Convection and Heat Transfer in the Atmosphere

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The dew point: cumulus clouds and flat bottoms

As solar radiation warms the ground soon after sunrise, air is warmed and expands. As parcels of warm air are driven upwards by buoyancy forces they expand further and cool. In dry air convection soon stops. A dry atmosphere is stable with temperature reducing by 9.8 °C per km (the dry-air *lapse rate*). The situation becomes unstable and more interesting if water vapour is present.

Moist-air rises and cools like dry air until it reaches the dew point level where water vapour begins to condense into droplets of liquid water (clouds). On humid mornings in tropical places like Bangkok and Rayong, glasses and camera lenses fog up when taken outside for the same reason: because the temperature of the item taken from an air conditioned room is below the dew point of the air outside. As clouds form, latent heat is released and the rising air cools more slowly. The moist-air lapse rate is around 6.5°C at low levels. The rising parcel of moist air that now contains a cloud is not as cold as the surroundings and convection continues upwards. The effect can be seen in the image below.

Fig 1 – flat bottomed cumulus clouds at Jomtien. Image: Bob Hayden-Gilbert.

Cloud forms at the dew point level. Convection continues upwards because of the release of latent heat. At high levels the rising cumulus cloud begins to evaporate.

Convection can only take place if cooler air is displaced downwards. Convection flows are turbulent. In a flat pan of heated water and in the atmosphere the currents form *convection cells*. A cloud forms at the top of each cell in a semi-regular pattern like sheep in a field.

Fig 2 – clouds on convection cells over Sukhothai.

The same effect is seen in a stereo image taken from a plane on approach to Bangkok.

Fig 3 – cross-view stereo pair of clouds at the dew point layer.

To view in 3D cross your eyes so that you see three blurred images, one beside the other in a horizontal line. Pay attention to the central image and wait for your brain to refocus your eyes. When that happens the central image will become clear and pop into 3D.

Pyrocumulus: upward convection above a fire

In figure 4 water droplets have condensed on smoke particles from burning rice straw and the release of latent heat has driven vertical convection with some rotation. At high levels the cloud is evaporating. This type of cloud is known as pyro-cumulus, pyro meaning fire. In the second example (figure 5) the cloud has formed in the same way but the convection has taken a different form.

Fig 4 – convection with rotation above a rice straw fire outside Bangkok.

Fig 5 – convection above a fire in Bangkok, capped at a layer of warmer air.

Anvil clouds: stalled upward convection

When a rising cumulus cloud reaches a layer of reduced lapse rate the release of latent heat may be insufficient to maintain the vertical motion of the cloud mass and the cloud spreads into what is known as an *anvil cloud*. In Thailand, with little wind and high humidity, saucer shaped anvil clouds form at low levels.

Fig 6 – a spreading anvil cloud in Bangkok.

A rising cumulus cloud may spread for some time at an inversion layer (a region of lowered lapse rate) until breakout convection continues the upward resumes the upward rise of the cloud.

Fig 7 – breakout convection above a recently formed anvil cloud in Bangkok.

We have several images of breakout convection from the Bangkok area but no time lapse video. With the availability of weather-proof cameras wth time-lapse functions it may be possible to to collect this footage, but in the meantime single images are all we have. In the absence of video figure 8 below shows that the phenomenon depends on the conditions and is not an accident. Three anvil clouds are shown at sunset in Songkla in southern Thailand. The cloud on the left was almost identical to the other two when first seen but by the time the camera was brought upstairs it had begun to dissipate.

Fig 8 – anvil clouds and breakout convection in Sonkhla. Image: Martin Nicholson.
https://www.flickr.com/photos/jacobs_ian/39025525740/in/dateposted-public/

Mammatus clouds: downward convection

Convection in the atmosphere is normally driven by the release of latent heat and clouds expand upwards, but that is not always the case. When the density of air air in a cloud layer is slightly greater than that in a layer of very humid air below, slow gentle downward convection may result and the bottom of the layer breaks up into hanging bags. The cloud formation is known as mammatus and is normally seen after heavy rain at relatively low levels (1000 -3000 m).

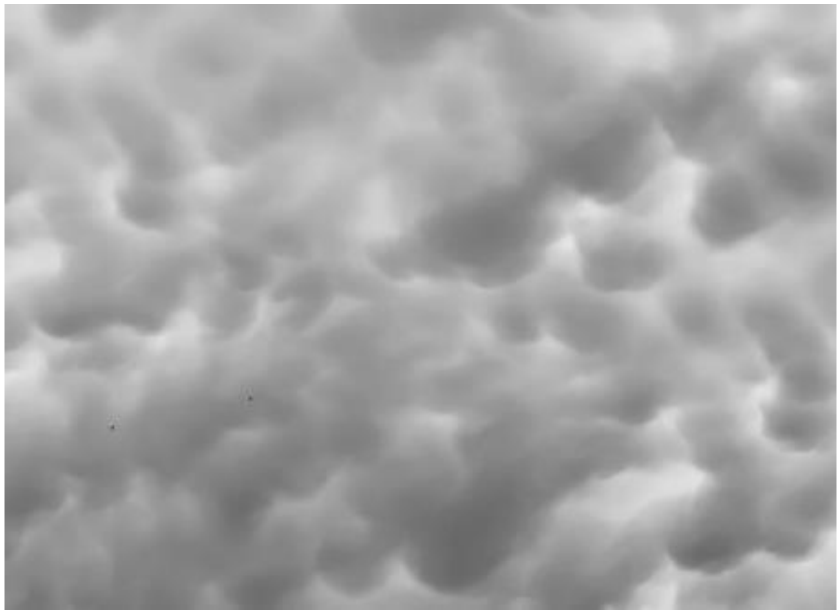

Fig 9 – downward convection in the afternoon over Bangkok.

Mammatus is unusual but is a spectacular sight, especially when bottom-lit at sunset, and is often photographed.

Fig 10 – mammatus at sunset over Bangkok.

Mammatus (downward convection made visible by cloud) may occur at high levels. Figure 11 below shows cirrocumulus cloud made up of super-cooled water droplets at ~ 40°C in the very clean air above the ice of engine tails behind a passing plane.

Fig 11 – cirricumulus-mammatus at sunset over Bangkok.

The final image in this series shows downward convection visible in a rare cirrocumulus-mammatus formation that looks like ink falling in warm water.

Fig 12 – high level downward convection.

Further reading

The lapse rates: 9.8 °C/km in dry air and 6.5 °C/km in moist air, are discussed in simple terms on the web along with the ideal gas law and adiabatic cooling.

http://eesc.columbia.edu/courses/ees/climate/lectures/atm_phys.html