PRECIPITATION AND LIGHTNING

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Contents

Summary

Storms are responsible for dangerous high winds, precipitation, and lightning. In this article we review the major processes in the life cycles of storm clouds, focusing on the formation of precipitation and lightning. We then discuss some of the major midlatitude storm systems.

1. How Do Clouds Form?

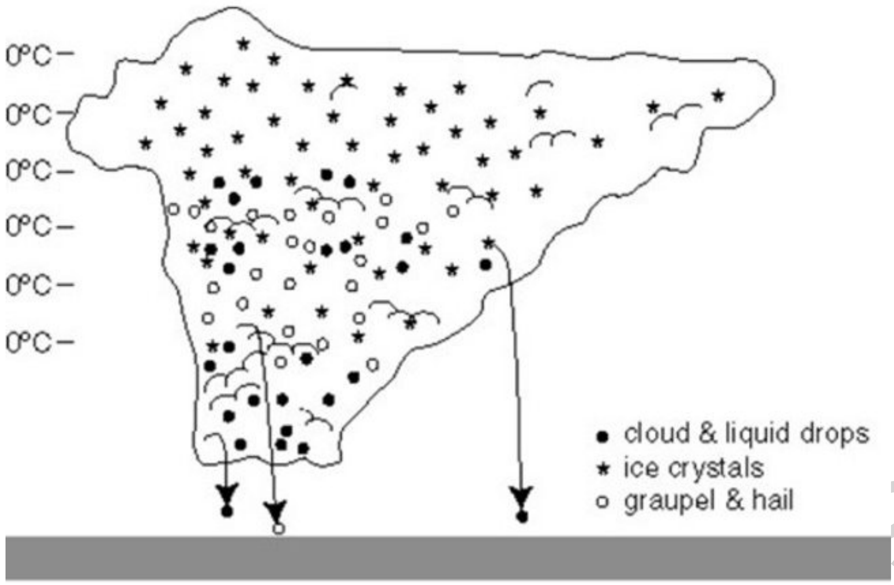

Figure 1. A schematic representation of the various kinds of hydrometeors within a cloud. Graupel and hail are irregularly shaped, as they are formed by collisions of supercooled drops and ice particles. The form (liquid or ice) of the precipitation at the ground depends not only on where it formed inside the cloud but also on the temperature and humidity of the clear air environment through which the precipitation particles fall. (From Baker 1999.)

Clouds form when moist air rises (as a result of mechanical lifting, convergence, or positive buoyancy). The rising air is subject to decreasing environmental pressure as it ascends, so it expands, cools, and the relative humidity in it rises. Figure 1 shows a schematic picture of a cloud that accents the various kinds of water and ice particles in it and their contributions to precipitation.

1.1 Warm Cloud Processes

At temperatures above 0ºC, drops form by vapor condensation on certain small solid and partially liquid particles, termed 'atmospheric aerosol particles'. These are ubiquitous in the troposphere. The preferred candidates for nucleation of cloud drops are usually larger than 0.1 micron in diameter, and consist of salts (often ammonium sulfate or ammonium bisulfate), organic acids, and often some insoluble material like mineral dust. In remote areas there are typically around 10 to 100 cm^{-3} droplets at cloud base, while near populated areas the droplet concentration can be over 1000 cm^{-3}, most forming on anthropogenic aerosols.

As a parcel of air containing droplets continues to rise, the droplets grow by continued condensation; they tend to have a range of sizes, reflecting the size range and compositions of the aerosol particles on which they form. Condensation is accompanied by the release of latent heat, which warms the cloudy air, makes it less dense than the air surrounding it, and accelerates it upward.

When some of the drops reach around 20 μm in radius, they begin to fall against the updraft, and can collide with smaller, rising droplets below them. Coalescence of the colliding drops results in even larger drops that form 'warm rain'. As a general rule of thumb, approximately one million cloud drops must coalesce to form a single raindrop. The rain falls through the cloud, and into the subcloud air, where it either evaporates or continues to the surface. A drop of 100 microns falls at roughly 1 m s^{-1} relative to its surroundings.

1.2 Clouds with Ice

The 0ºC isotherm is at an altitude of 2 to 4 km over much of the Earth's surface. Supercooled water drops tend increasingly to freeze as the temperature falls in a rising air parcel, although some supercooled liquid drops have been found well below –35ºC. Since freezing is accompanied by release of latent heat, glaciation contributes to the upward acceleration of cloudy air.

Formation of ice particles at temperatures close to 0ºC can be facilitated by the presence of a class of insoluble aerosol particles termed 'ice nuclei'. These are thought to be largely mineral (dust) but have been associated with biological activity, oceanic sources, urban sources, and emissions from jet contrails. These produce small numbers of ice crystals at high temperatures; at $T \approx -10$ºC there are typically only a few ice particles per liter.

1.2.1 Precipitation from Cold Clouds

Much of the precipitation at middle and high latitudes begins initially in the ice phase, although the falling frozen particles can melt on the way down and fall to the surface as rain.

If a few ice particles form in a supercooled region of cloud, they grow rapidly at the expense of the liquid drops. Eventually some of the ice particles become so large they fall against the updraft, making collisions with rising smaller ice particles and supercooled drops. The rate of supply of supercooled drops from below is proportional to the updraft velocity and the size achieved by particles before they begin to sediment also increases with the vertical velocity. Thus cumulonimbus clouds, in which the updraft velocities are high, can produce heavy local precipitation, whereas precipitation from stratiform clouds tends to be lighter, although since these clouds occupy such large areas, they are responsible for deposition of substantial total amounts of water.

When supercooled drops and ice particles collide, the liquid drops freeze to the ice, forming rime. The particles that grow from the rime and other ice particle collisions are called 'graupel'. Hailstones are essentially graupel particles that have grown to more than about 5 mm in size after many collisions with supercooled drops. They are generally less than a few centimeters across, although they are occasionally much larger. The largest known hailstone, collected in Kansas, weighed 766 g and had a circumference of 44 cm. Sedimentation of these particles leads to precipitation in the form of rain (if the ice particles melt on their way to the surface), snow (aggregates of vapor-grown ice particles), sleet (freezing rain), or hail (rimed ice).

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Biographical Sketch

M. B. Baker obtained a B.A. in Physics from Cornell University, an M.S. in Physics from Stanford, and a Ph. D. in Physics from the University of Washington. She is a professor of Geophysics and Atmospheric Sciences at the University of Washington. Her main research interests involve the microphysical processes that occur in clouds, including the evolution of cloud particles, ice crystal growth, and the electrification of thunderstorms.