MODEL CHANGES OF OPERATIONAL NUMERICAL WEATHER PREDICTION AT JAPAN METEOROLOGICAL AGENCY

By Hiroshi Itoh

1. INTRODUCTION

A computer system of JMA-NAPS* was replaced by a present system HITAC-680H and HITAC S-810 last year. The present computer system is 10 times faster than the former one HITAC M-200H. This high ability of the present computer system makes it possible to describe more fine structures of atmospheric disturbances. The present objective analysis models are using finer grid systems than former ones. At the same time the prediction models were improved so as to increase the accuracy of numerical calculation and to simulate more exactly the behaviors of the small scale disturbances.

Outlines of main changes in present objective analysis models and numerical prediction models of JMA are briefly described in the following sections.

* NAPS: Numerical Analysis and Prediction System

2. OBJECTIVE ANALYSIS

The following three improvements are made in the present models (Table 1).

(1) The first one is to increase an ability of horizontal resolution by using more fine grid system. The grid size in the present global analysis model is about 180 km, whereas that in the former one is about 270 km. This grid size is the same as the transformed grid size in the global prediction model as described later. The grid size in Asia analysis and in Japan analysis became about half comparing with former ones. The

present Asia analysis and Japan analysis could describe the small scale disturbances more precisely than former ones. However, the grid sizes used in Asia analysis and Japan analysis are not the same as those used in the corresponding prediction models. It is because the grid size used in an analysis model is dependent on the density of observation stations.

(2) The second one is to adopt an advanced method of interpolation technique. The three dimensional optimum interpolation is used in the present models, whereas the two dimensional optimum interpolation is used in the former one. In the former models distributions of meteorological elements on a pressure level are analyzed by using data just on the same pressure level. On the other hand, in the present model those are analyzed by using data not only on the same level but on the adjacent levels. We can expect that the three dimensional structure of disturbances are expressed more reasonably in the present model.

(3) The third one is to change the time interval of performing operational analysis and prediction from 12 hourly cycle to 6 hourly cycle. Accordingly, data at 06Z and 18Z which were not used in the former analysis are used in the present analysis. Above-mentioned improvements are summerized in Table 1.

Figure 1 shows horizontal domains of AANL and JANL. The domain of AANL is covered with 93x81 grid points and the grid point of (58, 46) is put on 31°N and 140°E. The domain of JANL is covered with 69x69 grid points and the grid point of (45, 46) is put on 31°N and 140°E.

3. NUMERICAL WEATHER PREDICTION MODEL

JMA has the following 4 prediction models. They are (a) the global spectral model (GSM) for an extended forecast, (b) Asia spectral model (ASM) and (c) Japan spectral model (JSM) for a daily forecast and (d) Typhoon model (TYM) for typhoon movement.

(a) Global spectral model (GSM)

The forecast domain of the former model for an extended forecast is on the northern hemi-sphere and has an artificial wall boundary along the equator. Accordingly, the predicted patterns are not correct in low latitudes, especially, in case that cross equatorial currents are predominant. Effects of uncorrect forecasts may intrude into middle latitudes when forecast periods become longer. In order to extend forecast periods further we have to remove the wall boundary along the equator and to expand a forecast domain all over the globe. Besides, GSM gives TYM the lateral boundary values. Since typhoon track will have to be predicted frequently on the low latitude area, GSM is better than HSM from this standpoint.

Number of sigma-levels is changed from 12 to 16. They are increased in the upper troposphere and stratosphere (Figure 2). The reason is as follows. As shown in Figure 2, number of forecast levels (sigma-coordinate) of the former model (HSM) is smaller than that of analysis levels (p-coordinate) in the above-mentioned layers. Therefore, some informations involved in the analyzed fields may be lost in the process of transformation from analysis level to forecast level. On the other hands, first guess values of objective analysis have to be prepared by interpolation or extrapolation techniques using 6-hour forecasts on sigma-levels. In order to increase the accuracy of transformation from p-coordinate to sigma-coordinate and vice versa number of forecast levels is increased in the present model.

As shown in Table 2, maximum wave number in the east-west direction is 63 in the present model, whereas it was 42 in the former one. A size of transformed grid is about 180 km in the present model and is about 270 km in the former one, on which non-linear terms and physical quantities, for example, rainfall amounts are estimated. Improvement of horizontal resolution may bring increases of forecast accuracy.

In addition, parameterization schemes for cumulus convection, vertical fluxes of momentum, sensible heat, etc., and schemes for radiation are changed into more precise ones which were used in the former VFM.

Effects of mountain drags which come from downwards momentum flux due to gravitational mountain waves are introduced in the present global model. According to the opinion of some member at JMA introduction of this effects seem to give desirable influences on prognostic results.

Figure 3 and Figure 4 show forecasts of surface pressure and rainfall amounts from the initial time on Feb. 8th 12 GMT of this year. Development or decay of cyclones over north pacific are simulated better by GSM than by HSM, especially, development of weak cyclone far off Japan Islands is well predicted in 48-hour and 72-hour forecasts due to GSM. Figure 5a and Figure 5b show 8-day forecast of surface pressure over northern hemisphere due to GSM and HSM respectively. Anticyclone over Siberia, cyclone near Aleutian Islands and anticyclone over North America etc. are simulated more exactly by GSM than by HSM. Figure 6 shows skill scores of daily forecasts during 8 days due to GSM and HSM. These pictures show that forecast results of the present model are fairly improved comparing with those of the former model.

(b) Asia spectral model (ASM)

Since the former FLM adopted the grid system of 127 km interval, disturbances were not sufficiently simulated for small scale phenomena less than 1000 km. On the other hand, the former VFM with 63.5 km grid size fairly well simulated the variations of the small scale phenomena. Therefore, the present model has aimed to use nearly equal grid size with the one of the former VFM.

A big difference between the present and former regional models is that the present one uses the spectral method for horizontal representation of variables, whereas the former one uses the grid point method. It is because the spectral method has various advantages to numerical calculations comparing with the grid point method. The spectral method for a limited area with time dependent lateral boundary values was developed by Y. TATSUMI (1986), and his method was adopted for the present regional forecast models.

As shown in Table 3, in the present model maximum wave numbers of double Fourier series are 83x70 and the size of transformed grid is about 75 km and nearly equal with the grid size of the former VFM. Vertical level number is changed from 12 to 16 and increased at lower troposphere and near tropopause in order to improve forecasts in the atmospheric boundary layer and near jet stream level (Figure 7). Forecast domain is expanded westwards and southwards (Figure 7). Westward extention comes from the change of forecast period from 36 hours to 48 hours (Table 3). Southward extention aims to improve the predictions of typhoon movement and disturbances in low latitudes.

(c) Japan spectral model (JSM)

The former very fine-mesh model (VFM) was constructed to predict the so-called meso α-scale disturbances which have the scale of several hundred kilometers in space and a day in time. The former VFM could well simulate not only the synoptic scale disturbances but also the meso α-scale disturbances. The present JSM aims to obtain higher accuracy than that of VFM. For that purpose several model changes were performed.

As shown in Table 4, maximum wave number is 62x62 and number of transformed grid is 97x97 and its size is about 40 km at 60°N. Vertical level number was changed from 13 to 19 and they were increased at lower troposphere and near jet stream layer (Figure 8). Since small scale phenomena are strongly influenced by surface conditions, for example, land-sea distribution, etc., it is necessary to simulate successfully atmospheric behaviors in the boundary layers. Atmosphere has rather comprehensive structures near jet stream. So, it is necessary to increase vertical sigma levels in the jet stream layer.

Forecast area of JSM is shown in Figure 8 and it is extended both westwards and southwards. Schemes for physical process are basically the same as those of the former VFM, but prediction of the surface ground temperature is improved and effect of evaporation from rain drops is introduced in the condensation process to improve the forecast of weak rainfall area. Figure 9 shows one example of 24-hour forecast due to JSM. It is noticed that distributions of rainfall amount are exactly predicted.

(d) Typhoon model (TYM)

The special model with a movable multi-nested grid (MNG) had been used operationally for the typhoon track prediction, since abilities of the former computer system were limited. The present typhoon model adopts a uniform grid system with high resolution of about 50 km. A uniform grid system has two advantages for operational use. First, it is easy to improve and develop the prediction model. Secondly, it is easy for a uniform grid model to simulate multiple typhoons at the same time.

The MNG model has a systematic error in which the predicted positions of typhoon center tend to be deflected comparing with the actual ones when a typhoon approaches the middle latitudes. T. Iwasaki, H. Nakano and M. Sugi (1987) assumed that this discrepancy comes from a prescribed heat source for cumulus convective process which is used in the MNG model. They thought that the introduction of a more realistic heating process is necessary. Thus, they developed a typhoon movement prediction model with cumulus parameterization. Their model is used operationally after replacing by the present computer systems. Comparisons of both models are shown in Table 5.

Table 6 shows mean errors of predicted typhoon positions for the present operational model and the former one. Accuracies of predicted positions of typhoon center in 24-hour forecast are nearly equal for both models, but those of 48-hour forecast are remarkably improved in the present model. Figure 10 shows four examples of predicted typhoon track obtained by both models. In cases of (a) and (b) the predicted directions of typhoon movement obtained by the present model are fairly well, but those which are obtained by the former one are deflected comparing with the actual ones. Results of test runs show that 48-hour forecasts of typhoon track are improved in the present model.

Table 1 Comparisons between the present objective analysis models and the former ones

Global analysis	Name	GANL	GNAL
	Grid size	1.875° x 1.875°	2.5° x 2.5°
	Interpolation	Three-dimensional optimum interpolation	Two-dimensional optimum interpolation
	First guess	6-hour predictions due to global spectral model	12-hour predictions due to hemi-spheric spectral model
Asia analysis	Name	AANL	FANL
	Grid size	150 km	254 km
	Interpolation	Three-dimensional optimum interpolation	Two-dimensional optimum interpolation
	First guess	6-hour predictions due to global spectral model	12-hour predictions due to hemi-spheric spectral model
Japan analysis	Name	JANL	VANL
	Grid size	80 km	127 km
	Interpolation	Three-dimensional optimum interpolation	Two-dimensional optimum interpolation
	First guess	12-hour predictions due to Asia spectram model	FANL

Table 2 Comparisons between the present global model and the former hemi-spheric model

	GSM	HSM
Representation of variables	Spectral method	Spectral method
Resolution	16 levels, T63 (180 km)	12 levels, T42 (270 km)
Fluxes in surface boundary layer	Monin-Obukhov's similarity theory *	Bulk method
Fluxes in Ekman layer	Level 2 version of closure model **	Eddy diffusivity
Parameterization for cumulus convection	Kuo's scheme *** Shallow convection ****	Kuo's scheme
Radiation	Short wave: Lacis and Hansen's scheme Long wave: 4-band model	Katayama's scheme
Forecast period	3 days (2/a day) 8 days (1/a day) 15 days (3/a month)	3 days (2/a day) 8 days (2/a week)

*, **, ***: These schemes are described in the 1st reference.
****: The scheme is described in the 4th reference.

Table 3 Comparisons between the present regional model over Asia and the former one.

	ASM	FLM
Representation of variables	Spectral method	Grid point method
Resolution	16 levels, E83x70 (75 km)	12 levels, 127 km
Fluxes in surface boundary layer	Monin-Obukhov's similarity theory	Bulk method
Fluxes in Ekman layer	Level 2 version of closure model	Eddy diffusivity
Parameterization for cumulus convection	Gadd and Keer's scheme	Gadd and Keer's scheme
Forecast period	48 hours (2/a day)	36 hours (2/a day)

Table 4 Comparisons between the present regional model over Japan and the former one

	JSM	VFM
Representation of variables	Spectral method	Grid point method
Resolution	19 levels, E62x62 (40 km)	13 levels, 63.5 km
Fluxes in surface layer	Monin-Obukhov's similarity theory	Same as JSM
Fluxes in Ekman layer	Level 2 version of closure model	Same as JSM
Parameterization for cumulus convection	Gadd and Keer's scheme	Same as JSM
Forecast period	24 hours (2/a day)	24 hours (2/a day)

Table 5 Comparisons between the present typhoon model and the former one

	TYM	MNG
Representation of variables	Spectral method	Grid point method
Forecast domain	4000 km x 4000 km	Northern hemi-sphere
Horizontal resolution	Maximum wave number: 51 Transformed grid system: 81x81 (50 km)	Typhoon area: 31x31 (73 km) Intermediate area: 31x31 (145 km) Outer area: 65x65 (291 km)
Vertical resolution	8 levels	3 levels
Orography	Smoothed mountain	No mountain
Condensation heat	Water vapour prediction for large scale motion. Kuo's parameterization scheme for cumulus convection.	Dry model. Axial symmetric heat function.
Fluxes in surface boundary layer	Bulk method (Using an analyzed sea surface temperature)	Bulk method (No sensible heat flux)
Fluxes in Ekman layer	Eddy diffusivity	Eddy Diffusivity
Forecast period	48 hours	48 hours

Table 6 Mean position error (km)

	Before recurving	In recurving	After recurving	Total
=24 MNG	159.7 (10)	102.3 (13)	158.7 (13)	138.6 (36)
TYM	178.4 (10)	130.3 (13)	128.9 (13)	143.1 (35)
=48 MNG	481.5 (10)	286.9 (12)	415.4 (13)	390.2 (35)
TYM	310.8 (10)	294.3 (12)	292.4 (13)	298.3 (35)

Numeral in parenthesis is sample number.

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1) Electronic Computation Center, JMA, 1983: Outline of operational numerical weather prediction at Japn Meteorological Agency, 92PP.

2) Iwasaki, T., H. Nakano and M. Sugi, 1987: The performance of a typhoon track prediction model with cumulus parameterization. J. Meteor. Soc. Japan, 65, 555-570.

3) Tatsumi, Y., 1986: A spectral limited-area model with time-dependent lateral boundary conditions and its application to a multi-level primitive equation model. J. Meteor. Soc. Japan, 64, 637-664.

4) Tiedtke, M., 198 : The sensitivity of the time-mean large-scale flow to cumulus convection in the ECMWF model, ECMWF Tech. Rep. No. 4 297 ∿ 316.

Figure 1 Horizontal domain for Asia Analysis (outer) and Japan Analysis (inner)

Figure 2 Prediction levels and Analysis levels in the vertical directions. Left: sigma-levels of the former northern hemi-spherical model (HSM), Central: pressure-levels of Analysis model, Right: sigma-levels of the present global model (GSM)

Figure 3 Surface pressure and rainfall amounts of 48-hour and 72-hour forecast from the initial time 1988 Feb. 8th 12 GMT due to GSM (center) and HSM (bottom), and observed surface pressure for verification (top).

Figure 4 Same as Figure 3, but 96-hour and 120-hour forecasts.

Figure 5(a) Surface pressure of 8-day forecast from the initial time 1986 Dec. 17th 12 GMT due to GSM (lower) and observed surface pressure for verification (upper)

Figure 5(b) Same as Figure 5(a), but due to HSM.

Figure 6 Daily mean tendency correlations for predicted 500mb height fields over northern domain of 20°N. Upper chart(A) shows mean values of 13 experiments using initial data in winter of 1987 and lower one (B) shows those of 7 experiments using initial data in summer of 1987. Open circles denote the values for GSM and triangles denote those for HSM.

Figure 7 Forecast domain for the present ASM (upper) and the former FLM (lower), and vertical sigma-levels (right). Sigma-level and thickness of each layer is shown in mb assuming surface pressure P_0 = 1000mb. Height contours of mountain are drawn which are obtained by interpolation of data on 10"x10" mesh system and not smoothed.

Figure 8 Same as Figure 7, but the present JSM and the former VFM.

Figure 9 24-hour forecast of surface pressure, wind, and rainfall from the initial time 1988 March 11th 00 GMT due to JSM (upper) and observed rainfall amount for verification (lower).

Figure 10 48-hour typhoon tracks from the initial time of 12th 12 GMT (A), 13th 00 GMT (B), 14th 12 GMT (C) and 15th 12 GMT in 1987 September. The Observed typhoon centers are denoted 12 hourly by closed circles and the predicted ones are denoted 12 hourly by open circles for the present TYM and by triangles for the former MNG respectively.

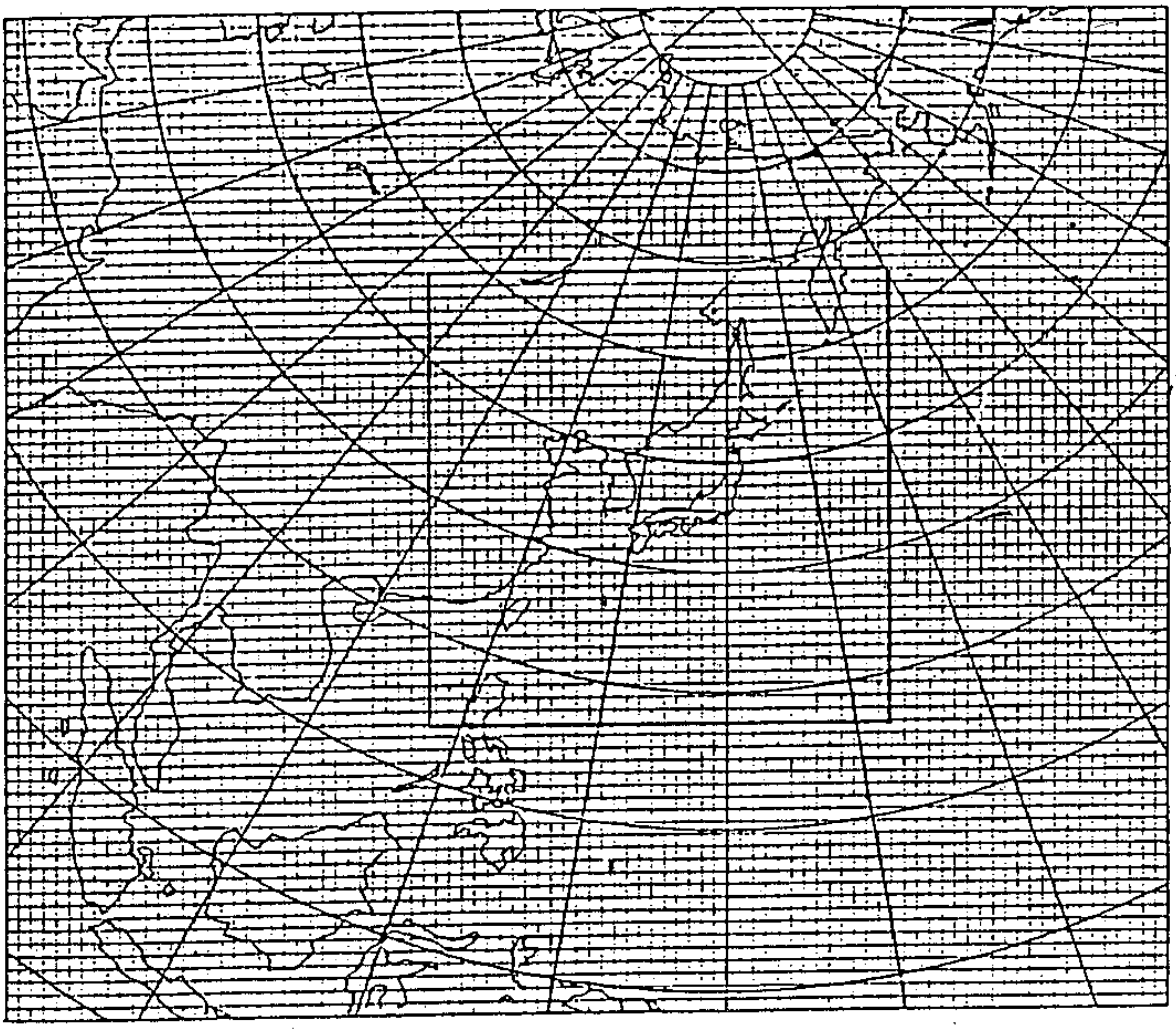

Figure 1

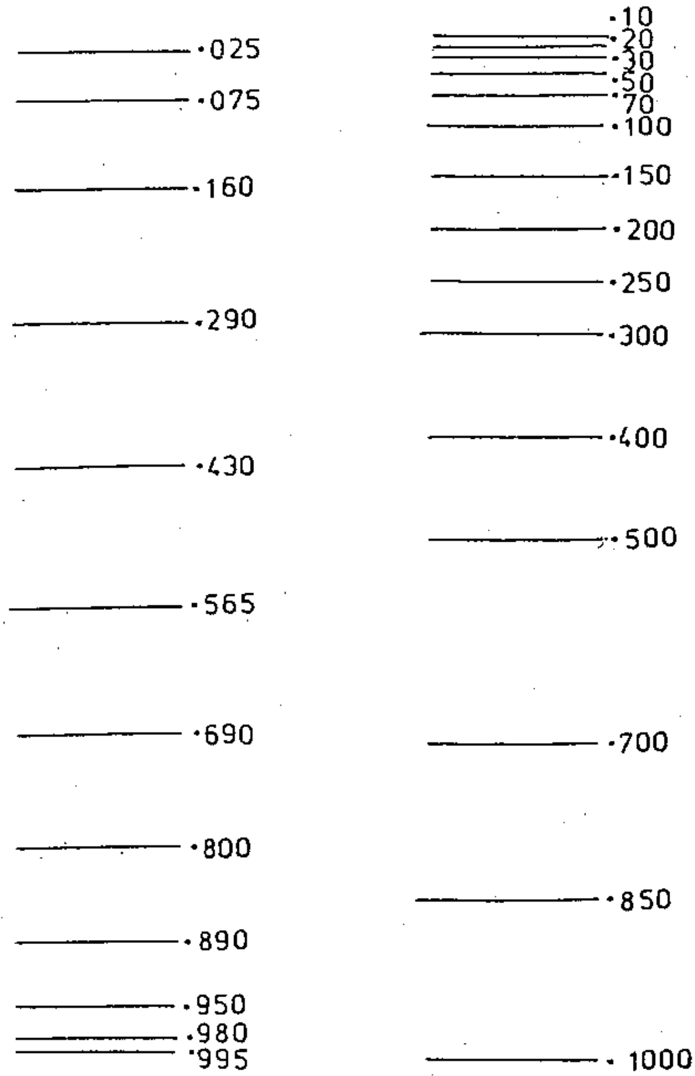
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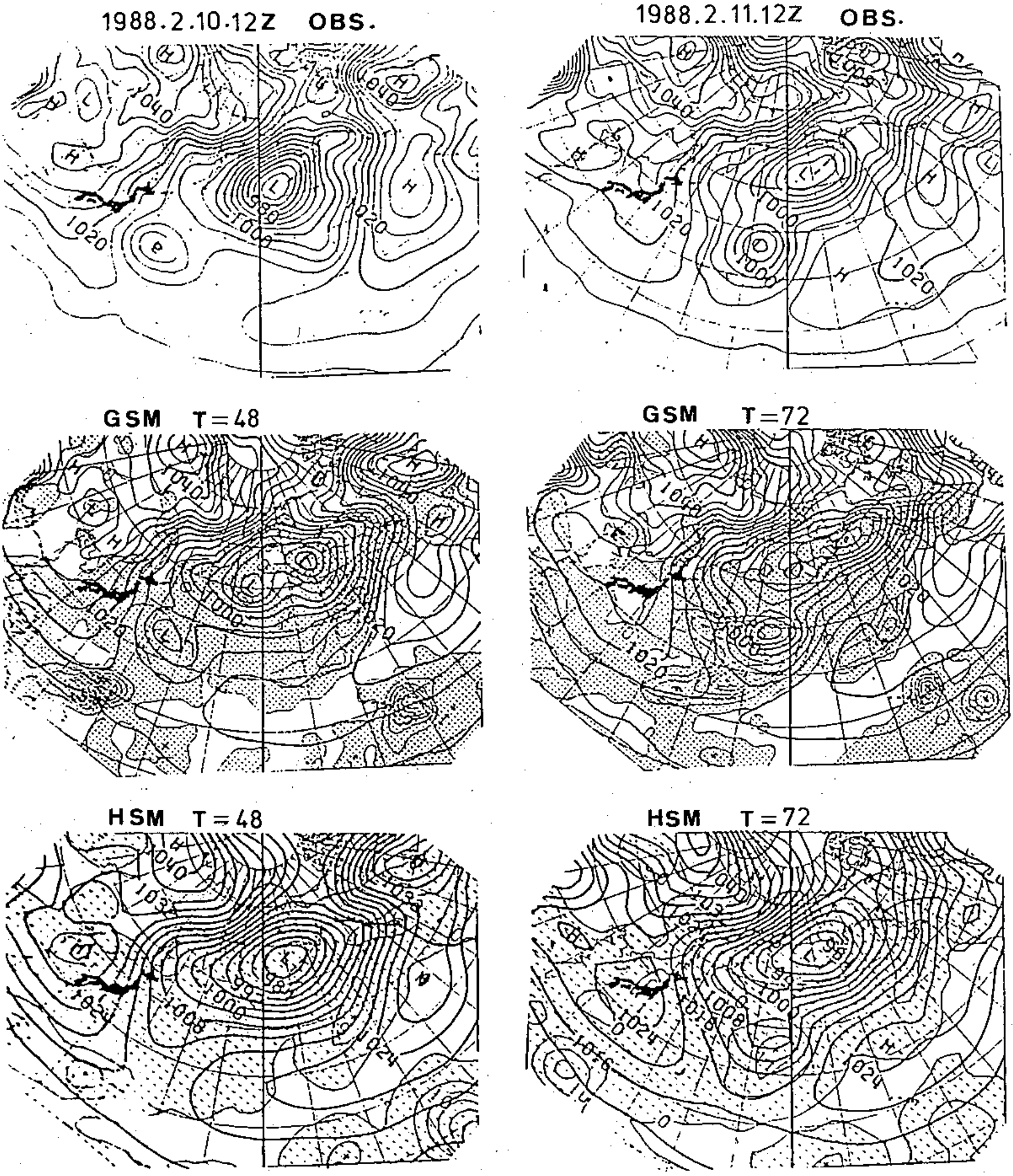
Figure 2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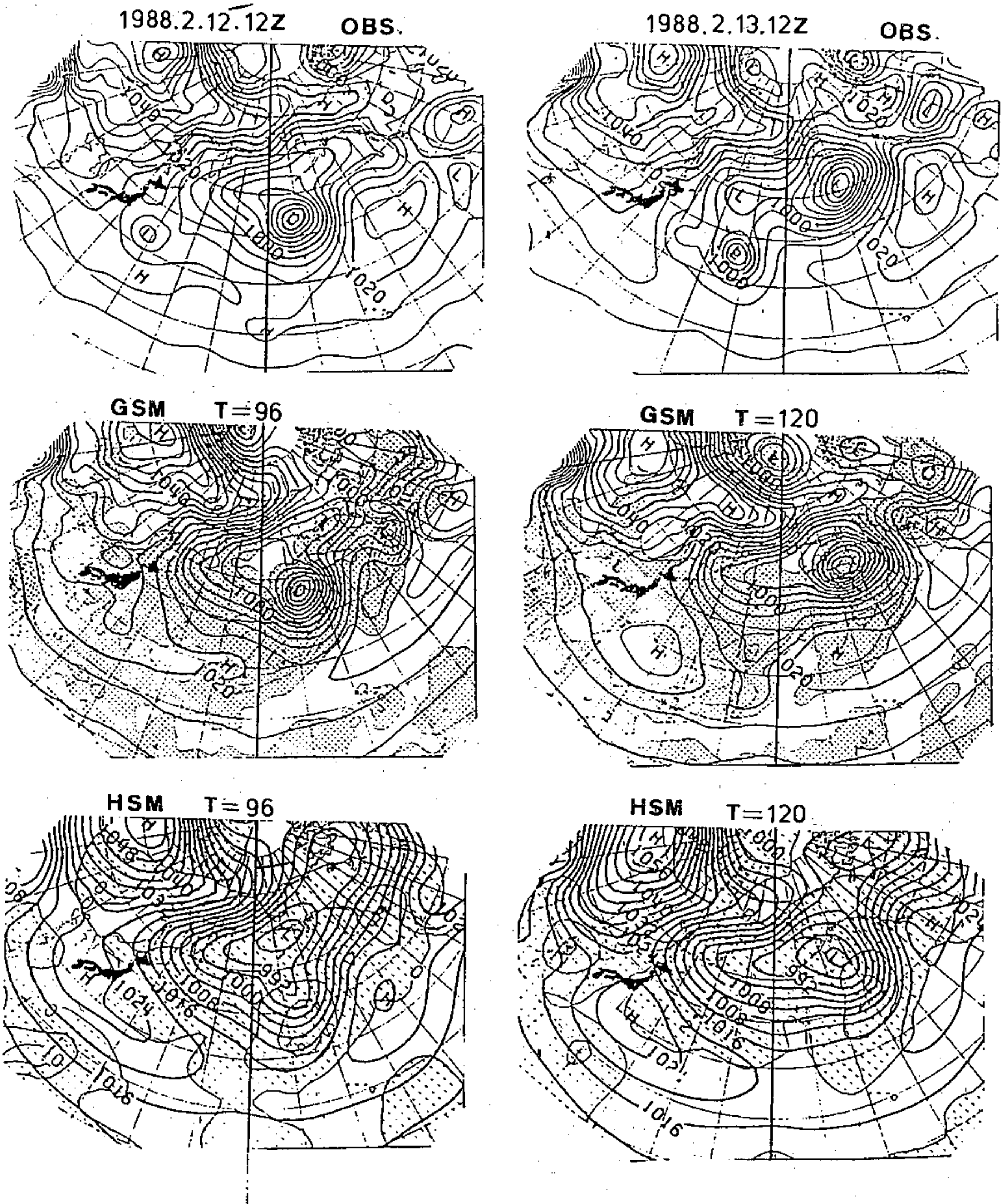
GSM T=72
HSM T=48
HSM T=72

Figure 3



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T=96
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T=120

Figure 4

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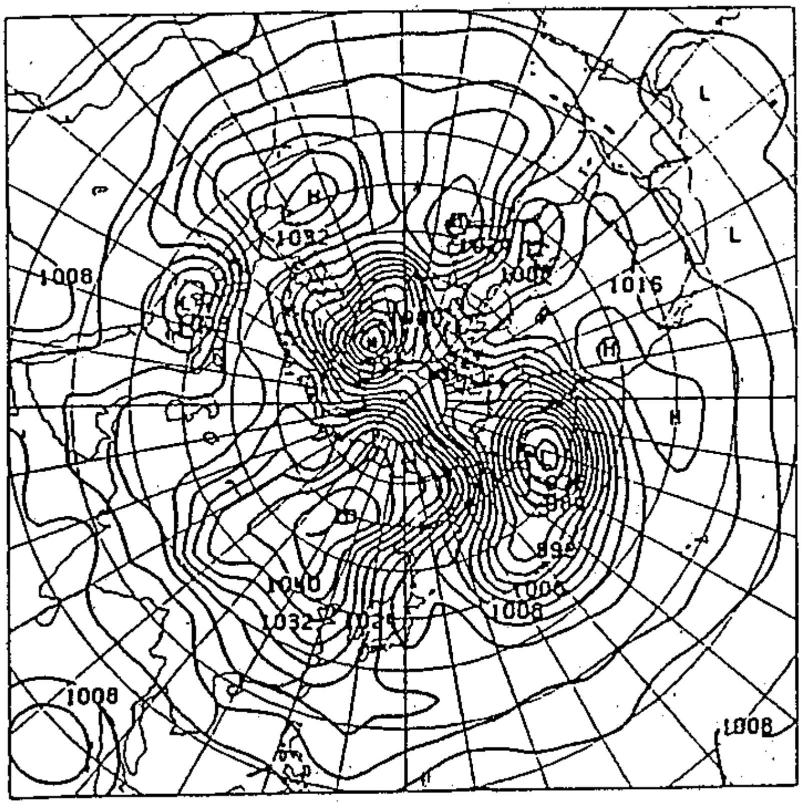


1986 12 17 12Z T=192 PS **GSM** (T63)

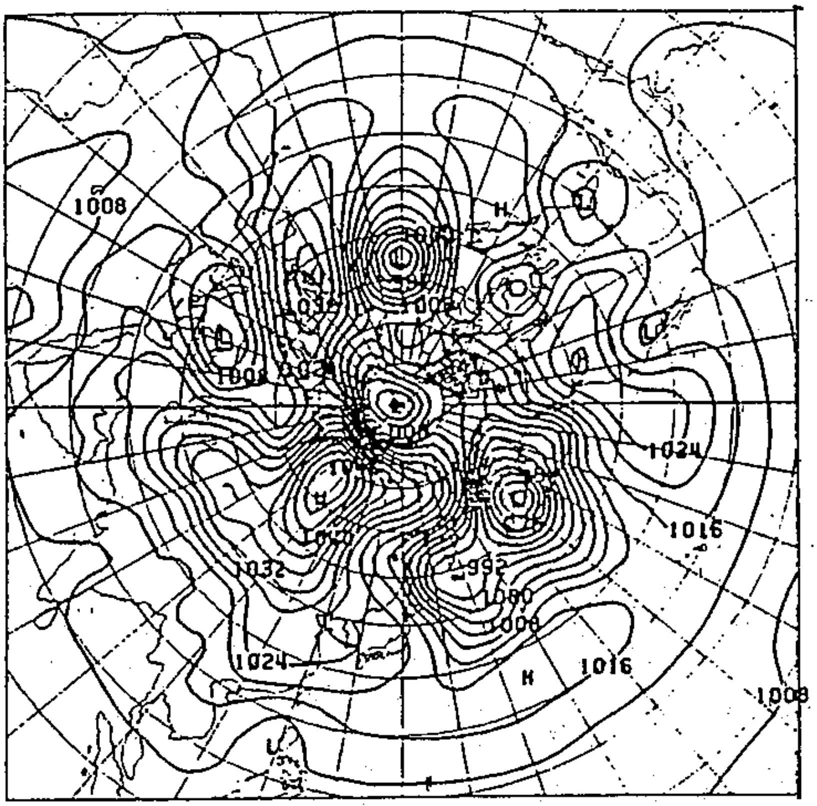
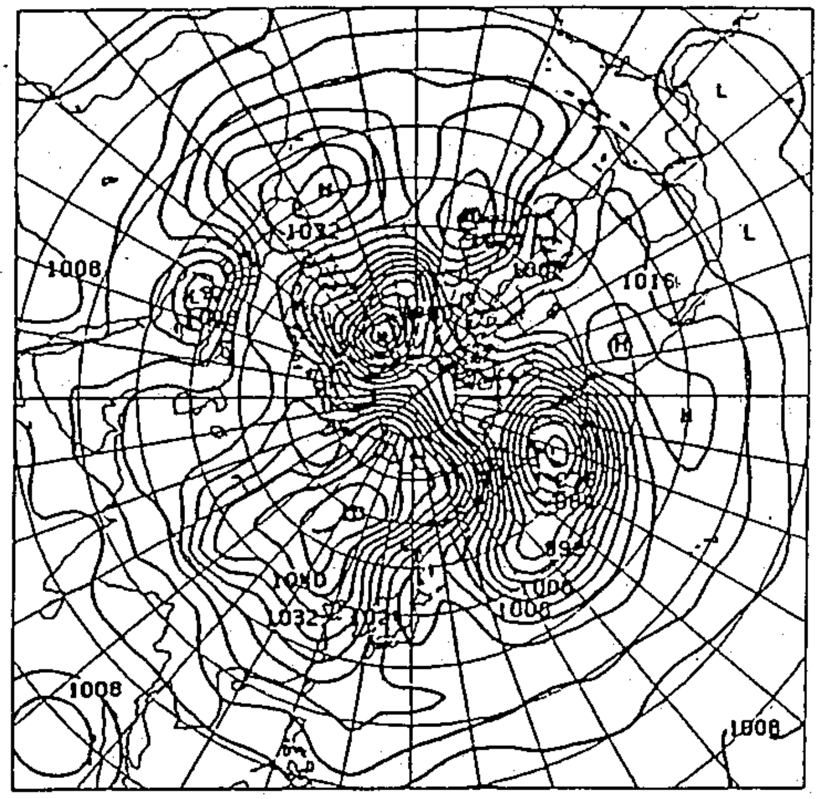


Figure 5(a)

1986 12 25 12Z T=192 PS OBS



1986 12 17 12Z T=192 PS RR(68-92) HMS(T42)

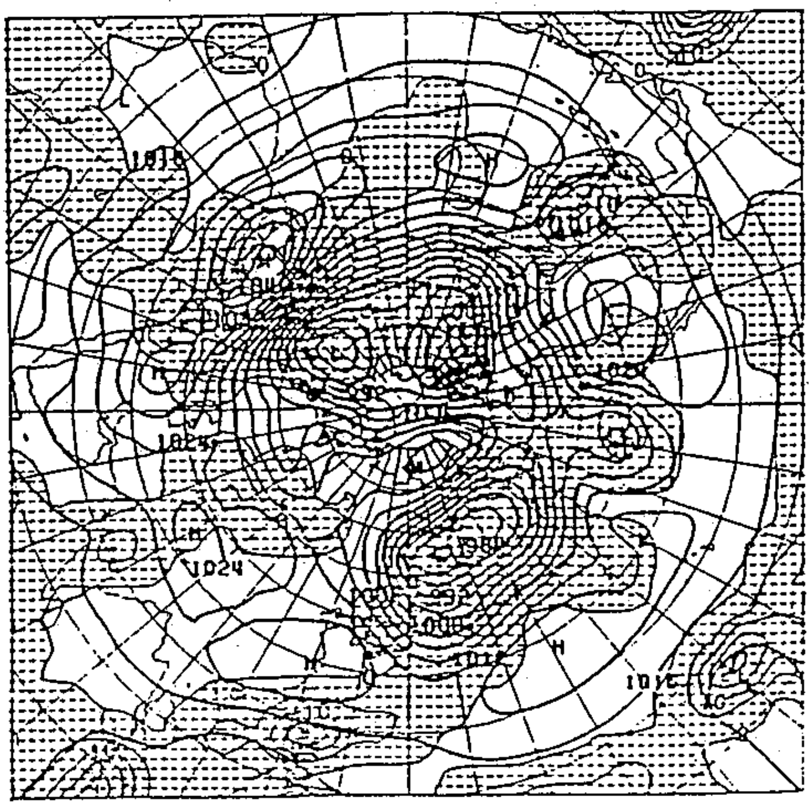


Figure 5(b)

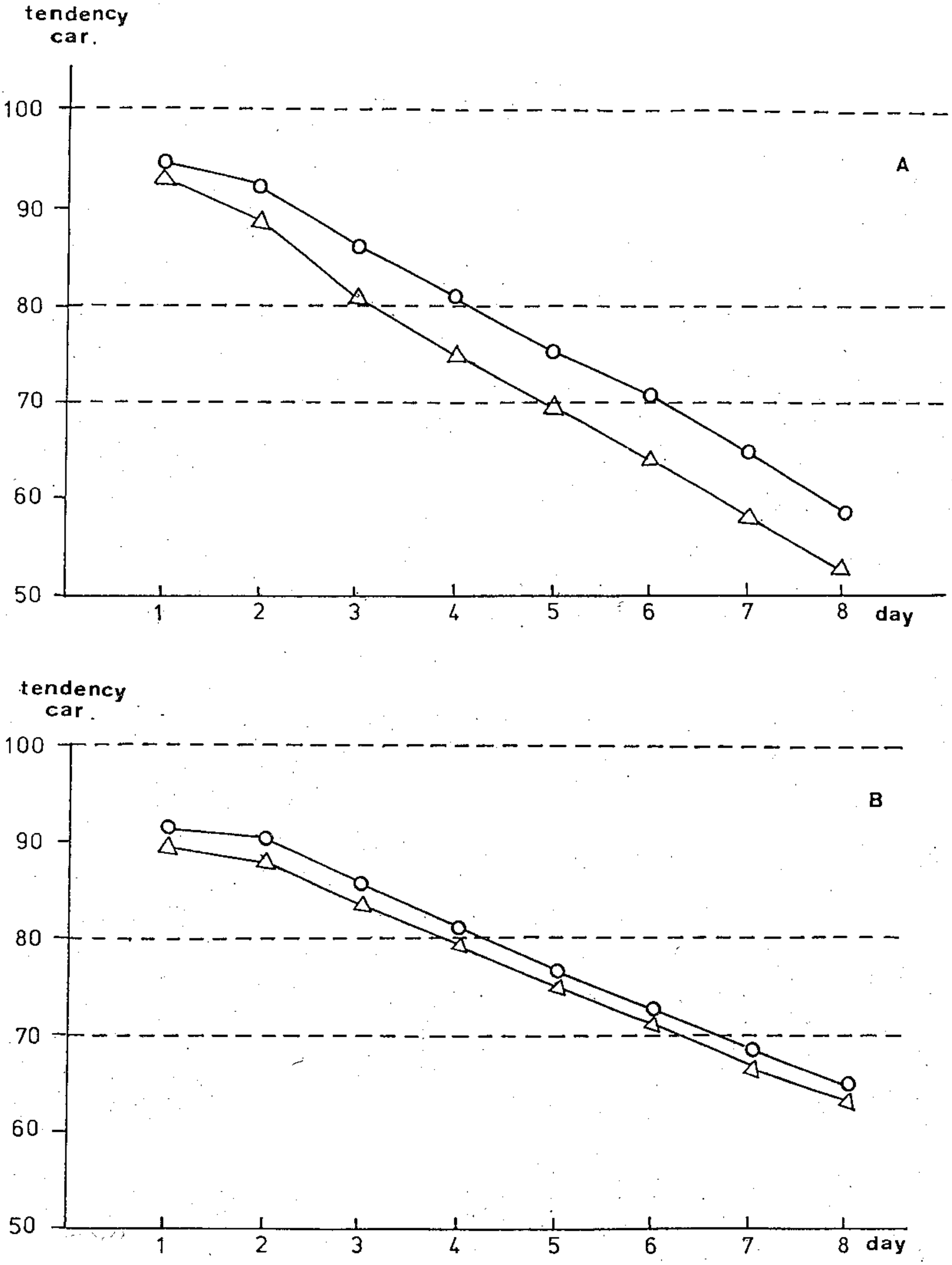


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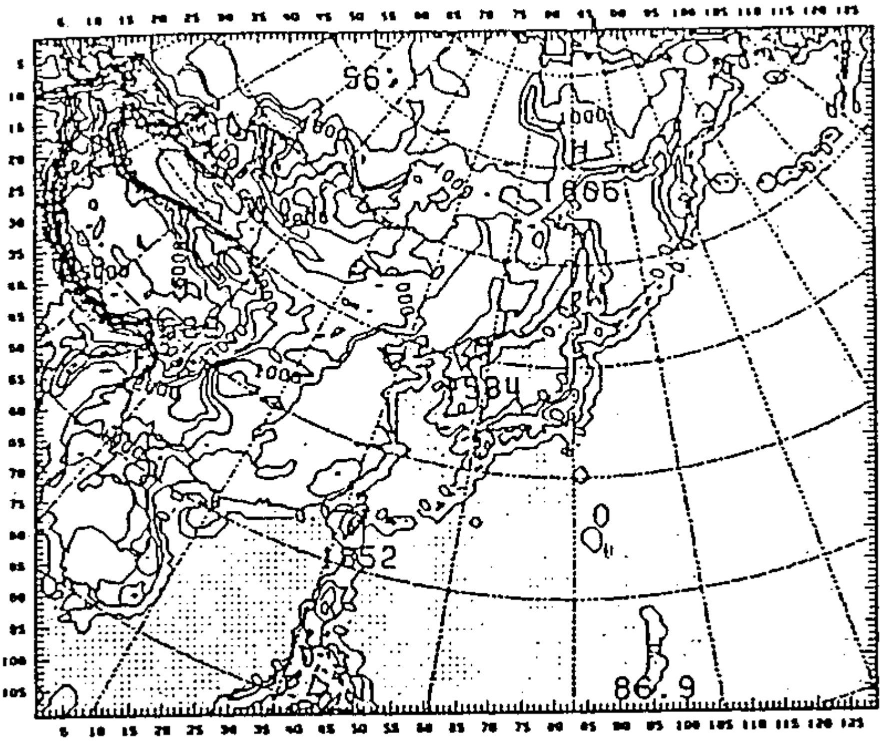
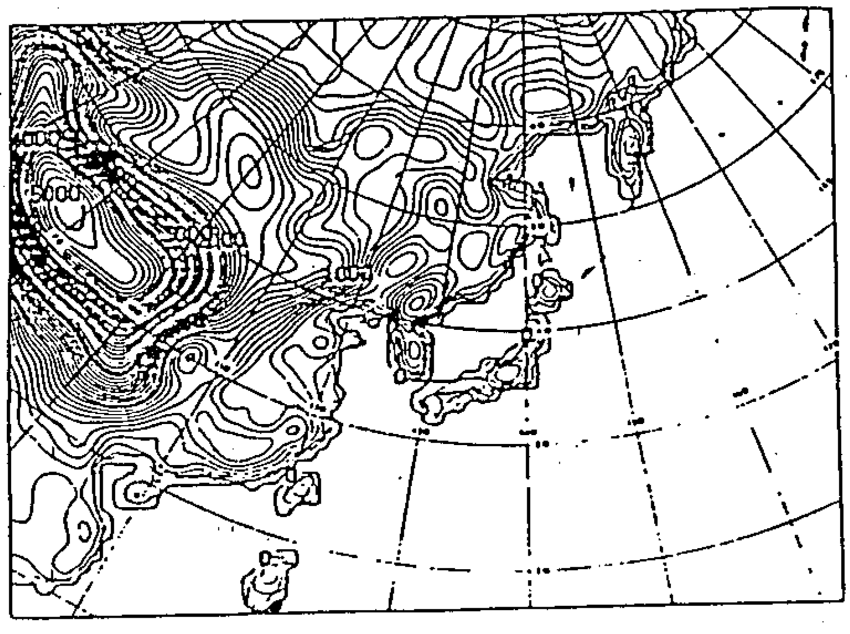
Figure 6



16L-ASM

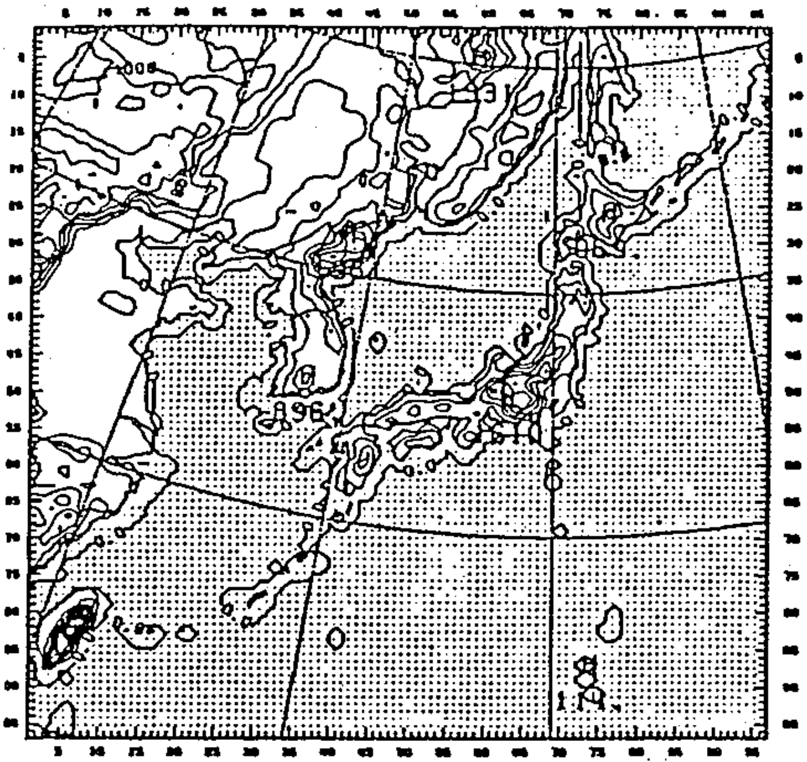
	P	ΔP
16	25	50
15	75	50
14	130	60
13	195	70
12	270	80
11	350	80
10	430	80
9	510	80
8	590	80
7	670	80
6	750	80
5	830	80
4	900	60
3	950	40
2	980	20
1	995	10



12L-FLM

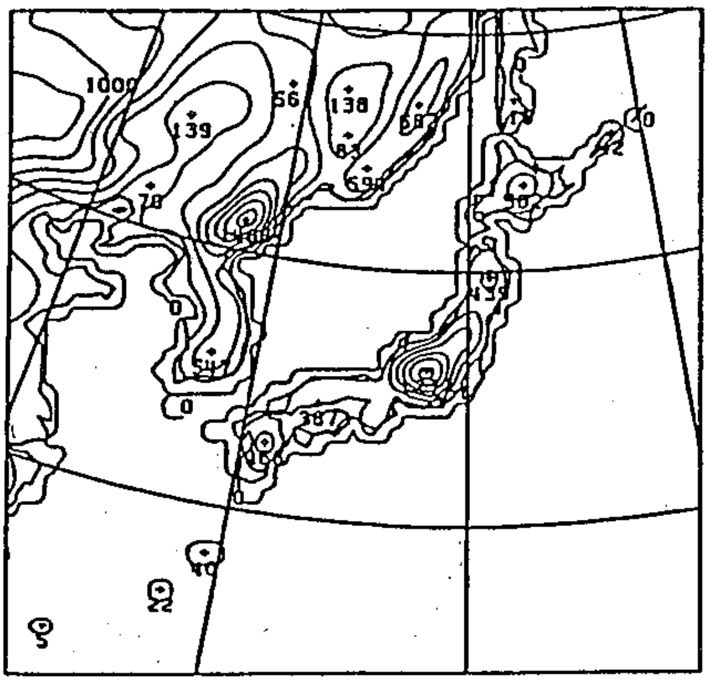
p	ΔP
25	50
75	50
150	100
250	100
350	100
450	100
550	100
650	100
750	100
850	100
950	60
980	40

Figure 7



19L-JSM

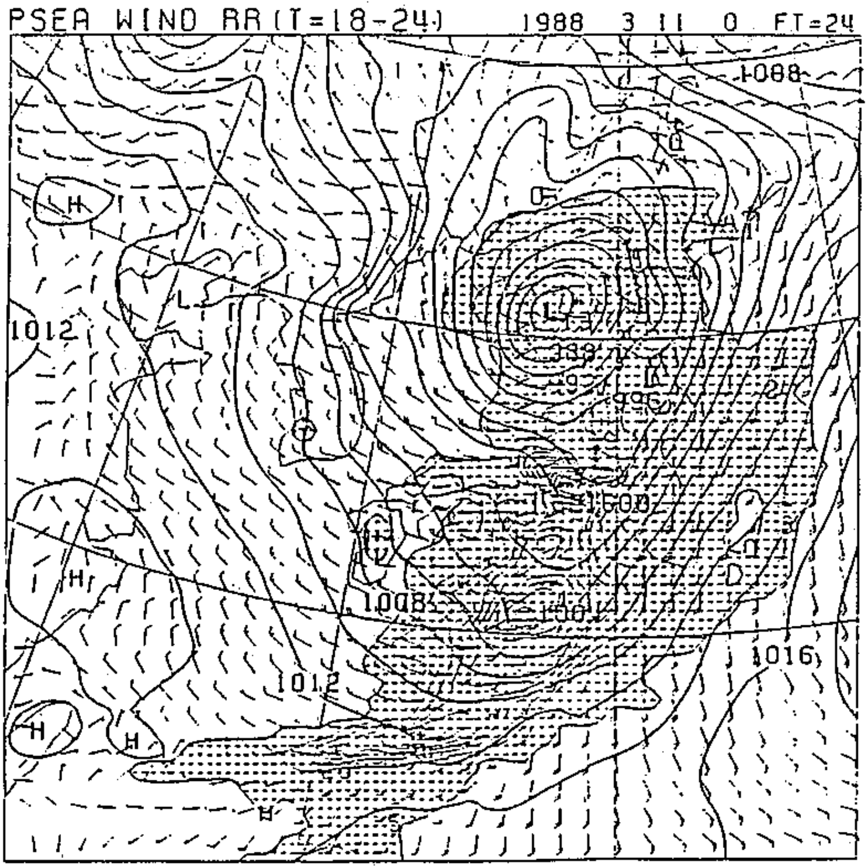
	P	ΔP
19	30	60
18	90	60
17	150	60
16	210	60
15	275	70
14	345	70
13	420	80
12	500	80
11	580	80
10	660	80
9	735	70
8	800	60
7	855	50
6	900	40
5	935	30
4	960	20
3	977.5	15
2	990	10
1	997.5	5



13L-VFM

P	ΔP
160	120
280	120
395	110
500	100
595	90
680	80
755	70
820	60
875	50
920	40
955	30
980	20
995	10

Figure 8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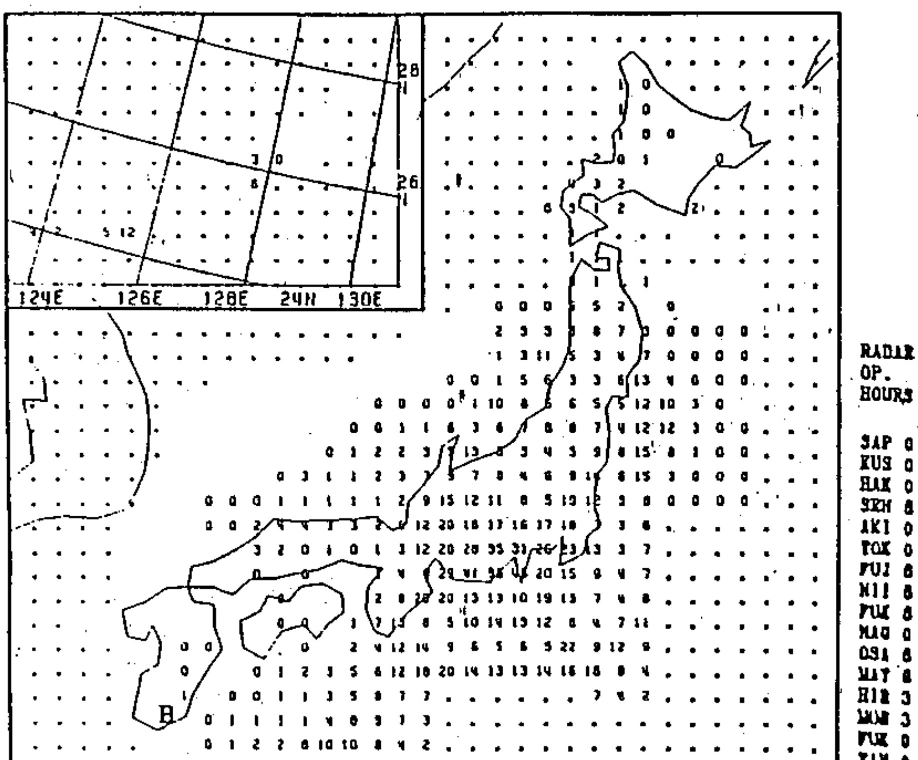
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Figure 9

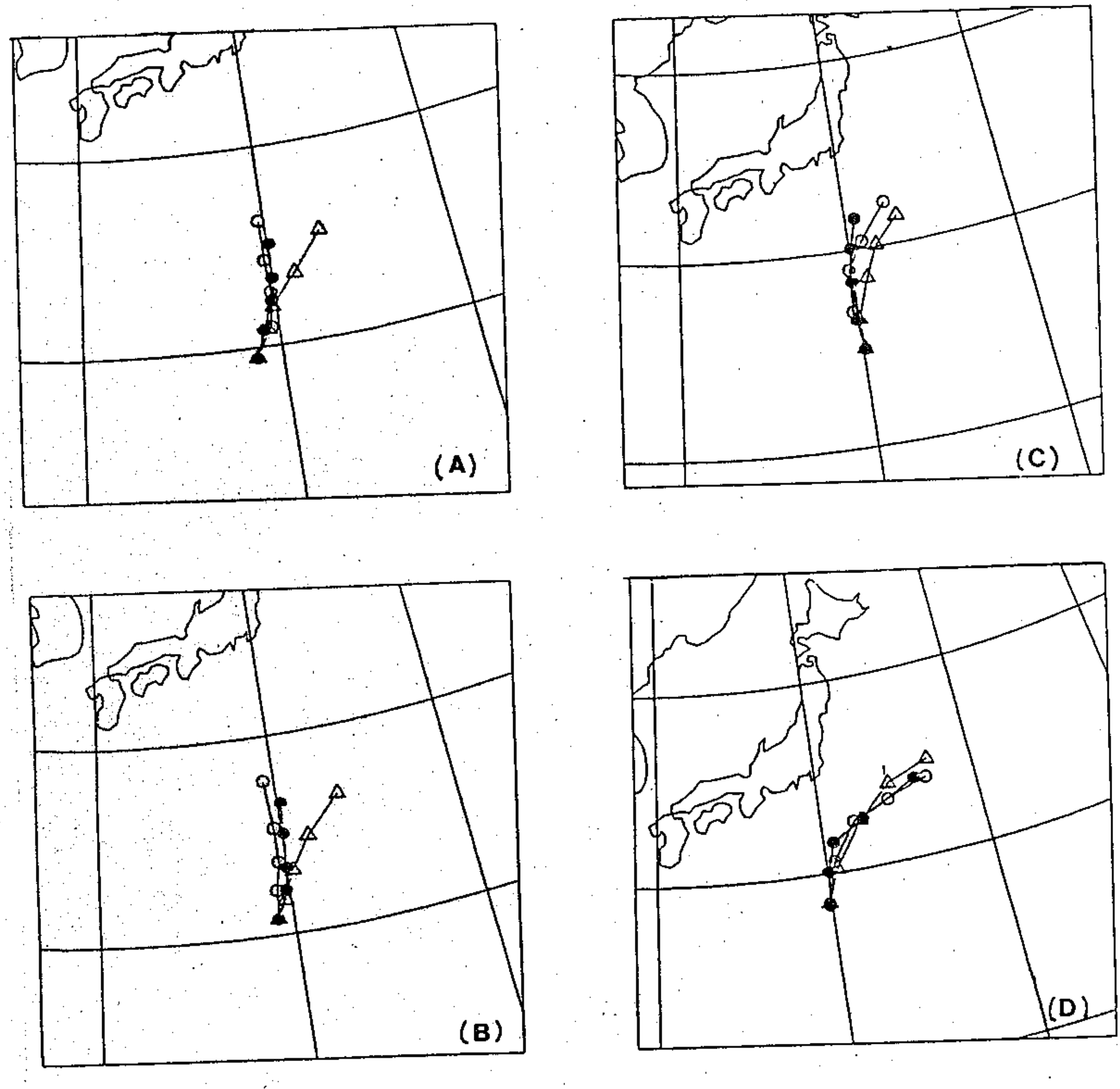

Figure 10