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Comment

Interactive comment on “Physical and chemical characterisation of PM emissions from two ships operating in European Emission Control Areas” by J. Moldanová et al.

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We would like to thank the anonymous referee #2 for his thorough review of our manuscript. Here come answers to the comments in chronological order (the pages and line numbers refer to the AMTD paper):

1. Abstract: The abstract have been rewritten and shortened substantially. The first paragraph has been skipped.
2. Abstract: Only mean measured emission factors with one significant number are now presented in the abstract to avoid confusion between estimate of the measure-

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ment uncertainty and the measurement standard error (the error bars). The error bars are kept in the main text and are calculated from multiple samples taken on exhaust from the same type of fuel (influence of different PM metrics and engine load is not filtered) and express combined variability of parameters that are included in calculation of EF (typically concentration of species in the exhaust, exhaust flux and fuel consumption per time unit). Uncertainties of emission factors comprise of uncertainties in all these parameters, these are discussed in the ‘methodology’ part for each measurement technique.

3. Abstract: All units were set to g/kg-fuel.

4. P. 3939, I. 2: In the instrumentation part the different principals for particle diameter sizing for the EEPS instrument (electrical mobility) and GRIMM instrument (optical) are expressed. The GRIMM instrument is calibrated with 1 μm latex particles and micro dolomite polydisperse powder. Dragan et al. (2013) have compared performance of several aerosol spectrometers including Grimm 1-108 for different types of aerosol particles characterised also by scanning electron microscopy sizing. They found in general a good performance of the Grimm 1-108 instrument, however it underestimated particle diameter for highly absorbing particles with $\text{Pd} < 1 \mu\text{m}$. We have added a sentence discussing differences between the particles diameters measured by the different instruments to the “Results and discussion” section.

5. Section 2.3, uncertainties EC/OC: During the EC/OC method validation “expanded uncertainty” U is determined. Mostly, it is based on reproducibility (vc), recovery (tv) and if it is available, precision (j) is also used. Expanded uncertainty is uncertainty multiplied with 2.

$$U_c = [(\text{vc})^2 + (U_j)^2 + (U_{\text{tv}})^2]^{(1/2)}$$

$$U = U_c * 2$$

In our validation of U for EC and OC for low total carbon (TC) levels was the same, i.e.

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31%. For high levels it differed, 24% for EC, 16% for OC and 14% for TC. Since our samples were in the lower range the uncertainty of 31% was used. Since EUSAAR2 protocol uses most often transmission for pyrolysis correction, necessity to discuss the difference between reflectance and transmission in the paper is questionable. Chow et al. (2004) published results where the ratio of reflectance- to transmission-corrected EC for EUSAAR2 protocol was about 1.7. Maenhaut (2009) discussed that there is a tendency for larger EC/TC ratios with reflectance correction method comparing to the transmission method when using the same thermal protocol.

6. Section 2.3, absorption cross section for transmissometer: The reference was added: Chow J.C., Watson J.G., Green M.C., and Frank N.H.: Filter light attenuation as a surrogate for elemental carbon. JAWMA 60, 1365 – 1375, 2010.

7. Section 2.3, DTT: The use of total mass of the quartz filter (=analysed quartz filter piece, this was added to the text) is based on the fact that it is not possible to determine correctly mass of the extracted fraction due to quartz fibres which come to the extract. There is a logics in using all PM mass as in our results we describe correlation of DTT measured on quartz filters with OC and EC and it is much higher for OC than EC. Indeed there are studies where EC gives higher correlation with DTT, but there are differences in sampling and types of extracted filters that influence the results. Specific DTT results are true for the specific conditions during the sampling, extraction and the measurement protocol.

8. P. 3946, l. 29, EF(CO₂): The emission factors expressed in g kg⁻¹-fuel indeed do not change with the engine load as expected. Emission factors for the same gases in g kWh⁻¹ show decrease from full to low load (from 80 to 30%) on S1 due to the decreased specific fuel consumption (SFC) while a decrease in engine load from 57 to 47 % on S2 caused an increase in SFC and EFs for CO₂ and SO₂ (expressed as g kWh⁻¹) with 1% and 4% for HFO with FSC 1% and MGO, respectively. This was added to the text.

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9. Section 3.1 – difficulties with referring to different engines and fuels: We agree that it is rather difficult to get a clear picture in this diverse set of measurements. Unfortunately, it is not easy to achieve the whole experimental matrix when doing measurements on board commercial vessels, especially when the PM sampling demanding long sampling periods is considered. We have put a large effort to clearly distinguish between the individual experiments (measurement of 1 fuel type on 1 engine under 1 load condition). Discussion on PM mass on P3947L4-6 was changed to refer to the individual experiments.

10. Fig. 2, TSP » PM10: This is most likely due to the presence of giant particles in the exhaust channel, often originating from the exhaust channel wall sediments. This is discussed on P3947L13-19.

11. P. 3948, I.4: Differences in measurement principles are stressed in the Experimental section. Here a brief comparison is presented with the uncertainties given as it gives some indication on the gap between the instruments.

12. Fig. S1 & S2 has been changed into schematic drawing.

13. P. 3948, Comparison with Lack et al. (2009) was added for EF(PN). Engine and conditions in Lack et al., 2012 are quite different from ours (large slow-speed engine, different fuel quality, transient conditions of fuel switch). Since the results are anyway in line with papers we are referring to and we are not presenting a review paper we have not included this comparison.

14. Fig. 4 Comparison of size distributions ME and AE: The following text have been added: Size distribution of particles emitted from the auxiliary engine shows few particles in the ultrafine mode and a peak at ~200 nm similar to size distribution of S1_HFO1%_ME-low while for particles with Pd>300 nm the size distribution is more similar to that from S1_HFO1%_ME-full. The exhaust flow in the channel was rather similar to the main engine at full load which could in combination with technical condition of the engine and exhaust system explain presence of the coarse particles.

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15. Fig. 4 high/low load, comment ultrafine particles: A similar comment was given by referee #1. We have therefore added the following text to the discussion: Comparing the number size distributions for the main engine at full and low main engine loads we can see much higher emission of particles with PD ~ 10 nm at full load comparing to the low load. Taking the measured PM composition into consideration we can speculate that higher amounts of sulphate formed at high engine load (Figure 6) could result in nucleation of large number of volatile particles while a lower sulphate formation at low engine load led to less nucleation and the condensable material in the exhaust could instead contribute to the growth of the ultrafine particles into the accumulation mode, which is higher in the low engine load exhaust. This would mean that the increase in accumulation-mode particles is not a result of higher soot formation at low engine load conditions, something what is actually supported by results of the EC analysis (Figure 7).

16. P. 3949, volatility: Following text was added to the Experimental part to clarify the thermodenuder data: Size-dependent particle losses in thermodenuder (up to 30%) can be calculated by an empirical function given by Dekati. This function was verified under our experimental conditions through comparison of size distributions of particles bypassing and passing the cold thermodenuder. All volatility data presented in the paper are corrected for the particle losses in the thermodenuder.

17. Section 3.3, mass closure: The mass closure is presented in Figure 6 as the ‘undefined’ part of the PM mass. We have 2 different filter types and different components analysed on each making calculation of propagation of uncertainty difficult.

18. P. 3950, I. 2, the ash residuals: This statement has been deleted as ash residuals are never used in the paper.

19. Fig. 6, P. 3950: There is the following statement in the figure caption: Sulphate-bound H₂O is calculated as SO₄2[−] * 0.8 (after Petzold et al., 2008)

20. Fig. 6, P. 3950, mass closure: The undefined mass is the difference between PM

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mass and sum of individual species analysed. This information was added to the text (P3950, L10)

21. P. 3950, l. 11: The particle losses in thermobalance were accounted for (see p.16). The lack of knowledge on particle density is of course a problem which is not easily solved. Comparison of these 2 figures for volatility gives information on difference of the 2 methods used.

22. Uncertainties: We do not report uncertainties of the individual EFs, we do report the standard deviations in multiple samples analysed. This information was added to the text (P3950, L19). The uncertainty is calculated for SO₂ as the large discrepancy between measured and from fuel S content calculated EF(SO₂) was found. Uncertainties of EF for species are not only propagated from the uncertainties of the analytical techniques but also from uncertainties coupled to the fuel specific fuel and energy consumption of the ship and from the PM sampling technique.

23. P. 3951, l.5, what is experiment: See p.9. Text 'With experiment a measurement on 1 engine with 1 constant engine load and using 1 fuel is understood.' was added (Section 2.1)

24. P. 3951, l. 10: The figure was changed to comparison of EF(OC) and EF(BC) in g/kg-fuel and the text was adjusted.

25. Fig. 8 – the scale have been changed

26. P. 3952 – Thanks for a good suggestion. The values were put into a table and the text shortened.

27. P. 3952: The % conversion of sulphur was in error in abstract. This was corrected in accordance with the text on P. 3952.

28. P. 3954, l. 24: The 'global view' is seen from the perspective of the electron microscope when the magnification is decreased by few 100×. We changed the 'global' to 'panoramic'.

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29. P. 3594, definition of the ‘primary soot particles’ and ‘soot agglomerates’: At first appearance the primary soot particles are defined as the simple spherical black carbonaceous particles and word ‘soot’ is added to ‘agglomerates’.

30. Subsections were added to section 3.3

31. P. 3935, I.18: Navigation (similar to aviation) is often used in same meaning as shipping and was used to avoid repeating of the word ‘shipping’.

32. P. 3935, I.26: The word ‘only’ was deleted.

33. P. 3937, I.11: RoRo is explained

34. Section 2.2: The organisation background of the campaigns was skipped.

35. P. 3955: All supplementary figures were re-numbered and all call-outs were changed.

References: Dragan, G.C., Schnelle-Kreis, J., Karg, E., Zimmermann, R.: A laboratory evaluation of four commercial particle sizers under several aerosol types, proceedings of the European Aerosol Conference, 1-6 September 2013, Prague, <http://eac2013.cz>.

Chow, J. C., Watson, J. G., Chen, L.W. A., Arnott, W. P., and Moosmuller, H.: Equivalence of elemental carbon by thermal/optical reflectance and transmittance with different temperature protocols, *Environ. Sci. Technol.*, 38, 4414–4422, 2004.

Maenhaut, W. (2009) in Kuhlbusch, T. A. J. et al., Measurement of Elemental and Organic Carbon in Europe; Report of the preparatory workshop for a future standard measurement method, JRC EUR 23992 EN – 2009.

Interactive comment on Atmos. Meas. Tech. Discuss., 6, 3931, 2013.

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