

Cloud Notes for SIO 218

October 11 and 16, 2001

Satellite Observations

Satellites observe cloudiness by measuring electromagnetic radiation at a variety of wavelengths (e.g., visible, infrared, microwave). Most satellites use *passive* remote sensing (the satellite measures whatever radiation happens to be reflected or emitted by the Earth) but a few current and upcoming satellites (TRMM, Cloudsat) use *active* remote sensing (the satellite measures the return of its own emitted radar or lidar signal). Active remote sensing is costly in power resources and hence not frequently implemented. Two common satellite orbits are *geostationary* and *sun-synchronous* (polar-orbiting). Geostationary satellites are GOES-East (U.S.), GOES-West (U.S.), Meteosat (Europe), and GMS (Japan). Sun-synchronous polar orbiters are typically in “morning” or “afternoon” orbits.

	<u>geostationary</u>	<u>sun-synchronous</u>
orbital inclination	0°	99°
orbital period	1 day	100 minutes
altitude above equator	36000 km	800 km
orientation to surface	above same point on Earth at all local times of day	above different points of Earth all at same local time of day
low- and midlatitude sampling	most of hemisphere and complete diurnal cycle	narrow swaths and limited diurnal cycle
polar sampling	not observable	overlapping swaths can provide nearly complete diurnal cycle
advantages	simultaneous view of large area of Earth at all times of day	close-up view of Earth and good polar sampling
disadvantages	far away and cannot view poles	geographical gaps and poor diurnal sampling at lower latitudes

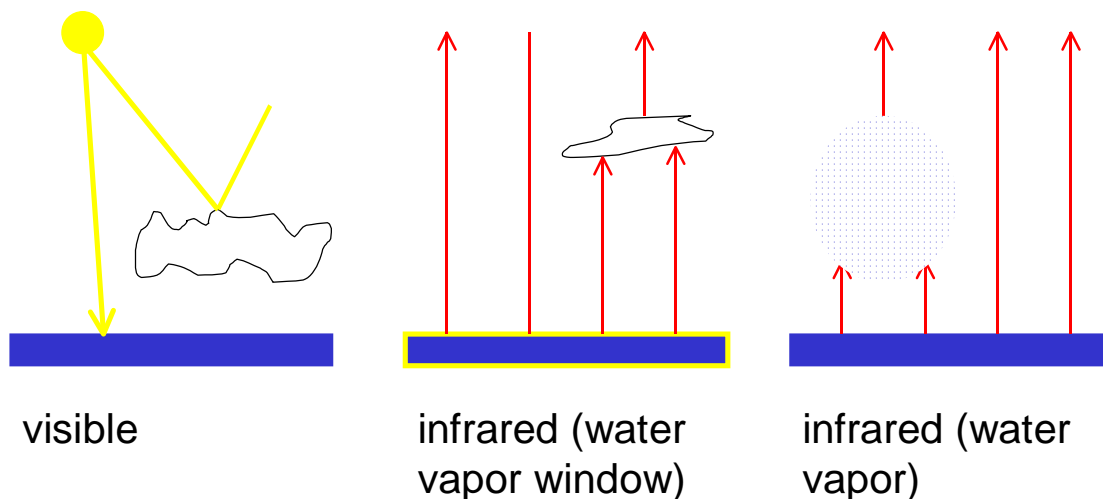
Satellite Observing Wavelengths

Visible: The source of visible radiation is the Sun. It is primarily transmitted through the clear atmosphere but is partially reflected by clouds. The surface (except snow/ice) primarily absorbs visible radiation. Measurement of reflected visible radiation is used to identify cloudiness at any level of the atmosphere during daylight hours. Clouds may be difficult to identify if they are thin (and thus not very reflective) or if they occur over snow and ice.

Infrared (water vapor window): The surface of the Earth emits infrared radiation (also the Sun in the near infrared). Clouds absorb and re-emit infrared radiation. The clear atmosphere absorbs little and emits little radiation at the wavelength of the water vapor “window”. The amount of emitted radiation increases with increasing temperature of the emitting substance (and is thus related to height above the surface). Measurement of infrared radiation in the water vapor window is used to identify cloudiness and especially the height of cloud top at all hours of the day. Clouds may be difficult to identify if they are very thin (and thus partially transmissive) or if they occur over cold surfaces.

Infrared (water vapor): As for infrared in the water vapor window, except the clear atmosphere absorbs and re-emits infrared radiation at water vapor wavelengths (most of the infrared spectrum). The amount of absorption and re-emission increases with increasing specific humidity. Measurement of infrared radiation at water vapor wavelengths is used to identify moist regions of the atmosphere.

Microwave: Emitted by the surface, water vapor (depending on wavelength), and cloud liquid water. Measurement of microwave radiation is used to estimate total water vapor and liquid water in the atmospheric column over oceans.



Well-Mixed Cloudy Boundary Layer

Balances

- entrainment \Leftrightarrow subsidence
- entrainment drying \Leftrightarrow surface moistening
- entrainment warming \Leftrightarrow radiative cooling

Positive feedback

- more cloud \Rightarrow more radiative cooling
- more radiative cooling \Rightarrow more turbulence
- more turbulence \Rightarrow more moisture mixing
- more moisture mixing \Rightarrow more cloud

Negative feedback

- more turbulence \Rightarrow more entrainment
- more entrainment \Rightarrow more stratification
- more stratification \Rightarrow less moisture mixing
- less moisture mixing \Rightarrow less cloud
- less cloud \Rightarrow less radiative cooling
- less radiative cooling \Rightarrow less turbulence

Decoupled Cloudy Boundary Layer

Decoupling arises when the turbulence is not sufficiently strong to keep the boundary layer well mixed. In this case turbulence generated at the surface keeps the surface-based layer well mixed and turbulence generated at cloud top keeps the cloud/subcloud layer well mixed. An increase in stratification separates the two layers, and this transition typically occurs just below the lifting condensation level. Cumulus clouds intermittently penetrate the transition layer and mix up moisture to maintain the stratocumulus. Eventually entrainment causes the stratocumulus to evaporate and the cloud/subcloud layer ceases to be well mixed. Contributions to decoupling are the increase in temperature in the cloud layer caused by entrainment of warm air from the inversion and the increase in temperature associated with latent heat release in the cloud layer.

Decoupled Trade Cumulus Boundary Layer

Structure

- the surface-based layer is well-mixed
- the cloud layer is slightly stratified
- a stable transition layer separates the surface-based layer and cloud layer
- a weak trade inversion caps the cloud layer
- the lifting condensation level (cloud base) occurs at the transition layer
- plumes intermittently penetrate the transition layer to form cumulus in the cloud layer

Balances

- entrainment into cloud layer \Leftrightarrow subsidence at trade inversion
- entrainment into surface-based layer \Leftrightarrow subsidence at transition layer
- cloud layer entrainment drying \Leftrightarrow moistening from cumulus evaporation
- surface-based layer entrainment drying \Leftrightarrow moistening from surface evaporation
- ascent in cumulus cores \Leftrightarrow compensating subsidence in surrounding clear air
- entrainment warming \Leftrightarrow radiative cooling

Processes

- plumes cannot penetrate to cloud layer \Rightarrow moisture builds up in surface-based layer
- moisture builds up in surface-based layer \Rightarrow lifting condensation level descends
- lifting condensation level descends \Rightarrow clouds form beneath transition layer
- clouds form beneath transition layer \Rightarrow extra buoyancy from latent heat release
- extra buoyancy from latent heat release \Rightarrow plumes can penetrate transition layer
- plumes penetrate transition layer \Rightarrow moisture leaves surface-based layer
- moisture leaves surface-based layer \Rightarrow lifting condensation level rises
- lifting condensation level rises \Rightarrow plumes cannot penetrate to cloud layer

Links

Satellite cloud images:

<http://http.rap.ucar.edu/weather/satellite.html>

My research results:

<http://meteora.ucsd.edu/~jnorris/results.shtml>

Human Intentional and Inadvertent Modification of Precipitation

Basic facts about warm cloud (liquid only) precipitation

- water vapor condenses onto liquid when the atmosphere is supersaturated, i.e., relative humidity (RH) > 100%
- due to surface tension effects, pure water droplets cannot spontaneously form until RH > 300%
- in the real atmosphere *cloud condensation nuclei* (CCN) help water droplets form even when RH < 100%
- in the real atmosphere CCN are always present
- when RH < 100% water droplets remain tiny haze droplets
- when RH > 100% water vapor continues to diffuse to droplets and they grow into cloud droplets
- small cloud droplets flow around one another and do not coalesce
- large cloud droplets collect small droplets and grow into drizzle or rain drops
- at low CCN concentration a small number of large droplets form that are large enough to coalesce to form precipitation
- at high CCN concentration a large number of small droplets form that are too small to coalesce to form precipitation
- CCN concentration is typically low over ocean and warm clouds readily precipitate
- CCN concentration is typically high over land and warm clouds do not precipitate

Basic facts about cold cloud (liquid and ice) precipitation

- water vapor deposits onto ice when the atmosphere is supersaturated *with respect to ice* and temperature < 0 °C
- pure ice crystals do not spontaneously form until temperature < -40 °C
- in the real atmosphere *ice nuclei* help ice crystals form when temperature > -40 °C
- in the real atmosphere ice nuclei are often *not* present and clouds are made of only *supercooled* liquid droplets for temperature < -20 °C
- RH with respect to ice > RH with respect to liquid water (i.e., the atmosphere may be supersaturated with respect to ice at the same time it is subsaturated with respect to water)
- when ice crystals appear, water vapor diffuses away from supercooled droplets and goes to ice crystals (Bergeron process)
- ice crystals often grow large because there are few ice nuclei
- large ice crystals collect supercooled water droplets (riming) and other ice crystals (aggregation) to form precipitation
- collisions between falling ice crystals and ascending droplets can cause charge separation and subsequent discharge through lightning

Human modification of precipitation

Cloud seeding is an attempt to induce a non-precipitating cloud to precipitate or precipitating cloud to precipitate more. It has been difficult to determine the general effectiveness of cloud seeding due to lack of rigorous statistics (e.g., how do you know that the cloud would not have rained anyway without seeding?). The typical method of cloud seeding is introducing ice nuclei via airplane into a cloud of only supercooled water droplets. This will create ice crystals that grow by diffusion at the expense of the water droplets. Hopefully the ice crystals will grow large enough to start collecting droplets and fall out as precipitation. The conversion of liquid to ice also releases latent heat that gives extra buoyancy to the cloud to help it grow bigger.

Putting in many ice nuclei ends up only producing many small ice crystals that do not grow large enough to precipitate. This has been done in an attempt to suppress hail.

During the Second World War ice nuclei were introduced into supercooled fogs at airfields to convert the many small droplets to a few large ice crystals that settled out and were easier to see through. No solution has been found to the problem of clearing out warm fogs.

Human activities increase CCN concentration and may inadvertently suppress warm cloud precipitation.

A personal anecdote

One of the advantages of being a meteorologist is the ability to make *nowcasts* (i.e., forecasting what the weather will be during the next half hour). One afternoon several years ago I had hiked up with some friends to the top of a mountain in Colorado. Cumulus clouds were growing all around and one of my companions anxiously eyed a nearby cloud that was growing suspiciously large. He asked me if I thought it would produce lightning (the leading cause of death on Colorado mountaintops). Noticing the sharp cloud boundaries, I replied that we need not worry about lightning unless the cloud became *glaciated* (converted to ice) since the presence of ice in a cloud is necessary for lightning. It is easy to tell the difference between ice and liquid in a cumulus cloud because liquid has a very sharp cloud edge but ice has a diffuse and fuzzy cloud edge. This difference results from the fact that relative humidity with respect to ice is greater than relative humidity with respect to liquid water. When cloud droplets mix with dry air at the cloud boundary the mixture is subsaturated so the droplets immediately evaporate. When ice crystals mix with dry air at the cloud boundary the mixture is still supersaturated so the crystals do not sublimate and are able to drift farther away. After finishing my impromptu cloud lecture I noticed that the top of the nearby cloud had gotten fuzzy and reported this new development to the group. We started walking down the mountain and a minute later this turned into running down the mountain after lightning began to strike a mile away. I was pleased that my forecast had indeed verified but next time I think I ought to allow for more lead time.

Extratropical Low Cloud Characteristics

	<i>Sc</i>	<i>Cu under Sc</i>	<i>Cu</i>	<i>Cb</i>	<i>fog</i>	<i>St</i>	<i>Ns</i>	<i>no cloud (ocean only)</i>
<i>boundary layer profile</i>	well-mixed	weakly decoupled	strongly decoupled	no well-defined	strongly stratified	weakly stratified	no well-defined	strongly stratified
<i>capping inversion</i>	strong	less strong	weak or none	boundary layer	surface-based	weak or none	boundary layer	surface-based
<i>boundary layer height</i>	shallow	less shallow	least shallow	layer	very shallow	shallow or deep	layer	very shallow
<i>large-scale vertical motion</i>	strong downward	less strong downward	weak downward or none	weak upward or downward	weak upward or downward	weak upward or downward	strong upward	strong downward
<i>air – surface temperature difference</i>	usually negative	negative	negative	negative	strong positive	weak negative or positive	weak negative or positive	strong positive

Sc = stratocumulus

Cu = cumulus

Cb = cumulonimbus

St = stratus

Ns = nimbostratus

inversion = temperature increase with height

decoupled = the surface-based mixed layer is separated from the cloud layer by a slightly stratified transition layer

Here I am defining the boundary layer as the portion of the atmosphere at least intermittently in contact with the surface on time scales of a few hours. This more expansive definition includes the cloud/subcloud layer as well as the surface-based layer for decoupled cases. A stricter definition would limit the boundary layer to the portion of the atmosphere continuously in contact with the surface (only the surface-based layer for decoupled cases). Cumulonimbus and nimbostratus extend through most of the troposphere and have no distinct boundary layer that is confined to the lower troposphere.