Chapter 7

Clouds

Introduction: Formation of clouds is another of the many physical processes that take place continuously day in and day out on the earth. A cloud is a visible mass of liquid droplets or frozen crystals made of water or sometimes certain chemicals suspended in the atmosphere above the surface of the Earth. They are also known as ‘aerosols’. We study clouds in the ‘cloud physics’ branch of meteorology. Cloud Physics is the study of the physical processes that lead to the formation, growth and precipitation of clouds.

Clouds have drawn great interest in the humans. Unlike Earthquakes, Volcanoes, Tsunamis and the Tides, Cloud is something which one can see with the eyes and the same is accessible for experimental study. Y. Liu, et al have given the following poem depicting the interest shown by man on clouds:

“Clouds are pictures in the sky
They stir the soul
They please the eye
They bless the thirsty earth with rain
Which nurtures life from cell to brain
But no! They are demons dark and dire
Hurling hail, wind, flood and fire
Killing scarring, cruel masters Of destruction and disasters
Clouds have such diversity
Now blessed, now cursed
The best, the worst
But, where would life without them be?

Thus, clouds are as important as presence of air in the atmosphere. The climate and the weather both depend on clouds which control pollution in the atmosphere by means of precipitation. According to the Hindu mythology, Varuna, the God of rain is controlled by Lord Indra who alone has command on clouds to shower rain on Earth. In the great
Epic, *Mahabharata*, *Arjun* vowed to kill *Jayadrath* before Sun set on a day for the killing of *Arjun’s* son, *Abhimanyu*. In the day of war, much before Sun set, *Lord Krishna* with his supernatural powers, covers the entire Sun by a thick cloud and created an artificial eclipse. *Jayadrath*, thinking that the Sun is set, came out from his hiding and *Arjun* immediately killed him.

It is the clouds that control the energy cycle and water cycle of the Earth. For a deep study, we have to deal with cloud microphysics which has to be parameterized and form the core of cloud physics. According to 7.2 Gregory Falkovich, et al, Cloud physics has for a long time been an important part of atmospheric science. Apart from the clouds being beautiful, lot of theory involving dynamics, turbulence, microphysics, thermodynamics and radiative transfer interact on a wide range of scales from sub-micron to kilometers. Cloud can be looked upon as a composite non-linear system which involves many interactions and feedback and is actively linked to a web of atmospheric, oceanic and even cosmic interaction.

In this chapter we shall theoretically deal with cloud parameterizations and other related topics.

**REVIEW OF LITERATURE**

**Physics of cloud formation:** 7.3 Paul W Zitzewitz has given a brief idea regarding formation of clouds. As warm air rises into the atmosphere through convection currents, the air expands as it experiences low atmospheric pressure. When it expands, the warm water vapor suddenly cools and gets condensed forming droplets of water in the air. When there is large accumulation of such condensed droplets, they get themselves attached to dust particles present in the air to form clouds. 7.2 Gregory Falkovich, et al has added more physics to theory of cloud formation. They say that the amount of water that can exist as vapor in a given volume increases with temperature. When the quantity of water vapor is in equilibrium above a water surface such as the ocean, the pressure exerted by vapor is the vapor pressure and the relative humidity 100%. At this stage of equilibrium, the number of molecules evaporating from the water becomes equal to the number of molecules getting condensed in the air. At a stage when the relative humidity exceeds 100%, it is called super saturation which is essential according to Kohler theory and it occurs in the absence of condensation nuclei which is the flat surface of water.
The saturation vapor pressure is proportional to temperature and hence cold air has a lower saturation point than warm air. The difference between these values is the basis for the formation of clouds. Cloud condensation nuclei are necessary for cloud formation because of the Kelvin effect according to which the change in saturation vapor pressure due to the curved shape of the drop.

A theory explaining how the behavior of individual droplets leading to form a cloud is the “Collision-Coalescence Process”. The droplets interact with each other either by colliding or bouncing off or by not combining to form smaller droplets. The droplets will never become small and fall to the ground as precipitation. As water droplets have relatively low surface tension, the collision-coalescence process makes up a significant part of cloud formation.

Tor Bergeron discovered a primary mechanism for the formation of ice clouds and is known as the “Bergeron Process”. The process is based on how much water vapor a given volume can hold and on what the vapor is interacting with. According to basic hygrometry, the saturation vapor pressure with respect to ice is lower than the saturation vapor pressure with respect to water. Water vapor will be supersaturated when it interacts with an ice droplet. The vapor will try to attain equilibrium, but the extra vapor will condense and form ice and join with the ice droplet. These ice droplets will end up as nuclei for large ice crystals. This happens at temperatures between 0°C and −40°C. Liquid water will spontaneously nucleate and freeze. The surface tension of water allows the droplet to stay liquid well below its freezing point. When this happens, we get super cooled liquid water. If there are only few ice nuclei, ice droplets will not be formed.

**Cloud seeding**:- Cloud seeding is a process to get rain artificially from the clouds. The process involves in seeding the clouds with artificial ice nuclei to encourage precipitation. Excess artificial ice nuclei are added so that there will be more nuclei compared to the amount of super cooled liquid water and will facilitate rain showers.

**History of Cloud Physics and Classification of Clouds**:- Study of cloud physics started as early as 14th century. Otto von Guericke (1602-1686) was the first to suggest that clouds were composed of water bubbles. Later in 1847, Agustus Waller used a
spider web to examine cloud droplets under a microscope. William Henry Dines (1880) and Richard Assmann (1884) confirmed the observations done by the earlier workers.

**Classification of Clouds:** The Handy Science Answer Book compiled by the Carnegie Library of Pittsburg has dealt with a short historical account and classification of clouds. The French naturalist Jean Lamarck (1744-1829) proposed in 1802 the first system for classification of clouds. This system was not fully accepted and in the following year an Englishman, Luke Howard (1772-1864) presented a cloud classification system which is well accepted and followed even today. Clouds are classified from their general appearance and their height from the ground for example, ‘heap clouds’ and ‘layer clouds’. They are given Latin names for example, when they are curly or fibrous, then they are called ‘cirrus’. When lumpy or piled, then ‘cumulus’. If the height is above 6000 meters, then ‘cirro’. When the height is 1500 to 6000 meters, then the name given is ‘alto’. When the cloud is a precipitating one, then a prefix such as nimbo or nimbus is added. Clouds are classified into four major groups or types and the same is shown in the following table 7.1.

![Table 7.1 (Table Contents Credit: 7.4)](image)

<table>
<thead>
<tr>
<th>Group or Type</th>
<th>Height</th>
<th>Name</th>
<th>Composition/Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 High Clouds</td>
<td>5000 m To 13,650 m</td>
<td>‘Cirrus’ <em>(from Latin, ‘Lock of hair’)</em></td>
<td>Composed almost entirely of ice crystals Thin, feather-like crystal clouds in patches or narrow bands. The large ice crystals that often trail downward in well-defined wisps are called ‘mares tails’</td>
</tr>
<tr>
<td></td>
<td></td>
<td>‘Cirrostratus’</td>
<td>Thin, white cloud layer that resembles a veil or sheet. This layer can be striated or fibrous. Because of the ice-content, these clouds are associated with the halos that surround the Sun or Moon.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>‘Cirrocumulus’</td>
<td>Thin clouds that appear as small white flakes or cotton patches and may contain super-cooled water</td>
</tr>
<tr>
<td></td>
<td>Middle Clouds</td>
<td>2000 to 7000 m</td>
<td>‘Altostratus’</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>3</td>
<td>Low Clouds</td>
<td>About 2000 m</td>
<td>‘Stratus’</td>
</tr>
<tr>
<td>4</td>
<td>Clouds With Vertical development</td>
<td>300 to 3000 m</td>
<td>‘Cumulus’</td>
</tr>
</tbody>
</table>
There are many clouds which are not included in the above table and having different names. In Fig. 7.1 (a), (b), (c), (d), (e), (f), (g), (h), (i) and (j) are shown pictures of various clouds over Swifts Creek, Australia in the foreground in Denmark forming over mountains in Wyoming.

Fig. 7.1 (a) Cumulus cloudscape
Fig. 7.1 (b) Cumulonimbus cloud
Fig. 7.1 (c) Altocumulus lenticularis

Fig. 7.1 (d) Cumulonimbus capillatus with cirrus spissatus on top
Fig. 7.1 (e) Cumulus fractus in Nepali sky
Fig. 7.1 (f) Cumulus turning to Strato cumulus over port of Piraeus in Greece

Fig. 7.1 (g) Cumulus and stratocumulus appearing together
Fig. 7.1 (h) Cumulonimbus dissipating at dusk
Fig. 7.1 (i) Cirrus uncinus and cirrus fibrates together
Fig. 7.1 (j) Altocumulus merging into Altostratus near horizon

Fig. 7.1 (k) Stratocumulus stratiformis clouds

Fig. 7.1 (l) Nimbostratus cloud

Fig. 7.1 (m) Altocumulus and cirrocumulus clouds

Fig. 7.1 (n) Grey stratocumulus cloud

Fig. 7.2 and Fig. 7.3 are pictures taken from Cloud Physics Research published by Centre for Atmospheric Science, Manchester, UK. and the same are given below:

Fig. 7.2 The Sphinx Observatory, Switzerland

Fig. 7.3 Flying for cloud studies beneath the anvil of a large thunderstorm.

In Fig. 7.4 is shown various stages of life in a cumulonimbus cloud.
Paul W. Zitzewitz in his Handy Physics Answer Book says that the clouds and the ground act as a giant Capacitor. The charged regions of the clouds act as conducting plates and the air between them acts as an insulator. The same thing occurs between the lower part of the cloud and the ground. The air between these sections acts as the insulator, but when the forces exerted by charges on the air molecules are large enough, they can rip the electrons from the molecules. The result is formation of ion which is positively charged along with free electrons. The air is changed from an insulator to a conductor. The mobile electrons gain more energy producing more ions and more free electrons. When the negatively charged electrons and the positively charged ions combine, a light and spark is produced with the release of tremendous energy creating thunder and lightning.

Y. Liu, et al have dealt with the Effective Radius and Spectral Dispersion under Cloud Parameterizations. One of the key variables used in the calculation of liquid water clouds is the effective radius, \( r_e \) defined as the ratio of the third to the second moment of a droplet size distribution. It is expressed as a third power law of the ratio of the cloud liquid water content to the droplet concentration and is given by the following expression:

\[
r_e = \beta \left[ \frac{3}{4\pi \rho_w} \left( \frac{L}{N} \right) \right]^{1/3}
\]

Where \( r_e \) is the effective radius in \( \mu m \), \( L \) is the liquid water-content in \( gm^{-3} \), \( N \) the total droplet concentration in \( cm^{-3} \) and the quantity \( \beta \) is a dimensionless parameter and is a function of the spectral shape and expressed as
where $\varepsilon$ is the spectral dispersion defined as the ratio of the standard deviation and the mean radius of the droplet size distribution and $s$ is the skewness of the droplet size distribution. Some of the values and expressions for $\beta$ for various types of distributions are worked out and are listed below in the following table - 7.2.

### Table 7.2 (Table contents Credit: 7.1)

<table>
<thead>
<tr>
<th>No.</th>
<th>Symbol</th>
<th>Name of type of distribution</th>
<th>Value / Expression for $\beta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>MO</td>
<td>Mono disperse droplet size distribution</td>
<td>$\beta = 1$</td>
</tr>
<tr>
<td>2</td>
<td>MM</td>
<td>Maritime cloud droplet size distribution</td>
<td>$\beta = 1.08$</td>
</tr>
<tr>
<td>3</td>
<td>MC</td>
<td>Continental cloud droplet size distribution</td>
<td>$\beta = 1.14$</td>
</tr>
<tr>
<td>4</td>
<td>GL</td>
<td>Gaussian-like distribution</td>
<td>$\beta = \frac{(1 + 3\varepsilon^2 + s\varepsilon^2)^{2/3}}{(1 + \varepsilon^2)}$</td>
</tr>
<tr>
<td>5</td>
<td>WB</td>
<td>Weibull form of cloud droplet size distribution</td>
<td>$\beta = 104 \frac{\Gamma^{-2/3} \left(\frac{3}{b}\right)}{\Gamma\left(\frac{3}{b}\right)} b^{1/3}$ where $\Gamma$ is the Gamma function $b$ and $\varepsilon$ are related by $\varepsilon = \frac{2b\Gamma\left(\frac{2}{b}\right)}{\Gamma^2\left(\frac{1}{b}\right) - 1}^{1/2}$</td>
</tr>
<tr>
<td>6</td>
<td>GM</td>
<td>Gamma droplet size distribution</td>
<td>$\beta = \frac{(1 + 2\varepsilon^2)^{2/3}}{(1 + 3\varepsilon^2)^{1/3}}$</td>
</tr>
<tr>
<td>7</td>
<td>LN</td>
<td>Lognormal droplet size distribution</td>
<td>$\beta = (1 + \varepsilon^2)$</td>
</tr>
</tbody>
</table>

A graph of $\varepsilon$ versus $\beta$ is shown in Fig. 7.5. It is seen from the graph that the Lognormal droplet size distribution is shown by the thick line at the top and the Gaussian-like
distribution by dotted line at the bottom. The other distributions are situated in between the two and lying in the patch shown. The value of $\beta$ derived from measurements is to increase monotonically with $\epsilon$ for both continental and maritime clouds.

The relation between the spectral dispersion $\epsilon$ and the parameter $b$ is shown graphically in Fig. 7.6 in accordance with the equations in Table 7.6.

The authors have concluded that dealing with cloud physics is a challenge with trivial mathematics. Theories in the mainstream have been established in the Hilbert functional space. In fact, one has to take for granted the use of Hilbert space in the study of clouds.

The authors say that for any further work in the subject one has to from Hilbert functional space to some generalized functional space.

Marat Khairoutdinov, et al have dealt with a new cloud parameterization in a Large-Eddy Simulation Model of Marine Stratocumulus. Our understanding of the processes in the planetary boundary layer particularly in the stratocumulus-topped boundary layer can be done by large-eddy simulation model. Past experiments suggest that a heavily drizzling stratocumulus-topped boundary layer is more common and widespread as drizzle can significantly modulate the dynamics and evolution involved in the process. One of the method is to predict a drop size distribution function in which the drops are distributed among many size categories of bins. The methods are complicated and trivial because each drop is subjected to advection by wind, condensation, gravitational sedimentation, coalescence, and other processes.

Another method is to shape the drop size distribution into a truncated series of basis functions usually Gamma or Lognormal distributions. A most common approach to cloud microphysics is to predict many drop size distribution moments rather than the distribution itself. The moments can represent water-content, drop concentration, effective radius, radar reflectivity, etc. Such a method is termed bulk microphysical parameterization. According to Kessler, the water-content is of two types, non-
precipitable cloud water and precipitable drizzle water. If $q_c$ is the cloud water-content, then

$$\left(\frac{\partial q_r}{\partial t}\right)_{auto} = \alpha (q_c - q_{co}) H (q_c - q_{co}) \quad \ldots (1)$$

where $\alpha$ is a tuning constant, $H(x)$ the Heaviside step function, $q_{co}$ the threshold water-content and is arbitrary with $\alpha$.

A more concise and appropriate expression for the auto conversion is given by Manton and Cotton as follows:

$$\left(\frac{\partial q_r}{\partial t}\right)_{auto} = \pi k_1 E \ r_{vc}^4 N_c \ q_c \ H (r_{vc} - r_0)$$

$$= \beta q_c^{7/3} N_c^{1/3} H (r_{vc} - r_0) \quad \ldots (2)$$

Field Experiments: These experiments are carried out using aircraft. A set of microphysical instruments such as the Particle Measuring System has been used. The got invaluable data for study of where $N_c$ is the cloud drop concentration in cm$^{-3}$, $k_1 = 1.19 \times 10^6$ cm$^{-1}$s$^{-1}$ is the Stoke’s constant, $E$ the mean droplet collision efficiency, $r_0$ the arbitrary threshold radius and $r_{vc}$ the drop mean volume radius and is given by

$$r_{vc} = \left(\frac{r^3}{\rho_a - \rho_w}\right)^{1/3} = \left(\frac{4\pi \rho_w}{3\rho_a}\right)^{-1/3} q_c^{-1/3} N_c^{-1/3} \quad \ldots (3)$$

where $\rho_a$ and $\rho_w$ are the densities of air and water respectively. Expressions (1) and (2) are better expressions than those given by Kessler.

The authors have followed the methodology of Kessler. The liquid water is divided into cloud and precipitable rain/drizzle water. They selected a number of spectra from four different Large-Eddy simulation models with explicit microphysics of the Stratocumulus-topped boundary layer with light and heavy drizzle. The mass gain/loss for each drop was computed. The average results for each simulation as a function of drop radius is shown in Fig. 7.7 (Credit: 7.6).
The authors, in their paper with rigorous mathematics, followed the methodology of Kessler applied the theory to marine boundary layer clouds. One of the salient features adopted by them is the inclusion of the total Cloud Condensation Nuclei as a separate prognostic variable.

The method facilitates to predict the cloud drop concentration based on super saturation fitting in a microphysical model.

MA Jianzhong, et al have given an exhaustive account of the Recent Progress in Cloud Physics Research in China during the period 2003-2006. They have dealt with the interaction between aerosol, cloud and radiation processes being the key issue in current climate research. Clouds absorb and reflect solar radiation affecting weather and climate. The authors have included in their paper cloud field experiments, cloud physics and precipitation, cloud physics and hail suppression, artificial rain enhancement, cloud physics and lightning and climate change. We shall give a brief account of this interesting paper.

Cloud physics and cloud model simulations. What is important is the evolution of cloud hydrometer spectrum and the precipitation. The authors could show that when the aircraft flew into stronger precipitating cloud bands, the spectrum was wider with an increase in mean diameter and concentration. During the operation of precipitation-enhancement for the measurement of vertical-integrated cloud liquid water-content, an airborne Upward-Looking Microwave Radiometer was developed.

In addition to measurements using aircraft, they carried out remote sensing on the ground base as a long-term observation and also being economical. It was shown that the initial fields of mesoscale numerical model including the retrieved cloud microphysical messages would be helpful for numerical now casting of the precipitation.

Observations for both macro and micro physical characteristics of clouds were carried out by using satellites also. For this, they have used Advanced Very High Resolution Radiometer. The effect of a precipitation enhancement operation using silver iodide was viewed by using NOAA-14 satellite. Some advanced studies in clouds could be done using the meterological satellite FY-1C which was launched on 10 May 1999.

Observations from base to the top of the cloud could be carried out during the heaviest rainfall also by using the Precipitation Particle Image Sensor, which is a balloon-borne video sounder from which images of precipitation particles could be
caught on a camera. In addition to the images, the video sounder could record electric charge on the particles, the ambient temperature, humidity and pressure.

**The precipitation mechanism:** For precipitation of stratiform clouds, a seeder-feeder mechanism was applied. The ice cloud (seeder cloud), mixed ice water layer and liquid water layer made a contrition to rainfall by 25.5%, 31.3% and 43.1% respectively. The precipitation of convective clouds is determined by cold cloud raining process. It is shown that graupels play an important role in the precipitation and their formation is closely related to ice crystals. The argument is that the warm rain process can make a contribution to precipitation even though cold rain process is the main precipitation mechanism.

The effects of cloud physical processes during a heavy rainfall can be studied by mesoscale models with explicit cloud schemes. The cloud top temperature of black body observed from a satellite was generally used to compare with the cloud-top temperature simulated by the model. The change of cloud droplet spectra can modify the microphysics and radiative process of the atmosphere which in turn affects the surface precipitation.

**Hail suppression:** Hail is formed due to an accumulation of super cooled raindrops. Former researchers with hail-bin microphysics used the hail cloud model to simulate the formation of growth of hail storm. The hail storm intensity and hail size depend on mesoscale humidity and dynamics. They also showed that the formation and growth of hails are due to cloud condensation mechanism. Heat and mass transfers play a critical role during the hail growth. It was found that the simulated melting rate, evaporation rate and dry-wet growth rate of a hailstone increases by 12-50%, 10-200% and 10-40% respectively. Seeding tools of silver iodide containing artillery shells and rockets are widely used in hail suppression. The mechanism of hail suppression proposed by them is that a number of seeding ice crystals are produced by seeding so as to increase the graupel and frozen drops. The size of the hailstone will be decreased resulting a decrease in its intensity and kinetic energy. The mechanism of Cave Channels has been proposed for hail suppression.

**Artificial rain enhancement:** Stratus clouds are usually observed during the dry seasons and precipitation can be done on those clouds. The authors have suggested
that supersaturated water vapor with respect to ice would be converted into precipitation after ice seeding besides super cooled water, and the release of sublimation latent heat leads to the increase of temperature and an updraft in the seeded cloud regions, thereby facilitating a cloud precipitation. Silver iodide seeding should be done before the activation of ice nuclei so as to improve the enhancement. Increasing ice crystals and decreasing super cooled water are recommended. There is a quantity known as ‘quasi-precipitation efficiency’ defined as the ratio of precipitation water to the total water resource in the atmosphere over the region. It is found that the efficiency is better with silver iodide than any other such as liquid carbon dioxide.

Lightning:- Somewhere in the beginning of this chapter, we mentioned that cloud acts as a capacitor and produces thunder and lightning. The lightning density depends on the latitude and distance from the coastal areas. Experiments confirmed the existence of a lower positive charge region involved in the lightning discharge and also revealed the inverted charge structure opposite to the normal polarity.

The authors of the view that the cloud physics research creates interest in studying cloud physics from a variety of topics covering cloud field experiments, planned weather modification, cloud precipitation and rain enhancements, etc. The in-cloud conditions were really revealed by the experiments using aircraft.

Yahui Huang, et al have extensively dealt with the development of ice in a cumulus cloud over southwest England. They carried out experiments on 4 July 2005 in Cornwall, southwest England using FAAM BAe 146 aircraft called the ICE and Precipitation Initiation in Cumulus (ICEPIC) project.

The development of precipitation in convective clouds through the ice process remained a key problem in cloud physics. What is needed is to forecast the location, timing and quantity of precipitation. Ice particles will be formed in the clouds at temperatures between –4 and –10°C by primary ice nucleation. The process that works in cumulus clouds is the Hallet-Messop process in which ice particles were produced between –3 and –8°C for both small \( (d \leq 13 \ \mu\text{m}) \) and large \( (d \geq 24 \ \mu\text{m}) \) cloud drops to co-exist with graupel particles. The rate of production of ice crystals can be appreciably increased in the presence of super cooled rain drops, which can be a source of secondary ice crystals due to the ejection of ice particles. One has to identify ice nuclei
for example, desert dust and the same is difficult in real clouds. The experimenters caused a transition by ice nucleation initiated by oxidized organic aerosol coated with sulfate in the most polluted areas of the clouds.

The authors have presented in the paper a limited number of measurements of the development of ice in a cumulus cloud and compared the same with the results of a 2D cloud model with sophisticated microphysics. Measurements were carried out with the help of fast forward scattering spectrometer probe, cloud and precipitation probes, along with the cloud particle imager.

The aircraft penetrated a system of clouds as they ascended and experiments were conducted on clouds lying at heights between 3 km and 6 km. The line of clouds were aligned with the wind in an IMW-SE direction. The 0°C level was at an altitude of about 1.8 km. The direction of wind was west to west-north-west and the speed was 8 ms$^{-1}$ near the surface increasing to about 12 s$^{-1}$ at an altitude of 2 km. Four penetrations were made near ascending cloud tops between pressures 720 and 675 mb.

**Mathematical treatment (Rate of production of Ice) (Credit: 7.8):**

The rate of production of ice, $P_0$ (observed) was calculated according to the formula given by Harris-Hobbs and Cooper as under:

$$P_0 = \frac{[Cd(L_2) - Cd(L_1)]}{t_{21}}$$

where $Cd(L)$ is the cumulative size distribution for crystals smaller than $L$; $t_{21}$ is the time for growth between $L_1$ and $L_2$ and given by

$$t_{21} = \frac{(L_2 - L_1)}{G(T)}$$

here $G(T)$ is average growth rate of ice particle.

The predicted rate of production, $P$ is calculated from the formula,

$$P = C f(T) \int_{r_0}^{R_0} g(R) \pi (R + r)^2 [V(R) - v(r)] N(R) n(r) E(R, r) dR dr,$$

Here, $R$, $V(R)$ and $N(R)$, $[r$, $v(r)$ and $n(r)$ are, respectively the graupel (droplet) equivalent radius, fall speed and size spectrum, $E(R, r)$ is the collection efficiency for graupel-droplet collisions. $C$ is a coefficient depending upon the cloud collisions and has values 0.146, 0.207 and 0.117 for experiments Q15, Z14 and H13 respectively; $R_0$ and $r_0$ are the respective minimum sizes for $R$ and $r$ that lead to secondary ice production.
The function \( f(T) \) is unity at \(-5^\circ C\) and linearly vanishes to zero at \(-3\) and \(-8^\circ C\). The function \( g(R) \) is given by

\[
g (R) = \frac{\int_{r<6.5} n (r) r^2 E (R, r) \, dr}{\int_{\text{all}} n (r) r^2 E (R, r) \, dr}
\]

The three values of the coefficients, \( C \) are from the results of experiments by Messot.

It was observed that there was a marked increase in the concentration of ice particles at a height of 3 km after 45 minutes and the concentration was 37 and 23 cm\(^{-3}\) and the same after 50 minutes was 20 and 10 cm\(^{-3}\).

A sensitivity test was performed with aerosol particle concentration almost double to see whether there is any glaciation and precipitation and it was found that the quantity of warm rain delayed for 5 minutes and got decreased. But, however, the Hallett-Messop process increased the concentration of small cloud droplets.

And finally, in the following Fig. 7.8 is shown a typical aircraft used for cloud physics research.

**Conclusion:-** Clouds occupy about 60% of the Earth’s surface as is evident from the Nasa satellite image shown in Fig. 7.9. Apart from giving us rain, clouds work as an envelope over the surface of the Earth in controlling the heat of the Sun.

When the continents and oceans were formed, almighty in creating clouds so as to control the climate for better life on the planet. If there were no clouds, the radiant heat from the Sun continuously falling on the surface of the Earth, will increase the temperature and make life one of discomfort to live in. We may not always see the clouds above the sky. This is because of the curvature of Earth. If there is no cloud in one region, it is certainly there in another region in the neighborhood. There is no question of
clouds permanently disappearing or getting exhausted. Water formed from the clouds flows as rain into the rivers and oceans which on evaporation give rise to formation of clouds and the water cycle is maintained.

Thus, formation of clouds is really an ideal physical process created by the almighty in order to maintain life on the Earth.

REFERENCES:
