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# Evolution of weather radar technologies: New developments, resource requirements, spectrum allocation constraints (ET-ORST, Task 7)

### SUMMARY

This document provides information on Evolution of weather radar technologies: New developments, resource requirements, spectrum allocation constraints in China. With 20 year’s evolution, China weather radar network has achieved big benefits to meteorologists, hydrologists, aviation users and society. But there are still issues on data quality, reliability of data, distinction between weather and clutter signals, quality control and rainfall rate accuracy.

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1. **The existing Weather Radar Issues in China:** With 20 year’s evolution, China weather radar network has achieved big benefits to meteorologists, hydrologists, aviation users and society. The 190 operational S & C radars have provided valuable data during severe weathers. Even though, there are still issues on data quality, reliability of data, distinction between weather and clutter signals, quality control and rainfall rate accuracy.
2. Radar Echo Intensity Uniformity: Stability for single Radar, and intensity uniformity for multiple radars.
3. Non-met. Echo: ground clutter, super refraction echo, sea clutter, wind farmer, bird/insect echo and electromagnetic interference.
4. Range folder and velocity ambiguity.
5. Ghost Echo: signal processor, calibration, antenna angle code and other radar failures.
6. Insufficient data application in numerical weather prediction model.
7. Short term warning based on radar observation need to be strengthened.
8. Observations environment issues: for example, mountainous area, megacity high buildings, RF protection issues, e.g. Hainan weather radar in China.
9. Lack of Metadata measurement, change, verification standards
10. **Application Requirements:**
11. The quantitative precipitation estimation precision: rivers, reservoir, lakes of security, flash flood disaster prevention, urban waterlogging warning need more accurate and timely rainfall data.
12. Automatic identification of severe convective weather: automated identify tornado and thunderstorm with more leading time and reduce the false alarm rate.
13. The numerical model prediction application requirements: Range folder and velocity ambiguity, Ghost Echo, Radar Echo Intensity Uniformity must be solved.
14. Base data and application products sharing: volume scan strategy limited the extensive application of civil aviation, water conservancy and other departments.
15. **CMA’s Weather Radar Implementation Plan- 2020:**
16. 101 existing S-band radars will be upgraded to dual-pol.
17. Additional 48 dual-pol S-band radars will be added to improve observation capability of boundary layer in high impact regions and key areas, e.g. tornado, low layer shear line, downburst. In addition, 25 X-band dual-pol radars will also be deployed.
18. Several testbeds (dual polarization radar, cloud radar and lidar to promote application of new technology in operation) will be established to improve real-time calibration ability, maintenance and training.
19. Key components will be upgraded, e.g. signal processor, klystron and frequency synthesizer.
20. Data format, data quality control, operational procedures will also be standardized.
21. Weather radar metadata standards and database will be established and realize to exchange metadata with OSCAR database machine-to machine.
22. Fast data transmission strategy from radar sites to any of users through change the scanning strategies.
23. Improve real time monitoring system ability by upgrading Atmospheric Observing System Operation and Monitoring (ASOM) to manage all national operational observation systems’ quality, analysis data issues and reporting all failures which may occur.
24. High mountain observation mode for typhoon in coastal area to improve monitoring ability for offshore typhoons will be on operation.
25. Researches on X-band networking, solid-state transmitter technology and phased array radars.
26. **New Developments:**

**Key technologies of Radar system upgrade:**

1. consistency and insulation of antenna beam:
* horizontal and vertical polarization of beam
1. coherence and stability of amplitude-phase of dual channel of receiver
* temperature compensation to key components
* high stability of environment temperature for key components
* improve consistency of dual channel components
* receiver of dual channel system work in the same electromagnetic environment
* enhance the maintainability
* the difference of amplitude≤ 0.2dB; the difference of phase≤2°; dynamic range≥95dB
1. calibration technology of dual-polarization system:
* amplitude and phase calibration of receiving branch of dual channel system ( apparatus in machine room)
* amplitude and phase calibration of receiving branch of dual channel system (receiving link apparatus, like rotary joints): indicating the subtle variations of amplitude and phase brought by different position of azimuth and pitch joints.
* feeder loss calibration of dual transmitting branch: sample and calibrate the phase difference of transmitting branch to augment the accuracy of calibration.
* amplitude and phase check and correction of transmitting output signal
* accuracy of echo intensity≤0.5dB for dual polarization system
* amplitude consistency of receiving machine of dual channel system≤0.2dB (online calibration)
* phase consistency of receiving machine of dual channel system≤≤2° (online calibration)
* amplitude calibration of feeder link≤0.05dB (after correction)
* phase calibration of feeder link≤0.1°(after correction)
1. processing of digital instantaneous frequency and signal
* digital IF and signal processor is jointly developed by MetStar and Chengdu University of Information Technology
* highly integrated and low failure rate
* four channel processor and support of phase encoding technique
* suitable for single/dual polarization, multi-wavelength band
* application of dual channel algorithm can improve detection sensitivity by 2.5~4 dB, having the ability to detect the weak echo.
* multiple order correlation coefficient (CC) algorithm (cooperation with Oklahoma University, the algorithm is applied in WSR-88D radar)
* Application of linear programming differential phase shift (KDP), this algorithm is a joint work with Nanjing University, which can improve the data quality of KDP.
1. meteorological product and algorithm
* primary display product of dual polarization: differential reflectivity Z, correlation coefficient, differential phase shift (Z)
* advanced dual polarization algorithm product: classification of particle phase state, identification of melting layer, dual polarization quantitative precipitation estimation

**Radar system upgrade include following specifications:**

1. antenna: change the dual polarization transmitting source , consistency of dual polarization beam reaches 0.1° @3dB, the intersect insulation is 35dB
2. feeder line system: upgrade to dual branches system with horizontal and vertical branch, capable of online switch function between single and dual polarization mode
3. transmitter: upgrade with additional function of real-time sampling and correction of frequency , power stability is improved (0.1 dB), limit improvement factor reaches 55 dB, inhibition capability of phase noise / ground is improved (0.1°)
4. receiver: upgrade to dual channel system, to improve the stability of amplitude and phase of receiver, and expand the dynamic range
5. digital instantaneous frequency: upgrade to four channels to augment the integration and lower the failure rate
6. signal processor: upgrade the Doppler algorithm to dual polarization signal processing algorithm, including identification and filtering of clutter, filtering of ocean clutter etc.
7. calibration system: upgrade with additional link calibration and method, improving the accuracy of echo intensity to 0.5 dB, the consistency of dual polarization amplitude is 0.2dB, the consistency of phase is 2°
8. meteorological radar software: expand to dual polarization data processing system, operating system is updated to Linux
9. **Resource requirements:**
10. Standards, quality control methods and product algorithms are desirable.
11. In the background of global weather radar data exchange, real-time calibration technology is needed to solve uniformity of the global weather radars data.

ANNEXES: **CMA’s recent progress in weather radar**

 **Submitted by Dr. LI, Bai**

**CMA’s recent progress in weather radar**

**1.1 Making out a new weather radar development plan**

 CMA has made out a new weather radar development plan by the end of 2016, which mainly includes:

* To further improve scientific layout of CMA weather radar network. CMA plans to increase new weather radars in high impact regions and key areas to enhance observation capability of boundary layer. As is known to all, China has very complex terrains. In addition, with the urbanization of many local cities in recent years, high buildings impose very serious beam blockage on existing weather radars, and hence clearance environment for radar observation is degraded dramatically. Moreover, from a operational perspective of weather radar network construction, in some high impact regions, existing radar network has very limited observation capability for boundary layer, so that many important weather systems such as tornado, low layer shear line, downburst, and so on are difficult to detect effectively.
* Radar dual polarization upgrade to enhance observation capability.

CMA plans to upgrade existing operational weather radar network gradually from 2017, including S-band and C-band weather radars. In the next five years, about 90 weather radars will be updated to the dual polarization weather radar.

* To establish regional test and measurement platform for weather radar to improve real time calibration ability.

CMA plans to build a few regional radar test and maintenance center to improve fault repair and calibration ability for weather radars. At present, CMA only conducts comprehensive test and calibration for each operational weather radar once each year, which is still not enough compared with Britain and Germany in European radar network. Under the background of WMO global weather radar data exchange, future radar data quality especially homogeneity and consistency is very important, which is a challenge to effective test and calibration for operational weather radar network.

* To establish integrated testbed for meteorological radars and advance continuous stable development of new radar technologies and hence provide valuable information for CIMO guide.

Under the framework of WMO global weather radar data exchange, it can be foreseen that more and more meteorological radar data (weather radar, dual polarization radar, millimeter wave cloud radar, wind profiler, lidar, etc.) will be put into operation and become important parts of global observation data. Therefore, more experimental and research work related with meteorological radar (precipitation radar, wind profiler, millimeter wave cloud radar, etc.) needs to be conducted. So CIMO needs to make out more standards, quality control methods and product algorithms. To establish integrated testbed will lay solid foundation for all of these.

* 1. **To conduct comprehensive examination of operational weather radar network so as to promote weather radar quality, which mainly includes:**
* To upgrade key components in radar system such as signal processor, klystron, frequency synthesizer and so on.
* To standardize data format, quality control methods and nodes and establish standard unified quality control system for operational weather radar network.
* To establish CMA weather radar metadata standards and metadata database.
* To build faster operational procedure for radar data transmission so as to satisfy requirement of short term forecast and nowcasting.
	1. **To update and improve real time monitoring ability of Atmospheric Observing System Operation and Monitoring (ASOM), and to establish national-level and provincial-level monitoring operational system for integrated observation network.**
	2. **To conduct experiment in dual polarization radar, cloud radar and lidar to promote application of new technology in operation.**

At present, CMA is deploying network experiment in cloud radar, lidar and wind profiler, as well as research and development in X-band networked radars and solid-state transmitter technology. CMA is now establishing weather radar observation modes suitable for China. For example, CMA has established high mountain observation mode for typhoon in coastal radar network to improve monitoring ability for offshore typhoons.

**1.5 To carry out bilateral and regional weather radar data exchange (incorporated into 3.1(1))**

Since 2012, the weather radar data have been exchanged between China and Korea. Korea through the Sino-ROK special bilateral line under the regulations of GTS. Radar data transmitted from China to South Korea contain 5 kinds of products from 6 radar sites including Yantai, Qingdao, Dalian, Yingkou, Tianjin and Shenyang. And radar products contain base reflectivity, composite reflectivity, velocity, vertical integrated liquid and one-hour precipitation. Radar data transmitted from South Korea to China include one product(CAPPI) from 10 radar sites. The exchange frequency is once per hour, while the requirement is 10 minutes.

At same time, radar data have been exchanged, in the past few years, by the MSTP special line between Guangzhou and Hong Kong on the basis of network requirement of WMO Information System (WIS) to the GISC responsibility zone.

Basedata of two radars (Guangzhou and Shenzhen) are offered by Guangdong Meteorological Bureau to Hong Kong Observatory, and the frequency of transmission is 6 minutes. Accordingly, HK Observatory also provides base data to Guangdong Meteorological Bureau and the frequency of transmission is 6 minutes, too. In addition, the mosaic of 10 radars (9 radars in Guangdong Province and 1 radar in HK) is made and sent in real-time to Hong Kong for the purpose of monitoring severe weather. In addition, a cooperation have been made between CMA and Macao meteorological agency , jointly to build the s-band dual polarization weather radar in Zhuhai and the radar data exchange also has been performed .

1. **Several proposals on IPET-OWR workplans**

 The present workplan is overally complete, but it is really a difficult task to finish all the items included in the workplan during 2016 to 2019 and it is a big challenge to the expert team. Therefore, to achieve the goal of the workplan , I put forward following proposals for reference.

* 1. Under the background of WMO global weather radar data exchange, establishing weather radar metadata standards and metadata database should be included as key tasks, because they are related with stable and reliable application of weather radar data in a very long time, and hence are fundamentals of all the application. In the workplan, this work should be discussed in detail. If necessary, an expert panel meeting can be held at some proper time, in which the key factors that affect weather radar base data should be summarized. For example, for CMA radars, there are multiple choices in notch filter width used for clutter suppression. If different notch filter widths are adopted, it will result in non-uniformity (inhomegenity) in radar network data.
	2. Operational calibration for weather radar should be included as an important quality control method in CIMO guide. With new technology entering weather radar network in various nations, different technologies will have an effect on basic elements in weather radar observation such as reflectivity, radial velocity and spectrum width. Especially the ongoing radar dual polarization upgrade in many countries will have more crucial influences on base data quality. Therefore, to establish effective test and calibration methods (including test nodes, test methods, calibration methods, test procedure, etc.) for various frequency band, technical mode and types of weather radars, is very important and necessary to ensure global weather radar data uniformity. This work should be summarized in detail in IPET-OWR workplan and can be operated in practice.
	3. Under the framework of WMO, choosing some places with good conditions to set up integrated testbed for meteorological radars and deploy experiment work related with IPET-OWR, is an effective and valuable information source for CIMO guide in future. In this aspect, the NSSL testbed operated by NOAA has provided valuable references for us. Besides, quantitative snow estimation experiment conducted in Japan has also achieved good progress, which sets a good example. Based on previous CIMO tasks and work progress finished by weather radar expert team, it is necessary to set up an IPET-OWR expert team, which can promote the completion of CIMO tasks effectively and positively. However, we also have to adimit that due to relative loose organizing structure and busy daily work of some experts, it is hard to ensure work progress in some CIMO tasks. Therefore, setting up a few integrated testbeds is helpful for conducting experiment work for weather radar regularly or irregularly, so as to promote the completion of tasks.
1. **Evolution of weather radar technologies**

The development of weather radar is in a stage of continuous emergence and rapid growth of new technologies, which mainly exhibits in the following aspects:

1. Key hardware makes great progress: To deal with the main problem disturbing the long-term stability and reliability of weather radar, high power transmitter is gradually transforming towards solid state transmitter. This makes it possible to operate a weather radar network in a highly reliable and stable condition. Not only the stability is greatly improved, but also the cost of operation and maintenance is greatly reduced.In particular, the rapid development of X-band solid state weather radar, will provide a feasibility for developing countries, especially those countries in urgent need of building weather radar network.
2. For the range and velocity ambiguity problem that always plaguesus, with the application of phase coding technology and dual-PRF technology, it provides a new way to solve the problem of range and velocity ambiguity, which has substantial improvement for quantitative application of radial velocity.
3. In the background of global weather radar data exchange, how to realize the real-time calibration technology and method of operational weather radar network is a problem that we must solve in the development of radar technology, which is an important way to ensure the global uniformity of weather radar data. We not only need to establish anoperational systemfor real-time effective monitoringof weather radar, but also consider quantitative test and real-time calibrationmethodsfor main radar technical parameters thataffect radar base data (base reflectivity, radial velocity and spectrum width).
4. The development of weather radar technology is transforming from traditional rain measurementtowardsobtaining various elements of the clear air, as well asacquiring the elements of the cloud development stage, precipitation stage and disaster generation stage. The observation technology for the whole weather process including the four stages of clear air—cloud—precipitation—disaster result is gradually formed.