Clouds

Textbooks and web sites references for this lecture:

- Joseph M. Moran e Michael D. Morgan, Meteorology, The Atmosphere and the Science of Weather, Mc Millan College Publishing Company, 1994, ISBN 0-02-383341-6 (§ 7)

Clouds

- Clouds just don't happen - there's always a "reason"
- A particular cloud's shape and location depend on (and can therefore tell us about): the movement of the air; amount of water vapor in air; stability (flat clouds = stable air while puffy clouds = unstable air)

Clouds result when air becomes saturated away from the ground

They can

- be thick or thin, large or small
- contain water drops and/or ice crystals
- form high or low in the troposphere
- even form in the stratosphere (important for the ozone hole!)

Clouds impact the environment in many ways

- Radiative balance, water cycle, pollutant processing, earth-atmosphere charge balance, etc….

Cloud Classification

In 1803, Luke Howard devised the basic system of cloud classification, still used today

Based on Latin names

Two parts to a cloud's name:

- Shape (example: cirrus, stratus, cumulus)
- Height (cloud base & vertical extent)

but also important is the appearance of the cloud

Shapes

- Cirrus = curly and wispy
- Stratus = layered or stratified
- Cumulus = lumpy or piled up

Heights

- Cirrus = high level (bases above 7 Km)
- Altus = mid level (bases 2-7 Km)
- Nimbus = producing precipitation
- Cumulus = vertically extended

Classification of clouds using *latin* names

- Based on their **form**:

  cirrus, i.e. fibrous (*cirrus*=hair) as formed by ice

  layered, i.e. most developed horizontally than vertically, also disposed in many vertical layers, associated with small verical velocities (≅ 30 m/s or more)

  cumuliform i.e. puffy, covering small areas, associated with large vertical velocities (≅ 30 m/s or more)

- Based on the **heigth of their basis**:

  high (7-18 Km), with T < -25 °C formed completely by ice

  medium (2-7 Km), with (-25 < T < 0) °C composed by supercooled water sometimes mixed with ice

  low (0-4 Km), with T > -5 °C composed by water droplets

  vertically developed (0-3 Km), they begin at the LCL

- Subclassified on the basis of their **somatic characteristics**:

  castellanus developed with tower shape

  congestus crammed in piles

  fractus indented

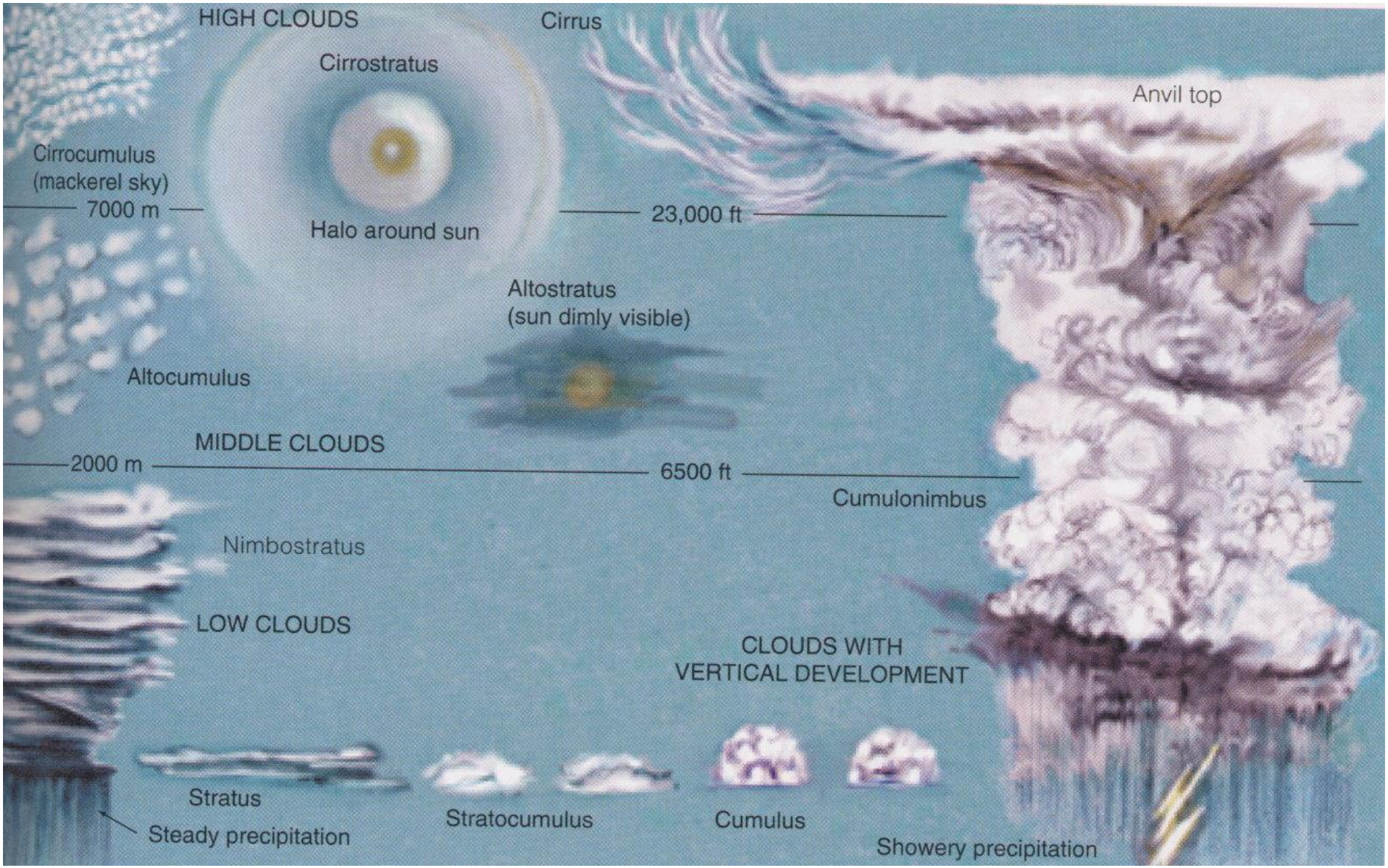
  humilis vertically not much developed

  lenticularis shaped like a lens

  mammatus with roundish protrusions

  uncinus shaped like a hook

Cloud type summary



High Clouds

- High clouds
  - White in day; red/orange/yellow at sunrise and sunset
  - Made of ice crystals
  - Cirrus (=hair)
    - Thin and wispy
    - Move west to east
    - Indicate fair weather
  - Cirrocumulus
    - Less common than cirrus
    - Small, rounded white puffs individually or in long rows (fish scales; mackerel sky)
  - Cirrostratus
    - Thin and sheetlike
    - Sun and moon clearly visible through them
    - Halo common
    - Often precede precipitation

- Cirrus = high altitude wispy clouds
- Quite thin and often have a hairlike or filament type of appearance.
- Made up of ice particles
- The curled up ends (called mares' tales) as depicted in the following picture are very common features.

High Clouds: cirrus

Cirrus

Cirrocumulus

- Cirrocumulus (Cc): high cumulus cloud, composed by small roundish white globes disposed in wave-like way, rarely cover all sky and can show shadows; it is possible to see individual “puffy” features

Cirrocumulus

Cirrostratus

Cirrostratus (Cs): high-level stratus clouds, not as thin as cirrus and less defined than cumulus; nearly transparent, leaves sunshine to pass (more or less), forming a white thin veil (or sheet) partially or totally covering the sky; it can show shadows

Cirrostratus

Contrails

PSC Cloud Photo

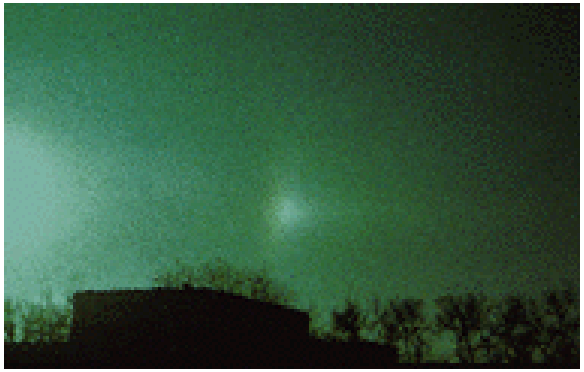
- Contrail is short for “condensation trails”
- Formed from vapor contained in the exhaust of a jet engine when it condenses in cold air aloft
- After some time it becames a cirrus cloud

Middle Clouds

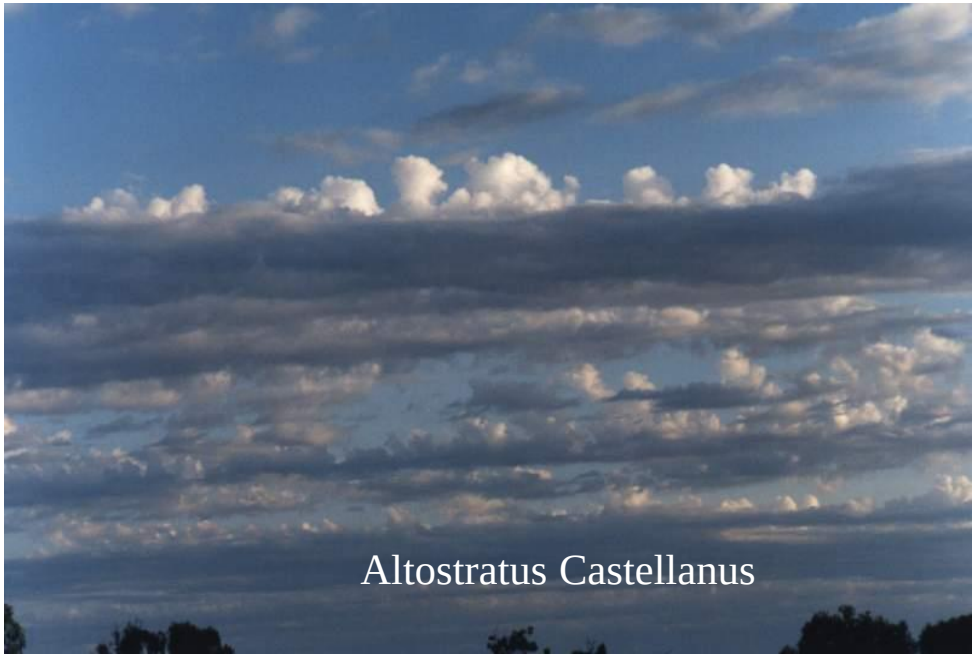
- Altocumulus
  - <1 km thick
  - mostly water drops
  - Gray, puffy
  - Differences from cirrocumulus
    - » Larger puffs
    - » More dark/light contrast
- Altostratus
  - Gray, blue-gray
  - Often covers entire sky
  - Sun or moon may show through dimly
    - » Usually no shadows

Altostratus

•Altostratus (As) uniformed -gray layers that can cover all the sky, with such thickness can totally darken the Sun or create halos; they can give light rains.



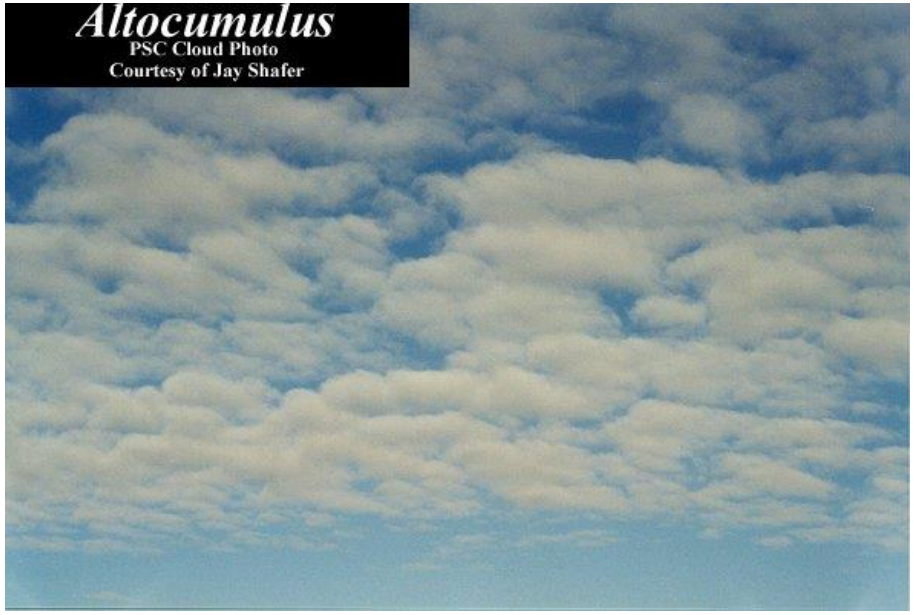
Altostratus



Altocumulus

- Altocumulus (Ac): midlevel cumulus clouds; spots or puff sometimes waved or bands parallels (due to wave also no orographic), of dimensions > Cc, with net contours (water vapor), sometimes disposed contours in more layers

Altocumulus



Low Clouds

- Stratus
  - Uniform, gray
  - Resembles fog that does not reach the ground
  - Usually no precipitation, but light mist/drizzle possible
- Stratocumulus
  - Low lumpy clouds
  - Breaks (usually) between cloud elements
  - Lower base and larger elements than altostratus
- Nimbostratus
  - Dark gray
  - Continuous light to moderate rain or snow
  - Evaporating rain below can form *stratus fractus*

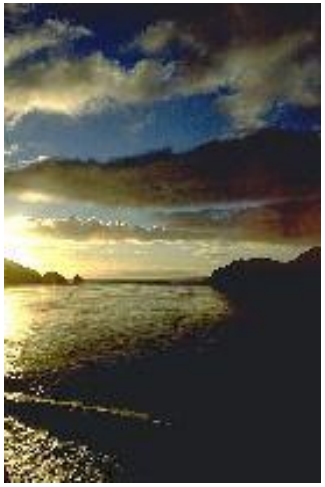
Nimbostratus

Nimbostratus (Ns) between middle clouds and those lower parts, extended jagged darkgray (between Sc and St) because of moderately thick, somtimes it is associated with Cb which provoks shower, alternating rainfall more weak but persistent.

Stratocumulus

- Stratocumulus (Sc): shape of large puffy or coils separated by serene sky, sometimes it is disposed undulates in the presence of atmospheric wave , rarely brings rains

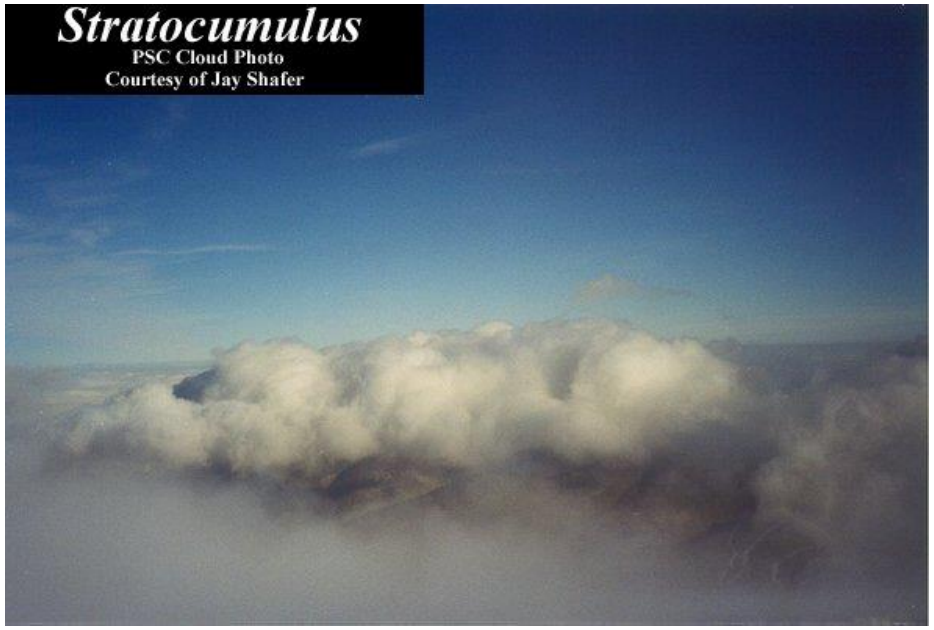






Stratocumulus

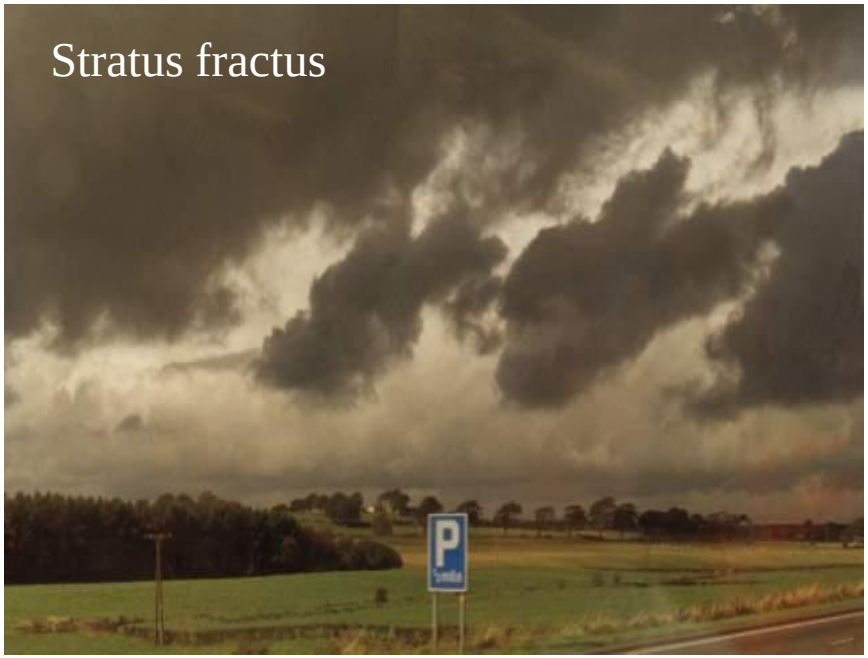


Stratus

- extended grey-uniformed covering all the horizon and also the peaks of hills (high fog), sometimes can “come down” until earth (fog), produces only drizzles

Stratus

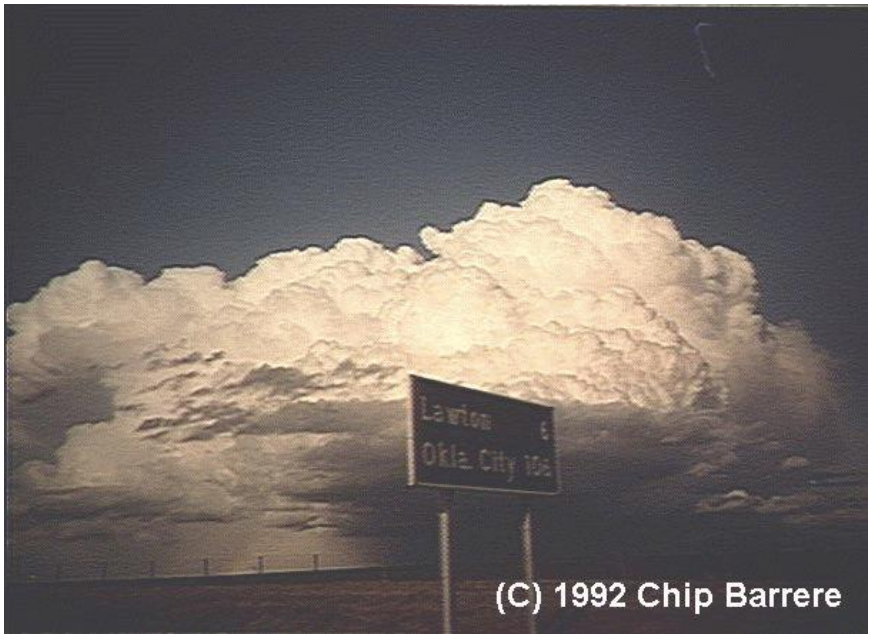
- Stratus clouds are usually the lowest clouds
- Often appear as an overcast deck, but can be scattered
- The individual cloud elements have very ill-defined edges compared to cumulus
- Fog is just stratus clouds lying down on the surface



Stratiform cloud layers

Vertically developed clouds

- Cumulus
  - Puffy “cotton”
  - Flat base, rounded top
  - More space between cloud elements than stratocumulus
- Cumulonimbus
  - Thunderstorm cloud
  - Very tall, often reaching tropopause
  - Individual or grouped
  - Large energy release from water vapor condensation



Cumulus Clouds

- Cumulus clouds are puffy (like popcorn, cauliflower)
- Often have noticeable vertical development
- Cells can be rather isolated or they can be grouped together in clusters as shown
- The base of a cumulus cloud can look like a stratus cloud if it is overhead.
- Thick cumulus can make skies dark (filters out sun’s rays)

Cumulus

- Cumulus (Cu) resembles to puffy of cotton punctuating the sky; their thickness follow the cycle of the solar radiation, with great cover in afternoon and dissolution towards evening; it does not give rain; since LCL depends on ground surface RH, their distribution and thickness depends on the surface (less frequent on sea, snow,…)

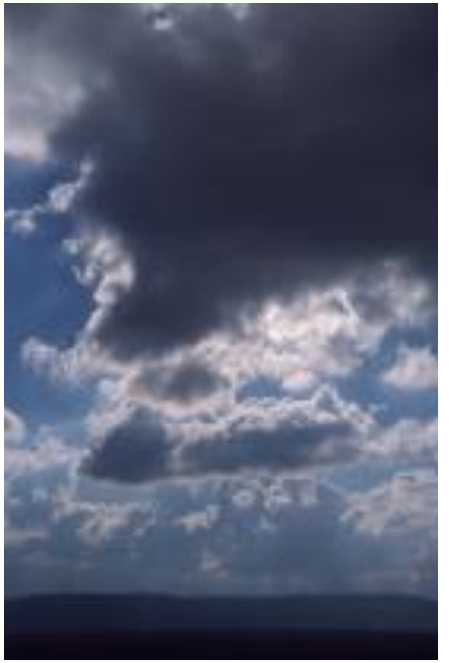






Cumulus congestus

- Cumulus congestus (Tc)when the atmosphere is a little bit unstable, the vertical extension of the Cu tends to be grow and the cloud assumes the typical aspect of cauliflower; it can cause isolated showers



Cumulonimbus

Cumulonimbus(Cb)when the ascending currents in the Tc catch up the tropopause and invert their way, they form the Cb; the strong descendent currents generate precipitations much intense (but short), also snow or hailstorm; sometimes it appears the anvil for distension of the air on climb in tropopausa and/or the stratosphere









- Cumulus clouds with precipitation and thunder/lightining activity

Cumulonimbus

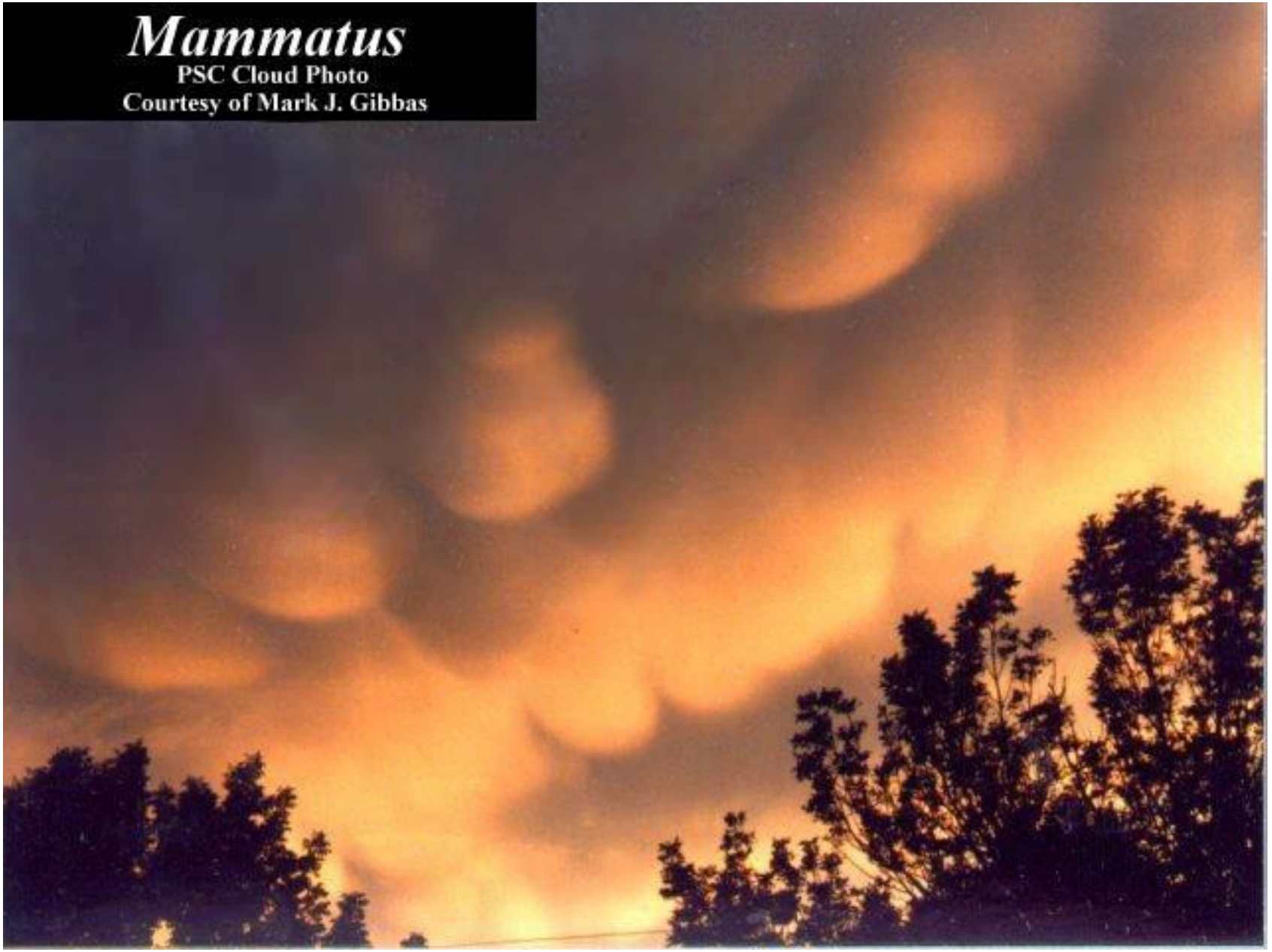
Cumulonimbus with anvil

Cumulonumbus with anvil

Cumulonimbus with Pileaus cap

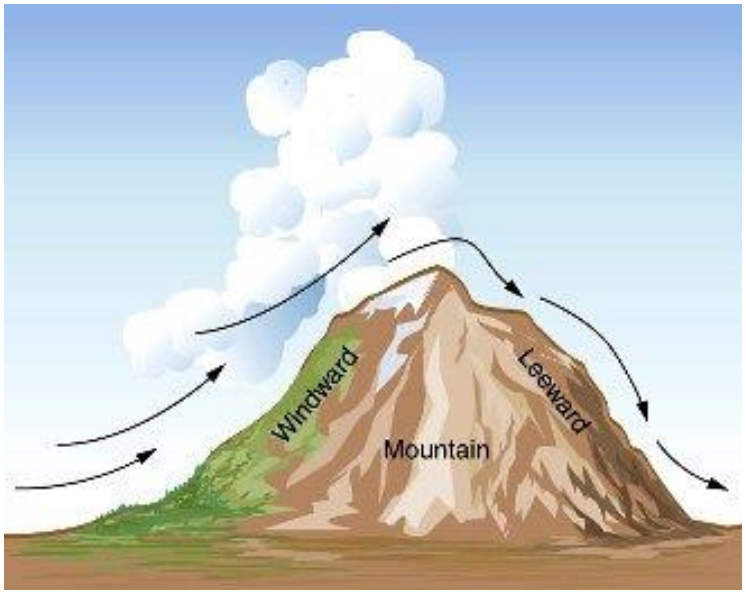
Cumulonimbus with tornado

Cumulonimbus mammatus



Orographic clouds

- Clouds can also be caused by mountains or hills
- Result to air flowing up and over mountains which causes condensation to occur and clouds to form
- Forced lifting along a topographic barrier causes air parcel expansion and cooling
- Clouds and precipitation often develop on upwind side of obstacle
- Air dries further during descent on downwind side



Cap Clouds

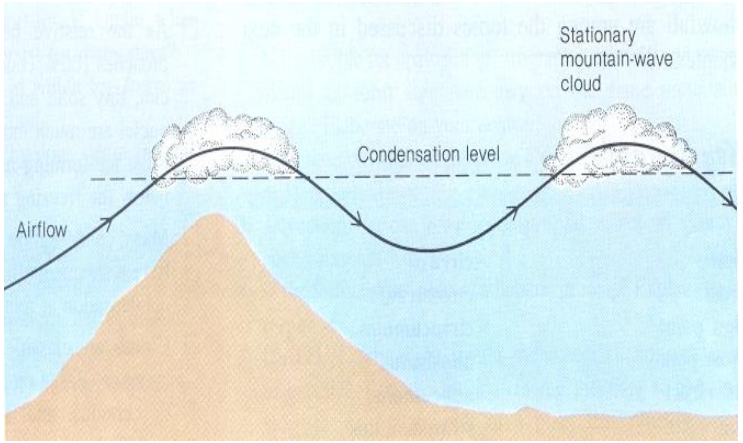
- Air containing water vapor lifted until it is saturated, producing liquid water cloud droplets which can "cap" the summit

Lenticular and flag clouds

- **Lenticular clouds** (like a lens) or orographic waves clouds look like flying saucers. They are created by the waved currents crossing the mountains when, in the crest of the wave, the LCL is reached or exceeded; they have a lens shape and remain nearly stationary because the generating waves are stationary; they enter in the category of Ac; usually present downwind to large mountain ranges (e.g. Alps during foehn conditions). Sometimes these clouds are formed only near the peak, extending leeward (flag **clouds)**





Lenticular clouds

- Stable air flowing over a mountain range often forms a series of waves
  - Think of water waves formed downstream of a submerged boulder
- Air cools during rising portion of wave and warms during descent
- Clouds form near peaks of waves
- A large swirling eddy forms beneath the lee wave cloud
  - Observed in formation of rotor cloud
  - Very dangerous for aircraft

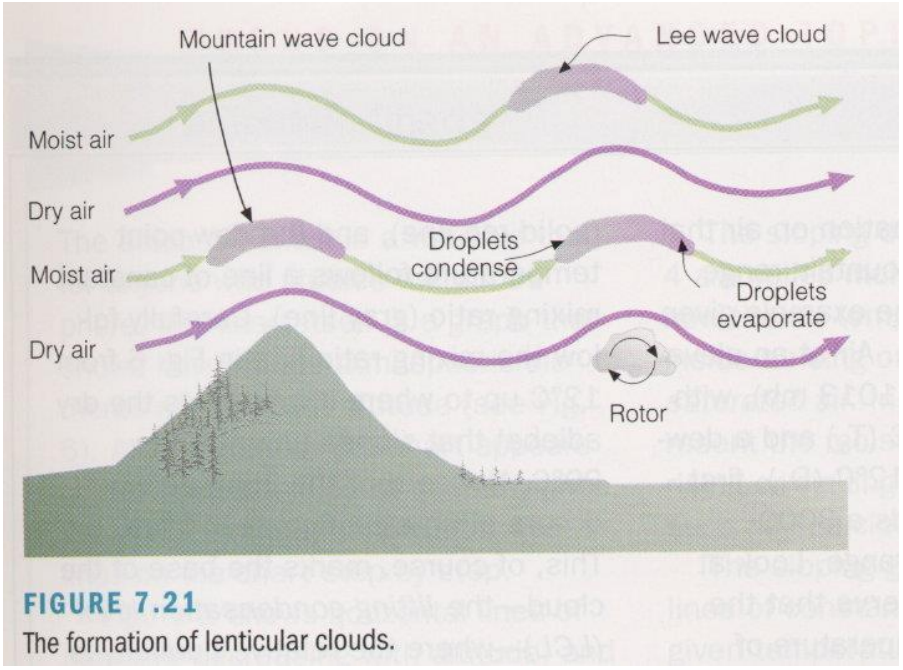
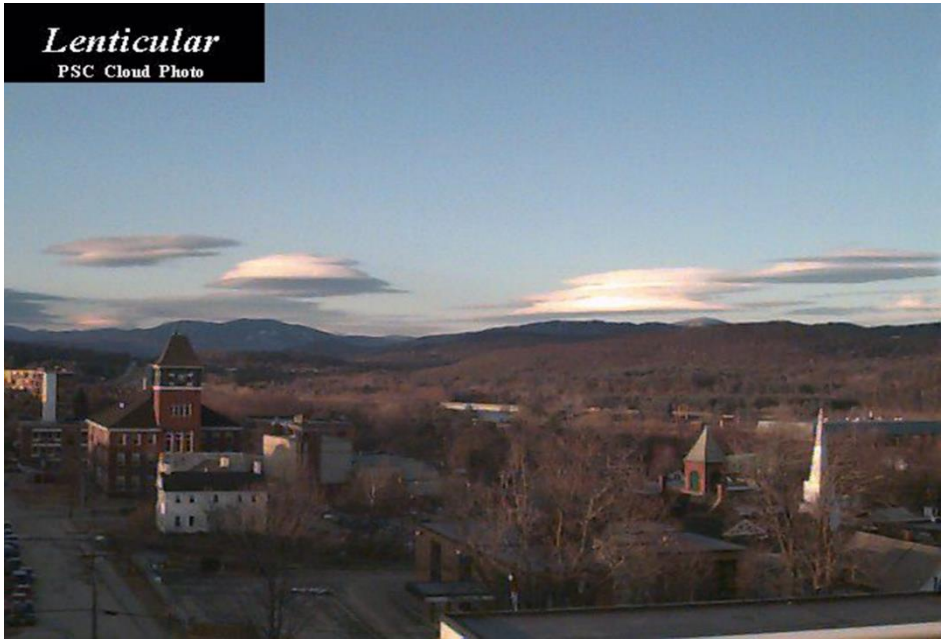
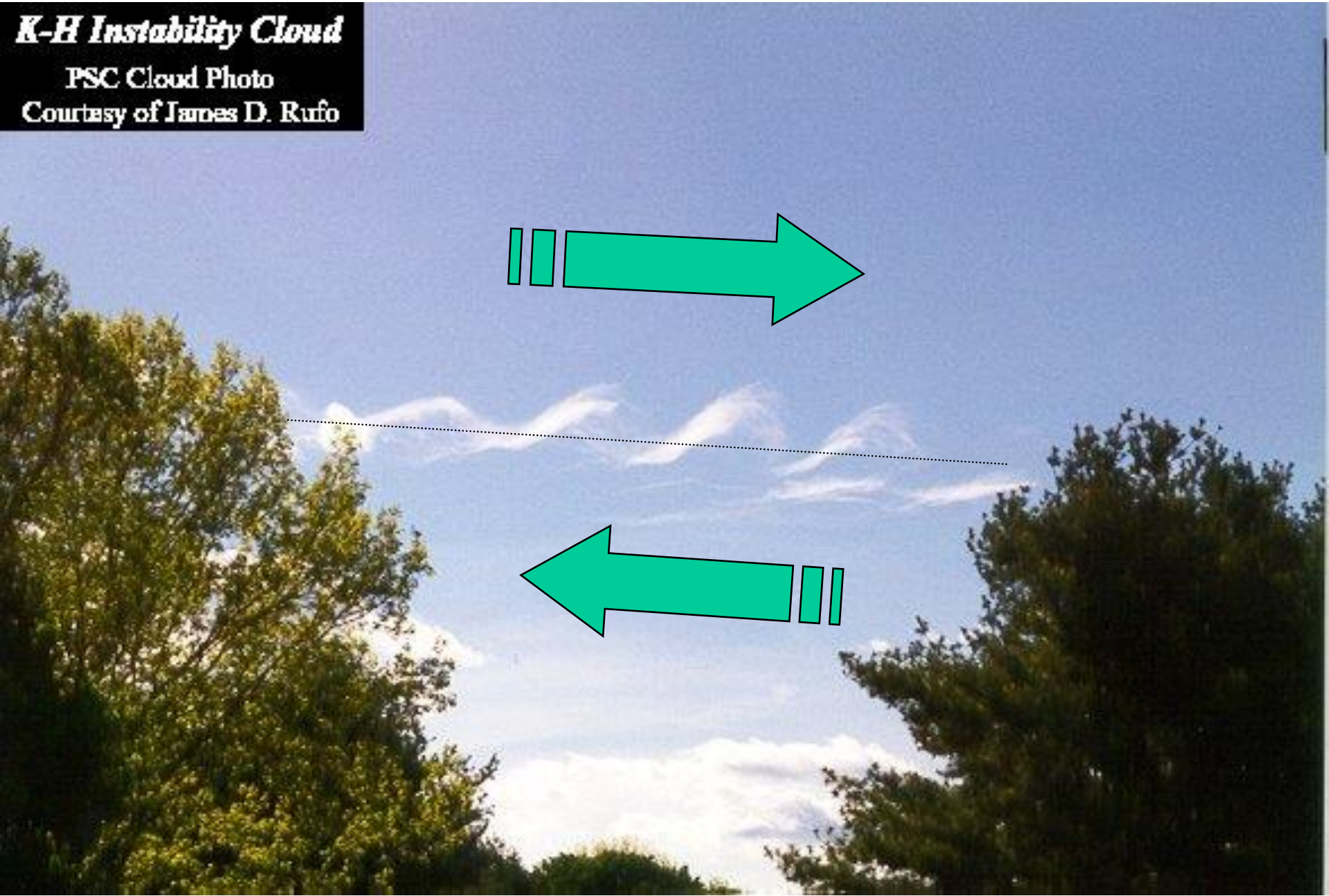


FIGURE 7.21
The formation of lenticular clouds.

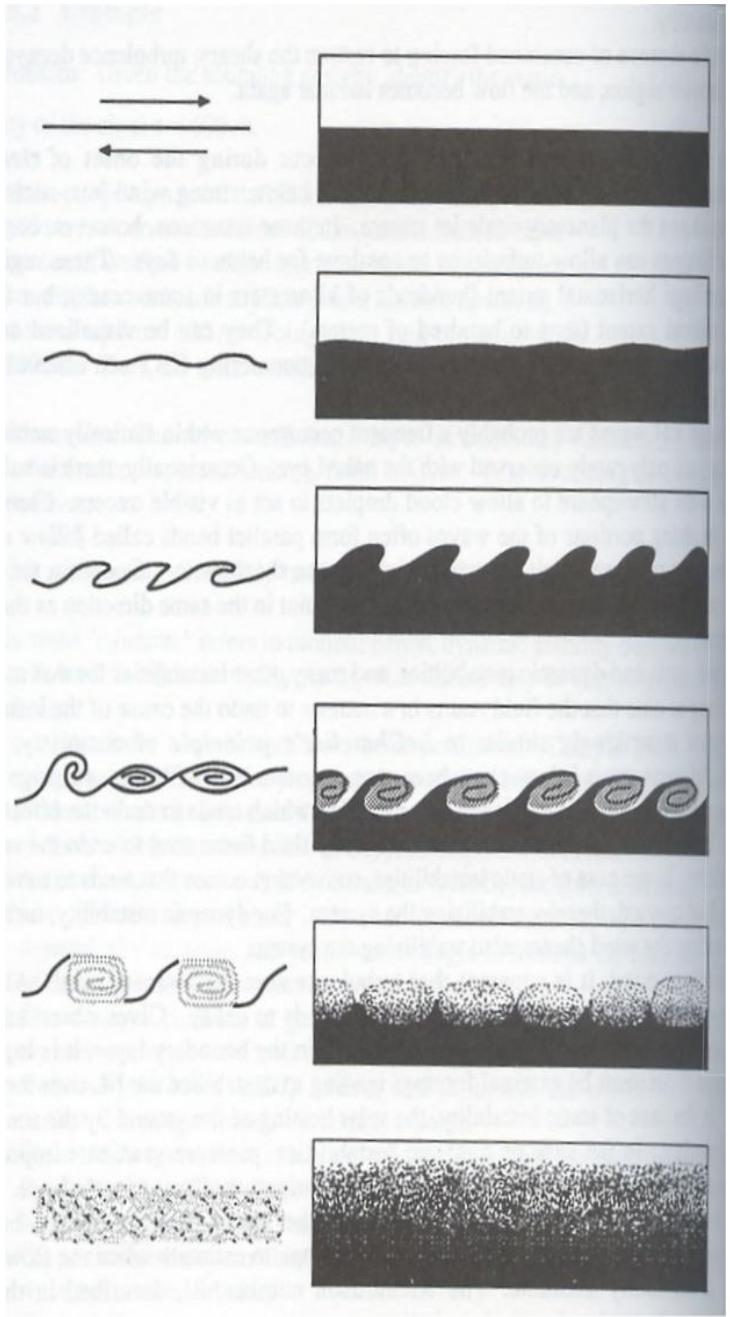


Lenticular clouds

Billow (Kelvin-Helmoltz) clouds



Kelvin-Helmholtz waves



- A shear exist across a density interface – initially, flow is laminar
- If a critical value of shear is reached, then the flow becomes dynamically unstable, and gentle waves begin to form at the interface (crests normal to the shear direction)
- Wave amplitudes continuously grow, eventually reaching the roll-up or breaking point (K-H wave)
- Within each wave, there exists some lighter fluid that has been rolled under denser fluid, resulting in patches of static instability (on radar, we see braided ropelike patterns, “cat’s eyes”)
- Static instability combined with continued dynamic instability caused each wave to become turbulent
- Turbulence spreads throughout the layer, causing a diffusion or mixing of the different fluids. In this phase, some momentum is transferred between the fluids, reducing the shear between the layers. The formerly sharp interface becomes a broader and more diffuse shear layer
- This mixing can reduce the shear before a critical value and eliminate dynamic instability. In this case, turbulence decays in the interface region, and the flow becomes again laminar

Clean air turbulence (CAT)

- The generation of Kelvin-Helmoltz waves is suspected to occur during onset of clean air turbulence (above and below jet streams)
- In these situations, however, continued dynamic forcing can allow turbulence to continue for hours or days
- These regions have large horizontal extent (even > 100 Km) but usually limited vertical extent (10-100 m) → large pancake-shaped regions of turbulence
- The CAT regions are rarely visible by naked eye, unless there is sufficient moisture in the atmosphere to allow cloud droplets to act as visible tracers: in this case, associated clouds (oriented perpendicularly to shear vector) are called ***billow clouds***

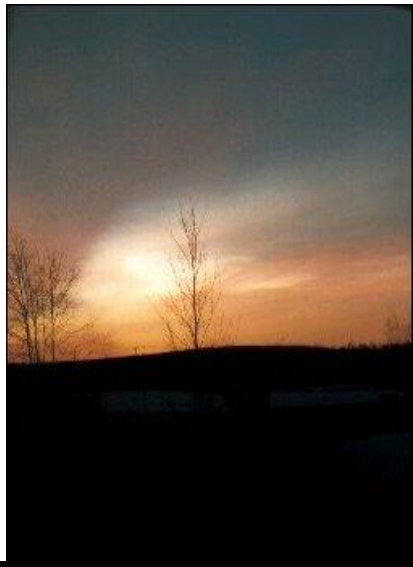
Arcus clouds

A **shelf cloud** is a low, horizontal, wedge-shaped arcus cloud. It is attached to the base of the parent cloud (usually a thunderstorm). Created by the cold air downdraft of convective clouds that force lifting of warm/humid air, with the leading edge called a gust front. The non-straight form is due to wind shear. Sometimes wrongly called as wall cloud as an approaching shelf cloud appears to form a wall made of cloud. Presence of twists or rising dust in a very low shelf cloud indicates a potentially violent wind squall.

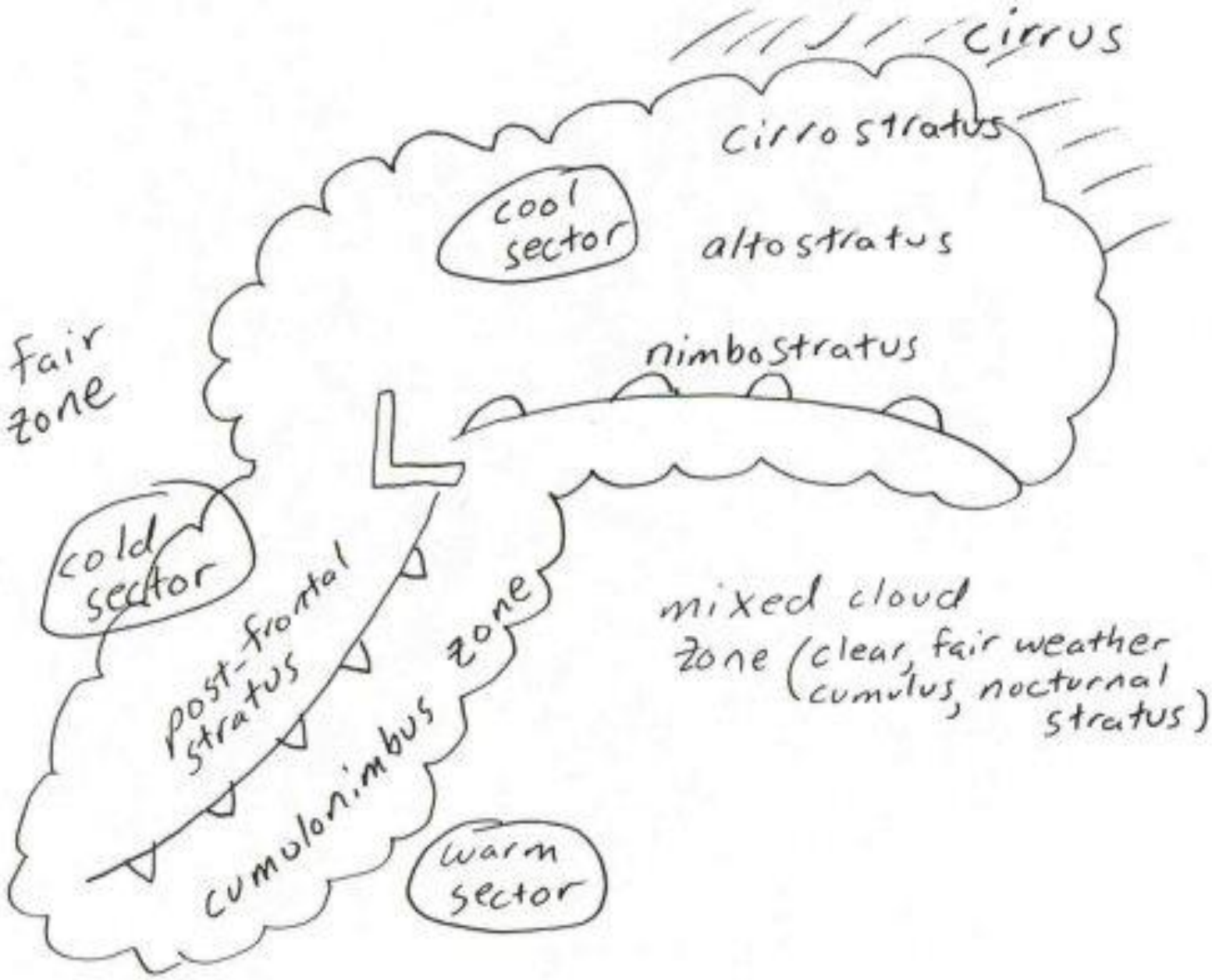
A **roll cloud** is a low, horizontal, tube-shaped, and relatively rare arcus cloud. Differently from shelf clouds, they are completely detached from other cloud features. Roll clouds usually appear to be "rolling" about a horizontal axis. They are a solitary wave called a soliton, which is a wave that has a single crest and moves without changing speed or shape. Frequently observed in Queensland, Australia (called Morning Glory) in October, where is associated with sea breezes. Sometimes associated with downdrafts from thunderstorms.

Non-tropospheric clouds

- **Nacreous clouds**, quite coloured, present in the high stratosphere (where T≅0°C → soild or supercooled water vapor); with shape of Ci, and veiled; usually visible at high latitudes in winter, better at the sunset; their genesis and evolution is mysterious



- **Noctilucens clouds**, waved, shaped like Ci, are located in the high mesosphere (T<-50°C), composed by ice deposited on aerosols (by meteorites?); very rare, visible only at high latitudes immediately before or after the sunset


cirrus
cirrostratus
cool sector
altostratus
nimbostratus
fair zone
cold sector
post-frontal stratus
cumulonimbus zone
warm sector
mixed cloud zone (clear, fair weather cumulus, nocturnal stratus)

Effects of cloud condensation nuclei

Results of cumulus clouds grown in marine and continental air

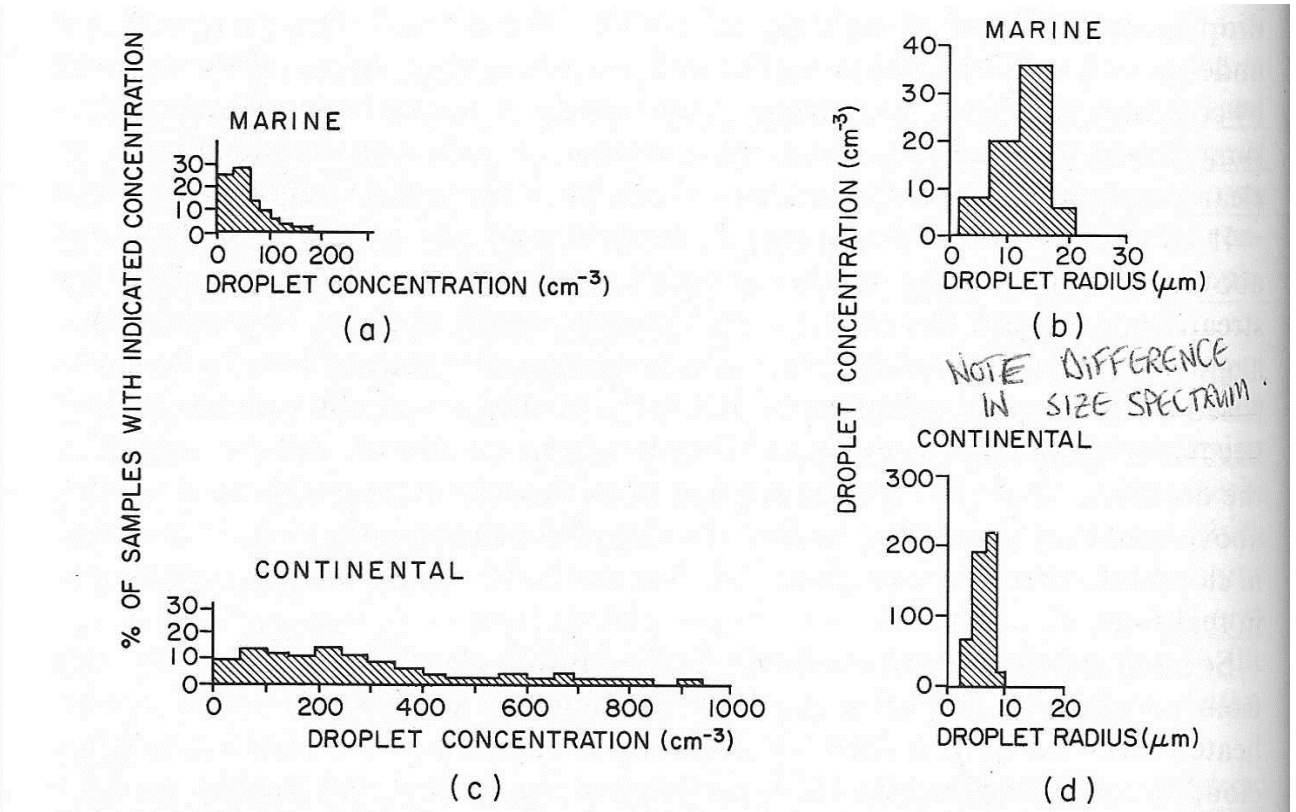


Fig. 4.15 (a) Percentage of marine cumulus clouds with indicated droplet concentrations. (b) Droplet size distributions in a marine cumulus cloud. (c) Percentage of continental cumulus clouds with indicated droplet concentrations. (d) Droplet size distributions in a continental cumulus cloud. Note change in ordinate from (b). [From *Tellus* **10**, 258–259 (1958).]