Vol.14 No.2 JOURNAL OF TROPICAL METEOROLOGY December 2008

Article ID: 1006-8775(2008) 02-0109-04

A STUDY ON VARIABLE QUANTITATIVE PRECIPITATION ESTIMATION USING DOPPLER RADAR DATA

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Abstract: With the pros and cons of the traditional optimization and probability pairing methods thoroughly considered, an improved optimal pairing window probability technique is developed using a dynamic relationship between the base reflectivity Z observed by radar and real time precipitation I by rain gauge. Then, the Doppler radar observations of base reflectivity for typhoons Haitang and Matsa in Wenzhou are employed to establish various Z-I relationships, which are subsequently used to estimate hourly precipitation of the two typhoons. Such estimations are calibrated by variational techniques. The results show that there exist significant differences in the Z-I relationships for the typhoons, leading to different typhoon precipitation efficiencies. The typhoon precipitation estimated by applying radar base reflectivity is capable of exhibiting clearly the spiral rain belts and mesoscale cells, and well matches the observed rainfall. Error statistical analyses indicate that the estimated typhoon precipitation is better with variational calibration than the one without. The variational calibration technique is able to maintain the characteristics of the distribution of radar-estimated typhoon precipitation, and to significantly reduce the error of the estimated precipitation in comparison with the observed rainfall.

Key words: typhoon; radar quantitative precipitation estimation; variational calibration; verification

CLC number: P458.1.24 **Document code:** A

1 INTRODUCTION

The use of Doppler techniques in weather radars has greatly improved the detecting ability of the latter. Apart from capturing information like echo intensity available with conventional weather radars, Doppler radars can also pick up radial velocity and spectral width. It can also perform effective monitoring of severe storms within its measuring range and quantitative estimation of precipitation and other information. With the development of new methods and techniques concerning radar remote sensing, observations of higher spatial and temporal resolution and with more parameters will be available for the monitoring and research of mesoscale weather processes (Liu et al.[1]). Finger-echoes and mesoscale cyclones are observed by radar when a supercell is at its maximum (Hu et al.[2]). With continuous Doppler observations of 36 weather processes with convective clouds in summertime, the features of convective cloud echoes and variations of their structures are studied and summarized by Li et al.[3]. It is apparent that the Doppler radar has become an important means for the monitoring, forecasting and pre-warning of abrupt and destructive weather, for it offers the advantages of high detecting power and automation.

At present, much work both at home and abroad has been done in quantitative estimation of rainfall using just the data of elevation angle of the Doppler, mainly focusing on the precipitation brought about by stratiform and convective clouds. As the Z-I relationship available with the radar itself, where $Z=A\times I^b$, Z is the reflectivity factor, I the hourly rainfall and A and B the empirical coefficients, gives hourly precipitation that usually differs much from the observation, various approaches have been tried to seek

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Received date: 2007-06-28; **revised date:** 2008-08-08

Foundation item: Key Project of Social Development in Zhejiang Province (2006C13025, 2007C13G1610002)

Biography: JI Chun-xiao, female, senior engineer, mainly undertaking numerical weather prediction and application of radar data.

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solutions to the coefficients *A* and *b* in the *Z-I* relationship. Following the definition of the relationship, observed data of raindrop spectra have been used to determine it (Zhang et al.[4]) while comparisons have been made between radar-measured *Z* values and rain rates recorded with corresponding surface rain gauges to get it, which is mainly in two of the following ways: One is the optimal processing and the other the *A*-value averaging. Studied climatologically, historical data from local radars and rain gauges are used to set up the *Z-I* relationship with the technique of probability fitting. This method was first put forward by Miller [5]. These two methods were compared by Zhang et al.[6], who showed that the latter was much advantageous over the former in terms of the relative error of the climatological *Z-I* relationship. With full account of the pros and cons of the two approaches, this study sets up an immediate relationship between *Z* and *I* and determines an improved technique of optimal window probability fitting.

In order to increase the accuracy of radar-based estimation of rainfall, a variety of ways of calibrating have been put forward. One of them is the incorporation of rain gauge and radar measurements by plane fitting and mathematical connection of their advantages, which proves to be one of the efficient ways to calibrate the radar-derived rainfall. An averaging calibration was put forward in the early 1970s with both desirable results and shortcomings that the distribution of precipitation was also smoothed out [7]. Based on it, a new concept of “calibrating through averaging correction factors” was suggested by Dai et al.[8]. Both of the techniques are known for their ease to handle and accuracy in estimating total regional precipitation after calibration, though smoothing the centers of both strong and weak precipitation to result in unrealistic reproduction of the precipitation field. The Kalman Filter was used to calibrate the radar-based rainfall for Hefei, Anhui Province, with the relative error being about 20.32% [9]. With the introduction of the variational method in the meteorological field [10], the variational method is used to run objective analysis of heavy rains based on observations by radar and rain gauge and satisfactory results are achieved [11]. Since then, this method has been widely used in calibrating this type of rainfall by Chinese meteorologists and large amount of achievements have been acquired. The rain rate and regional rainfall, which are estimated with the radar, are calibrated using the variational method [12]. The results indicate that the relative error of convective precipitation, with rainfall unevenly distributed, is reduced from 100% - 200% before the application of the method to 20% to 30% after it. As shown in Deng et al.[13], the use of rain gauge in calibrating quantitatively estimated radar-based rainfall can yield much improved accuracy than that with the use of radar alone: the relative error can increase from 56% to 9.9% if the variational method is used. This method takes full account of the spatial and temporal variation and the viewpoint of extremes makes the real correction closer to the theoretic correction, as shown in Fu et al.’s application of the method in calibrating regional rainfall measured by the weather radar [14]. According to Wang et al.[15], who applied the method in calibrating digital weather radars’ estimation of rainfall, both the shape of rain area and structure of precipitation, as reflected by radar estimates, remain consistent across the point of calibration and meso- and small- scale features of precipitation, as measured by the radar between various rain gauges, are also retained.

As typhoon-inflicted precipitation is usually extensive in area and high in intensity, networks of rain gauges with conventional density can not only have inaccurate measurement of regional rainfall but also usually neglect the main centers of typhoon-related heavy rain or fail to reflect the true distribution and evolvement of rain rates. At present, the use of Doppler measurements in quantitative estimation of hourly rainfall from typhoons is still uncommon. With the Doppler data measured at Wenshou and mesoscale automatic rain gauge observations made across Zhejiang province, this study uses an improved technique of optimal wind probability fitting to determine the coefficients *A* and *b* dynamically before obtaining the hourly rainfall quantitatively measured by the Doppler. The variational technique is used to calibrate the hourly rainfall of typhoon estimated by the Doppler for desirable results and the error is quantitatively analyzed. It is essential for the forecast of the area and movement of typhoon-related heavy rain.

2 SELECTION OF DATA

For the two typhoons selected for this study, Haitang and Matsa, computation is run of the basic reflectivity and corresponding rainfall data taken within 1 h (over 10 volume scans) by the Doppler at Wenzhou from the mesoscale automatic rain gauging network in Zhejiang province. For the coverage of the Wenzhou Doppler, there are 159 observation sites that have the 1-h rainfall for Typhoon Haitang with the maximum at 78.0 mm; there are 205 sites that have the 1-h rainfall for Typhoon Matsa with the maximum at 37.2 mm. As the observation of real rainfall is not available over the sea surface, no analysis will be made of the data estimated by the radar for the area.

3 DYNAMIC COMPUTATION OF THE *Z-I* RELATIONSHIP

The improved technique of optimal window probability fitting is used to determine the *Z-I* relationship for the time at and after the landfall of the two typhoons and different *A* and *b* are known (Table 1). It is known from the table that the coefficients vary much between different typhoons and significant difference can also be found in the same typhoon at different time of the day. In addition, the coefficients are related not only with the intensity of typhoon echoes but also with the area of strong echoes. When the echo intensity and area evolve steadily with time, the coefficients vary little. It is then inferred that it is not entirely reasonable to use fixed *Z-I* relationship to estimate rainfall. Hourly rainfall can be quantitatively estimated from *A* and *b* as listed in Table 1.

Table 1 The coefficients *A* and *b* of the *Z-I* relationship with different typhoons

Typhoon	time/UTC	*A*	*b*
Haitang	2005.7.19.17：00	324.9	1.2
	2005.7.19.18：00	153.7	1.5
	2005.7.19.19：01	252.2	1.3
	2005.7.19.20：01	214.0	1.3
	2005.7.19.21：02	108.0	1.6
Matsa	2005.8.5.19：03	17.8	1.9
	2005.8.5.20：03	24.4	1.8
	2005.8.5.21：04	27.7	2.0
	2005.8.5.22：04	26.1	1.9
	2005.8.5.23：05	27.7	1.8

4 ANALYSIS OF THE RESULTS

Fig.1 gives the distribution of estimated rainfall varying with time, which is determined with the wind field based on the mesoscale surface automatic gauging network in Zhejiang and corresponding variational calibration. It shows that the fitting technique described above has good correspondence with the wind field.

See the Chinese edition of the journal for more details.

5 ANALYSIS OF THE ERROR

The number of observation stations verified in this study is kept under 30% of the total of the rainfall stations. See Table 2 for details. It is known from it that the mean rainfall estimated via the variational calibration is closer to the observation. Different extent of reductions can be found in the mean absolute error and relative error. It can be seen that the accuracy of radar-based rainfall is made much higher.

Table 2 Statistics of the error of estimated rainfall

Time/UTC	2005.7.19. 17-18	2005.7.20 .00-01	2005.8.5. 20-21	2005.8.5. 23-00
Mean observed rainfall /mm	8.70	4.41	5.42	4.46
Mean observed rainfall before calibration/mm	5.85	2.91	3.21	3.00
Mean observed rainfall after calibration /mm	7.01	4.11	4.65	4.52
Mean absolute error before calibration/mm	5.79	3.09	3.53	2.59
Mean absolute error after calibration /mm	2.19	1.17	1.36	0.62
Mean relative error before calibration/%	9.50	19.76	18.30	26.28
Mean relative error after calibration /%	1.38	7.55	11.27	11.05
Total rainfall/sites	289	382	267	301
Total rainfall after variational calibration/sites	241	319	197	226
Verified rainfall / sites	48	63	70	75

6 SUMMARY

An improved optimal window probability fitting technique and data of the typhoons Haitang and Matsa collected by the Doppler in Wenzhou are used in this study to determine the coefficients *A* and *b* dynamically so that the hourly rainfall is estimated and calibrated using the variational technique. The results have been satisfactory.

(1) On the basis of fully taking into account the pros and cons of the optimal method and probability fitting technique, the reflectivity factor *Z* by the radar and the rainfall measured real-time by the rain gauge are used to isolate direct association between them.

(2) As shown in the computations, the *Z* – *I* relationship differs much by the typhoon and so does the resultant hourly rainfall.

(3) The typhoon-related rainfall estimated with the method clearly reveals the spiral cloud bands and meso- and small- scale rain belts inside; the estimated rainfall is generally close to the observation, which is very important for operational forecast of typhoon-related rainfall.

(4) When calibrated through the variational technique, the estimated rainfall shows clearly the corresponding links between the typhoon rain belts and the dynamic structure of the surface mesoscale flow field.

(5) As shown in the statistic analysis, the hourly rainfall estimated with variational calibration is better than the one without it. The variational method can both retain the distribution characteristics of the radar-estimated hourly rainfall and reduce the error between the estimation and observations so that the estimated hourly rainfall is closer to the observations.

***Acknowledgement*:** The authors would like to extend their whole-hearted appreciation for Dr. Zhao Kun, who has given his full support and enthusiastic instruction for this paper.

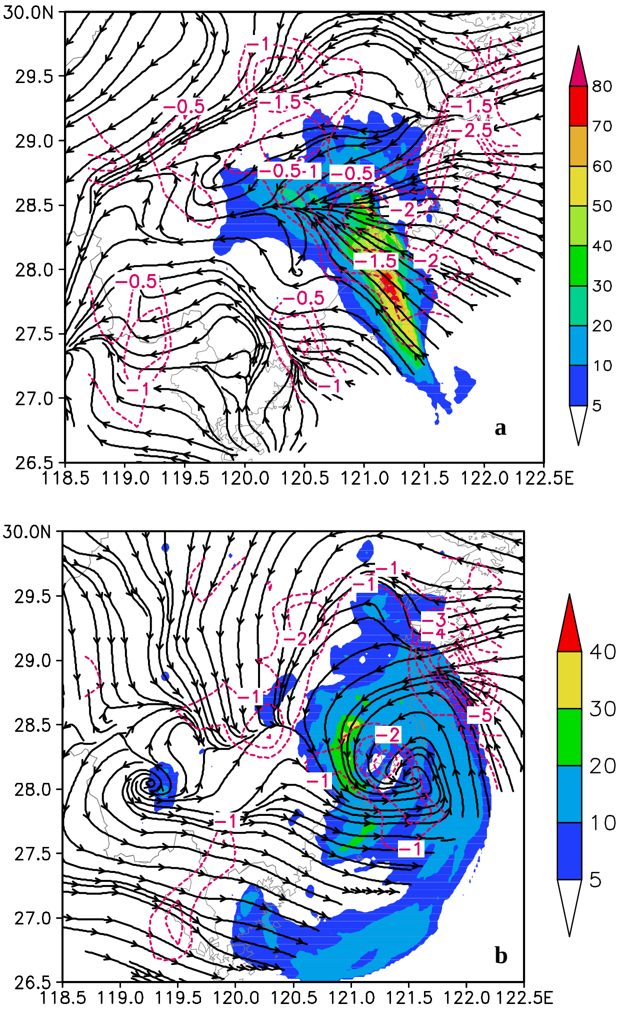

Fig.1 Estimated typhoon rainfall that has been calibrated (mm, the shades), 2-min. flow and divergence fields ($\times 10^{-4} s^{-1}$, the dashed line) for 17:00 – 18:00 July 19 (a) and 20:00 – 21:00 August 5, 2005 (b).

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Citation: JIN Chun-xiao, CHEN Lian-shou and XU Xiang-de, et al. A study on variable quantitative precipitation estimation using Doppler radar data. *J. Trop. Meteor.*, 2008, 14(2): 109-112.