

# Response to the Referee #2 for the “Insights on Ozone Formation Sensitivity in Southeast and East Asian Megacities during ASIA-AQ”

Cho et al.

We would like to thank the reviewer for their careful reading of the paper and for providing useful comments which improved the manuscript. We reply here to each review comment (comment shown in italics). Blue text represents the corresponding correction in the manuscript.

## Anonymous Referee #2

### Specific comments

**Comment #1:** *In Introduction, Line 65-75, after discussing NO<sub>x</sub>- and VOC-sensitive regimes, please consider adding a few sentences about the “transitional regime” because ozone formation is not either or, and more studies in recent years reveal that the formation regime at local scale could shift within a day, modulating peak ozone formation rates (Mazzuca et al., 2016; Guo et al., 2021; Tan et al., 2024; Stockwell et al., 2025). Such context will facilitate your point that “...nonlinearity makes it more difficult to navigate and inform the direction of emission reduction strategies” and better pave the road for the subsequent discussions in Section 4.*

*-Mazzuca et al., 2016 (<https://doi.org/10.5194/acp-16-14463-2016>)*

*-Guo et al., 2021 (<https://doi.org/10.1016/j.atmosenv.2021.118624>)*

*-Tan et al., 2024 (<https://doi.org/10.1016/j.scib.2018.07.001>)*

*-Stockwell et al., 2025 (<https://doi.org/10.5194/acp-25-1121-2025>)*

**Response #1:** We agree with the reviewer that ozone formation sensitivity is not strictly limited to two discrete regimes and that transitional conditions can occur. To highlight this point, we added a brief description of transitional regimes in the Introduction (Lines 73–75): “**Between these two regimes, transitional conditions may occur when precursor levels lie near the ridge line separating NO<sub>x</sub>- and VOC-sensitive regimes. Under such conditions, ozone formation sensitivity can shift as precursor levels and photochemical conditions evolve, even on local and diurnal scales (Mazzuca et al., 2016; Guo et al., 2021; Tan et al., 2018; Stockwell et al., 2025).**”

**Comment #2:** *In Methods, Line 106-110, please consider adding more contexts about the early ozone season of East/Southeast Asian for the months of February and March. What are the knowns and unknowns from the existing literature? On the other hand, despite earlier understanding that the summer monsoon of Southeast Asia could alleviate local air pollution, recent studies identified summer ozone episodes in the region as well, especially across South China and transported to Southeast Asia (Zhou et al., 2025). Please briefly justify the 1) scientific logic behind the timing of your campaign, 2) key questions it targeted in the scope of ozone chemistry, and 3) its limitations and caveats (e.g. how representative is the winter ozone formation regime from an annual perspective?), so that the broader audience who are not familiar with the region could have a clearer picture. If deemed necessary, please consider moving a portion of this description to the Introduction.*

*-Zhou et al., 2025 (<https://doi.org/10.1021/acs.est.5c10258>)*

**Response #2:** We thank the reviewer for this insightful comment regarding the scientific rationale and seasonal context of the ASIA-AQ campaign timing. The timing of the campaign was determined by the broader scientific objectives of ASIA-AQ, as outlined in the mission white paper, which aimed to characterize regional air quality, including both gaseous and particulate pollutants, as well as their precursors, sources, and transport processes across diverse meteorological and chemical regimes in Southeast and East Asia, rather than focusing on a single pollutant or season.

To address the reviewer's points, we have revised Section 2.1 to clarify the regional seasonal context of the observations. Specifically, the measurement period corresponds to the pre-monsoon season in the Philippines and Thailand, which is favorable for active ozone formation. In Taiwan, the campaign represents a transitional period prior to the peak ozone season, during which photochemical activity is already significant. Lastly, South Korea was in a late winter period, outside the typical peak ozone season.

We acknowledge that the campaign does not uniformly represent peak ozone season conditions across all regions, particularly for South Korea. However, this study does not aim to provide a comprehensive seasonal characterization. Instead, it focuses on the chemical regimes sampled during the campaign period. Ozone production sensitivity is primarily governed by precursor conditions, and the ASIA-AQ observations captured a broad range of these conditions across the studied regions. This allows for robust characterization of ozone production sensitivity across diverse chemical environments.

To further support the interpretation for South Korea, we additionally compare our results with observations from the KORUS-AQ campaign (April–June 2016), which represents peak ozone season conditions in the region (Sect. 4.1.3).

Lines 109-122: “The ASIA-AQ campaign, conducted in February and March 2024, targeted specific regions across major urban centers in Southeast and East Asia: the Philippines (6–15

February), South Korea (17 February–11 March), Thailand (16–25 March), and Taiwan (15 February, 13 and 27 March). The timing of the campaign was determined by the broader scientific objectives of ASIA-AQ as described in the ASIA-AQ white paper ([https://espo.nasa.gov/asia-aq/document/ASIA-AQ\\_White\\_Paper](https://espo.nasa.gov/asia-aq/document/ASIA-AQ_White_Paper)).

Briefly, ~~For tropical and subtropical~~ the Southeast Asian regions (Philippines, and Thailand, and Taiwan), this period corresponds to the pre-monsoon season, characterized by a relatively dry conditions and warm season with enhanced solar radiation, which are is favorable for active ozone formation photochemistry (Toh et al., 2013; Marvin et al., 2021). In Taiwan, the campaign period represents a transitional phase prior to the peak ozone season, during which photochemical activity is already significant (Lin et al., 2014). In contrast, South Korea was in its late winter season, outside the typical peak ozone season, with generally reduced photochemical activity with peak aerosol pollution. Lower temperatures and weaker solar radiation limited photochemical activity compared to the tropical other regions (Lee and Park, 2022; Kim et al., 2023). Despite these seasonal differences, the campaign sampled a broad range of NO<sub>x</sub> and VOC conditions across the studied regions, enabling characterization of ozone production sensitivity across diverse chemical environments.”

**Comment #3 & #4:** *In Results, Section 3.2, isopleths of PO<sub>x</sub> across a varying range of NO<sub>x</sub> and VOC levels are used to show the sensitivity regimes of ozone formations in each area. Yet your criteria of “high production rates” is not consistent across areas (>40 ppbv/hr for MM in Line 249, >20 ppbv/hr for BMR in Line 280, >15 ppbv/hr for TKMA in Line 303, and not explicitly written out for SMA). It is even more confusing when you summarize the fractions into Table 1. The note “a” of the table specifies that “High PO<sub>x</sub> denotes upper 50% in the PO<sub>x</sub> distribution (above the median)” which seems again inconsistent with your text descriptions. From your Figure 4 for example, the color scale is around 0-50 ppbv/hr. Clearly your median PO<sub>x</sub> in MM cannot be 40 ppbv/hr. Please revise and provide a less arbitrary criteria for area-by-area interpretation and intercomparison.*

*Same issue for NO<sub>x</sub> and VOCs, for example, your Line 303 describes TKMA at “moderate NO<sub>x</sub> (4-10 ppbv) and “moderate VOCs (> 40 ppbv)” but Line 280 calls BMR under “relatively low NO<sub>x</sub> (7-18 ppbv)” and “moderate-to-high VOC (> 40 ppbv)”. Please revise and make them consistent for interpretation.*

**Response #3 & #4:**

We thank the reviewer and agree that the original descriptions could be confusing.

The “high production rates” reported in the text were intended to qualitatively describe regions of high PO<sub>x</sub> within each background isopleth (contours) in each city, rather than to define a consistent quantitative threshold across regions. To clarify this, we have revised the text from “high production rates” to “regions of the highest PO<sub>x</sub>” together with indicative values (e.g., using “e.g.”).

In contrast, Table 1 is based on the statistical distribution of observed PO<sub>x</sub> values. To remove ambiguity, we have revised the terminology in Table 1 to “Above-median PO<sub>x</sub>” and updated the footnote to indicate that this refers to values above the median of the observed data points (shown as dots in the isopleths).

We also acknowledge that the use of qualitative descriptors such as “low”, “moderate”, and “high” for NO<sub>x</sub> and VOC could imply inconsistent classification across regions. To address this, we have revised Section 3.2 to consistently report numerical ranges of NO<sub>x</sub> and VOC across all regions as follows:

Lines 285-286: “...under ~~moderate~~ **high** NO<sub>x</sub> (> 15 ppbv) ...”

Line 319: “...under ~~relatively low~~ **moderate-to-high** NO<sub>x</sub> (7–18 ppbv) ...”

Lines 343-344: “...occur at **low-to-moderate** NO<sub>x</sub> (4–10 ppbv) and **moderate-to-high** VOC mixing ratios (> 40 ppbv).”

Lines 375-376: “...occur at low NO<sub>x</sub> levels below 5 ppbv **and high VOC conditions (> 65 ppbv)** ...”

#### **Technical corrections:**

**Comment #5:** *In Abstract, Line 43-47, “In contrast, Seoul, under colder and low solar irradiance conditions, exhibited a primarily VOC-sensitive regime...” is confusing. Even though Seoul is in a higher latitude compared to the other three areas, it is not necessarily the determining factor of its ozone formation regime (or at least not shown in the data analysis). The current description is prone to be mistaken as drawing connections between lower temperature & solar irradiance and the VOC-sensitive regime, which is not the case. SMA’s VOC-sensitive regime could be simply due to its highest ground-level NO<sub>x</sub> as shown in your Figure 2. Please rephrase.*

**Response #5:** We thank the reviewer for pointing this out. We agree that the previous wording could be interpreted as implying a causal relationship between colder temperatures or lower solar irradiance and the VOC-sensitive regime observed in Seoul. Our intention was only to describe the contrasting environmental conditions among the cities rather than to attribute the regime classification to these factors. We have therefore revised the sentence as follows:

“In contrast, Seoul, ~~under colder and low solar irradiance conditions~~, exhibited a primarily VOC-sensitive regime **associated with its higher NO<sub>x</sub> conditions relative to the other cities**, underscoring the importance of VOC-focused strategies.”

**Comment #6:** *Somewhere in the Methods/Results, please make it clear that your VOCR represents non-methane VOCs (NMVOC) because your Table S2 contains CH<sub>4</sub>.*

**Response #6:** Corrected: Line 207: “..., and non-methane VOC reactivity (VOCR),...”

**Comment #7:** *Somewhere in the manuscript, please make it clear that your 0-D box model and the subsequent result analysis assumed all measured O<sub>3</sub> are secondary and formed from your co-measured precursors. In reality, transboundary vertical transport and regional transport could modulate your observed O<sub>3</sub> greatly. Detailed wind analysis coupled with night-time surface background O<sub>3</sub> analysis shall be preferred, but it might be well out of the scope of this manuscript.*

**Response #7:** We agree with the reviewer that the scope of the analysis should be stated more clearly. The purpose of this study is to diagnose local photochemical ozone production sensitivity, rather than to attribute the observed ozone mixing ratios themselves to local versus transported sources. We have therefore added the following statement in Lines 407-409:

“It should be noted that the analysis diagnoses local photochemical ozone production across the NO<sub>x</sub>–VOC precursor space. Transport processes such as regional advection or vertical mixing may influence the observed ozone mixing ratios but are not explicitly represented in this study.”