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# Effects of Weather on Small UAS

## Goals of This Lecture

According to the FAA's UAS Airman Certification Standards, a Remote PIC should be able to demonstrate knowledge of:

- Weather factors and their effects on performance.
  - Density altitude.
  - Wind and currents.
  - Atmospheric stability, pressure, and temperature.
  - Air masses and fronts.
  - Clouds
  - Thunderstorms and microbursts.
  - Tornadoes.
  - Icing.
  - Hail.
  - Fog.
  - Ceiling and visibility.
  - Lightning.

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## Lecture Text & Additional Notes

In this lecture, we're going to cover effects of weather on unmanned aerial systems.

Now, when it comes to the FAA's UAS Airman Certification Standards, here are the concept areas that commercial drone pilots need to understand. In this lecture, we'll go through each one of these concepts in full detail.

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- Density altitude
  - Wind and currents
  - Atmospheric stability, pressure, and temperature
  - Air masses and fronts
  - Thunderstorms and microbursts
  - Tornadoes
  - Icing
  - Hail
  - Fog
  - Ceiling and visibility
  - Lightning

And before we dive in here, I just wanted to remind you that you can go through this video and the below quiz as many times as you'd like to feel comfortable with these concepts.

### The Different Types of Altitude

A quick note on altitude definitions. There are a few ways to think about altitude:

- **Absolute Altitude** - the height above ground level (AGL)
- **True Altitude** - the height above mean sea level (MSL)
- **Density Altitude** - how we measure the density of air
- **Indicated Altitude** - the height your altimeter shows you (when you're at sea level under standard conditions, indicated altitude is the same as true altitude)
- **Pressure Altitude** - the indicated altitude when the barometric pressure scale is set to 29.92 inHg (inches of mercury)

For a means of reference and something you may need to recall on your Aeronautical Knowledge Test, **the standard air temperature and pressure at sea level is 15° C and 29.92" Hg.**

It's a good idea to review each of these definitions and to make sure you fully understand each.

## Density Altitude

Density altitude is the altitude relative to the standard atmosphere conditions at which the air density would be equal to the indicated air density at the place of observation. It's the

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vertical distance above sea level in the standard atmosphere at which a given density is to be found. In a sense, it's the altitude at which your UA "feels" like it's flying.

If that sounds like gibberish to you, that's OK. Here's what you really need to know:

**The density of air is defined by the pressure altitude and ambient temperature and can have a significant effect on your aircraft's performance. When the density altitude is high, you'll experience reduced aircraft performance.**

Why is this? Because when the density altitude is high, the air is less dense, and your propellers become less efficient in thin air. As your density altitude increases, the performance of your UA decreases.

As you might imagine, this is VERY important when you're flying in a mountainous or other high-elevation environment. Taking off to 200 feet above-ground-level (AGL) is a LOT different at sea level than it is in the Colorado mountains. All other conditions equal, you're going to go through a battery much more quickly in the Colorado mountains than you are at sea level. This is density altitude at work.

But it's not just altitude that can affect density altitude. It's the temperature as well. If you're flying on a hot and humid day, you'll also experience reduced aircraft performance.

Why is this? Because as the temperature increases, the air molecules spread out. Your propellers or motors don't have as much air to grab on to.

Higher Density Altitude Occurs at:

- Higher elevations
- Lower atmospheric pressures
- Higher temperatures
- Higher humidity

Lower Density Altitude Occurs at:

- Lower elevations
- Higher atmospheric pressures
- Lower temperatures
- Lower humidity

So again, the thing to remember here is that higher density altitude means thinner air, and with thinner air you'll experience reduced aircraft performance. Your propellers or motors

don't have as much to grab on to. Lower density altitude means thicker, denser air, and stronger aircraft performance.

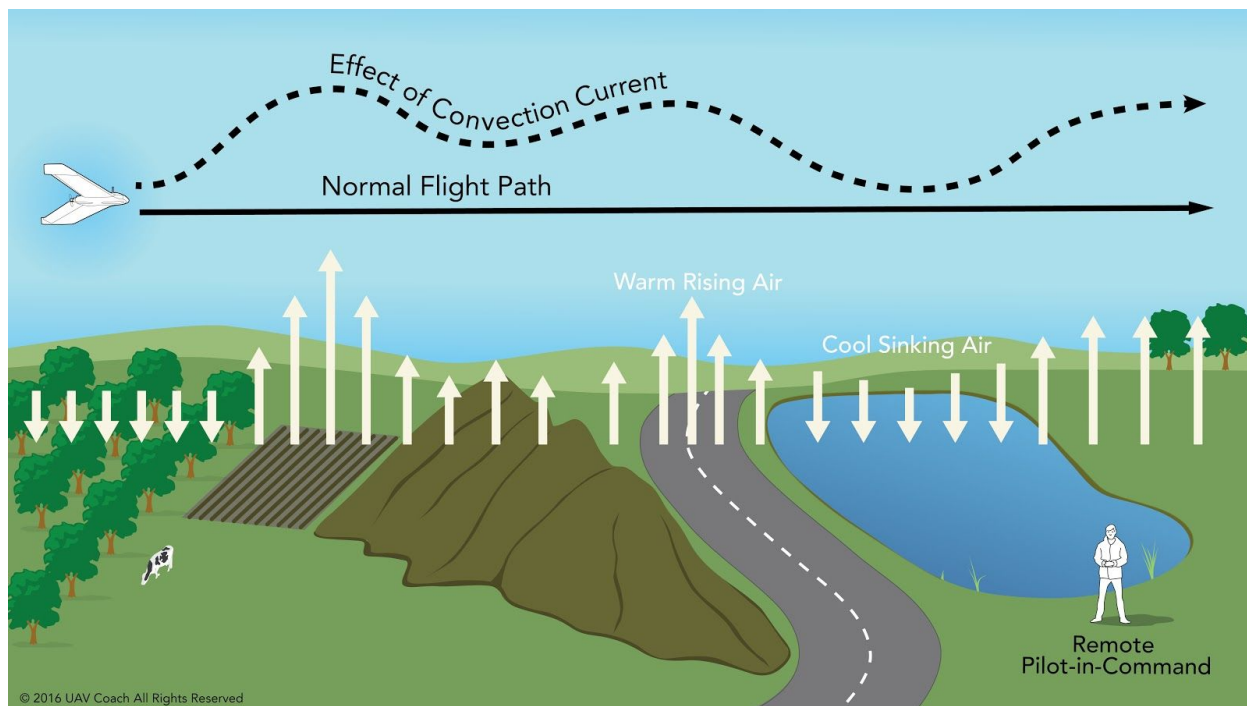
## Wind and Currents

In this section of the lecture, I want to focus on wind and currents.

While wind patterns and the theories of circulation are accurate for large scale atmospheric circulation, they do not take into account changes to the circulation on a local scale. For example, believe it or not, but the friction of the wind blowing along the surface of the earth actually changes its direction from, say 2,000 ft. AGL. Local conditions, buildings and other manmade structures, geological features, and other anomalies can change the wind direction and speed close to the Earth's surface as well. And that's where I want to focus.

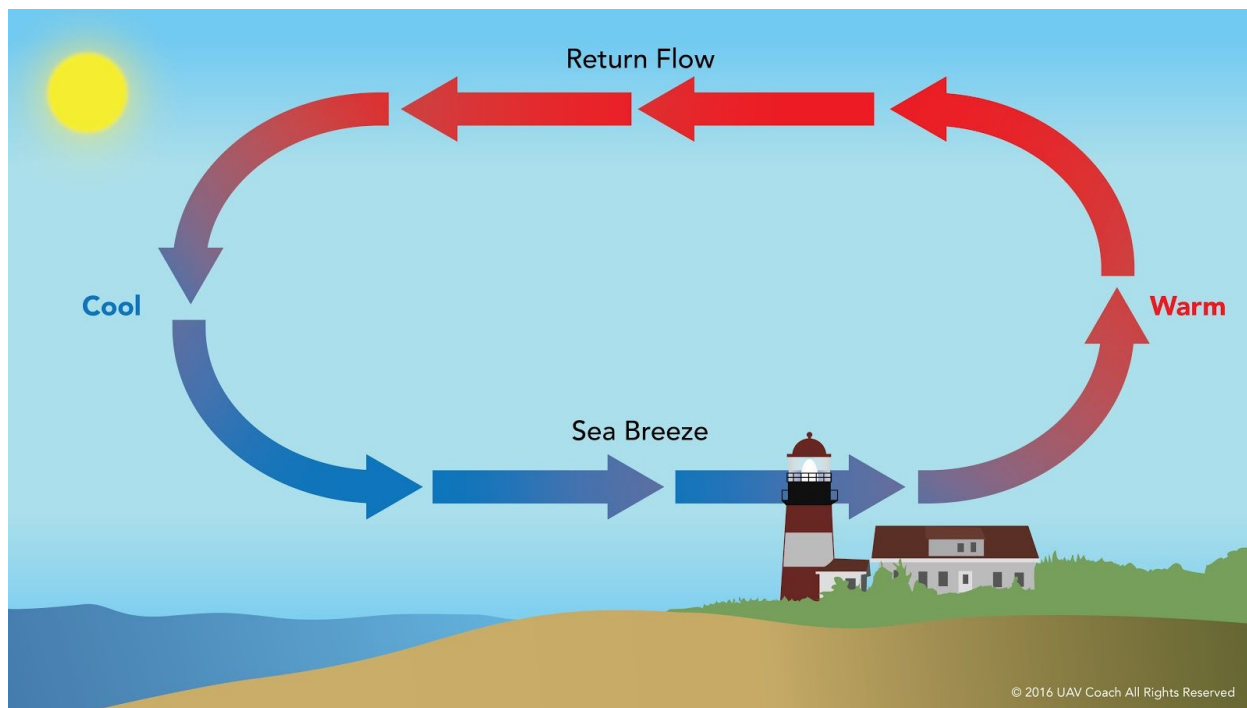
### Convective Currents

Different surfaces radiate heat in varying amounts. Plowed ground, rocks, sand, and barren land give off a large amount of heat; water, trees, and other areas of vegetation tend to absorb and retain heat. This uneven heating of the air creates small areas of local circulation called convective currents.

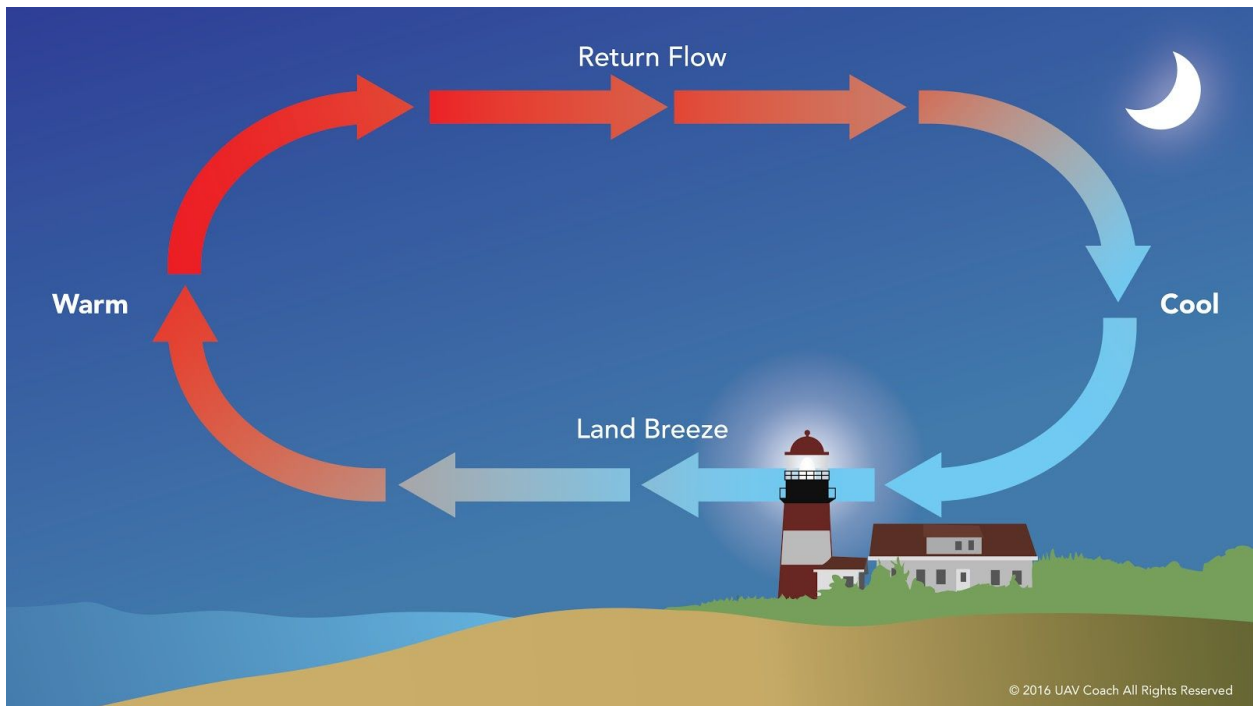


Convective currents cause that bumpy, turbulent air sometimes experienced when flying at lower altitudes during warmer weather. On a low-altitude flight over different types of surfaces, updrafts are likely to occur over areas like pavement or sand, and downdrafts often occur over water or expansive areas of vegetation like a group of trees.

This is particularly true when it comes to the shores of large bodies of water. The land will heat up faster than the water, so the air over the land becomes warmer and less dense. It rises and is replaced by cooler, denser air flowing in from over the water. Ever heard of a sea breeze? Not the drink...the weather phenomenon. That's what's happening here.



And at night, the opposite happens. The land cools faster than the water, so the warmer air over the water rises and is replaced by the cooler, denser air from the land. This creates an offshore wind call a land breeze.



Anywhere there is uneven heating of the Earth's surface, you'll find convective currents.

### **Effect of Obstructions on Wind**

Another atmospheric hazard exists that can create problems for remote UA pilots. Obstructions on the ground can affect the flow of wind, and this can be an unseen danger. Ground topography and large buildings can break up the flow of the wind and create wind gusts that change rapidly in direction and speed.

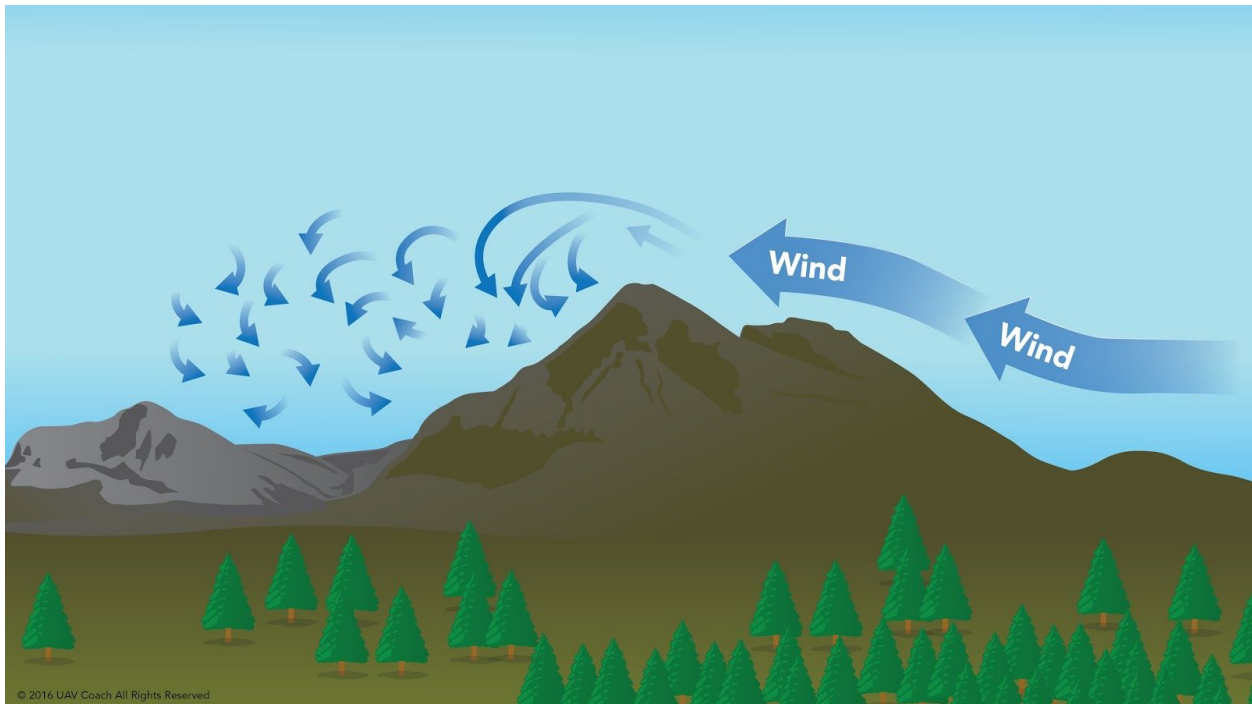


These obstructions range from manmade structures like hangars, to large natural obstructions, such as mountains, bluffs, or canyons. Of course, the intensity of the turbulence associated with ground obstructions depends on the size of the obstacle and the primary velocity of the wind, but just know that you need to be especially vigilant when flying around large buildings or large natural obstructions.

This is one of the many reasons it's important to scout out your flight environment and to map your shots ahead of time, deliberately considering large obstructions and how that might affect your flight operations.

We'll talk through an example. Let's say you're flying your Unmanned Aircraft in the mountains. In a mountainous environment, you've got wind that flows smoothly up the windward side of the mountain, but on the other leeward side, the wind follows the contour of the terrain and can be quite turbulent. **This is called a katabatic wind.** The stronger the wind, the greater the downward pressure. The wind will actually push your UA down toward the mountain. If you don't know how to recognize a downdraft, which is downward moving air, then things can get quite severe. Therefore, it's important to be aware of how natural and manmade obstructions affect wind flow.





## Wind Shear

Alright, what's wind shear?

Wind shear is a sudden, drastic change in wind speed and/or direction over a relatively small area. Wind shear can occur at all altitudes, in all directions, and it's typically characterized by directional wind changes of 180° and speed changes of 50 knots or more.

Low-level (low-altitude) wind shear can be particularly hazardous for remote pilots, due to the proximity of your UA to the ground. Wind shear can cause violent updrafts and downdrafts, and due to increased wind speed, it can push your aircraft around horizontally with sudden, unforeseen force.

Wind shear is commonly associated with passing frontal systems, thunderstorms, and temperature inversions with strong upper level winds (greater than 25 knots).

## Microburst

One type of wind shear is a microburst. A microburst is associated with convective precipitation, which is shorter and more intense. A microburst typically occurs in a space of less than one mile horizontally and within 1,000 feet vertically for about 15 minutes. It can





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produce severe downdrafts of up to 6,000 feet per minute (fpm). It can also produce a hazardous wind direction change of 45 degrees or more, in a matter of seconds.

Microbursts are often difficult to detect because they occur in relatively confined areas. Many airports around the country have wind shear alert systems to warn pilots. This system is called the low-level wind shear alert system (LLWAS).

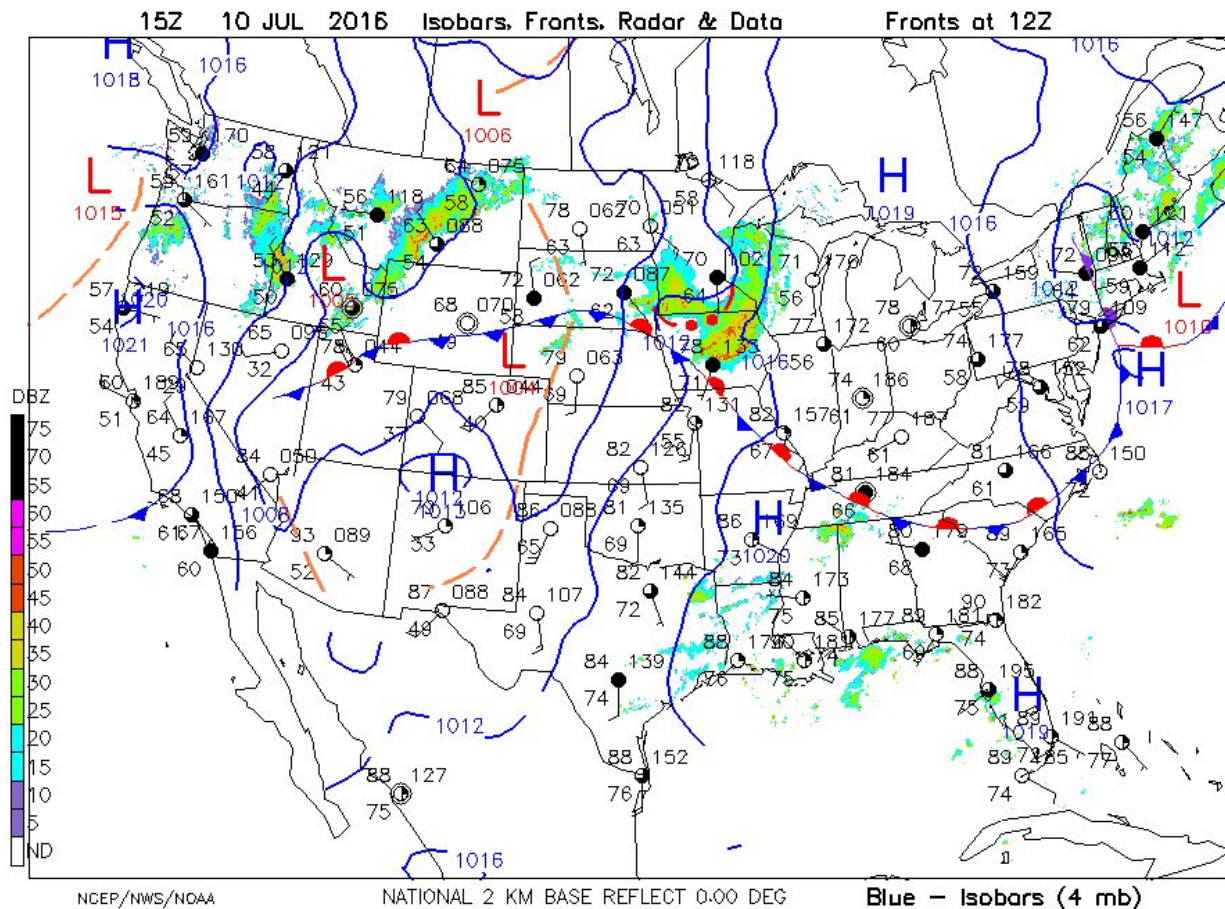
Remember, wind shear can affect any flight and any pilot at any altitude. Always be alert to the possibility of wind shear, particularly when flying in and around thunderstorms and frontal systems. Definitely expect wind shear in a temperature inversion whenever wind speed at 2,000 to 4,000 ft. AGL is 25 knots or more.

### **Wind and Pressure Representation on Surface Weather Maps**

Surface weather maps provide information about fronts, areas of high and low pressure, and surface winds and pressures for each station.

This type of weather map allows pilots to see the locations of fronts and pressure systems, but more importantly, it depicts the wind and pressure at the surface for each location.

Here's an example of a surface weather analysis for the United States on July 10th, 2016. I got this from the American Meteorological Society.



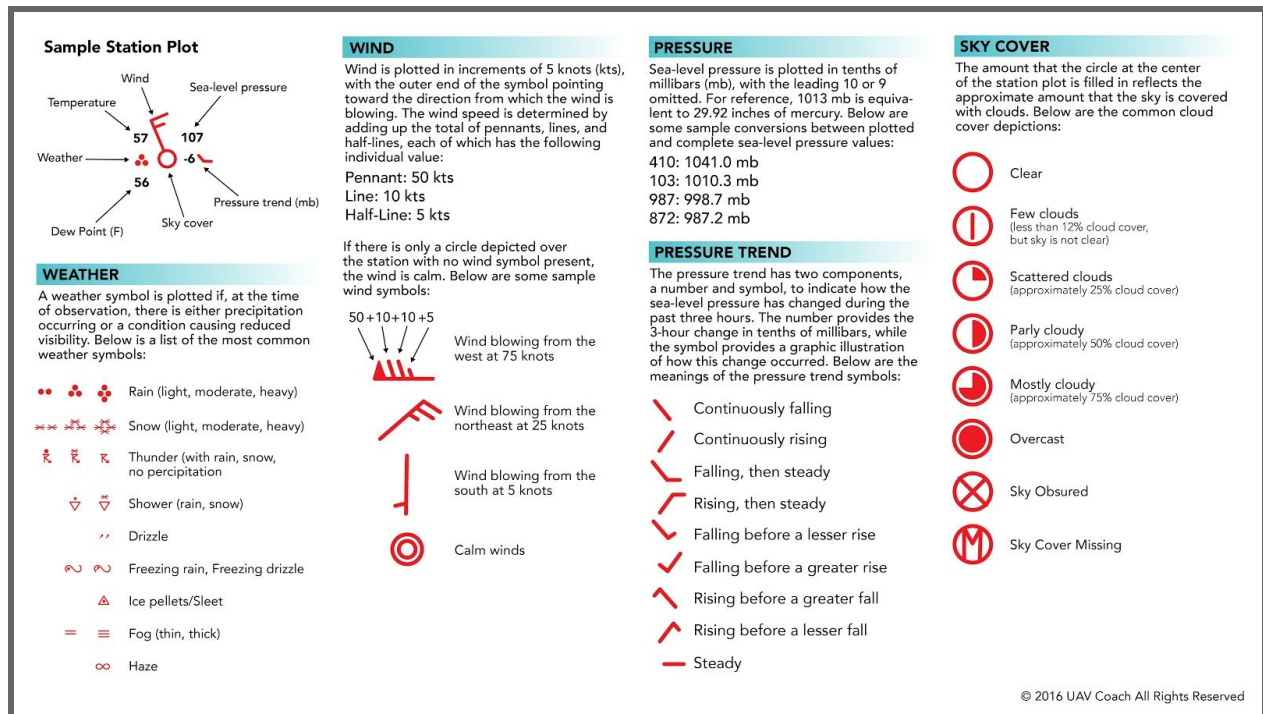
So there are a few things happening in this weather surface analysis map.

First, you'll see a bunch of circles with barbs or pennants, and some surrounding numbers. Each of these circles represents a station model and reveals to us information about the temperature, the sky cover, the wind speed, the wind direction, and some other observations.

The arrow points in the direction from which the wind is blowing.

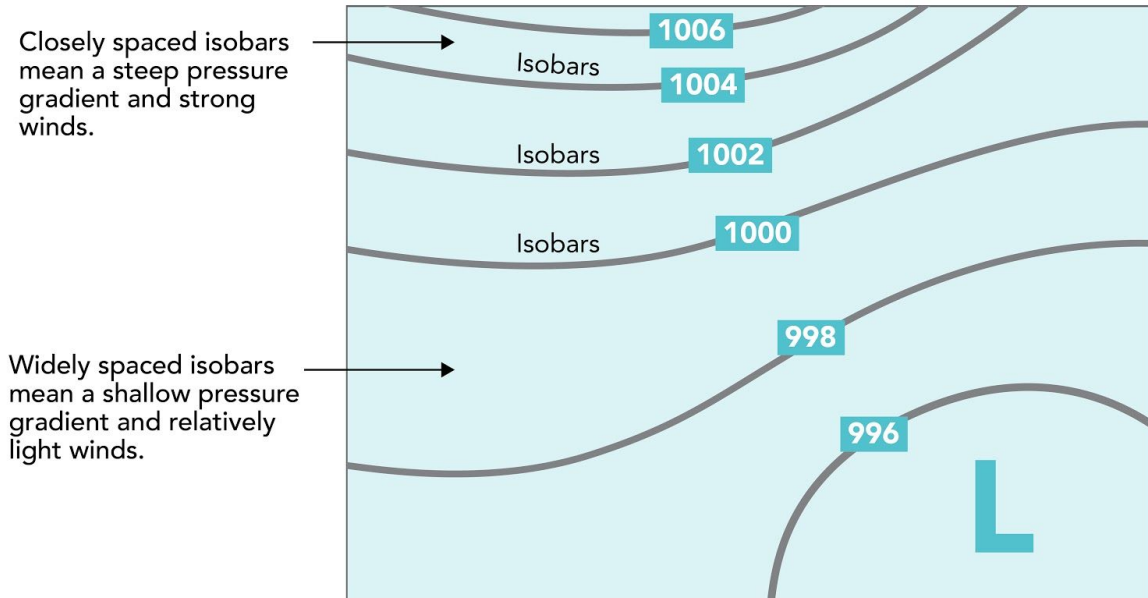
Yes, **winds are described by the direction from which they blow, thus a northwest wind means that the wind is blowing from the northwest toward the southeast.** (Think of these like arrows, with the barbs being the feathers and the opposite end the "head" of the arrow.)

The speed of the wind is depicted by barbs or pennants placed on the wind line. Each barb represents a speed of ten knots, while half a barb is equal to five knots, and a pennant is equal to 50 knots.



A surface weather map can also help you to depict pressure. The pressure for each station is recorded on the weather chart and is shown in mb.

Also, isobars are lines drawn on the chart to depict areas of equal pressure. These lines result in a pattern that reveals the pressure gradient or change in pressure over distance.



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Isobars are similar to contour lines on a topographic map that indicate terrain altitudes and slope steepness. For example, isobars that are close together indicate a steep wind gradient where strong winds prevail. Shallow gradients, on the other hand, are represented by isobars that are spaced far apart and are indicative of light winds.

## Atmospheric Stability, Pressure, and Temperature

OK, still with me? Remember, it's OK to go through this lecture as many times as you'd like.

In this section, let's talk about the relationship between atmospheric stability, pressure, and temperature. First, a few things to keep in mind:

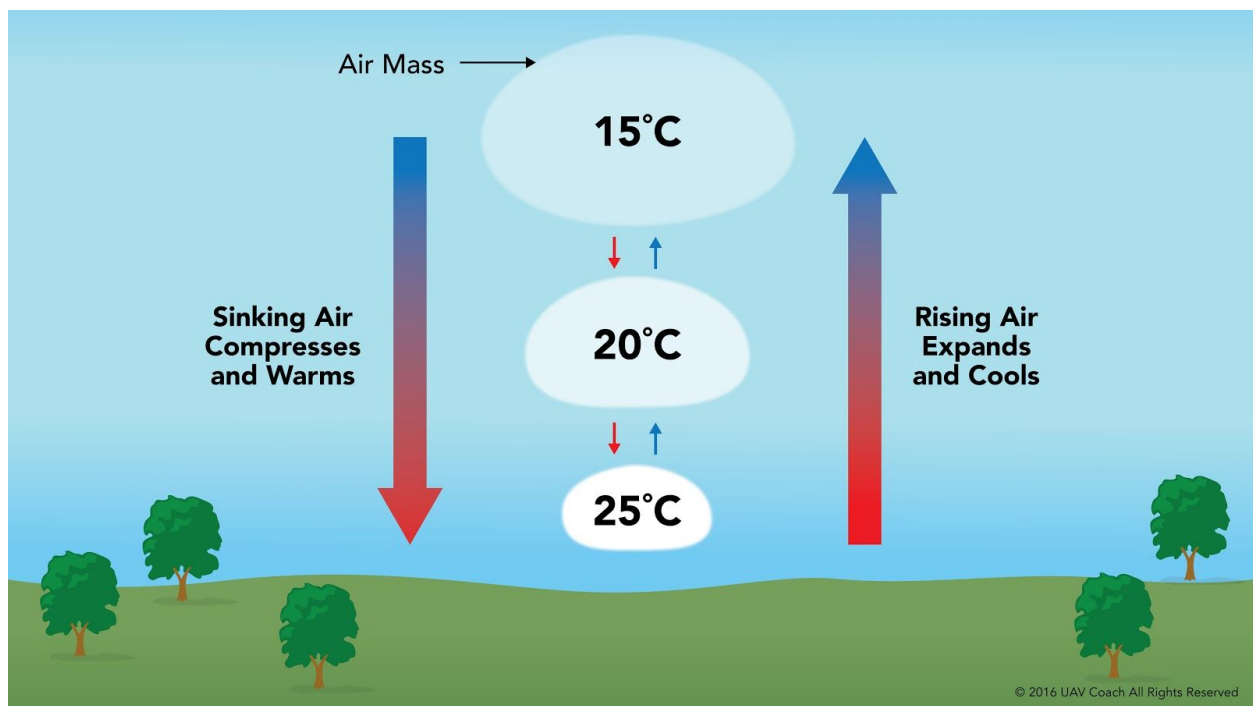
- 1) Every physical process of weather is accompanied by (or is the result of) a heat exchange.
- 2) The stability of the atmosphere correlates with its ability to resist vertical motion. A stable atmosphere makes vertical movement of air difficult. An unstable atmosphere allows an upward or downward disturbance to grow into a vertical (or convective) current.
- 3) Instability, as you might imagine, can lead to significant turbulence, extensive vertical clouds, and severe weather.

Let's walk through a few things that can be happening in the atmosphere at any given time.

### Adiabatic Heating & Cooling

When air rises, it expands and cools, and when air descends, it compresses, and the temperature increases.

And this temperature change, which takes place in all upward and downward moving air, is known as adiabatic heating and adiabatic cooling.



As the air increases in altitude, the rate at which the temperature decreases is referred to as its lapse rate. Remember that -- lapse rate. As air ascends through the atmosphere, the average rate of temperature change, or lapse rate, is 2°C per 1,000 feet in unsaturated air. So on average, the air is cooling by 2°C every 1,000 feet that air goes up.

This lapse rate is how you can determine the stability of the atmosphere. Without getting into any mathematics here, if you think about this average lapse rate of 2°C per 1,000 feet and compare it to the existing lapse rate right now, you can get a sense of how stable or unstable the atmosphere might be. The bigger the gap between the two, the more unstable the atmosphere.

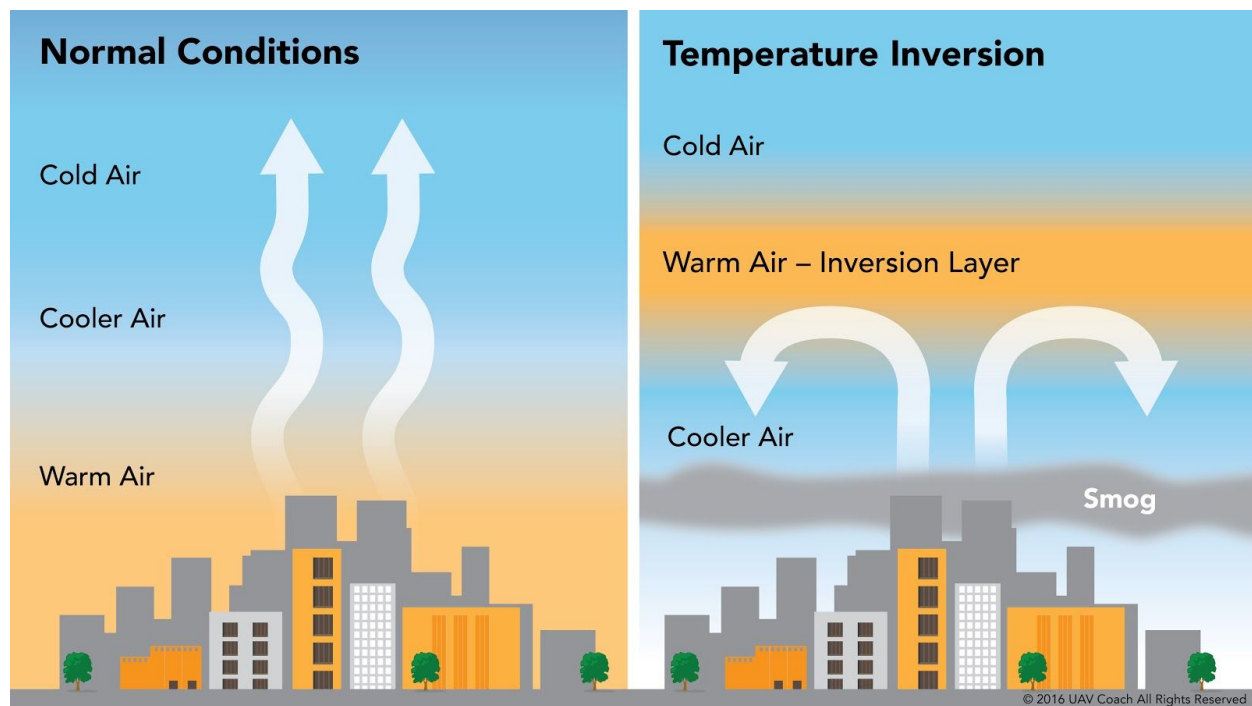
So let's talk a little more about atmospheric stability.

The combination of temperature and moisture determine the stability of the air and the resulting weather. **Cool, dry air is very stable** and resists vertical movement, which leads to good and generally clear weather. Stratiform clouds may be present in this case. The greatest instability occurs when the **air is warm and moist**, as it is in the tropical regions in the summer. Turbulence and showery precipitation are prevalent. Typically, thunderstorms appear on a daily basis in these regions due to the instability of the surrounding air.

### Temperature Inversion

As air rises and expands in the atmosphere, the temperature decreases. However, an atmospheric anomaly can occur called a temperature inversion where the opposite happens.

When the temperature of the air **RISES** with altitude, this is called a temperature inversion. Inversion layers are typically these layers of smooth, stable air close to the ground. The temperature of the air increases with altitude to a certain point, and that's the top of the inversion.





The air at the top of the inversion layer acts as a kind of lid, keeping weather and pollutants trapped below. If the relative humidity of the air is high, it can contribute to the formation of clouds, fog, haze, or smoke, resulting in diminished visibility in the inversion layer.

Surface based temperature inversions occur on clear, cool nights when the air close to the ground is cooled by the lowering temperature of the ground. The air within a few hundred feet of the surface becomes cooler than the air above it.

## **Moisture and Temperature**

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

The amount of moisture present in the atmosphere is dependent upon the temperature of the air. Every 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.

Water is present in the atmosphere in three states: liquid, solid, and gaseous. All three forms can readily change to another, and all are present within the temperature ranges of the atmosphere. As water changes from one state to another, an exchange of heat takes place. These changes occur through the processes of **evaporation**, **sublimation**, **condensation**, **deposition**, **melting**, and **freezing**. The only ways water vapor is added into the atmosphere is through evaporation or sublimation.

**Evaporation** is the changing of liquid water to water vapor.

**Sublimation** is the changing of ice directly to water vapor, completely bypassing the liquid stage. If you've ever seen dry ice, you've seen sublimation at work.

## **Relative Humidity**

Humidity refers to the amount of water vapor present in the atmosphere at a given time. Relative humidity is the actual amount of moisture in the air compared to the total amount of moisture the air could hold at that temperature. For example, if the current relative humidity is 65 percent, the air is holding 65 percent of the total amount of moisture that it is capable of holding at that temperature and pressure. While much of the western United States rarely sees days of high humidity, relative humidity readings of 75 to 90 percent are not uncommon in the southern United States during warmer months.

## **Temperature / Dew Point Relationship**



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The dew point, given in degrees, is the temperature at which the air can hold no more moisture. As moist, unstable air rises, clouds often form at the altitude where temperature and dew point reach the same value. At this point, the air is completely saturated, and moisture begins to condense out of the air in the form of fog, dew, frost, clouds, rain, hail, or snow. Typically, when the temperature and the dew point converge, you will have fog. For example, if the outside air temperature is 64°F and the dew point is 59°F, AND it is dusk (i.e., temperature is falling), you will most likely have fog or low clouds as the temperature and dew point converge.

### Calculating a Cloud Base

As moist, unstable air rises, clouds often form at the altitude where the temperature and dew point reach the same value. As a remote pilot, you're going to want to understand how to calculate the cloud base to know how far under the clouds you should be operating under at any given time. Remember, under Part 107 you need to operate at least 500 feet below clouds, and the elevation at which the cloud base can form depends on the temperature and the dew point.

So how do you calculate a cloud base?

- Find the difference between the surface temperature and the dew point. This value is known as the "spread".
- Divide the spread by 4.4 (if temperatures are in °F) or 2.5 (if temperatures are in °C), then multiply by 1000.
- This will give you the cloud base in feet AGL (Above Ground Level).

As an example, let's say that the surface temperature is 75 °F and the dew point is 71 °F.

- $75 - 71 = 4$  (that's your spread)
- $(4 / 4.4) \times 1,000 = 909$
- So your cloud base is 909 feet AGL (Above Ground Level)

### Drone Operation in Freezing Weather

The **pilot** can be greatly affected by the cold. Numb fingers can be a very bad thing when the feel of the controls on the remote is so important. With a numb thumb one could easily bump the throttle down and not feel it. A bad bump could mean reducing thrust enough that the bird falls from the sky, or perhaps a bump up in throttle might turn the bird into a kamikaze. Also, we talk about Batteries more in the our lecture called Small UAS Maintenance and Inspection, but I should mention here that **batteries** can also be greatly

affected by the cold. This is very important to keep in mind for those who time flights rather than keeping an eye on battery voltage.

## Air Masses and Fronts

Air masses are kind of what you'd think they'd be -- large bodies of air.

When air masses stagnate in (or move really slowly over) an area that has pretty uniform temperature and moisture characteristics on a day-to-day basis, the air mass takes on those temperature and moisture characteristics. This happens in places like polar regions, tropical oceans, and dry deserts.

And the way that these air masses are categorized is based on temperature characteristics (polar or tropical) and moisture content (maritime or continental).

Air Mass Examples:

- Continental polar air mass - forms over a polar region and brings cool, dry air with it.
- Maritime tropical - forms over warm tropical waters and brings warm, moist air with it.

Here's where air mass gets interesting. When an air mass passes over a warmer surface, that air mass is warmed from below. And this causes convective currents to form, which causes the air to rise. When the air rises, this creates an **unstable air mass with good surface visibility**. This moist, unstable air has good visibility, but it also causes turbulence, cumulus clouds, and showers.

Unstable air tends to display the following characteristics:

- Cumuliform clouds
- Turbulent air
- Good visibility
- Showery precipitation

Now, when an air mass passes over a colder surface, convective currents do not form. Instead, you get a **stable air mass with poor surface visibility**.

Stable air tends to display the following characteristics:

- Stratiform clouds

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- Smooth air
  - Fair-to-poor visibility in haze and smoke
  - Continuous precipitation

You might be wondering, if there aren't any convective currents, why is there poor surface visibility? Well, because there's no convective current, there's no air rising, and because there's no air rising, all the smoke, dust, and other particles can't rise out of the air mass. They're trapped near the surface, making it harder to see. Stable air masses with poor surface visibility can produce steady precipitation, low stratus clouds and fog.

## Fronts

As an air mass moves across bodies of water and land, eventually it comes in contact with another air mass that has different characteristics.

Ever heard of the term "front"? Well, a front is that boundary layer between the two different air masses or areas of pressure. An approaching front of any type always means that weather changes are imminent. Within a front, there will ALWAYS be a change in the wind direction (shifting wind) and also in the temperature.

Fronts are named according to the temperature of the advancing air relative to the temperature of the air it is replacing. And while no two fronts are the exact same, there are four basic categories to think about:

Symbols for surface fronts and other significant lines shown on the surface analysis chart



**Warm front (red)\***



**Cold front (blue)\***



**Stationary front (red/blue)\***



**Occluded front (purple)\***

\*Note: Fronts may be black and white or color depending on their source.  
Also, fronts shown in color code do not necessarily show frontal symbols.

Source: FAA-H-8083-25B

- Warm
- Cold
- Stationary
- Occluded

## Warm Front

A warm front happens when a warm mass of air advances and replaces a body of colder air. As the warm air is lifted, the temperature drops and condensation occurs. A warm front often has high humidity. Also, warm fronts move **SLOWLY**, typically 10 to 25 miles per hour (mph).

## Cold Front

A cold front happens when a cold, dense, mass of stable air advances and replaces a body of warmer air. Cold fronts move twice as fast as warm fronts, usually progressing at a rate of 25 to 30 mph. However, extreme cold fronts have been recorded moving at speeds of up to 60 mph.

Usually, a cold front moves in a manner opposite that of a warm front. This cold, stable air is really dense, so it stays close to the ground and acts kind of like a snowplow, sliding under the warmer air and forcing the less dense air aloft.

## **Warm vs. Cold Fronts**

Just two more things I wanted to call out here when thinking about the difference between a warm and a cold front.

- 1) Weather Activity - While warm fronts bring low ceilings, poor visibility, and rain, cold fronts bring sudden storms, gusty winds, turbulence, and sometimes hail or tornadoes. A cold front can be characterized by its shifting wind conditions and violent weather.
- 2) Approach Speed - Warm fronts provide advance warning of their approach and can take days to pass through a region. Cold fronts are fast approaching with little or no warning, and they make a complete weather change in just a few hours.

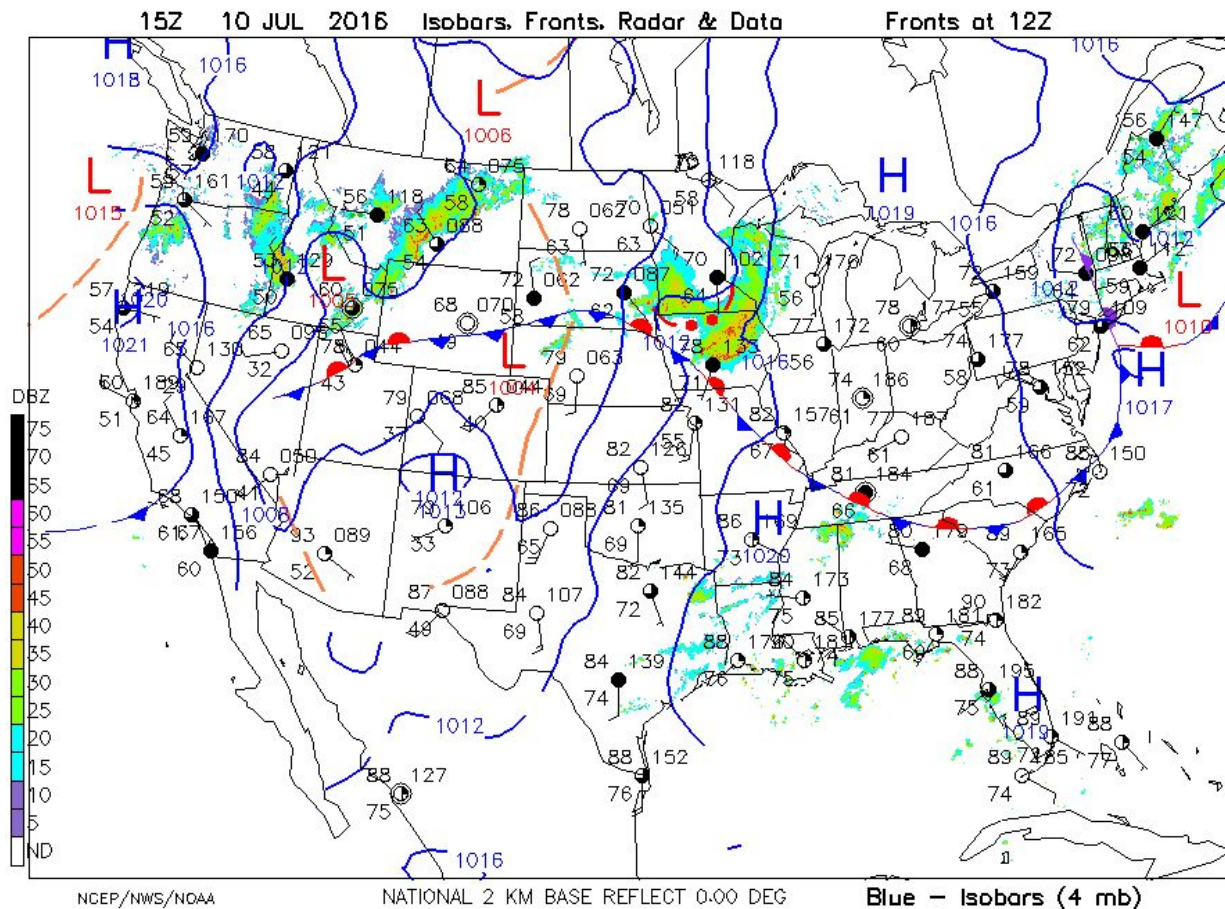
## **Stationary Front**

When the forces of two air masses are relatively equal, the boundary or front that separates them remains stationary and influences the local weather for days. This front is called a stationary front. The weather associated with a stationary front is typically a mixture that can be found in both warm and cold fronts.

## **Occluded Front**

An occluded front occurs when a fast-moving cold front catches up with a slow-moving warm front. There are two types of occluded fronts that can occur, and the temperatures of the colliding frontal systems play a large part in defining the type of front and the resulting weather. I'm not going to go into detail about those in this course.

Earlier in this lecture, we took a look at a surface analysis map, and we learned how to read that map for things like sky cover, wind direction, and wind speed.



But you can also see front activity on the map too!

Check out the long line that starts in Nevada and runs east across the U.S. That line has blue triangles and red semi-circles. Those indicate a stationary front. Here's the full legend for fronts so that you can understand what all the colors and symbols mean.

## Clouds

A few key things to remember about clouds:

- **If you see lenticular clouds, expect turbulence.** Wind can be blowing quite strong through lenticular clouds.

- To pilots, the most dangerous type of cloud is a cumulonimbus, or thunderstorm cloud. Since rising air currents cause cumulonimbus clouds, they are extremely turbulent and pose a significant hazard to flight safety.

## Thunderstorms

Understanding thunderstorms and the hazards associated with them is critical to the safety of remote flight. If an unmanned aircraft enters a thunderstorm, it could experience updrafts and downdrafts that exceed 3,000 feet per minute!

### Thunderstorm Phases

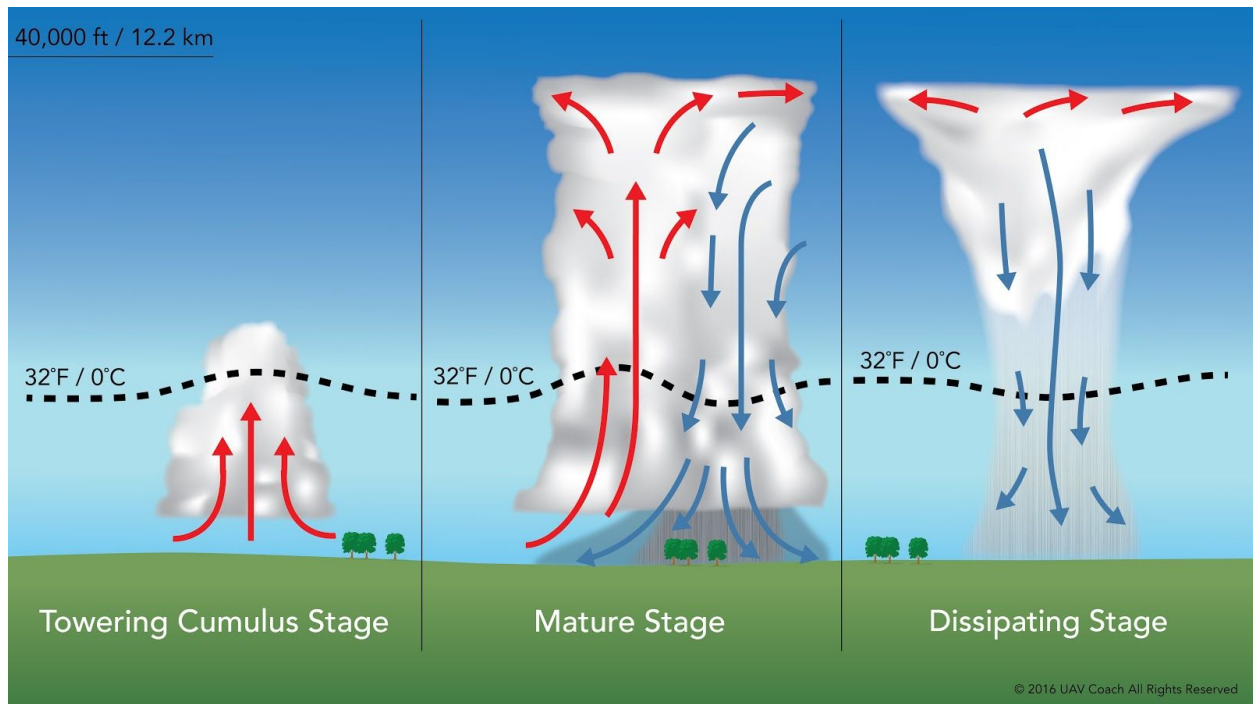
Thunderstorms are produced by cumulonimbus clouds. They form when there is:

- Sufficient water vapor or moisture (**Did you know that “nimbus” means rain?**);
- An unstable lapse rate (and remember, the lapse rate describes the rate of change of the temperature as the air increases in altitude); and
- An initial upward boost to start the process (heat)

A thunderstorm makes its way through three distinct stages before dissipating:

- 1) It begins with the **cumulus stage**, in which lifting action of the air begins. If sufficient moisture and instability are present, the clouds continue to increase in vertical height. Vertical development always means wind shear and turbulence, which is almost always more than an sUAS can handle. Continuous, strong updrafts prohibit moisture from falling. The updraft region grows larger than the individual thermals feeding the storm.
- 2) Within approximately 15 minutes, the thunderstorm reaches the **mature stage**, which is the most violent time period of the thunderstorm's life cycle. **At this point, drops of moisture, whether rain or ice, are too heavy for the cloud to support and begin falling in the form of rain or hail.** This creates a downward motion of the air. Warm, rising air; cool, precipitation-induced descending air; and violent turbulence all exist within and near the cloud. Below the cloud, the down-rushing air increases surface winds and decreases the temperature.
- 3) Once the vertical motion near the top of the cloud slows down, the top of the cloud spreads out and takes on an anvil-like shape. At this point, the storm enters the **dissipating stage**. This is when the downdrafts spread out and replace the updrafts needed to sustain the storm.





Generally, the most severe thunderstorm conditions (like destructive winds, tornadoes, heavy hail, etc.) are associated with squall line thunderstorms. A squall line is a nonfrontal, narrow band of thunderstorms usually ahead of a cold front.

You can't always see a thunderstorm. An embedded thunderstorm is obscured by other clouds.

A good rule of thumb is to not operate an unmanned aircraft within 20 nautical miles (NM) of a thunderstorm, since hail may fall for miles outside of the clouds.

## Tornadoes

Not that you'd likely be operating an unmanned aircraft with tornadoes nearby, it's important to know that any cloud connected to a severe thunderstorm could spawn tornadic activity, even if it's miles away from the main thunderstorm cloud.

## Icing

I'll keep this section simple. Ice is bad. Pilots should be alert for icing anytime 1) the temperature approaches 0°C, and 2) there's visible moisture in the air. Specifically, airframe icing would be when ice builds up on your UA and it can no longer sustain flight. Under certain conditions, it can occur very quickly. The worst conditions would be freezing rain, because the rain will freeze immediately upon contact. In the same way that frost can change the aerodynamic qualities of the propellers, ice can do the same thing. Any presence of frost or ice will dramatically and negatively affect the UA's ability to fly.

## Hail

Possible hail should be anticipated with any thunderstorm, especially beneath the anvil of a large cumulonimbus cloud. Here's the interesting thing about hail. It can be encountered in clear air several miles from thunderstorm clouds. So don't think that just because the thunderstorm isn't right on top of you that it's safe to fly. Even small hailstones can damage your unmanned aircraft, so exercise extreme caution if there's thunderstorm activity in your area, even if it's distant.

## Lightning

It goes without saying...lightning is bad news.

A lightning strike can not only damage your Flight Controller and other electronic equipment, but it can also induce permanent errors in the magnetic compass.

Lightning discharges, even if they're somewhat distant, can also disrupt your radio communications.

## Fog

Fog is a cloud that begins within 50 feet of the surface.

Fog typically occurs when the temperature of air near the ground is cooled to the air's dew point. The dew point is the temperature at which the air will have 100% humidity -- it's fully saturated with water vapor. At this point, the water vapor in the air condenses and becomes visible in the form of fog. **Clouds, dew, and fog will always form when water vapor condenses.**

It's not advisable to operate an UA in fog conditions. As you might imagine, it's much tougher to maintain a direct line-of-sight to your aircraft if there's a bunch of fog.

Since fog is classified according to the manner in which it forms, there are a few different types of fog:

### **Radiation Fog**

Radiation fog typically forms during a nuclear explosion. No, I'm just kidding! Wanted to see if you were paying attention! Radiation fog typically forms in low-lying areas like a mountain valley. Radiation fog happens when the ground cools rapidly due to terrestrial radiation, and the surrounding air temperature reaches its dew point. It'll form on clear nights, with relatively little to no wind present.

Then, as the sun rises in the morning and the temperature increases, radiation fog lifts and eventually burns off. Also, an increase in wind speed can speed up the dissipation of radiation fog.

### **Advection Fog**

Advection fog is common in coastal areas where sea breezes can blow moist air over cooler land masses. Think about the beautiful and foggy beaches of northern California, Oregon, or Washington.

Advection fog is likely to form when a layer of warm, moist air moves over a cold surface. Unlike radiation fog, wind is required for advection fog to occur. Winds of up to 15 knots allow the fog to form and intensify; above a speed of 15 knots, the fog usually lifts and forms low stratus clouds. This type of fog can persist for days.

### **Upslope Fog**

Upslope fog occurs, well, up a slope, when moist, stable air is forced up sloping land features like a mountain range. Like advection fog, upslope fog requires wind for formation and continued existence. And unlike radiation fog, which can burn off with the sun, upslope fog can persist for days.

### **Steam Fog**

Steam fog is common over bodies of water during the coldest times of the year, and because of that, it's also known as sea smoke. Steam fog forms when cold, dry air moves

over warm water. As the water evaporates, it rises and resembles smoke. Low-level turbulence can occur (and icing can become hazardous) with the presence of steam fog.

## Ice Fog

Finally, there's ice fog, which occurs in cold weather when the temperature is way below freezing, and water vapor forms directly into ice crystals. It's unlikely that you'd be operating an unmanned aircraft in this environment, but it's still kind of interesting to think about. Conditions favorable for the formation of ice fog are low-lying areas where the temperature is really cold, usually  $-25^{\circ}\text{F}$  or colder. Ice fog happens mostly in the arctic regions, but during winter seasons, ice fog can also form at middle latitudes.

## Ceiling and Visibility

As you may recall from the Drone Law & FAA Regulations module, remote pilots must keep their UA at least 500 feet below clouds and 2,000 feet horizontally away from clouds. Also, there's a minimum flight visibility requirement of 3 statute miles.

In aviation, a **ceiling** is the lowest layer of clouds reported as being broken or overcast, or the vertical visibility into an obscuration like fog or haze. **Current ceiling information is calculated by the temperature and the dew point** and is reported by the aviation routine weather report (METAR) and automated weather stations of various types. We cover weather information sources in another lecture within this module.

**Visibility** refers to the greatest horizontal distance at which prominent objects can be viewed with the naked eye. Current visibility is also reported in METAR and other aviation weather reports, as well as by automated weather systems.