Flood Runoff Simulation Using Grid-based Radar Rainfall and Vflo^{TM} Model

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1. Introduction

Flood disasters from localized heavy rainfall and flash floods have recently been an increasing trend in Korea. In order to reduce flood damage, it is important to observe and predict rainfall, which is an important hydrologic factor. Therefore, the use of radar rainfall data that can help the tracking of development and movement of rainfall's spatial distribution is drawing much attention in hydrology.

When analyzing runoff in hydrology, grid-based distributed rainfall-runoff model (Vflo^{TM}) is increasingly used because it enables more detailed examinations of spatial flux changes in the basin as compared to existing lumped hydrologic models. Especially, the use of radar rainfall data that can create, correct, or forecast the rainfall data with short observation period and the physical-based distributed runoff model using GIS are increasing. It is expected that they will be very useful when estimating runoff in unobserved basins in the field of hydrology.

Physical-based distributed model was first introduced by Freeze and Harlan (1969). Vieux, B. E. et al. (2004), who developed the Vflo model used in this study, evaluated the physical-based model for the application on flash floods; while Vieux, B. E and Koehler, E. (2005) studied the Vflo model using GIS. Kim Byeong-Sik et al. (2008) suggested a flood estimation method linked to radar rainfall data corrected by the distributed model and conditional integration method. They proved that the conditional integration method can actually be used in the interpretation of flood runoff.

Based on above studies, this study created a raw-radar data by Mean-Field Bias (MFB) correction method and Statistical Objective Analysis (SOA) correction method, which correct the grid-type radar rainfall data using rainfall data on the ground. Then, various hydrologic parameters had been created on GIS to reflect the characteristics of the basin. Lastly, the usefulness of radar rainfall data and the accuracy of correction methods were evaluated by comparing the runoffs using physical-based distributed model (Vflo^{TM}).

2. Study Method and Theoretical Background

This study evaluated the accuracy of corrected radar rainfall data by way of runoff simulations before correction and after correction by using raw-radar data, which had been created by applying Z-R formula on the rainfall data observed at Biseulsan Rainfall Radar from August 15 to 17, 2010. The radar rainfall was corrected by Mean-Field Bias (MFB) and Statistical Objective Analysis (SOA).

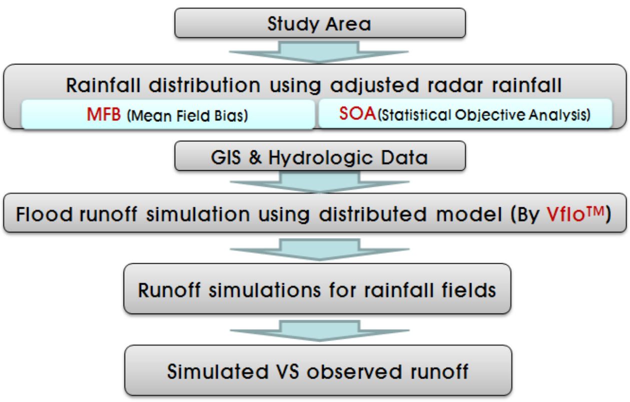


Fig. 1 Study flow diagram

2.1 The Concept and Theory of the Vflo Model

The Vflo model used in this study is a physical-based distributed model (PBDM), which provides hydrologic model solution using radar rainfall system and GIS. This model is designed to process the hydrologic parameters extracted by linking various hydrologic parameters with GIS. It can be said that this model removed the empirical factor, which became an issue in the estimation of parameters.

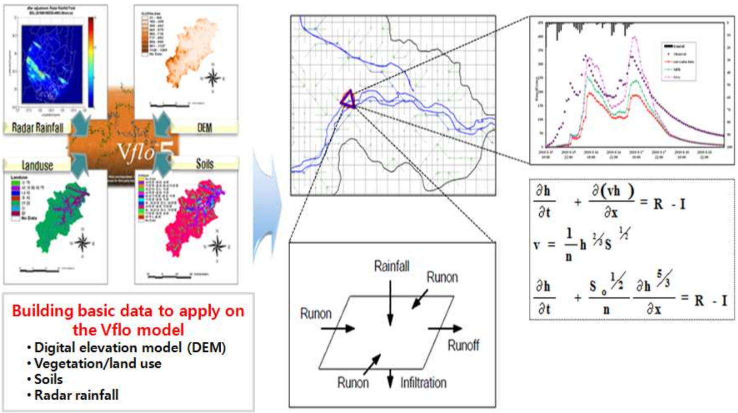


Fig. 2 Configuration and concept of the Vflo model

Vflo model expresses the water flow in the basin as the governing equation using kinematic wave equation. This concept, consisting of simplified momentum equation and continuity equation, expresses the ground runoff caused by excess rainfall in the form of one-dimension continuity equation. It calculates the river flow by using finite element method on the input data of soil map, vegetation/land-use map, topography map, and rainfall data created in the format of grid-based numerical map while assuming the flow of direct runoff as uniform flow.

$\frac{\partial h}{\partial t}+\frac{\partial(vh)}{\partial x}=R-I$: One dimension continuity equation of ground surface flow

$v=\frac{1}{n}h^{2/3}S_o{}^{1/2}$: Empirical formula of Manning assuming the ground surface flow as uniform flow

$\frac{\partial h}{\partial t}+\frac{S_o^{1/2}}{n}+\frac{\partial h^{2/3}}{\partial x}=R-I$: Governing equation to track the ground surface flow

2.2 Radar Rainfall Data Correction Method using Rainfall on Ground

1) The Mean-Field Bias (MFB) method is also called the G/R method. It corrects the radar rainfall data by uniformly applying the correction factor calculated by comparing the rainfall on ground and radar rainfall on the whole area, on which the radar rainfall data is to be estimated. The basic formula used in this study is the following:

$$R_c = f \times R_r \quad (f = R_g / R_r)$$

Here, f : Correction coefficient of each grid, R_g : Rainfall at rainfall on ground grid point, R_r : Rainfall at radar grid point R_c : Rainfall at corrected radar cell.

2) Statistical Objective Analysis (SOA) had been suggested by Pereira et al. (1998) based on the optimum interpolation method of Gandin (1963). It accurately estimates the rainfall of an area that does not have observed data for rainfall on ground using the rainfall on ground data and radar rainfall data. It adds the observed data and radar data using the weight value calculated from the error range of each.

$$P_a(x_i, y_i) = P_{ar}(x_i, y_i) + \sum_{k-1}^{K} w_{ik}[P_g(x_k, y_k) - P_r(x_k, y_k)]$$

$$w_{ik} = \frac{f(d_{ik})}{\sum_{k-1}^{K} f(d_{ik})}, \qquad f(d_{ik}) = \frac{1}{d_{ik}^a}$$

Here, $P_a(x_i, y_i)$: Rainfall corrected at the grid point (i), $P_{ar}(x_i, y_i)$: Radar rainfall at grid point (i), $P_g(x_{ki}, y_k)$:

Observed rainfall at the rainfall station, $P_r(x_k, y_k)$: Radar rainfall of grid point relevant to the location of rainfall station (k), w_{ik} : Weight value, K : Number of rainfall stations, (x, y) : Coordinate, d_{ik} : Distance between the points (i, k) .

The core idea of Statistical Objective Analysis (SOA) method is applying the optimum weight value, which used the correlation function between the rainfall stations.

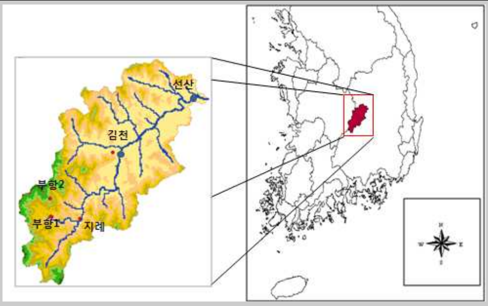
2.3 Radar and Object Basin for This Study

Biseulsan Rainfall Radar Station gives out dual-polarimetric radar data for the first time in Korea. The specification is in Table 1.

The object basin is Gamcheon river basin (mid-watershed), which is a tributary of the Nakdong River. This basin has good topography spatial data, which can be used in the interpretation of rainfall-runoff. The basin also has its hydrologic data available and has relatively small impact of back water effect. The basin area of Gamcheon river basin is 1005.33 ㎢ and waterway length is 74.27 ㎞. There are a national river (Gamcheon), 17 local rivers, and seven standard basins in Gamcheon basin.

Location (latitude/longitude)		35° 42’ 54” / 128° 32’ 12”
Altitude of antenna		1,085 m
Frequency		2,795 MHz (S-band)
Transmission method		Simultaneous H/V
Maximum transmission output		750 KW
Calculation variables		Z, Vr, SW, ZDR, ΦDP, KDP, ρHV
Observation strategy (rainfall radar)	cycle	2.5 minutes
	radius	100 km
	altitude	-0.5°~1.6°(low altitude, five altitudes)
Opening date of observation station		June 10, 2009

Table 1. Specification of Biseusan Rainfall Radar Station



Rainfall station	Water level station
Gimcheon, Jirye, Buhang-1, Buhang-2, Seonsan (five locations)	Gimcheon, Seonsan (two locations)

Fig. 3 Basin status

3. Radar and Vflo Data

3.1 Radar Rainfall Data Generation and Basis Analysis

Radar rainfall data was created by applying the Z-R formula on the early stage UF data observed at Biseulsan Rainfall Radar from 10:30 of August 15 to 09:00 of August 17, 2010.

$$z = 231R^{1.6}$$

The raw-radar data before correction calculated from above Z-R formula in the form of rainfall intensity had been converted to cumulated rainfall. The data from 182 aboveground rainfall stations in the observation range of Biseulsan Rainfall Radar had been used. Mean-Field Bias (MFB) and Statistical Objective Analysis (SOA) methods that were previously explained had been applied.

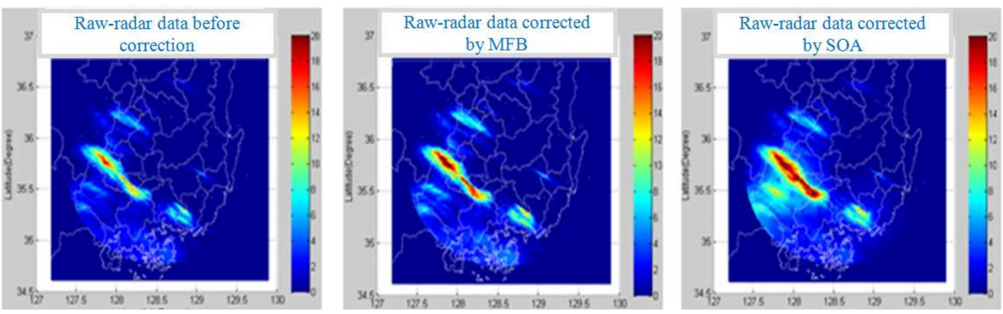
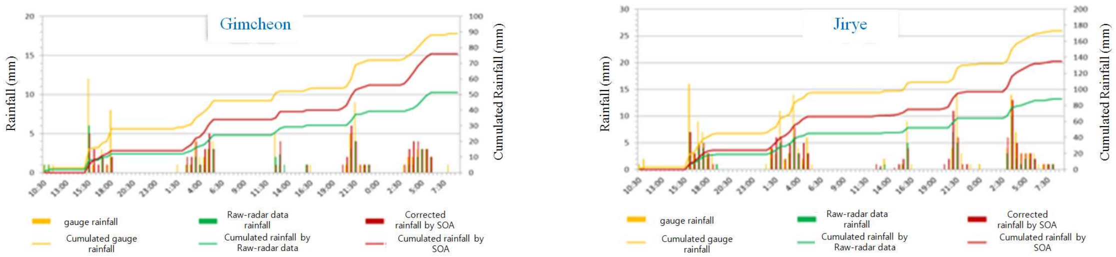
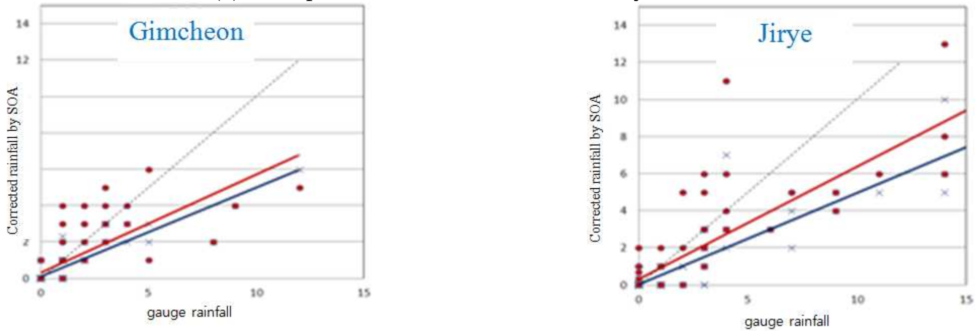


Fig. 4 Examples of each corrected radar image

Figure 5 (a) is the comparison of 30-minute cumulated rainfall for each rainfall station in the Gamcheon basin. It was possible to confirm that the raw-radar data was underestimated than the rainfall on ground and the SOA-corrected rainfall approached the rainfall on ground. In addition, the SOA-corrected rainfall was closer to 1:1 linear form with rainfall on ground in Figure 5(b), which is the Q-Q plot of each location before correction and after correction.



(a) Comparison of cumulated rainfall by location

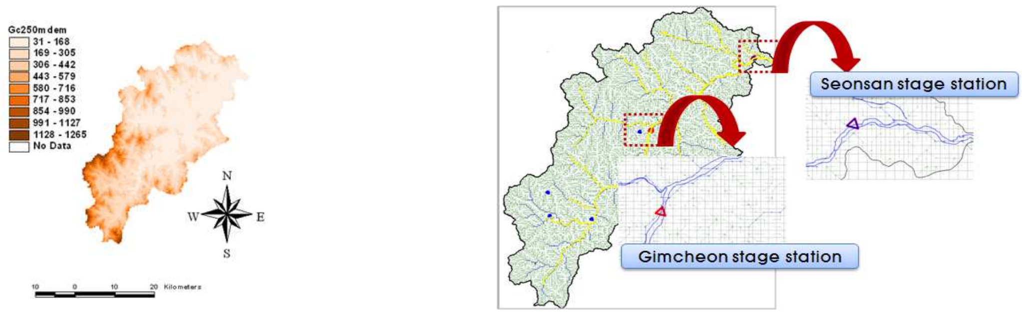


(b) Q-Q plot comparison by location

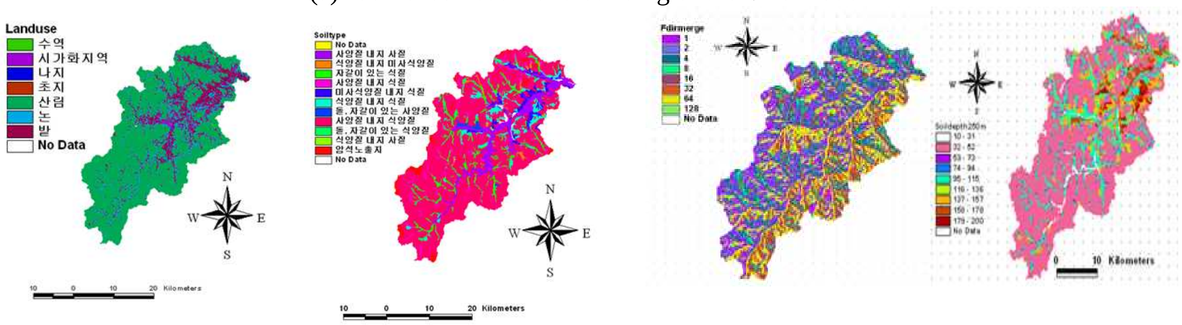
Fig. 5 Cumulated rainfall (30 minutes) and Q-Q plot comparison by location

3.2 Generation of Vflo parameter data using GIS

Vflo model grid network was created based on various Vflo model input data created by applying (i) three basic topography spatial data related to basin characteristics such as Digital Elevation Model (DEM), vegetation/land-use map and soil map, (ii) the typical luminous intensity coefficient on the land use classification suggested by Vieux, and (iii) Green-Ampt penetration parameters. (Fig. 6)



(a) Gamcheon basin and building of the Vflo model



(b) Vflo parameter input data

Fig. 6 Model building and parameter input data

4. Results

In order to evaluate whether the corrected radar raw-radar data by Mean-Field Bias (MFB) method and Statistical Objective Analysis (SOA) method realistically express the rainfall distribution with certain rainfall accuracy, runoff had been estimated for two water level observation locations using the distribution Vflo model.

When the observed runoff and simulated runoff had been examined against peak discharge, the simulated runoff by raw-radar data was significantly smaller than the observed runoff. The simulated runoff by radar rainfall data applied with Mean-Field Bias (MFB) and Statistical Objective Analysis (SOA) methods in this study fairly approached the observed runoff. Especially, it was possible to find that the corrected radar rainfall applied with Statistical Objective Analysis (SOA) agreed with the peak discharge, peak discharge occurring time, and overall runoff generation pattern at the two locations relatively better in general. (Fig. 7)

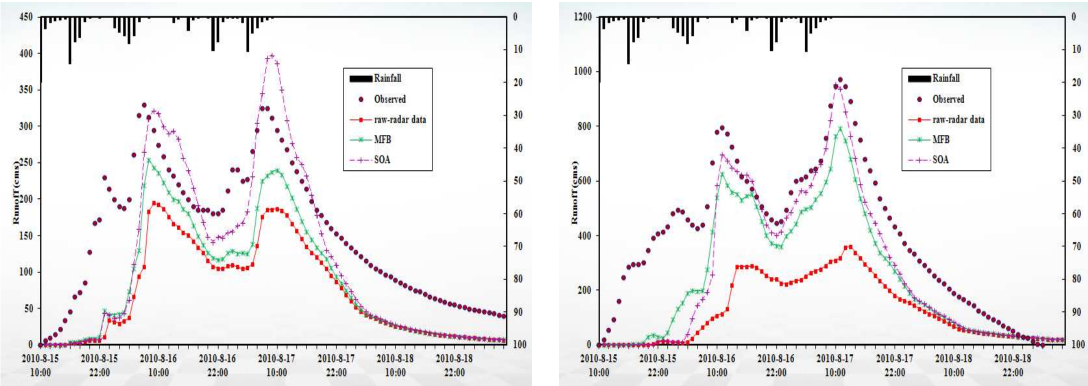


Fig. 7 Comparison of runoff graphs by correction method

In order to examine the runoff comparison result for each radar rainfall in more detail, error and model efficiency analysis had been done. For the error analysis, Mean Absolute Error (MAE), Root Mean Square Error (RMSE), Normalized Peak Error (NPE), and Peak Timing Error (PTE) had been used (Kim Byeong-Sik et al., 2008). According to the analysis result of error and model efficiency, the error values of MAE and RMSE had not been significantly satisfying because of the differences in the early stage of runoff caused by previous rainfall. However, the NPE on peak discharge had been on the level of 20% after correction, which had been 40-60% before correction. The model efficiency (ME) were 70-80% (Table 2). Especially in most error comparisons, the simulated runoff by Statistical Objective Analysis (SOA) showed the best result.

Gimcheon locations				Seonsan locations			
	raw-radar data	MFB	SOA		raw-radar data	MFB	SOA
MAE	66.18	51.68	18.56	MAE	259.01	127.17	89.18
RMSE	82.33	63.58	39.89	RMSE	320.84	139.57	117.26
NPE	-0.410	-0.230	0.205	NPE	-0.629	-0.186	-0.020
ME	0.29	0.58	0.70	ME	-0.28	0.75	0.82
PTE	1	0.5	0.5	PTE	1	0	0.5
Average (runoff)	86.17	103.82	138.62	Average (runoff)	159.93	297.97	331.71

Table 2. Error analysis and model efficiency results for each correction method

5. Summary and Conclusions

This study created raw-radar data of object basin using radar rainfall and rainfall on ground data. The distribution Vflo model had been used in the evaluation of correction method accuracy and the usefulness of radar rainfall, created by Mean-Field Bias (MFB) and Statistical Objective Analysis (SOA) methods.

(1) In this study, the raw-radar data rainfall showed the tendency of underestimation as compared to observed location rainfall and runoff.

(2) The location rainfall and runoff had been examined by radar rainfall data corrected by Mean-Field Bias (MFB) and Statistical Objective Analysis (SOA). Both methods showed better results when raw-radar data was used. Especially, the runoff and runoff pattern simulated by Statistical Objective Analysis (SOA) were very close to the observed runoff

and pattern. SOA showed the best results in most error analyses and model efficiency values.

(3) It was possible to confirm that the radar rainfall data corrected by Statistical Objective Analysis (SOA) have hydrologic usefulness as input material to runoff model.

Acknowledgment

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