Development of Global Daily Snow Depth Dataset and its Applications in the Third Pole Region

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Background

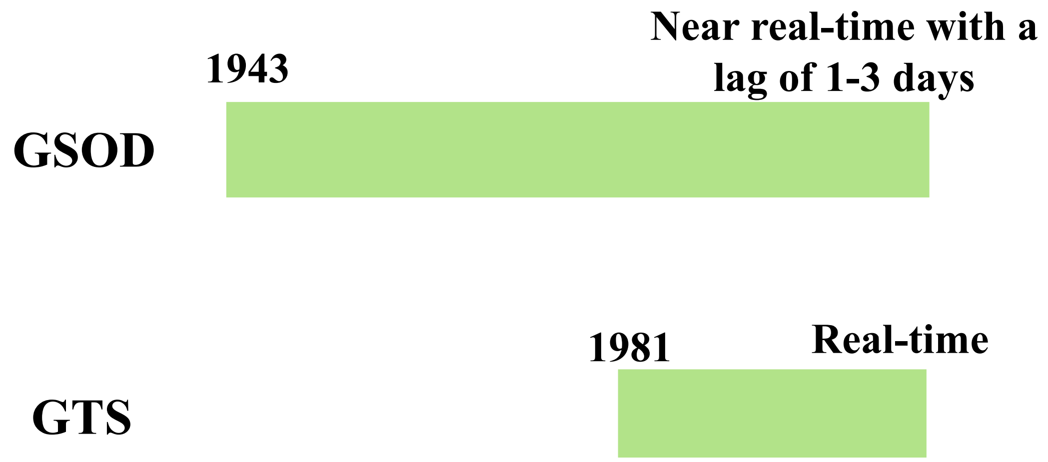
- Global warming has led to a general decline in snow cover, yet in some regions, the frequency of heavy snow events has instead increased.
- Snow depth is an indicator characterizing the physical state of snowpack, and one of the meteorological observation elements. It serves as a critical parameter for studying the climatic effects of snow as well as monitoring snow disaster.

High-quality in-situ snow depth observations serve as benchmark data, forming the foundation for snow weather, as well as providing a basis for the validation of models and satellite products.

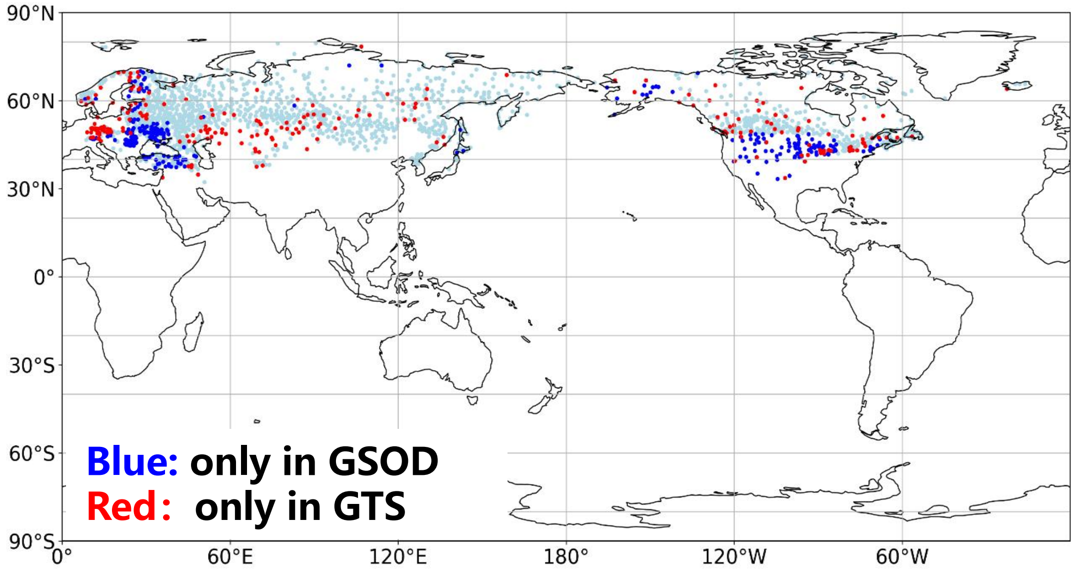
Background

In China, snow depth monitoring primarily relies on two key datasets: real-time snow depth data transmitted via the GTS and daily snow depth observations from the GSOD published by NOAA's NCEI

- GSOD provides longer time series and denser station coverage in North America and Europe, but with lower timeliness
- GTS features faster timeliness and greater station density in Asia, though with shorter historical records
- Both datasets only underwent basic quality control and contain much erroneous data, which may compromise weather and climate monitoring conclusions



Historical data length and timeliness of snow depth in GTS and GSOD



Number of sites outside China with non-zero snow depth in GTS and GSOD on January 1, 2016

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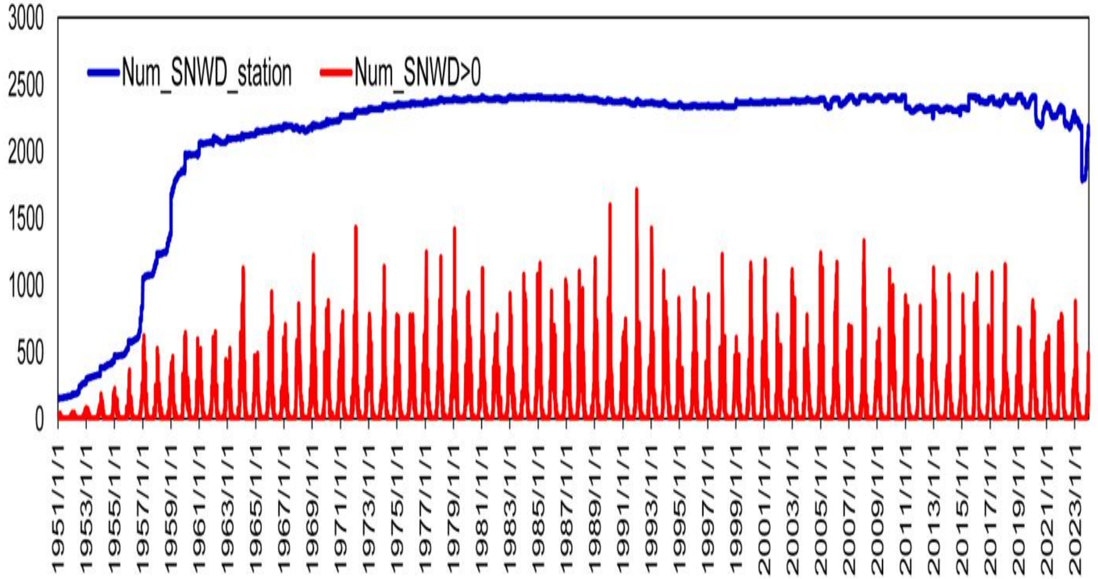
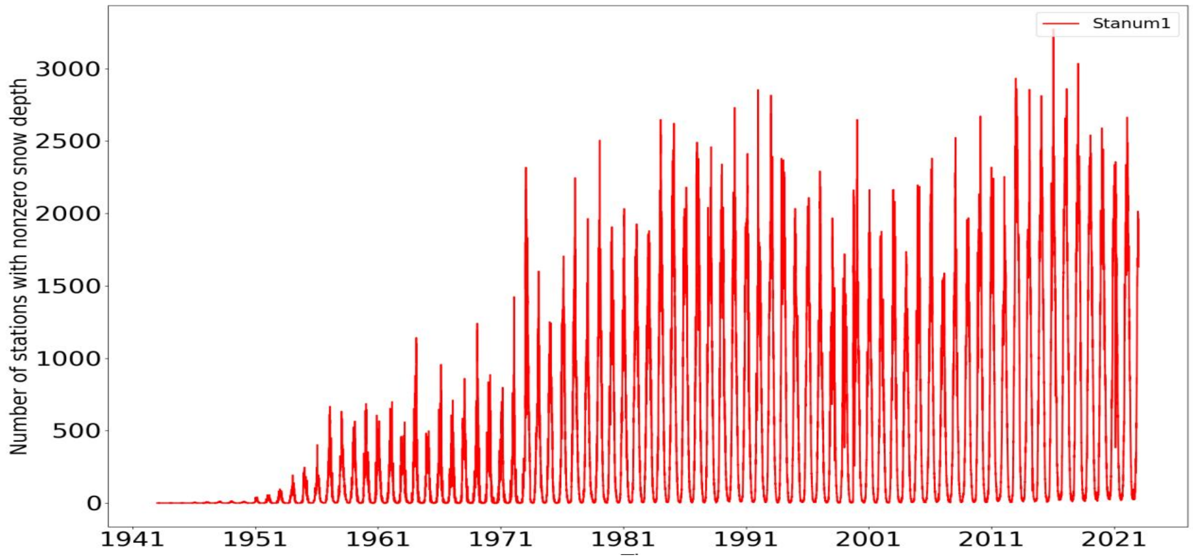
1、Data Sources

- **China Region:** Based on snow depth data **from national-level surface stations**, comprehensive quality control has been applied to identify and filter various types of erroneous data, particularly false "0 cm" reports. There are about 1000 stations with non-zero snow depth in winter
- **Regions outside China:** GTS and GSOD snow depth data were merged **with GSOD receiving higher priority.**
- Globally, the maximum number of stations with non-zero snow depth reaches 3,000.

Daily Variation in the Number of Snow Depth Observation Stations in China (1951–2022)

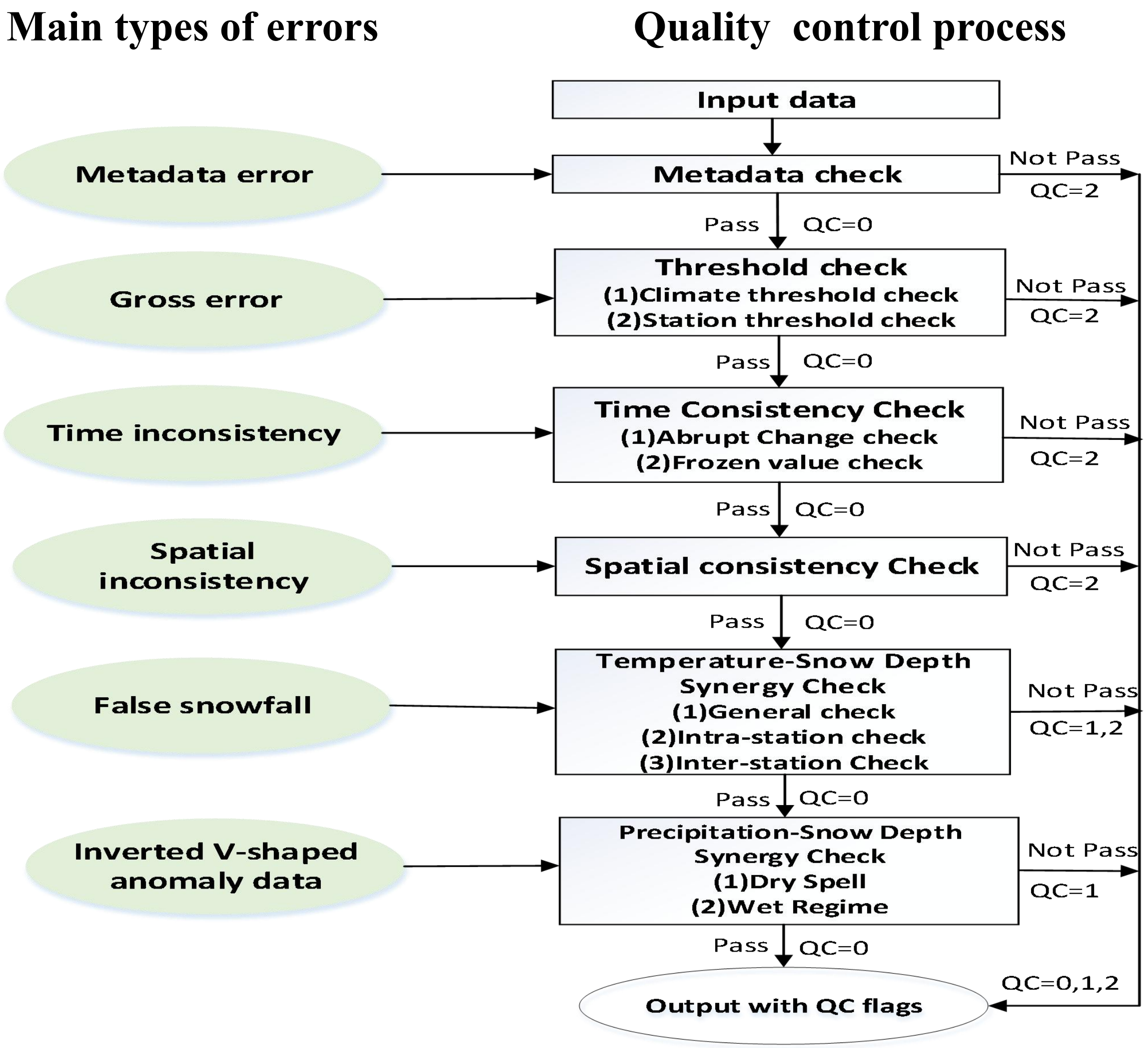


Daily Variation in the Number of Global Non-Zero Snow Depth Observation Stations (1943–2022)



2、Quality Control

- Through researching snow depth quality control methods and analyzing major error types, **a six-step quality control process** was established. The process is fully automated△



2、Quality Control

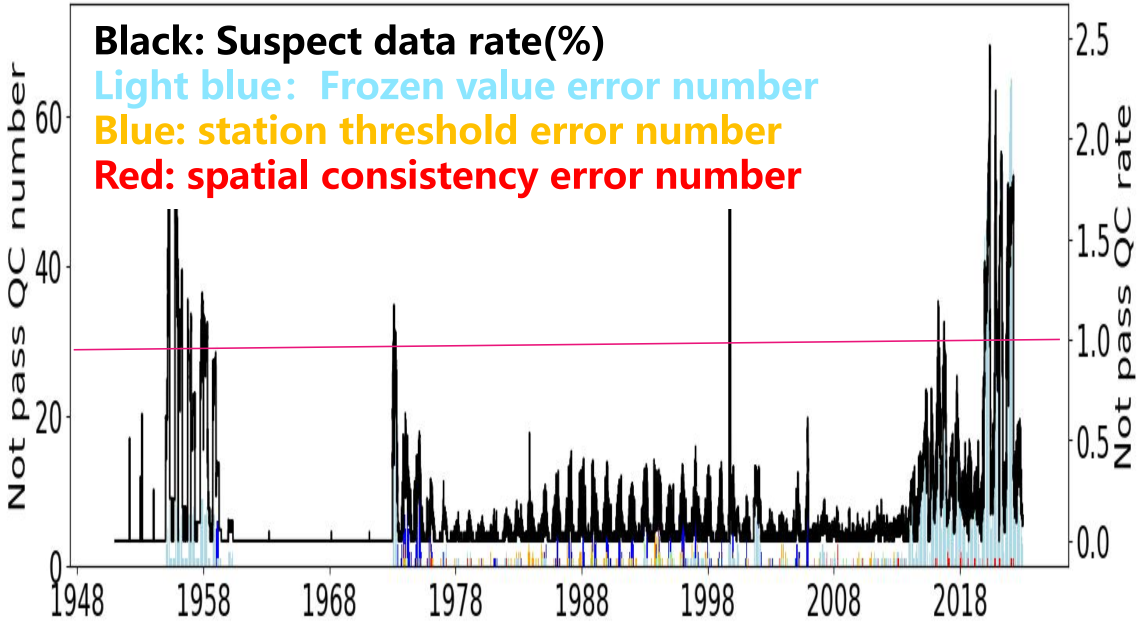
◆ **Proportion of different error types and temporal characteristics:**

- The **frozen value check** detect the highest number of error data, followed by **temperature synergy check**
- The erroneous **rate exceed 1% in certain months during 1955–1958, 1999, and 2020–2022**, while below 1% in other periods
- The "**frozen value**" become more pronounced **after 2015**

Proportion of different error types during 1943-2022

QC steps	Number of stations containing suspect data	Number of suspect data records	Proportion of suspect data
Station threshold check	2408	5953	0.009%
Abrupt Change Check	251	327	0.0007%
Frozen Value Check	226	66667	0.1%
Spatial Consistency Check	405	1047	0.002%
Temperature-Snow Depth Synergy Check	2249	6366	0.01%
Precipitation-Snow Depth Synergy Check	1101	2171	0.004%

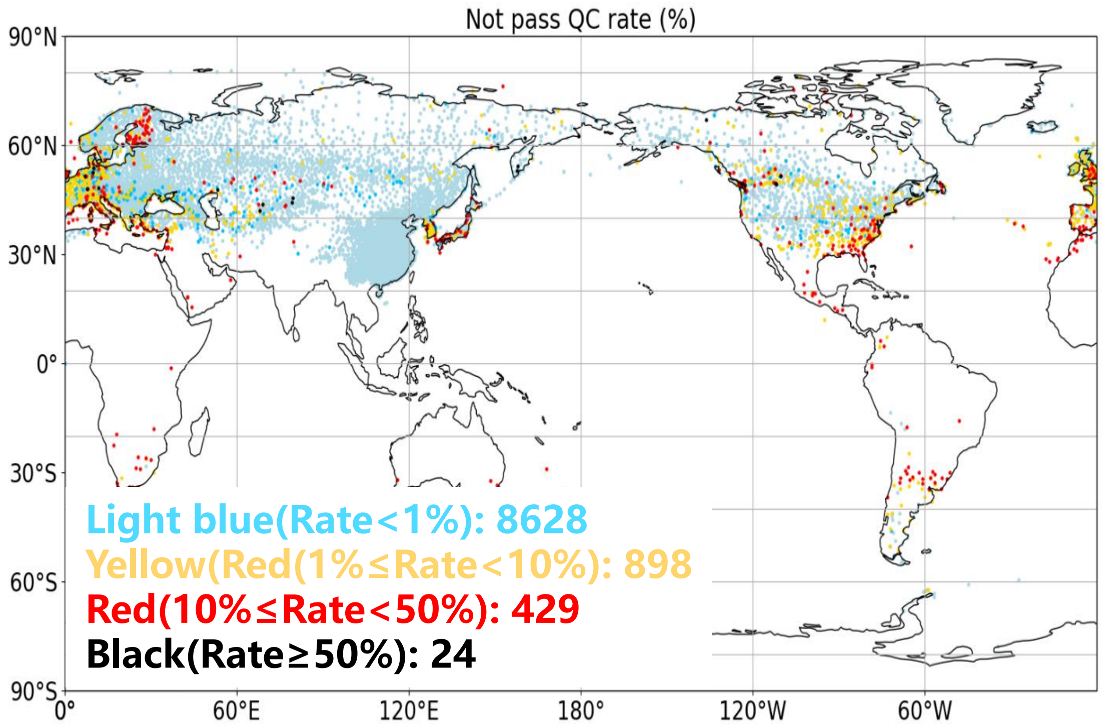
Temporal Characteristics of Suspect Data



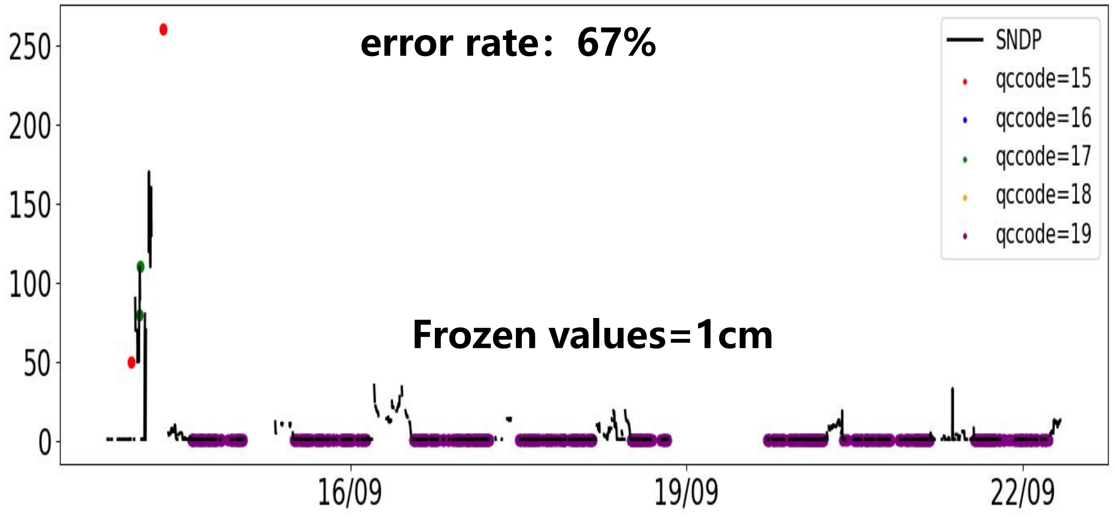
2、Quality Control

◆ **Spatial Distribution of Erroneous Rate:**

- **About 87% stations have an error rate of less than 1%.**
- **Stations with error rate exceeding 10% are distributed in eastern United States, western Europe, south America, and south Africa**
- **24 stations with error rate exceeding 50% are mainly located in in high-altitude regions of Asia, and the errors are mainly caused by frozen values**



Stanum:36785 (Lat:45.383，Lon:79.5，Hgt:628)

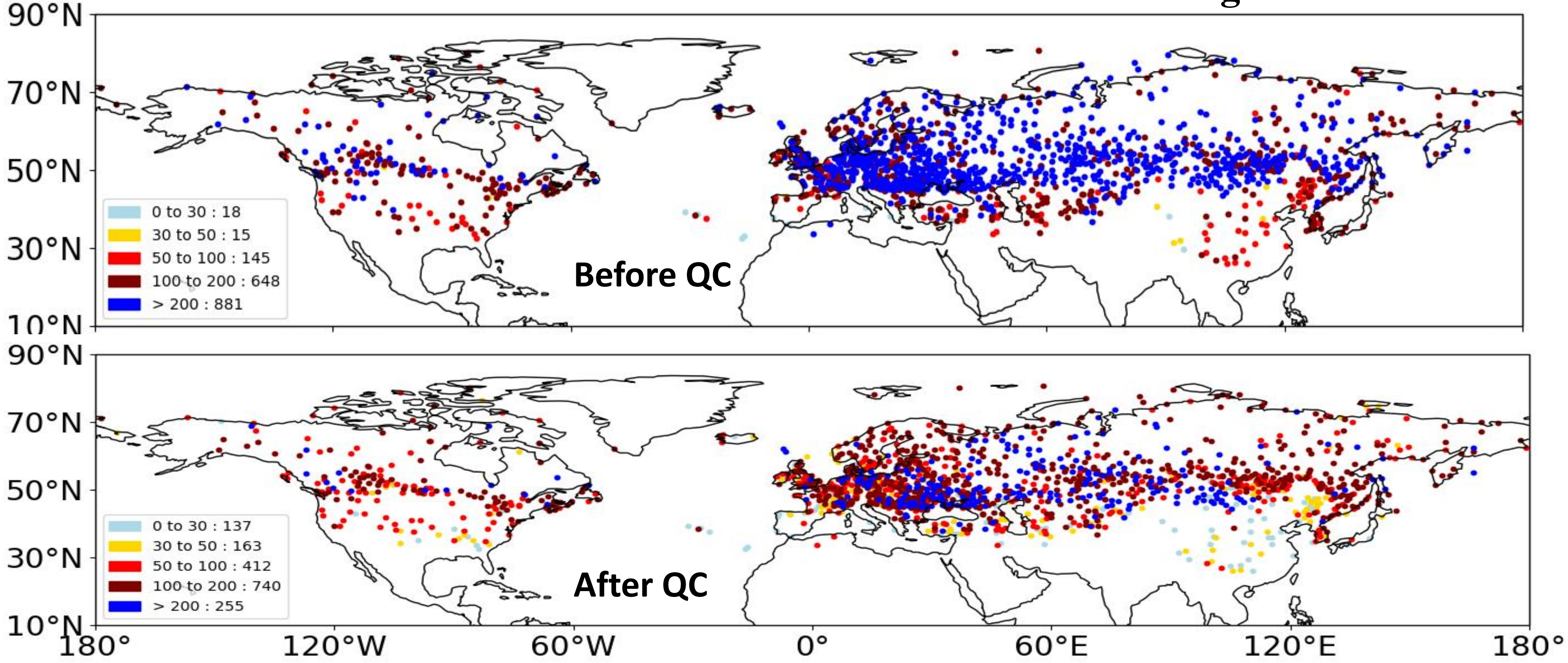


2、Quality Control

◆ Impact of Quality Control on Historical Extreme Values:

- The historical extreme values of snow depth at 1,706 stations were detected as error data
- After quality control, the historical extreme values at 640 stations were adjusted from over 200cm to below, resulting in a more reasonable distribution of extremes.

stations where historical extreme values have changed



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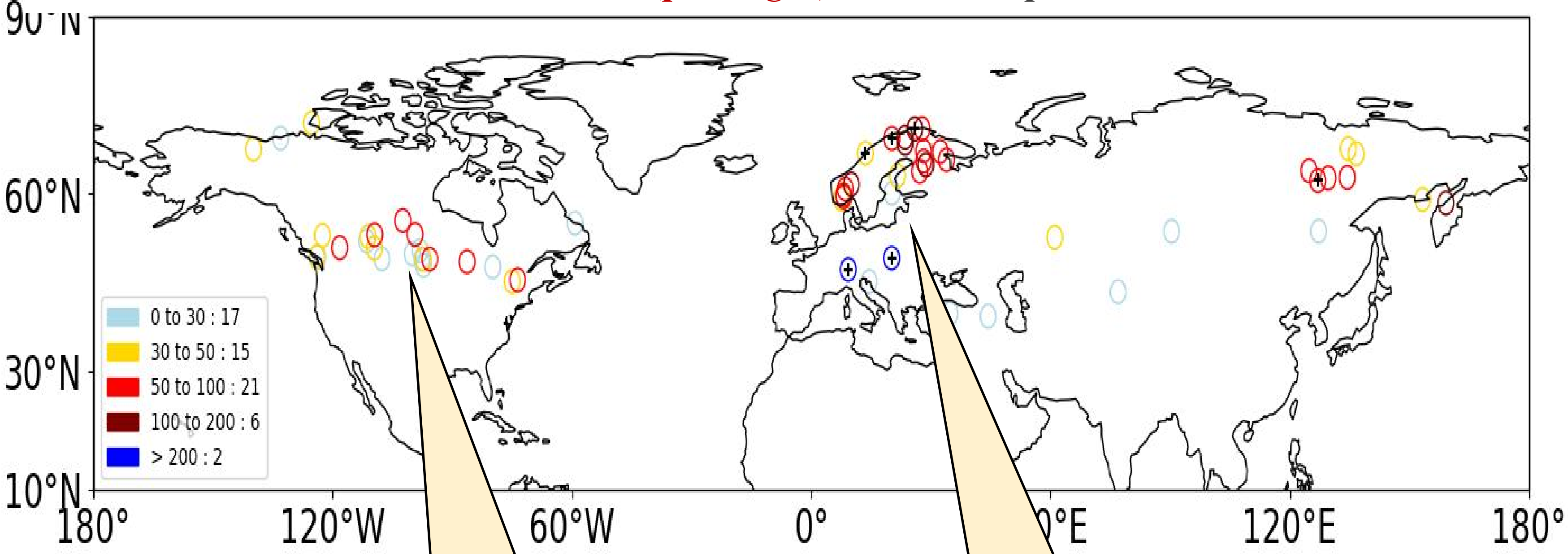
Monitoring Application of Dataset

- **Based on the dataset, the distribution of stations that break historical or monthly extreme records can be obtained in real time (20-minute delay), enabling rapid monitoring of snowstorm events.**

Distribution of stations where snow depth exceed the monthly extreme (open circles) and historical extreme (plus signs) values on April 1, 2023



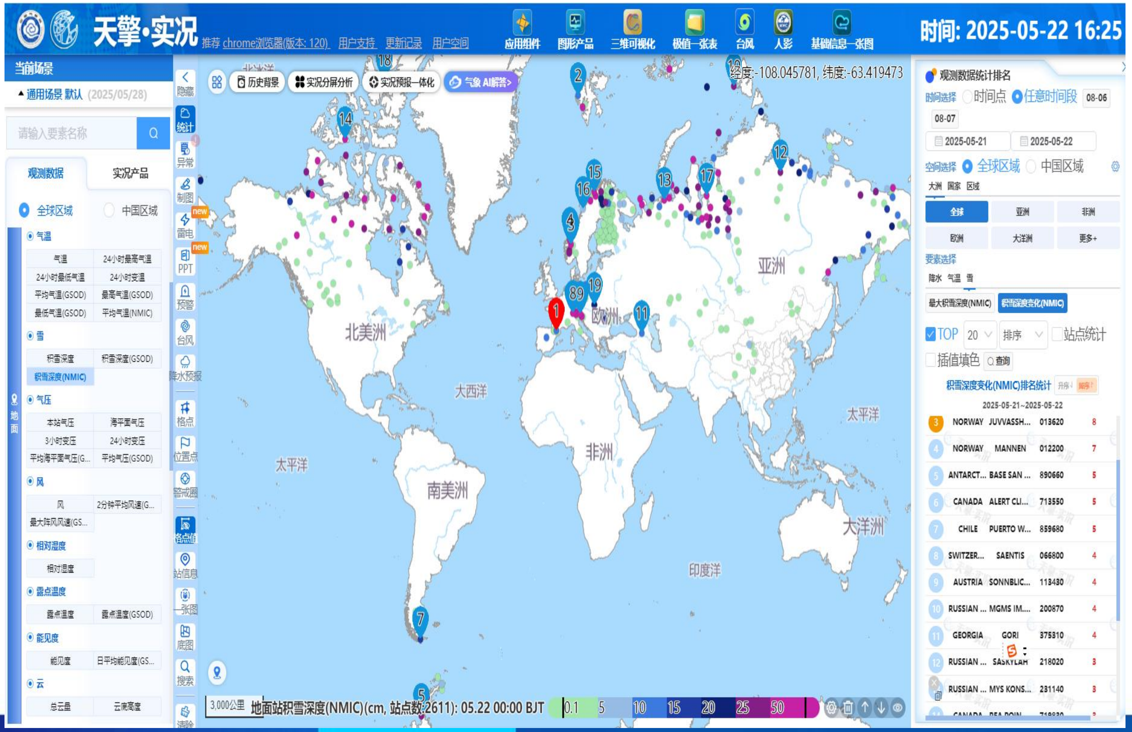
In early April, an extreme snowstorm event swept across Canada and the United States from west to east

In April, an "spring cold wave" brought snowfall to European countries

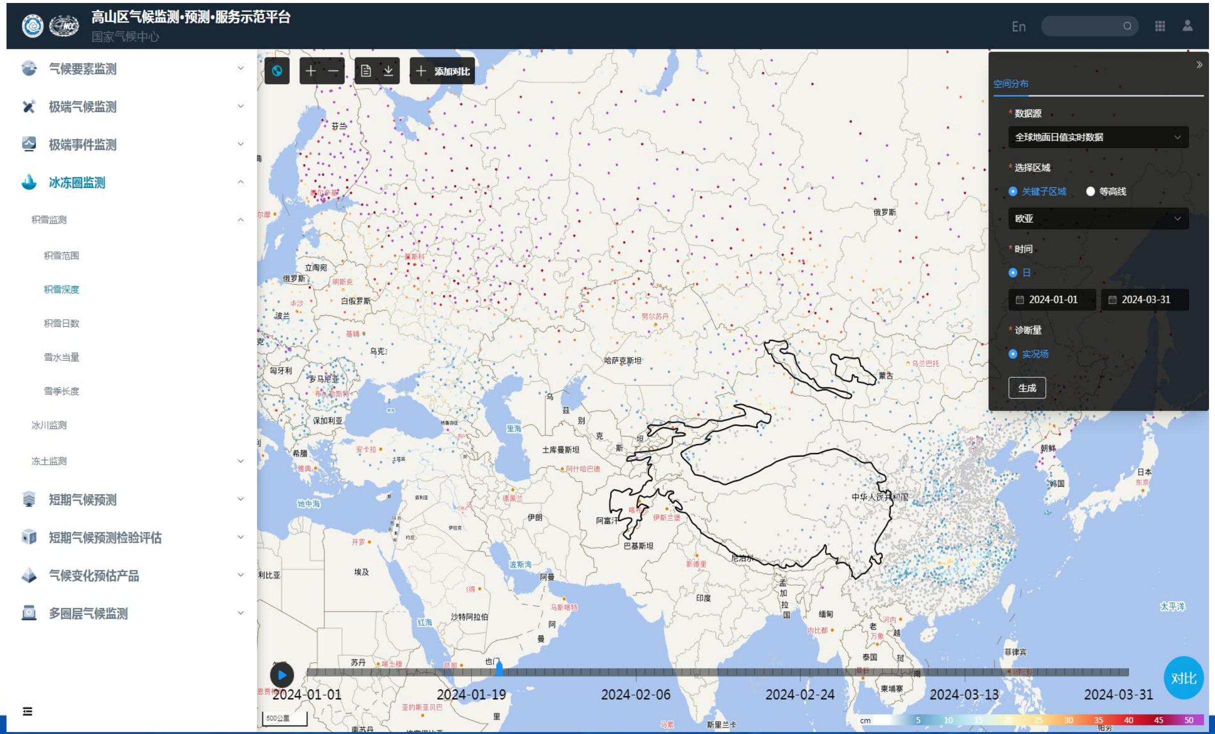
Monitoring Application of Dataset

- The dataset is utilized for real-time service on China's national operational platform. It allows for real-time access to daily snow depth at stations worldwide, across continents, and in different countries. Additionally, it provides rank of maximum snow depth over a given period△
- The dataset has been used to monitor the variation of snow depth in the Third Pole region platform.

China's nationall operational platform



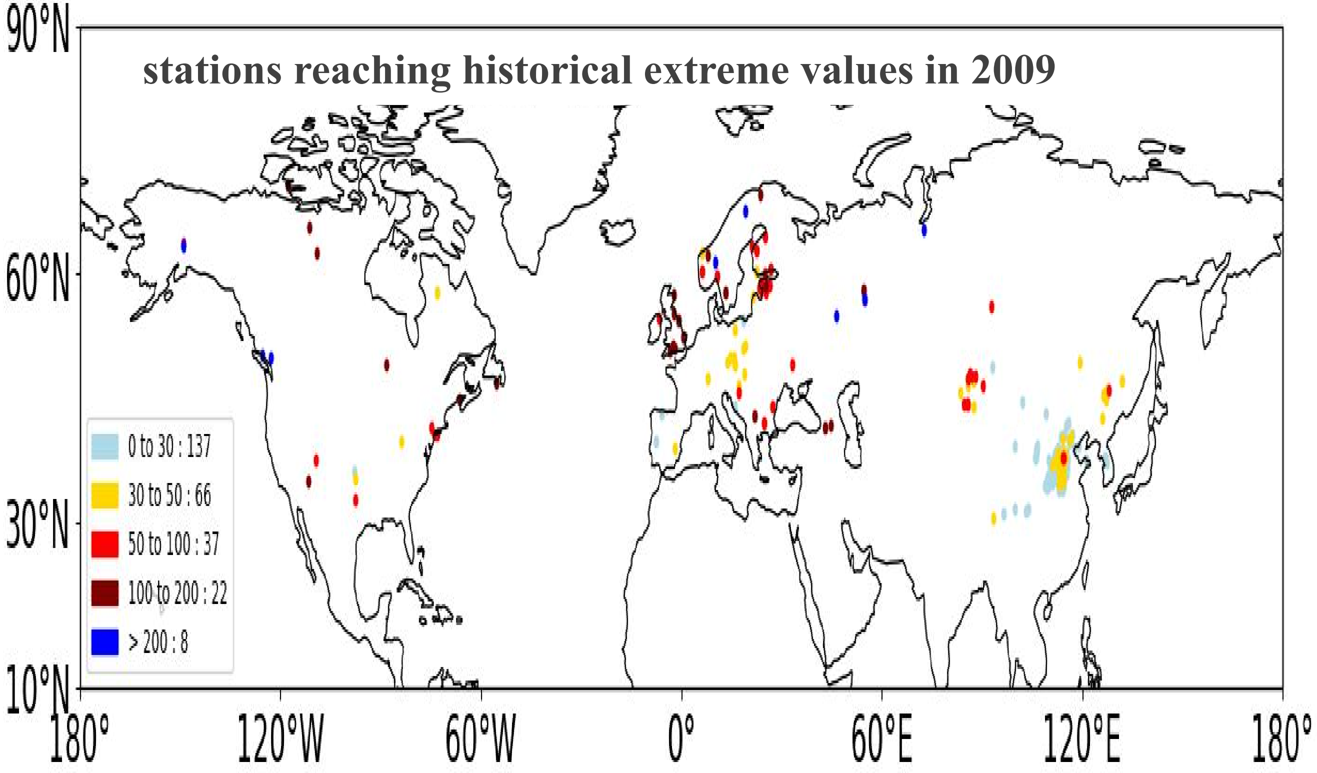
China’s Third Pole Monitoring and Forecasting Service Platform



Monitoring Application of Dataset

- 1993 was the year with the highest number of stations recording historical extreme value， and the top five years coincide with La Niña events, aligning with climate change patterns.
- Taking 2009 as an example， dataset can effectively reproduce the annual climatic extreme "Persistent cold waves and blizzards freeze the Northern Hemisphere "

Rank	Snow Accumulation Year	Number of sites with historical extremes	La Niña years
1	1993 199307-199406	418	1993
2	1972 197207-197306	372	1973
3	1983 198307-198406	318	1984
4	1976 197607-197706	275	1976
5	2009 200907-201006	270	2010



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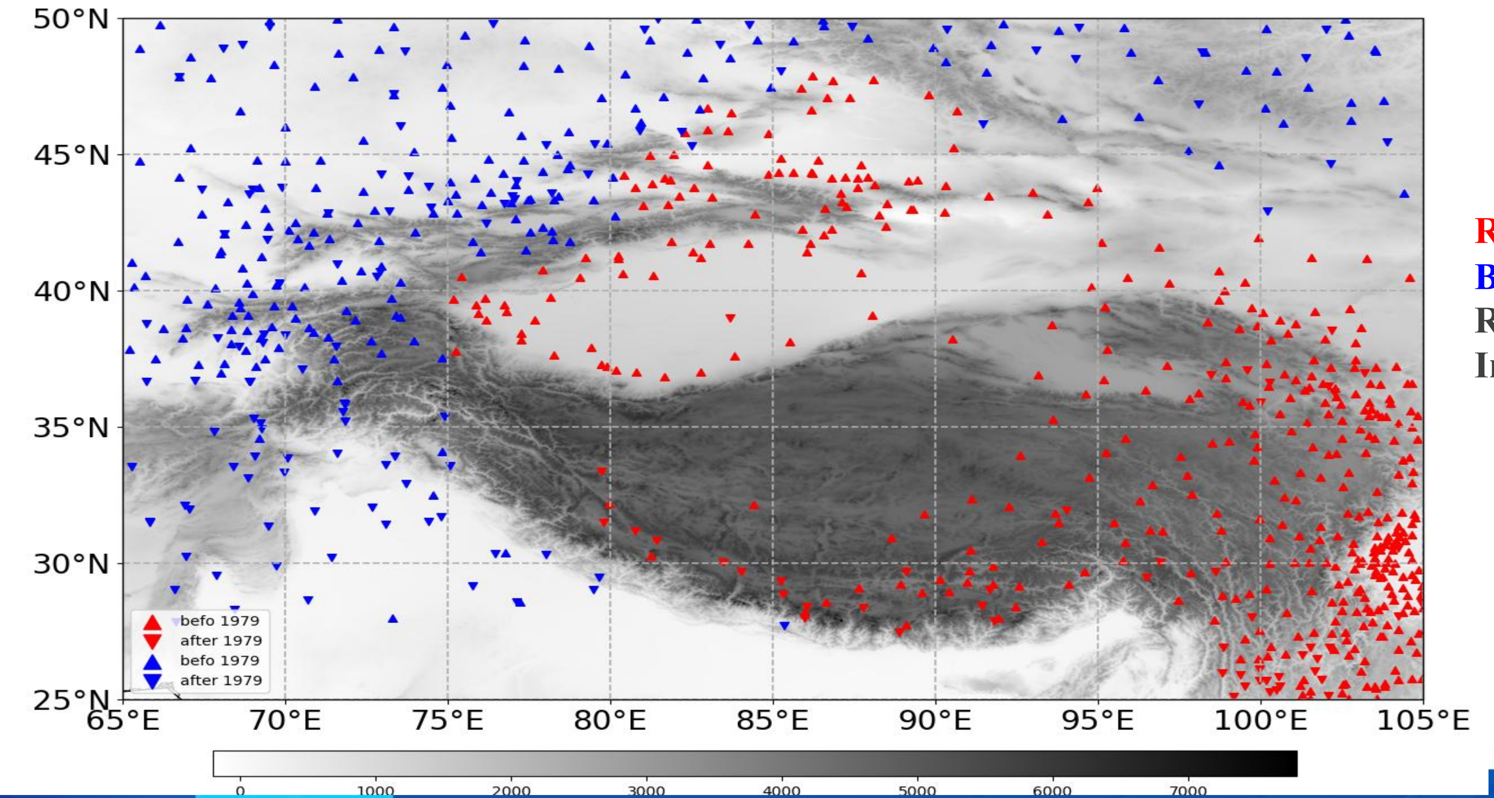
Climate Characterization of Snow Depth in TP region

- There are 768 stations in TP region, including 458 stations in China and 310 stations outside China.
- 79% of the stations recording non-zero snow depth before 1979, enabling long-term monitoring and research on snow variation.

768 stations in TPR (605 stations recording non-zero snow depth starting before 1979)

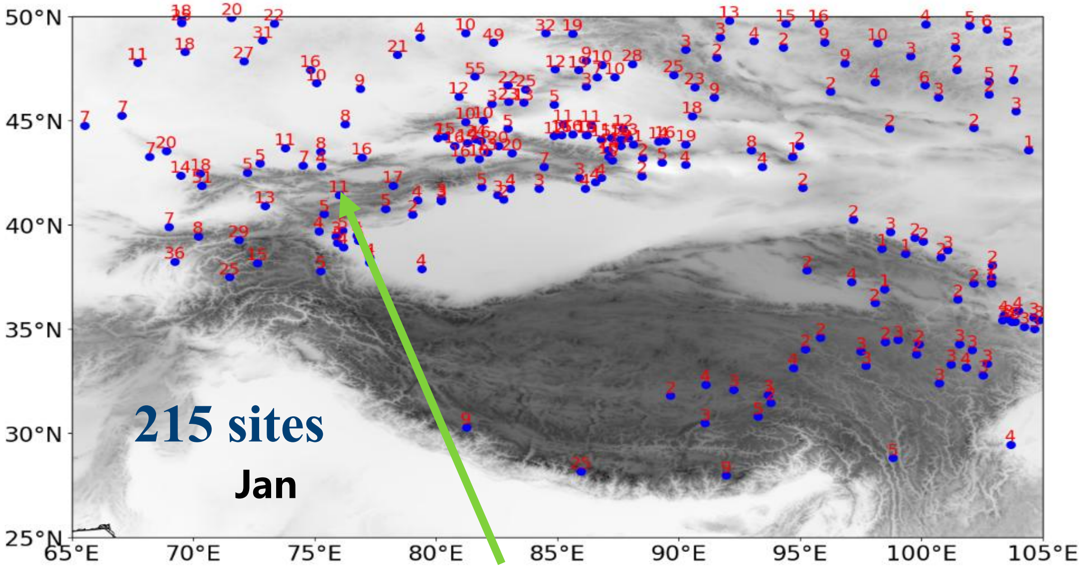


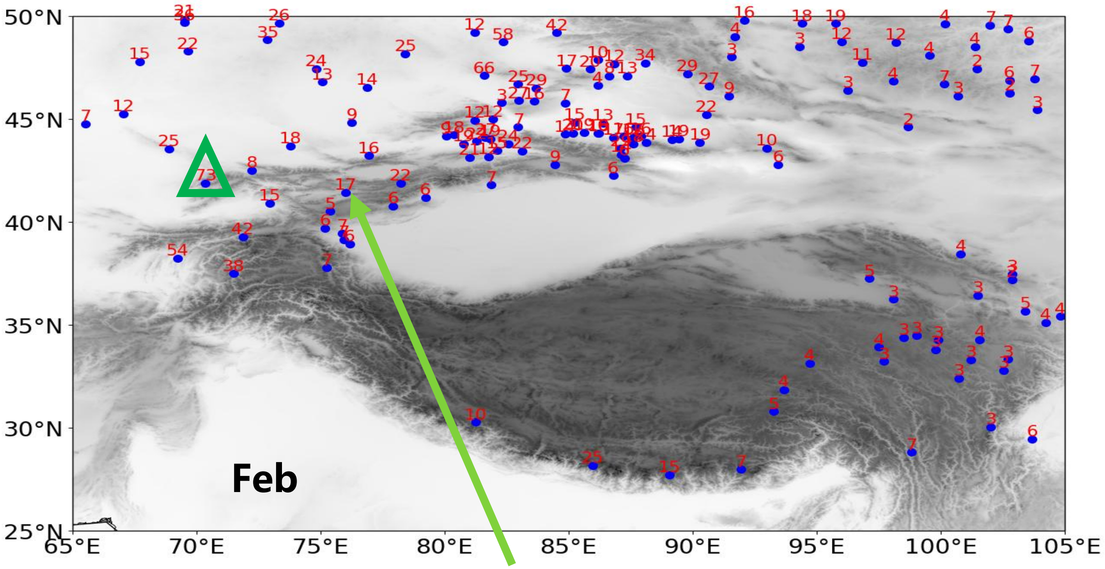
Red: stations in China(458)
Blue: stations Outside China(310)
Regular triangle: The non-zero starting year is 1979 or before
Inverted triangle: The non-zero starting year is after 1979

Climate Characterization of Snow Depth in TP region

- **In all months, January has the highest number of valid stations, while February shows the greatest mean snow depth**
- **Analysis of single-station series reveals a declining trend in monthly snow depth at most stations**

Mean snow depth (cm) in January and February across stations with ≥10 years of records





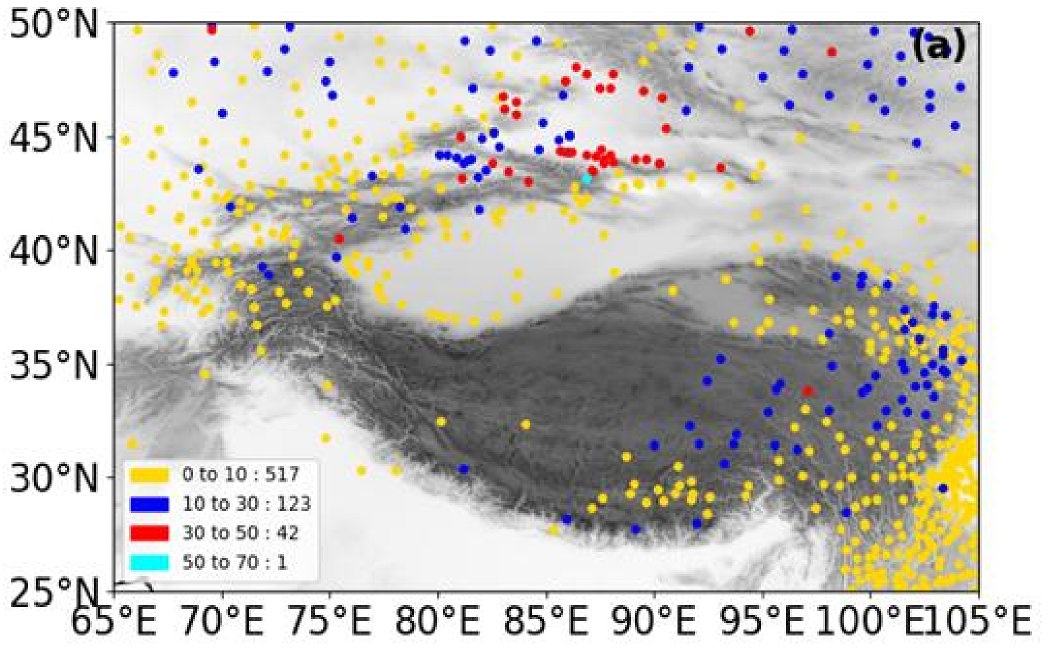
January series of snow depth at station 36974

February series of snow depth at station 36974

Climate Characterization of Snow Depth in TP region

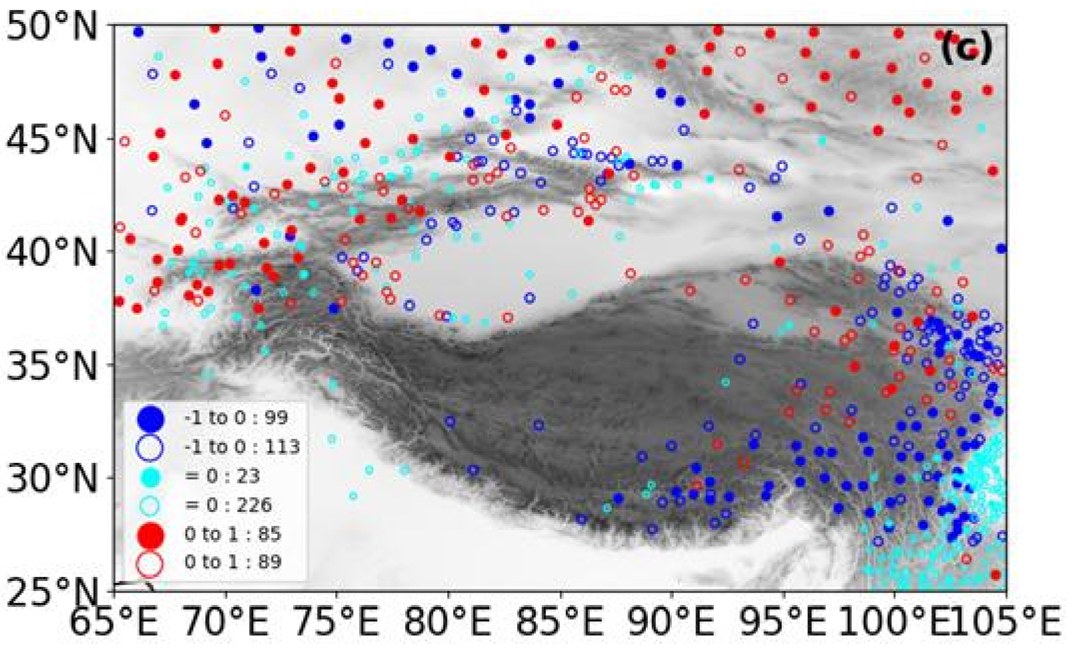
- **Snow days Fraction:** The ratio of snow-covered days to total days in a snow year. **43 stations show >30% snow days fraction** (>110 snow-covered days/year), **mostly in northern Xinjiang, China.**
- **Trend of Snow days Fraction:** Most stations in the eastern Tibetan Plateau exhibit a significant decreasing trend, with a decline rate of less than 1% per year. The Pamir Plateau and Mongolia exhibit a significant increasing trend.

Mean of snow days fraction during 1951-2023（%）



Trends of snow days fraction at each station (1951–2023) (%/yr)

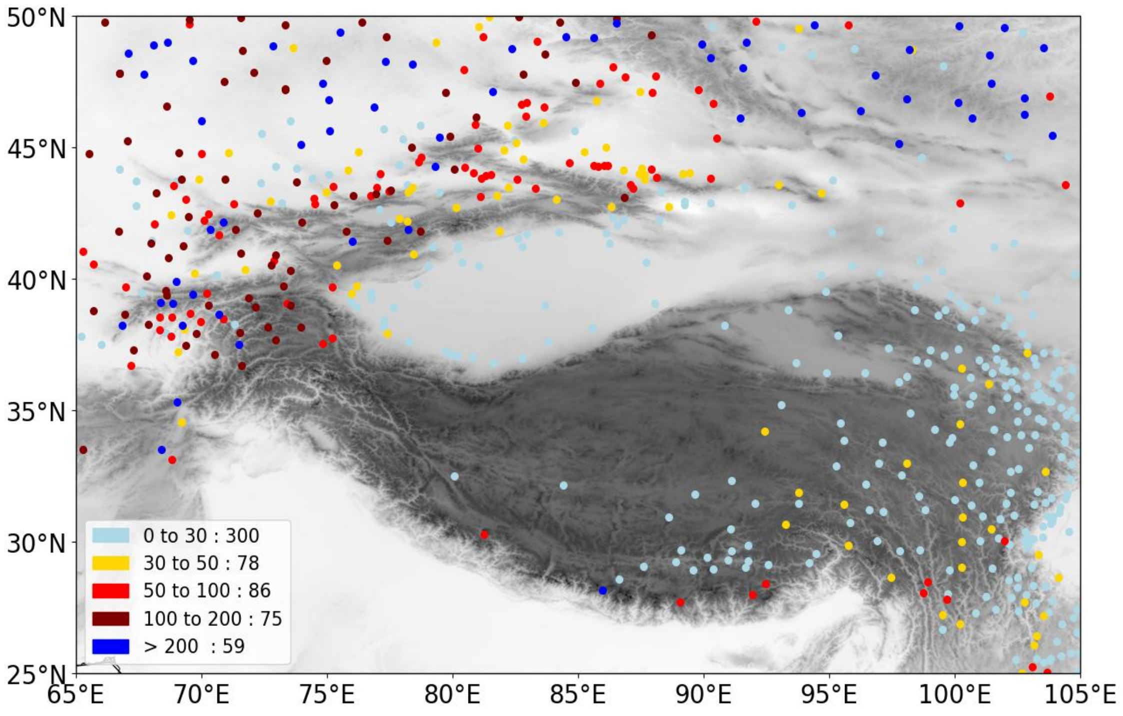
Filled markers denote results passing the significance test (p<0.05)



Climate Characterization of Snow Depth in TP region

- Stations with historical extreme value exceeding 100 cm are mainly located in the Pamir Plateau and regions north of 45°N.
- Nyalam station recorded an extreme of 230 cm in February 1989, marking the maximum snow depth ever documented in China's meteorological history.
- The year of 1993 and the month of February have the highest number of stations recording historical extreme values for yearly and monthly records respectively

Historical extreme values at each site



The year with the highest number of sites recording historical extreme value

Rank	Snow year	Number of sites with historical extremes
1	**1993** (199307-199406)	**30**
2	**2020** (202007-202106)	**23**
3	**2009** (200907-201006)	**20**

The month with the highest number of sites recording historical extreme value

Rank	Month	Number of sites with historical extremes
1	**February**	**123**
2	**March**	**102**
3	**January**	**101**

Summary

- The dataset integrates snow depth observations from GTS, GSOD, and CMA, with higher completeness than GSOD
- The dataset has undergone comprehensive quality control (QC), with substantial errors removed from historical records, enabling more accurate characterization of historical extremes in snow depth.
- The data acquisition and quality control processes are fully automated, operating with about 20-minute delay, enabling the monitoring of snow depth variation across global, continental, and TP region.

Thanks for your attention

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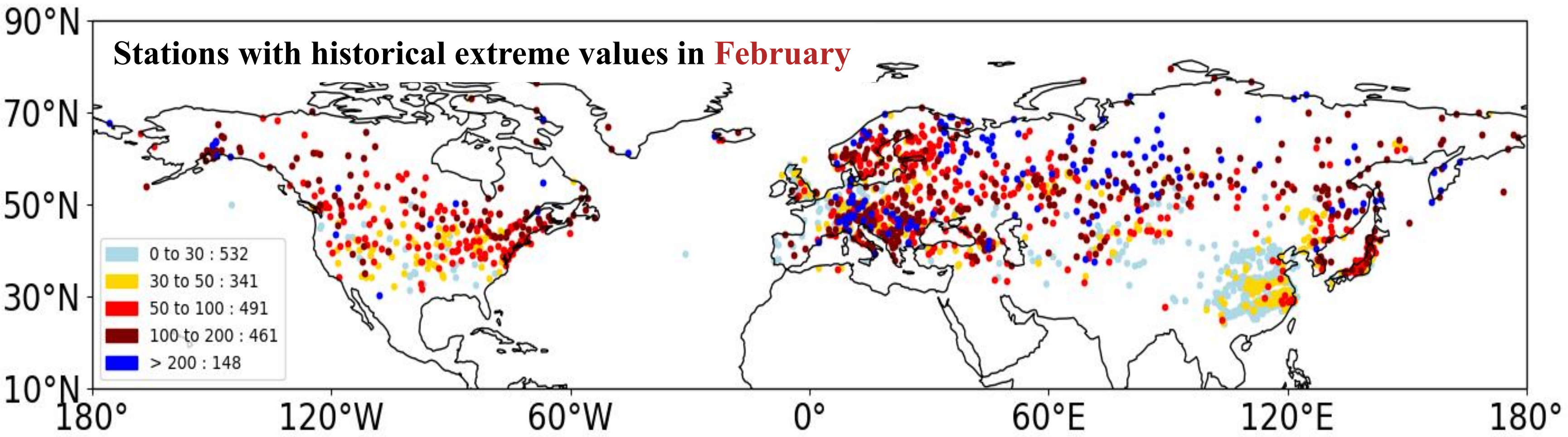
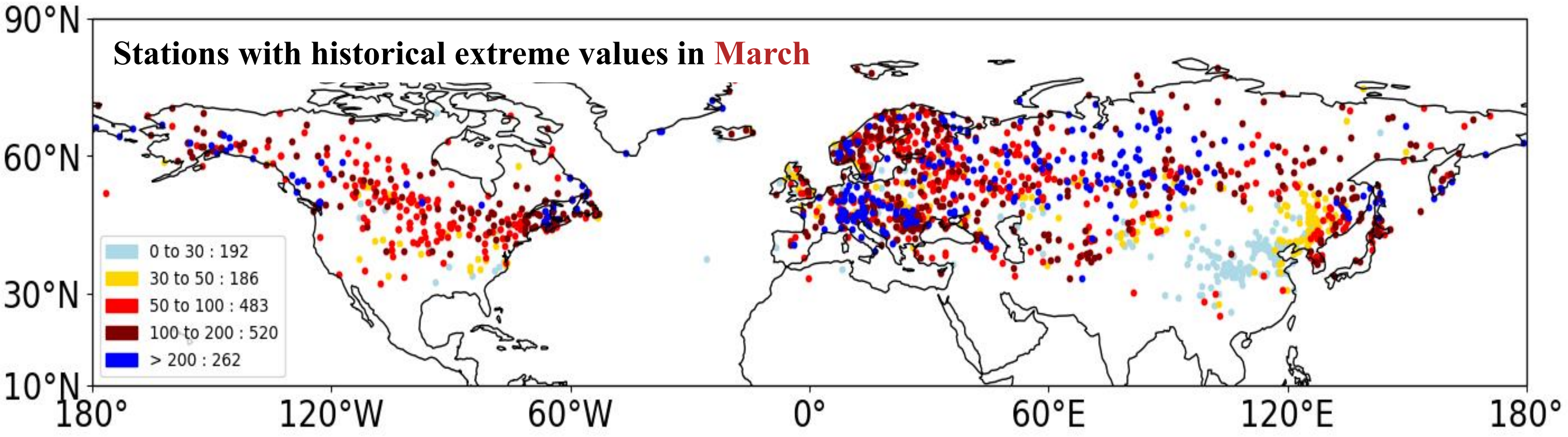
Monitoring Application of Dataset

- Statistical analysis revealed that **February had the highest number of stations (1,973) recording historical extremes**, while **March saw the most stations (782) with record-breaking snow depths exceeding 100cm**

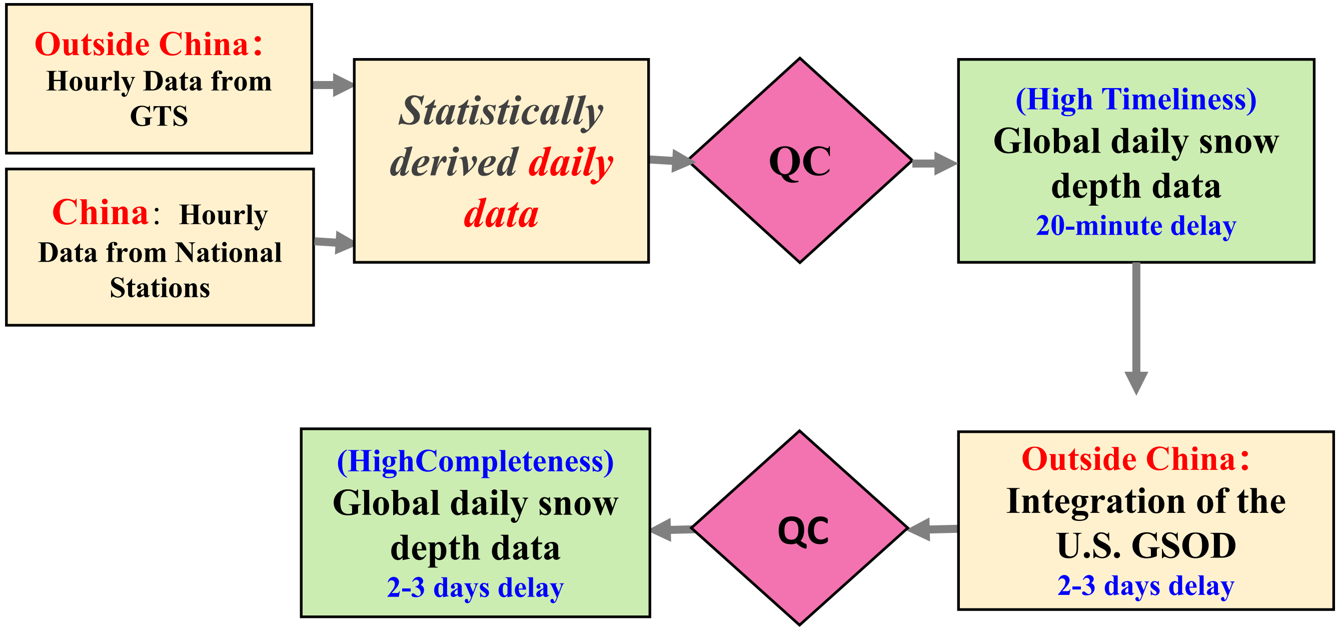




Monitoring Application of Dataset

Dataset Attributes and Update Policy

Variable	Snow depth
Temporal Resolution	Daily
Spatial Resolution	about 12,000 stations
Coverage	Global
Timeliness	20-minute delay
Length	1943-realtime

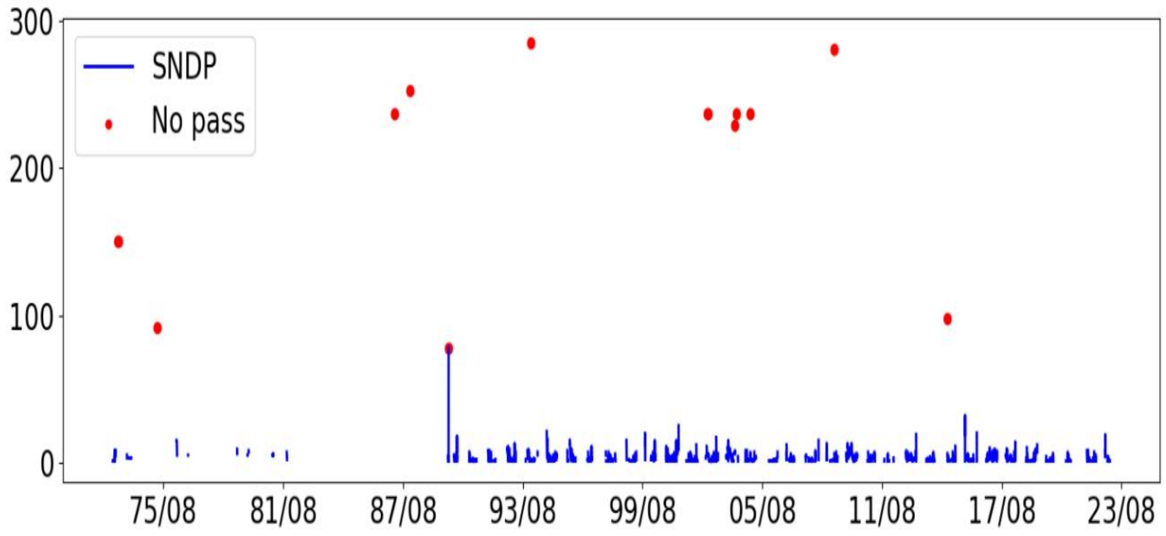


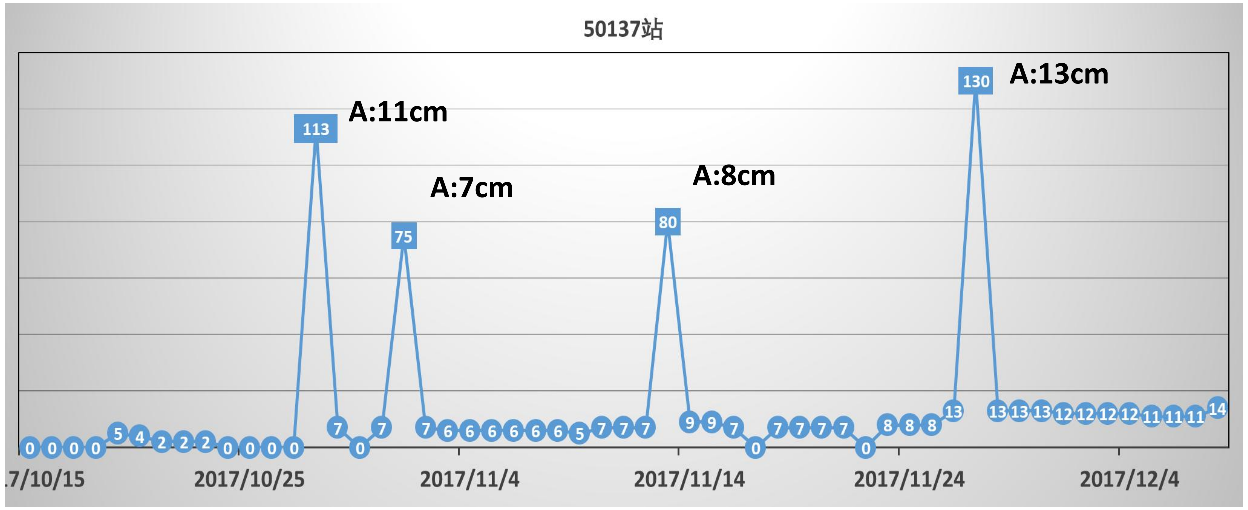
2、Quality Control

◆Threshold Check for Gross Errors：

- **Climatic Threshold Check: 0 – 762 cm**
- **Station Threshold Check：Observations exceeding the threshold $S_{i,j}$ for the respective grid cell are flagged as erroneous data. The threshold $S95_{i,j}$ is calculated based on historical snow depth data (1943–2022), computing the 95th percentile of daily station observations for each 1°×1° grid cell, separately for each month (January–December).**

$$S_{i,j} = 5 \times S95_{i,j}$$



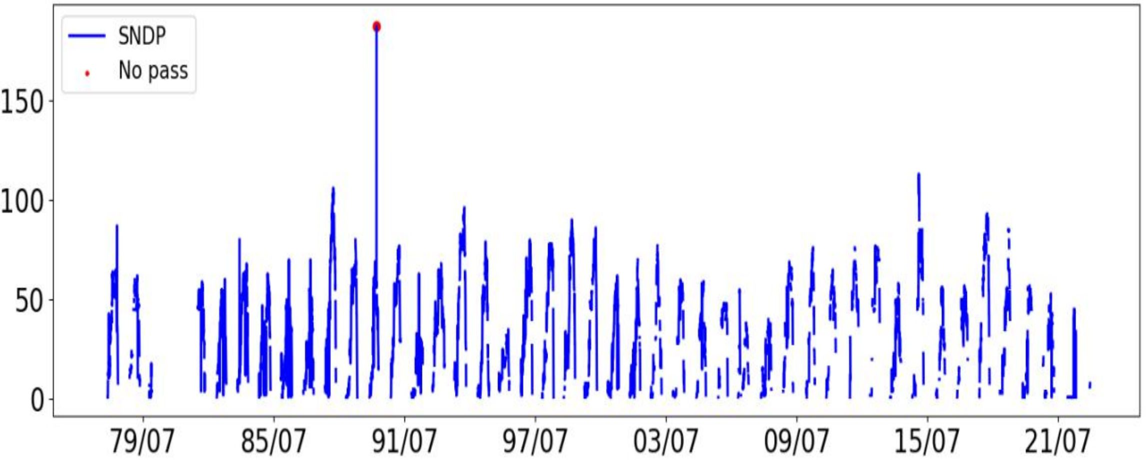


2、Quality Control

◆Temporal Consistency Check:

- **Daily Snow Depth Variation Check (for "Snow Depth Sudden Change"):If the difference between the current day's snow depth and the previous day's snow depth exceeds 127 cm, the observation is flagged as erroneous**
- **Error Statistics: Among the final 251 stations, a total of 327 erroneous records were identified, of which 324 records were due to abnormal snow depth increases.**

Station 02186, Sweden (Lat:65.544, Lon:22.122, Hgt:20m)

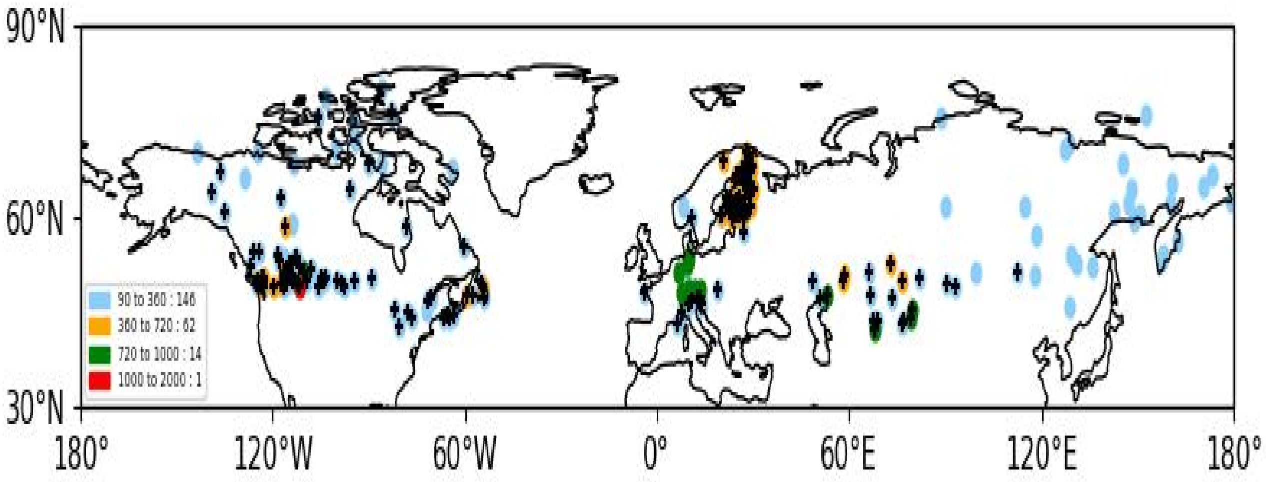


	Snow depth(cm)	Minimum temperature(℃)	Mean temperature(℃)	weather phenomenon	precipitation (mm)
[illegible]19900317)	56	9.4	18.5	No Snowfall	0
Current day(19900318)	187	12.3	22.4	No Snowfall	2.54
Next day(19900319)	50	14.1	16.7	No Snowfall	10.16

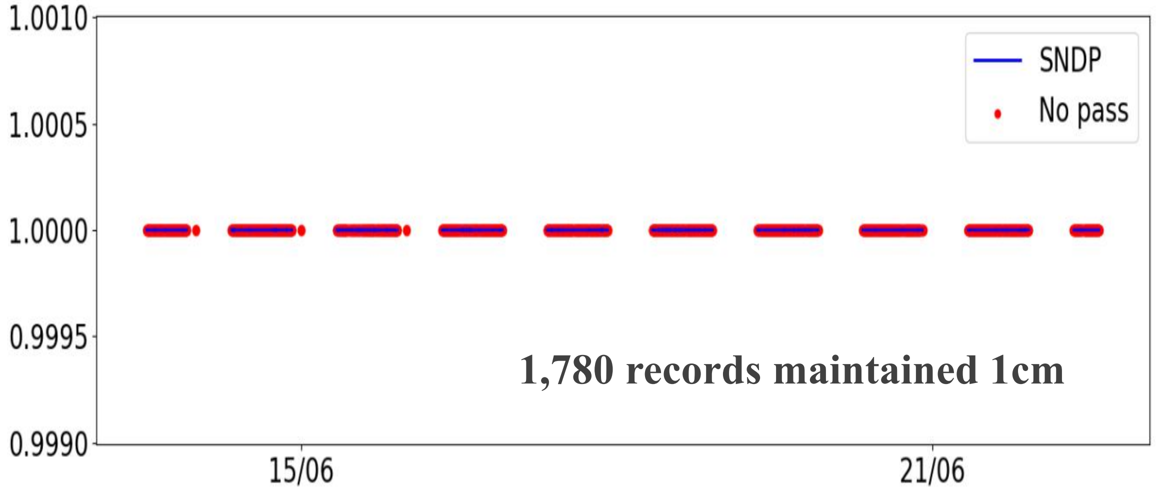
2、Quality Control

◆Temporal Consistency Check

- If the same non-zero snow depth value persists for more than 90 consecutive days, it is flagged as a frozen value.
- Evaluation Results： A total of 226 stations were found to have 66,667 records with stagnant values. The affected stations are predominantly located in high-altitude regions, with most stagnant values recorded as 1 cm. The longest stagnant period at a single station reached 1,780 days.



Stations containing frozen values and record counts (sites marked with ＋ indicate frozen values of 1 cm

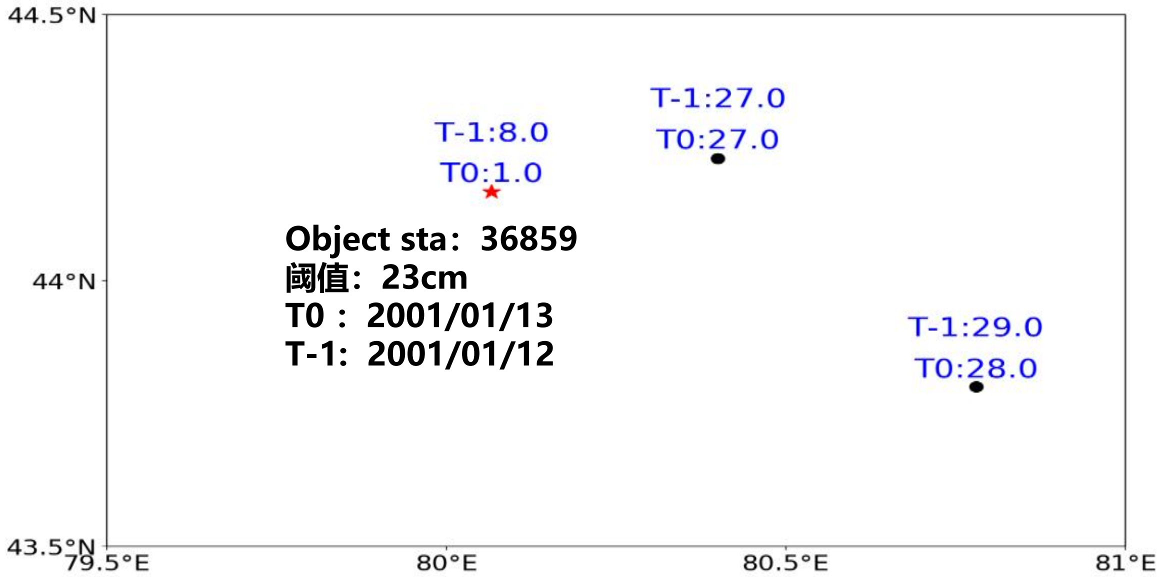


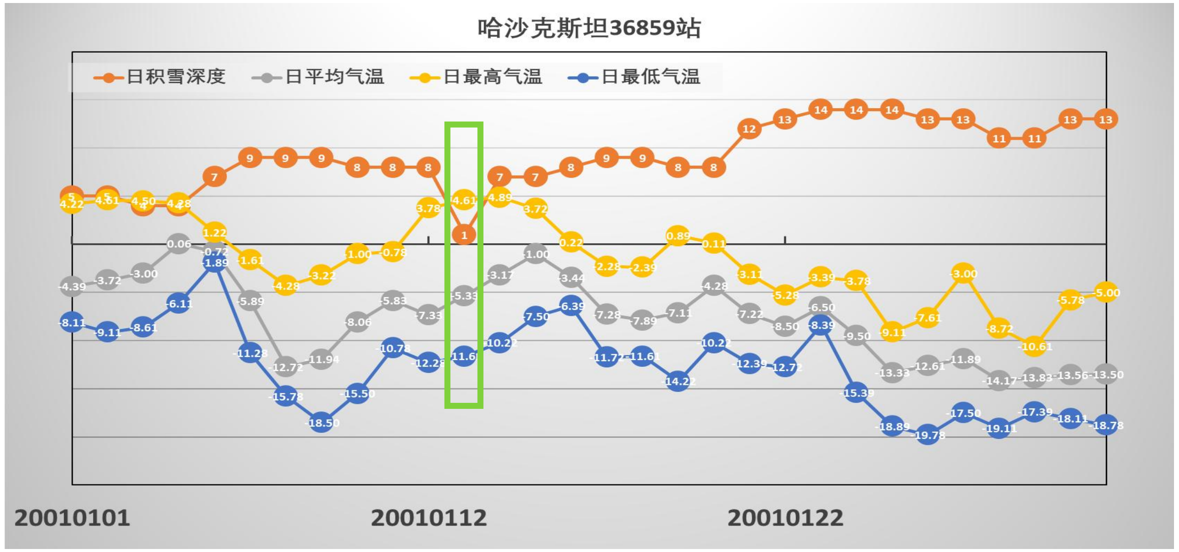
Station 71345,Canada（Lat:49.133，Lon:-111.65，Hgt:948m）

2、Quality Control

◆3.Spatial Consistency Check:

- **Threshold:** Based on historical snow depth data from 1943–2022, the 99th percentile of absolute snow depth differences is calculated for each station on monthly scale, using 2–7 neighboring stations (within a 75 km horizontal distance and 200 m elevation difference).
- **Decision Rule:** If the absolute difference between the target station's snow depth on the current day and the snow depth of 2–7 neighboring stations (both current day and previous day) exceeds the monthly threshold, the data is marked error.





2、Quality Control

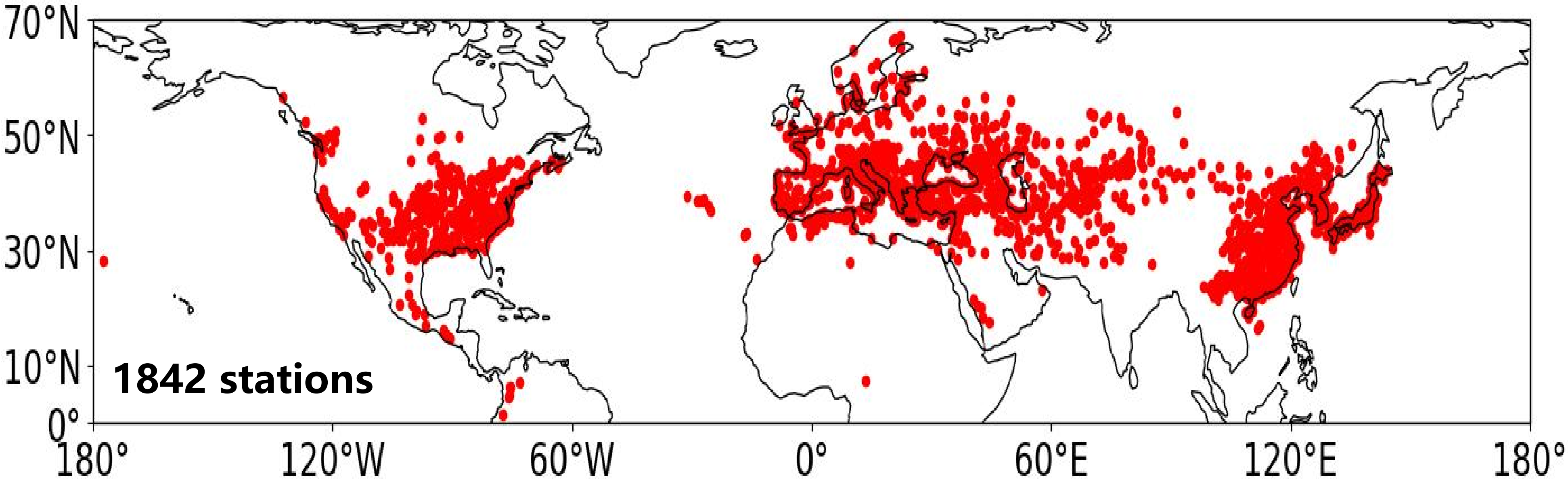
◆4.Temperature-Snow depth synergy check:

- **General Check:** SNDP>0 when lowest TMIN for station and calendar month≥7℃, SNDP(0) is error data
- **Intra and inter station synergy：**

  intra-station： SNDP(0)-SNDP(-1)>0 and min[TMIN(-1:0)] ≥7℃, SNDP(0) is error data

  inter-station： SNDP(0)-SNDP(-1)>0 and min[TMIN(-1:0)] at 2–7 neighbors≥7℃, SNDP(0) is error data

Stations where TMIN in July exceed 7°C across all recorded years (with valid samples >30)



2、Quality Control

◆5.Precipitation synergy: (Detection of inverted-V-shaped abnormal increases)

- **No-Precipitation Background:**

SNDP(0)-SNDP(-1)≥100mm & SNDP(1)-SNDP(-1)≤30mm & max[PRCP(-1:1)]=0, SNDP(0) is the error data

- **Precipitation Background:**

SNDP(0)-SNWD(-1)≥200mm &

SNDP(1)-SNDP(-1)≤50mm &

SNDP(0)-SNDP(-1)≥100[PRCP(0)+PRCP(-1)] &

SNDP(0)-SNDP(-1)≥100[PRCP(0)+PRCP(1)], SNDP(0) is the error data