10.2

THE METHOD OF FOREST FIRES RECOGNITION BY USING DOPPLER WEATHER RADAR

Kehui Huang * and J. Zhong, J. Zhu, X. Zhang, F. Zhao, H. Xie, F. Gu, B. Zhou, and M. Wu
Wenzhou Meteorological Bureau, Wenzhou City, Zhejiang Province, China

1. INTRODUCTION

Doppler weather radar can detect smoke plume, which emitted by forest fires. This new function of radar can contribute to detect forest fires in time. But the echoes of fires can not be found easily in PUP products, the main operation interface of the radar products. In order to detect fires echoes in time, a new method of recognition is needed and proposed.

In earlier 2007, the CINRAD-SA (China Next Generation Doppler Weather Radar) radar which located at the top of Daluoshan Mountain, Wenzhou City, southeast of China mainland, detected dozens of forest fires events. The ability of fires detection by radar was verified by several reports on forest and industrial fires too (Banta and Olivier 1992, Rogers and Brown 1997, Hufford and Kelly 1998).

These fires cases show the potential effective application in forest fires detection by using Doppler weather radar. There're some good applications on forest fires detection by using Lidar, which make use of the same principles as the weather radar, both regarding smoke plume as the back-scatter particles. Some reports (Fernandes Armando 2006, Andrei B. Utkin 2003) show that the lidar's valid detection ranges are only about 6.5 to 23km, varied by weather conditions. Compared to lidar, the effective detection range of weather radar reached as far as 110km, almost 5 times as the lidar.

The fires detection by Doppler weather radar has obvious advantages over other traditional methods. Firstly, the radar has high sensitivity in fires detection, which can detect some small size class forest fires that satellites can not detect. The smallest forest fires case which detected by radar, only burned 1ha in 2007. Secondly, the radar finish volume scan in every 6min, that means, radar can detect 240 times a day, which is more frequently than polar-orbiting satellite. Thirdly, the range of fires detection reaches as far as 110km, which means the radar can monitor more area of forest than the fire watchtower or video monitoring. Finally, without doubt, Doppler weather radar detection need no invest in hardware additionally. Therefore, the utility of the radar fires detection will benefit the forest fires protection. But till now, it seems that, there is no further research about how to realize the more effective and cheaper solution in forest fires detection by Doppler weather radar.

In this paper we present the facts of radar fires detection in Section 2, the characteristics of fires echoes on base reflectivity, velocity and spectrum width (SW), the groundwork for recognition in Sect.3, and then putting forward preliminary measures for how to realize the process of recognition in Sect.4.

2. FACTS OF RADAR FIRES DETECTION

From 2007 to 2009, more than dozens of forest fires cases, which confirmed by local Department of Forestry and Fire Protection, were detected by CINRAD-SA. Fig.1 is base reflectivity and corresponding radial velocity products at 0.5° elevation angle of 12 cases of forest fires events, which took place at different time and different places. As the figures show, it seems that the echoes of fires are so strong, that can be easily seen directly.

Fig.2 is the echoes of an ordinary fires event and clear-air conditions, at normal view (upper a and b) and by local amplification (below c and d) respectively, centered at the red circle. They show no much more differences between the upper two images (a and b, fires cases and clear-air conditions). After local amplification, the fires echoes are shown up in Fig. 2 c. The figures reveal that the fires echoes can not be easily found in PUP without zooming in, but they do have some obvious characteristics which can be distinguish from the background, even from the

* Corresponding Author address: Kehui Huang,
Qixiangju, No.1, Henghenan xincun, Wenzhou City, P.R.China, 325027
e-mail: khhuang@163.com

rain or clutter echoes.

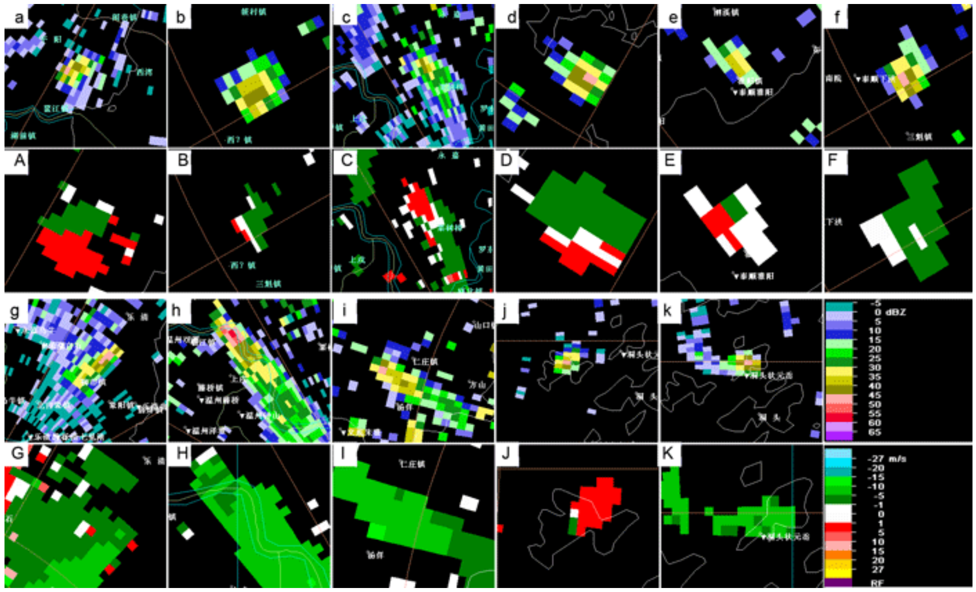

Fig. 1 The Base Reflectivity (in Low case From a to k) and corresponding Radial Velocity (in Capital From A to K) of Forest Fires Cases

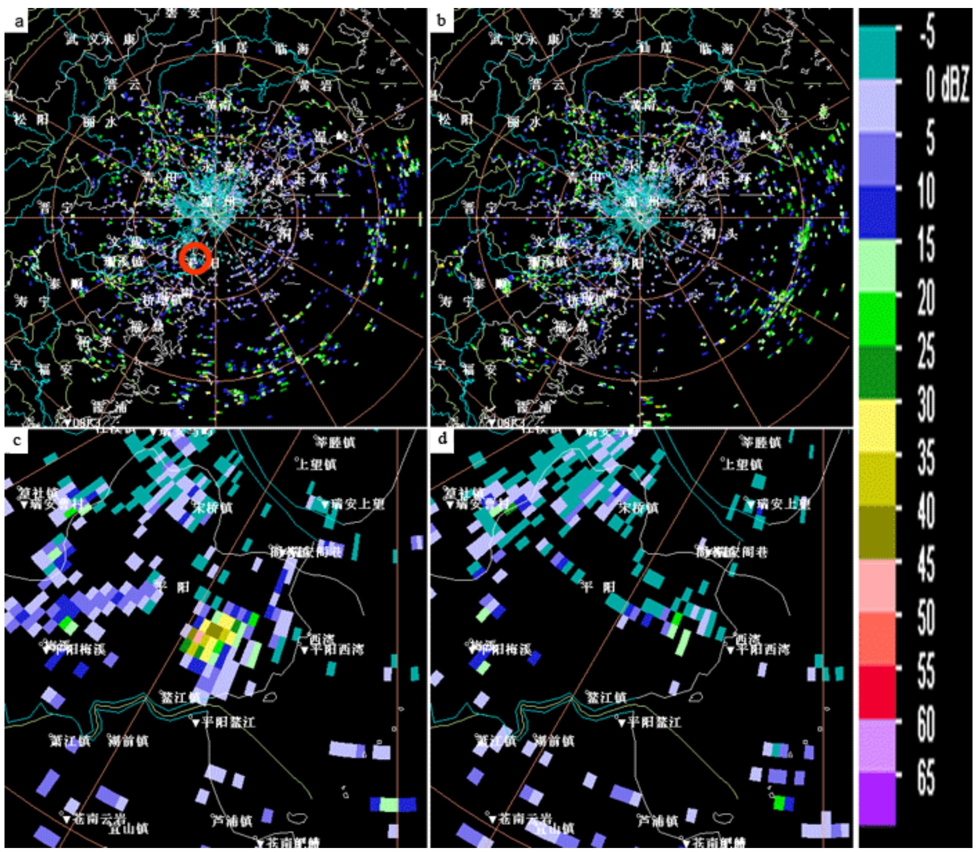

Fig. 2 Echoes of an ordinary fires event and clear-air conditions, at normal view (upper a and b) and by local amplification (below c and d) respectively, centered at the red circle

3. THE METHOD AND CRITERIONS OF RECOGNITION

In this section, we will present the characteristics of fires echoes and the criterions of recognition in base reflectivity, velocity and spectrum width (SW), which is the foundation of the recognition process.

3.1 *Base Reflectivity*

The base reflectivity, containing more useful and less useless information of fires echoes， is considered at first. The altitude of echoes can be gotten at different tilts, which can make it possible to distinguish fires echoes from others. As to composite reflectivity, which is commonly applied in weather operation, yet is not a better choice for fires detection? Because it contains maximum value of reflectivity from all levels, that may also have all kinds of echoes such as precipitation and cluster echoes in it, as well as lack of altitude information, will confuse the fires signal and increase the difficulty of recognition.

3.11 *Height and Range*

To recognize the fires echoes, the first factor take into account is the valid height and range wich which radar can detect. The valid range is mainly based on the top height of the smoke plume which can generate radar echoes. In these fires cases, echoes can only reach about 2.5km above the sea level, the same height reported by Rogers (R.R. Rogers 1997) ,which is one of the most important criterions for fires recognition. Obviously, the height of fires echoes is significant lower than that of most clutters and precipitation ones, the latter which usually reach as high as 4-5km to stratiform precipitation and even more than 10 km to convective precipitation.

Figure 3 is the range vs. height from radar beam height equation, according to the preset elevation angles of operational VCPs. Based on the height the smoke reaches, the echoes can not be distinguished from others until the following condition should meet, that is the elevation angles must exist, where the altitude is low than 2.5km at low tilts while greater than 2.5km at higher tilts at given range. In another word, radar beam must pass through the fires plume, and pass through over the plume; otherwise, we will not know what the echoes are. The R_{min} and R_{max} is the minimum and maximum fires detection range in theory. The valid ranges are from R_{min} to R_{max} which can meet the above-mentioned condition. For instance, at the range of 120km, which beyond the R_{max}, the lowest detection height is already exceeding 2.5km at the lowest tilt of 0.5°, where there will be no enough smoke plume that can generate fires echoes.

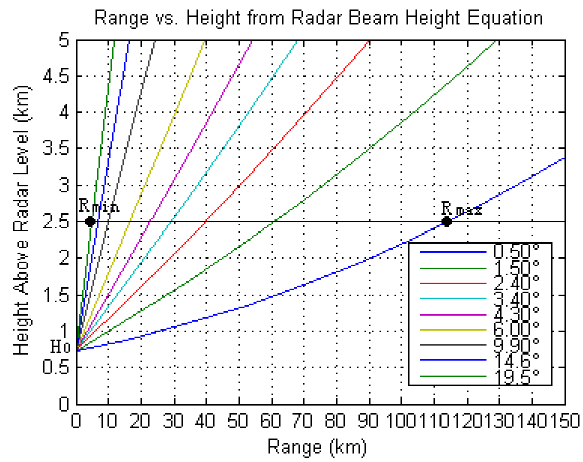

Fig. 3 Range vs. Height from Radar Beam Height Equation

Note: h_0 is the radar location at 734.7m above the sea level, with 9 preset elevation angles detection

3.12 *Intensity (structure texture)*

Another factor is the reflectivity intensity the fires produced. Cases study show that the fires echoes usually range from 20 to 48dBZ, in most cases, vary between 30-40dBZ. The strongest echoes can reach 58bBZ in extreme case, which took place under a cold air weather condition at Qiaoxia Town, Yongjia County, burnt about 90ha forest.

In PPI views of the fires, the texture structure usually shows a slightly stronger echo in the center near the fires spot， accompany slightly weaker echo in the vicinity. The vertical difference of the reflectivity is larger than precipitation; the echoes intensity center concentrates at the low altitude. Above the intensity center, the higher in altitude the weaker in intensity, when the altitude is higher above 2.5 km, the echoes usually less than 20dBZ. In another word, the value of vertical difference of the reflectivity is very large.

3.13 *Area*

The area of echoes is another key criterion in recognition. Small forest fires can generate large mount of smoke plume, thus the area of echoes will be several to hundreds pixels in continuance varied by the fires scale, where one pixel corresponding to one square kilometer. The area of fires echoes is usually greater than a threshold (default is 3×3 pixels), however, the area of noise or clutter echoes is seldom greater than that threshold value, which intensity is greater than 20dBZ.

3.14 *Movement*

The movement of the fires echoes relates to the environmental wind speed. In case of under low wind speed environment, the echoes center (maximum value) remains stable, less dynamic. While under high wind speed, the echoes center remain stable relatively, the echoes area extend toward the downwind, the spreading speed depends on the wind speed. After the smoke plume beyond the range and height in horizon and altitude of radar detection, the echoes will become relative stable.

By contrast to fires, precipitation has the property of good mobility, which echoes center moves fast or slowly in most cases.

3.2 ***Base Velocity***

In base velocity (radial velocity), velocity value block exists near the fires spot while fires take place. Under low wind speed, a block structure of low velocity value appears which has the continuity in azimuth directions and angles. In most cases, a divergence velocity couplet presents during its developed stages, which indicates the divergence over the fire spots (See Fig.1 A,B,C,D,E,G and J). Compared to fires, the velocity value of clutter is at or near zero, or a few irregular singularities, in another word, it has uncontinuity in velocity value.

3.3 ***Base Spectrum Width***

Base spectrum width (SW) is a measure of velocity dispersion within the radar sample volume. The primary use of this product is to estimate turbulence associated with mesocyclones and boundaries. In most cases, fires have a narrow SW which shares the same with clutter, but the SW of fires has continuity in horizontal distribution and intensity. While on the contrary, the SW of clutter has no continuality in space and intensity, the value may jump from 0 to more than 20m/s in very vicinity.

The use of SW data has been limited compared to reflectivity and Doppler velocity fields. This is due in part to the difficulty in relating to meteorologically significant phenomena (e.g., turbulence hazards to safe flight), and in part to the fact that the values are easily corrupted values are easily corrupted and thus spectrum widths are less reliable and more risky to interpret (M Fang et al. 2004). Under high wind speed, the SW seems have no differences with others. This SW can act as supplement to recognize the fires echoes, when the wind speed is low.

4. PROCEDURES OF RECOGNITION

The overview of flowchart on forest fires recognition is shown in figure 3, detailed descriptions of each step are given as the following.

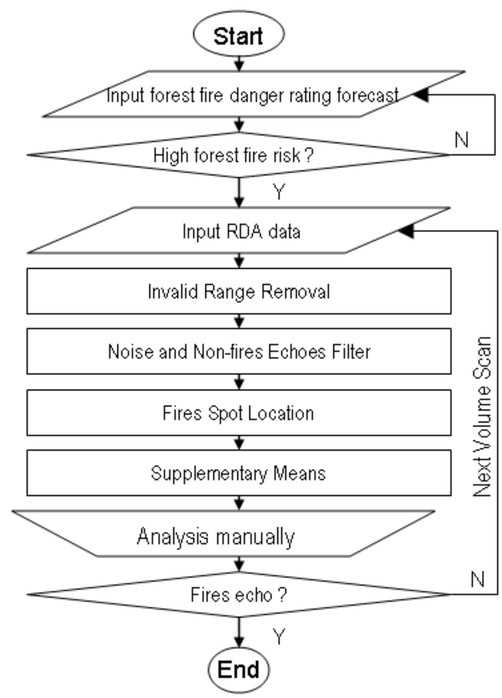

Fig.4 Flowchart of the Procedures of Forest Fires Recognition

4.1 ***Precondition***

Forest fires tend to take place in high risk of forest fires weather conditions, according to the investigation. In weather condition of high risk of fires, seldom precipitation echoes will occur in radar screen. The Forest Fire Danger Rating

Forecast issued by local weather forecast office will be taken into account at first as a precondition, when there will be high fires risk, the recognition of forest fires will be executed.

4.2 *Invalid Range Removal*

As described in Sect.3.11, the valid recognition ranges of fires are nearly from 10 to 110km away from radar location in horizon. In order to focus on the recognizable area of fires echoes and to reduce the unnecessary computing at the same time, in this step, the invalid echoes including the reflectivity, velocity and SW values for fires range from 0 to10km and more than 110km will be removed. Note that at a given range location in horizon, different tilts correspond different ranges.

4.3 *Noise and Non-fires Echoes Filter*

Before the non-fires echoes filter, a simple filter is applied to remove isolated reflectivity points or lines. In order to distinguish the fires echoes from others, two catalogues of echoes need to be removed, the precipitation and the clutter echoes.

4.31 *Precipitation filter*

Most convective precipitation and many stratiform precipitations have tops more than 4km above the ground level, while fires echoes lower than 2.5km in altitude, as mentioned above. It's easy to distinguish the precipitation echoes from fires according to their different heights. The method is that, consider the height of the echo at given intensity (default is 20dBZ), where its height exceeding 2.5 will be considered as non-fires echo, and the value of reflectivity, velocity and SW will be replaced by a missing flag in all tilts.

Movement is a sufficient and unnecessary condition to precipitation echoes. If the echoes center moves fast between two volume scans, they will be considered as precipitation echoes, then the value of reflectivity, velocity and SW will be replaced by a missing flag in all tilts.

4.32 *Noise filter and clutter filter*

After the precipitation filter, only the signals of noise, clutter and possible fires echoes exist. The clutter echoes such as those which associated with biological targets are usually contain small horizontal scale in reflectivity fields. Abnormal propagation (AP), which occurred under special atmospheric conditions, where radar beams propagate in a path that bends downward toward the earth's surface, are usually having little continuity in azimuth directions and angles, while the fires usually have the continuity in them. Moreover, in most cases, the intensity of ground or sea clutter usually is weak than a threshold (default is 20dBZ) at 0.5 ° elevation angle, while fires have a greater value at the same tilt. Therefore an area of reflectivity at a given threshold and neighborhood continuity check at 0.5 ° elevation angle can help identify and remove some noises, ground or sea clutters and AP echoes.

A simple filter is applied to remove the noise and the clutter echoes (Jian Zhang, et al. 2004), while remain the fires-like echoes. For any given reflectivity bin, X , at the lowest elevation angle of 0.5 ° , the number (N) of non-missing reflectivity observations is counted in a box of 3×3 , 5×5 or 7×7 (default is 3×3) bins that is centered at the given bin. The percentage (P_X) of non-missing values in the box is then calculated by:

$$P_X = N / N_{total}$$

Here N is the total number which reflectivity value is greater than a threshold value (default is 20dBZ), N_{total} (=9) represents the total number of bins (3×3) in the box. If the P_X is less than a threshold (default is 8/9), then the pixel X is considered non-fires echoes and will be removed, the velocity and SW value will be also removed at the same area.

After noise filter, the precipitation, some ground clutter echoes and isolated reflectivity points or lines are removed, while the possible echoes of fires remained.

4.33 *Velocity and spectrum width detection*

As stated in Sect.3.2 and 3.3, the fires have non-zero velocity value which has the property of continuity at low elevation angle of 0.5°in distribution and intensity, while the clutter is usually at or near zero velocity with the property of discontinuity. As for SW, fires also have non-zero SW value and the property of continuity both in distribution and intensity.

In this session, the schedule similar as the

Sect.4.32 will be applied to check the continuity of velocity and SW value both in distribution and intensity. Here N is the total number which velocity value or SW value is less than a threshold value (default is 15m/s to velocity, 5m/s to SW), N_{total} (=9) represents the total number of bins (3× 3) in the box. If the P_X is less than a threshold (default is 8/9), that means the continuity is poor in azimuth angles, then the pixel X is considered an non-fires echoes and will be removed, as well as the reflectivity value. This procedure will remove most of clutters.

Fires velocity couplet means that in a given area, different sign of velocity vector exists near the fires spot, while clutter's velocity vector will be the same as the environmental wind vector which usually has the same sign of wind vector. The sign check of the velocity is computed as the inequation below, sum the value of velocity with sign and absolute value respectively. If the sum of the velocity with sign is less than the absolute one, that means the different sign of velocity vector exists, which indicates the existence of the velocity couplet, in another word, it's very likely a fires event.

$$\sum_{j=1}^{ngates} \sum_{i=1}^{nrays} V_{i,j} < \sum_{j=1}^{ngates} \sum_{i=1}^{nrays} |V_{i,j}|$$

Here i and j are indices of reflectivity bins in azimuth and range directions respectively. V is the velocity value with sign, while $|V|$ is the absolute value of velocity; $nrays$ and $ngates$ are number of bins in a box centered at the given bin.

4.4 *Fires Spot Location*

Till now, most non-fires echoes removed and nearly only fires-like echoes remained if possible. Once the fires-like echoes were caught, the fires spot need to be located. The first step of this procedure is to find out the fires spot, which is a point of geographical coordinate. The maximum value of the reflectivity can be considered as the fires spot location, if there are several pixels with the same maximum value, take the geometric gravity center of the pixels as the spot. Read out the latitude and longitude value. The point of "fires spot" may drift several kilometers away from the real fires spot due to the action of the environmental wind. In order to decrease the inaccuracy of fires spot, an area of a circle will be drawn, taking the point of latitude and longitude as center, at a given threshold (default 5km) in radius, which indicate the approximately extent of fires spot. The given area of circle will be regarded as the fires-like spot.

4.5 *Supplementary Means*

Polar-orbiting satellite is one of the most important measures in fires detection; satellite can find fires-like spot, but can not confirm some small fires. If there is fires-like spot in satellite image, at the same time and same area, that will help to confirm the fires.

The meso-scale automatic weather station (AWS) can help to recognize whether there is a fires event or just precipitation near the fires-like echoes. If the AWS shows rainfall near the extent of fires-like echoes, that explain it is not a fires echo but precipitation one, while there is no rainfall, it's very likely a fires event.

The Geographic Information System (GIS) will be applied help to distinguish the possible forest fires from other fires, according to the GIS information, where there are information about the distributions of topography, forest, villages and towns, industrial zones, rivers and roads. Based on GIS, the fires category will be known approximately, as well as the village and town's place name of fires spot.

After recognition, an alarm will be issued; a conformation of whether there is a forest fires event or not, will be investigated and carried manually at last.

5. SUMMARY AND DISCUSSION

The paper described the main characteristics of forest fires echoes, according to the characteristics a preliminary method of recognition was proposed, which is mainly derived from the PUP products of Wenzhou radar station specifically. The characteristics of echoes, such as the height of fires and precipitations, ground or sea clutter and so on, may varied by altitude and latitude or topography.

The relationship between the fires size class, fires intensity and the echoes intensity is not so clear, as well as the ignition time and the radar first detection time.

The procedure of fires recognition has not been examined by computer program. Since the forest fires are small probability event to radar detection, in order to void misjudge of fires, the threshold values need to be adjusted.

Acknowledgements

Sponsored by Science and Technology Bureau of Wenzhou City, Grant No.S20080012.

References

Andrei B. Utkin, Armando Fernandes, Fernando Simons, Alexander Lavrov and Rui Vilar., 2003: Feasibility of forest-fire smoke detection using lidar International Journal of Wildland Fire.,12:159 - 166

FERNANDES Armando M, UTKIN Andrei B, LAVROV Alexander V, VILAR Rui M., 2006: Optimization of location and number of lidar apparatuses for early forest fire detection in hilly terrain., Fire Safety Journal ., 41: 144-154

Gary L.Hufford, H.Lee Kelley, William Sparkman, and Raymond K. Moore., 1998: Use of Real-Time Multisatellite and Radar Data to Support Forest Fire Management .Weather and Forecasting.,13:592-605.

J Zhang., 2004: WSR-88D reflectivity quality control using horizontal and vertical reflectivity structure. 11th Conferences on Aviation, Range, and Aerospace.

Kessinger, C., S. Ellis, and J. Van Andel, 2003: The radar echo classifier: A fuzzy logic algorithm for the WSR-88D. Preprints-CD, 3rd Conference on Artificial Applications to the Environmental Science,

American Meteorological Society, Long Beach, CA, 9-13 February 2003.

M Fang, RJ Doviak, V Melnikov., 2004: Spectrum Width Measured by WSR-88D: Error Sources and Statistics of Various Weather Phenomena. Journal of Atmospheric and Oceanic Technology, 21, 888-904.

R.M. Banta, L.D. Olivier, E.T. Holloway, R.A. Kropfli, B.W. Bartram, R.E. Cupp, and M.J. Post 1992: Smoke-Column Observations from Two Forest Fires Using Doppler Lidar and Doppler Radar .Journal of Applied Meteorology. 31:1328-1349.

R. R. Rogers and W. O. J. Brown., 1997: Radar Observations of a Major Industrial Fire .Bulletin of the American Meteorological Society.,78:803-814.