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Radar Rainfall Estimation on Hybrid Surface Based on Reflectivity Statistics

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1. Introduction

- The beam blockage and ground clutter lead to significant errors in radar-based quantitative precipitation estimation (QPE) over complex terrain.
- The hybrid surface rainfall (HSR) technique was developed to improve QPE based on radar reflectivity at hybrid at the lowest elevation angles that immune to beam blockage and ground clutter.
- The traditional HSR (THSR) does not take into account non-standard atmosphere and spatiotemporal variability of ground echoes in rain.
- To improve the weakness of THSR, we suggested fuzzy logic-based HSR (FHSR) technique and new ground echo mask using large dataset of radar reflectivity.

2. Radar Data

➢ **S-band Doppler weather radar (KWK) at the top of Mt. Kwanak**

Parameters	Values
Latitude (ºN)	37.4441
Longitude (ºE)	126.9639
Antenna Height (m)	641
Wavelength(cm)	10
Observation range (km)	240
Time resolution (min)	10.0
Azimuthal resolution (º)	1.0
Beam width (º)	0.94
Range resolution (m)	250
Elevation angles (º)	0.0, 0.4, 0.8, 1.2, 1.6, 2.0, 3.0, 4.2, 5.7, 9.8, 12.5, 15.8

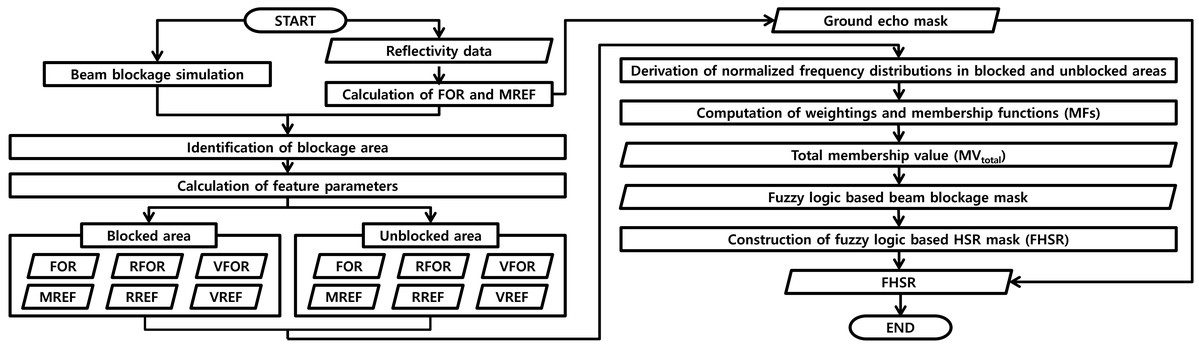
➢ **Usage rate of radar reflectivity during the summer for two years (2011-2012)**

◆ Periods : Summer (June to August) for two years from 2011 to 2012

Month/Year	Available volume files/Total volume files (Percentage)
06/2011	4,110/4,320 (95.1%)
07/2011	4,406/4,464 (98.7%)
08/2011	3,221/4,464 (72.2%)
06/2012	4,101/4,320 (94.9%)
07/2012	4,349/4,464 (97.4%)
08/2012	4,350/4,464 (97.4%)
Total	24,537/26,496 (92.6%)

3. Methodology

➢ **Flow chart for generating a hybrid surface based on reflectivity statistics**



➢ Construction of FHSR mask

◆ Definition of feature parameters

❖ **Frequency of Occurrence of Reflectivity(FOR)**
✓ Normalized frequency of radar reflectivity > 10 dBZ in total radar volume files

❖ **Mean reflectivity(MREF)**
✓ Mean reflectivity (> 10 dBZ)

❖ **Relative of FOR(RFOR) and MREF(RREF)**
✓ Ratio of FOR(MREF) to azimuthal mean FOR(MREF) at same distance from radar

❖ **Vertical gradient of FOR(VFOR) and MREF(VREF)**
✓ Variation of FOR(MREF) between two neighboring elevation angles

Feature parameters

$$\mathrm{FOR}(r,\theta,\phi)=\frac{\mathrm{n}(r,\theta,\phi)}{\mathrm{N}} \qquad \mathrm{MREF}(r,\theta,\phi)=10\log\left(\frac{\sum_{i=0}^{N}\mathrm{Z}_i(r,\theta,\phi)}{\mathrm{N}}\right)$$

$$\mathrm{RFOR}(r,\theta,\phi)=\frac{\mathrm{FOR}(r,\theta,\phi)}{\mathrm{MFOR}(r,\phi)} \qquad \mathrm{RREF}(r,\theta,\phi)=\frac{\mathrm{MREF}(r,\theta,\phi)}{\mathit{MMREF}(r,\phi)}$$

$$\mathrm{VFOR}(r,\theta,\phi)=\frac{\mathrm{FOR}(r,\theta,\phi+1)-\mathrm{FOR}(r,\theta,\phi)}{\mathrm{Elev.}(\phi+1)-\mathrm{Elev.}(\phi)} \qquad \mathrm{VREF}(r,\theta,\phi)=\frac{\mathrm{MREF}(r,\theta,\phi+1)-\mathit{MREF}(r,\theta,\phi)}{\mathrm{Elev.}(\phi+1)-\mathrm{Elev.}(\phi)}$$

r, θ, ϕ : indices of radar bin(r), azimuth(θ) and elevation(ϕ)
N : total number of radar files, **n** : frequency of radar reflectivity > 10 dBZ, **Z** : radar reflectivity(mm^6m^{-3})

◆ Ground echo (GRE) mask

❖ **Definition**
✓ two dimensional hybrid surface consisting of radar bin at the lowest elevation angles that immune GRE, it is determined using FOR and MREF

❖ **Identification of GRE**
✓ FOR ≥ 20.0 and MREF ≥ 25.0 dBZ

◆ Fuzzy logic-based beam blockage mask (FBK mask)

❖ **Definition**
✓ 2D hybrid surface of the lowest elevation angles that are affected by beam blockage (BBK)

❖ **Identification of BBK**
✓ using simulated bream blockage fraction (BBF), FOR and MREF

❖ **Weights**
✓ Weighs(w_i) are computed using overlap area of normalized frequency distributions (NFDs) between blocked and unblocked area

$$w_i=\frac{1}{A_i}\Big/\sum_{i=1}^{6}\frac{1}{A_i}$$

$\mathbf{A_i}$: overlap area of i th feature parameter using NFDs at blocked and unblocked area

❖ **Total membership value**
✓ MFs value of feature parameters at blockage area (MV^i_{block})

$$MV^i_{block}=\frac{NFD^i_{block}(p)}{NFD^i_{block}(p)+NFD^i_{unblock}(p)}$$

p : value of feature parameters, **NFD** : NFD at value of feature parameter p

✓ Total membership value (MV_{block}) is calculated using weights and MV^i_{block}

$$MV_{total}=\sum_{i=1}^{6}w_i\times MV^i_{block}$$

❖ **Identification BBK based on fuzzy logic**
✓ If MV_{total} ≥ 0.65

◆ FHSR

❖ **FHSR is two dimensional multi-elevation surface that immunes GRE and BBK and is generated by combination of GRE mask and FBK mask**

❖ **By comparing the elevation angles between GRE and FBK mask, radar bin with higher elevation is chosen**

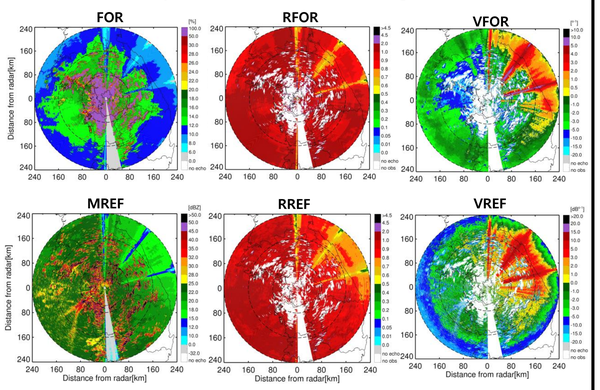
➢ Evaluation of hybrid surface rainfall

◆ **Rainfall verification is performed by comparison with precipitation estimation based on radar reflectivity at minimum elevation and automatic weather station(AWS)**
◆ **AWS sites in KWK radar coverage are used to obtain 24h-accumulate rainfall intensity (Max : 444 sites)**
◆ **Evaluations of rainfall estimation between FHSR and THSR are carried out using 3 rainfall cases.**

4. Results

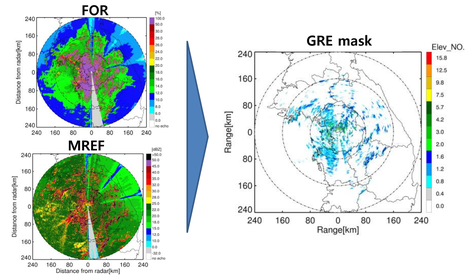
➢ Construction of FHSR mask

◆ PPIs of feature parameters at the elevation angle of 0.0º



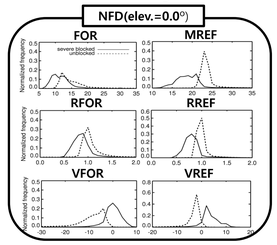
❖ The azimuth angles between 168 and 179º are not used
(The towers are located at the azimuthal direction, radar keeps silent)
❖ Distinct beam blockage at azimuth angles of 0º, 37º, and 76º

◆ PPI of GRE mask



◆ Fuzzy logic-based beam blockage mask

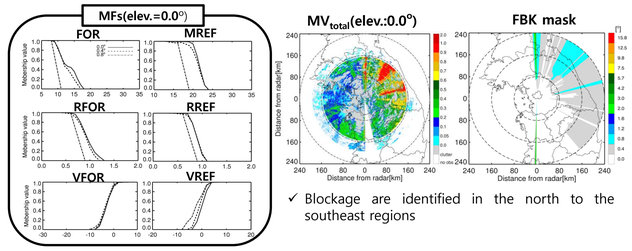
❖ **Determination of weights**



Elevation angle	Weights					
	FOR	RFOR	VFOR	MREF	RREF	VREF
0.0º	0.07	0.09	0.21	0.23	0.13	0.27
0.4º	0.11	0.11	0.20	0.21	0.13	0.24
0.8º	0.82	0.00	0.00	0.10	0.08	0.00

✓ The weight of FOR increases dramatically with increasing elevation angle

❖ **PPIs of MV_{total} at the elevation angle of 0.0º and FBK mask using MFs**

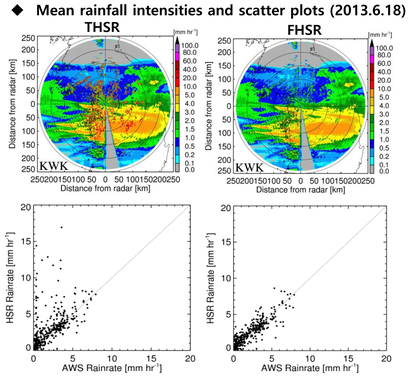


✓ Blockage are identified in the north to the southeast regions

◆ PPIs of FHSR and THSR

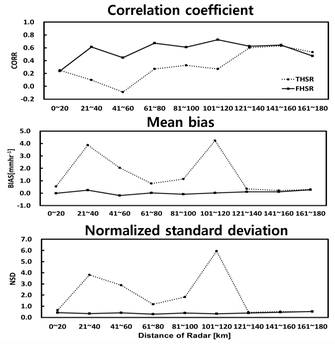
➢ Evaluation of hybrid surface rainfall

◆ Mean rainfall intensities and scatter plots (2013.6.18)



◆ Range effects of hybrid surface rainfall

❖ **Variation of skill scores as a function of distance**



❖ **Comparison of skill score between THSR and FHSR**

	2013.5.10.		2013.5.27.		2013.6.18.	
	THSR	FHSR	THSR	FHSR	THSR	FHSR
CORR	0.12	0.60	0.23	0.53	0.35	0.89
BIAS	1.16	-0.32	1.29	-0.04	1.62	0.28
SD	6.08	0.64	5.84	1.25	5.73	0.88
NSD	3.48	0.37	1.82	0.39	2.90	0.44
RATIO	1.66	0.82	1.40	0.99	1.82	1.14

✓ Correlation coefficients of FHSR were slightly higher (=0.53~0.89) than those of THSR (=0.12~0.35)
✓ Ratio of FHSR(=0.82~1.14) was closer to 1.0 than THSR(=1.40~1.82)
✓ Bias in FHSR(=-0.32~0.28 $mmhr^{-1}$) was slightly smaller than THSR (=-1.16~1.62 $mmhr^{-1}$).

5. Summary and conclusions

- FHSR mask considered the variability of ground echo and beam blockage in rain
- FHSR shows better performance than THSR
- Seasonal sensitivity of FHSR will be investigated and FHSR based on polarimetric data will be constructed.

6. References

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