The Front

September-October, 2002 National Weather Service Central Region Volume 1 Number 5

Atmospheric Pressure and Altimeters

Pressure altimeters are simple, silent sentries that follow air pressure surfaces, the topography of the atmosphere. Pilots need to know how these surfaces change and affect altitude.

Craig Sanders, Lead Forecaster
NWS, Duluth, MN

Pressure altimeters have been a crucial part of every cockpit since the early years of aviation. Paul Kollsman's efforts to make this an accurate instrument ushered in the art of instrument flying.

The altimeter is very accurate in performing its designed mission, vertically separating you from other aircraft, obstructions, and the terrain. Altimeter settings frequently provided by air traffic controllers enable an altimeter to do its silent task.

Air pressure is constantly changing. ASOSs and surface maps keep us informed about the horizontal pressure changes at ground level.

Pressure also varies vertically. A given pressure that the altimeter uses is not at the same altitude everywhere. Knowing a few more details about this aspect of the atmosphere should give you new appreciation about the importance of keeping your altimeter properly adjusted.

Basic Structure

If the earth were of uniform temperature, if the sun provided no heat, and if the earth didn't rotate, then pressure, and air density would be fairly uniform. The earth would have an uncomplicated pressure distribution as shown in Figure 1.

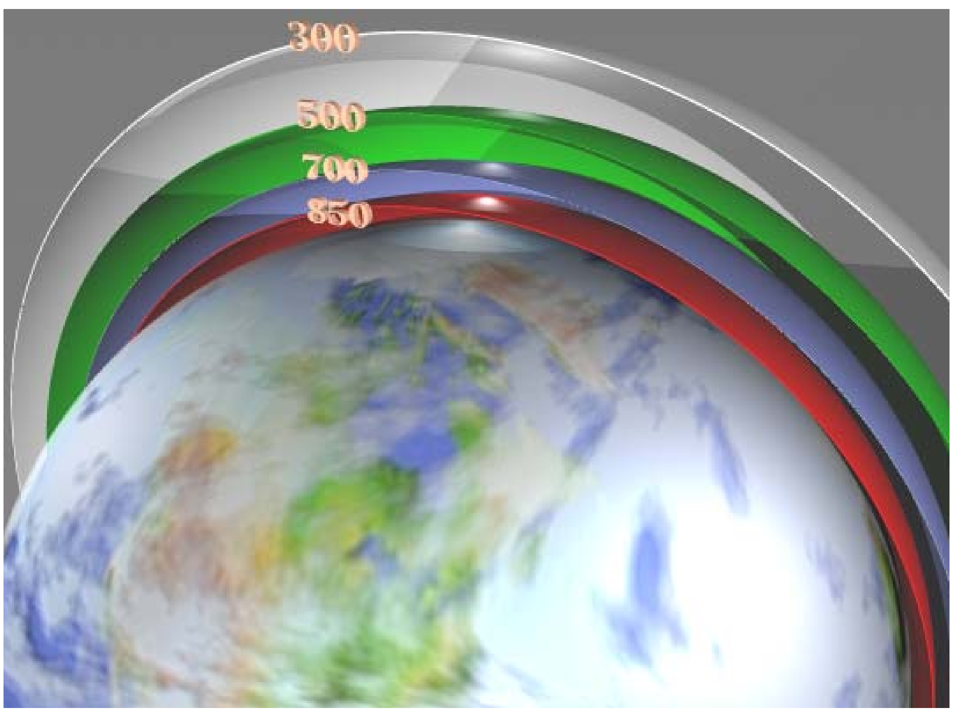


Figure 1. Air pressure decreases from a maximum near the earth's surface to nothing at the edge of space. If the world were of uniform temperature, then specific pressure readings would exist at known altitudes around the world. The earth would be encircled with concentric, invisible pressure surfaces. Specific pressure surfaces, namely 850, 700, 500 and 300 mb are used by computers to forecast upper level weather patterns.

In this issue:

Mission Statement

To enhance aviation safety by increasing the pilots' knowledge of weather systems and processes and National Weather Service products and services.

The pressure would decrease smoothly and predictably from about 1013.2 millibars (29.92 inches of mercury) at the surface to nothing at the limit of the atmoshpere. All the parcels of air feeling a pressure of 850 mb, 700 mb, or 500 mb, if visible, would appear as a set of concentrically nested spheres. Figure 1 shows this arrangement with half the pressure surfaces removed for easy viewing.

At about 5,000 feet above ground level (AGL), the pressure would be about 850 mb. At 10,000 feet AGL, a pressure of 700 mb would be measured, and at 18,000 feet, a barometer would show a pressure of 500 mb.

The real world is not that simple.

That simple structure, however, is not reality. Planetary heat exchange due to the sun's energy, coupled with the rotation of the earth, causes tremendous exchanges of air having different temperatures and densities around planet Earth. Regions of high and low pressure develop, and the simple vertical distribution of pressure, temperature and density is made complex. The bottom portion of Figure 2 shows what happens to the pressure spheres when mixing occurs. Pressure altimeters follow these wavy pressure surfaces.

If barometers were used to report air pressure at ground level throughout the country, the plotted values would have little use. Barometers at lower terrain elevations would report high pressure because of the weight of the air above pressing down. Mountain locations would always report lower air pressure.

Isobars, or lines of equal pressure, connecting stations with identical pressure readings would locate regions of high and low pressure, but the maps would be very similar to height lines on a topographic map. Tightly packed lines would indicate steep terrain. Widely space lines would imply gently sloping terrain.

To correctly analyze the current weather pattern and to track any recent changes, you would have to carefully compare charts from day to day and even from hour to hour. You would have to visually determine where pressure changes were occurring by comparing positions of these pressure lines and noting the very small changes over time. The job would be painstaking and tedious.

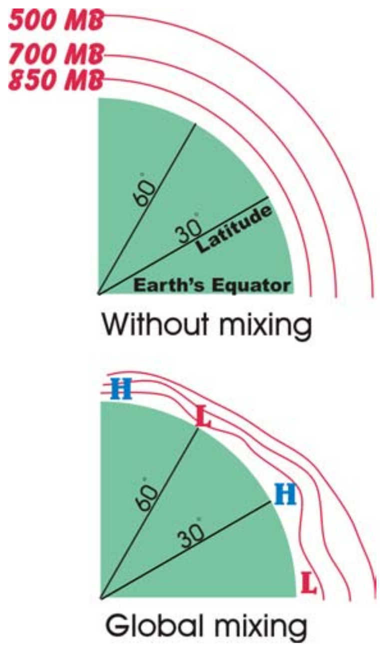


Figure 2. If the sun didn't heat the earth and the earth didn't rotate, the atmoshere would have a uniform distribution of attributes (top). However, due to heating and rotation, areas of high (H) and low (L) pressure exist, and the vertical location of specific pressure levels vary.

Reducing the Pressure

To make plots of air pressure meaningful, barometer readings are mathematically adjusted to read as if they were all taken at the same elevation. Mean Sea Level (MSL) is very nearly the same throughout the day despite the tides and is used as the plane of reference.

This is done by taking a barometer reading and mathematically lowering its elevation to the standard sea level. This is what is meant by "reducing" a reading to sea level. Figure 3 depicts the process. Air pressure increases as you reduce its actual elevation to where sea level would be directly beneath the barometer if the ground weren't there. The surface map in Figure 4 has a pressure pattern where all ASOS barometer readings have been reduced to sea level pressure.

Calibration is accomplished by using an idealized atmospheric distribution of temperature, pressure and air density known as the International Standard Atmosphere (ISA). The familiar pressure levels of 850 mb, 700 mb, 500 mb would exist at their respective altitudes of 5,000 feet, 10,000 feet and 18,000 feet every-

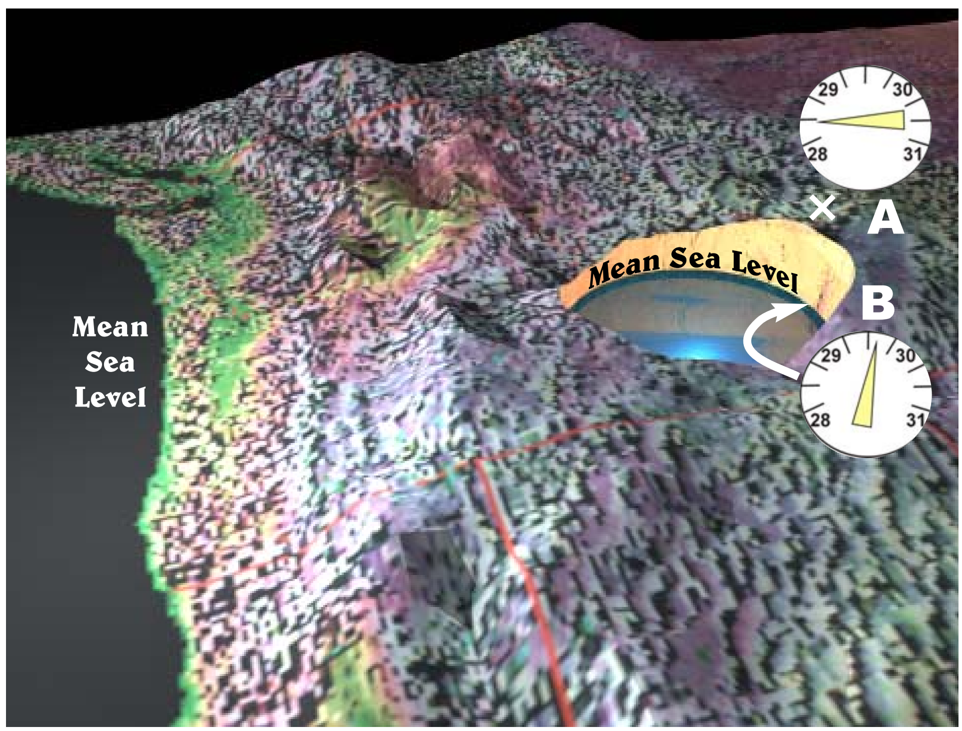


Figure 3 ASOS and AWOS barometers are calibrated to read pressure that would be found if the altimeter were at sea level instead of the higher elevation where it currently is. The actual atmospheric pressure (barometer A) is mathematically 'reduced" to sea level (barometer B). Mean sea level is the reference plane because the ocean's level is fairly stable despite tidal fluctuations. The International Standard Atmosphere is used as the standard to calibrate altimeters. The hole in the mountains of Washington in this image shows where measn sea level would be. All altimeters at or above FL180 use mean sea level pressure of 29.92 inches of Hg (1013.2 mb) as their reference setting.

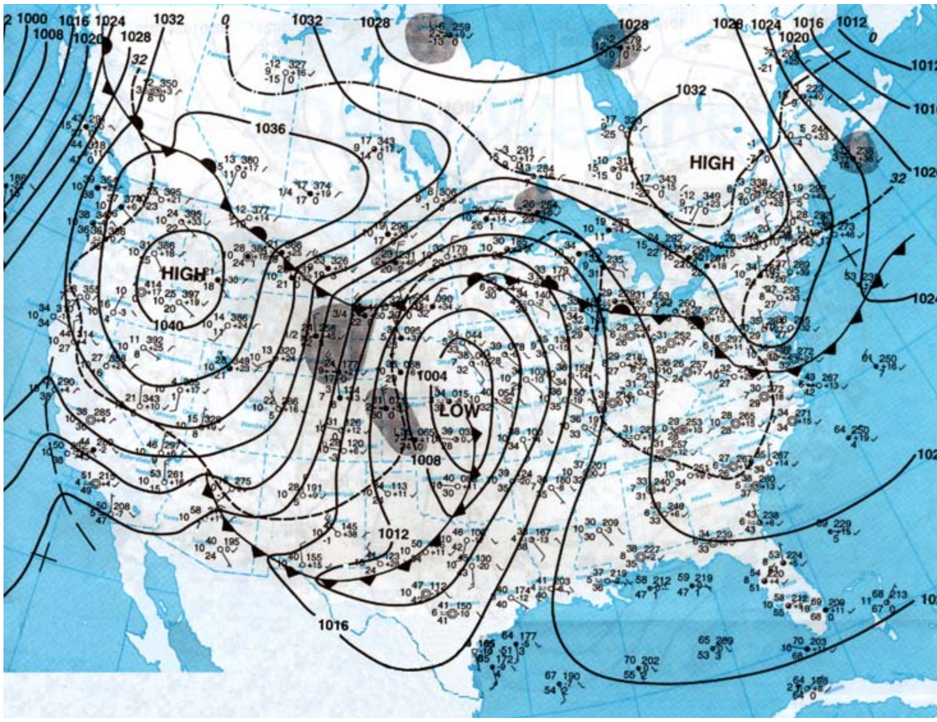


Figure 4. Areas of high and low pressure result from the atmosphere's attempt to redistribute excesses and deficiencies of heat and mass. Strong storms develop and promote rising air. Next to these storms, areas of high pressure with descending or subsiding air complete the process. Depicted here are conditions for 1200 UTC on February 9, 2002. The lines are isobars or lines of equal sea level pressure. The units are millibars, an international unit for pressure measurement.

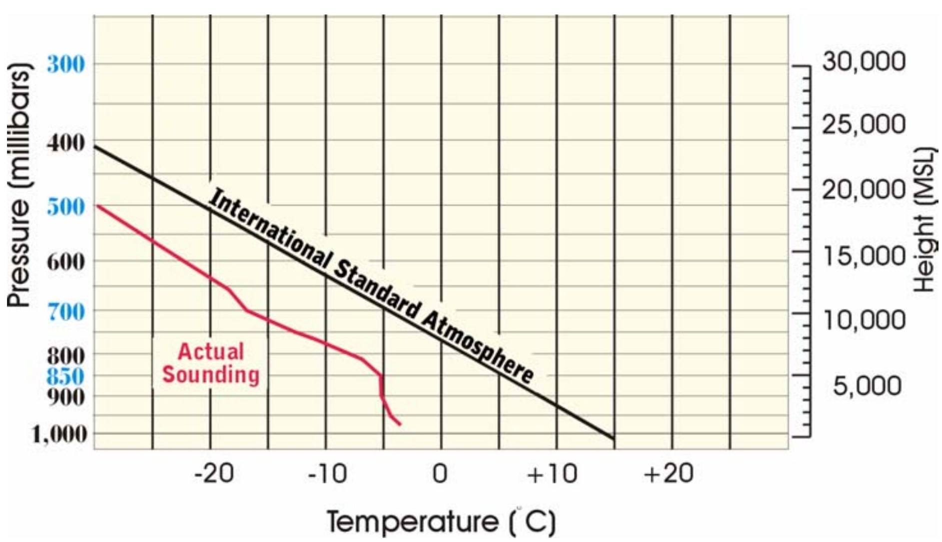


Figure 5. The International Standard Atmosphere (ISA) is an average, uniform distribution of pressure, temperature, and density. Actual conditions on any given day as measured by balloon soundings are often different. When differences are large, altimeter errors increase because pressure surfaces move to different levels vertically.

where around the earth. The ISA is plotted in Figure 5.

Pressure altimeters sense the pressure from the static system on board.. Using barometric pressure that you set in the Kollsman window, the altimeter is calibrated to show the altitude that that setting and the pressure it senses would be in the ISA. If the outside atmosphere is not close to the ISA, then the altitude shown will be in error.

Pressure Surfaces - the invisible topography of the air

Instead of the idealized structure of pressure planes shown in Figure 1, the atmospheric motion actually displaces those pressure surfaces upward over high pressure regions and downward over low pressure systems. Figure 6 depicts this more realistic situation.

Pressure planes or surfaces exist as domes over high pressure and as bowls under low pressure. They intersect the surface map at the isobars. A section of these pressure surfaces in Figure 6 has been removed and every other pressure surface has also been removed for clarity of explanation. The height of the pressure surfaces is also greatly exaggerated for better viewing.

ASOS altimeter settings tell which pressure surface is currently intersecting the earth at that airport. That pressure surface is at the same height above mean sea level as the runway is. Departing the airport, your aircraft is climbing above that pressure surface.

Pressure surfaces are changing altitude all the time in response to the air's natural mixing, rising, and falling. But the altimeter continues to reference that pressure plane. The altitude shown does not tell you whether the pressure plane is moving up or down or whether it's close to the ground. To avoid problems, you need to keep your little cockpit pal adjusted to the nearest altimeter setting or pressure plane.

Let's see how this works on a flight from Seattle, WA (SEA) to Rapid City, SD (RAP). Figure 7 is that route using a close up view from Figure 6. Before departing Seattle, you set the altimeter to read the field elevation of 429 feet. The pressure setting of 30.59 inches (1036 mb) shows in the Kollsman window, and is the same pressure given to you on the ATIS broadcast.

Enroute the altimeter reports altitudes relative to that 1036 mb (30.59 inch) pressure surface unless or until you change the setting in the Kollsman window. An indicated altitude of 9,500 ft MSL means that you are 9,500 ft above sea level or 9, 071 ft above that pressure surface. As far as the altimeter knows, the 1036 mb pressure surface is still at 429 ft MSL. So you cannot be sure that you are 9,500 ft above the terrain.

Your VFR flight is uneventful as you fly through the high pressure, and you forget to reset your altimeter while tracking southeast toward Rapid City Things seem OK, but as you fly over western Montana, invisible dangers begin to lurk.

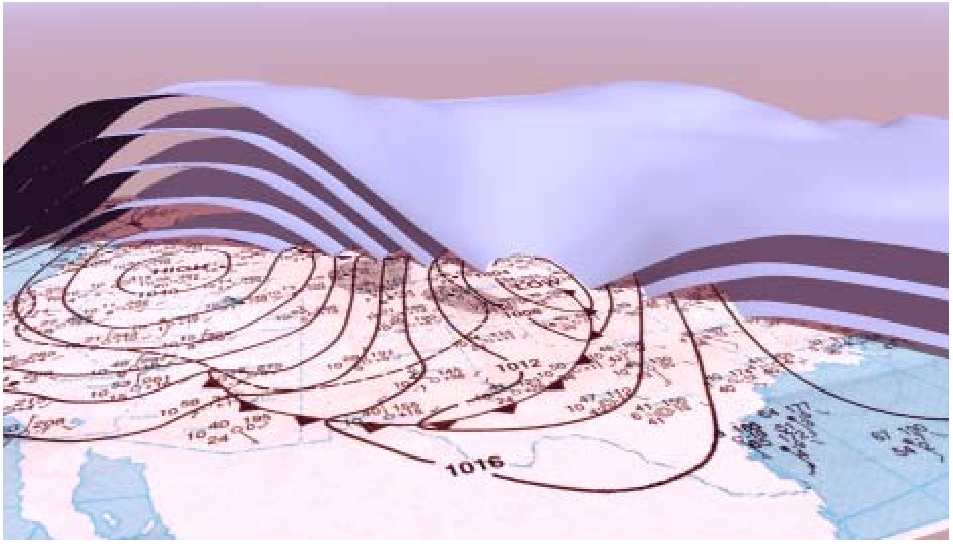


Figure 6. Pressure "surfaces" intersect the weather map at the respective isobars. If you take off where the air pressure is 1008 mb (29.77 inches) your altimeter will give altitude relative to that pressure surface. As the pressure surface changes altitude, your actual height above ground will change even though your altimeter is rock steady.

You are configured to fly lower than the MSL altitude showing on the altimeter, because the altimeter is not set to reference the closest and more appropriate pressure plane. The errors begin to show up a little east of Dillon, Montana (DLN) unless you perform a simple action.

High to Low - look out below

The 1036 pressure surface that the altimeter has been following has now sloped downward into the ground. At the very least you pose a danger to other air traffic because you are beginning to stray from the 9,500 ft MSL VFR altitude.The altitude error that you failed to remedy has now placed you in conflict with other traffic in Montana as you continue to intrude into the lower altitudes.

The solution is simple and fast. Reset the altimiter to the nearest ASOS altimeter setting. As you turn the adjusting knob, the altimeter hand will sweep counter clockwise back to indicate a lower altitude because the altimeter is now referencing the closest 1028 mb (30.36 in.) pressure surface. The altimeter indicates lower because you are now below the 1028 mb surface. That pressure surface intersects the ground near the Dillon MT (DLN) ASOS. You need to climb back to 9,500 ft using 1028 mb surface as your reference.

The point of this simulation is to emphasize the fact that altimeters are sensitive instruments that can indicate small changes in altitude.

For accurate altitude flying, they need to be adjusted at least every 100 n. mi. That is just a rule of thumb for "normal" conditions. When you're flying in areas where the pressure is changing rapidly (where the isobars on the surface map are close together), you need to adjust the altimeter more often.

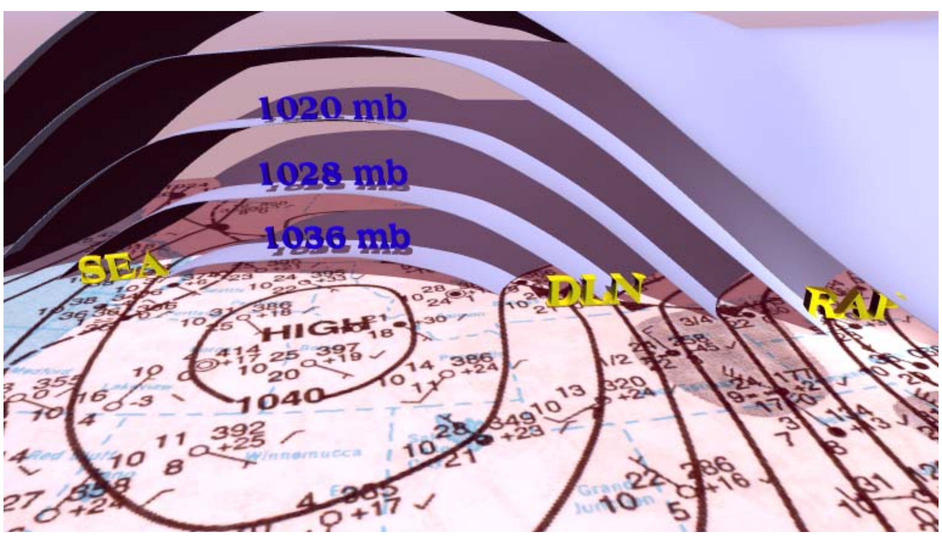


Figure 7. On a flight from Seattle, WA (SEA) to Rapid City, SD (RAP) the altimeter is set to local conditions prior to take off, and it follows the 1036 mb pressure surface. If not reset to local altimeter settings en route, the altimeter would lead you into lower altitudes or even into the terrain without warning. By resetting the altimeter regularly, you ensure that you are following the correct pressure surface.

Altimeter errors in the dead of winter

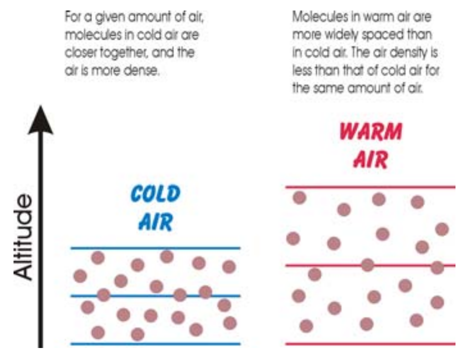


Figure 8. Cold air is denser than warmair for a given amount of air. The horizontal lines represent air pressure measured at certain altitudes. The pressure surfaces are lower and closer to-gether in cold air than they are in warm air.

Operating in bitterly cold air can present danger due to altitude errors. The altimeter reads correctly when conditions are near the ISA. Colder air causes pressure surfaces to drop as the air becomes denser and more compact in the vertical. The altimeter may be set to the correct setting given by ATC, but actually that pressure surface is now lower and puts you unknowingly at a lower altitude. Figure 8 depicts this condition. On the approach when arctic high pressure has glued itself to the landscape you need to be aware of the error. At an airport with a field elevation of 1,000 feet MSL and an air temperature of -20 degrees C (-11 degrees F) you could be flying 140 ft below where you think you are. A DRAFT version of an FAA Advisory Circular discusses these cold season errors. It's available at:

www.faa.gov/language/accold.pdf

Altimeter changes on the ground

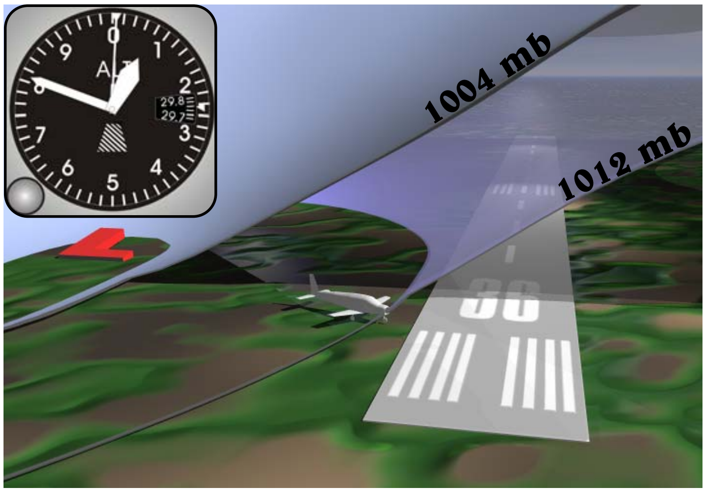


Figure 8a The 1012 mb (29.88 in Hg) pressure surface is at Wittman Field in Oshkosh, WI. For landing, the altimeter setting provided was 29.88 in. Hg. and the altimeter reads the field elevation of 808 ft. MSL. The pilot and friends leave the altimeter set at 29.88 and take in the fabulous AirVenture.

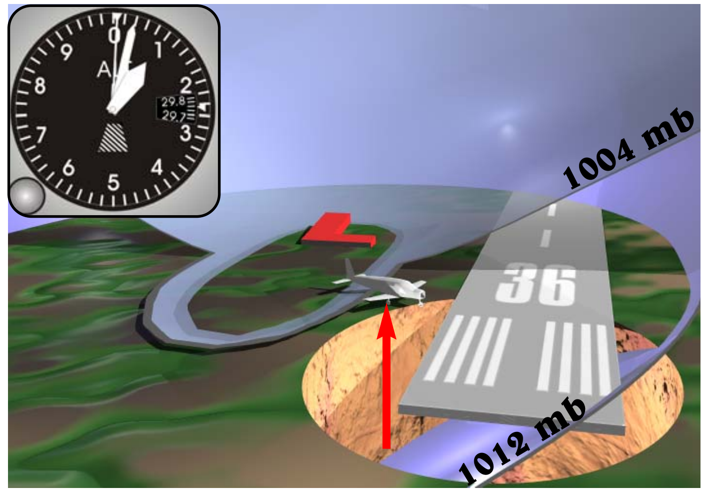


Figure 8b During the day, the low pressure center arrives with the 1004 mb (29.65 in Hg) pressure surface. At the end of a long day and without changing the setting in the Kollsman window, the altimeter now reads 230 ft MSL higher. The pressure has fallen 8 mb (0.23 in Hg). The altimeter reads 230 feet higher because the 1012 mb pressure surface is "below" the field.

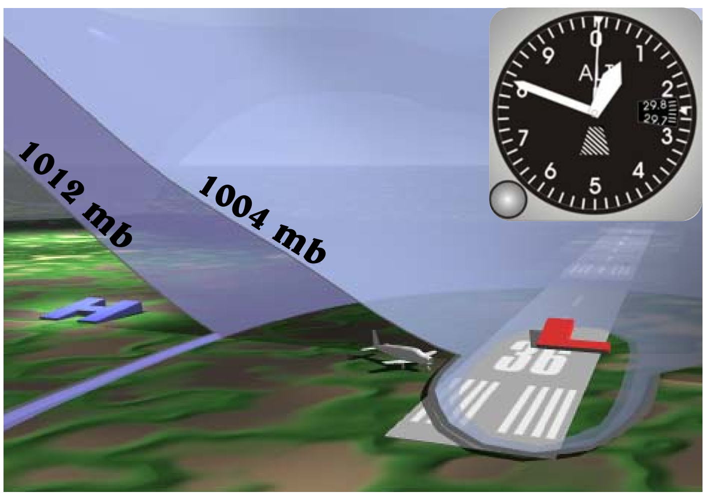


Figure 9a A high pressure ridge is approaching. The current altimeter setting, 1004 mb (29.65 in Hg) is the pressure surface at the ASOS site. The indicated altitude is 808 ft. MSL, and the Kollsman window is set at 29.65.

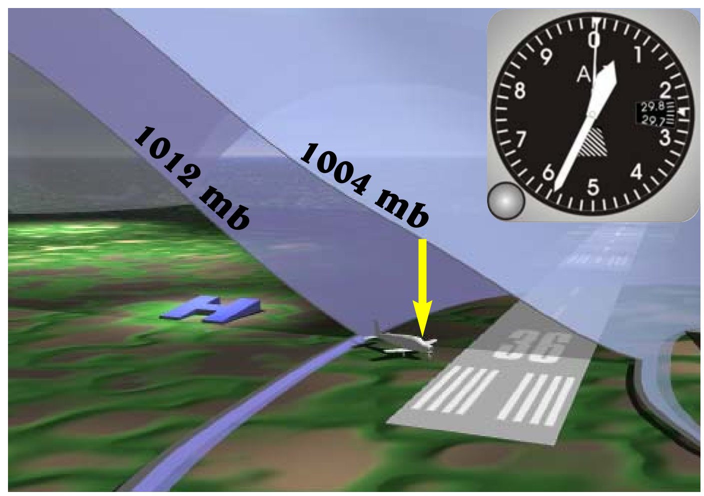
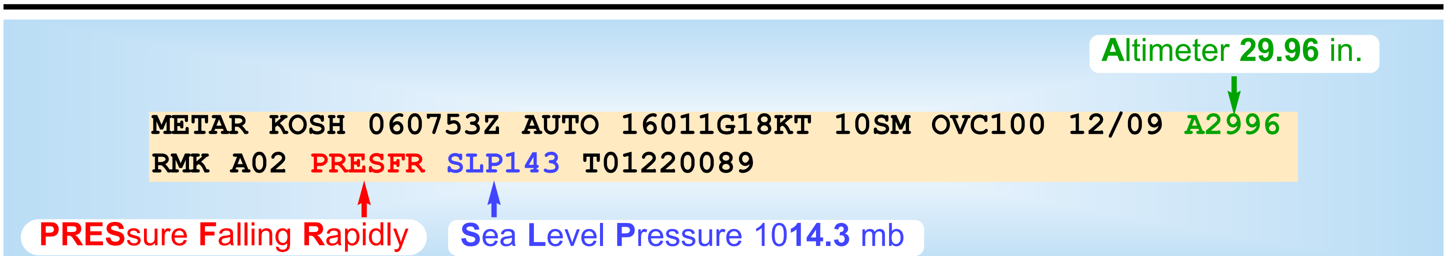


Figure 9b During the day the high pressure draws closer, and the 1012 mb (29.88 in. Hg) pressure surface arrives. The altimeter now reads 230 ft MSL lower. The 1004 mb pressure surface is above the airport. So the altimeter is below that surface and indicates a lower altitude relative to that 1004 mb surface..



METAR reports from ASOSs contain altimeter settings in inches of mercury. ASOSs also contain a Sea Level Pressure reading in millibars. These two pressure values are not exactly interchangable because they are calculated using different assumptions about the temperature structure of the atmosphere. Always use the altimeter setting because it is calculated the same way all altimeters are calibrated, by using the International Standard Atmosphere. When the pressure is falling at or greater than 0.06 of an inch of mercury per hour, the remark PRESFR is inserted into METAR reports. This is an alert for you to keep close tabs on the setting in the Kollsman window of the altimeter to make sure the altimeter is using the most appropriate pressure surface altitude.

...Say altitude!

There are several "flavors" of altitude in aviation and meteorology.

Pressure Altitude

The altitude in the standard atmosphere above the 29.92" (1013.2 mb) sea level pressure reference surface. Altimeters are set to 29.92 at or above FL180. This references a common pressure surface and does not require pilots to continually adjust their altimeters evey 100 miles. All aircraft reference a common level, and this helps insure reliable altitude separation

Indicated Altitude

The altitude read from the altimeter. It is not corrected for any differences due to abnormally cold or hot temperatures. In very cold air, an aircraft's indicated altitude would be lower than ture altitude because pressure surfaces are lower than they would be if conditions of the ISA existed at the current time. Likewise, indicated altitude would be higher than true if very warm temperatures existed.

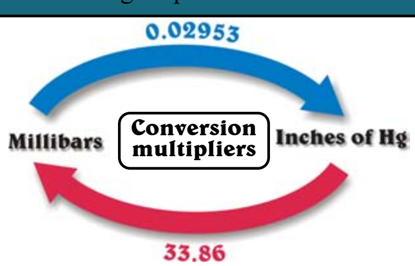
True Altitude

The altitude of an aircraft that is flying through conditions that match the idealized ISA. True altitude rarely exists. Any departure from standard conditions causes altimeters to read indicated altitude.

Density Altitude

The altitude corrected for temperatures that are different from those that would exist in the ISA. Density altitude is a performance measure for lift and engine power. It is not an altimeter issue.

The ISA assumes that air density depends only on temperature and pressure. Density decreases with increasing altitude. Air that is warmer than the ISA at any level is less dense than the air at that level in the ISA So hot air at an airport runway would be less dense than the air would be if ISA conditions were in place at that time. The existing density of the hot air would be equivalent to the air density found at a higher altitude in the ISA. High density altitude implies decreased engine performance and lift.



AS or SLP-what's the difference?

Altimeter Setting

On the ground - The pressue value to which an aircraft altimeter is set so that the altimeter at that airport will indicate the airport's field elevation.

In the air - The closest pressure "surface" that the altimeter uses to determine altitidue above mean sea level. This pressure surface value is set using the Kollsman window. The difference between the indicated altitude and the field elevation of the airport is the height above ground level (AGL).

Sea Level Pressure

The pressure value that a barometer at the airport would display if the barometer were lowered or "reduced" to the elevation of mean sea level. This calibrated value is based on observed temperatures now and 12 hours previous instead of using the International Standard Atmosphere which is used to calibrate altimeters. Knowing that existing temperatures can vary greatly from the the ISA values, Sea Level Pressure and Altimeter Setting values are similar, but they are not identical.

Final Approach

In summary

1. Altimeters report altitude relative to pressure surfaces.

2. Pressure surfaces slope and are always changing.

3. Pressure surfaces intersect the ground and may "exist" below local terrain. Your altimeter doesn't know whether the pressure surface it's following is above or below ground.

4. Going from high to low pressure areas, the pressure surfaces slope down "into the ground". Your altitude will be lower than indicated on the altimeter.

5. Reset your altimeter at least every 100 n. mi. to make sure it references the correct pressure surface. That is the one tied to the ASOS's altimeter setting.

6. Know where the ASOSs are along your route. Ask Flight Watch for frequent updates.

7. Altimeters are always slightly in error due to outside temperature and air density that are likely different from the International Standard Atmosphere. In cold air, the pressure surfaces will be lower than standard, and your actual altitude will be slightly lower than indicated because the pressure surfaces have compacted downward in the cold air.

8. When low pressure is moving in, an altimeter in a parked aircraft will show a higher altitude than it did when the aircraft was last used. See Figures 8a and 8b.

9. When high pressure is moving in, an altimeter in a parked aircraft will show a lower altitude than it did when the aircraft was last used. See Figures 9a and 9b.

10. Altimeter settings obtained from ASOS that are greater than 31 inches (1048.8 mb), or less than 28 inches (948.2 mb) will not be usable by most altimeters because the settings exceed the setting range of the insturment. This means that both arctic high pressure and tropical storms and hurricanes require careful planning for flights to ensure that the desired approaches will be usable when you arrive. Check forecast surface charts to see if the the 1050 mb or 948 mb isobar will be near your destination.

11. You cannot accurately convert from sea level pressures to altimeter settings on a METAR for in flight use. These pressures are derived using different assumptions about the atmosphere. Errors may be small, but they will be vitally important.

12. Scan ASOS reports for remarks that might indicate rapidly changing pressures. PRESFR means "Pressure Falling Rapidly at a rate equal to or greater than 0.06 of an inch of mecrury per hour. Given the fact that in lower levels, the pressure falls 1" for every 1,000 feet of altitude, that 0.06 inch change in pressure at the ASOS equates to a possible altimeter error of 60 feet. When low pressure is moving in, your altitude would be 60 feet lower than it would have been last hour.

The Front is published bimonthly and is available on the NWS Central Region aviation page at:
www.crh.noaa.gov/crh/aviation/thefront.html,
or on the AWC website at:
http://aviationweather.gov/front/

Send comments and suggestions to:
craig.sanders@noaa.gov
sally.pavlow@noaa.gov
james.roets@noaa.gov