An accurate quantitative precipitation estimation (QPE) is one of the most important elements in meteorological and hydrologic analyses. Extensive research efforts were devoted during the last few decades to develop rainfall estimation methods based on meteorological radar data combined with rain gauge information. While a considerable number of papers deal with radar-based QPE in temperate climatic regimes, only few have focused on dry climatic regions that occupy more than a quarter of the world land area.

The objective of the current study is to examine methods for radar-based QPE of storm rain depth for Israel, where the climate ranges from Mediterranean to dry types.

Israel is located at the southeast corner of the Mediterranean Sea. Israel climate varies from Mediterranean to dry with a sharp gradient of annual rainfall from 1500 mm in the north to only 30 mm in the south. Annual rainfall amounts increase with latitude and elevation and decreases with distance from the coast.

Data & Methods

Storm characteristics:

<table>
<thead>
<tr>
<th>Storm</th>
<th>Rain Depth (mm)</th>
<th>Topography</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mediterranean (V1-V5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mediterranean (V1-V5)</td>
</tr>
</tbody>
</table>

The analysis was applied to the twenty eight storms in the five-year record. The level of fit between the estimates and the gauge data in the validation areas may be interpreted as the performance of the radar rainfall estimation method in ungagged areas. In order to evaluate the achieved fit, rainfall estimates based solely on gauge data were computed using the IDW and Kriging spatial interpolation methods.

Scores of fit (weighted averaged scores)

<table>
<thead>
<tr>
<th>Method</th>
<th>Bias</th>
<th>RMSE</th>
<th>MAE</th>
<th>MBE</th>
</tr>
</thead>
<tbody>
<tr>
<td>WMR</td>
<td>0.49</td>
<td>0.94</td>
<td>0.84</td>
<td>0.62</td>
</tr>
<tr>
<td>Bulk</td>
<td>0.46</td>
<td>1.05</td>
<td>1.01</td>
<td>0.99</td>
</tr>
<tr>
<td>Kriging</td>
<td>0.51</td>
<td>1.07</td>
<td>1.01</td>
<td>0.98</td>
</tr>
</tbody>
</table>

Sensitivity Analysis

The effect of gauge density in training data set on error in validation areas was examined. The validation data were grouped into two categories according to their climate regime and the two areas with significant underestimations (V6 and V7) were removed from this analysis. The results indicate that applying the WMR method, 50 gauges (average density of one gauge per 470 km²) are more or less sufficient to achieve a stable error level of about 40% in terms of MSE and 0.9 in terms of Bias. Low sensitivity to gauge number is evident for the bulk adjustment method. The IDW method presents some sensitivity to gauge number for the dry climate areas.

Summary

Quantitative precipitation estimation based on radar and gauge data were derived for Mediterranean and dry climate regimes in Israel. The weighted multiple regression (WMR) method resulted in the lower level of errors for validation areas at range less than 100 km from the radar. For the Mediterranean validation areas that are less than 100 km distance from the radar (V1-V5) radar-based rainfall estimates are better than the gauge-only interpolation with the best performances of the WMR method. For the two far Mediterranean validation areas, V6 and V7, a significant underestimation of the radar-based rainfall methods is presented, most probably resulted from radar beam overshooting. For the all four dry climate validation areas (V8-V11) radar-based estimates are considerably better than gauge interpolation. The WMR method outperforms in all cases and the bulk adjustment method also results in relatively good level of fit. Gauge interpolation in these areas result in poor estimation of rainfall because of the insufficient gauge density.

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Radar Rainfall Estimation

Initial power-law

\[ Z = 316.8^R \]

Adjustment by dividing to Radar-to-Gauge ratio \( F = P/G \) or in log scale \( F = 10 \log_{10} F \) where G is gauge rain depth and P is the initial radar rain depth estimate above the gauge.

Gauge adjustment methods:

1) Bulk Adjustment: \( F_{ba} \) is assumed uniform and derived by

\[ F_{ba} = 10 \log_{10} \sum_{G} F/G \]

2) Weighted Multiple Regression – WMR:

\[ F_{w} = a_0 + a_1 \log(D) + a_2 \log(H) + a_3 L \]

Range dependency of radar-rainfall error

For the Mediterranean validation areas that are less than 100 km distance from the radar (V1-V5) radar-based rainfall estimates are better than the gauge-only interpolation with the best performances of the WMR method. For the two far Mediterranean validation areas, V6 and V7, a significant underestimation of the radar-based rainfall methods is presented, most probably resulted from radar beam overshooting. For the all four dry climate validation areas (V8-V11) radar-based estimates are considerably better than gauge interpolation. The WMR method outperforms in all cases and the bulk adjustment method also results in relatively good level of fit. Gauge interpolation in these areas result in poor estimation of rainfall because of the insufficient gauge density.

Training & Validation

Eleven 20x20 km² validation areas were defined for the analysis representing different climate regimes, terrain complexity and distance from radar system. Training is done for each storm by computing the radar-to-gauge ratios according to the above methods based on data in the training data set, which is composed from 247 gauges located outside the validation areas, and tested for the validation data sets for the same storm.

Application

The WMR method almost completely removes range-dependent errors in the radar estimates within the 100 km range.


Radar-ground clutter and beam blockage procedures:

Spatially-variant radar elevation angles were used such that the beam centre lays at least in a whole beam with and additional 500 meters above the ground, and has a clear sight from the radar to the test point.

The analysis was applied to the twenty eight storms in the five-year record. The level of fit between the estimates and the gauge data in the validation areas may be interpreted as the performance of the radar rainfall estimation method in ungagged areas.