

Interactive comment on “A possible role of ground-based microorganisms on cloud formation in the atmosphere” by S. Ekström et al.

S. Ekström et al.

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We thank both reviewers for their constructive comments and for their suggestions to improve this manuscript. Our replies are below and we have prepared a revised version of the manuscript that takes into account all these comments. The manuscript has also been re-written to generally improve clarity. We hope that these replies and the modifications are satisfactory. Below, we have also added a small note concerning some information on the surface tension measurements, which had been forgotten in the previous version of the manuscript but that we would like to add in the final version.

Reply to Reviewer 1:

1. The limited role of the microorganisms themselves as CCN mentioned in the in-

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roduction was actually referring to their size ($> 1 \mu\text{m}$), rather than their weight, and to the fact that large particles are not usually considered as efficient CCN. But since these aspects are indeed debated it is better to refer to articles discussing them, as suggested by Reviewer 1 (and we thank Reviewer 1 for suggesting several references). This sentence has been modified to be more neutral and refers now to Moehler et al., [2007], discussing in detail the role microorganisms on cloud droplet formation. The main point of this sentence was that molecules can be present in sub-micron particles, the usual size range for CCN, while this is more difficult for complete organisms. Since the submission of this manuscript we have also obtained very low surface tension values with PM1 samples, supporting the presence of biosurfactants in sub-micron particles.

2. The reference Charlson et al., [2001], discussing the role of organic compounds as surfactants for cloud formation, has been added to the manuscript (and we thank Reviewer 1 for pointing it out). This comment drew our attention on two aspects of our results that might be worth emphasizing in the text (abstract and conclusion): first, that the surface tensions reported in this work for aerosol samples ($\approx 30 \text{ mN/m}$) are, to our knowledge, the lowest ever reported for aerosols (mostly because we improved the extraction technique – see also the technical note below). Second, that previous model studies of the role of organic compounds on cloud droplet formation did not expect any organic compound to have such dramatic effect on the surface tension of aerosols ($\Delta\sigma/\sigma > 58\%$). The potential effect of biosurfactants on cloud formation can thus not be deducted from any previous model calculations and remains to be studied. These points are now mentioned in the discussion/conclusion.

3. This sentence has been re-written for clarity. The two rhamnolipid samples were both obtained from different strains of bacteria and extracted by different methods.

4. We thank Reviewer 1 for mentioning this reference and the microgel. Actually, microgels have very different molecular structures from the hydrophilic end/hydrophobic chain illustrated in this work. It is therefore difficult to predict their surfactant properties

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based on our results. As they are microbial secretions, they are likely to carry some biosurfactants, which might give them some surface active properties. However, as these compounds are very different from those studied here, we prefer to leave this discussion for future papers.

Reply to Reviewer 2:

1. Typos and mistakes have been corrected, and the text has been somewhat re-written to improve clarity.
2. To keep the abstract short, the term “CCN” has been removed from the abstract and is introduced only later in the introduction.
3. p. 10040. This part has been re-written to explain more clearly that the curves are obtained from the main extracts and series of their subsequent dilutions.
4. A legend has been added to Figure 2.
5. Empty symbols have been used for the aerosols extracts in Figure 3, to clearly distinguish from the curves for standards compounds.
6. We have now developed this part of the discussion a little, as the ability of these substances to transfer into aerosols while the microorganisms would stay at the surface of the Earth is an important argument here. Biosurfactants are not only present at the surface of microorganisms, but can also be mixed with other non-living primary material at the surface of the Earth, such as sugars, amino acids, and plant waxes. All these materials have been found in PM1 or PM2.5 aerosol particles (we have added some references), and the biosurfactants could be transported with them into aerosols, even if the exact transfer processes above continents are unclear. For marine aerosols, bubble bursting and wave breaking are the processes responsible for these transfers and have been shown to produce sub-micron particles.
7. This statement has been modified throughout the manuscript to be more cautious.

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Other note:

It has come to our attention that some information on the surface tension measurements had been forgotten in the previous version of the manuscript, but would be relevant to mention in the final version. Section 2.3 of the manuscript presents the technique developed in this work to extract the amphiphilic fraction of aerosols: a first fraction is extracted from the filter samples in water, and an absorbent is then added to extract the amphiphilic fraction from this water extract. To control the efficiency of this second step and its specificity to surfactants, the surface tension of some of the water extracts were measured before and after the second extraction. In all cases, the surface tension of the water extract increased back to the value for pure water after the second extraction, confirming that this second step had removed all the compounds responsible for the surface tension effects from these mixtures. For instance, with samples from the Amazonian forest, the first water extract from the filters had a surface tension of 53.1 mN/m. After extraction with the absorbent, this value increased back to 71.6 mN/m, which is, within uncertainties, the value for pure water. With the samples from Hyytiälä, Finland, the first water extract had a surface tension of 59.6 mN/m, but increased to 71 mN/m after the second step. This information has now been added to section 2.5 “Surface tension measurements”.

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