Reply

P. ALPERT, N. HALFON, AND Z. LEVIN

Department of Geophysics and Planetary Sciences, Tel Aviv University, Tel Aviv, Israel

(Manuscript received 8 January 2008, in final form 23 February 2009)

1. Introduction

In their comment, Givati and Rosenfeld (2009, hereinafter GR09) carry out a new analysis of the rain data in central and northern Israel and obtain the following results:

1) The orographic ratio (Ro) in central Israel between the mountain stations and the upwind stations with correlation coefficient of $r < 0.8$ did not decrease. They found a different result when the orographic ratio was computed between mountain stations and those stations with $r > 0.9$.
2) GR09 did not find a significant change in Ro in northern Israel except for the stations that are located at distances greater than 30 km from the seashore.
3) In both central and northern Israel at distances of a few kilometers from the seashore, GR09 found a slight increase in annual precipitation.

In this reply, we put the results presented by GR09 into a spatial context and show that the above three findings completely agree with and actually strengthen the conclusions of Alpert et al. (2008, hereinafter AHL08). At the same time, these results contradict the theory presented by Givati and Rosenfeld (2004, 2005, hereinafter GR04 and GR05).

2. Central Israel

GR09's analysis completely agrees with AHL08 about the lack of decrease of orographic rainfall with respect to the control seashore stations. As was mentioned above, GR09 found that the orographic ratio between the mountain stations and those that correlate with them with $r < 0.8$ (almost 50% of the cases) *did not change*. In Fig. 1 we show the distribution of all correlation values between the annual rainfall in each of the seashore and inner plain stations and the 14 mountain stations. It is not surprising to see that the correlations between most stations along the seashore and the mountain stations fall in GR09's lowest correlation category of $r < 0.8$. This is because the seashore stations are the farthest away from the mountain stations and are also the ones that do not have any orographic effects (see also Table 1). GR09 analyzed only Ro of seashore and mountain stations with annual rainfall correlation of $r > 0.85$ (see their Fig. 4b). These represent only 31 out of a total of 168 station pairs (18%) in the seashore strip. However, even in this limited analysis of GR09 it can be seen that the Ro slopes between the mountain stations and the stations at a distance of <10 km from the seashore are equally distributed around zero. In Fig. 2 we further expand this analysis and show that Ro for the 10 stations that are located next to the seashore (0–4 km from it) tends to be slightly positive, contradicting GR04's theory.

Viewing these results of GR09 in a spatial geographic dimension, it becomes clear that there is no basis for the claim that there is a decrease in rainfall in central Israel as compared with the seashore stations, regardless of their correlation. This is in agreement with the results of AHL08.

It is important to reemphasize what AHL08 argued—that the stations along the seashore (0–4 km from the shoreline), which are less affected by anthropogenic pollution, are the only ones that should serve as an uninterrupted reference or control for checking the theory about the suppression of orographic precipitation by air pollution. Furthermore, this narrow strip best represents the potential of the uninterrupted rain that enters Israel from the Mediterranean Sea, because from here on eastward the cloud system leaves the main source of its water vapor and its energy.

Corresponding author address: P. Alpert, Department of Geophysics and Planetary Sciences, Tel Aviv University, Ramat Aviv, Tel Aviv 69978, Israel.
E-mail: pinhas@cyclone.tau.ac.il

DOI: 10.1175/2009JAMC1943.1

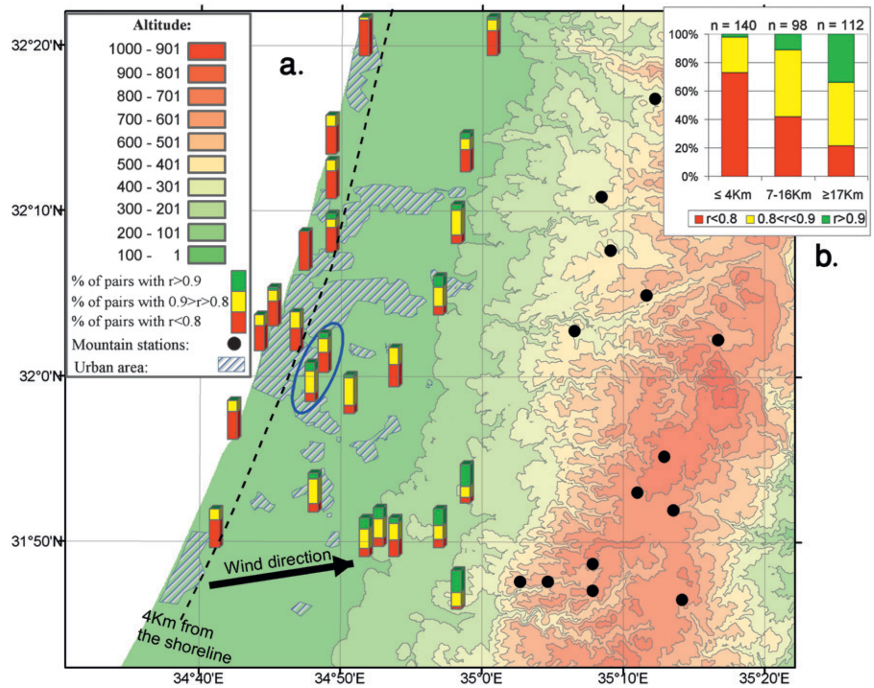

FIG. 1. The annual rainfall distribution of all correlation values between the plain stations and the 14 mountain stations paired with them by GR09: (a) each individual seashore and inner plain stations and (b) accumulated and sorted into three categories based on distance from the coast line. The categories are divided into a control region as defined by AHL08 (the seashore region up to 4 km from sea—see explanation in AHL08), and two inner plain regions, each containing an approximately equal number of rain gauge stations. Here *n* represents the total number of station pairs between each station in each strip and the 14 mountain stations. This figure and Fig. 2 are based on the calculations of GR09's Table 3. The two plain stations encircled in blue are discussed in the text and in Fig. 2.

As to the claim by GR09 that they observed a decrease in Ro for stations with annual rainfall correlation of $r > 0.8$ with the mountainous stations (especially the cases of $r > 0.9$), we can see in Figs. 1 and 2 that all those cases are only relevant to the inland stations and do not apply to the seashore stations. These inner stations are located downwind of the urban area at elevation of 50–340 m above sea level and are therefore influenced by urban effects (e.g., heat island, physical barrier, changes in moisture, albedo, and air pollution) and some dynamic orographic lifting of the air mass. If we combine the third finding of GR09, which in agreement with AHL08 shows that a small increase is observed in rainfall a few kilometers from the seashore (thus increasing the denominator in the ratio of mountain to inland stations), then it becomes clear why Ro between the mountain and these inland stations tends to decrease, as was pointed out by AHL08.

3. Northern Israel

GR09 state that there is no difference in Ro between the mountain stations and the seashore up to a distance of about 30 km from the coast. Figure 3 shows that in northern Israel a strip of 30 km contains in it all of the stations on the western slopes of the Galilee Mountains, all the way to the top of the upper Galilee Mountains and the water divide.

The stations where GR09 found a decrease in the rain amounts as compared with the upwind plain stations are *all on the lee side of the mountains and east of the water divide.* This observation by GR09 is in agreement with AHL08, who reported on a decrease in the annual ratio between the rainfall on the eastern slopes (lee side) and the upwind slope to the west. On the other hand, it is in contradiction with the theory of GR04, who stated in their abstract, "This effect (precipitation suppression due to air pollution) explains the pattern of greatest loss of precipitation at the midlevel of the upwind slopes, smaller losses at the crest, and enhancement at the downslope."

Another mechanism that was supposed to increase precipitation on the lee side (eastern side) of the Galilee Mountains (the catchment basin of the Sea of Galilee) with respect to the rain on the western slopes is the rain enhancement experiments and operations that have

TABLE 1. The linkage between correlation (following GR09's proposition) and the average distance from the seashore and height above mean sea level. Note that increasing the distance from the seashore (and thus the proximity to the mountain stations) corresponds to an increase in the correlation coefficient. Pair stations are all combinations of plain and coastal stations with the 14 mountain stations. There are 14 pairs for each of the 25 plain + coastal stations (350 pairs in total). Note that out of 140 potential pairs between the 10 stations next to the seashore (1–4 km) and the 14 mountainous stations, only 21 (15%) were examined by Givati and Rosenfeld, because of their criteria of rainfall correlation ($r > 0.85$). Also note that the temporal slopes of Ro with these stations are mostly positive, which contradicts the theory of GR04 and GR05. Negative slopes are mostly contributed by two stations at the eastern (polluted) side of the urban area at a distance of about 7–8 km (encircled in blue in Fig. 1a).

Correlation coef	No. of pair stations (% of all 350 pairs)	Mean distance from seashore (km)	Mean elev MSL (m)
$r > 0.9$	52 (15%)	22.0	146
$0.8 < r < 0.9$	131 (37%)	14.0	85
$r < 0.8$	167 (48%)	7.9	50

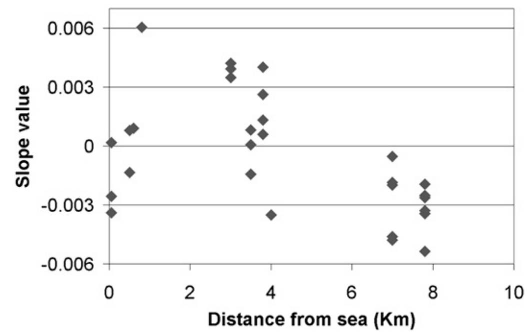

FIG. 2. All of the individual Ro slopes that were accumulated by GR09 in their Fig. 4b (for $D < 10$) but distributed according to their distance from the sea. Note that out of 140 potential pairs between the 10 stations next to the seashore (1–4 km) and the 14 mountainous stations only 21 (15%) were examined by Givati and Rosenfeld because of their criteria of rainfall correlation ($r > 0.85$). Also note that the temporal slopes of Ro with these stations are mostly positive, which contradicts the theory of GR04 and GR05. Negative slopes are mostly contributed by two stations at the eastern (polluted) side of the urban area at the distance of about 7–8 km (encircled in blue in Fig. 1a).

continued since the early 1960s. The results of AHL08 and now of GR09 show the exact opposite and cast more doubt about the success of the cloud-seeding operations in this area. Furthermore, GR09 show that the decrease in Ro is confined to the eastern Galilee while "[i]n the Jordan valley where the precipitation is not orographic, Ro no longer decreases." This statement completely contradicts the claim by GR05 that "[o]rographic clouds are those that mainly responded positively to the seeding in northern Israel."

What is evident from both AHL08 and GR09 is that there is a slight increase in rainfall in the lower western upslope of the Galilee Mountains and a more significant decrease on the lee side of the mountains. As AHL08 and GR09 found in central Israel, so is the case in northern Israel: the slight increase in rainfall a few kilometers from the coast is possibly connected to urban effects that influence the rainfall just downwind, as has been shown by many other works (see AHL08 for more details).

4. Summary

Putting the new analysis of GR09 in a spatial context shows that in agreement with AHL08 no decrease is observed in the orographic precipitation ratio between the stations on the upslope and those at the seashore.

The decreases in Ro that GR09 found are restricted to the eastern slopes of the Galilee Mountains. This contradicts the theory of rainfall suppression presented by GR04 that claims that the decrease in rainfall is found on the western upslope of the mountains. Furthermore, this finding contradicts the claim by GR05 that argues that cloud seeding, which is aimed at increasing rainfall on the eastern slopes of the Galilee Mountains, reaches its maximum impact in regions affected by orographic clouds.

Both GR09 and AHL08 found that a few kilometers downwind of the seashore line and the adjacent urban centers there is a slight increase in annual rainfall. It is therefore clear that calculating Ro between the mountain stations and this region shows a slight decrease due to the larger value in the denominator.

Since the results of GR09 confirm those of AHL08, we do not think it is valuable to repeat our discussion and the reasons why the theory presented by GR04 and GR05 is not valid (at least for Israel); we refer the reader to the original paper of AHL08.

Regarding the increase in rainfall downwind of the seashore, AHL08 raised the hypothesis that at least in part it could be related to urban effects. This idea has been shown to occur in other urban environments and was also shown by others to occur in central Israel (AHL08 and references therein). We did not, however, rule out other reasons for this observed increase.

In summary, we do not rule out the fact that aerosol pollution has some microphysical effects on precipitation, but we argue that other, probably dynamical, factors are much stronger and overshadow the effects of aerosols. This makes the job of identifying the aerosol effects much more complicated, as discussed with a full historical perspective by Levin and Cotton (2008).

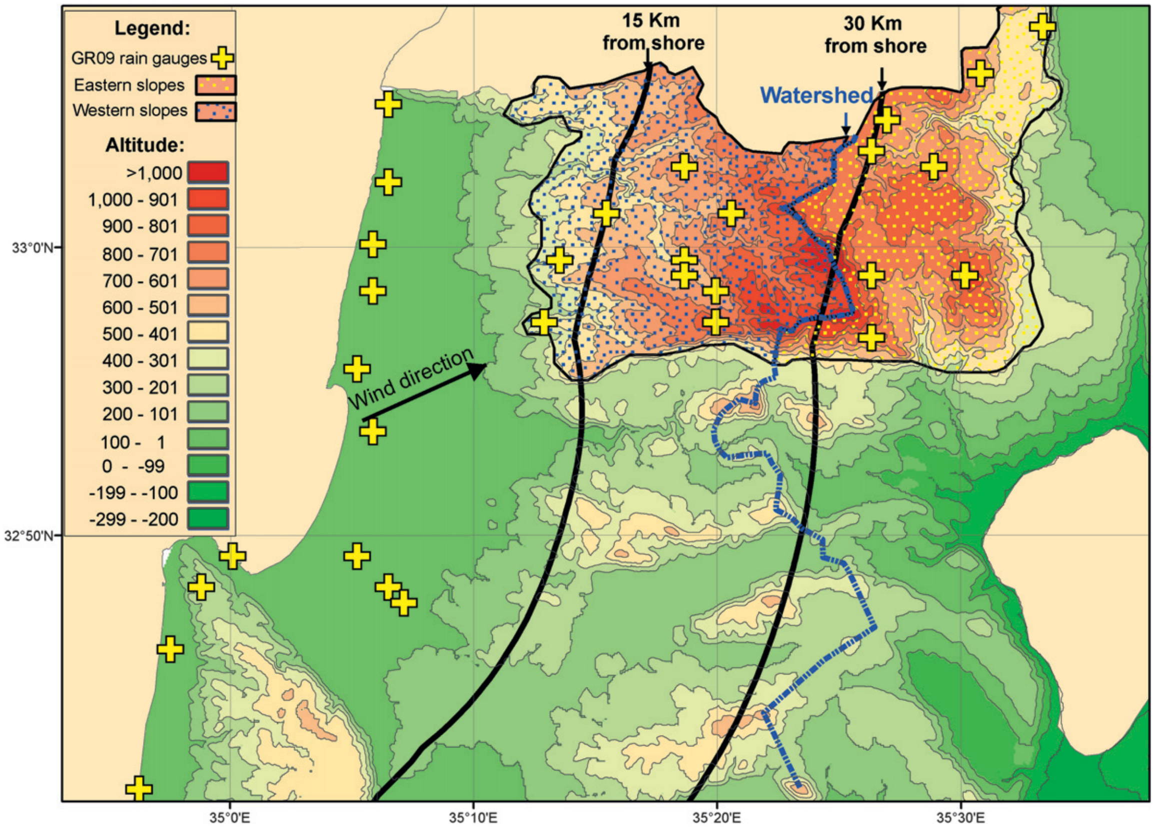

FIG. 3. The spatial distribution of the rain gauges used by GR09 in northern Israel. Note that all stations beyond the 30-km range from the shoreline are located on the eastern slopes (lee side) of the Galilee Mountains.

Acknowledgments. The authors thank the following projects that supported our research: EU-CIRCE, GLOWA-JR funded by MOS/BMBF, and the Israel Water Authority.

REFERENCES

Alpert, P., N. Halfon, and Z. Levin, 2008: Does air pollution really suppress precipitation in Israel? *J. Appl. Meteor.,* **47,** 933–943.

Givati, A., and D. Rosenfeld, 2004: Quantifying precipitation suppression due to air pollution. *J. Appl. Meteor.,* **43,** 1038–1056.

——, and ——, 2005: Separation between cloud-seeding and air-pollution effects. *J. Appl. Meteor.,* **44,** 1298–1315.

——, and ——, 2009: Comments on ''Does air pollution really suppress precipitation in Israel?'' *J. Appl. Meteor.,* **48,** 1733–1750.

Levin, Z., and W. R. Cotton, 2008: *Aerosol Pollution Impact on Precipitation: A Scientific Review*. Springer, 386 pp.