Synoptic Meteorology I: Geostrophic Balance Example

Recall the definition of geostrophic balance on an isobaric surface:

$$fv = \frac{\partial \Phi}{\partial x}$$

$$fu = -\frac{\partial \Phi}{\partial y}$$

where f is the Coriolis parameter, u and v are the zonal and meridional wind components, and Φ is the geopotential height = gz.

Several axioms follow from this definition:

- The geostrophic wind blows parallel to lines of constant geopotential height, with lower heights to the left of the wind. We can see this from the equations:
  - The north-south wind v exclusively depends on how the geopotential height changes in the east-west direction (associated with north-to-south–oriented isohypses).
  - The east-west wind u exclusively depends on how the geopotential height changes in the north-south direction (associated with east-to-west–oriented isohypses).
- Geostrophic balance has *not* been achieved where the total horizontal wind *does not* blow parallel to lines of constant geopotential height. This is most common in regions where the flow is accelerating (either becoming faster/slower or changing direction), such as in a jet streak, or being influenced by friction.
- Faster horizontal winds necessitate larger horizontal changes in geopotential height, whereas slower horizontal winds necessitate smaller horizontal changes in geopotential height. We can see this from the equations:
  - If u and or v have large magnitude, so too must the partial derivative (representing horizontal changes in geopotential height) on the other side of the equation.
  - Conversely, if u and/or v have small magnitude, so too must the partial derivative on the other side of the equation.
- Likewise, anomalously low or high geopotential heights (associated with cyclones and anticyclones, respectively) necessitate faster horizontal wind speeds, whereas spatially uniform geopotential heights necessitate smaller horizontal wind speeds. This can also be seen from the equations, except plugging in for the right-hand rather than left-hand side.

On the next page, you'll find synoptic analyses at 500 hPa and the surface valid at 0000 UTC 27 April 2011, just prior to the "Super Outbreak" severe weather event in the southeastern United States. We'll use these analyses to put these axioms to the test.

(Note: the isolines depicted in Figs. 1 and 2 are generated from numerical weather prediction model analyses. Although they are strongly influenced by the plotted observations, ***they do not technically represent observations themselves!*** *Use these analyses with caution.)*

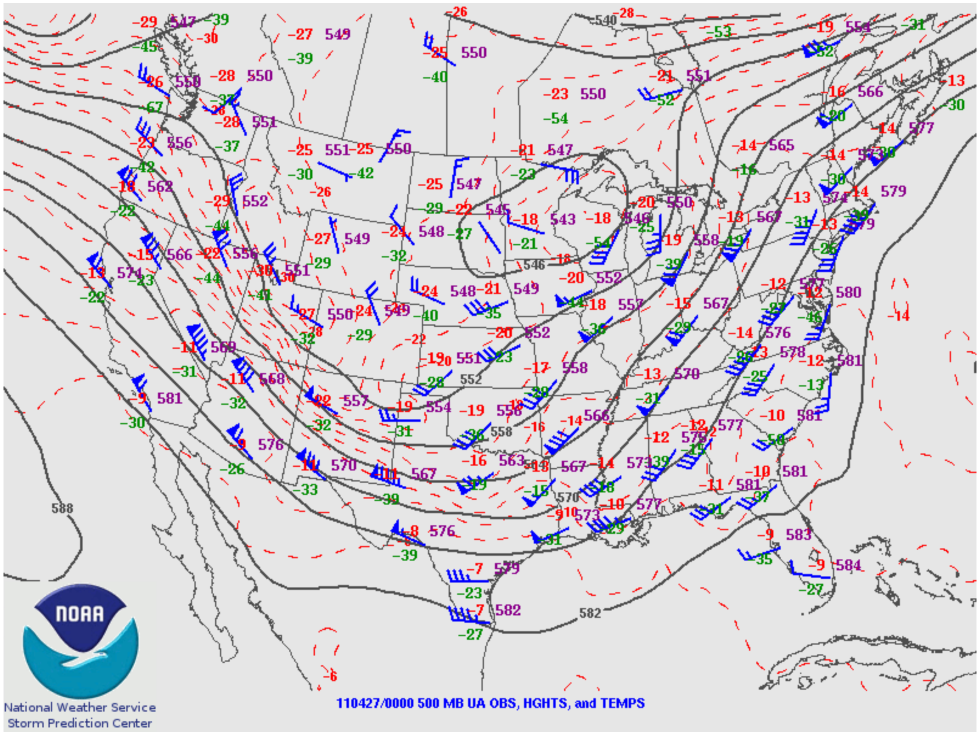

Figure 1. 500 hPa geopotential height (black contours every 60 m/6 dam), temperature (red dashed contours every 3°C), and station-model-formatted observations at 0000 UTC 27 April 2011. Figure obtained from the Storm Prediction Center.

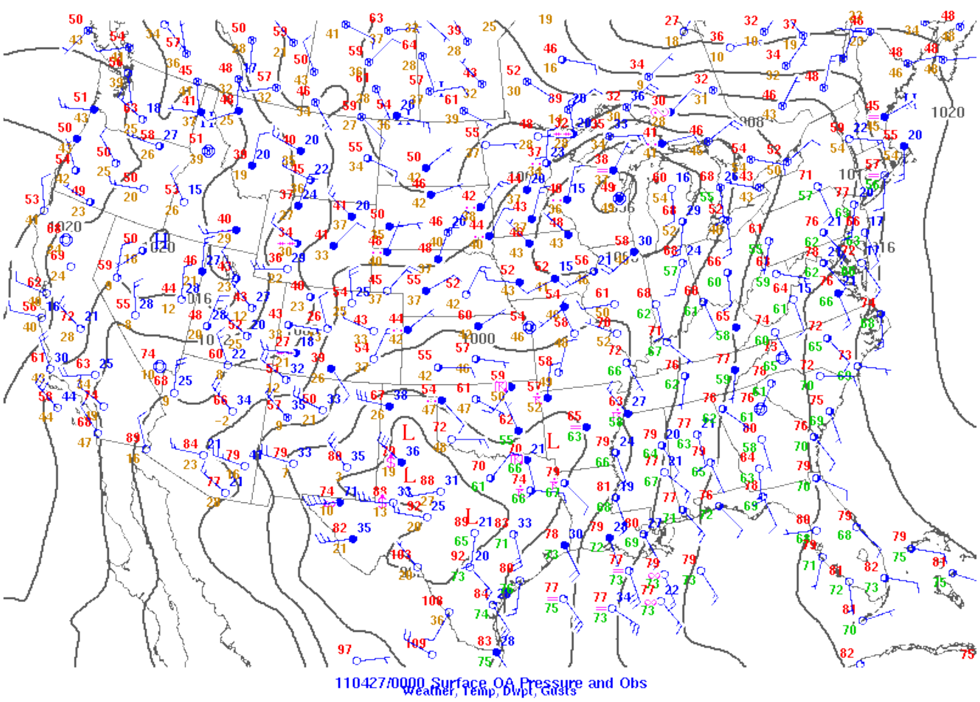

Figure 2. Sea-level pressure (contours every 4 hPa) and station-model-formatted observations at 0000 UTC 27 April 2011. Figure obtained from the Storm Prediction Center.

Let's start with Fig. 1. The horizontal wind parallels the isohypses over much of the United States and southern Canada. Notable exceptions include International Falls, MN and Moosonee, Ontario. Both locations are characterized by accelerating flow, whether due to curvature (in both locations) or accelerating flow (in Moosonee, as inferred by the greater packing to the isohypses to the east). The wind speed is fastest in the Intermountain West, where the 500 hPa height changes rapidly in the southwest-to-northeast direction. It is slowest in the northern Great Plains, where there are few isohypses. In all, this analysis is consistent with our axioms.

Let's now consider Fig. 2. The horizontal wind is generally *not* parallel to the surface isobars. This is not surprising given the influence of friction. We'll discuss precisely how friction influences the near-surface wind in a subsequent lecture. Even though geostrophic balance does not apply here, though, tenets of geostrophic balance are nevertheless apparent in the data. For instance, the winds are strongest near Lake Superior and the Four Corners region, both of which are places where there are rapid horizontal changes in sea-level pressure between areas of low and high pressure. In all, this analysis is also consistent with our axioms.

This is not a cherry-picked example! The same inferences would result from analyzing nearly any other case. You'll have the chance to diagnose these inferences in lab, but I encourage you to begin regularly analyzing weather maps to practice diagnosing these inferences for yourself! You'll find that the most-interesting weather often occurs where geostrophic balance does not hold – but that geostrophic balance often does a good job helping us understand what is happening even when it does not hold. A few sources of weather data are given by:

- NCAR Research Applications Lab: [RAP Real-Time Weather (ucar.edu)]
- NOAA NWS Storm Prediction Center: [Storm Prediction Center Forecast Tools (noaa.gov)]
- NOAA Aviation Weather Center: [AWC - METeorological Aerodrome Reports (METARs) (aviationweather.gov)]