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INFLUENCE OF BIOLOGICAL PARTICLES ON THE PRODUCTION OF CLOUDS IN TROPOSPHERIC CLOUDS OVER LAND MASS AND BODIES OF WATER

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ABSTRACT

Aerosol particles are largely made of natural materials, yet there is rising evidence that biological particles have a minimal, yet a significant part in its formation. There have been many studies that show the influence of biological molecules, including bacteria and pollen cells that can act as aerosols. These particles can then act as cloud condensing nuclei (CCN) or ice nuclei (IN), which form clouds. Numerous studies indicate that CCN and IN can form from biological particles which include, whole cells or even parts of the cell. Studies have also shown that there is a gene responsible for IN formation, which allow some cells to form IN. The cell size is also an important consideration because cells that are too large will grow too slowly, while those too small will grow quicker, but they will have a slower terminal velocity affecting the rate of precipitation. A brief consideration on human populated areas to desolate areas is provided as a base for comparison in CCN and IN formation, which ultimately influence climate. We note that biological particles form a measureable, yet insignificant part of CCN and IN.

INTRODUCTION

Research has shown aerosol particles to be imperative in cloud formation (Hoose, 2010). An aerosol particle is any particle that can act as either as a cloud condensation nuclei (CCN) or an ice nuclei (IN) (Möhler, 2007). Some examples of natural aerosols are haze, dust, sea salt, volcanic ash, etc (Hoose, 2010; Kolb, 2007). See figure 1 for an image of how these major contributors form aerosol particles.

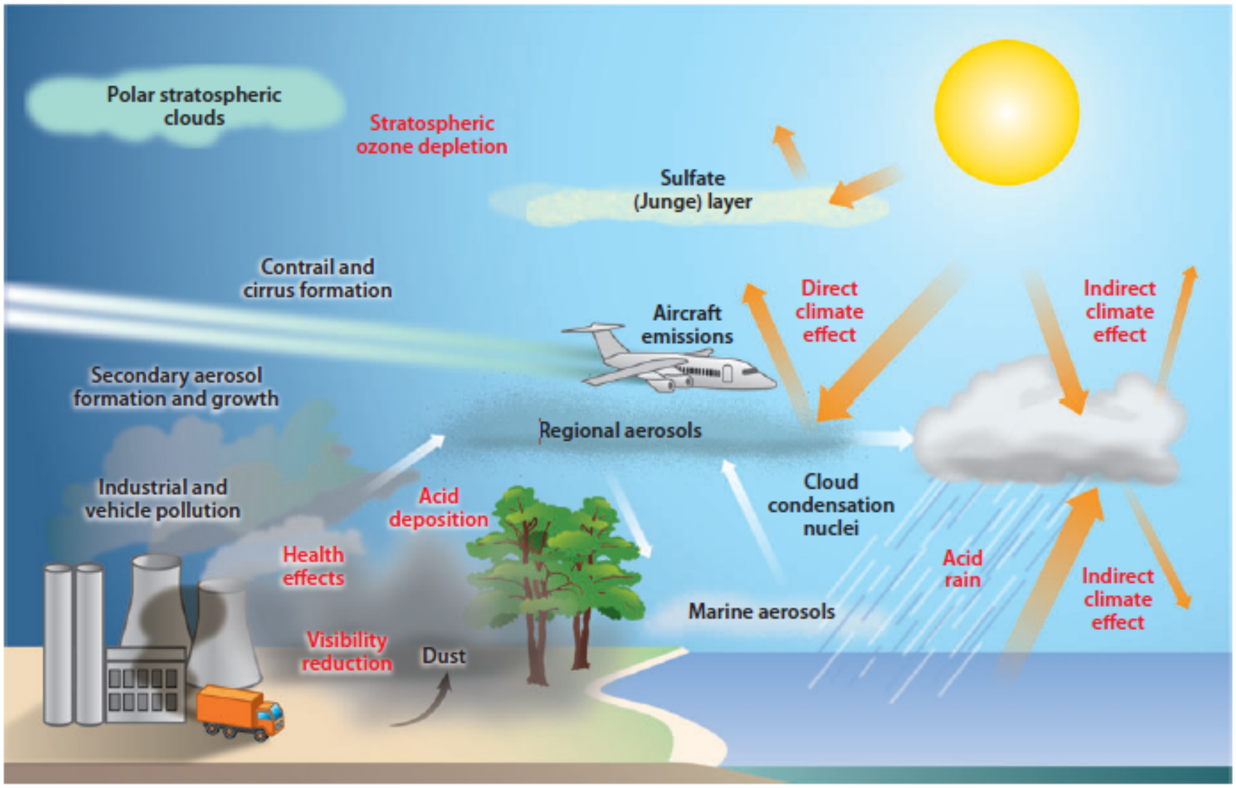

Figure 1: Major sources of aerosol particles. (Adapted from Kolb, 2007.)

All of these examples have one thing in common. They are all natural particles that have been formed by nature herself. Although, these aerosols make up the majority of all particles in the air, other particles can act as aerosol particles. Here, we examine these particles, to what extent they can serve as good aerosols, and whether we can identify and control another contributor, which makes up a small portion of all aerosols.

Before the other contributor is identified, a close examination on what constitutes a cloud aerosol is provided. Things to consider are size, shape, and chemical composition. By identifying similarities among the natural aerosol particles, we can deduce other particles that may be good aerosols. In the list above, the particles contain textures that range from fine to course, while the size ranges from 10^{-9}-10^{-4}m (Figure 2).

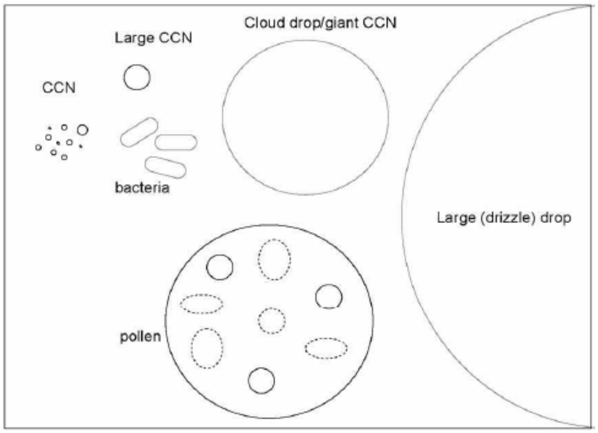

Figure 2. This figure shows the relative sizes of CCN, pollen, bacteria, and a drizzle drop, but a scale indicating exact size is not included. (Adapted from Möhler, 2010.)

The chemical composition differs from one to the next, but they can be holistically observed as particles that can form sulfates and salts. Both of these exhibit properties that allow water molecules to bind to their surface (Pöschl, 2005). As an increasing number of water molecules bind to a surface, the particle can become a CCN, which can become a raindrop in the end. With this in mind, biological matter can also serve as aerosols. Since bacteria and virus are extremely small biological particles, they fit the size requirement to be an aerosol. They also have the chemical composition necessary to potentially be a good aerosol.

Some commonly cited examples of biological particles that serve as aerosols are plant materials such as pollen, or microorganisms such as viruses and bacteria (*Erwinia carotovora* and *Pseudomonas syringae*) (Hoose, 2010; Möhler, 2007). *Pseudomonas syringae* are found on plant matter. We must modify Figure 1 to reflect this addition of particulate matter; and Figure 3 captures this change. As cells, bacteria possess a cell membrane and cell wall, which are coated in ionic particles onto which water molecules can bind, and attract other water molecules. This process is known as coalescence. Although it sounds simple, it is deceivingly complex.

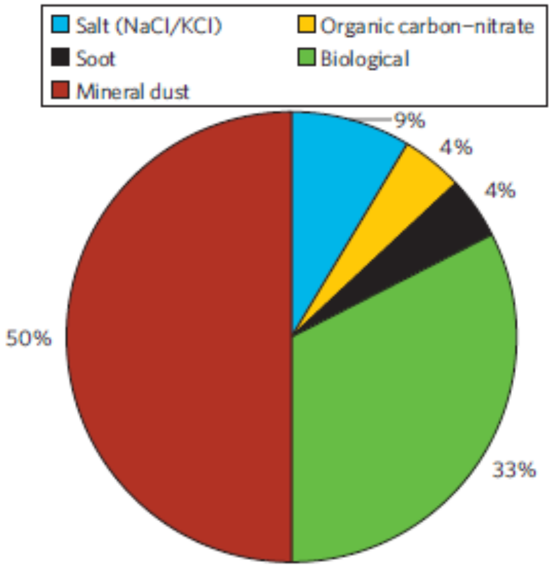

Figure 2: Here the pie graph illustrates the composition of salt, soot, mineral dust, biological constituents, and organic carbon-nitrates that can potentially make up CCN. (Adapted from Pratt, 2009).

Aerosol particles need to meet certain criteria: they need a surface unto which a phase change from vapor to water can occur, the ability to accelerate the coalescence of large particles, and the phase change from vapor to liquid to ice. Another requirement for condensation of water vapor occurs only when the relative humidity is greater than the saturation pressure (Möhler, 2007). A thermodynamic factor influencing cloud formation is Raoult's law. This law indicates that the relative humidity will decrease when other solute molecules are dissolved on the exterior of the particle (Möhler, 2007).

A living cell can affect the relative humidity in several ways. One, since it is covered in salts and ions, the amount of water that would have to condense on its surface is far greater than that would be required for other natural particles. However, let us assume that the cell does not have a large amount of salt concentration, so it would exhibit a similar affinity for the water molecules some of the natural particles. Two, a living cell would have processes that enable it to absorb water into it from an area of high water concentration to an area of lower water concentration by a process known as osmosis, thereby preventing any noticeable condensation on the cell. However, let us assume that the cell is completely saturated in liquid water. Three, if water vapor begins to condense on the cell surface, the cell will respond by excreting solute materials to balance the water concentration inside to outside of the cell; by application of Raoult's law, this will be make it increasingly challenging to raise the relative humidity high enough for sufficient water molecules to condense on its surface. Nonetheless, let us assume that the cell has excreted most of the unnecessary solute particles and brought the inside and outside water concentration in equilibrium (Möhler, 2007).

This equilibrium balance is measured by a property called "wettable." If the aerosol particle is wettable, then it will serve as a CCN. The biological particle, like natural particles, will be carried from place to place and above sea level through wind currents generated by the weather. The particle must grow in size, which can be achieved by several methods. A few common methods include: diffusion of water vapor onto the already growing particle, and collision of two smaller particles to form a larger particle (Lamb, 2008).

Research indicates that there are only a few biological aerosol particles that allow for CCN. However, aside from this major drawback, there are many advantages of biological aerosol particles. Sometimes, they can be activated as CCN at a far lower saturation level than other particles.

DISCUSSION

When considering the properties of aerosols, it is important to consider the source of the particle. For instance, an inorganic particle may be of a certain size, which begins to condense water vapor at a certain temperature, and it could serve as an IN. However, a biological aerosol may be of a different size, which begins to condense water vapor at different temperature than the inorganic particle. Additionally, particles have been examined to determine their growth rate. Research indicates that particle growth is inversely related to its size. While this is difficult to understand logically, allow the following reasoning to be the explanation for this phenomenon. Outside forces that act on the particle, disrupt the stability of the particle causing it to break apart, thus limiting its size.

Since the size of the particle influences its growth, there is reason to speculate that biological particles of a certain size will be preferred to others. The size that is optimal for cloud physics will exhibit a higher probability of forming CCN and IN. Further research has also shown that the fall velocity of the particle is related to the size of the particle (Möhler, 2007). This makes perfect sense because the fall velocity (terminal velocity) of an object is a function of its size and mass (Pöschl, 2005) (Figure 4).

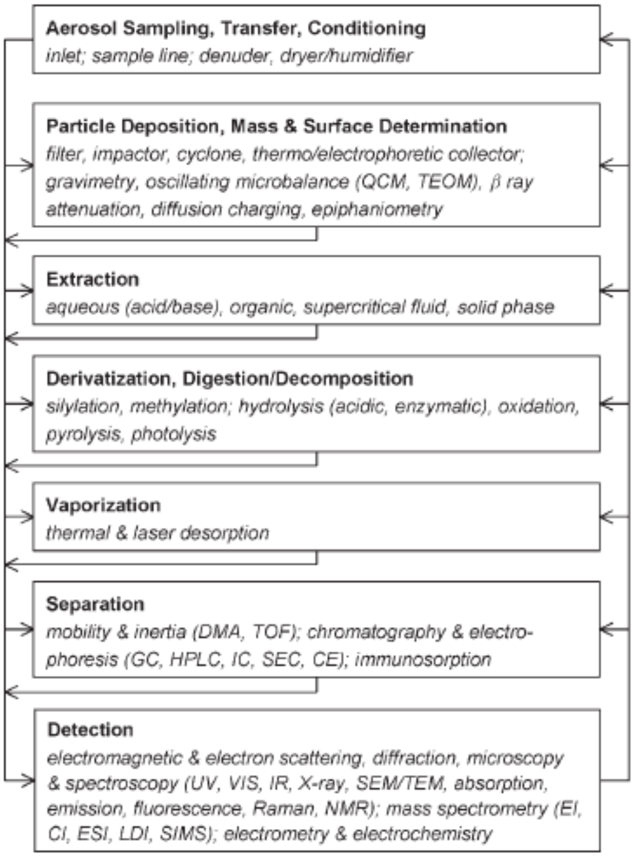

Figure 4: This image represents the tests and techniques used for characterizing aerosol particles. (Adapted from Pöschl, 2005).

Further research on the influence of biologically active particles showed that there is a relationship between a large amount IN and rich top soil resulting in high IN temperature. The implications of this study reveal that if the concentration can be maintained at a high level, then IN formation can be controlled resulting in a large amount of clouds. However, the research also shows that the IN is only found in decaying vegetation. Furthermore, the bacteria involved in the decay are specifically involved in the IN formation and not other bacteria.

Another research group performed a test that would more precisely determine the effects of biological particles on aerosol formation (Möhler, 2007). This group found that cells do not need to be active, nor do they need to be in their full shape. One way to test this is o freeze-dry cells and then pulverize them in a mortar and pestle. The latter steps allows for disruption of the cell wall breaking the cell up. Another method that can be utilized to break the cell wall of bacteria is sonication, as is frequently done to plant cells because of the presence of a cell wall (Möhler, 2007). Thereafter, the group used an airflow technology that allowed them to suspend the particles in air, thereby measuring the effects of the particles to form CCN or IN.

It was notices that not all particles would form CCN or IN, but only some. The number of cells that exhibit this ability was about 1 in 10,000. A group was able to trace the effects of the cells that showed the ability to form IN to a gene. The gene is not found most cells, but it can be transformed from one cell to another (Möhler, 2007). Now imagine if all of the cells in the air possessed this gene. The number of IN would increase by 10,000 fold resulting in a tremendous increase in clouds, leading a greater amount of precipitation. The amount of precipitation would affect the climate of a region because some areas are more densely populated than others.

Although studies show that genes contribute to the IN behavior, there are studies which show pollen can serve as IN sites. Pollen appears as a fine powder from plants, usually the gametes of the cell (Möhler 2007, Hoose, 2010). Several studies show that pollen can be used to form deposition, condensation, and immersion of water vapor onto itself. The major difference here is that pollen does not have genes that the bacterial cells have because pollen is not bacteria. Here, the main feature that allows nucleation is the surface of pollen. There several are differences between the two types of biological cells mentioned thus far; direct comparison of IN on bacteria to that on pollen cannot be made, but a comparison of the contact of nucleation to temperature of immersion can be made. The results consistently show that the contact of nucleation occurs at warmer temperatures. Just to briefly mention another biological contributor to CCN and IN, are fungal spores. They can be ranked with the bacteria, as they are another microbiological system (Pöschl, 2010).

Yet another study helps to display the effects of nucleation on clouds. The group found that IN is not the only factor in cloud formation, nor does it always result in a higher precipitation. This is an interesting result because it directly contradicts an earlier study where they found that a greater concentration of particles leads to a greater concentration in IN, which in turn leads to greater precipitation (rainfall). This confounding result, shows that there is not enough data to draw clear conclusions on the effects of biological particles on IN.

However, a couple of principles, help illustrate the concepts of cloud physics. First, the Bergeron-Findeison process describes the phase change of water to ice due to low pressure. This process draws on the fact that the mass of water in clouds decreases while the mass of ice increases. This process is favored, despite the fact that it opposes the third law of thermodynamic, since the entropy decreases when ice is formed, because of the low pressure surrounding the ice particles. Second, the Hallett-Mossop mechanism describes the secondary ice formation, which is due to the collision of ice particles (Pöschl, 2005; Möhler, 2007; Kroll, 2008). The importance of this mechanism is similar to that of the coalescence of water molecules. An interesting concept arises when one considers the effects of two particles of different constituents colliding to form one molecule. However, the leading question that arises is what kinds of molecules and particles collide to form one?

Using the mass spectrometer (MS) can help reveal their composition (Kroll, 2008). If a MS of cloud particles is obtained of both biological and dust particles, it becomes less clear about what their composition is and if there is actually uniqueness between the two types. It is true, MS breaks the molecules that enter it into fragments of the original sample, but molecules of protein and DNA have been observed by MS in the past, which are expected in the MS for the biological particles. Below, we see similar results of the two MS, suggesting that there is uniformity among all aerosol particles (Pratt, 2009) (Figure 5).

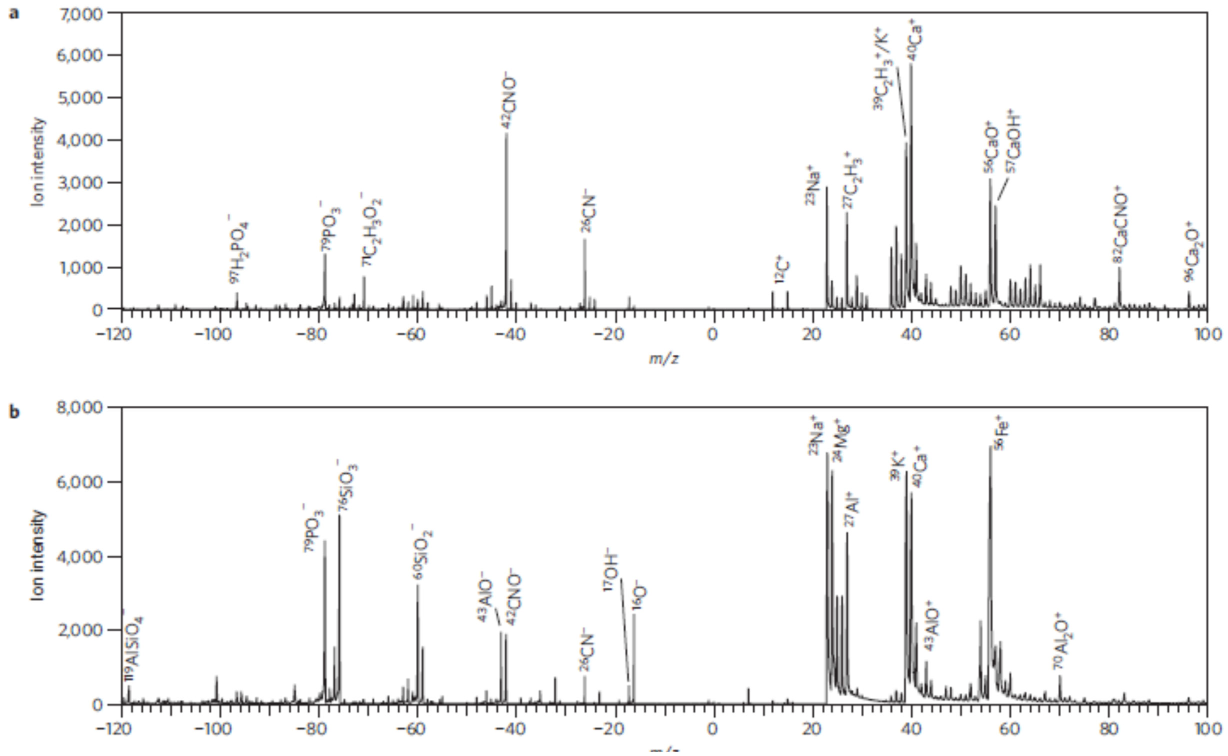

Figure 5: This mass spectrograph illustrates some of the constituents that make up aerosol particles.

CONCLUSION

Despite an abundance of research conducted to date, there is still a considerable amount of research that needs to be conducted. One group raised an interesting point: there are not any other candidates for IN aside from natural sources and biological sources. Other considerations that come from this study reveal possible mechanisms that may indicate ways that humans may be able to control the weather. For instance, taking the gene that allows IN to form on certain cells, and replicating that gene, followed by insertion into wild strains of the bacterium, *Pseudomonas syringae*. Other implications of this study may suggest that densely populated areas (urban areas) will not encounter as great an amount of precipitation as suburbia because there will be a greater number of bacteria due to the presence of more vegetation in suburban life.

With technological advancements and more research, the discrepancy about the extent to which biological particles influence the formation of aerosol particles and cloud formation and climate should be resolved. Monsoons, which are a part of the natural climate of the Indian subcontinent, cause heavy precipitation that are a result of aerosols (Niyogi, 2007). While climate is a broad term encompassing the weather in a region, a measure of aerosols and the amount of solar energy reaching Earth's surface are directly related (Satheesh, 2008). To many researchers dismay, there is a large amount of uncertainty associate with this measurement impeding successful research. Furthermore, researchers should be able to determine if there are ways in which we can manipulate the conditions and parameters surrounding aerosols, which would influence the weather. However, a strong consideration must be given to before we can fund research for trying to control weather and Mother Nature.

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