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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Surveillance of SO_2 and NO_2 from ship emissions by MAX-DOAS measurements and implication to compliance of fuel sulfur content" *by* Yuli Cheng et al.

Andreas Weigelt (Referee)

andreas.weigelt@bsh.de

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Overview: The manuscript present results from half a year of MAX-DOAS ship emission measurements at two different regions in the Chinese emission control area. With some examples the authors show the potential of the DOAS measurement technique to monitor ship emissions in general and of individual ships in transit. This is of high interest for the scientific community, dealing with ship emission measurements. However, the database the authors use for their conclusions is weak. Some analyses have to be improved. So mayor revisions are needed to consider this manuscript for publication in ACP.

General comments:

In the introduction the authors mention SO2 and NO2 to be the "main pollutants of ship emissions" (line 31-32). As the fuel consists of ca. 87% carbon, CO2 is by far the main pollutant in ship plumes. Beside CO2, Nitrogen monoxide (NO) is the second dominant pollutant in ship plumes. NOx is emitted mainly as NO and not as NO2. The NO2 is formed in the plume when the plume ages (NO + O3 –> NO2 + O2). Our measurements within the German ship emission monitoring network usually shows NO/NO2 ratios of above five when the plume age is less than 5 minutes. With increasing time the NO/NO2 ratio decreases to below 1 (age > 15 minutes). The MAX-DOAS instrument cannot measure CO2 and NO. Nevertheless, in the introduction the authors should consider CO2 and NO as the main pollutants of ships. They should also discuss influence of the NO –> NO2 transformation inside the plume to their measurements.

At the end of the introduction (Line 97-100) and in section 3.3 it is stated that the measurements can be used to estimate a fuel Sulphur content (FSC) from the SO2/NO2 ratio. As already mentioned in the first general comment the amount of NO2 and therefore the SO2/NO2 ratio strongly depends on the age of the plume. Directly at the stack the SO2/NO2 ratio should be highest and then decreasing with increasing time. The authors should consider this in their description and calculations.

Results presented in section 3.1 do represent only one measurement at one day. If the authors have "more than a dozen cycles" (line 220-221), why they don't show an average of all cycles. The presented cycle is a snapshot and might be not representative to draw conclusions. Well, even an average over one afternoon does represent only a snapshot of the situation. The authors should consider this in their discussion or should skip this section.

Also in Section 3.2 the authors discuss only data from two selected day. To make more general conclusions the authors have to average a longer time period (if possible all Wusong measurements).

Again in section 3.3 the conclusions are based on very little data points (only nine!), which is critical to make general statements. So for sound statements much more data have to be analyzed.

At least in the Conclusion the authors should discuss not only the advantages but also the limitations of the MAX-DOAS method, which are: - no NO and CO2 measurements (which are the main components inside the plume) - no measurement during twilight and night.

Specific comments

Line 15: It is confusing that the authors mention that the measurements took place in Shanghai and Shenzhen and the next sentence starts with “These three typical measurement sites. . .” In Section 2.2 it becomes clear that the measurements were performed at three sites in two regions –> please clarify in the abstract.

Line 37: consider also CO2 (see first general comment)

Line 42-43: what kind of important role do the ship emitted pollutants play in air quality, human health and climate? Political regulations, monitoring, enforcement, . . .?

Line 53-54: The authors have to distinguish different limits in different ECAs: So the maximum fuel Sulphur Continent (FSC) in ECAs at the US coast and Europe (whole Baltic- and North Sea) is 0.10% S m/m. Inside the Chinese ECA it is 0.50 % S m/m. By 2020 the maximum FSC is 0.50% S m/m all over the world (global Sulphur cap) which is not related to designated ECAs. As the use of exhaust gas treatment systems (Scrubber) is allowed as an alternative, the authors should mention this option, too.

Line 57: Are Scrubbers allowed in the Chinese ECA? If yes, this has to men mentioned here, too.

Line 64: “. . . usually fast detecting. . .” –> What is fast (minutes, hours, days,. . .)?

Line 69: the authors should give a reference (e.g. Kattner et al. 2015, or Seyler et al.

2017)

Figure 2: Do the authors have the copyright for the satellite pictures in Fig. b-d? If not, they have to cite the source.

Figure 3: It looks like graph (b) and (d) are mixed up, because the y-scales do not match the y-scales of graph (a) and (c). Can the authors confirm this? If not, the authors should comment in the corresponding discussion (line 170-175) why the scales are different

Figure 3 (line 180-181): Wouldn’t it be better co compare measurements with same elevation angle to minimize differences due to different optical length inside the planetary boundary layer (PBL)?

Line 190: What is located opposite the berth? Any industry which might emit NOx or SO2?

Line 196: Why only 10° angle for the reference spectrum? At 10° the way thru the PBL is still long and therefore might be influenced by emissions. Why the authors did not measure at 90° or at least at 65° like in Wusong?

Figure 4: In my opinion this figure is not necessary to explain the measurements. So if the authors want to save some space, they could skip this figure.

Line 208-210: please explain with compass direction (e.g. shift to north-west) to compare it to the given wind direction. What dose “MAINLY came from the south” mean? Here only one measurement (a 15 min scan) is discussed. Dose the wind direction changed during this 15 minute scan?

Line 220-221: If the authors have “more than a dozen cycles” why they don’t show an average of all cycles. The presented cycle is a snapshot and might be not representative to draw conclusions.

Line 253: ships in navigation or maneuver? Do the authors can exclude emissions

from the industry behind the river (visible in Fig 2 (c)) as a source?

Line 256-268: Why the authors do only check for the influence of wind speed? I would expect a much bigger correlation with wind direction because the optical length inside the polluted air and therefore the response signal is probably increased when the wind transports the polluted air towards the DOAS. On the contrary the optical length inside the polluted air and therefore the response signal is probably less when the wind transports the polluted air perpendicular to the DOAS (out of the field of view). The authors should check the wind direction dependency for all data. Why constant high wind speed (5-6 m/s is not high) unstable atmospheric conditions? As stated above, in my opinion the wind direction is of high importance as well.

Line 263-264: The close relation of SO2 and NO2 signal to the flow of ships (better use "ship density) is not clear on March 09 12:00-14:00. At this time the ship density is constant but SO2 and NO2 decrease.

Figure 7 and corresponding discussion: If the authors want to correlate SO2 and NO2 with traffic density and meteorological conditions, they should use all data and not only data from two days. They should create scatter plots (e.g. ship density on x and SO2 on y-axis) to find correlation coefficients. As the authors give a scan time of 7 minutes for the Wusong measurements (Table 1), each box-whisker-plot is based on only 4 measurements. This is not valid for this kind of plots. If the authors use all azimuth angles in one box, this is also not valid, because of different optical length and therefore not comparable measurement conditions.

Line 276-279: This conclusion might be true, but has to be proved not only by a snapshot but by an average as indicated in the comment above.

Line 282-283: To support the conclusion that the ships are the main source for NO2, the authors should roughly estimate the influence of the surrounding emission sources (especially the main roads and highway, because this could be a significant NO2 source).

Line 285-287: The meaning of this sentence in not clear. Do the authors mean that they want to use the complicated MAX-DOAS inland waterway measurements to check ships for compliance with fuel Sulphur regulations? It is not clear how the authors want to compare a theoretical SO2 emission (which unit?) with the MAX-DOAS measurement result (column density). This has to be explained in more detail. In my opinion comparing only SO2 from theoretical emissions to DOAS measurements does not work, because from the DOAS measurements you don't know whether you measure in line or perpendicular to the plume.

Line 292: largest container ports related to what? China, Asia, World?

Line 305-308: Why the big container vessel does not show any NO2 signal but the tug do so? The container vessel should emit even more NOx than the two tugs. Please discuss.

Line 314-316: This sentence put a question mark onto the measured plumes at 13:00 and 13:30. So the authors have to state that for the two earlier measurements no other ship could have caused the high signals (e.g. based on AIS analysis). Line 323: How the emissions are related to the operational status (was not discussed before)?

Line 326-327: "we try to further detailed SO2 emissions from the measurement" –> the meaning is not clear. Do the authors want to say that they try to analyze detected plumes in more detail?

Line 339: Which mathematical method? How the baseline is calculated (e.g. running mean or median; which averaging interval?)?

Line 351-355: The use of fuels with different Sulphur content is one possible explanation for the observation of different SO2/NO2 ratios. The age of the plume and the direct NO2 emissions is another plausible explanation. As already mentioned in the first general comment, ships mainly emit NO but not NO2. Therefore, directly at the stack the SO2-NO2 ratio is highest. When the plume ages NO2 is formed and the

SO2-NO2 ratio decreases. NO2 emissions are dependent on the kind of engine and the burning temperature of the engine as well. The authors have to consider this in their discussion.

Line 359-361: Is the main engine really operated with fuel with higher Sulphur content than the auxiliary engine? Do the authors have a source for this statement? I thought inside the Chinese ECA the maximum allowed fuel Sulphur content is equal to that allowed at berth.

Line 381: Do the authors mean vessel #IX instead of cargo #IV? What about vessel #V and #VIII? Are they allowed to use fuels with Sulphur content above 3% inside the Chinese ECA? I thought the limit is 0.5%

Line 391-394: from the SO2-NO2 ratio displayed in Fig. 12 it is not obvious which is the “irregular observed ratio”. I do agree that if the SO2-NO2 ratio is above 1.5 this is an indication for the use of fuel with high Sulphur content. But from this point of view vessel III, V, VIII, and IX should be indicated as non-compliant. Is it possible to estimate a kind of detection limit for the observation of non-compliant vessels? Is it possible to distinguish between 0.4 (compliant) and 0.8 (non-compliant)? This would address also the conclusion (Line 410-412).

Technical corrections

Line 15: ships instead of ship

Line 22: ad "the" in front of SO2/NO2. . .

Line 26: Combining instead of Combined

Line 27: What is meant with “logical Sulphur content”?

Line 28: “more accurate way ” –> than what?

Line 44: ad "of" in front of "kilometers"; remove "the" in front of "most"

Line 53: areas instead of zones

Line 57: should or must?

Line 85: close instead of closed

Line 95: ad “the” in front of instrument

Line 105-106: “. . .and stored in form of spectrum” –> It is not clear what is meant. The MAX DOAS instrument records spectra which represents the intensity of scattered sun light at different wave length (please give the scan interval). For each viewing direction and measurement interval a separate spectrum is recorded

Table 1: The measurement sites name and locations should start in the same line the operations AZ starts. At the moment it is little bit confusing that the line where the AZ is given starts above the site names.

Table 1: The authors should give the number of scan cycles, as well. As the measurements in Waigaoqiao last less than one day and one can takes 15 minutes I think there are not many scans available for analysis.

Line 186: ad “of” in front of “more than”

Line 189: ad “of” in front of “ships at”

Line 194: remove “can” in front of “covers about”

Line 204: increase instead of increases

Line 242: write “Beside of ocean-going ships, inland waterway vessels also contribute significantly to the amount of ship emissions. . . ” instead of “Besides ocean-going ship emissions, inland waterway vessels also contributed significantly to the ship emissions. . .” –> not the emissions, but the ships are ocean-going :-)

Line 245: close instead of closed

Line 246-247: This sentence is not clear. I suggest to split it.

Line 251: ad a space (direction of)

Line 252: lane instead of lanes

Line 256: use singular instead of plural: impact of ship traffic; measurement data

Line 273: what do the bars and the stars do represent?

Line 291: see instead of See

Line 299: remove “orderly” in front of “inbound”

Line 300: 2018 instead of 2019; two dots at the end

Line 302: remove “were” in front of “occurred”

Line 310: was instead of were

Line 323: “more or less” –>please be more precise!

Line 325: “for” instead of “with the”

Line 330: “was” instead of “can be”

Line 331: “stand for the peak concentration” –>do the authors mean “represent the peak concentration”?

Line 337-338: It is difficult to get the meaning of this sentence. Do the authors want to say that with temporal high resolved measurements (60 sec) it was possible to resolve individually the plume signals of passing ships? Please rephrase.

Line 340: Comma after DSCDs

Line 342: “are present” behind cm-2

Line 345: remove “In addition” in front of “the increases of pollutants”

Line 368: “on” instead of “about”

Line 374: “is” instead of “are”

Line 379: ad “the” in front of ”plume”

Line 380: “increase” instead of “growth”

Line 381: “to note” instead of “noted”; “circle instead of “dot”

Line 390: ad “high” in front of “sulfur content”

Line 393: “compliance monitoring” instead of “compliance”

Line 397: write “In this study we performed MAX-DOAS measurements to observe ship emissions of SO2 and NO2 in Shanghai. . .” instead of “In this study, we have performed the MAX-DOAS measurements observe the ship emissions of SO2 and NO2 in Shanghai. . .”

Line 400: delete comma

Line 402: better “. . . are correlated to ship traffic density at stable and unstable atmospheric. . .”

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