交通部中央氣象局委託研究計畫成果報告

General Upgrade to the CWB Global Forecast System (I)

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Report on

General Upgrade to the CWB Global Forecast System, Year 1

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1. Introduction

The second generation Global Forecast System (GFS) at the Central Weather Bureau (CWB) started operation in January 1995. The GFS consists of a global spectral forecast model and an objective analysis model which uses optimum interpolation (OI) method to analyze observational data. The current resolution of the forecast model includes 18 sigma-p levels in the vertical and 79 triangularly truncated waves (T79) in the horizontal. Since its operation in 1995, the quality control and GFS teams have constantly monitored the performance of the GFS. Among other problems, we have particularly noticed that (1) the GFS has relative worse scores compared with those from other Numerical Weather Prediction (NWP) centers, (2) the GFS height fields show small scale noise around or downstream of high terrain areas, and (3) the GFS sometimes falsely spins up a deep low in tropical areas. After we diagnose these three problems, we determine that the problems are possible to be improved or fixed without major development in numerical methods and physics parameterization schemes. We therefore, propose a cost-effective approach to improve the GFS in a two year project. In the first year, we concentrate in the upgrade to the forecast model by increasing model resolution and adjusting parameterization schemes. In the second year, we will focus on the upgrade to initial conditions by improving data resolution which is about 3 times higher than the GFS. In other words, the ECMWF and NCEP global models use 9 times and the US Navy model uses 4 times more waves to resolve the atmospheric circulation. The higher resolution will not only reduce numerical truncation errors in solving the governing equations, but also be able to resolve smaller scale weather systems. Consequently, the GFS should suffer by worse performance just for the resolution reason. Figure 1 shows an example of score comparison among global forecasts from the four NWP centers. In this 15 day period of January 1997, the 500 mb height anomaly correlation (AC) coefficients from the ECMWF and NCEP forecasts are very close to each other, while they are higher than those from the US Navy model and much higher than those from the GFS. The 15 day averaged AC from the ECMWF, NCEP, US Navy, and GFS are 0.9712, 0.9695, 0.9585, and 0.942 for 48h forecast; and 0.815, 0.82, 0.73, and 0.70 for 120h forecast, respectively. These scores clearly show that models with a similar resolution (ECMWF and NCEP) shares similar scores and models with a higher resolution have better scores. Another interesting point in this figure is that the relative score difference between the US Navy model and GFS is larger in 48h than in 120h forecast. This indicates that the GFS initial conditions are worse than those at other centers. When the GFS started operation in 1995, the Cray computer memory at the CWB was only 32 million words which could only support the T79 resolution. The Cray memory has been upgraded to 64 million words and therefore, the GFS can increase its resolution to better resolve the atmospheric circulation.

The second problem we try to fix is the one detected by the quality control term. The GFS height fields often show noises around or downstream of high terrain areas. Figure 2 shows two-year mean stationary waves of 500 mb height from the GFS 24h forecast for spring and winter seasons. The small scale noises shown in the stationary waves most likely come from terrain forcing. In spectral models, the terrain field suffers from small scale noises and negative values due to the nature of spectral truncation. Usually, we apply filters to control the noises and negative values. However, the filter will reduce the terrain height as well that makes the terrain forcing weaker. We have to compromise the amount of smoothing so that it is strong enough to control the noises but weak enough to maintain proper terrain forcing to the atmosphere. In the current operational GFS, We apply Lanczos filter once to the terrain field. The filtered terrain field still has sizable negative values but it produces better upper level jet forecasts. We believe the noises in the terrain field cause the stationary noises in the height fields. Besides the noises in height fields, the small-scale terrain noises will cause unrealistic precipitation near small-scale high terrain areas (Miller *et. al.*, 1995). When we increase the GFS resolution, we have to rebuild the terrain field to match the new resolution. We revise the method of preparing the terrain field in the meantime to correct the noisy problem around high terrain areas.

The third problem we try to fix is that the GFS sometimes falsely spin up a deep tropical low due to very heavy precipitation at there. The heavy precipitation mainly comes from the grid-scale precipitation which indicates the cumulus parameterization in the GFS is not efficient enough to remove the conditional instability in tropics. An example of a falsely spun low in 120h forecast can be found in Fig. 9b around 150 E°.

3. Improvement approach and related issues

There are two choice on increasing the model resolution: increasing the horizontal resolution or the vertical resolution. Due to the computational instability condition, the increase of horizontal resolution must be accompanied by the decrease of time step. Therefore, the increase of horizontal resolution is much more expensive than the increase of vertical resolution. However, the benefit in the increase of horizontal resolution is much higher than the increase of vertical resolution because the variation of atmospheric structure in the vertical is fairly smooth, except at boundary layer top and jet levels. After evaluating the available computer resource and timing constraint on the operational runs, we decide to increase the horizontal resolution to 120 waves (T120) without increasing the vertical resolution. The choice of the spectral model resolution is limited by the condition for Fast Fourier Transform: number of grids on a Gaussian latitude must be completely factorable by 2, 3, or 5. The T120 resolution is equivalent to 1 degree resolution in the Gaussian grid space. With this resolution, tropical cyclones may be resolvable in the GFS. Be able to resolve tropical cyclones is the major reason that we choose to increase the horizontal resolution as much as we can afford without increasing the vertical resolution.

To increase the horizontal resolution, we need to prepare new ground parameters and terrain field, modify the OI analysis program, and modify the global forecast model. The GFS team prepared the new ground parameters and terrain field for the T120 GFS. The number of OI analysis volumes and the size of the volumes were adjusted for the new resolution of 360 by 180 Gaussian grids. The grid dimension parameter, the size of working arrays, and a 15 times smaller horizontal diffusion coefficient were adjusted in the global forecast for the higher resolution. The major challenges of this work are to modify all resolution dependent parameters, fit the T120 GFS into the CWB computer memory, and make the T120 GFS run faster enough to meet the operational schedule. We found out that we have to revise the multitasking logic to save the working space. The revised T120 GFS takes about 52 million words memory for multitasking with 8 CPU's and 36000 seconds CPU time for 120h forecast with 5 times speed up by the multitasking.

The new T120 terrain field is prepared from the 10 minute resolution data base following Miller *et. al.* (1995). We apply a low-pass filter to remove $2\Delta x$ waves and reduce the amplitude of very high wave number waves in the terrain spectrum. From the ECMWF experience, too large amplitude in the short-wave tail of the terrain spectrum will cause vorticity and divergence fields at the bottom model level to have different spectral distribution. The large amplitude of short-scale terrain components will cause high wave number components of the divergence spectrum to have a larger amplitude than that for the vorticity. The large amplitude in high wave number divergence components derives noises in low level vertical velocity and in precipitation. By reducing the amplitude of high wave number terrain components, the divergence and vorticity spectrum will share the same rapid drop-off spectral distribution in high wave numbers and noises in precipitation near high terrain areas can be eliminated. From our numerical forecast experiments, we found out that filtering $2\Delta x$ waves by the low-pass filter is enough to remove the terrain induced noises both in precipitation and in height fields.

The GFS uses a relaxed Arakawa-Schubert (AS) cumulus parameterization proposed by Moorthi and Suarez (1992) to model cumulus convection. The parameterization simplifies the original AS by using numerical iterations to approximate interactions among different cloud types. In the version of the operational GFS, we use one iteration in each time step with 25% instability removal for each iteration. This choice may be not efficient enough to remove conditional instability so that grid scale condensation will pick up the left instability and cause so called grid-point storms. We modify the cumulus parameterization by using two iterations in each time step. Furthermore. we loose up the maximum flux constraint in the parameterization to allow more vigorous convection in the GFS. These changes should make the cumulus parameterization more efficient to remove conditional instability and improve the falsely deepening problem in tropics.

4. Results and comparison

The increase in horizontal resolution indeed makes significant improvement in GFS forecast performance. Figure 3 shows the comparison of northern hemisphere AC in 48h and 120h forecasts between the T79 and T120 GFS for a period of 1-23 January 1997. The T120 scores are significantly better than those of T79 in both 500 mb height and sea level pressure forecasts. The improvement in the sea level pressure forecast is larger than the improvement in 500 mb height. This is understandable since sea level pressure field has more variance which will be benefited more by the higher resolution. Similar big improvement can be found for S1 scores (Fig. 4) and 850 mb temperature standard deviation of forecast errors (Fig. 5). The averaged AC improvement in the first 15 days for 48h 500 mb height forecast is about 0.01, which is more than 60% of the averaged score difference between the US Navy model and the GFS for the same period. The 15 day averaged AC improvement for 120h 500 mb height forecast is about 0.05 which makes the GFS score even better than the score of the US Navy model. Similar improvement in scores are found for February 1997 which have been presented in the CWB Weather and Forecast Conference in March 1997. Figures 6 and 7 show the AC, S1, and RMS for March 1997. The improvement in March is still significant but the magnitudes are less than those for January and February.

The new terrain field prepared by the new method of first applying the low-pass filter has smaller magnitude in small-scale noises, while it also has lower peak values in the terrain height (Fig. 8). Since the only difference between the two methods is the application of the low-pass filter to remove $2\Delta x$ waves, the reduction in terrain peak values should relate to very high wave number components of the terrain field and should not effect the forcing to atmospheric long waves. The terrain prepared by the new method has significantly improved the noise problem created by the small-scale terrain forcing in the GFS forecast. Figure 9 shows an example of noises in 500 mb height and total precipitation from a T120 GFS control run at 00Z 17 May 1997. The noises can be seen along the 90 E° latitude in 48h forecast of 500 mb height (Fig. 9a) and around Saudi and Egypt in the 48h and 120h total precipitation forecast (Figs. 9e,f). Figure 10 shows the same forecast by the T120 GFS but with the new terrain field. The small-scale noises in 48h 500 mb height forecast are totally gone (Fig. 10a) and the small-scale noises in the total precipitation are greatly improved in both 48h and 120h forecasts (Figs. 10e,f).

The revised cumulus parameterization has also significantly improved the falsely deepening problem in tropics. In the 120h forecast of the control and new terrain run (Figs. 9d and 10d), a 998 mb low was predicted in 120h near 15N° and 155E°. The verify analysis at 00Z 22 May shows only a shallow low of 1010 mb around there (Fig. 11b). With the revised cumulus parameterization, the 120h forecast shows a low of 1004 mb at there (Fig. 12d) which is much better than the control run. In comparing the total precipitation between the two runs (Figs. 9e,f and Figs. 12e,f), we see that the revised cumulus parameterization produces more rain in the 48h forecast and less rain in the 120h. The change in the precipitation pattern is consistent with the problem we suspect that the parameterization scheme is not efficient enough to remove the convective instability so that the GFS produces too little rain at the early forecast period and too much rain at the later period.

5. Summary and next year plan

The three upgrades we proposed to improve the GFS performance are very successful. The forecast scores are significantly improved by increasing resolution from T79 to T120. The noises in height and precipitation forecasts around high terrain areas are much better improved with the new terrain field. The falsely deepening problem at tropical areas is improved by the revised cumulus parameterization. In the next year, this project will focus on improvement in initial conditions. We will revise the data assimilation method to use 6h incremental updates (Liou 1991) to improve the first guess for the OI analysis and reduce interpolation errors from pressure levels to sigma levels. We will revise the method in preparing initial conditions for temperature and mixing ratio. We will try to include the ECMWF 24h sea level pressure forecast as supplemental observational data for the OI analysis. We will include tropical cyclones in the GFS initial conditions so that the GFS can provide 7 day typhoon track forecasts to guide CWB forecasters. The GFS team is highly motivated to make the GFS be a reputable global forecast model in the world.

Reference

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Miller, M., M. Hortal and C. Jakob, 1995: A major operational forecast model change. ECMWF Newsletter Number 70 - Summer 1995, p2-8.

Moorthi, S. and M. Suarez, 1992: Relaxed Arakawa-Schubert: A parameterization of moist convection for general circulation models. Mon. Wea. Rev., 120, p978-1002.

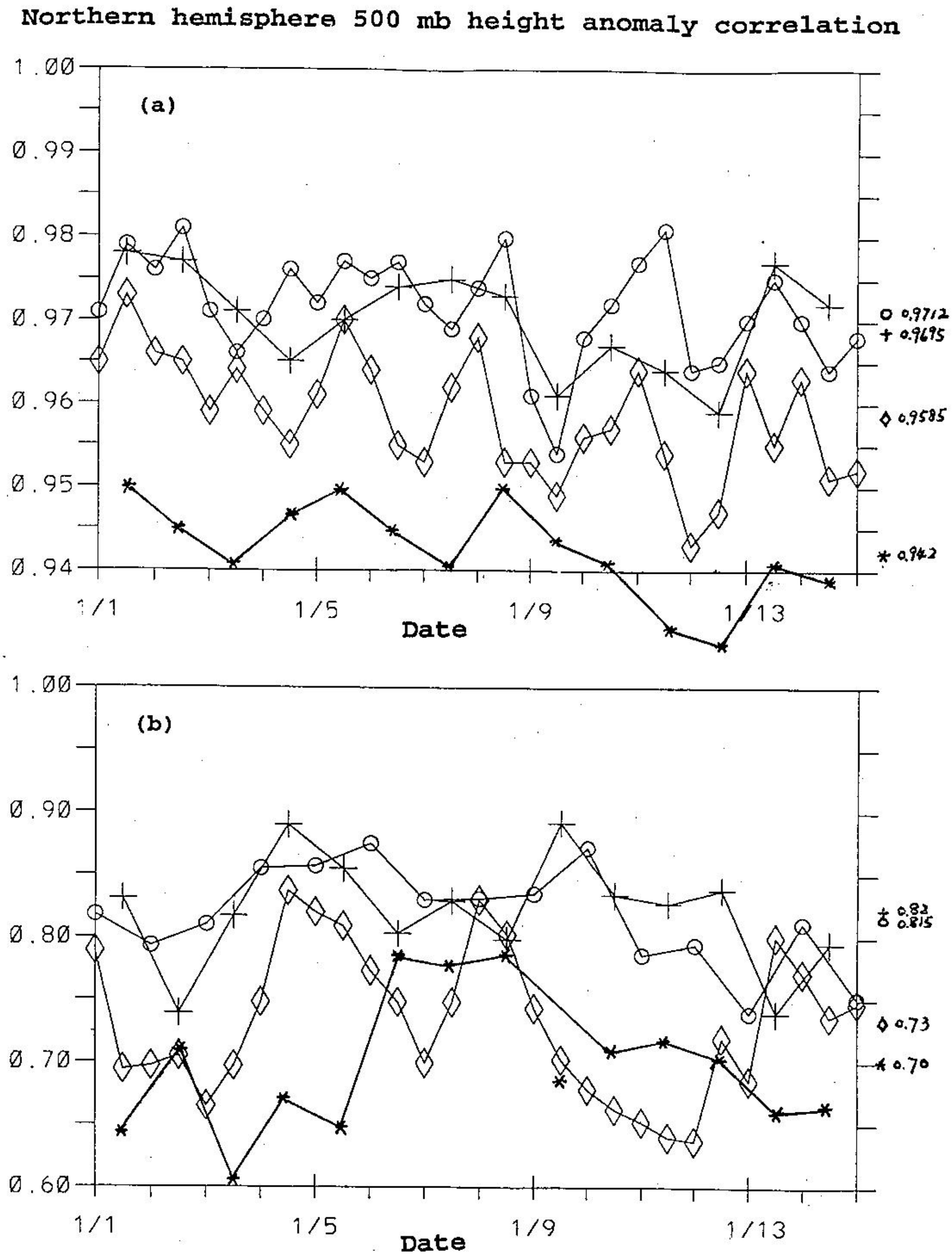


Fig. 1 Northern hemisphere 500 mb height anomaly correlation for (a) 48h and (b) 120h forecast from ECMWF (plus), NCEP (circle), FNMOC (diamond), and CWB (star) on 1-15 January 1997.

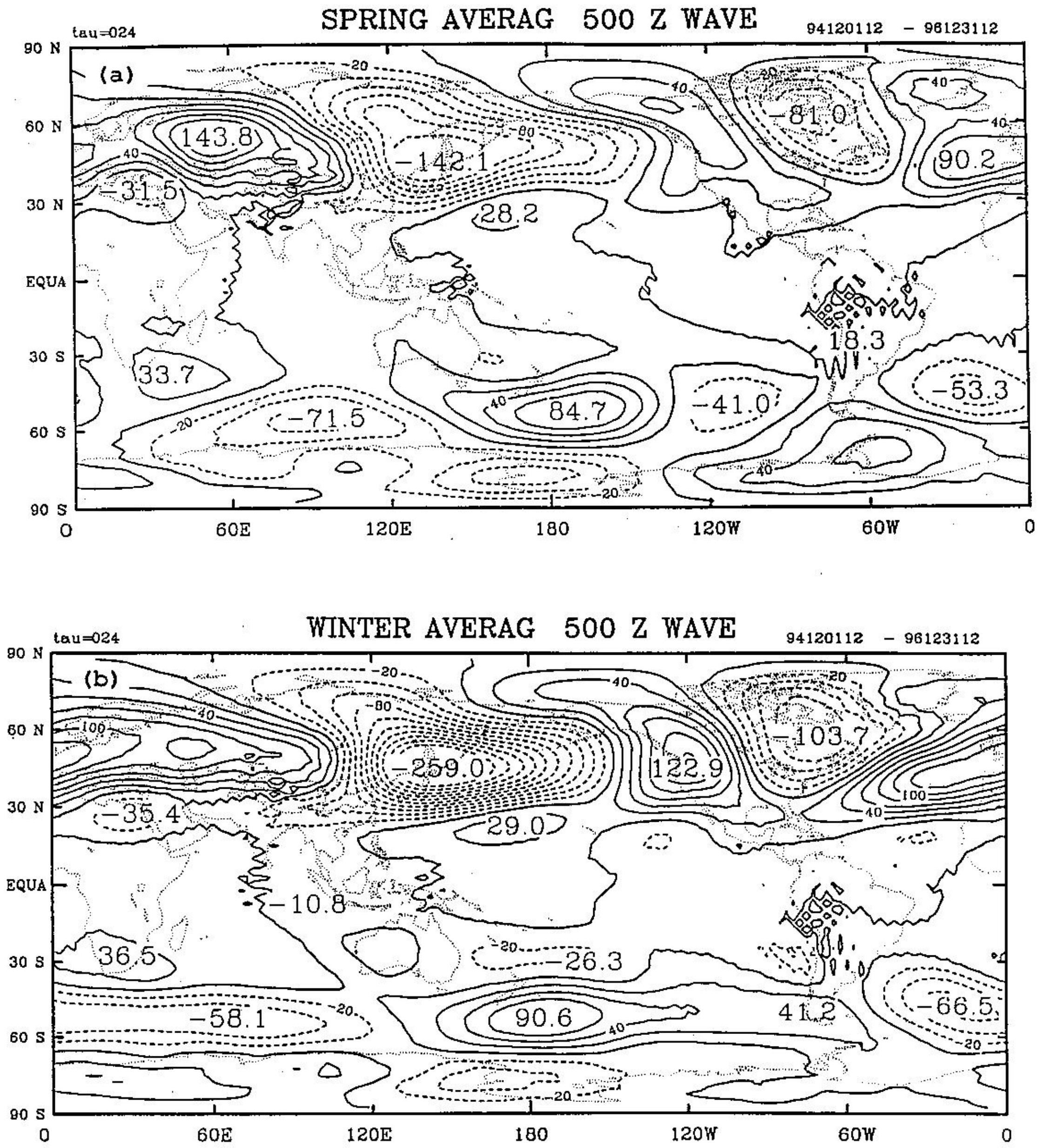


Fig. 2 Two-year mean stationary waves of 500 mb height from the GFS 24h forecast for (a) spring and (b) winter seasons.

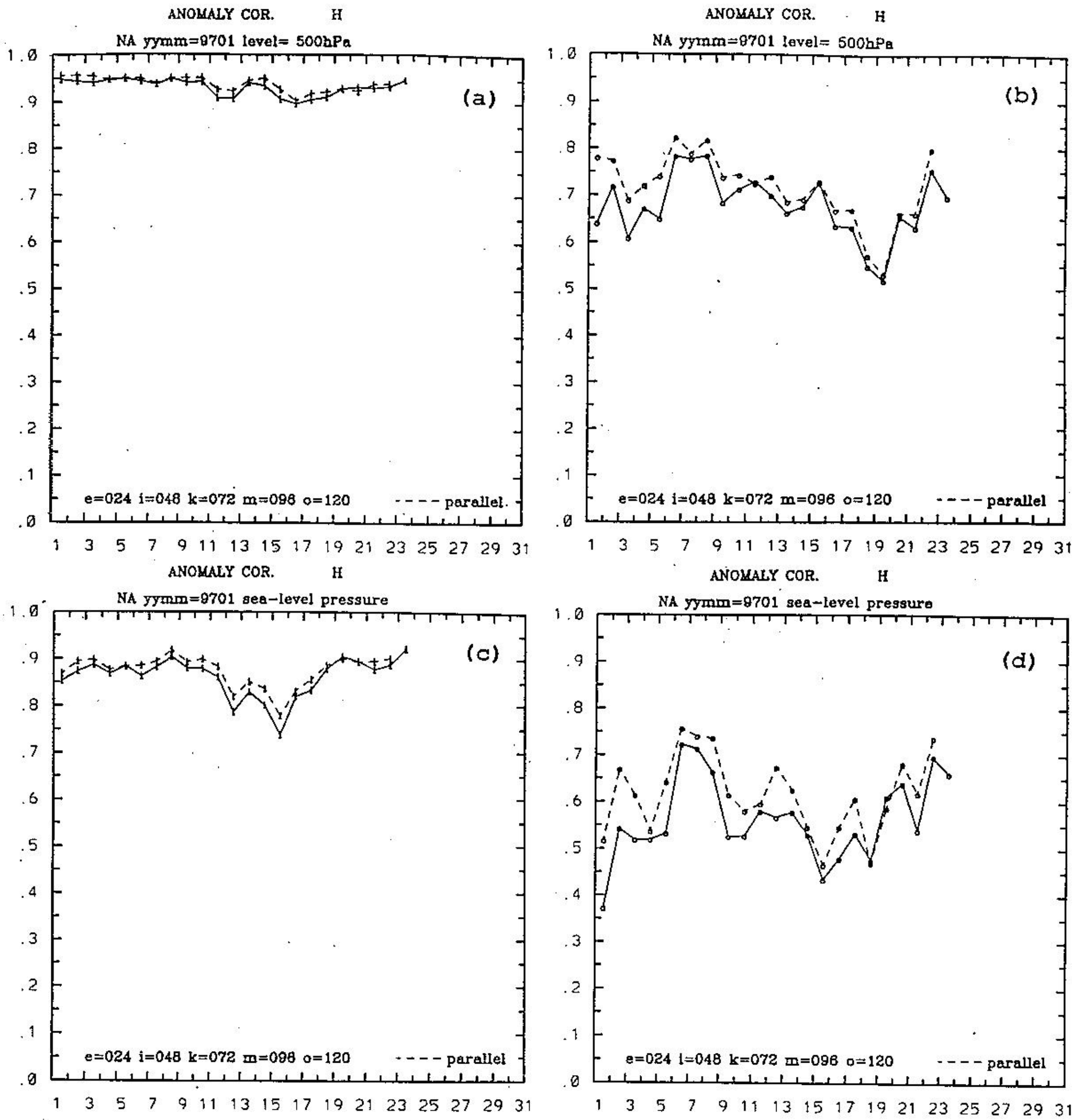


Fig. 3 Comparison of the T79 (solid) and T120 (dashed) GFS forecast scores of northern hemisphere anomaly correlation coefficients for (a) 48h 500 mb height forecast, (b) 48h sea level pressure forecast, (c) 500 mb height forecast, and (d) 120h sea level pressure forecast on 1-23 January 1997.

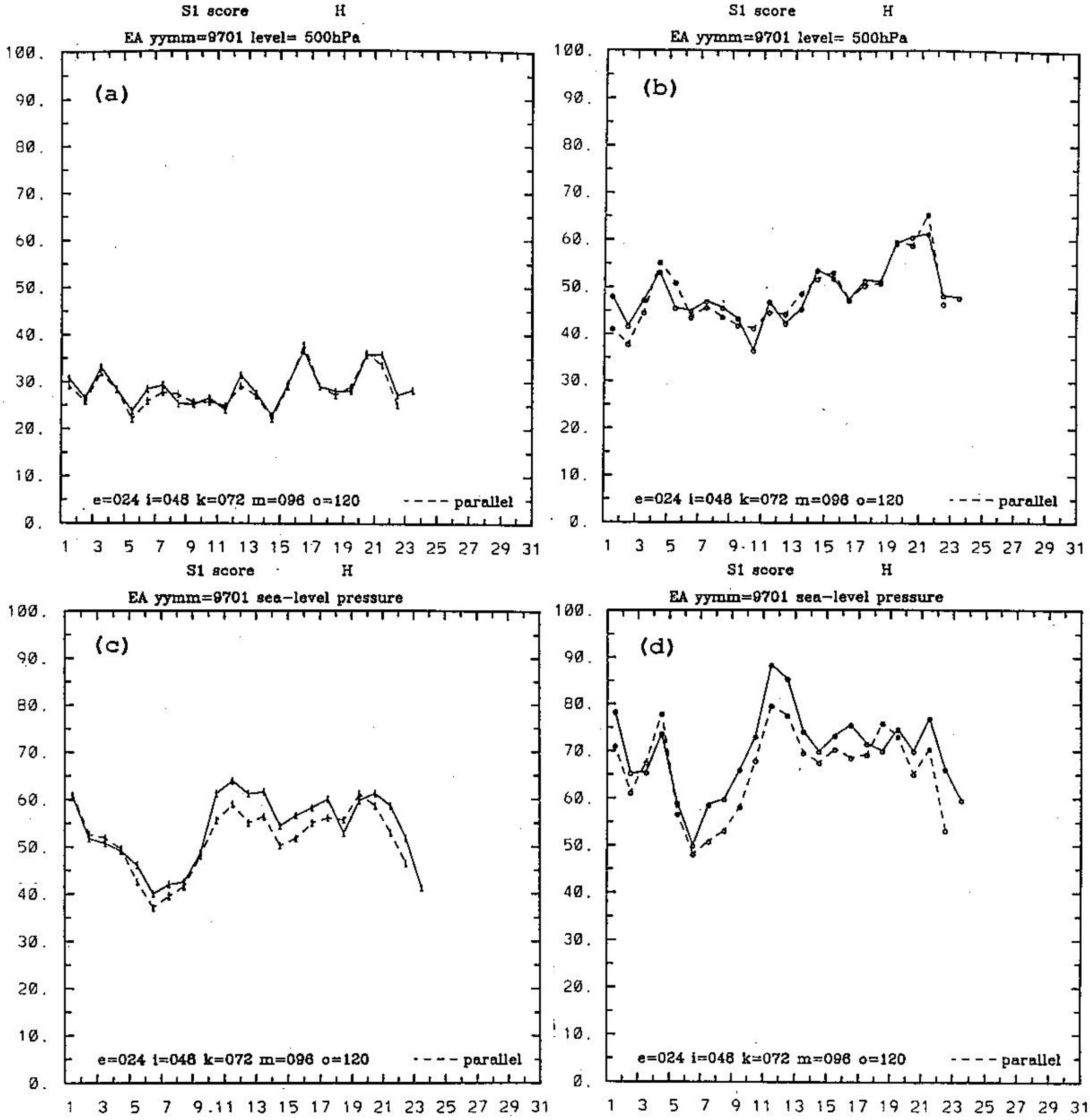


Fig. 4 Same as in Fig. 3, except for S1 scores.

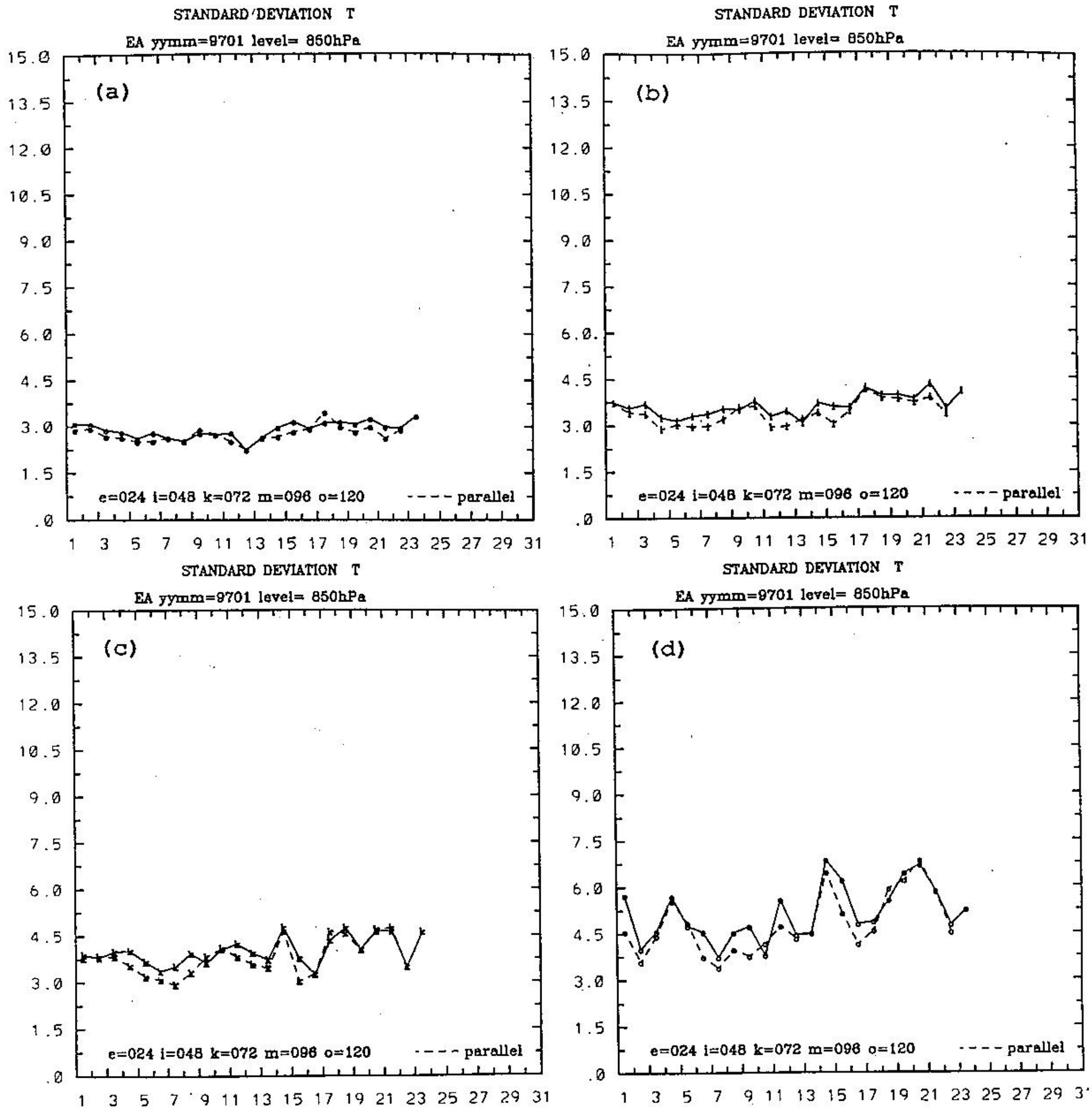


Fig. 5 Comparison of T79 (solid) and T120 (dashed) forecast scores of 850 mb temperature standard deviation for (a) 24h, (b) 48h, (c) 96h and (d) 120 forecast.

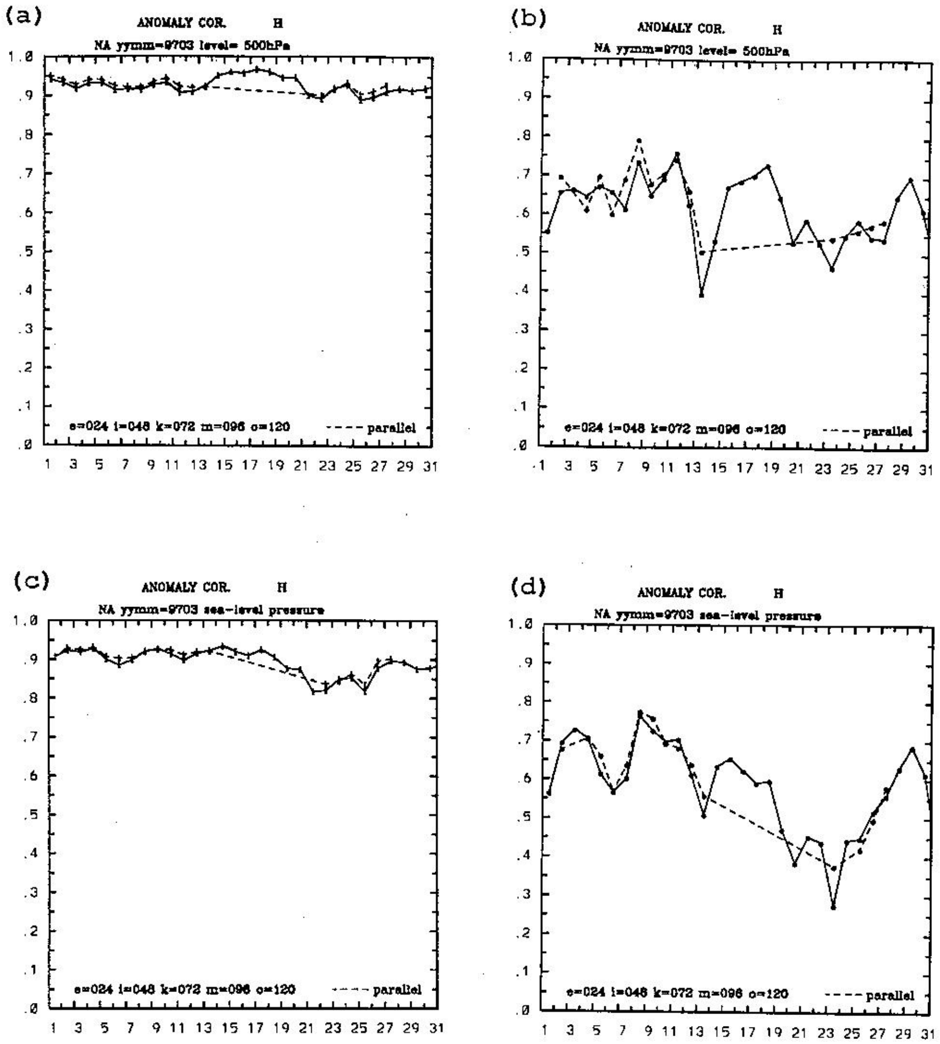


Fig. 6 Same as in Fig. 3, except for March 1997.

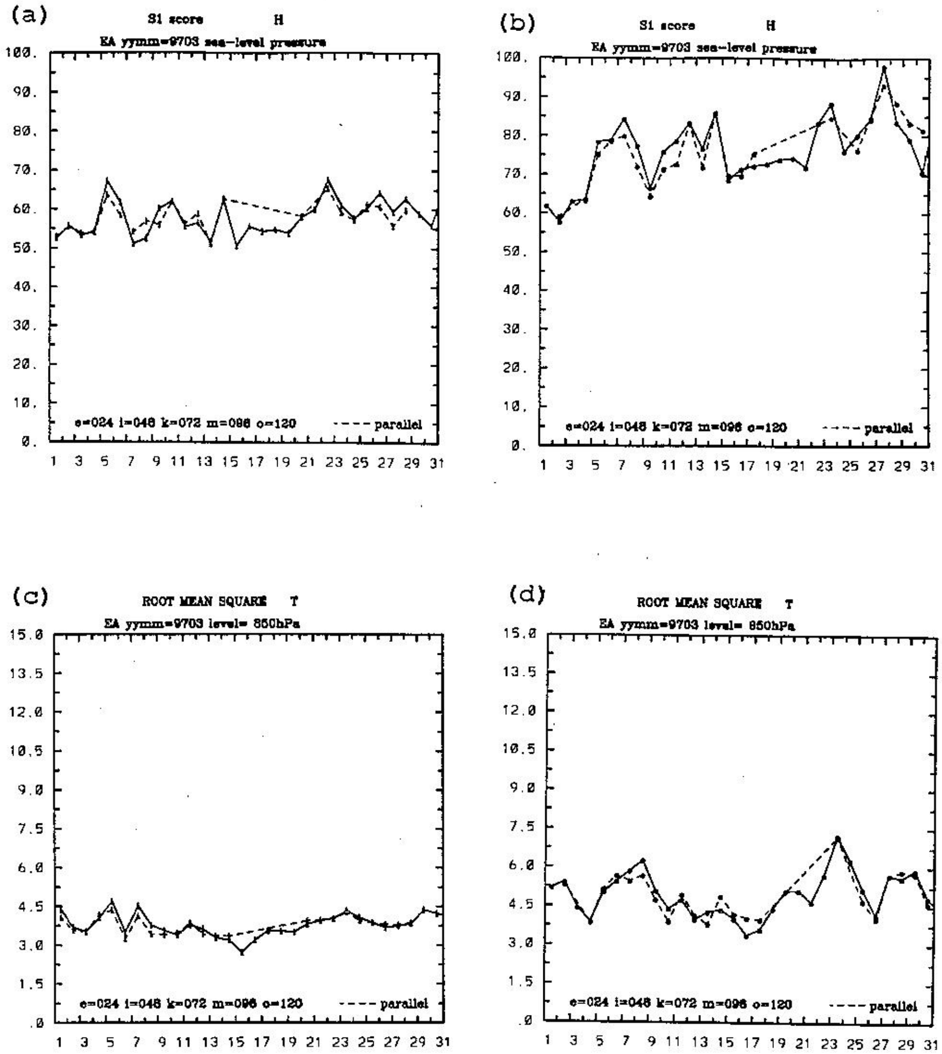


Fig. 7 Comparison of T79 (solid) and T120 (dashed) forecast scores of sea level pressure S1 scores for (a) 48h and (b) 120h forecast, and 850 mb temperature RMS for (c) 48h and (d) 120h forecast.

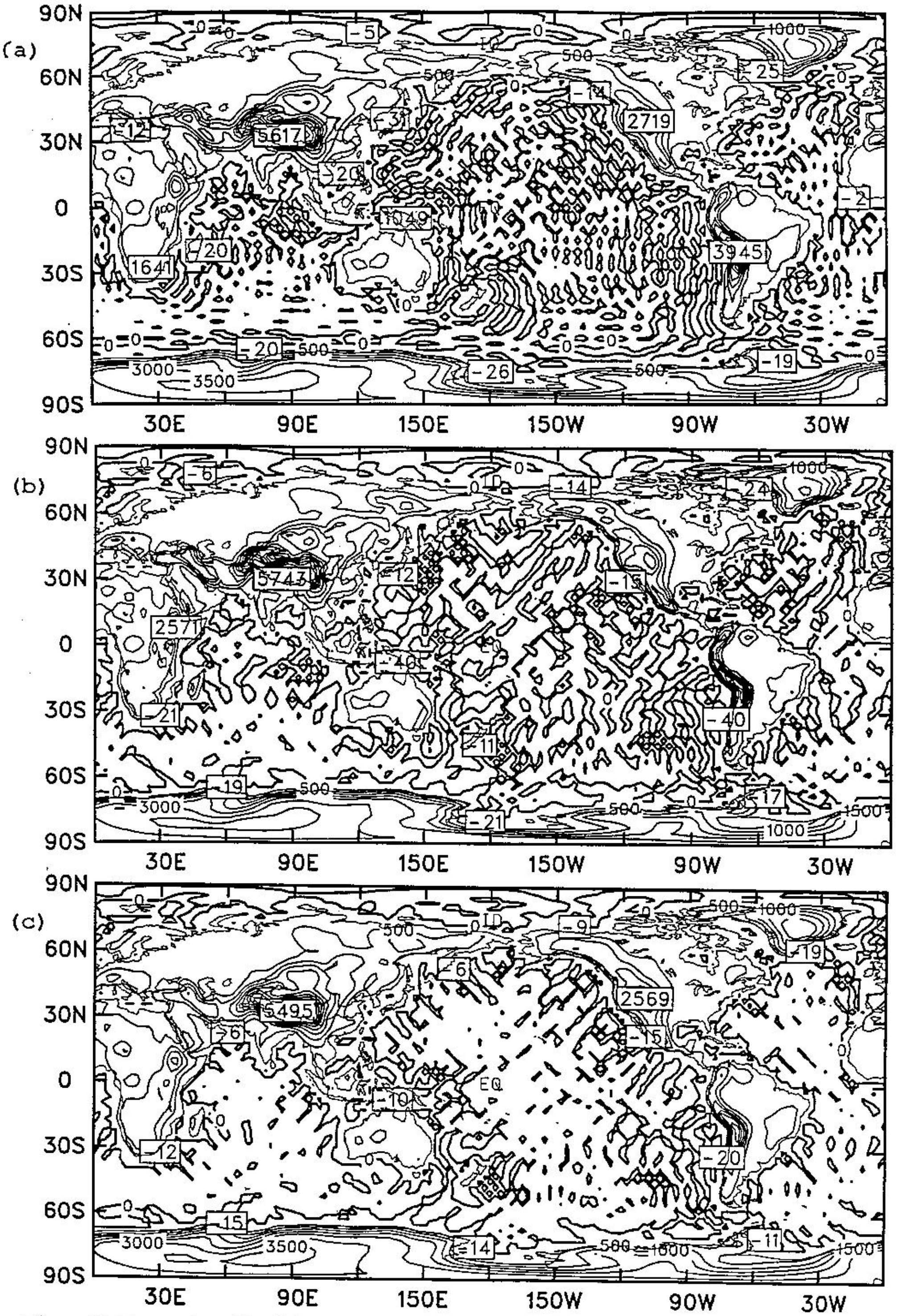


Fig. 8 Terrain field of (a) current T79 operational GFS, (b) T120 GFS created by the current method, and (c) T120 GFS created by the new method of applying a low-pass filter.

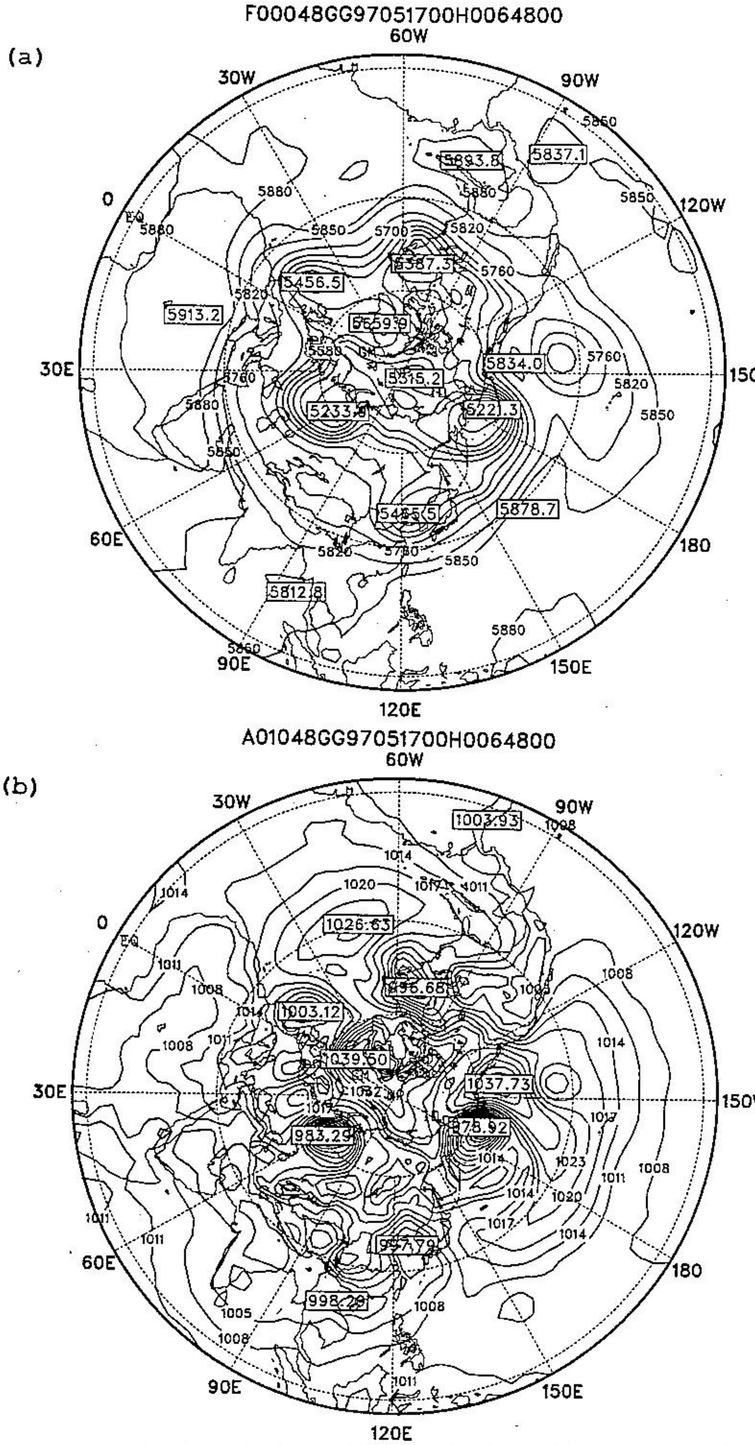
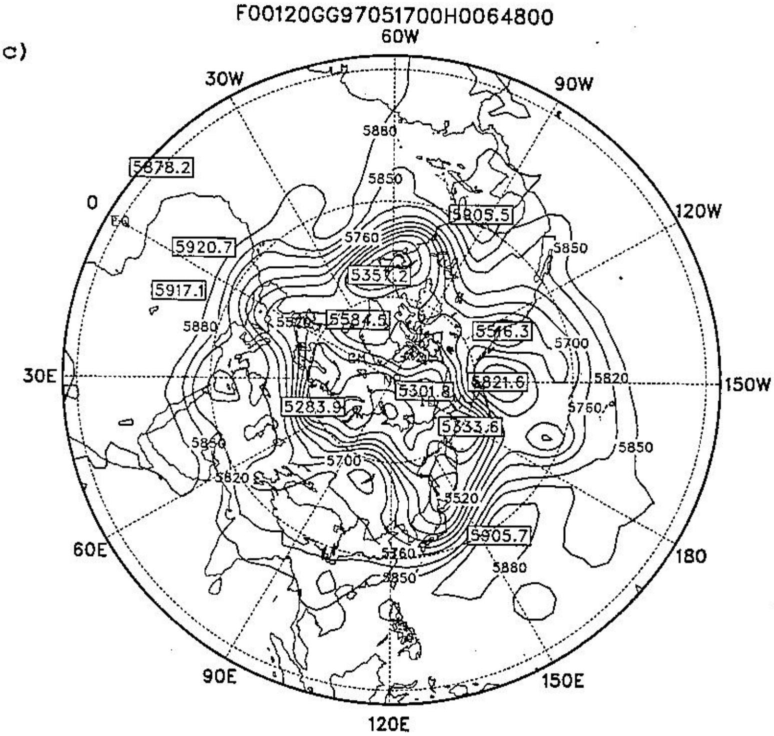


Fig. 9 Forecast fields of the T120 GFS from 00Z 17 May 1997 with unmodified terrain field and original cumulus parameterization for (a) 48h 500 mb height forecast, (b) 48h sea level pressure forecast, (c) 120h 500 mb height forecast, (d) 120h sea level pressure forecast, (e) 48h total precipitation forecast, and (f) 120h total precipitation forecast.

(c)



(d)

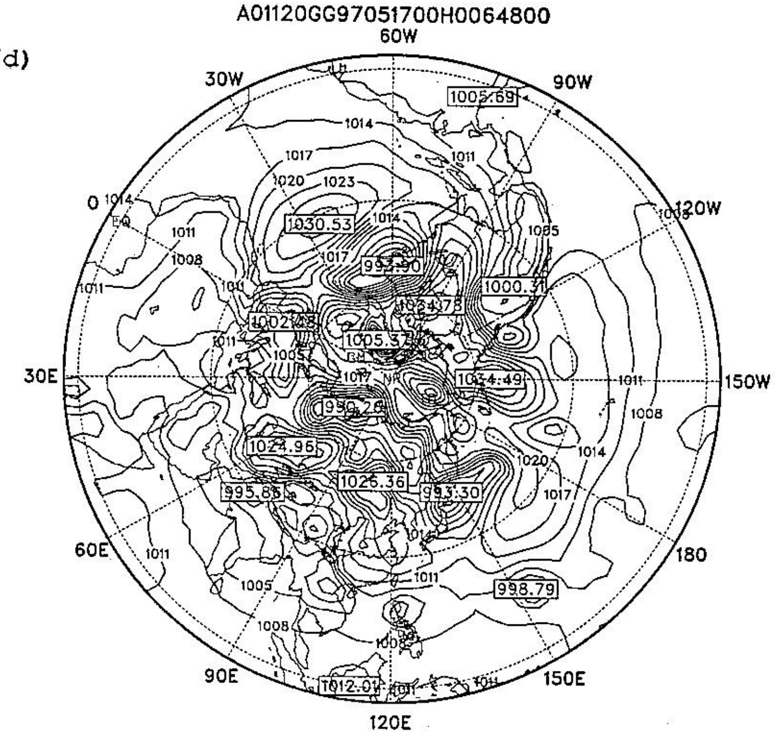


Fig. 9 (continued)

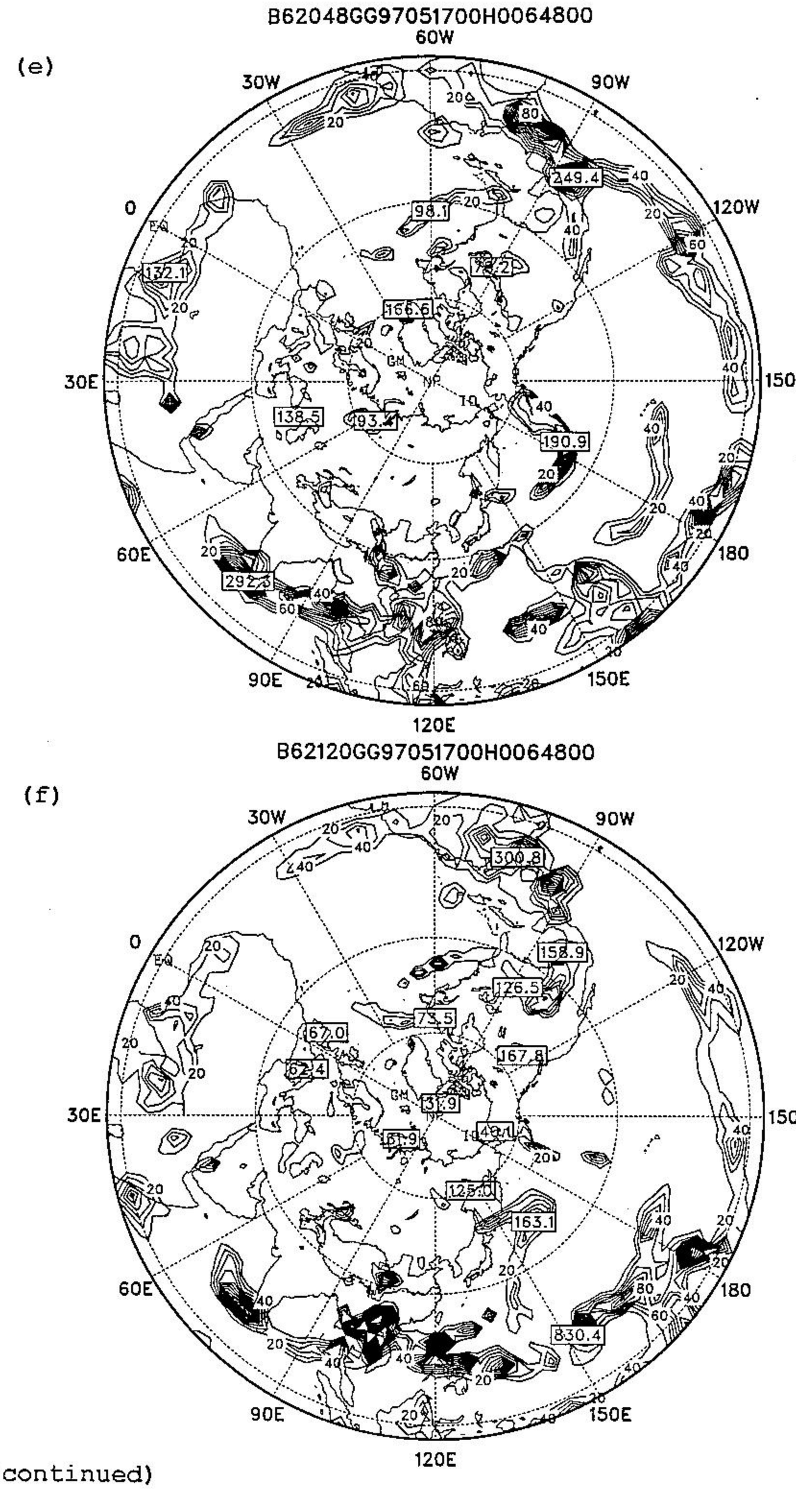


Fig. 9 (continued)

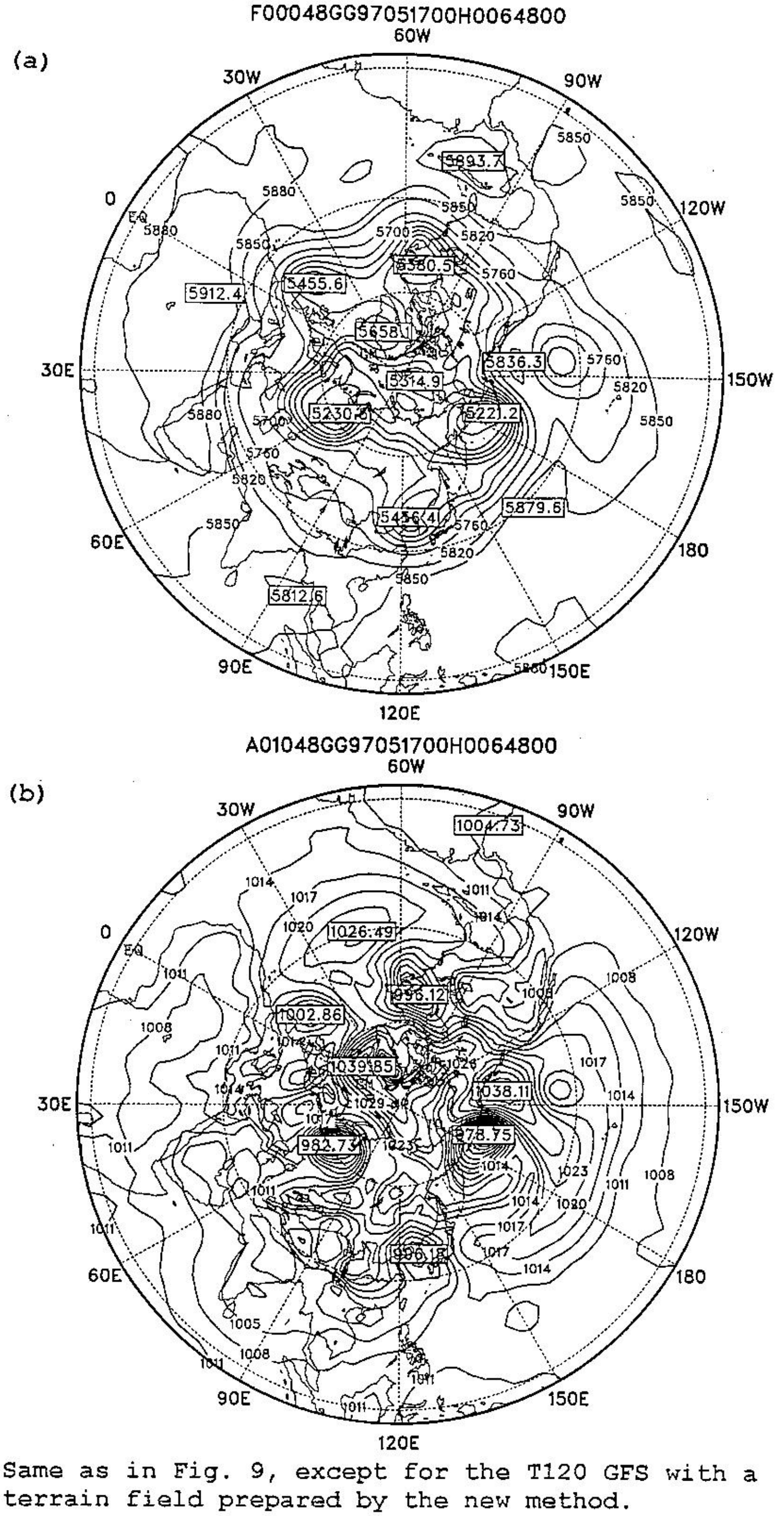
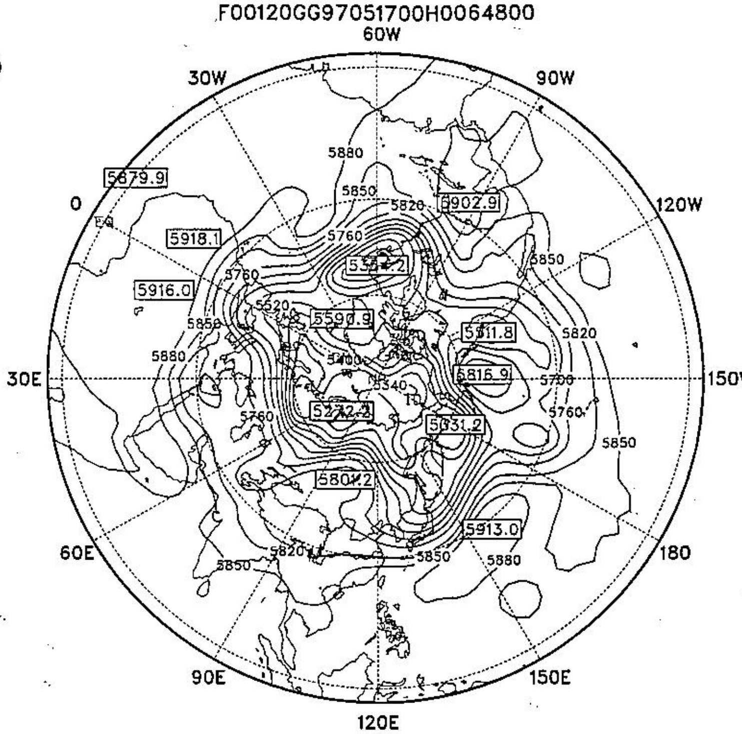


Fig.10 Same as in Fig. 9, except for the T120 GFS with a terrain field prepared by the new method.

(c)



(d)

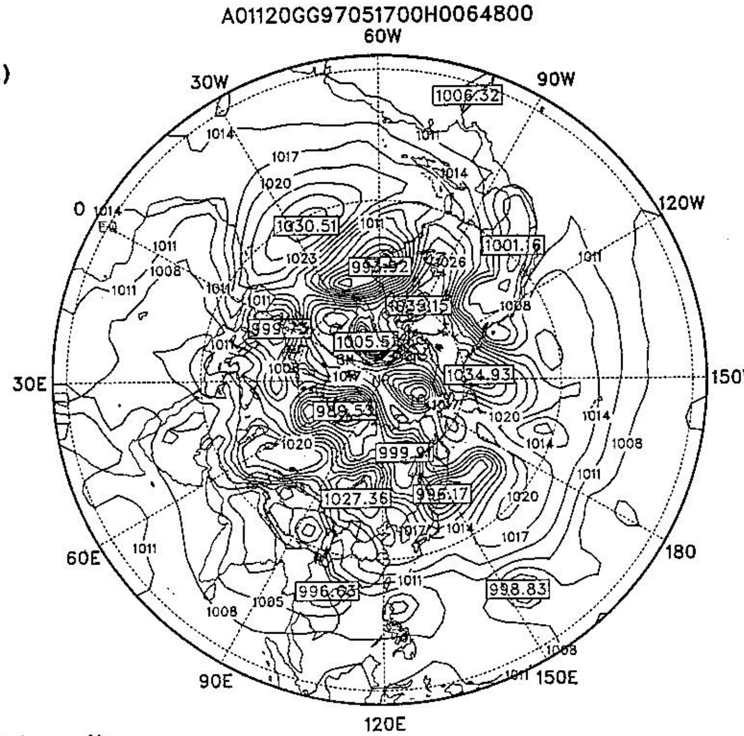
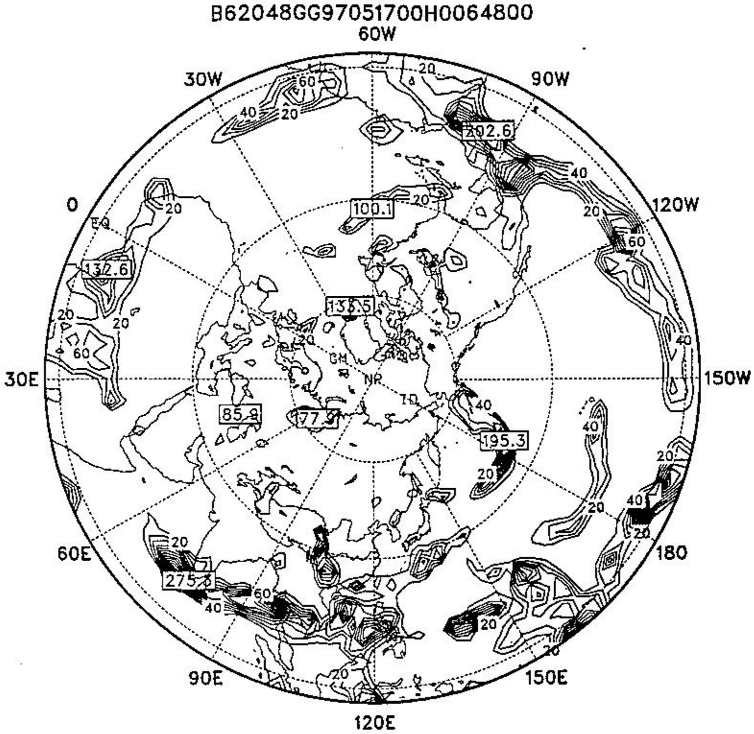


Fig.10 (continued)

(e)



(f)

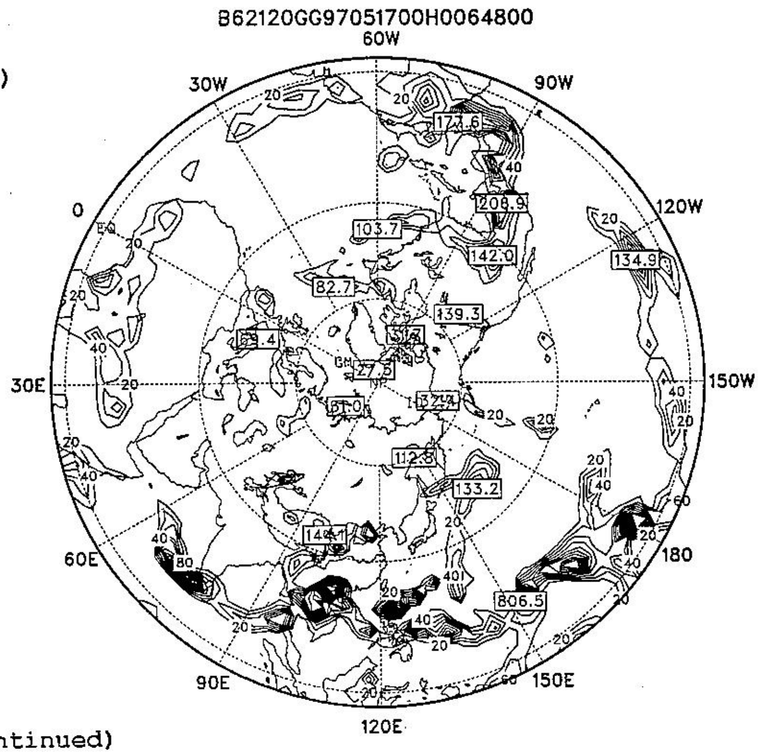


Fig.10 (continued)

97052200 MVOI ANAL

(a)

500 GEOP HEIGHT

(b)

SEA LEVEL PRESSURE

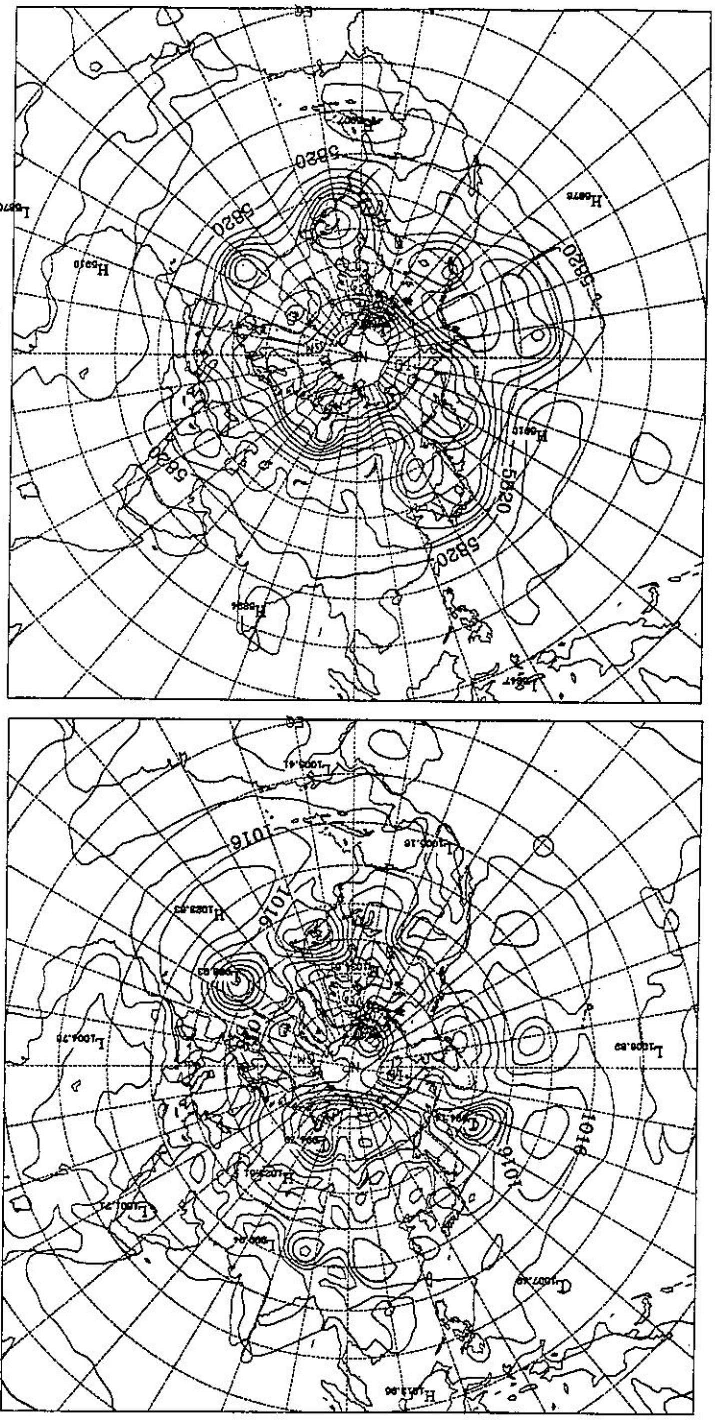


Fig.11 Analysis fields of (a) 500 mb height and (b) sea level pressure from the US Navy global model at 00Z 22 May 1997.

(a)

(b)

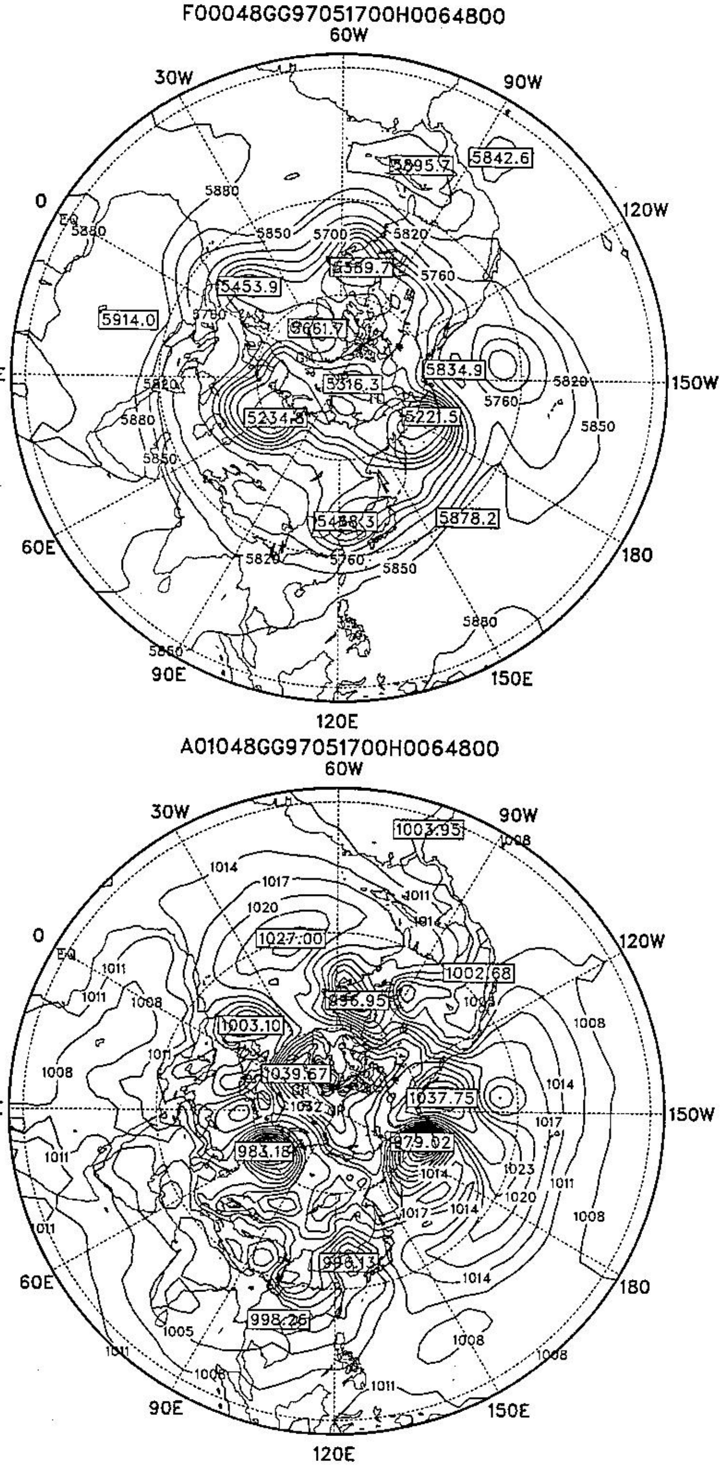


Fig.12 Same as in Fig. 9, except for the T120 GFS with the revised cumulus parameterization.

(c)

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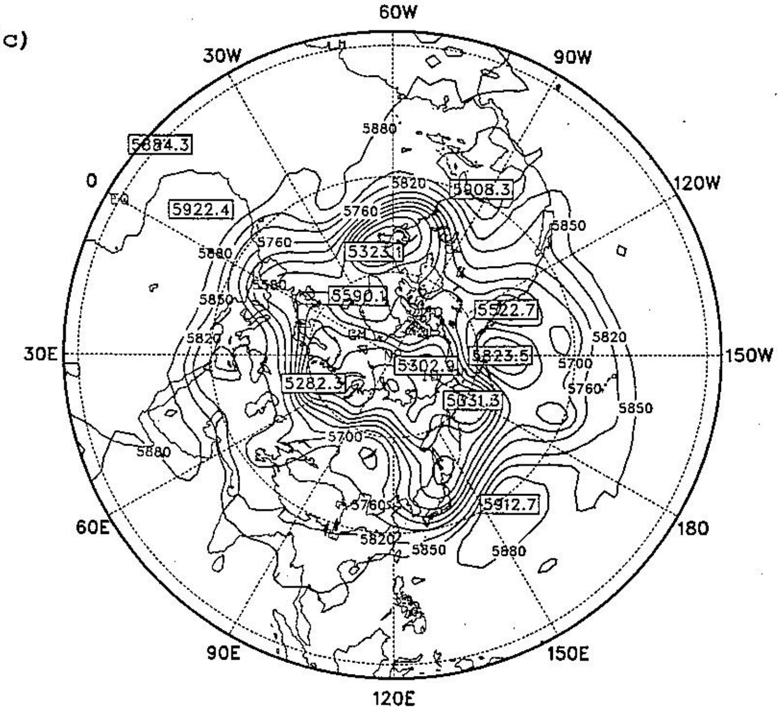

(d)

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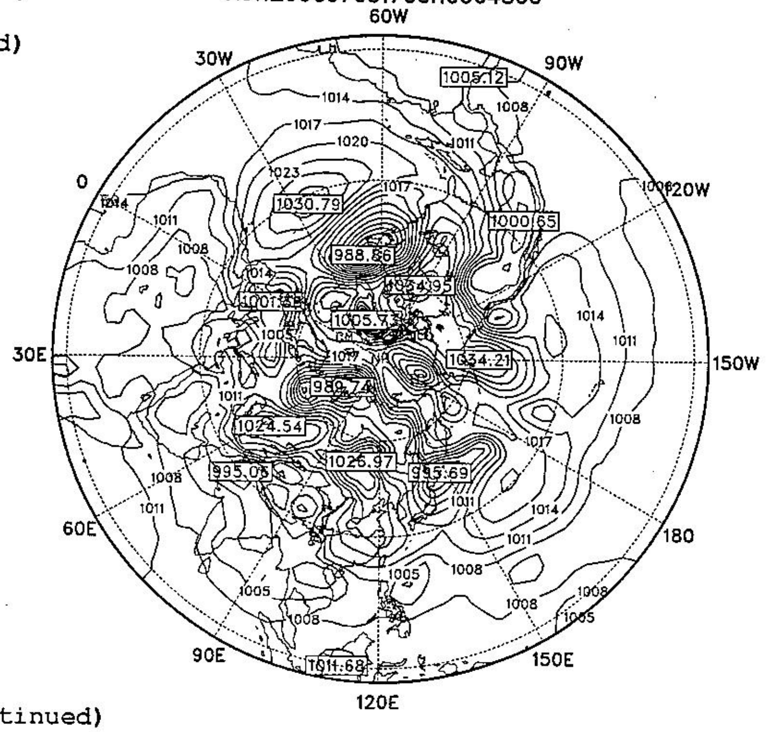

Fig.12 (continued)