Referee #2

General Comments

The study's goal of examining how cold conditions affect pollutants in Helsinki, Finland, using a variety of monitoring techniques, was evidently investigated. A comprehensive and well-rounded research plan is demonstrated by the use of two measurement sites and the integration of diverse methodologies such as source apportionment and particular analysis algorithms. Even though it describes the pollution events that were observed and their possible causes, it could do a better job of highlighting the unique viewpoints and contributions that this specific study adds to the body of knowledge already available on urban air pollution in the winter.

Specific Comments

1. It would be beneficial to mention if there was any specific reason for choosing that particular "five-weeks" in January–February 2022 or if it was a random selection. Also, details about how representative that period is for wintertime conditions in Helsinki could strengthen the study's context.

   Answer: There was a reason to select those weeks for the campaign as that period typically represent Finnish winter conditions with low temperature and minimum sunlight. It was already mentioned in the article that "The aim of the study was to investigate the role of wintertime conditions in aerosol formation and precursor gases, black carbon emissions, emission sources, and their influence on particles' physical and chemical properties."

   We added to manuscript (Introduction) also:

   During wintertime, temperature inversion episodes cause traffic related pollutants to be trapped on the boundary layer hindering the mixing and dilution of pollutants. Also, photochemical reactions are minimal during wintertime and the contribution of biogenic emissions is limited.

   And to section 3.1.1 (Meteorology):

   The conditions during the winter campaign (temperature, inversion episodes and variable snow cover) represented typical winter conditions in Helsinki.

2. The authors need to clearly explain the reason for restricting the mobile measurements (ATMo - Lab) to the daytime between 6:30 and 19:30. Since air pollution patterns can vary significantly between daytime and nighttime, and different sources might have different activity levels during these periods, it is essential to know how the exclusion of nighttime measurements might affect the source apportionment and understanding of overall pollution dynamics.

   Answer:

   The focus of ATMo-Lab measurements was to understand how the effects of road traffic vary at the studied street canyon compared to more-open-sections of the same road. Also, the aim was to study the dispersion of road traffic emissions to the adjacent streets in a built environment, which is very relevant for air quality in urban environments in general. Therefore, the measurements were conducted only between 6:30 and 19:30, because the effects of traffic were the clearest during that time. It is true that nighttime activity and conditions differ from daytime, and, thus, the ATMo-Lab measurement cannot be utilized in a comprehensive source

apportionment analysis like the stationary measurement data. Also, for a more practical reason, nighttime measurements with the ATMo-Lab at the studied location were not possible due to available resources.

We added to the manuscript:

The focus of the ATMo-Lab measurements was to understand how the effects of road traffic vary in the studied street canyon compared to more open sections of the same road. Also, the aim was to study the dispersion of road traffic emissions to the adjacent streets in a built environment.

and

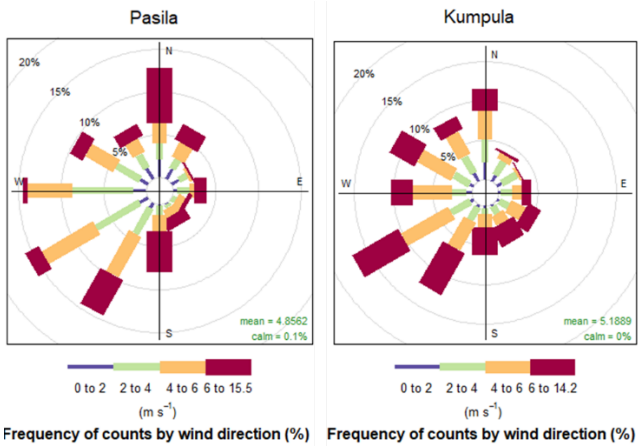
... because the effects of traffic were clearest during that time. Measurement setup inside the Aerosol and Trace-gas mobile laboratory ...

3. The authors must clearly describe the specific calculation method employed for determining the mixing height. Whether it's based on a particular theoretical model (e.g., a thermodynamic model, a boundary layer parameterization method, etc.), an empirical formula, or a combination of both, full relevant data and details should be provided.

   Answer: More detailed description of the mixing height calculation has been added to the supplement.

4. The suggestion to incorporate a wind rose diagram at Fig. 2 has the potential to enhance the comprehensiveness and interpretability of the presented data.

   Answer: The wind rose diagram has been added to Fig. 2 with the mention that the wind speed and wind direction were measured in Pasila weather station about 1 km distance from the Traffic Supersite station. The wind rose diagram gives an overall view of the prevailing wind direction. However, since the Traffic Supersite station is at a street canyon, the nearby tall buildings may alter the wind direction along the street lanes. Additionally, the wind rose plotted from the Kumpula weather station data is added. The Kumpula weather station stands next to the UB Supersite station.



5. The omission of standard values for the pollutant concentrations presented in lines 400 - 407. Without these reference values, it becomes extremely difficult for readers to assess the severity and significance of the measured pollutant levels. In addition to local standards, providing world

or international standards (such as those set by organizations like the World Health Organization for certain key pollutants) would offer a broader perspective.

Answer: The WHO reference values of $PM_{2.5}$, PM_{10}, NO_2 and O_3 have been added as suggested by the Referee.

6. Apart from summarizing the primary elements derived from the source analysis, it is advised to conduct additional analysis on the variations in the contributions of various sources in various pollution incidents and time periods (e.g., weekdays versus weekends, and daytime versus nighttime), as well as to thoroughly investigate the dynamics of the sources and their connections with weather and traffic patterns.

   Answer: More discussion about the variations of PMF factors are added to the text:

The hourly variations of total organics and the calculated factors HOA, BBOA, SV-OOA, LV-OOA, LV-OOA-BB, and Tr-OOA during non-episodic period are shown in Fig. S14 (workdays) and Fig. S15 (weekends). The hourly variation of HOA factor is clearly connected to traffic frequencies. In fact, its diurnal variation is similar to that of PN, NO_x and BC which are primarily from the engine emissions. During the weekends the diurnal pattern of HOA together with PN, NO_x and BC show higher concentrations during afternoon and late evening following the diurnal variation of traffic frequencies. The correlation coefficients (R^2) between HOA and NO and NO_2 were 0.67 and 0.74 respectively. The factor connected to biomass burning (BBOA) shows two peaks; one in midday and another in evening. The evening peak is probably connected to wood burning in Helsinki area. Wood burning takes places in detached houses in Helsinki in sauna stoves and housewarming purposes especially during cold months. The evening peak of BBOA was clearly seen also during weekends and it started already after late afternoon which is due to more active use of sauna stoves and fireplaces during weekends. The diurnal cycle of Tr-OOA during workdays (Fig S14) indicates that it was connected to local traffic related emissions. However, compared to HOA, its concentration did not clearly increase during afternoon and late evening on weekends. The concentrations of oxidised organic factors SV-OOA and LV-OOA were quite similar during the whole day, both on workdays and weekends. This indicates that their source was mostly of long-range or reginal origin. Concentration of LV-OOA-BB factor was also very stable during the workdays but showed increased concentrations during the evening on weekends. It is possible that the local or regional wood burning is shown in this factor during the weekends.

7. Validate and supplement the source analysis results with other research methods (e.g., emission inventory data, PCA, etc.) to enhance the credibility and persuasiveness of the results.

   Answer: We acknowledge this comment from the Referee, but we think that this topic is not in the scope of this article. The validation of source analysis results with other research methods is important and therefore requires a separate article to be done thoroughly.

8. The article has relatively little coverage on the chemical transformation mechanisms of pollutants during long-range transport. Research in this aspect should be strengthened. For example, by measuring the concentration changes of relevant precursors and products during the transport process, combined with the simulation of atmospheric chemistry models, analyze the generation processes and rates of secondary pollutants (such as sulfates, nitrates, secondary organic aerosols, etc.), and clarify the main chemical transformation reactions at different transport stages, so as to evaluate the impact of transport on the chemical composition and properties of pollutants more comprehensively.

   Answer: Regarding the chemical transformation mechanisms of pollutants during long-range transport, there are huge variations in the lifetimes of the studied VOCs. While the lifetime of benzene is several months, some of the terpenoids (e.g. limonene) are oxidized within a few hours. Therefore, the longer living VOCs are expected to accumulate in the long-range transported air

masses. Also, shorter living α-pinene was higher than the average during the episodes indicating impact of also more local/regional sources. Chemical transformation will be studied in follow-up papers.

In terms of secondary aerosol components sulfate, nitrate, ammonium and SOA, are mostly formed from gaseous SO_2, NO_X, and VOCs in the atmosphere. During the episodes of long-range transport emissions (E1-E3), their concentrations were clearly larger than during the traffic periods (Table 1). For the oxygenated OOA components, SV-OOA and LV-OOA, the increase during the episodes was not so clear, however, the concentration of LV-OOA with BBOA was much larger during the episodes than during traffic periods suggesting its being log-range transported. The analysis of the generation processes and rates of secondary pollutants, and the main chemical transformation reactions at different transport stages have not been studied in detail in this paper as its out of the focus of article. However, as it is an important aspect, it could be studied in later papers.

9. For regional transport, insufficient attention has been paid to the impact exerted by the terrain and the characteristics of the underlying surface in the vicinity of the measurement sites on the transport of pollutants.

   Answer: There was already some information about the effect of terrain in the text:

The $PM_{2.5–10}$ concentration was relatively low during the campaign. This is due to rainfall, snowfall, and snow covering the streets during the campaign which inhibited the formation and re-suspension of street dust. Most of the street dust is in coarse particle size, but it is in some degree also in fine particle size range. The lack of street dust episodes in winter explains, at least partly, why the mean $PM_{2.5}$ is also lower than that measured at the Traffic Supersite throughout in years 2015–2019 (Rönkkö et al., 2023b).

Technical Corrections

1. The lack of uniformity in the font used for pictures throughout the paper detracts from the overall professionalism and polish of the work.

   Answer: The figures have been changed so that similar fonts are now used.

2. Some of the sentences are longer and more complex in structure, which may cause some difficulty for readers to understand. For example: line 133–135.

   Answer: The sentence mentioned by the referee has been rewritten and the paper has been checked and rewritten to avoid long sentences.

Additional corrections

1. The one-hour averages have been recalculated due to some mistakes in the start and end times of the measured components. The error in one-hour average data did not cause any meaningful changes to the average values shown in Table 1 and Table S3 or the correlation coefficients

mentioned in text. However, these small changes have been corrected. The corrected data has been uploaded to Zenodo.

2. The text has been read throughout, and several long sentences have been shortened.
3. The Abstract has been changed so that no abbreviations are used.