

The Weather Never Sleeps

Pressure situation By Jack Williams

Tight isobars mean strong winds

The 1950s pop song "Little Things Mean a Lot" nicely sums up the apparent relation between air pressure and wind. The afternoon of August 29, 2005, a National Oceanic and Atmospheric Administration Lockheed P-3 measured a sea-level air pressure of 26.64 inches of mercury in the center of Hurricane Katrina, which was then over the Gulf of Mexico about 229 miles south of Lakefront Airport in New Orleans.

This was the fourth-lowest surface air pressure ever measured in a storm. That's important because the lower the pressure, the stronger the storm's winds are likely to be. That afternoon the winds around Katrina's eye were blowing at a sustained 165 mph, with faster gusts.

The low air pressure in Katrina's center is only half of the story. Wind speed depends on the differences between air pressures at the storm's center and those around the storm.

At 4 p.m. that day the northern edge of Katrina's winds were blowing across Lakefront Airport from the east at 20 mph with gusts up to 40 mph. The air pressure there was 29.62 inches of mercury. The difference of 2.98 inches of mercury in air pressure between the two locations, more than 200 miles apart, would seem tiny to a pilot who is familiar with the rule of thumb that the air's pressure decreases by about one inch of mercury for each 1,000 feet of altitude gained.

The pressure change from Katrina's outer edge to the deadly winds roaring around its eye is what you'd feel if you took off from Lakefront Airport and climbed almost 3,000 feet. That's not enough to make your ears pop--unless you have a severe head cold.

Even more important, we don't encounter 100-mph-plus winds going straight up, even though air pressure decreases much more than in any storm. Winds don't blow up toward lower pressures aloft because the force of gravity pulling air toward the Earth pretty much balances the force created by pressure differences, except in rare cases such as violent thunderstorms with fat updrafts and downdrafts.

While the 2.98 inches of mercury difference might not sound like much, it's obviously enough to create one of the strongest hurricanes on record.

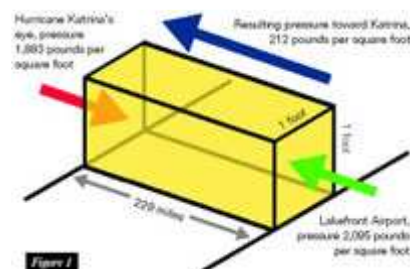
Differences in air pressure between a storm's center and locations all around the storm create winds, but understanding what makes the winds blow is easier if we begin by looking at only two places, such as Katrina's center and Lakefront Airport.

Look at Figure 1 (top right). The box represents a chunk of air a foot high, a foot wide, and 229 miles long stretching from Lakefront Airport to Katrina's eye. At Lakefront Airport on the right, the air pressure of 29.62 inches of mercury means that the pressure--in all directions, including toward Katrina on the left--is 2,095 pounds per square foot. On the left side, the air pressure is 1,883 pounds per square foot pressing in all directions, including toward Lakefront Airport. Subtract 1,883 from 2,095 and you see that a force of about 212 pounds per square foot was pushing from Lakefront Airport toward Katrina's eye. Similar forces were pushing air from Lakefront Airport, and places all around Katrina, toward the storm's center.

Imagine that the box was 458 instead of 229 miles long, but the pressure difference stayed the same. In that case, the 212 pounds per square foot of pressure would have to push twice as much air, which would greatly reduce the wind's speed.

Meteorologists call this combination of the pressure difference and distance between two places the pressure gradient force, or PGF. The term refers to horizontal forces action on air, but not to forces tending to push air up or down.

If the PGF were the only force involved, winds would blow straight toward a storm's center, like the spokes of a wheel going toward the hub. Winds don't follow straight lines because the Earth rotates under the atmosphere, which isn't attached to the Earth. Wind follows a curved path from the high pressure toward the low pressure, or high above the Earth, the wind circles low pressure. These

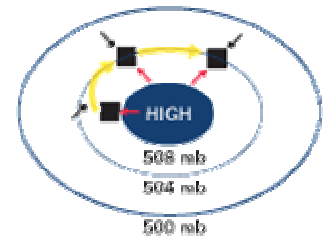
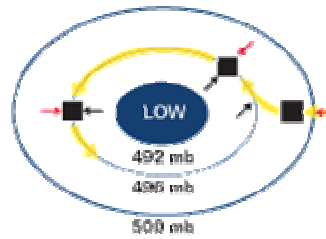


paths are counterclockwise around low air pressure and clockwise around high pressure in the Northern Hemisphere. South of the equator, air flows clockwise around low pressure and counterclockwise around high pressure.

The turning of wind, and other things such as ocean currents, in relation to the Earth as a result of Earth's rotation is called the *Coriolis force* after Gustave-Gaspard Coriolis, a French scientist who in 1835 first described mathematically how this works.

Figures 2A and 2B shows how this works around an area of low air pressure and an area of high pressure in the Northern Hemisphere when both the low and high pressure and the resulting winds are more than about a mile above the ground. The figures used are for air pressures found at an altitude of about 18,000 feet altitude. The units are *millibars* (mb), the metric system units used for pressures for higher altitudes.

In both figures the small boxes represent a "parcel" of air as the forces act on it. The blue circles represent areas of equal air pressure, called *isobars*, with the pressures marked on the lines. The yellow arrows show the path the wind follows. The red arrows are the *pressure gradient force* pushing from high toward low pressure, and the black arrows are the *Coriolis force*, which pushes moving air toward the right of its path.



Figures 2A and 2B illustrate how the Coriolis force changes a wind's direction.



Figure 3: Surface weather map, 7 a.m., August 29, 2005.

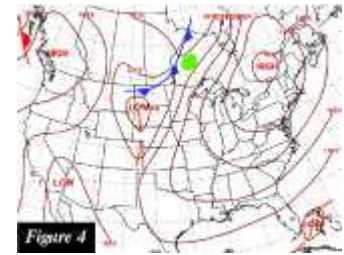


Figure 4: Surface weather map, 7 a.m., September 5, 2005.

Let's look at figure 2A first.

1. PGF pushes the wind toward the low pressure.
2. As the wind picks up speed, the Coriolis effect pushes it to the right.
3. As Coriolis pushes the wind toward higher pressure, PGF increases, growing stronger with shorter distance. This pushes the wind back toward the left.
4. After some back-and-forth oscillations the wind settles down on a path that balances PGF and Coriolis. Since no force opposes the wind, it circles counterclockwise around the low pressure.
5. The PGF pushes the air from high pressure toward low and Coriolis begins turning the wind to the right.
6. Eventually PGF and Coriolis reach a balance, as in Figure 2A.
7. The air circles the high-pressure center in a clockwise direction.

The Coriolis force depends on the wind's speed, increasing as the wind moves faster and decreasing as it slows. This explains why air spirals into the center of low pressure areas and spirals out from high pressure areas close to the ground. PGF explains why you can get an idea of where the strongest winds are by looking at a weather map that includes isobars. The winds are strongest where the isobars are closest together.

Figure 3, the surface weather map for 7 a.m. August 29 as Hurricane Katrina was moving ashore in Louisiana and Mississippi with winds of around 145 mph, is the ultimate example; it shows the hurricane as a bulls-eye of isobar lines on the Gulf of Mexico Coast.

Figure 4, the surface map for 7 a.m. Labor Day, shows why almost all of the United States enjoyed a mostly storm-free holiday. The lowest pressure in the country at the time was 1,008 millibars (29.77 inches of mercury) over the western Dakotas. At this time weather stations there were reporting winds in the 10-mph range. The dashed orange line going south from the "o" in "Low" over the Dakotas indicates a trough--an elongated area of low pressure. Later in the day this became the focus for a line of thunderstorms that kicked up some damaging winds, heavy rain, and marble-sized hail.

In the eastern third of the country, the 1,020-millibar (30.12 inches of mercury) isobar, which comes in from over the Atlantic Ocean at the Georgia-South Carolina border, goes into northeastern Texas and then swings north over the western end of Lake Superior, shows that all of the United States east and north of the line enjoyed a pressure of 30.12 inches of mercury or higher that morning--which meant mostly clear skies and no rain all day.

The 1,012-millibar (29.88 inches of mercury) low over the Bahamas east of South Florida turned out to be the map's most important weather feature. It became a tropical depression on Tuesday and grew into Tropical Storm Ophelia on Wednesday. What at first glance seems like an area with tiny differences in air pressure off the Florida Coast was growing into another threat.

Jack Williams is coordinator of public outreach for the American Meteorological Society. An instrument-rated private pilot, he is the author of The USA Today Weather Book and The Complete Idiot's Guide to the Arctic and Antarctic, and co-author with Bob Sheets of Hurricane Watch: Forecasting the Deadliest Storms on Earth.