Dear editor and reviewers,

We appreciate all your detailed and valuable suggestions on our manuscript (egusphere-2026-3859). We have carefully considered the comments and revised the manuscript accordingly. Please see the point-by-point response below and changes are marked blue in the revised manuscript.

Thanks very much!

Most sincerely,

Yujue Wang

Point-by-point response to review comments

Note: *Review comments are in 12 point italicized font*. Our responses are indented and in 12 point normal font. Revised text is in quotes and in 10 point blue font.

Referee #1

This work analyzed the ON abundance, sources, and its influence on aerosol light absorption in the marine atmosphere over East Asian marginal seas. The results highlight that continental outflows of air masses played important roles in regulating the formation of ON and the light absorption of marine aerosols. The quantitative ON data in marine aerosols are valuable for evaluating the effects of aerosol deposition on the marine ecosystem. It can be published in ACP after addressing the following comments:

Response: Thank you very much for the positive comments and detailed suggestions on our manuscript. We have now carefully addressed the comments and revised accordingly.

Section 2.2: In this work, total ON is quantified by a newly developed IN&ON analyzer. Water-soluble nitrogen and inorganic nitrogen are analyzed by a TN analyzer and ion chromatography. I understand the difference between water-soluble TN and IN is widely used to calculate WSON. However, have the authors compared the quantitative difference of nitrogen between IN&ON analyzer and ion chromatography? Would the inter-instrument quantitative differences influence the quantification accuracy of WSON?

Response: We compared the IN concentrations measured by ion chromatography, aerosol IN&ON analyzer, and TOC/TN analyzer (added in Fig. S2). The results suggested that the IN abundance quantified by the three instruments matched well with each other. This guarantees the accuracy of quantitative results of WSON and WION based on different analytical instruments. Related descriptions have been added in lines 103-105.

Lines 103-105:

"The abundance of inorganic nitrogen quantified by the aerosol IN&ON analyzer or by the TOC/TN analyzer matched well with that measured by ion chromatograph (Fig. S2), which guarantees the accuracy of quantitative results of WSON and WION based on different analytical methods."

Newly added Figure S2:

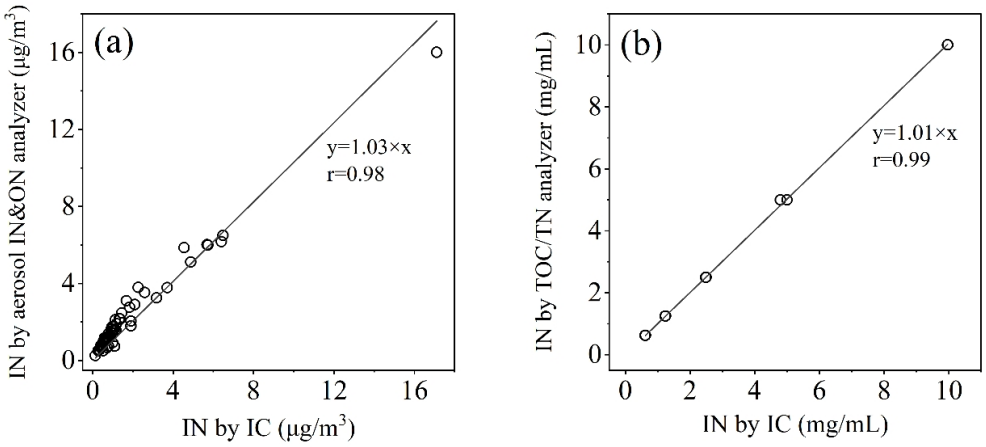

Figure S2 (a) Comparison of inorganic nitrogen (IN=[NH_4^+-N] + [NO_3^--N]) measured by aerosol IN&ON analyzer and by ion chromatograph (IC). (b) Comparison of IN concentrations in a mixed solution of NH_4Cl and KNO_3 measured by TOC/TN analyzer and IC.

Lines 135-144: How about the seasonal variation of organic carbon in marine aerosols? Is there any difference in temporal variations and sources between ON and OC in marine aerosols over marginal seas?

Response: The seasonal variation of OC concentrations and sources was added and compared with that of ON in lines 176-178 and 273-278.

Lines 176-178:

"The seasonal variation of aerosol ON was different from that of OC in marine aerosols, with an abundance order of spring (4.8 μg C/m³)> autumn (3.4 μg C/m³)> summer (2.7 μg C/m³). The dust storms in spring lead to a more obvious elevation of OC than ON in marine aerosols."

Lines 273-278:

"Based on our previous study (Zhang et al., 2025), dust contributed 50% of water-soluble OC and 70% of the water-insoluble OC in marine aerosols during the spring cruise, higher than that to WSON (45%) and WION (54%) resolved in this work. The higher contribution of spring dust to aerosol OC than ON, especially for the water-insoluble fractions, explained their different seasonal variations. The aerosol ON formation, however, was more driven by anthropogenic secondary pollutants, and thus aerosol ON was higher in autumn than in spring. Dust-related aerosol ON likely formed during the long-range transport of dust storms via mixing with anthropogenic pollutants."

Lines 174-189: I may suggest adding some specific examples of ON formation from aged biomass burning or secondary nitrate formation processes.

Response: Thanks for the suggestion. We have now added examples of ON formation related to aged biomass burning and secondary nitrate formation in lines 230-233.

Lines 230-233:

"For example, methyl-nitrocatechols can originate from the oxidation of VOCs emitted by biomass burning (Iinuma et al., 2010). Nitro-aromatic compounds (e.g., nitro-phenols, nitro-catechol, and their derivatives) can be formed via oxidation of anthropogenic toluene and benzene under high-NO_x conditions (Wang et al., 2019b). Under mild aqueous-phase conditions, nitration of guaiacol can produce nitroguaiacols via the nonradical mechanism (Kroflic et al., 2018)."

Lines 201-213: Could the authors provide more explanation of the dust-related ON formation? Is organic nitrogen transported from the dust source region by dust storms, or is it secondarily formed during long-range transport?

Response: During the spring observation, the dust-related ON resolved by PMF displayed a positive correlation with nitrate aerosols, which indicated the secondary formation of ON on dust particles via mixing with nitrate aerosols. Previous studies have suggested that aged dust particles could facilitate the formation of SOA via aqueous-phase or heterogeneous reactions, especially on nitrate-coated particles. Mineral components provided favorable conditions for heterogeneous nitration reactions and further ON formation in aged dust particles coated by nitrate. Related analysis has now been added in lines 266-273 and 277-278.

Lines 267-278:

"…, aged dust particles could facilitate the formation of SOA via aqueous-phase or heterogeneous reactions, especially on nitrate-coating particles (Li et al., 2025a). For the spring samples, dust-related ON formation displayed a positive correlation with nitrate aerosol concentration (Fig. S9), indicating the secondary formation of ON on dust particles via mixing with nitrate aerosols. Mineral components provided favorable conditions for heterogeneous nitration reactions and further ON formation in aged dust particles coated by nitrate (Kroflic et al., 2018; Nie et al., 2014). Dust storms, mixing with anthropogenic nitrate pollutants during transport through East Asia, are a major contributor to inorganic and organic nitrogen deposition in marginal seas. …Dust-related aerosol ON likely formed during the long-range transport of dust storms via mixing with anthropogenic pollutants."

Specific comments:

Lines 127-128: Please list the concentration ranges of ON over open ocean and in polluted continental environments for clear comparison.

Response: Revised accordingly (lines 150-156).

Lines 150-156:

"The observed aerosol ON over the YBS was among the ranges reported in previous studies over Mediterranean or Asian marginal seas (0.16-1.05 μg N/m³) (Sun et al., 2026; Tian et al., 2023; Violaki and Mihalopoulos, 2010), and lower than those in polluted continental environments (0.26-2.4 μg N/m³, e.g., urban Beijing, coastal Qingdao sites) (Shi et al., 2010; Wu et al., 2021; Xu et al., 2017). Under the joint influence of terrestrial transport and marine emissions, ON abundance in aerosols over the YBS was higher than that reported over open oceans (4.7-170 ng N/m³), such as

the Southern Ocean, Atlantic, and Pacific Ocean (Luo et al., 2018; Matsumoto et al., 2022; Miyazaki et al., 2011; Sun et al., 2026; Violaki et al., 2015; Wang et al., 2026)."

The legend in Fig. 1 (a) is small and difficult to read.

Response: Thanks for the reminder. We have now revised Figure 1 to be clear.

Revised Figure 1:

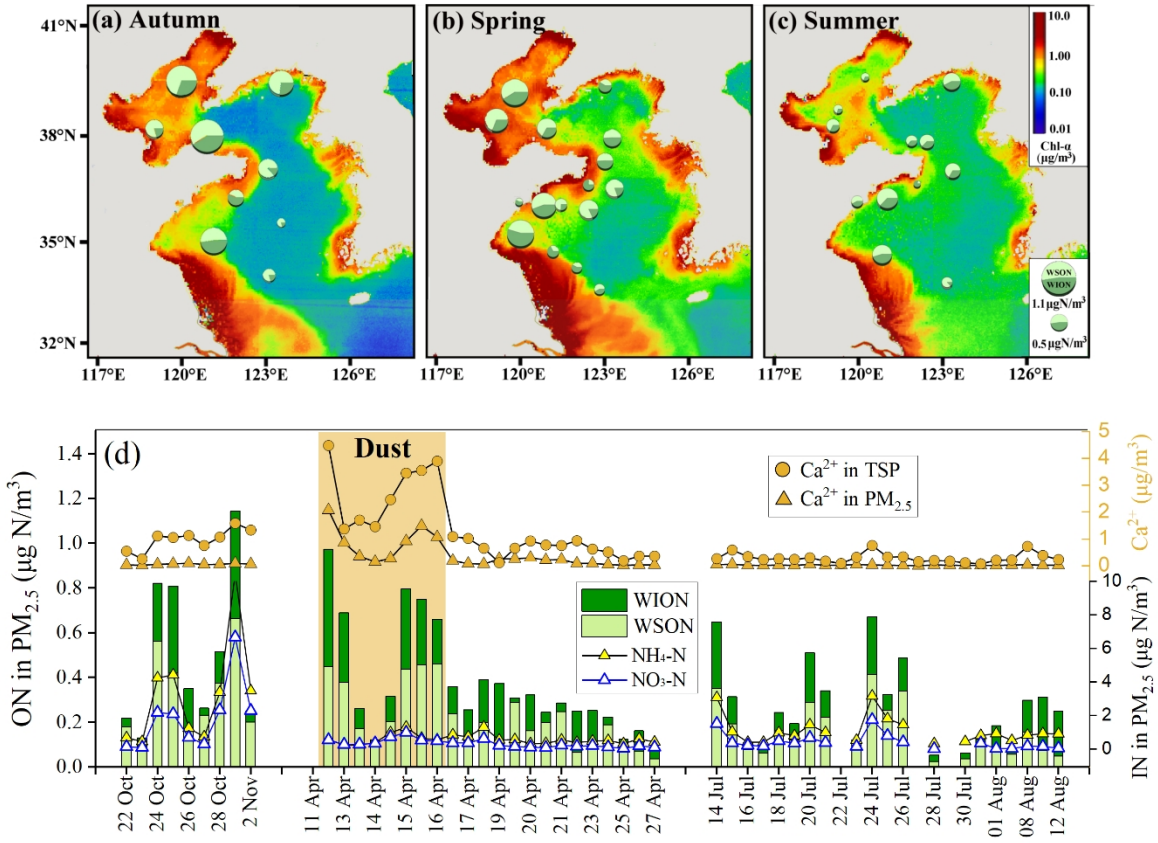

Figure 1. (a, b, c) Spatial distribution of organic nitrogen (ON) in $PM_{2.5}$ samples during cruises over the YBS. (d) Time series of ON, inorganic nitrogen (IN, including NH_4^+-N and NO_3^--N) in $PM_{2.5}$ and Ca^{2+} in marine aerosols during the observations. The color scales in panels (a-c) represent the sea surface Chl-a during the cruise. A dust episode was identified based on the Ca^{2+} concentration in TSP and marked by orange shading in panel (d).

Lines 247-250: Please show specific nitrogen-containing organic compounds to explain the higher light absorption capability of organic nitrogen in atmospheric aerosols.

Response: Revised accordingly.

Line 57: Change "emitted" to "emit".

Response: Revised accordingly.

Line 199: Change "orgnaic" to "organic".

Response: Revised accordingly.

Lines 291-293: Revise this sentence for clarity.

Response: As suggested, we have revised this sentence for clarity.

Referee #2

This manuscript presents valuable and timely data on aerosol ON over East Asian marginal seas. The analytical methods are state-of-the-art, and the source apportionment provides important insights into the sources and transformations of ON. The finding that continental ON drives light absorption has important implications for understanding the optical properties of marine aerosols.

However, the manuscript has several areas that require clarification and strengthening before it can be accepted for publication. The methodological details need to be expanded, particularly regarding the measurement techniques and PMF analysis. The interpretation of the dust source of ON needs to be refined. The figures, especially Figure 6, need to be improved for clarity. Statistical testing should be performed to verify the significance of key results.

The authors should address the comments (find details below), particularly the methodological clarifications, statistical analysis, and refinement of the dust source interpretation. With these revisions, the manuscript would make a significant contribution to our understanding of organic nitrogen in marine aerosols and its role in aerosol optical properties.

Response: Thank you very much for the overall positive comments and detailed suggestions on our work. We have now carefully addressed the comments and revised the manuscript accordingly, especially the methodology details, statistical analysis, and interpretation of the dust source of aerosol ON.

Major Comments:

Methodology and Data Quality

Q1 *The authors state that total suspended particles (TSP) and $PM_{2.5}$ were simultaneously collected, but the manuscript primarily focuses on $PM_{2.5}$ data. However, Figure 1d and the discussion of the dust episode reference Ca^{2+} concentrations in TSP (line 142). This inconsistency needs clarification. Were all analyses performed on $PM_{2.5}$ samples, or were some species measured in TSP? If both size fractions were analyzed, why is the focus exclusively on $PM_{2.5}$? This is particularly important because dust particles can be coarse-mode, and the ON associated with dust might be under-represented in $PM_{2.5}$ measurements.*

Response: Our previous observations over the YBS suggested that organics were dominant in fine particles, accounting for 60%-77% of the total organic mass concentration and 66%-88% of their absorption in TSP (Zhang et al., 2025). Thus, we mainly focused on the $PM_{2.5}$ results in this work, and concentrations of Ca^{2+} in TSP were only used to identify the dust episode more clearly. Due to limited samples based on shipboard observations, we did not repeat all the parameters in the $PM_{2.5}$ and the TSP samples. As suggested, we have now added the clarification in lines 112-114 and 178-181.

We agree with the reviewer that ON associated with dust can be in coarse mode

and might be under-represented based on the $PM_{2.5}$ measurement. We will investigate the coarse-mode ON associated with dust storms in our future work.

Lines 112-114:

"Our previous observations over the YBS suggested that organics were dominant in fine particles (Zhang et al., 2025). Thus, we mainly focused on the $PM_{2.5}$ results for further discussion, and concentrations of Ca^{2+} in TSP were only used to identify the dust episode."

Lines 178-181:

"It is noted that we only used the Ca^{2+} data in TSP to reflect the variation of coarse particles and identify the dust episode more clearly in this work. Other analyses were based on the $PM_{2.5}$ results, as previous observations have suggested that the organic mass and its absorption were dominant in fine particles over marginal seas (Zhang et al., 2025)."

Q2 *The sample numbers vary substantially across seasons (autumn: 9, spring: 22, summer: 20). While the authors acknowledge this limitation, the small autumn sample size (n=9) raises concerns about the statistical robustness of the seasonal comparisons, especially given the relatively large standard deviations. The authors should consider whether any autumn samples were potentially impacted by specific events that could skew the seasonal average, and discuss this limitation more explicitly.*

Response: During the shipboard cruises, aerosol samples were collected continuously along the cruise when the ship was sailing. The sampling covered the whole observation region over the YBS. Due to the difficult marine conditions and the tight schedule of the vessel in autumn, 9 sets of aerosol samples were collected during the autumn cruise. The samples cover the whole cruise and the observation region in this study, which thus could represent the general conditions during autumn over the YBS.

The relatively large standard deviation of ON concentration in autumn was due to its higher concentrations than in spring and summer. The relative standard deviation (RSD) of ON abundance was comparable across seasons (70%, 65%, and 69% for the autumn, spring, and summer samples). For the autumn cruise, air masses were transported from the continent (Fig. S1). Based on the PMF result, 59%-86% of aerosol ON in the autumn samples were contributed by anthropogenic secondary formation. Thus, the autumn samples were generally under anthropogenic pollutant-dominated conditions. The samples cover the whole observation region and can represent the general conditions in autumn over the YBS.

Related descriptions have been added in lines 84-87, 165-167, and 224-225.

Lines 84-87:

"Due to difficult marine conditions and the tight schedule of the vessel in autumn, 9 sets of aerosol samples were collected during the autumn cruise. Aerosol samples were collected continuously along the cruise when the ship was sailing, and sampling covered the whole observation region of the YBS. Thus, the samples can represent the general conditions of the YBS in each season."

Lines 165-167:

"The relative standard deviation (RSD) of ON concentrations in marine aerosols was comparable across seasons (70%, 65%, and 69% for the autumn, spring, and summer samples)."

Lines 224-225:

"The autumn samples were generally under severe impacts of transported anthropogenic pollutants, with 59%–86% of aerosol ON contributed by anthropogenic secondary formation."

Q3 *The calculation of WION = ON - WSON (line 97) assumes that WSON is a subset of ON. However, the ON measurement (by the aerosol IN&ON analyzer) and WSTN measurement (by TOC/TN analyzer) are based on different analytical principles. Could there be systematic differences between these methods that affect the WION calculation? The authors should provide more information on the comparability of these two methods.*

Response: We compared the IN concentrations measured by ion chromatograph, aerosol IN&ON analyzer, and TOC/TN analyzer (added in Fig. S2). The results suggested that the IN abundance quantified by the three instruments matched well with each other. This guarantees the accuracy of quantitative results of WSON and WION based on different analytical instruments. Related descriptions have been added in lines 103-105.

Lines 103-105:

"The abundance of inorganic nitrogen quantified by the aerosol IN&ON analyzer or by the TOC/TN analyzer matched well with that measured by ion chromatograph (Fig. S2), which guarantees the accuracy of quantitative results of WSON and WION based on different analytical methods."

Newly added Figure S2:

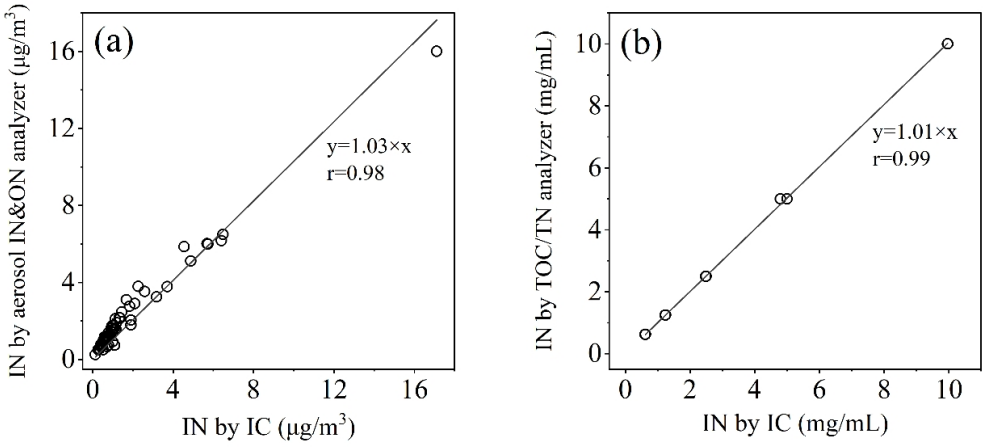

Figure S2 (a) Comparison of inorganic nitrogen (IN=[NH_4^+-N] + [NO_3^--N]) measured by aerosol IN&ON analyzer and by ion chromatograph (IC). (b) Comparison of IN concentrations in a mixed solution of NH_4Cl and KNO_3 measured by TOC/TN analyzer and IC.

Q4 *The blank correction procedures are only briefly mentioned (line 105). Given the low ON concentrations in marine environments, the blank contributions could be significant. The authors should provide more details on: (a) the blank levels and their variability, (b) whether field blanks were subtracted from each sample, and (c) the detection limits for ON, WSON, and WION.*

Response: The loading of total nitrogen on the field blank samples was 0.040-0.068 μgN/cm^2, much lower than in the collected aerosol samples. Total nitrogen on the corresponding field blank sample was subtracted from each sample (added in lines 106-108). The detection limits of the instruments are now added in lines 105-106.

Lines 106-108:

"Based on the measurement results of aerosol IN&ON analyzer, total nitrogen in the field blank samples was 0.040-0.068 μg N/cm^2, much lower than that in the collected aerosol samples (0.49-44.2 μg N/cm^2). Total nitrogen on the corresponding field blank sample was subtracted from each sample."

Lines 105-106:

"The detection limit of aerosol IN&ON analyzer was 96 ng N, and that of TOC/TN analyzer was 0.01 μg N/mL."

Source Apportionment

Q5 *The PMF analysis uses 11 input parameters (line 116), but the manuscript does not specify whether the data were normalized or scaled. Given that concentrations span several orders of magnitude (e.g., ON ~0.35 μg/m³ vs. NO_3^--N ~0.63 μg/m³), proper scaling is critical. The authors should describe their pre-processing steps and justify their choice of uncertainty calculations.*

Response: According to the EPA PMF user guide, we used the measured concentrations of components in aerosol samples as the input parameters for the PMF analysis (stated in lines 130-131). During our observations, concentrations of aerosol ON (0.35 ± 0.25 μg N/m³) and IN (0.63±1.06 and 1.59±2.14 μg N/m³ for NO_3^--N and NH_4^+-N) are on the same order of magnitude. Thus, no additional normalization or scaling was applied to the concentration matrix of the PMF model. The uncertainty calculation has now been described in lines 134-137.

Lines 130-131:

"Measured concentrations of components in the $PM_{2.5}$ samples were used as the input parameters of PMF, …"

Lines 134-137:

"Uncertainties (Unc) of the parameters were calculated according to the EPA PMF 5.0 user guide:

$$Unc = \sqrt{(EF \times c)^2 + (0.5 \times MDL)^2}$$

where EF is the error fraction, c is the concentration, and MDL is species-specific method detection limit. Data below MDL were replaced with the value MDL/2, and (5/6)×MDL was used as the

corresponding uncertainty value (Polissar et al., 1998). ”

Q6 *The PMF resolves five factors, but the "aged biomass burning" factor (factor 1) and "secondary nitrate formation" factor (factor 3) both appear to be associated with anthropogenic secondary pollutants. Figure 4 shows that these two factors together account for the majority of ON in autumn. However, the distinction between these factors is not entirely clear. Factor 1 is characterized by* K^+*, EC, WSOC, and secondary inorganic ions, while factor 3 is dominated by nitrate. Given that biomass burning also produces nitrate, how well-separated are these factors? The authors should provide more detail on the factor profiles (e.g., as a supplementary figure) and explain the rationale for keeping these as separate factors rather than combining them into a single "anthropogenic secondary" factor.*

Response: Thanks for your comments. We agree with the reviewer that nitrate can be formed in aged biomass burning aerosols. We compared the time series of ON contributed by aged biomass burning and secondary nitrate formation (added in Fig. S7). The resolved factor profiles of the sources are shown in Fig. S4, and the tracers of each source factor are marked in the corresponding panel. These two factors showed different temporal variations and were characterized by different tracers. Thus, they were resolved as two separate sources. Related descriptions have been added in the revised version (lines 210–212).

Lines 210–212:

“Both aged biomass burning and secondary nitrate formation were anthropogenic secondary pollutants. The two factors are characterized by different tracers (Fig. S4) and showed different temporal variations (Fig. S7) during the observations, which thus were resolved as two separate sources.”

Revised Figure S4:

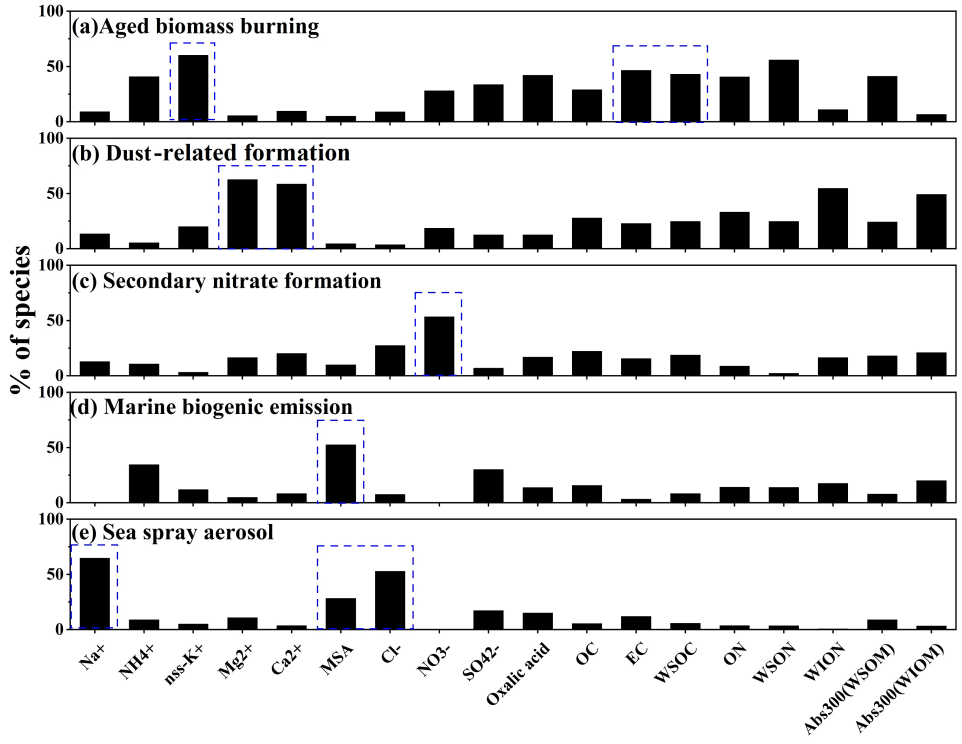

Figure S4 Explained source profiles resolved by PMF.

Newly added Figure S7:

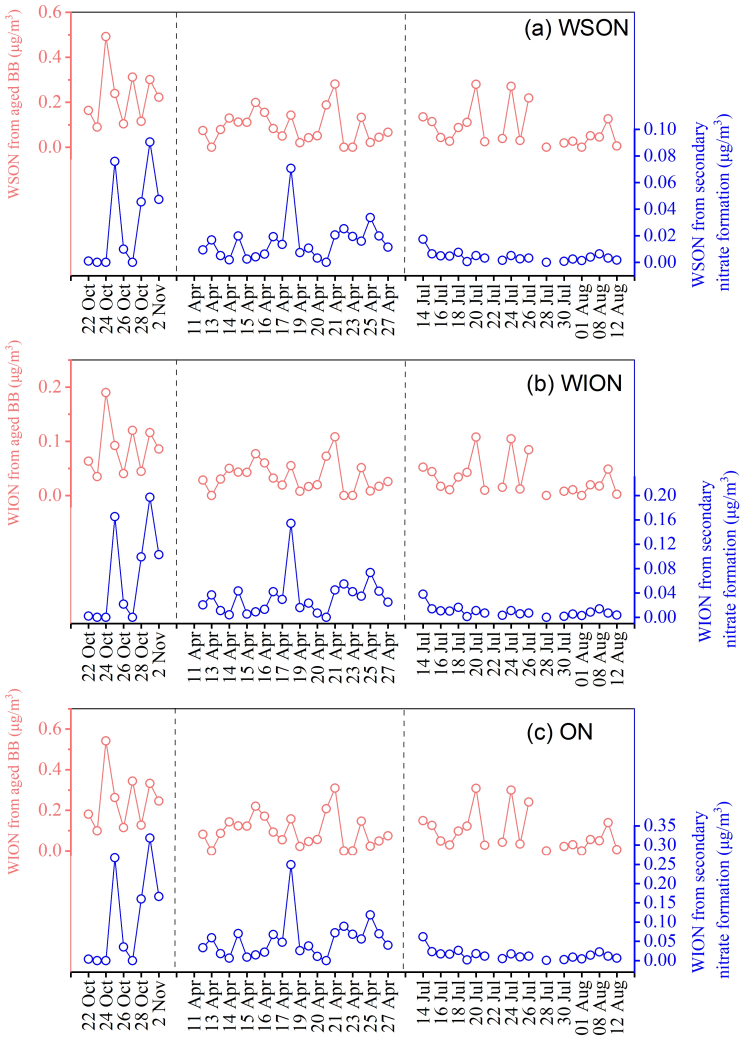

Figure S7 Time series of (a) WSON, (b) WION, and (c) ON contributed by aged biomass burning and secondary nitrate formation.

Q7 *The correlation between ON from secondary nitrate formation and RH (Figure S5) is interesting, but the analysis appears to be based on limited data points. For autumn (n=9) and spring (n=22), the authors should consider whether the observed correlations are statistically significant given the small sample sizes. Additionally, what is the mechanism for RH dependence specifically for nitrate-derived ON, and why would this dependence differ between seasons?*

Response: Thanks for the reminder. We checked the significance level of correlations between ON from secondary nitrate formation and RH in autumn and spring. For the autumn samples, ON from secondary nitrate formation is significantly correlated with ambient RH ($p<0.05$). For the spring samples, the correlation was not significant at the 0.05 level. We added the significant analysis in Fig. S8. Related descriptions are added or revised in the main text (lines 242-243 and 248-249).

The RH dependence for ON related to secondary nitrate formation was because ON formation via nitration of VOC precursors occurred in the aqueous phase. We

added an example to explain the mechanism in lines 244-246. Different dependence of nitrate-derived ON across seasons was attributed to different levels of ambient RH between seasons. Related analysis is now added in lines 250-254.

Lines 242-243 and 248-249:

"We noted that ON abundance from secondary nitrate formation increased with the increase in RH in autumn (Fig. S8), with a correlation coefficient of 0.78 ($p<0.05$)."

"For the spring samples, abundance of ON from secondary nitrate formation also showed an increasing trend with RH, but their correlation was not significant ($p>0.05$)."

Lines 244-246:

"For example, high RH promotes the aqueous formation of nitrated aromatic compounds (e.g., methyl-nitrocatechols) (Shi et al., 2023; Vidovic et al., 2018; Wang et al., 2019b). Nitration of guaiacol can produce nitroguaiacols via the nonradical mechanism under aqueous-phase conditions (Kroflic et al., 2018)."

Lines 250-254:

"The different dependence of ON formation on ambient RH was due to the higher RH in summer (79%±7%) than in spring (61%±18%) and autumn (54%±9%). Ambient humidity was not a limiting factor for aqueous formation of secondary organic aerosols (SOA) under the high RH in summer (Wang et al., 2023a). Under the low-RH conditions in autumn, humidity can be a more important limiting factor for ON formation, and elevated RH would favor its formation via aqueous reactions."

Revised Figure S8:

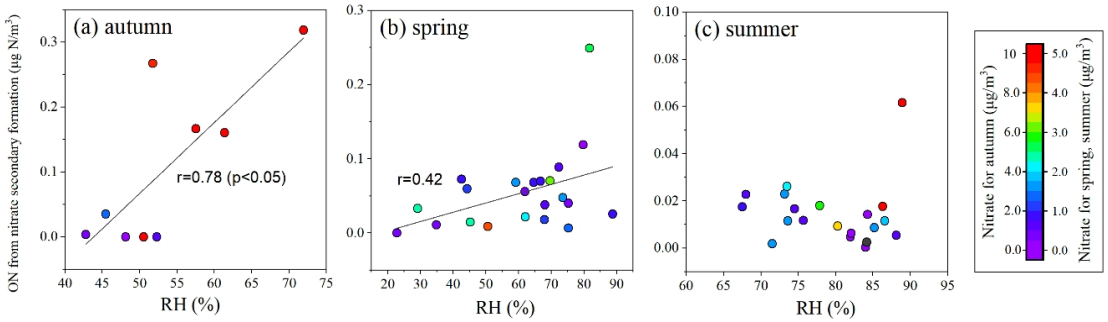

Figure S8 Variation of ON from nitrate secondary formation as a function of RH in each season. The markers are colored by nitrate concentrations. The spring and summer samples used the same color bar, and the autumn samples used a different one.

Q8 *The contribution of dust to ON in spring reaches 55%, with >80% during the dust episode. However, the authors also note that dust ON correlates with nitrate aerosol concentration (Figure S6). This suggests that the dust-associated ON may actually be formed through heterogeneous reactions with anthropogenic pollutants during transport, rather than being primary dust ON. The authors should consider whether this should be discussed as "dust-mediated formation of ON" rather than simply "dust source" of ON.*

Responses: Thanks for the suggestion. We agree with the reviewer that the dust-

associated ON was mainly secondarily formed via reactions with anthropogenic pollutants (especially anthropogenic nitrate aerosols), rather than from primary dust. As suggested, we changed the name of this source factor to "dust-related formation" throughout the manuscript in the revised version.

Optical Properties

Q9 *The use of Abs_{300} to represent light absorption is a significant methodological choice. While 300 nm is commonly used in BrC studies, why was this wavelength chosen rather than the more widely used 365 nm? The authors use MAE_{300}, but MAE_{365} would be more comparable to existing literature (see e.g., Dasari et al., 2019 Science Advances). If the data are available, the authors should consider presenting results at 365 nm and discussing any differences.*

Response: Thanks for your comments and kind reminder. We agree with the reviewer that Abs_{365} and MAE_{365} of BrC are more widely used and would be more comparable to existing literature. As suggested, we present the results at 365 nm and compare the organic aerosols absorption at 300 nm and 365 nm in lines 294-296.

Here, we used Abs_{300} and MAE_{300} because some values at 365 nm were quite low or close to the detection limit, especially for the summertime samples. The low absorption values would result in uncertainty for further analysis. Our recent work suggested that the Abs_{365} and Abs_{300} of marine organic aerosols over the YBS displayed a similar variation trend (Fig. S6 in Zhang et al., 2025). Thus, the analysis based on absorption at 300nm is reasonable for marine aerosol samples. Related description has been added in lines 296–301.

Lines 294-301:

"The Abs_{365} and Abs_{300} of organic aerosols were respectively 1.47±0.96 Mm^{-1} and 4.34±2.83 Mm^{-1}, and MAE_{365} and MAE_{300} were 0.43±0.21 m^2/g and 1.24±0.38 m^2/g during the cruises. Light absorption parameters at 365 nm are more widely used in existing literature (Dasari et al., 2019). For some of our marine aerosol samples, however, the Abs_{365} values were quite low or close to the detection limit, especially for the summertime samples, which could result in uncertainty for further analysis. Thus, we used the light absorption value at a wavelength shorter than 365 nm to investigate the BrC absorption properties and sources in marine atmospheres. Our previous work has suggested that the Abs_{365} and Abs_{300} of organic aerosols over the YBS displayed a similar variation trend (Zhang et al., 2025)."

Figure S6 in Zhang et al. 2025:

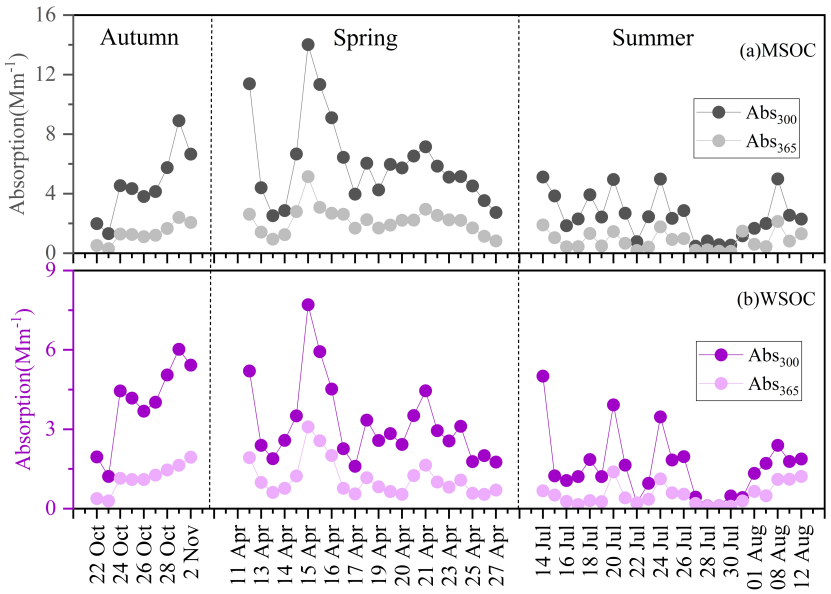

Figure S6 Light absorption coefficients of (a) MSOC and (b) WSOC at 300 nm (Abs_{300}) and 365 nm (Abs_{300}) for the $PM_{2.5}$ samples over the Yellow Sea and Bohai Sea (Zhang et al., 2025).

Q10 *The statement that "water-soluble organic nitrogen drove the light absorption" (line 238) is supported by Figure 5a, which shows a strong correlation between* Abs_{300} *of WSOM and WSOM for all seasons. However, Figure 5a shows only the correlation with WSOM concentration, not specifically with WSON. The authors should clarify whether the observed absorption is truly driven by nitrogen-containing organic compounds, or whether it simply correlates with the bulk WSOM concentration (which would include non-nitrogenous chromophores as well).*

Response: We agree with the reviewer that non-nitrogenous chromophores also contribute to the light absorption of organic aerosols. Figure 5a shows the correlations between the Abs_{300} of WSOM and the concentration of WSON, which indicated the importance of WSON on elevated absorption by organic aerosols. The correlation between WSOM absorption and WSON concentration was described in lines 302-303.

Lines 302-303:

"For the water-soluble organics, Abs_{300} of WSOM displayed strong correlations with WSON concentration in the marine aerosols across seasons over the YBS (Fig. 5a)."

Revised Figure 5:

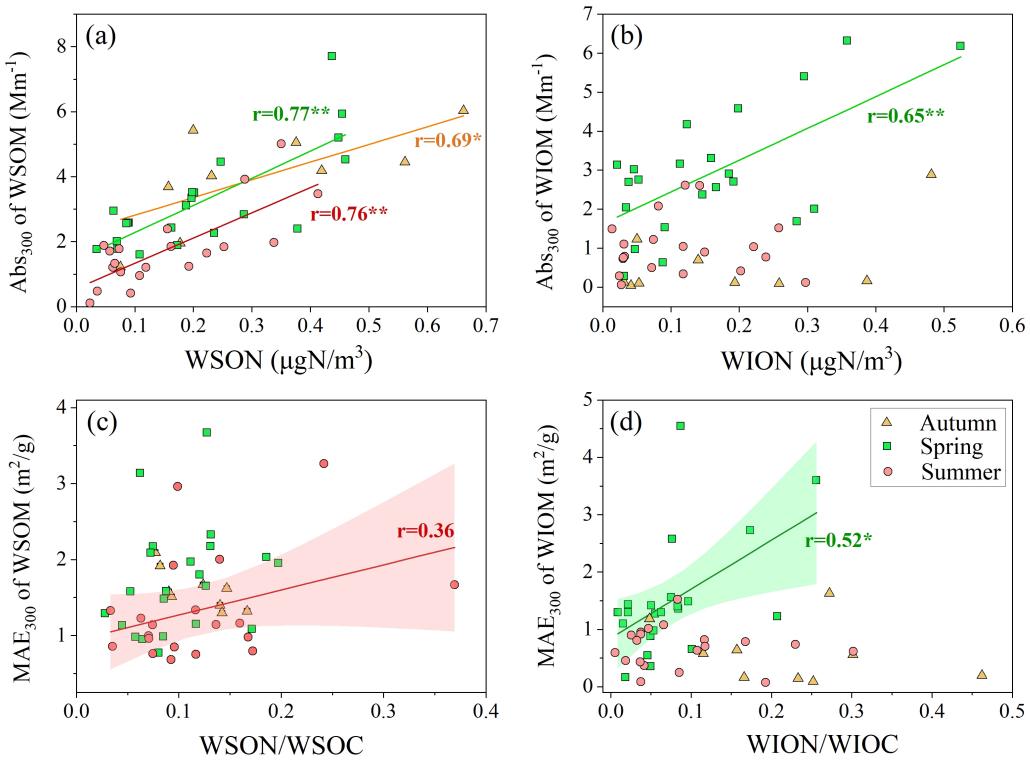

Figure 5. (a, b) Variations of Abs_{300} by WSOM and Abs_{300} by WIOM as a function of WSON and WION. (c, d) Variations of MAE_{300} for WSOM and MAE_{300} for WIOM as functions of WSON/WSOC and WION/WSOC mass ratios. The markers and fitted lines for the summer, spring, and autumn data are shown in red, green, and yellow, respectively. ** indicates the correlation is significant at the 0.01 level, and * indicates the correlation is significant at the 0.05 level.

Q11 *Figure 5d shows no clear trend for WIOM MAE_{300} vs. WION/WIOC in autumn and summer. The authors attribute this to the dominance of water-soluble organics in these seasons, but this explanation is somewhat circular. Could there be other factors, such as different chromophore compositions or photobleaching, that affect the absorption capability? The authors should discuss alternative explanations.*

Response: Thanks for the reminder. Alternative explanations have now been added in lines 326-328.

Lines 326-328:

"This was because light absorption of organic aerosols could also be contributed by non-nitrogenous chromophores (e.g., polycyclic aromatic hydrocarbons) in autumn or summer (Lin et al., 2018)."

Q12 *The conclusion that "continental aerosol ON modulated the light absorption by organic aerosols over marginal seas" (lines 293-295) is supported by Figure 6, but the correlation between continental WSON and Abs_{300} (r=0.80) is based on combined data from all seasons. Would this correlation hold within individual seasons? And*

why is there no correlation with marine-generated ON? The authors should provide more nuanced discussion of these relationships.

Response: Yes, the correlation between WSON and Abs_{300} also existed within individual season (added in Fig. S10). Marine-generated ON usually includes amino acids and protein-like organics, which are generally with low absorption within the UV to visible wavelengths. This could be the reason that no correlation existed between OA absorption and marine-generated ON. Related analysis has now been added in lines 342-344.

Lines 344-346:

"Light absorption of WSOM showed a strong positive correlation (r=0.80) with continental WSON (inserted chart in Fig. 6a). This correlation also held within individual season (Fig. S10)."

Lines 342-344:

"Organic nitrogen compounds in marine-generated aerosols (e.g., amino acids, protein-like organic matters) are generally with low absorption within the UV to Vis wavelengths. Thus, marine-generated ON likely played a minor role in the organic aerosol absorption over East Asian marginal seas."

Newly added Figure S10:

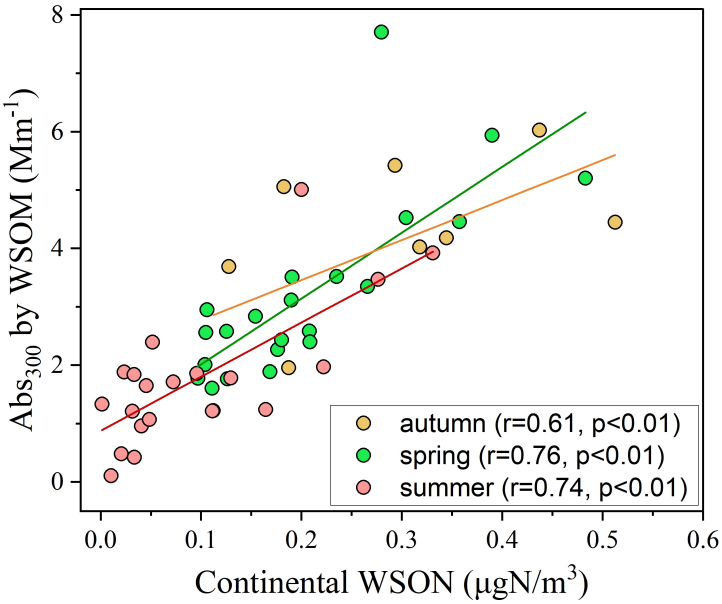

Figure S10 Variation of Abs_{300} by WSOM as a function of continental WSON within individual season.

Interpretation and Context

Q13 *The manuscript emphasizes the role of anthropogenic secondary pollutants in ON formation, but the relative importance of gas-phase vs. aqueous-phase formation pathways is not clearly distinguished. The authors discuss both VOC oxidation with NOx (gas-phase) and aqueous reactions (lines 194-197), but the PMF factor "secondary nitrate formation" likely includes both pathways. The authors should*

clarify whether they can distinguish between these mechanisms based on their data, and what the implications are for the solubility and optical properties of the resulting ON.

Response: Thanks for the suggestion. We cannot distinguish the gas-phase and aqueous-phase formation pathways of ON formation based on our PMF analysis. As suggested, we clarified in lines 254-258.

Lines 254-258:

"Our results indicated that increased ambient RH promoted the formation of light-absorbing ON in marine aerosols. It is noted that we cannot distinguish the gas-phase and aqueous-phase formation pathways based on the PMF analysis here. The resolved ON from secondary nitrate formation included both the aqueous-phase formation pathway as well as the gas-phase formation and further gas-to-particle partitioning pathway."

Q14 *The discussion of marine sources (lines 214-221) is relatively brief. Given the summer cruise was dominated by marine air masses, and marine sources contributed 53% of ON in summer, this section deserves more attention. What specific types of marine-derived ON compounds are expected? How do their chemical properties and optical characteristics compare to continental ON? The authors only mention amino acids and protein-like matter, but there is a growing literature on marine-derived brown carbon that could be referenced.*

Response: Marine-derived ON compounds usually include amino acids, protein-like organic matter, urea, etc., which are usually reduced organic nitrogen. Compared to continental ON, marine-generated ON was dominated by fluorescent components and had lower light absorption capability. Related statement has now been added in lines 281-285.

Lines 281-285:

"Amino acids, protein-like organic matter, urea, or other organic nitrogen compounds can be emitted from the ocean and enriched in marine aerosols (Matthews et al., 2023; Shi et al., 2010; Triesch et al., 2021; Wang et al., 2016). Marine-derived organic aerosols are usually enriched in fluorescent components related to marine biological activity (Miyazaki et al., 2018). These marine-generated reduced ON components are generally with lower light absorption capability compared with anthropogenic ON transported from the continent (Laskin et al., 2015)."

Q15 *The authors highlight that "organic matter in dust aerosols among the source regions usually has weak light absorption capability" (line 272), and that absorption increases during transport. This is an important point, but it is not supported by direct measurements. Do the authors have data on the absorption properties of dust before and after mixing with anthropogenic pollutants? If not, this statement should be framed as a hypothesis rather than a conclusion.*

Response: Thanks for the comment. This statement was deleted in the revised version. We did not have direct measurements of dust before and after mixing with anthropogenic pollutants. Here, we used the Ca^{2+}/NO_3^- mass ratio to roughly

indicate the variation of relative contribution of dust and anthropogenic pollutants. During the spring cruise, MAE_{300} of WIOM, dominated by dust-related sources, displayed a decreasing trend at an elevated Ca^{2+}/NO_3^- mass ratio (added in Fig. S11). This indicated that the light absorption capability of organic aerosols increased after mixing with anthropogenic pollutants. Related analysis has now been added in lines 349-353.

Lines 349-353:

"We used the mass ratio of Ca^{2+}/NO_3^- to roughly indicate the variation of relative contribution of dust and anthropogenic pollutants. The MAE_{300} of WIOM, dominated by dust-related sources, displayed an increasing trend at a lower Ca^{2+}/NO_3^- mass ratio in spring (Fig. S11). This indicated that light absorption of dust-related organics would increase via interactions with anthropogenic pollutants (e.g., nitrate aerosols) during long-range transport through East Asia."

Newly added Figure S11:

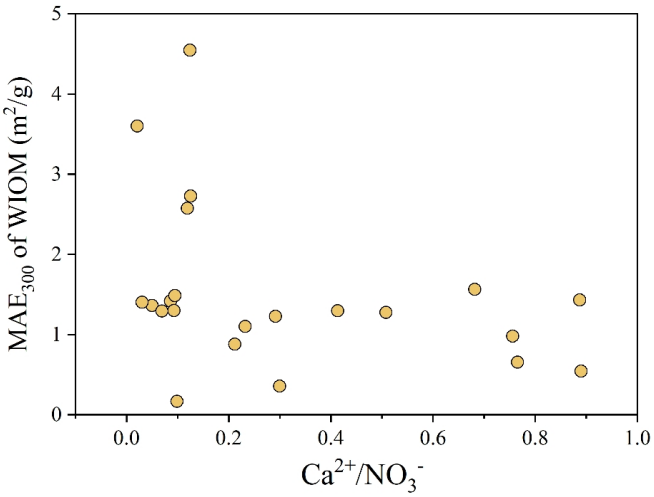

Figure S11 Variation of MAE_{300} of WIOM as a function of Ca^{2+}/NO_3^- mass ratio in spring.

Q16 *The implications for marine ecosystems and biogeochemical cycling are only briefly discussed in the introduction and conclusion. Given the significance of nitrogen deposition for marine productivity, the authors should elaborate on how the observed ON concentrations and sources might affect nutrient supply to the YBS and potentially the broader East Asian marginal seas. How do the ON deposition fluxes compare to IN deposition? What fraction of the total nitrogen deposition is ON in this region?*

Responses: Over the YBS, aerosol ON averagely contributed 22% of the total nitrogen (ON+IN) in marine aerosols. The fraction of ON among the total nitrogen in marine aerosols has been analyzed in lines 148-150. We agree with the reviewer that ON deposition played a role in nitrogen deposition for marine productivity. Our recent work suggested aerosol ON is important over the open Pacific Ocean (Wang et al., 2026). A modeling study has suggested that ON contributed 23% of atmospheric total nitrogen deposition in marine ecosystems on a global scale (Li et al., 2023). We will try to quantify the ON deposition fluxes and evaluate its effects

on nutrient supply to East Asian marginal seas in our future studies. Related descriptions have now been added in lines 156-158.

Lines 148-150:

"Organic nitrogen averagely accounted for 22% (range: 4%–60%) of the total nitrogen (ON+NH_4^+-N+NO_3^--N) and 6% (range: 2%–13%) of organic matters in marine aerosols over the YBS."

Lines 156-158:

"Recent observations suggested that external aerosol organic nitrogen from transported combustion emissions or aged anthropogenic pollutants is important in the West Pacific Ocean (Ito et al., 2014; Wang et al., 2026). On a global scale, ON contributed 23% of atmospheric total nitrogen deposition in marine ecosystems (Li et al., 2023)."

Minor Comments:

Lines 19-20: The statement "ON abundance, sources, or its influence on organic aerosol absorption remain unclear in marine atmosphere" could be more precise. While knowledge gaps exist, there have been previous studies on ON in marine aerosols (as cited). The authors should clarify what specific aspects remain unclear.

Responses: This sentence has been revised to be specific (lines 20-21).

Lines 20-21:

"However, observational evidence is lacking on the driving factors of ON formation or its role in organic aerosol absorption, especially in marine atmosphere."

Lines 23-24: The range of ON contribution to total nitrogen (4%-60%) is quite broad. The authors should mention whether this range represents seasonal variability, spatial variability, or measurement uncertainty.

Responses: Revised accordingly (lines 23-24).

Lines 23-24:

"Aerosol ON was 0.35 ± 0.25 μg N/m³, accounting for 4%–60% of total nitrogen across seasons."

Line 26: "aged biomass burning and secondary nitrate formation were the most important sources" - this is a conclusion from the study, and would be better placed in the discussion rather than the abstract.

Responses: This sentence is deleted in the revised version.

Line 100: The calculation of OM = OC × 1.6 uses a standard factor that may not be appropriate for all aerosol types (especially dust-containing samples where mineral matter contributes to mass but not OM). The authors should justify this choice or discuss its limitations.

Responses: We agree with the reviewer that mineral matter contributes to the mass of inorganic compounds, but not OM. We here used the factor 1.6 to convert organic carbon to organic matter (OM), and variation of mineral matter during dust episodes would not influence the OM abundance. Related references are now cited in lines 111-112.

Lines 111-112:

"Concentration of organic matter (OM) in the aerosol samples was calculated by multiplying OC by 1.6 (Turpin and Huntzicker, 1995; Wang et al., 2023b)."

Line 112: The input parameters for PMF include "Abs_{300} by WIOM and WSOM." How were these absorption values incorporated into the PMF model? Were they used as tracers or as variables to be apportioned? This should be clarified.

Response: Clarified as suggested (line 133).

Line 133:

"The Abs_{300} of WIOM and WSOM were included as variables to be apportioned rather than tracers."

Lines 117-118: The statement that "85% of the runs were acceptable" is vague. What criteria were used to determine acceptability? The authors should provide more detail on the diagnostic metrics used (e.g., Q/Qexp values, residual analysis).

Response: Here, we used bootstrap combined displacement methods (BS-DISP) to assess the robustness of the PMF results. In the BS-DISP uncertainty estimation, 85% of the runs were acceptable, and no factor swaps were observed. The PMF guidelines recommend at least an 80% mapping. According to the EPA PMF user guide, >80% indicates that the uncertainties can be interpreted and the number of source factors may be appropriate. Related description has been added in lines 141-143.

Lines 141-143:

"In the BS-DISP uncertainty estimation method, 85% of the runs were acceptable and no factor swaps were observed. According to the EPA PMF user guide and previous studies (Brown et al., 2015; Paatero et al., 2014), >80% indicates that the uncertainties can be interpreted and the number of source factors may be appropriate."

Figure 1d: The time series shows Ca^{2+} concentrations, but the y-axis label indicates these are TSP concentrations, while the other species are $PM_{2.5}$. The authors should either make the figure more clearly labeled or explain why Ca^{2+} is shown as TSP while ON and IN are $PM_{2.5}$.

Response: As suggested, we revised Fig. 1d to make it more clearly labeled and explain why we used Ca^{2+} in TSP while ON and IN in $PM_{2.5}$ in lines 178-181. Our previous observations over the YBS suggested that organics were dominant in fine particles, accounting for 60%-77% of the total organic mass concentration and 66%-88% of their absorption in TSP (Zhang et al., 2025). Thus, we mainly focused on the $PM_{2.5}$ results in this work, and concentrations of Ca^{2+} in TSP were only used to identify the dust episode more clearly.

Lines 178-181:

"It is noted that we only used the Ca^{2+} data in TSP to reflect the variation of coarse particles and identify the dust episode more clearly in this work. Other analyses were based on the $PM_{2.5}$ results, as previous observations have suggested that the organic mass and its absorption were dominant in fine particles over marginal seas (Zhang et al., 2025)."

Revised Figure 1:

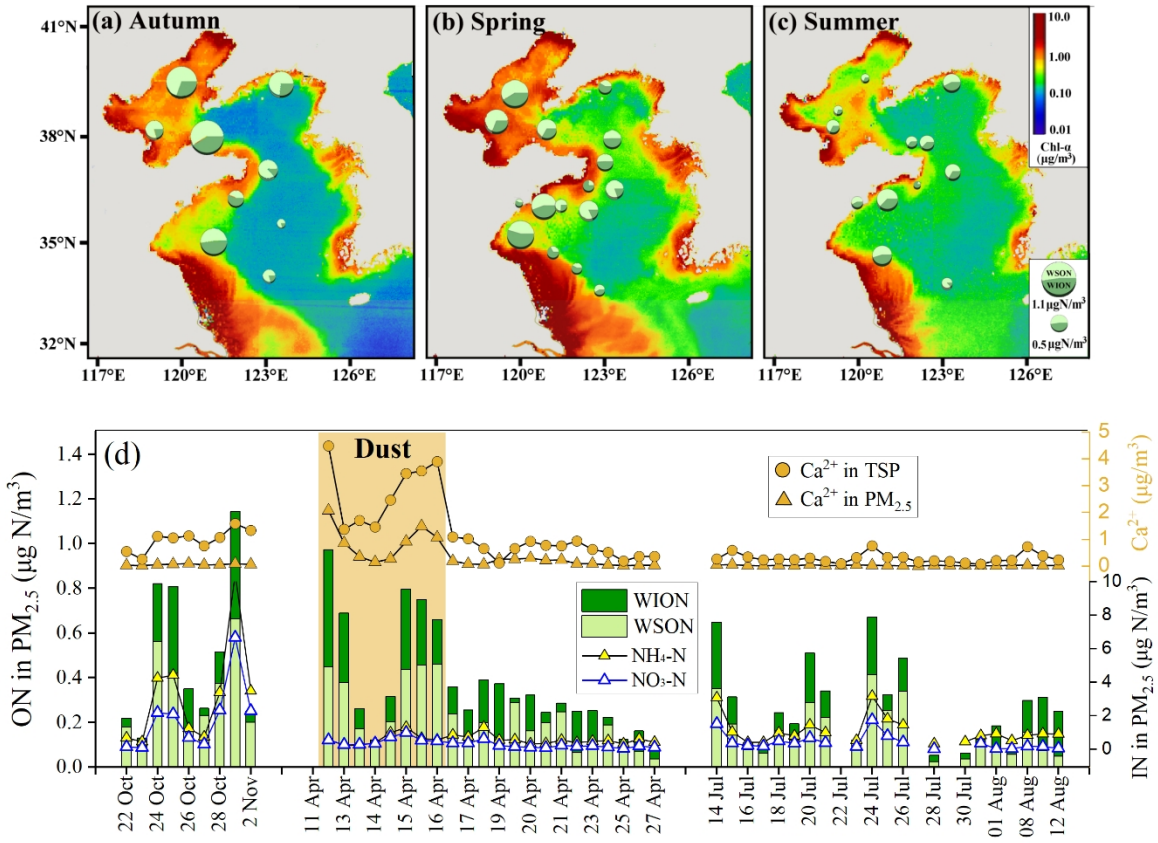

Figure 1. (a, b, c) Spatial distribution of organic nitrogen (ON) in $PM_{2.5}$ samples during cruises over the YBS. (d) Time series of ON, inorganic nitrogen (IN, including NH_4^+-N and NO_3^--N) in $PM_{2.5}$ and Ca^{2+} in marine aerosols during the observations. The color scales in panels (a-c) represent the sea surface Chl-a during the cruise. A dust episode was identified based on the Ca^{2+} concentration in TSP and marked by orange shading in panel (d).

Lines 135-136: The statement "following the abundance order of autumn > spring > summer" could be misleading since the differences between autumn and spring (0.50 vs. 0.37 μgN/m³) may not be statistically significant given the standard deviations and sample sizes. The authors should perform statistical tests (e.g., t-test, ANOVA) to determine if the seasonal differences are significant.

Response: Thanks for the reminder. As suggested, we added the statistical tests in lines 167-168.

Lines 167-168:

"The average ON concentrations in autumn and summer were significantly different at the 0.05 level, while differences between other seasons were not significant."

Lines 152-154: The discussion of WSON > WION and the relative fractions is interesting, but the authors should provide more context on what WSON/WION ratios have been observed in other marine environments and what they imply about aerosol aging.

Response: The relative contribution of WSON vs. WION over the Northwest

Pacific Ocean is now added in lines 196-199. Over marginal seas, higher WSON/WION ratios indicated an elevated contribution of aged anthropogenic pollutants in marine aerosols (added in lines 190-191).

Lines 190-191:

"Higher WSON/WION ratios indicated an elevated contribution of aged anthropogenic pollutants in marine aerosols over marginal seas."

Lines 196-199:

"A previous study over the open Northwest Pacific Ocean reported an average WION/ON ratio of 55%, and the contribution increased to 93% at 40–44°N (Miyazaki et al., 2011), much higher than the fraction of WION over the YBS. Miyazaki et al. (2011) suggest that marine biological sources significantly contributed to WION in marine aerosols."

Figure 3: The correlations between ON, WSON, WION and K^+, nitrate, and Ca^{2+} are shown separately by season. However, the r-values are presented without p-values. The authors should include significance levels to indicate which correlations are statistically robust.

Response: We have added significance levels in Fig. 3.

Revised Figure 3:

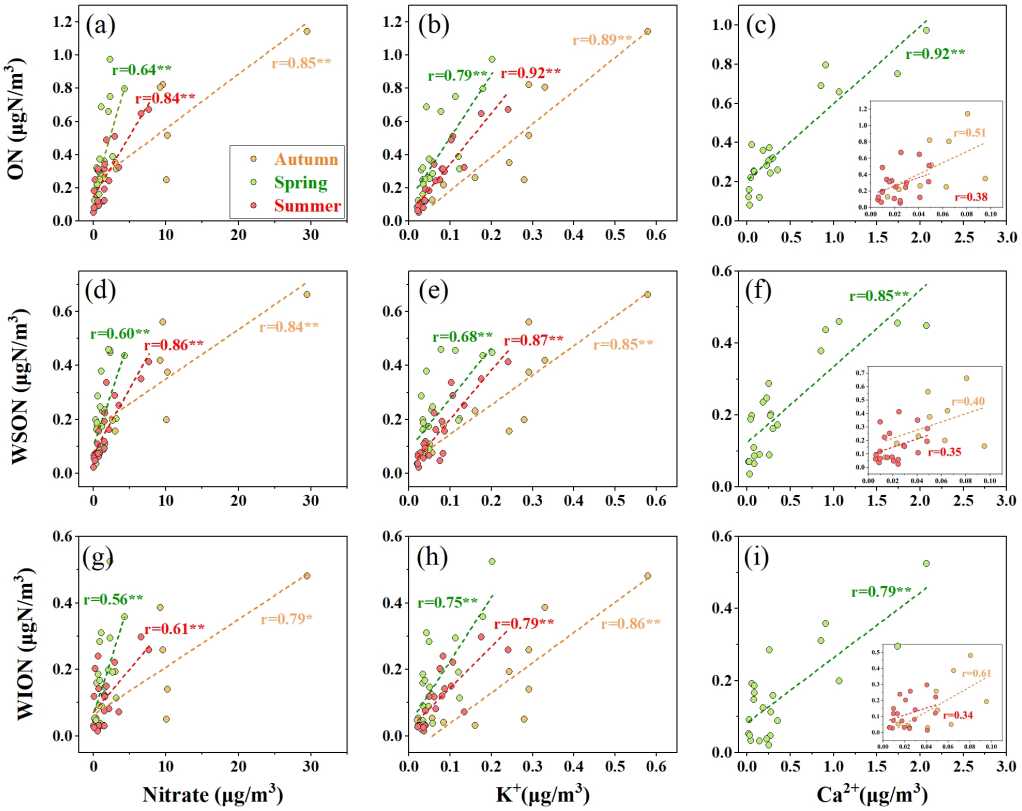

Figure 3. Correlation between (a-c) ON, (d-f) WSON, or (g-i) WION and secondary nitrate aerosols, K^+, and Ca^{2+} in $PM_{2.5}$ over the YBS. Data for autumn, spring, and summer are represented in orange, green, and red, respectively. The dashed lines and r-values are the fitted curves and correlation coefficients of the data in each season. ** indicates the correlation is

significant at the 0.01 level, and * indicates the correlation is significant at the 0.05 level.

Lines 288-292: The conclusion that "water-soluble ON drove light absorption" and "both WSON and WION played important roles" during dust storms is somewhat contradictory to the earlier statement that "water-soluble organic nitrogen drove the light absorption" (line 238). The authors should clarify that the relative importance of WSON vs. WION depends on the season and source influences.

Response: Thanks for the reminder. We have now revised these sentences and clarified the relative importance of WSON vs. WION depending on the season and source influences (lines 310-311 and 376-378).

Lines 310-311:

"Water-soluble organic nitrogen generally drove the light absorption by organic aerosols during non-dust periods over the YBS."

Lines 376-378:

"During non-dust periods, light absorption by marine organic aerosols was generally driven by water-soluble ON. Under the impacts of spring dust storms, both WSON and WION played important roles in organic aerosol absorption over the East Asian marginal seas."

Line 293-295: The conclusion that "marine-generated ON played a minor role in the light absorption" is based on the data, but the authors should consider whether this might be due to the specific optical properties of marine-derived ON (e.g., less chromophoric) or simply lower concentrations.

Response: We proposed that the minor role of marine-generated ON in light absorption was due to their lower absorption capability. Related explanation has been added in lines 283-285 and 342-344.

Lines 283-285:

"Marine-derived organic aerosols are usually enriched in fluorescent components related to marine biological activity (Miyazaki et al., 2018). These marine-generated reduced ON components are generally with lower light absorption capability compared with anthropogenic ON transported from the continent (Laskin et al., 2015)."

Lines 342-344:

"Organic nitrogen compounds in marine-generated aerosols (e.g., amino acids, protein-like organic matters) are generally with low absorption within the UV to Vis wavelengths. Thus, marine-generated ON likely played a minor role in the organic aerosol absorption over East Asian marginal seas."

Others:

Throughout the manuscript, the formatting of units is inconsistent (e.g., "μgN/m³" vs. "μg N/m³"). The authors should standardize units throughout.

Response: We now use the unit "μg N/m³" throughout the main text.

Fig. 1:

1. *The color scales in panels (a-c) are not clearly defined. What do the different colors represent? Is it ON concentration or another variable?*

   Response: The color scales in panels (a-c) represent the sea surface Chl-a during the cruise. We have now stated this in the figure caption.

2. *Panel (d) shows a dust episode marked in orange, but the criteria for defining this episode are not specified (e.g., Ca^{2+} concentration threshold). The authors should provide this information.*

   Response: The criteria for defining the dust episode has been added in lines 173-175 and the figure caption.

   Lines 173-175:

   "In addition, a dust episode was observed during 12-16 April during the spring cruise (Fig. 1d), when Ca^{2+} concentrations in TSP increased obviously to 1.36-4.47 μg/m^3, twice higher than the average values during the non-dust period (0.64±0.30 μg/m^3) in spring."

3. *The figure caption should specify that panels (a-c) show $PM_{2.5}$ ON concentrations.*

   Response: Revised accordingly.

   Revised Figure 1:

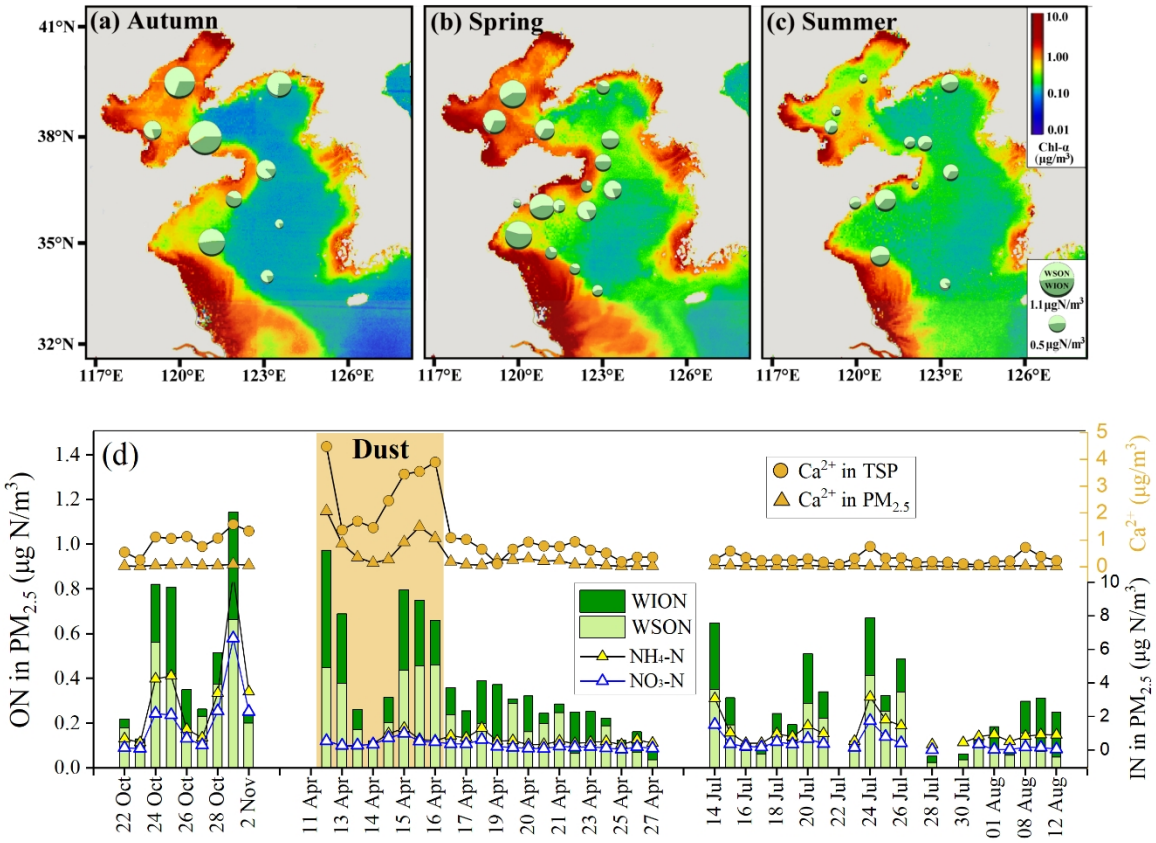

Figure 1. (a, b, c) Spatial distribution of organic nitrogen (ON) in $PM_{2.5}$ samples during cruises over the YBS. (d) Time series of ON, inorganic nitrogen (IN, including NH_4^+-N and NO_3^--N) in $PM_{2.5}$ and Ca^{2+} in marine aerosols during the observations. The color scales in panels (a-c) represent the sea surface Chl-a during the cruise. A dust episode was identified based on the Ca^{2+}

concentration in TSP and marked by orange shading in panel (d).

Fig. 5:

1. *Panels (a) and (b) show Abs_{300} vs. WSOM and WIOM, but the y-axis label is incomplete. It should read "Abs_{300} (Mm^{-1})" or similar.*

   Response: Revised accordingly.

2. *Panels (c) and (d) show MAE_{300} vs. ON/OC ratios, but the units for MAE are not provided in the figure. The equation for MAE (line 110) shows units of $m^2 g^{-1}$, but this should be confirmed.*

   Response: The unit of MAE has been added in Figure 5.

3. *The data points in panels (c) and (d) appear to be from different seasons but are colored inconsistently. The caption should clarify which color corresponds to which season.*

   Response: This is now clarified in the figure caption.

Revised Figure 5:

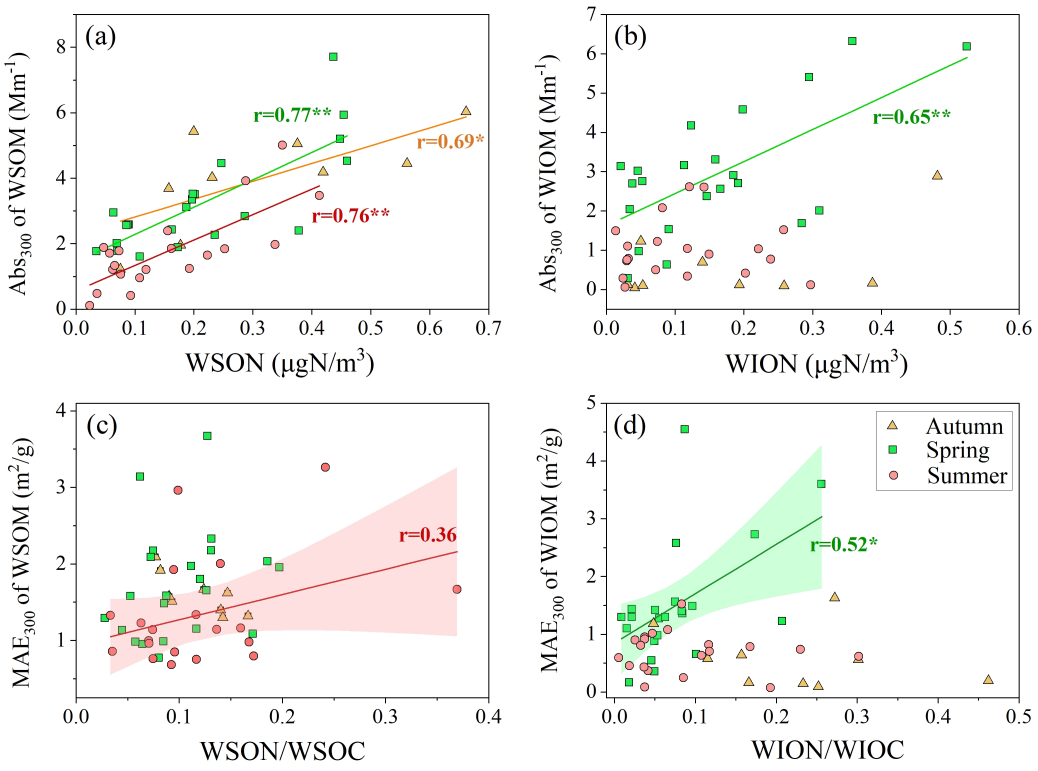

Figure 5. (a, b) Variations of Abs_{300} by WSOM and Abs_{300} by WIOM as a function of WSON and WION. (c, d) Variations of MAE_{300} for WSOM and MAE_{300} for WIOM as functions of WSON/WSOC and WION/WSOC mass ratios. The markers and fitted lines for the summer, spring, and autumn data are shown in red, green, and yellow, respectively. ** indicates the correlation is significant at the 0.01 level, and * indicates the correlation is significant at the 0.05 level.

Supp. Figs:

1. *Figure S1 shows 72-hr backward trajectories. The authors should specify whether these trajectories are for $PM_{2.5}$ samples or TSP samples, and whether the altitude of 500 m is representative of the boundary layer.*

   Response: In this work, the $PM_{2.5}$ samples and TSP samples were collected simultaneously. The backward trajectories of air masses represent the condition during each cruise. Here, we used the air masses from an altitude of 500 m, which can represent the marine boundary layer (stated in line 90).

2. *Figure S2 shows Q/Qexp variation with solution numbers. The authors should explain what Qexp represents and why the minimum in Q/Qexp occurs at 5 factors.*

   Response: We used Q/Q_{exp} to determine the number of source factors based on the EPA PMF user guide. Here, Q_{exp} was calculated by $(n \times m\text{-}p \times (n + m))$, where n, m, and p are the number of samples, the number of strong species, and the number of resolved factors. In PMF analysis, the Q/Q_{exp} ratio is an efficient way to understand the residuals of the solution and is used to determine the number of factor solutions. A noticeably decreased Q/Q_{exp} value suggests an improved solution, and the parameters experience less dramatic change. For our PMF result, the Q/Q_{exp} values decreased obviously before five-factor solution, and the change was relatively small after five-factor solution, as shown in Fig. S4. Thus, the variation of Q/Q_{exp} value suggested a five-factor solution. Related descriptions are now added in lines 138-140 and the caption of Figure S3.

   Lines 138-140:

   "For the PMF analysis, a noticeably decreased Q/Q_{exp} value suggests an improved solution, and the parameters experience less dramatic change (Wang et al., 2018). Fig. S3 shows the variations of Q/Q_{exp} with different solution numbers, and a five-factor solution is selected."

   Revised caption of Figure S3:

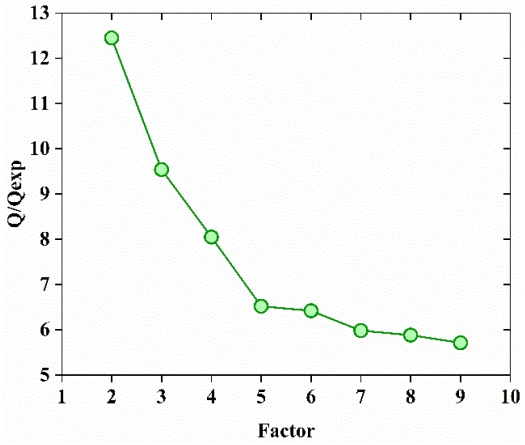

   Figure S3 Variation of Q/Q_{exp} with different solution numbers resolved by PMF source apportionment. Q_{exp} was calculated by $(n \times m\text{-}p \times (n + m))$, where n, m, and p are number of samples, number of strong species, and number of resolved factors.

3. *Figure S3 is not referenced in the main text. The authors should either reference it or remove it.*

   Response: Figure S3 (Fig. S4 in the revised version) is referenced in lines 204-212.

4. *Figure S4 shows PMF results vs. measurements. The authors should provide statistical metrics (e.g., R^2, slope, intercept) to assess the goodness of fit.*

   Response: As suggested, we have added the statistical metrics (e.g., R^2, slope, intercept) in Figure S6.

Newly added Figure S6:

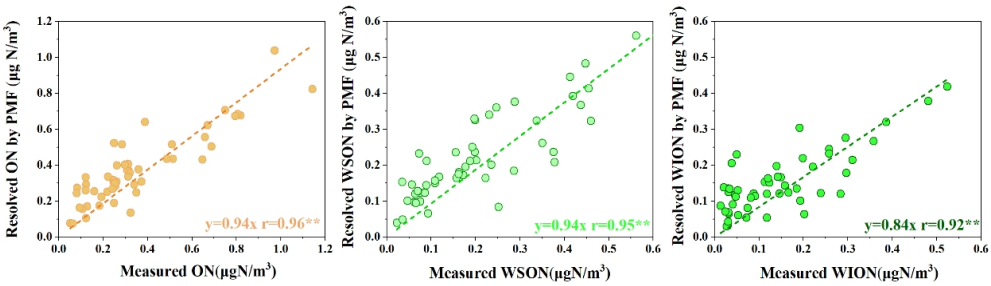

Figure S6 Comparison of ON, WSON, and WION resolved by PMF and measured concentrations. ** indicates the correlation is significant at the 0.01 level.

Other aspects for consideration:

1. *The discussion of brown nitrogen (Li et al., 2025b) is brief (lines 224-225). Given that this is a key recent finding, the authors should discuss how their results compare to or extend these global estimates.*

   Response: Thanks for the suggestion. We have now compared and extended in lines 353-358.

   Lines 353-358:

   "This work provided observational evidence that aerosol ON from continental pollutants modulated the light absorption of marine organic aerosols over marginal seas. Our results are consistent with a recent modeling study, which emphasized the importance of biomass burning, anthropogenic emissions, and secondary formation for light-absorbing brown nitrogen on a global scale (Li et al., 2025b). What's more, our observation also emphasized the vital role of dust, through mixing with anthropogenic pollutants, in aerosol ON formation and light absorption during dust-storm season, which needs to be considered in the model."

2. *The role of dust in ON formation (lines 210-213) could be better contextualized with previous studies on heterogeneous reactions on dust surfaces.*

   Response: Thanks for the suggestion. The role of dust particles in aerosol ON formation is explained in lines 266-273.

   Lines 266-273:

"On one hand, dust surface favors the gas-to-particle partitioning or the uptake of gaseous organic precursors (Li et al., 2025c). On the other hand, aged dust particles could facilitate the formation of SOA via aqueous-phase or heterogeneous reactions, especially on nitrate-coating particles (Li et al., 2025a). For the spring samples, dust-related ON formation displayed a positive correlation with nitrate aerosol concentration (Fig. S9), indicating the secondary formation of ON on dust particles via mixing with nitrate aerosols. Mineral components provided favorable conditions for heterogeneous nitration reactions and further ON formation in aged dust particles coated by nitrate (Kroflic et al., 2018; Nie et al., 2014). Dust storms, mixing with anthropogenic nitrate pollutants during transport through East Asia, are a major contributor to inorganic and organic nitrogen deposition in marginal seas."

3. *The comparison with other marine regions (lines 126-128) could be expanded. What are the typical ON concentrations in other marginal seas (e.g., Mediterranean, South China Sea)?*

   Response: We have added ON concentrations over marginal seas from previous studies in lines 150-153.

   Lines 150-153:

   "The observed aerosol ON over the YBS was among the ranges reported in previous studies over Mediterranean or Asian marginal seas (0.16-1.05 μg N/m³) (Sun et al., 2026; Tian et al., 2023; Violaki and Mihalopoulos, 2010), and lower than those in polluted continental environments (0.26-2.4 μg N/m³, e.g., urban Beijing, coastal Qingdao sites) (Shi et al., 2010; Wu et al., 2021; Xu et al., 2017)."

Reference:

Zhang, Y., Wang, Y., Li, S., Yi, Y., Guo, Y., Yu, C., Jiang, Y., Ni, Y., Hu, W., Zhu, J., Qi, J., Shi, J., Yao, X., and Gao, H.: Sources and Optical Properties of Marine Organic Aerosols Under the Influence of Marine Emissions, Asian Dust, and Anthropogenic Pollutants, *J. Geophys. Res., [Atmos.]*, 130, 10.1029/2025jd043472, 2025.