Study on the Forecast Index of Quantitative and Snow Depth in Yangzhou

Abstract: Based on the scope of Yangzhou, this thesis explores the causes and development mechanisms of snowfall in the Yangzhou region in recent years. Combining with the analysis of climate background when blizzards occur, this thesis discusses the relevant indicators of local snowfall forecast, such as water vapor, dynamics, wet potential vorticity and other physical characteristics, and compares and verifies them with the results of model forecasts, so as to establish a suitable quantitative judgment standard for local areas and provide reference for future forecast ideas. Meanwhile, by comprehensively analyzing multiple physical quantity indicators, extracting local snowfall forecast models, providing reference for snowfall depth forecast, and providing reference basis for public services and transportation meteorological services.

Keywords: Blizzard forecast; snow depth; artificial intelligence

Blizzards, as one of the most important meteorological disasters in winter and spring, have been analyzed and summarized by many experts and scholars, including the analysis of the research overview of heavy snowfall forecast in China, the study of blizzard weather and climate in China, the summary of climate characteristics of heavy to blizzard in a certain region, the analysis of the causes of disastrous blizzards, the analysis of cold flow and convection causing blizzards, the numerical simulation of the causes of blizzard weather, the study of snowfall characteristics in China, the study of blizzard prediction methods in a certain region, etc. However, in general, the research mainly focuses on the concentrated snowfall areas in northern China, while for the Yangtze River middle and lower reaches, as one of the four major concentrated snowfall areas in China, not much research have been seen on the prediction of heavy snowfall processes, especially snow depth. In recent years, there have been multiple regional snowstorms in the Yangzhou area. The heavy snowfall is concentrated and sudden, causing significant impacts on transportation, infrastructure, agriculture, and people's lives. The local forecaster has previously analyzed individual typical blizzard processes, but due to Yangzhou being located downstream of the Yangtze River, snowfall is often accompanied by rain and ice pellets, mostly transitioning from rain or sleet to snow. The linear relationship between precipitation and snow depth is poor, so it is necessary to clarify the concept model of blizzard forecasting and the indicators for predicting snow depth. This study explores the methods for forecasting heavy snowfall and snow depth in this region, focusing on factors such as system influence, atmospheric accumulation, dynamics, and water vapor conditions. The forecasting process is illustrated using the blizzard weather event that occurred in the Yangzhou area on December 18, 2023.

I. DATA SOURCE AND RESEARCH METHODS

A. Source of data

Located in the middle of Jiangsu Province in the eastern part of the Eurasian continent, Yangzhou belongs to the subtropical humid monsoon climate zone, with mild climate, abundant sunshine and plentiful rainfall, and distinct four seasons. Among the four seasons, winter is the longest, lasting for more than 4 months; summer comes next, lasting about 3 months; spring and autumn are relatively shorter, each lasting for more than 2 months. The data used in this thesis comes from the ground meteorological observation data of five national observation stations in Yangzhou, Baoying, Gaoyou, Yizheng, and Jiangdu, including the conventional data contained in the ground and upper air weather maps, with a time interval of 6 hours and a spatial resolution of 0.75°× 0.75°, and the vertical direction is 37 layers of ECWMF global reanalysis data. The data covers the years 1991 to 2021, a total of 31 years.

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B. Research Methodology

The Yangzhou snowfall process database was established through years of collected data. Regulation: If the snowfall at any station was greater than or equal to 10mm within 24 hours, and the snow depth was greater than or equal to 5cm, it would be recorded as one blizzard day. According to statistics, Yangzhou, Hanjiang, Baoying, Gaoyou, and Yizheng have had 6, 5, 8, 7, and 10 days of snowstorms respectively in the past 31 years. The local snow climate characteristics during the blizzard process in the Yangzhou area were analyzed. The physical quantities were calculated and analyzed using the ECWMF global reanalysis data with a time interval of 6 hours, a spatial resolution of 0.75°×0.75°, and 37 layers in the vertical direction. Combined with ground and upper air data, the forecasting methods for heavy snow and snow depth were explored from the aspects of influencing systems, atmospheric accumulation, dynamics, and water vapor conditions. The diagnostic analysis and forecasting process were illustrated using the blizzard weather process that occurred on December 18, 2023, as an example.

II. WEATHER AND CLIMATE CHARACTERISTICS OF THE BLIZZARD PROCESS IN THE YANGZHOU REGION

Table 1 Snowstorm Days in Yangzhou Region (Unit: Days)

<table>
<thead>
<tr>
<th>Site</th>
<th>Yangzhou</th>
<th>Jiangdu</th>
<th>Baoying</th>
<th>Gaoyou</th>
<th>Yizheng</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blizzard days (days)</td>
<td>6</td>
<td>5</td>
<td>8</td>
<td>7</td>
<td>10</td>
</tr>
</tbody>
</table>

From 1991 to 2021, there have been a total of 18 days of blizzards, ranging from 6 to 10 days in different areas. According to statistics, the cumulative snowfall of these processes is very concentrated compared to the annual snowfall, with a proportion of over 40%, and the majority of over 60%, indicating that in years when regional blizzards occur in Yangzhou, the total annual snowfall is composed of individual major snowfall processes, and the snowfall is concentrated and sudden, which is consistent with the conclusion that snowfall in the middle and lower reaches of the Yangtze River is concentrated within the year. Among them, 9 times appeared in January, 7 times appeared in February, and 2 times appeared in March. The process of rain or sleet turning into heavy snow accounts for 61% of the total, with a maximum rainfall and snowfall of 42.8mm occurring in January. The pure snowfall type blizzard process mainly occurs in the first half of January to February, accounting for 44% of the total. The maximum snowfall in 24 hours is 21.2mm. The maximum snow depth recorded was 30cm, which occurred on January 28, 2008 (Yizheng).

Pure snowfall blizzards mainly occur in the first half of January to February, which is also the coldest period of the year. The strength of cold air determines whether or not there will be heavy snowfall, while the presence of warm and moist air currents is crucial. Rain or sleet turning into blizzards mainly occurs in the second half of February to March, when the forces of cold and warm air are relatively equal. In order for heavy snowfall to occur, both forces must be strong. Therefore, the amount of snowfall in this region should be measured by the precipitation after the snowfall has turned into pure snow, and the depth of snow accumulation should also take into account the surface temperature. To make accurate predictions of blizzards and snow depth, one must consider both the strong cold air moving south and the strong warm and humid air moving north. Only considering the strength of the warm and humid air or only considering the strength of the cold air will not result in accurate predictions.

III. BLIZZARD WEATHER SITUATION AND IMPACT SYSTEM

A. Weather Situation Analysis

Fig. 1 Historical Blizzard System Impact Area
According to statistics, during the blizzard, the 500 hPa northern trough was located at 100°-115°E, 30°-40°N; the 700 hPa shear line was located at 105°-120°E, 30°-38°N; the 850 hPa shear line was located at 110°-120°E, 27°-32°N. The main factors affecting the system can be analyzed as follows: 500 hPa trough (100%), 500 hPa SW jet stream (100%), 700 hPa trough or shear (100%), 700 hPa low vortex (29.4%), 700 hPa SW jet stream (100%), 850 hPa large moist area with t-td≤2 (100%), 850 hPa shear (75%), 850 hPa low vortex (37.5%), 850 hPa jet stream (87.5% in total, including NE: 68.8%, SW: 12.5%, E: 6.25%, S: 6.25%), 925 hPa jet stream (80%, including NE: 60%, E: 20%), and surface cold front (100%).

All individual cases can analyze the 500 hPa trough, 500 hPa southwest jet stream, 700 hPa shear, 700 hPa southwest jet stream, 850 hPa wet area, and surface cold front. The jet stream at 850 hPa is mainly from the northeast, sometimes there may also be a southwest jet stream, an eastward jet stream, or a southward jet stream. Regarding the 500 hPa trough, previous researchers have summarized three types, namely the western blocking type, the low pressure belt type, and the Beihu high ridge type. But overall, it is the high-altitude situation of deep southwest jet stream under the situation of mid-latitude trough and southern branch trough. Therefore, the blizzard weather in the Yangzhou area is divided into two main categories, mainly distinguished by the direction of the low-level jet stream. The first category is typical blizzard weather, in which the high-altitude SW jet stream and the NE jet stream at 850 hPa and lower are dominant in the combination of high and low-level troughs or shears. The second category is atypical blizzard weather, in which the high-altitude SW jet stream and the existence of a water vapor convergence zone at 850 hPa in the combination of high and low-level troughs or shears, but the direction of the jet stream is in other directions.

Fig. 2 (a) West barrier type, (b) low pressure belt type, and (c) Beihu high ridge type schematic diagram

After statistical analysis, there have been 11 cases of the first type of blizzard in Yangzhou in the past 30 years, accounting for 61.11% of the total, and a total of 7 cases of the second type of blizzard, accounting for 38.89% of the total.

The conceptual model of blizzard weather in the Yangzhou area is shown in the figure below:

Fig. 3 Three-dimensional conceptual model of blizzard weather in Yangzhou.
Summary:
(1) The 500hPa upper-level cold trough drove the surface cold front southward, forming a descending branch in the upper atmosphere and a near-surface NE airflow. It converged north of the blizzard area, forming a deep, north-to-south inclined dry cold tongue in the upper atmosphere, and a noticeable cold layer near the surface.
(2) Southwest warm moisture airflow with a pressure of 850Pa or above was conducive to the formation of an inversion layer, providing special temperature and structural conditions for the occurrence of blizzards.
(3) The dry and cold northeast jet stream and the strong and warm moist jet stream converged in the blizzard area, creating favorable conditions for the convergence of water vapor and dynamics.
(4) When the lower-level cold and dry air encountered the warm moisture southwest airflow, it acted as a “cold pad” and wedges in, forming a convergence of dry and cold air with warm and moist air, further promoting the uplift of the warm and moist airflow.
(5) The area where cold and warm air meet showed obvious frontal generation, while forming a deep upward motion layer, which enhanced the effect of heavy snowfall. In addition, accompanied by the generation of low-level fronts, there was constantly dry and cold air being drawn into the warm and moist airflow, generating multiple secondary circulations at the intersection edge, leading to further strengthening of the upward motion.

B. Power Condition Analysis
According to statistics, the blizzard process was all affected by strong frontal zones. The SW airflow in the middle and lower levels was significantly overlaid with heat-induced winds, resulting in at least two strong SW jet streams between 500~850 hPa. These jet streams were generally stronger than the ones caused by vertical secondary circulation during local heavy rain. According to statistics, the wind speed at 500 hPa was generally greater than 24 m/s, and even reached as high as 40 m/s; at 700 hPa, the wind speed was generally greater than 16 m/s, and even reached as high as 20 m/s; at 850 hPa, the wind speed was generally greater than or equal to 12 m/s. The low-level SW jet stream was a strong conveyor belt of water vapor, heat, and momentum, which continuously transports warm and moist airflow for the formation of blizzards.

IV. Analysis of Water Vapor Conditions
According to statistics, the water vapor during the blizzard in the Yangzhou area mainly came from the Bay of Bengal and the northern South China Sea. The blizzard in Yangzhou basically met the following conditions: in the range of 25°-32°N, 105°-120°E, there were at least two wide humidity saturation zones at 500~850 hPa, with large water vapor flux and high extension height. The water vapor flux at 500 hPa is ≥8.0 g/(s·cm·hPa), and the axis of the water vapor flux was basically parallel to the axis of the blizzard. The greater the upstream water vapor flux, the greater the snowfall.

V. Blizzard’s Atmospheric Structure Analysis
A. Vertical Distribution of Temperature
As is well known, snow that falls to the ground is mainly formed in mixed clouds, where ice crystals and supercooled water coexist, which is conducive to the continuous growth of ice crystals and the rapid increase of both through collision and coalescence. The distribution of temperature layers below 500 hPa and the height of the 0°C layer have a significant impact on the formation of snow. The snowstorm process in Yangzhou area is always accompanied by the influence of strong cold air moving southward. In spring, snowstorms are accompanied by strong cold air outbreaks. Most of the snowstorm processes involve a phase change from rain or sleet to snow. When the change to snow occurs, the cold air has already penetrated below 850 hPa, and the temperature front generally lies between 30°—32°N with an intensity of up to 6°C/100 km. On the upper air chart, the 850 hPa temperature in Nanjing is generally ≤-5°C, and the local 2m temperature is below 3°C.

B. Stability condition analysis
Analyzing the historical cases of blizzards in Yangzhou, there is a cold air cushion in the lower atmosphere below 850 hPa. Between 850~700 hPa, there is an inversion layer. At 700 hPa, there is a warm layer. In the middle layer between 700~500 hPa, there is a height where convergence and upward motion occur, creating an unstable layer. Warm and moist airflow rises on the cold cushion, triggering condensation of water vapor and release of latent heat. Therefore, on some days with blizzards, there may also be severe convective weather.
VI. SATELLITE CLOUD IMAGE FEATURES

According to historical records, when blizzards occur in the Yangzhou area, the cloud cover over the eastern region of China is extensive but loosely structured. The bright temperature centers of the cloud systems are mostly located north of the Yangtze River, with cloud top brightness temperatures ranging from -30 to -40°C in winter and reaching -50°C in spring. The Yangzhou area is located in the overlapping zone of warm and humid low-level clouds and high-level cold clouds, with a southwest-northeast water vapor plume that has an unclear boundary and continues to move steadily northeastward.

The diagnostic process for forecasting blizzards in the Yangzhou region is as follows:

<table>
<thead>
<tr>
<th>Step</th>
<th>Name</th>
<th>Forecast indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Situation diagnosis</td>
<td>Both warm and cold air are strong; there are two west wind troughs in the north and south, mid-low level shear, southwest jet stream, and low-level cold pad.</td>
</tr>
<tr>
<td>2</td>
<td>Vertical temperature</td>
<td>Inversion, temperature below -4°C at 850 hPa, temperature below 3°C at 2m, surface temperature close to 0°C.</td>
</tr>
<tr>
<td>3</td>
<td>Power condition analysis</td>
<td>500–850 hPa altitude has a strong SW jet stream.</td>
</tr>
<tr>
<td>4</td>
<td>Analysis of water vapor</td>
<td>There are two or more broad saturated areas between 500–850 hPa, with large water vapor flux and convergence, and high expansion.</td>
</tr>
</tbody>
</table>

December 18, 2023 Blizzard Process Analysis

A. Actual situation

From the morning of the 18th, the city has experienced snowfall from the southwest to the northeast. The intensity of the snowfall weakened at night. As of 08:00 on the 19th, Baoying had light snow, Gaoyou had heavy snow, the southern region had blizzard conditions, with snow depths ranging from 2 to 11 centimeters, and the downtown area of Yangzhou had 10 centimeters of snow.

<table>
<thead>
<tr>
<th></th>
<th>Yangzhou</th>
<th>Baoying</th>
<th>Gaoyou</th>
<th>Yizheng</th>
<th>Jiangdu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total snowfall</td>
<td>13.1</td>
<td>2.4</td>
<td>7.6</td>
<td>12.7</td>
<td>12.6</td>
</tr>
<tr>
<td>19th, 08:00 AM</td>
<td>8</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>Maximum snow depth during the process</td>
<td>10</td>
<td>2</td>
<td>7</td>
<td>10</td>
<td>11</td>
</tr>
</tbody>
</table>
Fig. 4 Hourly precipitation and temperature in Yangzhou on December 18th

B. Weather conditions

Fig. 5 December 18th 8:00 (a) 20:00 (b) 500hPa Aerial Chart
This process was the transformation of the 500hPa trough from horizontal to vertical, and the upper level wind field changed to northwest or north wind, accompanied by the eastward movement of the westerly trough, with a cold center of -45°C in the upper level. 700hPa shear, southwest jet stream, forecast diagnostic process. 850hPa low vortex moving eastward. Meanwhile, a cold front was approaching on the ground. Through analysis of the temperature logarithmic pressure chart, warm and humid airflow was above 850hPa, close to saturation between 850-500, and a cold cushion below 700hPa, which was conducive to lifting.
C. **Pattern Comparison**

The main factor for the smaller precipitation forecast was the weaker forecast of the EC 700hPa jet stream compared to the pattern (figure omitted) and the deviation of humidity conditions from the actual conditions.
VII. SNOW DEPTH FORECAST

A. Snow Depth Forecast Approach

Snowfall is the main factor determining snow depth. In the process of snowfall, temperature and surface temperature also play an important role in the formation of snow accumulation. The temperature of the lower atmosphere determines the melting speed of snow near the surface, which in turn affects the water content of solid precipitation. Generally speaking, when the temperature is low, the snowfall tends to have a lower water content, mainly consisting of dry snow. This has a good cooling effect on the ground and is easy to accumulate and grow quickly. Conversely, wet snow forms slowly and grows slowly. Surface temperature is also very important for snow. If the surface temperature is high, more early snowfall is needed to absorb heat and slow down the melting speed of the snowfall, even if the snow accumulates and there is heat exchange between the surface and deep soil, it will still cause the snow to melt quickly. On the other hand, if the ground temperature is low, it is conducive to the formation and growth of snow.

On local Blizzard days, the snowfall process is mostly rain or sleet turning into snow. There is a significant difference in the ratio of snow depth to precipitation, and there are obvious regional differences, which are closely related to the specific distribution of temperature in each process and surface temperature. During the pure snowfall process, both the air temperature and surface temperature are below 0℃. When the temperature at 850 hPa is less than or equal to -8℃, it is favorable for the snow to accumulate. There is a high possibility that the 24-hour average Snowfall-to-Liquid Ratio (SLR) in Yangzhou will be greater than 10. The process of rain or sleet turning into snow, the majority of which has an average snow-to-liquid ratio (SLR) of less than 10 over a 24-hour period. In the northwest, it can reach 6 to 9, while in the southeast it is only 5 to 2.

B. AI-based Snow Depth Forecast

By collecting years of data from the previous text, the Yangzhou snowfall process database was established. Four machine learning models, including multiple linear regression, multiple nonlinear regression, decision tree, and neural network, were selected for prediction. The models were trained using the database to fit the parameters and ultimately achieve accurate quantitative prediction of snow depth. Considering regional differences and the requirement for fine-grained forecasting, analysis was conducted on four models for each of the five sites separately. It should be noted that if only Blizzard Day is selected, the data sample is too small, so as long as snow accumulation occurs during the snowfall process, it should be selected as a sample.

First, multiple linear regression model:

Principle: Multiple linear regression model is used to establish a linear relationship between independent variables (features) and dependent variables (targets). The model minimizes the sum of squared residuals by fitting a straight line (or a hyperplane in multidimensional cases) between the predicted values and the actual values.

Advantages:
Relatively simple, easy to understand and explain.
Fast calculation speed, suitable for large-scale datasets.

Disadvantages:
The fitting effect of non-linear relationship data is poor.
Sensitive to outliers and collinearity.
Ignored the potential interactions between independent variables.

Second, multiple non-linear regression model:

Principle: Similar to linear regression models, but allows for a non-linear relationship between the independent variables and the dependent variable. Usually, polynomial regression, exponential function regression, and other forms are used.

Advantages:
Able to better fit nonlinear relationships in data.
High flexibility, can choose different nonlinear function forms based on data characteristics.

Disadvantages:
It is easy to overfit, especially in high-order polynomial regression.
The interpretability of the parameters decreases as the complexity of the model increases.

Third, decision tree model:
Principle: Decision tree predicts the target variable by recursively dividing the data into two parts and constructing a tree. Each node is a conditional judgment, and the leaf nodes of the tree represent the final predicted result.

Advantages:
Easy to understand and explain, can be visualized.
Able to handle mixed types of data.
Insensitive to missing values.

Disadvantages:
Overfitting is easy, especially in decision trees that have grown too deep.
Unstable, small data changes can lead to huge changes in the tree structure.

Fourth, neural network model:
Principle: A neural network model is a network composed of multiple neurons (nodes), which learns the complex relationship between data through forward propagation and backward propagation. Each neuron has weights and biases, and the input signal is transformed into output through an activation function. This text specifically uses a fully connected neural network structure.

Advantages:
Able to learn and capture complex nonlinear relationships.
Performs well in large-scale datasets and high-dimensional feature spaces.
Has strong generalization ability.

Disadvantages:
The training process requires a large amount of computing resources and time.
Sensitive to hyperparameters such as parameter initialization, learning rate, and network structure.
The results of the model are not easy to explain.

C. Model Prediction

Through the above models, it was predict the snow depth of the blizzard weather process on December 23, 2023. The results are as follows:

<table>
<thead>
<tr>
<th>Station number</th>
<th>Snow depth predicted by decision tree model</th>
<th>Snow depth predicted by neural network model</th>
<th>Snow depth predicted by linear regression model</th>
<th>Snow depth predicted by nonlinear regression model</th>
<th>Actual maximum snow depth in centimeters</th>
</tr>
</thead>
<tbody>
<tr>
<td>58245</td>
<td>4.69</td>
<td>5.119999886</td>
<td>7.02</td>
<td>11.25</td>
<td>10</td>
</tr>
<tr>
<td>58244</td>
<td>4.69</td>
<td>5.110000134</td>
<td>7.94</td>
<td>6.77</td>
<td>11</td>
</tr>
<tr>
<td>58242</td>
<td>12</td>
<td>5.460000038</td>
<td>5.73</td>
<td>6.28</td>
<td>10</td>
</tr>
<tr>
<td>58241</td>
<td>11.44</td>
<td>4.710000038</td>
<td>4.85</td>
<td>6.77</td>
<td>7</td>
</tr>
<tr>
<td>58148</td>
<td>3.41</td>
<td>3.460000038</td>
<td>3.55</td>
<td>3.49</td>
<td>2</td>
</tr>
</tbody>
</table>

By comparing with the actual snow depth, it is found that the non-linear regression model has the best predictive effect at Yangzhou station, the linear regression model has the best effect at Jiangdu station, the decision tree has the best effect at Yizheng station, the non-linear regression model has the best effect at Gaoyou station, and all four models have good effects at Baoying station, with errors within 2cm, among which the decision tree has the best effect.

VIII. CONCLUSIONS AND DISCUSSION

(1) The weather system that causes heavy snowfall in the Yangzhou area mainly includes two west wind troughs, mid-low level shear, southwest jet stream, and low-level cold air damming.

(2) Yangzhou is located in the lower reaches of the Yangtze River. Snowfall often comes with rain and ice pellets, mostly turning from rain or sleet to snow. The determination of snowfall needs to consider the precipitation amount after converting to pure snowfall, and there are more factors affecting snow depth, also need to take into account the surface temperature. Therefore, the forecast of precipitation and snow depth for the regional blizzard in Yangzhou must take into account the simultaneous southward movement of strong cold air and the northward movement of strong warm and humid air, as well as their chronological order.
(3) During the regional blizzard in Yangzhou, there is a strong SW jet stream at 500-850 hPa altitude; there is a cold cushion below 850 hPa, and when the temperature at 850 hPa is less than or equal to -4°C and the temperature at 2m is less than or equal to 3°C, rain turns into snow, and snow accumulation increases significantly when the surface temperature approaches zero degrees; there is an inversion layer between 850-700 hPa, and strong convergence and upward movement of jet streams above 700 hPa lift warm and humid air, and release latent heat through condensation, providing dynamic and thermal conditions for blizzards.

(4) The 24-hour average SLR in the Yangzhou area is generally ≥10 for pure snow processes, < 10 for rain-to-snow processes, and < 5 in the southeast. The distribution of the entire layer of air temperature and surface temperature is closely related to SLR. It can be predicted by 850 hPa, 2m temperature, and surface temperature for precipitation phase transition and SLR. Based on accurate precipitation forecast, reasonable estimation of SLR can be made to make accurate snow depth forecast.

(5) Comparing the circulation patterns to find similar processes that have historically resulted in heavy snowfall, and then using the comparison of the vertical structure, dynamics, and moisture conditions to infer the precipitation and snow depth of similar processes, is also a feasible method. Obtain the diagnostic process for heavy snowfall events and snow depth forecast.

(6) Using machine learning methods to predict snow depth, different station model results are obtained, and four model methods are used to predict the snow depth during the snowfall process on December 18, 2023. More variables will be introduced in the future to continue exploring related objective forecasting methods.

(7) The future plan is to further upgrade the forecasting system, transforming the current discrete site-specific numerical prediction into a graphical representation of the entire continuous snow depth for the region. First, we hope to enrich and optimize numerical prediction into a graphical representation of the entire continuous snow depth for the region. Second, we will introduce a more suitable network fitting prediction model based on deep learning technology. Finally, we will combine image processing technology to generate a forecast image of snow depth for a specific area, meeting the demand for refined forecasting.

REFERENCES