Design and Development of a Quality Evaluation and Monitoring System for the Short-term Weather Forecast in Gansu Province

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Abstract: In order to further improve the development of the meteorological observation quality management system in Gansu Province, this article takes the organic integration of quality management and meteorological observation as the concept, and combines practical business applications to develop a scoring model to quantitatively evaluate the quality of short-term warning signals and observation data transmission in Gansu Province. At the same time, a visual model is developed to achieve a personalized monitoring and analysis system for the entire process of "monitoring warning service". System users can monitor the actual situation of various meteorological disasters, analyze disasters, and assess risks in the system, and display and apply decision information, thereby improving the scientific and standardized level of meteorological observation business management.

Keywords: Meteorological Disasters; Warning Signals; Observation Quality System

1. Introduction

Gansu Province is located in the intersection area of the Loess Plateau, Qinghai Tibet Plateau, and Mongolian high-pressure system, with complex terrain, diverse climate types, and frequent occurrence of catastrophic weather, which has caused great losses to the economic development and people's life and property safety of our province. Among them, severe convective weather often causes weather phenomena such as lightning, strong winds, hail, and short-term heavy rainfall, with particularly significant harm. Transferring meteorological disaster warning information to the affected population or relevant decision-making departments before or immediately after a disaster occurs not only enables timely warning and prevention of disasters, but also enables relevant business departments to analyze and evaluate the quality of warning signals, providing basic data support for improving warning levels[1]. However, due to the complex technical aspects involved in early warning signal evaluation, the evaluation process involves minute level massive meteorological data, and the evaluation logic and scoring rules are more complex. At the same time, it also involves multiple factors such as inconsistent evaluation data and methods, making it difficult to complete manually. In recent years, some provinces[2-4] have developed automated warning signal inspection systems to evaluate the accuracy, hit rate, missed report rate, false report rate, and lead time of several weather warning information in real time, achieving automatic inspection of warning signal quality; Hainan Province[5] has also conducted an automated evaluation of the effectiveness of early warning signals on this basis. However, the system has not been built on the meteorological big data cloud platform, lacking certain data security and stability.

On the other hand, the effectiveness of warning signal issuance is influenced by many factors, such as human factors, publishing system failures, transmission link interruptions, receiving terminal failures, and packet loss, which are uncontrollable factors and have uncertainty[6]. The root cause of the above uncertain factors is still the timeliness and completeness of observation data. In fact, as early as 2010, the World Meteorological Organization (WMO) and the World Meteorological Organization's Integrated Observing System (WIGOS) proposed the concept of a rolling needs assessment process[7]. By comparing and analyzing the user's observation needs and existing observation capabilities in a specific field, it is possible to analyze and evaluate the gaps and deficiencies in the observation system in that field, thus forming an evaluation result of the degree of satisfaction between the observation needs and observation capabilities in this field, improving the ability and level of future observation systems in that field, and ultimately improving the business development of users. Meteorological observation data plays an important role in weather warning and forecasting, and high-quality meteorological observation data is the foundation and prerequisite for meteorological operations, services, and scientific research. Forecasting and observation are closely related and mutually influential. Through automation technology, studying the relationship between meteorological warning signals and the quality of meteorological observation data can effectively strengthen the interaction and connectivity between observation and forecasting, thereby promoting the high-quality development of building a meteorological observation quality management system.

In summary, in order to accurately, standardize, and efficiently carry out the evaluation of the quality management system for short-term business in Gansu Province, this article develops a monitoring system for the entire process of “monitoring early warning service” based on the Gansu meteorological disaster warning signal release standards and effectiveness evaluation rules, combined with practical business applications, for strong convective short-term business. It provides a visual platform for decision-making services and meteorological information sharing, centrally displaying key information. System users can conduct real-time monitoring, disaster analysis, and risk assessment of various meteorological disaster weather conditions in the system, and display, apply, and review decision-making information.

2. Research Fundamentals

The quality system evaluation system proposed in this article is different from previous research, focusing on the organic integration of quality management and meteorological observation. It can not only achieve quality evaluation of warning signals, but also evaluate the transmission quality of observation data involved in the warning process, making it easier for decision-makers to analyze the relationship between the two and make statistical analysis. Therefore, how to scientifically formulate evaluation norms and standards is the basis of this study. Through research and analysis, this article designs a model based on the release standards and effectiveness evaluation rules of meteorological disaster warning signals in Gansu Province, combined with practical business applications, to achieve the calculation of indicators and effectiveness scores for different categories of short-term warning signals. The model is designed to achieve the calculation of transmission rate scores for observation data required for forecasting business. Below, we will provide a detailed introduction to the principles of the model.

2.1 Warning Signal Scoring Indicators

This research mainly evaluates the early warning signals of four weather processes, namely rainstorm, thunderstorm and gale, short-term heavy precipitation and hail, issued by Lanzhou Central Observatory. rainstorm refers to the precipitation process in Hexi area that has exceeded 30 mm in the past 12 hours and in Hedong area that has exceeded 50 mm; The assessment object is rainstorm orange and rainstorm red warning signals issued by meteorological stations at all levels in Hainan; Thunderstorm and strong wind refer to weather processes with an average wind force greater than or equal to level 6 or gusts greater than or equal to level 7 accompanied by thunderstorms; Short term heavy rainfall refers to a weather process in which the precipitation in the western part of the river is greater than or equal to 10mm in the past hour, and the precipitation in the eastern part of the river is greater than or equal to 20mm in the past hour; A solid precipitation process in which hail falls on the ground with a diameter greater than or equal to 5 millimeters.

Assessment of hit rate, accuracy, false alarm rate, missed alarm rate, and lead time for correctly issuing warning signals (accurate to minutes).

Hit rate:

$$TS = \frac{NA}{NA + NB} * 100\% \tag{1}$$

Accuracy rate:

$$TS = \frac{NA}{NA + NB + NC} * 100\% \tag{2}$$

Underreporting rate:

$$PO = \frac{NC}{NC + NB} * 100\% \tag{3}$$

Vacancy rate:

$$FAR = \frac{NB}{NA + NB} * 100\% \tag{4}$$

In the formula, NA represents the number of correct stations for issuing warning signals, NB represents the number of empty stations for issuing warning signals, and NC represents the number of missed stations for issuing warning signals. The warning signal inspection stations issued by the meteorological department are all observation stations within the corresponding administrative region. If one station experiences catastrophic weather that meets the release standards, it is considered that the warning signal has been issued correctly. The advance warning amount refers to the warning signal guidance product and warning release time of Lanzhou Central Meteorological Observatory minus the time when the corresponding catastrophic weather occurs in the first county (district), accurate to minutes.

Firstly, parse the warning signal grib2 file released by the central station to obtain the time and landing area of the warning signal; Obtain the actual weather process data results through the interface, obtain the actual occurrence time and landing area, compare the two, and obtain the hit rate, accuracy, missed report rate, false report rate, and time advance. When there is a new weather process, the model is updated to calculate the score of the most recent process. The specific process is as follows:

(1) Retrieve the warning signal product file from the system file directory, parse the file to obtain the forecast time of the weather process and the range of falling areas, and determine the falling area N1 of this hail forecast process based on the county-level zoning;

(2) Obtain the actual occurrence time of weather processes within 24 hours of the forecast time through the interface, as well as the actual landing area N2;

(3) The area included in both N1 and N2 is NA;

(4) The area included in drop zone N2 but not included in drop zone N1 is NB;

(5) The area N1 includes, but the area N2 does not include is NC;

(6) Calculate the hit rate, accuracy, miss rate, and false alarm rate of the forecast and warning based on the previous formula, and use warning signals to guide the product and warning release time one by one, minus the time when the corresponding catastrophic weather occurs in the first county (district), accurate to minutes, to obtain the advance warning amount.

Table 1. Table Example

Evaluation eigenvalue conditions for different weather processes / Early warning signal lead time T (Unit: minutes)	Warning signal has been issued			Unpublished Warning signal
	Meet standards	Not meeting the standard		
	Condition 1	Condition 2	Condition 3	Condition 4
(T1,∞)	G11	G21		
(T2,T1)	G12	G22		
(T3,T2)	G13	G23	-G3	-G4
...	...	...		
0	0	0		
(-30,0)	0	Reissue warning signals		
(-∞,-30)	-G1	Send a warning signal after 30 minutes.		

2.2 Warning Signal Scoring Indicators

According to the quality inspection method for warning signals, scientific consideration is given to the accuracy and advance quantity of warning signals, and comprehensive consideration is given to the corresponding correlation between the type, advance quantity, and actual situation of warning signals. The framework of effectiveness evaluation standards is shown in Table 1. In actual effectiveness evaluation business, warning signal effectiveness scoring standards are set based on different types of warning signals, where T is the cutoff value of the lead time; G represents the effectiveness score under different conditions and standards with different lead times. T and G are set based on the average level of various warning signals in various provinces across the country:

2.3 Data Transmission Scoring Model

This model evaluates the time efficiency of observation data transmission by determining the percentage of advance and lag in the time scale between the receipt time of different types of observation data and the transmission time of observation data, that is, the accessibility rate of a certain observation data when it is published and sent to different objects in a certain time period. The time scale for transmission of observation data is formulated in accordance with the data timeliness requirements formulated by the National Bureau. The evaluation index for the timeliness of observation data transmission is channel tracking feedback information, including sending time, receiving time, observation data transmission time scale, etc. Therefore, the following model relationship for the timeliness of observation data transmission can be established:

$$S = \frac{T - t_i - t_0}{T} * 100\% \tag{5}$$

In the formula: S represents the transmission timeliness of a certain observation data during a certain period of time, T is the warning time scale, t_0 is the generation time of the observation data, and t_i is the arrival time of the warning information.

3. System Design and Key Technologies

3.1 System Design

The overall structure of the platform is shown in Figure 1, which includes five levels: data support layer, data storage, technical support layer, business application layer, and display layer.

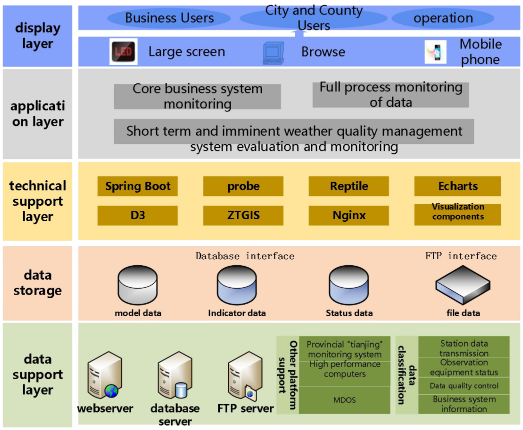

Figure 1. System Architecture Diagram

The data support layer includes basic environments such as hardware environment resources and network infrastructure services, while the technical support layer mainly implements service support for data. The technical support layer and data storage rely on the “Tianjing” operating environment. The structural design of the platform fully considers the storage, analysis, and processing needs of the massive observation data of the entire province's observation stations. The data is stored on the “Tianjing” provincial monitoring platform and can be read and written through a data interface. Data storage includes state data (such as device status, business process status, etc.), data indicator data (such as meteorological observation data, server performance indicators, etc.), model data based on state data and indicator data, and file data (such as video and image data), etc., which are stored in a mixed storage mode. They are stored in a transactional data storage environment and an analytical data storage environment based on data form and business attributes. The transactional data storage environment solves the problem of strong transactional data storage through virtual valley clustering technology, while the analytical data storage environment solves the problem of massive data storage through distributed table system technology. By relying on the dynamic parallel computing of the platform, the bottleneck of system computing power is solved. During the data retrieval process, by applying index databases and secondary index technology, massive data can be quickly retrieved, providing data synchronization function for data persistence services, and ensuring the consistency of data sources in various logical databases of the platform and external business system databases.

3.2 Response Time Performance Design

The system proposed in this article is aimed at monitoring the entire process of the three stages of “monitoring, early warning, and service” in the short term. It has high requirements for the response time of the system. From the perspective of user experience, it is necessary to control the response time of opening, displaying, and regular operations on the system function page within a short time range. For complex processes such as large-scale data processing and retrieval, statistical analysis data conversion, and data summary report generation, it is necessary to control the system response time within a reasonable range. In order to ensure user oriented response time, the system proposed in this article adopts Java language[8] for software design, and guarantees system response time through three layers: presentation layer, application layer, and data layer to meet project construction requirements and actual business needs.

Presentation layer response design: In the presentation layer, complex logic is simplified by encapsulating frameworks such as Struts and Portlets, combined with front-end technologies such as MVC, Ajax, Flex, and HTML5, to improve asynchronous response processing. Through reasonable arrangement of data representation, migration control, and processing flow for page actions, fast presentation layer response processing results are obtained;

Business layer response design: By uniformly encapsulating business logic components, distributed caching, asynchronous message processing, and other methods, the system's performance indicators such as concurrent users and resource utilization are controlled within a reasonable range, thereby improving the response speed of business data extraction logic.

Data layer response design: Adopting a variety of data storage designs, providing temporary cache persistence, a combination of relational databases, and NO SQL databases, adopting a certain anti normal form design to optimize data access performance, optimizing data retrieval logic through appropriate indexes, fixed views, and storage procedures, and improving data access response performance. For analytical data, ETL is used to import the data into the data warehouse. The data warehouse adopts a star themed model to further process and store analytical data for a long time, avoiding poor short-term transactional data that may lead to system performance degradation.

3.3 Unified Data Source

To unify data sources and ensure the timeliness of data acquisition, this article designs all data sources required by the system using the universal standard specifications of “Tianqing”[9-10]. It is based on the big data cloud platform data environment, aimed at meteorological business and scientific research, providing nationwide unified, standard, and rich data access services and application programming interfaces, and providing the only authoritative data access service for various application systems. Unified management of attribute information such as availability, permission request rules, request timeout time, data format, service call frequency, service call method, and other business requirements. Specifically, the system is based on the “Tianjing” platform for visual display, and all observation data information is obtained from the system product information (DI)and alarm information (EI) provided by the Tianjing system. The platform applies for development interfaces, selects the required fields, and uses the HTTP POST method. The IP is the address responsible for balancing on the local Tianjing server, with port 80 as the default. apikey is the Tianjing personal account authorization code, and the IP is the address responsible for balancing on the local Tianjing server, with port 80 as the default. apikey is the Tianjing personal account authorization code. In order to distinguish the monitoring information of business systems, it is necessary to create a topic message topic specific to the business system in the message middleware Kafka. The system develops a DI push function according to the Tianjing system interface specification, pushing the metadata information of observation data to Tianjing according to the standard, ensuring the consistency of metadata information obtained by the application side to the greatest extent.

4. System Applications

In December 2023, the quality evaluation and monitoring system for short-term warning signals proposed in this article has passed acceptance and been put into business application. Figure 2 shows the system's large screen display interface, which mainly displays ground truth data, high-altitude data, radar data, and satellite data. After collecting data, calculations are carried out to calculate the hit rate, accuracy, missed report rate, false report rate, and lead time for display. The system also calculates and displays based on single and monthly statistics, customizing a visualized view of the province's business from scenarios such as data transmission, forecast accuracy, benefit evaluation, and weather review, comprehensively, accurately, and intuitively displaying the overall operation status of the province's strong convection short-term business.

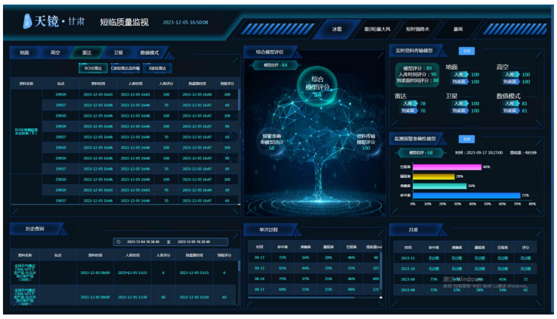

Figure 2. The Short-Term Weather Forecast Operation Business Quality Management System

5. Conclusion And Prospect

(1) The quality management system evaluation and monitoring system for short-term and short-term business proposed in this article analyzes the effectiveness and timeliness of warning information release, evaluates the situation of warning information release and the quality of observation data transmission, thereby improving the strategy and standards of warning information release, gradually deepening the quality management concept, and achieving the organic integration of quality management and observation business. Through real-time monitoring of the entire process of strong convective short-term business, shortcomings and deficiencies in meteorological observation business can be identified and improved in a timely manner, enhancing the scientific and standardized level of meteorological observation business management.

(2) The system provides key information visualization and statistical services, and provides various indicators required for monitoring in the three stages of strong convective short-term monitoring, early warning, and service in the form of visual charts on the same page, effectively improving the work efficiency of business personnel in decision-making. At the same time, the system quantitatively evaluates the transmission of observation data, the accuracy and timeliness of warning through models, and visualizes and analyzes from multiple perspectives such as real-time monitoring, forecasting and warning, historical results, and statistics, providing strong basis for the review of major weather processes.

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