

Reply to the Reviewers:

As a first note, we would like to express our gratitude for the efforts and work done by the reviewers. The comments we received helped us revise the manuscript and improve it significantly. The major revisions done, based on the main comments will be summarized first and then will be followed by specific point by point answers to all the comments.

General Comments:

In this manuscript we use rain-rate vertical profiles from the TRMM satellite for examination of the spatial and temporal distribution of clouds hydrometeor mass as a function of the distance from coastlines. Based on the reviewers comments we did further analysis of TRMM data and of winds data and we present the results in the revised version. We think the manuscript presents now a more complete picture with smaller uncertainties in the analysis and more evidences to support our hypothesis about the physical mechanisms behind the observed trends.

The main changes done in the revised manuscript:

1) **Substitution of TRMM Product:** Due to the comment that raised the issue of uncertainties attributed to microwave sensors in coastal areas and suspected artifacts in the data, we did further analysis and choose to present in the revised manuscript the results based on the TRMM 2A25 product (based only on the Precipitation Radar) instead of the TRMM 2B31 product (Precipitation Radar + Microwave Imager) that was used in the previous version. To our knowledge, this product serves as the best remote sensing option of rain in coastal areas and is insensitive to sea-land transitions compared to microwave based products. This way we reduced significantly the likelihood for artifacts in the data in coastal regions. Moreover, in the revised version we use the new TRMM 2A25 version 7 product that was recently released as a replacement for version 6. The new version is considered superior over land areas compared to the previous versions.

2) **Addition of Wind Data:** To further support our hypothesis that some of the observed trends in rain rates near coasts are indeed due to mesoscale breezes, we added low-level

wind data from Israeli Meteorological Service radiosondes, for the rain events. Bet Dagan station is located about 10 km from the coast and gives a good indication to the prevailing winds in the region. It gives direct evidence for the frequency of occurrence of land breeze during winter rain events. Additional analysis is done by sorting the rain mass spatial distribution in each event by the winds. Moreover we have added a new analysis using the QuikSCAT wind data to demonstrate convergent and divergent effects over the sea near the coast. Please see the comments below for more details on those new analysis results added to the manuscript.

3) Frictional Convergence (FC): In the revised version, we took into consideration the Frictional Convergence effect that occurs near the coast as a result of the change in the roughness of the surface. This effect is considered now in the manuscript as an equally important mechanism for coastline convergence as the land breeze and orographic forcing effects. Evidences are presented for the impact of this effect and its relative importance compared to the other effects, all influencing together on the rain distribution around coastal regions.

Reply to Reviewer # 1:

Our answers to the comments will be presented point by point (first answering the main comment and then specific comments marked by C#: and answer by A#.)

Main C: Microwave radiometry is known to have a difficulty in rainfall retrieval near coastlines (e.g., Nesbitt et al. 2004, J. Appl. Meteor., 43, 1016-1036; McCollum and Ferraro, 2005, J. Atmos. Oceanic Tech., 22, 498-512). This is because observed brightness temperature could be affected by warm land surface emissions when the radiometer footprint partially contains land surfaces even though the footprint center is located over ocean. In such cases, land surface emissions are often indistinguishable from warm radiation emitted by a thick layer of liquid water, and an anomalously high rain rate could be incorrectly reported. The lowest frequency channel of TMI (10.6 GHz) has an FOV size as large as 60_35 km², and therefore the coastal effect could reach 60 km (or maybe even farther) away from the coast.

It is unclear if combined PR and TMI algorithms suffer from the same problem, but I'm afraid that is quite possible as far as low-frequency brightness temperatures are used for constraining path-integrated attenuation in radar measurements as done by the 2B31 algorithm. Although any coastal rainfall issue may not have been reported for the 2B31 product in the literature as the authors pointed out (line 5 on page 15677), this fact does not totally eliminate my concern, given that the 2B31 product has drawn much less attention in the first place than the individual PR (2A25) and TMI (2A12) products in existing TRMM validation studies. The authors also noted (line 6 on the same page) that they tested 2B31 data around the globe and found no consistent bias in coastal areas, but coastal rainfall biases, if exist, would have a similar magnitude across the globe (to the extent that the coastal microwave emissivity doesn't change very much from one region to another) and would not exhibit much regional contrast in any case. In order to show that the 2B31 data don't have any such artifact, it would be crucial to add another figure comparable to Fig. 5 constructed with the PR rainfall (2A25) product so as to show that the present findings are insensitive to the choice of the dataset to analyze. The PR 2A25 data to be compared wouldn't necessarily have to cover the entire 13 winters but just a few winters may suffice. The TRMM PR is not affected

by surface emissions (except for the lowest levels containing surface clutters) and is free from the issues mentioned above. It would be also beneficial to duplicate the diurnal cycle diagram (Figs. 7 and/or 9) using the PR 2A25 data for reference. Land surface emissions would have a clear diurnal variation due to the surface temperature variability and potentially contaminate real rainfall signals. The author commented on an unexpected afternoon peak of offshore precipitation (line 26 on page 15678), which could be possibly an artifact arising from the radiometric contamination of land surfaces to microwave brightness temperature.

Main A: Thank you for the crucial comment. The major concern regarding the possible artifacts near coastlines when using a product that is based on microwave sensors was checked. We did further analysis and compared the results of the two products, the combined Precipitation Radar (PR) + Thermal Microwave Imager (TMI) product and the 2A25 product which is based only on the PR. Based on this comparison and in order to avoid the likelihood for artifacts we choose to present the 2A25 (PR) product results in the revised manuscript. Even though the PR data is noisier due to sparser sampling, we wanted to avoid this problem of an uncertainty in the data near coastlines. However, both of the datasets gives similar results showing that coastlines in the Eastern Mediterranean are indeed favored areas for precipitation formation.

C1: Introduction is somewhat lengthy and may better be shortened for clarity. Equation (2) and the related discussion on Page 15662, for example, can be entirely erased because the equation will never be used throughout the rest of the paper. This is more of a text book material that needs not to be repeated in journal papers.

A1: The introduction was shortened. Equation (2) and its explanation were removed, and another section discussing breezes over the Florida peninsula was removed also (lines 17-24 on page 15663).

C2: page 15668, line 20: The author claims that “2B31 product tends to give improved results and lower biases compared to the PR and TMI products alone.”

This is probably not true. None of the papers cited by the authors themselves (Masunaga et al., Wolff et al., Wolff and Fisher) showed that the 2B31 rainfall is consistently better than the other two products. By the way, the Wolff and Fisher (2008) paper is missing from the reference list.

A2: The description and evaluation of the TRMM 2B31 product in the methods section was removed and changed to the 2A25 product description: **"The TRMM product used in this work was the level 2, precipitation radar (PR) based 2A25 product (version 7), that provides vertical profile estimations of rain-rates. The product has a horizontal resolution of ~5km (~4km before August 2001) at nadir. The total swath is 250km and the vertical profile ranges from the surface up to 20km above the earth's ellipsoid, with a resolution of 250m (i.e. total of 80 vertical levels). The 2A25 algorithm relies on a hybrid attenuation correction method which combines the surface reference technique (SRT) and Hitschfeld-Bordan method (Iguchi et al., 2000; Meneghini et al., 2000; Meneghini et al., 2004). Retrieval errors of the algorithm are mainly attributed to the uncertainty of the *a priori* selected drops size distribution (DSD), incorrect physical assumptions (freezing height, hydrometeor temperatures) and non-uniform beam filling (NUBF) effects (Iguchi et al., 2009). Moreover, areas with large surface reference gradients (such as steep mountains) are subject to larger variance in the path attenuation estimation, and should therefore be dealt with caution (Meneghini and Jones, 2011). Due to the wavelength and effective signal to noise ratio of the PR (Kozu et al., 1994), 2A25 is inherently less sensitive to weak rain and drizzle (<0.7 mm/hr) which are common in cases of shallow cumulus and stratiform clouds. For more on the algorithm outline and uncertainties, see papers above...**

Many validation studies have been conducted for the 2A25 product. Validation results vary on spatial and seasonal temporal scales (Nicholson et al., 2003; Wolff et al., 2005), and are regionally dependent (Franchito et al., 2009). Like all TRMM level 2 products, 2A25 is outperformed in estimating accumulated rainfall by lower

resolution, rain-gauge calibrated TRMM products such as the 3B42 (Kummerow et al., 2000; Adeyewa and Nakamura, 2003; Nicholson et al., 2003). Nevertheless, 2A25 product has successfully been able to capture diurnal precipitation and climatological trends (Shin et al., 2000; Yang and Smith, 2006), and is considered to be well calibrated compared to ground validation radars (Wang and Wolff, 2009; Liao and Meneghini, 2009; Fisher and Wolff, 2010). Moreover, some of the weaknesses in performance (i.e. underestimation of rain-rates and surface clutter) over land compared to over sea previously reported (Wolff and Fisher, 2008; Iguchi et al., 2009) are expected to improve considerably as surface reference resolution increased from 1^0 to 0.1^0 and Z-R relations over land were recalibrated (changes done in the new version 7 product used in this work). In coastal regions, 2A25 is especially favorable compared to other rain products because of its high spatial resolution and relative insensitivity to land-sea surface transitions. Results based on the more commonly used passive microwave sensors raise serious doubts when used in coastal regions (McCollum and Ferraro, 2005).

Considering the uncertainties of 2A25, and our main goals, we decided to focus our attention on the qualitative and not quantitative conclusions that can be derived from the rain data." The missing reference Wolff and Fisher (2008) was added to the reference list.

C3: Page 15672, Equation (3): A factor of $1/2$ is missing from the exponential term.

A3: Equation (3) was removed from the revised version of the paper.

C4: Page 15680, line 15: Does the TRMM detectability have something to do with the Feingold and Levin (1986) paper? The TRMM didn't exist yet in 1986.

A4: The Feingold and Levin (1986) paper is used to derive a typical drop size for a given rain-rate in Israel, in order to estimate a shift of the surface rain rate distribution compared to the IHM distribution. It is not directly related to the TRMM products. We

revised the sentence in the manuscript: **“Moreover, by considering low end values of TRMM detectable rain rates (~1 mm/hr) that can be shown to correspond to a minimal drop size of ~0.7 mm (Feingold and Levin, 1986)...”**.

C5: Same page, line 19: “TRMM’s footprint” should be “TRMM PR’s footprint”.

A5: Thank you. We changed it in the text.