Clouds for pilots

Ed Williams

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Clouds are important to pilots!

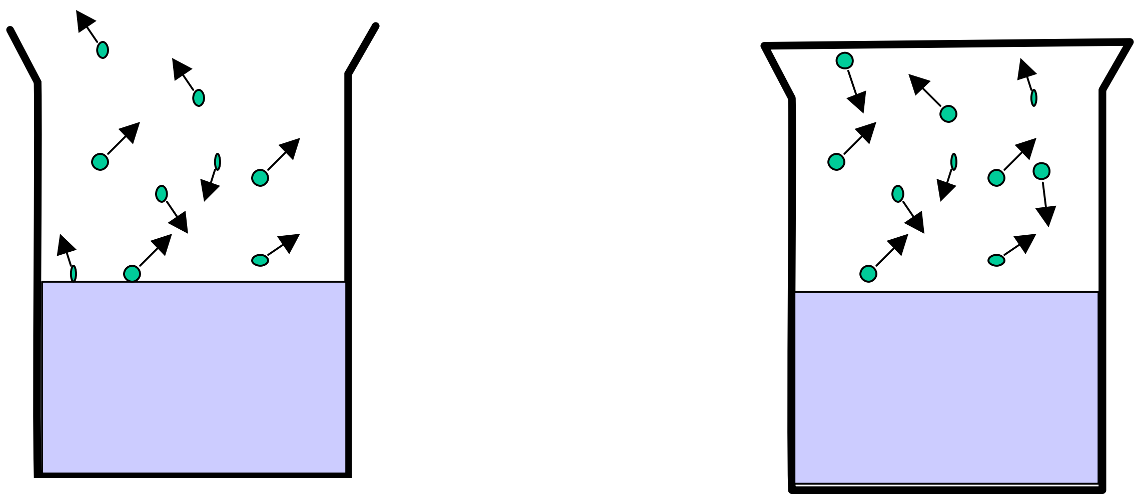
✍ Many of our weather problems are associated with clouds:
- Fog
- Thunderstorms
- In flight icing

✍ Cloud physics

✍ Cloud meteorology

Cloud Physics

Water enters the atmosphere by evaporation



In equilibrium, evaporation and condensation rates are equal.

At a given temperature, the water vapor reaches a definite *saturation vapor pressure*.

Above this pressure, condensation exceeds evaporation and vice-versa.

Saturation Vapor Pressure increases exponentially with temperature as the evaporation rate increases

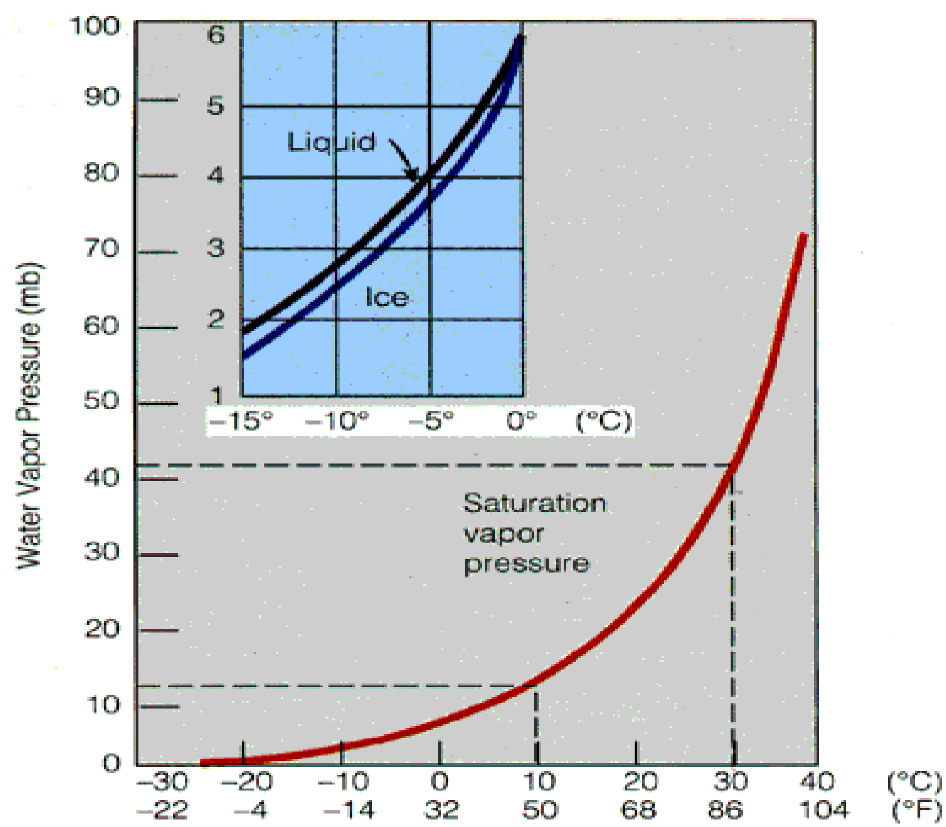
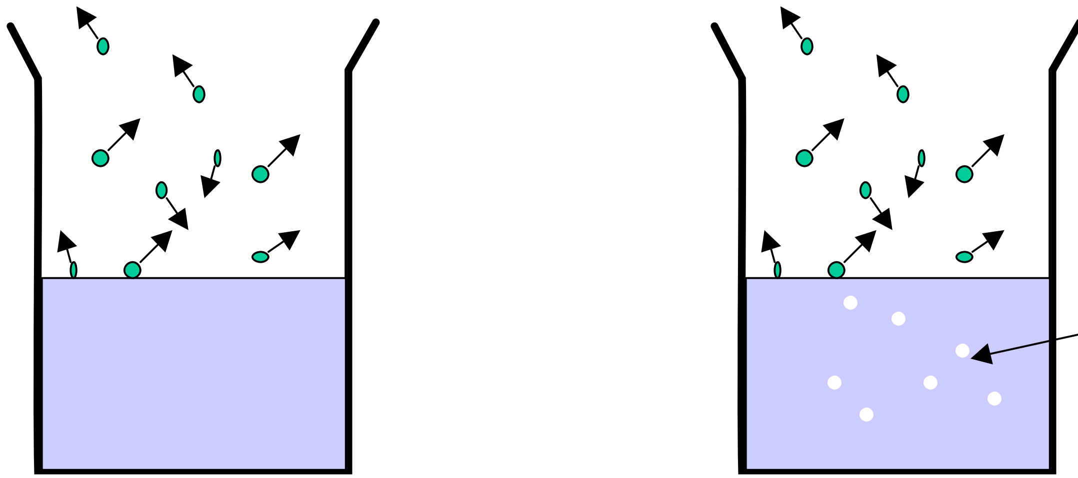


FIGURE 5.11
Saturation vapor pressure increases with rising temperature. Observe that, at below freezing temperatures, the saturation vapor pressure is greater over water than over ice.

Hot air is potentially much more humid.

Water evaporates more rapidly than ice sublimes.

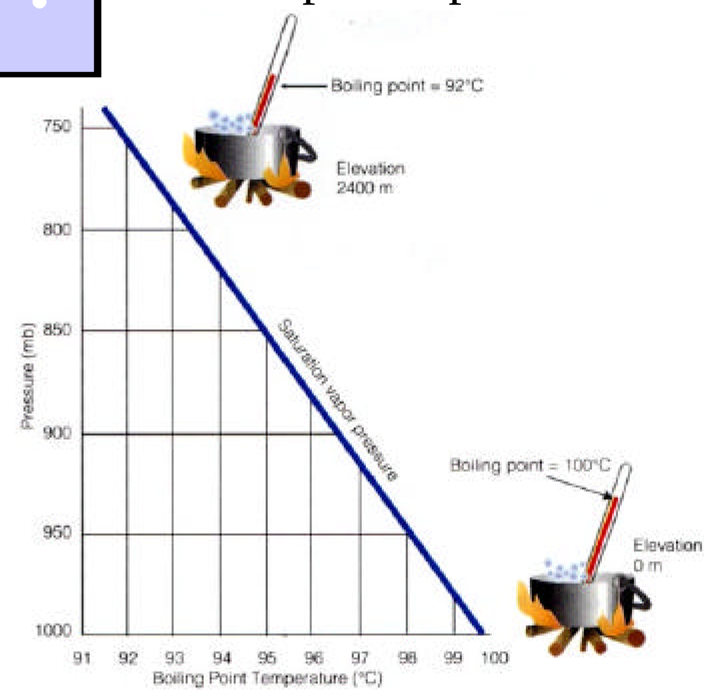
Water boils when the SVP equals atmospheric pressure, allowing bubbles to form.



Steam bubbles at atmospheric pressure*

Evaporation occurs at any temperature.

Boiling point decreases with altitude.



(*) plus hydrostatic pressure

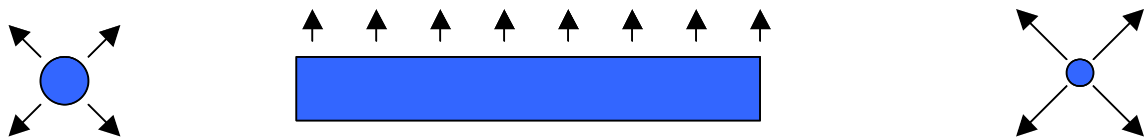
Relative humidity and the temperature-dewpoint spread are measures of the atmosphere's moisture content.

$$\text{Relative humidity} = \frac{\text{Actual vapor pressure}}{\text{Saturation vapor pressure}} \times 100\%$$

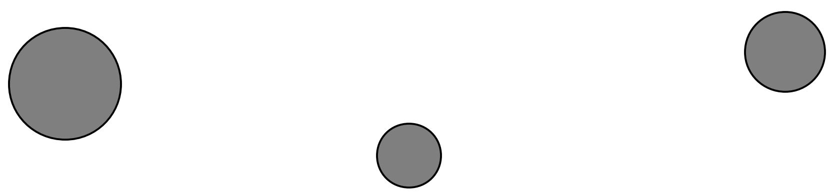
Dewpoint temperature = Temperature at which the actual vapor pressure would become saturated.

Temperature minus dewpoint is called the "spread".
The smaller the spread, the higher the humidity.

Clouds form by condensation of water vapor into tiny droplets.



Water molecules evaporate more readily from small drops.
It is thus difficult to spontaneously create droplets by cooling *pure* moist air below its dewpoint.



Cloud droplets actually form on *condensation nuclei* - dust, smoke, salt crystals etc. floating in the atmosphere.

Atmospheric haze and smog can occur when the air is less than saturated when the air contains *hygroscopic* nuclei from natural or man made pollution.

Moisture droplet come in a wide range of sizes!

Cloud nucleus	0.1	micron
Cloud droplet	10	micron
Large cloud droplet	100	micron
Mist	500	micron
Drizzle	1200	micron
Raindrop	3000	micron
Heavy raindrop	6000	micron

(1000 microns = 1 mm)

Droplets less than ~< 500 micron in diameter fall too slowly to reach the ground.

Clouds only generate precipitation when processes leading to droplet growth increase their size by a million times or more!

How does this happen?

The Wegener - Bergeron - Findeisen Theory of precipitation.

✍ All rain is melted snow!

Based on the following:

(1) nuclei for seeding ice crystal formation are ~100,000 rarer than water condensation nuclei. So above the freezing level most of the water vapor initially condenses in the form of *supercooled* water droplets.

(2) the vapor pressure over water is greater than over ice at a given temperature - because the water molecules bind more tightly to ice than liquid water.

(3) Water vapor thus migrates from the supercooled water droplets to the ice particles making them grow rapidly- *glaciation*.

(4) The snow falls out and (perhaps) melts in the warmer air below.

Cloud seeding - icing - tops of precipitating clouds.

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The Wegener Mechanism.

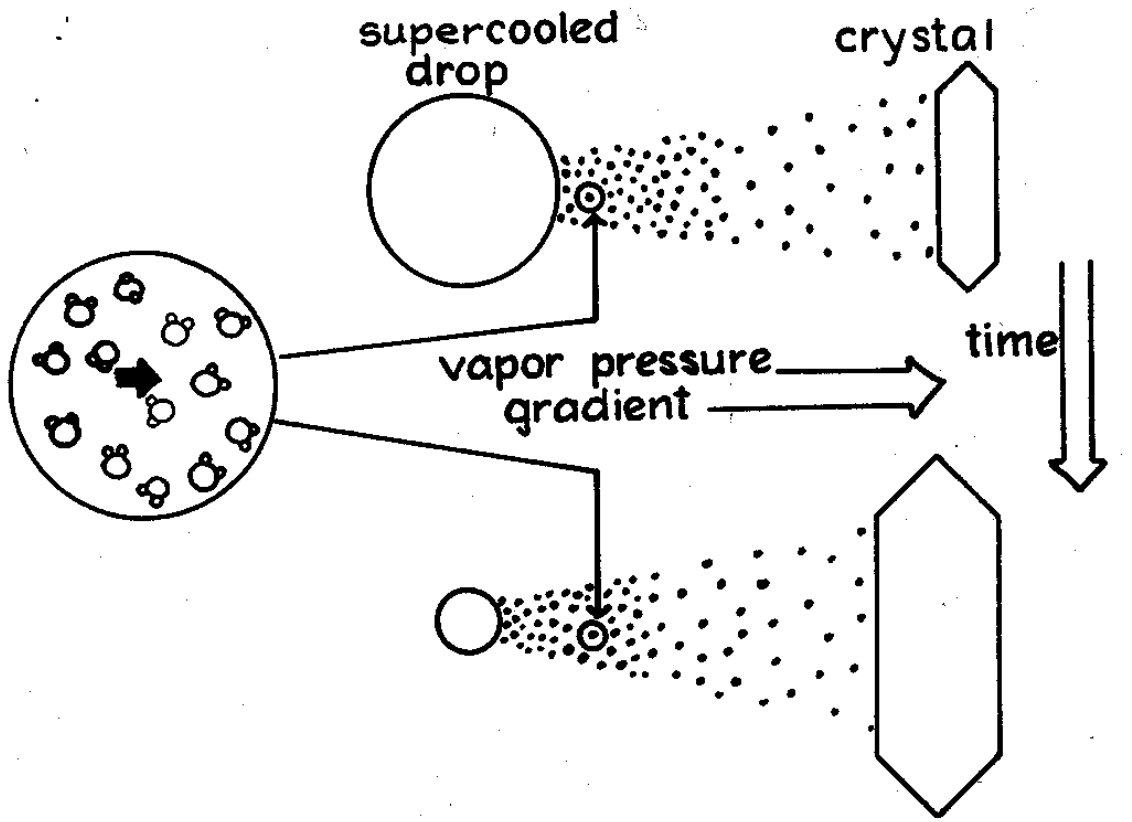


Fig. 20 Migration of water molecules from a supercooled water drop toward an ice crystal.

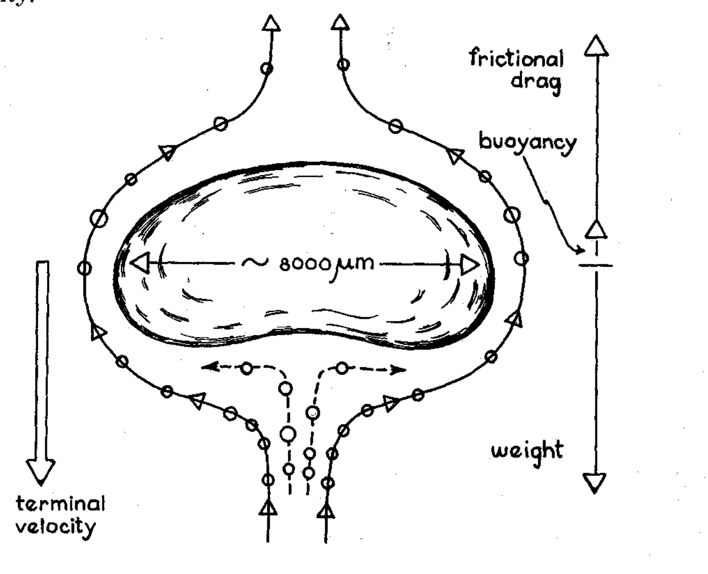
from Peterson's "Field Guide to the Atmosphere"

However, especially in the tropics, substantial rain can fall from warm clouds - that top out below the freezing level.

In addition to WBF, there's a secondary mechanism for droplet growth- *coalescence.*

Heavier drops overtake and collide with smaller ones. Not more than about 5x smaller or the small drop will get swept around the larger one.

Fig. 21 Distorted shape of an 8000 μm drop falling at its terminal velocity.



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Cloud meteorology

Clouds form when humid air is cooled or gains additional moisture

Fog is a (stratus) cloud whose base reaches the ground.

Low visibilities arise when the humidity approaches 100%.

Understanding these mechanisms can help us anticipate IFR and other inclement weather.

When air is lifted it expands and cools - increasing its relative humidity.

Adiabatic lapse rates:

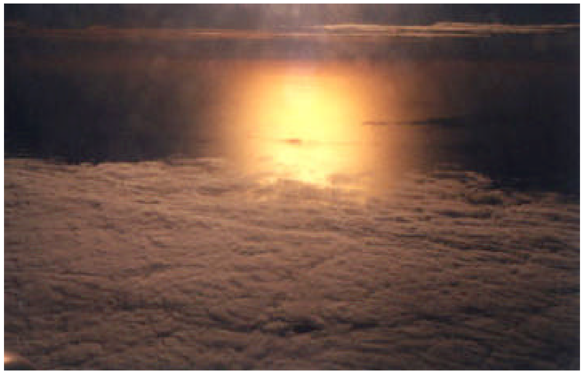
✍ Unsaturated air cools 5.5F/1000ft when lifted, but the dewpoint only drops 1.5F/1000ft. => ceilings at: (spread/4F) *1000ft

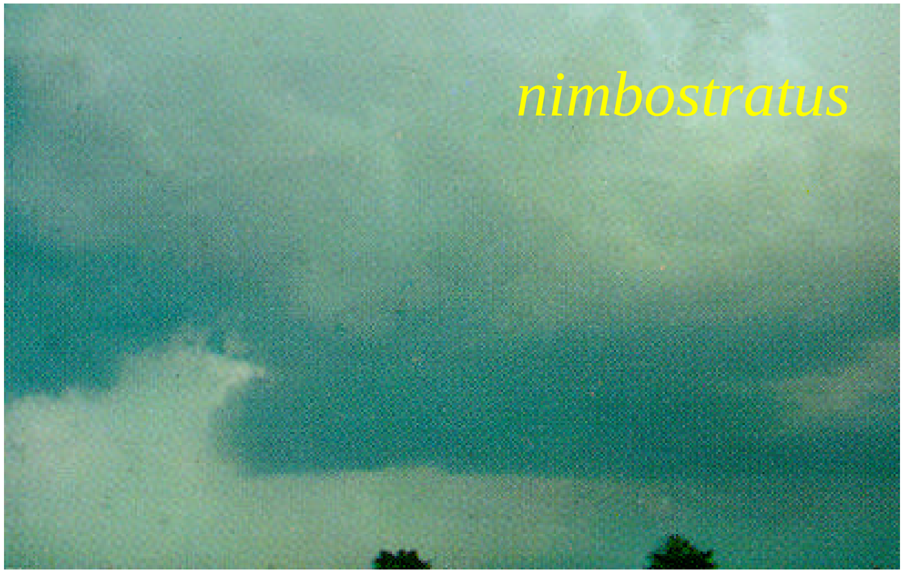
✍ Saturated air cools slower: 1-3F/1000ft, because of the release of *latent heat* as the moisture condenses out into clouds.

The air is *unstable* if the ambient lapse rate exceeds the adiabatic lapse rate. Rising air finds itself warmer than its surroundings and thus continues to rise.

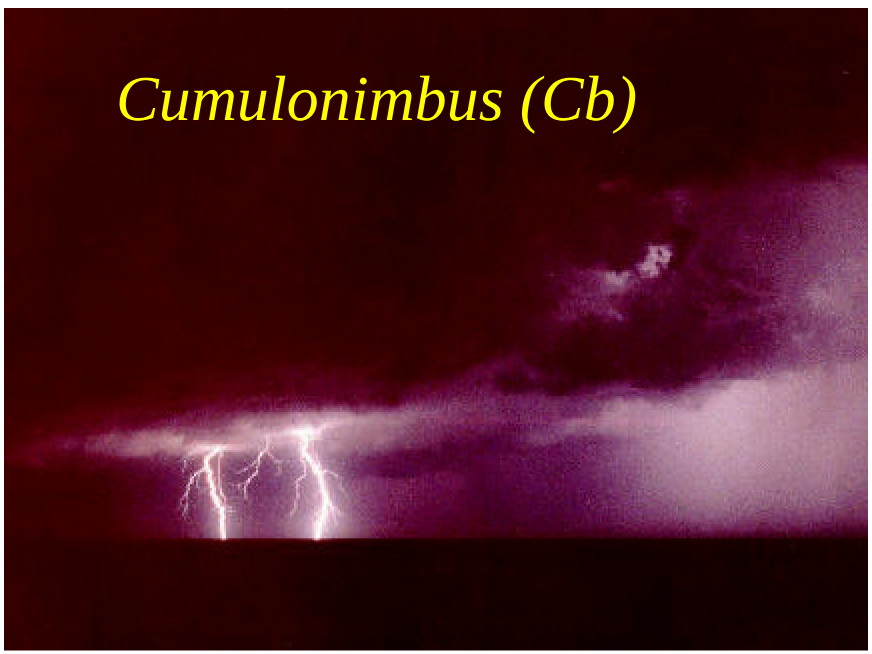
Up and down drafts - vertical mixing - gusty winds - *cumulus* type clouds - showery precipitation

Stratus type clouds form in stable air.

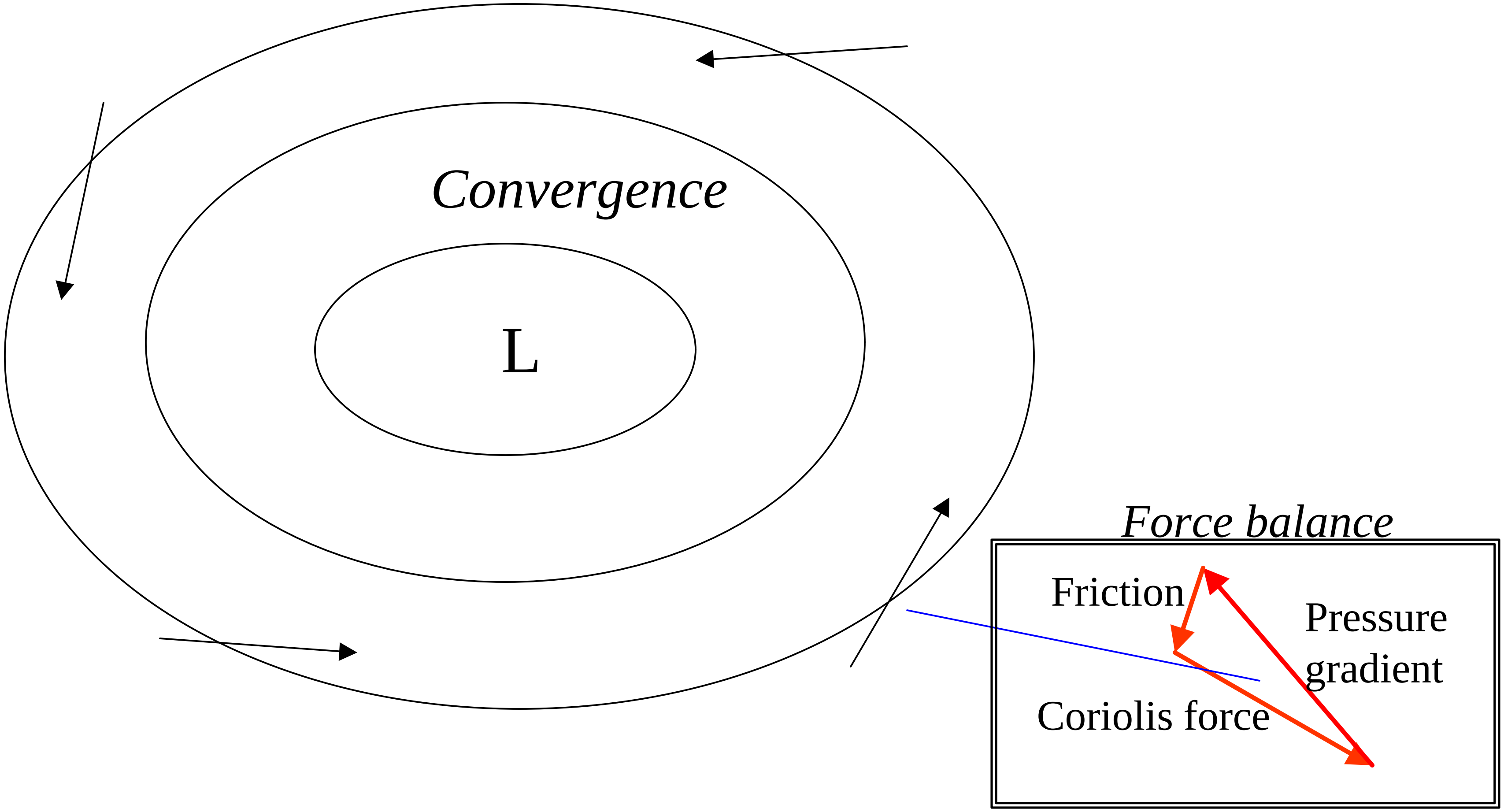




Cumulus type clouds form in unstable air

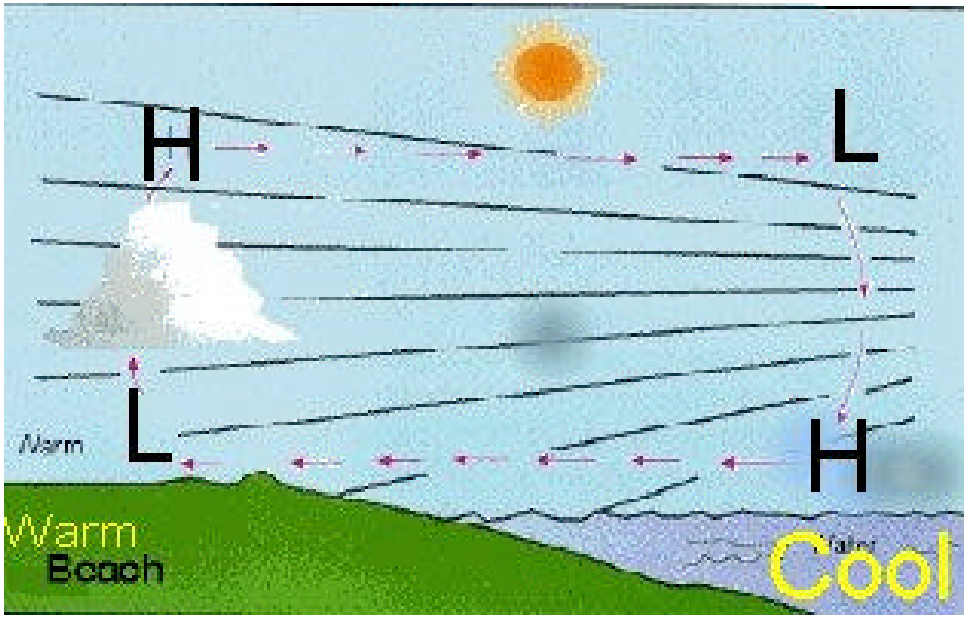


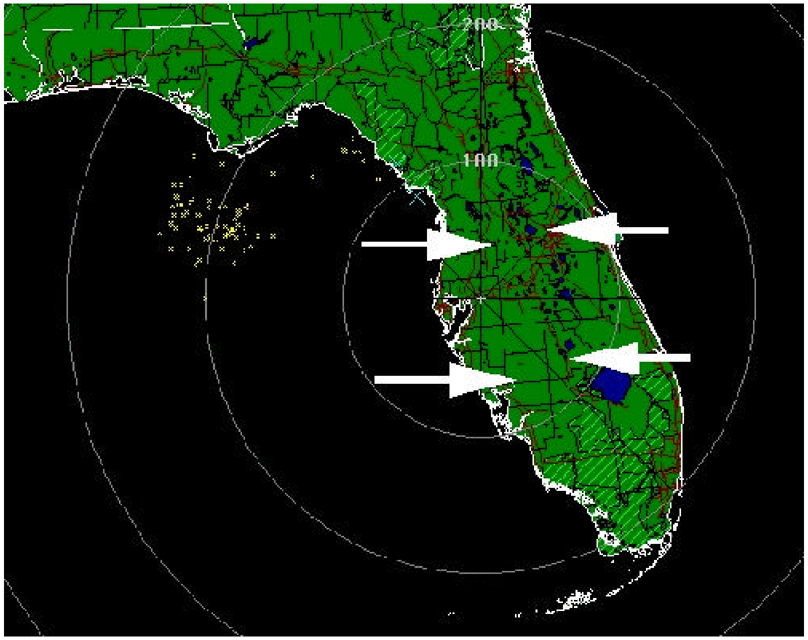
Widespread lifting occurs in low pressure areas.



Because of friction, surface winds cross the isobars at an angle converging on the low, and force air upward.

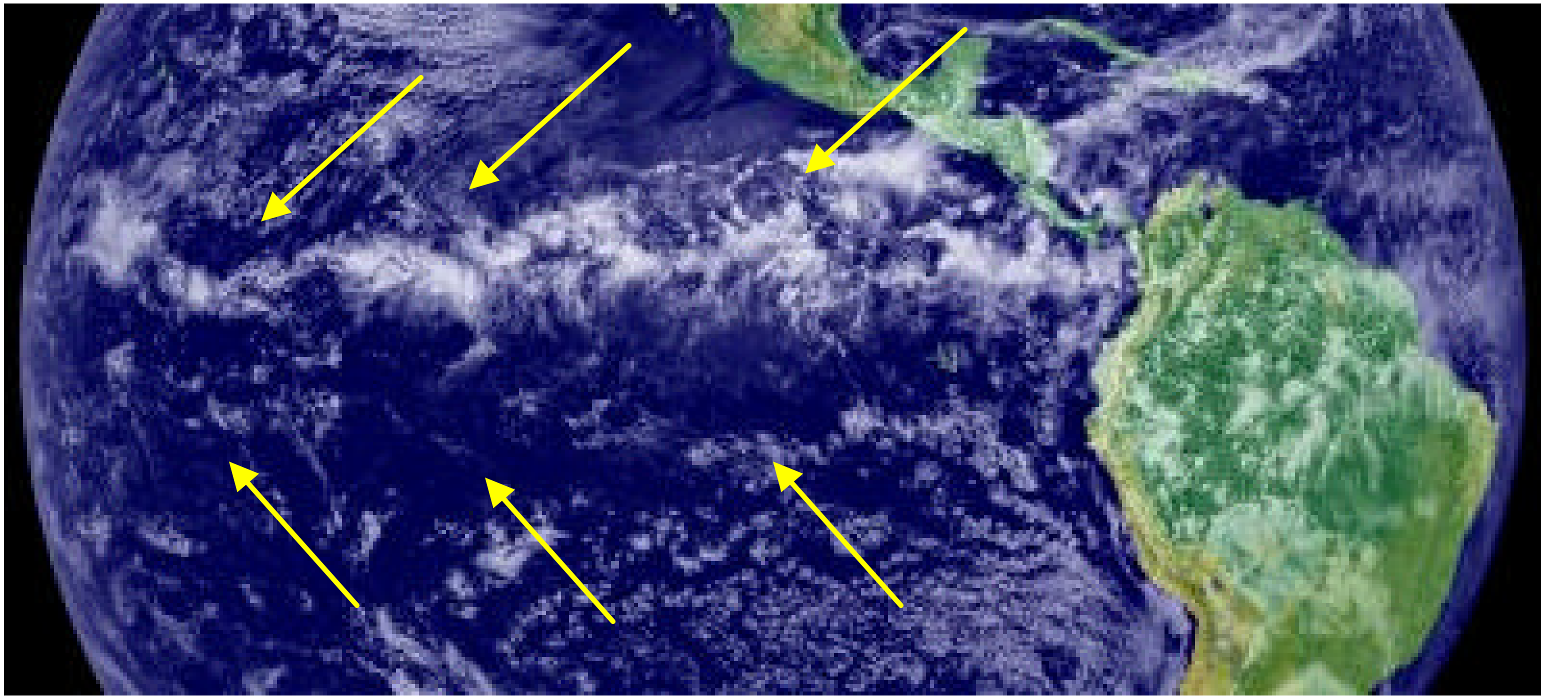
Converging sea-breezes make Florida a hotbed of TRW activity





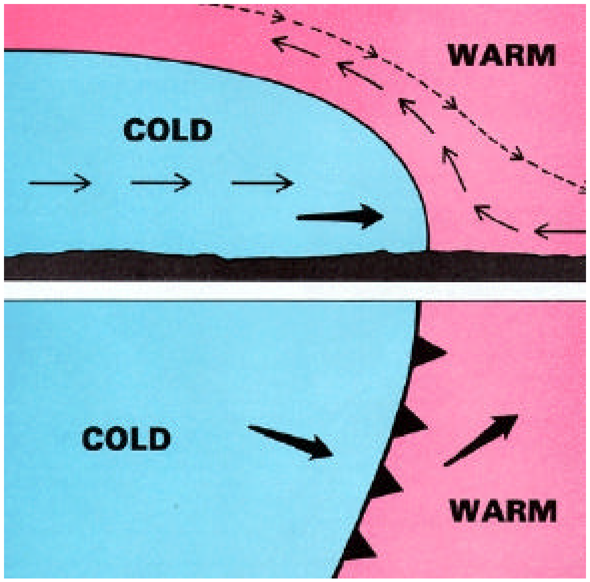
During the day, the land heats relative to the water driving a converging sea breeze circulation.

Convergence of the trade winds create TRWs in the ITCZ

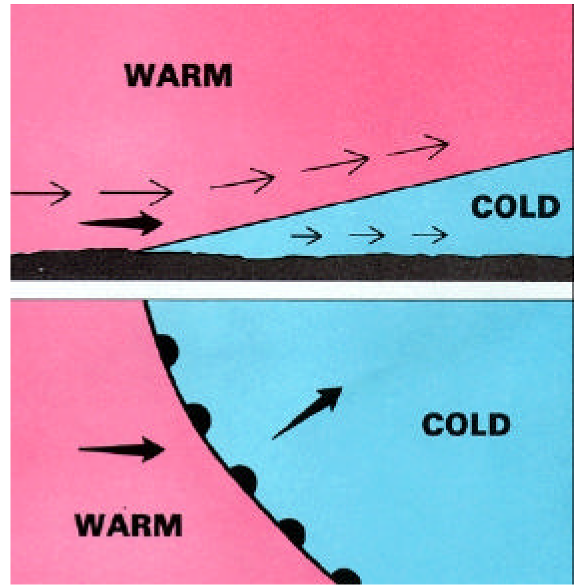


ITCZ = Inter-tropical Convergence Zone

Lifting creates clouds above the frontal boundary.



Cold Front



Warm Front

Unstable behind:
- cumulus, gusty winds
- showers

Stable ahead:
- stratus, steady precip
- lowering ceilings

Prevailing winds driving moist air up rising terrain can give widespread *upslope* fog.

SE winds off the gulf of Mexico give rise to *upslope* conditions along the front range of the Rocky Mountains.

Moist air adiabatically cools below its dewpoint as it is lifted.

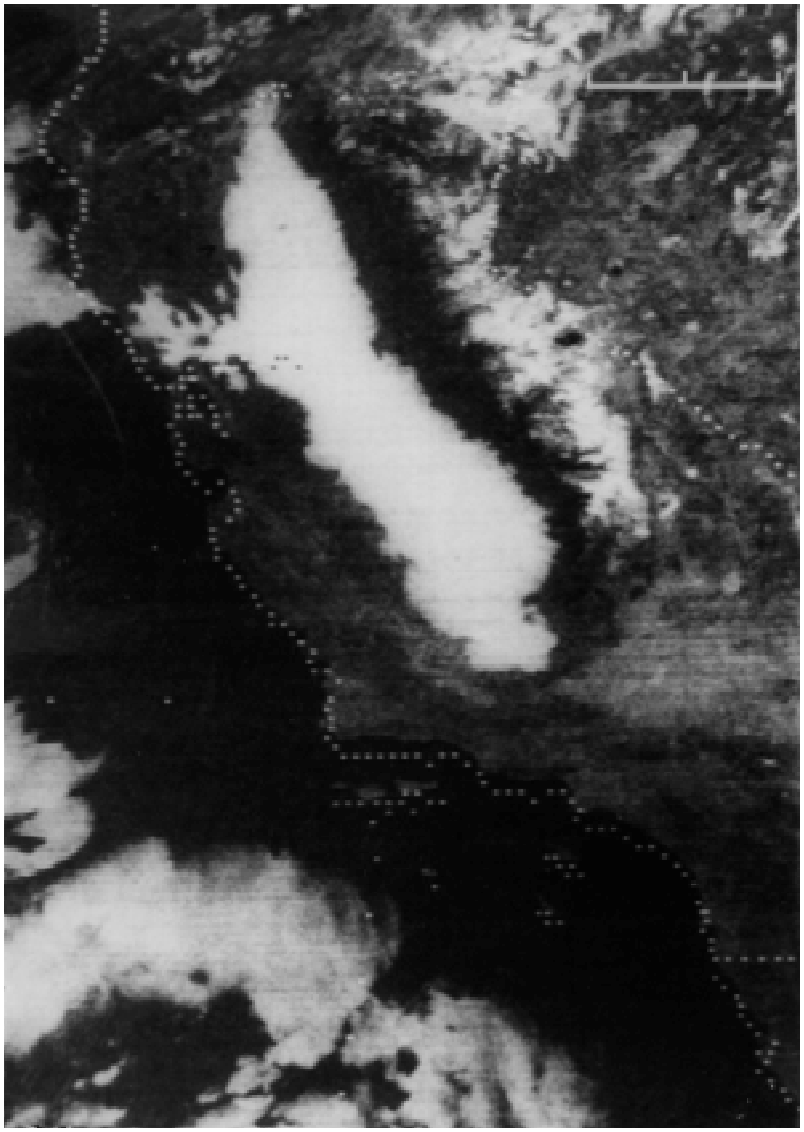
Radiation or *ground* fog occurs when the ground cools by radiation.

- ✍ Forms at night under clear skies, but high humidity.
- ✍ Radiation fog is restricted to land because water surfaces cool little from nighttime radiation.

- ✍ It is shallow when wind is calm.

- ✍ Winds up to about 5 knots mix the air slightly and tend to deepen the fog by spreading the cooling through a deeper layer. Stronger winds disperse the fog or mix the air through a still deeper layer with stratus clouds forming at the top of the mixing layer.

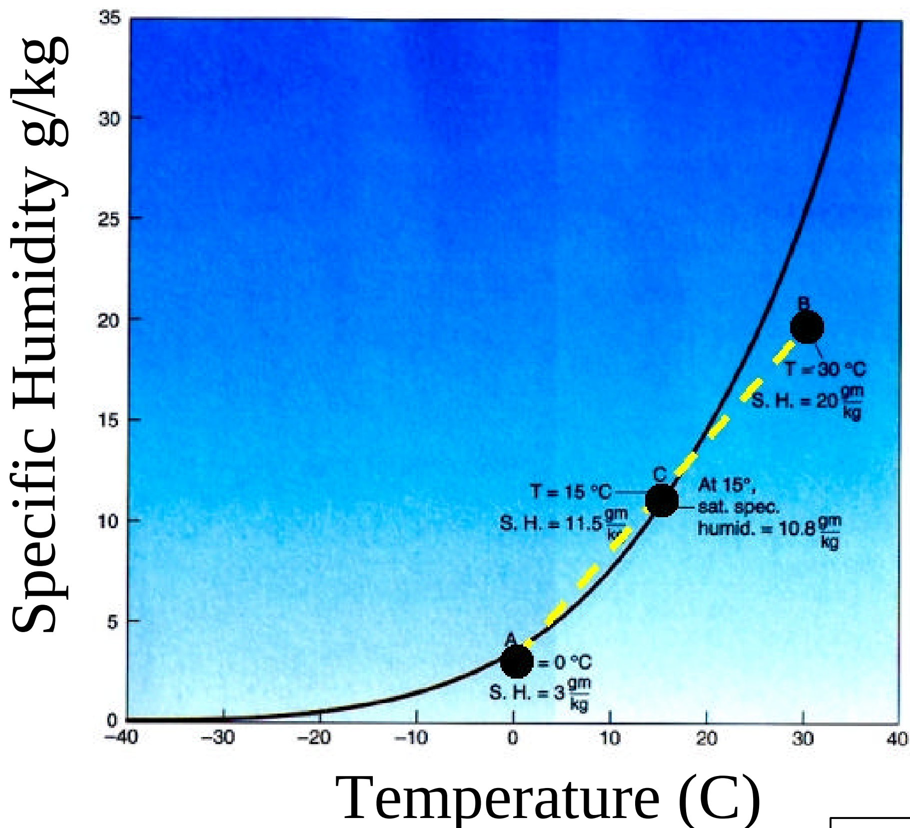
Visible satellite image shows radiation (Tule) fog in the Central Valley

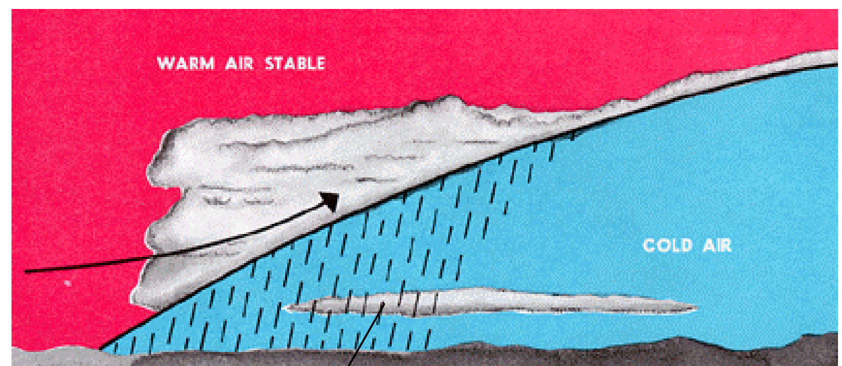


Long winter nights give maximum cooling.

The cooled saturated air rolls down into the lowest terrain.

Mixing cold and warm moist (but unsaturated!) air can make clouds.





Precip-induced fog and stratus

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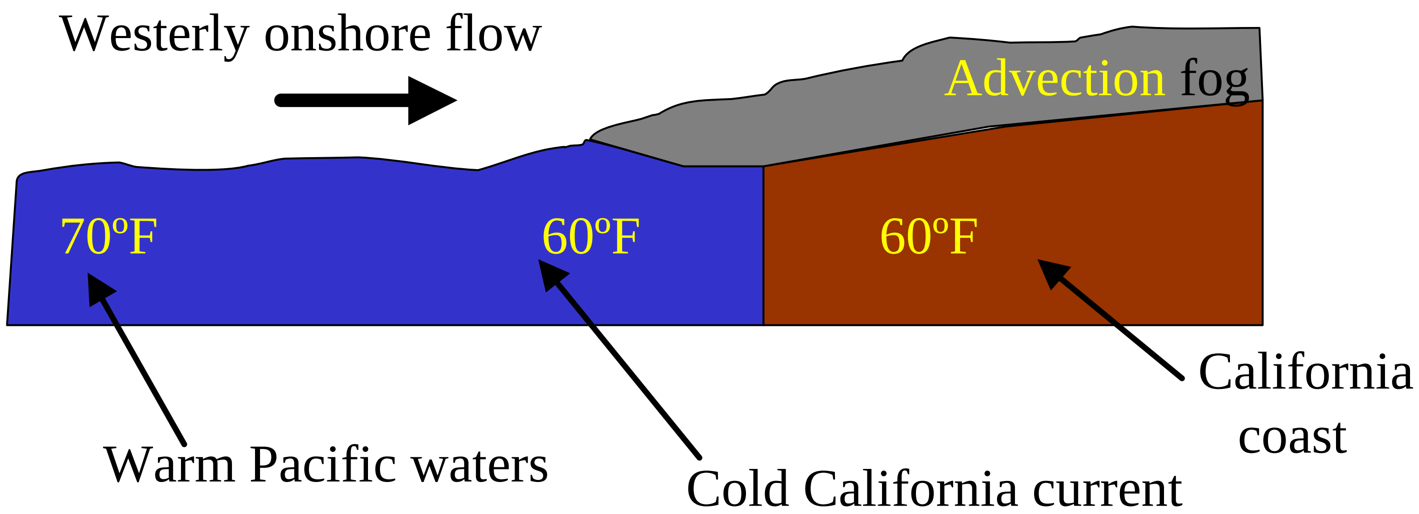
Advection of warm moist air over a cold surface is a fog maker.



Warm moist air off the Pacific is cooled to its dewpoint by the cold California current and then advected inland.

On the East coast, in winter, warm moist air from the Atlantic is cooled by the land.

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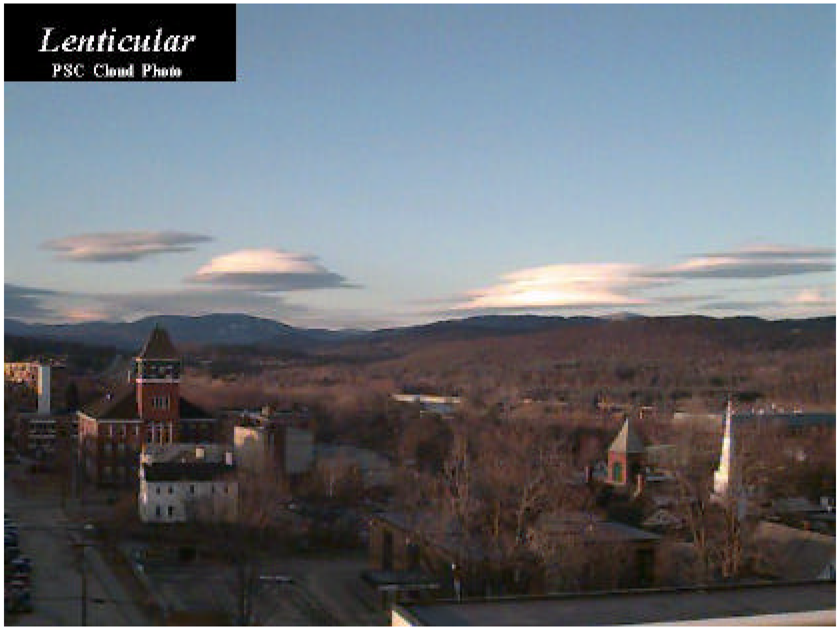
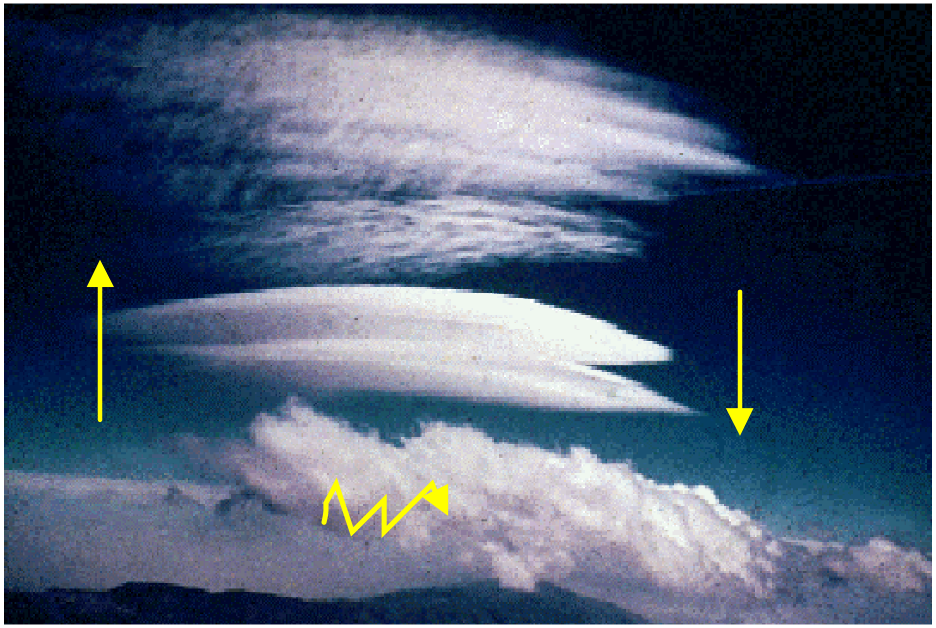
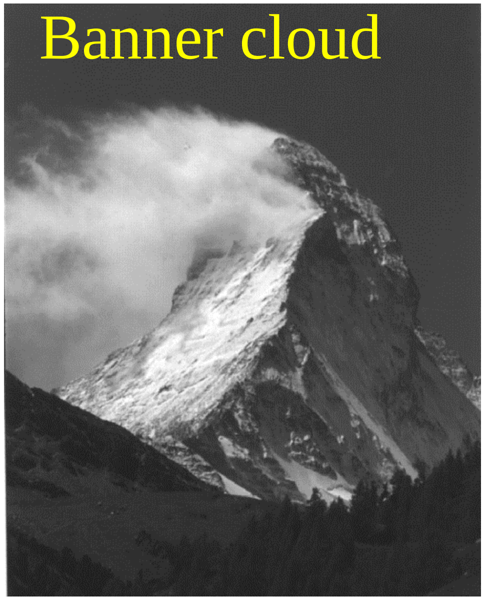
Lenticular clouds show the presence of mountain waves







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Thunderstorms development requires three ingredients:

- ✍ Unstable lapse rate

  Cu can build into Cb

- ✍ High moisture content

  The latent heat of condensation provides the megatons of energy.

- ✍ Lifting action

  Airmass

  Frontal

  Squall line

  Orographic

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The Cb lifecycle starts in the cumulus or building stage.

Mostly updrafts - triggered by the lifting action.

The mature stage is entered when it starts to rain.

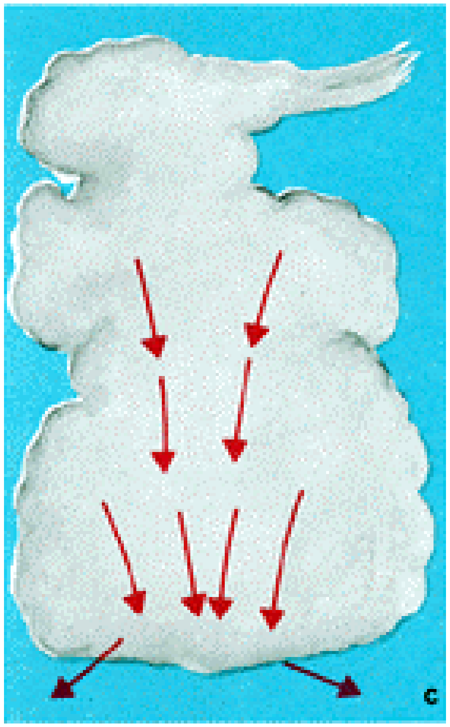
The cold rain entrains a downdraft in the core of the storm.

On reaching the ground it spreads as a gust front and severe LLWS.

Frequent lightning indicates a severe storm.

At night, distant lightning along a wide sector of the horizon likely indicates a squall line.

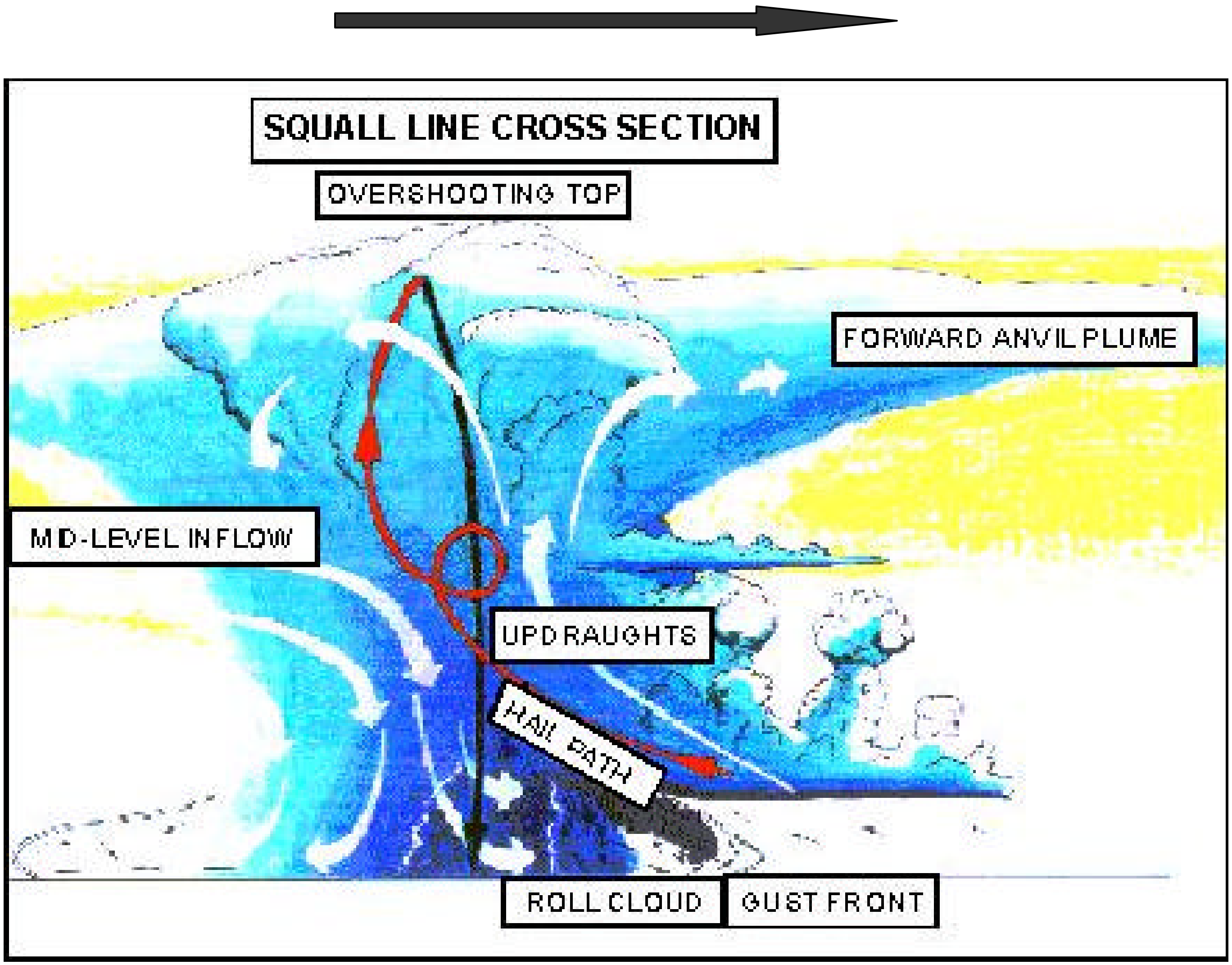
In a typical airmass thunderstorm, the downdrafts shut off the updrafts and the storm dissipates.



This cycle takes 20-30 minutes.

The most severe hazards are in the mature stage. It has up and downdrafts shearing to create severe turbulence. It has the worst icing and the possibility of hail.

Squall line and other steady state storms persist because the rain downdrafts are offset from the updrafts.



The cloud shapes can tell us about the storm's severity.

Crisp-edged, steeply-rising boiling clouds.

Over-shooting top back-shearing against the wind

Diffuse, fibrous anvil characteristic of weaker updrafts and less-severe storm.

Some thunderstorm characteristics

Stronger if:	**Weaker if:**
ANVIL • crisp edge, long and thick • spreads back against upper flow (usually to the west)	• diffuse edge
CORE • Large, solid, boiling cloud mass • cloud top overshoots anvil • rear of cloud almost vertical	• soft edged - no detail • rear of cloud leans forward
RAIN CURTAIN • dark and smooth • strong outward spreading near the surface • rain becomes progressively heavier	

Dry microburst at Stapleton airport

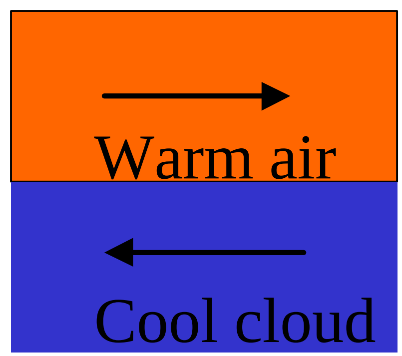
A wet microburst in western Texas

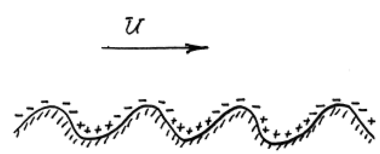
ACCAS (Alto-Cumulus Castellanus)

Indicates mid-level instability
that may later support TRW activity

Cirrus

Kelvin-Helmholtz clouds





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Clouds- I've left you with the hard part...

Make weather related decisions based on:

Reports and forecasts
What you see from the cockpit
You and your airplane's capabilities

Improved understanding of how weather patterns work should help.

Try to make sense of what you see and how your flights actually unfold, so that you can learn from them.