Analyses on Disastrous Weather Monitoring Capability of CINRAD and Future Development

LI Bai[1], GU Qingtong[1], LI Ruiyi[1], CAO Junwu[2], WANG Xu[3]

1 Atmospheric Observation Centre, CMA, Beijing, 100081
2 Hefei Sichuang Electronic Co. Ltd., Hefei, 230061
3 Chengdu University of Information Technology, Chengdu, 610225

Abstract

China has begun the large-scale construction of weather radar since 1990s, and now one weather radar operational network (namely CINRAD) for monitoring large, meso- and micro-scales disastrous weather events has been built and playing important roles in disaster prevention and mitigation. By using quite a lot of data from the network, this paper analyzes the detection capability of the radar network in monitoring the large-scale weather systems including cold front, extratropical cyclone, Jianghuai shear line, low-level jet stream and typhoon; the mesoscale weather systems such as quall line, gust front, hail and thunderstorm high in severe convective weathers as well as the Meiyu front rainstorm. In addition, the scanning strategy and parameter setting in the CINRAD operation model as well as the features and problems of its technical system are discussed. The progresses are as follows: (1) Improving the existing observation model: adding clear air mode and RHI vertical scanning mode to strengthen the radar detecting capability to clear air echoes and the refinement of vertical structure; setting high-mountain observation mode to enhance the capability to boundary layers. (2) Improving radar adaption parameter to solve the problem of range and velocity ambiguity. (3) Using pulse compression method to develop the detecting capability to weak echoes and keeping spatial resolution of radar data. (4) Making good use of radar networking technology to realize simultaneous observations in time and space on different scale disastrous systems. (5) Using Dual-polarization technology to improve the accuracy of quantitative precipitation estimation and identify the precipitation phase state. Based on the above five progresses, a preliminary scheme of radar technology upgrading is proposed. Finally, an outlook for the development of future CIMRAD is presented as well.

Key words: weather radar, observation model, detecting capability, development

1. Introduction

The theme of the 2013 World Meteorological Day is “Watching the Weather to Protect Lives and Property”. To celebrate the 50th Anniversary of the World Weather Watch (WWW) which was build in April 1963, this paper is offered by analyzing the capabilities of CINRAD in monitoring various disastrous weathers. Since the mid-1990s, China has begun to construct digital phased array Doppler weather radar network which is capable to measure precipitation quantitatively and obtain dynamic field structures of atmosphere. CINRAD has the characteristics of online real-time calibration, automatic volume scan mode, reasonable ground clutter suppression and scientific product algorithm, etc., having made the capabilities of measuring precipitation quantitatively and monitoring the structure and evolution of weather systems in large- and meso-scales improved significantly, so it is applied extensively in many fields, playing an important role in developing social economy and preserving people's lives and properties. However, through long-term application, CINRAD is found to have some problems that need prompt solutions. These problems include that the vertical resolution of mid and low levels is relatively low; the volume scan mode used at radar sites in mountainous regions, especially on high mountains, causes the monitored range of atmospheric boundary layers to get smaller; the detected range and velocity are indistinct; it is not so good at monitoring the weak echoes in clear-sky atmosphere and the early developing stage of weather systems; there are some obvious deviations in precipitation estimates and the synergistic ability of the network is not enough, and so on. To solve these problems, we propose a preliminary scheme in this paper to upgrade the monitoring capability of CIRAD under the current radar system on the basis of analyzing some existing technologies that are applied in China and abroad.

2. Monitoring capabilities of CINRAD to various disastrous weather systems

China is significantly influenced by monsoon climate. After into flood season every year, all sorts of weather systems frequently occur over China and they are the main causes for meteorological disasters. With regard to different scale weather systems, CINRAD shows different capabilities, which are primarily determined by the horizontal scale, vertical height, generation and development, moving speed and interior structure of the systems.

2.1 Monitoring capability to large-scale weather systems

Regarding the detection to large-scale weather systems, the monitoring capabilities of weather radar are essentially affected by the earth curvature, topography blocking or more due to the characteristics of large horizontal scales (usually beyond 1,000 km), long duration (usually from dozens of hours to several days) and slowly moving speeds. The major large-scale weather systems include cold (warm) front, extratropical cyclones (e.g. Jianghuai cyclone, Yellow River cyclone, Mongolia cyclone, etc.), high-level trough, shear line (e.g. Jianghuai shear line), jet stream, typhoon etc.. While detecting these weather systems, radar can collect different usable data of the systems.

2.1.1 Detecting cold (warm) fronts

When monitoring cold (warm) fronts, the CINRAD can gain relatively accurate data of frontal surface position, convergence and divergence intensities of frontal zones, fronts' moving trends and variation features by following the reflectivity and Doppler radial velocity information. But as far as a single radar is concerned, restricted by horizontal scales, it cannot afford to observe the whole structure of cold (warm) front, only being able to monitor part of the frontal surface.

Using the highly frequent data of every 5-6 min, cold fronts can be distinguished to be first-type cold front or second-type cold front according to the echo structures and evolution features of reflectivity factors. The reflectivity of the first-type cold front shows that the distribution of echo intensity fields is relatively uniform, usually in 25-45 dBz and being sheet. At the same time, the moving speed of the entire echo is relatively slow, as shown in Fig. 1a. The reflectivity of the second cold front is distributed in band patterns with echo intensity ranging from 35 to 60 dBz. The echo moves quickly as a whole, seen in Fig. 1b. In the strong second-type cold front, strong convergent structure can be distinguished out of the radial velocity field, accompanied by cyclonic structures in smaller scales at the same time. Fig.1c displays a typical wind field structure of cold fronts, from which the location and intensity of cold fronts can be seen and, moreover, the evolution of the cold front can be found out based on the evolution of time series.

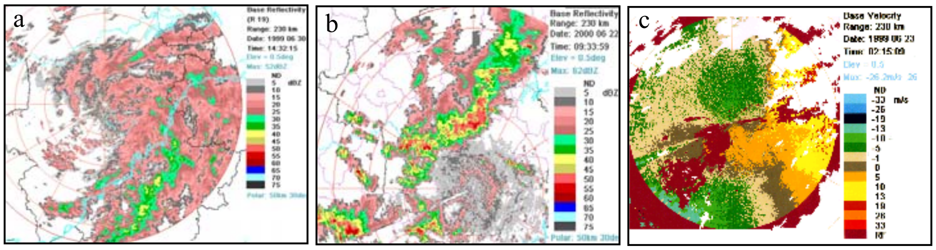

图 1a　1999 年 6 月 30 日 14:32 合肥雷达 0.5° 仰角第一型冷锋在雷达反射率因子上的表现

图 1b　2000 年 6 月 22 日 09:33 合肥雷达 0.5° 仰角第二型冷锋在雷达反射率因子上的表现

图 1c　1999 年 6 月 23 日 02:15 合肥雷达 0.5° 仰角冷锋风场在雷达径向速度图中的表现

Fig.1 Echoes of cold front by CINRAD at Hefei

(a) Performance of first-type cold front on the radar reflectivity factor at 14:32 BT 30 June 1999, elev.= 0.5°

(b) Performance of second-type cold front on the radar reflectivity factor at 09:P33 BT 22 June 2000, elev.= 0.5°

(c) Performance of cold front wind in the radar radial velocity at 02:15 BT 23 June 1999, elev.= 0.5°

2.1.2 Detection of extratropical cyclones

The extratropical cyclones affecting China mainland are Jianghuai cyclone, Yellow River Cyclone and Mongolia cyclone, etc.. Due to the thermal asymmetric structure of such cyclones, cold-warm frontal structure exists inside the cyclones. Weather radar can be used to observe the center of extratropical cyclone, its internal frontal structure, cyclonic shear above the cyclone, convergence intensity and moving speed, etc.. However, because extratropical cyclones are part of large-scale but shallow weather system, it is hard for one single radar to observe the whole structure of the weather system in detail, only that several radars can do the job by jointly working. Fig.2a and 2b show the reflectivity factor and radial velocity corresponding to extratropical cyclones.

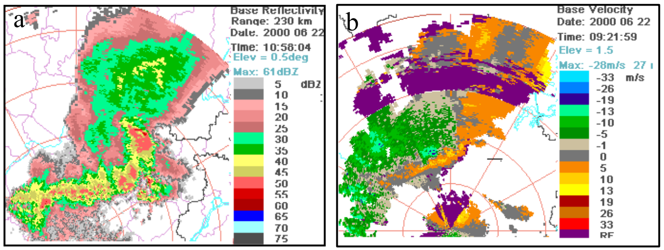

图 2a　2000 年 6 月 22 日 10:58 合肥雷达 0.5° 仰角江淮气旋反射率因子结构特征

图 2b　2000 年 6 月 22 日 09:21 合肥雷达 1.5° 仰角江淮气旋径向速度结构特征

Fig.2 Echoes of extratropical cyclones by CINRAD at Hefei

(a) Structure characteristics of radar reflectivity factor of extratropical cyclones at 10:58 BT 22 June 2000, elev.= 0.5°

(b) Structure characteristics of radar radial velocity of extratropical cyclones at 09:21 BT June

2000, elev.= 0.5°

In addition, the life cycle of an extratropical cyclone is divided into four stages which are wave, mature, occlusion and dissipation. In different stages, the characteristics of radar echoes are different. In wave stage, the radar reflectivity factors represent two precipitation areas, which are corresponding to warm frontal zone and cold frontal zone respectively. When getting to mature stage, the cold and warm frontal zones of extratropical cyclone develop more significantly, and correspondingly, the cold and warm frontal precipitation is reflected more clearly by radar reflectivity. Most of all, when the cold frontal zone of some extratropical cyclones is expressed as the second-type cold front, the generated precipitation is convective. In occlusion stage, the main feature of radar reflectivity is that the cold and warm frontal rainfalls are integrated into one, i.e., the two precipitation areas are connected together.

2.1.3 Typhoon observation

Typhoon is an important weather system affecting China and CINRAD plays a major role in typhoon observation. Weather radar has the monitoring capability of high temporal and spatial resolution and can catch important structure data of typhoon. For example, CINRAD can be utilized to locate typhoon, analyze the typhoon intensity, position typhoon center, determine the moving direction and speed of typhoon, the eye, the spiral rain belt and the maximum wind speed zone. Besides, the fine structure inside typhoon can be analyzed depending on the radar. Fig.3a and 3b show the asymmetrical structure of radial velocity of typhoon Saomai while Fig.3c and 3d present the front genesis reflectivity of typhoon Morakot, which can be used to analyze the evolution of typhoon.

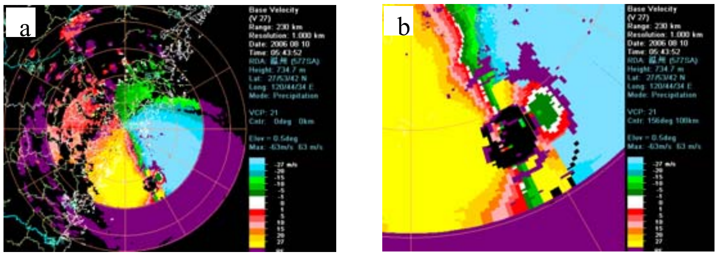

图 3a 2006 年 8 月 05:43 温州雷达桑美台风径向风速度非对称性结构 图 3b 图 3a 径向速度非对称结构局部放大

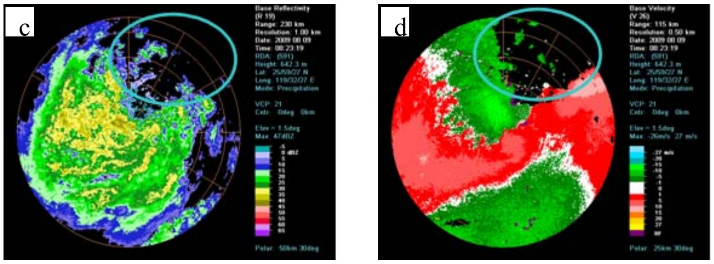

图 3c 2009 年 8 月 08:23 福州雷达莫拉克台风登陆时锋生反射率因子 图 3d 对应图 3c 锋生径向速度

Fig.3 Echoes of typhoon by CINRAD at Wenzhou (a, b) and Fuzhou (c,d)

(a) Asymmetrical structure of the radial velocity of typhoon Saomai at 05:43 BT 10 August 2006,

(b) Part of the enlarged image of the asymmetrical structure of radial velocity,

(c) Front genesis reflectivity factor of typhoon Morakot when landing at 08:23 BT 6 August 2009

(d) Corresponding radial velocity of front genesis

2.1.4 Low-level jet stream detection

Low-level jet is also an important weather system that influences China mainland. In especial, during the process of torrential rain events, jet stream contributes greatly to the generation and development of rainstorms. When jet is considered to be existing from synoptic charts, radar can be used to monitor the low-level jet, obtaining its intensity (i.e., the maximum speed of jet), direction, axis height and evolution characteristics, etc.. Analyzing the exit of jet relying on the observation of CINRAD network is of great significance for determining the rainstorm areas.

2.1.5 Large-scale shear line detection

CINRAD velocity images can be used not only to locate large-scale shear line, but also identify whether it belongs to warm shear or cold shear as well as the convergent intensity of shear and other characteristics. On the radial velocity maps there are three zone-speed lines, one long two short. The long zero-speed line goes through the whole velocity area while the two short zero-speed lines are distributed on its two sides and nearly perpendicular to it. Fig.4a shows the velocity of Jianghuai shear line. To ascertain the position of the Jianghuai shear line in this figure, the first step is to judge the spot of radar station, and the second step is to find out the longest zero-speed line. Taking the longest line as a boundary, it can be seen that the cold and warm areas on its two sides are placed opposite exactly. To the north of this line blows southeast-east wind and to the south is southwest-west wind. The wind directions converge on the two sides of the line. Therefore, the large-scale shear line can be judged located on this zero-speed line. Fig.4b is the sketch map of the wind field for Jianghuai shear line. The humidity difference on the two sides of the shear line is big, but the temperature difference is small. The weak convergent airflows develop into wide and stable precipitation belt with weak cyclonic waves disturbing. Because of the above characteristics, it presents a band echo with larger area and weak intensity on the Doppler radar reflectivity map, corresponding to the small disturbance on the shear line. Besides, there are several precipitation centers with different intensities on the echo belt.

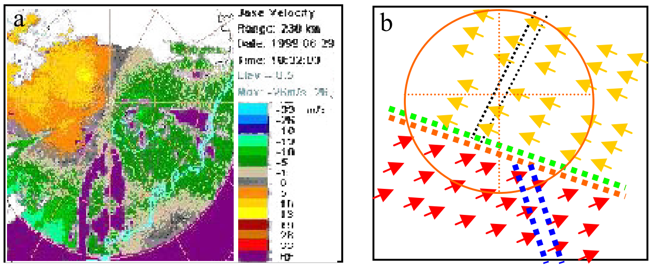

图 4a　1999 年 6 月 29 日 10:32 合肥雷达江淮切变线径向速度　　图 4b　图 4a 江淮切变线速度场示意图

Fig.4 Radial velocity echoes of the Jianghuai shear line by CINRAD at Hefei

(a) Corresponding radial velocity of the shear line at 10:32 BT 29 June 1999,

(b) Schematic diagram for the Jianghuai shear line velocity field

2.2 Detection capability to meso-scale weather systems

Due to the characteristics of fast generation and development but short-time lasting, meso- and micro-scale weather systems are not easily caught by conventional observing network, especially the whole process of their development. CINRAD uses the 5-6 min volume scan model to observe the meso- and micro-scale systems, being able to effectively monitor their whole processes of generation, development, mature and dissipation and reveal their generation conditions and evolvement regularities. More specially, Doppler weather radar can provide radial velocity, enabling us to understand their inner structures of flow fields and estimate their future developing trends.

The frequently seen meso-scale weather systems include hail storm (hailshooting), rainstorm (isolated torrential rains), squall line as well as the gust front, tornado and microburst which are incurred by severe convective storms. In addition, some other meso-scale weather systems like mesocyclone, meso-scale convergent line in the boundary layer and vertical shear are also included.

2.2.1 Hails

The hail is one of the disastrous weathers produced by meso-scale weather system. Weather radar is also the most effective means for the monitoring of hail process. Fig. 5a shows one hail process observed by weather radar. During the hail process the radar reflectivity is very strong, getting to 50-60 dBz or more in general. There is very notable convergence accompanying its generation and development and, moreover, the cyclones are convergent. This finding breaks through the morphology analysis of echo intensity done according to traditional radar meteorology, makes good use of the characteristic information of dynamic fields offered by the velocity field, and becomes clear about the development of hail clouds (Fig.5b, 5c).

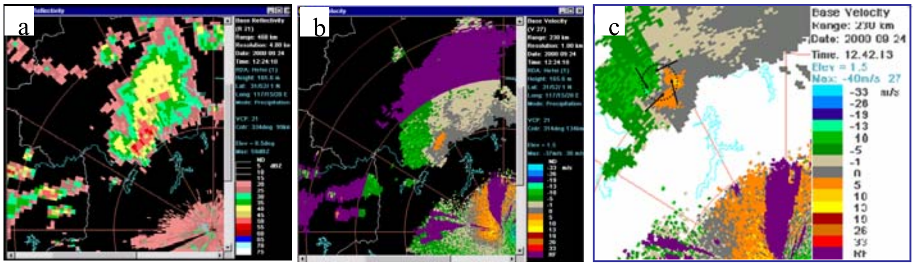

图 5a　2000 年 9 月 24 日合肥雷达 0.5° 仰角冰雹在雷达反射率因子上的表现

图 5b　对应图 5a 冰雹发生时合肥雷达 1.5° 径向速

图 5c　图 5b 径向速度的局部放大（黑色箭头指示风场气旋性旋转）

Fig. 5 Echoes of hails by CINRAD at Hefei

(a) Performance of hails on radar reflectivity factor at 12:24 BT 24 September 2000, elev.= 0.5°

(b) Radial velocity when hails occurred at elev.= 0.5°

(c) Part of the enlarged radial velocity (Black arrows represent the cyclonic winds)

2.2.2 Adverse wind zone in the process of rainstorm and hails

Whether it is hail process or rainstorm process, when analyzing the radar echoes, a kind of structure characteristic of “adverse wind zone” is often found to exist, which refers to the structure that the positive (negative) velocity completely encircles the negative (positive) velocity, and, furthermore, it is a structure for the positive (negative) velocity to work up to the negative (positive) velocity from zero. Such a structure denotes that there exist vertical circulations in the hail cloud areas or rainstorm precipitation cloud areas. Fig.6a presents an adverse wind zone structure of hail clouds that occurred over Nantong while Fig.6b shows the structure of the adverse wind zone in the rainstorm process observed in Nanchang.

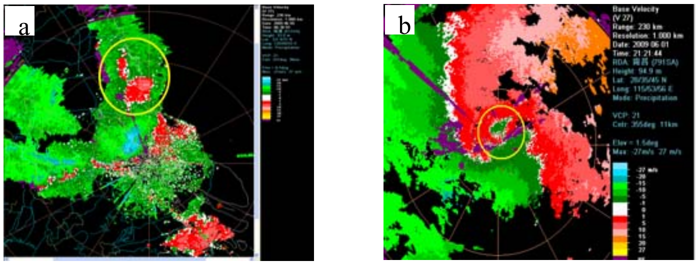

图 6a　2009 年 6 月 5 日 06:36 南通雷达探测到冰雹云中逆风区　　图 6b　2009 年 6 月 1 日 21:21 南昌雷达探测到暴雨中逆风区

Fig.6 Radial velocity echoes in adverse wind field

(a) Adverse wins in hail clouds observed by Nantong radar at 06:36 BT 5 June 2009

(b) Adverse winds in rainstorms observed by Nanchang radar at 21:21 BT 1 June 2009

2.2.3 Squall line

CINRAD adopts the auto-successive volume scan observation model which is very effective in monitoring the short-time severe convective weather process like squall line, gust front and the weather events accompanying such weathers.

Squall line is one meso-scale strong convective weather system often seen in China. It appears as band convective echo with intensity reaching 45-65 dBz, and moves fast, often creating disastrous weathers such as gusty winds, hails, etc.. Besides, all the places hit by squall line are to see air pressure descend a little first, but then quickly soar up so that wind direction changes abruptly and temperature drops dramatically. Fig.7 shows one squall line process that took place in Hebei province on 10 July 2012.

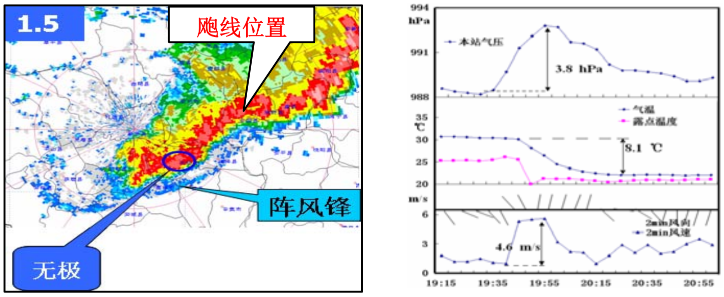

图 7a　2012 年 7 月 10 日 20:00 石家庄雷达 1.5° 仰角探测飑线反射率因子图　　图 7b　无极站自动站气象要素变化情况

Fig.7 Echoes of squall line by CINRAD at Shijiazhuang, Hebei

(a) Reflectivity factor of squall line observed by radar at 20:00 BT 10 July 2012, elev.= 0.5°

(b) Variation of weather elements at Wuji AWS

2.2.4 Gust front

Gust front is often together with strong convection. When severe weathers occur, the storm high deduced from storms forms intersections with the surrounding warm, humid airs, becoming narrow-band echoes in radar echo images which is often seen in clear skies. The characteristics of gust front passing through a place are similar with those of quall line essentially. Fig.8 displays the gust front along with a supercell event in Shangqiu, Henan province.

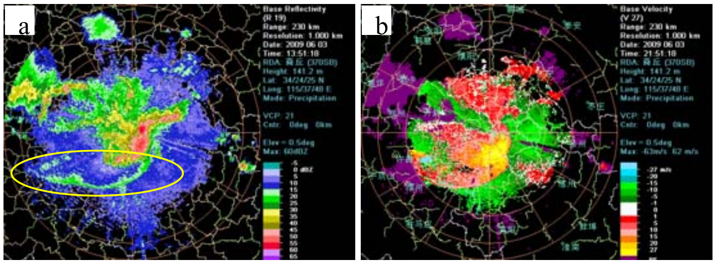

图8a　2009年6月3日21:51商丘雷达0.5°仰角超级单体中伴随阵风锋反射率因子图

图8b　对应图8a超级单体中伴随阵风锋径向速度图

Fig.8 Echoes of gust front by CINRAD at Shangqiu, Henan

(a) Reflectivity factor accompanying gust front in supercells at 21:51 BT June 2009, elev.= 0.5°

(b) Radial velocity accompanying gust front in supercells

2.2.5 Meso-scale thunderstorm high

In the supercell case in Section 2.2.4 there exists the phenomenon of meso-scale thunderstorm high. From the velocity in Fig.9a, it is found that around Shangqiu Radar Station, all the directions are in red color except the direction of northwest, which means the velocity field is far from the radar station. When eliminating the speed moving southeastward of the storm system, i.e., the relative radial velocity of storm (Fig.9b), it can be found that there are all velocities distributing away from the radar around the Shangqiu Station including the northwest direction. Only when radar station lies under thunderstorm high can such structures be observed. Fig.9c and 9d respectively illustrate the concept model formed by thunderstorm high and the observed facts on the surface.

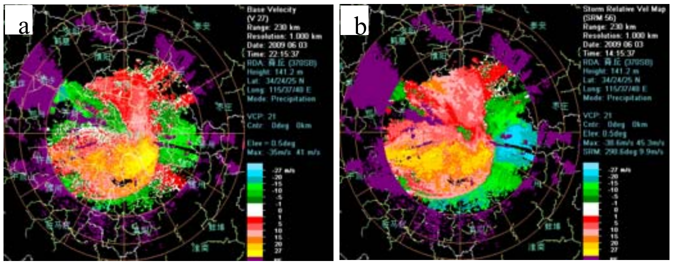

图9a　2009年6月3日22:15商丘雷达0.5°仰角超级单体中雷暴高压径向速度图

图9b　对应图9a商丘雷暴高压风暴相对径向速度

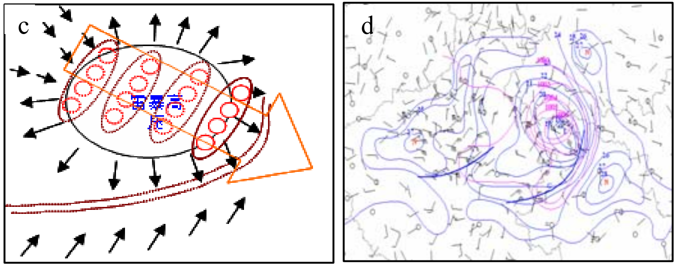

图9c　商丘雷暴高压概念模型

图9d　商丘雷暴高压对应地面实况

Fig. 9 Radial velocity echoes of thunderstorm high by CINRAD at Shangqiu

(a) Radial velocity of thunderstorm high in supercells at 22:15 BT 3 June 2009

(b) Relative radial velocity of thunderstorm high

(c) Conceptual model of thunderstorm high

(d) Surface observation corresponding to thunderstorm high

2.3 Detection capability to rainstorms

Rainstorm is one of the most serious disastrous weathers in China. The weather systems that contribute to the rainstorm process are divided into the rainstorm weather process with long duration and large scopes that are produced by large-scale weather systems and the localized rainstorm weather process with short duration and strong intensities generated by meso- and micro-scale systems, i.e., severe convective weather systems. Whether it is large-scale weather system, such as the widespread Meiyu frontal rainstorm process over Yangtze-Huaihe river basin (Jianghuai Basin) in July 2007, or the localized extremely severe torrential rain process created by severe convective weather system, just like the severe disastrous rainstorm that hit Beijing on 21 July 2012, CINRAD plays a significant role in monitoring operations.

Weather radar can detect the onset time and location of rainstorm during the whole generating and evolving process, and, at the same time, can obtain its intensity variation and duration. Particularly it plays a very good role in monitoring and warning the variation of heavy precipitation masses during rainstorm processes. Weather radar can effectively monitor and catch the intensity, variation of intensity, precipitation rate, accumulated precipitation amount and the internal structure characteristics of wind field of rainstorm precipitation masses. This is vital for judging whether rainstorm precipitation masses can develop persistently or not.

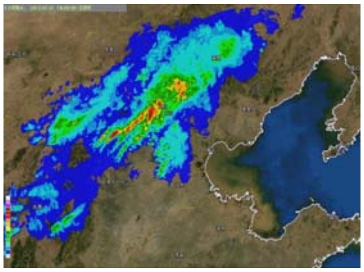

Fig.10 One-hour precipitation estimated by CINRAD at Beijing at 13:00 BT 21 July 2012

One of the most important functions of weather radar is the precipitation measurement. With the continuous progress of radar technology, radar has been correspondingly strengthened in the capability of quantitatively measuring precipitation. Using the Z-R relationship, precipitation intensity and accumulative rainfall amount during the rainstorm process can be accurately inverted. V. N. Bringi, V. Chandrasekar, an American radar expert[1], wrote in his book *Polarimetric Doppler Weather Radar Principles and Applications* that the main strong point of using radar to estimate precipitation is that it can catch large area (about 10,000 km^2) of observation data with very high temporal and spatial resolution. If using a rain gauge network to replace the special sampling of one radar whose range resolution is 150 m and azimuth resolution is be 1^{o} , more than 250,000 rain gauges need to be placed over the area with the radius of 150 km^2, and the measurements of these rain gauges need to be conveyed to a central station at the speed of light through an “inherent” network. Therefore, in addition to the quantitative measurement of precipitation, getting precipitation data with high temporal and spatial resolution quickly and efficiently is also a significant superiority of weather radar when it monitors rainstorm processes.

Fig.10 illustrates the one-hour precipitation distribution estimated by radar at 13:00 BT 21 July 2012 during the extremely severe rainstorm in Beijing. The precipitation measured quantitatively by radar successively indicates that the precipitation intensity of the rain masses that caused the July 21 extremely severe rainstorm in Beijing is extremely strong (the maximum rainfall amount estimated by radar quantitatively getting to 82.9 mm/h), and maintains in the same locality for a long time, nearly 10 hours for the longest.

For the large-scale rainstorm process produced by weather system, depending on its network technology advantages, weather radar can not only catch the fine structure features of the convective system and precipitation masses by using its characteristics of high temporal and spatial resolution, but get widespread large-scale structure features of landing typhoon and Meiyu frontal rainstorm processes, etc. through the network of radars, so being able to bring to light a complete system of the whole weather system. Fig.11a shows the large-scale wind field structure features during the July 21 Beijing extremely severe rainstorm process using the radar VWP network products and Fig.11b reveals the structure features of the precipitation masses during the Meiyu frontal rainstorm process obtained by the radar network technology. The application of the above-mentioned network products suggests that weather radar can not only get the large-scale characteristics of weather systems but also the meso-scale structure features of rainstorms.

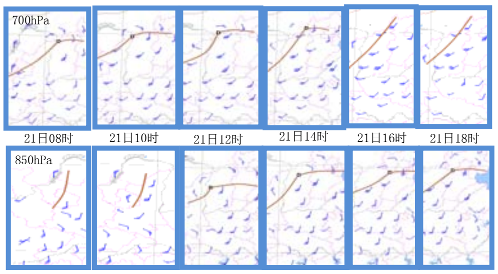

图 11a　2012 年 7 月 21 日 08 时至 18 时北京地区天气雷达 VWP 组网 700 和 850 百帕风场

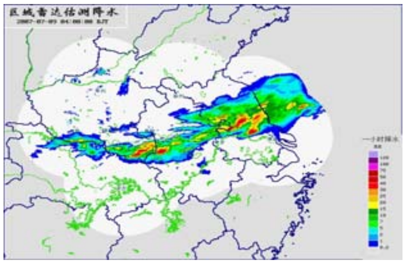

图 11b　2007 年 7 月 9 日 04:00 时组网雷达 1 小时估测降水

Fig.11 Radar network products in the process of rainstorm

(a) The 700 hPa (top) and 850 hPa (bottom) wind fields of weather radar VWP network in Beijing during 08:00-18:00 BT 21 July 2012

(b) One-hour precipitation estimated by radar network at 04:00 BT 9 July 2007

3. Existing problems and solutions

3.1 Proposal and analysis of problems

CINRAD has shown its great advantages no matter whether it is used in large-scale weather system monitoring or in meso-scale weather system monitoring or rainstorm monitoring, so we can use the high temporal-spatial resolution radar data to investigate all kinds of weather systems. However, in the actual applications it is found that some aspects in its scan strategy, technical system, functions, etc. need improving, and the details are as follows:

3.1.1 Low vertical resolution by the current scan strategy

CINRAD adopts volume scan mode for scanning. Two kinds of scan modes have been designed, one is precipitation model, using VCP11 and VCP21, and another is clear-sky model, using VCP31 and VCP32. For various reasons, the VCP21 mode is mainly used in current operations. This model can finish PPI scanning of 9 elevations in 6 min, the turning speed of radar antenna is slow relatively, and the reflectivity factor and velocity data collected by radar are accurate. However, the VCP21 scan mode has lower vertical resolution than VCP11 mode. Supposing the radar station stands at the height of 0 m and atmosphere is the standard atmosphere, then at the spot horizontally 70 km away from the station and under the height of 12 km VCP11 mode can collect 10 sampled data in vertical while VCP21 can only have 7[2]. Witt once detected the same windstorm by two radars using VCP21 mode and VCP11 mode respectively, and their products are quite different. He considered the cause for such difference mainly lies in the fact that VCP21 collects fewer samples in vertical and the resolution is low, so its products are coarse in comparison. Therefore, the current VCP21 scan strategy is not suitable for fine detections to vertical structures.

3.1.2 Weak covering ability in boundary layer observation by current scan strategy

Based on the going VCP21 scanning strategy, the scanned lowest elevation angle is 0.5°. Under the situation that the altitude of radar station is 0 m and atmosphere is the standard atmosphere, the 0.5° elevation scanning can effectively reduce the disturbance of ground clutters and the impact of the second trip echoes, but considering the earth curvature the echoes of nearly 70 % boundary layers within the horizontal distance of 300 km cannot be detected, causing the detection of boundary layer to have more blind zones. The topography of China is very complex and 40 % of the existing radar stations are built at the tops of mountains, so the lowest 0.5° elevation scanning makes the detection capability to boundary layer reduced further. The boundary layer is the passageway for the up-and-down conveying of atmospheric momentum, energy and all kinds of substances on the earth, and its coupling interaction with free atmosphere affects the generation and development of weather processes, so detections to atmospheric boundary layer need to be strengthened.

3.1.3 Weak capability in observing clear-sky echoes and weak echoes

Though the transmitting peak power of the S-band CINRAD can exceed 650 KW and the C-band radar can also have the transmitting peak power go over 250 KW, they still cannot meet the capability requirement for detecting weak echoes, especially for the clear-sky atmosphere detection. Of course, the pulse width can be changed in CINRAD observation mode designing, but real operations have indicated that whether it is wide pulse mode or narrow pulse mode, good clear-sky atmosphere and the early-stage weak echo data of weather systems still cannot be obtained.

3.1.4 Evident problem of range ambiguity

CINRAD employs the pulse transmitting system, whose maximum unambiguity range $R_{\max}$ and the maximum unambiguity velocity $V_{\gamma\max}$ both are correlated to the repetition frequency and restricted mutually. The relationship between the two is $R_{\max} \cdot V_{\gamma\max} = \frac{\lambda \cdot C}{8}$, where λ is wavelength and C is light velocity. At present, the scan method of CINRAD is primarily the batch mode of American WSR-88D, which is the scan mode of using high-low pulse repetition rate separation at low elevation angles. When using high repetition rate to measure velocity, if range ambiguity phenomenon appears, the principle that strong reflectivity factor has the priority to get the measured velocity value first is taken. Once the intensity values of the two are (一旦出现”二者”指 强度值相当时) the same, the velocity-measuring is hard to ascertain (designed as purple). In the existing operation mode the high-frequency PRF is set to 1014 Hz, being able to get ±27 m/s unambiguity velocity-measuring range. According to the formula $R_{\max} = \frac{1}{2}C \times \frac{1}{PRF}$, the unambiguity distance $R_{\max}$ =148 km in the time of high frequency. China’s important precipitation weather systems are widespread usually, such as Meiyu frontal rainstorm process, characterized by large range of rainfalls and weak convective systems mingled with stratiform precipitation cloud systems, so the maximum unambiguity range 148 km makes the range ambiguity problem in radial velocity plan stand out, failing to meet the need of detecting in horizontal ranges.

3.1.5 Precipitation estimate deviation

CINRAD is an important means to measure precipitation quantitatively, i.e., using the Z-R relation and by reflectivity factor, precipitation intensity can be worked out. Setting the coefficient of Z-R relation is associated with the phase of precipitation particles and the particle droplet spectrum. However, the current CINRAD is not equipped with the capability to distinguish the phases of precipitation particles in the detected target, neither can it output effective data for spectrum features of the rainfall particles in precipitation systems, so resulting in bigger deviations in the quantitative estimate of precipitation.

3.1.6 Insufficient capability in networking and cooperative observation

Application of networking technology and cooperative observation is an important aspect of fully exerting the monitoring capability of radar to disastrous weather. During the process of detection, single radar is not only restricted by its own detecting ability (including the power of transmitter, waveband, etc.), but by the influence of its surroundings, such as terrain, buildings, earth curvature, etc., so its actual detecting ability is greatly affected by these elements. For the present radar operation network, it adopts volume scan mode to do networking observation and cannot keep better consistence in time so that great differences are found existing in the data observed by netted radars for the same weather system, i.e., leading to the asynchrony of network observation in time and space. In addition, the existing operational observing mode does not make good use of the advantage of spatial distribution of radar network to do cooperative observation by several radars to realize fine observations to the weather systems in larger spatial scale and the meso- and miro-scale weather systems which develop rapidly in generation and dissipation.

3.2 Analysis on solutions to main problems

Since CINRAD has various problems found in actual observations, and on the premise that no big changes are to be done of the original radar technical system, system structure and hardware device, this paper propounds some solutions to the exiting problems to maximize the effectiveness of radar observations.

3.2.1 Establish observation modes suitable to weather features of China, enhancing the detection capability to boundary layer

(1) Increase scan modes for elevation angles and RHI observation to improve vertical resolutions in middle and lower levels

By the going VCP21 volume scan mode the samples taken vertically are not many and the resolution is low, so appropriate scan elevations can be added to improve vertical resolutions in middle and lower levels, such as VCP11 elevation scanning. However, the VCP11 mode has fast scanning speed, being able to scan 14 elevations in 5 min, and the radar antenna rotates fast too, which cannot ensure the accuracy of reflectivity and velocity of the samples. Therefore, when increasing the scan elevations of VCP21, the antenna speed needs to be kept at a slower level so as to ensure the sample numbers of reflectivity factor and radial velocity. Through adding elevation angles, fine detection capability of CINRAD to vertical structures can be improved. In addition, employing the observation mode of combining volume scan and RHI scan can further improve the capability of finely detecting vertical structures.

(2) Establish high-mountain observation model to strengthen the detection of atmospheric boundary layer

The present VCP21 scan mode takes the smallest 0.5° elevation scan. Affected by complex terrains and earth curvature, more blind zones exist in detecting atmospheric boundary layer. By extending the scan to angles smaller than 0.5° or even negative elevations, the detection capability of CINRAD to boundary layer can be strengthened. Particularly, those high-mountain radars need to have negative elevation scans. Fig.12 presents the observed images of typhoon Saola as it approached and landed the mainland by adopting low elevation and negative elevation observation modes at Fuzhou Radar Station during 1-2 August 2012. The results show that the reflectivity factor of typhoon Saola detected with the low elevation observation mode of 0° elevation and the negative elevation observation mode of -0.2° elevation is significantly stronger in intensity than the reflectivity by 0.5° elevation observation mode, and the shown color code is one grade stronger at least. In the figure the pink arrow is pointing to the outer clouds of the typhoon. However, the 0° elevation and -0.2° elevation also create the phenomenon of marine clutter, as shown by the red arrows in Fig.12b and 12c.

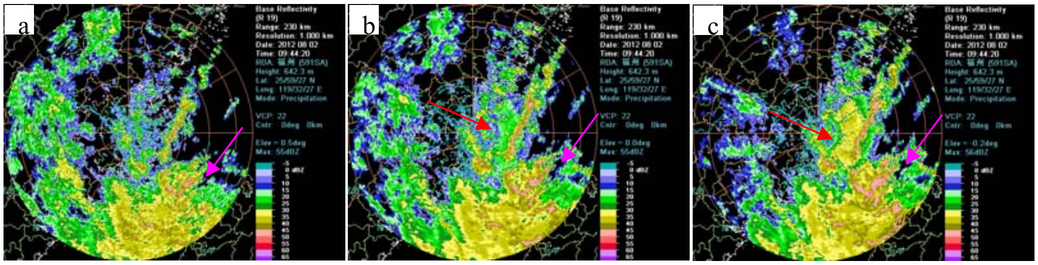

图 12a　2012 年 8 月 2 日 09:44 福州雷达 0.5°仰角探测苏拉台风反射率因子图

图 12b　0.0°仰角探测苏拉台风反射率因子图

图 12c　-0.2°仰角探测苏拉台风反射率因子

Fig.12 Reflectivity factors of typhoon Saola detected by CINRAD at Fuzhou at 09:44 BT 2 August 2012 at elevation angles of (a) 0.5°, (b) 0.0° and (c) -0.2°

(3) Build suitable parameter configuration of range and velocity to achieve the idealist observation

Section 3.1.4 has analyzed the high repet rate of 1014 Hz in the current operation mode, being able to get ±27 m/s unambiguous velocity-measuring range, but the maximum unambiguous range $R_{\max}$ is only 148 km. During the process of detecting Meiyu frontal rainstorm, typhoon and other extensive precipitation events, large part of uncertain zones are created in the range beyond 148 km. The major precipitation system in China is large-scope system, so it is of great necessity to ensure the range unambiguity in the detected range to be the first prior principle.

In order to ensure there is not any range ambiguity within 200 or 230 km, PRF should be designed as 738 Hz or 644 Hz. The correlation formula between pulse repetition rate PRF and maximum unambiguous velocity $V_{r\max}$ is: $V_{r\max} = \frac{\lambda}{4} \times PRF$, then the velocity-measuring ranges are derived, being ±18.75 m/s or ±16.3 m/s respectively. Therefore, within the range of 200 km or 230 km, the prior principle of range unambiguity can be realized. Fig.13 shows the comparison of different repetition rate scan tests and it is seen that the reduction of repetition rate can clearly increase the range of maximum unambiguous range making the purple zone disappear.

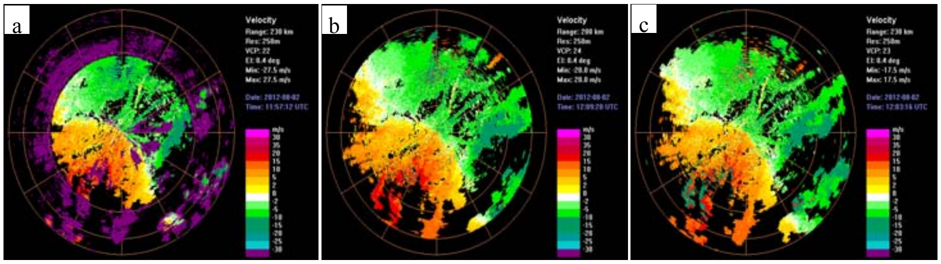

图 13a　PRF=1014Hz,不模糊距离为 148 公里

图 13b　PRF=738Hz,不模糊距离为 200 公里

图 13c　PRF=644Hz,不模糊距离为 230 公里

Fig.13 Radial velocity echoes observed by CINRAD at Tongling on 2 August 2012 with different PRF (a) PRF=1014 H_z, unambiguous range 148 km, (b) PRF=738 H_z, unambiguous range 200 km, (c) PRF =644 H_z, unambiguous range 230 km

3.2.2 Apply phase coding technique and dual PRF technique to solve the problem of range and velocity ambiguity

(1) Phase coding technique[3] :

This technique encodes by transmitting pulse phases and does not expect the spectrum scatter of echoes to reduce the influence of overlaid echoes on spectrum moment estimate of expected signals at the receiving ends. There are various methods in phase coding series, aiming to drive the spectrum scattering degree of echoes to get much bigger so that the expected echoes can be retrieved by comparatively simple methods. Therefore, through phase coding the unwanted echoes can be effectively restrained under the condition of keeping the maximum unambiguous velocity unchanged, retrieving those wanted echoes and reaching the purpose of enlarging unambiguous ranges. Meanwhile, the deviation of spectrum moment estimate resulting from echo overlaying can be eliminated, improving the accuracy of spectrum moment estimate of overlaid echoes.

Using the echo data of X-band dual-polarized Doppler weather radar, the mitigative range effects of the batch mode and SZ phase coding technique are compared and validated, shown as Fig.14. The results suggest that the ambiguity algorithm of SZ phase coding and mitigative range can retrieve the velocity of overlaid echoes, and moreover the gained velocity plan does not have large areas of purple zones (i.e., the ineffective zones by the ambiguity algorithm of mitigative velocity). The mitigative range ambiguity is significantly better than the conventional batch mode method. Besides, based on the continuity of velocity, the retrieved velocity is believable. At present, the SZ(8/64) coding can separate echo signals for four times at most, but due to the serious attenuation of X-band radar, there is not a case including echoes detected four times in actual applications and only fewer cases have the echoes by three times. When the three-time echoes appear, the phase coding algorithm can also retrieve their velocities more accurately. Though SZ phase coding algorithm has the scanning once more than the batch mode and the calculation is more complex than batch mode, it can meet the requirement of real-time processing by using the function in IPP performance database to realize FFT and reverse FFT operations and by reasonable software programming.

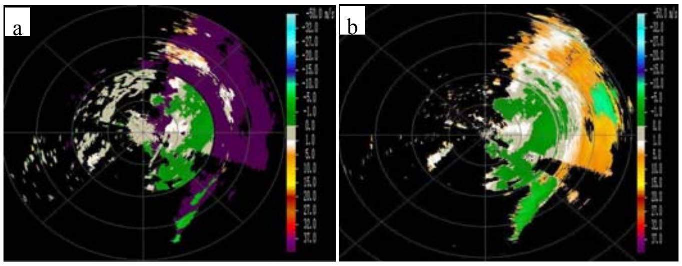

图 14a　批处理方法退距离模糊　　图 14b　SZ 相位编码技术退距离模糊(已做杂波滤波)

Fig.14 Mitigative range ambiguity by batch mode (a) and SZ phase coding technique (b, clutter filtered)

(2) Dual PRF mitigative velocity ambiguity technique[4]:

According to the equation $R_{\max} \cdot V_{\max} = \frac{\lambda \cdot C}{8}$, the maximum unambiguous radial velocity $V_{\max}$ and the detected range are negatively correlated. Therefore, to increase the maximum unambiguous velocity, the detected range needs to be decreased. But when the detected range is small, it is easy for twice echoes or even three-time echoes to emerge; when increasing the detected range, it is a must to decrease the measurable scope of velocity. In order to solve this conflict, the transmitting system of dual-pulse repetition frequency, i.e., the dual PRF function, can be adopted. That is, transmitting in different pulse repetition frequencies alternately, then using their phase differences and pulse repetition cycle differences to compute radial velocities. The basic principle is as follows:

For the target object with definite velocity, the phases detected by different pulse repetition cycles are different. From the equation $V = \frac{\lambda \bar{\theta}}{4\pi T}$, where λ is wavelength, T is pulse cycle and $\bar{\theta}$ is the phase difference between averaged two neighboring cycles (the maximum phase difference identified or detected by radar is 2π), the maximum unambiguous radial velocity $V_{\max}$ can be obtained, i.e., $\bar{V}_{\max} = \frac{\lambda}{4(T_1 - T_2)}$. Supposing $T_1 > T_2$, to improve the maximum unambiguous velocity, demand $T_1 - T_2 < T_2$, that is, $\frac{T_1}{T_2}$ is between1-2 while the maximum measurable range is resolved by T_2. For example, if demanding the maximum unambiguous detected range be 300 km, it needs to require $T_2 = 0.002$ seconds, which means the pulse repetition frequency is 500 Hz. When $T_1 = 0.0025$ seconds, i.e., PRF=400 Hz and $\bar{V}_{\max} = 53.50$ m/s; when $T_1 = 0.0027$ seconds, i.e., PRF=375 Hz and $\bar{V}_{\max} = 38.21$ m/s; when $T_1 = 0.003$ seconds, i.e., PRF=333 Hz and $\bar{V}_{\max} = 26.75$ m/s. Fig.15a and 15b compare the radial velocity plans by using single repetition frequency (PRF=1014 Hz) and dual repetition frequency (PRF=644:429 Hz). From the comparison result it is seen that after adopting dual repetitive frequency PRF=644:429 Hz, the unambiguous zone enlarges from 148 km to 230 km, and the purple zones disappear, and moreover the unambiguous velocity changes from ±27 m/s to ±34 m/s.

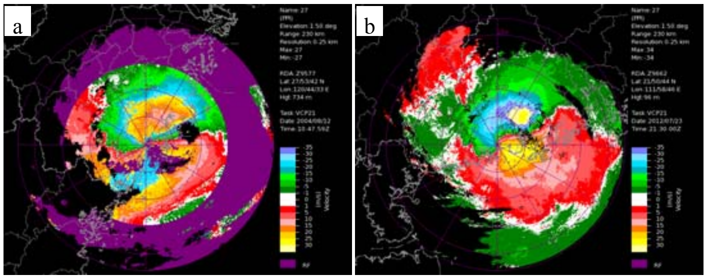

图15a 2004年08月12日10:47温州雷达1.5度仰角
单重复频率PRF=1014Hz时径向速度图

图15b 2012年07月23日21:30阳江雷达1.5°仰角
双重复频率PRF=644:429Hz径向速度图

Fig.15 Radial velocity echoes (a) by CINRAD at Wenzhou at 10:47 BT 12 August 2004, elev.= 0.5° when single repetition frequency PRF=1014 H_z, and (b) by CINRAD at Yangjiang at 21:30 BT 23 July 2012, elev.= 0.5° when dual repetition frequency PRF =644:429 H_z

3.2.3 Add clear-sky scan mode to improve the detection to weak echoes and clear-sky echoes by pulse compression technique

(1) Build clear-sky observation model to improve the early discovering ability for disastrous weathers

VCP31/VCP32 is set in the WSR-88D radar operational observation model in America. The two kinds of clear-sky observation models mainly adopt the method of transmitting wide pulse and reducing the scanning speed when radar takes samples for the purpose of increasing the accumulative total numbers and improving the detection capability to weak echoes or clear-sky echoes. In comparison, the weather radar observation models in China all use VCP21 mode, causing the radar to be obviously deficient in the capability of detecting weak echoes and clear-sky echoes. Therefore, it is very necessary to establish the clear-sky observation model based on wide pulse and low scanning speed to improve the early monitoring ability for disastrous weathers. But if using wide pulse transmission, the radial detected spatial resolution can be reduced. Take the CINRAD/SA as an example. Its narrow pulse is 1.7 *μs* and radial spatial resolution is about 250 m. If using 4 *μs* or 5 *μs* wide pulse, the spatial resolution can be 600 m and 750 m respectively. Therefore, using wide pulse transmission in clear-sky model can cause the average power of transmitter to soup up, which can increase the malfunction rate of radar transmitter. Therefore, improving the reliability of transmitter should also be considered.

(2) Adopt pulse compression technique to improve clear-sky echo monitoring capability

Pulse compression is a kind of signal processing technique. Its basic principle is to use wide pulse transmission of specific waveform at the transmitting end and, then, compress the received echoes into narrow pulse by pulse compression processing at the receiving end. Wide pulse transmission strengthens the average power, enhancing the detection of radar to weak echoes, and pulse compression processing improves the range resolution between objects, making echo structure clearly seen.

The application research of pulse compression technique in meteorological field has been carried out for years in other countries, and this technique has been applied in meteorological operations. The pulse compression technique is usually used in the solid-state radar system with lower transmitter power. Fig.16 shows a case that Traveling-Wave Tube (TWT) is used as transmitting device abroad and its peak power value of transmitter is around 8Kw, which is lower than the transmitting power of ordinary radar. Fig.16a and 16b display the comparison of dexterity and resolution of radar in the two systems of 40 μs wide pulse compression and 1 μs narrow pulse compression. Apparently, after compressed, the wide pulse of 40 μs used when radar transmits with lower power can gain the same range resolution as that of conventional high-powered radar with 1μs narrow pulse, but the detection capability of the former for weak echoes is prior to the latter[5].

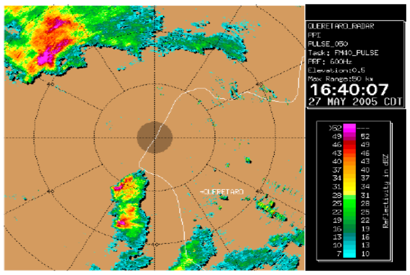

图 16a　采用 40 μ s 宽脉冲经压缩处理获得的反射率图

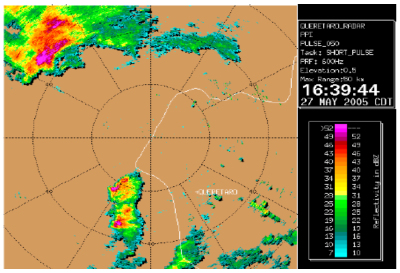

图 16b　采用高功率 1 μ s 宽窄脉冲经发射获得的反射率图

Fig.16 Radar echoes detected by using pulse compression technique abroad. Reflectivity factors obtained (a) through pulse compression by 40 μs pulsed width transmission and (b) by high-powered 1μs pulsed width transmission

In China, the application study of pulse compression technique in meteorological operations has been going on as well. Fig.17a, 17b and 17c show the comparison tests conducted by vehicle mobile phased array weather radar respectively with 1μs narrow pulse, 10 μs wide pulse but not compressed and 19 μs wide pulse under compression processing. The result suggests that the echoes by 19 μs linear FM pulse compression (Fig.17c) are stronger than the ordinary 1 μs narrow pulse echoes (Fig.17a), and the range resolution is higher than the ordinary 10 μs wide pulse (Fig.17b). In other words, this comparison means that Fig.17c which has adopted pulse compression technique has both the high range resolution of narrow pulse and the detection capability of wide pulse.

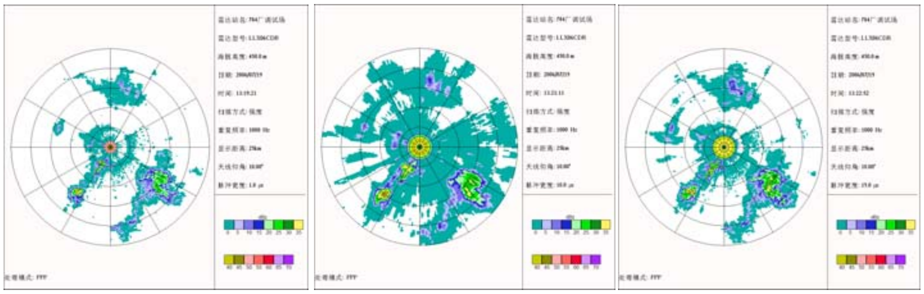

图 17a 采用 1μs 脉宽发射获得的反射率　图 17b 采用 10μs 脉宽发射不做压缩处理反射率　图 17c 采用 19μs 脉宽发射做压缩处理反射率

Fig.17 Radar echoes detected by using pulse compression technique in China. Reflectivity factors obtained (a) by 1μs pulse width transmission, (b) without compression obtained by 10 μs pulsed width transmission, and (c) with transmission obtained by 19 μs pulsed width

4. Outlook for the development of weather radar technology

Since weather radar came into being during World War II, it has been applied in many fields, developing from simulated signal radar at the early stage to digital signal radar. In 1980s, it was combined with Doppler technique, developing into the Doppler weather radar which is widely used in meteorological operations now. With the development of radar technology, electronic technology, computer technology, communication technology and GIS, weather radar has been gradually forming a radar technology system that blends together the techniques of Doppler, multiwavelength, multipolarization and phased array, and, meanwhile, the developing trend combining with networking technology and GIS technology. The future weather radar is to develop in the following aspects:

4.1 Application of networking and synchronization techniques to realize the cooperative observation to weather systems

With the gradual construction of large-scale radar network, it is necessary to realize the cooperative observation to the temporal and spatial synchronization and fine structures of large-scope or specific regional weather systems by using radar network. But to realize the above objective, the high efficient communication system suiting weather radar network, the technology of using satellite navigation system to achieve temporal synchronization and spatial synchronization and the system calibration technology of netted radars are greatly essential, because they are conductive to realize the consistency of time, space and ration of radar network observation. In addition, combining the high-resolution GIS information with cooperative observation will significantly improve the monitoring and warning capability of radar network to disastrous weathers.

4.2 Upgrade CINRAD dual polarization to improve the precision and accuracy of radar in measuring precipitation

It has been analyzed in Section 3.1.5, quantitatively estimating precipitation is one of the important applications of CINRAD. But because it is hard to distinguish precipitation particle phase and obtain particle spectrum signature data, deviations always exist in quantitative measurement of precipitation. Dual linear polarization technique can be used not only to get echo intensity of detected target, but to gain the differential reflectivity of precipitation particles Z_{DR}, differential phase shifting ϕ_{DP}, depolarization factor K_{DP}, correlation coefficient ρ and other parameters, through which the precipitation particle shapes can be identified, improving the precision of quantitative measurement of precipitation. Therefore, adding the dual linear polarization function to CINRAD is indispensable.

America has technically upgraded the dual linear polarization of more than 10 NEXRADs, emphatically testing the effect of dual linear polarization radar technique in improving the quantitatively measuring precipitation ability of radar. In order to examine the exact performance of the technique in operational application, since 2002, outfield comparison experiments of observation have been carried out in Oklahoma and other places in the central part of America. Fig.18a and 18b compare the quantitative measurement of precipitation between dual polarized WSR-88D radar and WSR-88D radar. In Fig.18b, it is seen that due to the impact of the hails in convective clouds the precipitation is obviously overestimated while in Fig.18a the dual polarization technique is used, eliminating the influence of hails, and the estimate on precipitation is more reasonable.

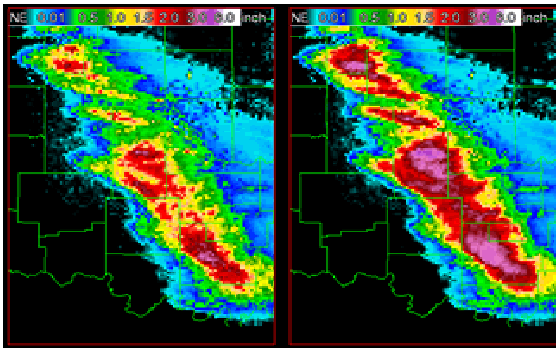

图 18a　双极化 WSR-88D 雷达一小时估测降水　　图 18b　WSR-88D 雷达一小时估测降水

Fig.18 Quantitative precipitation detected by dual linear polarization radar

(a) One-hour precipitation by dual-polarized WSR-88D radar, (b) One-hour precipitation by WSR-88D radar

At present, the key technical problems to be solved for the dual polarization Doppler radar include: the consistency of gain, beam shape and direction of the microsecond polarized switch with high power, high speed, high precision and high isolation as well as ultra-low sidelobe antenna under two kinds of polarizations; the stability of antenna-feeder system; the consistency of dual channels of receiver; the signal processors with high speed and high precision to ensure the reliability of observation data.

4.2 Develop millimeter wave radar technology to improve disastrous weather warning and predicting capability

One major way to improve the warning and forecasting capability to disastrous weathers is to observe the generation and development of clouds before the occurrence of the disastrous weather. Millimeter wave cloud radar provides technical support for the realization of this purpose. Currently, the band of cloud radar at home and abroad is usually 35GHz or 94GHz, whose corresponding wavelength is about 8 mm and 3 mm respectively. The related study[6] reveals the sensitivity of these two wavelengths to particle size and liquid water content (Fig.19a and 19b). Fig.19a shows that under the condition of same liquid water content, with the increase of particle size within the scope of 0-800 μm, the reflectivity factor of 8 mm wavelength cloud radar increases gradually. This indicates the 8 mm wavelength cloud radar is suitable to observe the clouds with particle size in the scope of 0-800 μm, which means to observe the nonprecipitating clouds, drizzles and weak precipitation clouds. Fig.19b shows that, under the same liquid water content, the 3 mm wavelength cloud radar reflectivity increases with the increase of particle size within the scope of 0-350 μm, but decreases with the increase of particle size within the scope of 350-800 μm. Therefore, the 3 mm wavelength cloud radar is suitable to observe the clouds with particle size in the scope of 0-350 μm, such as cirrus.

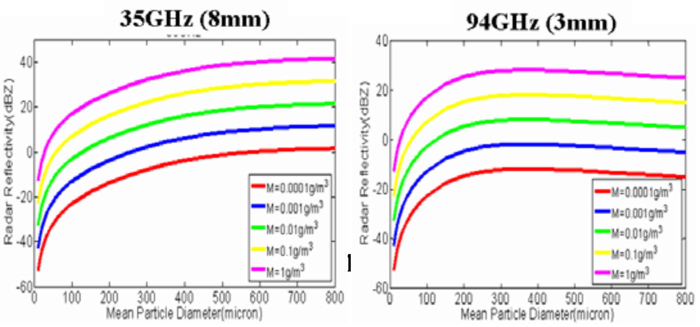

图 19a　8mm 波长雷达对粒子大小以及液水含量敏感性　　图 19b　3mm 波长雷达对粒子大小以及液水含量敏感性

图 19 毫米波雷达探测能力图

(a) Sensitivity of 8 mm wavelength radar to particle size and liquid water content

(b) Sensitivity of 3 mm wavelength radar to particle size and liquid water content

In addition, the millimeter wave radar has following characteristics[6]: the first is good beam direction, having very high spatial resolution. The beam width of millimeter wave radar is mostly from 0.4° to 0.6°. Relative to the beam width of 1.0° of CINRAD the directivity of the millimeter wave radar has been greatly improved; the second is the particles that the millimeter radar can detect include several-millimeter cloud particles to echo particles of weak precipitation, and the nonprecipitating clouds and weak precipitation clouds do not reduce them so much, so the radar can finely detect the physical structures of clouds. In a word, millimeter wave radar is an effective instrument for detecting the generation, development and evolution of clouds, and also is the important measure to improve the capability of warning and predicting disastrous weathers.

4.4 Adopt pulse compression technique to develop weather radar toward solid state and miniaturization

With the weather radar system developing toward the direction of low power, high reliable stability in general, transmitter technology gradually shows the developing trend for solid state transmitter system. Therefore, pulse compression technique has significant application values. The essence of the pulse compression technology is to increase the pulse transmitting width at transmitting end to enhance the average power of pulse transmission, and at the receiving end to compress the received signals into narrow pulse by pulse compressing technique. Such kind of signal processing has two advantages: (1) Through transmitting wide pulse, the transmitting peak power of radar can be depressed, avoiding using high power transmitting tube. Besides, using solid-state firmware can make radar smaller and lighter. (2) Under the condition of keeping the transmitting power unchanged, maintain the range distinguishing ability of radar and strengthen its detecting capability so that it can catch clear-sky echoes or weak echoes.

Compression can be divided into four categories including (1) linear FM pulse compression, (2) nonlinear FM pulse compression, (3) phase coding pulse compression and (4) time frequency coding pulse compression, of which the first three are used more often.

4.5 Develop air-borne meteorological radar to trace severe weather processes

At present, there are four sets of airborne Doppler weather radar systems used extensively. They are WP-3D airborne tail single beam vertical canning Doppler radar , airborne tail dual beam radar, ER-2 Doppler radar and dual polarization cloud radar. The scan strategies of these radars are divided into two types: one type can conduct quasi-dual Doppler radar volume scan and another can only do the directed scan.

The characteristics of airborne weather radar include: (1) Good flexibility, quickly tracing weather process. To bring its flexibility into full play and make it detect the dynamic and thermal structures as well as the micro-physical structures of disastrous weather systems, airborne phased array weather radar which can quickly scan should be developed. (2) By designing special flight path or scan strategy to create dual-radar observation data, and then based on the dual-radar inversed wind field data with higher precision, airborne radar can effectively trace severe weather processes when working.

4.6 Application of phased-array weather radar technique of fast scanning

Phased array technology came into being in 1930s, having been used in military affairs. What is different from the conventional mechanic scanning radar with only one transmitter and receiver antenna, phased array radar is composed of antenna arrays with many transceiver modules. It adjusts its scanning position and elevation angles by electronically controlling the phases of the multiple transmitting unit beams. The significant superiority of such kind of electronic scanning way of phased array radar to the mechanic scanning radar lies in its fast scanning speed.

Phased array radar has the fast scanning feature of antenna beam, so it can scan a cycle quickly in a short time, being suitable to monitor the fast developing severe convective weather systems such as thunderstorm, hails, tornados etc.. In 2002, the National Commission of Radar Technology of the United States recommended to use phased array technology to replace the original WSR-88D technology. In order to research the characteristic of phased array weather radar, America built the National Weather Radar Testbed. Besides, nine institutions including NSSL, Radar Operation Center (ROC), Oklahoma University (OU) and the U.S. Navy cooperatively reconstructed the retired Aegis phased array radar, establishing the phased array weather radar system of 2-Dimentional phase scanning, and installed it in Norman, Oklahoma to monitor the severe weathers like hails and tornados, etc.. On this basis, The U.S. also developed the mobile 1-dimentional phase scan X-band phased array weather radar, and carried out the outfield experiment from 2007 to 2008, tracing and observing tornados and hails. National Key Laboratory of Severe Weather of Chinese Academy of Meteorological Sciences, and other scientific research institutions developed S-band phased array weather radar and vehicle X-band phased array weather radar system.

Although phased array weather radar has the advantages of fast scanning, small power of transmit-receive unit, it has its bottlenecks in technology as well. The antenna of conventional weather radar is very directive, the power it radiates mainly focuses on the direction of beams. In comparison, phased array weather radar changes its beaming direction relying on the change of phases, so its beam width is no longer fixed and unchanging but varies with the change of elevation angles. When the beam is perpendicular to antenna array, the beam width is the smallest. The larger the beam points away from the normal, the larger the width of the beam is. Because beam width changes along with the elevations, the radar gain of phased array weather radar is not fixed and unchangeable, but changing with the elevations as well. When the beam points closer to the normal direction of antenna, the antenna gain becomes larger, and vice versa. Because phased array weather radar has unfixed beam width and unfixed gain, which brings some difficulties to quantitative observation. In addition, the calibration problem needs to be further gone into.

5. Conclusions

Since beginning to build CINRAD network in 1990s, China has made great progresses in large-scale and mesoscale disastrous weather monitoring, but some outstanding problems have been exposed during the real operations. Therefore, it is very necessary to put forward pointed initial schemes for upgrading the CINRAD network technically and further improving the monitoring capability of weather radar network.

(1) Improve the existing operational radar scan strategy. Through increasing scan elevations, improve vertical resolution, enhance fine detections to vertical structures. For coastal and high-mountain radar stations, add low-level and negative elevation observation to strengthen the observing ability of radar to boundary layers, which is helpful to further improve the discovery capability and analysis capability to meso- and micro-scale weather systems. At the same time, in the respect of adaption parameter of observation model, for the characteristics of continental weather system, establish the model that takes the objective of being favorable for eliminating the range ambiguity as the first norm and is suitable for continental weather observation. The future observation model should match with the observation strategy that combines volume scan with RHI scan.

(2) The main function of weather radar is to measure precipitation. The application of dual polarization technology will improve its quantitative measurement accuracy and precision of precipitation. Therefore, on the premise that there are not big changes to the current technical system, it is of a great necessity to gradually upgrade the operational radar network of China into

dual polarized Doppler weather radar system and, moreover, it is feasible technically.

(3) Due to the bottleneck of range and velocity ambiguity, the pulse Doppler system of weather radar has seriously restricted the detecting capability of radar, especially in the observation of Doppler radial velocity field. Adopting the present mature phase coding technique and dual PRF technique is one of the key skills to effectively improve the detection quality of radar in Doppler velocity field. Besides, it can greatly raise the quantitative application level of radar in radial velocity observation.

(4) Clear-sky atmospheric observation and the early monitoring of weak echoes are very important for improving the warning capability of disastrous weathers. On the condition that not big changes are to be done with the existing radar technical system, it is a feasible and effective way to apply the developed pulse compression technology to enhance the detection capability of clear-sky atmosphere and weak echoes, and through the pulse compression technology to promote weather radar to be solid-state and shrinking in size.

(5) Effective weather radar network and cooperative observation of multiple radars can not only observe meso-scale weather system but also monitor the large-scale weather systems like Meiyu frontal rainstorm process, extratropical cyclones, etc.. The critical point is to solve the problems of real-time calibration of netted radars and the temporal and spatial synchronization.

(6) Developing the detection technique of millimeter wave cloud radar and realizing the fine detection to cloud structures can effectively improve the early warning capability to disastrous weather events. Meanwhile, making use of the quickness and flexibility features of airborne weather radar to realize the purpose of tracing severe weather process is the aspect that China needs to enhance further.

References:

[1] V.N.Bringi, V.Chandrasekar, *Polarimetric Doppler Weather Radar Principles and Applications*. Translated by Li Chen, Zhang Yue and proofread by Zhang Peichang in 2010.

[2] Steadham R M, Brown R A, Wood V T. Prospects for faster and denser WSR-88D scanning strategies. 18th International Conference on Interactive Information and Processing Orlando, Florida, Amer. Meteor. Soc., J89-J91. 2002.

[3] Wang Xu and Li Bai, 2009: The research and realization of mitigative range ambiguity method of phase coding in WSR98/XD weather radar. Chengdu University of Information Technology,

[4] Ge Rongsheng, Wang Shunsheng and Zhang Peiyuan, 1988: CAMS Doppler weather radar system. No.88009 report of meteorological science and technology of Chinese Academy of Meteorological Sciences.

[5] Gu Qingtong and Li Bai, 2011. Study on mobile solid-state radar signal processing technology. Chengdu University of Information Technology.

[6] Zhong Lingzhi and Liu Liping, 2009. Calibration and analysis of China New Generation of cloud radar-HMBQ and its preliminary application in retrieving microphysics parameters, Chinese Academy of Meteorological Sciences.