Synoptic Meteorology II: Petterssen-Sutcliffe Development Theory Application

In our lecture on Petterssen-Sutcliffe Development Theory, we outlined the principle of "self-development" in the context of the life cycle of a synoptic-scale midlatitude cyclone. We now wish to apply this theory to a real-world example from the North Atlantic Ocean in mid-January 2013.

Like the idealized schematics presented in the lecture notes, we consider weather charts on two levels: at the surface and in the mid-troposphere. The fields depicted on each chart are as follows:

- **Surface**: 10-m wind (barbs; kt), sea level pressure (contoured every 4 hPa), and 1000-500 hPa layer-mean potential temperature (shaded every 3 K).
- **Middle Troposphere**: 500 hPa wind (barbs; kt), height (contoured every 60 m), and absolute vorticity (shaded every 8 x 10^{-5} s^{-1}).

Representative plots for each of five stages of a synoptic-scale cyclone's lifecycle (pre-genesis, genesis, development, maturity, occlusion) are provided at the end of these notes. We focus on ***analyzing*** the relevant fields and, from the overlap of the wind and vorticity/thermal fields, ***infer*** the relevant advection patterns (and associated forcing for cyclone development and/or motion).

We start at 0000 UTC 24 January 2013. Our initial area of focus is off of the mid-Atlantic coastline of the United States. At the surface (Fig. 6), a weak frontal boundary extends southwestward from a weak cyclone near 40°N, 50°W toward the South Carolina coastline. The layer-mean 1000-500 hPa temperature is relatively cold north and west of this front and relatively warm south and east. At 500 hPa (Fig. 1), there is a longwave trough across much of the western North Atlantic Ocean. Our feature of interest is the shortwave trough over the western Great Lakes that is moving toward the baroclinic zone.

We next progress to 1800 UTC 24 January 2013. Over the past 18 h (Fig. 7), a relatively weak surface cyclone has developed along the baroclinic zone in response to the cyclonic geostrophic relative-vorticity advection (and accompanying forcing for vertical motion) east of the shortwave trough axis. Weak lower-tropospheric warm-air advection is noted east and northeast of the surface cyclone. This implies an east-northeastward motion of the surface cyclone. The shortwave trough (Fig. 2) takes on more of a neutral (or north-south) tilt with time, whereas before it had more of a positive (or northeast-southwest) tilt. The shortwave trough is located somewhat northwest of the surface cyclone: the trough axis is just east of New Jersey whereas the surface cyclone is centered near 37°N, 65°W north of Bermuda. Thus, the system tilts against the westerly vertical wind shear with increasing height. Weak lower-tropospheric cold-air advection is noted west of the surface cyclone, in the base of the shortwave trough. This provides forcing for the amplification of the shortwave trough. Likewise, the weak lower-tropospheric warm-air advection east of the surface cyclone provides forcing for the amplification of shortwave ridging.

We next consider 1200 UTC 25 January 2013. As the surface cyclone moves northeastward (Fig. 8), it continues to develop in response to the cyclonic geostrophic relative-vorticity advection in the upper-troposphere east of the shortwave trough axis. In the 18 h since the last analysis time, the surface cyclone's minimum sea-level pressure has fallen from near 1004 hPa to near 988 hPa. The lower-tropospheric baroclinic zone has begun to acquire an S-shape, with warm-air advection maximized east of the surface cyclone and cold-air advection maximized west and southwest of the surface cyclone. This thermal advection pattern continues to be favorable for the amplification of the upper-tropospheric trough-ridge pattern, and that this has indeed occurred over the North Atlantic over the most recent 18 h. The upper-tropospheric pattern (Fig. 3) progresses eastward with a continuation of the processes noted above for the analysis valid 18 h earlier.

Explosive surface cyclone development occurs during the next 18 h, as evidenced by the surface chart valid at 0600 UTC 26 January 2013 (Fig. 9). The surface cyclone reaches an intensity below 940 hPa by this time. This is driven by the strong cyclonic geostrophic relative-vorticity advection in the upper-troposphere east of the shortwave trough axis. Likewise, there exists diabatic heating near this cyclone throughout its development (not shown), which substantially aids and accelerates the development process. The lower-tropospheric baroclinic zone has become complicated, with relatively warm air becoming isolated (or secluded) near the center of the surface cyclone. Warm-air advection is maximized east of the surface cyclone but is beginning to become weaker; cold-air advection is maximized south of the surface cyclone. Overall, the motion of the surface cyclone slows substantially at and after this period. Aloft (Fig. 4), this thermal advection pattern has led to the shortwave trough taking on a negative (or northwest-southeast) tilt. The slowing of the surface cyclone's forward motion is greater than the slowing of the shortwave trough's forward motion, reducing the vertical tilt between the features, characteristic of the system reaching maturity. Concordantly, the magnitude of the cyclonic geostrophic relative-vorticity advection aloft begins to weaken, reducing the forcing for the development (and maintenance) of the surface cyclone.

By 1200 UTC 27 January 2013 (Figs. 5 and 10), the shortwave trough and surface cyclone are vertically stacked, with no tilt against the vertical wind shear vector with respect to height. They have become somewhat cut off from the synoptic-scale westerly flow to the south of Iceland, near 60°N, 20°W. There is no discernible lower-tropospheric thermal or middle-upper tropospheric geostrophic relative-vorticity advection. As a result, there is no forcing for the maintenance (or movement) of the system, allowing friction to weaken the surface cyclone. At even later times on 27-28 January, the surface cyclone is yet weaker and is ultimately absorbed by another intense cyclone and accompanying shortwave trough that approaches from the southwest.

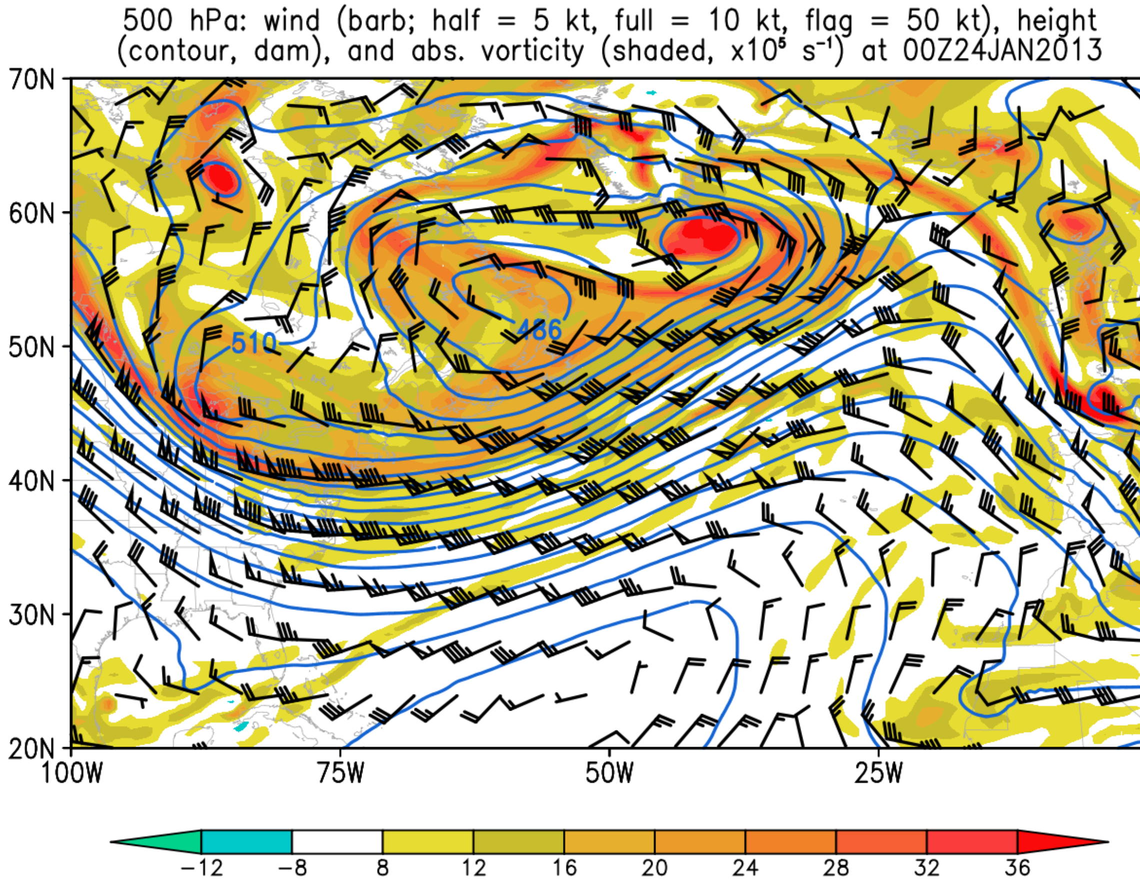

Figure 1. 500 hPa wind (barb, half = 5 kt, full = 10 kt, pennant = 50 kt), height (blue contours every 60 dam), and absolute vorticity (shaded every 8 x 10^{-5} s^{-1}) valid at 0000 UTC 24 January 2013.

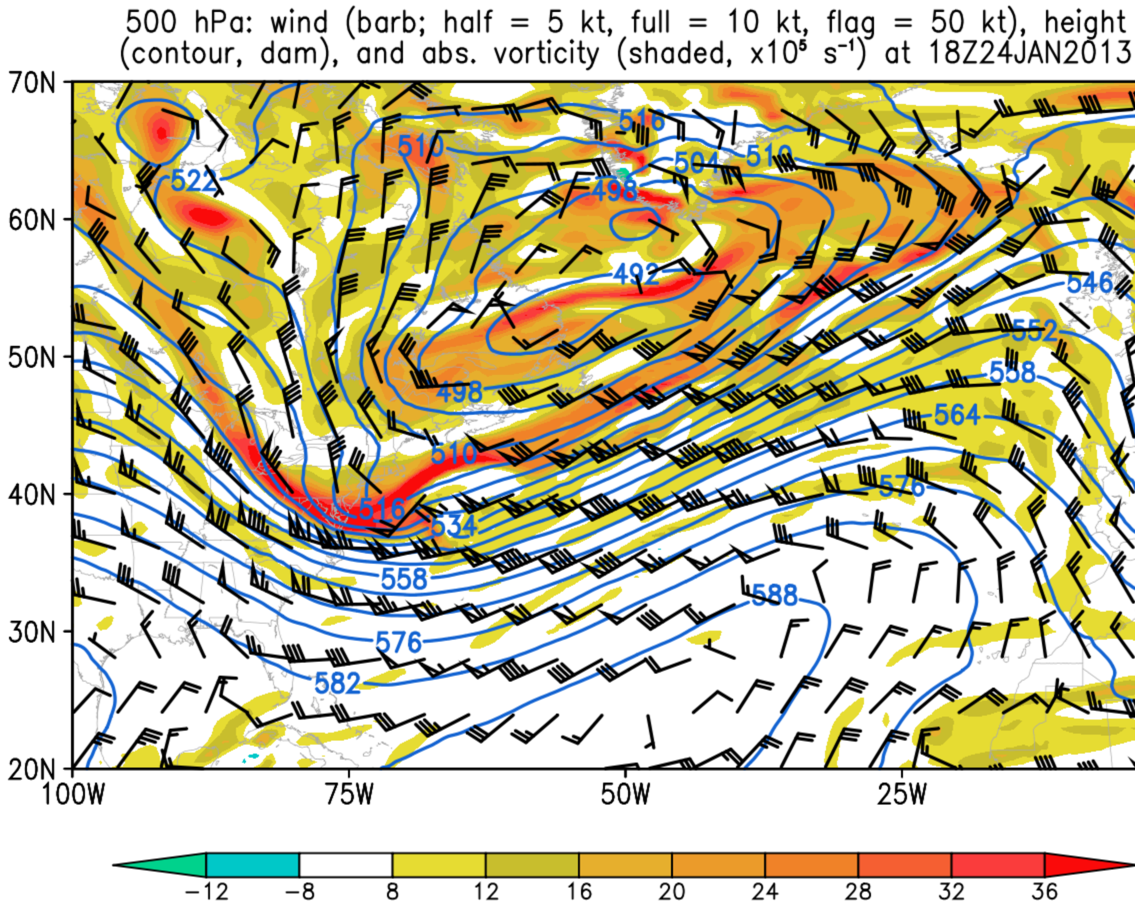

Figure 2. As in Fig. 1, except at 1800 UTC 24 January 2013.

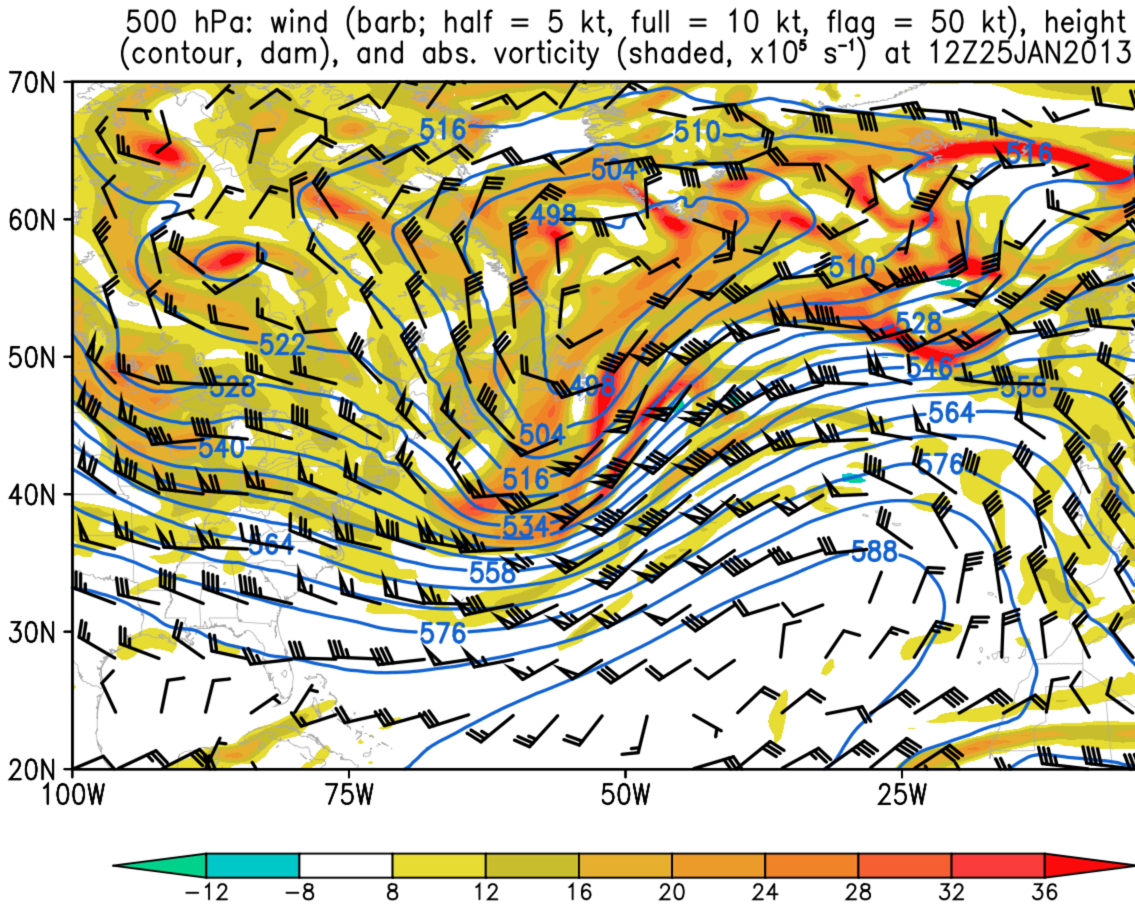

Figure 3. As in Fig. 1, except at 1200 UTC 25 January 2013.

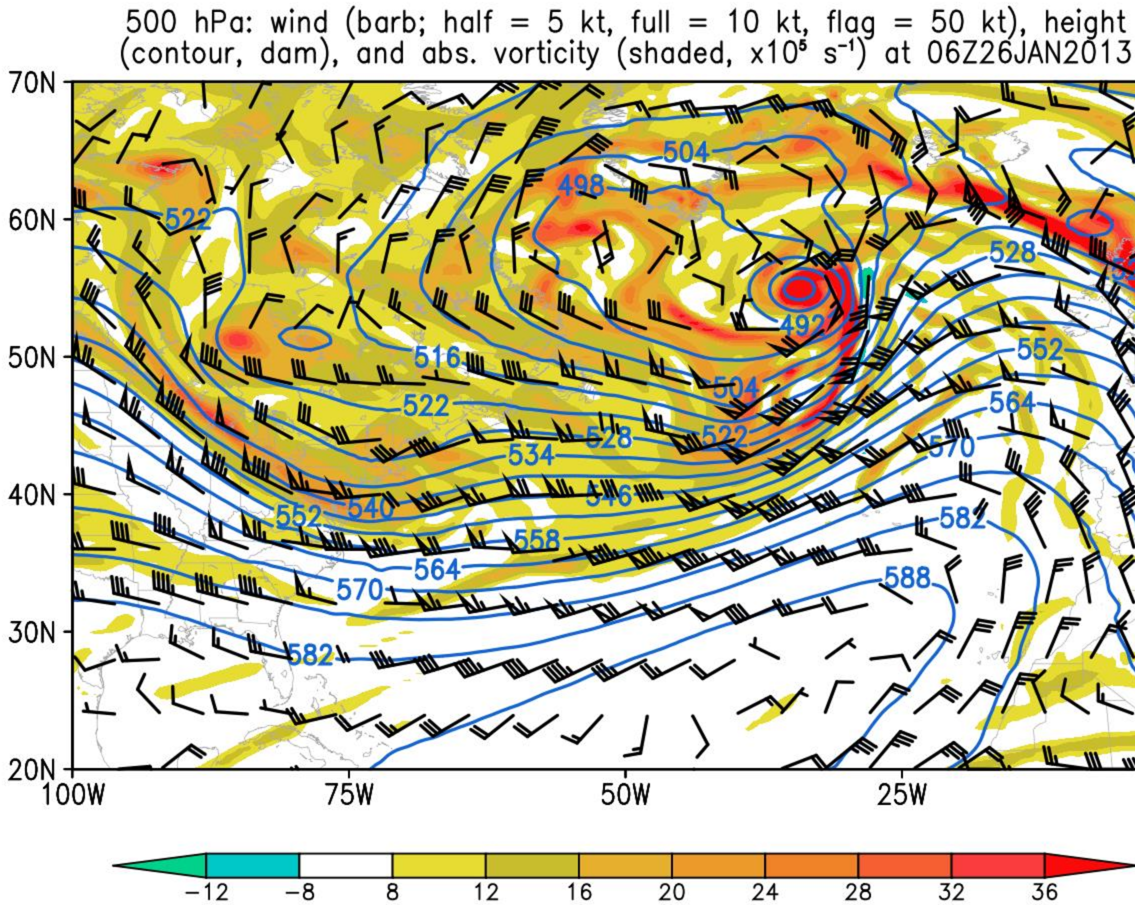

Figure 4. As in Fig. 1, except at 0600 UTC 26 January 2013.

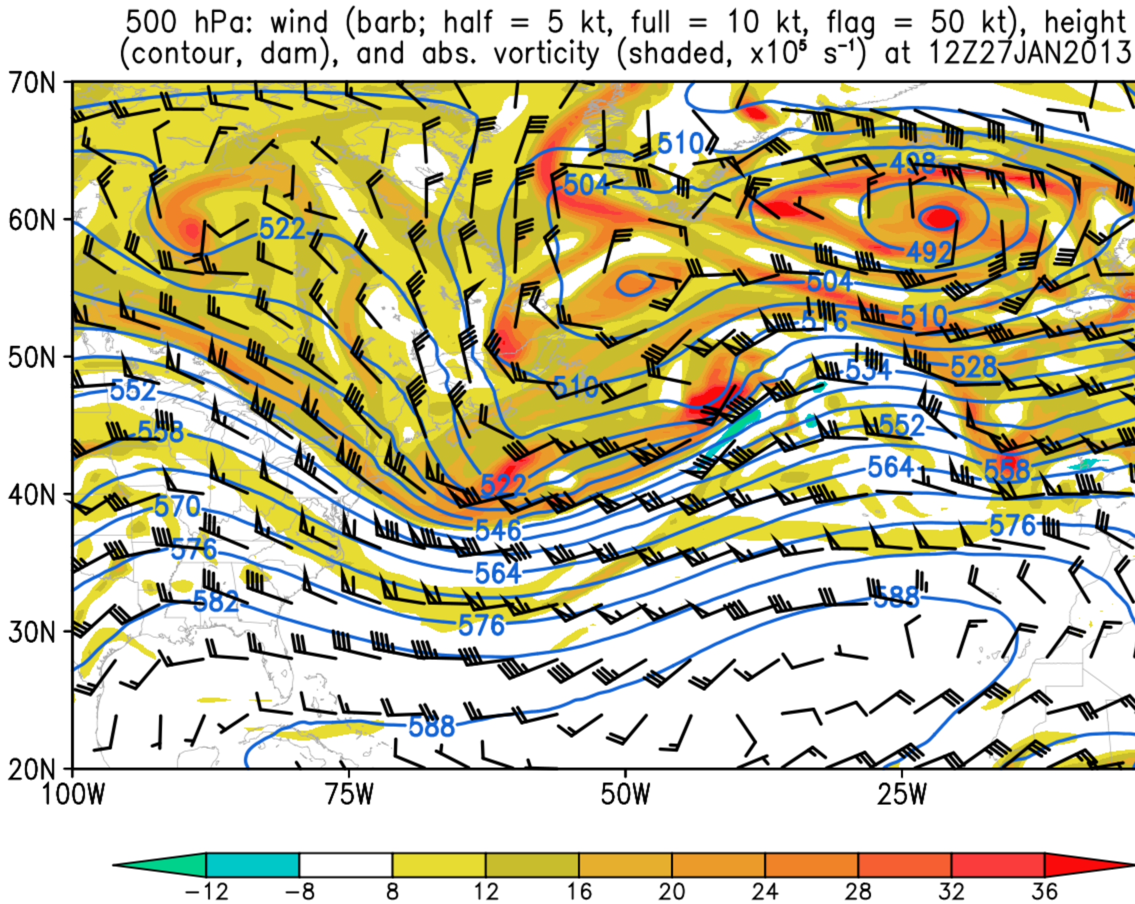

Figure 5. As in Fig. 1, except at 1200 UTC 27 January 2013.

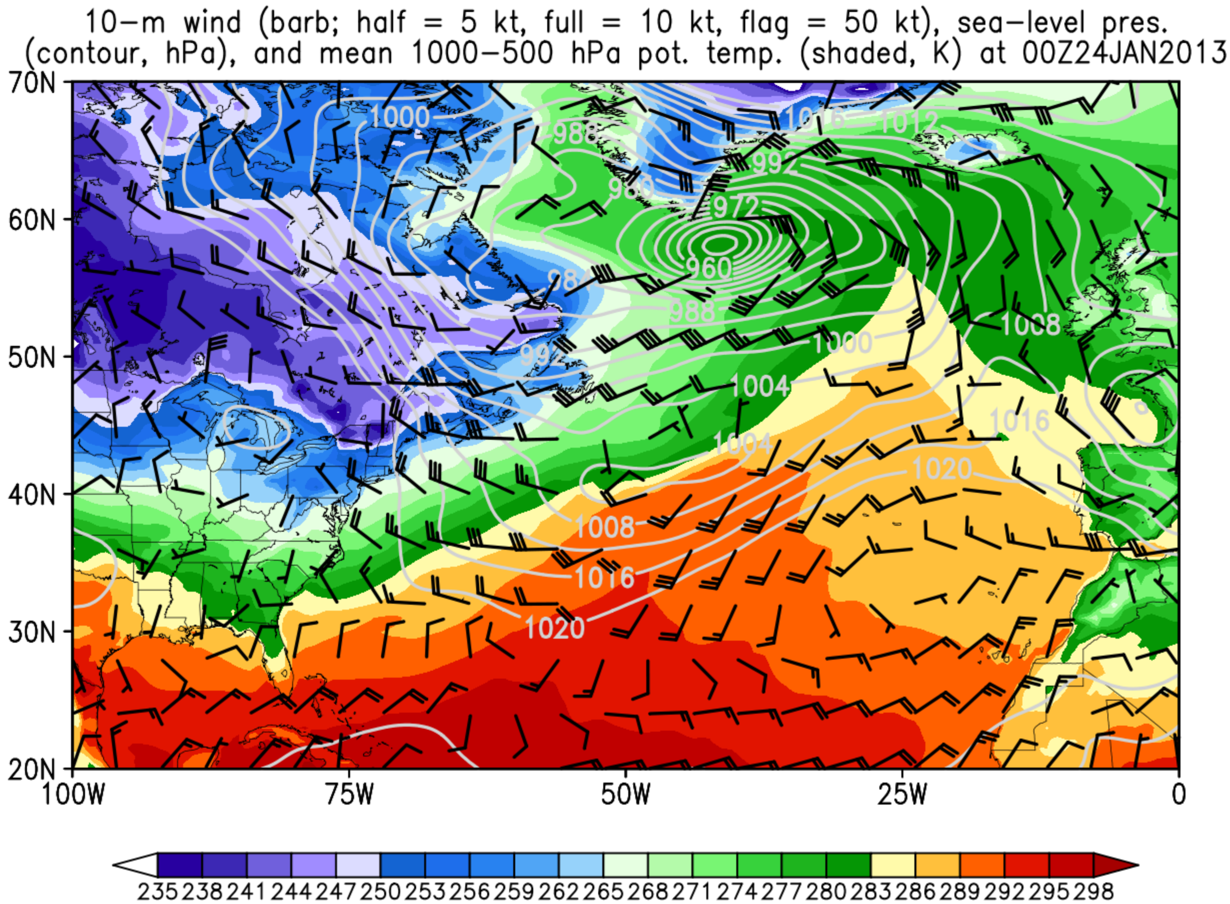

Figure 6. 10-m wind (barb, half = 5 kt, full = 10 kt, pennant = 50 kt), sea level pressure (grey contours every 4 hPa), and 1000-500 hPa layer mean potential temperature (shaded every 3 K).

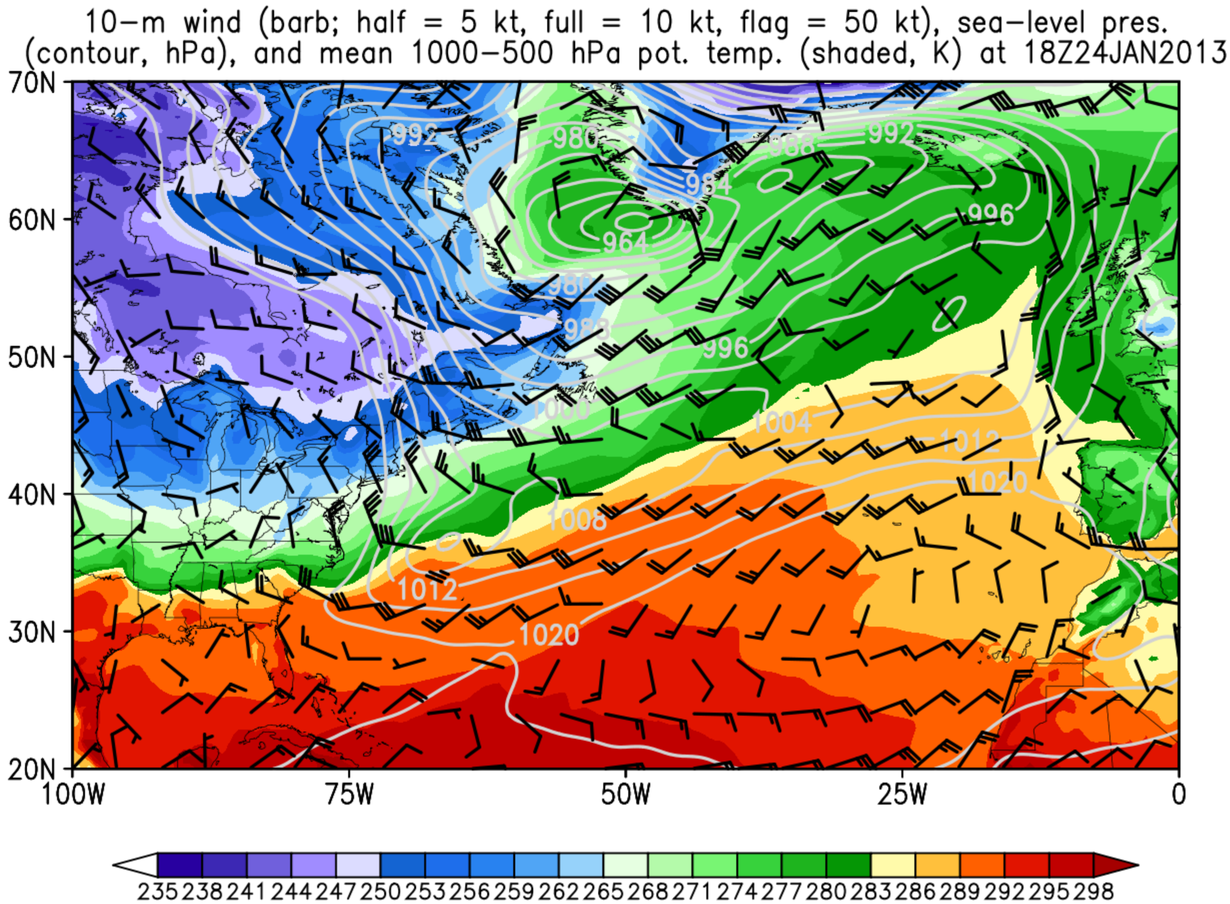

Figure 7. As in Fig. 6, except valid at 1800 UTC 24 January 2013.

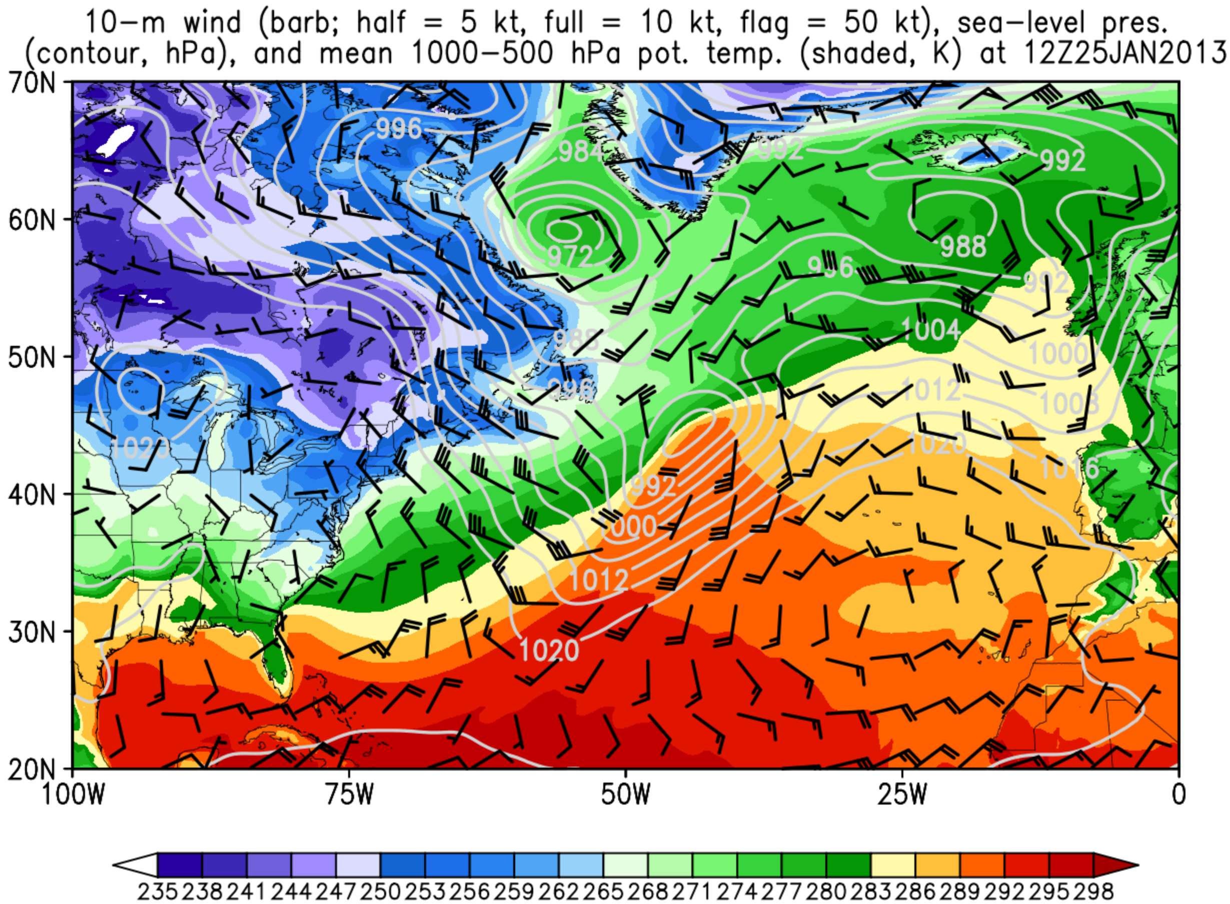

Figure 8. As in Fig. 6, except valid at 1200 UTC 25 January 2013.

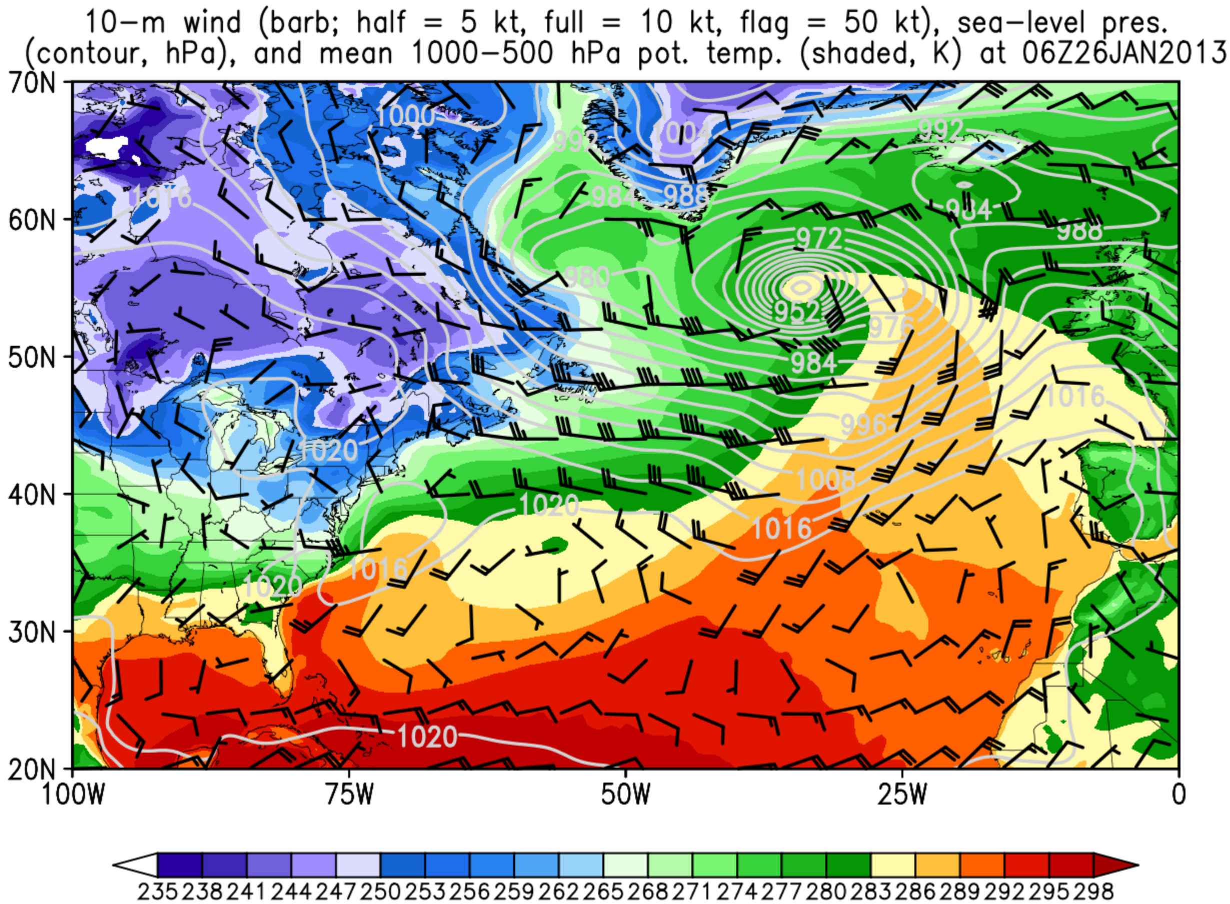

Figure 9. As in Fig. 6, except valid at 0600 UTC 26 January 2013.

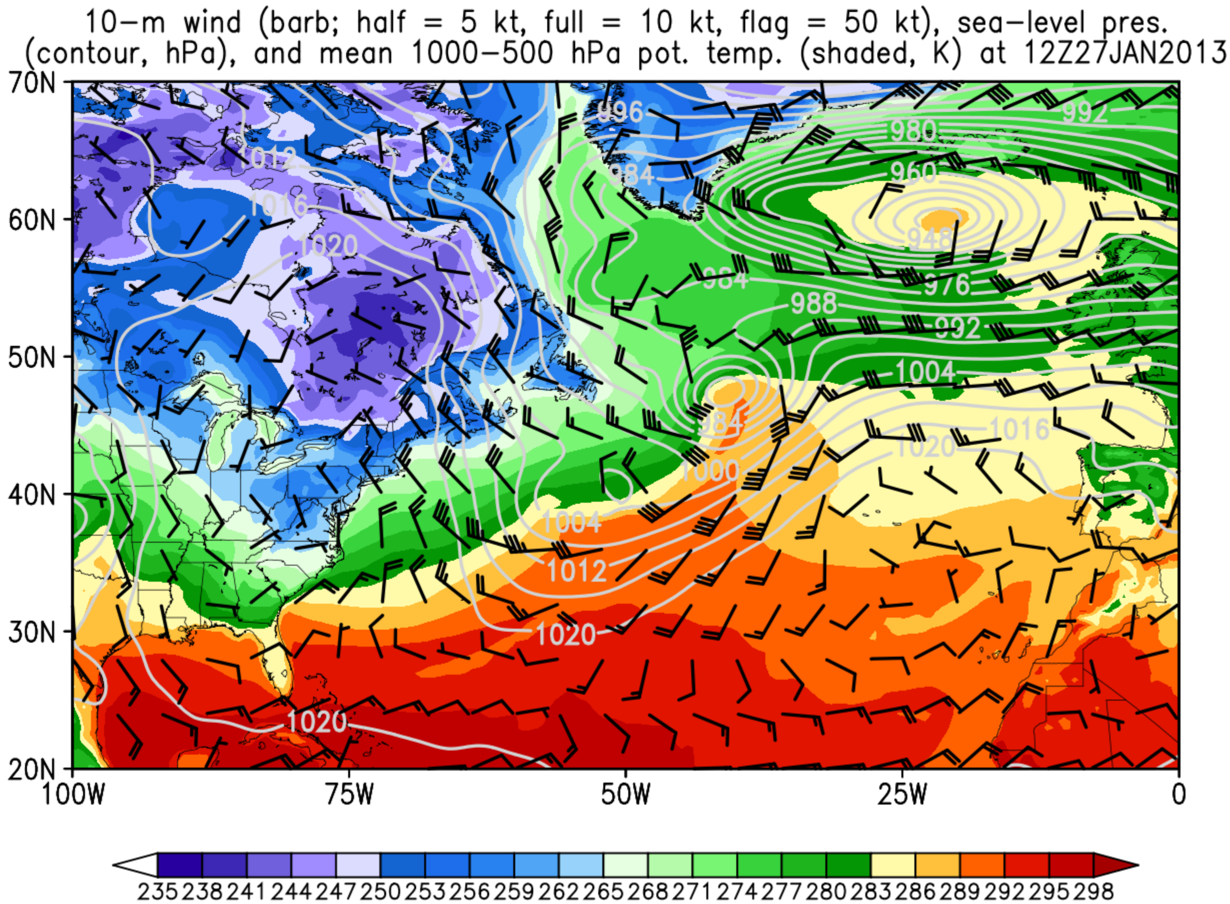

Figure 10. As in Fig. 6, except valid at 1200 UTC 27 January 2013.