Design and Implementation of Regional Numerical Weather Prediction Operation Management System

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***Abstract*—China Meteorological Administration (CMA) and regional centers have developed their own Numerical Weather Prediction (NWP) operation systems, which work process is complicated, including data preprocessing, analysis, model forecast, post-processing, visualization and other aspects but were lack of a unified management and monitoring. Based on the demands of NWP operation systems, this article gives a detailed description of research and development of the numerical weather prediction operation management system based on work flow. This system has achieved full operational management and monitoring the NWP operation systems and HPC systems of national and regional center, through interaction visual interface directly display the working process of numerical weather prediction models, and when there is a fault, timely provision of graphics and SMS messages warning function. This system has greatly improved work efficiency, provided guarantee for the stability of numerical weather forecast.**

***Index Terms*—Numerical weather prediction model; Trigger; Supervisor monitor scheduler; Monitoring and management; Streamlined schedule**

I. Introduction

Numerical forecasting is an important method for weather analysis and forecast. All regional centers successively input numerical forecasting model into real-time service operation [1-2]. In fact, complete numerical forecasting service model includes several links of observational data [3-5], such as preprocessing, analysis, mode forecast, post-processing and visualization. Additionally, its workflow is rather complicated. Currently, each part of numerical forecasting service can operate independently [6-8]. However, in the aspect of operation, there has been no sufficient process scheduling and uniform standard management of service system, risk control method of the service system and monitoring of numerical forecasting operation platform so that real-time service operation encounters difficulty [9-12].

Consequently, it is necessary to establish a set of uniform, universal and efficient operation and management system about numerical forecasting job, which can not only realize process scheduling management about application of numerical forecasting service but also achieve uniform monitoring of service application and platform at different regional centers [13-16]. This paper studies how to deploy job about numerical forecasting mode in high-performance computer system, designs and realizes operation and control system of numerical forecasting, ensures requirements of the whole numerical forecasting service for timeliness, improves existing operating environment of numerical forecasting service and provides guarantee for reliable operation of numerical forecasting service mode [17-20].

II. Requirements Analysis

According to features of numerical forecasting model, system design adopts SMS (Supervisor Monitor Scheduler) a functionalization programming language based on workflow as software solution of mode operation to realize a universal scheduling management function and finish control of operational workflow in the whole numerical forecasting model.

SMS software has been widely applied to the field of weather forecast, including European medium-range forecast center, European member countries and national environment forecasting center of America. Operation system of their numerical forecasting models is developed by using SMS. SMS supports UNIX platforms like SGI, HP, SUN, IBM and FUJITSU as well as commonly used Linux platforms.

SMS is a job scheduler, which allows users to operate many single tasks. Such tasks may be mutually dependent or time-dependent. If all processes are integrated into a time stream, SMS will provide a development module that faces workflow as well as describes working process, scheduling operation and monitoring management. The system adopts client/ server structure. The overall structure is shown in Figure 1.

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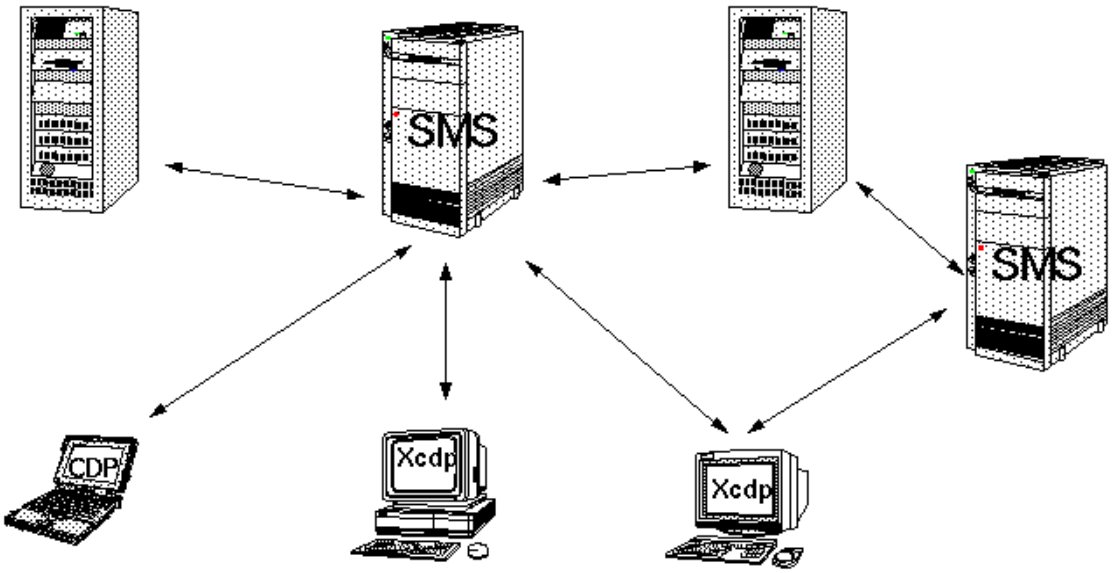

Figure 1. SMS Software Architecture

TABLE I
KEY TERMS OF SMS

Term	Connotation
Suite	In the aspect of definition, a complete workflow refers to set of families or tasks.
Family	It is a set of tasks and many small families integrate into a large one.
Task	Application operation is a core part of practical operation and processing in the whole procedure.
Event	Set up trigger points.
Meter	It is similar to event but has an integer value.
Label	It is used to show simple operation information.
Variable	It is similar to variable in Shell. Use of variable is quite flexible. By reasonable use, the whole workflow can be quite flexible and work related to operation and maintenance can be simplified.
SMS-file	SMS task script is used to generate operation.
job-file	It is used for SMS establishment and to submit actual procedures of tasks.
def-file	Definition file of workflow

SMS: as SMS operates by a single-thread server, it responds to service request of one client each time. The client submits several tasks to SMS sever, and can schedule tasks.

CDP: it is a client program based on command line. In addition, CDP is command-line control interface of SMS, which is used to define, submit, supervise and control tasks managed by SMS.

XCDP: XCDP is an X-Windows graphical user interface of CDP and window-type information, which provides visual expression of several tasks, expresses tasks as nodes with structure of a tree that has succession, uses different colors to show their different states and provides

definition of tasks as well as management and inspection about log records and files.

In SMS software, some key terms are defined. Such terms are quite important for programming based on SMS software. Related definitions and connotations are shown in Table I.

SMS manages suites and defines a complete workflow in suites. Suite is a set of families, while family is a set of tasks or other families. Tasks can have attributes like events, meters and labels etc. Under the situation of default, suites are mutually independent. Suites can be correlated across suites, but it is essential to avoid this situation. Under an ideal condition, suite is a self-contained unit. Definition of this dependency can be prohibited by setting SMS.

III. System Design

Operation and management system about numerical forecasting job adopts realization of multilevel technical framework [21-22]. From bottom to top, the overall framework is divided into system resource layer, operational scheduling management layer, operational monitoring and WEB service layer. The layered architecture realizes scheduling and monitoring of the service mode and is convenient for people being involved in management, operation and maintenance to implement management. Each layer is relatively independent, which simplifies systematic complexity, realizes flexible configuration of the system and lays a favorable foundation for stable operation and maintenance of service job [23-25]. The overall structure of the system is shown in Figure 2.

(1) System resources layer: it locates at the lowest bottom of the system, which acts as supporting environment of job scheduling management layer and job monitoring and WEB service layer, including platform resources like computer, server, storage, network and system software, serves as foundation of system operation and undertakes operation of numerical forecasting service mode.

(2) Job scheduling management layer: it is core of the whole service system operation and includes two parts. The first part involves design thoughts based on workflow, which realizes uniform scheduling management of the process by definition of job, scheduling, authority management, resource management, log management and operational control as well as submitting a job in a remote distance to system operation of high-performance computer. The second part collects or checks status information, data and product in the whole process of a job, carries out monitoring for status and resources of high-performance computer system platform and provides foundation for realization of visual monitoring by database management.

(3) Job monitoring and WEB service layer: by job monitoring, management and supervising business mode of WEB service layer as well as operating state of system platform and based on visual interface or WEB gateway, it realizes monitoring about operating status of all modes at each regional center. When failure occurs, figure and short-message warning functions are offered.

The system mainly includes two functions, i.e., job scheduling management as well as job monitoring and WEB service.

Operational scheduling management: its content mainly includes two aspects. On the one hand, it adopts building block design and realizes scheduling management of mode workflow, including job definition, job scheduling, job control, management about resource application, operational authority management and job log management etc. Realization of mode workflow is foundation and key of the whole operational management system. The completed mode can be described in the form of visual and common management figures which can be understood easily only when complicated numerical forecasting model is converted into a workflow and triggering condition and data flow direction in the process are analyzed. On the other hand, discover problems affecting operation of the model or mode failure in time by collecting operational logs about jobs, realizing initial data of the model and generating integrity tests of products after operation ends. At the same time, monitor system operation and resource status in order to prevent problems about foundation platform of mode operation from affecting the service model itself.

Job monitoring and WEB service: collected monitoring information directly manages operational job mode by functions like monitoring figure interface, including job canceling, re-submitting and auto reboot of jobs, and visually shows relationship among service modes and inside the same mode. When a certain step goes wrong, it is possible to decide impacts on next step and other modes. Also, establish WEB service platform, including modules like monitoring data processing, WEB page configuration and upgrading, statistical query about operational information, figure and short-message warning module and website authority management. And add short-message alarming method as a supplement to send fault message as soon as possible. Additionally, develop statistical query function for administrators, which can be used to learn service mode and data about historical operation of the system.

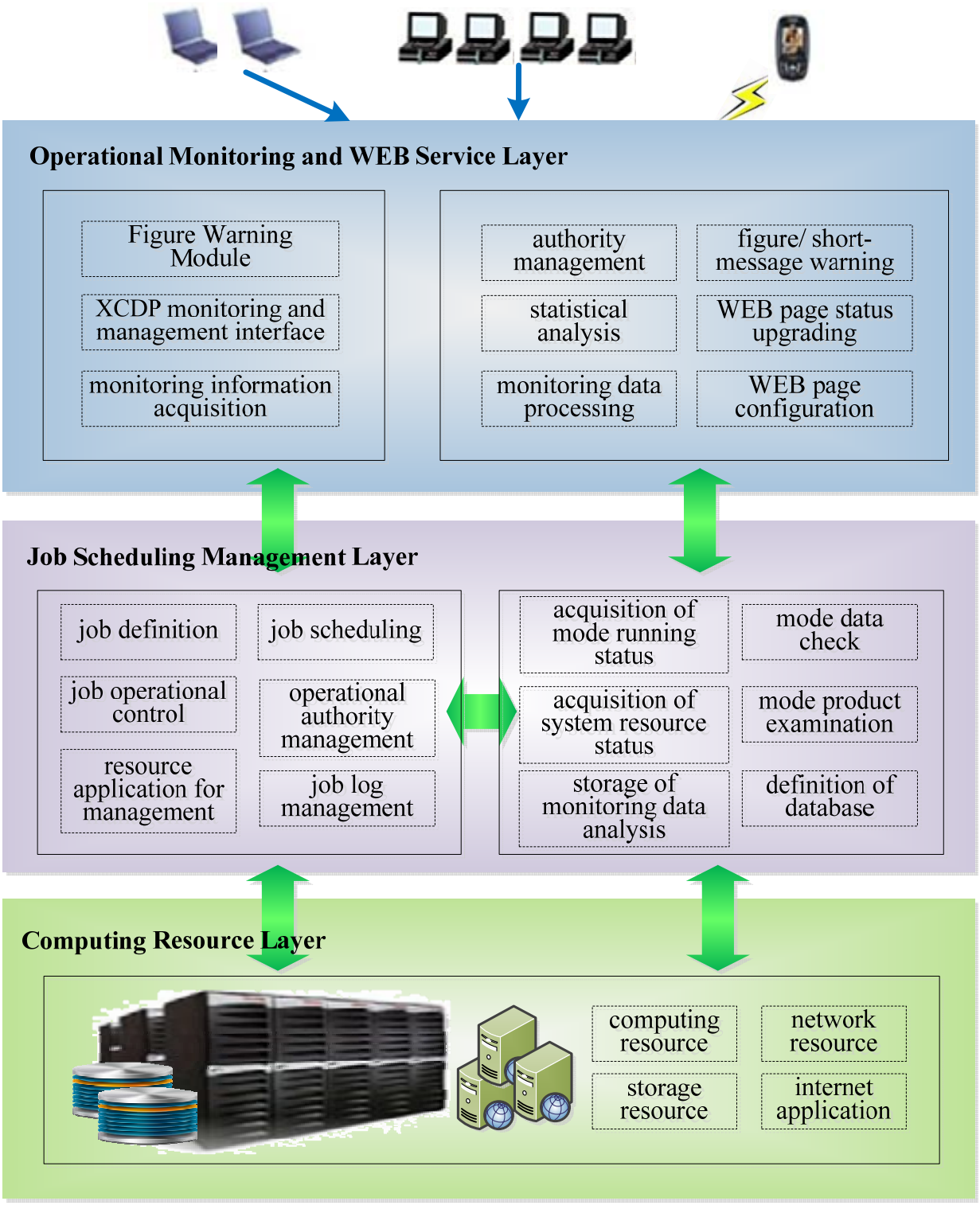

Figure 2. Overall Structure of the System

IV. System Implementation

Basically, the numerical forecasting service model system includes key procedures like data preparation, data assimilation, mode forecast, post-processing and product output, and operates regularly each day. The process of mode operation is shown in Table II.

Based on SMS software, define service process of the numerical forecasting mode at server, schedule and manage tasks, collect needed monitoring information and submit the numerical forecasting mode to high-performance computer system by remote dispatching. The numerical forecasting mode operates at high-performance computer system. At the same time, the client monitors controlled system according to configured parameters.

TABLE II.
THE PROCESS OF MODE OPERATION

Name of mode process	Description
prep	Acquisition and preprocessing of initial data
an	Analytical assimilation of initial data
Init	Initialization of mode
fcst	Operation of main mode
post	Post-processing of mode
prod	Product generation and transfer
archive	Data archiving and backup

In accordance with features of the mode itself, we do not only use time setting as a determinant of each sub-module's operation in a new mode operation framework but carry out implementation according to implementation process of the whole system after needed conditions are satisfied.

There is some dependency among all modes, so we re-plan and re-optimize preprocessing, post-processing and main body of the mode in the whole mode system:

- In the post-processing part, carry out acquisition and check about all data simultaneously;
- In the post-processing part, send data products to different users simultaneously;
- The original main mode module contains several sub-tasks, among which there may be dependency. Some of them can be implemented simultaneously. We divide main mode again, simplify operational scheduling and monitoring of each sub-module and ensure single-step recovery is possible after errors have occurred at each step.
- The overall part of the mode system is still realized according to the dependency order, for example, acquisition of original data → analysis → main mode → post-processing.

Main framework of the mode is realized by defining families and specific tasks. According to operational procedures of the mode, several families are defined in mode scheduling. At the same time, several tasks are defined in each family. Take GRAPES_MESO mode system for example. Operational framework of this mode is shown in Figure 3. In suites, define communication between parameter files and family and task.

Scheduling implementation about each specific task in numerical forecasting operation is realized by task script in SMSM and scheduling about each specific task can be realized by using modularization function. For content that has been defined in suites, it can be realized by task module. Each task mode is a script file whose suffix name is .SMS.

Each job has a display status in operation, and operational state usually includes the following aspects: completed, queued, submitted, operating, suspended and aborted. Different colors show different states of tasks. Changes in operational state are shown in Figure 4.

- After carrying out the command play (CDP), the operational state is unknown.
- After implementing the command begins (CDP), the operational state may be queued, completed, aborted or suspended. Suspended task means the task has been in the queue of implementation, which need be resumed by users.
- Once needed dependencies are removed, a task will be submitted by workflow engine. At this time, its state is submitted or aborted (if SMSCMD implementation fails).
- If the task is submitted successful, its stage will be active once it is started.

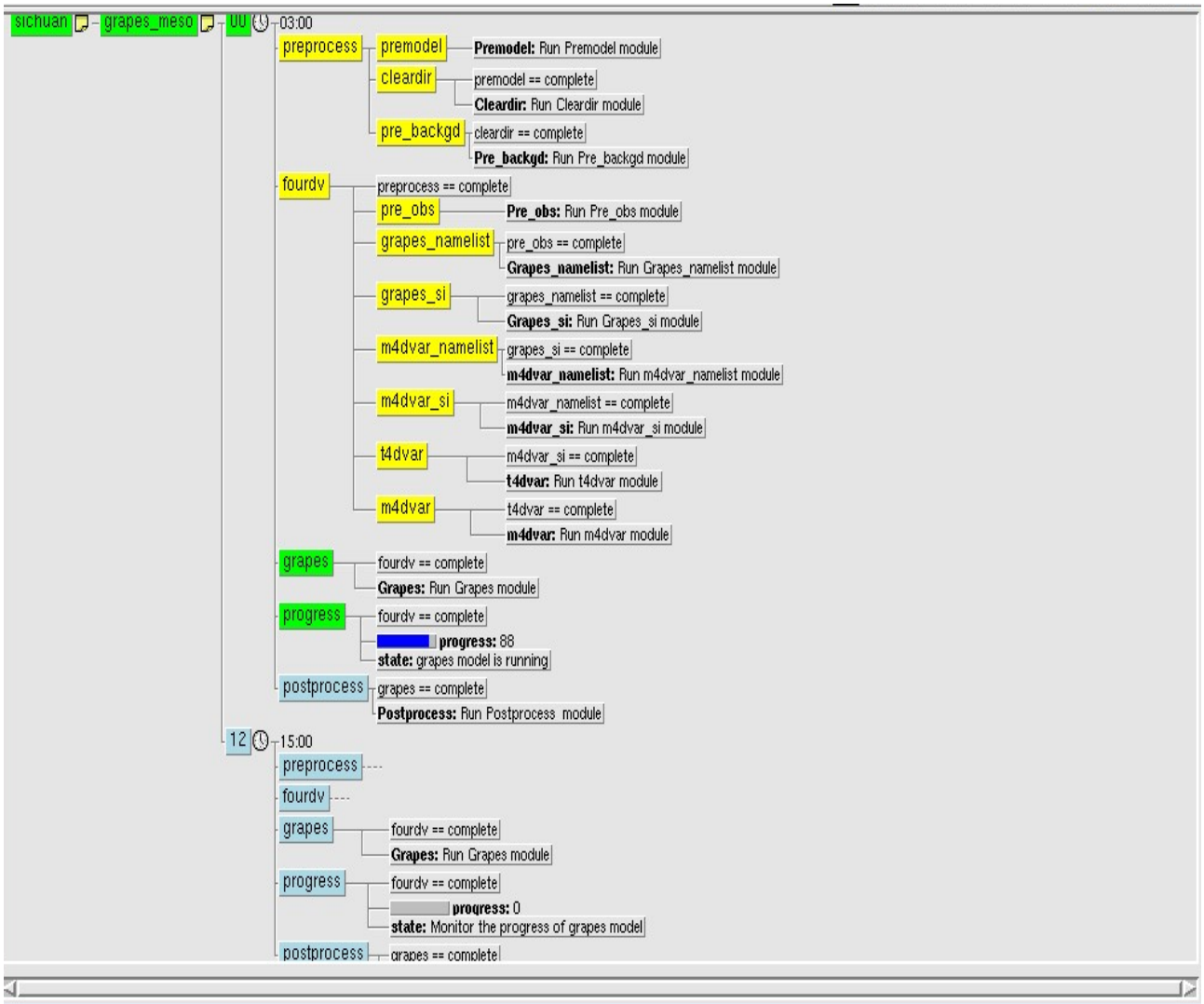

Figure 3. Operational Framework of GRAPES_MESO Mode

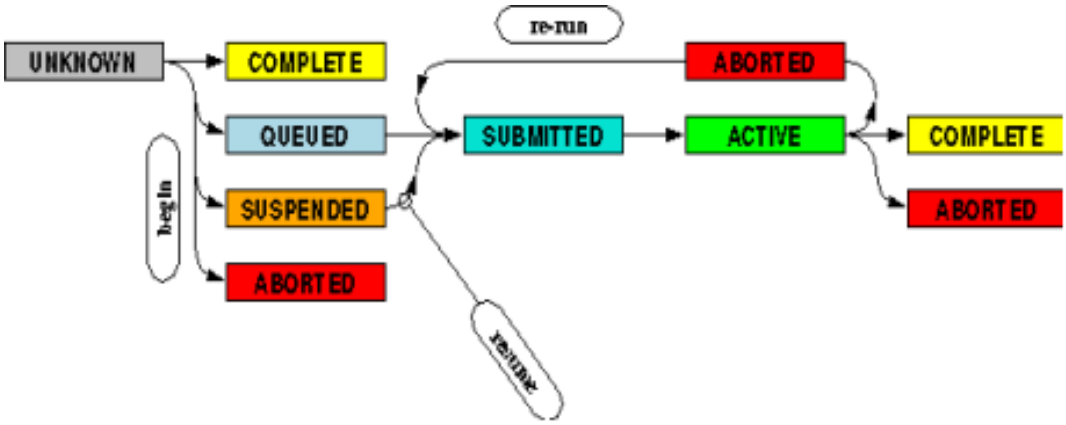

Figure 4. The Job Status of SMS

Control of the mode's operational process is mainly realized by time control and trigger control.

Time control: since the mode system need be started at fixed time regularly each day, define a certain time meter in the whole system. At this specific time shaft, the system forecasts continuously and dynamically. Time parameters include date, time and times of forecast and effectiveness of forecast. For starting time of the mode each time, forecasting time and time are used to identify the specific moment at which tasks are started, which takes

an hour as a unit and is usually expressed by international time. At the same time, since product service must need specific moment, this can be realized by time control as well.

Trigger control: By virtue of trigger control, dependency of each task or different steps in tasks is realized. When tasks are started, calculate its trigger expression first. If the result is true, start a task. Otherwise, the task will still be in a queuing state. Meanwhile, since some tasks can be implemented when some content of the last step is finished, this function can be realized by setting definitions of events.

As a real-time service system, it must operate constantly and dynamically and be able to solve results in time. Thus, degree of automation of the system is high. In the operational process of the whole system, accidental fault is one of the important causes for faults of the system. Usually, this kind of faults cannot be repeated or it is difficult to repeat them. Thus, to process such faults, we only need restart tasks. Therefore, the mechanism that important operational steps are reset again is taken. By setting the parameter about restoration times, select the number of times at which tasks are retried. If several times' restoration fails, carry out warning and manual intervention.

The high-performance computer system adopts job management software to manage tasks. After commands are submitted by using SMS, corresponding process number can be obtained. RID a specific configuration variable is used to store information about this process number, but job number of job management software cannot be obtained. Thus, it is impossible to obtain each job's operational sate to manage tasks. Therefore, interface with job management software is added to realize uniform scheduling about numerical forecasting mode. For the interface with the job management software loadleveler, it mainly focuses on how to use job number allocated by the system automatically after jobs have been submitted to replace management for SMS command process number.

For the numerical forecasting mode system, the time when main mode operates is long. If only overall state information is obtained, actual operating situations of the mode cannot be mastered really. Aiming at this problem, inspection on correctness of mode operation is added so that real-time display about operating progress of the main mode can be achieved.

Use WEB method to develop real-time operation monitoring and controlling platform for intensive and uniform numerical forecast, and realize functions of numerical forecasting service and high-performance system, such as operating state monitoring, failure warning and statistical query about operation.

We have established uniform operation management system about jobs of several regional modes, such as BJ_RUC mode about North China, GRAPES_TMM mode about South China, GRAPES_MESO mode about the southwestern region, WRF mode about the northeastern region and MM5 mode. We can implement management scheduling for all of the foregoing service modes. As a result, functions, i.e., monitoring alarm of jobs and breakpoint recreation, are realized.

After the system has been started, it operates stably. In consequence, original messy service operational environment and complicated maintenance and operation procedures have been changed, time of fault discovery and recovery has been shortened, as well as work efficiency and reliability of operation have been improved largely. In addition, uniform standards have been formed from data organization, operational scheduling and safeguard maintenance, which become criterion for development of numerical forecasting operation system in China in future.

V. Conclusions

This thesis starts with basic demands of operating environment of numerical forecast service, establishes operational management system of numerical forecasting service and realizes comprehensive operational management and monitoring of numerical forecasting service mode and corresponding computer system. By visual interface, it directly shows working process of numerical forecast and displays a job with high-tech content in an intuitive and popular way. In the design and realization of this system, it applies basic methods related to workflow, forms workflow of numerical forecast, analyzes trigger conditions and data flow direction of specific processes of the whole numerical forecast including data extraction, preprocessing, assimilation, mode forecasting, forecasting post-processing, forecasting product-making and distribution, and describe the whole complete system and complicated relationship by graphic mode. Up to now, this system has been applied to service operation. As service mode and computer system increase constantly, we will constantly perfect existing system and provide safeguard for stable operation of numerical weather forecast.

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