Research on comprehensive index of freezing disaster caused by rain and snow

Zhenxing Chang\textsuperscript{a}, Zhen Wei\textsuperscript{b}, Tao Chen\textsuperscript{c}, Guanning Wang\textsuperscript{c}, Na Ma\textsuperscript{d}, Huijie Zheng\textsuperscript{e}

Department of Engineering Physics, Tsinghua University, Beijing, China
\textsuperscript{a}czxing2008@163.com, \textsuperscript{b}weizhen@mail.tsinghua.edu.cn, \textsuperscript{c}wgn19@mails.tsinghua.edu.cn, \textsuperscript{d}915383953@qq.com, \textsuperscript{e}zhenghuijie@mail.tsinghua.edu.cn

\textsuperscript{*}Corresponding author: chentao.a@mail.tsinghua.edu.cn

Abstract—In this study, the ISD surface meteorological observation data set in NCEI database website under NOAA is used. The longitude and latitude range of the selected stations is 105°E~117.5°E, 24°N~32.5°N. The basic meteorological data of the winter from 2001 to 2010 are statistically analyzed. The statistical analysis shows that there is a short period of severe cooling to below 0℃ and relative humidity increasing in 2008, in addition, the observed wind speed did not change significantly, the wind direction changed disorderly, and the sea level pressure at different stations showed high consistency. Based on the statistical analysis, three basic meteorological elements, temperature, relative humidity and wind speed, are selected to normalize, and then the rain snow freezing disaster index is generated according to the weight. According to the unified standard, Guizhou Province is (0.65,0.3,0.05), Hunan and Jiangxi Province is (0.55,0.4,0.05). Through the qualitative evaluation of the weight factor scheme, it can reasonably reflect the situation of rain and snow freezing disaster.

1. Introduction

Since the snow disaster in southern China in 2008, many experts and scholars have carried out quantitative assessment of low-temperature rain and snow freezing disaster\textsuperscript{[1-2]}. For example, Wan Suqin et al.\textsuperscript{[3]} proposed a comprehensive index to measure the freezing process of rain and snow in 2008, covering precipitation and temperature. The final comprehensive index reflects well the severity of the rain and snow freezing disaster in 2008. Wang Ying et al.\textsuperscript{[4]} specifically used five indicators which were annual average freezing times, daily average temperature, freezing duration, daily average precipitation and precipitation duration to obtain the risk distribution of low-temperature rain and snow freezing disaster in China. Mao Shujun et al.\textsuperscript{[5]} selected the daily maximum and minimum temperature, daily average relative humidity and sunshine hours of the day based on the statistical analysis of meteorological element data for many years, integrated them to generate a comprehensive index representing the freezing rain and snow, and analyzed the risk degree of low-temperature rain and snow freezing in southern China. Wang Yuetong et al.\textsuperscript{[6]} constructed the evaluation index of freezing rain occurrence in Southwest China by using temperature, humidity and sunshine hours, and constructed the freezing rain intensity index by using the longest continuous days of annual freezing rain, the minimum average temperature value and the total number of freezing rain occurrence days per year.
All of these studies use the temperature, precipitation and sunshine data with daily and above as the minimum time resolution to quantitatively evaluate the rain and snow freezing disasters in different regions and years. Different from the previous study, this study uses the basic meteorological elements data with time resolution of 3 hours to synthesize the comprehensive index of rain, snow and freezing disaster, and generates the time series of winter comprehensive index from 2001 to 2010, and analyzes and compares them. From the comprehensive index every 3 hours, we can see that the whole process of snow disaster in 2008 is at a relatively high risk level, and many stations have four obvious upward fluctuations in the process, corresponding to the four rain and snow processes of 2008 snow disaster [7-9].

2. Index synthesis method

2.1 Normalization of temperature, relative humidity and wind speed
Considering that the dimensions of temperature, relative humidity and wind speed are different, they can not be directly added, so normalization is needed to generate dimensionless index.

(1) Generate cold index \( (I_c) \) for temperature \( (T_{max} = 35^\circ C, T_{min} = -15^\circ C) \):
\[
I_c = \frac{T_{max} - T}{T_{max} - T_{min}}
\]  
(1)

(2) Generate humidity index \( (I_h) \) for relative humidity \( (RH) \):
\[
I_h = \frac{RH}{100}
\]  
(2)

(3) Generate wind speed index \( (I_v) \) for wind speed \( (V) \) \( (V_{max} = 26 m/s, V_{min} = 0 m/s) \):
\[
I_v = \frac{V - V_{max}}{V_{max} - V_{min}}
\]  
(3)

2.2 Synthesis of rain and snow freezing disaster index
The synthesis of rain and snow freezing disaster index \( (I_d) \) is obtained by adding different weight factors \( (f) \) given to the cold indexes, humidity indexes and wind speed indexes. The specific calculation formula is as follows:
\[
I_d = f_1 \times I_c + f_2 \times I_h + f_3 \times I_v
\]  
(4)

Among them, the weight factor
\[
f_1 + f_2 + f_3 = 1
\]  
(5)

3. Weight selection

3.1 Weight factor selection range
Weight factors \( (f_1, f_2, f_3) \) consider 8 groups of selected schemes, see Table 1 for details.

| Scheme | \( f_1 \) | \( f_2 \) | \( f_3 \) |
|--------|--------|--------|--------|
| 1      | 0.85   | 0.1    | 0.05   |
| 2      | 0.75   | 0.2    | 0.05   |
| 3      | 0.65   | 0.3    | 0.05   |
| 4      | 0.55   | 0.4    | 0.05   |
| 5      | 0.45   | 0.5    | 0.05   |
| 6      | 0.35   | 0.6    | 0.05   |
| 7      | 0.25   | 0.7    | 0.05   |
| 8      | 0.15   | 0.8    | 0.05   |
3.2 Weight factor selection evaluation index
The selection of weight factor of the freezing disaster index in the central region is based on the winter of 2008 and that year's rain and snow freezing disaster. The unified method is adopted to generate quantitative composite index and select the optimal weight factor scheme. Firstly, two indicators are constructed. Index 1: the proportion of disaster index lower than the freezing value of rain and snow except the whole process of freezing rain and snow in winter of 2008. Index 2: during the four rain and snow processes in 2008, the disaster index is higher than the proportion of freezing value of rain and snow (since there is no freezing rain in the first process in Jiangxi Province, the scope of index 2 in Jiangxi Province is the last three rain and snow processes). The setting of rain and snow freezing value $F_{\text{main}}$ mainly refers to the research results of reference and makes minor changes[4].

$$F = f_1 \times I_c (0^\circ \text{C}) + f_2 \times I_h (80\%) + f_3 \times I_{VA}$$

(6)

The final synthetic index ($I_s$) is,

$$I_s = W_1 \times I_1 + W_2 \times I_2$$

(7)

$W_1$ and $W_2$ represent the weight of indicator 1 and indicator 2, and the selection of weighting factors of disaster index will be affected by the selection of $W_1$ and $W_2$. In order to reduce the influence of $W_1$ and $W_2$ on the selection of schemes ($f_1$, $f_2$, $f_3$), $W_2$ was fixed as 1, and $W_1$ was taken as natural number between 1 and 10, and the scheme ($f_1$, $f_2$, $f_3$) with the highest synthesis index was selected. The specific statistical results are shown in the table below.

| Weight factor scheme | Guizhou | Hunan | Jiangxi |
|----------------------|---------|-------|---------|
| 1                    | 5       | 1     | 4       |
| 2                    | 0       | 0     | 0       |
| 3                    | 9       | 1     | 0       |
| 4                    | 1       | 6     | 6       |
| 5                    | 0       | 4     | 0       |
| 6                    | 0       | 0     | 0       |
| 7                    | 0       | 0     | 0       |
| 8                    | 1       | 3     | 0       |
| Final selected scheme | (0.65,0.3,0.05) | (0.55,0.4,0.05) | (0.55,0.4,0.05) |

4. Result evaluation

4.1 Comparison of weight schemes of single station in 2008
As shown in Figure 1, the 2008 time series of rain snow freezing disaster comprehensive index of eight stations with different weight schemes of USAF sequence number of 578160 in Guizhou Province is shown. It can be seen from Figure 1 that the composite index has daily and several day periodic fluctuations similar to temperature and relative humidity. From the upper left to the lower left and from the upper right to the lower right in Figure 1, the weight of cold index gradually decreases, while the weight of humidity index increases gradually. When the weight factor of the cold index is the largest (the weight factor is 0.85), the comprehensive index time series can highlight the process of rain snow freezing disaster in 2008. With the gradual increase of humidity index, the fluctuation range of other time periods increases. When the weight factor of humidity index is the largest (weight factor is 0.8), the peak value of comprehensive index in other periods of the station is similar to that of rain, snow and
freezing disaster in 2008. Comparing the subgraph with higher weight of cold index (upper left) and that with higher weight factor of humidity index, it can be found that the subgraph with higher weight factor of humidity index has four small fluctuations in the process of rain and snow freezing disaster in 2008, while the subgraph on the lower right has basically kept constant in other periods except for the first obvious fluctuation.

Figure 1 The comprehensive index of snow and ice disaster in different weight schemes of 578160 station in Guizhou Province
The weight factor schemes ($f_1$, $f_2$, $f_3$) are marked on the top of each sub graph. The red dot line represents the contour line of the freezing value $F$ of rain and snow in the weight scheme. The yellow short dotted line is the mean value of the winter in the year.

4.2 Comparison of single site for many years

Figure 2 Time series comparison chart of composite index with weighting factor scheme of 578160 station in Guizhou Province (0.65, 0.3, 0.05)
The comparison chart of time series of comprehensive index is the comparison chart of other years and 2008. Yellow for 2008, blue for other years. Others are the same as Figure 1. As can be seen from Figure 2, using the weighting factor scheme selected by the above criteria, the comprehensive index of the station in other years is also close to, or even exceeds the maximum value of the rain snow freezing disaster process in 2008. However, the duration of the whole process of the snow disaster in the south of China in 2008 was longer than that in the last decade. In other years, there have been 5 to 10 days of processes beyond the freezing line (e.g. 2003 and 2005), indicating that there may have been snow and rain disasters during that period of the year. This site shows the process of rain and snow freezing disaster in 2008, which is higher comprehensive index and longer duration in which the index is beyond the freezing line of rain and snow.

4.3 Multi sites comparison in 2008

![Figure 3 Time series of comprehensive index of 8 stations in Guizhou Province in 2008](image)
In which, the weight factor scheme is (0.65, 0.3, 0.05), and the title of the subgraph represents the USAF serial number of the corresponding station of the subgraph. In Figure 3, using the weight factor scheme, 8 stations in Guizhou Province can show the process of rain and snow freezing disaster in 2008. The 2008 composite index of some stations can show the four rain and snow processes in the disaster process, such as stations 577310, 579320, etc. It is worth noting that the composite index of station 579160 is lower than the freezing value of rain and snow most of the time in the whole disaster process, but higher than its average comprehensive index in 2008. On the whole, the weight factor scheme reasonably represents the process of rain and snow freezing disaster in Guizhou Province in 2008, and even describes the four rain and snow processes.

Figure 4 Time series of comprehensive index of 8 stations in Hunan Province in 2008
Among them, the weight factor scheme is (0.55, 0.4, 0.05), similar to Guizhou Province, the weight factor scheme adopted in Hunan Province can better represent the disaster process and four rain and snow processes in 2008, 575840 and 576550 were typical stations for example. The time series of comprehensive index of 8 stations in Jiangxi Province is shown in Figure 5, and the weight factor scheme is (0.55, 0.4, 0.05).

Figure 5 Time series of comprehensive index of 8 stations in Jiangxi Province in 2008
5. Conclusion

Through the evaluation of the weight factor scheme of the comprehensive index in Guizhou, Hunan and Jiangxi, it can be considered that the weight selection standard of this study is reasonable, and the weight factor scheme selected by the standard can actually reflect the process of rain and snow freezing disaster in 2008, and the difference between 2008 and other years from 2001 to 2010.

Acknowledgment

The research is supported by the Project of National Key R&D Program of China (No. 2017YFC0803300), which is gratefully acknowledged.

References

[1] S.Y. Tao, and J. Wei, Severe Snow and Freezing-Rain in January 2008 in the Southern China, Climatic and Environmental Research, 2008(04): 337-350.
[2] Y. Xue, Y. L. Liu, and T. T. Zhang, Research on formation mechanism of coupled disaster risk, Journal of Natural Disasters, 2013, 22(02): 44-50.
[3] S. Q. Wan, Y. H. Zhou, L. Li, R. Q. Shi, G. F. Guo, and B. Chen, A Multi-index Synthetic Assessment Method for Extreme Climate Events of Sleet and Freezing with Low Temperature, Meteorological Monthly, 2008(11): 40-46.
[4] Y. Wang, X. Y. Wang, Z. H. Jiang, X. N. Zeng, Q. F. Ma, C. Cheng, and Q. Liu, Risk assessment and zoning of low temperature rain and snow freezing disasters in China, Meteorological Monthly, 2013, 39(05): 585-591.
[5] S. J. Mao, and D. L. Li, Comprehensive assessment of low temperature, snow and freezing weather in southern China based on meteorological elements, Journal of Glaciology and Geocryology, 2015, 37(01): 14-26.
[6] Y. T. Wang, and D. L. Li, Freezing rain disasters in Southwest China: characteristic analysis and evaluation, Journal of Glaciology and Geocryology, 2017, 39(05): 967-978.
[7] L. G. Zheng, S. J. Zhang, X. H. Guan, F. Yan, Y. Wu, J. R. Zhu, and Y. Liu, A review of public health emergency response to extreme weather disasters in central China's Hubei province in early 2018, Chinese Journal of Disaster Medicine, 2018, 6(07): 361-365.
[8] Z. Q. Lai, L. P. Zhai, Y. D. Zhang, and R. Huang, Analysis of a rare low-temperature snow and freezing disaster weather at the begining of 2016 in Guangxi Province, Journal of Natural Disasters, 2017, 26(01): 156-164.
[9] Q. Y. Kong, H. Lu, L. Jin, X. H. Zhou, and X. M. Shi, Particle Swarm-Support Vector Regression Forecasting Method for Low Temperature Rain and Snow Process, Journal of Natural Disasters, 2019, 28 (05): 125-133.