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In light of these ideas, a number of techniques have been suggested whereby clouds and precipitation might be artificially modified by cloud seeding.
Seeding Techniques
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- Introducing *artificial ice nuclei* into cold clouds (which may be deficient in ice particles) to *stimulate the production of precipitation* by the ice crystal mechanism.

- Introducing comparatively high concentrations of artificial ice nuclei into cold clouds to reduce drastically the concentrations of supercooled droplets and thereby inhibit the growth of ice particles by deposition and riming, thereby *dissipating the clouds* and suppressing the growth of precipitable particles.
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A more efficient technique might be to introduce *small water droplets* (radius $\approx 30 \, \mu m$) or hygroscopic particles (e.g., NaCl) *into the base* of a cloud.

These particles may grow by condensation, and then by collision-coalescence, as they are carried up and subsequently fall through a cloud.
Even in principle, the introduction of water drops into the tops of clouds is *not a very efficient method* for producing rain, since large quantities of water are required.

A more efficient technique might be to introduce **small water droplets** (radius ≈ 30 µm) or hygroscopic particles (e.g., NaCl) *into the base* of a cloud.

These particles may grow by condensation, and then by collision-coalescence, as they are carried up and subsequently fall through a cloud.

Seeding with *Dry Ice* can dissipate large areas of supercooled cloud or fog (Figure follows). This technique is used for clearing supercooled fogs at several international airports.
A γ-shaped path cut in a layer of supercooled cloud by seeding with Dry Ice (solid CO$_2$).
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However, silver iodide has been used in most cloud seeding experiments.

Obvious joke about clouds with silver linings
The ‘explosive’ growth of a cumulus cloud (indicated by the arrow) following seeding with silver iodide. After (a) 10 (b) 19 (c) 29 and (d) 48 minutes. Note that the neighboring unseeded clouds have not grown significantly.
Seeding experiments have been carried out in attempts to reduce the damage produced by hailstones.
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Seeding with artificial nuclei should tend to increase the number of small ice particles competing for the available supercooled droplets.

Therefore, seeding should result in a **reduction in the average size of the hailstones**.
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Inadvertent Modification

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These can change droplet concentrations in clouds downwind. (Figure follows).
The cloud in the valley in the background formed due to effluents from a paper mill. In the foreground, the cloud is spilling through a gap in the ridge into an adjacent valley.
Urban Heat Islands

Little vegetation or evaporation causes cities to remain warmer than the surrounding countryside.
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In the summer months increases in precipitation of 5–25% over background values occur 50–75 km downwind of some cities (e.g., St. Louis, Missouri).
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Unlike the rest of this site, this map is declared to be in the public domain.
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[Ben Franklin did not appreciate the danger of his proposal.]
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Later in the summer of 1752, Franklin carried out his famous kite experiment in Philadelphia and observed sparks to jump from a key attached to a kite string to the knuckles of his hand.
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The dielectric breakdown of cloudy air is about 1 MV m\(^{-1}\). All clouds are electrified to some degree. However, in vigorous convective clouds sufficient electrical charges are separated to produce electric fields that exceed the dielectric breakdown. This results in an initial *intracloud* lightning discharge. The onset of strong electrification follows the occurrence of heavy precipitation within the cloud in the form of graupel or hailstones.
Distribution of electric charges in a typical thunderstorm.
Most theories assume that as a graupel particle or hailstone (hereafter called the *rimer*) falls through a cloud it is charged negatively due to collisions with small cloud particles (droplets or ice), giving rise to the negative charge in the main charging zone.
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The exact conditions and mechanism by which a rimer might be charged negatively, and smaller cloud particles charged positively, has been a matter of debate for some hundred years.

Many potentially promising mechanisms have been proposed but subsequently found to be unable to explain the observed rate of charge generation in thunderstorms or, for other reasons, found to be untenable.
Lightning and Thunder
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1. Within the cloud itself
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4. Between the cloud and the ground (a ground flash).
(a) A time exposure of a ground lightning flash that was initiated by a stepped leader that propagated from the cloud to the ground.

(b) A time exposure of a lightning flash from a tower on a mountain to a cloud above the tower.
The return stroke of a lightning flash raises the temperature of the channel of air through which it passes to above 30,000 K in such a short time that the air has no time to expand.
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The high-pressure channel then expands rapidly into the surrounding air and creates a very powerful shock wave (which travels faster than the speed of sound) and, farther out, a sound wave that is heard as thunder.
The Global Electrical Circuit
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A schematic of the main global electrical circuit follows.
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The “fair-weather current continuously leaks positive charge to the Earth’s surface.

The circuit is completed by the transfer of net positive charge to the bases of electrified clouds due to the net effect of point discharges, precipitation and lightning.
Global frequency and distribution of total lightning flashes observed from satellite.
Monitoring of lightning flashes from satellites shows that the global average rate of ground flashes is about $12-16 \text{s}^{-1}$, with a maximum rate of about $55 \text{s}^{-1}$ over land in summer in the northern hemisphere.
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Over the North American continent ground flashes occur about 30 million times per year!
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Some important processes that play a role in cloud and precipitation chemistry are shown schematically in the following figure.
Cloud and precipitation processes that affect the distribution and nature of chemicals in the atmosphere.
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These processes, and their effects on the chemical composition of cloud water and precipitation, are discussed in turn.
Transport of Particles and Gases:
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Gases and particles are carried upward on the updrafts that feed clouds.

Some of these gases and particles are transported to the upper regions of the clouds and ejected into the ambient air at these levels.

In this way, pollutants from near the surface of the Earth (e.g., SO$_2$, O$_3$, particles) are distributed aloft.
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**Nucleation Scavenging:**

Some of the particles that enter the base of a cloud serves as cloud condensation nuclei (CCN) onto which water vapour condenses to form cloud droplets.

Thus, each cloud droplet contains at least one particle from the moment of its birth.

The incorporation of particles into cloud droplets in this way is called nucleation scavenging.
Dissolution of Gases in Cloud Droplets:
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As soon as water condenses to form cloud droplets, gases in the ambient air begin to dissolve in the droplets.

Since the liquid phase is increasingly favoured over the gas phase as the temperature is lowered, greater quantities of a gas become dissolved in water droplets at lower temperatures.
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Aqueous-Phase Chemical Reactions:

The relatively high concentrations of chemical species within cloud droplets, particularly in polluted air masses, lead to fast aqueous phase chemical reactions.

An important example is the conversion of SO$_2$ to H$_2$SO$_4$ in cloud water.
Precipitation Scavenging:
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Precipitation scavenging refers to the removal of gases and particles by cloud and precipitation elements (i.e., hydrometeors).

Precipitation scavenging is crucially important for cleansing the atmosphere of pollutants, but it can also lead to acid rain on the ground.
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Chemical Composition of Rain

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This gives rise to acid rain.

The high acidity is due to the incorporation of gaseous and particulate pollutants into the rain.

In addition to sulfate, many other chemical species contribute to the acidity of rain, for example, \( \text{NO}_x \) emitted from cars.
The formation of particles in the outflow regions of convective clouds may act on a large scale to supply large numbers of particles to the upper troposphere in the tropics and subtropics and also, perhaps, to the subtropical marine boundary layer.
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In this scenario, air containing DMS and SO$_2$ from the tropical boundary layer is transported upward by large convective clouds into the upper troposphere. Particle production occurs in the outflow regions of these clouds.
The formation of particles in the outflow regions of convective clouds may act on a large scale to supply large numbers of particles to the upper troposphere in the tropics and subtropics and also, perhaps, to the subtropical marine boundary layer.

In this scenario, air containing DMS and SO$_2$ from the tropical boundary layer is transported upward by large convective clouds into the upper troposphere. Particle production occurs in the outflow regions of these clouds.

These particles are then transported away from the tropics in the upper branch of the Hadley cell circulation, and then subside in the subtropics (Figure follows).
Transport of aerosol by the Hadley cell circulation.