16.3 GLOBAL CLIMATOLOGY OF 1000-500 HPA THICKNESS HIGHS AND LOWS

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1. INTRODUCTION:

Closed 1000-500 hPa thickness highs and lows are an important aspect of the midlatitude and subtropical weather and climate. High impact weather (e.g., heat waves, drought, flooding, severe convection) is often associated with these features. Given the importance of closed thickness highs and lows to high impact weather events, the purpose of this paper is to present the results of a global climatology of these features. This climatology will be constructed using the NCEP/NCAR 2.5 x 2.5 degree gridded re-analyses (Kalnay et al. 1996, Kistler et al. 2001) for the period 1951-2001. An illustrative case study of a closed thickness high over North America from July 1995 will also be shown. This case was associated with a severe heat wave in the midwestern US and severe mesoscale convective systems (MCSs) on the periphery of the high (e.g., Changnon et al, 1996; Bosart et al. 1998; Angel 1999).

Meteorologists have long known that closed lows and highs can be associated with significant weather. Classic papers by, for example, Palmen (1949) and Peltonen (1963) showed the structure and evolution of individual closed lows. Closed lows, and their closed high counterparts, are common occurrences in the atmosphere, as has been demonstrated by climatologies of closed lows and highs for the Northern and Southern Hemisphere (e.g., Lejenas and Okland, 1983; Trenberth and Mo, 1985; Bell and Bosart, 1989; Parker et al., 1989; Smith, 2003). Closed lows and highs that persist for days or weeks often are associated with atmospheric blocking patterns (e.g., Rex, 1950). When closed highs are especially persistent, or intense, over subtropical and midlatitude continental regions in the warm season, high impact weather of the type noted above can result (Livezey, 1980; Namias, 1982).

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2. DATA/METHODOLOGY:

Gridded 1000-500 hPa thickness analyses were derived from the NCEP/NCAR re-analyses on a 2.5 x 2.5 degree latitude-longitude grid for 0000 and 1200 UTC, for 1951-2001. Closed thickness highs (lows) were counted if a grid-point was 30 m higher (lower) than all surrounding grid-points and the 1000-500 hPa thickness at the center grid-point was greater than or equal to 570 (less than or equal to 540) dam. Stationary highs and lows, defined as those lows/highs that were defined at a particular grid point for two consecutive time periods, were counted only once. For the case study, additional data sources were used: ECMWF 1.125 degree gridded datasets; NCEP unified precipitation datasets (UPD); and derived analyses from NOAA Climate Diagnostics Center website (http://www.cdc.noaa.gov). All analyses and figures were generated using the GEMPAK software package.

3. RESULTS:

a) Climatology:

Figure 1 shows the 1000-500 hPa closed thickness low climatology for the Northern and Southern Hemispheres (NH/SH). On an annual basis, NH closed lows maximize over northeast Asia and northeast North America, with a secondary maximum over northwest Europe in winter (not shown). There is also a weak summer maximum over northern Canada (not shown). Also of note, is the relative minima over western North America and the northeast Atlantic Ocean. These minima are present in all seasons (not shown). SH closed lows are concentrated poleward of 45 S and are most numerous between 50-65 S from the southeast Pacific to the southern Indian Ocean.

Figure 2 shows the 1000-500 hPa closed thickness high climatology for the NH/SH. In the NH, closed thickness highs are most common over continental regions in the subtropics and midlatitudes. Prominent summer maxima (not shown) are found over northwest Mexico, the southwestern US and High Plains, northwest Africa, and the Middle East. Secondary summer maxima are located over eastern North America and the eastern Atlantic Ocean, as well as eastern Asia and the western Pacific Ocean (not shown). SH maxima are found over western South

America, western southern Africa, and western Australia. These continental maxima expand eastward over the western oceans in summer (not shown).

b) Case study:

Figure 3 shows the mean 1000-500 hPa thickness pattern over North America for 6-10 and 11-15 July 1995. During 6-10 July 1995, a thickness ridge amplifies over western North America in conjunction with the transition of the Pacific-North American pattern (PNA) from negative to positive (not shown). In the subsequent 11-15 July period, the western North American thickness ridge flattens and moves eastward. The evolution of the 576 dam 1000-500 hPa thickness contour is mapped for 0000 UTC for 4-16 July 1995 in Fig. 4. Consistent with Fig. 3, note the rapid eastward expansion of the corridor of high thickness air from the Rockies to the Atlantic coast during the period 11-15 July. It is during this time that the severe heat wave was at its peak. The onset of the heat wave was also associated with a strengthening and sinking subsidence inversion as can be seen in the 0000 UTC 13 July sounding for Davenport (DVN), Iowa, shown in Fig. 5. Very high surface dew point temperatures (~26-28 C) were found below the subsidence inversion, likely a result of evapotranspiration processes. These high dew point temperatures, when combined with observed 35-40 C surface temperatures, resulted in convective available potential energy (CAPE) values that exceeded 5000 J/kg across much of the upper Midwest.

In order to show the synoptic scale structure of the flattening and eastward expansion of the 1000-500 hPa thickness ridge, we present in Fig. 6 maps of potential temperature on the dynamic tropopause (DT; defined by 1.5 potential vorticity, PV, surface) for 0000 UTC 13-14 July. These DT maps were constructed from the ECMWF 1.125 gridded analyses. Noteworthy features of Fig. 6 include transient PV disturbances that move: a) southwestward along the Atlantic coast; b) northward along the eastern slopes of the Rockies; c) northeastward across the northwestern US; and d) eastward in the strong jet across south-central Canada. Collectively, these PV disturbances rotate clockwise around the large continental anticyclone located over the central US.

The impact of these clockwise-rotating transient PV disturbances in the time-mean outgoing longwave radiation (OLR) and the precipitation distribution is shown in Fig. 7. The composite OLR distribution for 11-15 July shows a relative maximum that is collocated with the ridge shown in Fig. 6. A relative OLR minimum encircles this maximum. The corresponding precipitation distribution for the 72 h period ending 1200 UTC 14 July derived from the NCEP/UPD grids (Fig. 7) shows that the prominent rainfall swaths lie on the periphery of the continental high and are well correlated with the aforementioned ring of relatively low OLR values. Figure 6 and 7 together show a classic warm season "ring of fire" pattern in which transient PV disturbances (a.k.a. "ridge rollers") rotate clockwise around an intense continental anticyclone. Precipitation is maximized along the "convective freeways" that correspond with the relative OLR minimum. Poleward-moving transient PV disturbances and associated high theta-e air contribute to an axis of precipitation along the eastern slopes of the Rockies. Other transient PV disturbances move eastward in the strong westerlies along the poleward branch of the "convective freeway" and are associated with several severe derechos and MCSs. More widespread convection occurs near the coast of the southeast US and Gulf of Mexico in conjunction with transient PV disturbances moving southwestward and westward along the equatorward periphery of the intense continental high.

4. CONCLUSIONS:

A 51-year (1951-2001) climatology of closed 1000-500 hPa thickness highs and lows has shown that thickness lows occur preferentially over middle and high latitude continental regions in the cold season, while closed thickness highs occur preferentially over the lower and midlatitude continental regions in the warm season. Analysis of the July 1995 case study shows: a) transient PV disturbances rotate clockwise around the ridge; b) serial derechos form in equatorward jet entrance region poleward of the ridge; and c) MCSs are common on the eastern/southern flank of the ridge. Our analysis leads us to hypothesize that: a) the eastward expansion of the thickness ridge permits poleward advection of high theta-e air east of the Rockies into the equatorward entrance region of the aforementioned jet; b) extreme CAPE values develop as a shallow/strong subsidence inversion intensifies beneath the ridge; and c) evapotranspiration under this inversion over the well-watered Midwest likely contributes to the observed extreme surface theta-e values (380-400 K).

5. ACKNOWLEDGEMENTS:

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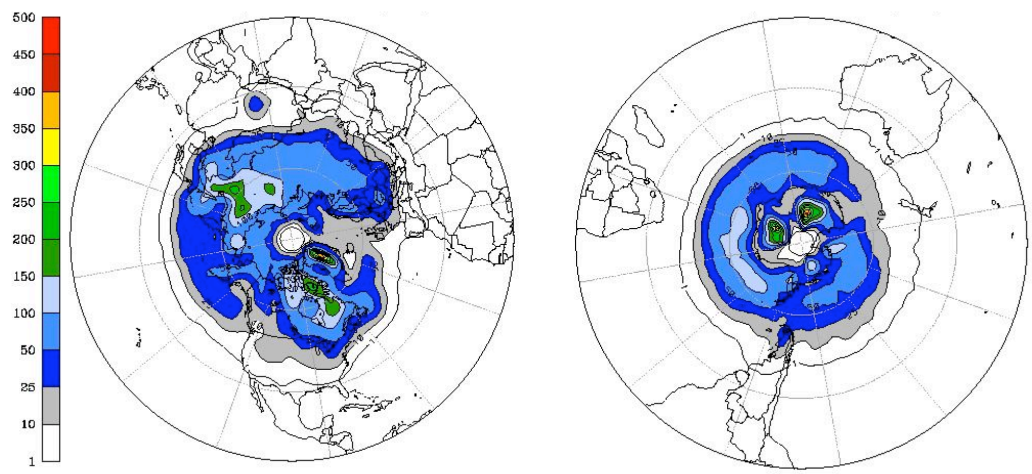

Figure 1: Occurrence of closed 1000-500 hPa thickness lows, less than or equal to 522 dam, for the Northern Hemisphere (left) and Southern Hemisphere (right), 1951-2001.

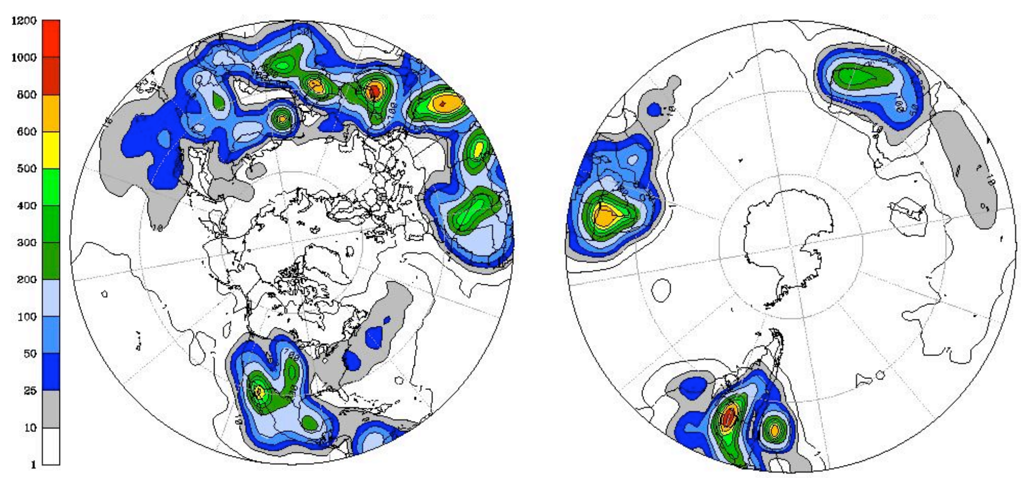

Figure 2: Occurrence of closed 1000-500 hPa thickness highs, greater than or equal to 570 dam, for the Northern Hemisphere (left) and Southern Hemisphere (right), 1951-2001

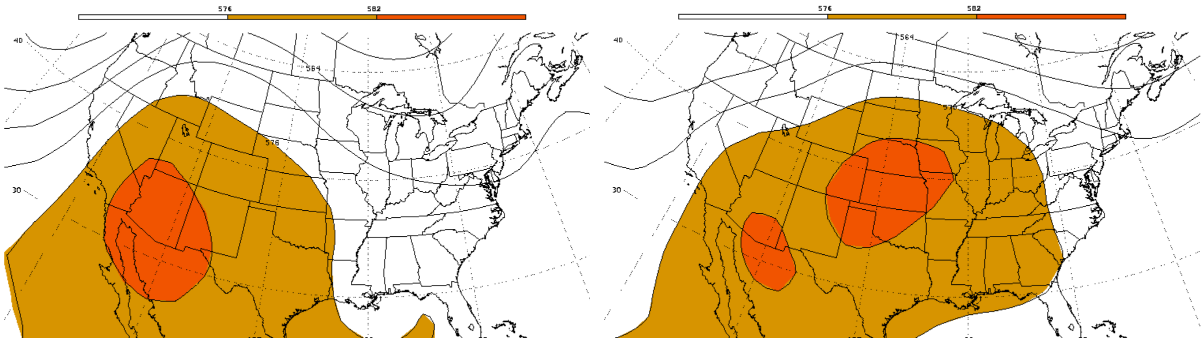

Figure 3: Mean 1000-500 hPa thickness (dam) for 6-10 July (left) and 11-15 July (right) 1995 (576 and 582 dam shaded).

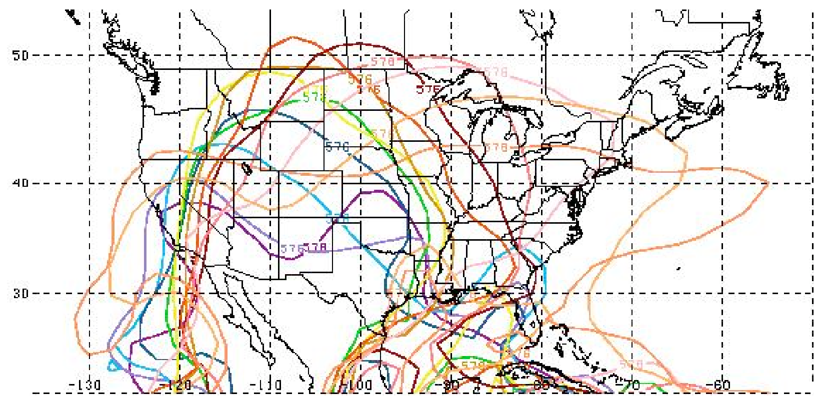

Figure 4: Evolution of the 576 dam 1000-500 hPa thickness contour for 4-16 July 1995 (evolution is from cool colors, beginning 4 July, to warm colors, ending 16 July).

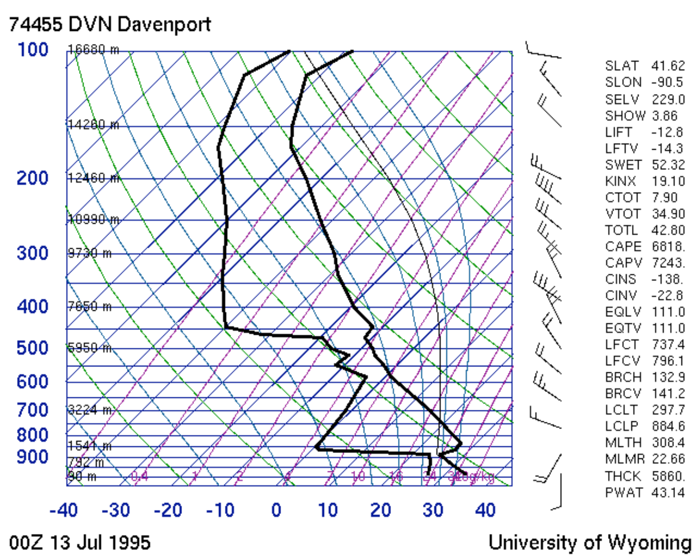

Figure 5: Sounding for Davenport (DVN), IA, on 0000 UTC 13 July 1995.

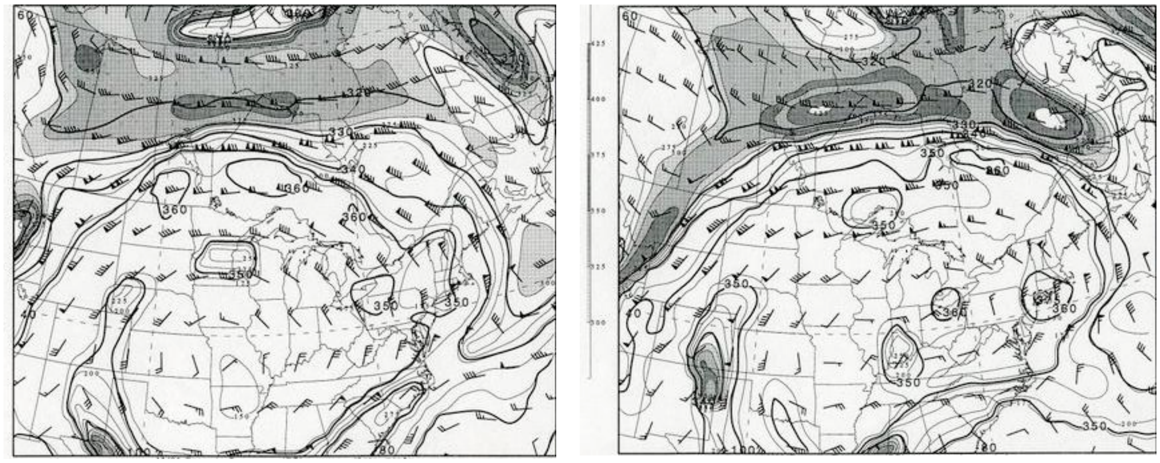

Figure 6: Dynamic tropopause (defined by 1.5 PVU surface) pressure (hPa; shaded), potential temperature (K), and winds (knots) for 0000 UTC 13 July (left) and 14 July (right) 1995.

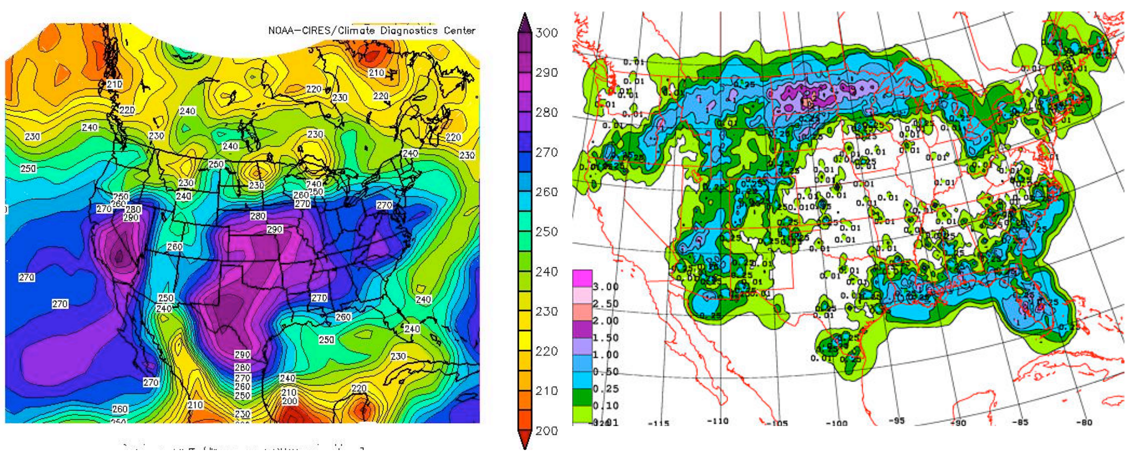

Figure 7: Time-mean outgoing longwave radiation (OLR, Wm^{-2}) for 11-15 July (left) and the precipitation distribution (inches) for 12-14 July (right) 1995.