A new operational medium-range numerical weather forecast system of China

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Abstract

A new global medium-range assimilation and prediction system T213L31 has been developed in National Meteorological Center of China Meteorological Administration (NMC/CMA) and put into full operation in place of previous operational system (T106L19) on September 1st 2002. T213L31 is the first operational medium-range weather forecast system of NMC/CMA that runs on the massive parallel computer and runs twice a day, one from 00 UTC up to 72h range and the another from 12 UTC up to 10 days, and its operational running marks the new stage of the operational medium-range numerical weather forecast of the NMC/CMA.

1 Introduction

As the important technical base of meteorological forecasts, development and improvement of numerical forecast including improving data analysis and assimilation technique to produce better initial data, fining and perfecting physical processes, increasing model resolutions are the most efficient methods to enhance the whole meteorological forecast quality. In 1990s, rapid development of parallel computational techniques and large scale parallel computers provide conditions for realizing numerical forecast model with higher resolutions and more complex physical processes. Many developed countries such as ECMWF (European Centre for Medium-Range Weather Forecasts), America, Canada, England, France, Germany, Japan and Australia devote themselves to accelerate the development of operational numerical forecast systems. China Meteorological Administration (CMA) also realize that it is important to further develop its numerical forecasts with the new techniques continuously and quickly, so that it can catch up with the developed countries and meet the increasing meteorological forecast service requirements of social and economical developments. At the end of 1999, in order to satisfy computational needs of operation and research, CMA bought IBM SP with 88 CPUs and peek calculation speed up to 80 GFLOPs. At the same time, the development and production of domestic high performance parallel computers are speeded up to make research on higher resolution model become possible.

This paper addresses technical problems resolved in the development of our T213L31 system, features of its model component and some verification results of its products.

2 Development of T213L31 model

CMA introduced IFS model with cycle 18r2 from ECMWF, which is the operational version of the latter in mid and late 1990s. Because the model is originally programmed based on VPP700 vector computers, which are very different from IBM SP scalar computer of CMA, the preliminary transplantation of the model is mainly concentrated on resolving incompatibility between two computers. In addition, in order to run the model with high speed, ECMWF use long vector length to take advantage of its vector processor computational nodes with large memory, which decrease calculating speed of nodes and consume too much memory for our computer based on superscalar techniques. So we change long vectors to short scalars suitable to SP to take advantage of the function of SP cache and decrease memory use of the model greatly.

After the changes to the model above, the model with T213L31 resolution can be run on SP with so low speed that 10-day forecasts using 4 processors take 42 hours and cannot satisfy operational time requirement. Therefore, in accordance with the features of SP, we optimize and reform the model in the following aspects:

Optimization of calculation programming

Because SP is large-scale computer based on superscalar techniques with 5 float processing parts, taking advantage of roles of the 5 parts is key to speed up CPU calculations. By means of adjusting the order of DO loop to increase cache hit rate, we optimized 12 subroutines connected with Legendre transform, short wave radiation, Fast Fourier Transform (FFT) related to large quantity of computations to make speed be doubled, running time decrease twice, one step integration using 4 CPUs only need 9s after optimization compared to the original 18s, bring about a striking effect and so 10-day forecasts can be finished in 20 hours on 4 processors.

Amelioration of message passing mechanism

Message passing is a programming mode extensively applied on distributed scalable parallel computers and workstation network, while Message Passing Interface (MPI) is a standardized and portable message-passing library to realize the programming mode. The original schemes use a synchronous blocking message passing mechanism based on cache, which need data copies between user space and system cache, so bring about extra expenditures, delay communication and occupy additional system memory. Furthermore, for blocking communication, it is only after data are copied from user to system cache (for message sender) or from system to user space (for message receiver) that processors can go further, which is relative safer but increases communication time. In order to enhance speed-up and shorten communication time, we change the model's communication style to asynchronous and non-blocking mechanism to overlap communication and calculation time and conceal communication delay, because in this style processors only initialize a message send or receive operation and return immediately to continue the following computational work without waiting for the completion of communication.

Joint application of distributed and shared memory parallelization

SP is a parallel computer system composed by symmetric multiple processors, with 10 nodes and 8 CPUs on each node. The original parallel schemes use each CPU as a single node, which make SP's high-speed communication protocol US cannot be used, because with this style at most 4 CPUs on each node can be used. In order to take advantage of all CPUs on each node, only IP protocol choice can be used with the original parallel schemes, while IP has slower communication speed compared to US, so we modify the schemes, applying OpenMP to realize multiple thread parallel processing (OpenMP is a industrial standard of shared memory parallel programming) within nodes and MPI to realize parallel processing between nodes. The mixed parallel program decrease the calculation and memory consumption and enhance computational speed with one time step integration on 64 CPUs decreasing further from 9s to about 6s.

3 Basic features of T213L31

3.1 *Dynamic features*

- T213L31 is global spectral model with triangular truncation of 213 waves, whose horizontal resolution is 60 km in grid point space, vertical counterpart is 31 η layers, and so horizontal and vertical resolution in troposphere doubled compared to the previous operational global model T106L19.
- Reduced Gaussian grid points are used to reduce calculation greatly, and memory requirements and result storages obviously, which is realized through decreasing Gaussian grid points number of parallels outside the equator so as to make grid point lengths of these parallels approximately equal to the former, under the condition that the left points is suitable for FFT. It is important that the saving of global points by 30% is achieved with little changed calculation accuracy.
- Semi-Lagrangian advection scheme, observing fluid movement when following the fluid particles is used in T213L31, compared to Eulerian method studying fluid movement at fixed positions used in T106L19. With the former, integration time step length, advection-wind-unlimited in contrast to the latter, can increase by a factor of 5, i.e. from 3 to 15 minutes, so total steps to complete 10-day forecasts decrease five-fold, under the same computational stability conditions as the latter scheme. Some experiments show that, forecast accuracy is little influenced by using semi-Lagrangian advection scheme, while CPU time decrease by five times, so it produce four times as much efficiency as Eulerian method, taking account of 20% extra expenditures of the former.

3.2 *Physical features*

Compared to the previous operational model T106L19, T213L31 includes some newer physical parameterization schemes with more realistic physical concept, such as radiation, orographic drag, cumulus convection, cloud and land surface processes.

In T213L31, clear-sky longwave fluxes are calculated by emissivity method and reliance of long wave absorption on temperature and pressure is described by a better scheme than T106L19. Not only p-type continuous absorption of water vapour considered in T106, but also e-type not included in T106 are described in T213 (*Morcrette*, 1990). Shortwave fluxes are calculated by photon path distribution method to separate the parameterization of the scattering processes from that of the molecular absorption, with Delta-Eddington approximation used to treat the former and Pade approximation for transmission function (*Fouquart and Bonnel*, 1980).

To describe effects of large and subgrid scale orography on atmospheric flows, T213 employs respectively mean orography and a new subgrid scale orographic drag parameterization scheme (*Lott and Miller*, 1996) developed from that in T106 (*Baines and Palmer*, 1990), with considering both gravity wave drag and blocked flow drag, leading to more similar total drag to observation than the latter. Compared to envelop orography used in T106, which is artificial enhancement of the real orography to make up underestimation of subgrid scale orographic drag, mean orography overcome the obvious drawbacks of the former, such as more low level data are rejected in assimilation and excessive convective precipitation caused by artificial orography enhancement.

Different from T106, in which the scheme of Kuo (*Kuo*, 1974) is used for deep convection vertical diffusion scheme (*Tiedtke*, 1983) is introduced in for shallow convection, T213 choose mass flux scheme to parameterize convection processes, introducing cumulus downdraft, cumulus momentum transportation and midlevel convection parameterization absent in T106, resulting in more realistic physical concept (*Tiedtke*, 1989).

Prognostic cloud scheme in T213 (*Tiedtke*, 1993) properly describe dynamic effects of subgrid scale condensation and has more direct association with radiation, dynamics and hydrostatic processes than diagnostic cloud scheme in T106 (*Slingo*, 1987).

The land surface parameterization of T106 based on thermal and water income and expenses of two active soil layers and a 'climate layer' with a fixed soil temperature and humidity value monthly as lower boundary condition (*Blondin*, 1987). In T213, soil is divided into 4 layers with soil temperature and humidity of these layers being forecasted under the thermal and water lower boundary condition being zero thermal flux and free drainage (*Viterbo and Beljaars*, 1995). The main difference between two schemes lies in that the latter consider week-season time scale soil hydrostatic process, and describe the processes more physically.

4 Development of global objective analysis scheme

We construct analysis scheme of T213 based on Optimization Interpolation (OI) analysis scheme of our previous system T106 by upgrading OI serial programs to match the resolution of the new global model, i.e., realizing 213 wave triangular truncation spectral coefficients analysis on 31 η vertical layers. By use of MPI, we also parallelize some CPU consuming subroutines of the upgraded serial programs to reduce computational time and get portability.

OI analysis program divides the globe into many small 'square boxes', with computation between different boxes being independent and determined by observation data amounts in the boxes. However, because of uneven spatial distribution and time variety of observation amounts, computational amounts are known in advance, the method of distributing fixed number of boxes to each processor can lead computational load imbalance between processors, we take advantage of master-slave parallel method. In this method, master processor is only responsible for continuously distributing different of tasks to slave processors which receive tasks, complete computation and then send its results to master, when master receive results, it send the slave another tasks till all tasks are completed. By this method, every processor is busy though their speed and completed tasks maybe different, so the best load balance is achieved.

5 Verification of products

Since test running of T213 system, we have been verifying and evaluating its products and arrive at the conclusion that its performance is better than T106, our previous operational system.

Valid forecast time extended

Based on the analysis on anomaly correlation coefficients of the 500-hPa height forecasts, it shows that the valid forecast time of T213L31 system has been extended 1 more day over both North Hemisphere (NH) and East Asia (EA) than that of T106L19 system. In other words, the valid forecast time of T213L31 is 6 (5) days in the winter/spring and 5 (4) days in the summer over NH (over EA) (Fig. 1). At the same time, the root mean square errors (RMSE) of 500 hPa height forecasts decrease in varying degrees through 1 to 10 day forecast, and the decrease of the RMSE appears more obvious in the winter/spring than in the summer. Therefore, the variation of the RMSE from T213L31 forecasts with seasons is relatively smaller compared to that from T106L19 (Figure omitted).

Precipitation forecast skill improved

Threat Scores (TS) of light rain forecast of T213L31 is 5-10 percent higher than that of T106L19, while bias decreases lightly, which shows that the rainfall region forecast of T213L31 model is improved obviously compared to that of T106l19. For the forecast of 24h accumulated rainfall greater than 10 mm, 25 mm and 50 mm, TS of T213L31 model are higher and forecast biases are also somewhat bigger than those of T106L19, however, the increase on bias in rainy season is not obvious (Fig. 2)

Comparison of verification results with models of other country

Fig. 3 shows 500 hPa height anomaly correlation coefficient comparisons in North Hemisphere from April 7 to September 20, 2002 between ECMWF, CMA and JMA. Among three models, ECMWF is the best, with useful valid time 6-7 days in Spring, 5-6 days in Summer, JMA is second to and T213 is 5 days valid time in Spring and 4-5 days in Summer.

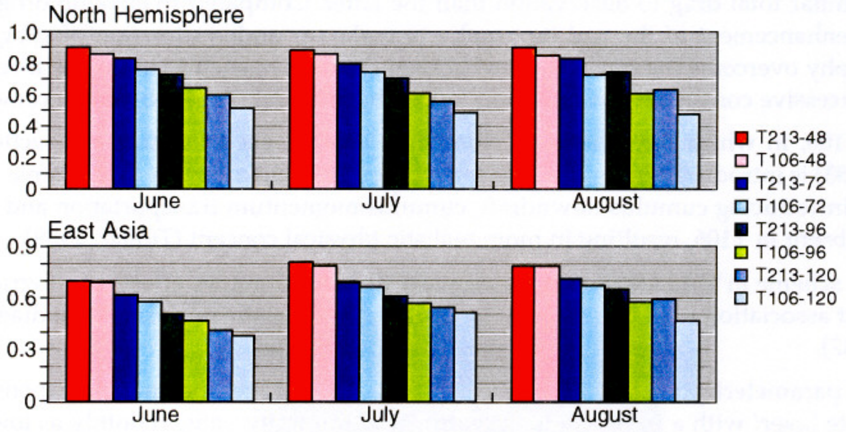

Fig. 1 Anomaly correlation coefficients of the 500-hPa height forecasts for T213 and T106 in North Hemisphere (upper figure) and East Asia (lower figure). Each group of columns is for different month, i.e. June, July and August respectively. In each group, different colours represent different valid times. (Red colours represent for 48, blue for 72, green for 96 and purple for 120 -hour forecasts respectively), and the lighter one of the same colour is for T106, the darker one is for T213.

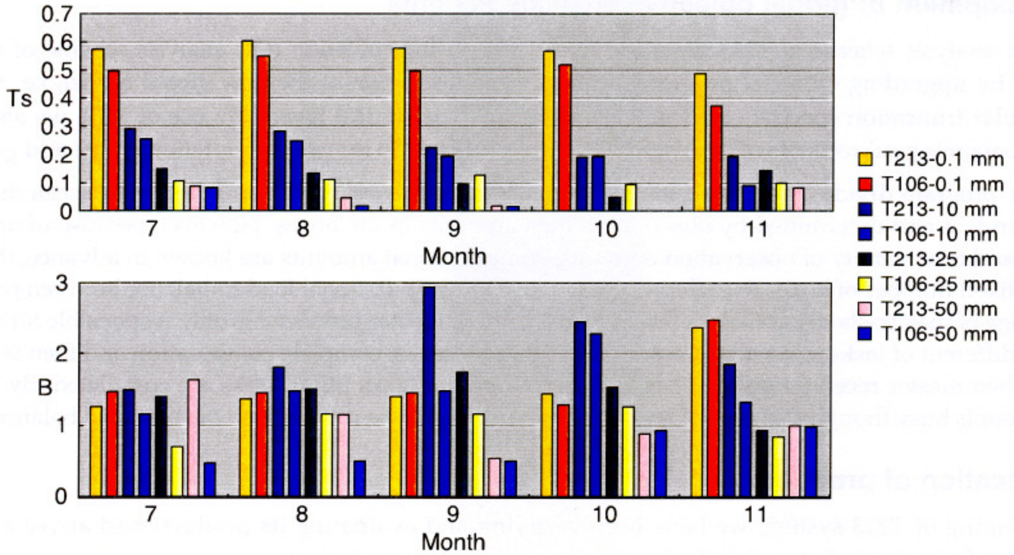

Fig. 2 Threat score (upper figure) and bias (lower figure) verification in rainy season of China with T213 and T106 and different ranks of rainfall L, M, H, S, T which mean light, middle, heavy, storm and torrential rain respectively.

6 Prospects for development

In next years, we will further improve our operational global numerical forecast system in such aspects as realization of Stable Extrapolation two-time level Scheme to overcome noise in forecast fields causing by time-extrapolation in original two-time level semi-Lagrangian scheme with the kindly help of Dr. Hortal of ECMWF, use of linear Gaussian grid, raise of resolution to $T_L511L60$ before 2008, use more physical components in the models, improvement of assimilation algorithms, with more efforts put on satellite and radar observation data, development of surface analysis.

At the same time, we have another group of researchers engaging in the development of a unified model, with common dynamic frame used by multiply scale, i.e., global, mesoscale and climate, 4D-Var with stressing on the use of satellite data, physical processes suitable to different scales and supportive environment such as program coding standards, graphic package, interface for research and development, product interpretation.

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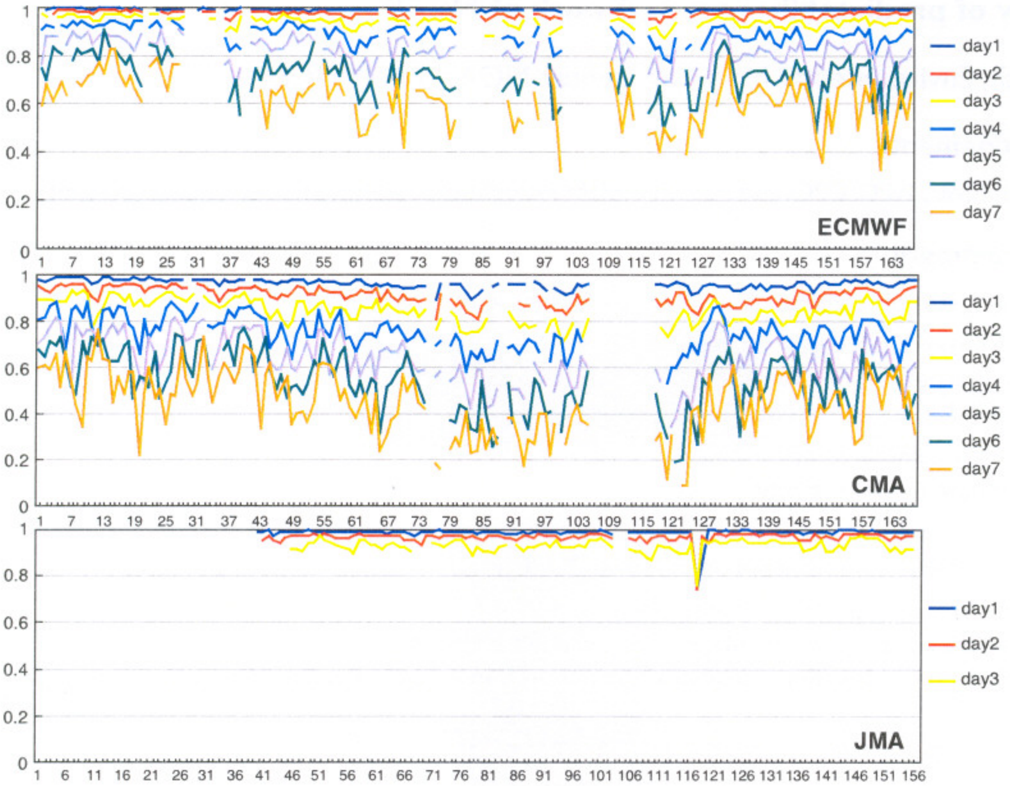

Fig. 3 500 hPa height anomaly correction coefficient evolution with day in Hemisphere for ECMWF (upper figure), CMA (middle figure) and JMA (lower figure, only first 3 days forecast are available). Lines with different colour represent the forecast from the 1st day to 7th day.

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