Dear editor and reviewers,

We thank the reviewers for the positive and constructive evaluation of our manuscript. All comments are addressed below and greatly helped to improve our manuscript. We have now revised Figure 9 and included an explanation for the observed difference in NEE and N_{neg} between the studied ecosystem (line 408-437).

We would like to make a note that we have corrected the measurement period at Haltiala croplands to ‘06/2021-10/2022’ from ‘01/2022-12/2022’. All available data for both NAIS and CO_2 fluxes at Haltiala cropland are from 2021/06-2022/10 so far. We modified the text and the code so now it is the right date range. After revision, the midday CO_2 uptake rate and N_{neg} in summer in Haltiala cropland decreased from 19.69 μmol m^{-2} s^{-1} and 3.08 cm^{-3} to 10.42 μmol m^{-2} s^{-1} and 2.66 # cm^{-3}, respectively. Similarly, for Tvärminne coastal area, the date range in Tvärminne coastal was revised from 2022.06-2023.05 to 2022.06-2023.08 (in the code). After revision, the midday CO_2 uptake rate and N_{neg} in summer at Tvärminne site decreased from 0.01 μmol m^{-2} s^{-1} and 1.46 cm^{-3} to -0.01 μmol m^{-2} s^{-1} and 1.2 # cm^{-3}, respectively. The related figures and figures were all revised. However, the main conclusions remained without changes. Detailed responses to the comments can be found below.

Anonymous Referee #1, 28 Spe 2024

The authors analyzed and presented the net ecosystem exchange (NEE) and the number concentration of negative intermediate ions (N_{neg}) measurements across sites in different ecosystems. They introduced the novel framework "CarbonSink + Potential" to highlight the importance of boreal ecosystems in the climate system. This framework offers an interesting and new perspective on how boreal ecosystems directly absorb CO_2 and indirectly influence the radiation balance, thereby mitigating global warming and climate change.

This topic is both significant and relevant to the scope of Biogeoscience. While the paper is generally well-written, the analysis remains preliminary, and the main argument lacks clarity. I believe further analysis is needed to enhance the overall quality of manuscript. Here are some major comments I have:

1. I suggest that the authors change the way they present the data. Figures 2-4 and Figures 6-8 show two series of data for NEE and N_{neg}, respectively. I wonder why the authors presented the mean, 25th, and 50th percentiles for NEE (and the 50th and 75th percentiles for N_{neg}) separately in different panels. There are other effective options, such as box plots or violin plots. Additionally, could you combine the results for the different ecosystems? This could make it easier to see the differences between the ecosystems.

Reply: Thank you for the suggestion. In box plots (see examples below), the information is clustered together, making it too messy to include all ecosystems also in the same figure. As the main aim is to present the potential of CO_2 uptake (50th and 25th percentile) and aerosol production (50th and 75th percentile), we would prefer the original way of presenting the data. However, if the editor or reviewers insist, we can change the way of presenting the results.

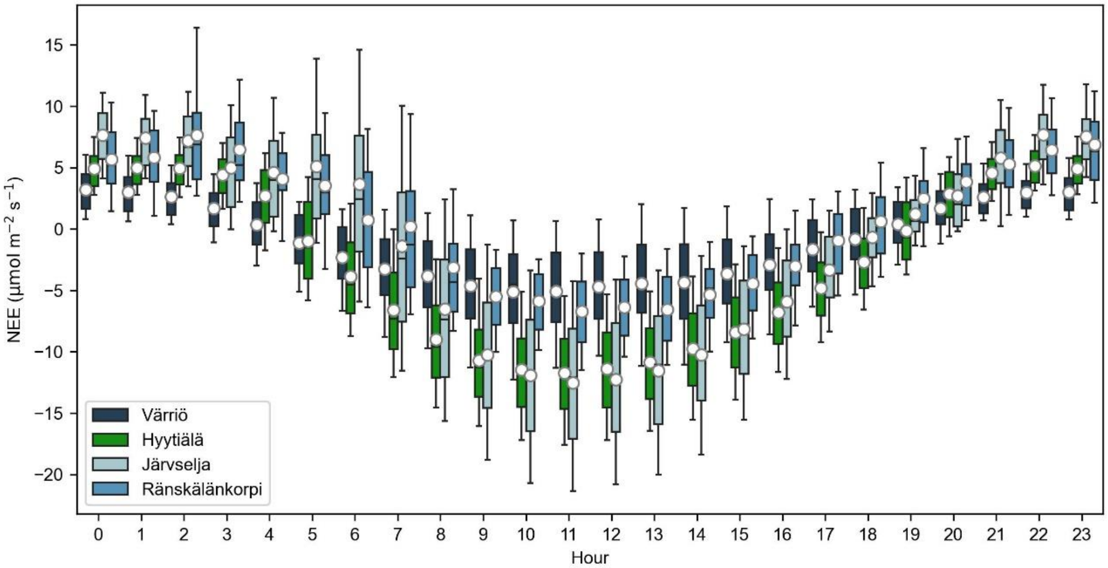

Figure example1. The diurnal plot of the NEE in summer. The circles are mean values and the lines in the boxes are median values.

It is an interesting approach to consider the role of terrestrial ecosystems as direct carbon sinks and indirect sources of new particle precursors and aerosols. However, the comparison conducted in this study did not integrate these two concepts very well. For example, a recent study by Weber et al. (2024) illustrated this integration effectively. I wonder if the authors could provide an estimation of the relative importance of these two concepts.

Reply: The relative importance of CO_2 uptake and aerosol production can be compared by their contribution to radiative forcing, as done in the study by Weber et al., (2024). However, the process of aerosol growth, the radiation scattering effect, and aerosol-cloud interactions take place on a regional scale, whereas we aim to emphasize here the ecosystem-scale potentials of CO_2 uptake and aerosol production. We do this by utilizing the datasets of negative ions in specific size range, 2-2.3 nm. This is novel in our work and allows us to quantify ecosystems' climate cooling potential regarding aerosol production with a simplified method. How the ecosystem-scale CO_2 uptake and aerosol production impact the regional climate remains a topic to be addressed in a follow-up study.

2. Most of the analysis in this study is based on the diurnal cycle, but it lacks depth in data interpretation. I suggest conducting further analysis to provide more insights. For example, different ecosystems exhibit distinct terpenoid emission patterns. Many boreal needleleaf

forest ecosystems are dominated by monoterpenes (Boy et al., 2022), which are important precursors for particles. However, the fen at the Siikaneva site also has high isoprene emissions (Vettikkat et al., 2023), which could suppress the formation of new particles (Kiendler-Scharr et al., 2009). In addition, Vettikkat et al. (2023) reported high temperature sensitivity of terpenoids. I noticed that meteorological data was mentioned in Section 2.2 of the paper, but I did not see any related analysis. Could the authors incorporate additional analysis using meteorological data? For instance, how does N_{neg} respond to temperature changes? How do different vegetation components or types affect the NEE and N_{neg}?

Reply: It is true that different ecosystems may exhibit distinct terpenoid emission patterns and show different responses to temperature and radiation, which can further influence aerosol production. However, the responses of N_{neg} (aerosol production) and NEE to air temperature did not present a uniform trend and it is difficult to tell how different ecosystems respond differently to air temperature changes.

For example, when the PPFD is between 400 and 800 μmol m^{-2} s^{-1} in summer (figures below), there is a slight decreasing trend of N_{neg} with increasing air temperature for sites other than Hyytiälä forest, which may be related to the cluster stability. In the case of NEE, all forest sites showed an increasing trend with air temperature, in contrast to the Siikaneva peatland. However, all the correlations were weak (R< 0.3). Air temperature can both increase the rates of respiration and photosynthesis, which makes it quite site-specific whether NEE (net CO_2 flux) will increase or decrease with air temperature. For N_{neg}, other factors, such as H_2SO_4 concentration, can distinctly impact the clustering formation. As the plots did not help to address our main research questions, we are not including them in the manuscript.

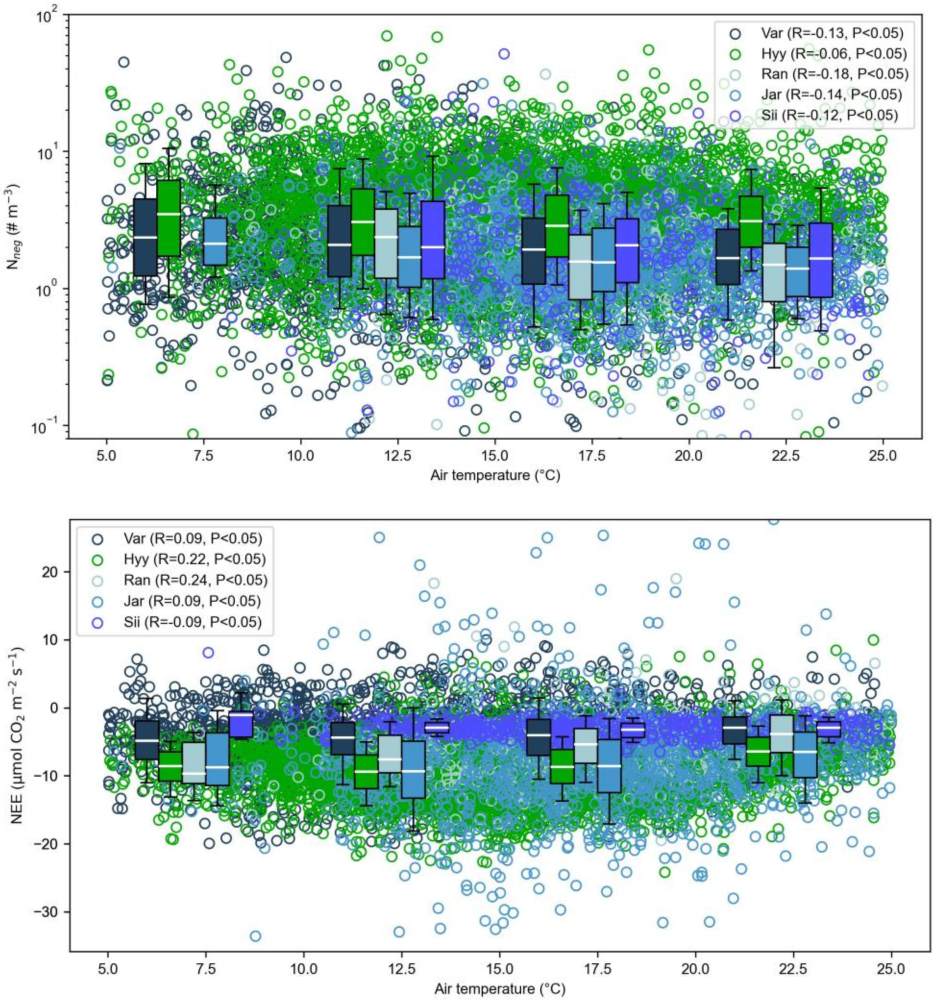

Figure example2: The responses of N_{neg} and NEE to air temperature in summer when the photosynthetic photon flux density (PPFD) is between 400 and 800 μmol m^{-2} s^{-1}. Half-hourly mean data are presented. The boxes are distributions of N_{neg} and NEE in each air temperature bins of 5-10, 10-15, 15-20, 20-25°C.

We now have revised Figure 9 and added two paragraphs (lines 396-426), briefly reasoning why we see different NEE and N_{neg} across the studied ecosystems. This included the analysis of air temperature and radiation:

"Multiple factors can cause the difference in NEE and N_{neg} across the sites despite the similar seasonal and diurnal variation patterns. The CO_2 uptake rate at midday in summer increased with an increasing air temperature in both studied forests and agricultural fields (Figure 9). Moreover, the CO_2 uptake rate at midday in summer increased with LAI across the studied forest ecosystems (Table 1 and Figure S9). As F-RAN was selectively harvested (Section 2.3), the leaf area was decreased, which can result in a lower CO_2 uptake rate than other forests under similar air temperature and PPFD. Additionally, the peat soil at F-JAR and F-RAN can induce higher respiration (Figure 2). Hence, even though the LAI and air temperature at F-JAR were 23% and 10% higher than that in F-HYY, respectively, the NEE at F-JAR was only 4% lower than that at F-HYY. In the agricultural fields, the LAI and air temperature were comparable or higher than that in the forests, which may explain the high momentary CO_2 uptake rate at summer midday in the agricultural fields.

In the case of N_{neg}, the precursor of aerosol production largely influences N_{neg}. The trends of N_{neg} varying with air temperature and radiation were not evident (Figures 9 and S9). H_2SO_4 formation can drive the nucleation process and is influenced by the sulphur dioxide concentration and radiation. As the garden area and agricultural fields in this study are located in or nearby cities, the SO_2 concentration there may be enhanced due to the anthropogenic pollution and its long-range transport. Also, the terpene emissions can initiate NPF, which has been observed in Siikaneva peatland and led to stronger NPF there than that in F-HYY (Junninen et al., 2022; Huang et al., 2024). However, these events were reported to occur mostly in the late evening. Different plant species can emit different types of BVOCs (Guenther et al, 2012), e.g., monoterpenes are found dominant in coniferous forests and isoprene dominant in broadleaf forests. The oxidation products of monoterpenes can enhance aerosol formation and growth (Rose et al., 2018), while isoprene has been reported to inhibit new particle formation (Kiendler-Scharr et al., 2009). As birch species are mixed with coniferous species in F-JAR, the possibly higher isoprene emission than in the other three predominantly coniferous forests may partially explain the lower N_{neg} in F-JAR. Moreover, the enhanced NH_3 in agricultural fields can play a synergistic role with both H_2SO_4 and low volatile organic compounds in clustering (Dada et al., 2023), which may explain the generally high N_{neg} in the three studied agricultural fields.”

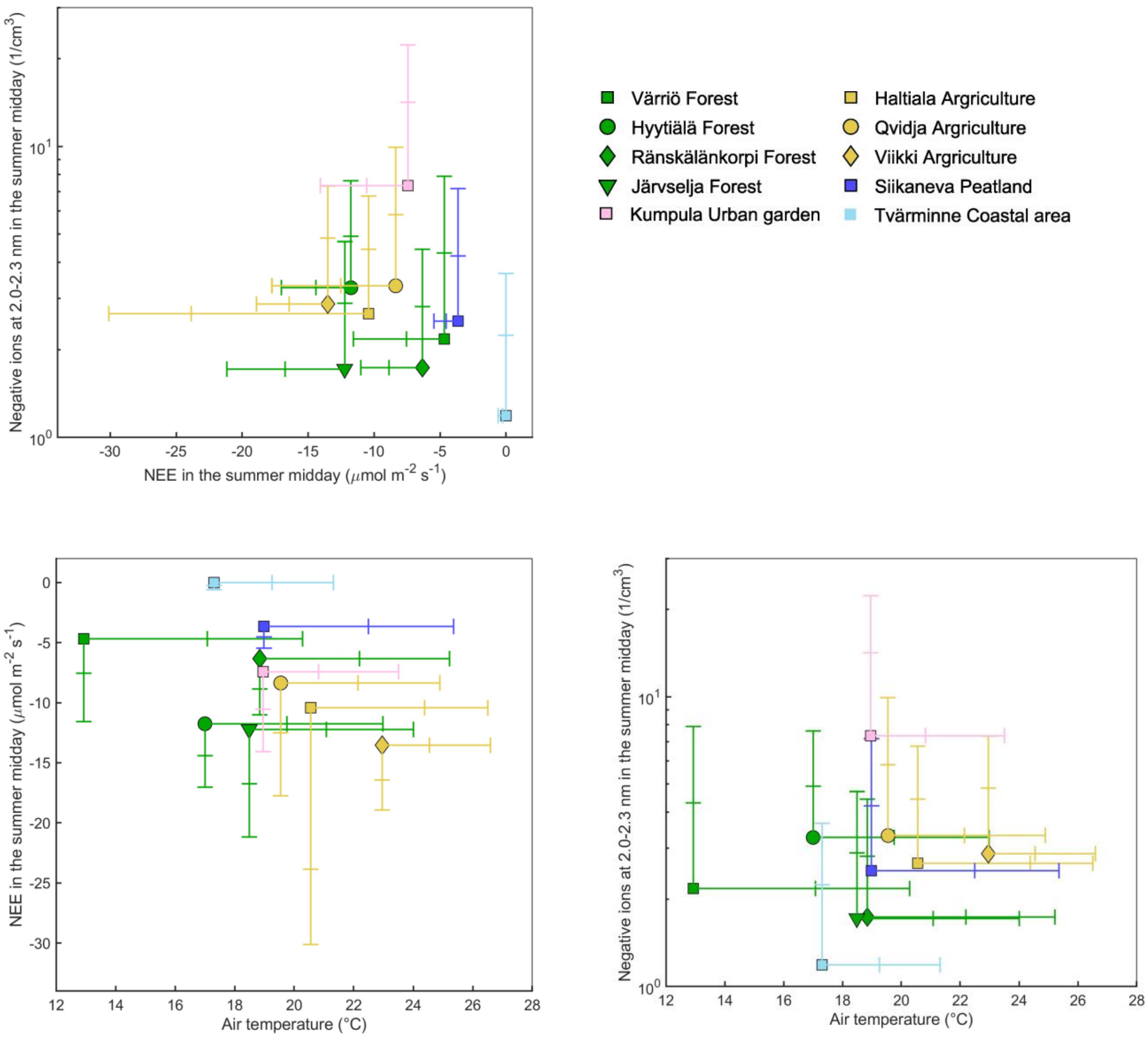

Figure 9. Comparison between median NEE, median negative intermediate ions at 2.0-2.3 nm, and median air temperature at midday in summer between the sites. The error bars are 10th and 25th percentile for NEE, 75th and 90th percentile for the negative intermediate ions, and 75th and 90th percentile for the air temperature at each site.

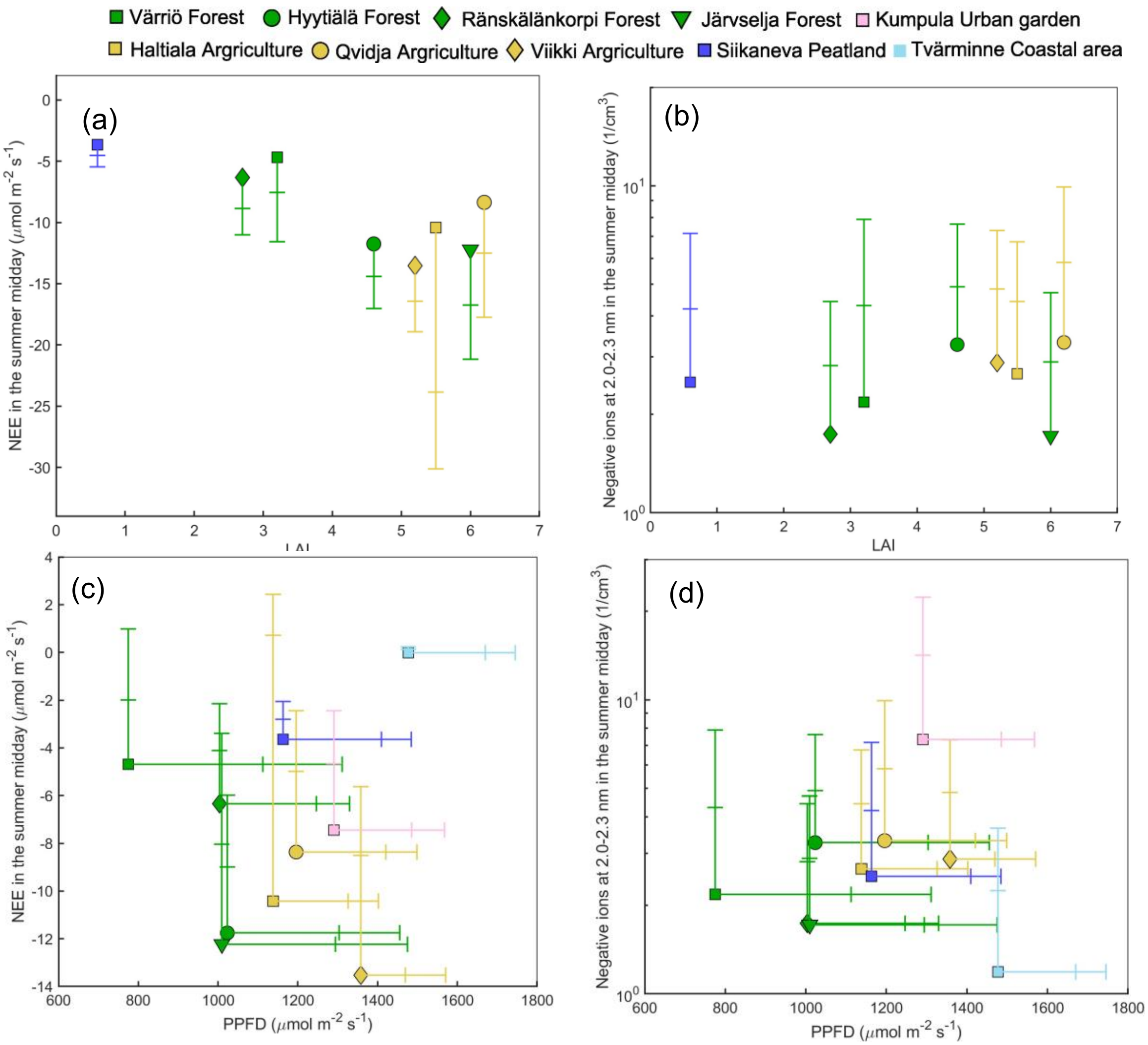

Figure S9. Comparison between median NEE, median negative intermediate ions at 2.0-2.3 nm, leaf area index, and median photosynthetic photo flux density (PPFD) at midday in summer between the sites. The error bars are 10th and 25th percentile for NEE, 75th and 90th percentile for the negative intermediate ions, and 75th and 90th percentile for PPFD at each site.

Minor comments:

Line 180: The data periods differ among sites. Although the authors claimed that they would not discuss inter-annual variation, data from shorter periods, especially as short as one year, will still be affected by it, which may affect their diurnal cycles and comparisons with other sites. I think the authors should aware this and demonstrate the potential impact of inter-annual variation on their analysis.

Reply: We now have added the standard deviation of NEE and N_{neg} at summer midday for all measurement years in Table 2 and discussed the potential impact of inter-annual variation on the result in lines 386-395 “It should be noted that only 1 year of data were applied in the stations with newly established atmospheric measurement, i.e., A-VII, although measurements continue. The inter-annual variation of NEE has been widely observed in many ecosystems, e.g., F-HYY (Neefjes et al., 2022) and A-QVI (Heimsch et al., 2021), possibly due to inter-annual change in temperature and precipitation. In the reported year in A-VII, the air temperature was higher than average in years 2015-2020 (Finnish Meteorological Institute; Figure S8). Since a higher air temperature can simultaneously increase the rates of respiration and photosynthesis in an ecosystem, the influence of an increased air temperature on the net CO_2 flux, i.e., NEE, is quite site-specific. More observation years are needed to reduce the estimation errors of NEE. Compared with NEE, the N_{neg} at summer midday was relatively stable across different years (Table 2). Hence the measured N_{neg} in the reported year is likely representative of local aerosol production at the site."

Line 400: I don't understand the purpose of Figure 9. The error bars represent different percentiles on the x and y axes, and the meaning of the dots is not explained (are they means? medians?). In addition, I expected the authors to discuss the relationship between NEE and N_{neg}, but this scatter plot does not seem to address that. It is more like putting data together.

Reply: Line 413 for the figure caption is revised "Figure 9. Comparison between the median NEE, median negative intermediate ions at 2.0-2.3 nm, and median air temperature at midday in summer between the sites. The error bars are the 10th and 25th percentiles for NEE, the 75th and 90th percentiles for the negative intermediate ions, and the 75th and 90th percentiles for the air temperature at each site". The Figure 9 has been revised and we now briefly discuss the factors that can cause the observed differences in NEE and N_{neg} across the ecosystems (see reply above). The main scope is to present the potential of different ecosystems influencing the CO_2 uptake and local aerosol production. By clustering similar ecosystems, Figure 9 clearly demonstrates that the differences in NEE and N_{neg} are associated quite strongly with the type of an ecosystem, and not only with meteorological drivers.

The direct connection between NEE and N_{neg} was weak within sites (see example picture below for Hyytiälä forest in summer, when the photosynthetic photon flux density is higher than 600 μmol m^{-2} s^{-1}. The 10^{th}, 25^{th}, 50^{th}, 75^{th}, and 90^{th} percentile of N_{neg} in each NEE bin were plotted). Explaining the correlation between NEE and N_{neg} is out of scope of the present manuscript and will be investigated in follow-up studies.

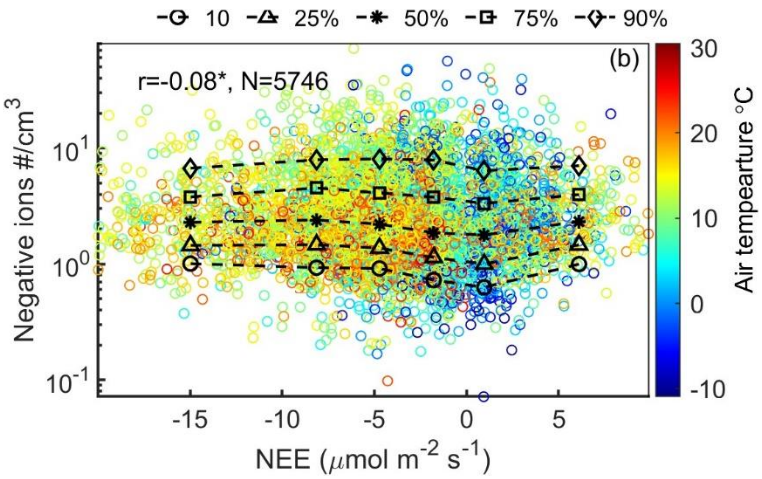

Figure example3. The correlation between NEE and N_{neg} at Hyytiälä forest in summer when PPFD is above 600 μmol m^{-2} s^{-1}. Half-hour mean data are used.

Reference

Boy, M., Zhou, P., Kurtén, T., Chen, D., Xavier, C., Clusius, P., Roldin, P., Baykara, M., Pichelstorfer, L., Foreback, B., Bäck, J., Petäjä, T., Makkonen, R., Kerminen, V.-M., Pihlatie, M., Aalto, J., and Kulmala, M.: Positive feedback mechanism between biogenic volatile organic compounds and the methane lifetime in future climates, npj Climate and Atmospheric Science, 5, 72, 10.1038/s41612-022-00292-0, 2022.

Kiendler-Scharr, A., Wildt, J., Maso, M. D., Hohaus, T., Kleist, E., Mentel, T. F., Tillmann, R., Uerlings, R., Schurr, U., and Wahner, A.: New particle formation in forests inhibited by isoprene emissions, Nature, 461, 381-384, 10.1038/nature08292, 2009.

Vettikkat, L., Miettinen, P., Buchholz, A., Rantala, P., Yu, H., Schallhart, S., Petäjä, T., Seco, R., Männistö, E., Kulmala, M., Tuittila, E. S., Guenther, A. B., and Schobesberger, S.: High emission rates and strong temperature response make boreal wetlands a large source of isoprene and terpenes, Atmos. Chem. Phys., 23, 2683-2698, 10.5194/acp-23-2683-2023, 2023.

Weber, J., King, J. A., Abraham, N. L., Grosvenor, D. P., Smith, C. J., Shin, Y. M., Lawrence, P., Roe, S., Beerling, D. J., and Martin, M. V.: Chemistry-albedo feedbacks offset up to a third of forestation's CO2 removal benefits, Science, 383, 860-864, 10.1126/science.adg6196, 2024.

Anonymous Referee #2, 30 Spe 2024

Potential of carbon uptake and local aerosol production in boreal and hemi-boreal ecosystems across Finland and in Estonia

Piaopiao Ke et al.,

This manuscript explained and researched the CO_2 uptake and local aerosol production at different types of stations in Finland. Authors analysed each NEE and N_{neg} characteristics at each station and compare between them. Introduction is very persuasive and interesting why this study is necessary. However, the way to describe the result of experiments is not kind to the readers. Result was simple and it seems like lack of discussion. I also wonder whether the conclusion gives the answer to the question in the Introduction section. Hopefully authors read the manuscript carefully with reader's view and revise/describe them explicitly.

General comments

1. Title mentioned 'boreal and hemi-boreal ecosystem' but all manuscripts are not linked to boreal and hemi-boreal region. Authors did not explain which site is belonging to boreal or hemi-boreal. According to the category in Table 1, there are forest, agricultural, peatland, urban garden and coastal area. It was hard to match to the title. Authors should consider how to make this manuscript well match to the title and more interesting.

   Reply: We have now added references assigning climate zones to these sites, in line 117 "F-JAR, C-TVA, and A-QVI belong to hemi-boreal ecosystems, while the other ecosystems are boreal (Mäki et al., 2022)". In Table 1, the climate zone of each station is added.

2. Authors did not make station ID and mentioned the station name directly (Table 1). But readers are not familiar with Finish and hard to follow up what type of station with only station's names. Hope authors reconsider the way to explain station' name.

   Reply: We now have added the station ID for each site and revised the name throughout the manuscript. We hope this is clear now.

Sites (Site ID)		Location	Selected period	Mean air temperature (°C)	Rainfall (mm/yr)	Dominant plant species	Peak LAI	Climate Zone
Forest	Hyytiälä, SMEAR II (F-HYY)	61°51'N, 24°17'E	11/2009 - 12/2022	4.8	709[1]	Scots pine and Norway spruce	4.6	Boreal
	Värriö, SMEAR I (F-VAR)	67°46'N, 29°35'E	3/2019-12/2022	0.4	601[2]	Scots pine	3.2	Boreal

	Ränskälän korpi (F-RAN)	61°10’N, 25°16’E	4/2021-12/2022	5.4	600[3]	Norway spruce, Scots pine, downy birch	----	Boreal
	Järvselja, SMEAR Estonia (F-JAR)	58°16’N, 27°16’E	10/2016-12/2020	6.8	500-750[4]	Birch species, Scots pine, Norway spruce	6	Hemi-boreal
Agricultural fields	Haltiala, SMEAR Agri (A-HAL)	60°16’N, 24°57’E	6/2021-10/2022	6.5	700[5]	Oat	5.5	Boreal
	Qvidja (A-QVI)	60°18’N, 22°24’E	12/2018-8/2022	7.0	679[6]	Timothy, meadow fescue	6.2	Hemi-boreal
	Viikki, SMEAR Agri (A-VII)	60°13’N, 25°01’E	7/2022-6/2023	6.5	792[5]	Timothy (2022), Barley (2023)	5.2	Boreal
Peatland	Siikaneva, SMEAR II (P-SII)	61°50’N, 24°12’E	11/2019-12/2022	5.0	710[7]	Moss and sedges	0.6	Boreal
Urban garden	Kumpula, SMEAR III (G-KUM)	60°12’N, 24°58’E	5/2016-12/2022	6.3[5]	731[5]	Mixed	------	Boreal
Coastal area	Tvärminne (C-TVA)	59°51’N, 23°15’E	6/2022-8/2023	7.2[5]	639[5]	Seagrass and seaweed	-----	Hemi-boreal

3. In many paragraphs, authors did not suggest table/figure # but also values. For example, *L367-369: The momentary net CO_2 uptake rate at midday in summer was highest in agricultural fields, followed by the forests. The urban garden in this study displayed distinct net CO_2 uptake, lower than the forests and higher than the open peatland*. Next to the highest, it needs value. Lower than or higher than, authors can suggest certain values. Without certain values, all explanations such as “lower than, higher than, highest, similar” are very boring and insufficient to deliver what authors would like to say.

   Reply: We have now revised the descriptions throughout the manuscript and added exact values for the differences, such as in lines 371-378: “The agricultural fields generally had higher N_{neg} than the studied forests and the open peatland (P-SII) had 23% lower N_{neg} than F-HYY but 15-46% higher than the other forests. The N_{neg} at the coastal area was the lowest. The momentary net CO_2 uptake rate at midday in summer was highest in agricultural fields, followed by the forests. The urban garden in this study displayed distinct net CO_2 uptake, 37% lower than the forests and ~2 times that in the open peatland. The coastal area at midday in summer was a very weak CO_2 sink. In the urban garden area in G-KUM, median N_{neg} was double that in F-HYY, while the median NEE only reached 63% of that in F-HYY". For general descriptions, such as in Line 271, "For median values in summer, N_{neg} was found to be the highest in the urban garden, followed by the agricultural fields (Figure 9)", we would like to follow the present way to keep the manuscript concise.

4. Hope authors can describe the sufficient reason after the result, for example, in section 3.3. This is scientific paper not a report.

Reply: In this study, we aimed to present the different potential of CO_2 uptake and aerosol production across different ecosystems; hence we reported directly measured CO_2 fluxes and local aerosol production, indicated by the negative ions at 2-2.3 nm. We focus on the comparison of potentials and have now briefly investigated the reasons that could cause the difference in NEE and N_{neg} between the ecosystems. We have revised Figure 9 and added a corresponding discussion in two paragraphs in Section 3.3 (Line 396-426):

"Multiple factors can cause the difference in NEE and N_{neg} across the sites despite the similar seasonal and diurnal variation patterns. The CO_2 uptake rate at midday in summer increased with an increasing air temperature in both studied forests and agricultural fields (Figure 9). Moreover, the CO_2 uptake rate at midday in summer increased with LAI across the studied forest ecosystems (Table 1 and Figure S9). As F-RAN was selectively harvested (Section 2.3), the leaf area was decreased, which can result in a lower CO_2 uptake rate than other forests under similar air temperature and PPFD. Additionally, the peat soil at F-JAR and F-RAN can induce higher respiration (Figure 2). Hence, even though the LAI and air temperature at F-JAR were 23% and 10% higher than that in F-HYY, respectively, the NEE at F-JAR was only 4% lower than that at F-HYY. In the agricultural fields, the LAI and air temperature were comparable or higher than that in the forests, which may explain the high momentary CO_2 uptake rate at summer midday in the agricultural fields.

In the case of N_{neg}, the precursor of aerosol production largely influences N_{neg}. The trends of N_{neg} varying with air temperature and radiation were not evident (Figures 9 and S9). H_2SO_4 formation can drive the nucleation process and is influenced by the sulphur dioxide concentration and radiation. As the garden area and agricultural fields in this study are located in or nearby cities, the SO_2 concentration there may be enhanced due to the anthropogenic pollution and its long-range transport. Also, the terpene emissions can initiate NPF, which has been observed in P-SII and led to stronger NPF there than that in F-HYY (Junninen et al., 2022; Huang et al., 2024). However, these events were reported to occur mostly in the late evening. Different plant species can emit different types of BVOCs (Guenther et al, 2012), e.g., monoterpenes are found dominant in coniferous forests and isoprene dominant in broadleaf forests. The oxidation products of monoterpenes can enhance aerosol formation and growth (Rose et al., 2018), while isoprene has been reported to inhibit new particle formation (Kiendler-Scharr et al., 2009). As birch species are mixed with coniferous species in F-JAR, the possibly higher isoprene emission than in the other three predominantly coniferous forests may partially explain the lower N_{neg} in F-JAR. Moreover, the enhanced NH_3 in agricultural fields can play a synergistic role with both H_2SO_4 and low volatile organic compounds in clustering (Dada et al., 2023), which may explain the generally high N_{neg} in the three studied agricultural fields."

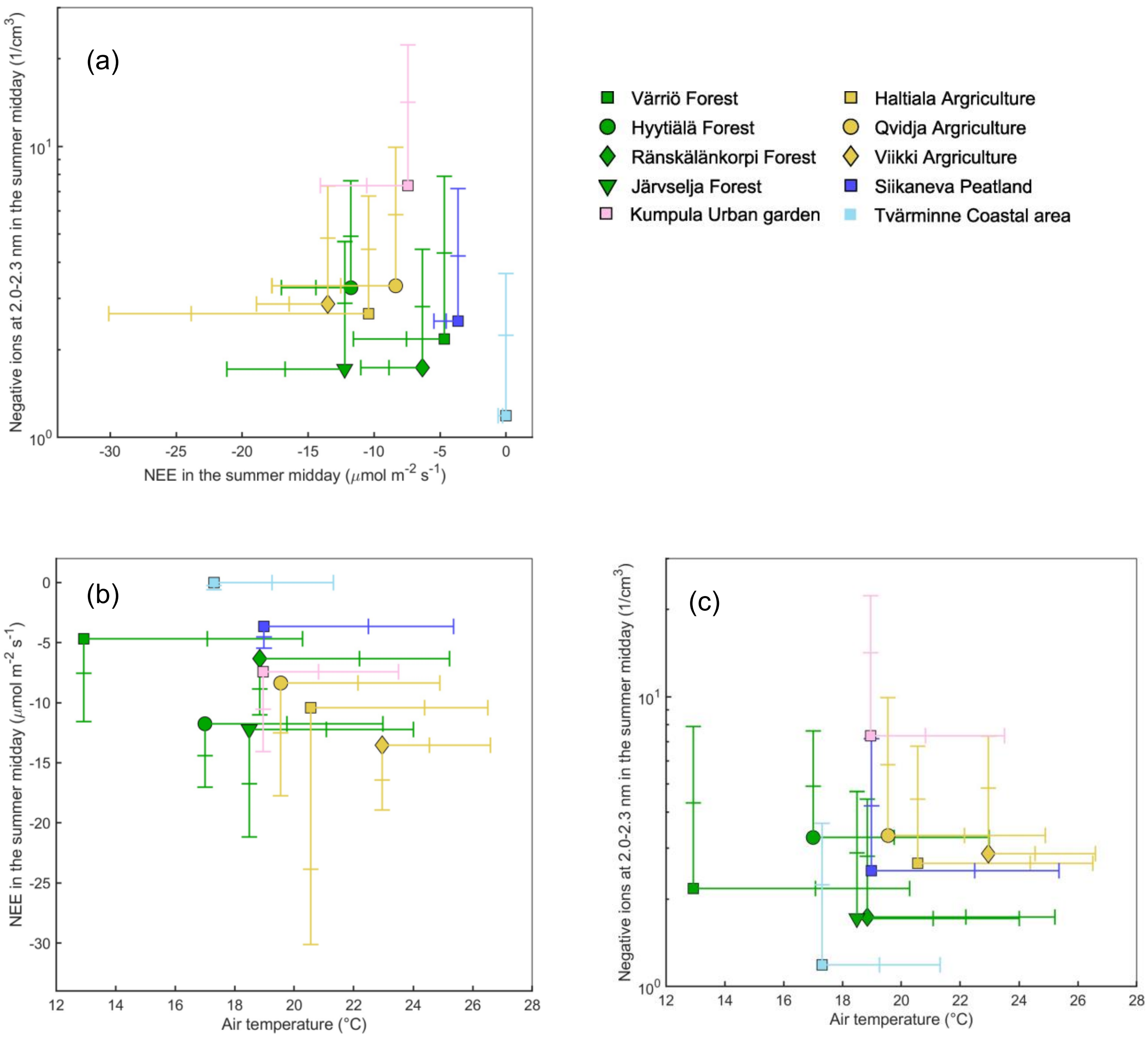

Figure 9. Comparison between median NEE, median negative intermediate ions at 2.0-2.3 nm, and median air temperature at midday in summer between the sites. The error bars are 10th and 25th percentile for NEE, 75th and 90th percentile for the negative intermediate ions, and 75th and 90th percentile for the air temperature at each site.

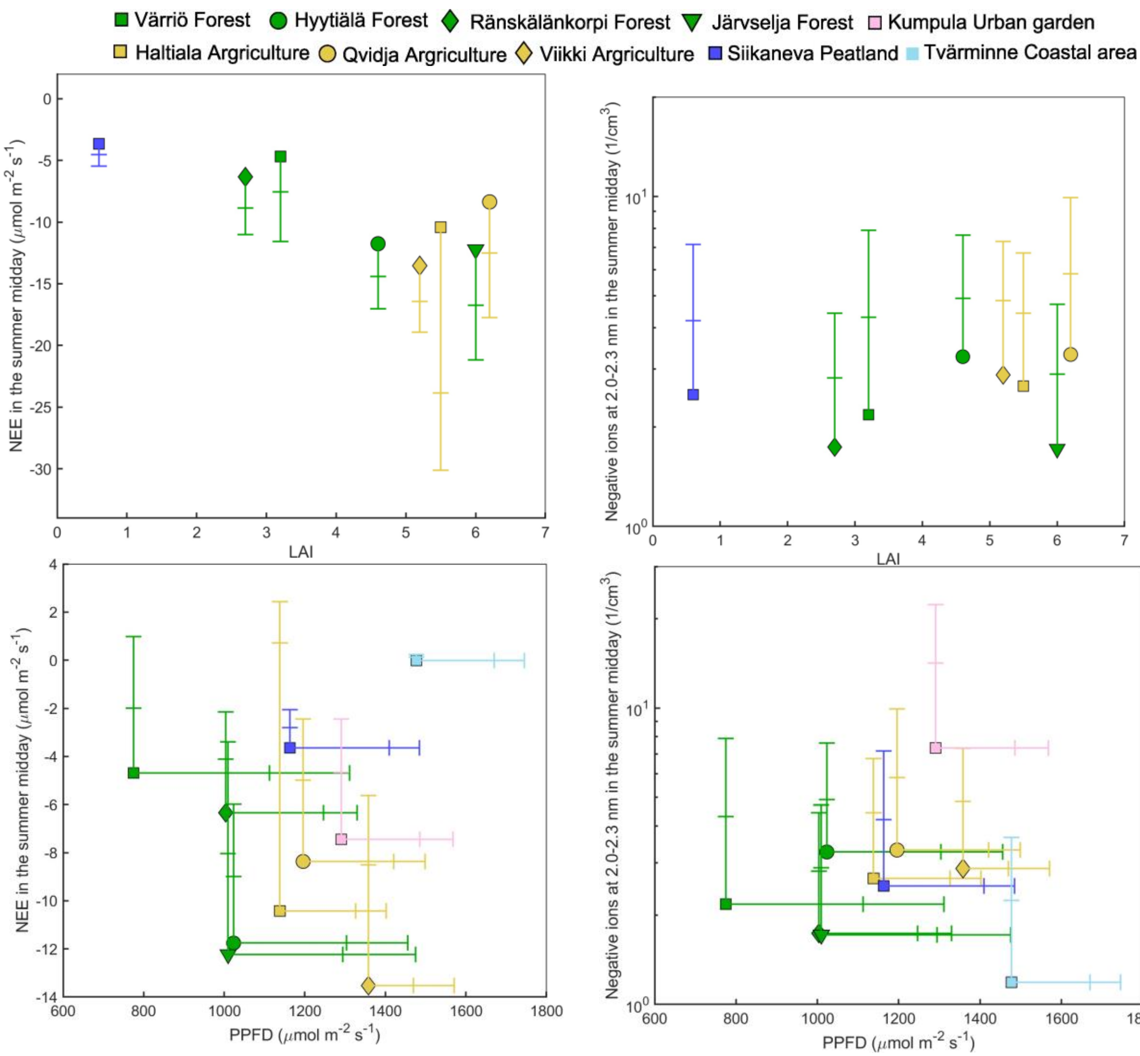

Figure S9. Comparison between median NEE, median negative intermediate ions at 2.0-2.3 nm, leaf area index, and median photosynthetic photo flux density (PPFD) at midday in summer between the sites. The error bars are 10th and 25th percentile for NEE, 75th and 90th percentile for the negative intermediate ions, and 75th and 90th percentile for PPFD at each site.

Minor comments

1. L58: Räty et al., 2023 was not on the reference list.

   Reply: It is now added to the list.

2. L86: long-term datasets. What's the definition of 'long-term' here? Only long-term datasets are from Hyytiälä station and others are less than a decade.

   Reply: It is revised to "This study utilized 1 to 10 year-long datasets of intermediate ion concentrations."

3. Table 1: Between the category (such as Forest and Agricultural) it would be good to have a line.

   Reply: The lines are added now.

4. Table 1: Hope station name can be reconsider. Especially Hyytiälä station is 'reference station', used everywhere but in the forest category. Author can name stations with their characteristic.

   Reply: The site ID is now added (see response to the major comment 2) and used throughout the manuscript. We took Hyytiälä forest as a reference station as it is one typical ecosystem type in Finland and has the longest record of data and endures relatively little anthropogenic interference. Hence, we still kept the Hyytiälä site in forest category.

5. Table 1: Location. Hope author can add height of each station.

   Reply: We added this information in Table S1. We have added in line 145 "The inlets for all the NAIS in the studied sites are 1-2 m high above the ground." and in line 170 "The fluxes were measured above the ecosystem canopies and below 30 m. The detailed measurement height for each site is listed in Table S1.

   L133: *at same heights*. Please add values.

   Reply: The height information is included in Table S1. As the measurement heights (1-70 m) vary between the stations, dependent on the ecosystem canopy height, we referred to Table S1 in the text.

6. L137: *Diameter range*. Does it mean particle size?

   Reply: Yes, it describes the range of particle size in diameter.

7. L140: *The data were cleaned*. What does it mean? Does it mean 'filtered' or 'selected'?

   Reply: This is now deleted as it is the same meaning of 'quality-checked' under this context. "The data were quality-checked, considering e.g. the potential interference of rainfall and snow events on the measurements (Manninen et al., 2016)."

8. L142: *total particle concentration*. Is it mass concentrations or number concentrations or others?

   Reply: It is a number concentration. It is revised as "The ion and total particle number concentration" in the text.

9. L151: *their footprints are constrained within the ecosystem scale*. Don't authors think that it can be differed according to the height of station?

   Reply: Indeed, the footprints of both eddy covariance and N_{neg} are impacted by the height of the station. This sentence is revised as "their footprints are constrained within the ecosystem scale when measured at a height between 1 and 70 m (Section 2.2 and Table S1)." The forest canopy is below

30 m and even shorter for agricultural fields and peatlands. The footprint for eddy covariance (Kljun et al., 2015) and N_{neg} (Tuovinen et al., 2024) are within the studied ecosystems.

10. L153: *outside the active hours of the ecosystem, were taken as the background concentration at each site*. This sentence is conflict against L352-357.

    Reply: The ecosystem at nighttime is assumed to be relatively inactive with no photosynthesis and low BVOC emission. The nighttime clustering explained in L352-357 is more likely a consequence of meteorological conditions associated with atmospheric chemical reactions. To clarify the difference between drivers for daytime and nighttime clustering, the sentence is revised as "However, these negative ions clustered at nighttime are likely unable to grow >3 nm in diameter (Mazon et al., 2016)."

11. L194: *tower*. Hope to add the tower height.

    Reply: The tower height can differ largely with the measurement station. Here we added the measurement height in case of confusion. We revised the text as "The NAIS equipment was positioned in the border between the control and clear-out, ~230 m east from the eddy covariance tower (measurement height of 29 m)".

12. L203: *interference.* What kind of interference?

    Reply: There is an experimental area (for different cutting heights) between 30° and 140° of the eddy covariance mast in the agricultural grassland. The different management in the experimental area may influence the measured CO_2 uptake and N_{neg}. This sentence was revised to avoid confusion "For A-QVI, NAIS and eddy covariance data from wind directions between 30° and 140° were discarded due to another experimental plot located in that part of the field (Heimsch et al., 2021)".

13. L205: *fields*. What is the possible source to affect on data?

    Reply: Revised as "Similarly, at A-VII, only measurements from wind direction between 145° and 245° were included in the analysis to avoid data from other nearby fields with different vegetation and management activities." Vegetation and management activities, such as fertilization, may impact the CO_2 uptake, emission of BVOCs and NH_3 concentration.

14. L226: *In the other seasons, the urban garden area was a net source of CO_2 most of the time, similar to the results previously reported for the years 2006-2010 from the same site (Järvi et al., 2012)*. Most of section did not explain the reason. Why is that?

    Reply: This part is now revised (L230): "There are residential buildings and traffic within the eddy covariance measurement footprint in G-KUM. The CO_2 emissions from the residential buildings, traffic and bare soil outweighed photosynthetic uptake of CO_2 except during summer daytime".

15. Figure 2-4: Why did authors add 50^{th} and 25^{th} graph? It would better to add median with standard deviation to see the variation of the values since experimental periods are different at each station.

Reply: The 50th percentile (median) of the NEE described the average status of CO_2 fluxes. For the 25th percentile of CO_2 fluxes, they corresponded to the conditions when the ecosystem is very active. In the case of N_{neg}, 75th percentile can be a sign of new particle formation event (Aliaga et al., 2023). We want a uniform presentation of NEE and N_{neg} in the manuscript. Also, as we aimed to emphasize the CO_2 uptake and local aerosol production potentials, we prefer keeping the original way of presenting the data.

16. L237: *In the case of agricultural fields in summer (Figure 3), the Haltiala site had higher momentary net CO_2 uptake than the other two agricultural sites*. Why don't authors add specific value for 'higher than' precisely?

    Reply: It is revised to "In the case of agricultural fields in summer (Figure 3), the A-HAL and A-VII croplands had 2-5 μmol m^{-2} s^{-1} (for midday median values) higher momentary net CO_2 uptake rate than the other agricultural grassland." The similar issue, i.e., the specific values for "higher than" or "lower than", in the whole manuscript have been revised.

17. L239: *Qvidja was a CO_2 sink during daytime with a similar uptake rate to the Hyytiälä forest.* Add specific value and figure #.

    Reply: This line is revised as "A-QVI was a CO_2 sink during daytime with a comparable uptake rate to the F-HYY (ranging between 0 and 4 μmol m^{-2} s^{-1})."

18. L240: *The different plant species (Table 1) and management activities between the agricultural fields likely caused the differences in their seasonal CO_2 fluxes*. This is very confusing to readers. In table 1, authors mentioned of plants type but not management activities. I confirmed that it was described in the section 2.1, it would be good to add table 1.

    Reply: We now added the description of management activities in the three agricultural fields in Section 2.3 (line 143) "A-QVI was harvested in June and August, A-VII was harvested twice in August during the reported period, and A-HAL was harvested once around the end of August during the measurement periods. The sowing (over-seeding for A-QVI and only in 2022) and first fertilization in the year usually takes place at the end of spring." And following line 240 "The different plant species (Table 1) and management activities between the agricultural fields likely caused the differences in their seasonal CO_2 fluxes. During the measurement period, perennial plants were grown in A-QVI, while the growth of the annual crops in A-HAL and A-VII relied on the sowing and fertilization date, normally at the end of spring. This may explain the springtime CO_2 emission in A-HAL and A-VII. In the summer, the A-HAL and A-VII was harvested only in August, while A-QVI was harvested in June and August separately, which may explain the higher CO2 uptake rate in A-HAL and A-VII."

19. L294: *The median values of N_{neg} in the daytime in spring were higher than those in the Haltiala and Viikki croplands, Siikaneva peatland, and Kumpula urban garden area*. I cannot understand what this sentence means.

Reply: Revised as follows "The N_{neg} in the daytime in spring were significantly higher than those in the summer at A-HAL and G-KUM (Mann-Whitney U test based on daily medians, $P<0.05$)"

20. L296: *summer median values were higher*. Please finalize the sentence. Higher than what?

    Reply: Revised "At F-VAR, F-HYY, and F-RAN the median values in summer were significantly higher than those in spring ($P<0.05$). For other sites, the difference was not significant ($P>0.05$)".

21. L338: *The application of fertilizers in agricultural fields is known to remarkably increase the atmospheric concentration of ammonia (NH_3)*. This sentence seems to be generalized to all stations. Please add specific type of regions.

    Reply: It is revised to "The application of fertilizers is known to remarkably increase the atmospheric concentration of ammonia (NH_3) in agricultural fields, e.g., observed in A-QVI (Olin et al., 2022)".

22. Figure 9: I cannot understand the meaning of bar in Figure 9.

    Reply: Line 413 for the figure caption is revised "Figure 9. Comparison between the median NEE, median negative intermediate ions at 2.0-2.3 nm, and median air temperature at midday in summer between the sites. The error bars are the 10th and 25th percentiles for NEE, the 75th and 90th percentiles for the negative intermediate ions, and the 75th and 90th percentiles for the air temperature at each site". The main scope is to present the potential of different ecosystems influencing the CO_2 uptake and local aerosol production. The 25^{th} and 75^{th} percentile for NEE and N_{neg} were presented, respectively, to show the higher range of ecosystem CO_2 uptake rate and local aerosol production.

23. Table 2: There is no explanation of 'c' (superscript) and there is no 'b' in the table.

    Reply: The 'c' is revised to be 'b' in Table 2.

24. L409: Summary and conclusions or only summary?

    Reply: It is "Conclusions"

25. L416: What are 10 stations belonging to hemi-boreal station? Why did not author define 'hemi-boreal' and 'boreal' in the manuscript?

    Reply: This has been addressed and please check the response above.

26. L421-423: Why didn't authors add the reasons?

    Reply: This line is revised as "A distinct CO_2 uptake in the urban garden at midday in summer was observed, resulting from the strong photosynthesis of vegetation inside. The uptake rate was 37%

lower than that in F-HYY but ~2 times of that observed in the open peatland". We also simply explained why agricultural fields presented generally high CO_2 uptake and aerosol production in Line 490 "The results showed that the agricultural fields had similar or even 15% higher CO_2 uptake potentials compared to F-HYY during the summer, possibly due to the high leaf area index and air temperature in the agricultural fields." and line 500 "In agricultural fields, the synergetic role of NH_3, H_2SO_4, and low volatile organic compounds originating from BVOC oxidation may play a synergistic role in clustering and induce a high N_{neg} comparing with other ecosystem types.".

27. L431: What's the difference between reference station and background station? Please add the definition.

Reply: The background site in this context means the sites that receive little human interference. Here we actually did not need the concept of background sites, and the text is revised as "Note that the urban garden and agricultural sites in Helsinki might be more influenced by air pollution compared to the forests and open peatland that received little anthropogenic interference and pollution".

Reference

Kljun, N., Calanca, P., Rotach, M. W., and Schmid, H. P.: A simple two-dimensional parameterisation for Flux Footprint Prediction (FFP), Geoscientific Model Development, 8, 3695-3713, https://doi.org/https://doi.org/10.5194/gmd-8-3695-2015, 2015.
Tuovinen, S., Lampilahti, J., Kerminen, V.-M., and Kulmala, M.: Intermediate ions as indicator for local new particle formation, Aerosol Research, 2, 93-105, https://doi.org/10.5194/ar-2-93-2024, 2024.