Assessment and selection of regional automatic weather stations in China based on RRR principle of WMO

Guo Jianxia[1], Pei Chong[1], Zhang Wenlong[2],Xue Zhengzheng[3], KangJiaqi[1], Shao Changliang[1], Chen Yizhi[4], Chen Dongdong[1], Xu Chonghai[1],Tian Weihong[5], Xin Yu[6], He Xiaochuan[7]

1. Meteorological Observation Center of CMA, Beijing, 100081, China
2. Institute of Urban Meteorology, CMA, Beijing, 100089,China
3. Ningxia Meteorological Observation Center, Yinchuan, 750002, China
4. CAAC North China Regional Administration, Beijing, 100710, China
5. National Meteorology Center, Beijing, 100081,China
6. Institute of Desert Meteorology，CMA，Urumqi, 830002，China
7. Shanghai Meteorological Information and Technical Support Centre, Shanghai, 200030, China

Abstract

The density of the national surface weather stations is not enough to monitor the small and medium scale severe weather events, as well as to meet the high-resolution numerical forecast system for data assimilation and verification. On the other hand, more than 58,000 AWS were built by different local offices without unified standard. In order to strengthen the capability of the national network to serve the monitoring, prediction of the high-impact weather events, the assessment and selection of regional AWS is carried out.

The process is divided to three stages. The first stage is the quality assessment of AWS. The instruments, environment, calibration and maintenance of AWS were evaluated station by station, and the data deviation against the EC reanalysis field was assessed at this stage. The second stage is evaluation for the needs of weather system analysis and severe weather events monitoring to AWS. 7 kinds of weather systems and 4 kinds of severe weather events were considered at this stage. The third stage is evaluating the needs of numerical forecast model to AWS. The methods of Observation System Experiments (OSEs), Observation System Simulation Experiments (OSSEs), and Forecasting Sensitivity to Observation (FSO) were used at this stage. At last, based on the results of above stages, the total of 8174 AWS were selected from more than 58,000 regional AWS to supply the national weather station network. The spatial resolution of the national surface observation network is from 30 to 200km (average 71km) to 15-90km (average 33km).

The performance of the new network is inspected by weather analysis and NWP prediction. The results show that the majority characteristics of weather events with 20-50km scale can be captured by the new network. The data from the new network assimilated to the NWP system shows the positive impact to the prediction.

This work practices the WMO RRR principle for optimize the layout of observation network.

Key words: AWS, quality assessment, NWP impaction, layout of network

1. Introduction

Existing China's state-level AWS make up the basic meteorological elements observation network of 30-200km (mean 71km) on land and support the weather, climate monitoring and forecasting business. At the same time through the GTS data form, in data assimilation of numerical prediction system, the surface observation data has been more mature and stable application. However, the density of national AWS is not sufficient to monitor the weather of middle and small scale disasters, nor can it meet the application and inspection requirements of high resolution numerical prediction system for data assimilation. On the other hand, as the pace of China's comprehensive national strength enhanced and the rapid development of social economy, with the support of local government and relevant departments, the regional AWS rapid development. Till 2016, the total number of the regional AWS has reached more than 58,000, a large network of AWS support for local government services. However, due to the independent construction of all regions, there are such cases as regional AWS instrument construction, operation maintenance level and site environment and observation data quality, makes the regional station observation data can't get the effective use of user, especially the numerical prediction center, application of regional AWS data is very limited. In order to improve the capability of state-level AWS network for medium and small scale weather system, promote the interaction between the construction of the observation system and the construction of the numerical prediction system, the decision of optimizing the national synoptic observation network is made. For reducing the duplication of investment and construction, we decided to select a number of regional AWS to supplement the national synoptic observation network to achieve the objective of optimization. The project last three years. This paper reviewed and the process.

2. The main methods

To update and develop of observation system, WMO put forward the principle of the Rolling Requirements Review process (RRR). The basic idea of RRR is the development of observation system is derived from the demand of users. The process jointly reviews users' evolving requirements for observations and the capabilities of existing and planned observing systems. Follow the principle of RRR, we designed four phases to implement our project. In the first phase, the current situation of all existing regional AWS is reviewed. Then the monitoring requirements of high impact weather systems and severe weather events were analyzed in the second phase. The requirements of numerical weather prediction to AWS were analyzed in the third phase. In the final phase, the comprehensive decisions are made based on the analysis of the previous three phases. The general process is showed in Fig.1.

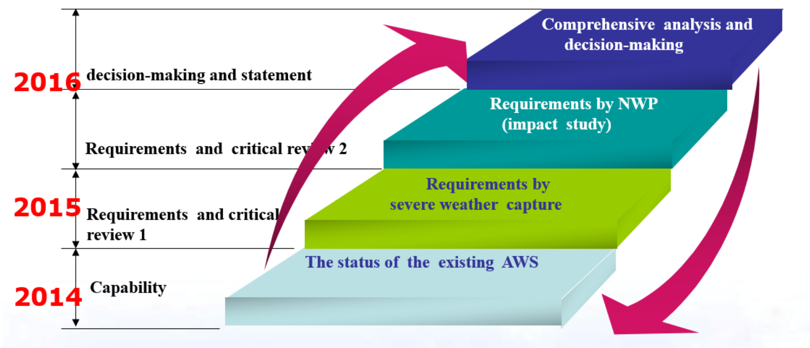


Fig.1. The process of AWS evaluation and selection

2.1 Method for reviewing the status of existing regional AWS

Nine indicators in three respects (equipment, guarantee and site) were proposed for the field investigation of regional AWS. And the minimum requirement of each indicator is presented in table 1.

Table 1. The indicators and the minimum requirements for the equipment, guarantee and site of regional AWS

	Category	Indicator	Minimum requirements	Weight points
1	Equipment	license	Equipment with the Equipment license from CMA	20
2	Guarantee	Power supply	Good power supply, will not cause more than 72 hours work stop due to power supply problems	10
3		Communication	Good Communication, will not cause more than 72 hours work stop due to Communication problems	10
4		Access	Good Traffic, will not cause more than 72 hours work stop due to Traffic problems	10
5	Site	Instrument installation location	Land station installed on the ground; rivers and lakes station installed in a dedicated platform	10
6		land cover conditions	Grass, natural bare land	10
7		Site area	Large enough, no interaction between the observation instruments	10
8		Surrounding environmental conditions	No influence on the observation of the shelter and cause abnormal changes in the meteorological elements of the source of interference, the data is better representative.	10
9		Thunder prevention	Thunder prevention satisfies the requirement of automatic station Thunder prevention technology standard	10

Due to the need for on-site field investigation of all sites, the workload is very large, 31 provinces observation department of Meteorological Bureau in China participated in this work.

2.2 Method for reviewing the requirements of monitoring severe weather systems

From the perspective of weather analysis, it is necessary to have enough observations to monitor the activity area of weather system and events, including the source area, occurrence, development, path and the die process, as well as scale information, without redundancy, as far as possible the economic efficiency.

Using comprehensive observation data in recent 10 years, in view of seven main weather system, including low pressure, convergence line, low vortex, low trough, front, shear line, and subtropical high, and four kind of severe weather events, including heavy rainfall, gale, hail, thunderstorm, to carry out the analysis. The characteristics of the scale, activity area, occurrence, development and evolution process of the weather system, the sensitive areas of the severe weather events, such as the source, strengthen or weaken area, high-risk area, and moving path, were analyzed. Moreover, the reasonable demand of AWS density and observation elements is analyzed.

Due to China's vast territory, the complex terrain cause a greatly varies of weather and climate in different area. Consider the different needs for monitoring across the country, a group of experienced forecaster and data analysis experts from 31 provincial weather services participated in the work.

2.3 Method for reviewing the requirements of numerical weather prediction

At present, China has a national operational numerical forecasting system and 8 regional operational numerical forecasting systems. The mode coverage, resolution, assimilation scheme and physical process are all different. In order to ensure the availability and reliability of the regional AWS selection results, all the operational model participated in the evaluation test. The Observation System Experiments (OSEs), Observation System Simulation Experiments (OSSEs) and Forecast Sensitive to Observation Experiments (FSO) were carried out to the regional AWS, focusing on the effect of different density of AWS on the prediction results of typical cases. Some models also did batch experiments for a certain period.

3. Main results

3.1 The situation of the regional AWS

The site surveys of more than 58,000 regional AWS in the country were conducted, and the proportion of AWS sites that met the minimum requirements of the 9 indicators in table 1 was shown in figure 2. More than 90% of the existing regional AWS sites are equipped with licensed instruments, and more than 80% of the sites can meet the minimum requirements of the power supply, communication, access, more than 70% of the sites to meet installation location, surface cover, field area, thunder prevention, just 60% of the sites to meet the minimum requirements of Surrounding environment. So, there are more than 30,000 regional AWS is reliable from the observing aspect.

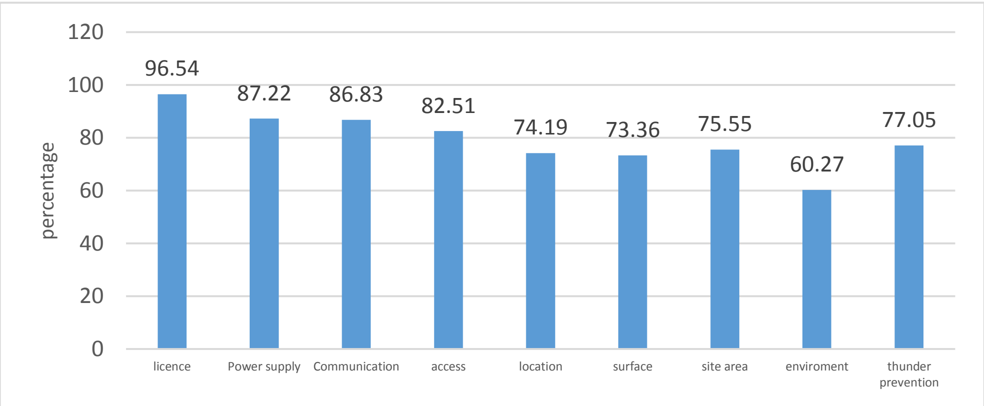


Fig.2. The proportion of the regional AWS that meet the minimum requirements

We have originally thought that good observations are useful. Therefore, the first selection layout of 9819 regional AWS from the sites that meet the minimum requirements were recommended to NWP center for evaluation. Unfortunately, no good results have been achieved.

3.2 Results from weather systems and events analysis

The statistical results of the major impacts of weather systems and the types of severe weather in each region were described in table 2. And the number of regional AWS sites from the activity area suggested by 31 provinces was also showed. The total number is 14626 AWS.

Table 2. The main weather systems and severe weather types in each region of China

Region	Main weather system	Severe weather types	AWS sites of recommendations
Northwest	Frontal system, followed by low vortex and convergence line	Rainstorm and hail	2356
Southwest	Low vortex, frontal, shear line, mesoscale convection system,	Heavy rain, hail, gale, thunderstorm, etc	1951

	mesoscale convergence line, low slot, etc		
NorthChina	Cold vortex, followed by low slot, front and so on	Thunderstorms and rainstorms, followed by hail and gale	3201
Northeast	Mesoscale convective system, mesoscale convergence line, northeast cold vortex, cyclone, etc	Heavy rain, hail, gale, etc	1869
CentralChina	North China cold vortex and low trough, frontal, mesoscale low vortex, mesoscale convection system	Rain, srong wind, snow, cold, hail	1188
EastChina	Shear line, mesoscale convection system, front, low vortex, low pressure, etc	Strong convective weather, rainstorm, typhoon, thunderstorm, hail, wind, etc	2737
SouthChina	South China static front, southwest vortex, shear line, tropical cyclone	Typhoons, rainstorms, hail, etc	1324

According to the 30 years data (1981-2010), in China's main land area, the four types of severe weather (thunderstorm, gale, hail, heavy rainfall) are mainly distributed in the south of the Yangtze river basin and the qinghai-tibet plateau, xinjiang and north China region (figure 3). These areas are the key areas where the observations need to be strengthened.

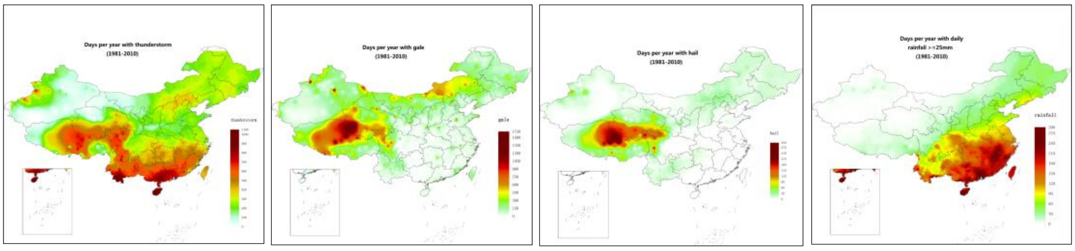


Fig.3 The spatial distribution of the frequency of severe wether (thunderstom, gale, hail, heavy rainfall) in China

The initial setting of 15km radius as the control line for national AWS density, and 10km radius as the control line for the key areas AWS density. The following means on paper conducted to the 14626 candidate regional sites. Firstly, removed all regional AWS sites which are in the national stations' radius mentioned above. Secondly, did Thiessen polygon for the rest of the candidate regional sites, keep the sites which polygon edge satisfy the distance is greater than 15 km, repeat Thiessen polygon analysis, until all the distance between the sites is more than 15 km. Finally, add some sites in the key areas to increase the density of AWS in these areas. Then, the second layout of 6638 selection of regional AWS was produced.

The 6,638 scheme was provided to NWP center again, the obvious effect was obtained. It means the necessary to combine the weather analysis with the site selection.

3.3 Results from numerical weather prediction analysis

3.3.1 The data quality of regional AWS

Due to the unified standards and strict quality control for the national stations, the data of national AWS is widely used by users. However, the regional AWS are mainly supported by different regional funds, lack of unified plan and unified standards and quality examination. Users do not believed the data could be safely used.

To check the data quality of the regional AWS, we conducted a four months deviation analysis of the regional AWS data against the EC analysis field, and compared with that of national stations. The results shows that the deviation levels of air temperature, dew-point temperature and wind direction from the regional AWS were close to that from the national stations, the deviation levels of the pressure and wind speed from the regional AWS were slightly lower than national stations (figure 4). It is obvious that the data quality of the regional AWS can basically meet the requirement of numerical prediction.

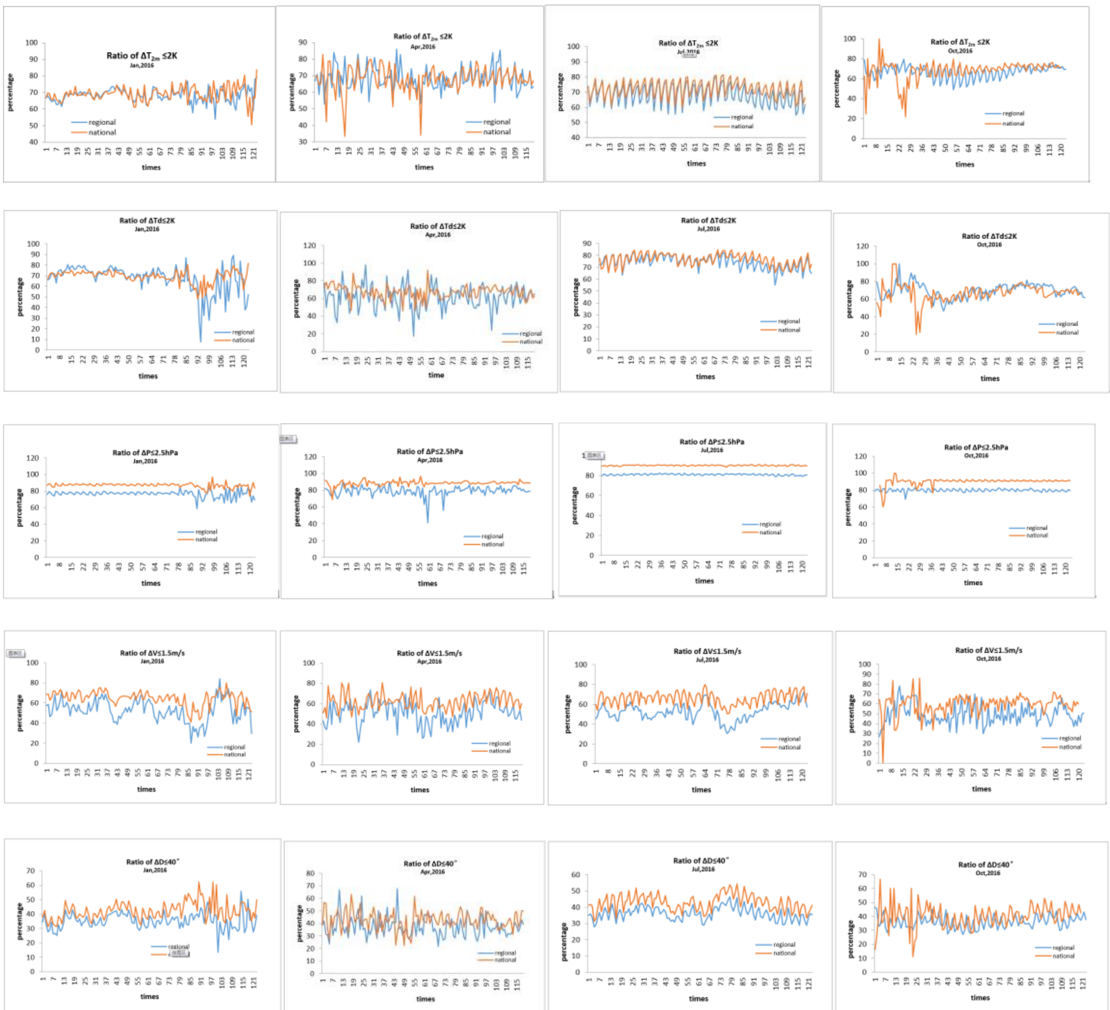


Fig.4. The comparison of the deviation level against the EC analysis field between the regional AWS and the National AWS (The rows from top to bottom are temperature, dew point temperature, air pressure, wind speed, wind direction, respectively. The column from left to right are January, April, July and October 2016, respectively.)

Figure 5 is the distribution of every 10000 rank based on the deviation of the regional AWS to the EC analysis field. It can be seen that the top 10000 sites are mainly distributed in southeastern China, ranking the later site distribution moves to the Midwest, explain the reason of the deviation may be associated with complex terrain.

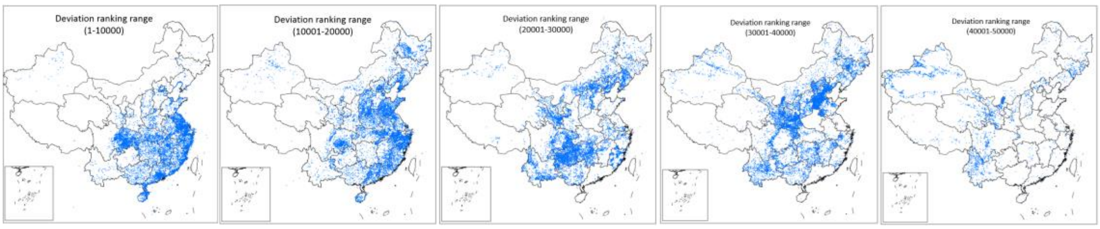


Fig.5. The distribution of every 10000 rank based on the deviation of the regional AWS against the EC analysis field

3.3.2 Numerical prediction system for the experiments

A total of ten units to participate in the work, National Meteorology Center (NMC,NWP Center) and South China region adopted China's independent research and development of GRAPES regional numerical forecast system, the other units adopted the kernel of WRFv3.3-3.7 numerical forecasting system. The models of NMC and 8 regional center are the operational prediction model system, Meteorological Observation Center (MOC) use the research model system. Most of the assimilation methods are 3DVAR, east China is 4VAR, and southwest is ADAS. And the assimilation scheme for AWS is the Ruggiero scheme, except the central China regional choice the Guo scheme.

Table 3. Numerical prediction system for the experiments

INSTITUTE/CMA	NMC	MOC	north of China	east of China	south of China	centre of China	northeast of China	southwest of China	Xinjiang China	Northwest of China
SCOPE	Nationwide	Nationwide	Beijing/Tianjin/Hebei/Shanxi/Neimenggu	Jiangsu/Zhejiang/Anhui/Fujian/Jiangxi/Shandong/Shanghai	Guangdong/Guangxi/Hainan	Hubei/Henan/Hunan	Liaoning/Jilin/Heilongjiang …	Sichuan/Yunnan/Guizhou/Tibet/Chongqing	Xinjiang	Gansu/Shaanxi/Qinghai/Ningxia
QC	GRAPES	MDOS	MDOS	MDOS	MDOS	OPERATION	MDOS	MDOS	MDOS	OPERATION
MODEL	GRAPES	WRF	WRF	WRF	GRAPES	WHMM	WRF	SWC-WARMS	WRF	WRF
ASSIMILATION	3DVar	3DVar	3DVar	4DVar	3DVar	3DVar	3DVar	ADAS	3DVar	3DVar
SENSITIVITY TEST	osse+ose	density	density+batch	density+batch	density	density	density+batch	density	density+batch	density+batch

3.3.3 Strategy of numerical experiments

Since the selection of 6638 regional AWS has proved to be positive for numerical forecasting, the purpose of this numerical prediction experiments is to illustrate the optimal density of the AWS. Based on the previous work, 14626 regional AWS are supplied for the density experiments. OSEs is the mainly experiments to the typical cases. No need all units do OSSEs and FSO, depends on the condition and the capability.

3.3.4 Typical cases

Table.4. showed the typical cases selected by each units. The total of 47 strong convection weather cases, 1 blizzard and 1 strong cooling were selected. These cases basically covers China's major heavy precipitation weather patterns.

Table 4. The typical cases selected by each units

region	Case description
NMC and MOC	4 typical rainstorms, Covering south China, north China and southwest China respectively
East part of China	3 strong convection, 1 Meiyu period precipitation process, 2 typhoon processes
North China regional center	5 cases of strong precipitation in the four categories of strong precipitation, such as low vorticity, high air trough, side high edge and heavy rain
Central China regional center	9 cases of weather systems such as Meiyu rain, typhoon, southwest vortex and low-rise shear line
Southwest regional center	The southwest vortex, the high - air trough caused by the local heavy rain process and the heavy rain and strong cooling weather process, a total of 4 cases
Northeast regional center	6 isolated cases of cold vortex (low vortex), higher rear end, and typhoon-induced convection in northeast China

Northwest regional center	7 cases of heavy precipitation and hailstorm under the influence of Mongolian low vortex and west wind trough
Xinjiang regional center	4 local heavy rainfall processes in the background of low vortex, central Asian trough and Siberian trough in four central Asian countries
total	The 47 strong precipitation cases, 1 blizzard and strong cooling, covered China's major heavy precipitation weather patterns

3.3.5 The problem for assimilation rate of AWS

In case of 3DVAR assimilation method with Ruggiero scheme, when the model terrain is above than the site 100 m, the data cannot be assimilated.

At the beginning of the numerical simulation work, it was found that the difference between the topography and the model terrain in most parts of China was greater than 100m (figure. 6), which resulted in the failure of most regional AWS to be assimilated.

There are two ways to improve: one is to improve the mode resolution, and the other is to expand the range of height difference acceptable to the model, and revised the data with the height and assimilated into the model.

According to the tests, the model resolution increased from 18 km to 9 km, the rate of the assimilated AWS increased from 50% to 57.1%, the effect is limited. While expanding the height difference threshold assimilation number increase quickly, as tolerance to 300 m altitude difference threshold, the rate of assimilated AWS increased to 84.8% (figure 7).

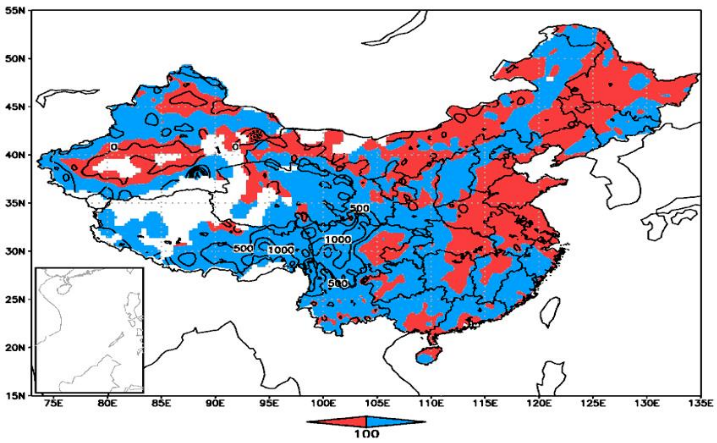


Fig.6. The difference of model terrain and the site elevation when model horizontal resolution is 18km (red <100m, blue>100m)

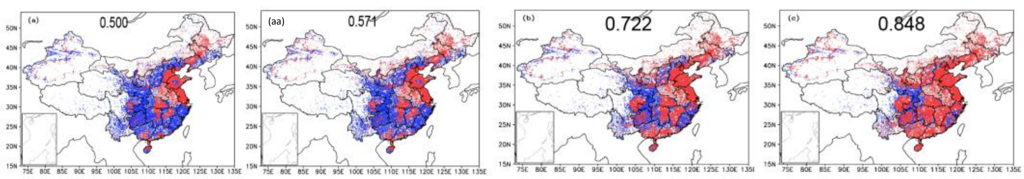


Fig.7. Variation of the ratio of assimilated AWS with the model resolution or the altitude difference threshold (a) 18km horizontal resolution, (aa) 9km horizontal resolution, (b) the altitude difference threshold expend to 200m, (c) the altitude difference threshold expend to 300m.

(Red dots: the sites were assimilated, blue dots: the sites were refused）

North China regional center adopts expand altitude difference threshold, and the AWS data were revised with height, the assimilation absorption rate of the regional AWS in Beijing area increased from 66% to 94%. The model test results show that the high initial temperature and water vapor in the mountains was effectively reduced, and the error prediction of precipitation in the mountains area caused by the false heat convection was reduced, so the precipitation forecast capability for the mountainous area was improved.

3.3.6 Results of density experiments

NMC did half a month continuous batch test for the two kinds of density of 15km and 30km. The results show that the forecast score of heavy rainfall of 15km in cold started run, and 30km in life cycle run is better than that of control and other experiments (Fig.8.).

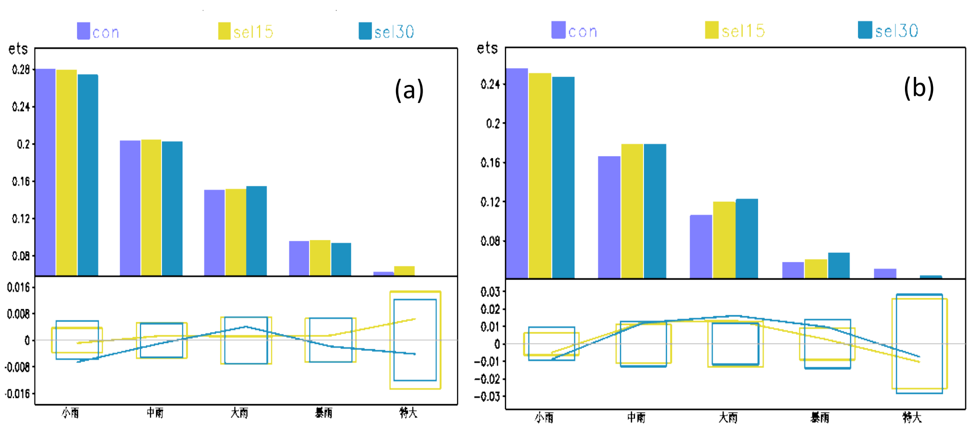


Fig.8. The forecast score of two kinds of density experiments by NMC

(a) Cold start run (b) warm start run

The results of density experiments from the east China regional center show that the sensitivity of the forecast score to the AWS density is varies according to the cases. The forecast score increase with the density of AWS in the case of typhoon Matmo and Meiyu rainfall. But the forecast scores are not sensitive to the AWS density, even do not assimilate the AWS can obtain better results (Fig.9.).

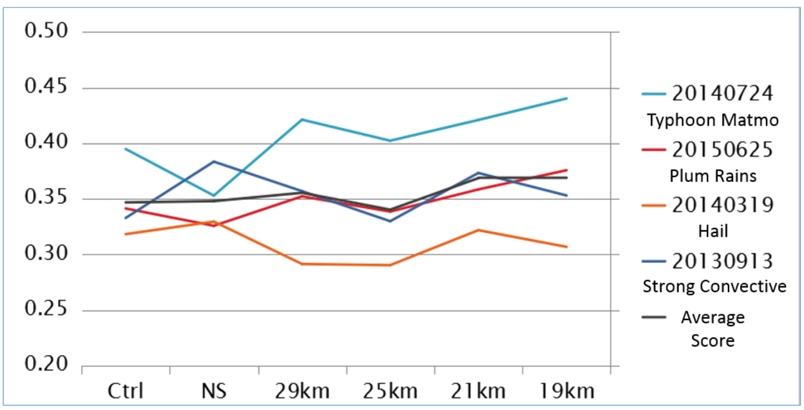


Fig.9. The forecast score varies with the density of AWS in east China regional center

3.3.7 Results of Observation System Simulation Experiments

The typical rain belt (torrential rain in north China, plum rain in jianghuai, heavy rain in south

China) were selected to do density OSSE experiments (Fig.10.). First, using the method of singular vector to identify the observation sensitive area. Then, simulated AWS data in the sensitive area, and do a series of density experiments. The results show that in the sensitive area of north China rain belt, increase 200 AWS would improve the 2-24 hours forecast, continue to increase AWS will have a negative effect. The increase of 600-800 AWS in the sensitive area of jianghuai plum rain belt has obvious positive effect in the first 10 hours, and no positive effect after 10 hours. The other schemes have no positive effect. An increase of 400 AWS in the sensitive areas of south China's rainstorm belt may improve the forecast from 13 to 24 hours, while the other schemes have no positive effect. This result indicates that for numerical prediction, the AWS are not the more the better, there should be have a suitable scale.

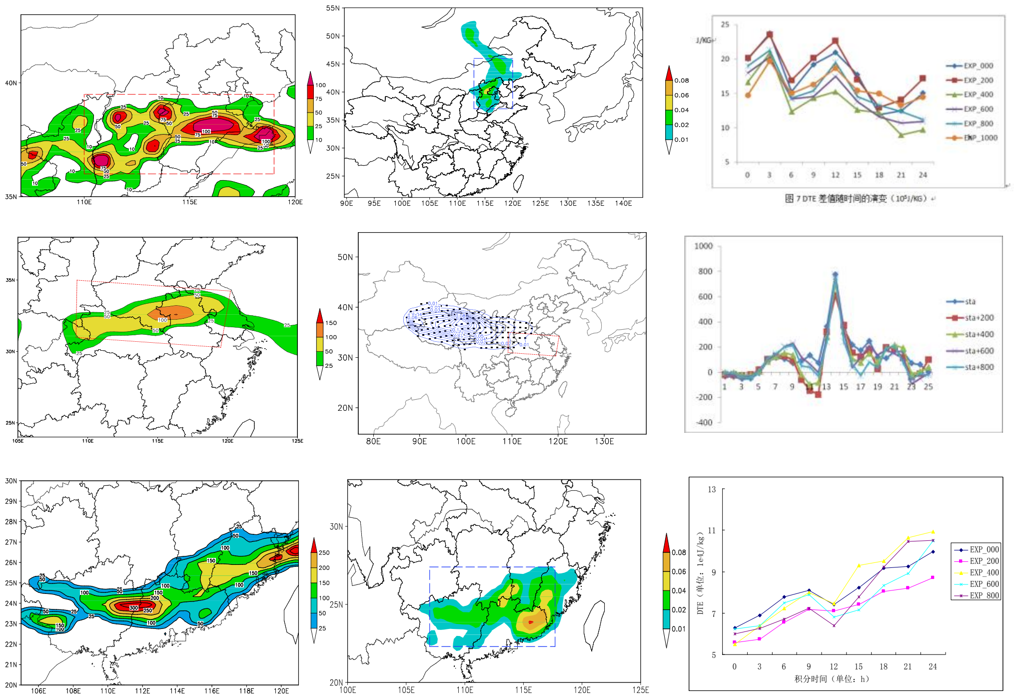


Fig.10. OSSE for AWS density in sensitive area of different rain belt in China

(The rows from top to bottom: north China torrential rain belt, jianghuai plum rain belt, south China's rainstorm belt

The column from left to right: the map of rain belts, the sensitive area of AWS, the DTE of different experiments)

A series of simulated AWS data with a density of 10km, 15km and 30km are produced uniformly throughout the country. The OSSEs conducted by GRAPES model. According to the results (figure 11), 15 km resolution may improve the heavy rainfall forecast technique of 12-24 hours, the more density of AWS, not the better of the forecast score.

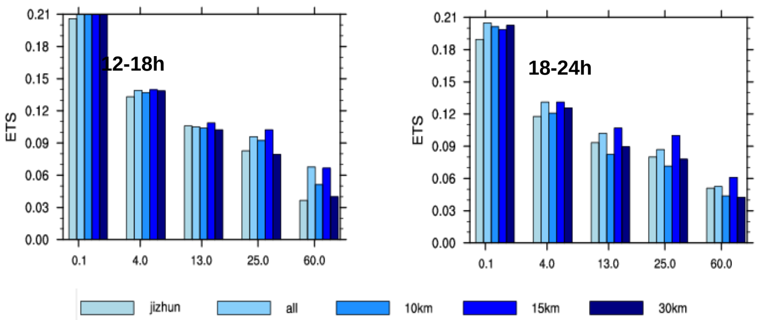


Fig.11. the forecast score of rainfall in OSSEs of different density of AWS

3.3.8 Results of Forecast Sensitive to Observation experiments

Using WRFDA 4DVAR adjoint model, calculate contribution to the prediction of AWS. Due to the high computational cost, the 27 km resolution was adopted, however, because of its low resolution, more AWS cannot be assimilated. Therefore, the FSO results of each station is only for the selection of reference.

Figure 11 shows the batch results of 10 days in the country. It can be seen that the contribution of the AWS varies with the start time of the day. The positive contribution is more than the negative contribution.

The Xinjiang regional center carried out a seven-month batch tests, and the east China regional carried out a one-month batch tests, with similar results.

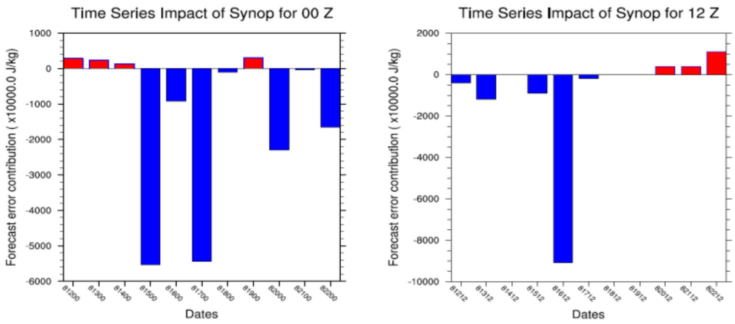


Fig.11. the results of 10 days FSO experiments

3.4 The final scheme of the selection AWS

Composite in the previous three phases evaluation work, the final selection of the Regional AWS under the following principles: The total number is controlled by the 15km distance for the whole country and 10km for the key area; Give priority to the number of AWS with positive contributions to the numerical predication; The selection results based on the synoptic analysis was retained as a second priority. The observation condition is the basic reference to choose the AWS.

According to this principle, the final choice of 8174 regional AWS upgraded into the national AWS network (figure 12). Figure 13 shows the changes of the average national level AWS spacing before and after the supplement of the selected AWS, from 30-200 km, up to 15-90 km, basic can satisfy the needs of monitoring and analysis of 20 to 50 km weather system, and the requirements of 3 to 30 km resolution of numerical forecast system.

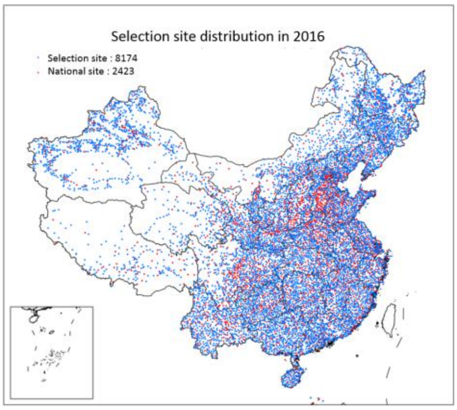


Fig.12. the final scheme of selected regional AWS

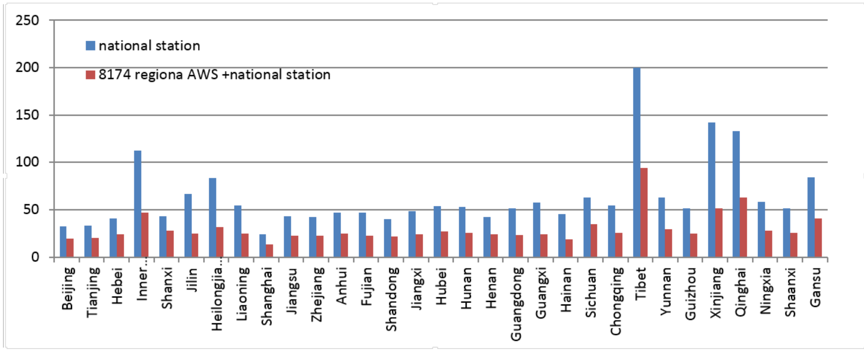


Fig.13. the changes of the average national level AWS spacing before and after the supplement of the selected AWS

3.5 verification of the final results

Fig.14 shows the density of AWS changes with the process of the work. After three years of the selection and complement, the density of sate AWS network in the eastern, central and western is a certain degree of strengthening, in Beijing, Shanghai, and Guangzhou large urban agglomeration and other key areas, such as southwest mountainous area and so on, the network density is higher than other areas. Western China is still sparsely populated, with the huge challenges for a more dense network. This is a reasonable distribution at present stage.

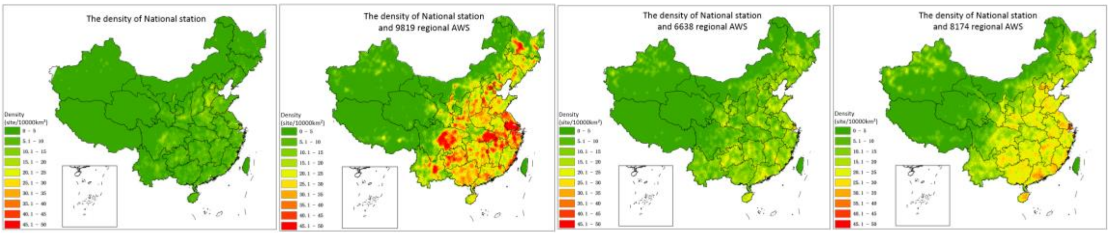
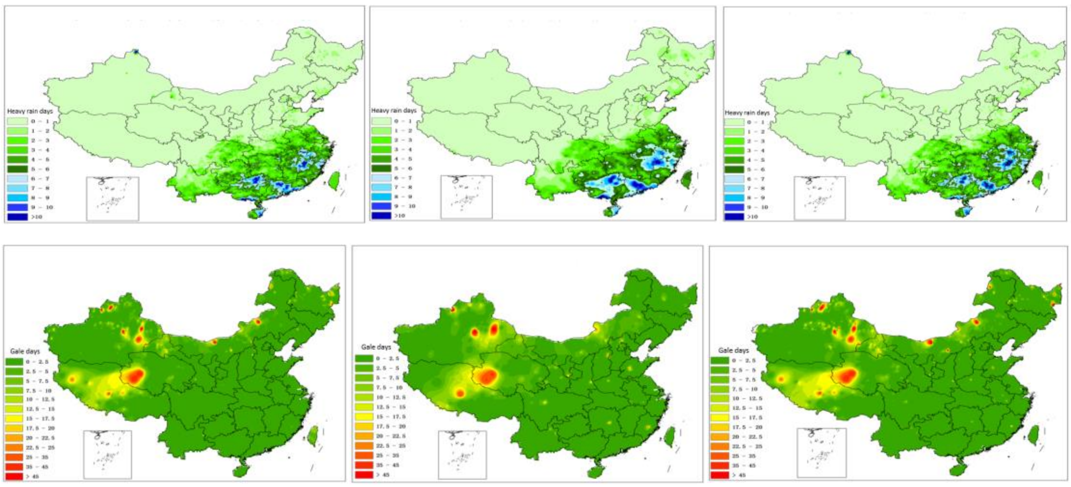


Fig.14 the AWS density changes with the project process

Using all AWS data from 2014 to 2015, verified the capability of the final AWS network.

Figure 15 shows the distribution of the heavy rain days, gale days, surface pressure, surface humidity, it can be seen that the original national AWS network is not enough to characterization the middle and small scale structure of torrential rain area, gale area, and the elements of surface pressure and humidity, but the new network did well.



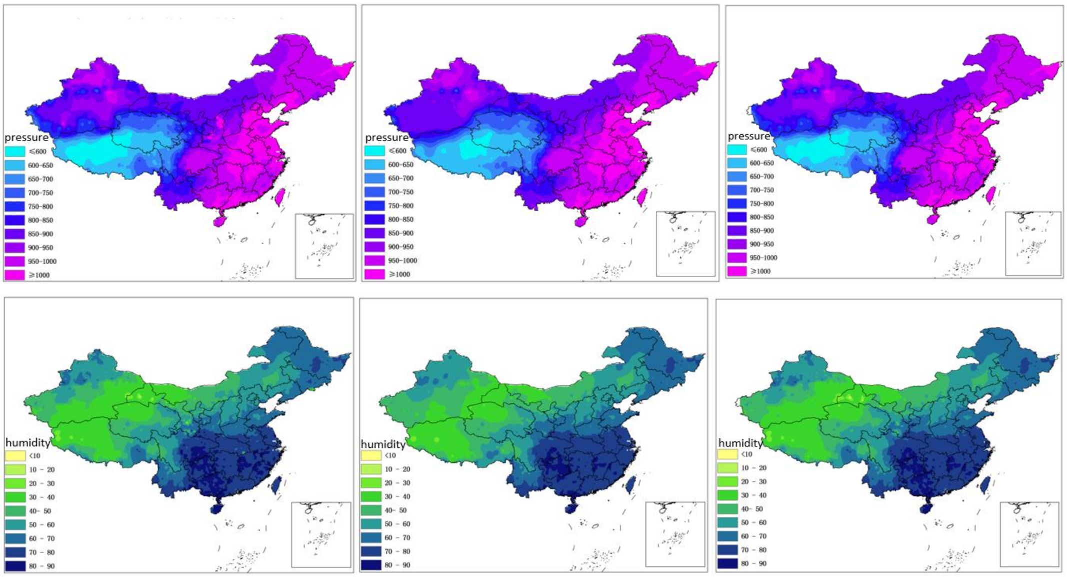


Fig.15. The distribution of the heavy rain days, gale days, surface pressure, surface humidity

(The rows from top to bottom: heavy rain days, gale days, surface pressure, 2m humidity

The column from left to right: all AWS, the original national AWS network, the new national AWS network.)

4. Conclusions and discussions

4.1 The benign interactive business pattern between observation and prediction was preliminarily formed

Under the principle of the WMO RRR, China complete the optimization scheme of national AWS network. This work is a huge system engineering project, different levels of observation and prediction department involved, benign feedback between observation and prediction. With the deepening of the process, both the observation and prediction ability are improved. Therefore, this work has initiated the benign interaction mechanism of observation and prediction in China, showing positive mutual win effect. The specific process is shown in figure 16.

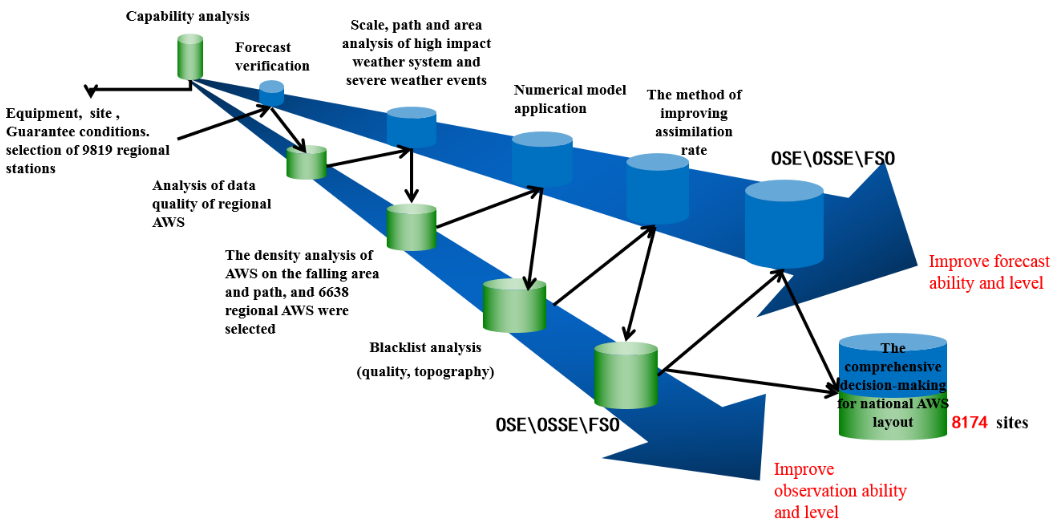


Fig.16 The benign feedback process between observation and prediction

4.2 A more scientific and reasonable national AWS network is Obtained

After a series of optimization processes, through the dynamic adjustment, the national AWS network was optimized step by step, embody the scientific nature and rationality of the process.

4.3 This project lasted long, invest more manpower, get a lot of basic data, the technique of critical review is explored and practiced. All of these laid a solid foundation for the continuous Rolling Requirements Review of integrated observation network in the future.

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