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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Measurement report: Altitudinal variation of CCN activation across the Indo-Gangetic Plains prior to monsoon onset and during peak monsoon periods: Results from the SWAAMI field campaign" *by* Mohanan R. Manoj et al.

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At the outset, we thank the reviewer for the meticulous review, constructive comments and the overall appreciation of the work. We have considered each of the comments carefully and revised the manuscript. Our responses to the comments, which formed the basis for the revision, are given below along with the page and line numbers in the

revised manuscript, where the revisions are incorporated.

Reply to comments of Anonymous Reviewer #1 (RC1)

1) In the Introduction section, authors should insist more on previous works in India dealing with CCN, since they practically refer only to CAIPEEX campaign (airborne measurements). Looking the literature, I can see several other works with ground instrumentation as well, some of them also cited later in the manuscript like Dumka et al. (2015), Jayachandran et al. (20020a, 2020b), etc.. You may also see Jayachandran, et al., 2018 (Atm.Res.), Dipu et al. (2013, AtmEnv), Bhattu et al. (2014, AtmEnv). . .

Yes. There have been several works with CCN in India, in addition to those cited by the reviewer. However, most of these studies were ground-based focusing on case studies or long-term measurements on seasonality. However, we focus on the vertical structure of CCN characteristics within the ABL and in the free troposphere and the changes that occur in these properties as the season changes from just prior to the onset of Indian monsoon to its active phase. There are very few studies, if not none, dealing with such details and addressing to the changes in the aerosol characteristics leading to these changes. Accordingly, our measurements did not cover the near surface CN and CCN properties. As such, we have cited only those studies dealing with vertical structure of CN/CCN properties and that explains why our references have been limited to airborne measurements. As it emerges in our study, the vertical structure of CCN characteristics significantly differs from the surface and also vary with the phase of the monsoon. Nevertheless, as suggested by the reviewer, we have cited a few ground-based measurements that address to at least a few of the features examined in this study (page 2, lines 48-49; page 2-3, lines 56-79 and page 3, lines 87-88).

2) Line 83: BBR is not located in the eastern IGP, but at the eastern Indian coast. This should be mentioned here, since reader has a wrong thought about the geographical distribution of the sites. Also, you should clarify that JPR is at the arid zone and is not also considered as a standard IGP site.

We agree partly. While Bhubaneswar is located just south of the eastern boundary of the IGP. Jodhpur and Jaipur are located at the southern tip of the western IGP, even though they exhibit arid characteristics, and are chosen for the convenience of aircraft operations. Furthermore, the sorties towards and from these base stations have been mostly through the core IGP region. The Indo-Gangetic Plain (IGP), also known as the Indus-Ganga Plain and the North Indian River Plain, is a 2.5-million km2 fertile plain encompassing northern regions of the Indian subcontinent, including most of northern and eastern India, the eastern parts of Pakistan, virtually all of Bangladesh and the southern plains of Nepal. The region is named after the Indus and the Ganges rivers and encompasses a number of large urban areas. The plain is bound on the north by the Himalayas, which feed its numerous rivers and are the source of the fertile alluvium deposited across the region by the two river systems. The southern edge of the plain is marked by the Chota Nagpur Plateau. On the west rises the Iranian Plateau (source Wikipedia). While representing the IGP, it is often observed that the Rajasthan Plain and the southern part of the upper Ganga Plain are excluded because of the arid or semi-arid nature. We have provided a figure, that shows the geographical extent of the IGP (IGP is not confined to India, it is defined by the rivers Indus, Ganges and Brahmaputra as detailed below) and the base stations (https://commons.wikimedia.org/w/index.php?curid=2454397). As per the broad definition of IGP, JDR is part of the Rajasthan plain and Jaipur is located very close to the Punjab Haryana plain and upper Ganga plain and surrounded by the plains on three sides. Both Jaipur and Jodhpur are located in semi-arid parts of western India. The figure and explanations clarify this beyond doubt. We have revised the manuscript accordingly (page 4, lines 112-113). The map of the IGP was taken from https://commons.wikimedia.org/w/index.php?curid=2454397. Last accessed on 16-Feb-2021.

3) Line 114: The reference Dee et al. (2011) should accompany the meteo dataset used i.e. ERA-Interim or ERA-5 reanalysis. So, this should be referred here.

Complied with in the revised manuscript (page 5, lines 149-151).

4) Lines 145-147: I would expect a more detailed discussion here related with aerosol hygroscopicity and types over the IGP region. Obviously, aerosol chemical properties play the major role in aerosol hygroscopicity and CCN activation. These chemical properties, as well as aerosol types should be discussed here, in view of changes in CCN and hygroscopicity. Literature, global and Indian, are rich in this issue and should be used here.

This is an important suggestion. We draw the attention of the reviewer to the discussion already provided on the importance of hygroscopicity, aerosol types and size distribution (pages 8-9, lines 248-289). We have also added a few more references in pages 7 (lines 216-219) and page 8 (lines 249-251).

5) Line 150: Correct as CN and CCN

Corrected in the revised manuscript (page 6, line 192).

6) Line 159: There is only marginal differences in the AR compared to Lucknow. I think that there is no important difference between these AR values deserving further explanation from the view of the physical and chemical aerosol point of view. So, authors should refer to marginal or slight differences between these sites, at least for the AR values near the surface, indicating low aerosol hygroscopicity.

It is true that there is only a marginal difference in the AR between Lucknow and Bhubaneswar. But, what makes it worth discussing further is that, this difference arise due to the changes in the vertical distribution of the CCN concentration, while that of the CN remained well comparable at Lucknow and Bhubaneswar.

7) Lines 169-170: This difference in aerosol types also exists in the vertical between west and east IGP and this should be further discussed in the manuscript, along with dominant aerosol types and chemical compositions between the regions.

Yes, the reviewer is absolutely right, and this is an important outcome. We have dis-

cussed the changes in aerosol types with altitude across the IGP and the main points are highlighted in the conclusions. This study does not explore the chemical composition (as these were not determined) but concurrent measurements of chemical composition are reported by Brooks et al. (2019), which is referred wherever necessary to strengthen our arguments.

8) Line 221: The role of the water-soluble organics should be highlighted here.

We did not find that this is required here, because the main point is the reduction in activation efficiency due to enhancement in BC concentration; this adequately takes care of the observations.

9) Lines 127-248: References are needed here.

We re-examined this portion and found that most of the important and relevant works are cited. However we have added more references explaining the role of changes in chemical composition and size distribution of aerosols on the CCN activation (page6, lines 173-176, 188-189; page 7, lines 216-219; page 8, lines 249-251; pages 10, lines 298-300).

10) Lines 249- 251: A recent work at the Indian Himalayas (Nainital site, 1958 m; Dumka et al., 2021, STOTEN), which classified the aerosol types based on in situ surface observations showed that the fresh BC aerosols of local origin (BC-dominated type) was much less hygroscopic than the coated and aged "large-BC type", which was mostly transported by the IGP. This finding supports the current results and should be an advance in the discussions about different hygroscopicity levels from various aerosol types in India.

Yes, we agree. We have cited this work and a related work in the revised manuscript (pages 10, lines 298-299).

11) Lines 255-257: This statement is true and also supported by previous studies that show an increase in water-vapor content (from AERONET) during pre-monsoon

dust events over the IGP (Prasad and Singh, 2007, JGR; Sarvan Kumar et al., 2015, Aeolian Research, etc), indicating a mixing of marine-dust air masses. In addition, more recently, Dumka et al. (2019, JGR) showed that the dust emissions and dust-storm propagation over the Thar desert in pre-monsoon is highly controlled by the SW monsoon density currents over the land area, which may increase the WVC, and therefore, the aerosol hygroscopicity.

Yes, the reviewer is correct. However, our point here is the gathering of moisture by the airmass passing over ocean. Furthermore, we have not encountered any dust storm or associated changes in columnar water vapour during our measurements.

12) Lines 340-367: In the major findings discussed here, you may increase the literature overview about aerosol size and chemical properties.

Complied with in the revised manuscript (page 13, line 394-395, 403, and 416-418).

13) Line 345: Delete “IGP”.

Corrected in the revised manuscript.

14) Line 366: Delete "of".

Corrected in the revised manuscript.

15) Figure 1: The experimental sites should be clearly visible in Fig. 1. Increase the fonts, make the sites clearly visible.

Figure 1 has been modified in the revised manuscript.

16) Figure 6: Caption. Correct the figure numbers there.

Corrected in the revised manuscript.

We thank the reviewer for the detailed comments.

References Brooks, J., Allan, J.D., Williams, P.I., Liu, D., Fox, C., Haywood, J., Langridge, J.M., Highwood, E.J., Kompalli, S.K., O’Sullivan, D., Babu, S.S., Satheesh,

S.K., Turner, A.G., Coe, H., 2019. Vertical and horizontal distribution of submicron aerosol chemical composition and physical characteristics across northern India during pre-monsoon and monsoon seasons. Atmos. Chem. Phys. 19, 5615-5634.

Please also note the supplement to this comment:
https://acp.copernicus.org/preprints/acp-2020-1233/acp-2020-1233-AC1-supplement.pdf

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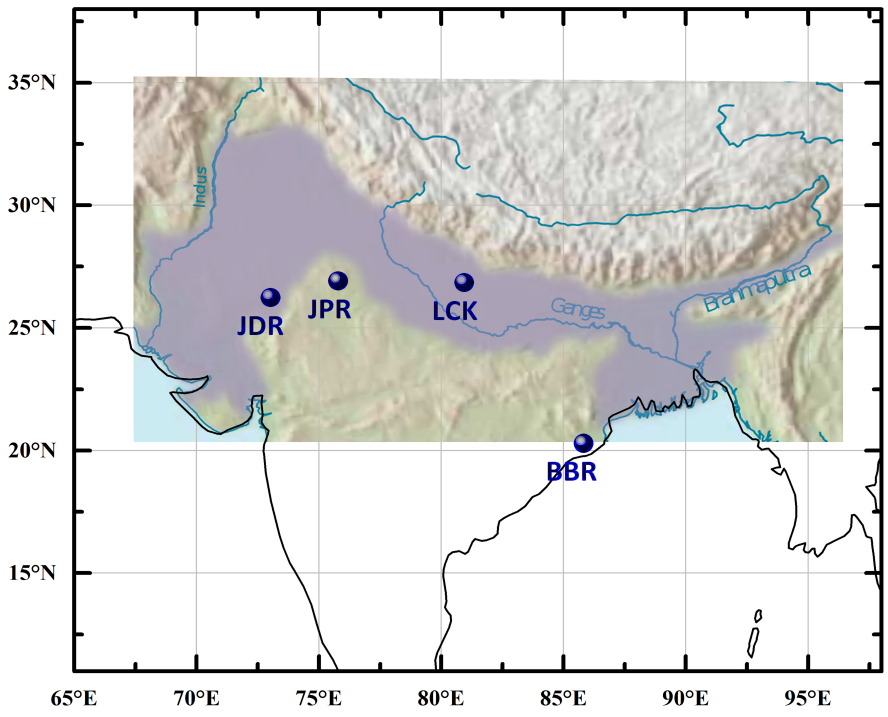

Fig. 1. Figure 1. The Indo-Gangetic Plain is represented by the shaded (blue-magenta) region. The measurement sites are represented by the circles.