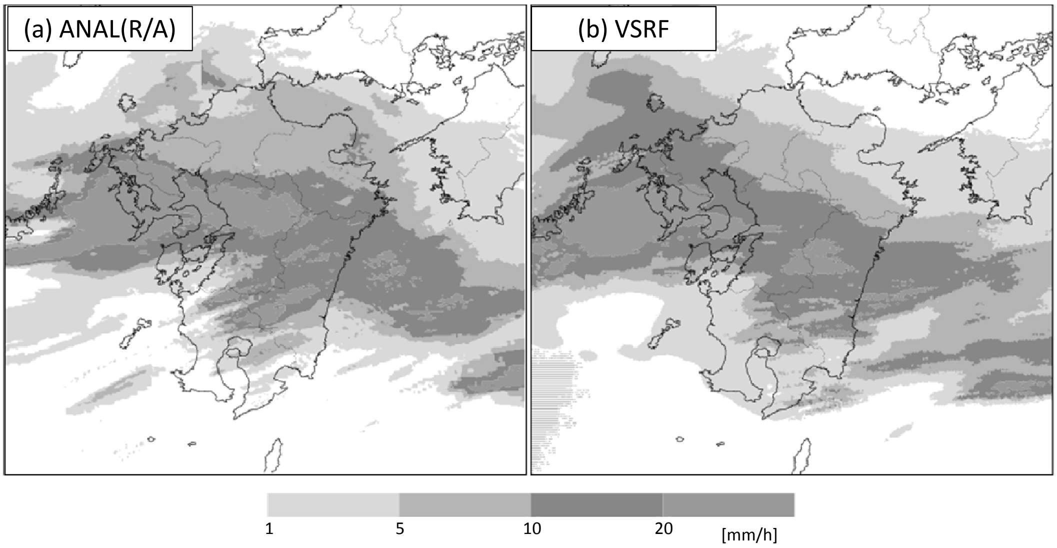

Figure 4.4.3: An example of (a) the Radar-Raingauge Analyzed Precipitation at 20UTC 23 June 2012 and (b) the 3-hour forecast of precipitation of VSRF at the same valid time

The accuracy of VSRF has been statistically verified with the Critical Success Index (CSI)[2]. Forecasts are compared with precipitation analysis after both fields are averaged in 20km $\times$ 20km grids. The threshold value is set as 1mm/hr. Indices from 1-hour to 6-hour forecasts for June 2012 are shown in Figure 4.4.4, together with those of the extrapolation, MSM, and the persistence forecasts.

It can be seen that the scores get worse as forecast time gets longer. Up to three hours, the extrapolation forecast keeps its superiority to MSM, but the relationship of them becomes reverse after four hours, while VSRF behaves best performance through all forecast times.

4.5 Hourly Analysis

The hourly analysis provides grid point value data of three-dimensional temperature and wind analysis every hour, assisting forecasters in monitoring the atmosphere. Imagery products are also available to users in the aviation sector through a meteorological information web page.

The configuration of the hourly analysis system is listed in Table 4.5.1. The hourly analysis uses an objective analysis scheme of a 3-dimensional variational (3D-Var) method, which is implemented as a part of the "JMA Nonhydrostatic model"-based Variational Analysis Data Assimilation (JNoVA; Honda *et al.* 2005). The analysis uses the latest Meso-scale Model (MSM, Section 3.5) forecast as the first guess (a 2-4 hour forecast depending on the analysis time). The domain of the hourly analysis is the same as that of the MSM (MA) (Figure 2.6.2), covering Japan and its surrounding area (3,600 km by 2,880 km) at the same horizontal resolution as that in the MSM (with a grid spacing of 5 km). The hourly analysis has fifty vertical layers defined in the z*-coordinate, with the top of the domain at 21,801 m.

[2]The CSI is the number of correct "yes" forecasts divided by the total number of occasions on which that event was forecast and/or observed. It is also cited as "Threat Score".

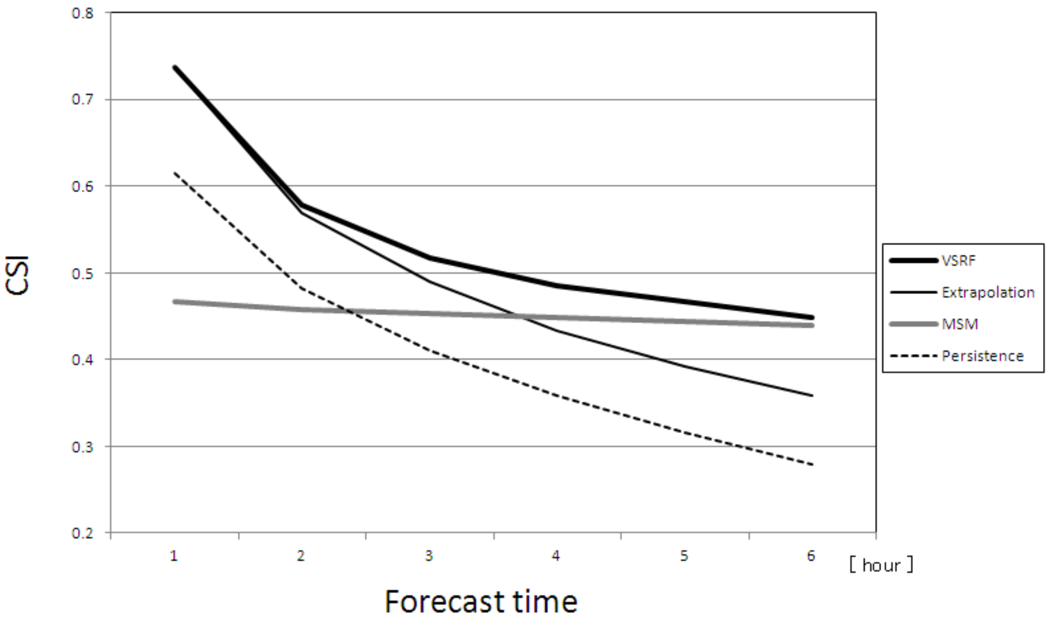

Figure 4.4.4: CSI of the very-short-range forecasting (VSRF) of precipitation averaged within the 20km×20km grids for June 2012, together with that of the extrapolation, MSM, and the persistence forecast. Threshold value is 1mm/hr.

The observations assimilated in the analysis are from wind profilers (wind), Doppler radars (radial velocity), ACARS (Aircraft Communications Addressing and Reporting System, wind and temperature), satellite AMV (Atmospheric Motion Vector, wind), and AMeDAS (Automated Meteorological Data Acquisition System, surface station data over Japan, wind and temperature). The data cut-off time is set to 20 minutes past the hour to enable the product to be distributed before 30 minutes past the hour.

In order to obtain a good fit to the surface observations on land, the 3D-Var analysis uses a short background error correlation distance and a small observation error on the surface. Thus, the surface field on land has typically large increments. The followings are modifications of the 3D-Var scheme and additional post-processings introduced to handle this situation appropriately.

Table 4.5.1: Configuration of the hourly analysis system.

analysis scheme	3D-Var
analysis time	every hour (on the hour)
observation	wind profilers (wind), Doppler radars (radial velocity), ACARS (wind and temperature), satellite AMV (wind), AMeDAS (wind and temperature)
cut-off time	20 minutes past the hour
first guess	the latest MSM forecast (forecast time = 2-4h)
analysis variable	horizontal wind (u and v components), temperature
domain	the MSM domain (3,600km by 2,880 km, grid spacing 5km), 50 vertical layers
product distribution	around 30 minutes past the hour

- In the 3D-Var analysis, the surface and the upper air fields are treated as uncorrelated. Thus, the surface observations only have contribution to analysis increments on the surface, but not to those in the upper air. Analysis increments on the surface and in the upper air are not consistent at this point.
- After the 3D-Var analysis is completed, a surface filter is applied on the surface temperature and wind fields. This filter is designed to attenuate the surface increments over the sea with distance from the coastline, reducing excessive increments in sea regions near the coastline located within the range of correlation from the land observations.
- After applying the surface filter, the increments on the surface and in the upper air are merged in each vertical column within the boundary layer of the first guess. This makes the surface and the upper air increments consistent. The weight of the surface increment attenuates with height above the ground, and approaches to zero at about the height of the boundary layer.

4.6 Guidance for Short-range Forecasting

4.6.1 Overview

To provide the first guess of forecast target to forecasters, various kinds of forecast guidance are produced from the output of the NWP models. The parameters of the guidance for short-range (up to 84 hours) forecasting are listed in Table 4.6.1.

Table 4.6.1: Parameters of the guidance products for short-range forecasting

Parameters	Target		Model	Forecast hour	Method*
Categorized weather over 3 hours (fair, cloudy, rainy, sleety, snowy)	Grids	20km	GSM	KT=6,9,12,...,81,84	NRN
		5km	MSM	KT=3,6,9,...,30,33	
Mean precipitation amount over 3 hours	Grids	20km	GSM	KT=6,9,12,...,81,84	KF & FBC
		5km	MSM	KT=3,6,9,...,30,33	
Maximum precipitation amount over 1, 3 and 24 hours	Grids	20km	GSM	KT=6,9,12,...,81,84	KF & NRN
		5km	MSM	KT=3,6,9,...,30,33	
Probability of precipitation over 6 hours > 1mm/6h	Grids	20km	GSM	KT=9,15,21,...,75,81	KF
		5km	MSM	KT=6,12,18,...,24,30	
Maximum temperature in the daytime (09-18 local time)	Points	AMeDAS	GSM	Today to 3 days after	KF
			MSM	Today and tomorrow	
Minimum temperature in the morning (00-09 local time)	Points	AMeDAS	GSM	Today to 3 days after	KF
			MSM	Today and tomorrow	
Time-series temperature	Points	AMeDAS	GSM	KT=3,4,5,...,81,84	KF
			MSM	KT=1,2,3,...,32,33	
Wind speed and direction	Points	AMeDAS	GSM	KT=3,6,9,...,81,84	KF & FBC
			MSM	KT=1,2,3,...,32,33	
Maximum wind speed and direction over 3hours	Points	AMeDAS	GSM	KT=3,6,9,...,81,84	KF & FBC
			MSM	KT=3,6,9,...,30,33	
Daily minimum humidity	Points	SYNOP	GSM	Today to 3 days after	NRN
			MSM	Today and tomorrow	
Snowfall amount over 12 hours	Points	AMeDAS	GSM	KT=24,36,48,60,72	NRN
Maximum snowfall amount over 3,6,12 and 24 hours	Grids	5km	GSM	KT=6,9,12,...,81,84	DIAG
			MSM	KT=3,6,9,...,30,33	
Probability of thunderstorm over 3 hours	Grids	20km	GSM	KT=6,9,12,...,81,84	LGR
			MSM	KT=6,9,12,...,30,33	

* KF: Kalman Filter, NRN: Neural Network, LGR: Logistic Regression, FBC: Frequency Bias Correction, DIAG: Diagnostic method

The first objective of the guidance is to reduce forecast errors, mainly bias errors, of NWP output such as in surface temperature. The second objective is to derive quantitative values of parameters not directly calculated in the NWP models, such as probability of precipitation.

To cope with frequent model upgrades, JMA developed methods of adaptively correcting the statistics of the relationship between NWP output and the corresponding observation. The methods, based on Kalman Filter and Neural Network, were put into operational use for the first time in 1996. Since then the adaptive methods have been applied to most of the parameters, replacing the formerly used non-adaptive multivariate regression method.

In the following subsections, Kalman Filter and Neural Network used in the guidance system are explained in Subsection 4.6.2 and Subsection 4.6.3, respectively, and the utilization of the guidance in forecasting offices is summarized in Subsection 4.6.4.

4.6.2 Guidance by Kalman Filter

4.6.2.1 Kalman Filter

As a statistical post-processing method of NWP output, Kalman Filter (KF) was developed in JMA on the basis of earlier works of Persson (1991) and Simonsen (1991). The notation of KF, which basically follows that of Persson (1991), is as follows:

- y: predictand (target of forecast)
- $\boldsymbol{c}$: predictors ($1 \times n$ matrix)
- $\boldsymbol{X}$: coefficients ($n \times 1$ matrix)
- $\boldsymbol{Q}$: covariance of $\boldsymbol{X}$ ($n \times n$ matrix)
- τ: sequence number of NWP initial times

First, the observation equation, which is a linear model for relating the predictand with the pre-selected predictors, and the system equations are given as:

$$y_\tau = \boldsymbol{c}_\tau \boldsymbol{X}_\tau + v_\tau \tag{4.6.1}$$

$$\boldsymbol{X}_{\tau+1} = \boldsymbol{A}_\tau \boldsymbol{X}_\tau + \boldsymbol{u}_\tau \tag{4.6.2}$$

where v_τ is the observational random error whose variance is D_τ, and $\boldsymbol{u}_\tau$ is the random error vector of the system, whose covariance matrix is $\boldsymbol{U}_\tau$. The matrix $\boldsymbol{A}_\tau$ describes the evolution of the coefficients in time and is set to the unit matrix in this case;

$$\boldsymbol{A}_\tau \equiv \boldsymbol{I} \tag{4.6.3}$$

The objective of KF is to obtain the most likely estimation of the coefficients $\boldsymbol{X}_{\tau+1/\tau}$, whose subscripts denote that this is an estimate using the observation corresponding to the forecast at τ and used for the prediction at $\tau + 1$. In contrast, single subscripts in Eq. (4.6.1) and Eq. (4.6.2) denote the "true" values at τ. $\boldsymbol{X}_{\tau+1/\tau}$ is obtained from the previous estimate $\boldsymbol{X}_{\tau/\tau-1}$ and the forecast error:

$$\boldsymbol{X}_{\tau+1/\tau} = \boldsymbol{X}_{\tau/\tau} \tag{4.6.4}$$

$$= \boldsymbol{X}_{\tau/\tau-1} + \delta_\tau (y_\tau - \boldsymbol{c}_\tau \boldsymbol{X}_{\tau/\tau-1}) \tag{4.6.5}$$

where

$$\delta_\tau = \boldsymbol{Q}_{\tau/\tau-1} \boldsymbol{c}_\tau^{\mathrm{T}} (\boldsymbol{c}_\tau \boldsymbol{Q}_{\tau/\tau-1} \boldsymbol{c}_\tau^{\mathrm{T}} + D_\tau)^{-1} \tag{4.6.6}$$

$\boldsymbol{Q}$, the covariance of $\boldsymbol{X}$, is updated as follows:

$$\boldsymbol{Q}_{\tau+1/\tau} = \boldsymbol{Q}_{\tau/\tau} + \boldsymbol{U}_\tau \tag{4.6.7}$$

$$= \boldsymbol{Q}_{\tau/\tau-1} - \delta_\tau \boldsymbol{c}_\tau \boldsymbol{Q}_{\tau/\tau-1} + \boldsymbol{U}_\tau \tag{4.6.8}$$

Eq. (4.6.4) and Eq. (4.6.7) are derived from Eq. (4.6.2) and Eq. (4.6.3).

Finally, the forecast value is calculated with the updated coefficients and predictors at $\tau + 1$;

$$y_{\tau+1/\tau} = \boldsymbol{c}_{\tau+1}\boldsymbol{X}_{\tau+1/\tau} \tag{4.6.9}$$

For some forecast parameters, temperature for example, the predictand y is the difference between the NWP output and the observation, while for the others, precipitation amount for example, y is the observation itself.

In the forecast guidance system with KF, D_τ in Eq. (4.6.6) and $\boldsymbol{U}_\tau$ in Eq. (4.6.8) are treated as empirical parameters of controlling the adaptation speed.

4.6.2.2 Frequency Bias Correction

With KF, the most likely estimation of the predictand which minimizes the expected root-mean-square error is obtained. However, the output has a tendency of lower frequency of forecasting rare events, such as strong wind and heavy rain, than the actual. To compensate this unfavorable feature, a frequency bias correction scheme is applied to the KF output of some parameters.

The basic idea is to multiply the estimation of KF, y, by a correction factor $F(y)$ to get the final output y^b:

$$y^b = y \cdot F(y)$$

To determine $F(y)$, a number of thresholds t^i are chosen to span the given observation data set first. Then corresponding thresholds f^i for the forecast data set are adjusted so that the number of observation data smaller than t^i should approximate to that of forecast data smaller than f^i. Finally the correction factors are computed as follows:

$$F(f^i) = t^i/f^i$$

$$F(y) \text{ for } f^i < y < f^{i+1} \text{ is linearly interpolated between } F(f^i) \text{ and } F(f^{i+1}).$$

Since KF is an adaptive method, f^i is also updated each time the observation y_τ corresponding to the estimates of KF $y_{\tau/\tau-1}$ is available. The update procedure is as follows:

$$f^i_{\tau+1} = \begin{cases} f^i_\tau(1+\alpha) & \text{if} \quad y_\tau < t^i \quad \text{and} \quad y_{\tau/\tau-1} > f^i \\ f^i_\tau(1-\alpha) & \text{if} \quad y_\tau > t^i \quad \text{and} \quad y_{\tau/\tau-1} < f^i \\ f^i_\tau & \text{otherwise} \end{cases}$$

where α is an empirical parameter to determine the adaptation speed. This frequency bias correction is applied to the guidance for wind and precipitation amount.

4.6.2.3 An Example of the Guidance by Kalman Filter (3-hour Precipitation Amount)

In this guidance, the predictand is the observed 3-hour accumulated precipitation amount averaged within a 20km × 20km square, and the following nine parameters derived from GSM forecast are used as predictors.

1. NW85: NW – SE component of wind speed at 850hPa
2. NE85: NE – SW component of wind speed at 850hPa
3. SSI: Showalter's stability index
4. OGES: Orographic precipitation index
5. PCWV: Precipitable water contents × wind speed at 850hPa × ascending speed at 850hPa
6. QWX: Σ (Specific humidity × ascending speed × relative humidity) between 1000 and 300hPa
7. EHQ: Σ (Depth of wet layer × specific humidity) between 1000 and 300hPa
8. DXQV: Precipitation index on winter synoptic pattern

9. FRR: Precipitation by the model (GSM)

Figure 4.6.1 is an example of precipitation forecasts. The model(GSM) (C) predicted very little or no precipitation in the area M, where the observation (A) shows weak precipitation. On the other hand, the guidance (B) predicted weak precipitation in this area, showing better results. Examination of the coefficient values shows orographic effect by OGES enhanced precipitation amount in this area.

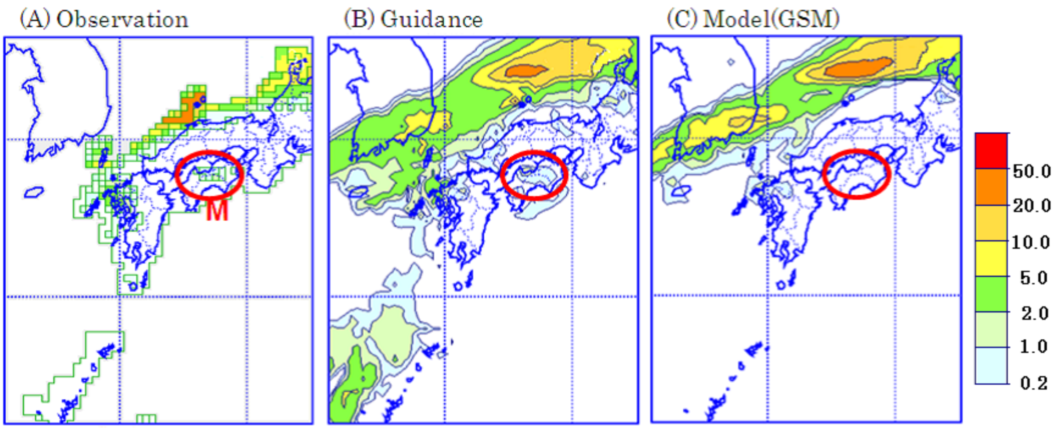

Figure 4.6.1: Mean precipitation amount over 3 hours. (A) Observation. (B) Forecast by the Guidance. (C) Forecast by the Model (GSM).

4.6.3 Guidance by Neural Network

4.6.3.1 Neural Network

The Neural Network (NRN) is one of the artificial intelligence methods and is an effective technique to analyze non-linear phenomena (Yanagino and Takada 1995). Its basic element is called a “neuron”, and multiple neurons are linked together to construct a hierarchical neural network, as shown in Figure 4.6.5. The first layer is called the “input layer”, the last layer is called the “output layer”, and the layers between them are called “hidden layers”.

When a signal is put into the input layer, it is propagated to the next layer through the interconnections between the neurons. Simple processing is performed on this signal by the neurons of the receiving layer prior to its propagation to the next layer. This process is repeated until the signal reaches the output layer.

A schematic diagram of a neuron is shown in Figure 4.6.2. The input of each neuron is a weighted sum of the outputs of other neurons, and the output is a function of its input. This function is called an “activation function”, and a sigmoid function shown in Figure 4.6.3 is usually used.

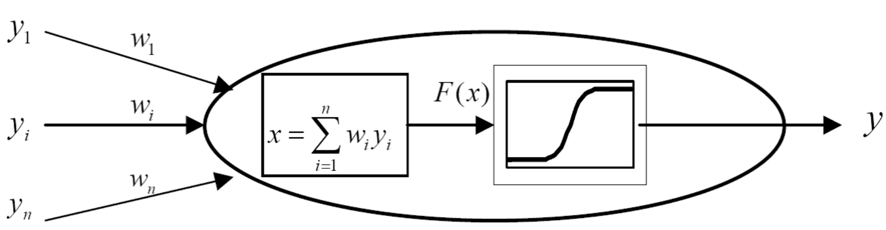

Figure 4.6.2: A schematic diagram of the neuron

$$F(x) = \frac{1}{1+e^{-(2/c)x}}$$

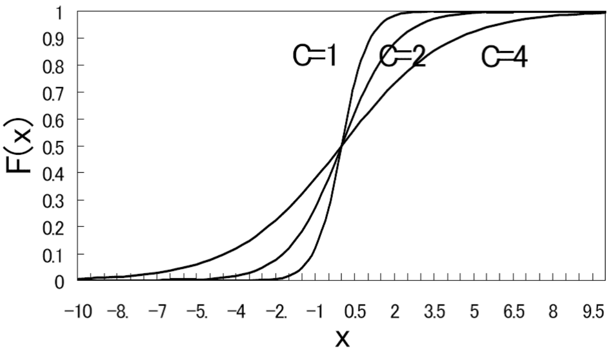

Figure 4.6.3: Examples of the sigmoid function

The weights of NRN are iteratively adjusted through learning numerous sets of input/output data. The most popular way to adjust weights is the “back propagation of error” algorithm described as follows:

1. At first, weights are initialized with randomized values.
2. The NRN gets a set of input values and calculates output.
3. The weights are adjusted to make the NRN output approach the “supervisor data” (correct values of the output variable).
4. Processes of 2 and 3 are iterated until the error measure falls below a specified value or a specified maximum number of iterations is reached.

4.6.3.2 An Example of the Guidance by Neural Network (Categorized Weather)

In the forecast guidance system, a Neural Network model is constructed at each grid or observation point from the sets of NWP output and observed weather elements. Categorized weather is one of the forecast guidance parameters to which NRN is applied. Figure 4.6.4 shows an output example of categorized weather guidance. In this guidance, a NRN model is used to derive sunshine duration, which is used to determine the non-precipitating weather categories (fair or cloudy). The NRN is constructed at each AMeDAS station, and output values (3-hourly sunshine duration) are interpolated to grid points. The precipitating weather categories (rain, sleet, snow) are determined from the KF-based precipitation amount guidance described in Subsection 4.6.2 and another NRN. The constitution of the sunshine duration NRN model is shown in Figure 4.6.5, and its characteristics are summarized as follows:

1. It is a 3-layered Back Propagation Network.
2. As an activation function of each neuron, a linear function is used in the input and output layer, and a sigmoid function is used in the hidden layer.
3. In learning processes, NWP output is used as input data, and sunshine duration observed at each AMeDAS point is used as supervisor data.
4. The weights of the network are modified at every time when the observation corresponding to the forecast is obtained.

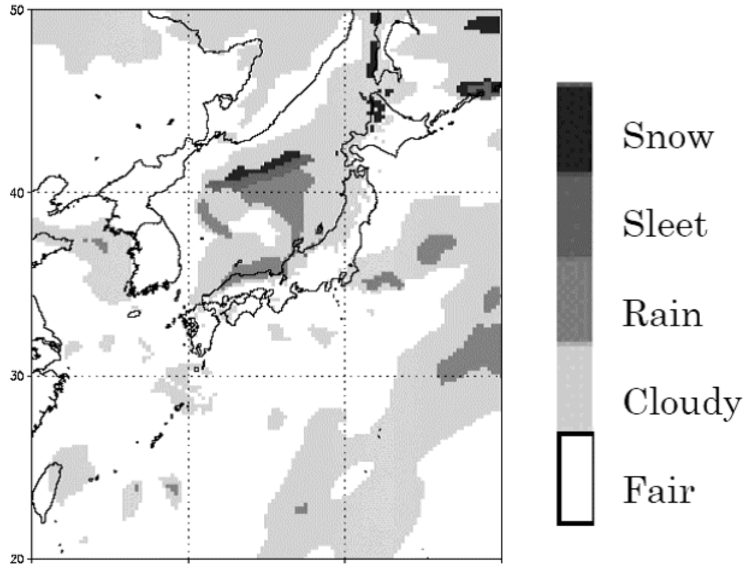

Figure 4.6.4: An example of output of the categorized weather guidance

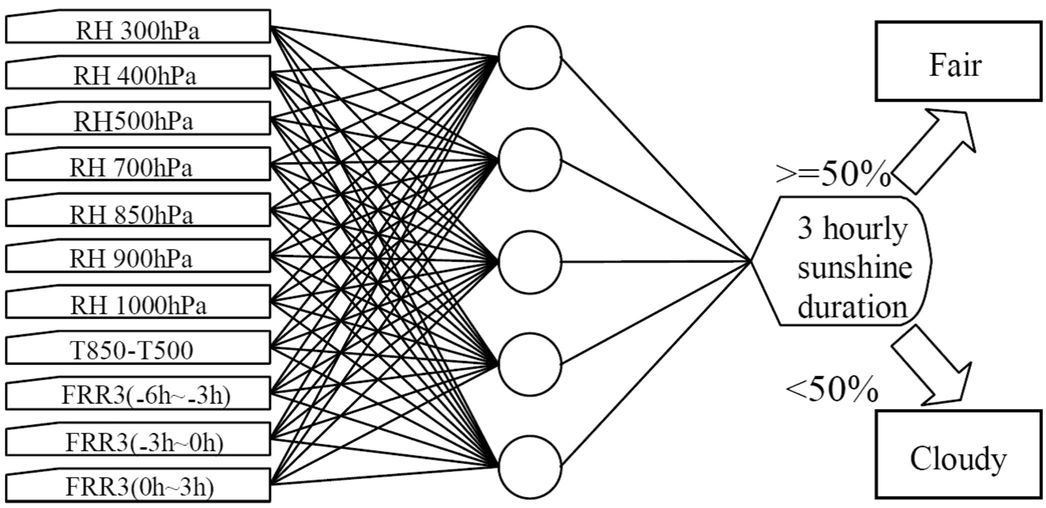

Figure 4.6.5: Neural Network for fair/cloudy determination. RH: Relative Humidity, FRR3: Precipitation over 3 hours.

4.6.4 Utilization of the Guidance at Forecasting Offices

The forecast guidance products are disseminated to forecasting offices and used as a draft of a weather forecast in the forecast editing software. Figure 4.6.6 shows an example of its data entry screen. The forecasters revise elements (time series data of categorized weather, PoP, temperature etc.) on the display considering the current weather condition and empirical knowledge. The processed data are then composed to the forecast bulletin and disseminated to the users.

To make a draft of the weather forecast bulletin automatically, an algorithm shown bellow is used:

1. 3-hourly dominant weather categories are derived from the majority of the categorized weather on the grids in the forecast area .

2. The draft of the weather forecast bulletin for a day is derived from the sequence of 3-hourly dominant weather categories over the forecast area. Some examples of the algorithm are shown in Table 4.6.2.

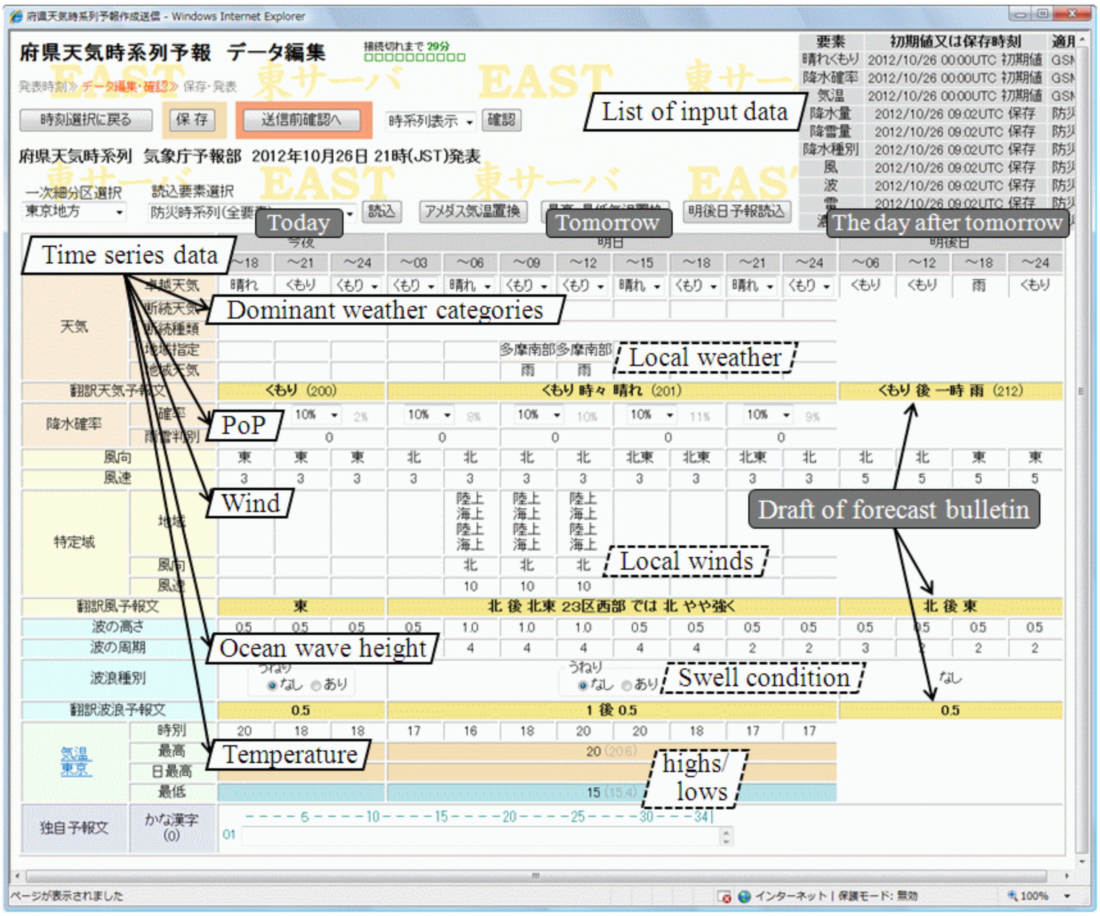

Figure 4.6.6: An example of a data entry screen of the forecast editing software

Table 4.6.2: Examples of the algorithm for making a draft of the weather forecast bulletin

Sequence of 3-hourly categorized weather*								Draft of a weather forecast bulletin
0 - 3	3 - 6	6 - 9	9 -12	12-15	15-18	18-21	21-24	
F	F	F	F	C	F	F	F	Fair
R	R	R	R	R	S	S	S	Rain, snow from the evening
C	R	F	R	C	F	R	C	Cloudy, occasional rain
C	R	C	C	C	C	R	C	Cloudy, rain in the morning and the evening

* F:Fair C:Cloudy R:Rain S:Snow

4.7 Application Products for Aviation Services

4.7.1 Aerodrome Forecast Guidance

The Terminal Area Forecast guidance for Long range flight (TAF-L guidance) and that for Short range flight (TAF-S guidance) were integrated to the guidance for Terminal Area Forecast (TAF guidance) in May 2007. The TAF guidance is derived from the output of MSM 8-times a day and gives hourly predictions upto 33 hours (03, 09, 15, 18UTC initial times) and upto 15 hours (00, 06, 12, 18UTC initial times). The predicted parameters of these guidances are listed in Table 4.7.1.

Table 4.7.1: Parameters of Aerodrome Forecast Guidance. (for 91 airports in Japan)

Parameters	TAF guidance
Visibility	Minimum visibility during an hour Probability of minimum visibility during 3 hours < 5km and 1.6km
Cloud	Cloud amount and height of 3 layers at minimum ceiling during an hour Probability of minimum ceiling during 3 hours < 1000ft and 600ft
Weather	Categorized weather every hour
Temperature	Maximum temperature in the daytime, minimum temperatures in the morning and temperatures every hour
Wind	Wind speed and direction every hour Wind speed and direction of hourly maximum peak wind
Gust	Probability of gust during 3 hours Gust speed and direction of hourly maximum peak gust
Thunder	Probability of thunder during 3 hours

4.7.1.1 Visibility

The minimum visibility and the probability of minimum visibility in TAF guidance (VIS) use statistical interpretation of the model output. The VIS is calculated by linear equations whose coefficients are adapted by Kalman filter (see Subsection 4.6.2.1) with the predictors and METAR reports. The VIS consists of three linear equations classified by weather (rain, snow, no precipitation). The following predictors from the output of MSM are used for each equation.

- no precipitation: $(1 - Rh)^{1/2}$,$Qc^{1/2}$,where Rh is surface relative humidity ($0 \sim 1$), Qc is cloud water content near surface(kg/kg).
- rain: $RR^{1/2}$, $(1 - Rh)^{1/2}$,$Qc^{1/2}$,where RR is precipitation amount (mm).
- snow: $RR^{1/2}$, $(1 - Rh)^{1/2}$, $VV * T$,where VV is surface wind speed (m/s), T is surface temperature (°C, only < 0)

Frequency bias correction (see Subsection 4.6.2.2) is applied to parameters calculated by three equations. After that one parameter is chosen depend on weather category, which is predicted by weather guidance(described later).

4.7.1.2 Cloud

The TAF cloud guidance uses statistical interpretation of the model output. First, each cloud amount at 38 layers (0, 100, . . . , 1000, 1500, . . . , 5000, 6000, . . . , 10000, 12000, . . . , 30000 ft) is calculated by neural net (see Subsection 4.6.3), then three cloud layers are searched upward from surface like METAR reports. The input data (predictors) are relative humidity at three model levels, temperature lapse rate between surface and 925hPa from MSM. The utilization of neural net was introduced in March 2006, improved forecast score.

The TAF probability of minimum ceiling guidance uses statistical interpretation of the model output. It predicts probability of minimum ceiling during 3 hours becomes below 1000ft and below 600ft. The predictors are precipitation amount during 3 hours (rain,snow,hail), precipitation amount during 3 hours (snow), temperature lapse rate between surface and 925hPa, relative humidity, E-W component of wind speed, S-N component of wind speed, cloud amount, cloud ice content, cloud water content at 1000ft and 600ft from the height of airport. The logistic regression (Agresti 2002) was introduced to predict probability of minimum ceiling in December 2010.

4.7.1.3 Weather

The weather guidance predicts categorized weather (fine, cloudy, rainy, snowy and the intensity of precipitation). The TAF weather guidance uses diagnostic method to interpret MSM output into categorized weather (JMA 1997). But only to determine precipitation type (rain or snow), instead of MSM temperature the hourly temperature guidance is used, which improves accuracy of precipitation type prediction.

4.7.1.4 Wind and Temperature

The wind and temperature guidance are calculated with the same methods as the guidance for short-range forecasting (see Section 4.6).

4.7.1.5 Gust

The TAF gust guidance predicts the probability of gust during 3 hours and the speed and direction of the hourly maximum peak gust. It utilized Kalman Filter and Frequency Bias Correction. Predictors are gust speed predicted by MSM, surface wind speed, maximum wind speed in boundary layer. The TAF gust guidance was introduced in December 2012.

4.7.1.6 Thunder

The Probability of Thunder(PoT) guidance predicts the probability of thunder during 3 hours around airport. It utilizes logistic regression and 6 predictors are used in 12 potential predictors, especially SSI, CAPE and precipitation amount during 3 hours are always used for predictor. The TAF PoT guidance was introduced in May 2007.

4.7.2 Products for Domestic Area Forecast

4.7.2.1 Grid-point Values of Significant Weather

Aviation impact variables derived from the MSM output are calculated at model vertical layers and interpolated to flight levels. It is used to produce domestic area forecast in JMA. This purely aviation-oriented dataset is called SIGGPV (Grid-Point Values of Significant weather), whose specifications are listed in Table 4.7.2. The parameter Vws, which is an indicator of Clear Air Turbulence (CAT), is calculated as vertical wind shear between the model levels in kt/1000ft. The parameter TBindex (Kudo 2011) is a combined index of multiple turbulence indices derived from MSM, which is an indicator of various kind of turbulence, i.e. CAT, mountain-waves and cloud related turbulences. The parameters Csig and Cbtop are indicator of cumulonimbus amount and height of cumulonimbus cloud, they are calculated based on Kain-Fritsch convective scheme which is used in the MSM. The parameter Icing is an indicator of aircraft icing. It is derived from empirical equation, which is consists of temperature and dew-point temperature. As illustrated in Figure 4.7.1, SIGGPV, which is distributed as binary data and can be visualized on terminals at aviation forecast offices, is also used for production of the following fax-charts.

Table 4.7.2: Specifications of SIGGPV

Base model	MSM
Forecast time	T=0-15, 1 hourly (initial = 00, 06, 12, 18 UTC) T=0-33, 1 hourly (initial = 03, 09, 15, 21 UTC)
Grid coordinate	Polar Stereographic (60°N, 140°E), 40km, 83 × 71
Parameters	U, V, T, Rh, Psea, Rain, Csig, Cbtop, Trpp[surface] U, V, T, W, Rh, Icing, Vws, TBindex[1,000 - 55,000 ft / every 2,000 ft]

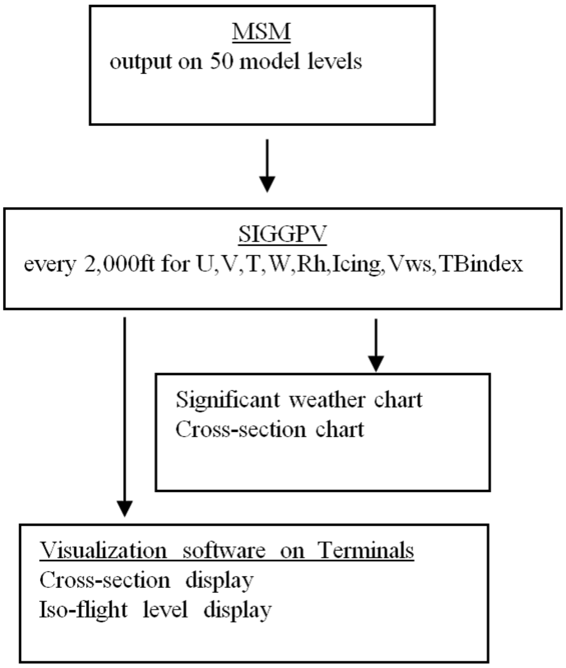

Figure 4.7.1: Data flow of products for domestic area forecast

4.7.2.2 Domestic Significant Weather Chart

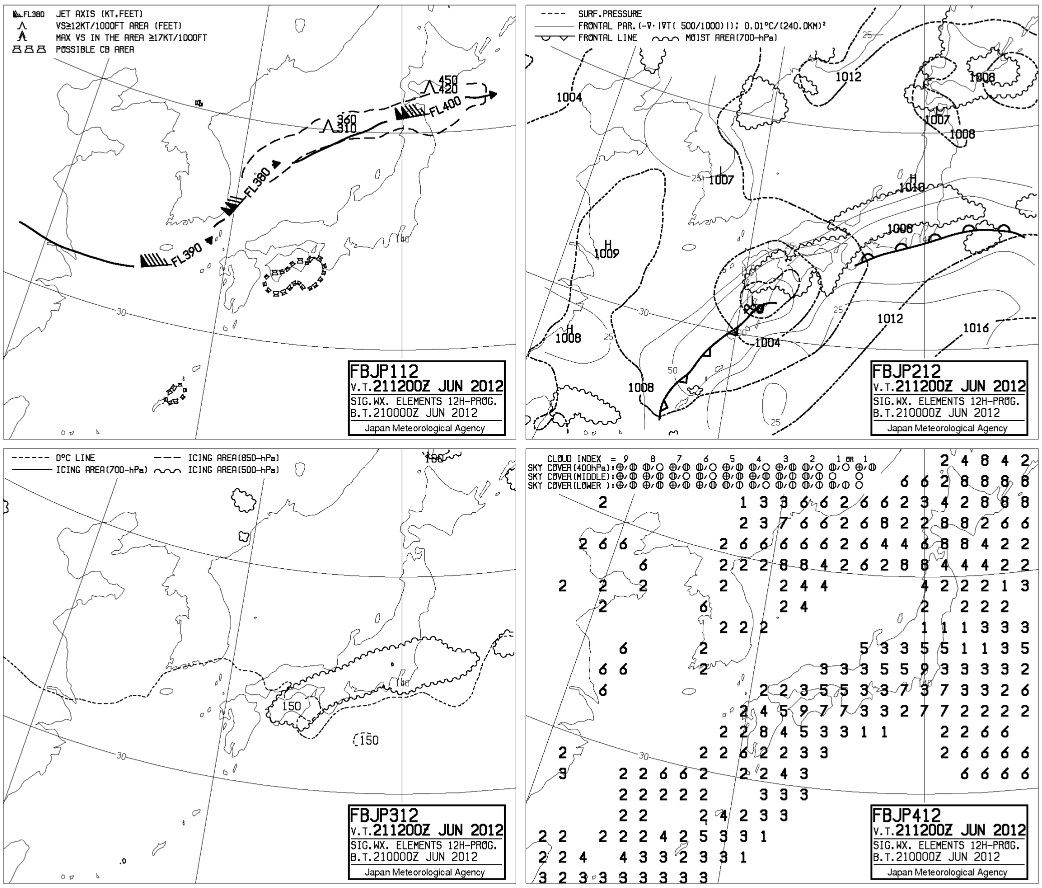

Figure 4.7.2: An example of the domestic significant weather chart

This chart shows 12- hour forecast fields of the parameters listed below in four panels: (Figure 4.7.2)

- Upper-left:
  - Jet stream axes.
  - Possible CAT areas.
  - Possible Cb areas.
- Lower-left:
  - Contours of 0°C height.
  - Possible icing areas at 500, 700 and 850hPa based on the -8 D method (Godske 1957)
- Upper-right:
  - Contours of sea level pressure.
  - Moist areas at 700 hPa.
  - Front parameters $DDT = -\nabla_n |\nabla_n T|$, where T is mean temperature below 500hPa and ∇_n denotes the horizontal gradient perpendicular to the isotherms.

– “NP fronts” drawn along the maxima of DDT.

- Lower-right:
  – Cloud indices indicating the low, middle and upper cloud amount.

4.7.2.3 Domestic Cross-section Chart

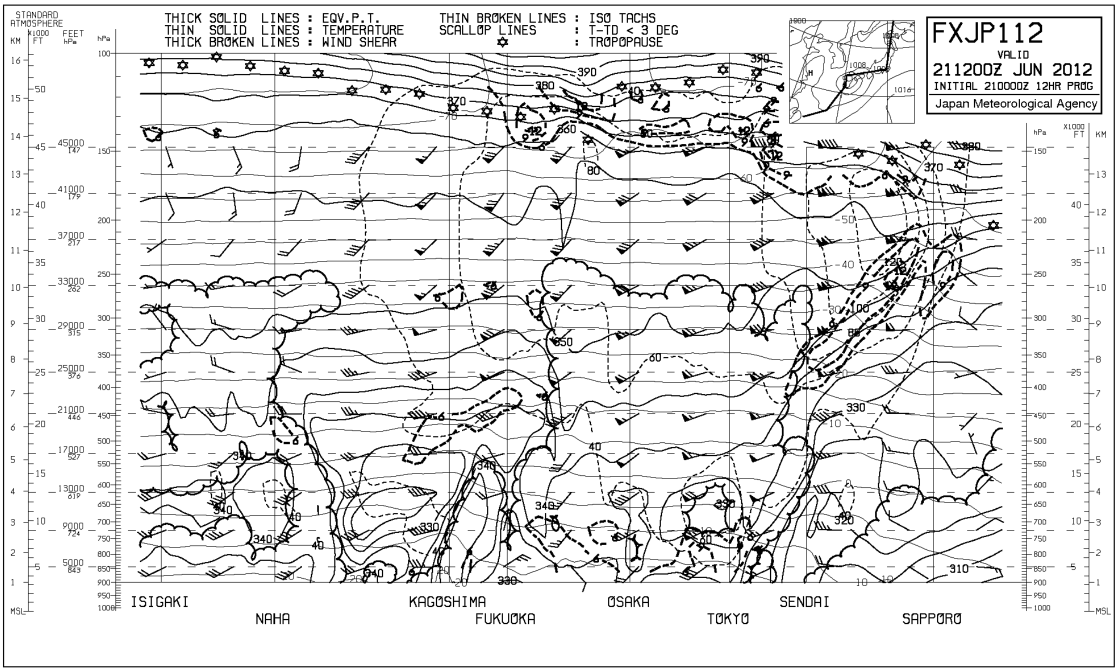

Figure 4.7.3: An example of the domestic cross-section chart. Only the lower part of the fax, corresponding to 12- hour forecast, is shown.

This chart shows 6- and 12-hour forecast fields along the major domestic route. The information drawn is: temperature, equivalent potential temperature, wind barbs and isotachs, moist areas, vertical wind shear and tropopause height (Figure 4.7.3).

4.7.3 Products for International Area Forecast

Global Grid Point Values are derived from the GSM four times a day and distributed in thinned GRIB codes, a format compatible with the products from the World Area Forecast Centers (WAFC). In addition to the parameters included in the WAFC products, Vws, an indicator of CAT and Cbtop, pressure of the top of Cb areas are derived with the same method as that in domestic SIGGPV (see Subsection 4.7.2).

JMA produces 13 Significant weather (SIGWX) charts and 18 Wind and temperature (WINTEM) charts, they are based on the WAFS Significant weather data provided form the World Area Forecast Centers (WAFCs).

4.8 Products of Ensemble Prediction System

4.8.1 Products of the EPS for One-week Forecasting

To assist forecasters in issuing one-week weather forecasts, some products of ensemble mean are made from output of the EPS.

An example of ensemble average chart of mean sea level pressure and precipitation is shown in Figure 4.8.1.

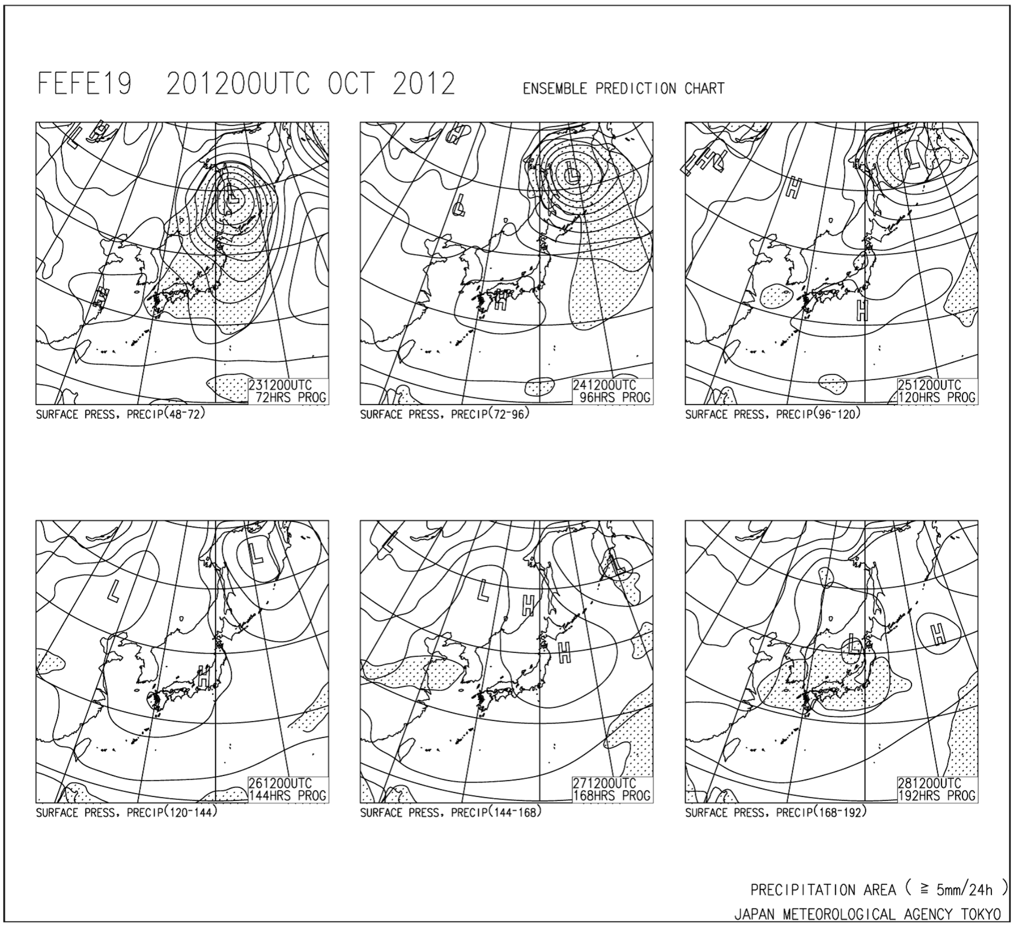

Figure 4.8.1: Ensemble average chart of mean sea level pressure and precipitation from day 2 to 7. This schematic chart is produced by averaging over all members.

4.8.2 Products of the One-month and Seasonal EPSs

4.8.2.1 Forecast Maps and Diagrams

Various kinds of forecast maps and diagrams are produced using the direct outputs from the operational EPSs. Major contents are as follows:

- Ensemble mean maps
- Ensemble spread maps

- Diagrams of time series of varies indices calculated from the ensemble mean and the individual member forecasts (for domestic users only)
- Outlook of sea surface temperature deviations for Ninõ regions to support monthly El Ninõ outlook (Figure 4.8.2)

4.8.2.2 Gridded Data

Gridded data of the model output has been provided via the TCC (the Tokyo Climate Center) website. The products are as follows:

- One-month EPS
  - Daily mean ensemble statistics
  - Daily mean forecast of the individual ensemble member
- Seasonal EPS
  - Monthly mean ensemble statistics
  - Monthly mean forecast of the individual ensemble member

4.8.2.3 Probabilistic Forecast Products

Probabilistic forecasts of three-category (e.g., above-, near-, below-normal) and probabilistic distribution functions are produced using the direct model outputs and hindcast datasets (Figure 4.8.3).

4.8.2.4 Hindcast Dataset and Verification Results

A hindcast is a long set of systematic forecast experiments for past cases, and is performed using forecast models identical to the current operational version. JMA provides not only the operational products but also the hindcast dataset. The Hindcast datasets are used statistically to calibrate real-time forecasts and to evaluate the prediction skill of models.

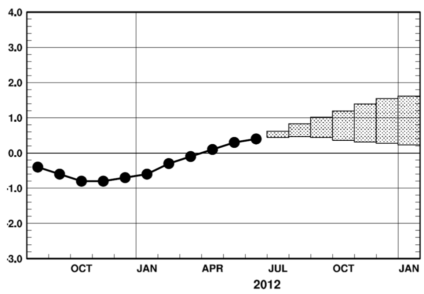

Figure 4.8.2: Outlook of the SST deviation for NINO.3 by the seasonal EPS. The thick line with closed circles denotes the observed SST deviation available at the time of issuance, and the boxes denote the prediction. (ensemble mean collected systematic biases). Each box denotes the range of SST anomaly with the probability of 70% estimating with hindcast results.

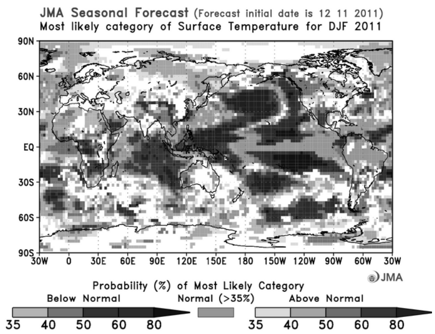

Figure 4.8.3: Probabilistic forecast map of surface air temperature for seasonal prediction. Probability is estimated using a numerical guidance, which applies the Model Output Statistics (MOS) technique based on hindcast result. This figure is monochrome, but it is color illustration in actual.

4.9 Atmospheric Angular Momentum Functions

The Atmospheric Angular Momentum (AAM) functions were proposed to evaluate the earth rotational variation by precisely estimating the variation of the atmospheric angular momentum. To monitor the atmospheric effect on the earth rotation, JMA sends the AAM products to NCEP which is the sub-bureau of International Earth Rotation Service (IERS) through GTS. The AAM functions are expressed as follows (Barnes *et al.* 1983).

$$\chi_1 = -\,1.00\left[\frac{r^2}{(C-A)g}\right]\int P_S \sin\phi\cos\phi\cos\lambda\, dS$$
$$-\,1.43\left[\frac{r}{\Omega(C-A)g}\right]\iint (u\sin\phi\cos\lambda - v\sin\lambda)\; dPdS, \qquad (4.9.1)$$
$$\chi_2 = -\,1.00\left[\frac{r^2}{(C-A)g}\right]\int P_S \sin\phi\cos\phi\sin\lambda\, dS$$
$$-\,1.43\left[\frac{r}{\Omega(C-A)g}\right]\iint (u\sin\phi\sin\lambda + v\cos\lambda)\; dPdS, \qquad (4.9.2)$$
$$\chi_3 = -\,0.70\left[\frac{r^2}{Cg}\right]\int P_S\cos^2\phi\, dS\; -\, 1.00\left[\frac{r}{\Omega Cg}\right]\iint u\cos\phi\, dPdS. \qquad (4.9.3)$$

In Eq. (4.9.1) to Eq. (4.9.3), P is the pressure, $\int dS$ is the surface integral over the globe, (ϕ, λ) are latitude and longitude, u, v are the eastward and northward components of the wind velocity, P_S is the surface pressure, g is the mean acceleration of gravity, r is the mean radius of the earth, C is the polar moment of inertia of the solid earth, A is the equatorial moment of inertia, and Ω is the mean angular velocity of the earth.

Functions χ_1 and χ_2 are the equatorial, and function χ_3 is the axial component. Every component is non-dimensional. The first term of each component is a pressure-term, which is related to the redistribution of the air masses. The second term is a wind-term, which is related to the relative angular momentum of the atmosphere.

The variation of the AAM functions calculated from the JMA global analysis data has been reported to well correspond to the variation of the earth rotation. Figure 4.9.1 shows the seasonal variation of the observed earth rotation and the calculated atmospheric relative angular momentum (the wind term of χ_3). The calculation was carried out by National Astronomical Observatory of Japan (Naito and Kikuchi 1992).

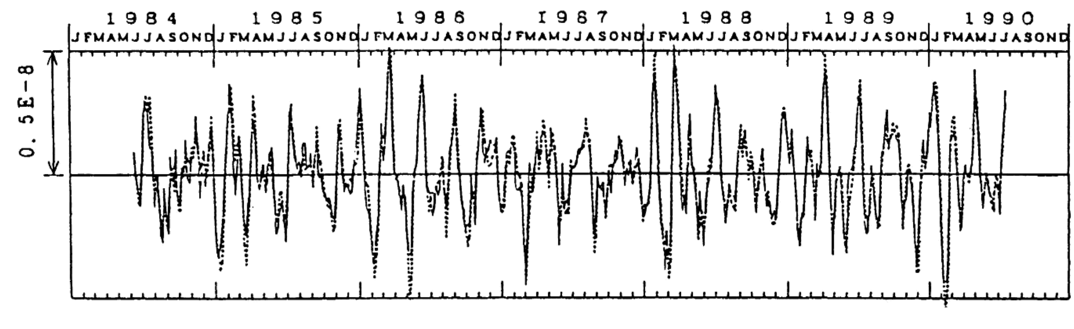

Figure 4.9.1: Seasonal variations of the observed earth rotation (solid line) and the calculated atmospheric angular momentum (broken line). Both data are 150 days' high-pass filtered.

Since early 1993, the AAM functions calculated from the JMA global analysis data at 00UTC, 06UTC, 12UTC and 18UTC have been provided operationally. Now, the AAM functions calculated from the JMA global 8-day forecast data at 12UTC also have been provided operationally.

The AAM functions which are calculated in a test period between 21 June and 30 September 1992 are shown in Figure 4.9.2. In this figure, day 1 - 102 corresponds to 21 June - 30 September 1992. Each term of the AAM functions is multiplied by 10^7. The broken line shows the 6-hourly values of the AAM functions (difference from the period mean values), and the solid line shows the 5-10 days' band-pass filtered values. It can be noticed that an oscillation that has a 5-10 day period is remarkable in each term of the each component, which implicitly means that there is a 5-10 day period oscillation in the global scale atmosphere.

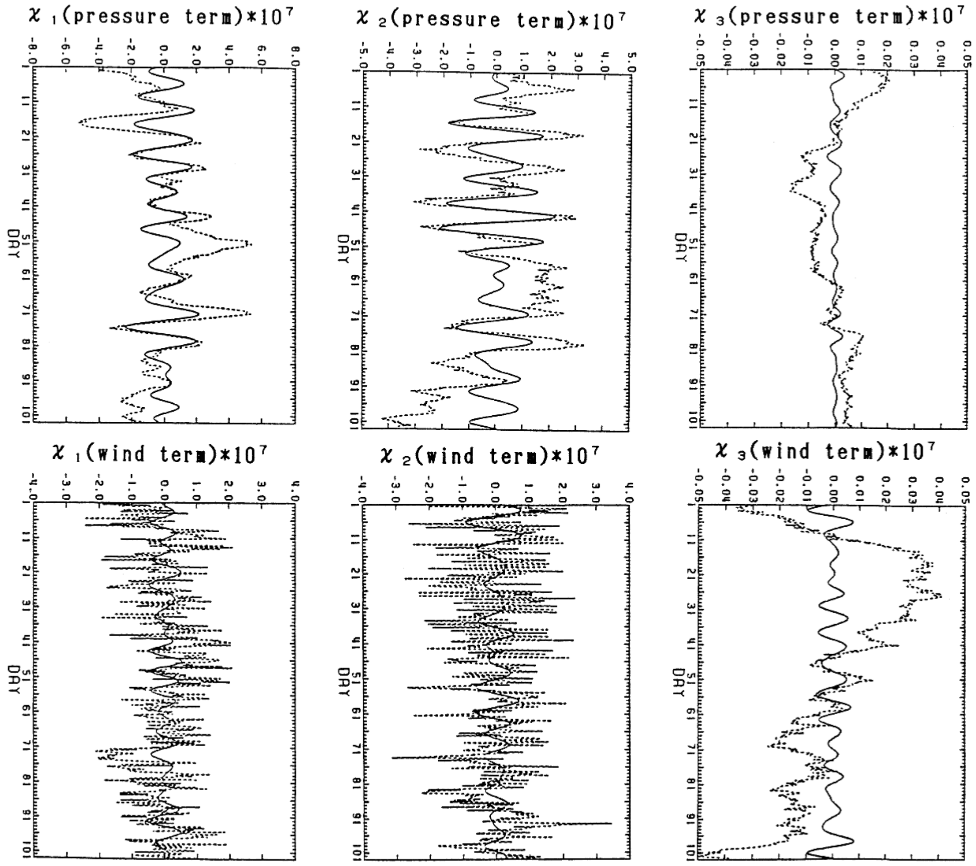

Figure 4.9.2: Pressure terms (top) and wind terms (bottom) of the AAM functions. The left panels are the χ_1 component, the center ones are the χ_2 and the right ones are the χ_3. Day 1 - 102 corresponds to 21 June - 30 September 1992. The broken line shows the 6-hourly values of the AAM functions, and the solid line shows the 5-10 days' band-pass filtered values. Each value is multiplied by 10^7.