

CUMULUS AND STRATUS CLOUDS MICROSTRUCTURE

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Summary: Clouds are the most visible elements of the sky and significantly contribute to the weather we experience every day. Clouds play an important role in the global energy and water budgets and affect the climate of the Earth. The presence of clouds affects the radiation balance of the region, the temperature of the air and exposed surfaces. Cloud formation requires moisture, aerosol particles and a process of cooling the air. The properties of many minute particles, that make up the cloud, characterize its microstructure. The special flight laboratory of University of Žilina presents unique device for obtaining information especially concerning the cloudy formation (base and upper-level cloudiness, state of matter, visibility in particular cloud types), turbulence, icing and concentration of the environmental gases and short-waves and long-waves radiation as well. This laboratory is a part of project „Centre of Excellence for Air Transport“ ITMS 26220120065 and will be irreplaceable source of meteorological information within the airport area and equally along chosen flight route.

Key words: Water vapour. Cloud microphysics. Cumulus clouds. Stratus clouds. Water droplets.

INTRODUCTION

Water vapour plays a crucial role in atmospheric processes and is the most variable of the major constituents of the atmosphere. It contributes more than any other component of the atmosphere to the greenhouse effect. The distribution of water vapour is intimately coupled to the distribution of clouds and rainfall. Because of the unusually large latent heat associated with water's change of phase, the distribution of water vapour plays a critical role in the vertical stability of the atmosphere and in the structure and evolution of atmospheric storm systems. The advection of water vapour and its latent heat by the general circulation of the atmosphere is an important component of the Earth's energy balance. In addition, water plays a critical role in many chemical reactions that occur in the atmosphere.

1. THE ROLE OF WATER VAPOUR IN CLOUD FORMATION

There is a strong interaction between temperature and moisture. Warmer air can hold more water vapour at equilibrium than colder air. Air that holds this equilibrium amount is saturated. If the air is cooled below dew point temperature, some of the water vapour condenses into liquid. Release of latent heat warms the air.

When unsaturated air parcel is lifted, it cools dry-adiabatically. If it is lifted high enough, its temperature T will drop to the dew point temperature T_d and cloud will form. Dry air must be lifted higher than moist air; saturated air needs no lifting at all. The height at

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which saturation occurs is the lifting condensation level LCL (saturation level). It can be used as a measure of humidity and for cumuliform clouds is very well approximated by

$$z_{LCL} = T - T_d \quad (1)$$

Where $a=0,125 \text{ km}/^\circ\text{C}$. This expression cannot be used for stratiform clouds because they are not formed by air rising vertically from the surface. LCL level serves as a measure of total water content for saturated (cloudy) air. Clouds or fog forms when the total water content of the air exceeds the saturation value.

2. CLOUD MORPHOLOGY AND MICROSTRUCTURE

Clouds are the main regulators of the terrestrial climate. It is important to monitor their properties (e.g., vertical and horizontal dimensions, cloud cover) on a global scale. Information on amount and cloud base position is of great importance for aviation. The individual water droplets and ice crystals that constitute a cloud are created by condensation and lost by evaporation or precipitation. The cloud continues to live by steady creation of new droplets.

Clouds are classified according to their visual appearance from the ground. The complete international classification distinguishes three major cloud types:

- *cumulus* clouds with vertical development,
- *stratus* clouds in flat-appearing layers,
- *cirrus* clouds with fibrous or smooth appearance.

Clouds are classified into ten genera; each of them can have several species and varieties. Low clouds with bases up to 2 km include Stratocumulus, Stratus, Cumulus and Cumulonimbus. Mid-level clouds, with bases between 2 and 7 km, include Altocumulus, Altostratus and Nimbostratus. High clouds with altitude more than 7 km include Cirrostratus, Cirrocumulus and Cirrus (fig. 1). The most important clouds for air transport are low-level clouds.

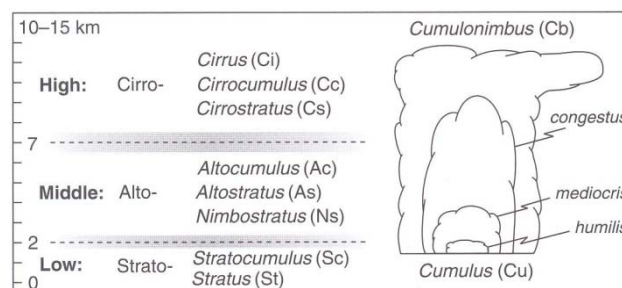


Fig. 1 - Schematic summary of the major cloud types (Source: Lamb and Verlinde, 2011)

Microstructure of the cloud is described in terms of temperature, vapour content, vertical velocity, liquid water content and cloud droplet spectra. During the last 40 years lots of instruments and experimental techniques has been developed to measure these quantities, e. g. radar, lidar and other remote sensing techniques for measuring cloud properties. However,

the most reliable technique is in-situ measurement using research aircraft equipped with necessary sensors and instruments. The common instruments for measuring microphysical parameters of the cloud are:

- Temperature is measured by fast response thermometers (e.g. Rosemount sensor),
- Humidity can be recorded with a dew point hygrometer,
- Cloud liquid water concentration can be measured with Johnsons-Williams sensor, which deduces the water amount from the heat lost by hot wire due to the evaporation of the droplets,
- Vertical velocities are computed from the measurements recorded by an accelerometer and sensors for air speed, attack angle and sideslip angle,
- Cloud droplet spectra are measured with an instrument called forward scattering spectrometer.

2.1 Microstructure of cumulus clouds

Cumulus clouds are caused by convection in unstable air. Their horizontal and vertical extents are comparable. The vertical extent depends on the depth of the unstable layer and its degree of instability. A typical length of cumulus cloud is 3 km and can grow vertically throughout the troposphere and penetrate a few kilometres into the stratosphere. These clouds usually produce rain, lightning and thunder and are called Cumulonimbus clouds.

Microstructure of cumulus cloud is usually a function of height. Measurements of updraft speed, temperature and liquid content show significant variations and indicate difficult dynamic, thermodynamic and microphysical processes in convective clouds. The microstructure of these clouds depends on cloud base temperature, type and concentration of condensation and ice nuclei, the stratification of temperature and humidity, vertical windshear and large scale convergence. Cumulus clouds have high liquid water contents which is associated with strong updrafts. The peak gusts are found in the upper third of cloud. The variability of the vertical air velocity indicates the presence of turbulence in the cloud. Cloud droplet diameter is between 2 and 30 μm and increases from the cloud base to the cloud top. In the middle and upper portions of the cloud the droplet concentration decreases with increasing altitude.

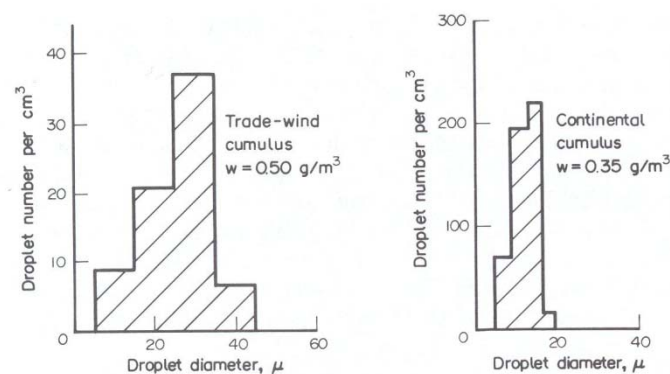


Fig. 2 – Droplet spectra in trade-wind cumulus and continental cumulus (Source: Rogers and Yau, 1996)

It is extremely difficult to make accurate measurements of humidity in cumulus clouds. Humidity sensors have a long response time and are not capable to measure rapid fluctuation in cloud. Therefore humidity information is obtained by other means. e.g. using simultaneous measurements of updrafts and droplet spectra.

2.2 Microstructure of stratus clouds

Stratus clouds are widespread cloud layers, which often cover areas of 10^6 km². They can be thin and non-precipitating or thick enough to produce widespread rain or snow. They are formed by frontal lifting or orographic lifting of air that is statically stable. Stratus cloud at the ground is usually called fog and may be caused by radiational cooling of the air near the ground, by advection or mixing of air masses, which have widely different temperatures.

Vertical air motions in stratiform clouds are much weaker than those in cumulus clouds (a few tens of centimetres per second). The weak, long-lasting ascent can produce widespread continuous rain. Stratus clouds appear to be horizontally homogenous, but there is a fine variability in clouds structure (fig. 3).

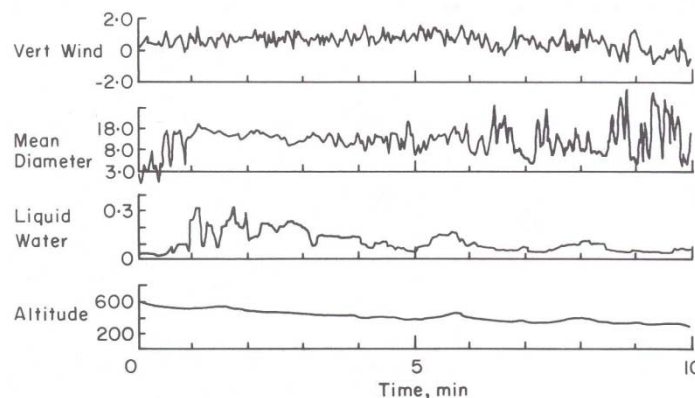


Fig. 3 - Records of vertical air velocity (m/s), mean droplet diameter (μm), liquid water content (g/m^3) and altitude in stratus cloud. (Source: Rogers and Yau, 1996)

Liquid water contents of stratus clouds are usually $0,05 - 0,25 \text{ g}/\text{m}^3$. In Stratocumulus and deep Nimbostratus the values can reach nearly $1 \text{ g}/\text{m}^3$. The average liquid water content over horizontal layers increases with height because of droplet sizes increase. The droplet concentration is approximately constant throughout much of the cloud.

Stratus clouds are often capped by the temperature inversion, which inhibits its vertical growth. Turbulent fluctuations near the cloud top cause mixing the dry air into the cloud layer. This leads to evaporation of droplets near cloud top. The evaporation causes cooling near cloud top leading to moving air parcels downwards into the body of the cloud. Significant cooling is also caused by loss of longwave radiation from cloud top.

2.3 Probability of ice in clouds

When a water cloud is cooled to temperatures below 0°C there is a chance that ice crystals will begin to appear. In the atmosphere there is a weak supply of particles that can

serve as centres of ice formation. Ice crystals are not observed until the cloud is cooled to -10°C or less. The cloud water in supercooled state common appears in the atmosphere. Because concentration of ice nuclei varies in time and space, it is not possible to say at what temperature and how many ice crystals will appear.

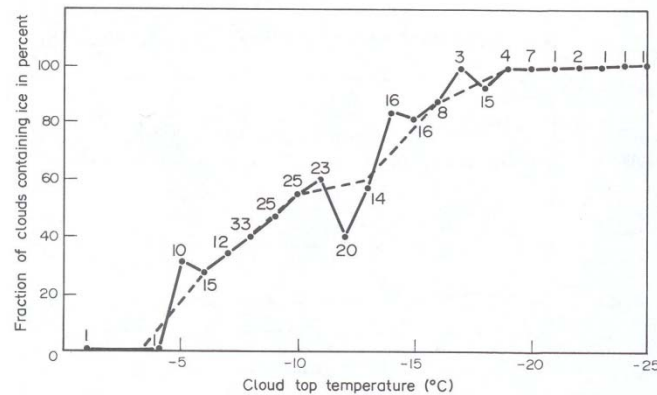


Fig. 4 – Clouds containing ice in dependence of cloud top temperature. The number above each point is the number of observation at that temperature. (Source: Rogers and Yau, 1996)

Ice formation depends also on cloud type, cloud age and geographical location. Precipitation develops more likely in cloud that is thick and contains ice. The continental clouds must be thicker than maritime clouds for the same probability of precipitation. In maritime clouds there are few droplets but of large size, which can collide and coalesce with each other.

CONCLUSION

Moisture and aerosol particles affect the ability of clouds to produce precipitation. These two components regulate the radiative properties of clouds. Atmospheric moisture originates near the surface from evaporation of surface water and transpiration of plants. Moisture is transported upward by atmospheric motions. The surface is also dominant source of aerosol particles serving as condensation nuclei. The particles making up the cloud may be solid, liquid or mixture of both. Clouds made solely of liquid droplets are termed warm clouds. Warm clouds typically form in the lower atmosphere when ice is not important to cloud microphysics. The development of warm cloud depends on condensation which is activated on aerosol particles and causes initial growth of liquid droplets. Subsequent processes collisions between droplets, coalescence and disruption during the formation of mature cloud. Such processes can occur also in colder clouds, containing ice particles, in case that ice does not interfere significantly. Cloud droplets grow from small (radius app. $10\ \mu\text{m}$) to large (radius app. $1\ \text{mm}$) raindrops. Rain formation requires relatively large droplets. Cold clouds involve both ice and liquid water and are therefore more complicated than warm clouds.

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