交通部中央氣象局委託研究計畫成果報告

CWB 全球與區域波譜模式短期氣候預報能力之改進（一）

計畫類別：□國內　　■國外
計畫編號：MOTC-CWB-93-3M-02
執行期間： 93 年 2 月 1 日 至 93 年 12 月 31 日
計畫主持人：莊漢明
執行單位：METSOFT

中華民國九十三年十一月二十八日

Annual Report of 2004
For the first year project on the Improvement of CWB Global and Regional Spectral Models for Short-range Climate Prediction

Hann-Ming Henry Juang

November 28, 2004

Abstract

The major theme of this project has three folds. The first one is to implement prognostic cloud scheme into CWB global spectral model (GSM). It is known that precipitation is one of the major meteorological event even in climate prediction, and it is found that prognostic-type of cloud parameterization is better than traditional cumulus parameterization. The simple cloud scheme with one-type of cloud is enough for climate simulation for global model. In this report, it includes the method of the simple cloud scheme, the implementation steps in CWB GFS, and the test of TOGA CORE case in one-dimensional prognostic results and a full dimensional daily weather results

The results from the TOGA core show a positive improvement in terms of heating rate in vertical column as compared to observation. The weather test, though only three days shown here, indicates no de-gradation in all fields as compared to the original one without cloud scheme.

1. Introduction:

It is a major work for numerical model to keep improving its performance through the effort of research activities and implement to operational suites. The performance of the numerical model for operational suite has two aspects, one is the performance of the computational efficiency, another is the performance of the meteorological accuracy. In this project, we are going to work on performance of accuracy especially in prognostic cloud scheme; we have implemented prognostic cloud scheme into CWB GSM. With a better parameterization to be close to atmospheric features should give more accuracy of meteorological results.

Since Zhang et al. (1989) successfully reproduced the mesoscale structure and evolution of a 10–11 June 1985 squall line case using a three-dimensional model with a standard rawinsonde dataset, it has been recognized that inclusion of proper precipitation physics in a mesoscale model can lead to a significant improvement in the precipitation forecast. They argued that separate treatment of the convective portion with a cumulus parameterization scheme and the grid-resolvable portion with a prognostic cloud and precipitate scheme is the best approach for a mesoscale model. As greater computer resources have become available, prognostic cloud schemes for grid-resolvable precipitation have been incorporated into operational mesoscale models. For example, Belair et al. (1994) implemented a prognostic cloud and precipitate scheme into the Canadian regional finite-element model and successfully reproduced the mesoscale convective system studied by Zhang et al. (1989).

The prognostic cloud scheme provides promising results not only in regional model, most of the operational global model are used it with a simple or bulk form, such as NCEP GFS and ECMWF global model. There are several reasons for this. First, the global model resolution is increasing, and the prognostic scheme advects cloud substances all directions, that is more realistic than the parameterization of large-scale precipitation, which adjusts cloud property immediately with rainfall. However, due to the necessity of spin-up cloud water in cloud scheme with coarse resolution model, cumulus parameterization has to be used together with prognostic cloud scheme.

One of the difficulties in implementing a prognostic cloud scheme within a spectral model centers around the treatment of negative liquid species due to spectral decomposition. Some previous studies with spectral models worked around this difficulty by ignoring dynamical processes such as advection and diffusion processes for liquid species (e.g., Tiedtke 1993; Mannoji 1995). However, it is obvious that the advection of cloud species is important and cannot be ignored. And we have to implement it for CWB GSM and CWB RSM. In fact, it has been implemented into NCEP RSM (Juang and Kanamitsu 1994; Juang et al 1997), see Hong et al (1998) for cloud scheme.

Finally, the seasonal forecast has been operational in several centers, such as ECMWF EFS, and NCEP SFM (Kanamitsu et al, 2002). For Taiwan area, the global model with regional model, such as NSM here, may provide not only the large scale pattern of the seasonal trend, but also the mesoscale feature over the Taiwan area for our benefit to have better seasonal forecast as possible as we can.

2. Methods:

For the first year, we have implemented a simple cloud scheme into CWB GFS. The cloud schemes evaluated are classified according to the complexity of the microphysical processes (CLD*n*, the number of predicted water substance) included. Hereafter, the CLD1 scheme includes only the instantaneous removal of the super-saturation. This scheme uses the water vapor mixing ratio as its only prognostic variable. This is the current operational scheme for CWB GFS (Liou et al 1997) and recently developed CWB RSM (Juang et al 2003). CLD2 is the prognostic cloud scheme with ice physics developed by Sundqvist et al. (1989). In this scheme precipitate is diagnosed from the predicted clouds. The scheme was implemented into NCEP GFS recently. CLD2 is the one which we have implemented into CWB GFS for this year. Let's describe thos method from equation to cloud forcing. The prognostic equations for water vapor (q_v), cloud water/ice (q_{ci}), and snow/rain (q_{rs}) species are, respectively,

$$\frac{\partial q_v}{\partial t} = -u\frac{\partial q_v}{\partial x} - v\frac{\partial q_v}{\partial y} - \dot{\sigma}\frac{\partial q_v}{\partial \sigma} + F_{q_v}^{hdif} + F_{q_v}^{vdif} + F_{q_v}^{impl} + F_{q_v}^{\exp l} \qquad (1)$$

$$\frac{\partial q_m}{\partial t} = -u\frac{\partial q_m}{\partial x} - v\frac{\partial q_m}{\partial y} - \dot{\sigma}\frac{\partial q_m}{\partial \sigma} + F_{q_m}^{hdif} + F_{q_m}^{\exp l} \qquad (2)$$

And the thermodynamics equation should be

$$\frac{\partial \theta_p}{\partial t} = -u\frac{\partial \theta_p}{\partial x} - v\frac{\partial \theta_p}{\partial y} - \dot{\sigma}\frac{\partial \theta_p}{\partial \sigma} + F_\theta^{hdif} + F_\theta^{vdif} + F_\theta^{impl} + F_\theta^{\exp l} + F_\theta^{rad} \tag{3}$$

where the density temperature, θp, is given by

$$\theta_p = \theta_v \frac{1+q_v}{1+q_v+q_{ci}+q_{rs}} \tag{4}$$

and the virtual temperature, $\theta_v = (1 + 0.608q_v)\theta$.
All symbols in (1)–(3) follow the conventional notation, q_v is specific humidity, and q_m is specific cloud water. The *F*'s represent tendency terms as indicated by the superscript for the variable in the subscript: rad (radiation), vdif (vertical diffusion), hdif (horizontal diffusion), impl (heating due to subgridscale precipitation physics), and expl (heating due to grid-resolvable precipitation physics). The microphysical processes in the scheme contain condensation of water vapor into cloud water (ice) at water saturation, accretion of cloud by rain (ice by snow), auto-conversion of cloud to rain (ice to snow), evaporation (sublimation) of rain (snow), initiation of ice crystals, and sublimation or deposition of ice crystals. The expl terms in CLD1 can be expressed as

$$F_{q_v}^{\exp l} = E_c + E_r - C_b - C_g \tag{5}$$

$$F_{qm}^{\exp l} = C_b' + C_g - P - E_c \tag{6}$$

$$F_\theta^{\exp l} = \frac{L}{C_p \pi}\left(C_b + C_g - E_c - E_r\right) - \frac{L_f}{C_p \pi} P_{sm} \tag{7}$$

where Ec and Er are evaporation rates of cloud and rain, Cb and Cg are condensation rates of convection and grid-scale, and C'b is net condensation. P is precipitation rate from cloud and Psm is melting rate of snow. The details of them can be found in Zhao and Carr (1997) and Hong et al (1998).

For numerical stability, a split time step for each model column is applied on computing the fallout terms, so that precipitate does not cross over any vertical grid within a single loop of the calculation. Implementation of the prognostic cloud scheme necessitated several additional considerations. First, negative values of cloud water/ice crystals and snow/rain are set to zero *in gridpoint space (physics space)* before microphysical processes are computed. In other words, negative values in gridpoint space due to the vertical and horizontal advection, and horizontal diffusion calculations are eliminated. Note, however, that negative values that arise from the spectral representation are carried over during the model integration. With this treatment the negative values remain very small compared to the positive values. Second, a split time integration approach is applied for the microphysical processes. Since the CWB GSM and RSM employs a fairly large time step at a given grid size due to the implicit time integration scheme, the microphysical processes could produce an unreasonable evolution of clouds even though maintaining mass conservation for all the prognostic liquid species. This probably arises due to the fact that, with a relatively large time step for microphysics calculation, relatively fast processes (such as condensation and ice nucleation) are represented as slow processes while at the same time slow processes (such as sublimation/deposition, evaporation of raindrops) become relatively fast processes. To overcome the above limitation stemming from a large time step, it can be implemented a prognostic cloud scheme into a global model with the prescribed relaxation time, that is used to express condensation/evaporation and deposition/sublimation as finite but rapid microphysical processes.

3. Implementation

To have minima changes to the original code, no prognostic variables are added, the cloud water variable is using specific humidity together. Instead of introducing extra variable, an integer is introduced to control which version of cloud scheme to integrate, which is ncld, and dimension for specific humidity is lev*ncld, where lev is number of vertical layer. When ncld=1, it is original large-scale precipitation, no cloud water will be prognostic variable, when ncld=2, the simple CLD1 cloud scheme as described above is used, and they are located at the lev+1 to lev*ncld in prognostic variable of specific humidity.

For cold start, there is no cloud water, so all specific cloud water are zero, but there are restart variable introduced for physics variables for three time level to do integration in cloud scheme. All dynamic codes related to specific humidity are modified to have lev*ncld, so the codes can be use for original large-scale precipitation, and ncld>1 cloud schemes.

First, we coded ncld into the dimension for specific humidity insides of all dynamics codes, including linear/nonlinear forcing and spectral transformation etc. A run with ncld=1 as modified code and a run with the original code are compared. They are bit reproducible, it indicates there are bugs free after introducing ncld. Second, we initialized cloud water with zero values and run with ncld=2, the result is also bit-reproducible. The final test is to run with cloud scheme with ncld=2, after helps from CWB for two bugs fixed, the result shows reasonable rainfall. Table 1 shows the details of the changes.

4. Result

The results from this report contain two parts; the first part is a one-dimensional test on TOGA CORE data from 19 December 2003 to 9 January 2004. The integration time step is 10 min, the large scale data provided advection for T and q. Two experiments of this configuration are conducted, ncld=1 and ncld=2. The results are compared with observation, which is obtained from 30 min intervals of observed data, and is interpolated to 10 min to compare with model outputs.

Figure 1 shows precipitation rate in every 10 min during the entire experimental period. The left hand panels are from ncld=1 as indicated by cwb, the righ hand panels are from ncld=2 as indicated by Micro cloud. Upper panels labeled as (a) are total precipitation in mm/day for every time step in 10 min from observation in black and model in red. Bottom panels labeled as (b) are the same as (a) but observation in black, covection rain in green and grid-scale rain in purple. The results show that ncld=2 has much reasonable rainfall as compare to observation. The excessive rainfall over Dec 25 to Dec29 from the ncld=1 experiment indicates a unreasonable behavior of large-scale precipitation scheme, however, ncld=2, the implemented cloud scheme, provides a reasonable, not-excessive, rainfall over that period.

Figure 2 shows total heating rate during the entire period in every time step. Left panels are from ncld=1 as labeled with cwb and right panels are from ncld=2 as labeled with Micro cloud. Upper panels are heating rate (K/day) labeled by (a) from observation. Bottom panels (b) are the same as (a) but from model results. Figure 3 shows the heating rate of convection and grid-scale at a given location at (336.5E, 9N). Upper panels are from ncld=1 as labeled with cwb. Bottom panels are from ncld=2 as labeled with Micro cloud. Left panels are convective heating rate and right panels are grid-scale heating rate, in every 10 min. Both Figs 2 and 3 have the same conclusion as that in Fig. 1, that ncld=2 has a better and reasonable results, especially during the period of Dec25 to Jan09.

The second part is from an arbitrary weather type of test. As we know that NCLD=1 is the same as the original large-scale precipitation which should be the same as the original model result, and NCLD=2 is the explicit cloud scheme which replaces large-scale precipitation, however, it has only one type of cloud-water existed at a given grid point.

Figure 4 show the 24 hr forecasted mean-sea-level-pressure (MSLP) in hPa from (a) ncld=1 and (b) ncld=2 with contour interval of 5 hPa. The pattern and local maxima and minima labeled as H and L are similar to each other. It implies that the newly implemented cloud scheme didn't influence too much as the total mean field in terms of MSLP. It is as expected which can be used to measure whether it is a successful implementation. Figure 5 shows the total rainfall after 24 hr integration, again the pattern and local values are proximity between ncld=1 and ncld=2. Note that, ncld is bit reproducibility as compare to the model code without introduced ncld.

Figures 6 and 7 as the same as Figs. 4 and 5, respectively. The same conclusion can be found from Figs. 6 and 7 as the same as Figs. 4 and 5. There is no de-gradation of the implementation of ncld=2 and from the one-dimensional test of TOGO core, we can expect that ncld=2 will be a better and reasonable cloud scheme for CWB GFS. The further testings and comparisons in statistical values will be performed in the following years.

6. Conclusion

To improve climate forecast, better model physics, which used to resolve the model sub-scale physics, are required. The most significant model physics for weather and climate is precipitation, and we know the prognostic cloud scheme is better than the large-scale precipitation while the model resolution is growing higher and higher. The results from this report show the same conclusion.

Though the general results from the weather range of the forecast shows there is similar results from the original one, but the features and structure of the precipitation are consistent better than the original parameterization of large-scale precipitation. The TOGA CORE one-dimensional test shows a positive result from the newly-implemented cloud scheme. These results conclude a successful implementation of the explicit cloud scheme. It is unclear whether explicit cloud scheme with only one prognostic cloud water is enough or not, the further more cloud water types as ncld=3 and ncld=5 may be implemented into CWB RSM, and possible in CWB GFS to examine its sensitivities and necessity for global models.

References

Belair, S., D.-L. Zhang, and J. Mailhot, 1994: Numerical prediction of the 10–11 June 1985 squall line with the Canadian regional finite-element model. *Wea. Forecasting,* **9,** 157–172.

Hong, S.-Y., H.-M. H. Juang, and Q. Zhao, 1998: Implementation of prognostic cloud scheme for a regional spectral model. *Mon. Wea. Rev.*, **126**, 2621-2639.

Juang, H.-M. H., S.-Y. Hong, and M. Kanamitsu, 1997: The NCEP regional spectral model: An update. *Bull. Amer. Meteoro. Soc.*, **78**, 2125-2143.

Juang, H.-M. H., and M. Kanamitsu, 1994: The NMC nested regional spectral model. *Mon. Wea. Rev.*, **122**, 3-26.

Juang, H.-M.H., C.-H. Shiao, and M.-D. Cheng, 2003: The Taiwan Central Weather Bureau regional spectral model for seasonal prediction: multi-parallel implementation and preliminary result. *Mon. Wea. Rev.*, **131**, (accepted).

Kanamitsu, M., A. Kumar, H.-M.H. Juang, J.K. Schemm, W. Wu, F. Yang, S.-Y. Hong, P. Peng, W. Chen, S. Moorthi, and M. Ji, 2002: NCEP dynamical seasonal forecast system 2000. *Bulletin Amer. Metero. Soc.*, 83, 1019-1037.

Liou, C.-S., J.-H. Chen, C.-T. Terng, F.-J. Wang, C.-T. Fong, T. E. Rosmond, H.-C, Kuo, C.-H. Shiao, and M.-D. Cheng, 1997: The second-generation global forecast system at the Central Weather Bureau in Taiwan. *Wea. Forecasting*, **12**, 653-663.

Lin, Y.-L., R. D. Farley, and H. D. Orville, 1983: Bulk parameterization of the snow field in a cloud model. *J. Appl. Meteor.,* **22,** 1065–1092.

Mannoji, N., 1995: An explicit cloud predicting scheme implemented in the Florida State University global spectral model and its impact. *J. Meteor. Soc. Japan,* **73,** 993–1009.

Sundqvist, H., E. Berge, and J. E. Kristja´nsson, 1989: Condensation and cloud parameterization studies with a mesoscale numerical weather prediction model. *Mon. Wea. Rev.,* **117,** 1641–1657.

Tiedtke, M., 1993: Representation of clouds in large-scale models. *Mon. Wea. Rev.,* **121,** 3040–3061.

Zhang, D.-L., E.-Y. Hsie, and M. W. Moncrieff, 1988: A comparison of explicit and implicit predictions of convective and stratiform precipitating weather systems with a meso-beta scale numerical model. *Quart. J. Roy. Meteor. Soc.*, **114,** 31–60.

Zhao C., and F. Carr, 1997: A prognostic cloud scheme for operational NWP models. Mon. Wea. Rev., 125, 1931-1953.

Table 1. Listing of all code changes.

control ncld=1 or 2	: include/param.h	
variables with lev*ncld	: include/grid.h	qt, qp
	: include/spec.h	qnew, qold, qten, qrefs
	: model/intgrt.f	qvadv, qvadvv, qvadvu, qbar
routines with ncld	: getrdy incrini gather_spec scatter_spec sigful outflds joinrs joinsr ujlinrs ujoinsr tranrs transr hdiffu aimadv tendget intgrt gridnl diabat vstruc	
new variables for restart	: include/phygrid.h common/phyncld/ ftp, fqp, fpdp, ftp1, fqp1, fpsp1	
new routines for transform	: rstrantq rstrandz	
new routines for cloud scheme	: gscond precpd fpvs (fpvs is called by gscons and precpd) (gscond and precpd are called by diabat)	

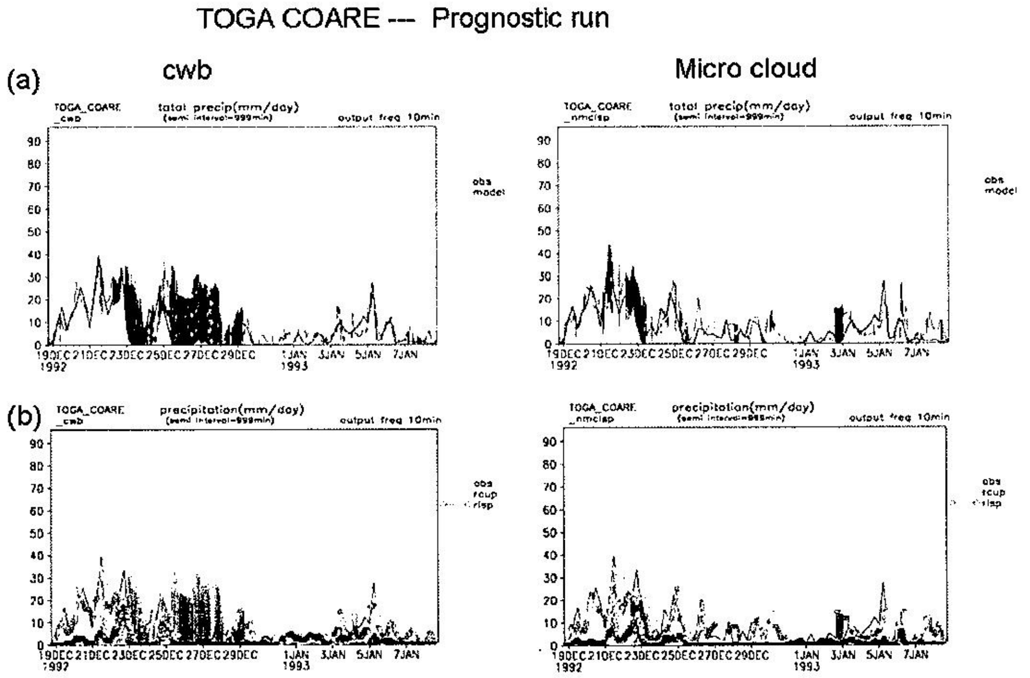
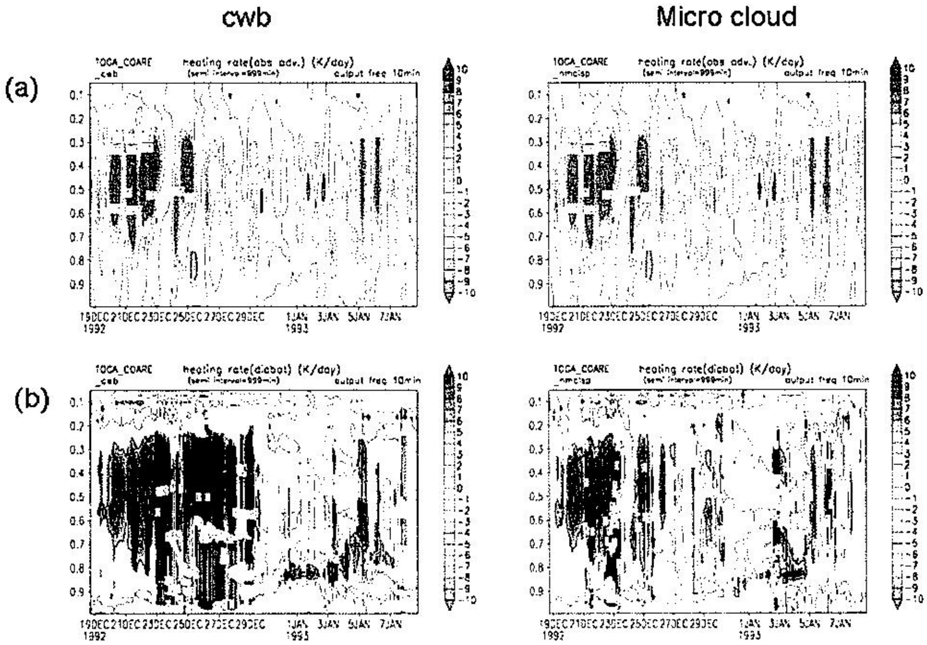


圖1(a)二個版本模擬的總降水(紅線)與觀測值(黑線)之比較。

(b)二個版本模擬的積雲降水(綠線)與網格尺度降水(紫線)。

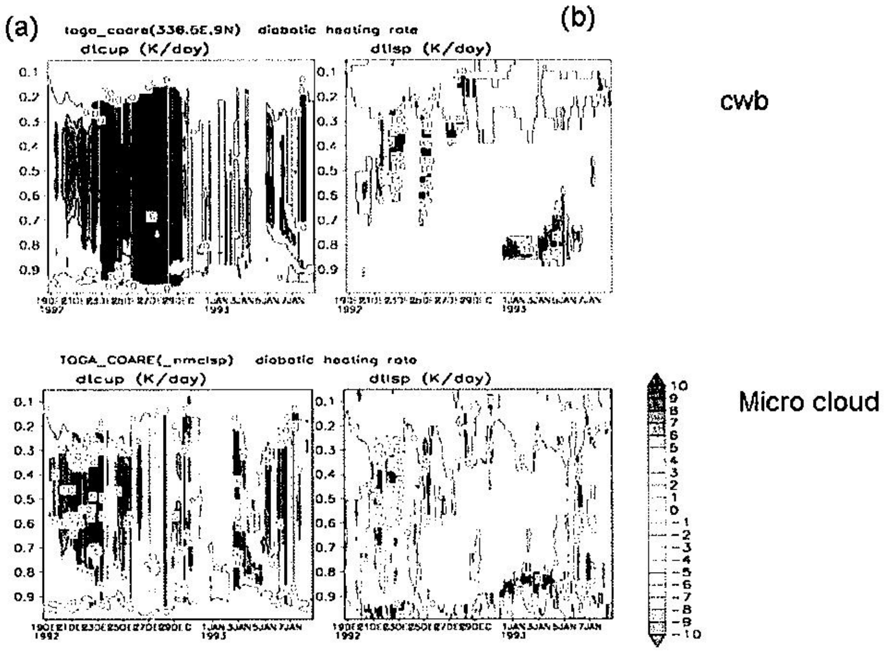
Fig. 1. The left hand panels are from ncld=1 as indicated by cwb, the righ hand panels are from ncld=2 as indicated by Micro cloud. Upper panels labeled as (a) are total precipitation in mm/day for every time step in 10 min from observation in black and model in red. Bottom panels labeled as (b) are the same as (a) but observation in black, covection rain in green and grid-scale rain in purple.



(a)觀測提供之溫度場大尺度作用力(水平平流及垂直平流)。

(b)二個版本模擬的非絕熱加熱率(cup+lsp+pbl)於時間及垂直方向的分布。

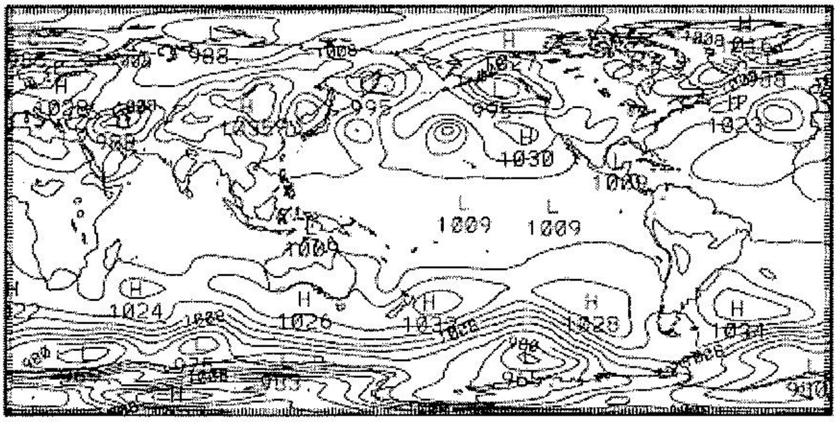
Fig. 2. Left panels are from ncld=1 as labeled with cwb and right panels are from ncld=2 as labeled with Micro cloud. Upper panels are heating rate (K/day) labeled by (a) in every time step, 10 min, from observation. Bottom panels (b) are the same as (a) but from model results.



二個版本模擬的(a)積雲降水加熱率及(b)網格尺度加熱率於時間及垂直方向的分布。

Fig. 3. Upper panels are from ncld=1 as labeled with cwb. Bottom panels are from ncld=2 as labeled with Micro cloud. Left panels are convective heating rate and right panels are grid-scale heating rate, in every 10 min at a give point at (336.5E, 9N).

(a) MSLP (hPa) NCLD=1 after 24hr Forecast



(b) MSLP (hPa) NCLD=2 after 24hr Forecast

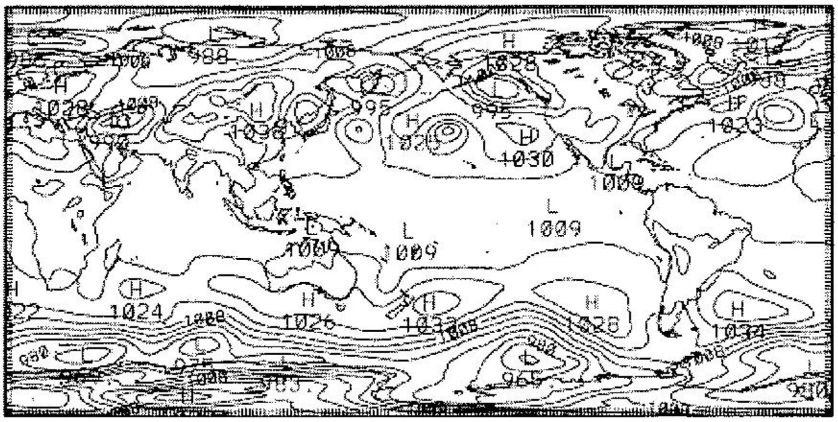
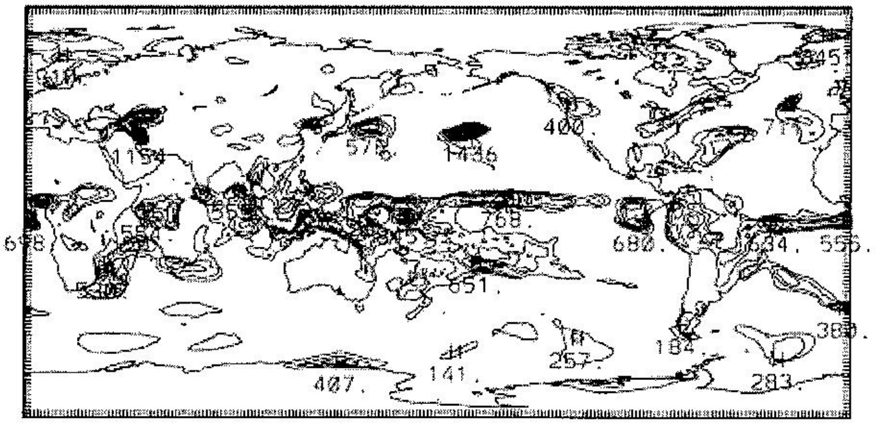


Fig. 4. Mean sea level pressure in hPa from experiments of (a) ncld=1 and (b) ncld=2 after 24 hr forecast. Contour interval is 5 hPa.

(a) 24hr accumulated rainfall NCLD=1 after 24hr Forecast



(b) 24hr accumulated rainfall NCLD=2 after 24hr Forecast

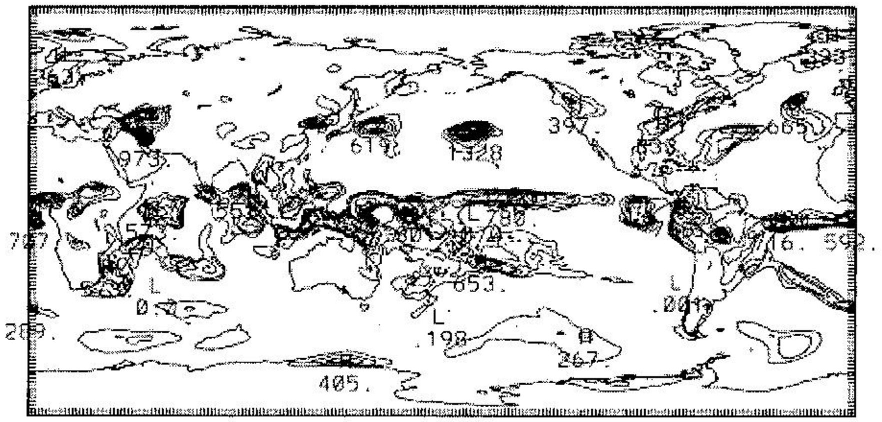
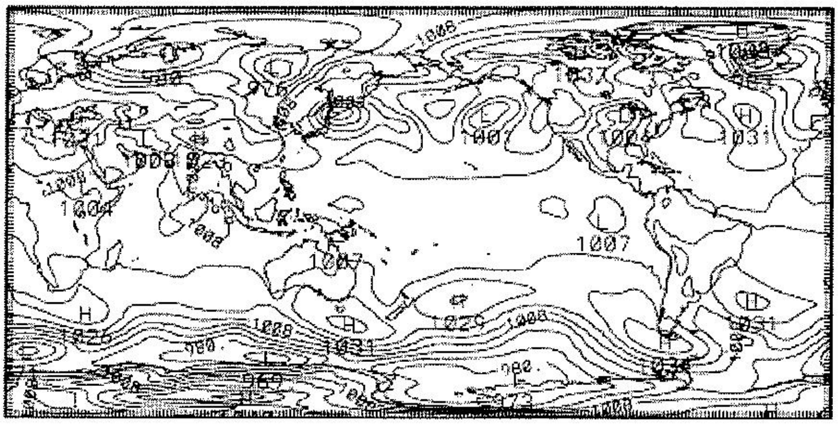


Fig. 5. 24 hr accumulated total rainfall in (mm/month) from (a) ncld=1 and (b) ncld=2 with contour intervals of 90 mm/month after 24 hr integration.

(a) MSLP (hPa) NCLD=1 after 72 hr Forecast



(b) MSLP (hPa) NCLD=2 after 72 hr Forecast

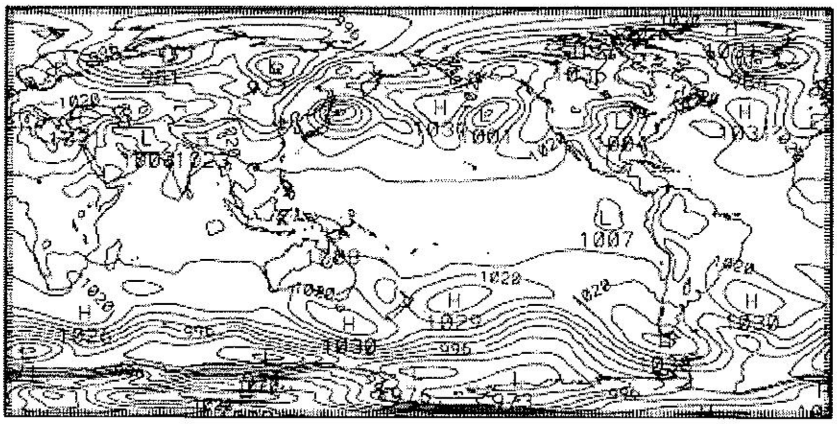
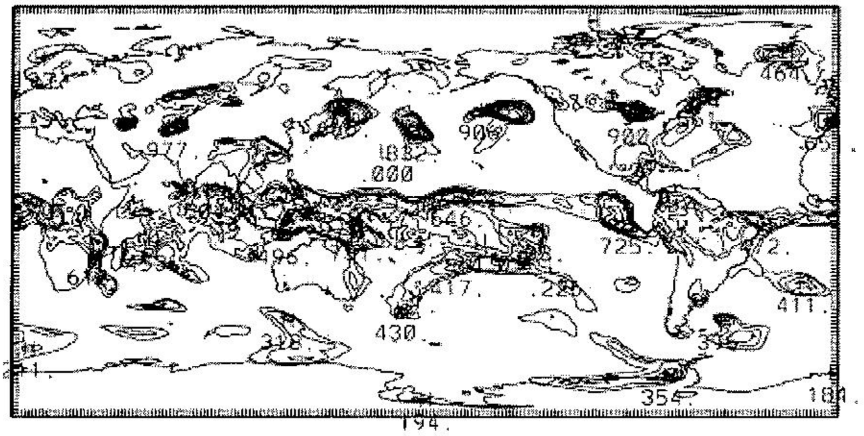


Fig. 6. The same as Fig. 4, except after 72 hr integration.

(a) 24hr accumulated rainfall NCLD=1 after 72hr Forecast



(b) 24hr accumulated rainfall NCLD=2 after 72hr Forecast

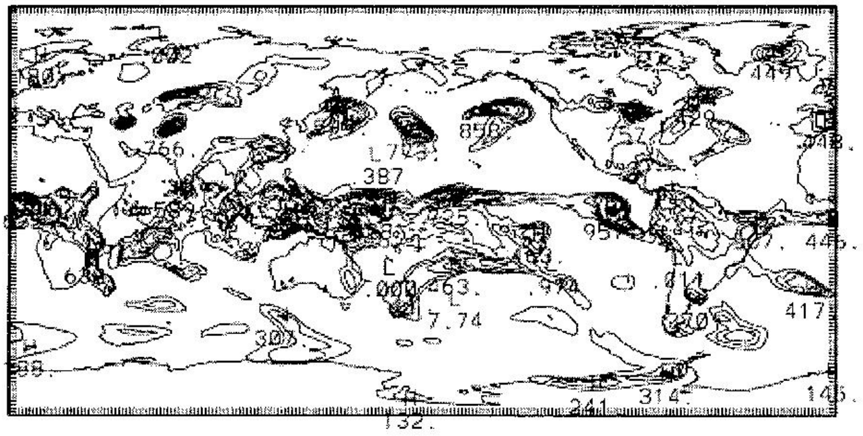


Fig. 7. The same as Fig. 5, except after 72 hr integration.