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**Editorial**

# Are Microbes in the Atmosphere Enough to Affect Cloud Processes and Climate?

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Microbes can be found in the air surviving and thriving in the extremes of cold, oxidants, irradiation and desiccation. Indeed, bacteria and fungi have been detected in various atmospheric layers, such as the boundary layer (up to 1.5 km altitude), the upper troposphere (up to 12 km altitude) and even the stratosphere at altitudes of 20 km and 41 km above the sea surface [1,2]. Due to their small size, microbes can be transported over long distances within or between continents, and thus are able to reach the most distant areas of the world. Despite their importance, the composition of microbial communities in the atmosphere is still not well described and thus our knowledge about the atmospheric microbial habitats is rather limited [3-6]. As a consequence, the potential interactions of air microbes in their chemical environment has been largely ignored and the current numerical climate models lack microbial components [7]. However, the presence of microorganisms in the atmosphere in the form of bioaerosols can have many meteorological and climatic implications through their impact on atmospheric physicochemical processes [8]. Bioaerosols as being a group of organic aerosols can be an important player in climatic processes, as they can interact with the solar and terrestrial irradiation by absorption and scattering processes [9]. In addition, bioaerosols can also be efficient cloud condensation nuclei (CCN), provided that their surfaces are wettable [10,11]. It has been suggested that the largest bioaerosols such as pollens grains may act as 'giant CCN', i.e. they may form cloud droplets at lower supersaturations than most other aerosol particles and quickly grow to large droplet sizes, thereby facilitating rain formation [12,13]. Interestingly, the most active ice nuclei discovered so far are of biological origin. Despite these findings, still remains debatable as to whether the concentration of microbes in the atmosphere is sufficient to affect cloud processes and climate.

The chemical reactions triggered by microbial cells can take place only in the cloud droplets but it is unclear if microbial cells concentration is high enough to justify an effect in cloud chemistry. A series of studies have shown that mean concentrations of microbes in ambient air can be greater than $1 \times 10^4$ cells $m^{-3}$ over land whereas over the sea may be lower by a factor of 100 - 1000 [14]. However, concentrations of microbes in cloud waters have been found to be much higher compared to ambient air, accounting about $1.5 - 2.5 \times 10^3$ cells $cm^{-3}$ (or $1.5-2.5 \times 10^9$ $m^{-3}$; [15]). Considering that clouds may contain up to 109 droplets m-3 [16], then it can be assumed that each droplet may roughly contain up to 1 - 3 microbial single cells and thus if microbial cells in clouds are active then their contribution to cloud water chemistry could not be ignored. DeLeon-Rodriguez., *et al*. (2013) demonstrated that live bacteria in cloudy air masses over the Caribbean Sea, represent an important and underestimated fraction of micrometer-sized atmospheric aerosols accounting on average around 20% of the total particles [17].

On a global scale the total number of microorganisms in clouds reaches about $10^{19}$ cells. Although this estimate seems low compared with the $10^{26}$ microorganisms estimated to occupy lakes and rivers and with the $10^{29}$ microorganisms reside in the oceans, microbial levels in clouds appear sufficient to affect physicochemical processes in the atmosphere. Additionally, clouds could play a major role in disseminating microbes over long distances. According to Amato., *et al*. (March 2012, Microbe magazine) "*clouds provide atmospheric oases for microbes and microbial cells in clouds are sufficiently plentiful to affect the atmosphere*". The microbes can make it into clouds, where they can begin the breakdown of organic compounds and they finally "rained" out of the clouds through wet deposition, further demonstrating their multiple roles in clouds and climatic processes (e.g. [18] and references therein). Thus, more research is needed to study these roles in order to include microbial components in atmospheric models.

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