Rainfall estimation in mountainous regions using X-band polarimetric weather radar

Shakti P.C.¹, ², M. Maki¹, ², S. Shimizu², T. Maesaka², D-S Kim², D-I Lee³, H. Iida⁴

¹ Graduate School of Life and Environmental Science, University of Tsukuba, Tsukuba, Japan
² National Research Institute for Earth Science and Disaster Prevention (NIED), Tsukuba, Japan
³ Pukyong National University, Busan, Korea
⁴ Japan Weather Association, Tokyo, Japan

ERAD 2012 Toulouse, France, 25-29 June 2012
Outline of the presentation

» Introduction
» Study area and observation
» Modified DEM method
» Results
» Conclusion
Research has shown that comparison between gauge recorded rainfall rate and estimated rain rate using X-band polarimetric weather radar has a good harmony especially over a flat area (Park et al. 2005b, Maki et al. 2005).

But, research on the estimation of precipitation over the mountain region specially in the case of X-band weather radar are limited due the complex topography as well as an inadequate surface observation.

And, another major problem is **partial beam blocking (PBB)** during the radar operation:

- Makes uncertainty to get the quantitative precipitation estimation.
- Various direct and indirect methods have been used but still not clear about the suitable methods to address beam blocking problems (Zrnic and Ryzhkov, 1996, Vivekanandan et al., 1998, Germann et al., 2006, Lang et al., 2009).

**FIG.1.** Schematic diagram shows major errors: attenuation and partial beam blockage during the radar operation.
Study area & observation

FIG. 2. Study area; (a) Location of the MP-X (Ebina) radar over the whole map of Japan. (b) Coverage range of radar observation in the Kanto region. (c) Close view of Hakone region (area of red rectangle in Fig. b). Red circles are the location of raingauge stations. Triangle and star symbol are the location of JW and 2DVD disdrometers and raingauge.
FIG. 3. PPI images of BBR (Beam Blockage Rate) and $Z_{H_{att}}$ at elevation angles between $1.4^\circ$ and $2.7^\circ$.

FIG. 4. Range profiles of $Z_{H_{att}}$ and corresponding BBR at elevation angles between $1.4^\circ$ and $2.7^\circ$. Two black dots indicate $Z_{H_{dsr}}$ derived from disdrometer observations located close to an azimuth angle of $241^\circ$. 
TABLE 2. Dates, durations, and surface data collection methods for the selected rainfall events. Time periods reflect the start and end of rainfall

<table>
<thead>
<tr>
<th>Name of event</th>
<th>Date</th>
<th>Time period</th>
<th>Surface observation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Start (UTC)</td>
<td>End (UTC)</td>
</tr>
<tr>
<td>Case_1</td>
<td>09 Oct 010</td>
<td>11:00</td>
<td>15:00</td>
</tr>
<tr>
<td>Case_2</td>
<td>29 Oct 010</td>
<td>14:30</td>
<td>23:20</td>
</tr>
<tr>
<td>Case_3</td>
<td>04 Jul 011</td>
<td>13:50</td>
<td>14:40</td>
</tr>
<tr>
<td>Case_4</td>
<td>07 Jul 011</td>
<td>11:00</td>
<td>18:30</td>
</tr>
<tr>
<td>Case_5</td>
<td>19 Jul 011</td>
<td>12:00</td>
<td>15:00</td>
</tr>
<tr>
<td>Case_6</td>
<td>19 Jul 011</td>
<td>20:00</td>
<td>0:00</td>
</tr>
<tr>
<td>Case_7</td>
<td>19 Aug 011</td>
<td>7:45</td>
<td>10:15</td>
</tr>
<tr>
<td>Case_8</td>
<td>21 Sep 011</td>
<td>2:00</td>
<td>7:00</td>
</tr>
</tbody>
</table>
Modified DEM method

The reflectivity observed over the mountainous region can simply expressed in logarithmic form

\[ 10^{Z_{H_{\text{dem}}}} = 10^{Z_{H_{\text{att}}}} - 10 \times (1 - BBR) \]  

where, \( Z_{H_{\text{dem}}} \) and \( Z_{H_{\text{att}}} \) are the corrected reflectivity using DEM method and attenuation corrected reflectivity. BBR is the fractional beam blockage rate.

The filtering process, ground clutter, and other additional problems frequently occur in the presence of PBB in mountainous regions, and which should be addressed. In such case, DEM method can be modified as follows

\[ 10^{Z_{H_{\text{mod}_{\text{DEM}}}}} = 10^{Z_{H_{\text{att}}}} - 10 \times (1 - BBR) - 10 \times F \]

Factor \( F \) represents the power loss caused by unknown errors over the mountainous area, and is considered to be zero in the case of no PBB.
Eq. (2) expressed in terms of the elevation angle ($\theta$) is

$$10 \ H_{\text{mod}_{-} \text{dem}} \equiv 10 \ H_{\text{att}} - 10 \ H_{\text{mod}_{-} \text{dem}}$$

$$= 10 \ H_{\text{att}} - 10 \ H_{\text{mod}_{-} \text{dem}} - 10 \ H_{\text{att}}$$

$$= 10 \ H_{\text{att}} - 10 \ H_{\text{att}}$$

$$= 10 \ H_{\text{att}} - 10 \ H_{\text{att}}$$

$$\Delta Z_{H} \rightarrow 0 \text{ (if BBR=0)}$$

FIG. 5. Schematic diagram showing the identification of true reflectivity at a PBB elevation angle $\theta$. 

$Z(\theta)_{\text{H}_{-} \text{mod}_{-} \text{dem}} = Z(\theta^{*})_{\text{H}_{-} \text{att}}$

Mountain

Mountain

$\theta^{*}$

$\theta = \theta^{*}$
Modified DEM method

Assumption:

- No significant change should be present in the vertical profile of precipitation amounts.
- Upper fixed elevation angle (with no partial beam blockage) should be below melting layer.
- PPI scanning elevation angles should be altered in small steps; e.g., from 0.2° to 0.5°, depending on the location of the radar and the topography. I.e. special observation is required.

Limitation:

- Method cannot be applied in the case of significant change in vertical profile of the precipitation amounts.
- Method cannot be applied if beam blockage rate reaches about 100%.
Validation of attenuation correction:

Method proposed by Bringi et al. (2001) is used for the attenuation correction.

![Figure 6](image)

**FIG. 6.** Comparison of time series of $Z_{H_{\text{att}}}$ and $Z_{H_{\text{raw}}}$ over the Kowakien station disdrometer site at an elevation angle of 1.9°, from 20:00 to 24:00 UTC on 19 July 2011. Error bars indicate the standard deviation of the radar data.

| Name   | Time periods (UTC) | cor  | MAE (dB) | RMSE (dB) | NE (%)  | NB (%)
|--------|--------------------|------|----------|-----------|---------|-------
| Case_3 | 13:45-15:00        | 0.84 | 3.71     | 4.91      | 11.63   | -1.64
| Case_4 | 13:00-16:00        | 0.40 | 3.52     | 4.51      | 15.87   | -12.35
| Case_5 | 12:00-17:00        | 0.90 | 4.16     | 5.11      | 12.48   | -2.59
| Case_6 | 20:00-24:00        | 0.85 | 2.97     | 4.92      | 9.08    | -3.96
| Case_8 | 02:15-07:30        | 0.79 | 2.33     | 3.17      | 5.98    | 0.21

**TABLE 2.** Relationship between $Z_{H_{\text{att}}}$ (at an elevation angle of 1.9°) and $Z_{H_{\text{dsd}}}$ for five rainfall events over the Kowakien station.
Results

Relationship between $\Delta Z_H$ and BBR:

FIG. 7. Relationship between $\Delta Z_H$ and BBR for the eight rainfall events. The solid line is the average of all events.
Results

PBB correction:

**FIG.8.** Range profiles of reflectivity and corresponding BBR: (a) $Z_{H\_att}$, (b) $Z_{H\_dem}$, (c) $Z_{H\_mod\_dem}$ and (d) BBR at elevation angles between 1.4° and 2.7° on 19 July 2011. Two black dots indicate $Z_{H\_dsd}$, derived from disdrometer observations located close to an azimuth angle of 241°.
Results

PBB correction:

FIG. 9. PPI images of $Z_{H_{\text{dem}}}$ (top) and $Z_{H_{\text{mod\_dem}}}$ (bottom) at elevation angles of 1.7° and 1.9° on 19 July 2011.
Results

Validation of modified DEM method:

TABLE 3. Relationship between $Z_{H_{\text{mod\_dem}}}$ and $Z_{H_{\text{dsd}}}$ at different elevation angles over the Prince station on 19 July 2011.

<table>
<thead>
<tr>
<th>Elevation angle</th>
<th>cor</th>
<th>MAE (dB)</th>
<th>RMSE (dB)</th>
<th>NE (%)</th>
<th>NB (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.4°</td>
<td>0.83</td>
<td>2.18</td>
<td>2.86</td>
<td>5.87</td>
<td>1.65</td>
</tr>
<tr>
<td>1.7°</td>
<td>0.85</td>
<td>2.88</td>
<td>3.76</td>
<td>8.13</td>
<td>-4.98</td>
</tr>
<tr>
<td>1.9°</td>
<td>0.88</td>
<td>3.14</td>
<td>3.81</td>
<td>9.01</td>
<td>-4.90</td>
</tr>
<tr>
<td>2.1°</td>
<td>0.89</td>
<td>4.04</td>
<td>4.82</td>
<td>11.67</td>
<td>-9.73</td>
</tr>
<tr>
<td>2.7°</td>
<td>0.89</td>
<td>3.23</td>
<td>4.36</td>
<td>9.34</td>
<td>-7.06</td>
</tr>
</tbody>
</table>

FIG. 10. Comparison of time series of $Z_{H_{\text{dsd}}}$, $Z_{H_{\text{dem}}}$, and $Z_{H_{\text{mod\_dem}}}$ over the Prince station disdrometer site at elevation angles of 1.4° and 1.7° between 20:00 and 24:00 UTC, 19 July 2011. Error bars indicate the standard deviation of the radar data.
Results

Rainfall estimation: Derived an appropriate Z-R relationship based on scatter simulation using all events of disdrometer data at Kowakien (located around the mountain).

Kowakien: Derived an appropriate Z-R relationship based on scatter simulation using all events of disdrometer data at Kowakien (located around the mountain).

Prince: Derived an appropriate Z-R relationship based on scatter simulation using all events of disdrometer data at Kowakien (located around the mountain).

FIG. 11. Comparison of time series of $R(Z_{H_{mod\_dem}})$ and $R(\text{Gauge})$ at elevation angles of 1.7° (top) and 1.9° (bottom) between 20:00 and 24:00 UTC, 19 July 2011. Error bars indicate the standard deviation of the radar data.
Results

Rainfall estimation:

FIG. 12. Scatter plot of $R(Z_{H\text{-mod\_dem}})$ and $R(\text{Gauge})$ 10-minute average rain rates from four rainfall events at an elevation angle of 1.7°.

<table>
<thead>
<tr>
<th>Station name</th>
<th>1.4°</th>
<th>1.7°</th>
<th>1.9°</th>
<th>2.1°</th>
<th>2.7°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kowakien</td>
<td>BBR</td>
<td>NE</td>
<td>NB</td>
<td>BBR</td>
<td>NE</td>
</tr>
<tr>
<td>Yunohana</td>
<td>14</td>
<td>29</td>
<td>-3</td>
<td>&lt;1</td>
<td>29</td>
</tr>
<tr>
<td>Prince</td>
<td>29</td>
<td>30</td>
<td>4</td>
<td>28</td>
<td>-6</td>
</tr>
<tr>
<td>Fuji View</td>
<td>62</td>
<td>27</td>
<td>5</td>
<td>30</td>
<td>23</td>
</tr>
</tbody>
</table>

TABLE 4. BBR, together with NE and NB of 10-minute average rain rates obtained from reflectivity corrected by the modified DEM method [$R(Z_{H\text{-mod\_dem}})$] for different elevation angles at the five raingauge stations.
Results

Spatial distribution:

FIG. 13. One-hour accumulated rainfall between 22:00 and 23:00 UTC, 19 July 2011 for elevation angles of 1.7° and 1.9°.
Conclusion

• We conclude that the DEM method is not appropriate for correcting PBB, even though it has been widely used for this purpose due to its simplicity.

• Corrected reflectivity using the modified DEM method showed good agreement with reflectivity derived from disdrometer observations, which indicates that this modified DEM method can be an effective approach to overcoming the effect of beam shielding in mountainous areas.

• Estimated rainfall rates derived from reflectivity corrected using the modified DEM method were also tested against rainfall rates based on raingauge data, showed a good agreement between radar and gauge observation which also support the accuracy of modified DEM method.

• The amount of missing reflectivity data was greatest at higher BBRs, and the probability of uncertainty in \(\Delta Z_H\) increases at a higher BBR. Therefore, we suggest that the modified DEM method is applicable up to a BBR of 70% when calculating QPE.
Thank you very much

Questions and suggestions ???

Photo: Hakone top © Shakti, 2010

ERAD 2012 Toulouse, France, 25-29 June 2012