

Clouds

- How do clouds form?

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Condensation & Cloud Drop Formation

- Condensation = phase transition from water vapor → liquid water phase
- Water does not easily condense without a surface present
 - Vegetation, soil, buildings provide surface for dew and frost formation
 - Particles act as sites for cloud & fog drop formation

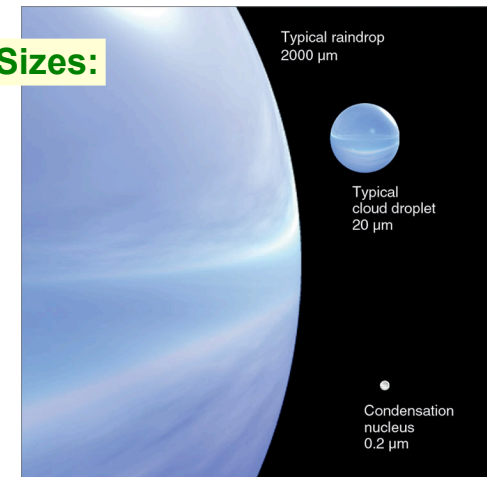
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Cloud & Fog Drop Formation

- If the air temperature cools below the dew point (RH > 100%), water vapor will tend to condense and form cloud/fog drops
- **Fog** is essentially a cloud that forms with its base touching the ground
- Drop formation occurs on particles known as **Cloud Condensation Nuclei (CCN)**
- The most effective CCN are water soluble
- Without particles clouds would not form in the atmosphere:
 - RH of several hundred percent required for pure water drop formation

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Typical Sizes:



Cloud Condensation Nuclei (CCN)

- Not all atmospheric particles are CCN
- Good CCN are **hygroscopic** (they “like” water)
- Many hygroscopic salt and acid particles are found in the atmosphere:
 - Natural CCN (e.g. **sea salt**, vegetation burning)
 - CCN from human activity (e.g. pollutants)
- The solute effect:
 - Condensation of water on soluble CCN dissolves particle
 - Solute particles at drop surface displace water molecules → reduce likelihood of water molecules escaping to vapor
 - Reduce saturation vapor pressure from value for pure water drop

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Clouds

- Clouds result when air gets saturated (RH = 100%) away from the ground (rising air expands and cools)
- Clouds 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 (crucial for the ozone hole), and even² form in the mesosphere, 80 km above ground!
- Clouds impact the environment in many ways
 - Radiative balance, water cycle, pollutant processing, earth-atmosphere charge balance, ...

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Cloud Classification

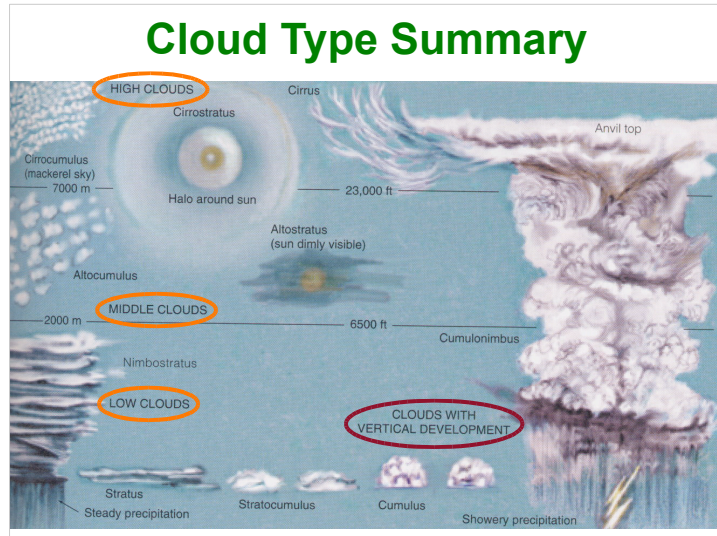
- Clouds are traditionally identified by the World Meteorological Organization's International Clouds Atlas. Weather observers throughout the world use the same classification (10 principal cloud forms).
- Latin root words are the basis for the descriptive scheme:
 - **Cumulus** = heap or pile
 - **Stratus** = to flatten out or cover with a layer
 - **Cirrus** = curl of hair or tuft of horse hair
 - **Nimbus** = precipitating
 - **Altim** = height

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Cloud Classification

- Clouds are categorized by their height, appearance, and vertical development:
 - **High Clouds** → generally above 16,000 ft (~ 5 km) at middle latitudes
 - **Cirrus, Cirrostratus, Cirrocumulus**
 - **Middle Clouds** → 7,000 to 23,000 ft (2–7 km)
 - **Altostratus, Altocumulus**
 - **Low Clouds** → below 7,000 ft (2 km)
 - **Stratus, Stratocumulus, Nimbostratus**
 - **Vertically developed clouds** (via convection)
 - **Cumulus, Cumulonimbus**

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High Clouds



- White during the day, red/orange/yellow at sunrise and sunset, made of ice crystals
- **Cirrus**: thin and wispy, move west to east, indicate fair weather
- **Cirrocumulus**: less common than cirrus, small rounded white puffs individually or in long rows
- **Cirrostratus**: thin and sheet like, sun and moon clearly visible through them, Halo common, often precede precipitation

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Cirrus Display at Dawn



Cirrocumulus



at sunset

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Cirrostratus (with Halo)



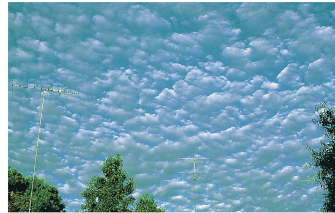
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Con_(densation)trails



Middle Clouds

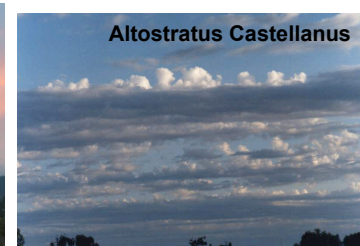
- **Altostratus:**
 - less than 1 km thick
 - mostly water drops
 - gray, puffy
 - differences from cirrocumulus: larger puffs, more dark/light contrast
- **Altostratus:**
 - gray, blue-gray
 - often covers entire sky
 - sun or moon may show through dimly (usually no shadows)



Altostratus



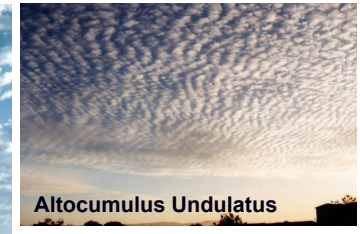
Altostratus Castellanus



Altostratus



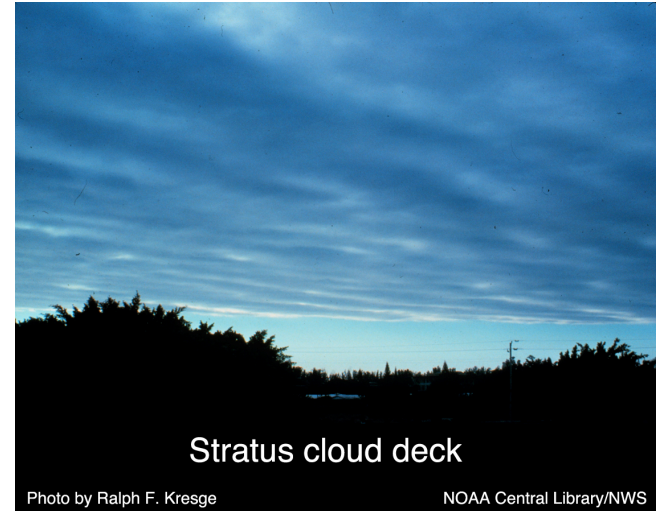
Altostratus Undulatus



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*

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Looking down on an Eastern Atlantic Stratus Deck




Strato-cumulus






Vertically Developed Clouds

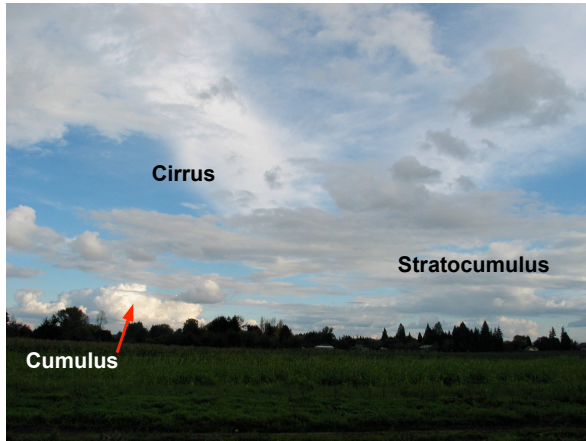
- **Cumulus:**
 - puffy “cotton”
 - flat base, rounded top
 - more space between cloud elements than stratocumulus
- **Cumulonimbus:**
 - thunderstorm cloud
 - very tall, often reaching close to tropopause
 - individual or grouped
 - large energy release from water vapor condensation



Cumulus
PSC Cloud Photo



Often the sky is fairly complex



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Unusual Clouds

- **Lenticular Clouds:** clouds forced by flow over topography
- **Pileus:** similar to lenticular clouds, but forced by flow over a thunderstorm top
- **Mammatus:** baglike sacks that form underneath cumulonimbus tops or underneath other clouds
- **Polar Stratospheric Clouds:** cirrus-like (ice) clouds that can form in the stratosphere during polar night
- **Noctilucent Clouds:** highest clouds on earth, ice clouds ~ 80 km above ground!

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Pileus Clouds



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Mammatus Clouds



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Polar Stratospheric Clouds ("Mother of Pearl Clouds")



Photo courtesy Andreas Dömbrack

Noctilucent Clouds



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