Radar-based quantitative precipitation estimation over Mediterranean and dry climate regimes

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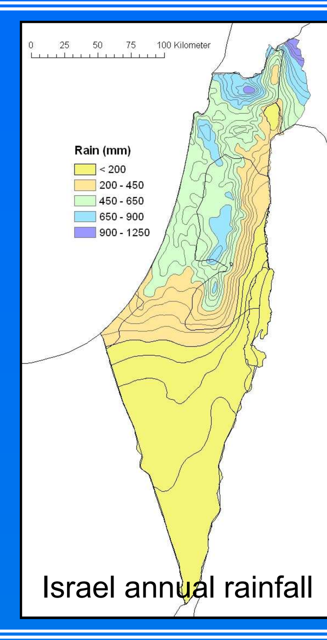
Introduction

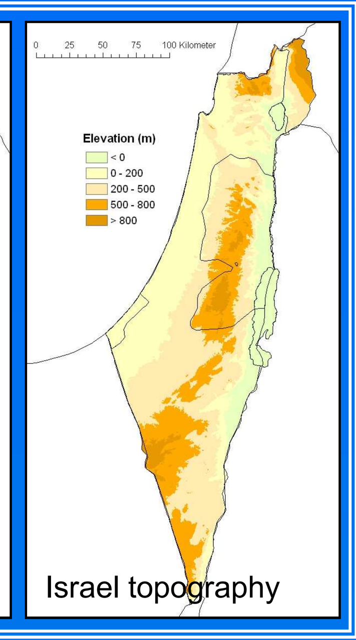
An accurate quantitative precipitation estimation (QPE) is one of the most important elements in meteorological and hydrologic analyses. Extensive research efforts were devoted during the last few decades to develop rainfall estimation methods based on meteorological radar data combined with rain gauge 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 word 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.

Study Region

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.


Israel annual rainfall


Israel topography

Data & Methods

Data:

Record: 1998/1999 – 2002/2003.

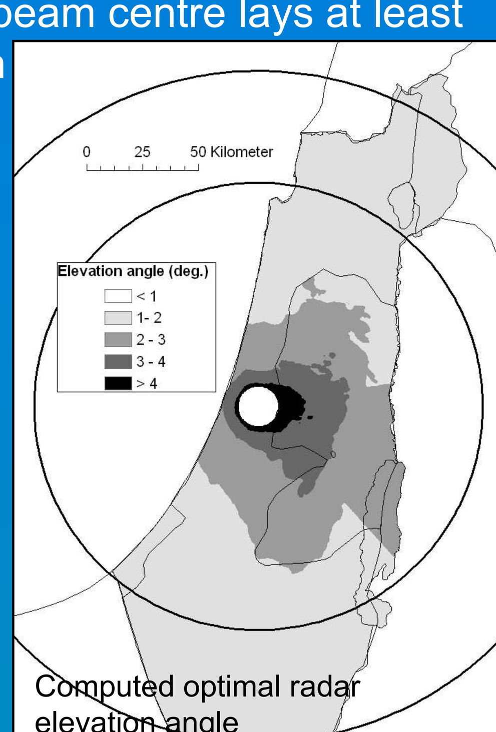
Radar data: 5 minutes time resolution, 1.4°x1 km spatial resolution.

Gauge data: daily rain depth.

Estimated data: storm rain depth.

Radar ground-clutter and beam blockage procedures:

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



Computed optimal radar elevation angle

Storm characteristics:

Storm	From	To	Ng	Mean(mm)	Min(mm)	Max(mm)	Std(mm)
1	14/12/1998	01/01/1999	199	77.1	0.2	284.4	64.1
2	12/12/1999	15/12/1999	193	34.1	0.4	92.3	19.9
3	24/12/1999	27/12/1999	192	11	0.3	33.5	6.7
4	01/01/2000	12/01/2000	199	111	1.1	227.9	40.4
5	14/01/2000	02/02/2000	199	164.4	16.3	317	60.6
6	05/02/2000	06/02/2000	167	3.9	0.1	18.7	3.8
7	12/02/2000	17/02/2000	194	49.7	0.3	107.5	23
8	07/12/2000	26/12/2000	202	106.2	10.1	165.3	30.7
9	02/01/2001	06/01/2001	190	8.3	0.1	31.9	5.8
10	16/01/2001	25/01/2001	199	79.9	17.1	168.6	30.2
11	03/02/2001	09/02/2001	197	34.1	2.8	78.6	13.3
12	13/02/2001	24/02/2001	197	53.2	2.9	105.9	17.8
13	15/11/2001	17/11/2001	181	8.5	0.1	50.2	8.3
14	25/11/2001	27/11/2001	187	12.4	0.4	52.6	9.3
15	29/11/2001	09/12/2001	204	147.1	1.2	416.8	70.5
16	12/12/2001	15/12/2001	198	15.5	0.1	46.5	9.8
17	18/12/2001	21/12/2001	195	27.3	3.8	59.3	13.7
18	02/01/2002	16/01/2002	201	125.3	12.3	234.5	43.5
19	19/01/2002	23/01/2002	199	35.2	3.8	93	16.3
20	27/01/2002	30/01/2002	200	16.7	1.7	40.7	8
21	12/03/2002	22/03/2002	177	25.5	0.2	124.8	23.9
22	25/03/2002	07/04/2002	198	74.8	7.1	166.2	33.2
23	23/11/2002	25/11/2002	191	6.4	0.3	25.5	4.9
24	08/12/2002	12/12/2002	200	48.1	6.3	121	21.2
25	15/12/2002	27/12/2002	200	131.2	14.8	269.3	37.2
26	13/01/2003	23/01/2003	200	41.1	6.2	115.9	16.2
27	27/01/2003	30/01/2003	147	48.4	0.2	171.9	46.1
28	01/02/2003	27/03/2003	199	378.5	11.7	742.5	132.2

Radar Rainfall Estimation

Initial power-law: $Z = 316R^{1.5}$

Adjustment by dividing to Radar-to-Gauge ratio $F = P^*/G$ or in log scale $F_{dB} = 10Log_{10}F$

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_{dB} is assumed uniform and derived by: $F_{dB} = 10Log_{10}\sum_{i=1}^{N} P^*_i \Big/ \sum_{i=1}^{N} G_i$

2) Weighted Multiple Regression – WMR: $F_{dB} = a_0 + a_D Log(D/60) + a_H H + a_L(L-32)$

where D is distance from the radar (km), H is ground height above sea level (km), and, L is latitude in decimal degrees.

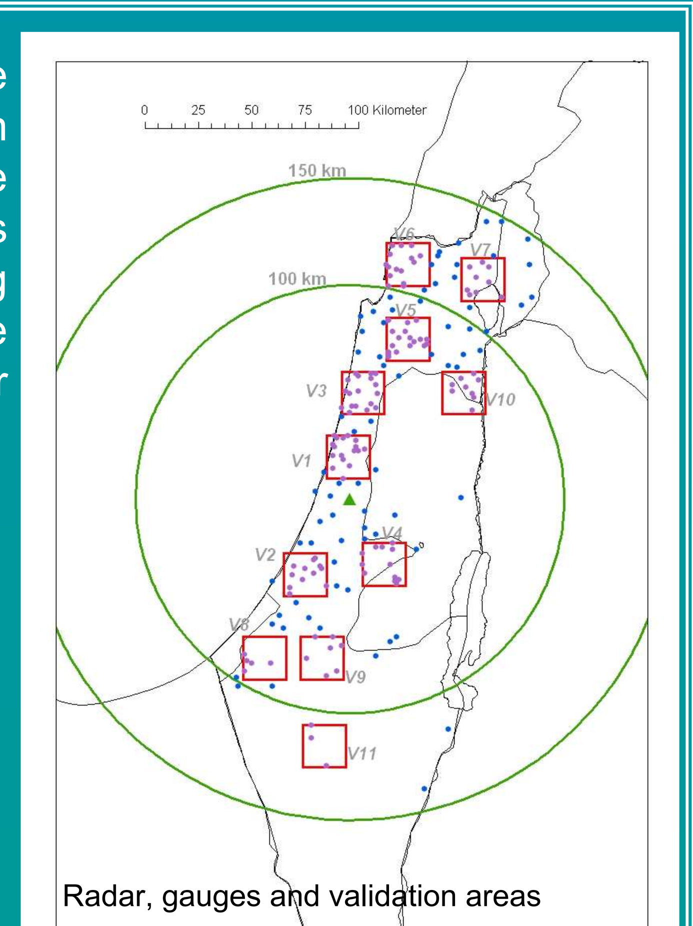
Parameters: a_0, a_D, a_H, and a_L are derived by weighted multiple regression between the dependent variable, F_{dB}, at gauge location and the independent variables for each gauge according to the equation above.

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 74 gauges located outside the validation areas, and tested for the validation data sets for the same storm.

Validation area characteristics:

Num	Gauge num	Height Mean (m)	Radar height mean (m)	Mean distance (km)	Annual rain (mm)	Climate regime
V1	15	49	1025	23	586	Mediterranean
V2	9	71	1302	40	453	Mediterranean
V3	18	42	1574	51	595	Mediterranean
V4	18	663	1881	34	549	Mediterranean
V5	17	120	2104	79	579	Mediterranean
V6	12	128	2637	112	688	Mediterranean
V7	12	148	2918	119	546	Mediterranean
V8	9	105	2007	89	231	Dry
V9	5	288	2244	73	227	Dry
V10	7	-36	2244	76	342	Dry
V11	1	357	2772	115	110	Dry



Radar, gauges and validation areas

Application

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 ungauged 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)

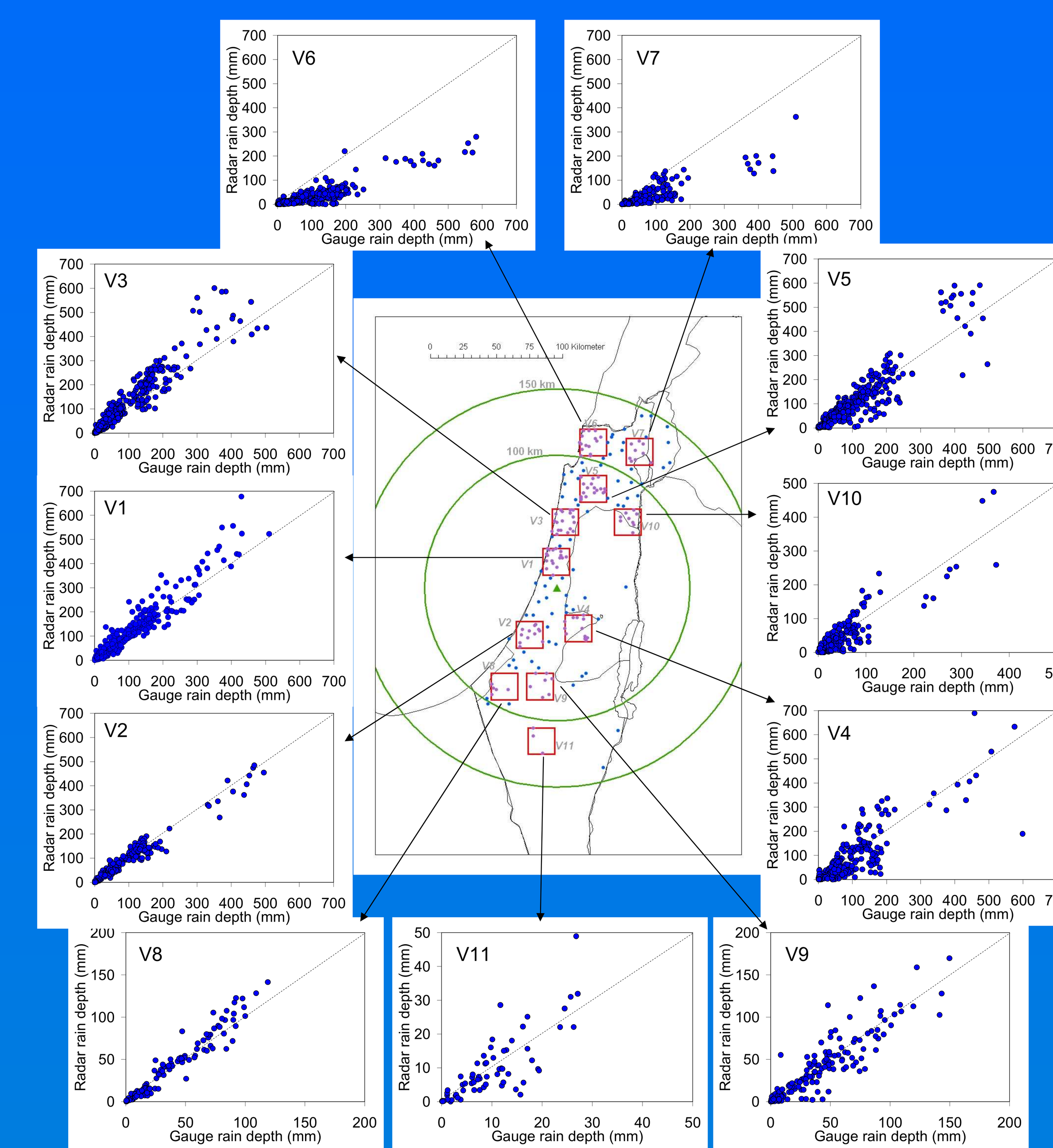
Bias $\sum_{i=1}^{N} P_i \Big/ \sum_{i=1}^{N} G_i$

	BulkAdj	WMR	KRIG	IDW
V1	2.64	1.12	0.84	0.94
V2	1.74	1.00	0.62	0.74
V3	1.86	1.30	0.90	0.82
V4	1.29	0.93	0.59	0.90
V5	1.05	1.01	0.80	0.88
V6	0.26	0.32	0.99	0.85
V7	0.35	0.44	0.87	0.83
V8	1.19	1.08	0.80	0.60
V9	1.09	0.97	0.80	1.80
V10	1.11	0.97	0.84	1.61
V11	0.89	1.00	0.64	7.12

Fractional Standard Error

$$\sqrt{\frac{1}{N}\sum_{i=1}^{N}(P_i - G_i)^2} \Big/ \frac{1}{N}\sum_{i=1}^{N} G_i$$

	BulkAdj	WMR	KRIG	IDW
V1	1.80	0.32	1.11	0.47
V2	0.80	0.19	0.93	0.42
V3	0.93	0.41	1.13	0.48
V4	0.80	0.49	0.90	0.61
V5	0.36	0.34	1.01	0.52
V6	0.78	0.72	1.14	0.50
V7	0.69	0.61	1.13	0.30
V8	0.29	0.21	1.09	0.48
V9	0.38	0.30	0.82	1.02
V10	0.47	0.47	1.05	0.77
V11	0.47	0.46	0.95	6.31

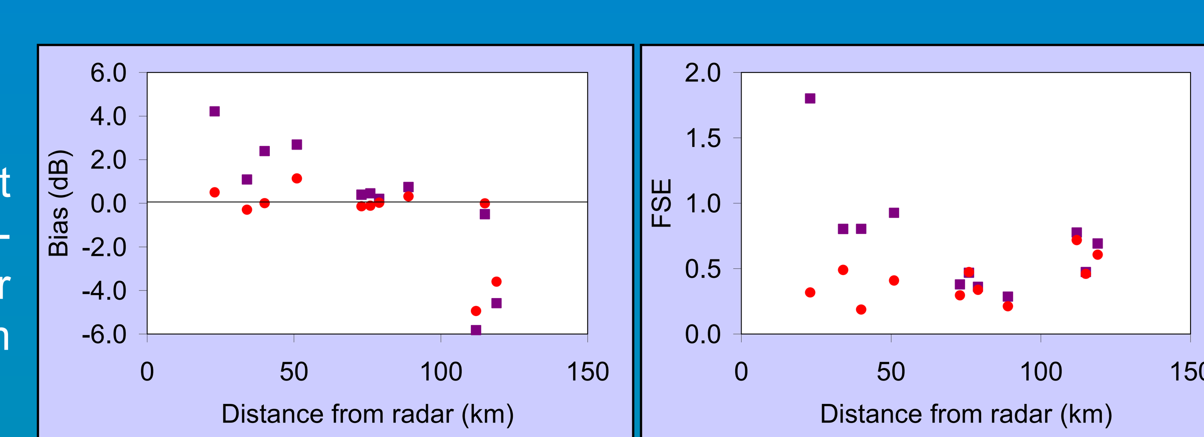


Comparison of gauge and radar-based storm rain depth in validation areas

For the Mediterranean validation areas that are less than 100 km distance from the radar (V1-V5) radar-based rainfall estimations 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.

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

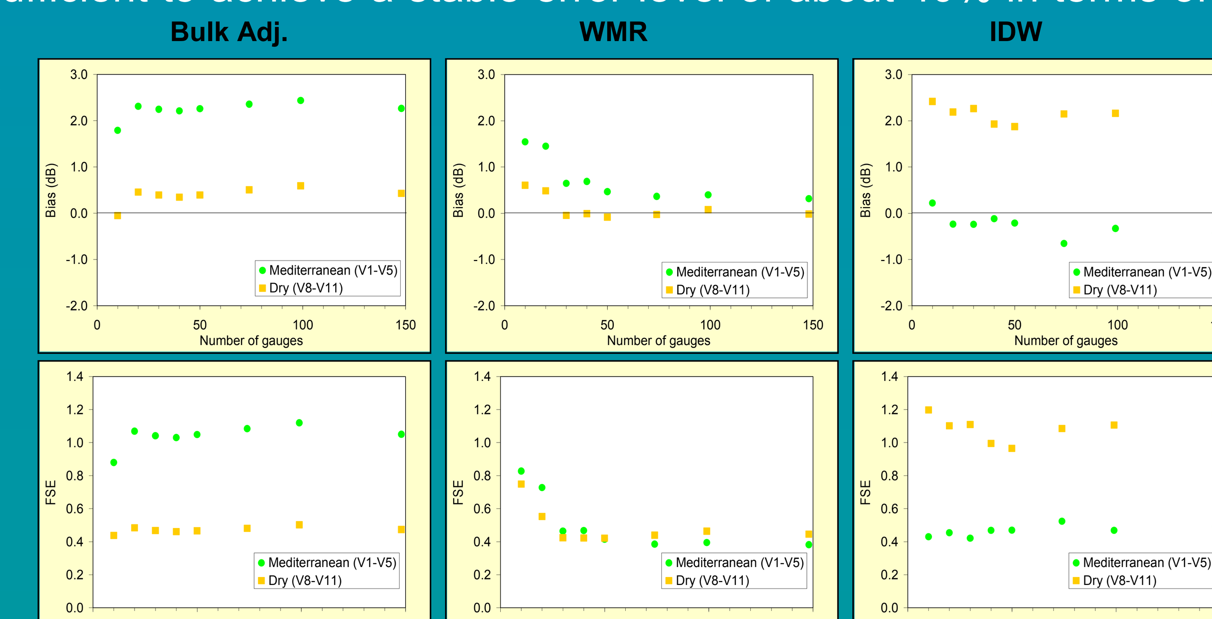


Range dependency of radar-rainfall error

Sensitivity Analysis

The effect of gauge density in training data set on error in validation areas was examined. The validation areas 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 FSE and 10% (0.4 dB) 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.



Sensitivity of rainfall estimate errors to number of gauges in the training data set

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. In the dry climate validation areas the standard bulk adjustment method also provided relatively good estimates. Radar-based estimates outperformed gauge interpolation estimates.

Acknowledgements. Radar data were provided by E.M.S Mekorot and gauge data by the Israel Meteorological Service. Partial funds for the research project were provided by the Israel Science Foundation (grant no. 880/04), the Israel Ministry of Science and Technology and the Israel National Water Commissioner.