26 December 2002 Beartooth Mountain Snow Event

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Introduction

One area in WFO Billings CWA that has been particularly challenging for snow forecasting is in and around the Beartooth Mountains, including the town of Cooke City (figure 1). This is partly due to poor radar coverage upstream of the Beartooths and over them and also because winter time observations are mainly limited to SNOTEL sites clustered in a few areas. Another reason is due to less research previously done on heavy snow events in and around the Beartooth Mountains compared to more populated areas.

A recent climatology study performed on Cooke City revealed that 20% of 24 hour 8 inch or greater snow events occur with broad 700-500mb southwest flow over the area. The orientation of flow is typically a result of an approaching upper level trough heading into Washington and Oregon (see figure 2). An approaching upper level trough is relatively easy to relate to a heavy snow pattern because of the typical moisture advection and dynamic and mechanical forcing associated with such a feature. Another pattern that brings abundant moisture and significant snow is associated with the passage of an upper level ridge. This pattern is not as readily associated with significant snow, although it is nearly as common. Figure 3 shows the mean daily 500mb height for this pattern based on twelve upper level ridge cases that brought 8 inches or more snow to Cooke City in 24 hours or less. Since about 20% of the significant snow in the last 10 years has occurred in this pattern, the WES was utilized to train forecasters on one such event that occurred on 27 December 2002. This paper will discuss some of the more important aspects that lead to 6 to 12 inches of snow on the southwest side of the Beartooths on 27 December 2002.

Meteorological Environment and Forcing

A strong jet extending across the Pacific Ocean on 26 December resulted in the development of an upper level short wave trough off the Washington coast early on the 27th. As the water vapor and Eta 500mb heights show in figure 4, a ridge pushed into the Rockies ahead of this short wave trough by 06Z on 27 December. A middle level moist tongue was pushed inland as shown by the Eta 600mb equivalent potential temperature and winds (figure 5). The orientation of this moisture surge is very similar to mean 600mb specific humidity from 12 similar events (figure 6). Meanwhile at the surface, a 1030mb high remained strong over northwest Wyoming as a surface trough was situated over central Montana. This brought strong gap flow conditions and near high wind conditions to Livingston Montana, giving forecasters another problem to handle.

The short wave trough pushed into British Columbia and the Pacific Northwest and the ridge axis became positioned over Montana by 18Z on the 27th (figure 7). At the same time, moisture spread into southwest Montana and snow began to fall in the Beartooth Mountains (figure 8). As the snow began, Livingston exceeded high wind criteria. The down slope flow in the lee of the Rockies along with dry and windy conditions in the lower elevations prevented little if any precipitation from reaching ground despite returns on radar.

The 26 December 12Z Eta, 30 hours in advance of the event, shows strong middle level convergence in the equivalent potential temperature ridge axis associated with the snowfall. The convergence appears to be related to a jet maximum moving into Washington and Oregon (figure 9). The Eta also shows a band of instability extending northwest to southeast through Montana, with lapse rates exceeding 7C/km. This instability is in the same layer as the convergence moving east across Montana (figure 10). Despite a significant increase in middle level moisture in a ridge axis, thermal advection through the entire event was fairly insignificant. A time height of equivalent potential temperature, divergence, and temperature advection over Cooke City summarizes this forcing (figure 11). This passage of convergence and greatest instability corresponds very well to the greatest returns on radar in figure 8 and heaviest precipitation reported via SNOTELS. More than half of the 6 to 12 inches of snow reported fell in the 6 hour period from 18Z on the 27th to 00Z on the 28th of December 2002.

Discussion

Even though the upper level ridge axis was positioned over Montana, a significant snow event occurred in the Beartooth Mountains. Much of the snowfall can be attributed to abundant middle level moisture coupled with middle level convergence and steep lapse rates. Not only was this forcing located in the layer of greatest instability, but it was also situated in the dendritic layer (not shown) where ice crystal growth is highest. The climatology study for Cooke City shows the steep lapse rates typically resides in the dendritic layer, regardless of the pattern (figure 12). The 27 December 2002 was no exception to this idea.

The snowfall was mainly distributed in the southwest Beartooths, upwind of the crest. Downwind of the crest, snowfall was limited to a few inches. Temperatures slightly warmer than 0C likely played a role in less snow, but total liquid equivalent precipitation was also significantly less. The fact that the flow was mainly flowing down the slopes likely played a bigger role in the reduced precipitation. If 700-500mb isentropic lift were greater, to better counter act the down slope flow, there may have been more snow on the northeast slopes.

Figure 1

Figure 2

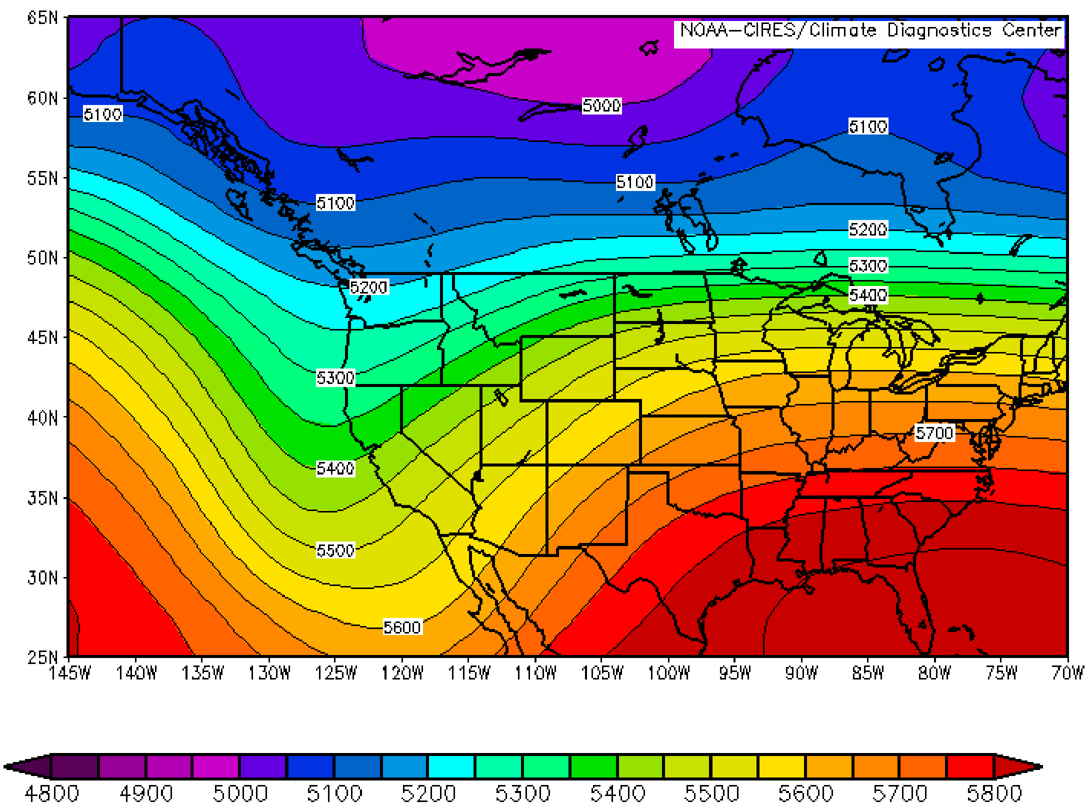

Figure 3

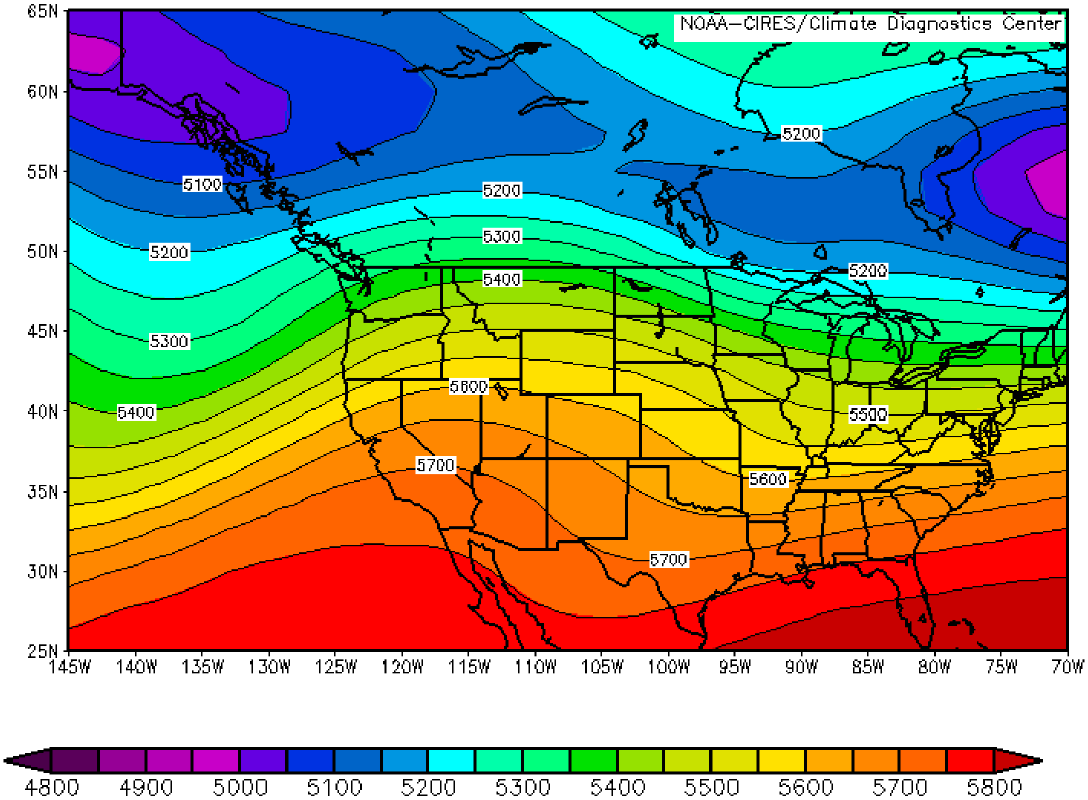

Figure 4

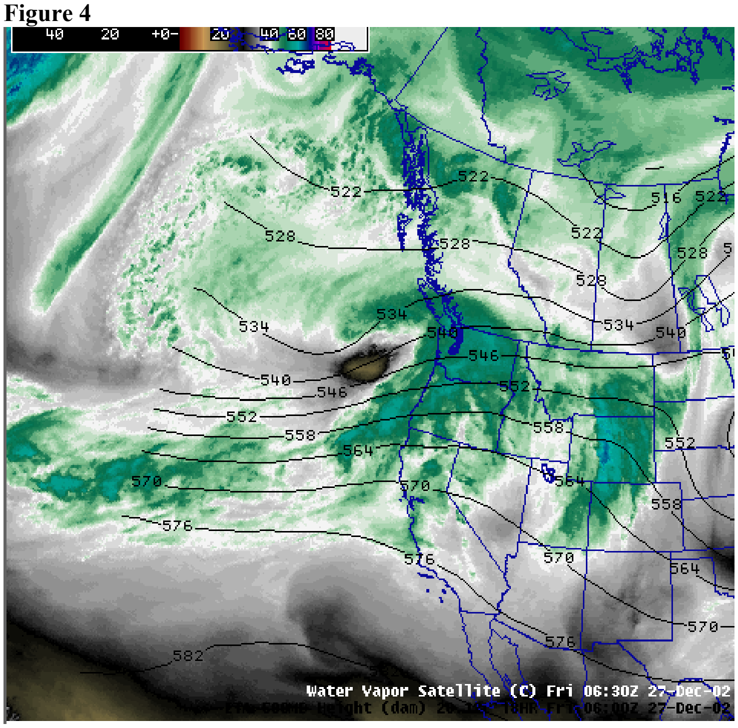

Figure 5

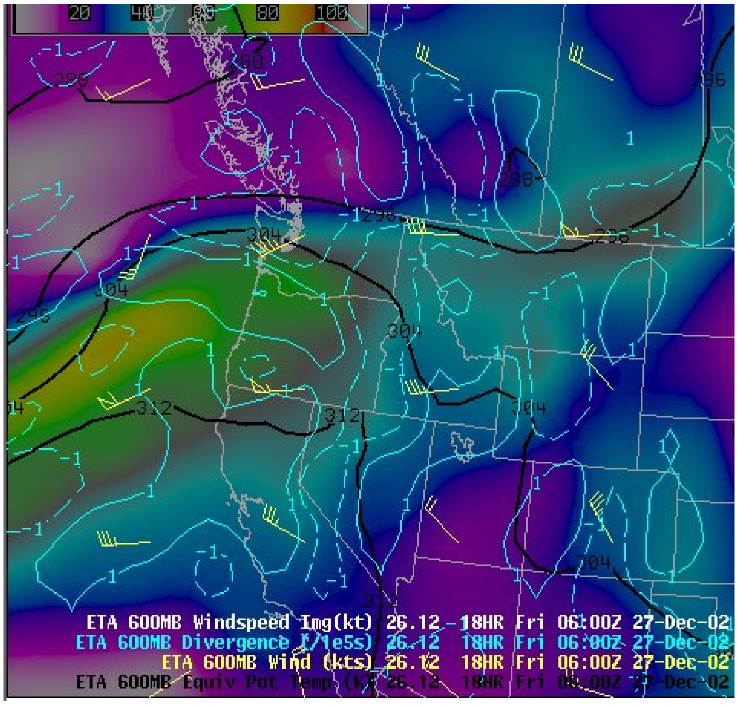

Figure 6

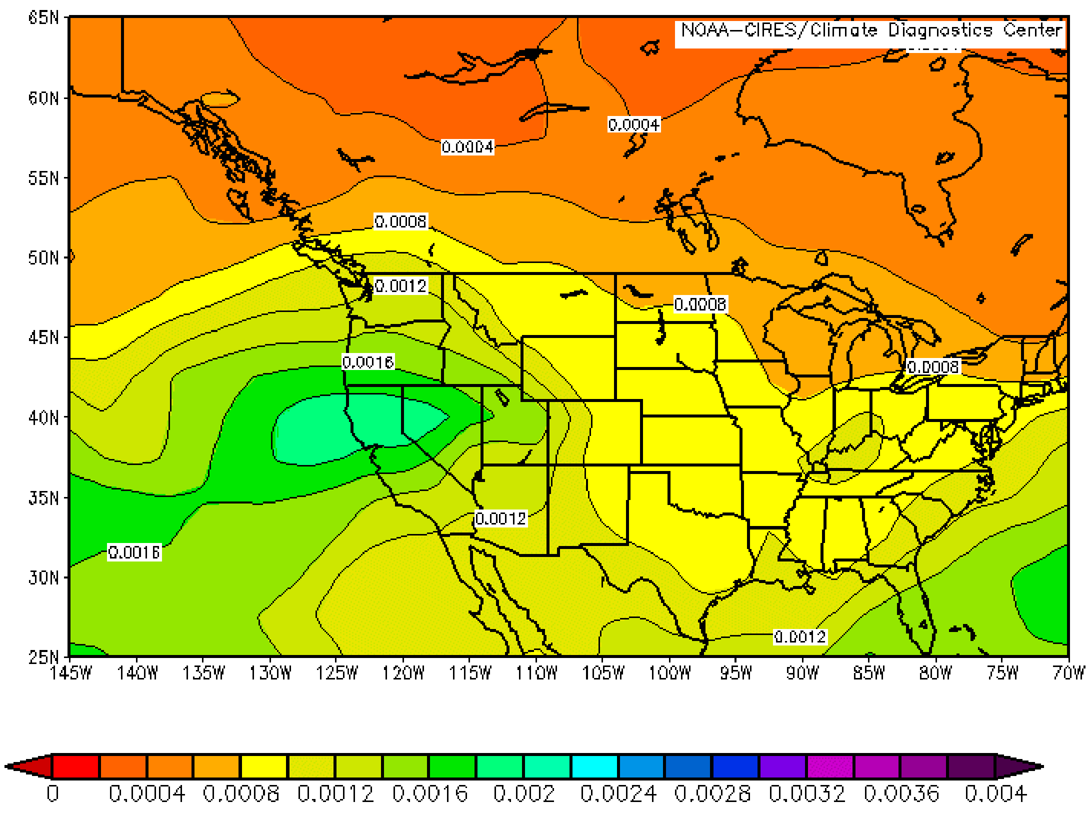

Figure 7

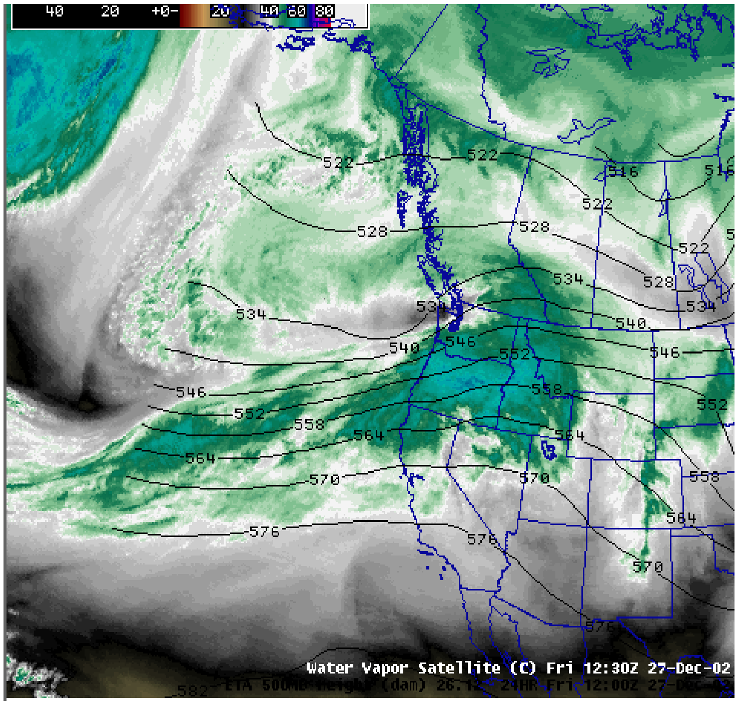

Figure 8

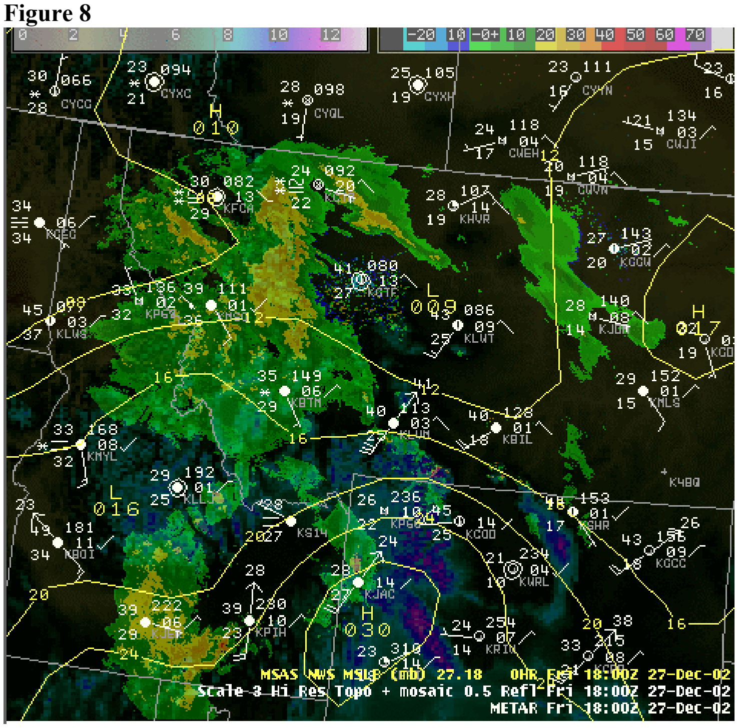

Figure 9

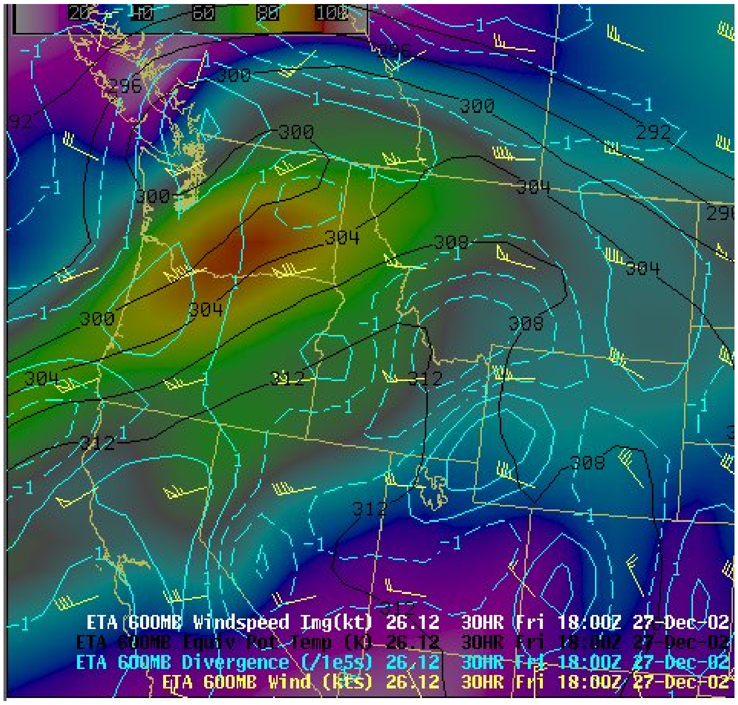

Figure 10

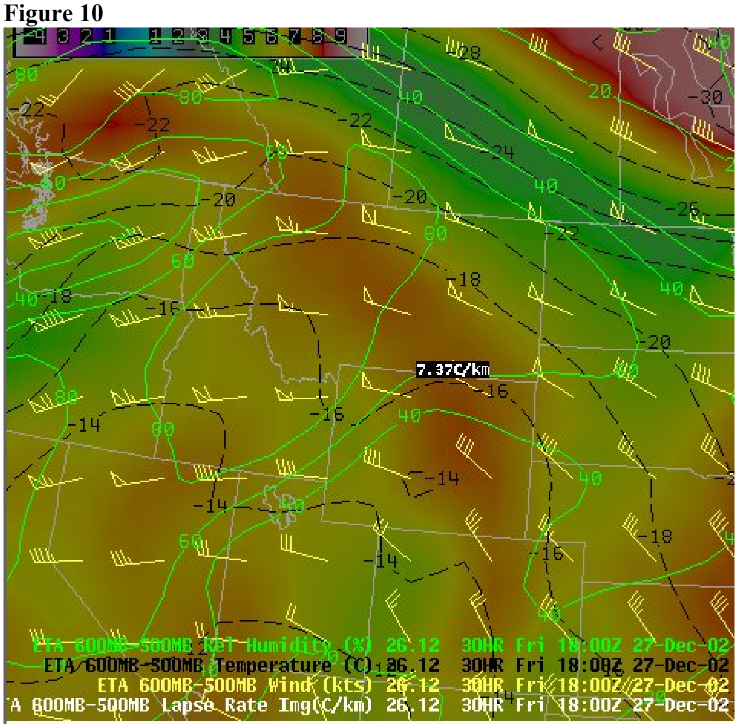

Figure 11

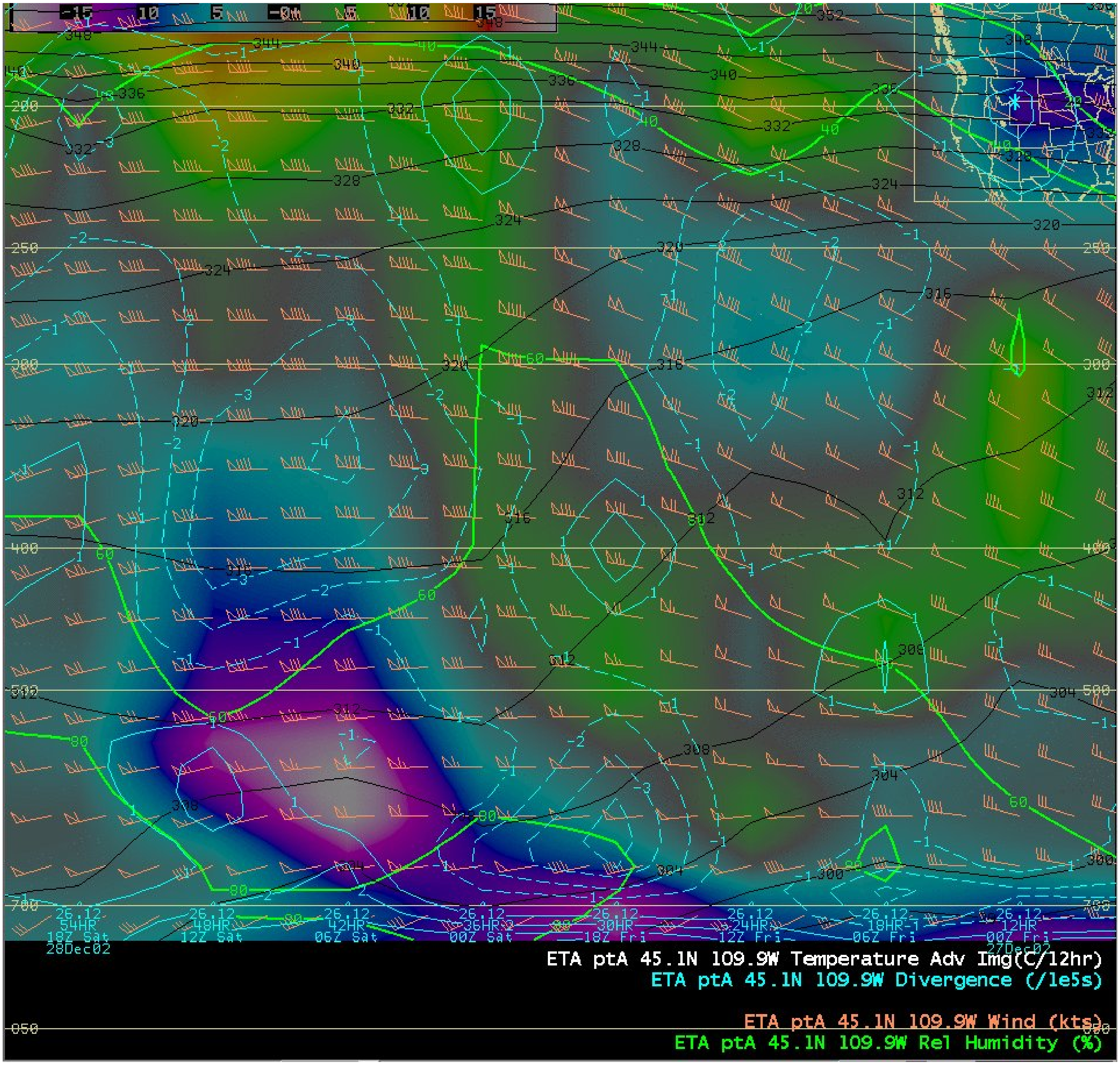
ETA ptA 45.1N 109.9W Temperature Adv Img(C/12hr)
ETA ptA 45.1N 109.9W Divergence (/1e5s)
ETA ptA 45.1N 109.9W Wind (kts)
ETA ptA 45.1N 109.9W Rel Humidity (%)
26.12 54HR 18Z Sat 28Dec02
26.12 48HR 12Z Sat
26.12 42HR 06Z Sat
26.12 36HR 00Z Sat
26.12 30HR 18Z Fri
26.12 24HR 12Z Fri
26.12 18HR 06Z Fri
26.12 12HR 00Z Fri 27Dec02

Figure 12

LEWISTOWN
NEIHART
MOSBY
JUDITH GAP
SUMATRA
WHITE SULPHUR SPRINGS
HARLOWTON
ROUNDUP
RINGLING
RYEGATE
HYSHAM
MELVILLE
WILSALL
RAPELJE
POMPEYS PILLAR
BELGRADE
BIG TIMBER
BILLINGS
HARDIN
LIVINGSTON
GALLATIN GATEWAY
ABSAROKEE
Beartooth Mtns
PRYOR
MINER
LODGE GRASS
RED LODGE
WARREN
COOKE CITY
POWELL
CANYON
CODY
GREYBULL
OLD FAITHFUL