Hurricane Katrina (2005), gradient wind, the centripetal force, and spin

ATM 210 -- Fall 2023 -- Fovell
Review

• Four fundamental forces influence the horizontal wind
  – Pressure gradient force (PGF)
  – Coriolis force
  – Centripetal or centrifugal force
  – Friction force

• Coriolis is a self-serving apparent force that explains real, important phenomena

• Centrifugal is a self-serving apparent force that is often centripetal force and/or inertia in disguise
Gradient wind balance: Recipe: PGF + Coriolis + Centripetal
Gradient wind balance:
CCW around L, CW around H in NH
Reminder: tropical cyclones do not form on, or cross, the equator

61 years of tropical cyclone tracks
Hurricane Katrina (2005)
Oblique view
Surface chart showing sea-level pressure (SLP)

09 UTC 8/29/2005

Flow parallel to curved isobars $\rightarrow$ gradient wind
Tighter isobar spacing $\rightarrow$ faster winds
CCW flow around L pressure
That wind would have been stronger if straight-line
09 UTC 8/29/2005

Surface winds use **knots** $\leftarrow$ nautical mile per hour
1 kt $\sim$ 1.2 mph $\sim$ 0.5 m/s $\sim$ 1.9 km/h
09 UTC 8/29/2005

Note some winds NOT parallel to isobars
Some component towards L ← friction [soon]
Question #1: We often see strong flow around L, but almost never around H. Why?
Question #2: Curving flow involves centripetal force. But where did the force come from?
Question #3: Why use centripetal force and not centrifugal force?
You in the cylinder ride. CCW or CW, it’s all the same pain.
At any instant, **inertia** wants you moving **straight**
You may interpret this as a centrifugal force, pushing you against the wall.
But it’s really a *centripetal force*, supplied by the *wall*.
Centripetal force points in towards the center of spin.
Adding centripetal to the L means flow curves CCW

(in NH)
Adding centripetal to the H means flow curves CW
But this does not explain where the centripetal force came from, why the speed changes, and why CCW flow is subgeostrophic and CW flow is supergeostrophic.
Start with geostrophic balance: PGF + Coriolis
There is a force balance. No acceleration. Yet.
Suppose the air path is towards curving isobars…
Air *can* cross isobars. But the forces will become unbalanced.
Notice also that this path is carrying the air towards higher pressure!
PGF always points H → L
Coriolis always to right…
...but note the forces are no longer opposing. They are **unbalanced**.
A component of the PGF is now **opposing** the motion. The air **slows down**.
Coriolis is proportional to speed. As the air **slows**, Coriolis gets **weaker**.
PGF “wins” the tug-of-war, turning the wind.
As the wind turns, so does Coriolis, always to the right.
So the air **slows** into the CCW turn as PGF gains the upper hand.

The wind is now subgeostrophic. Straight-line flow would be faster.
Where is the centripetal force?
It is the force imbalance.
Implications of Newton’s 1\textsuperscript{st} and 2\textsuperscript{nd} laws

- Unbalanced forces $\rightarrow$ acceleration
- Acceleration is a change of speed, direction, or both
- Air circulating CCW around a large-scale L (cyclone) parallel to isobars is \textit{constantly changing direction}
- A portion of the PGF is acting against the motion, slowing the air down
- You don’t need a centrifugal force to explain this
- You don’t really need a centripetal force either
Do the same for CW flow and see the air *speeds up* as it curves CW

So why don’t we see stronger winds around anticyclones (H)?
Typical situation.
Something is breaking the symmetry.
Part of the answer: **spin makes low pressure**

And it doesn’t matter which way you stir. **Cyclostrophic flow**: “to turn in a circle”.

Spin supports the low and works against the high.
[end]