

## Reply to the Comments:

*The authors are thankful and appreciated to the reviewer and editor for their suggestions and insights. We are happy to incorporate all the suggests for better and comprehensive representation of the present work, and for making it easier to reader prospective.*

## The Comments

This manuscript discussed about the Black carbon (BC) and Brown Carbon (BrC) variability based on measurements from March 2021 to March 2022 over Gangtok and their link with meteorological conditions obtained from satellite observations. They discuss the inter-relationship between BC and BrC emissions and their potential impact on climate, with the co-emission of CO<sub>2</sub> and the impact on temperature and the potential role of BC/BrC as cloud condensation nuclei. I don't think the manuscript can be accepted as it is, the main reasons are addressed in the major comments.

S. No.	Comments	Replies
<b><i>Major comments:</i></b>		
1.	I addressed only a small part of the grammatical issues in my minor comments, but the authors should seek the advice of an editor to revise the manuscript's language accuracy.	<i>Thank you for the suggestion we have addressed the issues and tried to rewrite the most part of the Manuscript.</i>
2.	There is no mention of the mass absorption cross section used to estimate the mass concentration of BrC and considering the uncertainties around such value for BrC, it would be best to avoid using BrC mass concentrations and use BrC absorption coefficient at 370 nm instead.	<i>We have addressed the issues and incorporated the changes as per suggestion through entire Manuscript.</i>
3.	Also, it is hard to see the link between LULC 2000, 2010 and 2020 and how it impacts the BC/BrC emissions and climate with only the measurement from 2021 and 2022. It might be easier to just state that the growing urbanization of the region may be at least partially responsible for the level of BC/BrC and CO <sub>2</sub> observed.	<i>Yes, we agree with reviewer of putting It might be easier to just state that the growing urbanization of the region may be at least partially responsible for the level of BC/BrC and CO<sub>2</sub> observed. However, we put the actual scenario rather just telling, because there is not such study of LULC change to this region to cite. And just state that.</i>
4.	There is a need for more references to support the different ideas mentioned in the discussion.	<i>We have tried to add some new relevant references in the discussion section as per suggestion. Shaddick et al., 2020; Rana et al., 2023; Huang et al., 2017; Stjern et al., 2023; Liu et al., 2020; Wang et al., 2020; Igarashi et al., 1988; Johnson and Hamilton, 1988;</i>

		<i>Sarkar, 2018; Liu et al., 2021; Wu et al., 2022; Yoo et al., 2014; Ohata et al., 2016; Ge et al., 2021; Wu et al., 2022; Zhu et al., 2021; Li et al., 2023a; Jung et al., 2023; Zhang et al., 2020; Li et al., 2023b; Davis, 2017; Chiodo et al., 2018; Xiao-lei et al., 2022.</i>
<b>Minor Comments:</b>		
1.	Page 4 line 125: what does the author mean by “fragile forest covers” and “The Gangtok is a densely populated city”.	<i>The modification is made as mentioned here. (see page 4, line no. 128) “Moreover, Sikkim has one of the most fragile forest covers. However, the Gangtok is densely populated city and capital of state Sikkim which is situated in the East Sikkim district (see figure 1a).”</i>
2.	Page 6 equation 3: It is mentioned in the text “the negative log-log slope” so I would assume that a minus is missing in the actual equation.	<i>Thank you, yes it was mistakenly missed during editing, Now we made the correction. We have put in the proper way.</i>
3.	Section 3.1: The way all the equations are numbered and the reference to the supplement is very confusing.	<i>We made the correction and changed in the equation number throughout the entire manuscript. Please see section 3.1 and supplementary,</i>
4.	Page 6 Equation 1: The following writing is confusing “ $\sigma_{BC} + BrC(370 \text{ nm})$ ” for the total absorption coefficient at 370, maybe write it $\sigma_{BC+BrC}(370 \text{ nm})$ .	<i>Yes, we agree to suggestion, and we made the change and corrected as per suggestion please see the equations 1,2,3 and 4.</i>
5.	Page 6 Equation 2: Again, the way the equation is written is confusing. “ $\sigma_{BC}(\lambda) = \beta \lambda^{-AAEBC}$ ” please rewrite the equation with “ $-AAE_{BC}$ ” as an exponent to lambda.	<i>Yes, we agree to suggestion, and we made the change and corrected as per suggestion please see the equations 1,2,3 and 4.</i>
6.	Page 6 Equation 4: You mention in the text “Equation (3.16) was employed to determine $\sigma_{BrC}(370 \text{ nm})$ by substituting $\sigma_{BC}(\lambda)$ at 370 nm, which was obtained using equation (3), into equation (3.13) (refer to supplementary methodology S1.1, S1.2, and figure 187 S2 for details). Shouldn’t equation (4) be “ $\sigma_{BrC}(370\text{nm}) = \sigma_{BrC+BC}(370\text{nm}) - \beta(370\text{nm})^{-AAEBC}$ ,”?	<i>we made the change and corrected as per suggestion please see the equations 1,2,3 and 4.</i>
7.	Page 8 lines 244-245: “BC BCbb, BC BCff” Please remove extra BC and “apparently”.	<i>Thank you, we have removed the extra BC, and apparently. Please see page 8, line no. 248.</i>
8.	Page 8 lines 244-249: BCff peaks at 9am, CO2 at 10am and BrC/BCbb at 11am? What can you infer from	<i>We have looked into the suggestion and made the possible changes and rephased it with some addition, so that it does not</i>

	these differences? Also, you mentioned that the same is observed for meteorological conditions? Can you be more precise because if their temporal variations were similar, it could mean that the meteorological conditions are driving the BC and BrC changes, which is not really the case here.	<i>contradict with itself. Please see page no 8, line 244-254.</i>
9.	Page 9 lines 260-262: “BrC is found the highest with maximum fluctuation during 10th January to 30th March that is pointing towards winter wood burning for the subsistence as similar observed BCbb.” Please rephrase	<i>Rephased the lines and made it easier for reader. Please see page no 9, line 265-268.</i>
10.	Page 9 lines 262-267: What can you infer from the highest variations and concentrations of BC, BrC... and what could be the reasons behind such variation during March for BC and April for BrC ?	<i>The possible region has been added for the explanation. Please see page no 9, line 270-273.</i>
11.	Page 9 line 270: “The good significant” and line 272 “strong significant correlation” remove significant in both cases. Furthermore, aren’t BC and BCff and BCbb and BrC expected to correlate based on the way they are calculated?	<i>We rephased it as per suggestion and significant term is removed. Se page no. 9, line 277-280.</i>
12.	Page 9 lines 273-275: “A good significant positive correlation between CO2 and BC/BCff suggesting that fossil fuel burning is one of the causes of CO2 concentration or vis versa.” In figure 5, CO2 doesn’t seem correlated to anything else than himself.	<i>We have made the changes and rephrased the sentence along with the reference. Please se page 9, line 280-282.</i>
13.	Page 9 lines 275-277: “Dewpoint temperature and CO2 has strong significant positive correlation coefficient suggesting to positive radiative forcing of the CO2.” Some reference would be welcome and can the correlation be considered strong with a correlation coefficient of 0.22?	<i>The sentence is rephrased and some relevant references are also added. Please page 9, line 282-283.</i>
14.	Page 9 lines 285-292: “However, cloud condensation nuclei formation and precipitation are prompted by	<i>We agreed with the reviewer and this is a probable explanation for comments. And explanation is also added to the</i>

	<p>aerosols (BC and BrC). Thereafter, BC and BrC have crucial role in precipitation mechanism.” Also, BC being mainly hydrophobic, how good would BC particles be as CCN and which conditions would be required to efficiently play such role?</p>	<p><i>Manuscript. Please see page 10, line 300-321.</i></p> <p><i>“However, BC particles can still act as CCN under certain conditions. For example, when BC particles mix with other aerosols, such as sulphates or nitrates, they can become more hydrophilic and more efficient as CCN (Moteki, 2023). Additionally, BC particles can be coated with organic material, such as brown carbon (BrC), which can increase their hygroscopicity and make them more efficient as CCN (Liu et al., 2020).</i></p> <p><i>The conditions required for BC particles to efficiently play the role of CCN depend on several factors, including their size, mixing state, and the atmospheric conditions. For example, smaller BC particles are more efficient as CCN than larger ones (Moteki, 2023). The mixing state of BC particles also plays a role, as externally mixed BC particles are less efficient as CCN than internally mixed ones (Liu et al., 2020). Atmospheric conditions such as relative humidity and temperature also affect the efficiency of BC particles as CCN. For example, higher relative humidity and lower temperatures can increase the efficiency of BC particles as CCN (Moteki, 2023).</i></p> <p><i>Moreover, BC particles are mainly hydrophobic and less efficient as CCN compared to more hydrophilic particles; they can still act as CCN under certain conditions. These conditions include the size and mixing state of the particles, as well as the atmospheric conditions such as relative humidity and temperature (Ohata et al., 2016; Moteki, 2023; Liu et al., 2020). Additionally, relative humidity over study region is very high during entire year with the favourable temperature. Thereafter, BC and BrC have crucial role in precipitation mechanism (Zhu et al., 2021; Li et al., 2023a)”.</i></p>
15.	<p>Page 10 lines 293-299: Most phrases here are poorly written and need serious revisions to convey the observations clearly.</p>	<p><i>Thank you, we rephased the lines see page 10-11, line 322-325.</i></p>

16.	Page 10 lines 298-299: How do you explain that the scavenging seem to be only affecting BC <sub>bb</sub> and not BC or BC <sub>ff</sub> ?	<i>Yes, it is affecting the all-constituents of BC, and BrC like BC<sub>bb</sub>, BC<sub>ff</sub>, etc. Please see page 10-11, line 320-321.</i>
17.	Page 10 line 300: “pattern” instead of “patten” and what does the relative humidity and temperature justify? This sentence is not clear.	<i>The line is rephrased and correction has been made. please see page 11, line 322-324.</i>
18.	Page 10 line 308: “Figure 7 discusses” please rephrase.	<i>Rephased as per suggestion. Please see page 11, line 328-329.</i>
19.	Page 10 lines 312-314: “approved” please use another verb and add reference regarding the important convective activity during the monsoon season in the Bay of Bengal.	<i>The sentence is rephrased and references are added as per suggestion. Please see page 11, line 335-338.</i>
20.	Page 10 lines 318-319: “supporting the convective rain (i.e., rain out scavenging) of all pollutants” do you mean scavenging of pollutant by convective rain here?	<i>Yes, Rephrased and Witten in the detail along with references. “The least concentration of BC, BC<sub>ff</sub>, BC<sub>bb</sub>, and BrC is observed during the monsoon months (Liu et al., 2020; Moteki, 2023). This observation supports the convective rain, as rain out scavenging, of all pollutants (Brooks et al., 2019; Liu et al., 2020; Moteki, 2023; Sankar et al., 2023). During the monsoon season, the region experiences high convective activity, which is added from the Bay of Bengal (Brooks et al., 2019; Liu et al., 2020; Moteki, 2023; Sankar et al., 2023). The convective rain is an effective process for removing air pollutants from the atmosphere (Liu et al., 2020; Moteki, 2023).” Please see page 11, line 341-350.</i>
21.	Figure 2,3 and 4: Wouldn't box plot be a better option than average and standard deviation? If the blox plot are hard to read maybe had the median in the Table S2 and S3.	<i>Earlier we tried the box plot but it was not representing well so we put line with SD. We have added the median in the table S3.</i>
22.	Figure 6: add the sampling site on, at least, one of the maps.	<i>The figure 6 and 7 are change and the point location of study site is pointed.</i>
<b><i>Supplementary information:</i></b>		
1.	Section 1.1: the notation is not consistent between the main text and the supplement (e.g. $\sigma_{BC}(\lambda)$ and $b_{abs}(\lambda)$ ).	<i>The equations are changed. Please see supplementary as well as main manuscript section.</i>
2.	Page 3: “ATN and BC relationship is given in figure (S7) for the daily	<i>Thank you, changed it.</i>

	data.” You are probably referring to figure S2 here.	
3.	Page 3 Equation 3.4: instead of $B(\lambda)$ , do you mean $BC(\lambda) = b_{\text{abs}}(\lambda) / \sigma_{\text{abs}}(\lambda)$	<i>The equations are changed. Please see supplementary.</i>
4.	Page 4 equation 3.7 and 3.8: Shouldn't “- aff” and “-abb” be exponent?	<i>The equations and numbering are changed. Please see supplementary.</i>
5.	Page 5 equation 3.12: Do you mean BCff?	<i>The equations and numbering are changed. Please see supplementary.</i>
6.	Page 6 Figure S2: Please correct the figure’s caption.	<i>It is corrected as mentioned.</i>
7.	Page 7 Figure S4: Please correct the figure “Total could cover” to “total cloud cover”	<i>It is corrected.</i>
8.	Page 8 Figure S5: The BC and BrC data seem to still have zero did you estimate the limit of detection of the instrument? Should those points be included in the comparison?	<i>Yes, it is included. Zore is there because of two-digit values because the values were 0.00000x likewise.</i>