Current state and future of radar-based flood forecasting

Dong-Jun Seo, PhD
The University of Texas at Arlington

Kyotaek Hwang
Korea Institute of Construction Technology

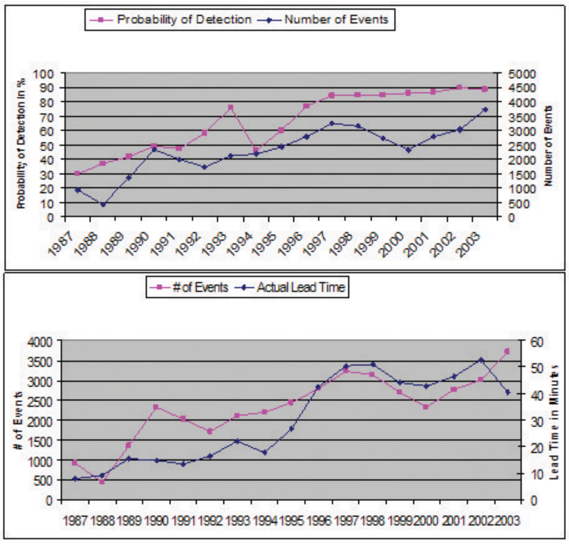
Dong-Ryul Lee, PhD
Korea Institute of Construction Technology

Ⅰ. Introduction

This article provides a U.S.-centric view of the current state and future of radar-based flood forecasting. While it is drawn primarily from the U.S. experience, the overall situation and future directions are similar in other weather radar-advanced countries.

Since the deployment of the WSR-88D's in the early to mid-1990's, the state of flood forecasting has changed dramatically in the U.S. The greatly positive impact has been limited, however, to those regions and seasons (or storm types) where the radar can estimate near-surface precipitation well. The U.S. experience, in this respect, demonstrates that successful flood forecasting hinges on the quality of quantitative precipitation estimates (QPE) from the radar. In the U.S., radar QPE is used for forecasting of flash floods as well as river floods and for continental scale hydrologic, or land surface, modeling. In this summary, we focus on radar-based flash flood forecasting while touching on radar-based forecasting of river floods as necessary.

Because of their short-fused nature, radar QPE plays a particularly critical role in forecasting of flash floods. Where and when radar can see or estimate near-surface precipitation well, radar QPE is used almost exclusively to issue flash flood watches or warnings by the National Weather Service (NWS) Weather Forecast Offices in many

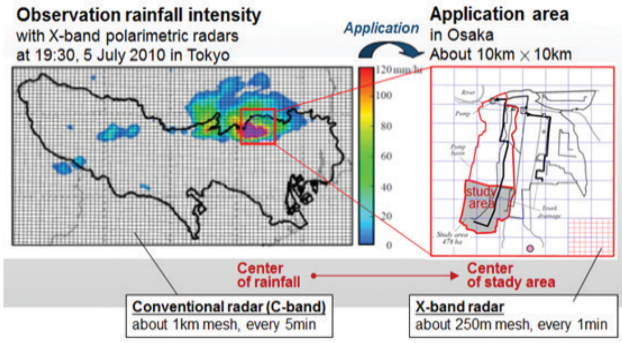


〈Figure 1〉 Trend in probability of detection (upper) and lead time (lower) of NWS-issued flash flood forecasts (source NWS/OCWWS)

parts of the country. In general, radar QPE has performed extremely well for flash flood forecasting for convective events for which, owing to the depth of the precipitation system and the relatively uniform vertical profile of reflectivity (VPR), radar can estimate near-surface precipitation well. 〈Fig. 1〉 shows the dramatic improvement in probability of detection (left) and forecast lead time (right) for NWS flash flood forecast following deployment of the WSR-88D network in the early to mid-1990's through the late 1990's.

Ⅱ. Flooding forecasting in urban areas

Urbanization and the accompanying need for

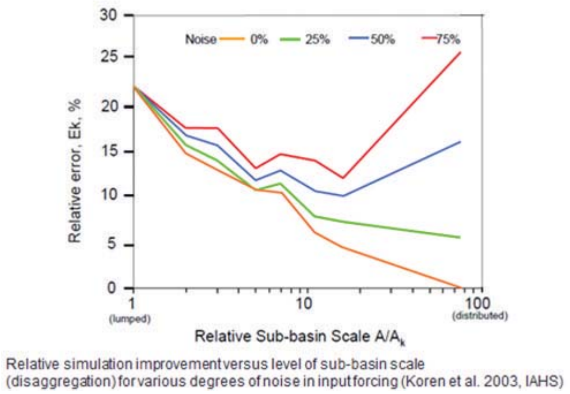


〈Figure 2〉 An example application of high-resolution radar QPE and hydraulic modeling for urban flood forecasting (from [1])

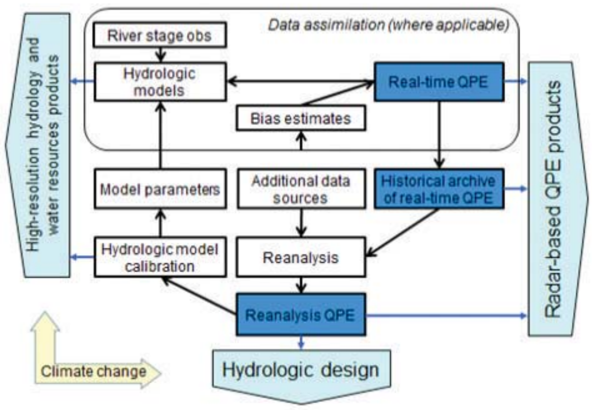
spatio-temporally more detailed information for water hazards mean that the future of flood forecasting will rely more heavily on radar QPE, and that the push for higher resolution precipitation information in both space and time will continue. For example, 〈Fig. 2〉 shows an area in Osaka, Japan, where high-resolution radar QPE is used for urban flash flood forecasting.

Urbanization and the accompanying need for spatio-temporally more detailed information for water hazards mean that the future of flood forecasting will rely more heavily on radar QPE, and that the push for higher resolution precipitation information in both space and time will continue.

To improve the quality of flood forecasting at a fine scale, however, the radar QPE must be sufficiently accurate at that scale such that the errors in radar QPE do not translate in the hydrologic models into large errors in runoff as the resolution increases. 〈Fig. 3〉 shows the sensitivity of the error in runoff as a function of the spatial resolution and magnitude of error in QPE as obtained from a synthetic experiment. While only a synthetic result, the figure does suggest that, unless the higher-resolution radar QPE is sufficiently accurate, higher-resolution



〈Figure 3〉 Translation of error in QPE into error in runoff as a function of the spatial resolution of QPE (x-axis) and the magnitude of error in QPE (orange, green, blue and red)



〈Figure 4〉 Schematic of radar-based QPE product suite for hydrologic applications

hydrologic simulation, including flood prediction, may not result in increased accuracy.

Ⅲ. Multisensor QPE

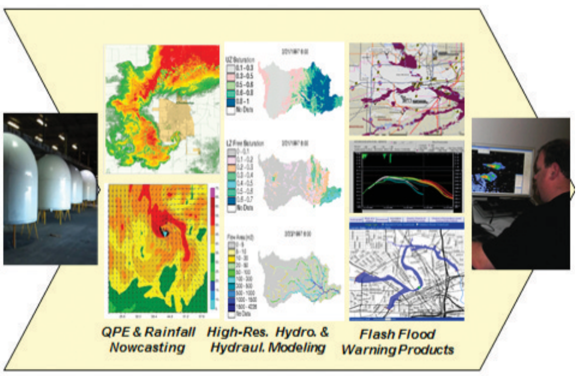
Even with increased accuracy expected from polarimetric radar, the QPE system that supports flood forecasting must bring in all other skillful data, in particular the rain gauge data, to improve areal coverage and absolute accuracy of QPE. For this purpose, an application called the Multisensor Precipitation Estimator (MPE, [2]-[3]) is used in NWS. 〈Fig. 4〉 depicts how the rain gauge data (i.e. as part of additional data sources) may be used in real time, near-real time and reanalysis modes to produce a suite of high quality radar-based QPE products which can be used for various hydrometeorological, hydrologic and hydroclimatological applications.

Unless the land cover is largely impervious, accurate knowledge of the soil moisture conditions is necessary for accurate flood forecasting. Because real-time observation of soil moisture is difficult to obtain, particularly over an area (large or small), one generally has to rely on model-simulated soil moisture. For a hydrologic model to simulate soil moisture states accurately, the precipitation forcing must be unbiased across a range of temporal scales and as accurate as possible at the scale of hydrologic modeling. For this, bias correction in radar QPE using rain gauge data is a requisite. Due to the general sparsity of rain gauge networks, it is, in general, not possible to estimate fast-varying biases in radar QPE. One can, however, estimate biases at larger time scales of aggregation relative to gauge QPE from which a most timely bias with sufficiently small sampling uncertainty may be obtained [4]-[5]. In gauge-rich areas, merging of radar QPE and rain gauge data can significantly improve the accuracy of radar-based QPE. At the NWS River Forecast Centers which produce river forecasts in the U.S., the radar-gauge merged product as quality-controlled by human forecasters is considered the “best” QPE available.

Ⅳ. Nowcasting

One of the most important advantages of radars over rain gauges is that the former provides spatially continuous data that may be used for nowcasting. It is widely accepted that precipitation nowcasting is generally skillful up to about 30 min though, for certain precipitation systems, the lead time may be significantly longer. For flash flood forecasting, extending the forecast lead time is necessarily of critical importance, and hence the forecast system must include nowcasting components [6]. Numerous techniques for nowcasting have been developed over the years (see e.g. [7]). With much increased computing power, it is now possible to apply data assimilation techniques for estimation and projection of motion vectors for nowcasting (see e.g. [8]). Beyond nowcasting, polarimetric radar, with its ability to distinguish hydrometeor types, offers possibilities for real-time assimilation of its base data into fine-scale numerical weather prediction (NWP) models for short-term quantitative precipitation forecast (QPF). 〈Fig. 5〉 shows an illustration of the radar-based flash flood forecast process.

One of the most important advantages of radars over rain gauges is that the former provides spatially continuous data that may be used for nowcasting.



〈Figure 5〉 Illustration of radar-based flash flood forecast process

Ⅴ. Conclusions

Tremendous advances have been made in the last 20 years in the science, technology and engineering of radar-based QPE and flood forecasting systems. It is expected that the use of radar will spread more widely, and play an even more important role in flood forecasting in the coming years. For flash flood forecasting, the value of radar QPE and nowcast is unmatched. To realize fully the potential of radar-based QPE and flood forecasting, however, a number of significant challenges remain. In this report, we summarized the status, recent advances, outstanding issues and emerging areas for radar-based flood forecasting toward fully realizing its promise.

Experience with the WSR-88D network in the U.S. indicates that the most serious sources of error in radar QPE for operational hydrologic forecasting are the systematic biases arising from the sampling geometry of the radar beams vs. the reflectivity morphology of the precipitating clouds, and the uncertainties in the microphysical parameters and in discriminating hydrometeor type. The latter is expected to be mitigated by polarimetric radars. The systematic biases are particularly important in the cool season and in complex terrain. The uncertainties are particularly important for small-scale low-centroid tropical moisture-fed events that produce extreme amounts of rainfall.

Estimation theory states that, if the individual sensors possess skill in estimating precipitation, observations from multiple sensors may be combined to produce estimates that are more accurate than those obtainable from the individual sensors alone. In this report, we introduce an operational application of the above principle, the Multisensor Precipitation Estimator (MPE), toward generation of highest-quality precipitation analysis for all seasons, for all terrains, and over a wide range of spatiotemporal scales of aggregation. Challenges for multisensor QPE and radar-based flood forecasting include accounting for the detection bias in radar QPE, ensuring statistical consistency across a wide range of scales of aggregation, improving accuracy through parameter optimization to address nonlinear effects, synergistically advancing real-time estimation and reanalysis, probabilistic and ensemble estimation and prediction, and verification and diagnostic evaluation.

Tremendous advances have been made in the last 20 years in the science, technology and engineering of radar-based QPE and flood forecasting systems. It is expected that the use of radar will spread more widely, and play an even more important role in flood forecasting in the coming years.

References

[1] Kimura, M., 2011. Study on real-time flood forecasting method for locally heavy rainfall with high-resolution X-band polarimetric radar information. International Symposium on Weather Radar and Hydrology, Apr 18-21, Exeter, UK.

[2] Breidenbach, J., D.-J. Seo, P. Tilles and M. Fortune, 2002. Multisensor precipitation estimation for use by the National Weather Service River Forecast Centers, 16thConf on Hydrology, AMS.

[3] Seo, D.-J., A. Seed, and G. Delrieu, 2010. Radar-based rainfall estimation, chapter in AGU Book Volume on Rainfall: State of the Science, F. Testik and M. Gebremichael, Editors.

[4] Seo, D.-J., J. P. Breidenbach, and E. R. Johnson, 1999. Real-time estimation of mean field bias in radar rainfall data. J. Hydrol., 223, 131-147.

[5] Seo, D.-J., and J. P. Breidenbach, 2002. Real-time correction of spatially nonuniform bias in radar rainfall data using rain gauge measurements, J. Hydrometeor., 3, 93-111.

[6] Vasiloff, S.V., D.-J. Seo, K. Howard, J, Zhang, D.H. Kitzmiller, M.G. Mullusky, W.F. Krajewski, E.A. Brandes, R.M. Rabin, D.S. Berkowitz, H.E. Brooks, J.A. McGinley, R.J. Kuligowski, and B.G. Brown, 2007. Improving QPE and Very Short Term QPF- An Initiative For A Community-Wide Integrated Approach, Bull. Amer. Meteor. Soc.,88, 1899-1911.

[7] Golding, B.W., 1998. Nimrod: a system for generating automated very short range forecasts. Meteorol. Appl., 5, 1-16.

[8] Turner, B. J., I. Zawadzki, U. Germann, 2004: Predictability of Precipitation from Continental Radar Images. Part III: Operational Nowcasting Implementation (MAPLE). J. Appl. Meteor., 43, 231-248.

Dong-Jun (DJ) Seo Ph.D.

1976~1983년 Soil and Water Major, Dept. of Agricultural Engineering, SeoulNational University (B.S.)
1983~1985년 Hydrology and Water Resources Program, Dept. of Civil and Environ. Eng., Massachusetts Institute of Technology (M.S.)
1985~1988년 Hydrology and Water Resources Program, Dept. of Civil and Environ. Eng., Utah State University (Ph.D.)
2000~2004년 Research Hydrologist and Hydrometeorologist,NOAA/NWS /OHD/HL, Silver Spring, MD, & Associate/Project Scientist, UCAR.
2005~2010년 7월
Leader, Hydrologic Ensemble Prediction Group, NOAA/NWS/OHD/HL, Silver Spring, MD, & Project Scientist, UCAR.
2010년 8월~Associate Professor & Water Resources Area Coordinator, Department of Civil Engineering, The University of Texas at Arlington.

〈관심분야〉
Water forecasting, Hydrologic data assimilation, Hydrologic modeling, Hydrologic applications of weather radar, Geostatistics, Optimal estimation and control

황 교 택

2009년 8월 한양대학교 (공학사)
2011년 8월 한양대학교 (공학석사)
2012년 8월~현재 한국건설기술연구원 연구원

〈관심분야〉
수문원격탐사, 레이더 수문기상

Dong-Ryul Lee Ph.D.

1981~1985년 Dept. of Civil Engineering, ChungnamNational University (B.S.)

1985~1986년 Hydrology major, Dept. of Civil Engineering, Korea University (M.S.)

1991~1995년 Hydrology and Water Resources Engineering major, Dept. of Civil Engineering, Korea University (Ph.D.)

2003년 8월~2006년 12월
Project Leader of "Development of Integrated Water Evaluation and Planning System", Water Resources Research Department, Korea Institute of Construction Technology, Korea.

2007년 1월~2007년 12월
Visiting Professor, Department of Civil Engineering, Colorado State University, Fort Collins, Colorado, USA.

2008년 1월~2010년 9월
Research Fellow, Water Resources Research Department, Korea Institute of Construction Technology, Korea.

2010년 10월~ Present Head, Research Fellow, Water Resources Research Division, Korea Institute of Construction Technology, Korea.

〈관심분야〉
Radar hydrology, Water resources planning, Water supply and demand forecasting, Drought analysis and management, Integrated water resources management, Water-related sustainable development indicators, Rainfall-runoff modeling, Low-flow analysis, Evaluation of climate change impact on water resources