Synoptic Meteorology I: Other Force Balances Application

The Effects of Friction on Near-Surface Winds

Recall that friction acts as a drag on winds near the surface. Because the magnitude of the Coriolis force is directly proportional to the wind speed, surface friction also reduces the Coriolis force, in turn causing it to no longer balance the horizontal pressure gradient force. With the horizontal pressure gradient force now exceeding the Coriolis force, air near the surface flows across isobars from high toward low pressure, and a new balance between the horizontal pressure gradient force, Coriolis force, and friction is achieved.

This is not just a dynamical construct, however – we can see it in real-world data! As an example, let us consider the isoplethed surface analysis from week 1's isoplething example, repeated below:

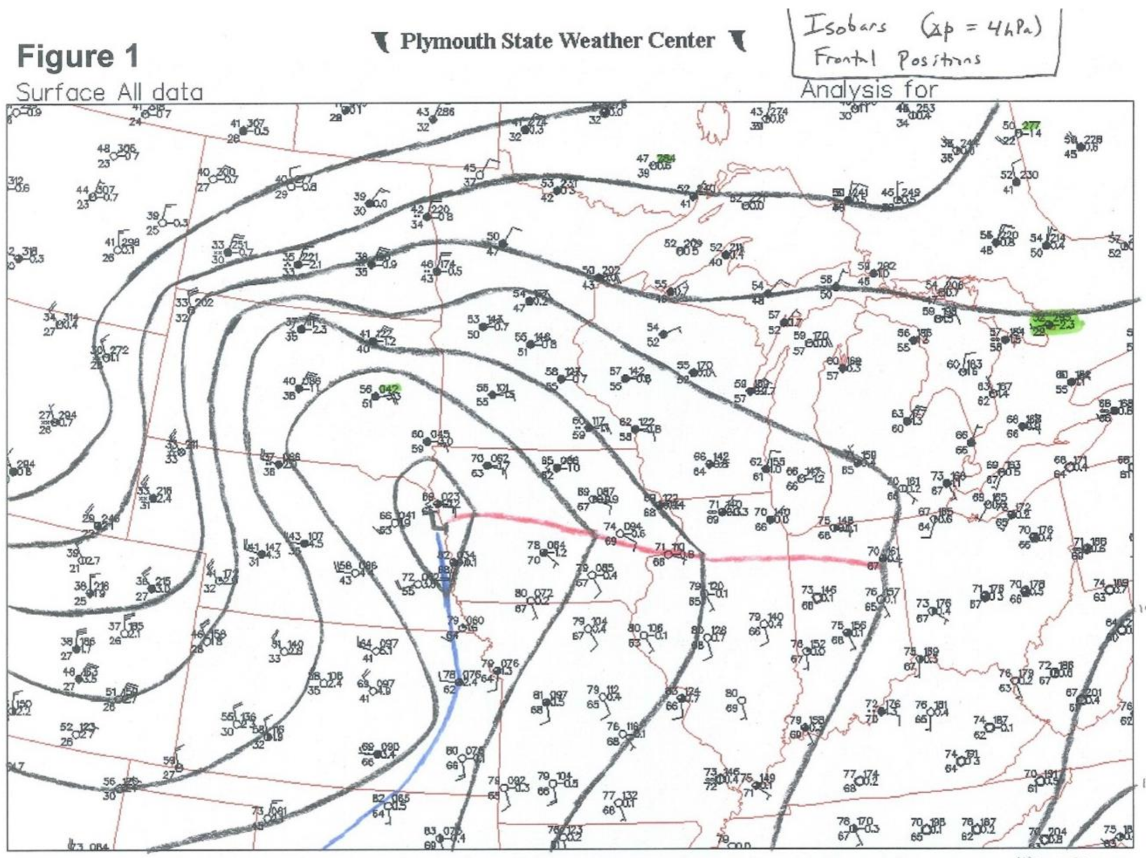

Fig. 1. Surface observations (encoded per the surface station model) and manually drawn isobars (black contours every 4 hPa) and fronts (red and blue lines).

If geostrophic balance were to hold at the surface, we would expect the surface wind observations to parallel the isobars. However, they do not because friction disrupts geostrophic balance. Instead, the surface wind observations indicate flow directed inward toward the lowest pressure along the Nebraska/Iowa border, consistent with the theory summarized above.

Flow Curvature and the Geostrophic vs. Gradient Wind

Although friction does not meaningfully impact the wind above the planetary boundary layer, there are nevertheless other forces that can cause the wind to not be purely geostrophic. One of the most common such forces is the centrifugal force, which is associated with flow curvature (or rotation).

The centrifugal force is always directed *outward*. Thus, under gradient wind balance,

- For anticyclonic flow, the horizontal pressure gradient and centrifugal forces point outward whereas the Coriolis force points inward.
- For cyclonic flow, the Coriolis and centrifugal forces point outward whereas the horizontal pressure gradient force points inward.

Whereas under geostrophic wind balance,

- For anticyclonic flow, the horizontal pressure gradient force points outward and the Coriolis force points inward.
- For cyclonic flow, the Coriolis force points outward and the horizontal pressure gradient force points inward.

Recall again that the magnitude of the Coriolis force is directly proportional to the wind speed. For anticyclonic flow in gradient wind balance, the Coriolis force has to balance two forces rather than just one. As a result, the Coriolis force must be larger, and thus the wind speed must be larger, than it would be under geostrophic wind balance. Thus, the gradient wind (approximating the total wind) around an anticyclone is supergeostrophic – i.e., larger than the geostrophic wind.

For cyclonic flow in gradient wind balance, the Coriolis force has help from the centrifugal force in balancing the horizontal pressure gradient force. As a result, the Coriolis force must be smaller, and thus the wind speed must be smaller, than it would be under geostrophic wind balance. Thus, the gradient wind (approximating the total wind) around a cyclone is subgeostrophic – i.e., smaller than the geostrophic wind.

We can illustrate this with actual data – in this case, drawn from Lab 6. Enclosed below are plots of the full horizontal wind and the ageostrophic wind at 500 hPa for 1200 UTC 28 October 2021. Note the two cyclones, one over the south-central United States and one east of New England. The ageostrophic wind with both cyclones is anticyclonically curved. If we recall that the full wind is equal to the geostrophic plus the ageostrophic wind, we can infer that the geostrophic wind (which is not shown) must be larger than it otherwise would be to counteract the anticyclonically curved ageostrophic wind to result in the total wind – i.e., the full/gradient wind is subgeostrophic.

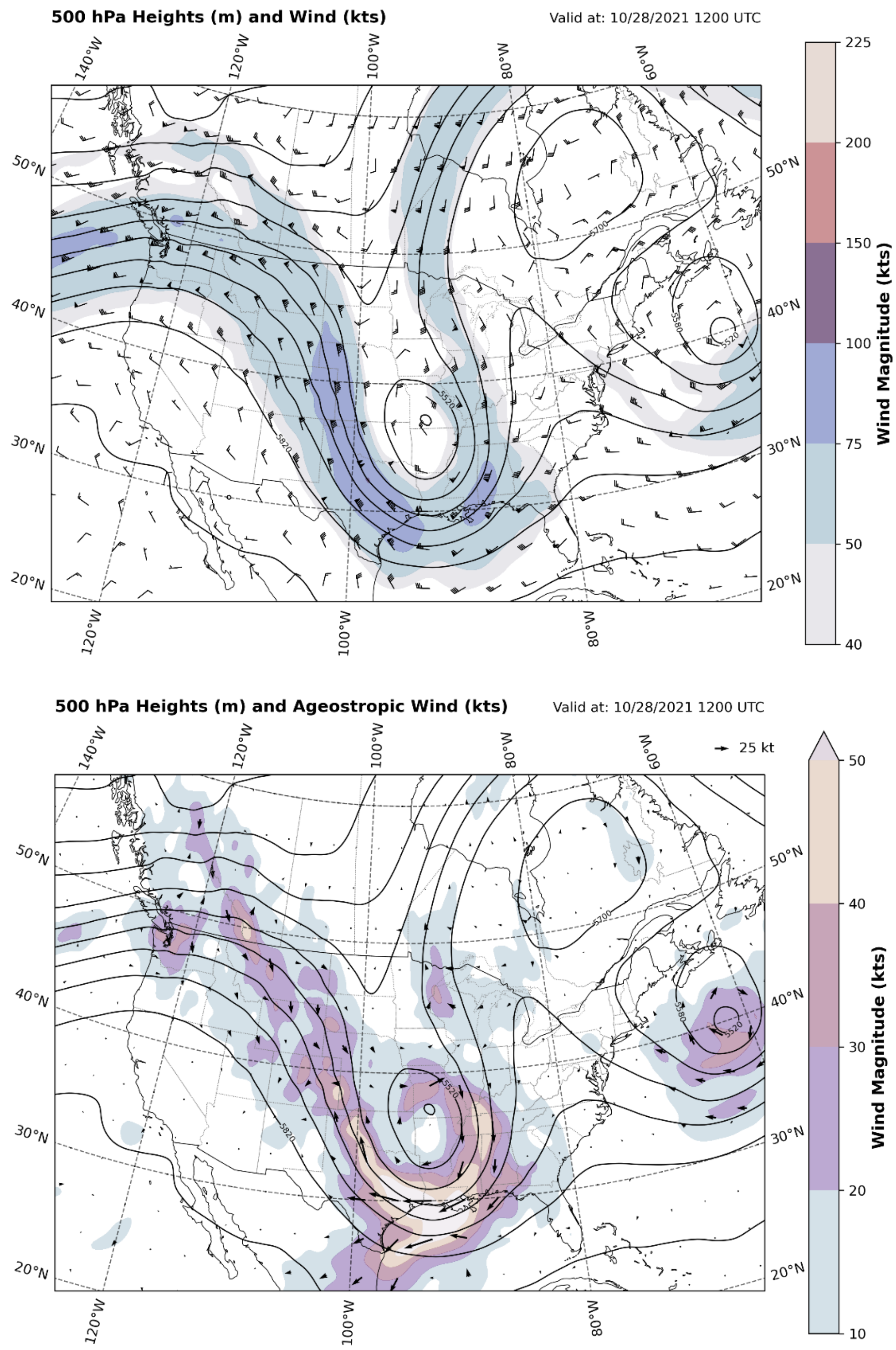

Fig. 2. (top) 1200 UTC 28 October 2021 0-h GFS-analyzed 500 hPa height (contours; m), wind speed (shaded per the color bar at right in kt), and horizontal wind barbs (half-flag: 5 kt, flag: 10 kt, pennant: 50 kt). (bottom) 1200 UTC 28 October 2021 0-h GFS analyzed 500 hPa height (contours, m), ageostrophic wind speed (shaded per the color bar at right in kt), and ageostrophic wind vectors (reference vector shown at upper right).