Atmos. Chem. Phys. Discuss.,
https://doi.org/10.5194/acp-2018-420-AC2, 2018

Atmospheric Chemistry and Physics
Discussions

Interactive comment on "Aerosol liquid water content in the moist southern West African monsoon layer and its radiative impact" *by* Konrad Deetz et al.

Konrad Deetz et al.

konrad.deetz@kit.edu

Received and published: 4 August 2018

Answer to Referee #2a Konrad Deetz 25 July 2018

Dear Referee (Atmospheric Chemistry and Physics),

thank you for your report from 10 July 2018. We have accounted for the comments and suggestions in the revised manuscript version. Please find our replies (marked with #) to the individual comments in the following.

Sincerely, Konrad Deetz on behalf of all coauthors

Referee comments: (0) Water uptake onto aerosol may increase the size of the aerosol

population as well as their impact on global radiative budget. However, the models used nowadays do not take this effect in account properly. This study is based on simulations results to evaluate the impact of Aerosol Liquid Water Content (ALWC) on shortwave and longwave radiations over Southern West Africa. The authors try to estimate the effect of cloud presence, aerosol size and dynamical processes on ALWC. The manuscript is well written and definitely within the scopus of ACP. Therefore I recommend publishing this work after the authors address the following comments.

(1) There are a lot of figures in this paper and I felt like most of them were not correctly described in the text. Indeed, each line drawn on a plot deserves at least a small explanation otherwise there is no need to plot it.

The figures are necessary to transport our findings to the reader. The number of figures increased because we actively decided to repeat some of the pivotal figures also for the time period 6-7 July 2016 in the appendix (in addition to our main focus 2-3 July 2016). This is done to support our findings, making them more robust within our limited capacity to run further computationally expensive model realizations. We think that all figures are described in detail. If you have the feeling that a figure is not correctly described please indicate which passage has to be revised.

(2) This kind of study is highly dependent on RH fields. In this manuscript, only profiles observed on July 2, 3, 5 and 6 2016 were compared to simulations results at two different locations (Lamto and Abidjan). Could you compare horizontal RH fields over West Africa for both periods?

We agree, RH is the predominant factor for ALWC. We are convinced RH profiles from soundings are appropriate to evaluate the modeled RH. Radiosounding is one of the most accurate measurement techniques for quantifying RH. Horizontal fields of observed RH are not available from DACCIWA observations. Also remote sensing does not provide horizontal RH fields but statements about the total column water. However, remote sensing is extremely limited over SWA due to the frequent cloud cover.

(3) Could you add more explanation about the dynamics of the Atlantic inflow? Indeed, sea breeze could be comparable to the Atlantic inflow but the occurrence time is not exactly the same. The AI front is moving inland during the night, which is quite unusual. During the night the ground temperature is getting colder in comparison to sea surface temperature. Therefore, I would rather imagine a land breeze. In few words, what is dynamically explaining this inflow?

We suggest, the two counteracting effects "pressure difference" and "turbulence difference" determine the AI front and its propagation. During day the land is subject to stronger heating than the Gulf of Guinea, leading to stronger turbulence over land. The turbulence mixes the horizontal momentum of the monsoon flow vertically, impeding the monsoon flow and establishing a frontal structure near the coast. In the evening, the turbulence over land decreases allowing the pressure difference (pressure gradient in direction land-sea) to overcome the effects from turbulence. The front starts to penetrate inland, transporting the post-frontal air characteristics (cool air, low-level jet) inland. Therefore during night the monsoon flow (directed from ocean to land) overcompensates the land breeze that we would expect in the classical land-sea breeze concept. Please also refer to our companion paper in which we describe the mechanisms of AI in detail: Deetz, K., Vogel, H., Knippertz, P., Adler, B., Taylor, J., Coe, H., Bower, K., Haslett, S., Flynn, M., Dorsey, J., Crawford, I., Kottmeier, C., and Vogel, B.: Numerical simulations of aerosol radiative effects and their impact on clouds and atmospheric dynamics over southern West Africa, Atmos. Chem. Phys., 18, 9767–9788, 2018. https://www.atmos-chem-phys.net/18/9767/2018/acp-18-9767-2018.pdf

(4) P7 L 15-24 : (a) The Aerosol Inflow involves an increase of RH a decrease of temperature but also brings different types of aerosols inland. You discuss the meteorological conditions that have for sure an influence on the ALWC but you never suggest that aerosol components may also have an impact. (b) Section 3.3 (Impact of aerosol modes): First, you should details the different types of aerosols that are predominant during each phase and the mean size distribution associated with each phase. (c) Do

you separate the aerosol modes in term of chemistry within your model? (d) It seems, according to P8 L25, that coarse mode is only made of sea salt particles. (e) How do you take into account dust then? (f) The comparison with chinese field campaigns need to be clarified. Are the different types of aerosols similar in China and Africa? (g) Did Chen et al. (2012) performed their measurements during the monsoon period?

We have separated this remark in subsections (a)-(g): (a) In a draft version of our manuscript we have had a further subsection that dealed with the effect of the aerosol composition on ALWC during the diurnal evolution. In fact, ACC is dominating in all three phases. In Phase 2 the ALWC contribution from ACC increases because the RH increases. The ALWC contribution from sea salt is generally higher during daytime (although more sea salt is transported inland during night). This is because sea salt also takes up water at RHs that are significantly below 95 % (daytime drying) which is not the case for the submicron particles within ISORROPIA II. Therefore during daytime sea salt has strongest contributions to the total ALWC. Although, the analysis of these aspects are interesting we decided to exclude it from this study for two reasons: - The discussion of the aerosol composition impact on ALWC is strongly dependent on how it is parameterized in the model. E.g. for sea salt we use the parameterization of Lundgren et al. (2013) which can lead to significant different results when using another parameterization. - Furthermore, the analysis of these aspects distract from the actual goal of this study. We wanted to find a relationship between the ALWC and its impact on the radiative transfer in shortwave and longwave. Section 3 is meant as a rather short transfer part that leads the reader to the core topic assessed in Section 4. Additionally it has to be considered that the ISORROPIA is based on the equilibrium solution. This works well in general but can also lead to substantial deviations. Water is a component of this equilibrium and therefore we cannot separately assess the impact of specific aerosol components on the ALWC.

(b) The manuscript points out that ACC is dominating in all Phases. In Figure E1 we now have added (in addition to the aerosol diameter) the aerosol number concentration of the different modes (Review-figure-1).

(c) The aerosol treatment in COSMO-ART is described in detail in Vogel et al. (2009). All aerosol species in COSMO-ART (except of pollen and volcanic ash, which are not considered in this study) are allocated to lognormal aerosol modes. But of course the aerosols undergo aerosol chemistry (e.g. deposition of sulfuric acid on soot particles).

(d) No, COSMO-ART considers sea salt, mineral dust and coarse mode anthropogenic particles in the coarse mode. But with respect to ALWC, only sea salt is relevant within the coarse mode. Therefore this study focuses on sea salt in COARSE.

(e) Mineral dust is treated as chemical inert in COSMO-ART. Of course this is a shortcoming, because aged mineral dust in the atmosphere can also be subject to ALWC or other chemical reactions. These effects are not considered in COSMO-ART. It has to be considered that in the research period 2-3 July/ 6-7 July mineral dust plays no role in the monsoon layer.

(f) This aspect refers to a remark that came up already in the first review. Therefore I copy my thoughts and the revision at this place: When focusing on the study of Bian et al. (2014), the observations are related to the time period July-August 2009 and focusing on the chinese provinces Shandong, Hebei, Pekin and Tianjin. The climate in this area is in between humid subtropical and humid continental Summers are hot and rainy with temperatures around 24-28 °C in July with the precipitation maximum in summer via influences from the monsoon. A qualitative analysis of Terra Modis satellite images (of course only one overfly per day) revealed that in the 62 d period of July-August 2009 Shandon was fully covered by clouds on 55 d and partly covered by clouds on 7 days. Therefore the weather conditions during the DACCIWA campaign and HaChi campaign are very similar. Both studies focus on the NH summer. Both areas are located in the NH summer monsoon area with high temperatures and are very frequent covered by clouds. The measurement site for the study of Bian et al. (2014) is Wuqing. For this location, Liu et al. (2011) [Figure 3] shows measurements

of temperature and relative humidity for July-August 2009. Temperature variations are between 20 °C and 32 °C. Relative humidity variations are between 40 % (mostly 60%) and 95 %. The latter is similar to what is modeled for southern West Africa (Fig. 3 in our manuscript) and to what was observed in southern West Africa at Save supersite (Kalthoff et al., 2018, Fig. 3).

Wuqing is about 90 km away from the Gulf of Bohai. So also HaChi focuses on the area near the coast. Wuqing is surrounded by large cities (Peking (80 km away, 21.5 million inhabitants, megacity), Langfang (30 km away, 4.4 million inhabitants), Tianjin (40 km away, 15.5 million inhabitants, megacity), Tangshan (100 km away, 7.6 million inhabitants)). Also southern West Africa has several large cities especially near the coast. However, the populations are generally smaller but on the same order of magnitude (Lagos: 13.7 million inhabitants, Abidjan: 5 million inhabitants). Based on MODIS observations, Bian et al. (2014) show that the averaged AOD values are generally above 0.6 in the research area and 0.7 above Wuqing. For the DACCIWA region we found averaged MODIS AOD values of 0.4-0.7, slightly smaller to what was observed in the HaChi region. However, the validity over land is limited because southern West Africa is virtually always covered by clouds, restricting the observations to a few days.

Based on these findings we came to the conclusion that the general meteorological and aerosol conditions are similar for HaChi and DACCIWA and therefore allow a qualitative comparison e.g. of the ALWC values between both sites.

We added the following passage in the conclusions to account for your remark: "HaChi and DACCIWA both focus on the northern hemispheric monsoon season, capture coastal areas that are frequently covered by clouds, have similar temperature and relative humidity conditions (Liu et al., 2011; Kalthoff et al., 2018) as well as similar aerosol loadings (Bian et al. (2014); Deetz et al. (2018a), allowing for a qualitative comparison of modeled ALWC with measurements during HaChi."

(g) The study of Chen et al. (2012) mainly focus on January 2010 so not on the monsoon period in contrast to Bian et al. (2012) and Liu et al. (2011).

(5) P10 Section 4.2 : In this section, you are using 3 different figures to describe the effect of ALWC on the shortwave, longwave radiations and 2-m temperature. (a) However, I felt like I did not have any explanations on what you observed. As an example, L16-18 'a decrease in SSR can be observed when considering ALWC for ICA and OCA'. Could you explain why you have the same order of magnitude for OCA and ICA (where the RH should be higher)? (b) 'A change in the cloud cover' âGËŸ Š the cloud is disappearing or strengthening? These are examples, but the entire section is written the same way. (c) According to your conclusions it seems that the cloud presence doesn't affect much the effect of ALWC on radiation. Could you provide anywhere in your manuscript the meteorological and aerosol size distribution differences between OCA and ICA?

We have separated this remark in subsections (a)-(c): (a) We have applied two model realizations, one is the reference run in which the ALWC is considered in the radiative transfer calculations and the other run is the experiment ("No-ALWC") in which the ALWC is neglected in the radiative transfer. As expected, the incomins surface shortwave radiation (SSR) decreases when we consider ALWC in the radiative transfer. The median reduction is -28 W m-2 for the in-cloud area (ICA) and -15 W m-2 outside of clouds. As expected the reduction is higher in clouds because there the RH is higher and therefore the ALWC increases compared to areas outside of clouds. For ICA the reduction is twice as high as for OCA. It has to be considered that the radiative transfer is a two-stream model (just up and down). The intensity of an incoming beam that passes a certain column is reduced in case of ICA by the ALWC in clouds but also by the ALWC below and above the clouds. In case of OCA the light intensity is reduced only by ALWC outside of clouds in the total column. (I) Even in OCA the RH can reach very high values near 100 % and (II) in ICA the clouds mostly will span only a very small fraction of the total vertical column. (III) Most of the path in OCA AND ICA will be cloud free. The aspects (I-III) let deduce that the ALWC surplus from cloudy regions

can be high but nevertheless the difference in SSR between ICA and OCA will not be extraordinary high.

(b) We revised the corresponding sentence in the manuscript: "The positive values north of 8 âŮę N in Phase 3 are related to a change in cloud cover (more clouds in Reference), which is not a general feature." If you have detect further imprecise statements, please specify.

(c) Figure E1 (see Review-figure-1) now shows the median aerosol number density for the separate modes on 3 July 2016 6 UTC in the lowest 1500m AGL. Furthermore, Review-figure-2 shows boxplots of the wet diameters for areas with a cloud water greater than zero (in clouds, ICA) and for areas with a cloud water equal zero (off clouds, OCA) also on 3 July 2016 6 UTC in the lowest 1500m AGL. For this time the meteorology (differences in temperature and RH) looks as follows: see Table presented in Review-figure-4.

Review-figure-2 is added in the manuscript as Figure E2 and we added the following passage in the end of Section 4.1: "For Reference on 3 July 6 UTC, Figure E2 shows the median wet diameter separated in ICA and OCA for the lowest 1500 m AGL over Ivory Coast, highlighting the effect that submicron particles (Fig. E2a) need a RH near 100 % to significantly grow, whereas sea salt (Fig. E2b) already shows a growth due to ALWC at lower RH values. The median temperature for ICA (OCA) is 20.9°C (21.7°C) and the median RH for ICA (OCA) is 99.9% (93.2%)."

Minor comments : (6) Page 2 L10 : replace natrium by sodium

We have changed the manuscript accordingly.

(7) Page 3 L14-16 : I'm not sure I understand this sentence. You claim : " The RH increasingly affects the relationship between the amount of aerosol and the cloud droplet number concentration". I believe that larger RH could involve more or larger cloud droplets. These results are not from 2015: : :

We removed this passage and the citation because this is less relevant as you have described.

(8) Page 3 L28 : I believe that there were no GF measured during AMMA.

We have corrected the citation.

(9) P5 L4 : Could 5% of the mass concentration of soot particle be defined considerable ?

We have rephrased this sentence.

(10) P5 L16-17 : 'Furthermore, : : : process studies'. I do not understand this sentence. The undisturbed moosoon condition favor NLLS presence? Also, NLLS is not defined in the acronym list.

We removed the "and" in the corresponding sentence. Yes, undisturbed monsoon conditions favor the process studies, because then the conditions are very similar from day to day, making a short simulation period qualitatively respresentative for longer time periods. Undisturbed monsoon conditions also favor NLLS presence because e.g. the passage of an MCS can disturbe the NLLJ and with that the evolution of NLLS. We added NLLS in the acronym list.

(11) P5 L28 : please remove 'by a a decrease'

We have changed the manuscript accordingly.

(12) P9 section 3.4 : Is this AOD within cloud ? Are you talking about interstitial aerosols? Then the clouds are just considered as a vector for RH increase? There are numerous studies that have shown the contribution of the ALWC to the total AOD (Brock et al., 2015 and 2016; Crumeyrolle et al., 2014; Beyersdorf et al., 2016; Orozco et al. 2016; Eck et al. 2014).

Yes, we consider clouds as areas where the RH maximizes. And here we don't focus on cloud optical thickness but on the radiative effects that come from the ALWC. Yes,

you can term it interstitial aerosol. It is right that this effect was already analyzed in several former studies. Nevertheless, the topic is still relevant. The weather forecast model COSMO (not the research model COSMO-ART) still does not consider this effect when calculating the radiative transfer. This study is also meant as a motivation for the model developer to consider these effects, especially when they do forecasts in moist tropical regions. We have not stated that our finding about the strong impact of ALWC on AOD is completely new. We just higlighted this finding as a step towards the subsequent analysis of the ALWC - radiation relationship. But we added the following passage in the introduction to consider your remark: "Several studies analyzed the implication of ALWC to AOD (e.g. Brock et al. 2016, Beyersdorf et al. 2016). Brock et al. (2016) combine aircraft observations with a simple model to analyze the sensitivity of the AOD towards meteorological and aerosol properties in the southeastern United States. The results indicate highest (lowest) sensitivities towards RH (dry and wet aerosol refractive index)."

(13) P12 L22 : please remove 'The' : 'on THE one hand'

"On the one hand ... on the other hand ..." is a fixed term. Please specify if we misunderstood your remark.

(14) P13 L3 : please replace 'AI affected' - 'AI affects'

We have changed the manuscript accordingly.

(15a) Figure 4 : I'm sure this is a typo : ' same ass '

We have changed the manuscript accordingly.

(15b) Relative ALWC should be a proxy for the hygroscopicity of aerosols right ? If yes then it needs to be stated somewhere. And you should present mean aerosol size distribution before this figure for the different phases.

We added the following sentence in the introduction: "The relative ALWC can be seen as a proxy for the hygroscopiciy of an aerosol species." Figure D1 shows the median

mass concentration of the single aerosol species, Figure E1 (Review-figure-1) presents the median number concentration as well as dry and wet diameters. Furthermore figure E2 (Review-figure-2) is added to separate the analysis of dry and wet diameters to ICA and OCA. We disagree that a further analysis of the aerosol size distribution, now separated in the three AI phases, is appropriate. Adding more and more figures will distract the reader from the main outcomes and also contradicts your remark (1).

(16) Figure 5 : You should add on the different figures ‘TOTAL’ , ‘AIT’, ‘ACC’ and ‘COARSE’

We have adapted the figure accordingly.

(17) Figure 6 : Could you add the RH on this figure ?

We have adapted the figure accordingly (see Review-figure-3).

(18) Figure 9/10/11 : Could you add on the figure ICA and OCA . I’m sure that will also be clearer if there is REF and REF-No_ALWC

We have adapted the figure accordingly.

Interactive comment on Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2018-420, 2018.

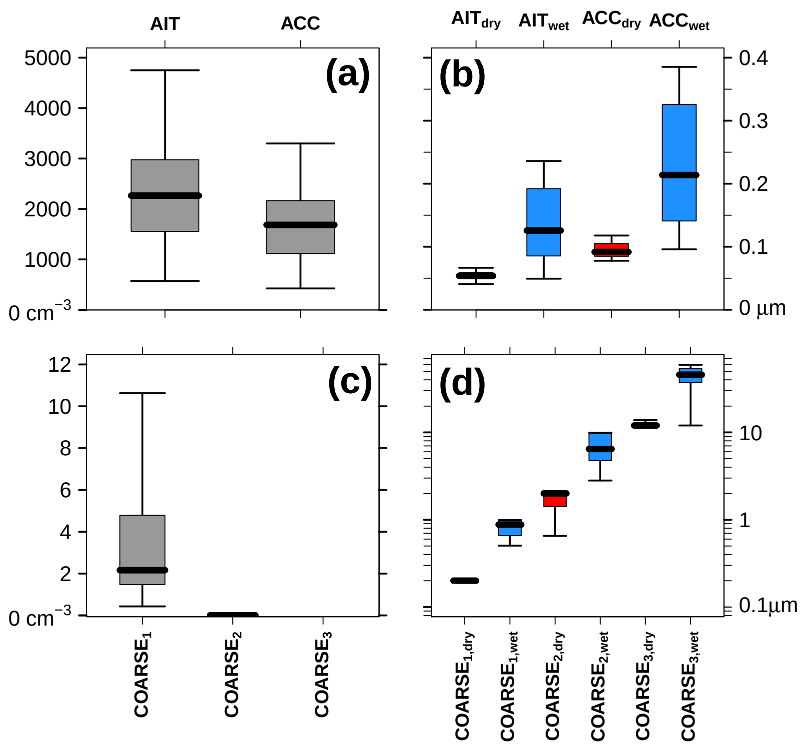

Fig. 1. Boxplots of (a) aerosol number density (cm-3) and (b) dry (red) and wet (blue) aerosol diameters (um) for AIT and ACC and boxplots of (c) aerosol number density (cm-3) and (d) dry and wet diameter.

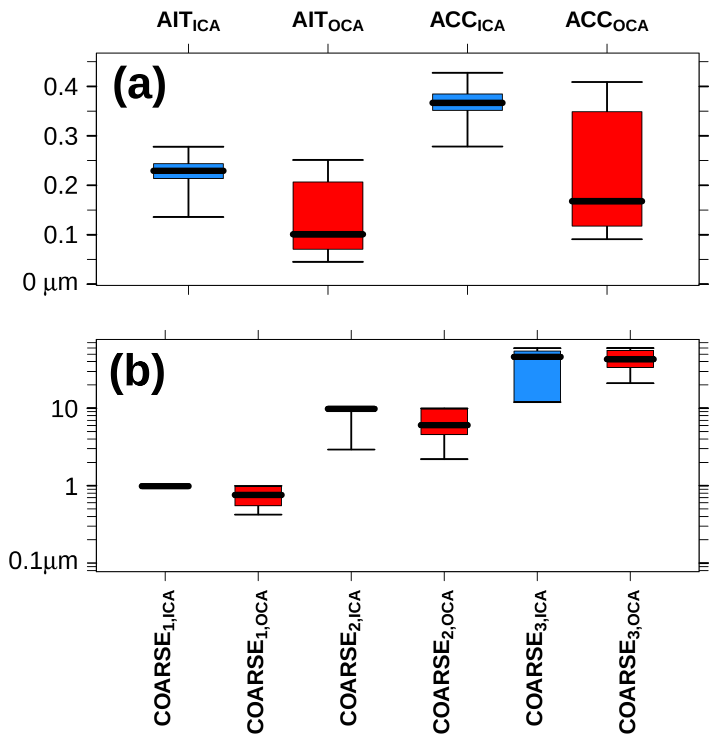

Fig. 2. Boxplots of aerosol wet diameters (um) for (a) AIT and ACC and (b) COARSE, splitted in the three COSMO-ART sea salt modes as median in the lowest 1500 m AGL on 3 July, 6 UTC by separating in ICA/OCA.

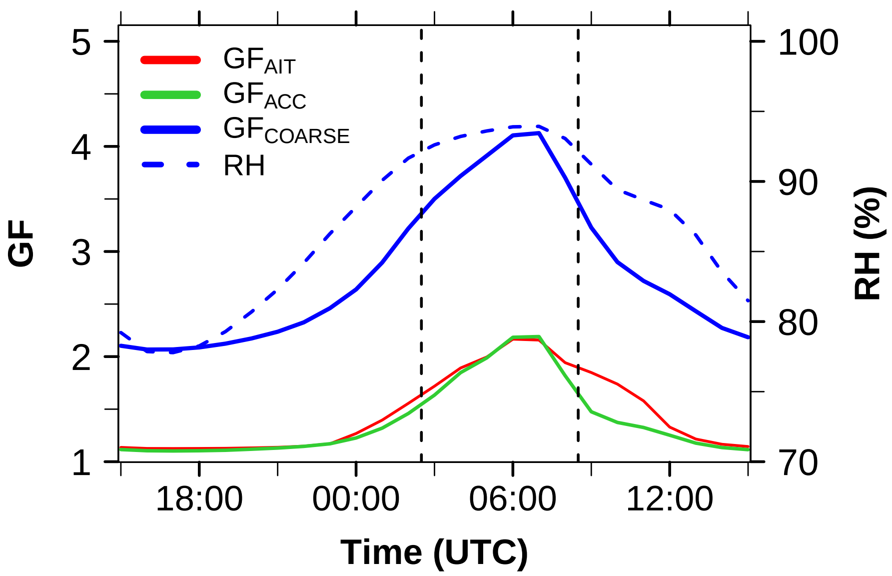

Fig. 3. Diurnal cycle of the median GF (%) of GF_AIT (red), GF_ACC (green), GF_COARSE (blue) and RH (%) (blue dashed) in the lowest 1500 m AGL over Ivory Coast (7.5° W–3° W, 4–10° N) on 2-3 July.

	in clouds		off clouds	
Temperature °C (median and standard deviation)	20.9	2.0	21.7	2.3
RH % (median and standard deviation)	99.99	1.4	93.2	4.9

Fig. 4. Table summarizing the meteorological conditions on 3 July 2016 6 UTC for "in clouds" (ICA) and "off clouds" (OCA) in the lowest 1500m AGL.