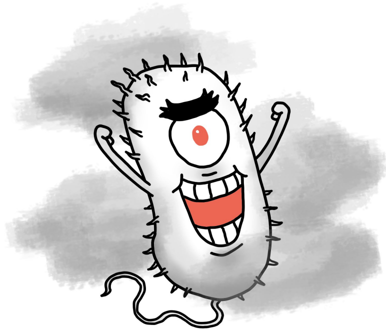
How much of an Arctic cloud comes from the ocean?

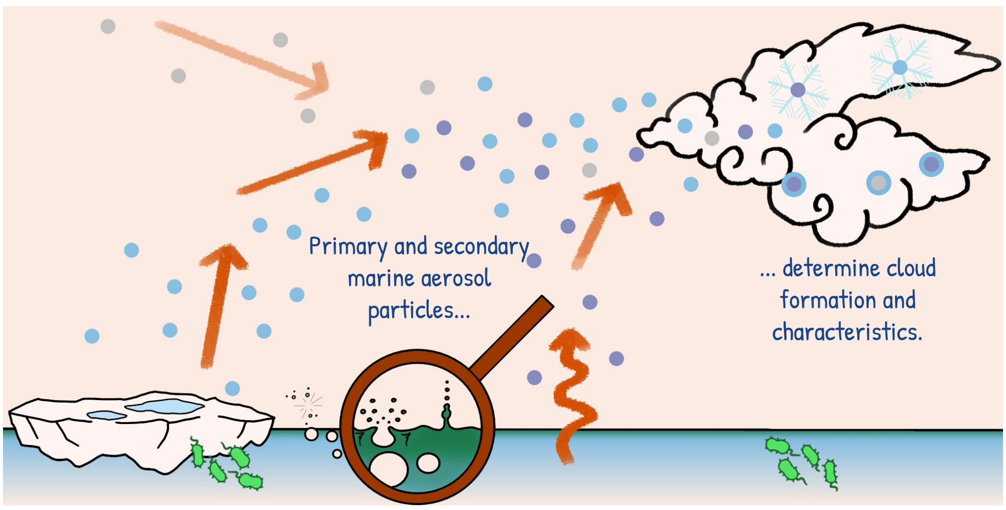


Water vapor rises from the sea, eventually condensing into droplets or ice crystals that form clouds. Yet, this process also requires tiny airborne particles—and the sea supplies many of them.

Clouds do not form from water vapor alone. Tiny airborne particles are needed as "seeds" on which water droplets or ice crystals can grow. In the atmosphere, such particles are called **aerosol particles**.

Water vapor condenses on them, which is why they are also called **cloud condensation nuclei**. Their effectiveness varies: larger and more hygroscopic particles generally promote cloud formation more efficiently[1,2].

You can observe this effect yourself on cold autumn or winter days, when your breath becomes visible as you exhale. The warm, moist air from your lungs cools rapidly and condenses on particles in the surrounding air. Near a campfire or an older vehicle with heavy exhaust, this "breath cloud" appears denser, whereas in a remote park it is fainter. There are fewer particles suspended in the air. Without them, neither the small cloud you see when breathing out in the cold nor the larger clouds in the sky could exist.



There are also special aerosol particles that cause water droplets to freeze into ice crystals, known as **ice nuclei**. They contain certain substances that enable water to freeze at temperatures slightly below 0°C. Without these substances, water can often remain liquid down to -38°C[3]. Although much remains unknown in this field, certain proteins, complex sugar compounds, and mineral dusts are considered important ice nuclei in the atmosphere[4].

But where do these important aerosol particles come from? Aerosols originate from many sources, including forest fires, shipping, and long-range air pollution. Although emissions of human origin now even reach high latitudes, the Arctic atmosphere is still relatively pristine. As a result, natural aerosol particles play a larger role in cloud formation. Beyond desert dust, the ocean surface is increasingly recognized as a relevant source[5]. And the Arctic has plenty of that.

Seawater contains 96.5% water, while the rest is primarily salts. Less than 0.01% comprises organic compounds, a diverse mix of dissolved and particulate substances. These include algae, bacteria, marine fungi, dead cell debris, as well as fats, carbohydrates, and proteins[6]. The uppermost layer of the sea, known as the **sea surface microlayer**, is particularly relevant to the atmosphere, as this is where biological substances accumulate[7]. During the summer and early autumn months, high concentrations of such substances with great potential to act as ice nuclei are found there, especially in the Arctic marginal ice zone and in melt ponds on the pack ice[8,9]. It remains unclear under which conditions, they are released from the sea ice.

Wind sets the sea surface in motion, and the combined action of breaking waves and bursting bubbles injects tiny droplets of seawater into the air.

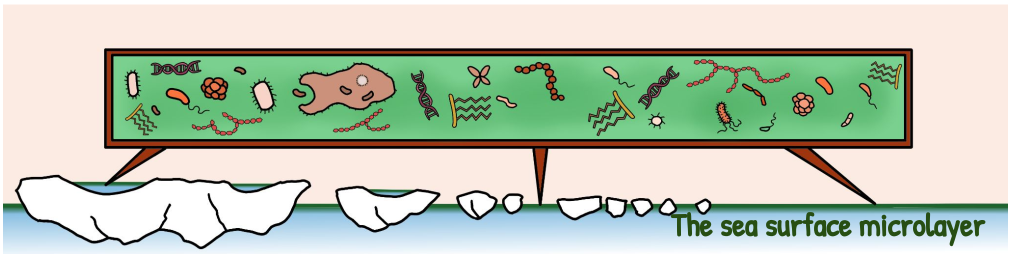
This **sea spray** contains all the chemical components of seawater and, when it dries, forms **primary marine aerosol particles** of various sizes[6,10]. Very large particles often fall back into the sea quickly, contributing little to atmospheric processes. Supermicron aerosol particles measuring 1 to 10 micrometers, about one-tenth the thickness of a human hair, consist mainly of sea salt. As particle size decreases, the proportion of organic substances (e.g., carbohydrates and proteins) increases until they dominate in particles smaller than one micrometer[11].

In addition, the sea also releases various gases, including sulfur and nitrogen compounds[12]. These gases are often produced during the decomposition of plants, animals, and microbes. Some of these marine microbes actively produce these gases as well.

These include dimethyl sulfide (DMS), which gives the sea its characteristic smell. Under the influence of light and atmospheric radicals (tiny, highly reactive molecules in the air that attack other compounds), they are oxidized into substances that form small liquid droplets or solids in the atmosphere, known as **secondary marine aerosol particles**[13].

Both these secondary particles and the salty primary marine aerosols are usually highly hygroscopic and act as efficient cloud condensation nuclei. In addition, some marine organic compounds can influence ice formation in clouds[4,14,15]. Together, they shape clouds and their properties worldwide, with particular strong impact in the Arctic.

Global warming is causing Arctic sea ice to shrink, expanding the area of open water[16]. This allows more marine aerosol particles, including chemically altered ones, to enter the atmosphere—with consequences for Arctic clouds that are still not fully understood.



In the clean Arctic atmosphere, every cloud seed counts, and marine particles have a notable effect. Their exact contribution is still under investigation. With the decline of sea ice, their influence on clouds and climate is likely to increase.

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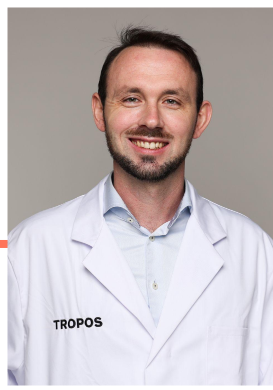

Funded by the Deutsche Forschungsgemeinschaft.

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