Meteorology I

Aviation weather theory

A little bit about myself

- Andi Kravljaca
- 35 years old
- Stockholm

- Masters degree in physics, field and particle theory from the University of Stockholm
- One semester of post-grad meteorology studies at the Institution for Meteorology at the University of Stockholm
- A teaching degree from the Stockholm Institute for Education.

A little bit about myself

Sources:

PHAK, an FAA resource.

- https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/phak/media/14_phak_ch12.pdf

- http://www.free-online-private-pilot-ground-school.com/Aviation-Weather-Principles.html

Air as a fluid medium

LLL: Lava Lamp Laws

- Hot stuff rises

- What goes up must come down

- Nature abhors a vacuum

What is weather anyway?

Differences in air density caused by changes in temperature result in changes in pressure.

This, in turn, creates motion in the atmosphere, both vertically and horizontally, in the form of currents and wind.

Motion in the atmosphere, combined with moisture, produces clouds and precipitation otherwise known as weather.

Four key concepts:

Density - Pressure - Temperature - Moisture

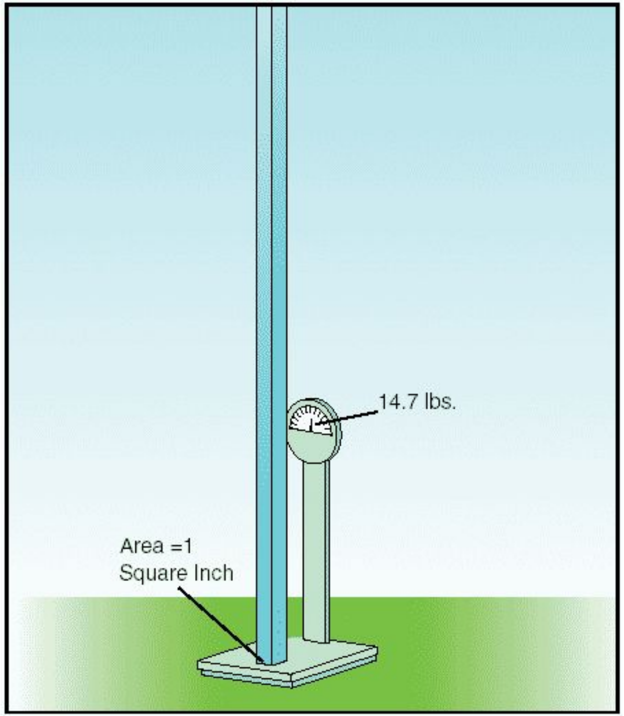
Pressure and density

At sea level, the atmosphere exerts pressure on the Earth at a force of 14.7 pounds per square inch. This means a column of air 1-inch square, extending from the surface up to the upper atmospheric limit, weighs about 14.7 pounds.

Equivalent to:

1013 hPa (mbar)

29.92 inHg



Pressure and density

The actual pressure at a given place and time will differ with altitude, temperature, and density of the air.

To provide a common reference for temperature and pressure the International Standard Atmosphere (ISA) has been established.

- 1013 hPa (29.92 inHg) at 15 deg C (59 deg F) at sea level.

Pressure and density

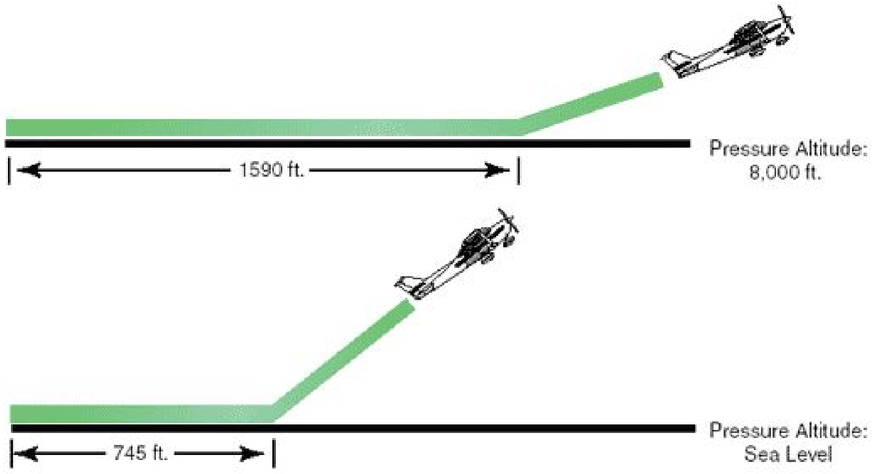
Where does altitude come in?

- Air gets less dense, and air pressure decreases the higher we go.

Gravity attracts closer objects more.

Molecules further away from the earth are standing on the molecules below them, causing compression.

The effect is exponential, but at low altitudes, pressure decreases by about 12 hPa for every 100 meters. (roughly 1 inHg every 1000 feet)



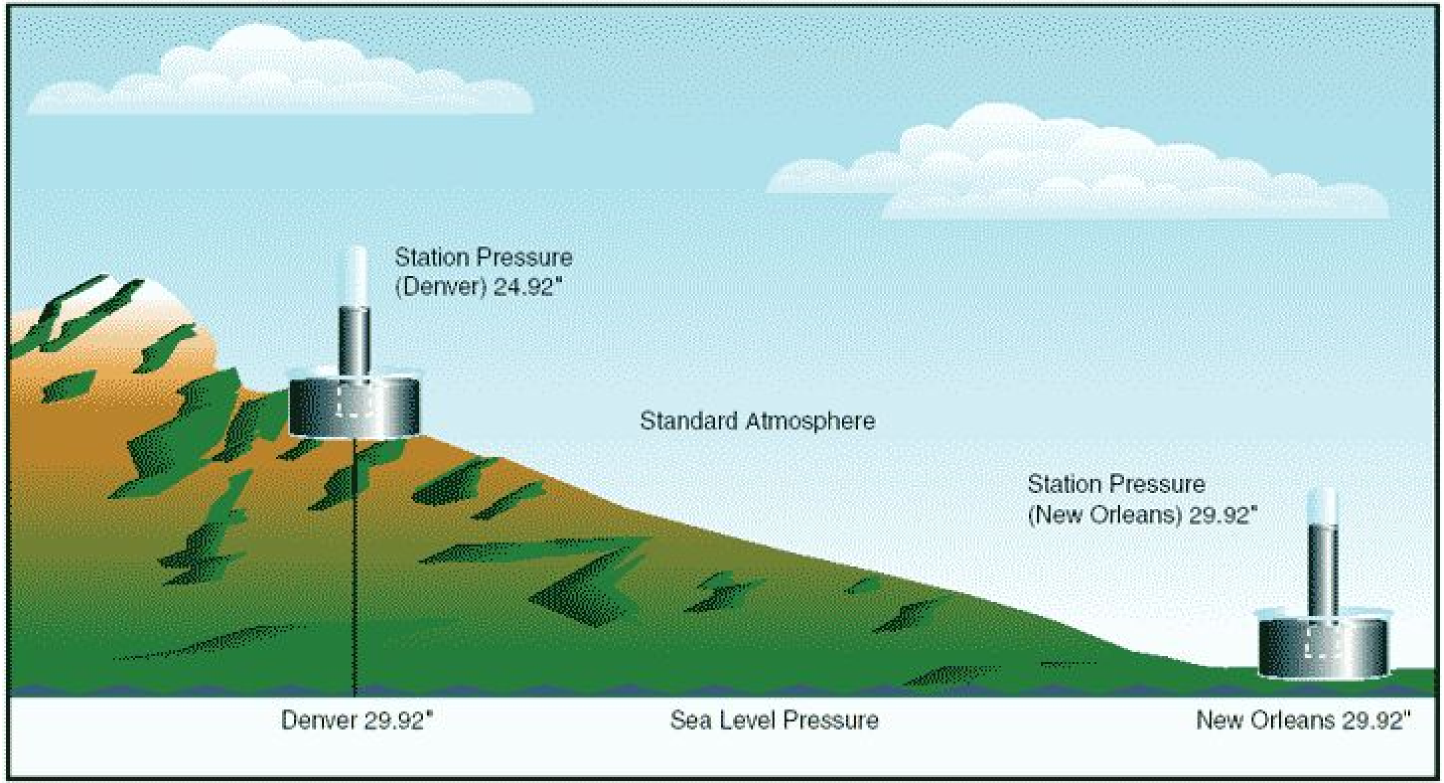
TAKEOFF DISTANCE

PRESS ALT FT	0°C		PRESS ALT FT	0°C	
	GRND ROLL FT	TOTAL FT TO CLEAR 50 FT OBS		GRND ROLL FT	TOTAL FT TO CLEAR 50 FT OBS
S.L.	745	1320	5000	1185	2125
1000	815	1445	6000	1305	2360
2000	895	1585	7000	1440	2635
3000	980	1740	8000	1590	2960
4000	1075	1920			

Some important notes about altitude and pressure

QFE = Is mean sea level pressure corrected for temperature, adjusted for a specific site. It will read zero at airfield elevation and after take off will read your HEIGHT above that specific airfield. If you fly to another airfield of different elevation and/or different QFE pressure, you will have to ensure you reset that particular airfields QFE if you want your altimeter to read zero on touchdown.

QNH = The pressure measured at station then reduced down to mean sea level pressure. When set on your altimeter it will read your ALTITUDE. Sat on the tarmac at your airfield the altimeter will display the airfields elevation above mean sea level. This is almost universally what we use.


Station Pressure
(Denver) 24.92"
Standard Atmosphere
Station Pressure
(New Orleans) 29.92"
Denver 29.92"
Sea Level Pressure
New Orleans 29.92"

Temperature

Where does altitude come in?

$$\Gamma_w = g \frac{1 + \frac{H_v\, r}{R_{sd}\, T}}{c_{pd} + \frac{H_v^2\, r}{R_{sw}\, T^2}} = g \frac{1 + \frac{H_v\, r}{R_{sd}\, T}}{c_{pd} + \frac{H_v^2\, r\, \epsilon}{R_{sd}\, T^2}}$$

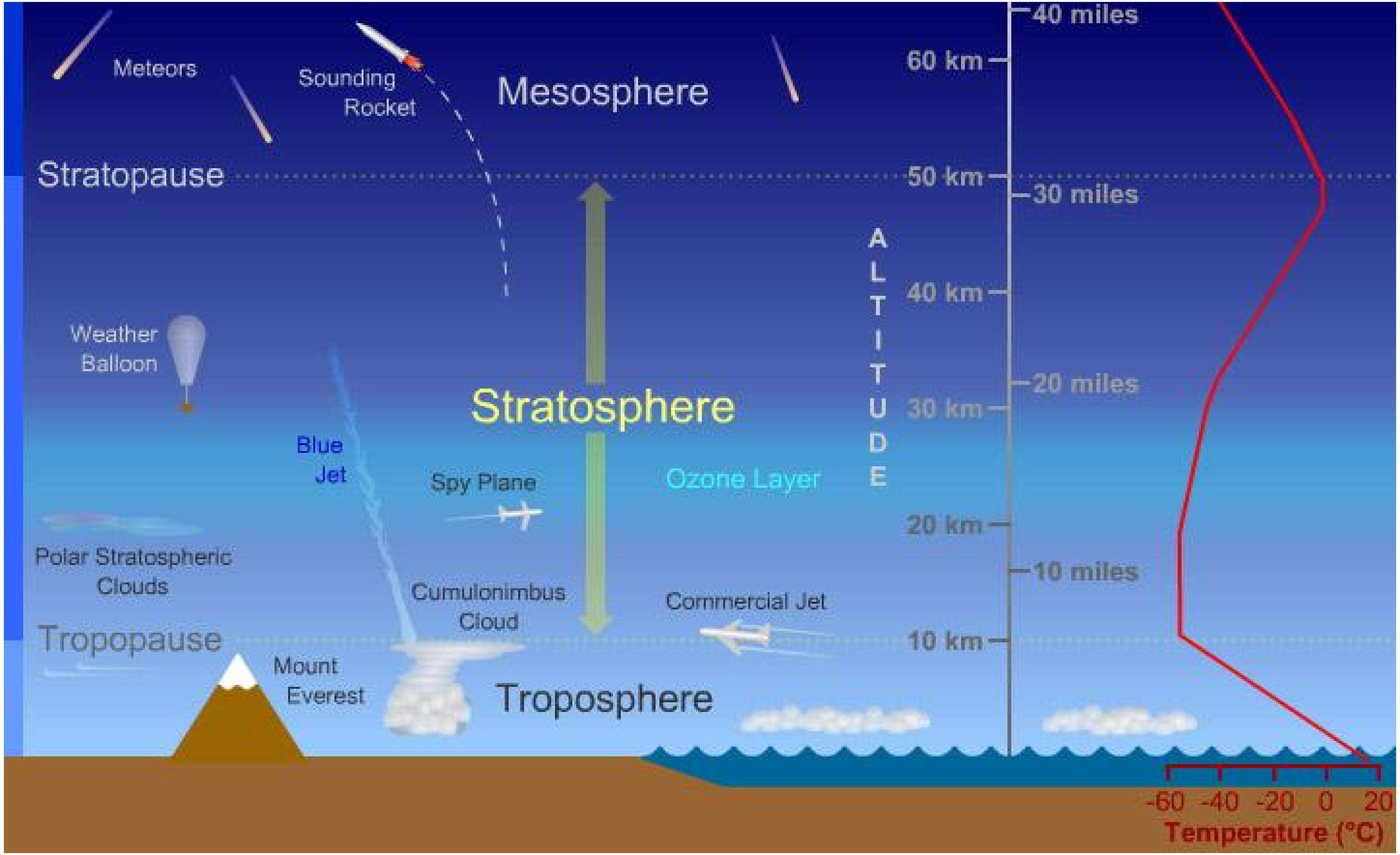
- Air gets colder the higher we go.

Lapse rate

- roughly −2 °C (-4 °F) per 1,000 ft

If the temperature at sea level is 70 degrees F, what is the approximate temperature at 6000 feet, given ISA?

- 46 degrees;   70-(4*6)



Meteors
Sounding Rocket
Mesosphere
Stratopause
Weather Balloon
Stratosphere
Blue Jet
Spy Plane
Ozone Layer
Polar Stratospheric Clouds
Cumulonimbus Cloud
Commercial Jet
Tropopause
Mount Everest
Troposphere
ALTITUDE
60 km
50 km
40 km
30 km
20 km
10 km
40 miles
30 miles
20 miles
10 miles
-60 -40 -20 0 20
Temperature (°C)

Temperature - Where is the heat coming from?

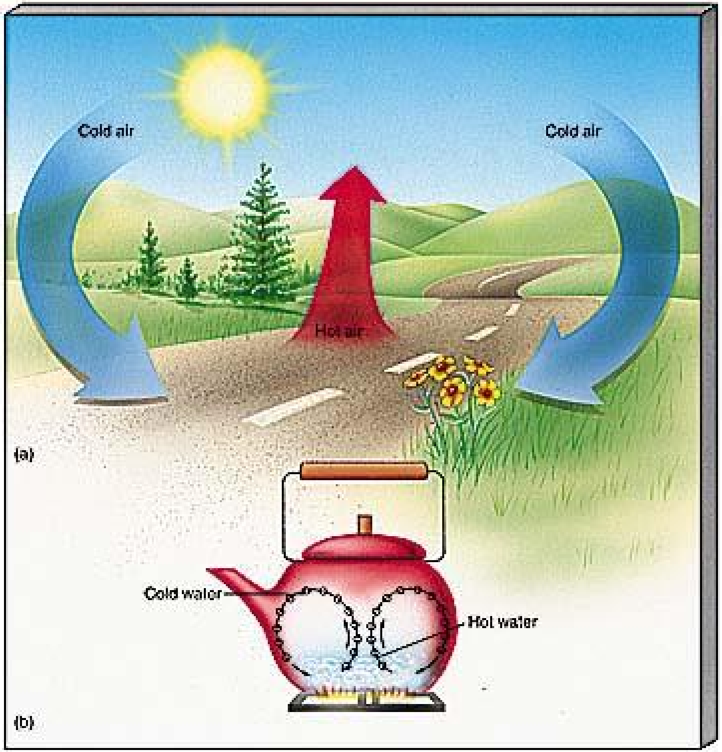
A lava lamp is heated from below, like a kettle.

Why does the sun heat the ground and not the air, directly?

The sun sends massive amounts of energy, but air is transparent to most of this energy.

Energy is stored in the ground, and released as heat which air can absorb.

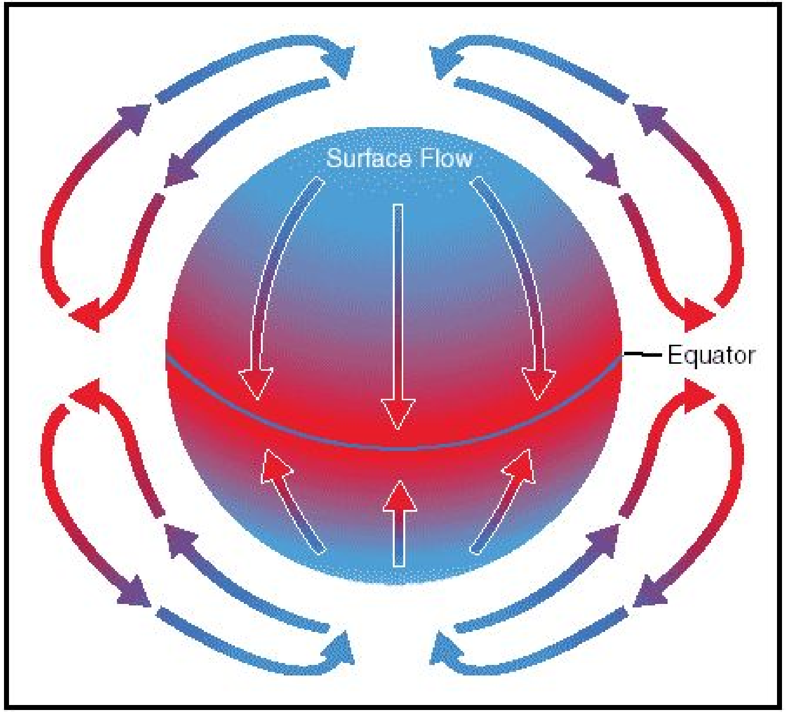
Lucky for us!



Temperature - convective current

Atmospheric circulation - movement of air around the surface of the Earth.

Solar heating causes air to become less dense and rise in equatorial areas. The resulting low pressure allows the high-pressure air at the poles to flow along the planet´s surface toward the equator. As the warm air flows toward the poles, it cools, becoming more dense, and sinks back toward the surface. **Easy, right?**



Temperature - convective current

Wrong. Accurate weather forecasting is a modern miracle!

Imagine attempting to forecast, accurately, how a lava lamp would look in four days, given that you know the state it's in now.

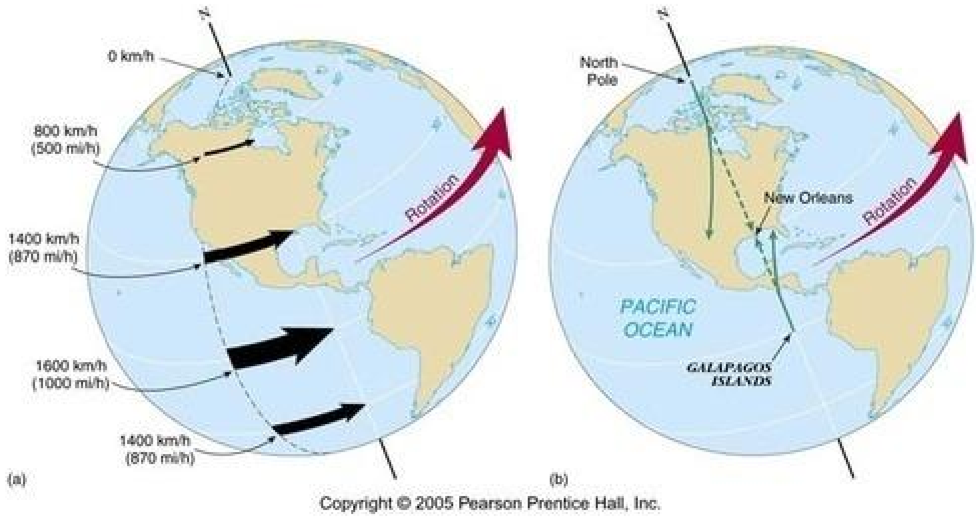
Now imagine a lava lamp that's hundreds of miles high, and tens of thousands of miles wide – and because clouds block out the sun – where the heat at the bottom is unevenly and unpredictably distributed.

Supercomputers are used for two primary functions in the world. Cryptography and signal processing on the one hand, and weather forecasting on the other.

Coriolis Force

Ever wonder why we launch rockets near the equator?

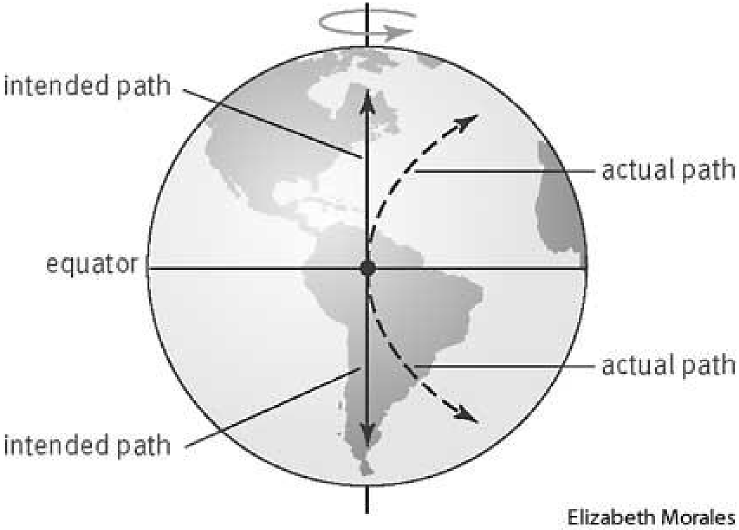
The Earth's rotation speed helps us go faster!



Coriolis Force

What happens if we go North or South instead?

The Earth's rotation speed changes under us. Our boost works against us.



Coriolis Force

Affects:

- Long range navigation
- Artillery
- Ocean current formation
- Weather systems

Does not affect (measurably):

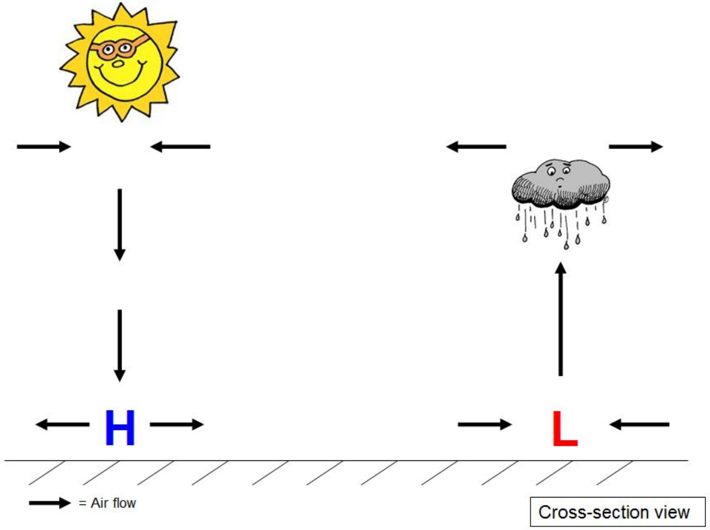
- Your toilet bowl

Pressure systems

High-pressure systems are generally areas of dry, stable, descending air. Typically associated with ‘good weather’ for this reason.

Conversely, air flows into a low-pressure area to replace rising air. This air tends to be unstable, and usually brings increasing cloudiness and precipitation.

Thus, bad aviation weather is commonly associated with areas of low pressure.

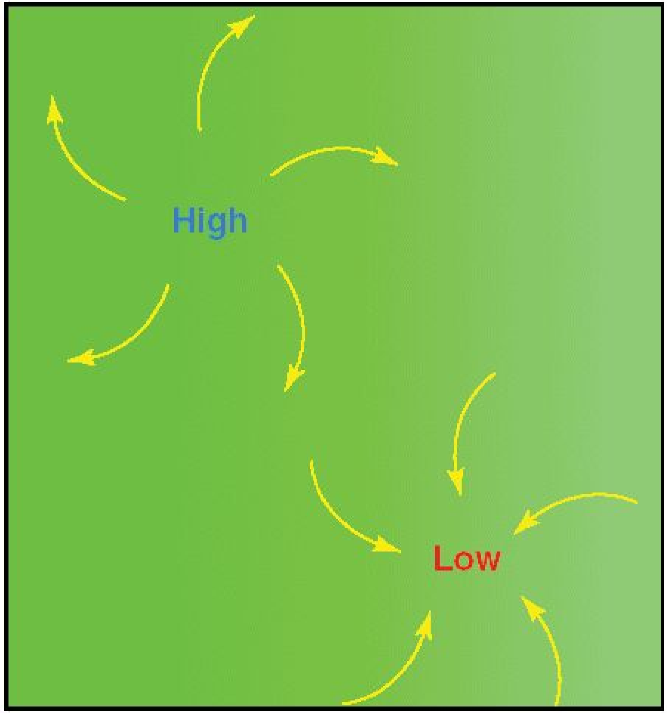


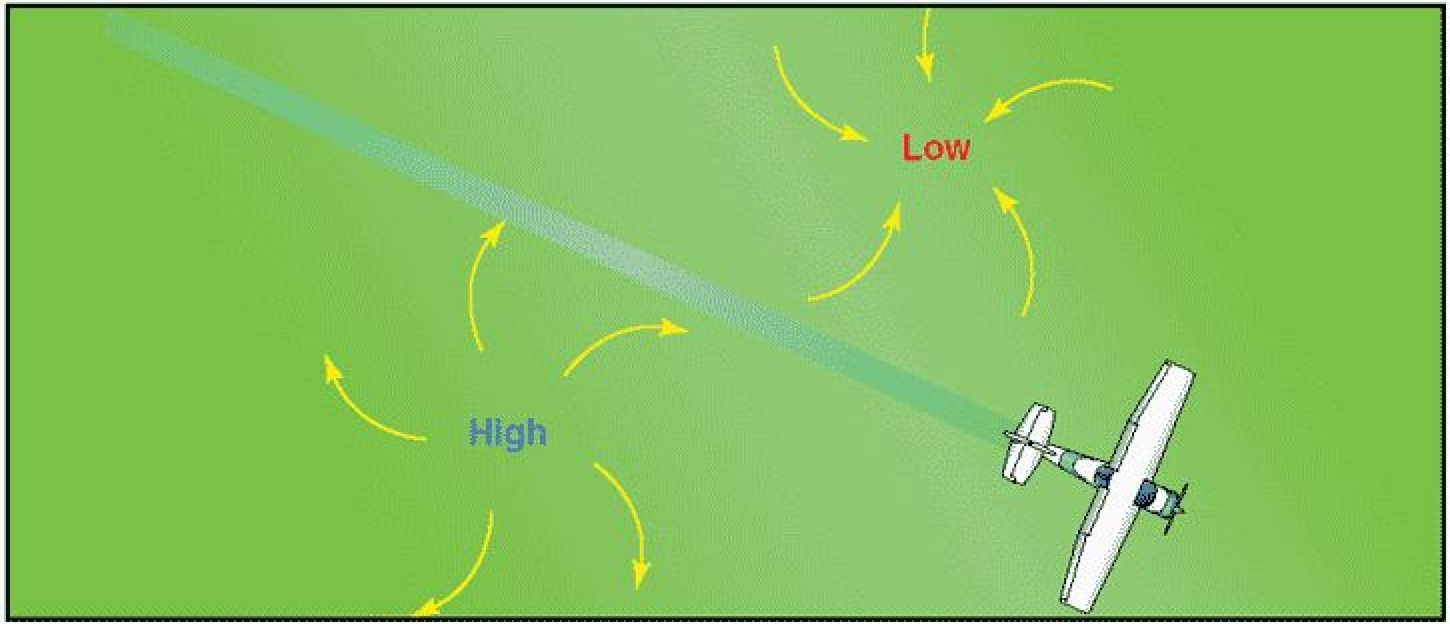
Coriolis Force and weather

Air flows from areas of high pressure into those of low pressure.

In the Northern Hemisphere, this flow of air from areas of high to low pressure is deflected to the right; producing a clockwise circulation around an area of high pressure.

The opposite is true of low-pressure areas; the air flows toward a low and is deflected to create a counter-clockwise circulation.



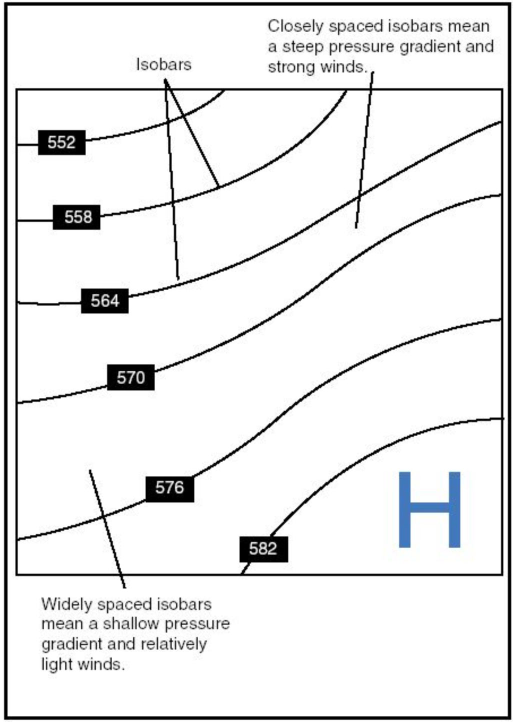

Low
High

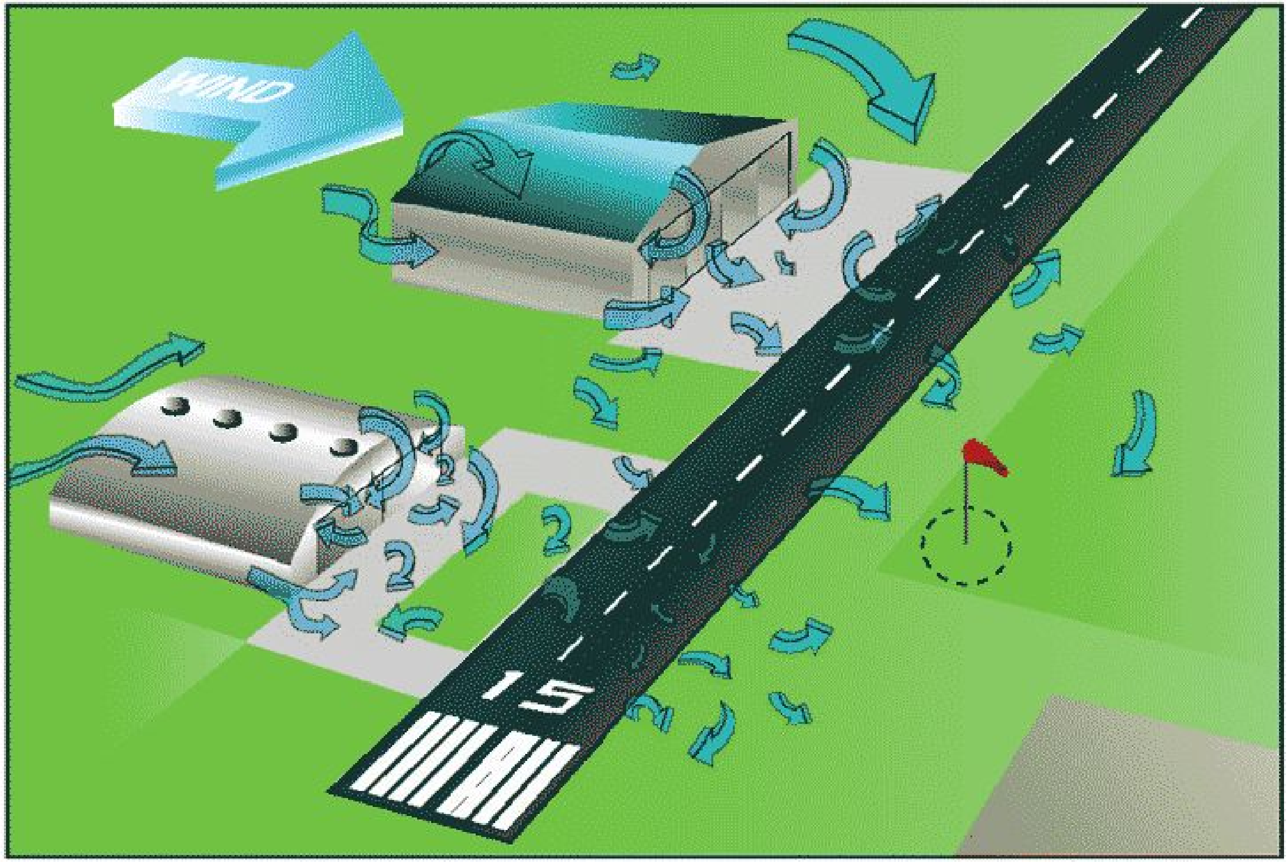
Wind and pressure systems

Isobars are lines drawn on the chart to depict areas of equal pressure.

Isobars that are closely spaced indicate a steep gradient and strong winds. Shallow gradients are represented by isobars that are spaced far apart.

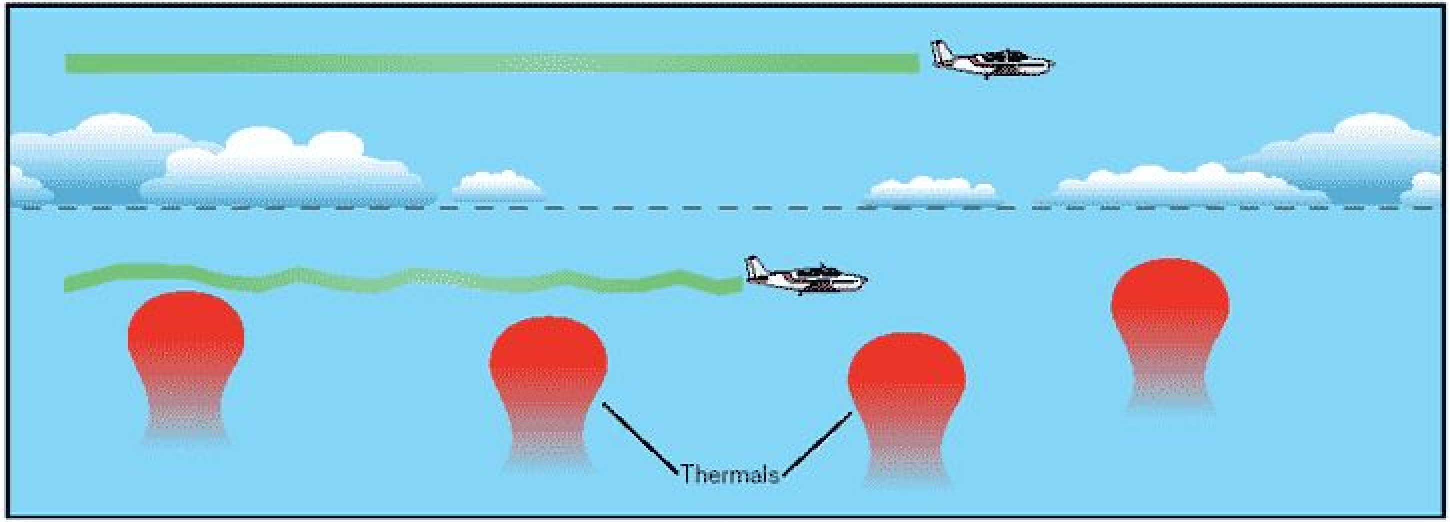
Close to the ground, wind direction changes and windspeed decreases due to friction with the surface. 2,000 feet above the ground the wind will be 20° to 40° to the right of surface winds, and the windspeed will be greater.

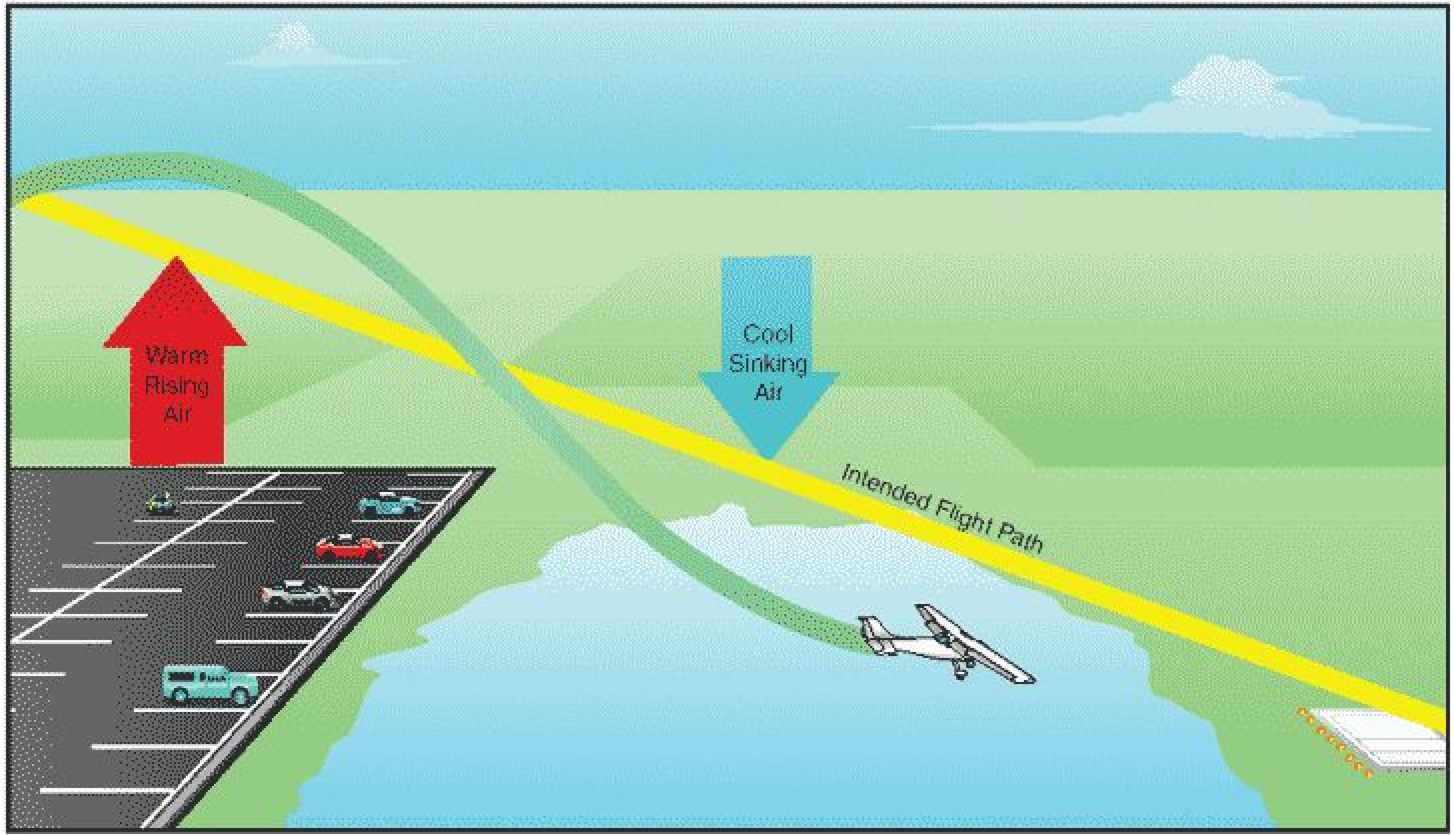


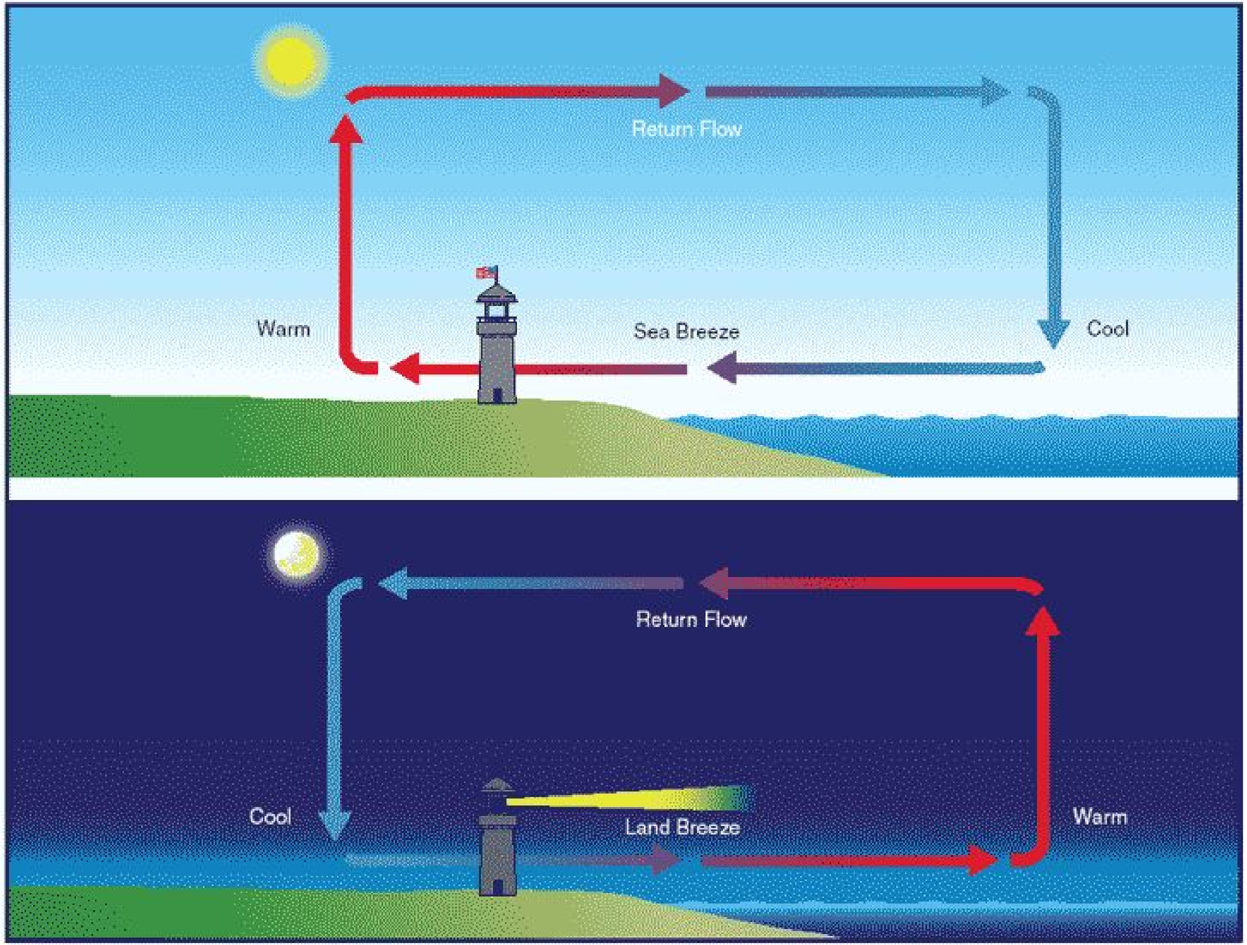

WIND
15

Temperature - Here comes that lava lamp again

Different surfaces radiate heat differently. Plowed ground, rocks, sand, and barren land give off a large amount of heat; water, trees, and vegetation absorb and retain heat.




Warm
Rising
Air
Cool
Sinking
Air
Intended Flight Path



Return Flow
Warm
Sea Breeze
Cool
Return Flow
Cool
Land Breeze
Warm

Moisture and humidity

The atmosphere, by nature, contains moisture in the form of water vapor.

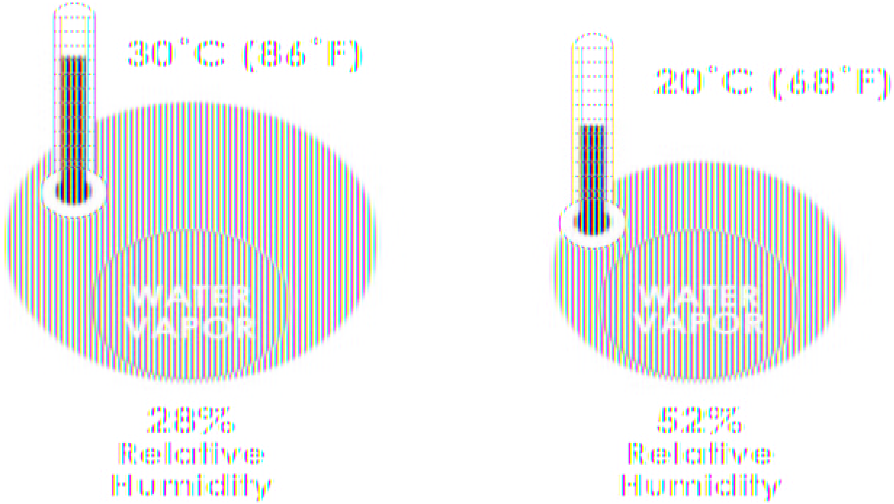
WATER VAPOR IS NOT STEAM. "Wet steam" as we call it, is the visible mist or aerosol of water droplets. It's drops of liquid water. Water vapor is water gas, and is invisible.

Water is present in the atmosphere in all three states: liquid, solid, and gaseous, and all three forms can readily change to another.

Clouds, fog and mist are caused when water vapor becomes wet steam.

Moisture and humidity

The amount of moisture air can hold, changes with temperature. A 20°F increase in temperature doubles the amount of moisture the air can hold. Conversely, a decrease of 20°F cuts the capacity in half. We call this *relative humidity*.



Moisture and humidity

When air exceeds 100% relative humidity, it is full. It can not take on any more water vapor. Any additional water in the air has to find other forms to exist in - fog, dew, frost, clouds, rain, hail, or snow.

If we cool an air mass, it will reach a temperature point where its relative humidity reaches 100%, as the temperature decreases. Once this temperature is reached, any further reduction in temperature will transform water vapor from gas to liquid.

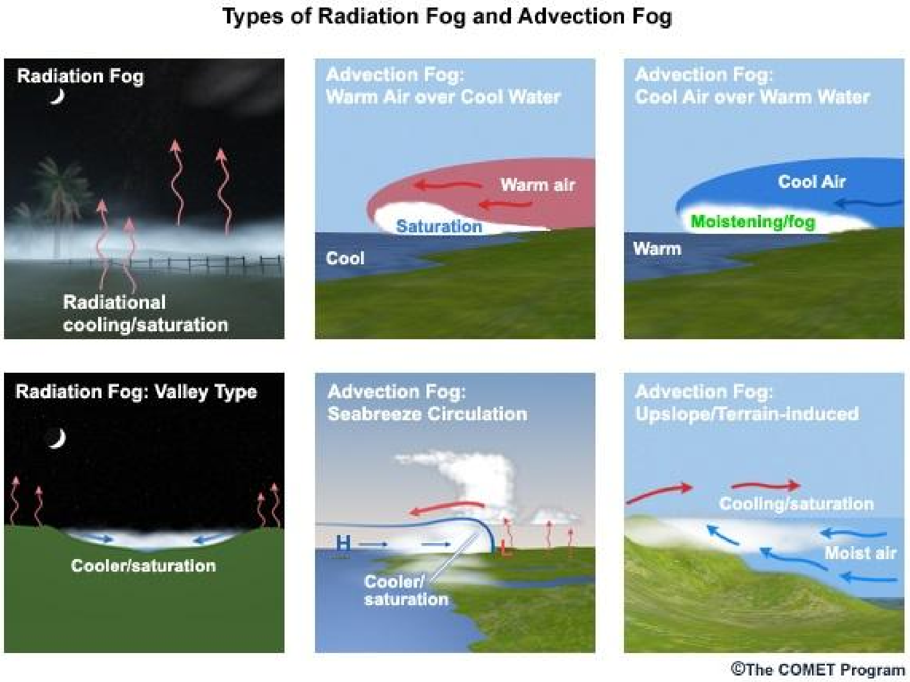
We call this point the ‘dew point’.

How far the current temperature is from the dew point, and the direction the temperature is going in, gives us an indicator of things like fog risk.

Moisture and humidity - Fog

Fog is formed when air near the surface is brought below its dew point.

- Warm air over cold ground or water
- Cool dry air picking up moisture
- Radiation fog
- Advection (movement) fog



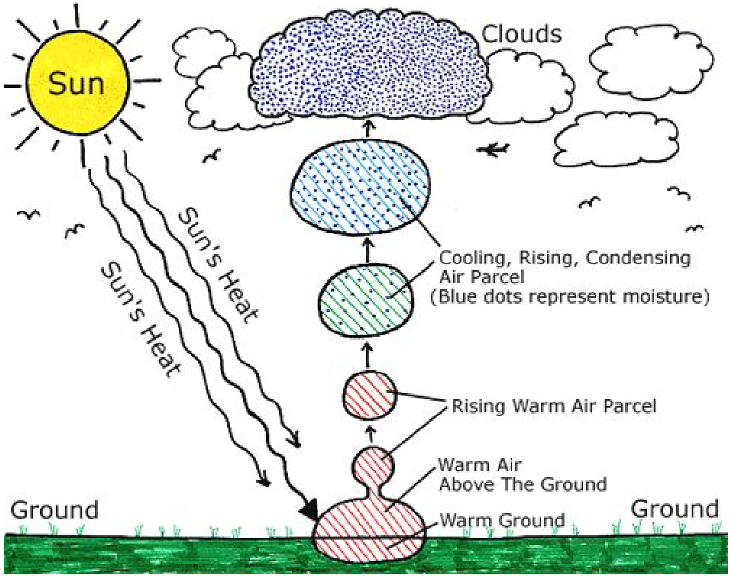
Moisture and humidity - Clouds

We reach the dew point by cooling air. Air cools as it rises. As moist air rises, clouds form at the altitude where temperature and dewpoint reach the same value.

Where does this happen? Roughly:

Cloud base in 1000s of ft = (Temperature - Dew point)/4

If it's 85 degrees with a dew point of 50, it's (85-50)/4 = roughly 9000ft.

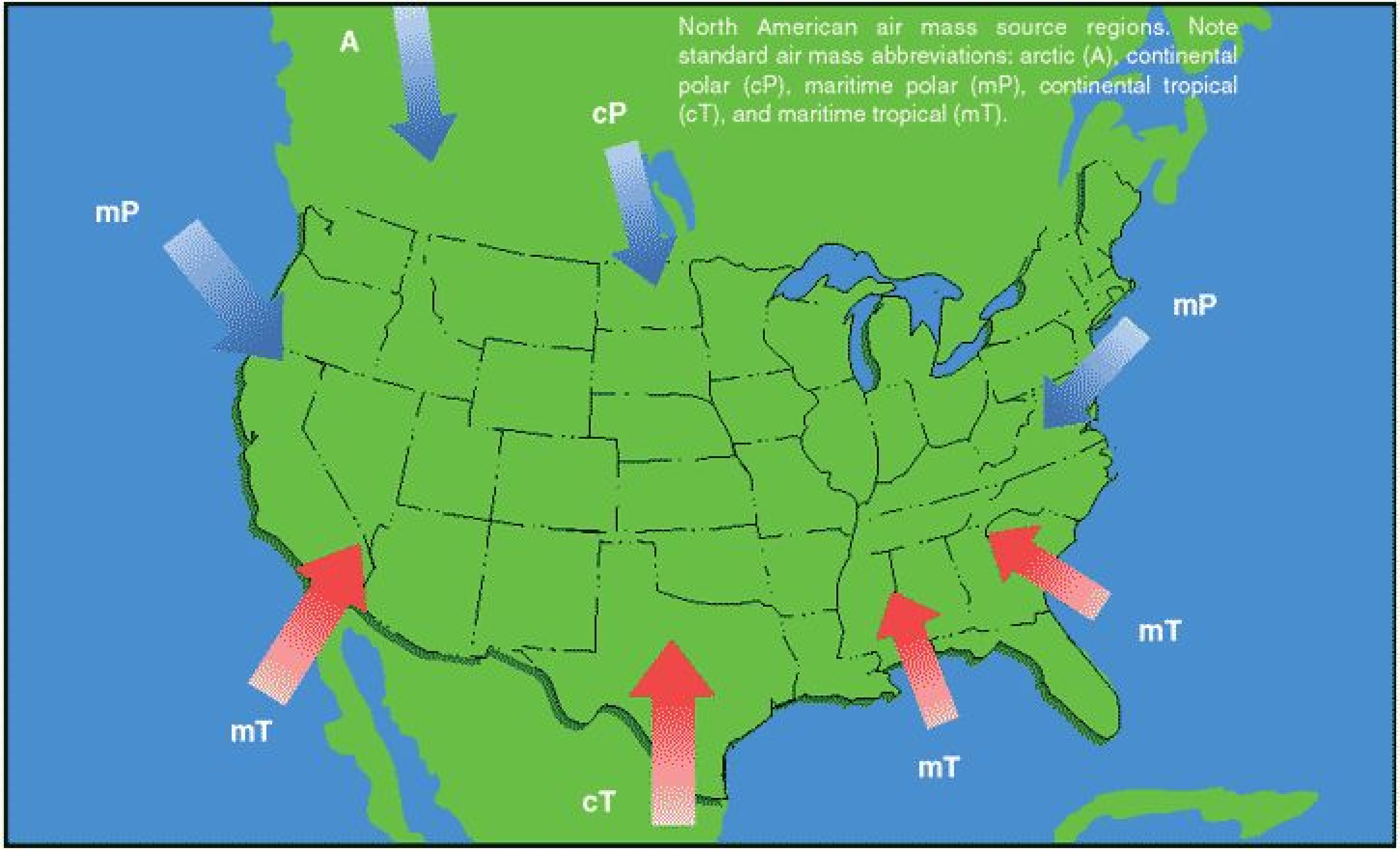


Air masses

Air masses are large bodies of air that take on the characteristics of the surrounding area, or source region.

A source region is an area in which the air stays still for a long period. The air mass thus takes on the temperature and moisture characteristics of the source region. Areas of stagnation can be found in polar regions, tropical oceans, and dry deserts. Air masses are classified based on their region of origination:

- Polar or Tropical
- Maritime or Continental


North American air mass source regions. Note standard air mass abbreviations: arctic (A), continental polar (cP), maritime polar (mP), continental tropical (cT), and maritime tropical (mT).
A
cP
mP
mP
mT
mT
mT
mT
cT

Air masses

A continental polar air mass forms over a polar region and brings cool, dry air with it.

Maritime tropical air masses form over warm tropical waters like the Caribbean Sea and bring warm, moist air.

As the air mass moves from its source region and passes over land or water, the air mass is subjected to the varying conditions of the land or water, and these modify the nature of the air mass.

Air masses - the snow cannon (case study)

If the Gulf of Bothnia freezes early, there will be little snow. If it freezes late, it will be very snowy. Why?

Dry, arctic air passes from Finland over the water and drinks up moisture. It reaches the coastline, and is elevated, reaching its dewpoint and dumping snow over the coastal cities.

If there is ice in the way, the air can't take on moisture and stays dry. No snow.

Similar to Great Lakes blizzards.

Air masses - fronts

Fronts occur when one air mass displaces another.

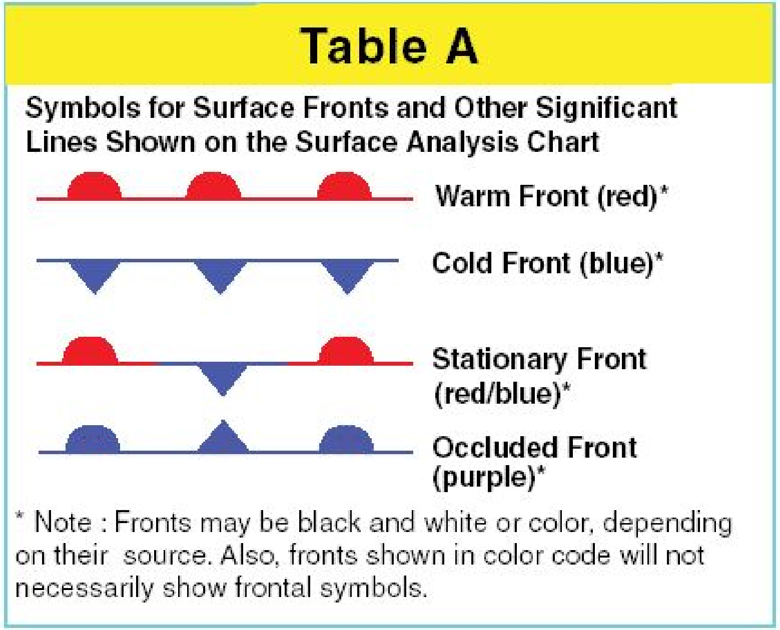
An air mass passing over a warmer surface will be warmed from below, and convective currents form, causing the air to rise. This creates an unstable air mass with good surface visibility. Moist, unstable air causes cumulus clouds, showers, and turbulence to form. (cfr Cold fronts)

An air mass passing over a colder surface does not form convective currents, but instead creates a stable air mass with poor surface visibility because smoke, dust, and other particles cannot rise out of the air mass and are trapped near the surface. A stable air mass can produce low stratus clouds and fog. (cfr. Warm fronts)

Fronts

As air masses move across bodies of water and land, they eventually come in contact with another air mass with different characteristics. The boundary layer between two types of air masses is known as a front.

- Cold front
- Warm front
- Stationary front
- Occlusion front



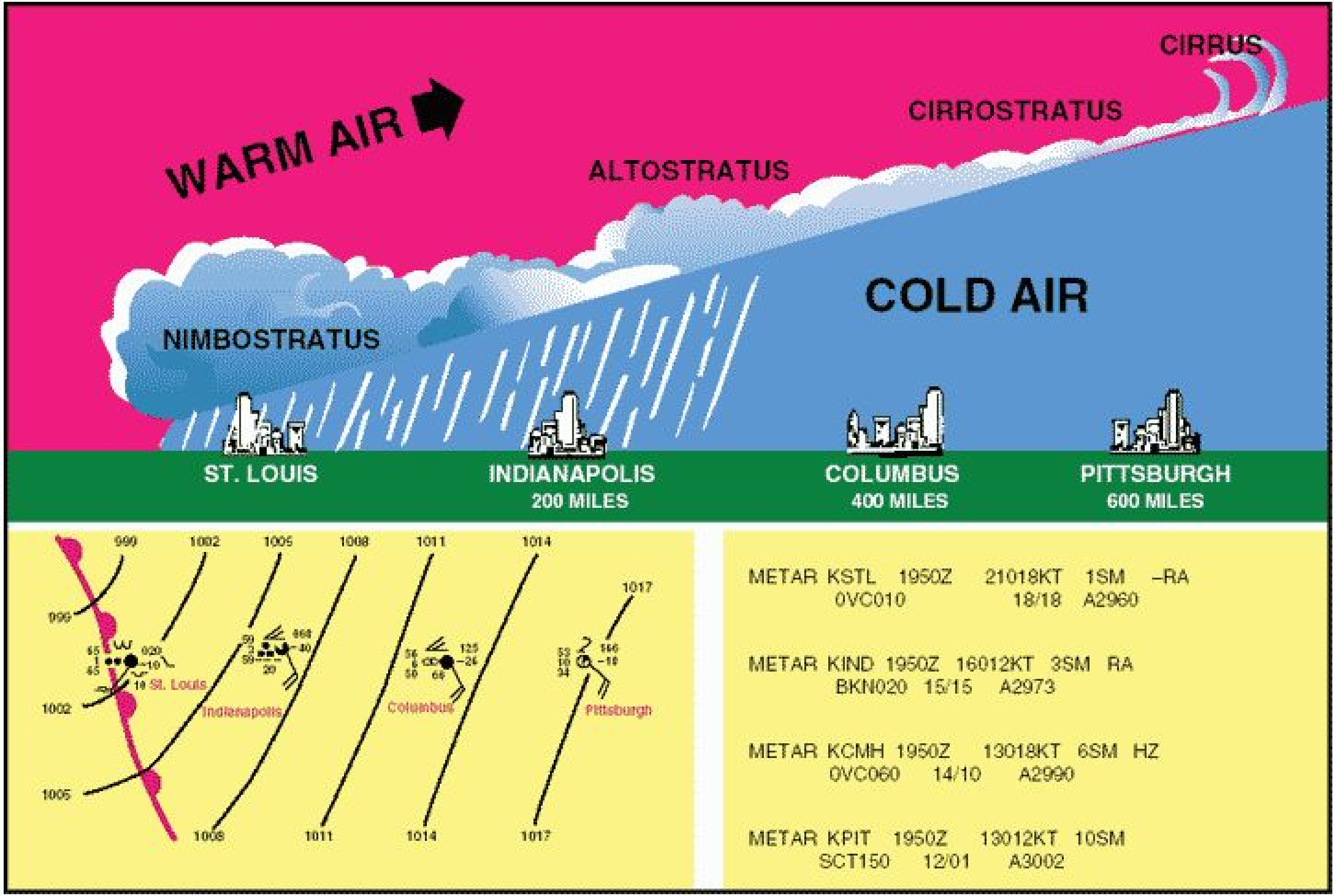
Fronts - Warm front

A warm front occurs when a warm mass of air advances and replaces a body of colder air. The advancing front slides over the top of the cooler air and gradually pushes it out of the area.

Warm fronts contain warm air that often has very high humidity. As the warm air is lifted, the temperature drops and condensation occurs.

Overcast, light rain or drizzle. The visibility is generally poor.

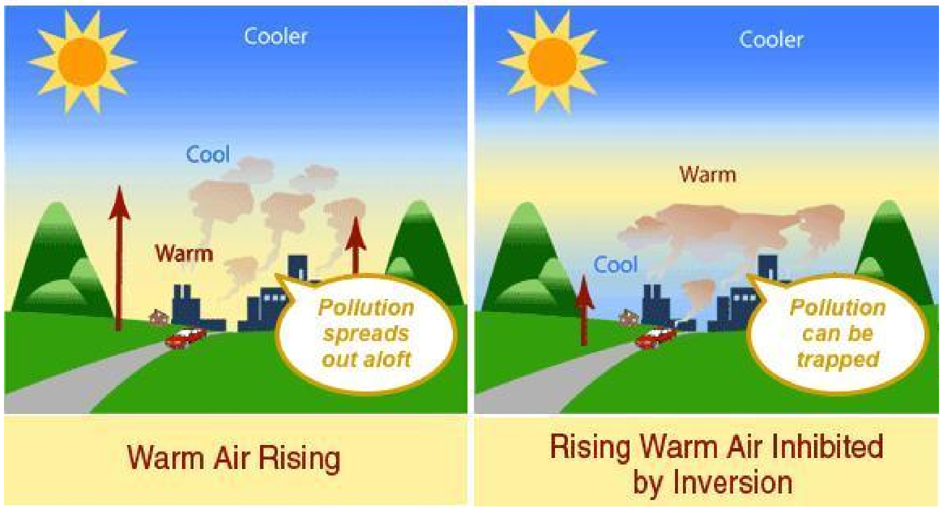
Warm fronts move slowly, typically 10 to 25 miles per hour (m.p.h.).


CIRRUS
CIRROSTRATUS
WARM AIR
ALTOSTRATUS
COLD AIR
NIMBOSTRATUS
ST. LOUIS
INDIANAPOLIS
200 MILES
COLUMBUS
400 MILES
PITTSBURGH
600 MILES
999
1002
1005
1008
1011
1014
1017
St. Louis
Indianapolis
Columbus
Pittsburgh
METAR KSTL 1950Z 21018KT 1SM -RA
0VC010 18/18 A2960
METAR KIND 1950Z 16012KT 3SM RA
BKN020 15/15 A2973
METAR KCMH 1950Z 13018KT 6SM HZ
0VC060 14/10 A2990
METAR KPIT 1950Z 13012KT 10SM
SCT150 12/01 A3002

A little about inversions

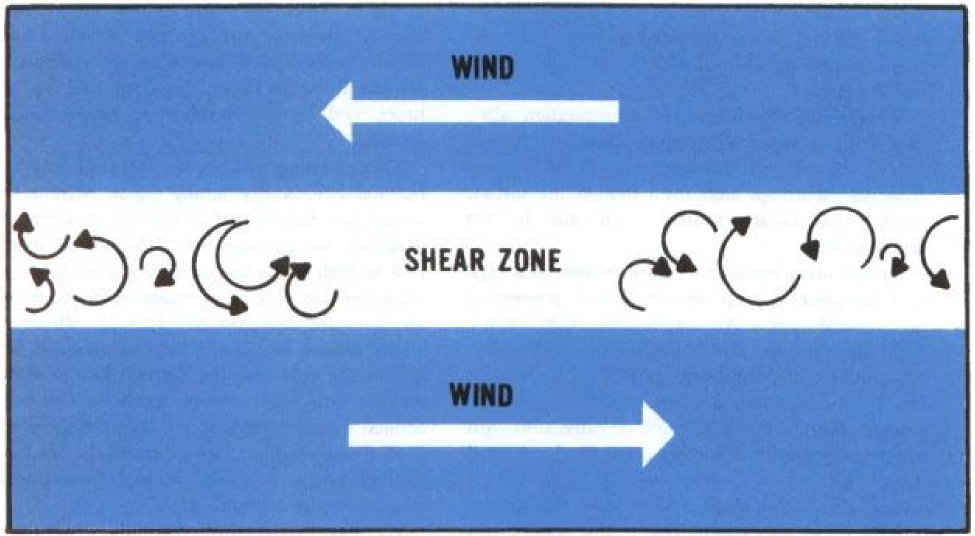
What happens when warmer air slides over top of colder air?

If warmer portions of the colder air rise, they experience a ‘stop’ once they reach a warmer layer they can’t climb over!



A little about inversions

If the wind in one air mass is going one way, and the wind in another air mass is going another, pilots will experience wind shear when traveling in and out of this boundary layer.



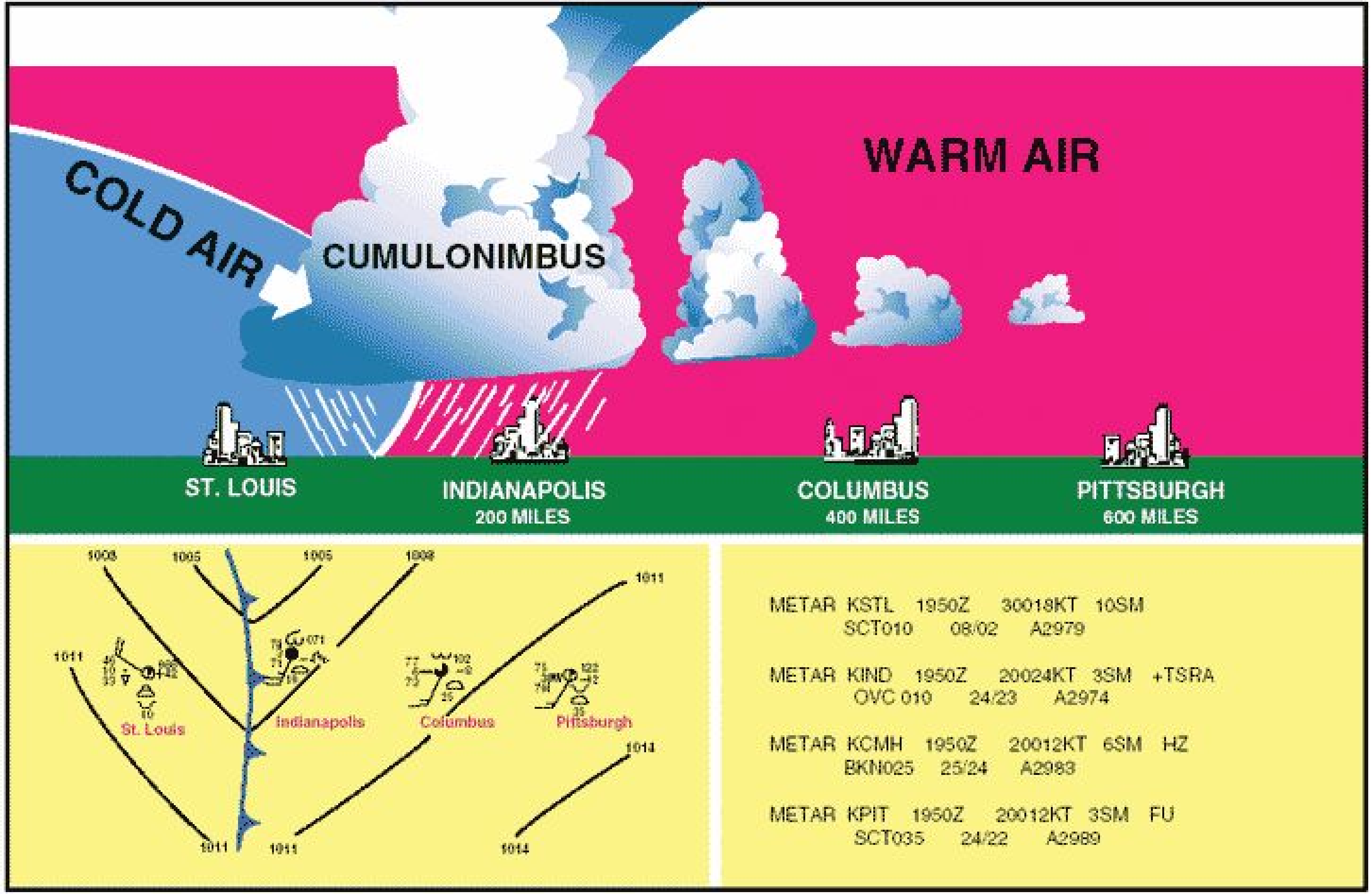
Fronts - Cold front

A cold front occurs when a mass of cold, dense, and stable air advances and replaces a body of warmer air.

Because it is so dense, it acts like a snowplow, sliding under the warmer air. The rapidly ascending warmer air causes its temperature to decrease suddenly, forcing the creation of clouds.

Towering cumulus or cumulonimbus clouds dominate the sky. Heavy rain showers, lightning, thunder, hail. After front passage, good visibility.

Faster than warm fronts, moving at a rate of 25 to 30 mph - up to 60mph!

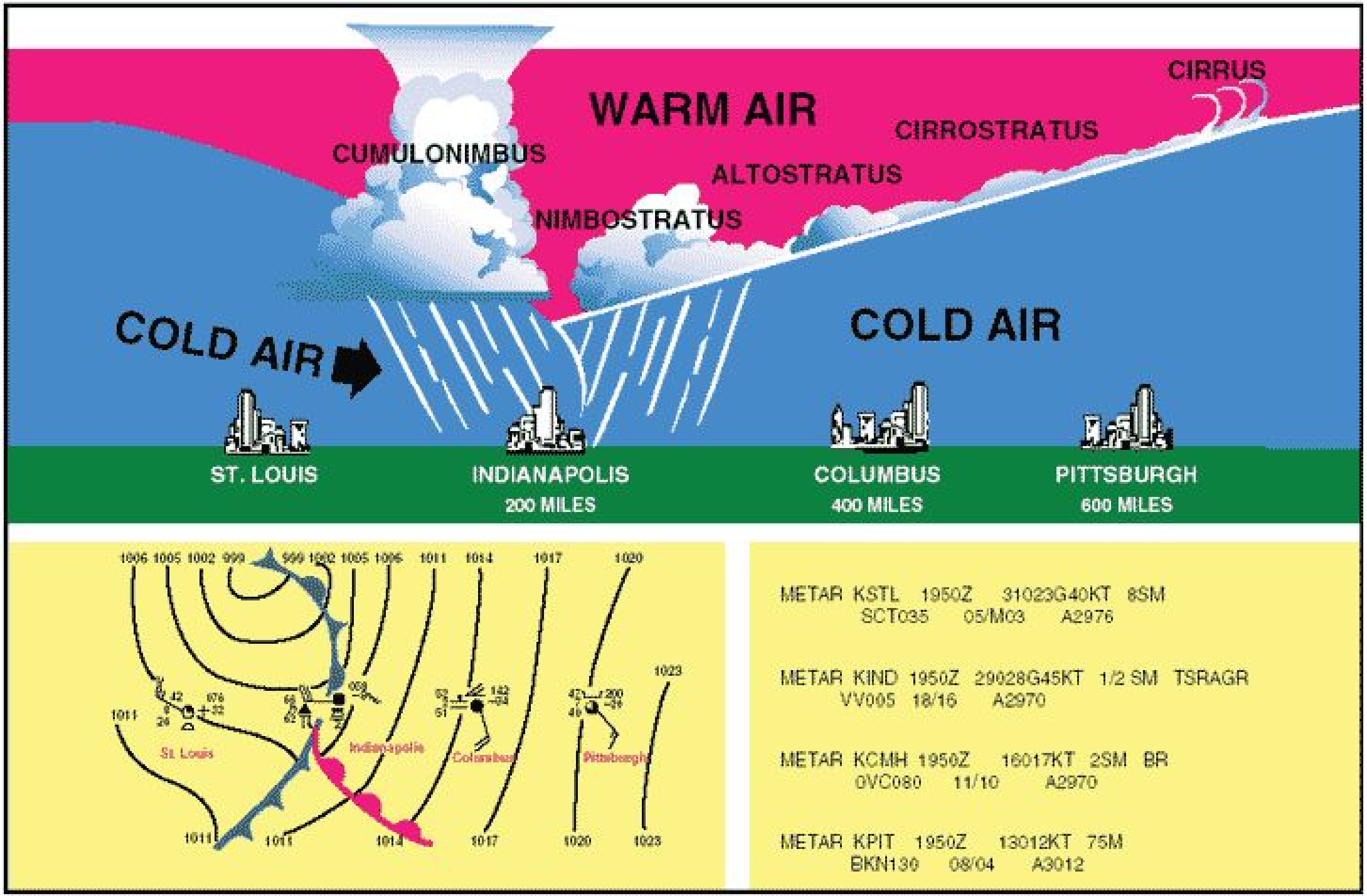

WARM AIR
COLD AIR
CUMULONIMBUS
ST. LOUIS
INDIANAPOLIS
200 MILES
COLUMBUS
400 MILES
PITTSBURGH
600 MILES
St. Louis
Indianapolis
Columbus
Pittsburgh
METAR KSTL 1950Z 30018KT 10SM
SCT010 08/02 A2979
METAR KIND 1950Z 20024KT 3SM +TSRA
OVC 010 24/23 A2974
METAR KCMH 1950Z 20012KT 6SM HZ
BKN025 25/24 A2983
METAR KPIT 1950Z 20012KT 3SM FU
SCT035 24/22 A2989

Fronts - Occlusion front

If cold fronts move faster than warm fronts, what happens when a cold front catches a warm front?

As the occluded front approaches, warm front weather prevails, but is immediately followed by cold front weather.

In the worst case, the cold front is ALSO pushed up over the air ahead. The weather will be even more severe. Embedded thunderstorms, rain, and fog are likely to occur.


WARM AIR
CIRRUS
CIRROSTRATUS
CUMULONIMBUS
ALTOSTRATUS
NIMBOSTRATUS
COLD AIR
COLD AIR
ST. LOUIS
INDIANAPOLIS
200 MILES
COLUMBUS
400 MILES
PITTSBURGH
600 MILES
1006 1005 1002 999 999 1002 1005 1006 1011 1014 1017 1020
1023
1011
St. Louis
Indianapolis
Columbus
Pittsburgh
1011 1011 1014 1017 1020 1023
METAR KSTL 1950Z 31023G40KT 8SM
SCT035 05/M03 A2976
METAR KIND 1950Z 29028G45KT 1/2 SM TSRAGR
VV005 18/16 A2970
METAR KCMH 1950Z 16017KT 2SM BR
OVC080 11/10 A2970
METAR KPIT 1950Z 13012KT 7SM
BKN130 08/04 A3012

Thank you.