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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*.

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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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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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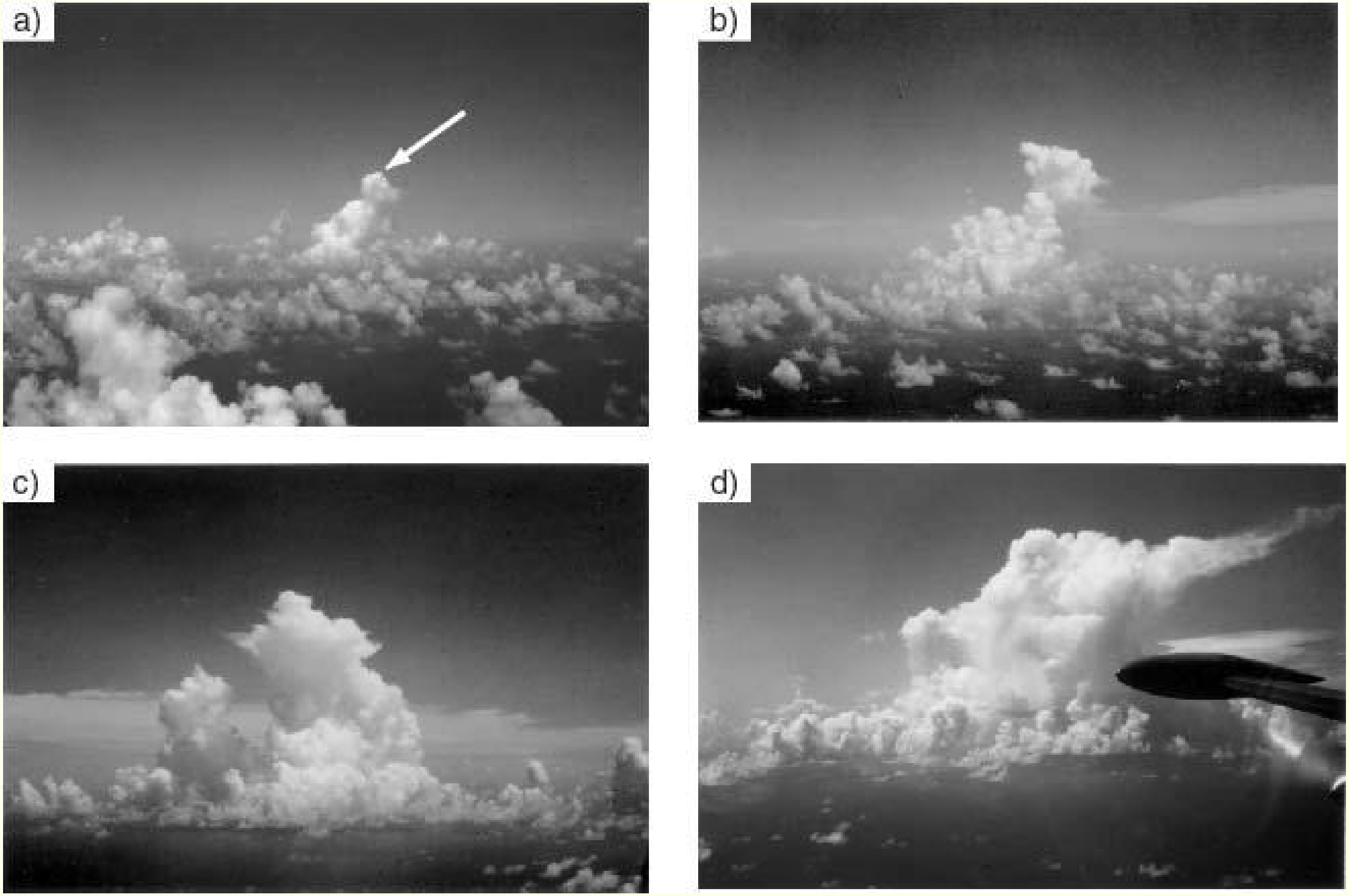
However, silver iodide has been used in most cloud seeding experiments.

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.

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

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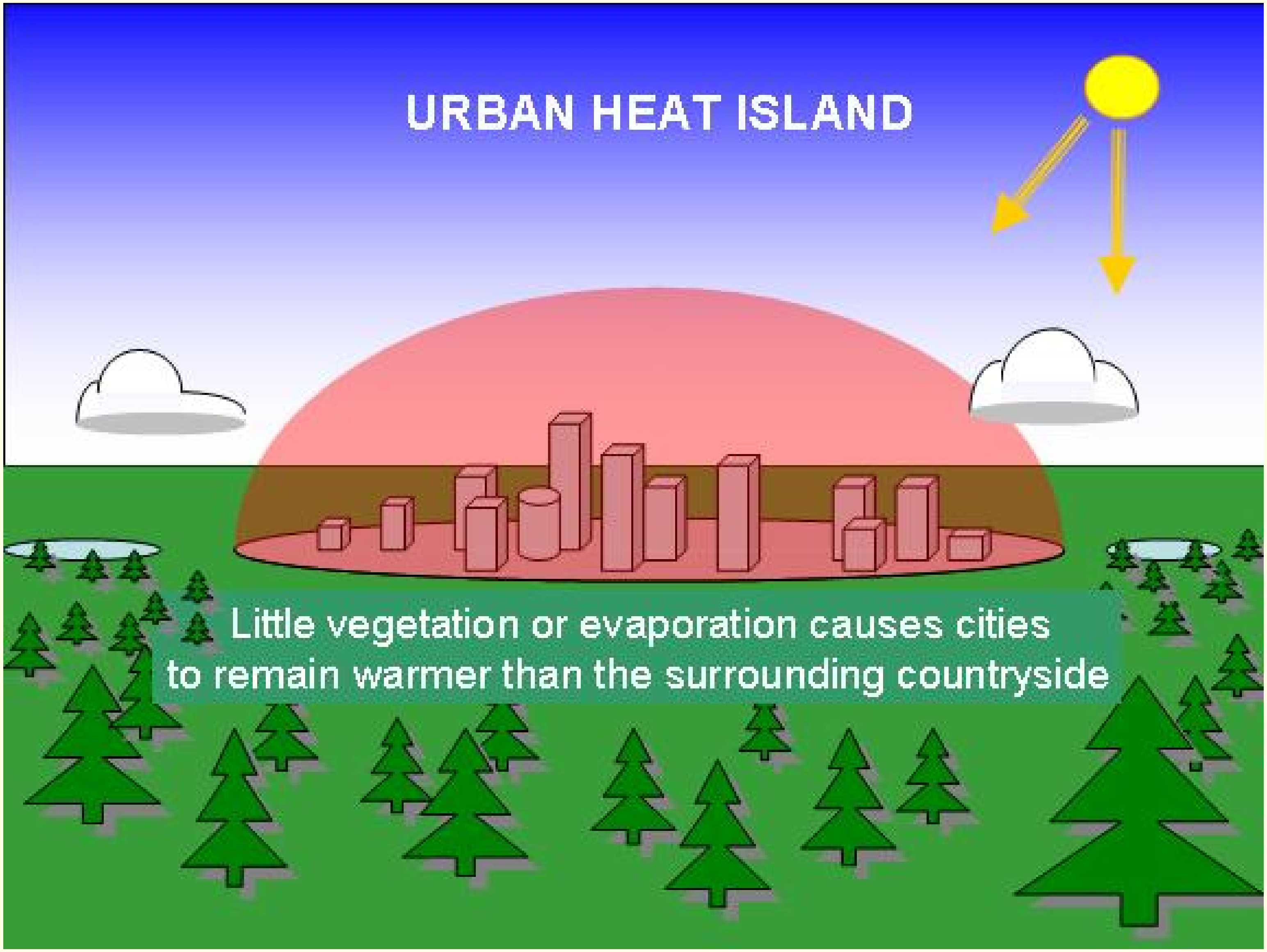
These can change droplet concentrations in clouds downwind. (Figure follows).

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



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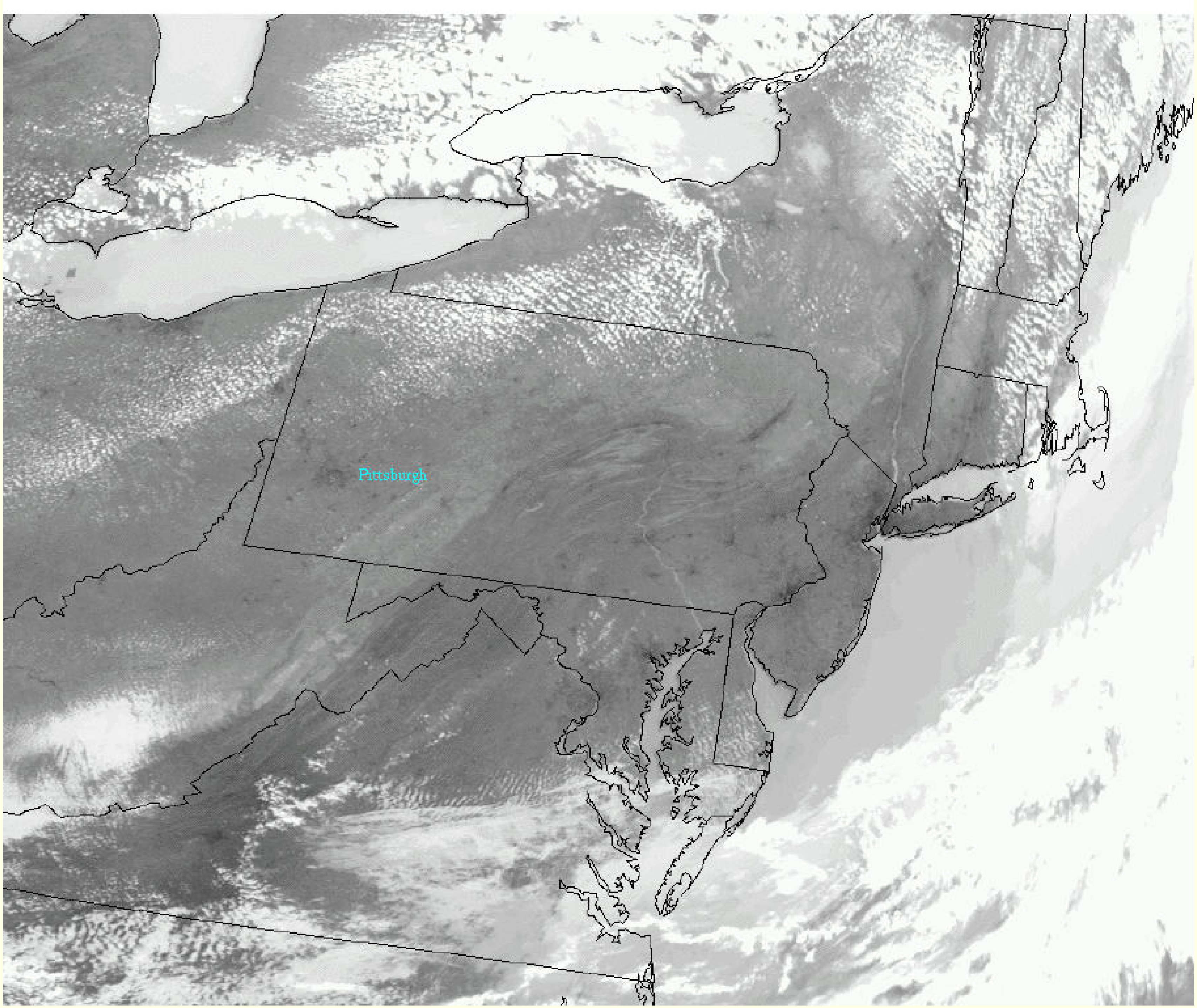
In the summer months increases in precipitation of 5–25% over background values occur 50–75 km downwind of some cities (e.g., St. Louis, Missouri).


Pittsburgh

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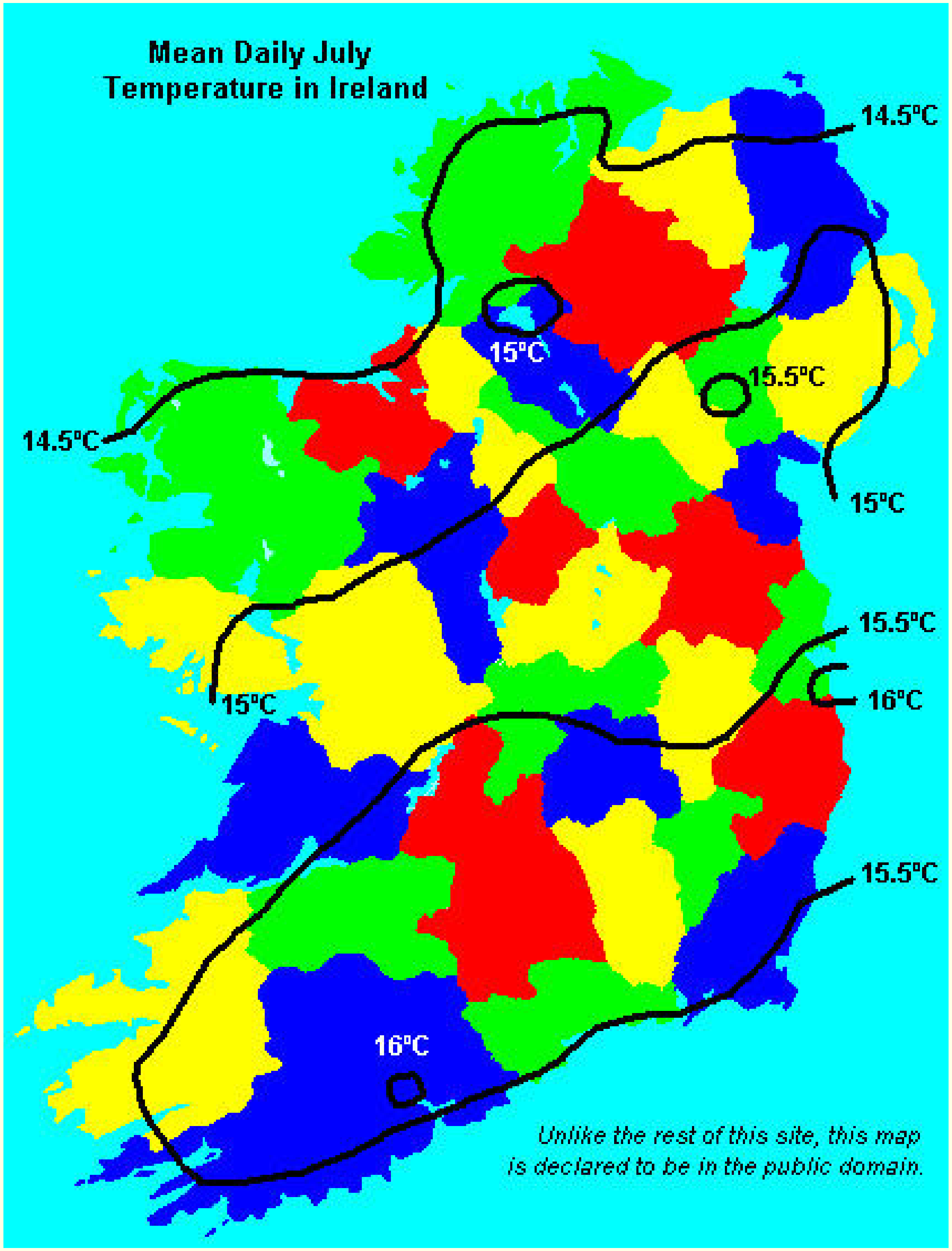
Model simulations show that enhanced upward air velocities, associated with variations in surface roughness and the heat island effect, are most likely responsible for these anomalies.


Mean Daily July
Temperature in Ireland
14.5°C
14.5°C
15°C
15.5°C
15°C
15°C
15.5°C
16°C
15.5°C
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Unlike the rest of this site, this map
is declared to be in the public domain.

7 Thunderstorm Electrification

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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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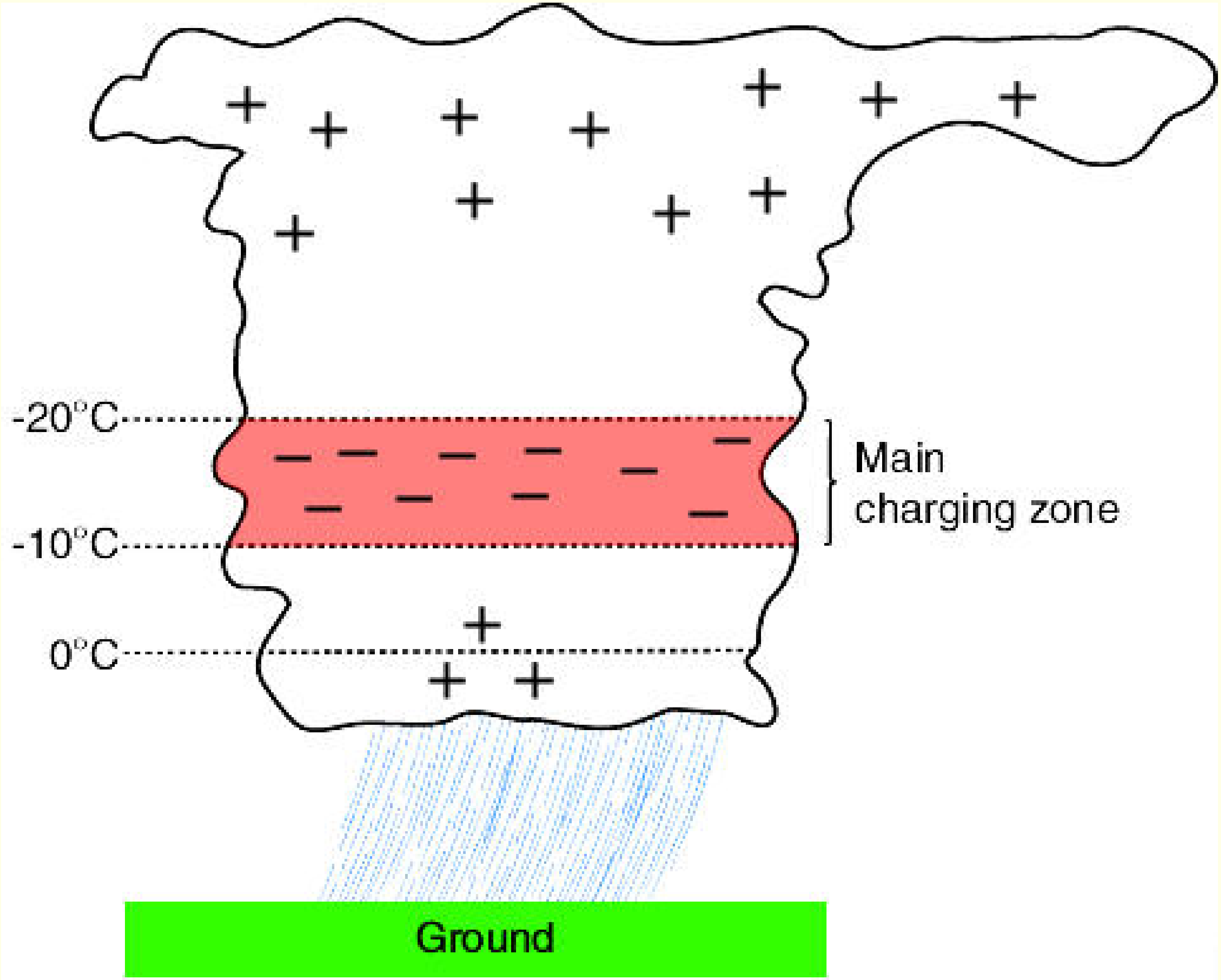
The onset of strong electrification follows the occurrence of heavy precipitation within the cloud in the form of graupel or hailstones.



Distribution of electric charges in a typical thunderstorm.

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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.

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3. **From the cloud to the air**
4. **Between the cloud and the ground (a *ground flash*).**

(a)

(b)

(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.

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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*.

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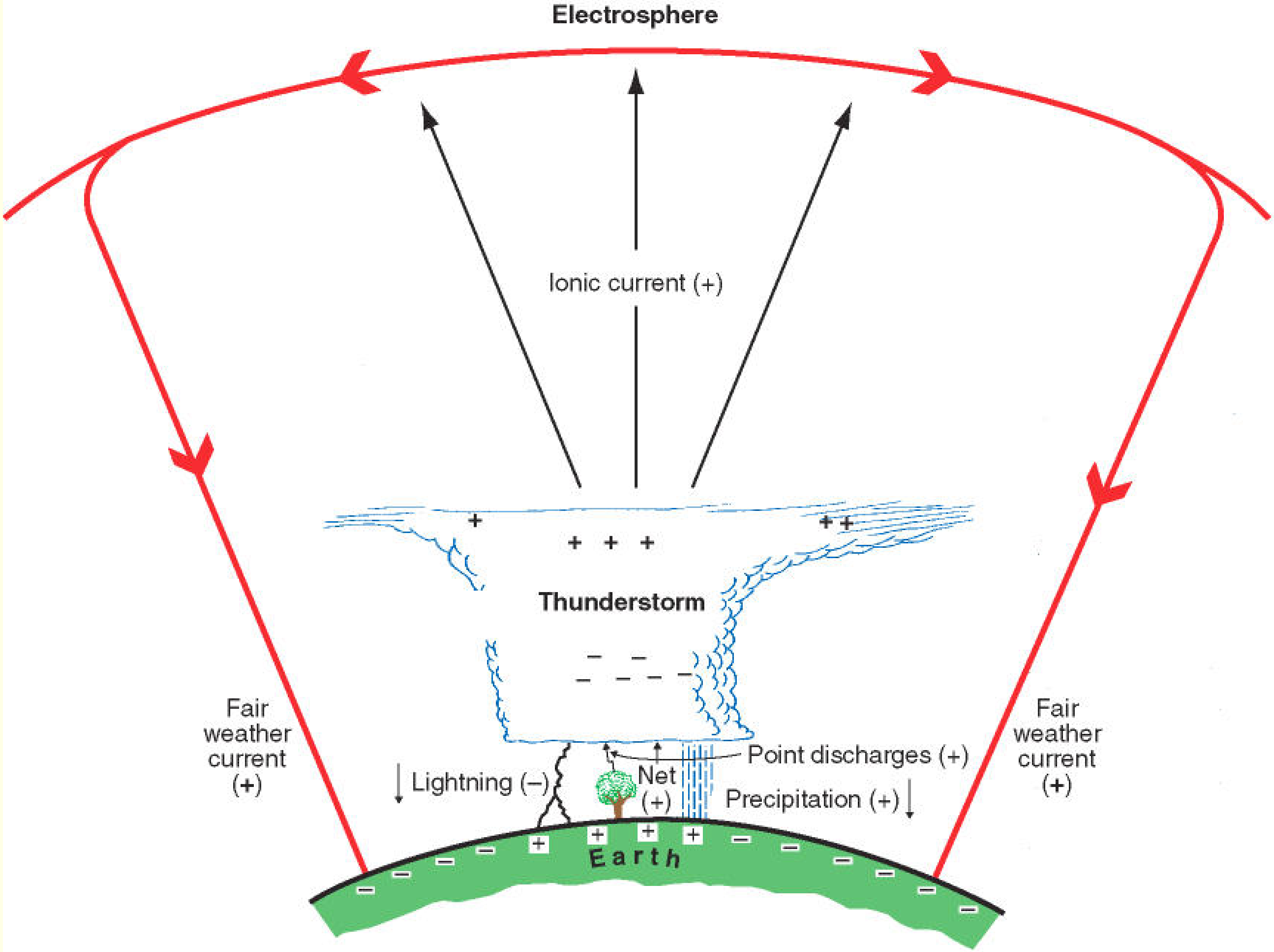
A schematic of the main global electrical circuit follows.



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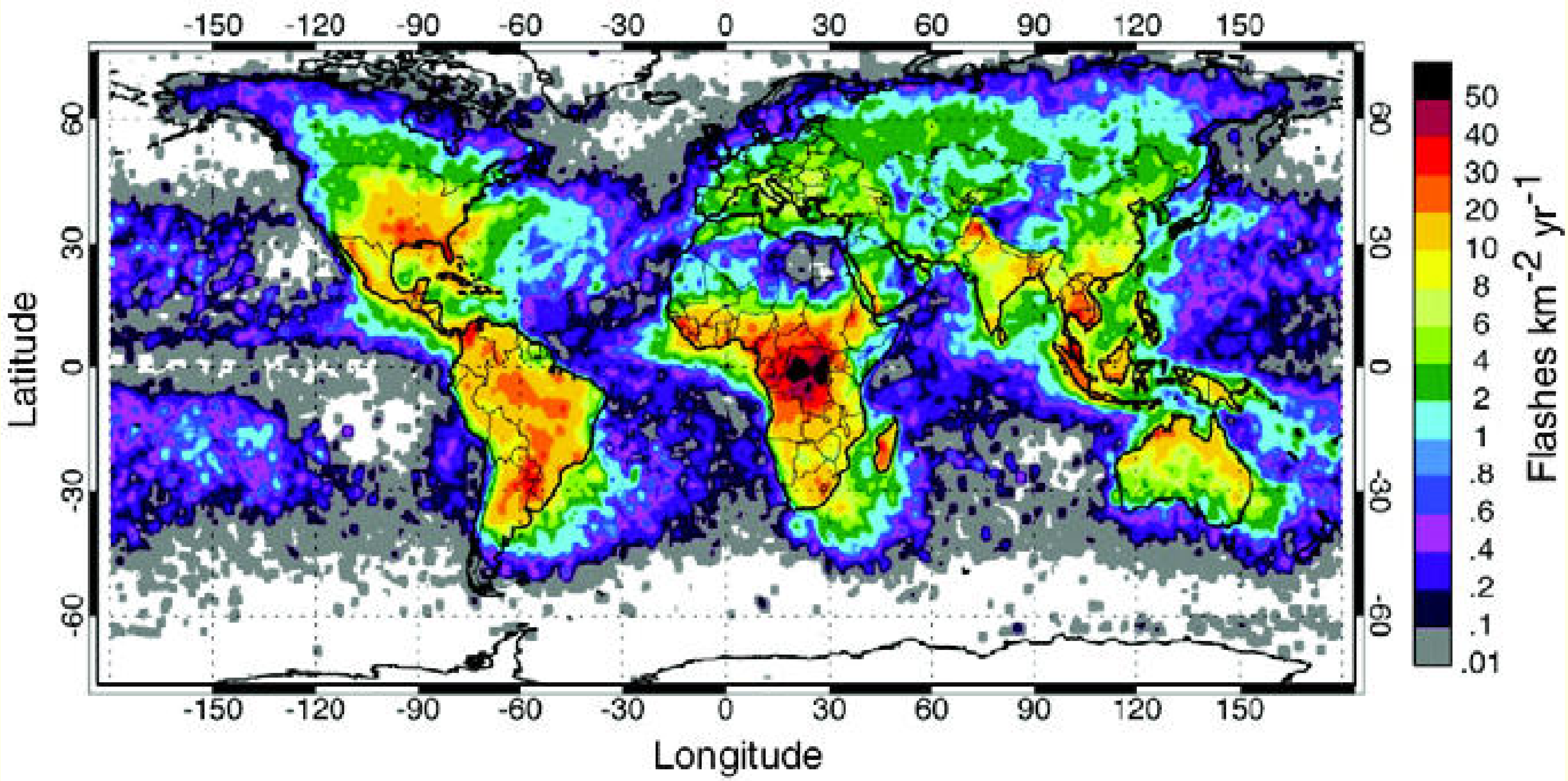
The circuit is completed by the transfer of net positive charge to the bases of electrified clouds due to the net effect of point discharges, precipitation and lightning.



Global frequency and distribution of total lightning flashes observed from satellite.

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Over the North American continent ground flashes occur about 30 million times per year!

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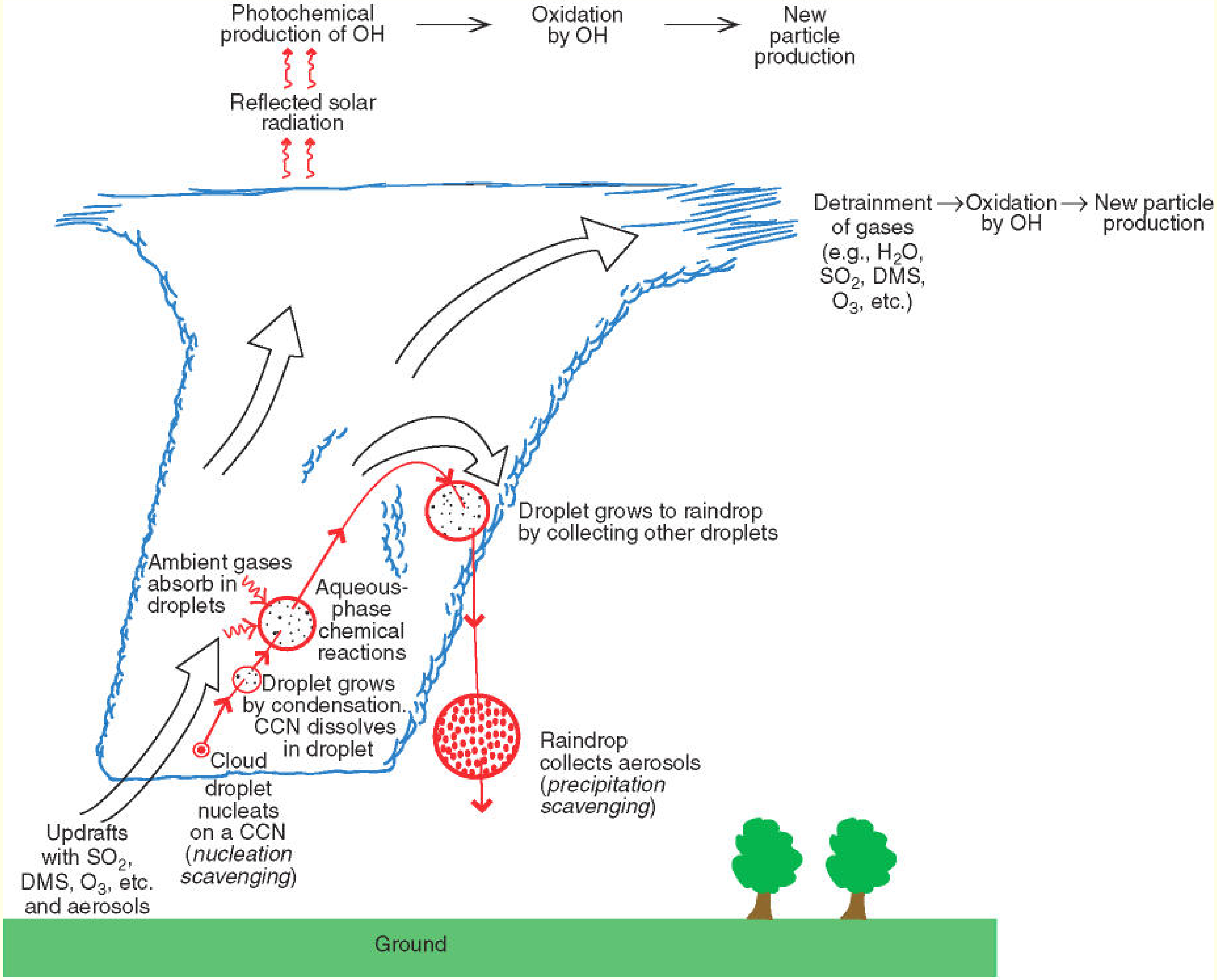
Some important processes that play a role in cloud and precipitation chemistry are shown schematically in the following figure.



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These processes, and their effects on the chemical composition of cloud water and precipitation, are discussed in turn.

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Nucleation Scavenging:

Transport of Particles and Gases:

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.

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.

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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_2SO_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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The pH of rainwater in *polluted air* can be significantly lower than 5.6.

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, NO_x emitted from cars.

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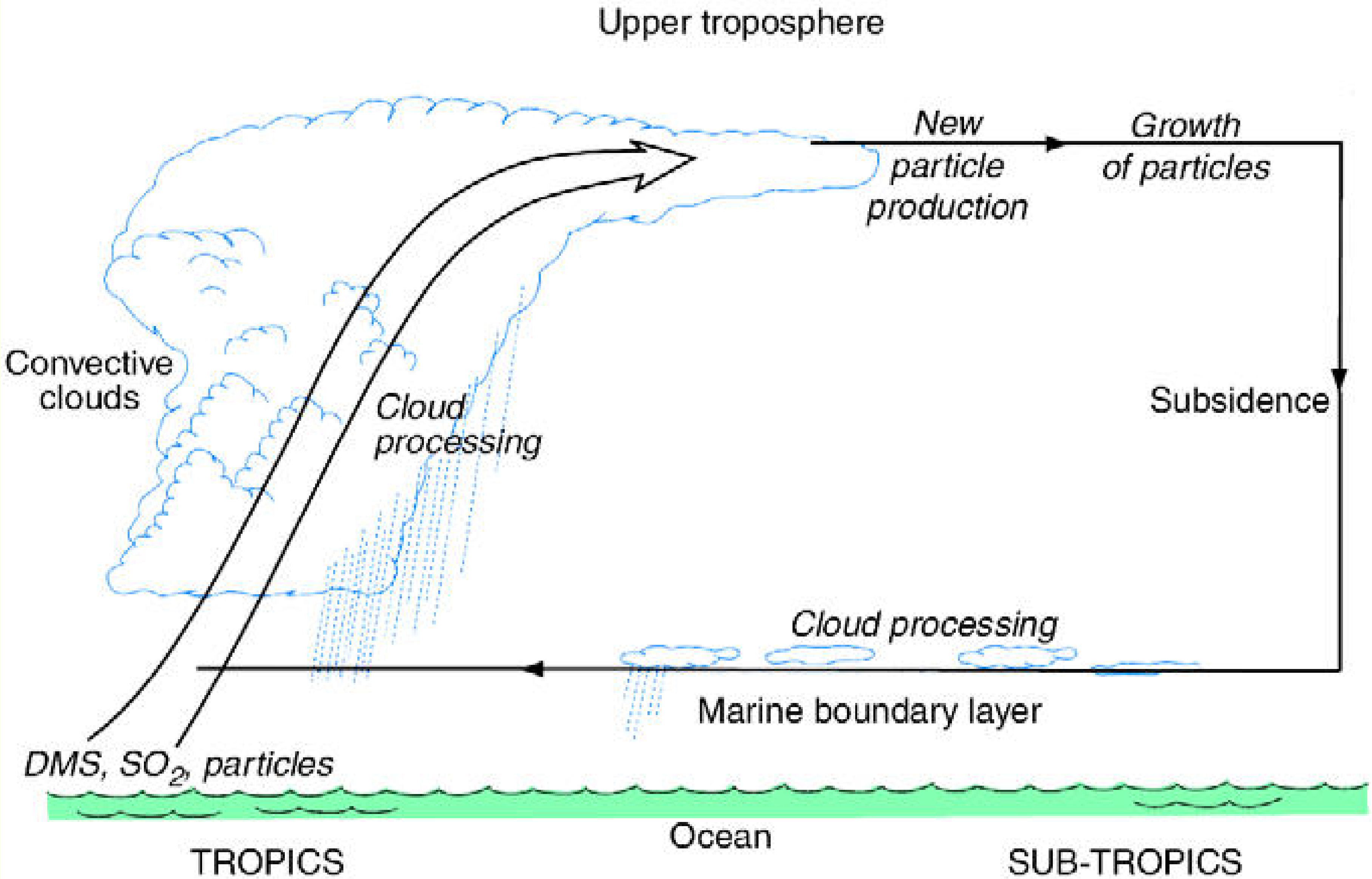
These particles are then transported away from the tropics in the upper branch of the Hadley cell circulation, and then subside in the subtropics (Figure follows).



Transport of aerosol by the Hadley cell circulation.