Clouds and Convection

Cumulonimbus

Cumulonimbus from Space

Stratus and Mist
Clouds interact with both solar and terrestrial radiation.

Thick clouds reflect sunlight well and so influence planetary albedo.

Clouds are also fairly efficient absorbers/emitters of terrestrial radiation and so contribute to the greenhouse effect.
Thin High Clouds

Mostly composed of ice crystals and because they are thin solar radiation passes through, yet infrared radiation is mostly absorbed.

Contribute more to the greenhouse effect then the planetary albedo.
Thick Low Clouds

- Often composed of water (sometimes ice too)
- Highly reflective so they increase planetary albedo
- Good blackbody radiators
- Their temperature is similar to the surface temperature

But still they usually their reduction in absorbed solar is more than their enhancement of the greenhouse effect
Greenhouse Effect of Clouds

Cloud: $F_{out} = \sigma T^4$

- $= 5.67 \times 10^{-8} \times 250^4$
- $= 221 \text{ W/m}^2$

Surface: $F_{surface} = \sigma T^4$

- $= 5.67 \times 10^{-8} \times 288^4$
- $= 390 \text{ W/m}^2$

LW flux lost to space is 169 W/m² less due to cloud plus surface receives an additional 221 W/m² of radiation. Does this compensate for the loss of absorbed solar flux?

What is assumed?
- Cloud is a perfect blackbody
- Cloud emits with cloud top temperature
Local Energy Balance
Only Clouds in the Atmosphere!

For a Thin High Cloud with $T_{top}=270K$ and $A=0.2$

\[ F_{in} = (S/4)(1-A) \]
\[ = 1370/4 \times 0.8 \]
\[ = 274 \text{ W/m}^2 \]

\[ F_{out} = \bar{\sigma}T^4 \]
\[ = 5.67 \times 10^{-8} \times 250^4 \]
\[ = 221 \text{ W/m}^2 \]

\[ F_{in} - F_{out} = 53 \text{ W/m}^2 \]

Net incoming radiation is higher than outgoing so the planet is not in balance. What happens? It warms till it is in balance, or the cloud goes away!
Local Energy Balance
Only Clouds in the Atmosphere!

For a Thick Low Cloud with $T_{top}=280K$ and $A=0.8$

Net incoming SW
\[ F_{in} = \frac{S}{4}(1-A) \]
\[ = \frac{1370}{4} \times 0.2 \]
\[ = 137 \text{ W/m}^2 \]

Outgoing LW
\[ F_{out} = \sigma T^4 \]
\[ = 5.67 \times 10^{-8} \times 280^4 \]
\[ = 349 \text{ W/m}^2 \]

\[ F_{in} - F_{out} = -212 \text{ W/m}^2 \]

Net Incoming radiation is lower than outgoing so the planet is not in balance. What happens? It cools till it is in balance, or the cloud goes away!
Thermal structure of the atmosphere

[Diagram showing the thermal structure of the atmosphere with layers including Troposphere, Stratosphere, Mesosphere, and Thermosphere, along with their corresponding altitudes and pressure levels.]
Convection

Heating a gas (or fluid) from below results in rising plumes (thermals) of warmer air separated by sinking cool air.

Thermals start out as “hot spots” near the ground. They rise until they run out of **buoyancy** (until their density is equal to the density of the air around them). **Thermals expand and cool as they rise.**

If thermals rise high enough, the water vapor in them condenses and a cloud forms.

**Dry** convection carries no condensate (but it does carry water vapor) while **moist** convection carries condensate (think clouds)

Convection transports heat and moisture in the atmosphere
Why do thermals expand and cool as they rise?

**Adiabatic approximation** - To a good approximation thermals rise without losing heat to the surrounding air.

Because atmospheric pressure decreases with height, the surrounding air pushes with less force on thermals as they rise. This causes them to **expand** as they rise.

Because they do work to increase their volume, they lose energy so they **cool**.

Familiar examples of **adiabatic expansion**:
- Air escaping from an aerosol can or a tire
Clouds form when rising thermals cool enough so their temperature reaches the condensation (or saturation) point for water vapor. Thermals may continue to rise, causing convection in the clouds.

**Parcel of air** - a volume of air with similar properties.

All lifted air parcel (not just thermals) experiences adiabatic expansion. Sinking air parcels experiences adiabatic compression.

Sinking air parcels warm and therefore evaporate condensate if they have any. The condensate doesn’t last long. Clouds do not exist in areas with sinking air.
The **Dry Adiabatic Lapse Rate** is the rate of cooling for a rising air parcel that is unsaturated

\[ \sim 10 \, \text{C/km} \]

The atmosphere takes on the dry adiabatic lapse rate if it has just experienced dry convection.

But the atmosphere is neither perfectly unsaturated or perfectly saturated. Also the real atmosphere is heated throughout by absorbing radiation as well as by convection. The real lapse varies between about 4 and 9 C/km.
Atmospheric Stability of a Dry Atmosphere

The atmosphere temperature profile is unstable if the rate that the temperature decreases with height is greater than the dry adiabatic lapse rate.

When this occurs an air parcel that lifts spontaneously will find itself warmer than its new surroundings even though it cools as it lifts.

The atmosphere never remains unstable for long.

When the atmosphere is pushed towards an unstable temperature profile, it often reacts violently with thunderstorms or tornadoes.
Unstable Atmosphere

- Dry Adiabatic Lapse Rate
- Actual Lapse Rate more negative than -10 C/km
- Temperature decreases more rapidly than -10 C/km

Parcel keeps rising when released $T_{\text{parcel}} > T_{\text{air}}$
Stable Atmosphere

Dry Adiabatic Lapse Rate

When released $T_{\text{parcel}} < T_{\text{air}}$

Parcel falls to original position

If parcel rises it cools at -10 C/km

Actual Lapse Rate less negative than -10 C/km

Temperature decreases more slowly than -10 C/km
**Stable Air**

Defined by small temperature decrease with height

- Caused by weak surface warming
- Forced sinking in the down draft of convection, on the downwind side of mountains, or due to large scale atmospheric circulation
- Warm air transported over cold air near the surface

**Unstable Air**

Defined by large temperature decrease with height

- Caused by strong surface warming
- Forced lifting on the windward side of mountains or due to large scale atmosphere circulation
- Cold air transported above region with warm air near surface
Convective clouds appear lumpy cumulus and cumulonimbus is the extremely tall version.

Large scale lifting, common in the Puget Sound Convergence Zone, creates stratus clouds.

Cirrus clouds are the very high clouds that typically arrive before a storm.