The key to solving the mystery that winds blow around, instead of towards, the low pressure center.

Pressure gradient force:
Pressure diff/distance

**Coriolis Force**

\[ \text{Coriolis Force} = 2 \times \text{Earth Rotation Rate} \times \sin(\text{latitude}) \times \text{velocity} \]

The Coriolis force (CF) turns wind in parallel to isobars

→ **Geostrophic wind**

A balance between PGF and CF
**Geostrophic wind**
(William Ferrel, 1856; Buys Ballot, 1857)

- **Direction:** in parallel to isobars, with high pressure to the right and low to the left in the Northern Hemisphere (opposite in the Southern Hemisphere)
- **Magnitude:** proportional to the spacing of isobars (analogous to river flow)

**Gradient wind**

a better approximation for curved wind than geostrophy, important in hurricanes

Balance among the pressure gradient force, Coriolis force, and centrifugal force due to curved flow.
Bottom-line points

• Why is there wind? Horizontal variations in temperature (pressure gradient force).

• In NH, wind blows counter-clockwise around a low pressure, and clockwise around a high. (Facing the direction wind blows, high pressure to the right and low to the left.)

  Empirical

• Why does it blow the way it is? Balance of pressure gradient and Coriolis forces. Physical/dynamical

• Coriolis force: An apparent force due to Earth’s rotation, directing to the right of the wind vector and proportional to the wind speed in magnitude.

• Surface friction helps the wind to gain a component from high toward low pressure.

• In SH, all the rules remain the same except reversing the direction.

Hydrostatic Balance

What keeps air from rising due to the upward pressure gradient force?

A balance between gravity and the pressure gradient force.

Pressure gradient

Gravity
Station pressure

Altitude correction to Sea level pressure

Diagram (a)

Diagram (b)

Diagram (c)

Sea Level Pressure Chart
Isobars

Trough
Ridge

(a) Surface map

(b) Upper-air map (500 mb)
Isobaric Maps:
Measuring height on surfaces of constant pressure
A vertical coordinate transformation
to simplify mathematical equations for atmospheric motion

- Height contours on isobaric maps are equivalent to pressure contours at sea level.
- Warmer air column expands in volume/vertical → the 500 mb isobaric surface is taller than a cold air column.

500 hPa map: wind, geopotential height, & temperature

The westerly jet stream → longer westward-bound flights.
Read cloud for wind direction and pressure patterns

Isobars

L

H

Wind

(a)  

(b)  

(c)  

Read Clouds II

GOES upper-level winds from cloud drift, water vapor Imager & Sounder

September 10, 1998

GOES Visible Winds at low levels

http://cimss.ssec.wisc.edu/tropic/
Friction

- Air in contact with the surface experiences frictional drag, effectively slowing the wind speeds.
  - Magnitude: depends upon wind speed and surface roughness
  - Direction: opposite to the movement of the air parcel
- Planetary Boundary Layer (PBL) – the lowest ~1-2 km of the atmosphere which experiences friction.
- Free Atmosphere – the remaining atmosphere which is free from frictional effects above the PBL.

Effect of surface friction?

If the wind speed is reduced by friction, the Coriolis force will decrease and not quite balance the pressure gradient force

→ Force imbalance (PGF > CF) pushes wind in toward low pressure
Friction allows surface wind to attain a cross-baric component directing from high to low.

Upward motion in lows
- Rain & other severe weathers
- Hurricanes always have low-pressure centers (latent heat of condensation fuels the growth of storm)

Subsidence in highs
- Fair weather and dry
Review of Forces

1. Pressure Gradient Force – changes in pressure over a distance causes air to move.
2. Gravity – only acts in the vertical direction
3. Coriolis Force – due to Earth’s rotation
4. Centrifugal Force – when there is curved flow
5. Friction – only important near the Earth’s surface

Only the first two forces listed above can cause winds in air that is initially at rest, and the last three are in action only when there is relative motion.
Review of Force Balances

- Geostrophic Balance
  Pressure Gradient Force = Coriolis Force
  (+ friction in PBL)
- Gradient Wind Balance
  Pressure Gradient Force = Centrifugal + Coriolis Forces
- Hydrostatic Balance
  Pressure Gradient Force = Gravity
A source of waves moving to the left. The frequency is higher on the left, and lower on the right. → High-pitch sound from an approaching car.

Doppler (1842) effect

Wind in a supercell seen from a Doppler radar.

All-weather global wind observations by satellite-borne microwave scatterometer

Wind → Ocean waves → Reflection of Sunlight
Wind near Hawaii (high in red & low in blue) from satellite scatterometer

A science article at http://earthobservatory.nasa.gov/Study/Wake

Key Words

- Station pressure, sea level pressure
- Isobar, surface map, isobaric map
- Mid-latitude cyclone, anticyclone
- Trough, ridge
- Pressure gradient & Coriolis forces
- Geostrophic wind
- Gradient wind, contripetal force
- Zonal and meridional wind
- Friction layer (difference in weather between lows and highs)
- Hydrostatic equilibrium