Synoptic Meteorology II: Quasi-Geostrophic Omega Equation Examples

The below images, obtained from Tom Galarneau's QG Diagnostics webpage, provide data that we can use to evaluate the forcing terms to the quasi-geostrophic omega equation. Two notes:

- When evaluating the differential vorticity advection term, vorticity advection on the lower of the two isobaric surfaces (e.g., at 850 hPa if evaluating the omega equation at 700 hPa) is often assumed to be negligible compared to that on the upper of the two isobaric surfaces (e.g., at 500 hPa). Thus, the analyses below – which emphasize forcing for vertical motion at 700 hPa – use 500 hPa geostrophic advection of geostrophic relative vorticity as a proxy for the differential advection term. On the website above, the relevant plots are listed under the quasi-geostrophic height tendency equation section.
- As before, we neglect the friction and diabatic heating terms to the full omega equation.

We first focus on a shortwave trough in the central United States at 1200 UTC 20 February 2019. We see that 500 hPa geostrophic absolute vorticity is maximized in the base of this trough along 100°W (Fig. 1). Given the first note above, this implies that there is differential cyclonic vorticity advection to the east and northeast and differential anticyclonic vorticity advection to the west and southwest, which is confirmed by Fig. 2.

With respect to the Laplacian of the temperature advection term, we see that 700 hPa temperature advection is a local maximum east of the trough and local minimum southwest of the trough (Fig. 3). This forcing term is maximized near the local maximum and minimum (Fig. 4).

In this example, both terms provide forcing for ascent ahead of the 700 hPa trough axis, with each term having similar magnitude but the differential vorticity advection term covering a greater area. Both provide forcing for descent along and behind the 700 hPa trough axis, with each term having similar magnitude and areal extent. The total forcing, given by the sum of Figs. 2 and 4, is depicted in Fig. 5. This confirms total forcing for ascent ahead of the 700 hPa trough axis and descent along and behind the 700 hPa trough axis.

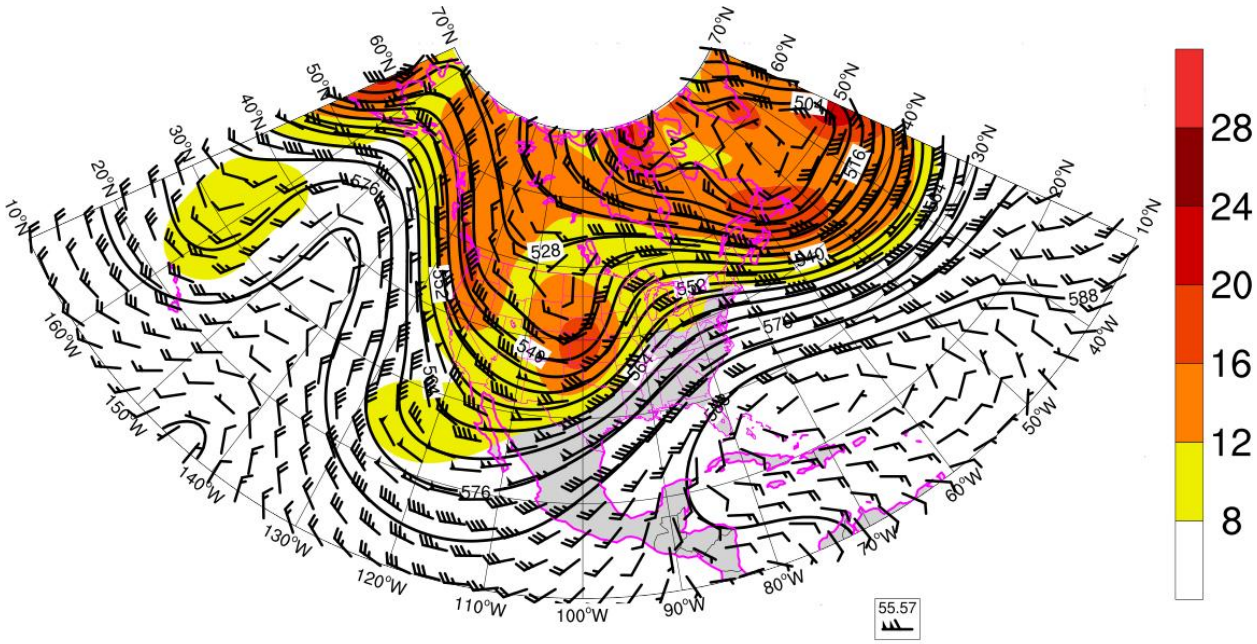

Figure 1. 500 hPa geopotential height (contours every 6 dam = 60 m), geostrophic wind (barbs; reference barb at lower-right), and geostrophic absolute vorticity ($x10^{-5}$ s^{-1}; shaded per the color bar at right) from the 0-h Canadian global model (CMC) analysis at 1200 UTC 20 February 2019.

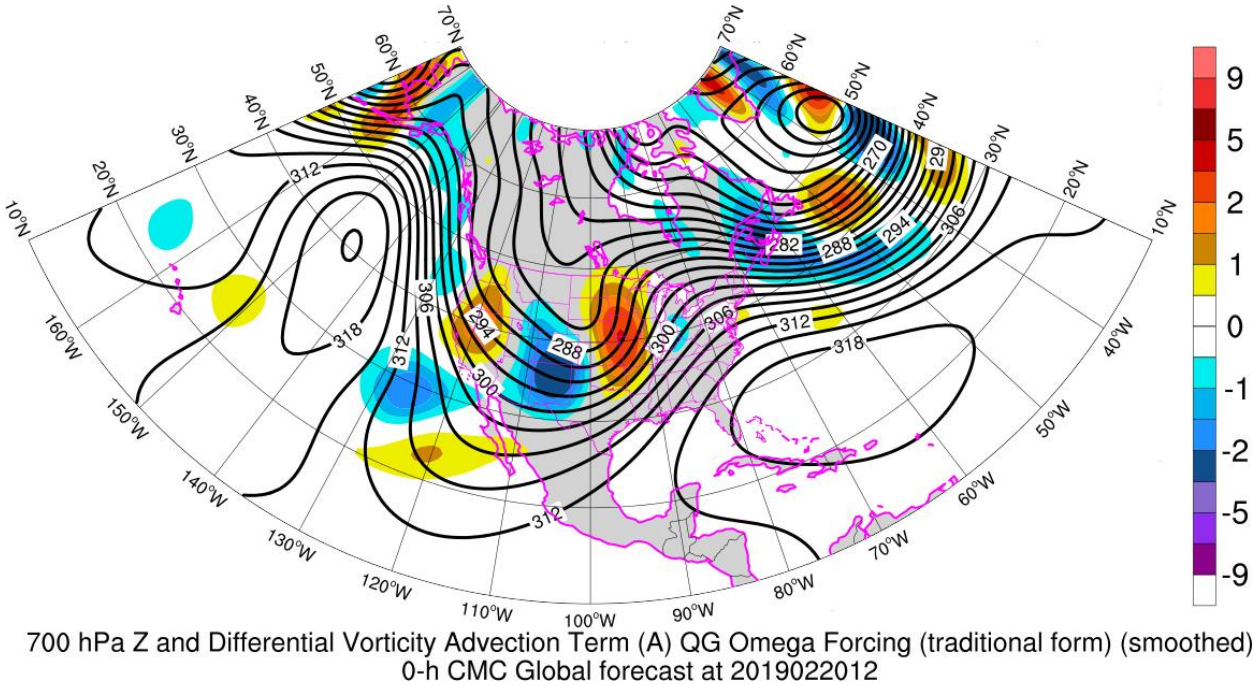

Figure 2. 700 hPa geopotential height (contours every 3 dam = 30 m) and geostrophic advection of geostrophic absolute vorticity ("term A"; $x10^{-12}$ Pa m^{-2} s^{-1}, shaded per the color bar at right) from the 0-h CMC analysis at 1200 UTC 20 February 2019.

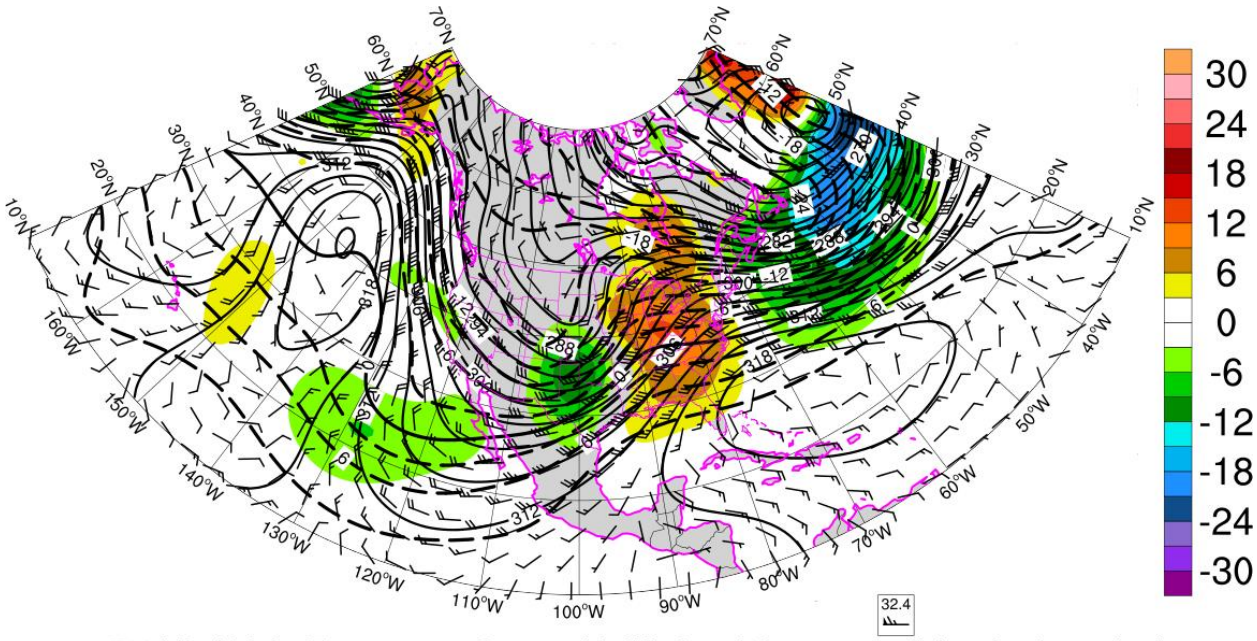

Figure 3. 700 hPa geopotential height (solid contours every 3 dam = 30 m), temperature (dashed contours every -3°C), geostrophic wind (barbs; reference barb at lower-right), and temperature advection (°C day^{-1}; shaded per the color bar at right) from the 0-h CMC analysis at 1200 UTC 20 February 2019.

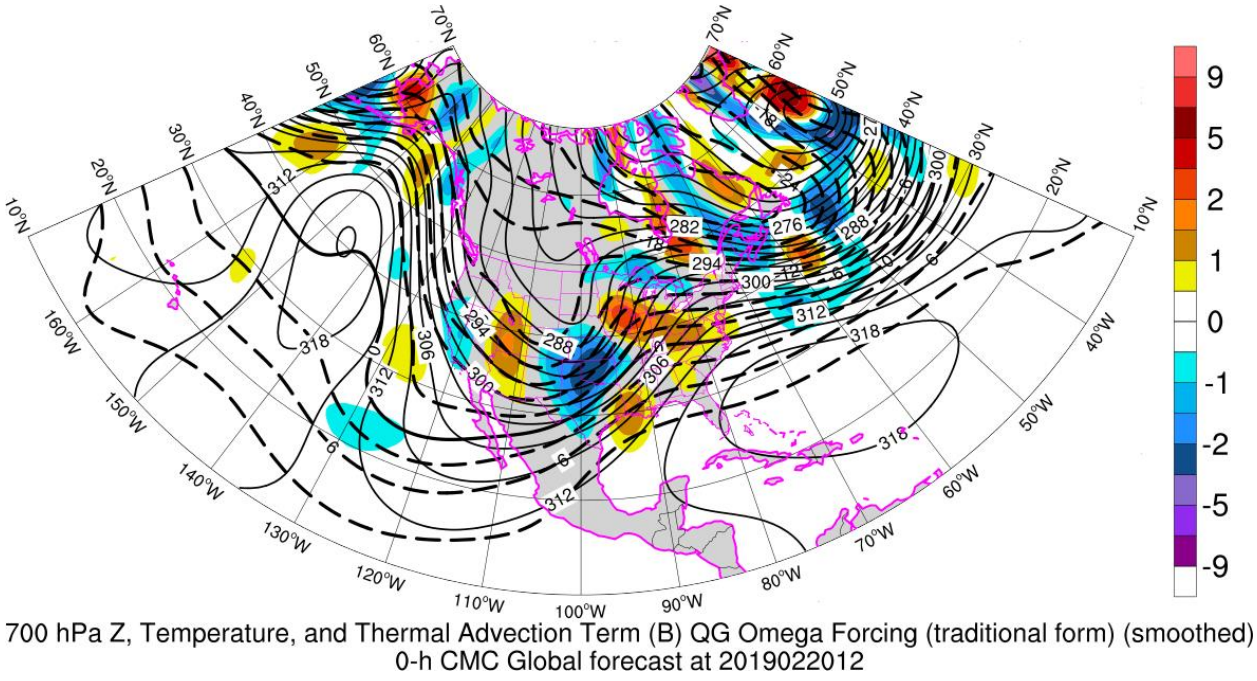

Figure 4. 700 hPa geopotential height (solid contours every 3 dam = 30 m), temperature (dashed contours every 3°C), and Laplacian of temperature advection ("term B"; x10^{-12} Pa m^{-2} s^{-1}, shaded per the color bar at right) from the 0-h CMC analysis at 1200 UTC 20 February 2019.

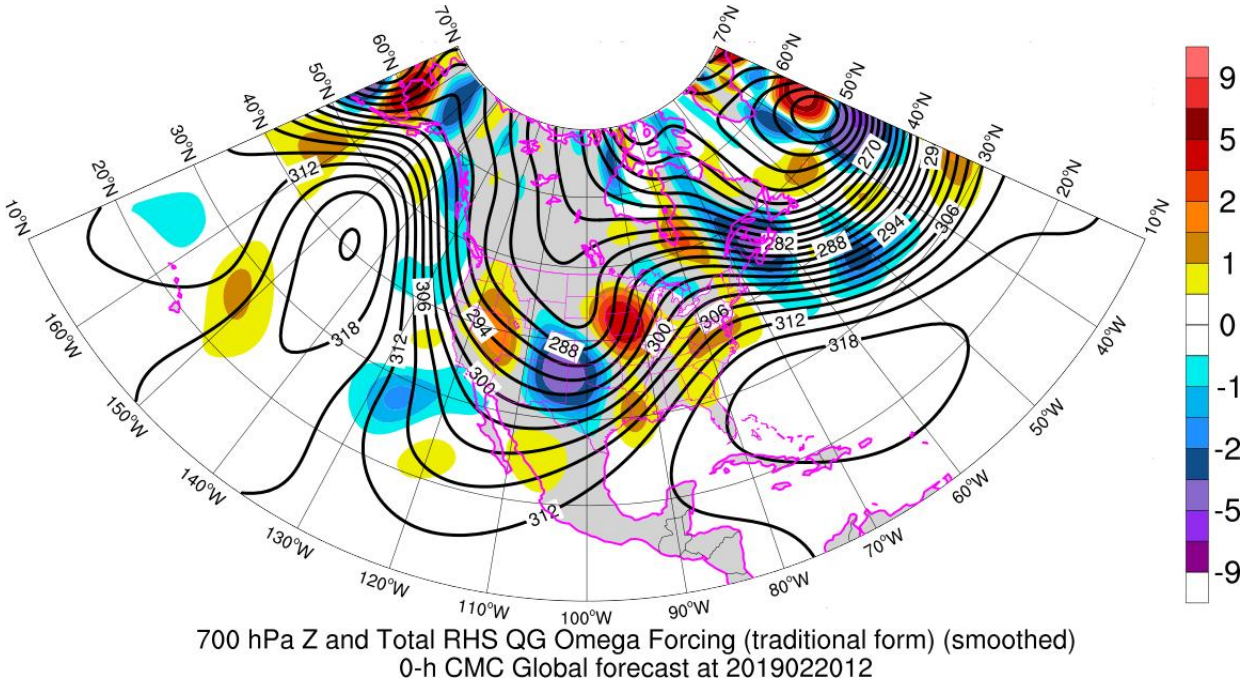

Figure 5. 700 hPa geopotential height (contours every 6 dam = 60 m) and the sum of the forcing terms depicted in Figs. 2 and 4 ($x10^{-12}$ Pa m^{-2} s^{-1}, shaded per the color bar at right) from the 0-h CMC analysis at 1200 UTC 20 February 2019.

We next focus on another trough in the central United States, this one from 1200 UTC 24 February 2019. In this case, 500 hPa geostrophic absolute vorticity is maximized in the base of the trough over the Great Lakes region (Fig. 6). Given the first note above, this implies differential cyclonic vorticity advection to the east and northeast and differential anticyclonic vorticity advection to the west and southwest, which is confirmed by Fig. 7.

With respect to the Laplacian of the temperature advection term, we see that 700 hPa temperature advection is a local maximum northeast of the trough and local minimum south of the trough (Fig. 8). This forcing term is again maximized near the local maximum and minimum (Fig. 9).

In this example, both terms provide forcing for ascent ahead of the 700 hPa trough axis, albeit with some spatial displacement: forcing for ascent from the differential vorticity advection term is south of that from the Laplacian of temperature advection term. Likewise, both terms are associated with forcing for descent behind the 700 hPa trough axis, with the most negative forcing from each term located over the central Mississippi River valley. However, forcing for descent associated with the Laplacian of temperature advection term wraps around the trough base (Fig. 9), even intersecting forcing for ascent from the differential vorticity advection term in the southern Great Lakes (Figs. 7 and 9). The total forcing, given by the sum of Figs. 7 and 9, is depicted in Fig. 10.

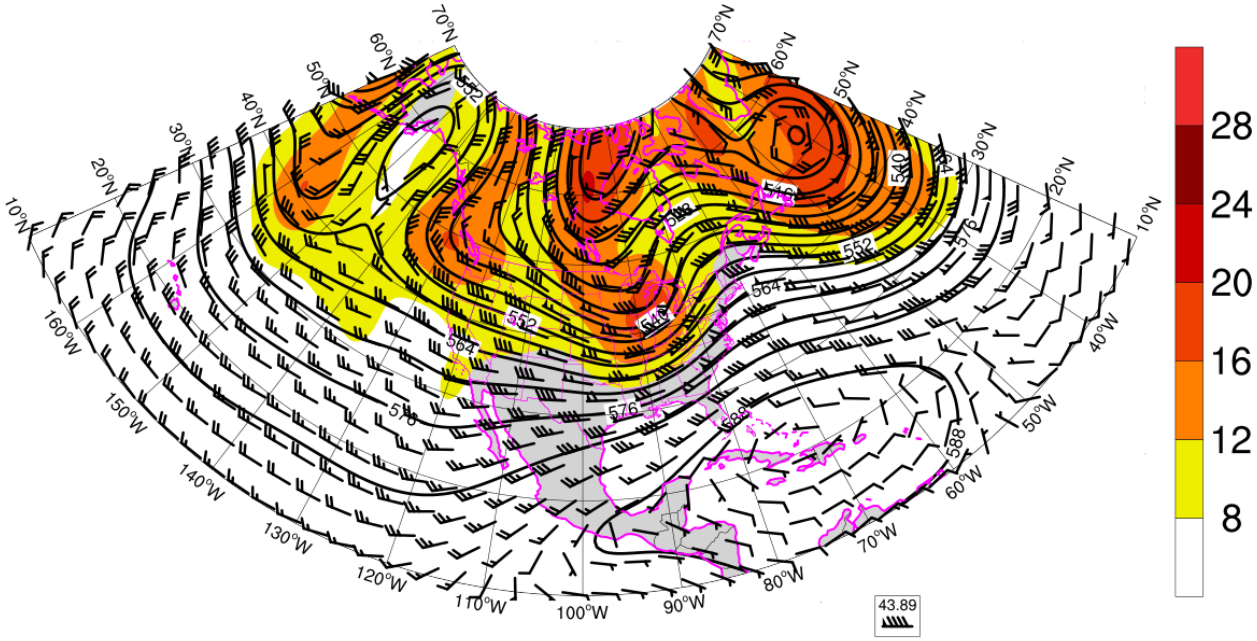

Figure 6. As in Fig. 1, except at 1200 UTC 24 February 2019.

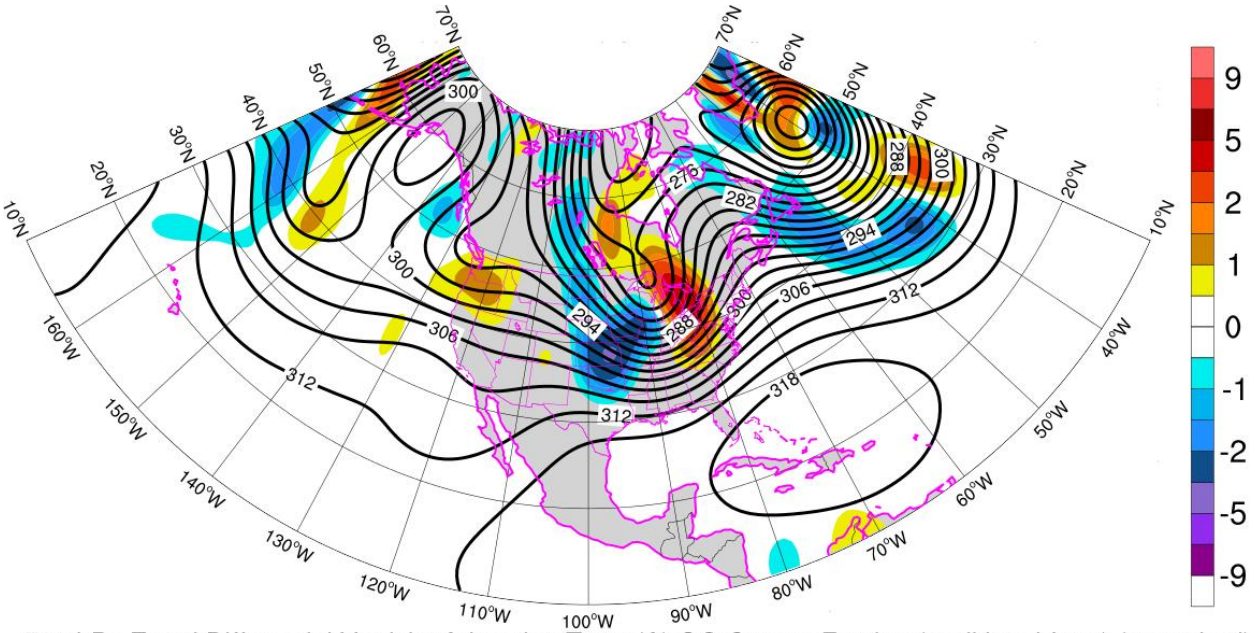

Figure 7. As in Fig. 2, except at 1200 UTC 24 February 2019.

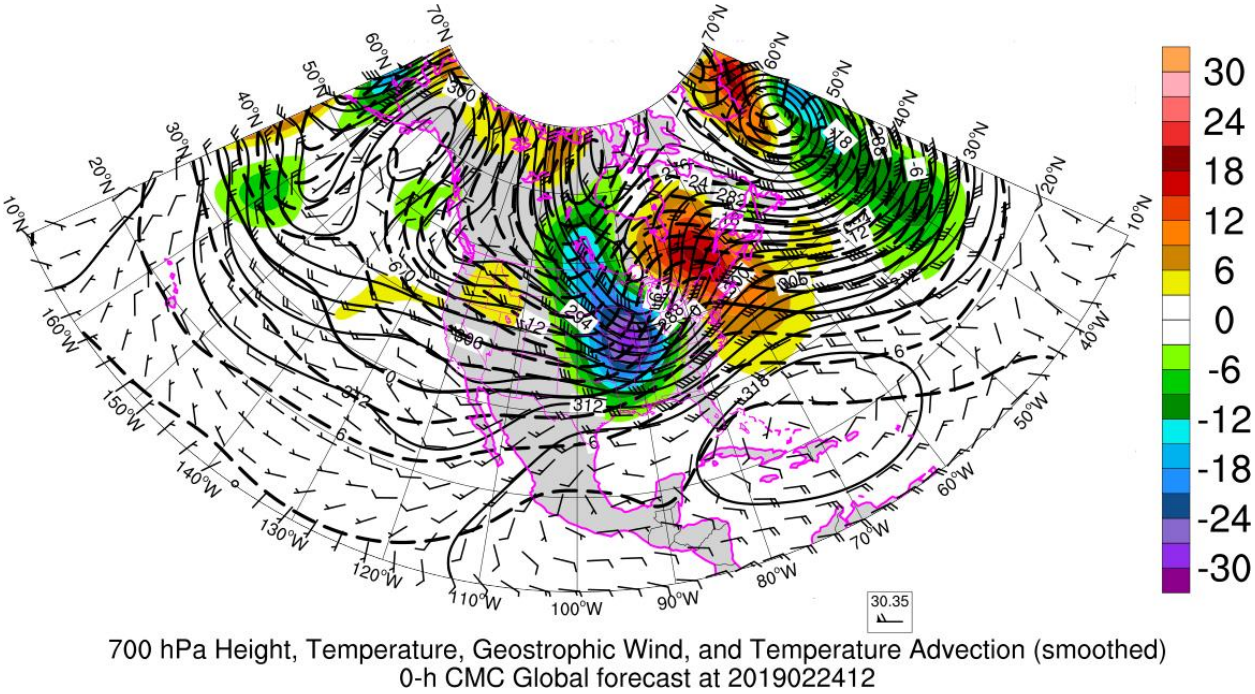

Figure 8. As in Fig. 3, except at 1200 UTC 24 February 2019.

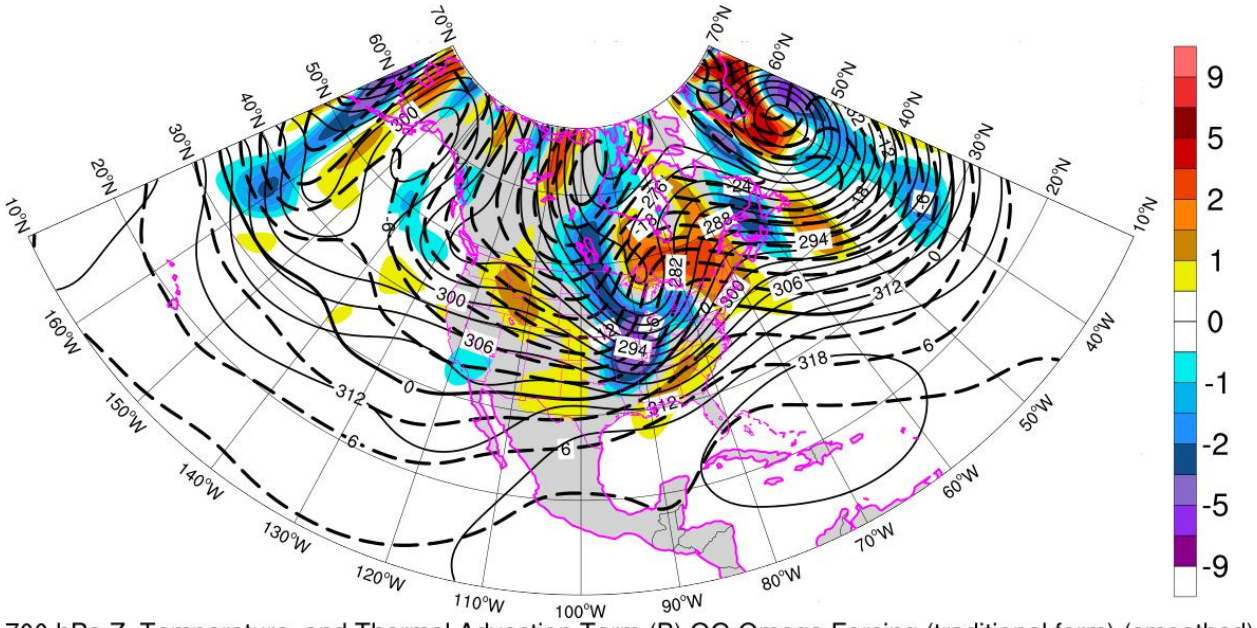

Figure 9. As in Fig. 4, except at 1200 UTC 24 February 2019.

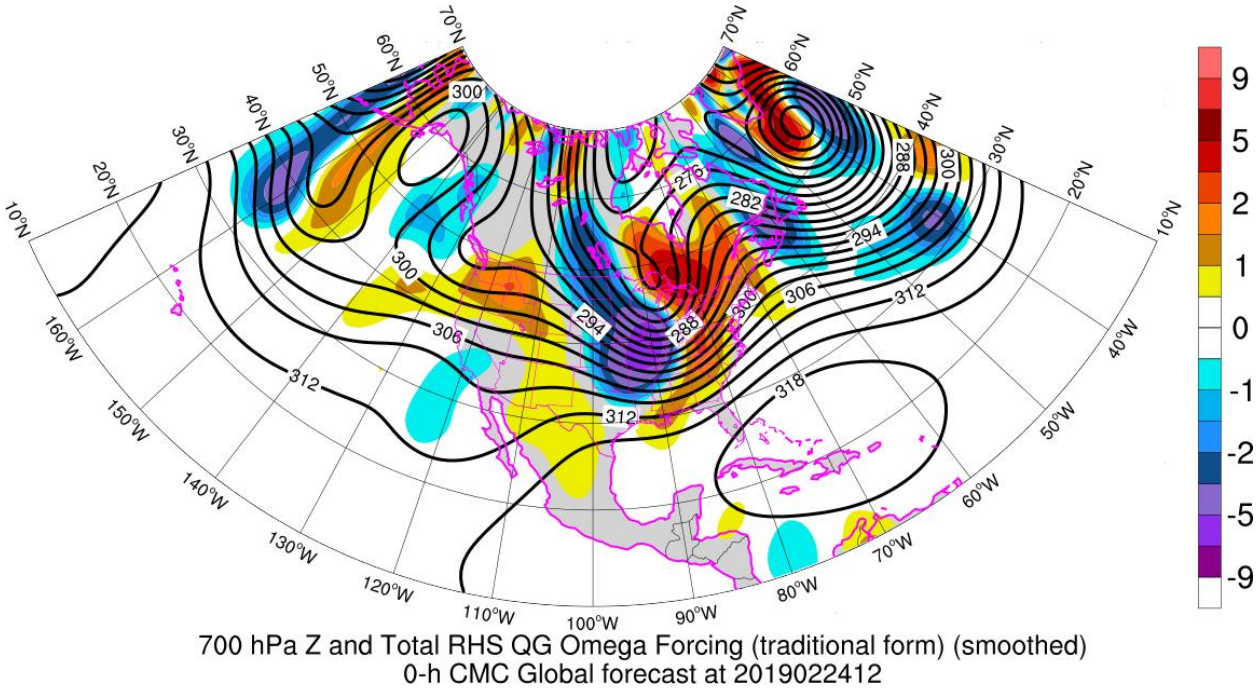

Figure 10. As in Fig. 5, except at 1200 UTC 24 February 2019.