Chapter 4

NWP Application Products

4.1 Summary

NWP results provide useful information both for the general public and for special applications. Against this background, JMA provides these data in real time to its own local observatories, to private companies and to related organizations both in Japan and abroad. Facsimile charts served for a long time as the primary means of NWP output provision, but the development of telecommunication infrastructure and sophisticated visualization systems has now made dissemination based on gridded values the essential method.

In addition to raw NWP data, application products derived from NWP output are also disseminated. An example of such products is information on parameters not explicitly calculated in NWP models, such as probabilistic forecasts, data on turbulence potential for the aviation sector, and error-reduced estimation of NWP output. These are calculated based on the statistical relationship between NWP output and corresponding observations. JMA disseminates Very-short-range (15-hour) Forecasts of Precipitation, Hourly Analysis of horizontal wind and temperature fields, and a number of forms of guidance for short-range forecasting. To support mid-to-long-range forecasting, various forecast charts and gridded data for weekly, monthly and seasonal forecasts are also disseminated.

In the following sections, the specifications of NWP application products and their utilization by JMA are described.

4.2 Weather Chart Services

Facsimile chart provision is a conventional service operated to disseminate the results of NWP in graphical form. Under this service, JMA 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 readily accessible by international users (i.e., those provided through GTS and JMH).

The development of the Web complements and supports innovation in these services, and a number of related projects are under way worldwide. JMA takes part in international initiatives such as the Project on the Provision of City-Specific Numerical Weather Prediction (NWP) Products to Developing Countries via the Internet in WMO Regional Association II (RA II) and the Severe Weather Forecasting Programme (SWFP) involving WMO RAs II and V. The Agency's own projects in this regard include the JMA Pilot Project on EPS Products and 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 the past 12 h for 24 h forecast, and over the past 24 h for others), H: geopotential height, J: wave height, O: vertical velocity (ω), P: MSL pressure, T: temperature, W: wind speed (isotachs), Z: vorticity; Symbols for other drawings: a: wind arrow from gridded data, b: observation plots, d: hatch for area $T - T_d < 3$ K, g: arrow for prevailing wave direction, j: jet axis, m: wave period, s: daily mean sea surface temperature, t: temperature numbers, x: streamlines; Symbols for dissemination and temporal specialty: ’: sent to GTS, *: sent to JMH, ¶: only for 00 UTC, §: only for 12 UTC.

Model	Area (see Figure 4.2.1)	Forecast Time							
		Analysis	12h	24h	36h	48h	72h	96h 120h	144h 168h 192h
GSM	A’ (Far East)	500 (H, Z)’ 850 (T; a)+700 (O)’		500 (T)+700 (D)’* 500 (H, Z)’* 850 (T; a)+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, a)+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)’					
	W (West Pacific)	200 (x)’ 850 (x)’		200 (x)’ 850 (x)’		200 (x)’ 850 (x)’			
	D (N Hem.)	500 (H, T)’§							
Ocean Wave	X (Japan)	Surf(J; b, g, m)’*		Surf(J; b, g, m)’*					
	C” (NW Pacific)	Surf(J; g, m)’*	Surf(J; g, m)’*			Surf(J; g, m)’*			
Sea Surface Temperature	C”2 (NW Pacific)	Surf(s)’*¶							

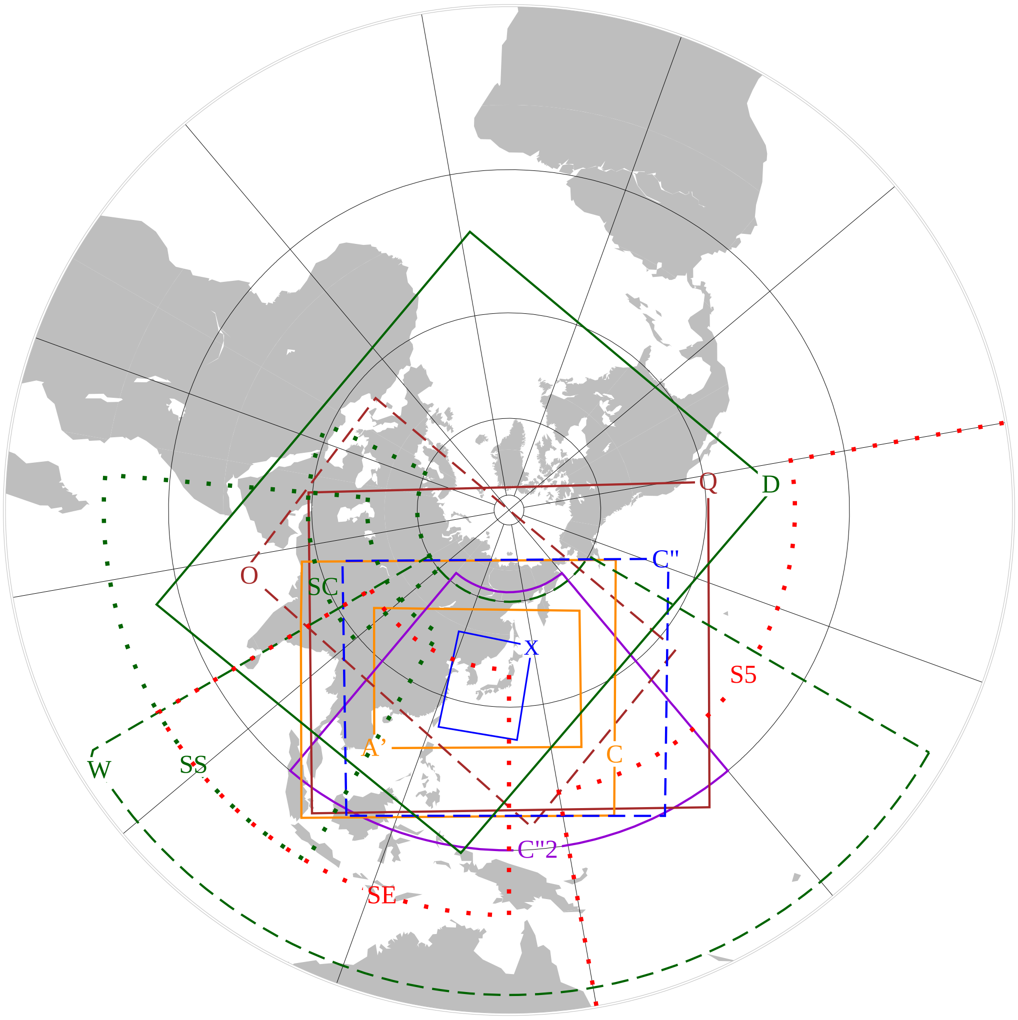

Figure 4.2.1: Areas for charts disseminated through GTS and radio facsimile JMH (symbols A', C, C", C"2, D, O, Q, W and X). The dotted boxes labeled SE, SS, SC and S5 are areas of SWFP products for Southeast Asia, South Asia, Central Asia, and WMO Region V, respectively (for information).

4.3 Gridded Data Products

As part of JMA's general responsibility in meteorological information service provision, gridded data products are distributed to domestic and international users. In line with the requirements of the WMO Information System (WIS), this data service utilizes both dedicated and public (i.e., 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 provision to government agencies and the Meteorological Business Support Center, which is in charge of managed services for general users including those in the private sector.

The portal to JMA's international services over the Internet is the website of the Global Information System Centre (GISC) Tokyo[1]. Currently, the international service for gridded data products includes the GSM, the Global Ensemble Forecast (One-week) and the Ocean Wave Model as listed in Table 4.3.1 and Table 4.3.2.

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

Table 4.3.1: List of gridded data products transmitted through GTS and the GISC Tokyo website. Symbols for content: D: dewpoint depression ($T - T_d$), E: precipitation (from initial time), E_6: precipitation over the past 6h, G: prevailing wave direction, H: geopotential height, J: wave height, M: wave period, O: vertical velocity (ω), P: MSL pressure, R: relative humidity, T: temperature, U: eastward wind speed, V: northward wind speed, W: vertical wind shear, X: stream function, Y: velocity potential, Z: vorticity, μ: average over ensemble, σ: standard deviation over ensemble. The symbols °, *, ¶, §, ♯, ♭, †, ‡are notes on availability, as detailed in the table.

Model	GSM	GSM	GSM
Service Channel	GTS and GISC	GTS and GISC	GTS and GISC
Code form	GRIB Edition 1	GRIB Edition 1	GRIB Edition 1
Area	Whole Globe	20°S–60°N 60°E–160°W	Whole Globe
Resolution	1.25° × 1.25°	1.25° × 1.25°	2.5° × 2.5°
Contents 10, 20 hPa	H, U, V, T	H, U, V, T	H*, U*, V*, T*
30, 50, 70hPa	H, U, V, T	H, U, V, T	H°, U°, V°, T°
100 hPa	H, U, V, T, $W^{\sharp}$	H, U, V, T	H°, U°, V°, T°
150 hPa	H, U, V, T, $W^{\sharp}$	H, U, V, T	H*, U*, V*, T*
200 hPa	H, U, V, T, X, Y, $W^{\sharp}$	$H^{\S}$, $U^{\S}$, $V^{\S}$, $T^{\S}$, X, Y	H, U, V, T
250 hPa	H, U, V, T, $W^{\sharp}$	H, U, V, T	H°, U°, V°, T°
300 hPa	H, U, V, T, R, O, $W^{\sharp}$	H, U, V, T, D	H, U, V, T, D*‡
400 hPa	H, U, V, T, R, O, $W^{\sharp}$	H, U, V, T, D	H*, U*, V*, T*, D*‡
500 hPa	H, U, V, T, R, O, Z, $W^{\sharp}$	$H^{\S}$, $U^{\S}$, $V^{\S}$, $T^{\S}$, $D^{\S}$, Z	H, U, V, T, D*‡
600 hPa	H, U, V, T, R, O		
700 hPa	H, U, V, T, R, O, $W^{\sharp}$	$H^{\S}$, $U^{\S}$, $V^{\S}$, $T^{\S}$, $D^{\S}$, O	H, U, V, T, D
850 hPa	H, U, V, T, R, O, X, Y	$H^{\S}$, $U^{\S}$, $V^{\S}$, $T^{\S}$, $D^{\S}$, O, X, Y	H, U, V, T, D
925 hPa	H, U, V, T, R, O	H, U, V, T, D, O	
1000 hPa	H, U, V, T, R, O	H, U, V, T, D	H, U*, V*, T*, D*‡
Surface	P, U, V, T, R, E†, $E_6{}^{\flat}$†	$P^{\P}$, $U^{\P}$, $V^{\P}$, $T^{\P}$, $D^{\P}$, $E^{\P}$	P, U, V, T, D*‡, E†
Forecast time range (*from–until/interval*)	0–84h/6h †: except for analysis ♯: 0-36h/6h, ♭: 6-36h/6h	0–84h/6h	0–72h/24h *: Analysis only
Extension on 12UTC	96–192h/12h	§: 96–192h/24h ¶: 90–192h/6h	96–192h/24h °: 96–120h/24h
Initial times	00, 06, 12, 18UTC	00, 06, 12, 18UTC	00UTC and 12UTC ‡: 00UTC only

Model	Global Ensemble Forecast (One-Week)	Ocean Wave Model
Service Channel	GTS and GISC	GTS and GISC
Code form	GRIB Edition 1	GRIB Edition 2
Area	Whole Globe	75°S–75°N, 0°E–359.5°E
Resolution	2.5° × 2.5°	0.5° × 0.5°
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	00UTC and 12UTC	00,06,12,18UTC

Table 4.3.2: List of gridded data products transmitted through the GISC Tokyo website. Symbols for content: C_L: low cloud amount, C_M: middle cloud amount, C_H: high cloud amount, E: precipitation (from initial time), H: geopotential height, N: total cloudiness, O: vertical velocity (ω), Di: relative divergence, 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, W: wind speed, G: gusts, μ: average over ensemble, σ: standard deviation over ensemble, ρ: probability of ensemble prediction results (parentheses represent probability thresholds). The symbol †is a note on availability, as detailed in the table.

Model	GSM	GSM
Service Channel	GISC	GISC
Code form	GRIB Edition 2	GRIB Edition 2
Area	Whole Globe and also 5°S–90°N, 30°E–165°W	Whole Globe
Resolution	0.5° × 0.5° (0.25° × 0.25° for surface)	1.25° × 1.25°
Contents		
10, 20, 30, 50, 70, 100, 150hPa	H, U, V, T, R, O	H, U, V, T
200 hPa	H, U, V, T, R, O, X, Y	H, U, V, T, X, Y
250 hPa	H, U, V, T, R, O	H, U, V, T, Z ,Di
300, 400 hPa	H, U, V, T, R, O	H, U, V, T, R, O
500 hPa	H, U, V, T, R, O, Z	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, R, O, Z, Di
800 hPa	H, U, V, T, R, O	
850 hPa	H, U, V, T, R, O, X, Y	H, U, V, T, R, O, X, Y
900 hPa	H, U, V, T, R, O	
925 hPa	H, U, V, T, R, O	H, U, V, T, R, O, Z, Di
950, 975 hPa	H, U, V, T, R, O	
1000 hPa	H, U, V, T, R, O	H, U, V, T, R, O
Surface	P, U, V, T, R, E†, P_S, N, C_L, C_M, C_H	U, V, T, R, P, E†
Forecast time range (*from–until/interval*)	0–132h/3h †: except for analysis	0–132h/6h
Extension on 00 and 12UTC	138–264h/6h	144–264h/12h
Initial times	00, 06, 12, 18UTC	00, 06, 12, 18UTC

Model		Global Ensemble Forecast (One-Week)
Service Channel		GISC
Code form		GRIB Edition 2
Area		Whole Globe
Resolution		1.25° × 1.25°
Contents	250hPa	μU, σU, μV, σV
	500hPa	μH, σH
	850hPa	μU, σU, μV, σV, μT, σT, μW, σW, ρT(±1, ±1.5, ±2)
	1000 hPa	μH, σH
	Surface	μP, σP, ρE(1, 5, 10, 25, 50, 100 mm/24h), ρW(10, 15, 25 m/s), ρG(10, 15, 25 m/s)
Forecast time range		0–264h/12h
Initial times		00UTC and 12UTC

4.4 Very-short-range Forecasting of Precipitation

JMA has operated a fully automated system for analysis and very-short-range forecasting of precipitation since 1988 to provide the following products for monitoring and forecasting of local severe weather conditions:

1. Radar/Raingauge-Analyzed Precipitation (R/A; a type of precipitation analysis)
2. Very-Short-Range Forecasting of Precipitation (VSRF; a type of precipitation forecast)
3. Extended VSRF (ExtVSRF; a type of extended precipitation forecast)

The data in these products show a close correlation with rainfall amounts observed using raingauges. From R/A and VSRF, indices with close ties to landslides, flooding and inundation are produced and used to issue advisories and warnings for these phenomena. The products are provided to local meteorological offices, local governments and broadcasting stations which have responsibility for disaster mitigation. This section outlines how the products are created.

Table 4.4.1: Specifications of Radar/Raingauge-Analyzed Precipitation (R/A), Very-Short-Range Forecasting of Precipitation (VSRF) and Extended VSRF (ExtVSRF)

	R/A	VSRF	ExtVSRF
Spatial resolution	1 km	1 km	5 km
Update interval	10 min.	10 min.	1 hour
Analysis/Forecast element	1 hour accumulated rainfall amount	1 hour accumulated rainfall amount	1 hour accumulated rainfall amount
Forecast time	-	Up to 6 hours ahead	From 7 to 15 hours ahead
Forecast interval	-	1 hour	1 hour
Time required to execute	About 5 min. after observation time	About 8 min. after observation time	About 18 min. after observation time

4.4.1 Analysis of Precipitation (R/A)

R/A enables estimation of accurate one-hour precipitation amounts based on precipitation intensity as observed using radars and rainfall amounts observed using raingauges. It involves the use of data from 46 radars (20 JMA units and 26 operated by other organizations) to cover large areas at a higher spatial resolution than the raingauge network as well as data from up to 10,000 raingauges (1,300 AMeDAS units and 8,700 operated by other organizations) to determine actual amounts of precipitation. JMA uses the Z-R relationship to convert the radar reflectivity factor to precipitation intensity. The Kdp-R relationship (Bringi and Chandrasekar 2001) is also clarified for dual-polarized JMA radar, and is used to estimate high-intensity precipitation in ten-minute precipitation amounts close to analysis times.

The one-hour cumulative precipitation amounts estimated using radar observation usually differ from those observed with raingauges. Radar amount calculation is based on cumulative precipitation intensity over an hour, and values are calibrated using raingauge data to enable more accurate estimation (Makihara 2000). A schematic diagram of this procedure is shown in Figure 4.4.1. First, the radar data are quality controlled to remove ground and sea clutter, bright band and weak echoes unrelated to rainfall on the ground. Satellite imagery and NWP gridded data are used for this purpose. Then, the primary calibration factor over the entire detection range of each radar is calculated by comparing radar precipitation to that of neighboring radars and raingauge data with differences in radar beam height taken into account. Next, the secondary calibration factor is calculated by comparing radar precipitation calibrated with the primary factor to raingauge data at grids where raingauges are located to evaluate local heavy precipitation more accurately. For grids with no raingauges, factor calculation is based on weighted interpolation of values for surrounding grids where raingauges are present. A nationwide composite chart of all radar calibrated precipitation data is created using the maximum value method, in which the largest value is selected if a grid has several data from observation by multiple radars.

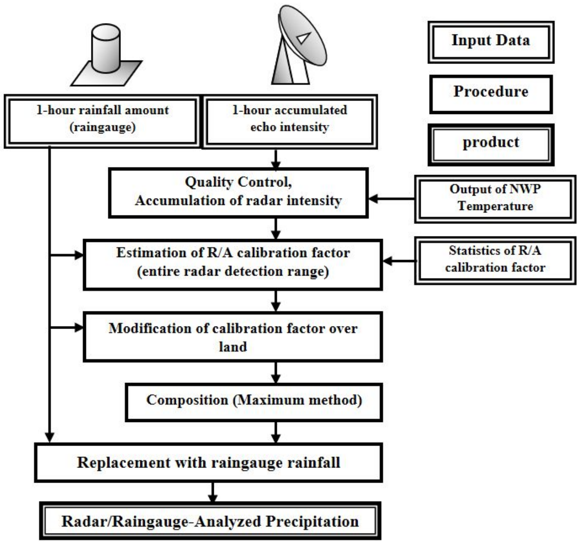

Figure 4.4.1: Flow of Radar/Raingauge-Analyzed Precipitation

4.4.2 Forecasting of Precipitation up to 6 hours ahead (VSRF)

VSRF, which employs the calibrated precipitation intensity determined in the course of R/A as the initial value and is formulated from extrapolation and model forecasts, is a superior estimate of precipitation.

A schematic diagram of the related procedure is shown in Figure 4.4.2. Two methods are used for VSRF. One is the extrapolation of movements of analyzed precipitation systems (i.e., extrapolation forecasts; referred to here as EX6). In the course of extrapolation, the growth and decay of precipitation systems caused by orographic effects and echo intensity trends are taken into account. The other method involves precipitation forecasts of the MSM and LFM, which are available after around two hours from the initial time for the MSM and one hour for the LFM. EX6 is more skillful than MSM and LFM forecasts, although the forecast time is short and skill rapidly diminishes. Meanwhile, the skill of MSM and LFM forecasts degrades gradually and is comparable to that of EX6 when the forecast time reaches a few hours. To produce better model forecasts (referred to here as BLD), JMA introduced a blending technique involving weighted averaging of MSM forecasts and LFM forecasts. This is similar to the merging technique outlined below (see Subsection 4.4.2.2)

The merging technique essentially involves weighted averaging of the EX6 and the BLD. As merging weights are set close to zero for the BLD in the first hour, the products are similar to EX6 output. Thereafter, merging weights for the BLD increase with forecast time. These are determined by comparing the skills of the BLD and the EX6 with R/A. The forecast time steps are two or five minutes, and forecast precipitation is accumulated to produce hourly forecasts up to six hours ahead.

4.4.2.1 Processes assumed in EX6

Extrapolation vectors (i.e., the movement vectors of precipitation systems) are evaluated using a generalized cross-correlation method involving comparison of precipitation system locations at the initial time with those at 0.5, 1, 2 and 3 hours before.

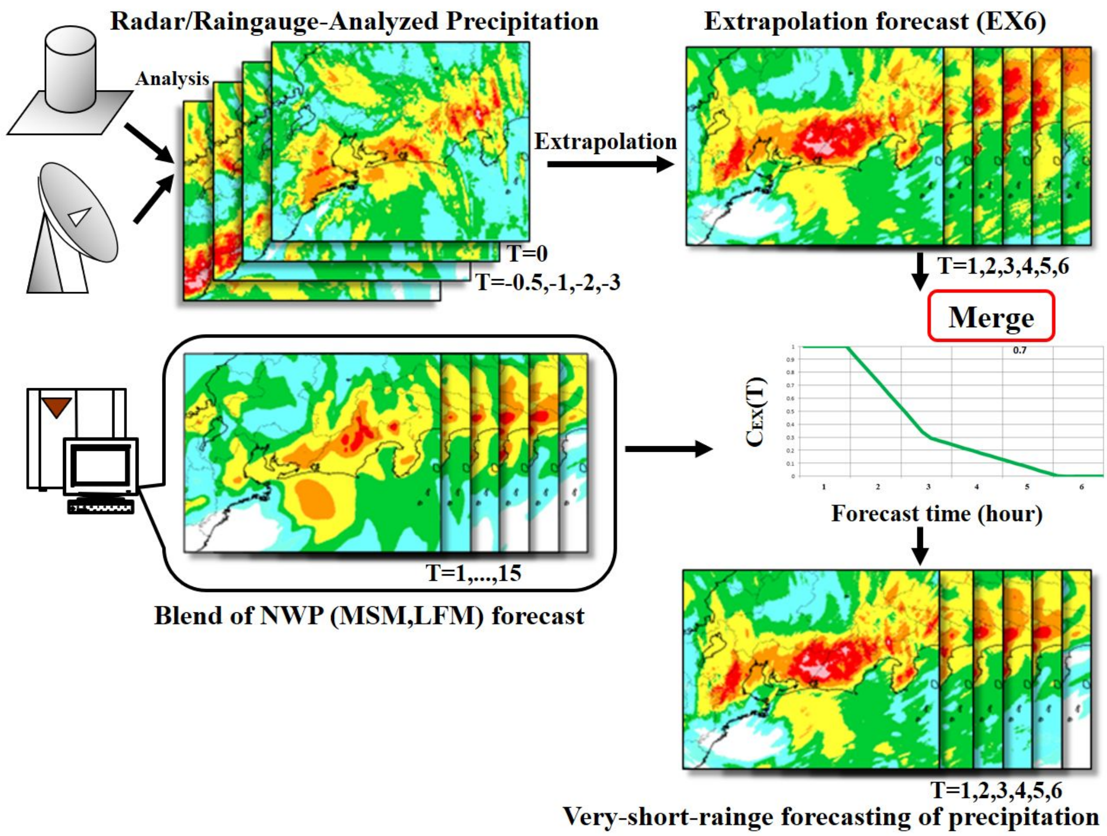

Figure 4.4.2: Schematic representation of very-short-range precipitation forecasting

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

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

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

Echo intensity trends can also be determined by comparing the current area average of echo intensity to a past one. Movement vectors for intensity trends are calculated in addition to extrapolation vectors. The vectors move echo intensity trends, which in turn change forecast precipitation.

4.4.2.2 Merging Technique

First, the relative skill of the EX6 and the BLD are estimated. The EX6 from three hours before is verified against the current analysis. For the BLD forecast, the latest available data are verified against the current analysis. The relative reliability coefficient C_{RR} is defined as follows:

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

where D_{EX} is the two-dimensional pattern distance, or the two-dimensionally extended Levenshtein distance, between the EX6 and the analysis, and D_{BLD} is the two-dimensional pattern distance between the BLD forecast and the analysis.

The relative weight of the extrapolation forecast $C_{EX}(T)$ is then determined using C_{RR} and the function $C(T, BR)$, where BR [2] is blend reliability and T denotes the forecast time as indicated in the merge process of Figure 4.4.3

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

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

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

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

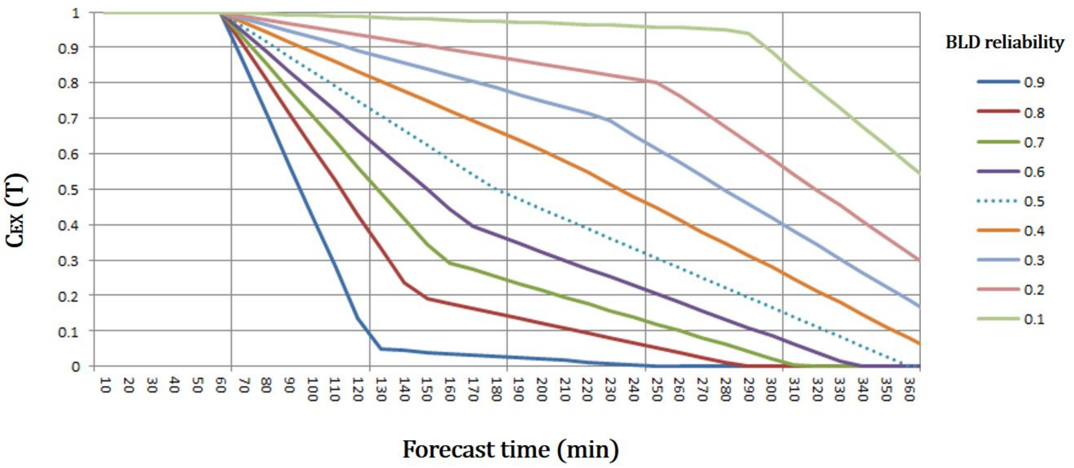

Figure 4.4.3: Dependence of $C_{EX}(T)$ on forecast time and BLD reliability

4.4.2.3 Example and Verification Score of R/A and VSRF

R/A and VSRF examples are shown in Figure 4.4.4. R/A for the Kinki region in the central western area of Japan for 14:50 UTC on 23 August 2018 is shown in the left panel (a), and the three-hour VSRF forecast for the same valid time (i.e., initial time 11:50 UTC 23 on August 2018) is shown in the right panel (b). The intense rain band is well forecasted.

VSRF accuracy has been statistically verified with the critical success index (CSI)[3]. Forecasts are compared with precipitation analysis after both fields are averaged in 5 × 5km grids. Indices from 1- to 6-hour forecasts for July 2018 are shown in Figure 4.4.5.

It can be seen that scores deteriorate with longer forecast times. EX6 maintains its superiority to BLD up to three hours, but the relationship reverses after this time. VSRF exhibits the best performance for all forecast times.

[2] $BR \equiv Score(BLD)/(Score(BLD) + Score(EX6))$

[3] The CSI is the number of correct "Yes" forecasts divided by the total number of occasions on which the event was forecast and/or observed. It is also cited as the threat score (see Subsection A.2.9).

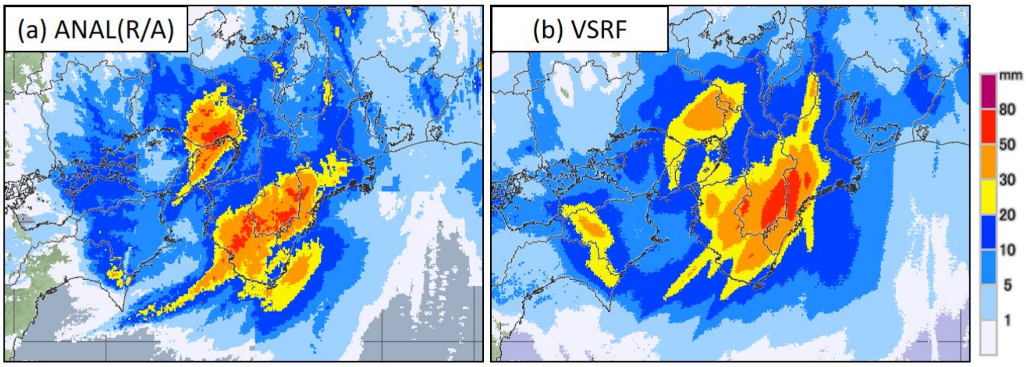

Figure 4.4.4: (a) the Radar/Raingauge-Analyzed Precipitation for 11:50 UTC on 23 August 2018, and (b) 3-hour VSRF forecast of precipitation for the same valid time.

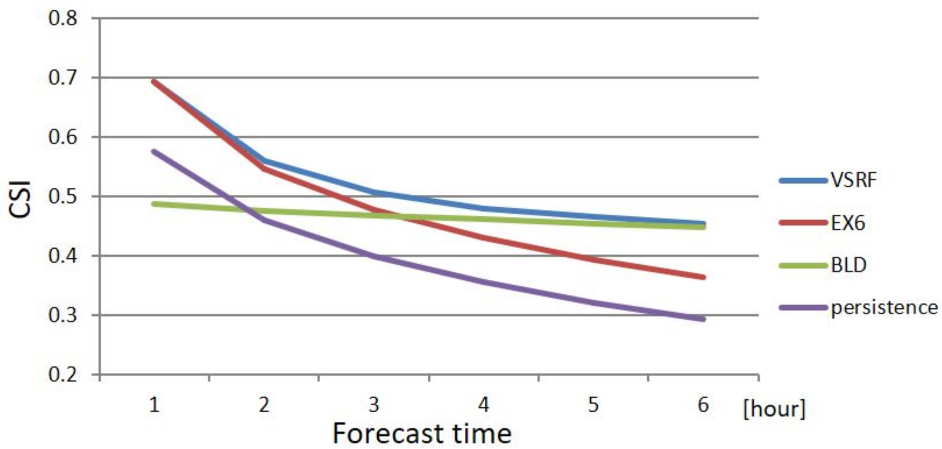

Figure 4.4.5: CSI of very-short-range forecasting (VSRF) of precipitation averaged within 5 × 5km grids over land for July 2018, together with that of EX6, BLD and persistence forecasting. The threshold value is 1.0mm.

4.4.3 VSRF Forecast Range Extension to 15 hours (ExtVSRF)

4.4.3.1 Basic Concept of ExtVSRF

In June 2018, JMA launched an extended VSRF forecast called ExtVSRF to support early judgement on the need for evacuation and other measures by clarifying the tendency of rainfall toward dawn when heavy rain falls in the evening. The extended forecast facilitates understanding of overall precipitation distribution as a trend, and was developed as a separate product from VSRF.

The flow of ExtVSRF calculation is shown in Figure 4.4.6. The forecast is derived from a combination of MSM precipitation amount forecasts, MSM Guidance for mean and maximum precipitation amounts and LFM Guidance for maximum precipitation amounts, and is not merged with the EX6 because the latter's precision from 7 to 15 hours ahead is significantly poorer than that produced by the combination of these guidance forecasts.

The latest available guidance forecasts for mean precipitation amounts and maximum precipitation amounts are divided into two groups, and are verified with current analysis using the fraction skill score (FSS)[4]. The forecast with the best score from each group is chosen and mixed with the weighted average.

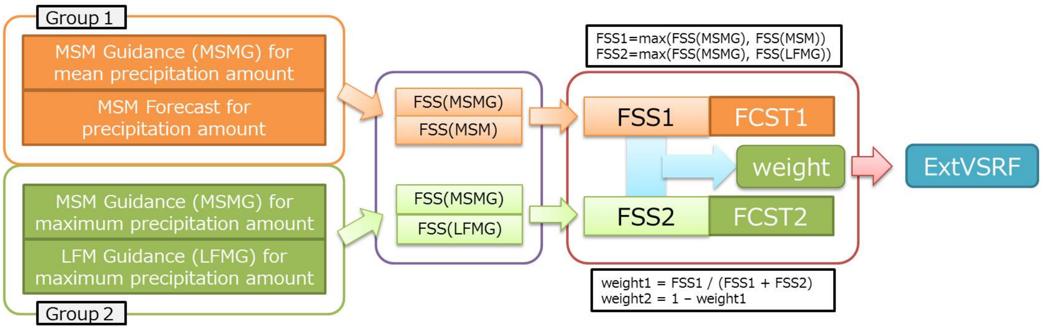

Figure 4.4.6: Extended VSRF flow chart

4.4.3.2 ExtVSRF Verification Score and Example

An example of R/A and ExtVSRF is shown in Figure 4.4.7. The R/A for the western area of Japan at 23 UTC 19 June 2018 (08 JST 20 June 2018) is shown in the left panel (a), and the 14-hour forecast of ExtVSRF at the same valid time (i.e., initial time 09 UTC 19 June 2018 (18 JST 19 June 2018)) is shown in the right panel (b). The intense rain band is well forecast, and it is understandable that this morning rainfall will be heavy at the moment of previous early evening.

The accuracy of ExtVSRF has been statistically verified with FSS data. Forecasts are compared with precipitation analysis in 5×5km grids. Indices from 1- to 15-hour forecasts for July/October 2017 and January 2018 are shown in Figure 4.4.8 together with those of VSRF and MSM Guidance forecasts for mean precipitation amounts. It can be seen that ExtVSRF is superior to MSM Guidance for all forecast times.

4.5 Hourly Analysis

Hourly analysis provides hourly gridded data on three-dimensional temperature and wind, to help forecasters in continuous atmospheric monitoring. Meteorological imagery products are also provided to the aviation sector online.

[4] In FSS, verification incorporates consideration of position gaps and indicates the accuracy of precipitation distribution (see Subsection A.2.12).

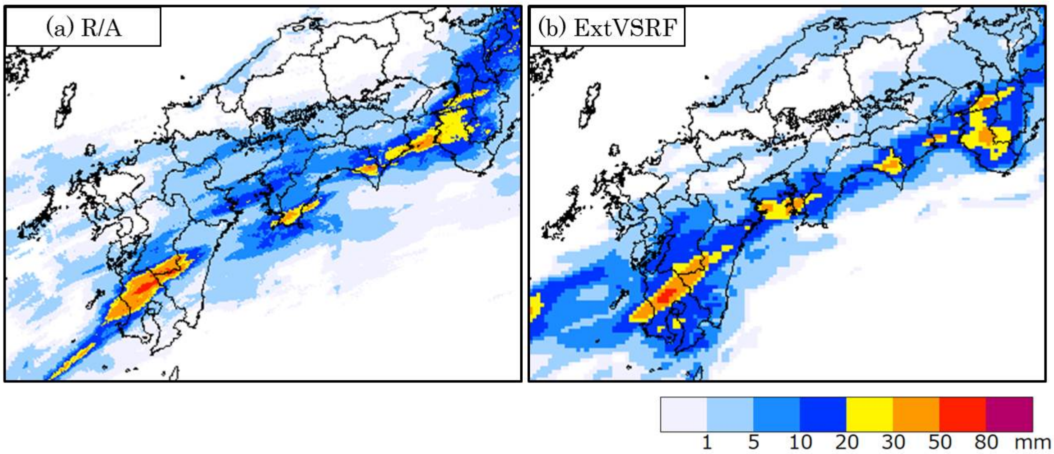

Figure 4.4.7: (a) Radar/Raingauge-Analyzed Precipitation at 23 UTC on 19 June 2018, and (b) 14-hour ExtVSRF forecast of precipitation for the same valid time.

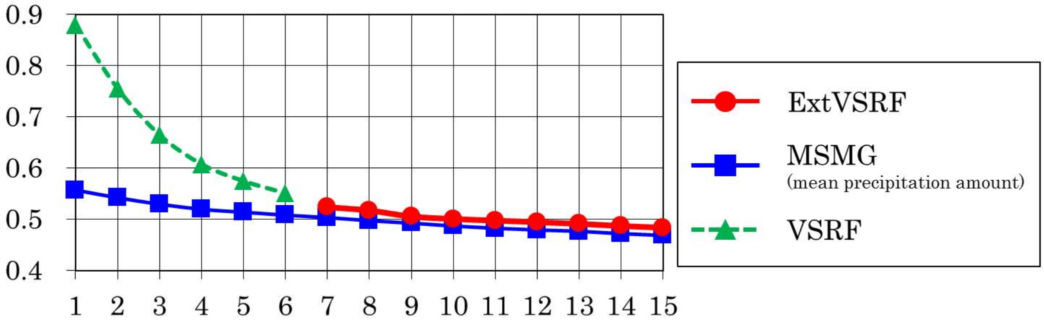

Figure 4.4.8: FSS of the Extended VSRF (ExtVSRF) for June 2017, October 2017 and January 2018 together with that of VSRF and MSM Guidance forecast for mean precipitation amount. The threshold value is 1 mm.

The configuration of the hourly analysis system, which is based on 3D-Var, is given in Table 4.5.1. Analysis involves the use of 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 covers Japan and its surrounding area at a horizontal resolution of 5 km with 721 × 577 grid points. There are 48 vertical layers defined for hybrid terrain-following coordinates (Subsection 3.5.3) with the top of the domain at 21,801 m.

The observations assimilated in the analysis are from AMeDAS (the Automated Meteorological Data Acquisition System; Japan surface station data on wind and temperature), Wind Profiler (wind), Weather Doppler radar (radial velocity), AIREP, AMDAR (wind and temperature), and AMVs from Himawari-8 (Atmospheric Motion Vectors, wind). The data cut-off time is set to 18 minutes past the hour so that products can be distributed by 30 minutes past the hour.

In order to obtain a good fit to surface observations on land, the 3D-Var in the hourly analysis adopts a short background error correlation distance and a small observation error on the surface. Thus, the surface field on land typically has large local increments. Outlined below are modifications of the 3D-Var scheme and additional post-processing performed to address this situation.

Table 4.5.1: Hourly analysis specifications

Analysis time	Every hour (on the hour)
Analysis scheme	3D-Var
Data cut-off time	18 minutes past the hour
First guess	2, 3 or 4-hour forecast by the MSM
Domain configuration	Japan and its surrounding area Lambert projection: 5 km at 60°N and 30°N, 721 × 577 Grid point (1, 1) is at the northwest corner of the domain. Grid point (489, 409) is at 140°E, 30°N.
Vertical coordinate	z-$z^{\star}$ hybrid
Vertical levels	48 levels up to 22 km
Analysis variables	Wind, temperature, surface wind and surface temperature
Observations (as of 31 December 2017)	AMeDAS, Wind Profiler, Weather Doppler radar (radial velocity), AIREP, AMDAR, and AMVs from Himawari-8
Post-processing	Surface filtering (followed by adjustment of the increment within the boundary layer)
Product distribution	Before 30 minutes past the hour

- The control variables at the bottom level are treated as uncorrelated to those at other levels in 3D-Var analysis because the large analysis increments at the surface need to be adjusted independently with a surface filter as described below.
- After 3D-Var analysis is complete, a surface filter is applied to the surface temperature and wind fields to attenuate surface increments over the sea with distance from the coastline and reduce excessive increments in sea regions near the coastline within the range of correlation from land observations. Analysis increments on the surface and in the upper air are not consistent at this point.
- After application of 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 to make the surface and upper-air increments consistent. The weight of the surface increment attenuates with height above the ground, and approaches zero around the top of the boundary layer.

4.6 Guidance for Short-range Forecasting

4.6.1 Overview

JMA provides various kinds of forecast guidance to support forecasters in their work. Objectives of guidance are to reduce systematic errors in NWP output, such as temperature and wind, and to derive quantitative values not directly calculated in NWP models, such as probability of thunderstorm and weather categories. Table 4.6.1 lists the guidance provided for short-range forecasting (up to 84 hours) at JMA.

To cope with frequent model upgrades, JMA uses methods that allow ongoing adjustment of statistical equations. These adaptive approaches, which are based on Kalman filtering and a neural network, replaced the previous non-successive multivariate regression method in 1996 and have since been applied to various guidance values.

The Kalman filtering and neural network used in the guidance system are outlined in Subsection 4.6.2 and Subsection 4.6.3, respectively, and utilization of guidance at forecasting offices is summarized in Subsection 4.6.4.

4.6.2 Guidance Based on Kalman Filtering

4.6.2.1 Kalman Filtering

As a statistical post-processing method for NWP output, JMA developed guidance using Kalman filtering (KF) on the basis of earlier work conducted by Persson (1991) and Simonsen (1991). KF evolves coefficients based on the following equations:

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

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

where y represents predictand (i.e., the target of forecasting), $\boldsymbol{c}$ represents predictors ($1\times n$ matrix), $\boldsymbol{X}$ represents coefficients ($n\times 1$ matrix) with covariance matrix $\boldsymbol{Q}$ ($n\times n$ matrix), v represents observation noise with variance $\boldsymbol{D}$, $\boldsymbol{u}$ represents system noise ($n \times 1$ matrix) with the covariance matrix $\boldsymbol{U}$ ($n \times n$ matrix), and $\boldsymbol{A}$ ($n \times n$ matrix) describes the evolution of the coefficients in time.

Eq. (4.6.1) relates to observation, and is a linear expression relating the predictand and predictors. Eq. (4.6.2) is a system exprssion denoting the time evolution of the coefficients. In guidance, the time evolution matrix $\boldsymbol{A}$ can be treated as a unit matrix:

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

The objective of KF is to determine the most likely estimation of the coefficients $\boldsymbol{X}_{\tau+1/\tau}$, whose subscript denotes an estimate at $\tau + 1$ based on observation at τ. In contrast, the single subscripts in Eq. (4.6.1) and Eq. (4.6.2) indicate the variables are stochastic variables at τ. $\boldsymbol{X}_{\tau+1/\tau}$ is determined from the previous estimate $\boldsymbol{X}_{\tau/\tau-1}$ and the forecast error:

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	FT=6, 9, . . . , 84	NN
		5km	MSM	FT=3, 6, . . . , 39/51**	
Mean precipitation amount over 3 hours	Grids	20km	GSM	FT=6, 9, . . . , 84	KF & FBC
		5km	MSM	FT=3, 6, . . . , 39/51	
		5km	MEPS	FT=3, 6, . . . , 39	
Maximum precipitation amount over 1, 3 hours	Grids	20km	GSM	FT=6, 9, . . . , 84	NN
		5km	MSM	FT=3, 6, . . . , 39/51	
		5km	MEPS	FT=3, 6, . . . , 39	
Maximum precipitation amount over 24, 48 and 72 hours (48, 72 hours:GSM only)	Grids	20km	GSM	FT=27, 30, . . . , 84	MLR
		5km	MSM	FT=24, 27, . . . , 39/51	
		5km	MEPS	FT=24, 27, . . . , 39	
Mean precipitation amount over 1 hour	Grids	5km	LFM	FT=1, 2, . . . , 10	LAF & FBC
Maximum precipitation amount over 1 hour	Grids	5km	LFM	FT=1, 2, . . . , 10	SLR & PPM
Probability of precipitation over 6 hours > 1mm/6h	Grids	20km	GSM	FT=9, 15, . . . , 81	KF
		5km	MSM	FT=6, 12, . . . , 39/51	
Maximum temperature in the daytime (09-18 local time)	Points	AMeDAS	GSM	Today to 3 days after	KF
			MSM	Today and tomorrow	
			MEPS		
Minimum temperature in the morning (00-09 local time)	Points	AMeDAS	GSM	Today to 3 days after	KF
			MSM	Today and tomorrow	
			MEPS		
Time-series temperature	Points	AMeDAS	GSM	FT=3, 4, . . . , 84	KF
			MSM	FT=1, 2, . . . , 39/51	
			LFM	FT=1, 2, . . . , 10	
			MEPS	FT=1, 2, . . . , 39	
Temperature	Grids	5km	GSM	FT=3, 4, . . . , 84	KF
		5km	MSM	FT=1, 2, . . . , 39/51	
		2km	LFM	FT=1, 2, . . . , 10	
		5km	MEPS	FT=1, 2, . . . , 39	
Time-series humidity	Points	SYNOP	GSM	FT=3, 4, . . . , 84	KF
			MSM	FT=1, 2, . . . , 39/51	
Wind speed and direction	Points	AMeDAS	GSM	FT=3, 6, . . . , 84	KF & FBC
			MSM	FT=1, 2, . . . , 39/51	
			MEPS	FT=1, 2, . . . , 39	
Maximum wind speed and direction over 3hours	Points	AMeDAS	GSM	FT=3, 6, . . . , 84	KF & FBC
			MSM	FT=3, 6, . . . , 39/51	
			MEPS	FT=3, 6, . . . , 39	
Daily minimum humidity	Points	SYNOP	GSM	Today to 3 days after	NN
			MSM	Today and tomorrow	
Snowfall amount over 6,12 hours	Points	AMeDAS	GSM	FT=9, 12, . . . , 84	NN & FBC
			MSM	FT=6, 9, . . . , 39/51	
Snowfall amount over 24 hours	Points	AMeDAS	GSM	FT=27, 30, . . . , 84	NN & FBC
			MSM	FT=24, 27, . . ., 39/51	
Snowfall amount over 3,6 hours	Grids	2.5km	LFM	FT=1, 2, . . . , 10	DM
Snowfall amount over 3,6,12 hours	Grids	5km	GSM	FT=9, 12, . . . , 84	DM
			MSM	FT=6, 9, . . . , 39/51	
			MEPS	FT=6, 9, . . . , 39	
Snowfall amount over 24 hours	Grids	5km	GSM	FT=27, 30, . . . , 84	DM
			MSM	FT=24, 27,. . . , 39/51	
			MEPS	FT=24, 27,. . . , 39	
Probability of thunderstorm over 3 hours	Grids	20km	GSM	FT=6, 9, . . . , 84	LR & LAF
			MSM	FT=6, 9, . . . , 39/51	
			MEPS	FT=6, 9, . . . , 39	
Visibility	Grids	20km	GSM	FT=3, 6, . . . , 84	DM
		5km	MSM	FT=3, 6, . . . , 39/51	

* NN: neural network, KF: Kalman filter, FBC: frequency bias correction, MLR: multiple linear regression, DM: diagnostic method, LR: logistic regression, LAF: lagged averaged forecast method, SLR: simple linear regression, PPM: perfect prognosis method

** 39 hours (03, 06, 09, 15, 18, 21 UTC initials), 51 hours (00, 12 UTC initials)

$$\boldsymbol{X}_{\tau+1/\tau} = \boldsymbol{X}_{\tau/\tau} \quad (4.6.4)$$
$$= \boldsymbol{X}_{\tau/\tau-1} + \boldsymbol{K}_\tau(y_\tau - \boldsymbol{c}_\tau \boldsymbol{X}_{\tau/\tau-1}) \quad (4.6.5)$$

where $\boldsymbol{K}_\tau$ is the Kalman gain can be written as follows:

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

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

$$\boldsymbol{Q}_{\tau+1/\tau} = \boldsymbol{Q}_{\tau/\tau} + \boldsymbol{U}_\tau \quad (4.6.7)$$
$$= \boldsymbol{Q}_{\tau/\tau-1} - \boldsymbol{K}_\tau \boldsymbol{c}_\tau \boldsymbol{Q}_{\tau/\tau-1} + \boldsymbol{U}_\tau \quad (4.6.8)$$

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

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

$$y_{\tau+1/\tau} = \boldsymbol{c}_{\tau+1}\boldsymbol{X}_{\tau+1/\tau} \quad (4.6.9)$$

For some forecast parameters (such as temperature), the predictand y is defined as the difference between NWP output and observations, while for others (such as precipitation amount), 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 for control of the adaptation rate.

4.6.2.2 Frequency Bias Correction

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

The basic concept involves multiplying the estimation of KF, y, by a correction factor $F(y)$ to obtain the final output y^b:

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

To determine $F(y)$, certain thresholds t^i are set to span the given observation data. The corresponding thresholds f^i for the forecast dataset are then calculated so that the number of observation data smaller than t^i approximates to that of forecast data smaller than f^i. Finally, the correction factors are computed as follows:

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

$F(y)$ for $f^i < y < f^{i+1}$ is linearly interpolated between $F(f^i)$ 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 used to determine the adaptation rate.

4.6.2.3 Example of Guidance (GSM) Based on Kalman Filtering (3-hour Precipitation Amount)

In this guidance, the predictand is the observed three-hour cumulative precipitation amount averaged within a 20×20km square. The following parameters derived from NWP output 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 (between 850 and 500hPa)
4. OGES: Orographic precipitation index
5. PCWV: Precipitable water content × Wind speed at 850hPa × Vertical p-velocity at 850hPa
6. QWX: Σ (Specific humidity × Vertical p-velocity × Relative humidity) between 1000 and 300hPa
7. EHQ: Σ (Excess from reference humidity × Specific humidity × Depth of wet layer) between 1000 and 300hPa
8. DXQV: Precipitation index in winter synoptic pattern
9. FRR3: Mean precipitation amount over three hours based on the GSM

In the sample precipitation forecasts shown in Figure 4.6.1, the NWP model (GSM) predicted very little or no precipitation in area M, while observation shows light precipitation. The guidance predicted light precipitation in this area, representing a better results. Examination of the coefficient values shows an orographic effect relating to the OGES enhanced precipitation amount in this area.

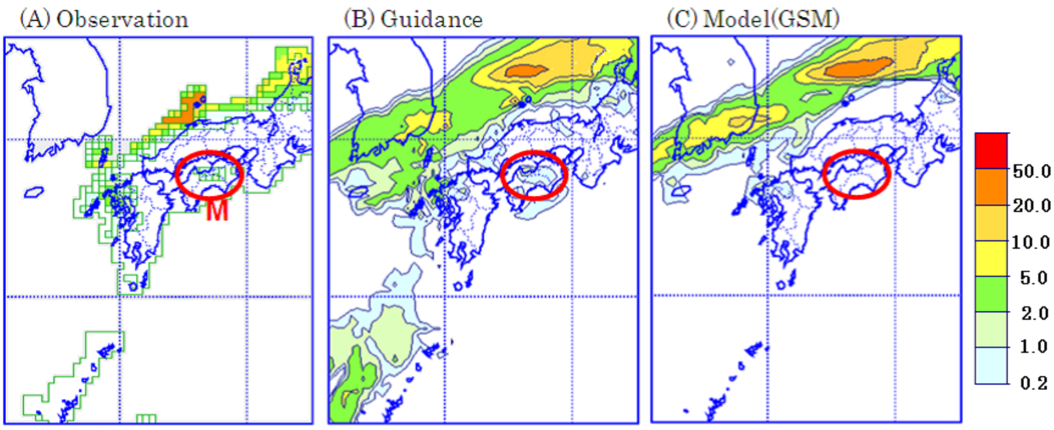

Figure 4.6.1: Mean precipitation amount over three hours: (A) observation, (B) guidance forecast, (C) NWP model (GSM) forecast

4.6.3 Guidance Based on a Neural Network

4.6.3.1 Neural Network

The neural network (NN) approach involves machine learning to support analysis of non-linear relationships between predictors and predictands (Yanagino and Takada 1995). In this method, multiple layers of neurons are linked to construct a hierarchical neural network as shown in Figure 4.6.2. The first layer is called the input layer and the last layer is called the output layer. Those between them are called the hidden layers.

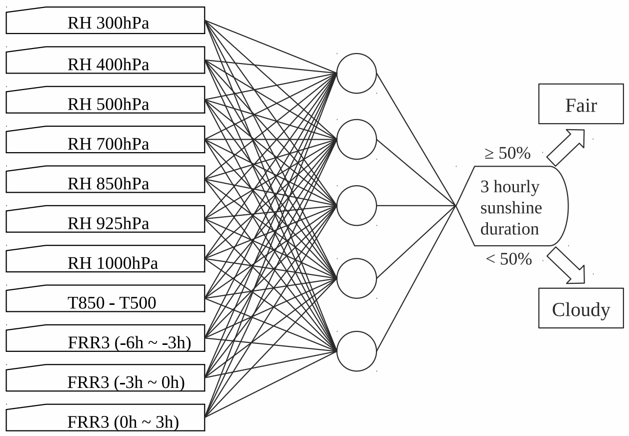

Figure 4.6.2: Neural network for fair/cloudy determination. RH: relative humidity, FRR3: precipitation over 3 hours

A signal put into the input layer is propagated to the next layer via inter-neuron connections. The signal is subjected to simple processing 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 4.6.3. 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 is called an activation function, and a sigmoid function as shown in Figure 4.6.4 is usually used for this purpose.

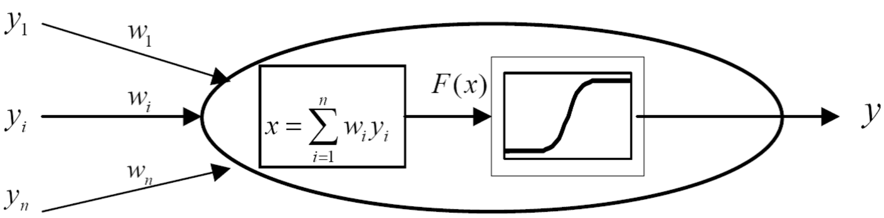

Figure 4.6.3: Schematic representation of a neuron

NN weights are iteratively adjusted using numerous sets of input/output data. The most popular adjustment method involves the back-propagation of error algorithm described as follows:

1. First, weights are initialized with randomized values.
2. The network calculates output values using a given set of input values.
3. Weights are adjusted to make the NN output close to the supervisor data (correct values of the output variable).
4. The processes of 2 and 3 are iterated until the error measure falls below a specified value or the number of iterations reaches a specified maximum.

Even in NN, the output has a tendency toward lower-than-actual frequency for forecasting of relatively rare events such as heavy snowfall. To compensate for this unfavorable characteristic in snowfall amount guidance,

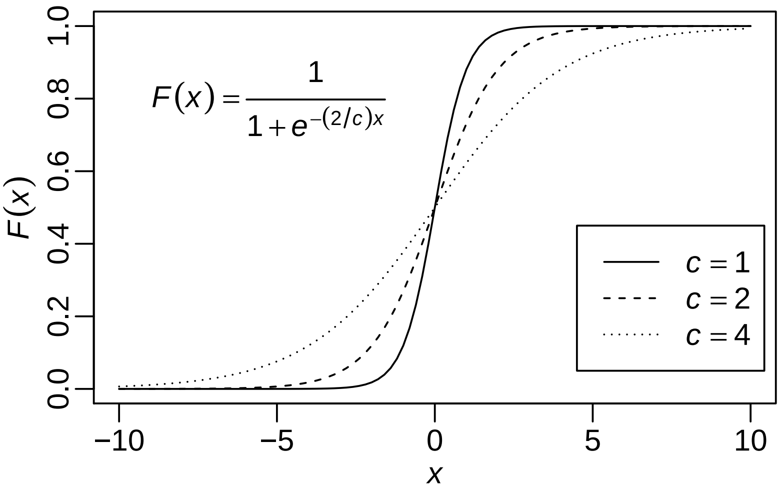

Figure 4.6.4: Examples of the sigmoid function

the frequency bias correction scheme is applied to the NN output using the same method for KF output (see Subsection 4.6.2.2).

4.6.3.2 Example of Guidance Based on a Neural Network (Categorized Weather)

In the forecast guidance system, a neural network model is constructed at each grid or observation point from sets of NWP output and observed weather elements. Categorized weather is one of the forecast guidance parameters to which the NN is applied. Figure 4.6.5 shows an example of output categorized weather guidance, in which an NN model is used to derive sunshine duration, which is in turn used to determine non-precipitation weather categories (fair or cloudy). The NN is constructed for each AMeDAS station, and output values (three-hourly sunshine durations) are interpolated to grid points. Precipitation weather categories (rain, sleet, snow) are determined from precipitation amount guidance and precipitation type guidance. The constitution of the sunshine duration NN model is shown in Figure 4.6.2, and its characteristics are summarized as follows:

1. The model incorporates a three-layer feed-forward neural network.
2. A linear activation function is used in the output layer and sigmoid activation functions are used in the hidden layer.
3. In the learning processes, NWP output is used as input data and sunshine durations observed at each AMeDAS point are used as supervisor data.
4. The weights of the network are modified when the observation data are obtained.

4.6.4 Utilization of Guidance at Forecasting Offices

Forecast guidance products are disseminated to observatories and used for drafting weather forecasts in editing software. Figure 4.6.6 shows an example of the data entry screen. Forecasters revise elements (time-series data of weather categorization, PoP, temperature etc.) on the display consideration of current weather conditions and empirical knowledge. The processed data are then composed to create a forecast bulletin and provided to users.

An algorithm incorporating the steps shown below is used to draft weather forecast bulletins automatically.

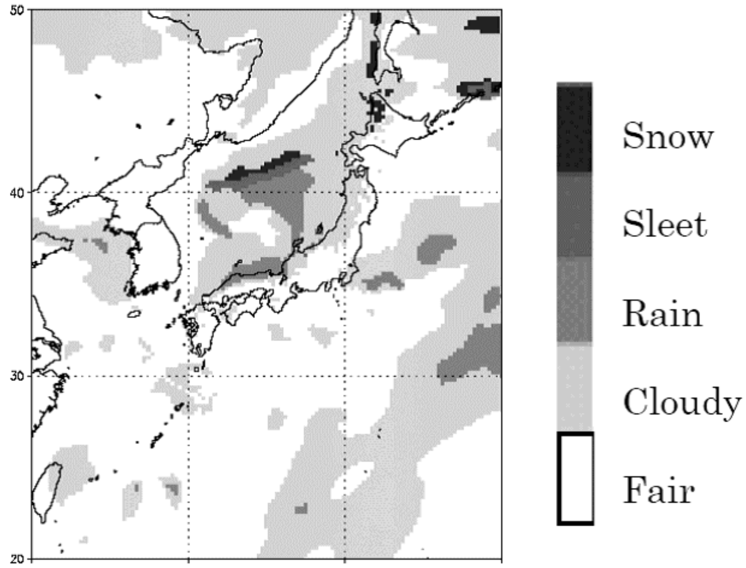

Figure 4.6.5: Sample output of categorized weather guidance

Table 4.6.2: Sample of the algorithm for weather forecast bulletin drafting

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

1. Three-hourly dominant weather categories are derived from the majority of weather categorization on grids in the forecast area.
2. The weather forecast bulletin for the day is derived from the sequence of three-hourly dominant weather categories over the forecast area. Examples of the algorithm are shown in Table 4.6.2.

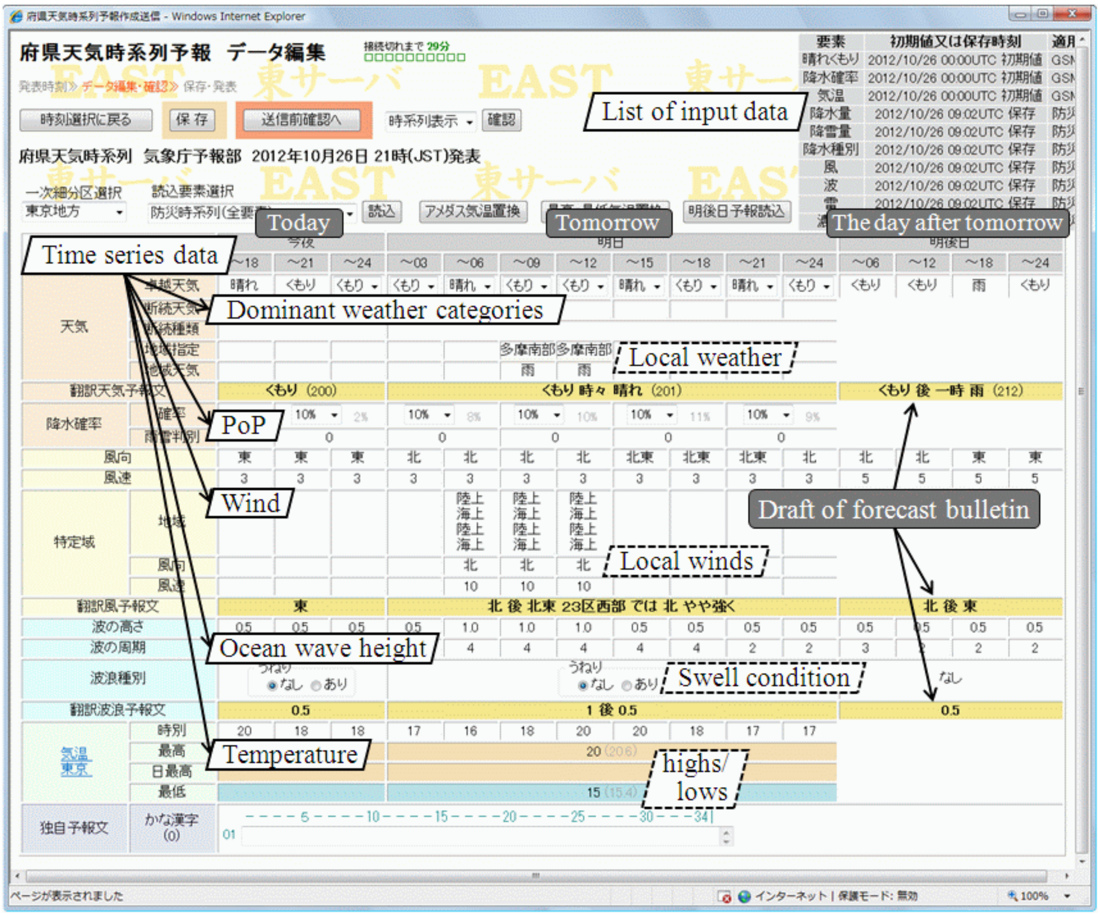

Figure 4.6.6: Sample data entry screen in forecast editing software

4.7 Application Products for Aviation Services

4.7.1 Aerodrome Forecast Guidance

Aerodrome forecast guidance (TAF guidance) is derived from the output of the MSM eight times a day and MEPS four times a day, providing hourly predictions up to 39 hours ahead (51 hours ahead at 00 and 12UTC initials on MSM). The predicted values in this guidance are listed in Table 4.7.1.

Table 4.7.1: Parameters of TAF guidance. (for 90 airports in Japan)

Parameters	TAF guidance
Visibility	Minimum and mean visibility during an hour Probability of minimum visibility < 5km and 1.6km during 3 hours
Cloud	Cloud amount and height of 3 layers at minimum ceiling during an hour Probability of minimum ceiling < 1000ft and 600ft during 3 hours
Weather	Categorized weather every hour
Temperature	Maximum temperature in the daytime, minimum temperature 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
Thunderstorm	Probability of thunder during 3 hours
Snow	Snowfall amount during 3 hours

4.7.1.1 Visibility

Minimum visibility and probability in minimum visibility guidance (VIS) are based on statistical interpretation of NWP output. VIS is calculated using linear equations whose coefficients are adapted via Kalman filtering (see Subsection 4.6.2.1) with the predictors and METAR reports. VIS consists of three linear equations classified by weather type (rain, snow, no precipitation). The following predictors from the output of the 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 over an hour (mm).
- Snow: $RR^{1/2}$, $(1 - RH)^{1/2}$, $VV \times T$, where VV is surface wind speed (m/s, only < 15), T is surface temperature (°C, $-10 < T < 0$)

To predict VIS, one out of the three equations is selected based on the weather category predicted by weather guidance (described later), and then frequency bias correction (see Subsection 4.6.2.2) is applied to outputs from the Kalman filter method.

4.7.1.2 Cloud

TAF cloud guidance involves statistical interpretation of NWP output. First, cloud amounts in each of 38 layers (0, 100, . . . , 1000, 1500, . . . , 5000, 6000, . . . , 10000, 12000, . . . , 30000 ft) are calculated using an NN (see Subsection 4.6.3), and the lowest three cloud layers are then extracted as with METAR reports. The input data (predictors) are relative humidity, the lapse rate between the surface and 925hPa, and the precipitation amount. Frequency bias correction (see Subsection 4.6.2.2) is applied to outputs from NN.

Guidance on minimum ceiling probability is based on statistical interpretation of NWP output, predicting the probability of the minimum ceiling during a three-hour period being below 1000ft and below 600ft. The predictors are precipitation amount over three hours (total precipitation and snow precipitation), the lapse rate between the surface and 925hPa, relative humidity, the E-W component of wind speed, the S-N component of wind speed, cloud amount, cloud ice content and cloud water content. Logistic regression (Agresti 2002) was introduced to predict minimum ceiling probability in December 2010.

4.7.1.3 Weather

Weather guidance predicts weather conditions based on a diagnostic method for the interpretation of MSM output into categories (fine, cloudy, rainy, snowy and precipitation intensity) (JMA 1997). To determine the preciptation type (rain or snow), hourly temperature guidance is used instead of MSM temperature. To determine precipitation type (rain or snow), the hourly temperature guidance is used instead of MSM temperature, which improves the accuracy of precipitation type prediction.

4.7.1.4 Wind and Temperature

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

4.7.1.5 Gust Winds

Wind gust guidance predicts the probability of wind gust during three-hour periods as well as the speed and direction of the hourly maximum peak gust. Wind gust guidance uses Kalman filtering, frequency bias correction and logistic regression to predict each variable. Predictors are gust speed calculated by the MSM, surface wind speed, maximum wind speed in the boundary layer, vertical wind shear between the surface and the boundary layer, SSI, and vertical p-velocity at 925hPa. TAF gust guidance was introduced in December 2012.

4.7.1.6 Thunderstorms

Probability of thunderstorm (PoT) guidance predicts the probability of thunderstorm during three-hour periods around airport. PoT is predicted using logistic regression. Six predictors are selected from twelve potential predictors, in which three predictors, SSI, CAPE, and precipitation amounts over the three-hour period, are always selected. PoT guidance was introduced in May 2007.

4.7.1.7 Snow

Snowfall amounts at airports are calculated from the grid-type snowfall amount guidance shown in Table 4.6.1. Snowfall amount guidance for TAF was introduced in October 2015.

4.7.2 Products for Domestic Area Forecast

4.7.2.1 Gridded Values of Significant Weather

Guidance variables for domestic area forecasts for flights, including turbulence, icing, CB clouds, tropopause height and vertical wind shear, are derived from MSM output. These values, together with common meteorological variables such as temperature, wind and humidity are used to produce domestic area forecasts and SIGMET information at JMA. This purely aviation-oriented dataset is called SIGGV (Gridded Values of Significant weather), with the specifications 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, and is an indicator of various kinds of turbulence including CAT, mountain waves and cloud-related turbulence. CB cloud amount and top height calculation are based on the parcel method. The icing parameter is an indicator of aircraft icing derived from an empirical equation incorporating temperature and dew-point temperature. As illustrated in Figure 4.7.1, SIGGV, which is distributed as binary data, can be visualized on terminals at aviation forecast offices. It is also used for the production of the fax charts detailed bellow.

Table 4.7.2: SIGGV specifications

Base model	MSM
Forecast time	T=0-39, 1 hourly
Grid coordinate	Polar Stereographic, 111×93
Parameters	U, V, T, RH, Psea, Rain, CB cloud amount, CB top height, Tropopause height, Icing, VWS, TBindex

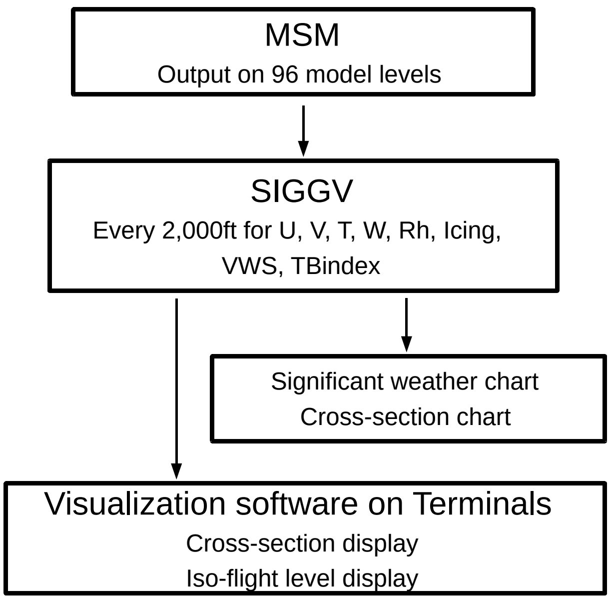

Figure 4.7.1: Data flow of products for domestic area forecast

4.7.2.2 Domestic Significant Weather Chart

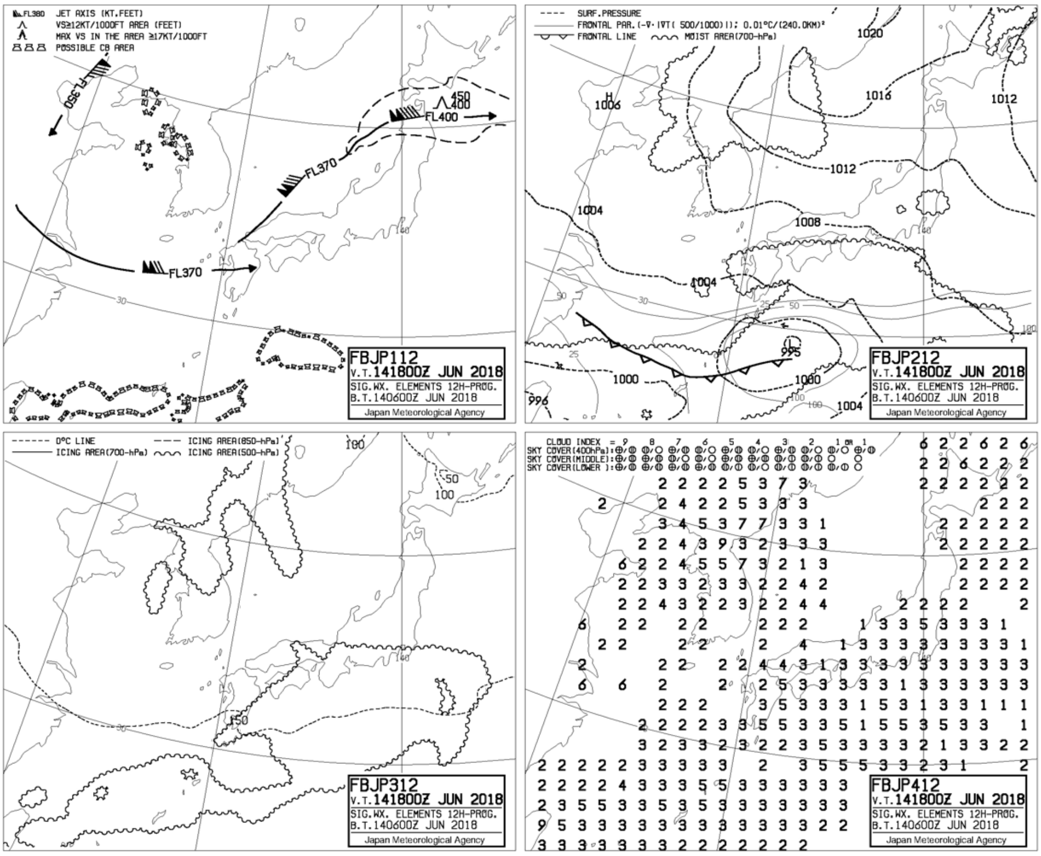

Figure 4.7.2: Sample domestic significant weather chart

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 low, middle and upper cloud amounts.

4.7.2.3 Domestic Cross-section Chart

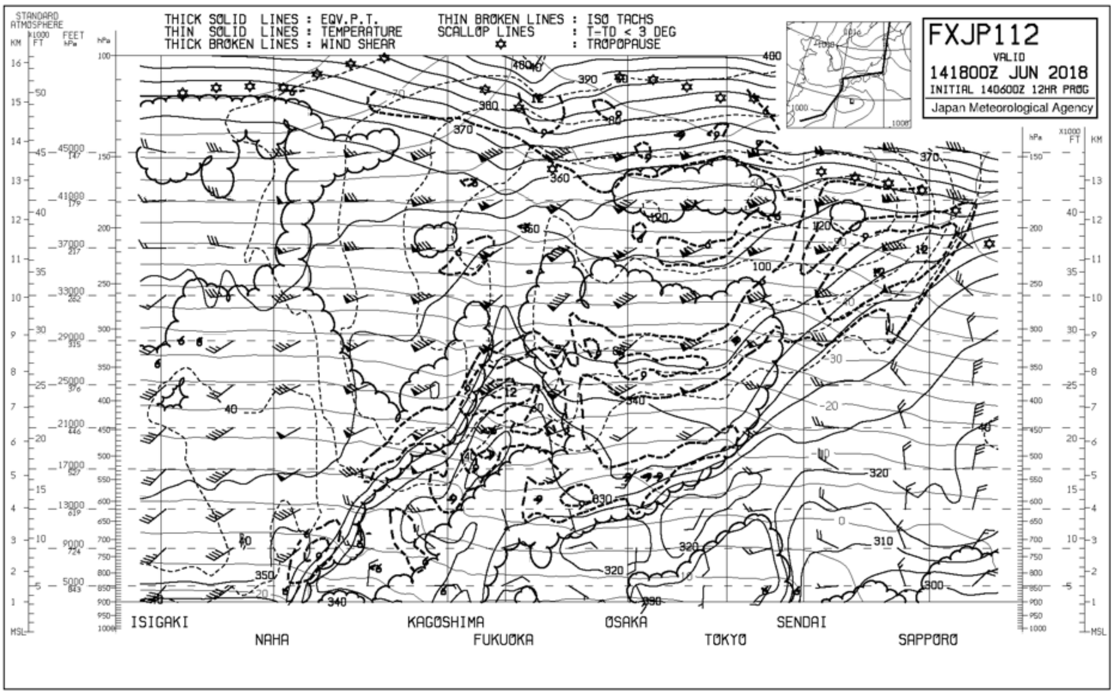

Figure 4.7.3: Sample domestic cross-section chart. Only the lower part of the fax, corresponding to the 12-hour forecast, is shown.

This chart shows 6- and 12-hour forecast fields along the major domestic route, which illustrates 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 code, a format compatible with products from the World Area Forecast Centers (WAFC). In addition to the parameters included in WAFC products, TBindex, Icing, VWS and Cb cloud top height are derived using the method used for domestic SIGGV (see Subsection 4.7.2).

JMA produces 13 significant weather (SIGWX) charts and 18 wind and temperature (WINTEM) charts based on WAFS significant weather data provided by World Area Forecast Centers (WAFCs).

4.8 Ensemble Prediction System Products

4.8.1 EPS Products for One-week Forecasting

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

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

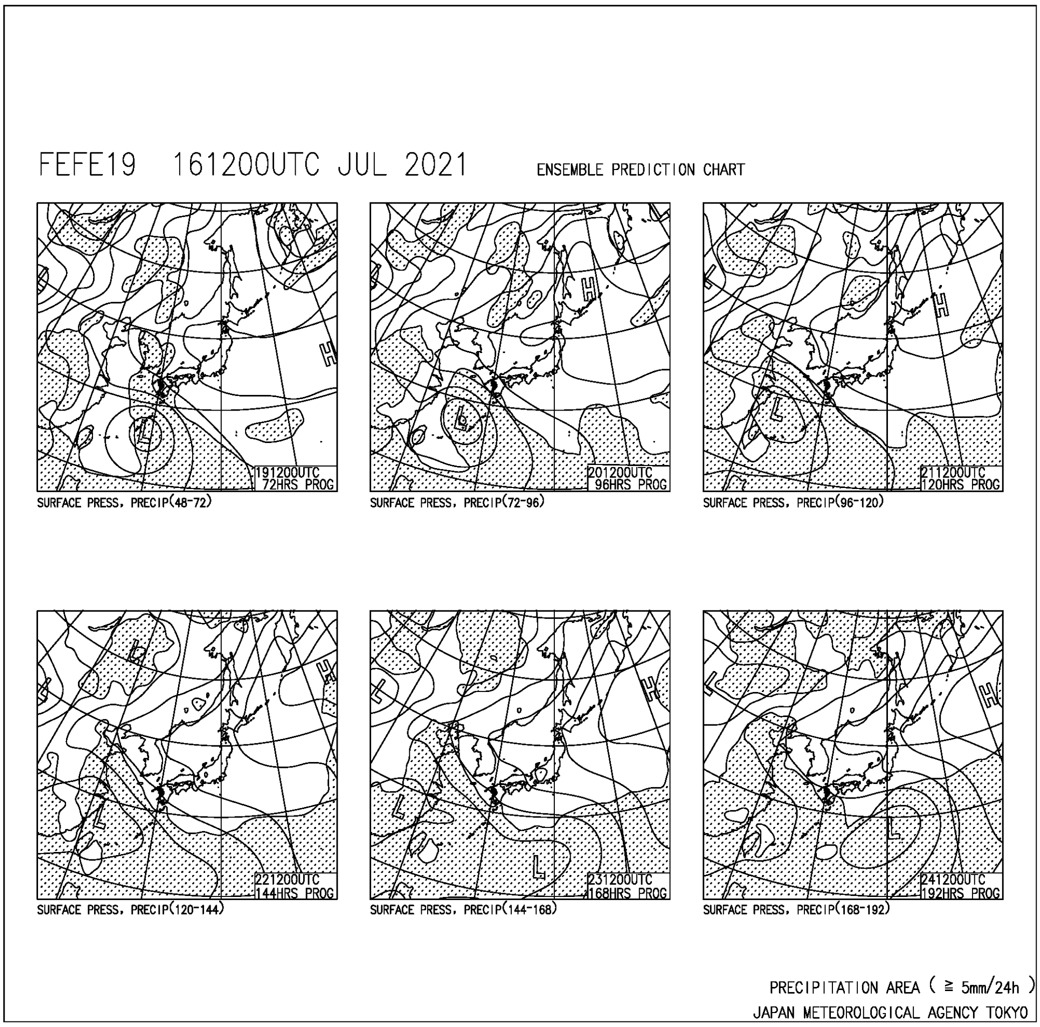

Figure 4.8.1: Ensemble prediction chart showing average mean sea level pressure and precipitation from day 2 to day 7. This schematic representation is produced by averaging with all members.

4.8.2 EPSs Products for One-month and Seasonal Forecasting

4.8.2.1 Standard Products

The following operational forecast and hindcast products from the Global and Seasonal EPSs are provided via the WMC (World Meteorological Center) Tokyo web-page on the TCC (Tokyo Climate Center) website.

- Ensemble mean maps
- Ensemble spread maps (for operational forecasts only)
- Verification maps and scores

4.8.2.2 Gridded Datasets

The following operational forecast and hindcast gridded datasets of the Global and Seasonal EPSs are provided to registered users via the WMC Tokyo web-page.

- Global EPS
  - Daily mean ensemble statistics (for operational forecasts only)
  - Daily mean forecast of individual ensemble member
- Seasonal EPS
  - Monthly and 3-monthly mean ensemble statistics (for operational forecasts only)
  - Monthly mean forecast of individual ensemble member

4.8.2.3 El Ninõ Outlook

Outlooks of sea surface temperature deviations in the Pacific and the Indian Ocean produced from the Seasonal EPS are provided via the El Ninõ Monitoring and Outlook web-page on the TCC website (Figure 4.8.2).

4.8.2.4 Probabilistic Forecast Products for Seasonal Forecasts

To support NMHSs (National Meteorological and Hydrological Services) in their production of seasonal forecasts, probabilistic forecast products with three-categories (e.g., above-, near-, and below-normal) are produced from the Seasonal EPS and provided via the WMC Tokyo web-page (Figure 4.8.3).

4.8.2.5 Forecast Products in Support of Early Warnings for Extreme Weather Events

To support NMHSs in their production of early warnings for extreme weather events, Extreme Forecast Index (EFI) warning maps and meteograms for major cities are produced from the Global EPS and provided to registered users via the WMC Tokyo web-page (Figure 4.8.4 and Figure 4.8.5). The EFI is a measure of EPS forecast deviation from climatological probability distribution (Lalaurette 2003). JMA uses a revised version of the EFI to add weight for the tails of probability distribution (Zsótér 2006).

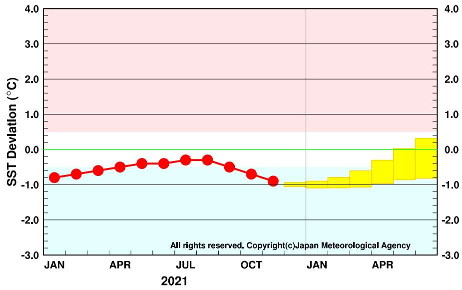

Figure 4.8.2: Five-month running mean of SST deviation for NINO.3. Red dots indicate analysis values, and yellow boxes indicate values predicted by the Seasonal EPS. Each box denotes the range in which the value is expected to be included with a probability of 70% or more.

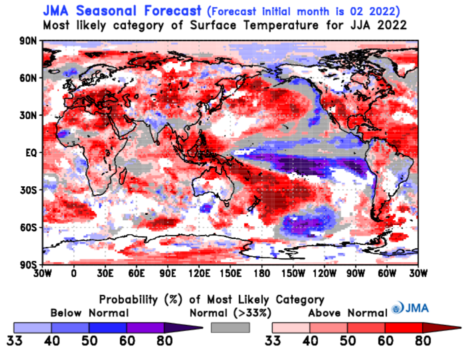

Figure 4.8.3: Probabilistic forecast map of surface air temperature for seasonal forecasting. Probabilities are estimated using numerical guidance with application of the Model Output Statistics (MOS) technique based on hindcast results.

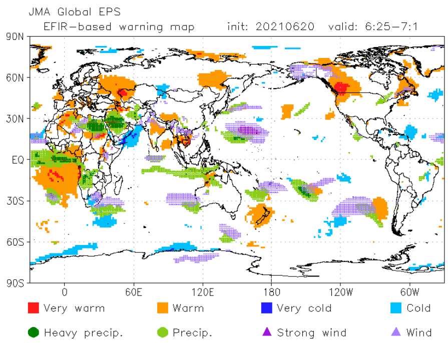

Figure 4.8.4: EFI warning map for temperature, precipitation and wind. Pale symbols indicate grids where the EFI is above 0.5, and dark symbols indicate grids where the EFI is above 0.8.

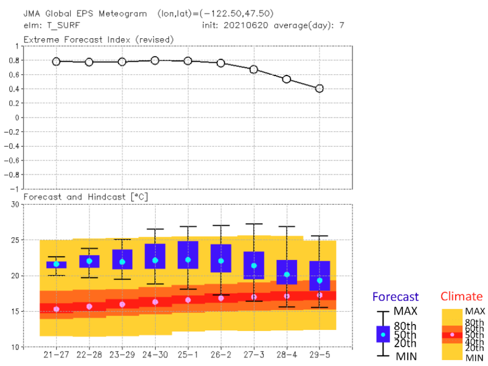

Figure 4.8.5: Meteogram of the Global EPS for temperature. The upper graph is an EFI timeseries representation, and the lower one is a timeseries representation of forecast ranges with cold color box-and-whisker plots and climatological values with warm shading.

4.9 Atmospheric Angular Momentum Functions

Atmospheric Angular Momentum (AAM) functions were proposed to support evaluation of the earth's rotational variations based on precise estimation of variations in atmospheric angular momentum. For monitoring of atmospheric effects associated with the earth's rotation, JMA sends AAM products to NCEP (a sub-bureau of the International Earth Rotation Service (IERS)) via GTS. The AAM functions are expressed as follows (Barnes *et al.* 1983):

$$\chi_1 = -1.00\left[\frac{r^2}{(C-A)g}\right]\int P_S \sin\phi\cos\phi\cos\lambda\, dS - 1.43\left[\frac{r}{\Omega(C-A)g}\right]\iint(u\sin\phi\cos\lambda - v\sin\lambda)\, dPdS, \quad (4.9.1)$$

$$\chi_2 = -1.00\left[\frac{r^2}{(C-A)g}\right]\int P_S \sin\phi\cos\phi\sin\lambda\, dS - 1.43\left[\frac{r}{\Omega(C-A)g}\right]\iint(u\sin\phi\sin\lambda + v\cos\lambda)\, dPdS, \quad (4.9.2)$$

$$\chi_3 = -0.70\left[\frac{r^2}{Cg}\right]\int P_S\cos^2\phi\, dS - 1.00\left[\frac{r}{\Omega Cg}\right]\iint u\cos\phi\, dPdS. \quad (4.9.3)$$

In Eq. (4.9.1) to Eq. (4.9.3), P is pressure, $\int dS$ is the surface integral over the globe, (ϕ, λ) are latitude and longitude, u and v are the eastward and northward components of wind velocity, P_S is 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.

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

Variations in AAM functions calculated from JMA global analysis data have been reported to correspond closely to variations in the earth's rotation. Figure 4.9.1 shows seasonal variations in observed earth rotation and atmospheric relative angular momentum (the wind term of χ_3) calculated by the National Astronomical Observatory of Japan (Naito and Kikuchi 1992).

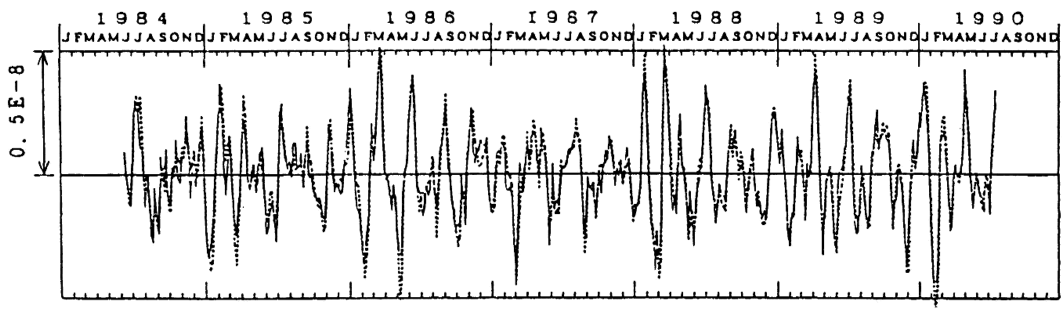

Figure 4.9.1: Seasonal variations in observed earth rotation (solid line) and calculated atmospheric angular momentum (broken line). Both sets of data are 150 days' high-pass filtered.

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

AAM functions calculated for a test period between 21 June and 30 September 1992 are shown in Figure 4.9.2, where days 1 - 102 correspond to this period. Each term of the AAM functions is multiplied by 10^7.

The broken lines show 6-hourly values of the functions (i.e., the difference from the period mean values), and the solid lines show band-pass filtered values for periods of 5-10 days. Oscillation with a 5-10 day period is notable in each term of each component, implying a corresponding oscillation with a similar period in the global-scale atmosphere.

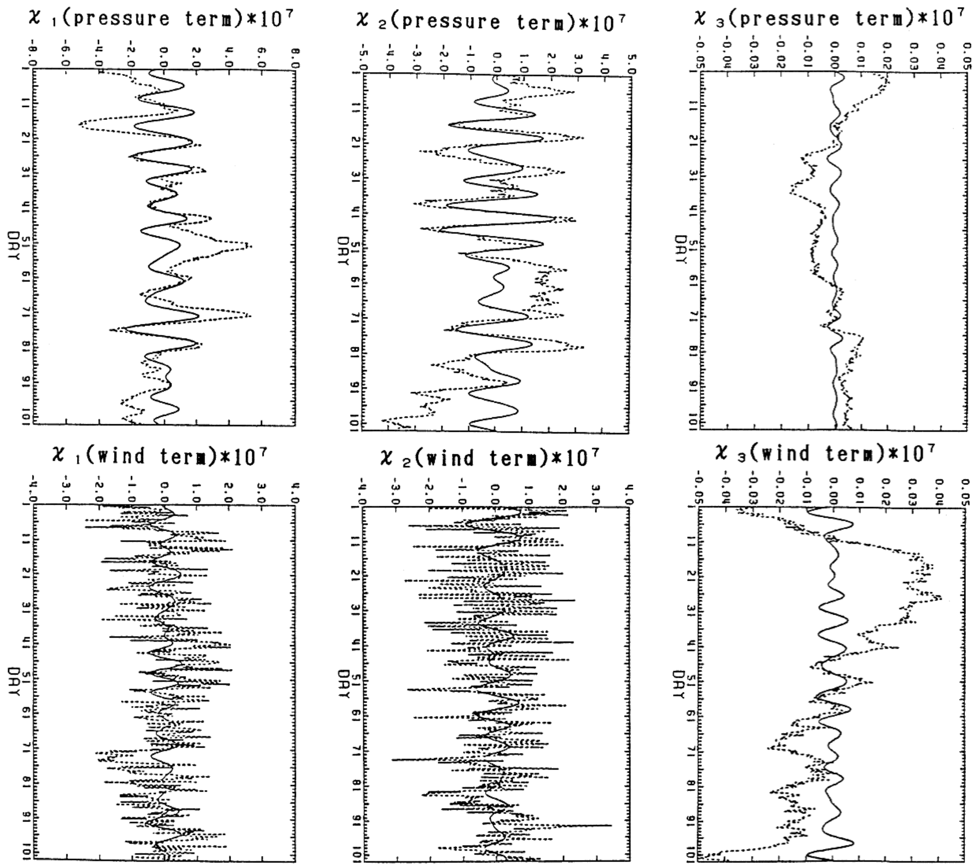

Figure 4.9.2: Pressure terms (top) and wind terms (bottom) of AAM functions. The left panels are the χ_1 component, the center ones are χ_2 and the right ones are χ_3. Days 1 - 102 correspond to 21 June - 30 September 1992. The broken lines show 6-hourly values of the functions, and the solid lines show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