A CASA-like Networked X-band Weather Radar System in Nanjing Area

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Abstract

Motivated by the CASA Dallas-Fort Worth (DFW) Urban Demonstration Network (Chandrasekar et al. 2013; Chen and Chandrasekar 2015), an X-band radar network is deployed in Nanjing area, China, to provide high-resolution observations for urban disaster mitigations. This CASA-like radar network consists of four X-band weather radars which are spaced approximately 40 km apart from each other. The network control center is located in Jiangning district of Nanjing, and the meteorological command is transferred through wireless network. Main research topics include multi-Doppler wind retrieval, quantitative precipitation estimation (QPE) and quantitative precipitation forecast (QPF). The existing remote sensors such as national weather service radar will also be used for creating multi-sensor based products. This paper will present an overview of the deployment of this radar network. The system's main control loop will be described in details, including the identification of the area of interesting (AOI) according to the end users' needs, transmission of the AOI information to the control center, as well as the determination of each radar's future scan strategy. In addition, recent field observations will be presented to demonstrate the capability of this network for urban weather hazards monitoring.

Index Terms--- X-band radar, Networked radar system, Collaborative Adaptive Sensing Mode

1. Introduction

Doppler weather radar is an important tool in modern comprehensive meteorological observation system, which can provide fundamental radar base data, observe the structure and velocity of horizontal wind field and vertical flow in the rain area, and measure the location, intensity, movement and evolution of precipitation (Chen and Chandrasekar 2015a; Willie et al. 2013; Zhang et al. 2014). Therefore, Doppler weather radar plays an essential role in the research on high-impact weather, short-term and imminent weather forecast and warning of meteorological disasters(Zhang et al., 2001; Yu et al., 2005; Liao et al., 2005; Chen and Chandrasekar, 2015b).

Weather radar network has good monitor for meso- and large-scale weather systems, and provides reliable observation data for weather forecasting(Chen et al. 2012). Relative to ten minutes to a few hours life history of strong convective weather, the 5~10 minutes scanning cycle of traditional weather radar is insufficient for analyzing and forecasting. Many hazardous weather phenomena occurred below 3 km above ground level, which are often undetected by the existing weather radar network because of the Earth's curvature, terrain blockages, and low resolution caused by radar beam broadening (McLaughlin et al. 2009). Each radar system may

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only detect 30% of the coverage below 1 km above ground level of the low troposphere because of long operating range. In order to overcome the coverage limitations inherent in long-range weather radar network, the concept of short-wavelength radar network was proposed by the U.S. National Science Foundation Engineering Research Center (NSF-ERC) for Collaborative Adaptive Sensing of the Atmosphere (CASA) (Chandrasekar and Jayasumana 2001; McLaughlin 2001; Mclaughlin et al. 2009; Junyent and Chandrasekar 2009; Junyent and Chandrasekar 2010). CASA’s first test bed of networked radar consisting four low-power, short-range, X-band, dual-polarization Doppler weather radars,was deployed in January and operated in April 2006 (Bharadwaj and Chandrasekar 2005; Brotzgeet al. 2005; Brewster et al. 2005). The test bed was advancedas a novel paradigm: distributed collaborative adaptive sensing (DCAS) (Chandrasekar et al. 2008; Brotzge et al.2010). The five-year high resolution radar observations, post-event analysis, and fundamental multi-disciplinary research during 2007–2011 operation had demonstrated success of the DCAS concepts (McLaughlin et al. 2009; Brotzge et al. 2010; Chandrasekar et al. 2012). Since 2012, CASA has embarked on the deployment of its first urban test bed in Dallas-Fort Worth (DFW) Metropex, in order to demonstrate the DCAS concept in an urban environment (Chandrasekar et al. 2013; Chen and Chandrasekar 2015b). The main research topics include but not limited to quantitative precipitation estimation (QPE) and forecasting (QPF), urban flooding and hydrologic modelling, hydrometeor identification and 3-D multi-Doppler wind retrieval (Chandrasekar et al., 2013). Research showed that the accuracy of small-scale hazardous weather forecasts is improved and forecast warning time is extended. The networked radar is certified feasible from technical and economic aspects and is helpful supplement to S/C-band weather radar network.

Motivated by CASA DFW urban demonstration network, the first local X-band radar network in China, composed of four X-band Doppler radars, was deployed in Nanjing in June 2014 by the Institute of Atmospheric Physics, Chinese Academy of Sciences, with partners of Nanjing NRIET Co. Ltd, China Electronics Technology Group Corporation, Chinese Academy of Meteorological Sciences and China Meteorological Administration (CMA) Meteorological Observation Center. Each of the radar adopts a new approach of self-adaptive sensing for scanning, with the expectation to obtaining accurate observations of high spatial and temporal resolution for area of interest.

The paper is organized as follows. A description of the CASA-like test bed in Nanjing area will be presented in section 2. Section 3 details the new approach of self-adaptive sensing for radar scanning, including the method to identify area of interest (AOI), scanning options for self-adaptive sensing, and statistical running time for the different scanning options. The cases studies are examined in section 4. Section 5 presents the opportunities and challenges for networked radar to the operation.

2. Networked Radar System in Nanjing Area

The networked radar system is composed of four X-band Doppler weather radars and spaced nearly 40 km apart, each radar has a maximum detection range of 60 km, which is fit for the optimization calculation to getting the maximum overlap area. Fig. 1 is a depiction of the networked radar system. Radars, which are marked with small red circles, are located in the towns of Jurong (short for JR), Lukou (short for LK), Gupinggang (short for GPG) and Yizheng (short for YZ) around Nanjing area. In addition, the networked radar locates in the overlapping area of the existing CINRAD radars, such as S-band radar in Longwangshan (short for LWS), Changzhou (short for CZ) and C-band radar in Ma’anshan(short for MAS). The total coverage is

22607.85km^2, the overlapping area of two-radar is 13025.30 km^2, 57.6% of the total coverage, and the overlapping area of three-radar is 6103.38 km^2, 27% of the total coverage, the overlapping area of four-radar is 3502.40 km^2, 15.5% of the total coverage. From the indications of overlapping area, we believe we can obtain more information about weather process in the low atmosphere. The control center of the networked radar locates in Jiangning district of Nanjing, and the meteorological command is transferred through wireless network.

3. Collaborative Adaptive Sensing Mode

The overall system's control architecture is divided into two consecutive parts: self-adaptive sensing for each radar and collaborative sensing for the networked radar system. In the first part, We mainly utilized the characteristics of reflectivity of PPI at elevation of 2.3° after quality control to determine the priority of AOIs, including the maximum reflectivity, the mean reflectivity, the area and the variation of three before-mentioned variables. The information is transferred to the control center for the consecutive part, tasks are generated and networked radar accomplished collaborative sensing on fixed scanning mode.

3.1 Self-Adaptive Sensing Mode

At the beginning of self-adaptive sensing mode, the radar completes a 360° scanning at the elevation angle of 2.3°, which provides temporal continuity to the data and situational awareness across the entire domain. Then the data flow to what is called the Meteorological Command and Control (MC&C) module, which ingests data as input from the sensing components, applies quality control (QC) on that data, and invokes detection methods on that data to identify the AOIs mainly based on the characteristics of reflectivity. Finally, task is generated to determine the angular sector and elevations scanning mode for the radar.

In the MC&C module, the process has been broken down into a series of steps:

I) The PPI data at 2.3° is deal with median filtering for QC firstly;

II) AOIs are selected through threshold (default value 35dBz, varying with seasons) and isolated points are avoid;

III) AOI's border is determined by the radial-azimuth positioning method and the area is calculated by ellipse method;

IV) Information of AOIs is calculated and stored, including the maximum reflectivity, the mean reflectivity, the area and the variation of three before-mentioned variables, range-azimuth information of AOIs' centroid is also inclusive;

V) The AOI priority is determined by the value of these information through modest arithmetic operation after normalization incorporation with users' concern;

VI) AOI with the maximum value is selected and the azimuthal scanning is determined by its horizontal dimension.

3.2 Collaborative Sensing Mode

Information of AOIs from different radars and meteorological command for self-adaptive sensing mode is transferred to the control center, AOI order is rearranged according to the calculated value. AOI with the maximum value is selected, corresponding location to each radar is calculated combining its centroid and border information, for simplification the shape of AOI is equivalent to circle. So the scanning strategy for each radar is depend on the radius of the circle (r), the distance to the radar (D) and the detection range of radar (R). If D is large than R, the radar will complete scanning strategy generated by the self-adaptive sensing. In other cases horizontal dimension is depend on the radio of r to D, which is primary factor for the generation of scanning strategy. Task generation processing time based on the priority of AOI is about 0.68s as shown in Fig 2. The MC&C process assigns sampling strategy to this AOI for collaborative sensing.

3.3 Sector Scanning Mode

Scanning Mode mainly depends on the horizontal dimension and scanning layers, which can be convertible. Sector scans were fixed to three modes: Mode I was made from the lowest elevation to the highest, starting at 1° elevation, followed by 3°, 5°, 7°, 9°, 11°, and 14°elevations (Fig. 3a); Mode II was wider sector scans, and fewer sector scans were completed (e.g., Fig. 3b), including 1°, 3°,5°,and 7°elevations; Mode III was fit for minimal significant reflectivity or when stratiform rain covered the domain, two 360°surveillance scans were performed by each radar at the lowest two elevation angles (Fig. 3c). Task generation processing time is about 0.68s, and scanning mode consuming time is about 60s, so the whole process can be achieved within 1.5min.

4. Cases Study

In the early morning of 27 Nov.2014, effected by enhanced warm air, a squall line evolved and moved southwest to northeast in Nanjing area. The squall line is a front part of precipitation system and composed of four main small cells. At 01:00UTC the squall line entered into the observation area of LK radar, heavy rainfall was observed in the Metroplex around 01:30-02:30UTC. An example of self-adaptive sensing technique, as shown in Fig. 4, demonstrates the ability to collect one 360° azimuthal scan (at 2.3°elevation) and up to seven 60°azimuth sector scans, all within a 1.5-mins time frame. A series of images from the LWS radar sites, collected between 01:32 and 01:38 UTC, indicated that the squall line was rapidly developing. During this period, the 1.5-mins surveillance scans showed more formation in the reflectivity (Fig. 5). Network reflectivity composite data showing the passage of a cluster of rain cells at 2.3 deg in Fig. 6. (GPG radar didn't work).

5. Discussion and Conclusions

An X-band radar network has been deployed in Nanjing area, China, which utilizes a distributed, collaborative, and dynamically adaptive and data-driven approach for atmospheric sensing. In consideration of wireless network communication and radar rotation speed, the overall system's control architecture is divided into two consecutive parts: self-adaptive sensing for each radar and collaborative sensing for the networked radar system. With this system, new research methods for feature detection, tracking, and anticipation are expected to be developed and demonstrated. By integrating the needs of the end-users in the planning, design and real-time scan optimization, it is expected that such a network will be used by private and public stakeholders.

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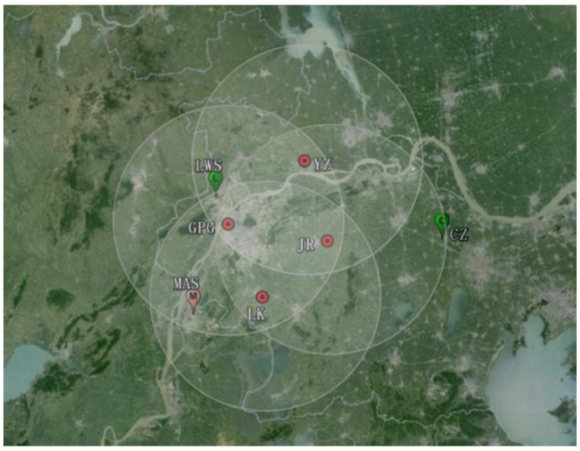

Total coverage	22607.85 km^2	
Two-radar overlap	13025.30 km^2	57.6%
Three-radar overlap	6103.38 km^2	27%
Four-radar overlap	3502.40 km^2	15.5%

Fig. 1 Distribution and characteristics of networked radar system and in Nanjing Area

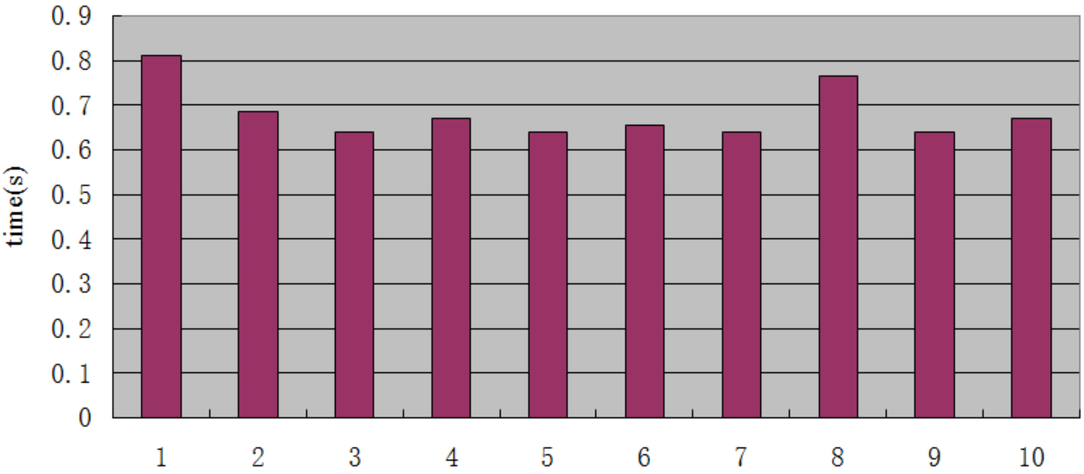

Fig. 2. Task generation processing time for collaborative adaptive sensing mode

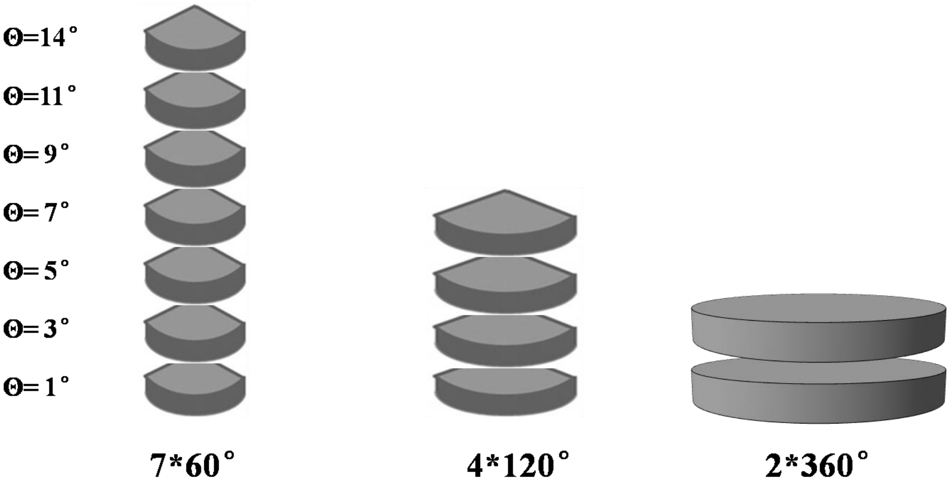

Fig. 3. Adaptive scanning used by networked radar. Adaptive scanning options include (a) narrowsector scanning, (b) wide sector scanning, and (c) low-level 360°surveillance scanning. Eachoption is completed about 65 s. The full 360°scan requires approximately 30 s to complete.

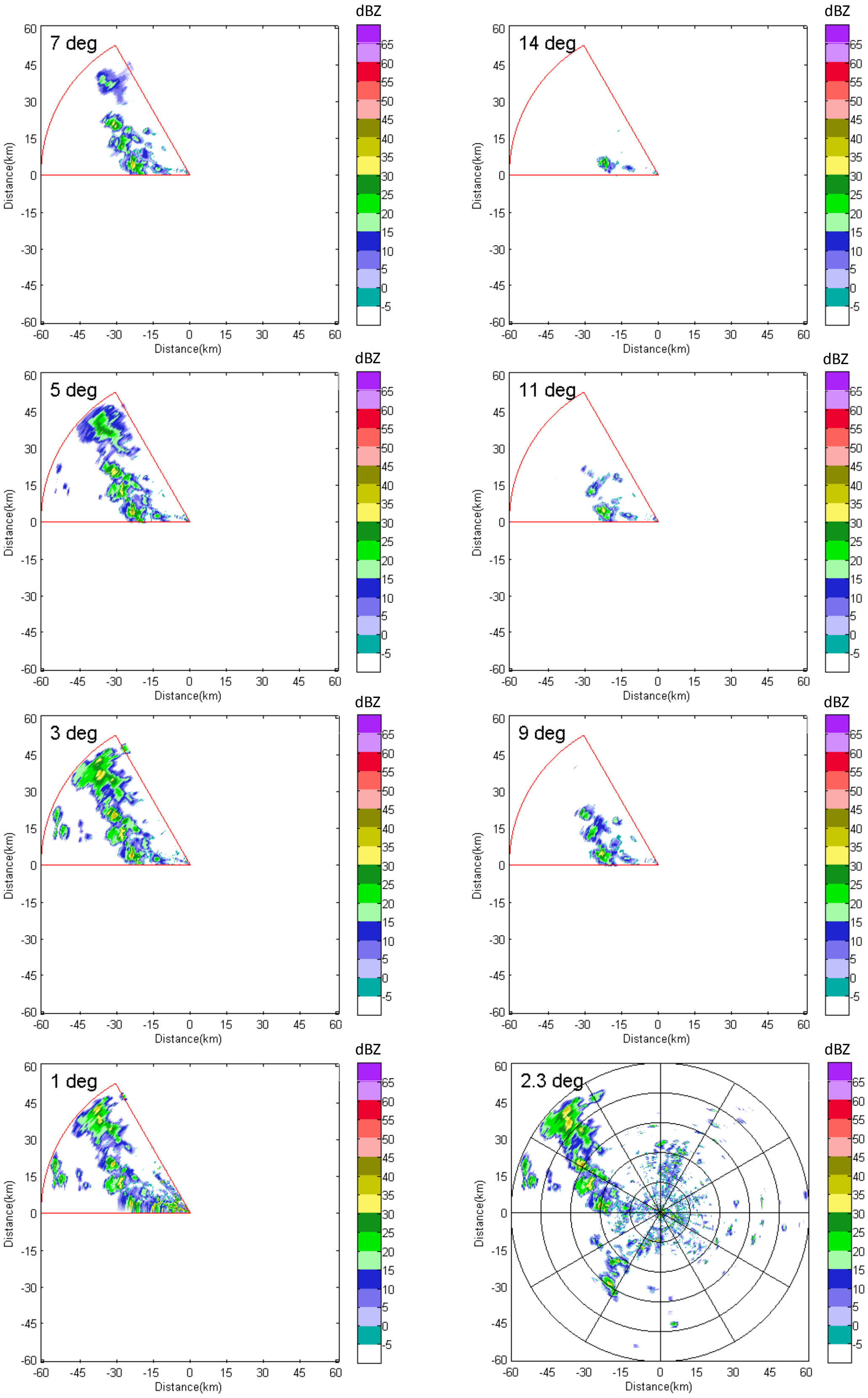

Fig. 4. The adaptive sector scanning capabilities as demonstrated by sensing the 27 Nov. 2014 storm near Lukou. Reflectivity data collected at 1°, 3°, 5°, 7°, 9°, 11°, and 14° elevations at times 01:32:24 UTC.

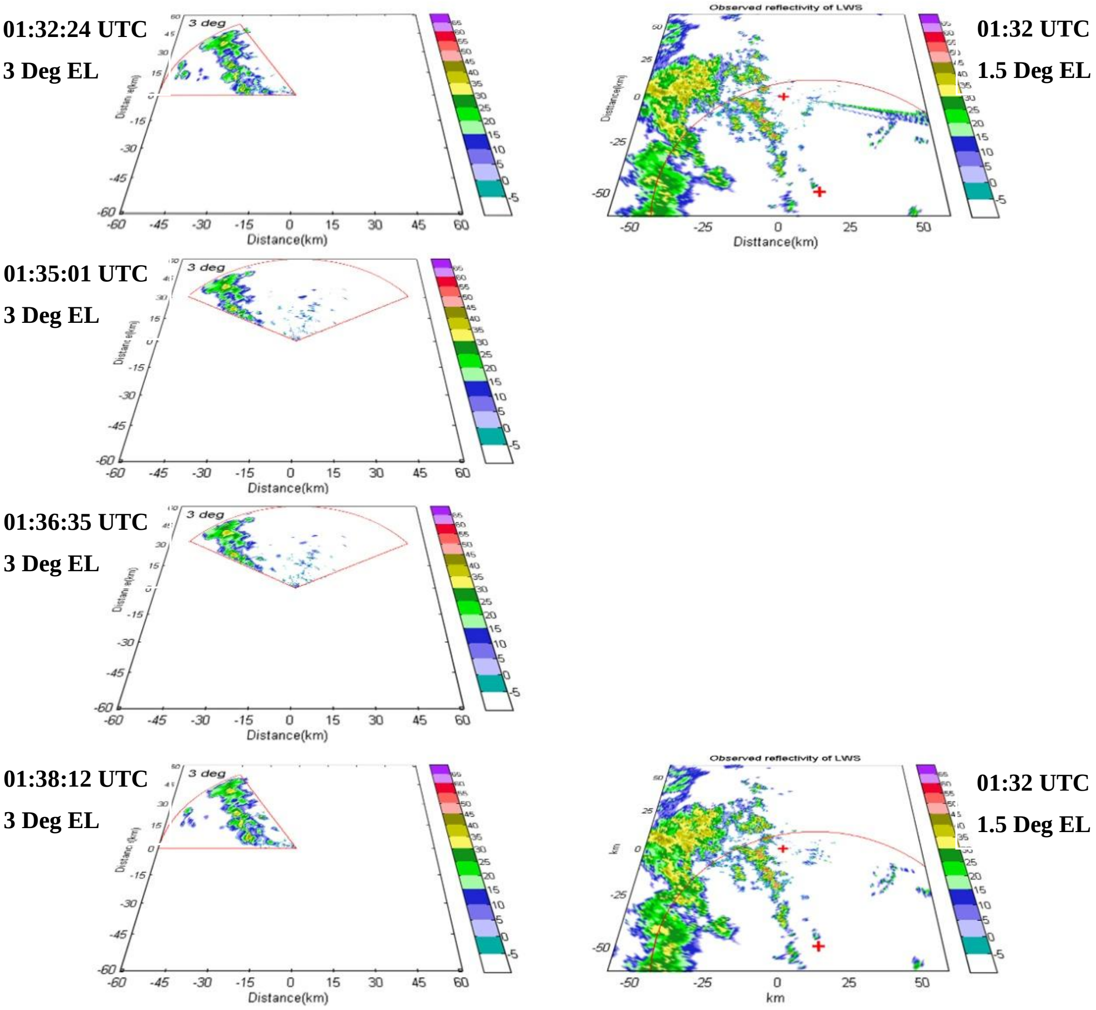

Fig. 5. Radar data collected 27 Nov. 2014. (left) The self-adaptive radar reflectivity at elevation of 3 deg with 1.5-min refresh rates. (right) As in the left panel but for the corresponding CINRAD data with coarser spatial resolution and at a 6-min update cycle.

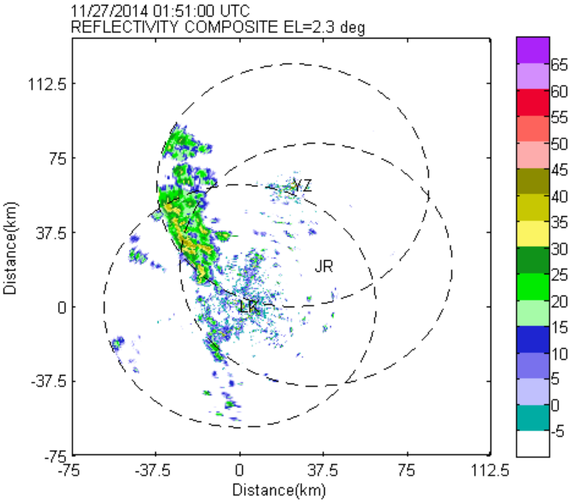

Fig. 6. Network reflectivity composite data showing the passage of a cluster of rain cells at 2.3 deg. Radar data were collected at 01:51:00 UTC 27 Nov. 2014 (GPG radar didn't work).