

## ***Interactive comment on “Assessment of small-scale variability of rainfall and multisatellite precipitation estimates using a meso-rain gauge network measurements from southern peninsular India” by K. Sunilkumar et al.***

**Anonymous Referee #1**

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Assessment of small-scale variability of rainfall and multisatellite precipitation estimates using a meso-rain gauge network measurements from southern peninsular India

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Decision: Major Revision

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The authors provide a very interesting paper with important contributions to the point to area perspective for rainfall validation using a complex terrain dense gauge network of a Megha-Tropiques test site over Southern India. Data is investigated for different monsoon seasons and compared to satellite MPEs. The topic is of high relevance to the science community.

In my view, this paper is an interesting read, investigates very interesting questions but definitely requires a thorough edit with respect to language and clarity. The points raised below are subdivided into major and minor comments.

Major Issues:

1. The title of the paper reads a little confusing because it contains four imprecisions. First, “multisatellite” should be “multi-satellite”; second, “a network measurements” should either read “network measurements” or “a network”; third, “meso-rain gauge” is not defined to my understanding and should read “mesoscale rain gauge” if this is meant; and fourth “southern peninsular India” contradicts the Abstract where the authors state that the work was done in “southeast peninsular India”. Please be clear and precise on what the title should be about so that it reflects the content of the paper. Would it clarify a little if the term “Southeastern India” is used instead of “Peninsular India”?
2. It is unclear from reading the abstract what refers to the 50x50 km gauge network, to large-scale Southern India and to stations. Please be very clear on notation, definitions, areas and instruments to not confuse the reader.
3. Chapter 3: Does the 45° cone refer to the usual wind direction? Maximum attention should be attributed to data quality according to wind undercatch, orography as well as lower and upper measurement limits of the gauges. Please clarify. There is actually no ground truth, though we all consider an in-situ measurement to show the truth. In reality, this is also far from truth and contains a variety of errors as well that I suggest to elaborate upon. They may be a function of wind speed and collection abili-

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ties of the gauge. Do the gauges handle extreme precipitation accurately? I know of shipboard high-tech gauges that suffer strongly from overcatch during ITCZ extreme rainfall when compared to disdrometers that are thought to be most accurate, although even they have their limitations. Calibrating three intensities with the lowermost bound at 31.5 mm/h makes me wonder. That is already a substantial amount of rainfall. How accurate are the gauges to detect drizzle and very low precip rates, in the extreme, a few drops, which is a precip minute? This may to a very large extent affect the occurrence of precip measured when compared to satellite data and immediately feeds back to the point to area perspective and beamfilling effects. Your calibration test is performed under ideal conditions, almost lab conditions. How does wind effect these measurements? How is the undercatch and what are the wind speed regimes during the monsoon season? How do extreme precipitation events influence the results? Given that under convective conditions I assume that the rain rate can easily excess 150 mm/h in Southern India. The maximum rain rate recorded by myself was 160 mm/h during an ITCZ thunderstorm event. This usually causes gauges to produce large biases of overcatch while wind speed produces undercatch. Please add information on these issues as they may to a large extent influence the results that you conclude when comparing the MPEs.

4. Figure 1. The paper would benefit from adding two more geographical maps. There is also space for them as the figure can inset them as a) to d), where c) and d) are the ones already presented. a) should present a geographical map of India maybe including orography showing the two monsoon system areas referred to as SWM and NEM. b) should show the larger geographical domain where the dense gauge network is located. The main reason is that the map presented in the current paper (Figure 1a) version can only be understood by forcing the reader to look at a geographical map on the internet or an atlas finding the lats/lon by him/herself. Please include. The black squares, triangles and dots are not easily separated visually to see the rate dependence on the results. As Figure 1 contains color in any case, I suggest that you additionally use colors for the symbols as well, such as red, blue, black to separate

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them easily.

5. The paper would strongly benefit from an edit by a native speaker. The sentences suffer too often from mixing singular and plural forms, times and wording errors. Please improve this rigorously as this reduces the readability of the paper a lot. I tried to list as many of these errors as possible in the minor issue section. It is, however, too much work to continue this throughout the paper.

6. Page 10395, line 13. The monsoon trough is not introduced to the reader. Please clarify the importance of that also with respect to the region investigated.

7. It is unclear from Figure 2 what's shown here. This is three years of data? Accumulation of 3 years of NE and SW monsoon precip? Average over a season/year/? Please indicate. The gradient of NEM is in the Northeast rather than east-west. Please explain. What makes the Northeast special during the NEM? I assume it's a seasonal average, if not, please make a seasonal average out of it.

8. Page 10398, line 10. Do the cyclones and thunderstorms belong to the SWM and NEM season precipitation are they investigated separately? That is not fully clear to me. Please make clearer.

9. The definition of small-scale and large-scale over the 36 gauges area on page 10398, line 14 needs more explanation. Is that definition used/developed by you or used elsewhere as well? If so, could you provide a reference? If it's your definition please explain why you chose this criterion. Your field is 50x50 km in size, so about the size of one passive microwave satellite pixel. Could also a rain rate, or its standard deviation, be used as a criterion. It may matter if the rainfall over the last 2 days and 75% of the gauges was very uniform (large-scale) or varied a lot (small-scale). How large is a typical evening thunder cell in Southern India? I just wonder if the temporal check is sufficient to define convective/stratiform/small to large scale precip. Did you perform a case study analysis e.g. with infrared satellite imagery to check if your categories and definition satisfy your findings?

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10. I am missing a thorough definition and description of the SW and NE monsoon systems. This should be done in the introduction and include a figure of the geographical areas covered by the monsoons. What is causing them, which flow directions to they take on a map? When cyclones occur? Do cyclones belong to the monsoon system? This would allow the reader to prize the results and findings of this paper in greater detail. Be aware that not all your readers know about the details of the Indian monsoon systems and the cyclone occurrences.

11. Why are cyclones part of the monsoons? So far I understood that the SW and NE monsoon is investigated, excluding local evening thunderstorms and cyclones because they do not belong to the monsoon system. However, page 10398, line 22 states, that the 75% of the gauges receive >60% of their rainfall from these large-scale systems. Please clearly define your wording! Define large scale vs synoptic scale and which system (e.g. cyclones, high/low pressure systems) belong to them. It seems you use the words location / station / gauge as synonyms for gauge. This confuses. Its much better to always use the same word, e.g. gauge. Please clearly define the SW and NE monsoon and what precip types belongs to them. I would expect that a cyclone massively disturbs your monsoon signal by dropping vast rainfall that is not associated with the monsoon system. Please clarify. Maybe I confuse things here, but if so, it calls for writing up things clearer. Maybe define scales to discriminate synoptic/large scale phenomena.

12. Page 10399, line 17. Does your technical 25 min threshold agree with the meteorology of the showers? If not, this method is not capable as a shower separator. And 0.5 mm/h is already a high value. Most often 0.01 mm/h as a minute value would represent reality. Would it make sense to use a high resolution device such as a disdrometer as to discriminate between showers? Surely you don't want to install 36 disdrometers (which would be great to do in any case) but maybe one to investigate typical durations for showers?

13. I made an in depth review of the writing style of the paper until page 10399.

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Because of the numerous remarks (see minor issue section) I decided to not proceed like that throughout the remainder of the paper. Hence, I recommend that the authors revise the rest of the paper accordingly including a proof read by a native speaker.

14. The cumulative rain event rate pdf in Figure 3 looks very interesting. By intuition I would have expected the pdf to be much steeper to saturate at much lower precip rates (e.g. below 1 mm). Is that because you have a lower detection threshold of 0.5 mm/h or because there is few to no low (drizzle) precipitation during the monsoon seasons? In other words, is the pdf explained by the gauge-resolution or the underlying precipitation falling? How would this pdf potentially look like if you had a disdrometer, capable of measuring down to 0.01 mm/h? How does your technical event definition (25 min because of one tip-gauge limitation) influence this graphs result?

15. MPE evaluation. Having such a high-res gauge field is great to investigate the MPE at various resolutions as the point-to-area effect probably gets to a fair comparison. However, I wonder about the representation of the low precip rates which are always (probably) the most difficult part to match between surface and aerial measurements. You set a threshold while gridding to 0.5 mm/3h and your gauges resolve 0.5 mm/h at the low end. I assume that reality sees probably most often minutes with rates below 0.5 mm/h. How much is that of an issue for the monsoon systems and hence comparisons. I like to see this at least discussed or mentioned. Chris Kidd often raised that tricky question of "How low you can get" or how low precip rates are in reality. You already show that the MPEs largely underestimate drizzle. In fact I like to raise the question, how large the gauges underestimate the drizzle themselves due to the tip-sampling issue? Underestimation of light rain and overestimation of intense rain is somewhat what I would expect from MPEs and agrees with many findings. It is great to see this with respect to high-res gauge data.

16. Is there an indication that the active instrumentation onboard TRMM (PR) outperforms the passive microwave results clearly? Is there an investigation ongoing that uses the GPM active and passive data over your test site?

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17. Conclusions point 5. . . .all MPEs severely underestimate the weak and heavy rain. I thought they underestimate the light and tend to overestimate the heavy? See page 10407, line 18, class 8-20 mm.

Minor Issues and typos:

Page 10390 Line 4. Southeast peninsular India contradicts the title “southern peninsular India”. Please clarify on the region. Is the term peninsular really needed? It sounds a little confusing because the India is more a continent, nowadays a subcontinent, rather than a peninsular.

Line 5. 3 hourly should be 3-hourly, multisatellite should be multi-satellite

Line 6. Does “arranged” mean evenly spaced? Figure 1 suggests that they are NOT evenly spaced by 10 km as stated. Please clarify.

Line 9. The sentence on the seasons is confusing as it states that “two seasons show seasonal differences”. Is it meant that spatio-temporal variability and differences in weather patterns are investigated for two monsoon seasons?

Line 11. “In wet spells” may read “during wet spells”

Line 13. It is unclear to me from the Abstract what is meant by “quadrants”. Does that refer to the investigated 50x50 km gauge network or to entire Southern India area?

Line 15: This sentence is confusing. I suggest “The diurnal cycle also exhibits large spatio-temporal variability at all the stations. . . .” What is “gauge”, what is “station”, what is “network”, what is “quadrant”? Please be very clear terminology. It’s very difficult to follow the storyline of the abstract. Please be aware that the Abstract should be understandable and make appetite to read without knowing the content of the rest of the paper. That’s not the case yet.

Line 19. What is “night-mid”? Why not just saying “between 20 and 02 LT . . .”? Please use 20 LT instead of 20:00 LT.

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Line 23. Should read “both monsoon systems or seasons”

Line 27. Should read “gauge rainfall data indicate that”. Weak rain should read light rain. Heavy rain should read high rain intensity. Is heavy rain always associated with convective precipitation?

Page 10391 Line 1. “Among the different MPEs investigated, the Climate . . .” Line 3. Please write out the TRMM acronym as well Line 4. “daily resolution compared to 3-hourly”

Introduction Line 10. Please include a reference. Precip is among all most important to understand the water and energy cycle regarding observation and modelling. Please include. Line 15. “a high density of gauges” Line 18. Sentence too long. Does microwave radars/images rely to satellite data exclusively? Please clarify. Line 20. Spatio-temporal. Please give a reference for the variability increase in hilly terrain. Line 23. If with “filling” beamfilling is meant please write that. Line 27. The long list of references should be attributed to the list given. So please sort the reference list regarding the topics they deal with (e.g. seasons, aggregation, correlation length). This gives the reader a much better view on the state-of-the-art of research in that field. Page 10392 Line 6. Do you mean “dense gauge networks”? I suggest “moreover” instead of “even” to make the point clearer. Line 8. I would sharpen this point: “This leaves large spatial data gaps in critically important areas due to the unavailability of gauges (e.g. . . .)”. Line 9. The timeliness aspect I recommend to split into a second sentence. Line 10. Replace “On the other hand” by However, . . . The high-quality aspect of the data should be mentioned as well. Line 12. Solve the bracket problem ( ) ( ). Maybe use . . . , e.g. . . . ( ). Line 13. Satellite remote sensing is capable of measuring near-real time . . . Line 14. . . including oceans and complex terrain where in-situ precipitation measurements are missing. . . Please provide references for ocean and complex terrain. Please note, that there has been made substantial improvement recently for systematic in-situ oceanic precipitation measurement (rain, snow and mixed-phase) for satellite validation within the OceanRAIN project: Klepp, C., 2015: The Oceanic Shipboard

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Precipitation Measurement Network for Surface Validation – OceanRAIN. Atmos. Res., Special issue of the International Precipitation Working Group (IPWG), 163, 74-90, doi: 10.1016/j.atmosres.2014.12.014. Line 15. Complex terrain is challenging for satellite retrieval to cover, especially for frozen surfaces, snow and light rain. That may not occur in your study area but maybe a reference may be useful to document that, e.g. the work done by Nai-Yu Wang. Line 17. active and passive microwave; multi-satellite Line 23. Please add the MPE references directly behind the data sets. Otherwise it is unclear which reference belong to which data set. Line 25. Does “sensor accuracy” point at inter/cross calibration issues? Line 27. Please provide references for these factors. Evaluation should be expanded to validation as well, because you don’t want to just intercompare them to see bias but understand their accuracy by validation to ground/surface reference data. Page 10393 Line 1. Can this long list of references be separated into applications? It would well improve readability and understanding if references are attributed to their applications. Line 5. Do you refer to evaluation or validation here? Line 11. Please solve the bracket problem. Do you mean “precisely” when you say “faithfully”? Please clarify. Line 15. Precipitation products Line 17. But reduce Line 18. or when the is aggregated in space and time Line 24. Aghakouchak misspelled with regard to references Line 26. be valid Line 27. vary Line 29. in different climatic regions Page 10394 Line 1. for monthly and seasonal Line 3. However, a detailed study ... Line. due to the lack of Line 8. ,are to measure and understand Line 10. This is the first paper Line 11. ... its establishment ... Line 12. Network doubles here. Better make two sentences. Does “though” mean “although”? Line 15. during the NEM. Also don’t use () (). Better use (;) Line 17. of in-situ measured rainfall and performance Line 18. as follows: A description ... Line 21. during both monsoon seasons Line 24. Results are discussed. ... Chapter 2 Line 27 and Figure 1. See major issue comment. The reader may not easily be aware with India geography and may miss the larger location setting and monsoon system areas involved. Please add two sub-figures to figure 1 according to major issue and Figure 1 comment. Page 10395 Line 4. Highest peak about 1000 m above sea-level. Line 5. In the North of the study

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region. Line 8. 35% of the annual rainfall Line 9. Please state if the remaining 10% are due to monsoon-unrelated thunderstorms. Phrase “in nature” unneeded Line 10. The stratiform rain fraction Line 12. () () should be (;) Line 13. And is generally not under the Line 19. Does that copious rainfall account for the 10% not attributed to monsoon systems? Chapter 3 Line 20. I suggest Mesoscale rain gauge network because I do not understand the meaning of meso-rain. I assume meso-rain is not what you mean. Line 21. The Gadanki gauge network is part of the Megha-Tropiques satellite validation program. I strongly recommend to introduce that in the abstract and introduction as well as this is very interesting to the reader. Line 23. A mesoscale-network Line 24. Centered around Gadanki Line 25. Can you be more precise with the 10 km inter-gauge distance as Figure 1 suggests that they are not all evenly-spaced at all. Line 27. Being an official validation site I suggest you name the gauges officially. Which company built them, which name do they have. Are they all identical? What is mL? Do you mean milliliter’s (ml)? Page 10396 Line 1. The gauges are solar ...and store ... data at 1-min resolution ...on a memory card Line 2. Additionally, the 1-min Line 3. Being should read is ...in near real-time about every 30-min to a server Line 4. What does GPRS stand for? Utility should read usefulness or importance? Line 6. Each system means each gauge? If so, use gauge pls. Line 8. Does the 45° cone refer to the usual wind direction? Maximum attention should be attributed to data quality according to wind undercatch and orography. Please clarify. Line 11. “In-situ ground truth”. There is actually no ground truth, though we all consider an in-situ measurement to show the truth. In reality, this is also far from truth and contains a variety of errors as well. They may be linked to wind speed and collection abilities. Do the gauges handle extreme precipitation accurately? I know of shipboard high-tech gauges that suffer strongly from overcatch during ITCZ extreme rainfall when compared to disdrometers that are thought to be most accurate, although even they have their limitations. Line 16. Do not bracket the second part, better make a full new sentence out of it. Line 19. Health should read operation or performance. Time shifts and temporal offsets between gauges Line 22. Into the gauge Line 25. Rectified means recalibrated? Line

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27. These kind of adjustments were required eight times during three years Line 28. How well the gauges estimate Page 10397 Line 1. 31.5 mm/h is already a substantial amount of rainfall. How accurate are the gauges to detect drizzle and very low precip rates? This may to a very large extent affect the occurrence of precip measured when compared to satellite data and immediately feeds back to the point to area perspective and beamfilling effects. This test is performed under ideal conditions, almost lab conditions. How does wind effect these measurements? How do extreme precipitation events influence the results? Given that under convective conditions I assume that the rain rate can easily excess 150 mm/h in Southern India. The maximum rain rate recorded by myself was 160 mm/h during an ITCZ thunderstorm event. This usually causes gauges to produce large biases. Furthermore, I recommend that you introduce a percentage value how accurate your 36 gauges (min/max) and on average perform with respect to the reference of the Young gauge. Please add a reference, why the Young device is allowed to be the reference. Is it a reference by international standard? Please also name the manufacturer and device name of your identical 36 gauges. I recommend that you introduce your site being part of Megha-Tropiques test program already in the abstract and introduction. That is important information with relevance to your results and findings. Chapter 4 Line 19. How different its pattern is from the climatology Line 22. Than in should read compared to Line 23. Your sentence on the percentages is not understandable. Do you mean this: The rainfall during the SWM accounts for 55% of the annual rainfall while the NEM contributes 30-35%. Please explain where the remaining 10 to 15% come from. Cyclones and thunderstorms? Page 10398 Line 1. This demonstrates the difficulty finding your results geographically. Figure 2 shows the max accumulation in the Northeast of the domain while in the text its explained that the southern tip receives most during NEM. If you include a broader area figure with both monsoon types one can much easier grasp the details of your findings. Line 4. In the Northeast sector of your 50x50 km box? Line 7. This becomes clear once I looked it up on a map. Please include as mentioned many times already. You are of course very familiar with your geographical setting. Your readers (and I)

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are probably not. Line 9. How much? 10 to 15%? Page 10399 Line 3. Towards the west Line 13. As an event with a rain duration. . .rain exceeding 0.5 mm. What is the lowest resolution to define a minute as a precip minute? One tip? That undersamples the occurrence of precip significantly! Please explain. What happens is precip fall but does not reach one tip of the gauge? It's still a precip minute but goes undetected? That biases intercomparison to satellite data. Line 14. The temporal gap Line 15. 25 min. (dot missing) Line 16. Please explain why the 25 min criterion is chosen. How fast do showers in your region move, how large are they? How large are gaps between showers? Please justify. Does your technical 25 min threshold agree with the meteorology of the showers? If not, this method is not capable as a shower separator. And 0.5 mm/h is already a high value. Most often 0.01 mm/h as a minute value would represent reality. Page 10400 Line 16. Can you pls explain wind shear-cold pool interaction Page 10401 Line 15. Is the cyclone Neelam part of the monsoon season or exluded from it? As it supplied copious rainfall it strongly influences the monsoon results. Line 19. Pls explain the acronym IQR Page 40403 Line 14. Will you explain later why the expectation of the evening peak does not meet the observation of the propagating systems? Line 22. Again, I wonder if cyclones are really part of the monsoon? Are they triggered by the monsoon itself or are they seeded from outside the monsoon region? As to my expectation cyclones (like hurricanes) are long-distance wanderers that may travel into the area of the monsoon and get superimposed on the monsoon system and as such do not belong to them. Page 10405 Do cyclones have a strong influence on the decorrelation length? Page 10406 Line 14. Table 1 gets called here first time. See comment above. Page 10408 Line 16. Is that mention in the introductory statements of the filed site that it's a semi-arid region with significant fraction of virga? Evaporation should say evaporation of falling rain to discriminate from evaporation from the ground.

Figures

Figure 1. What is meso-rain, topography (m). Please note that the stars refer to the individual gauge positions. They do NOT seem to be evenly spaced as introduced in

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the Abstract. Please note, that the quadrants cover an area of 50x50 km if that is the case. Please add color to 1b as suggested above.

Figure 2. I do not fully understand what's shown here. This is three years of data? Accumulation of 3 years of NE and SW monsoon precip? Seasonal average accumulation? Please indicate.

Figure 3. What is the difference between storm duration and rain duration? ...four quadrants color coded ... The term storm is not defined what you mean by that.

Table 1. Table 1 is called after Table 2. Reverse or call Table 1 already in the introduction where the MPEs are introduced.

Figure 4. I suggest to move the colorbar beneath the figure. Pls indicate in the text that rain accumulation is color-coded in mm.

Figure 7. Please indicate, that the black curve is the gauge reference and that the satellite MPEs are color-coded.

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