Responses to Editor's Comments

We are grateful to your thoughtful comments on the early version of the manuscript and the suggestions you made to improve the manuscript. We have revised the manuscript accordingly by making full use of these comments and suggestions. We also have invited a native English-speaking scholar to retouch the full text of the article. Below is our point-to-point responses to your comments, which are marked in blue color, while those modified in the revised manuscript and the revised Supplement are highlighted in red color.

1. In the next revision, please make clear in the track-change version which text was deleted, changed and added. This can be achieved by using 'track change mode' in word or by using 'Latexdiff' for Latex files. While I could see where text was added, I could only identify deleted text by tediously comparing the previous and current files next to each other.

Response: Thanks for your kind suggestion. We have used "track change mode" in the revised manuscript to highlight the changes we have made.

Abstract:

2. General comment: Please be aware that the following guidelines are for now just a recommendation but soon mandatory in ACP.

ACP recommendation: Abstracts should have fewer than 250 words and provide a concise and accessible summary of the purpose, results and implications of the research. ACP expects that abstracts will normally include the following components:

1) The topic of the article and why it is important

2) The status of scientific understanding

3) The gap in knowledge being addressed

4) The objectives, questions or hypotheses of the study

5) The approach such as modelling, measurements, machine learning, etc.

6) The main results with important quantitative information if appropriate

7) The importance and implications of the results

Your current abstract is about twice as long (~490 words). Please improve it and make it more concise and accessible.

Response: Thanks for your kind suggestion. We have shortened and revised the abstract as follows to conform to the above guidelines:

Dicarboxylic acid (Diacid) homologues are essential indicators of secondary organic aerosols (SOA) that exert considerable influence on climate changes and atmospheric chemistry. However, their sources and formation processes are poorly understood, leading to uncertainty in predicting the climate effect of SOA. A substantial drop in anthropogenic emissions during the COVID-19 lockdown (LCD) provides a "controlled experiment" to explore the effects of LCD measures and meteorological conditions on SOA. Here we investigated the difference in molecular distributions and stable carbon isotopic compositions ($\delta^{13}C$) of diacid homologues in $PM_{2.5}$ before and during the LCD. We found that the concentration and contribution of diacid homologues during the LCD were higher than before the LCD, indicating that the enhanced secondary oxidation could offset the reduction of anthropogenic emissions during the LCD. Higher oxalic acid (C_2)/diacids ratio and more positive $\delta^{13}C$ values of major diacids during the LCD suggested more aged organic aerosols. The enhanced C_2 and related species during the LCD were mainly derived from the promoted gaseous photochemical oxidation by the higher oxidants and stronger solar radiation. However, C_2 and related species before the LCD were dominantly derived from the aqueous oxidation of α-dicarbonyls depending on relative humidity and liquid water content. The increased $\delta^{13}C$ values of C_2 and other major diacids along with the high ratios of C_2/glyoxal, C_2/methylglyoxal, and C_2/diacids confirmed an isotopic fractionation effect during the oxidation process of precursors. Our results indicate that atmospheric pollution treatment depends on a balanced strategy and coordinated effort to control multiple pollutants.

Please see Lines 15-29, Page 1 in the revised manuscript.

Specific comments

3. l. 20: what is the 'alleviated aerosol effect via the dropped $PM_{2.5}$'? Do you simply mean 'lower $PM_{2.5}$'?

Response: Yes, we mean "lower $PM_{2.5}$".

4. l. 22: replace 'secondary inorganic aerosols' by 'secondary inorganics'

Response: Done.

5. l. 29: (i) replace 'was' by 'were'; (ii) why 'acidic aqueous oxidation'? Is acidity necessary? (iii) replace 'with α-dicarbonyls' by 'of α-dicarbonyls'

Response: Thanks for your suggestion.

(i) Done.

(ii) Yes, "acidity" is redundant, thus we deleted it in the revised manuscript.

(iii) Done.

6. l. 30: replace 'determined by' by 'depending on'

Response: Done.

Introduction:

7. l. 47: replace 'hygroscopic property' by 'hygroscopicity'

Response: Done.

8. l. 63/4: "More oxidized SOA are largely produced from aqueous oxidation, while less oxidized SOA are largely derived from gaseous photochemical oxidation (Hu et al., 2017; Yu et al., 2019)." – this sentence seems out of place here as the text before and after is only about diacids and not about total SOA. Either delete this sentence here or correct if Hu and Yu's studies are specifically about diacids as well.

Response: This sentence is about total SOA rather than only about diacids. Thus, we have deleted this sentence in the revised manuscript.

9. In the previous revision, I had commented: l. 58 – 67: (i) There are many lab and model studies that have explored the formation of oxalic acid, e.g. (Carlton et al., 2007; Crahan et al., 2004; Perri et al., 2009; Warneck, 2003). In these studies, the main oxidant was OH. Please comment on this and include appropriate references.

Neither could I find my comment in your author response, nor any related changes in the manuscript. This comment remains, now referring to l. 70 ff. Please either justify why you did not address it or make appropriate changes.

Response: Thanks for your kind suggestion. In the revised manuscript, we have commented on these references as follows:

As the most abundant diacid with the lowest molecular weight, oxalic acid (C_2) is an important end product of numerous formation pathways in the aerosols; thus its formation mechanism has attracted great attention in the last decade. The strong correlation of C_2 with SO_4^{2-} at different observation sites suggests that both species shared a common production pathway (i.e., in-cloud processing) (Ding et al., 2021; Jung et al., 2010; Shen et al., 2023; Yu et al., 2005). A modeling study by Warneck (2003) revealed that the in-cloud formation pathway of C_2 from the oxidation of olefins with OH $\cdot$ radicals is crucially mediated by glyoxylic acid (ωC_2). A field study in the marine atmosphere by Crahan (2004) further supported such a formation mechanism of C_2. However, Carlton et al. (2007) conducted chamber experiments and found that glyoxal (Gly) is oxidized by OH $\cdot$ radicals in aqueous phase to produce larger multifunctional compounds (not ωC_2) and ultimately degraded into C_2. This formation route of C_2 is different from the in-cloud processing. Furthermore, the C_2 formation via the ωC_2 pathway only accounts for less than 1% (Buxton et al., 1997; Calton et al., 2007). Perri et al. (2009) first confirmed that the oxidation of glycolaldehyde with OH $\cdot$ radicals can not only produce C_2, glycolic acid, and ωC_2, but also form oligomer, malonic acid (C_3), and succinic acid (C_4). Many studies have demonstrated that C_2 is also derived from the photochemical breakdown/ decomposition of longer-chain diacids such as C_3 and C_4 (Kawamura and Usukura, 1993; Meng et al., 2021; Yu et al., 2021), but this

process has been considered less important than the C_2 formation through the aqueous OH·radical oxidation (Carlton et al., 2007; Xu et al., 2022).

Please see Lines 49-63, Page 2 in the revised manuscript.

In addition, we have sought help from Professor Keding Lu's group to estimate the OH·radical concentration using the TUV model (5.3 version). Professor Lu is a leading expert at Peking University and is proficient in the sources and transformation mechanisms of atmospheric free radicals through field observation and dynamic simulation. Thus we have added Professor Lu and Houhua Zhou as co-authors.

We have added detailed methods for the OH·radical estimation in Section 2.3 as follows:

2.3 Calculation of aerosol liquid water content (LWC), particle in-situ pH (pH$_{is}$), and OH·radicals

Because of its short lifetime, high reactivity, and low concentration, the concentration of OH·radicals in the atmosphere is greatly difficult to measure. Therefore, we used the TUV model (5.3 version) to calculate the time series of photolysis frequencies of ozone ($J(O^1D)$) before and during the LCD in Jinan, and then multiplied it by a factor of 4×10^{11} to estimate the corresponding time series of OH·radical concentration (molecules cm^{-3}), based on the approximate linear relationship of OH·radical concentration to $J(O^1D$ (Lu et al., 2019).

Please see Lines 167-171, Page 5 in the revised manuscript.

We also added discussions about the difference and effect of OH·radical on C_2 formation as follows:

Being consistent with the variation of O_3 concentration, OH·radicals during the LCD (1.4×10^7 cm^{-3}) was 1.4 times higher than that (9.7×10^6 cm^{-3}) before the LCD (Table 1), which was also observed in other studies (Gaubert et al., 2021; Kang et al., 2021). The reduced NO$_x$ during the LCD could lead to higher OH·radicals, because less OH·radicals could be consumed with NO$_2$ to produce nitric acid (Gaubert et al., 2021). Additionally, the elevated O_3 concentration during the LCD could result in the enhanced OH·radicals, as OH·radicals is mainly derived from O_3 photolysis with water vapor in the atmosphere (Kang et al., 2021).

The correlations of the concentrations of Gly, mGly, and C_2 with OH·radicals were not straightforward ($p > 0.05$, Fig. S4), primarily because of the multiple sources (e.g., biomass burning, fossil fuel combustion, and other sources except for the aqueous OH·radical oxidation pathway) of C_2

(Cao et al., 2017; Narukawa et al., 1999; Xu et al., 2022) and the complexity of the local atmospheric environment. In addition, the equilibrium concentrations of each component varied continuously with their molar fractions in the aerosol phase during the reaction process, thus C_2 was not necessarily correlated directly with OH ·radicals.
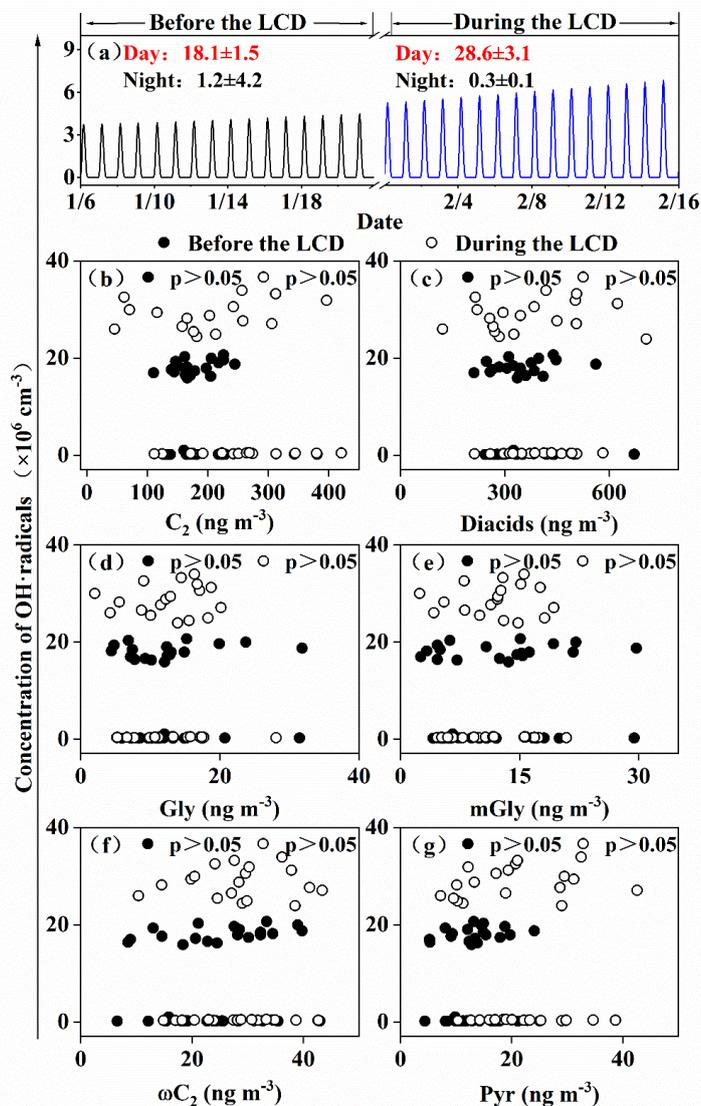
Figure S4. (a) Time series of OH ·radical concentration per hour, and correlations of OH ·radicals with (b) C_2, (c) Diacids, (d) Gly, (e) mGly, (f) ωC_2, and (g) Pyr before and during the LCD.

Please see Lines 200-205 (Page 6) and Lines 355-360 (Page 9) in the revised manuscript, respectively.

Section 3:

General comment:

10. My previous comment was not addressed in the text. "The subsections of Section 3 still have very little connection to each other. Instead of being repetitive, previously identified findings should be used and referred to in the further discussion: what did you conclude on the formation processes of C_2 in Section 3.2, how are these conclusions corroborated (or contradicted) in Section 3.3, what additional insight is gained in Sections 3.3, 3.4 and 3.5 etc.".

I was not asking about a summary of your results in your author response. However, I was suggesting that you refer to the individual sections in the manuscript. This could be done by cross-referencing the subsections, e.g. 'the findings discussed in Section 3.X are further supported by additional analysis....'. Currently Section 3 reads like individual lab reports on disconnected analyses. However, a scientific article requires that you connect the different parts of your study to justify the needs of the various analyses to come to comprehensive conclusions. Please make clear in every subsection what additional information was found on top of the findings that were presented in the previous sections. This way you demonstrate how the information derived from the various analyses build upon and complement each other.

Response: Thanks for your suggestion. We have added related text in the revised manuscript as follows:

…reflecting the presence of more aged organic aerosols during the LCD, which will be given more evidence in Section 3.5 (see Line 260, Page 7).

Such differences in the molecular characteristics and aging level of diacids and related compounds before and during the LCD indicate substantially different formation pathways and influencing factors during these two observation periods, which will be discussed in more detail in Sections 3.3 and 3.4 (see Lines312-314, Page 8).

Therefore, C_2 before the LCD was mainly derived from the aqueous production where LWC and RH appeared to be vitally important controlling factors as supported by positive matrix factorization (PMF) results that will be discussed in Section 3.6. Please see Lines 368-369, Page 10.

Being different from the time period before the LCD, the strong correlations of C_2, Gly, mGly, and ratios of C_2/Gly and C_2/mGly were not obtained with RH or LWC ($R^2 < 0.2$) during the LCD (Fig. 4b), suggesting the insignificant effect of the aqueous-phase formation on C_2 during the LCD. Please see Lines 395-397, Page 10.

, which was further supported by the results of stable carbon isotopic composition of diacids (discussed in Section 3.5) and PMF analysis (discussed in Section 3.6). Please see Lines 434-436, Page 11.

Thus, we investigated the stable carbon isotopic compositions of major diacid homologues to further discuss the atmospheric processes of diacid homologues and evaluate the aging degree of organic aerosols before and during the LCD (see Lines 440-442, Page 11).

…, which was in agreement with the results in Section 3.2 (see Line 501, Page 13).

To further quantitatively analyze the crucial sources and their relative contributions of diacids and related compounds,…(see Line 503, Page 13).

…again suggesting that the aqueous oxidation was the dominant formation pathway for these organic compounds before the LCD as discussed in Section 3.3 (see Line 529-530, Pages 13-14).

…, which was in agreement with the results as discussed in Section 3.4 (see Line 533, Page 14).

Specific comments

11. l. 185: 'Lack' implies the absence of HOx radicals. However, even during wintertime, the concentration of HOx is not zero.

Response: We agree with you. Thus we rephrased this sentence as "Wang et al. (2021) demonstrated that O_3 in Chinese megacities during the LCD is primarily produced from the NO_x-saturated regime, where the drop of NO_x can lead to the enhanced O_3 concentration (Liu and Wang, 2020).".

Please see Lines 189-191, Pages 5-6 in the revised manuscript.

12. l. 190: What do you mean by 'aerosol effect'? Please clarify. In the next sentence you refer to the 'aerosol radiative effect' – is this the effect you mean?

Response: Aerosol effect can be divided into the radiative effect and the effect on the hydrological cycle (Lohmann and Feichter, 2005). The aerosol radiative effect associated closely with this study exerts an important perturbation on the radiation budget (Lohmann and Feichter, 2005). In this study, "aerosol effect" and "aerosol radiative effect" mean the same thing, thus we have changed "aerosol effect" to "aerosol radiative effect" in the revised manuscript. Atmospheric aerosol can scatter or absorb radiation (aerosol–photolysis interaction), thereby cooling or warming the atmosphere directly and changing the photochemical formation of O_3 (Heald et al., 2014).

We have changed this sentence as follows:

Secondly, the reduction of NO_2 during the LCD could reduce the concentration of NO_3^- and further reduce the CCN number concentrations and additional shortwave cooling (Zaveri et al., 2021), thereby resulting in the alleviating aerosol radiative effects (aerosol–photolysis interaction) caused by aerosol absorbing or scattering solar radiation (Wu et al., 2020), which in turn enhanced the photochemical formation of O_3 (Liu and Wang, 2020).

Please see Lines 192-196, Page 6 in the revised manuscript.

13. l. 210: replace 'on' by 'of' (Comparison of...)
Response: Done.

14. l. 348: In l. 339 you state correctly that Gly and MGly are products from gas phase oxidation. Here you state now that LWC and RH promote the formation of these carbonyls. To my knowledge, only the oxidation products (e.g. glyoxylic acid) is formed in the aqueous phase and then oxidized to oxalic acid. I am not aware of any study that shows efficient formation of glyoxal and methylglyoxal are formed in the aqueous phase. Please add a reference to support your statement or correct the text.
Response: Sorry for this mistake. We have corrected this sentence as follows:

These discussions suggest that the higher LWC concentration and RH could promote the aqueous-phase formation of C_2 from Gly and mGly.

Please see Lines 366-367, Page 10 in the revised manuscript.

15. l. 364ff: This text is very unsatisfying and vague: A correlation between acidity and C_2 does not necessarily imply an acid-catalyzed mechanism. It could be a secondary factor, e.g. more SO_2 leads to more sulfate and lower pH, which in turn enhances solubility of glyoxal. This is, of course, speculation – however, so is also concluding on an acid-catalyzed C_2 formation, which would imply that protons are involved in the chemical pathways under the conditions present.

I understand that likely the LWC was different between the experiments by Jang et al. (2002), Surratt (2007) and Tan et al., respectively. However, were indeed pH and organic precursors very different? How do you know?

Please clarify this text and separate clearly observed trends from speculations and conclusions that cannot be proven based on the current data set.

Response: Thanks for your kind suggestion. We have rephrased this text as follows:

Such negative correlations were possibly because more SO_2 could lead to more SO_4^{2-} and lower pH_{is}, which in turn enhanced the solubility of Gly and mGly and ultimately promoted C_2 formation. Therefore, an acid-catalyzed C_2 formation may occur in the aqueous phase under the present atmospheric conditions before the LCD. However, Tan et al. (2009) reported that acidity had a minor effect on C_2 formation at cloud- and fog-relevant conditions via online experiments. Wang et al. (2015) suggested that the coarse particles during the dust period, which are alkaline, are favorable for the C_2 formation from ωC_2, largely because the reaction rate constant (3.6×10^8 M^{-1} s^{-1}) of ωC_2 with OH·radical to form C_2 is smaller than that (2.9×10^9 M^{-1} s^{-1}) of its anion, glyoxylate. At very acidic pH, C_2 is not only formed more slowly but also oxidized more slowly (Eugene et al., 2016; Herrmann, 2003). Those findings conflicted with each other, probably because the concentration levels of organic precursors, acidity, LWC, and other influencing factors were different from the cases in our field observations, thus further studies are necessary to elucidate the influencing mechanism of acidity on C_2 formation.

Please see Lines 383-393, Page 10 in the revised manuscript.

In the laboratory chamber study conducted by Surratt et al. (2007), isoprene and NO were injected into the reaction chamber and the inorganic seed aerosol was generated by atomization from an aqueous solution containing $(NH_4)_2SO_4$ and H_2SO_4. The concentrations of H^+ were 32 nmol m^{-3}, 275 nmol m^{-3},

407 nmol m^{-3}, and 507 nmol m^{-3} from stage 1 to stage 4, respectively. However, in the laboratory chamber study conducted by Jang et al. (2002), isoprene and acrolein were reacted in Teflon bags in the presence or absence of H$_2$SO$_4$ whose concentration was not obtained. Therefore, the pH and organic precursors reported in these two references were very different.

16. l. 394: My previous comment remains 'In your response to my previous round of reviews, you stated that O$_3$ is just a proxy for photochemical activity. The text here implies that O$_3$ was directly involved in the formation. Please be consistent. Your response was not satisfying 'O$_3$ can be considered as a proxy for photochemical activity, which does not mean that O$_3$ can't be involved in the formation.'
I agree that O$_3$ may be ONE oxidant that could possibly lead to diacid formation. However, other oxidants likely play a role too, which is not reflected in your current text.
I suggest replacing the sentence "In view of the significant enhancement of O$_3$ concentration and solar radiation during the LCD, it could be concluded that the production of C$_2$ and related compounds may be closely involved in the gaseous photochemical pathways driven by the higher O$_3$ concentration and stronger solar radiation."
By
"In view of the significant enhancement of O$_3$ concentration and solar radiation during the LCD, it could be concluded that the production of C$_2$ and related compounds may be driven by the higher oxidant concentrations."

Response: Thanks for your kind suggestion. We have replaced the sentence "In view of the significant enhancement of O$_3$ concentration and solar radiation during the LCD, it could be concluded that the production of C2 and related compounds may be closely involved in the gaseous photochemical pathways driven by the higher O$_3$ concentration and stronger solar radiation." by "In view of the significant enhancement of oxidant concentration (e.g., O$_3$ and OH·radicals) and solar radiation during the LCD, it could be concluded that the production of C$_2$ and related compounds may be driven by the higher oxidant concentrations.".

Please see Lines 409-411, Page 11 in the revised manuscript.

17. l. 397: replace 'SOA' by 'compounds'

Response: Done.

18. l. 401: since you cannot conclude on the absolute importance of O_3 in the diacid formation as compared to other oxidation pathways, I suggest adding 'or related oxidants' after 'O_3' in this sentence.

Response: We have added "or related oxidants" after O_3 in the revised manuscript (see Line 416, Page 11).

19. l. 424: The studies by Carlton, Fu and Warneck referenced earlier in this paragraph refer to the formation of C_2 by oxidation of (M)Gly in the aqueous phase. Thus, I do not understand your concluding sentence at the end of the paragraph.

Again, in the correlation of C_2 and C_2/(m)Gly with O_3, O_3 should be considered a proxy for other oxidants such as OH. Higher OH may trigger then more C_2 formation in the aqueous phase. Note that the oxidation of glyoxal in the gas phase – both by O_3 and OH – does not lead to C_2.

Response: We agree with your comments. Therefore, we have deleted these sentences.

20. Section 4

In my previous comment "This last section is merely a summary of your results. However, conclusions are not given, e.g. How do your results compare with previous studies? What do your results mean for our understanding of the state and/or behaviour of the atmosphere?" was not sufficiently addressed.

The added are very vague and general statements that repeat largely previous knowledge. Please address the questions posed in my previous comments.

Response: Thanks for your suggestion. We have rewritten this section as follows:

   This work has investigated the effects of variations in anthropogenic emissions and meteorological conditions on the formation pathways and influencing factors of diacidis and related compounds by taking advantage of COVID-19 LCD as a "controlled experiment". While previous studies focused on the importance of higher emission level and promoted secondary oxidation for producing more diacids and related compounds, this study strongly suggested that the enhanced secondary formation of diacids

and related species could offset the significant decline of organic precursors from anthropogenic pollutant emissions during the LCD. The sources and formation mechanisms of C_2 and diacids before and during the LCD were illustrated in Fig. 10. Before the LCD, higher RH and hygroscopic particles (e.g., SIA) led to an increase in LWC, which promoted the partitioning of water-soluble organic precursors (e.g., Gly and mGly) from the gaseous phase into the aqueous phase, thereby enhancing the aqueous formation of C_2 (Fig. 10). During the LCD, C_2 was derived from the photochemical degradation of longer-chain diacids (e.g., C_3 and C_4) that was driven by the stronger solar radiation and higher O_3 concentration and other oxidants (Fig. 10). In this study, we for the first time successfully quantified the relative contributions of aqueous-phase oxidation and gaseous-phase photochemical oxidation to the ambient C_2 and related species, which were 47.2% and 12.3% before the LCD and 16.1% and 50.5% during the LCD, respectively. The reactivity of ^{13}C was higher than that of ^{12}C in the gaseous photochemical oxidation, leading to higher $\delta^{13}C$ values of C_2 during the LCD than before the LCD (Fig. 10). Furthermore, more enriched ^{13}C in C_2 was observed during the aging processes of organic aerosols. To the best of our knowledge, this study was first conducted on the effect of OH·radicals on C_2 formation in the field campaign, though many studies have been performed in chamber experiments. We observed that C_2 was not necessarily correlated directly with OH·radicals in the aqueous oxidation, possibly due to the fact that C_2 has multiple sources (e.g., biomass burning and fossil fuel combustion) and the complexity of local atmospheric environment, which still needs to be elucidated by more field observations. These results are helpful for better understanding the sources, formation processes, and driving factors of SOA in the urban regions of East China. Nevertheless, our study suggested that, even if the primary emissions are practically reduced, we cannot completely solve the current air pollution problem in the North China Plain where the sources and precursors of secondary aerosols are extremely complicated. The balanced strategy and trans-regional joint control of major air pollutants are necessary to be considered together with meteorological conditions.

Overall, we obtained that the sources, formation mechanisms, and aging processes of SOA differed significantly during different time periods even at the same observation site. It is needed to conduct more field observations of SOA regarding the types of precursors, formation pathway via aqueous oxidation and gaseous photochemical oxidation, and aging level at different sites and in different time

periods to improve the accuracy of aerosol models and informing policy about effective air quality measures.
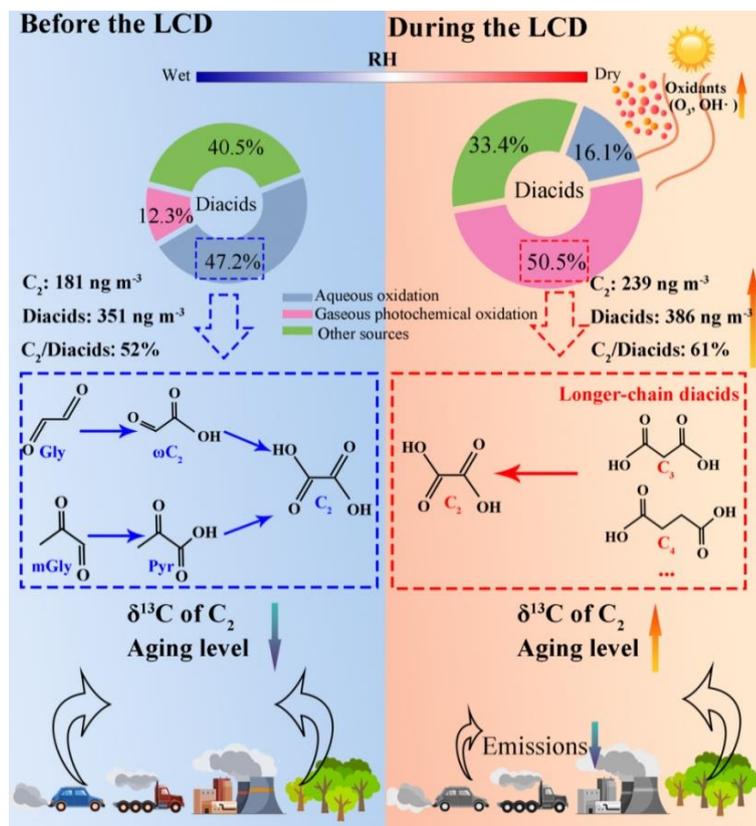
Figure 10. Schematic diagram illustrating the sources and formation mechanisms of C_2 and diacids before and during the LCD.

Please see Lines 539-568, Page 14 in the revised manuscript.

References

Buxton, G., N. Malone, T., and Arthur Salmon, G.: Oxidation of glyoxal initiated by OH in oxygenated aqueous solution, Journal of the Chemical Society, Faraday Transactions, 93, 2889-2891, 10.1039/A701468F, 1997.

Carlton, A. G., Turpin, B. J., Altieri, K. E., Seitzinger, S., Reff, A., Lim, H.-J., and Ervens, B.: Atmospheric oxalic acid and SOA production from glyoxal: Results of aqueous photooxidation experiments, Atmos. Environ., 41, 7588-7602, http://dx.doi.org/10.1016/j.atmosenv.2007.05.035, 2007.

Ding, Z., Du, W., Wu, C., Cheng, C., Meng, J., Li, D., Ho, K., Zhang, L., and Wang, G.: Summertime atmospheric dicarboxylic acids and related SOA in the background region of Yangtze River Delta, China: Implications for heterogeneous reaction of oxalic acid with sea salts, Sci. Total Environ., 757, 143741, https://doi.org/10.1016/j.scitotenv.2020.143741, 2021.

Enami, S., Hoffmann, M. R., and Colussi, A. J.: Stepwise Oxidation of Aqueous Dicarboxylic Acids by Gas-Phase OH Radicals, J. Phys., Chem. Lett., 6, 527-534, 10.1021/jz502432j, 2015.

Heald, C. L., Ridley, D. A., Kroll, J. H., Barrett, S. R. H., Cady-Pereira, K. E., Alvarado, M. J., and Holmes, C. D.: Contrasting the direct radiative effect and direct radiative forcing of aerosols, Atmos. Chem. Phys., 14, 5513-5527, 10.5194/acp-14-5513-2014, 2014.

Jung, J., Tsatsral, B., Kim, Y. J., and Kawamura, K.: Organic and inorganic aerosol compositions in Ulaanbaatar, Mongolia, during the cold winter of 2007 to 2008: Dicarboxylic acids, ketocarboxylic acids, and α-dicarbonyls, Journal of Geophysical Research: Atmospheres, 115, D22203, 10.1029/2010jd014339, 2010.

Lohmann, U. and Feichter, J.: Global indirect aerosol effects: a review, Atmos. Chem. Phys., 5, 715-737, 10.5194/acp-5-715-2005, 2005.

Lu, K., Guo, S., Tan, Z., Wang, H., Shang, D., Liu, Y., Li, X., Wu, Z., Hu, M., and Zhang, Y.: Exploring atmospheric free-radical chemistry in China: the self-cleansing capacity and the formation of secondary air pollution, National Science Review, 6, 579-594, 10.1093/nsr/nwy073, 2019.

Meng, J., Li, Z., Zhou, R., Chen, M., Li, Y., Yi, Y., Ding, Z., Li, H., Yan, L., Hou, Z., and Wang, G.: Enhanced photochemical formation of secondary organic aerosols during the COVID-19 lockdown in Northern China, Sci. Total Environ., 758, 143709, https://doi.org/10.1016/j.scitotenv.2020.143709, 2021.

Perri, M. J., Seitzinger, S., and Turpin, B. J.: Secondary organic aerosol production from aqueous photooxidation of glycolaldehyde: Laboratory experiments, Atmospheric Environment, 43, 1487-1497, https://doi.org/10.1016/j.atmosenv.2008.11.037, 2009.

Shen, M., Qi, W., Guo, X., Dai, W., Wang, Q., Liu, Y., Zhang, Y., Cao, Y., Chen, Y., Li, L., Liu, H., Cao, J., and Li, J.: Influence of vertical transport on chemical evolution of dicarboxylic acids and related secondary organic aerosol from surface emission to the top of Mount Hua, Northwest China, Science of The Total Environment, 858, 159892, https://doi.org/10.1016/j.scitotenv.2022.159892, 2023.

Warneck, P.: In-cloud chemistry opens pathway to the formation of oxalic acid in the marine atmosphere, Atmos. Environ., 37, 2423-2427, http://dx.doi.org/10.1016/S1352-2310(03)00136-5, 2003.

Xu, B., Zhang, G., Gustafsson, Ö., Kawamura, K., Li, J., Andersson, A., Bikkina, S., Kunwar, B., Pokhrel, A., Zhong, G., Zhao, S., Li, J., Huang, C., Cheng, Z., Zhu, S., Peng, P., and Sheng, G.: Large contribution of fossil-derived components to aqueous secondary organic aerosols in China, Nat. Commun., 13, 5115, 10.1038/s41467-022-32863-3, 2022.

Yu, J. Z., Huang, X.-F., Xu, J., and Hu, M.: When Aerosol Sulfate Goes Up, So Does Oxalate: Implication for the Formation Mechanisms of Oxalate, Environmental Science & Technology, 39, 128-133, 10.1021/es049559f, 2005.