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Winter precipitation fields in the Southeastern Mediterranean area as seen by the Ku-band spaceborne weather radar and two C-band ground-based radars

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ABSTRACT

The spaceborne weather radar onboard the Tropical Rainfall Measuring Mission (TRMM) satellite can be used to adjust Ground-based Radar (GR) echoes, as a function of the range from the GR site. The adjustment is based on the average linear radar reflectivity in circular rings around the GR site, for both the GR and attenuation-corrected *NearSurfZ* TRMM Precipitation Radar (TPR) images. In previous studies, it was found that in winter, for the lowest elevation of the Cyprus C-band radar, the GR/TPR equivalent rain rate ratio was decreasing, on average, of approximately 8 dB per decade. In this paper, the same analysis has been applied to another C-band radar in the southeastern Mediterranean area. For the lowest elevation of the "Shacham" radar in Israel, the GR/TPR equivalent rain rate ratio is found to decrease of approximately 6 dB per decade. The average departure at the "reference", intermediate range is related to the calibration of the GR. The negative slope of the range dependence is considered to be mainly caused by an overshooting problem (increasing sampling volume of the GR with range combined with non-homogeneous beam filling and, on average, a decreasing vertical profile of radar reflectivity). To check this hypothesis, we have compared the same *NearSurfZ* TPR images versus GR data acquired using the second elevation. We expected these data to be affected more by overshooting, especially at distant ranges: the negative slope of the range dependence was in fact found to be more evident than in the case of the lowest GR elevation for both the Cypriot and Israeli radar.

1. Introduction

All ground-based radars have to measure rain from close to long distances from the sensor itself. The radar sampling volume increases with the square of the distance. Since the variability of weather is high in the sampling volume at all ranges, radar echoes are blurred. The systematic component affected by the amount of blurring as well as overshooting with range can be investigated and compensated with a range-adjustment technique. It is known that, on average, the weather signal significantly decreases with height. At longer ranges, the lower part of the sampling volume can be in rain, whereas, the upper part of the same pulse can contain mixed-phase particles or even be without an echo. This overshooting phenomenon at longer ranges is amplified by the decrease of the vertical resolution and the Earth's curvature.

These argumentative effects cause an apparent decrease in the sensitivity of the Ground-based Radar (GR) with range: images of cumulative radar-derived rainfall amounts, using large data sets spanning several months or years clearly show unnatural circular features. The reader can refer, for instance, to Kracmar et al. (1999) for one year cumulative amounts in

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the Czech Republic, Gabella et al. (2005) for two years cumulative amounts in Switzerland, as well as the works by Vignal and Krajewski (2001) and Nelson et al. (2003).

But how does one quantitatively assess the range-dependence? Gabella et al. (2006) proposed to use the first ever spaceborne weather radar onboard the Tropical Rainfall Measuring Mission (TRMM) satellite. Indeed, ground-based and spaceborne sensors provide a complementary view: the GR measures rain from a lateral direction, while the spaceborne radar sees it from the top. On the one hand, the GR measures precipitation using a lateral view from close to long ranges. Because of the large variation, the scattering volume changes dramatically, increasing with the square of the distance. On the other hand, the TPR has the advantage of similar sized scattering volumes in all locations. This objectiveness stimulated the idea of using the TPR to estimate the influence of sampling volume of ground radars. There are two other important facts that would suggest using the spaceborne radar as a reference for the GR: 1) a great deal of effort has been made to provide the TPR with long-term, continuously monitored electronic stability and 2) the calibration factor is assumed to have an accuracy of within 1 dB (Kumagai et al., 1995).

TRMM was launched in November 1997, while the onboard precipitation radar was turned on in observation mode in December 1997. Since the activation of the first spaceborne weather radar onboard the TRMM satellite, it has been possible to monitor meteorological Ground-based Radar (abbreviated hereafter in this paper as GR) throughout the world (at latitudes covered by the satellite, namely, within ±35°) using the TRMM Precipitation Radar (abbreviated hereafter in this paper as TPR), despite the fact that there are enormous differences between the TPR and GR. In this respect, the different sampling volumes, geometrical viewing angles, operation frequencies, attenuation, sensitivity and times of acquisition should be noted. Hence, a quantitative comparison between spaceborne and ground-based weather radar is a challenge, as can be seen in several references (e. g., Bolen and Chandrasekar, 2000; Anagnostou et al., 2001; Liao et al., 2001; Keenan et al., 2003; Bolen and Chandrasekar, 2003; Houze et al., 2004; Amitai et al., 2004).

Results from Gabella et al. (2006) referred to a single site and were limited to the lowest elevation. In this paper, there is a further exploitation of the concept: 1) two sites are analyzed (note that the meteorological focus is still in the same geographical region, namely the southeastern Mediterranean area, where the absence (or presence) of few precipitation events may switch the climate characteristic from semi-arid to arid or vice versa); 2) the overshooting effect is assessed also for the 2nd elevation (as expected it is much larger than for the lowest elevation).

Section 2 provides an overview of the geographical, instrumentation and data characteristics of the two GR used in this study, as well as a brief description of TPR. Section 3 shows how TPR data could be used to adjust ground-based radar echoes as a function of the range from the radar site itself. The procedure has been applied to two Mediterranean sites, one in Cyprus and the other in Israel. Section 4 presents the results for both of these sites, using the lowest and the second elevation of both ground-based radars. The discussion and conclusions in Section 5 close the paper.

2. Study area, instrumentation and data description

2.1. The Doppler radar in Cyprus at 1325 m in altitude (Kykkos site)

In 1995, the Meteorological Service of Cyprus purchased a C-band Doppler radar, designed for nowcasting use. Since its installation on the Kykkos site, weather forecasters have been using the radar to issue warnings for hazardous weather. The interpretation of the radar products is purely qualitative for this application.

The radar was installed on the northwestern, mountainous region of the island. The radar site (Latitude: 34.98°; Longitude: 32.73°), is at 1310 m above-sea-level; the antenna tower is ~15 m. Fig. 1 in Gabella et al. (2006) shows a digital elevation map of the island, the radar site and, above all, the two sectors with considerable beam occultation, which is caused by the Troodos massif in the SE direction and the Tripylos hill in the NW direction. The nearby (10–15 km range) high Olympus peak (1951 m above sea level) in the Troodos massif causes considerable ground clutter, in addition to beam shielding behind it in a “large” sector (approximately between 100° and 140° azimuth). A much narrower sector (between 190° and 200° azimuth) is shielded by the closer Tripylos hill (1450 m above sea level).

With the antenna focus at 1325 m above-sea-level and in standard refractivity conditions, the beam axis at the lowest elevation (0° elevation) reaches a maximum altitude of ~2000 m at a 110 km range, which is the maximum distance used in this paper. The beam axis of the 2nd scan (1° elevation) reaches ~4000 m at the 110 km range. In this study, 2 μs pulses were transmitted with a pulse repetition frequency of 250 Hz. The raw reflectivity values were sampled using a 1° interval in azimuth and 500 m radial resolution range-bins. The main features of the GR are listed in Table 1.

2.2. The radar in Israel at 65 m in altitude (Shacham site)

The Israeli C-band radar is located close to Tel Aviv airport, which is about 15 km off the coast. The radar site (Latitude: 31.99°; Longitude: 34.90°), named Shacham, is at 42 m above-sea-level; the antenna tower is ~23 m. In their paper, Morin and Gabella (2007) display a digital elevation map of the country and the radar site: Israel's physiography consists of 3 main longitudinal strips: the coastal plain, the hilly regions (Galilee, Samaria and Judean Mountains) and the Jordan Rift valley. The hilly ridge east of the radar causes both ground clutter and beam blockage, which represent two major difficulties of radar rainfall estimation in complex terrain. The lowest elevation (1°, see below) is obviously more affected than the second one (1.6°). Additional ground clutter areas surround the radar at closer ranges, up to ~25 km.

With the antenna focus at 65 m and in standard refractivity conditions, the beam axis at 1° elevation (the lowest scan) reaches an altitude of ~2700 m at a 110 km range, which is the maximum analyzed distance in this work. The beam axis of the second scan (1.6° elevation) reaches ~3700 m at 110 km range. In this study, 2 μs pulses were transmitted with a pulse repetition frequency of 250 Hz. The raw reflectivity values were sampled using 1.4° intervals in azimuth and 1000 m radial resolution range-bins. The main features of the GR are listed in Table 1 (see also Gabella et al., 2011).