Two Similar Mountain Snow Events with Significant Model Dry Biases

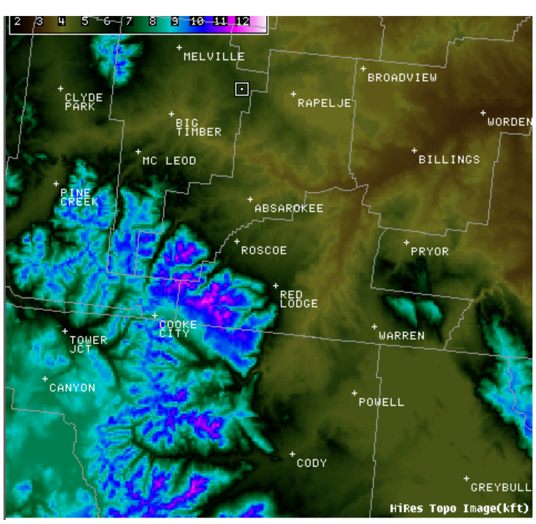
Don Moore
WFO Billings, MT

Introduction

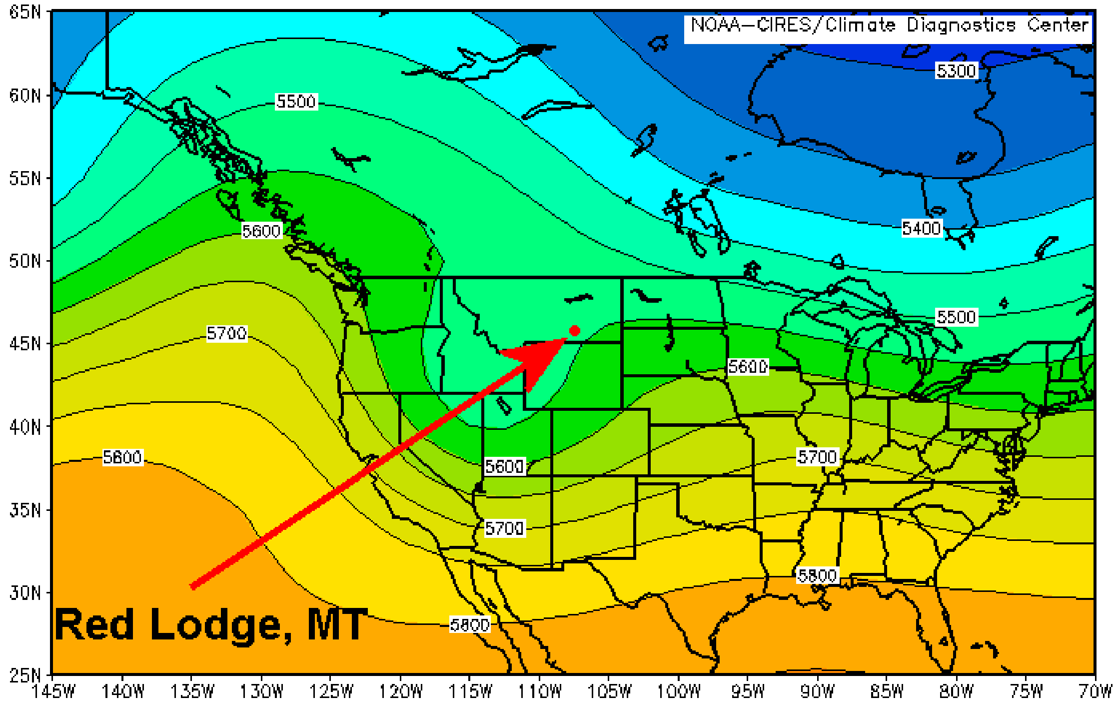
Mountain snow forecasting is always quite challenging due to orographic influences on wind and vertical motion. In past years there have been several events in and around Red Lodge, Montana that brought more significant snow than expected, partly due to model deficiencies in forecasting both forcing and precipitation. One of these cases occurred on 30 Oct, 2004 in which 24" inches of snow fell in the Beartooth Mountains near Red Lodge in under 18 hours. Meanwhile, all other mountains in WFO Billings' forecast area picked up 12 inches or less from the same storm. The GFS and Eta 12 hours before the snow started indicated under 0.50" of liquid precipitation while over 1" was observed. A similar event occurred on 29 Nov, 2004 in which 10" of snow fell at the same location over an 18 hour period while most other mountain sites saw 4-6" of snow. Models just before the snow started were again too light with the precipitation and only forecast around 0.10" of liquid while a half inch was observed.

The models do not always show a significant dry bias in the Beartooth Mountains and in fact at times have a wet bias. Determining this bias can be quite difficult at times and seems to be somewhat pattern dependent. Since the aforementioned cases have very similar thermodynamic profiles and forcing mechanisms, both cases will be briefly discussed to help forecasters better recognize the heavy snow potential and the possibility of poor model performance in future events. Since pattern recognition or the climatology of heavy snow events can aid forecasting in dealing with these difficult events, a quick discussion on heavy snow climatology will also be given.

Climatology of Heavy Snow Events at Cole Creek SNOTEL near Red Lodge, Montana

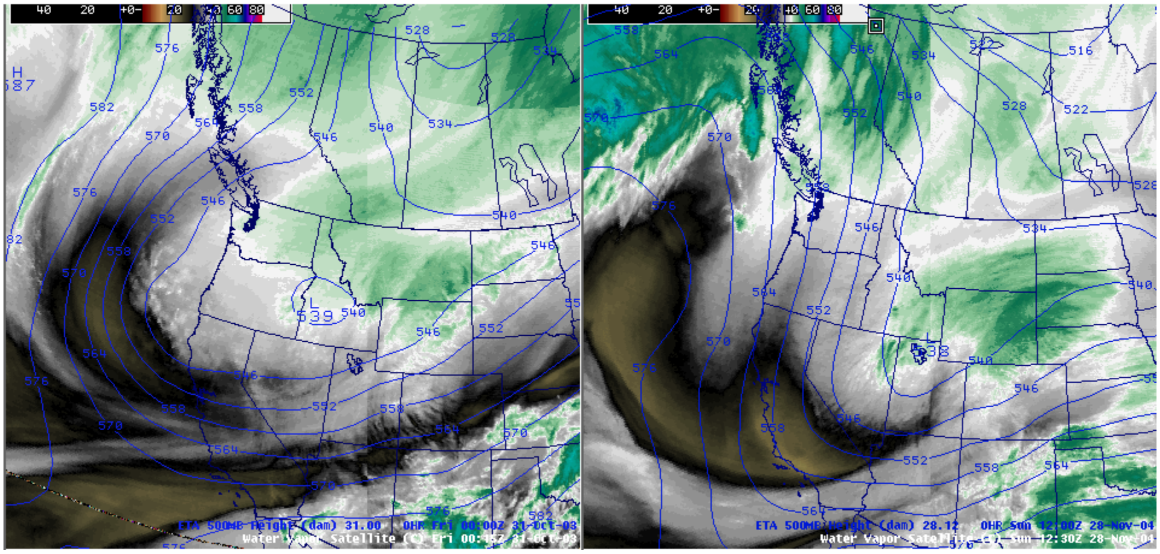


From 1991 to 2004 Cole Creek SNOTEL, at 7851 feet in the mountains above Red Lodge, reported 72 days in which 0.6 inches or more of snow water equivalent (SWE) occurred from 12am to 12am when temperatures were near or below freezing. Of those 72 days, 54 days were categorized as a common and recognizable pattern. The most common pattern identified is an upper level low that drops south out of the Pacific Northwest and toward the Great Basin or Colorado. This pattern consists of 26% of the 54 identified events. The key factor that separates Cole Creek upper level low snow events from other locations is the south or southeast movement of the upper level low. In all other locations in WFO Billings' forecast area, the upper level low that brings heavy snow typically moves east or northeast. The 500mb height composite of the most common heavy snow pattern at Cole Creek is shown below.

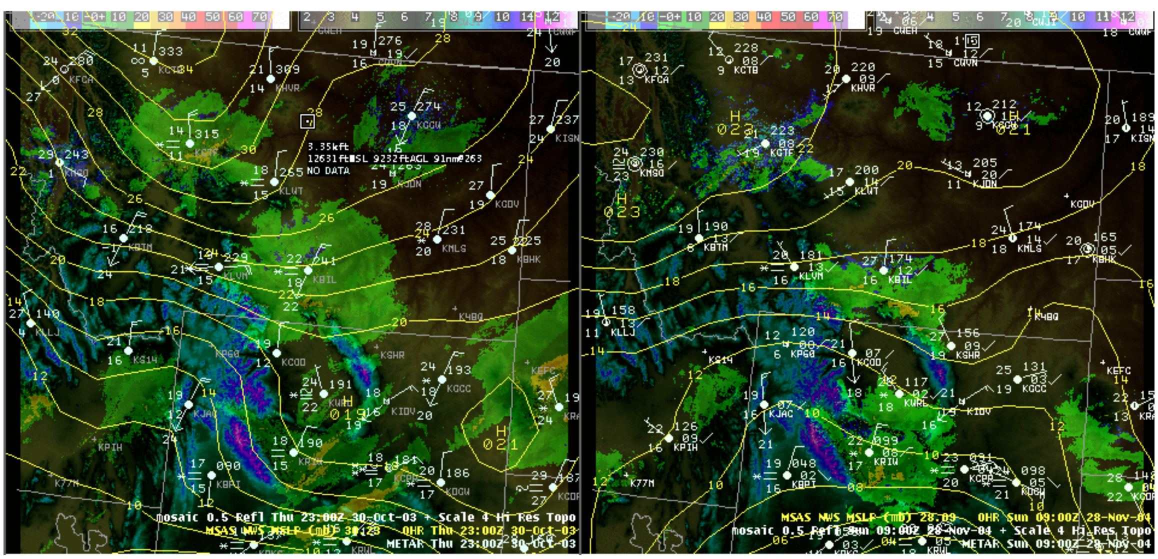


Comparison of 30 Oct, 2003 and 29 Nov, 2004 Heavy Snow Events

In both the 30 Oct, 2003 and 29 Nov, 2004 snow events, an upper level low was digging through Idaho and Utah with deep moisture spreading into Montana and especially Wyoming. This pattern is very similar to the aforementioned heavy snow pattern. The water vapor imagery with 500mb height overlay during a time of heavy snow is shown below (left graphic will always be the 30 Oct, 2004 case).



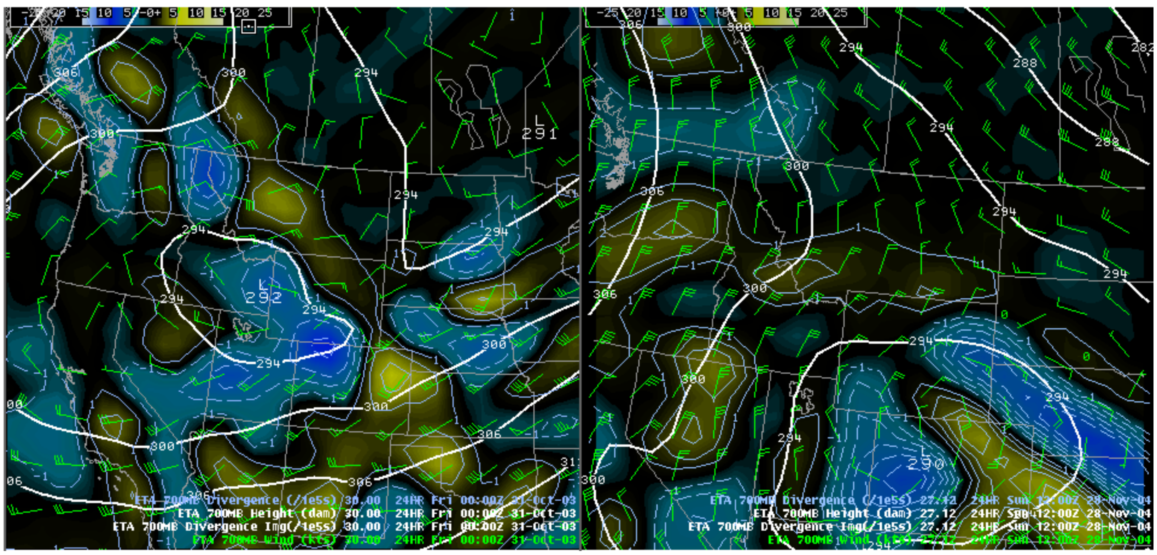
At the surface, high pressure was nosing into northern Montana while a surface low was situated well south of the area in Colorado. This left the region with 15 to 20 knots of northeast upsloping surface flow. Since lapse rates from the surface to near 600mb were at least moist adiabatic, with some positive CAPE indicated by the models, the upsloping flow was able to generate significant low level lift. Precipitation in the October event was more widespread than the November event, but in both events terrain enhanced precipitation is noted in the radar imagery. Shown below is the radar and MSAS sea level pressure with a topography overlay.



Most snow events in WFO Billings forecast area are typically associated with 700mb convergence (above the cold front) and divergence somewhere between 500 and 300mb.

However, in the two events presented, surface temperatures at Cole Creek were around 10 F (-12C) when the heaviest snow was observed. Since low level lapse rates were steep, ice crystal growth through deposition was maximized (-12C to -18C) below 700mb. As a result, the amount of ascent below 700mb was critical to the heavy snow potential.

Shown below is the Eta (GFS not shown for brevity) forecast of 700mb convergence (imaged yellow is divergence and blue convergence), wind, and heights. In the October event, a 24 hour forecast is shown while an 18 hour forecast is shown for the November case. Those forecast hours are used so that the time of heaviest precipitation is shown for both events using model data available prior to precipitation onset.

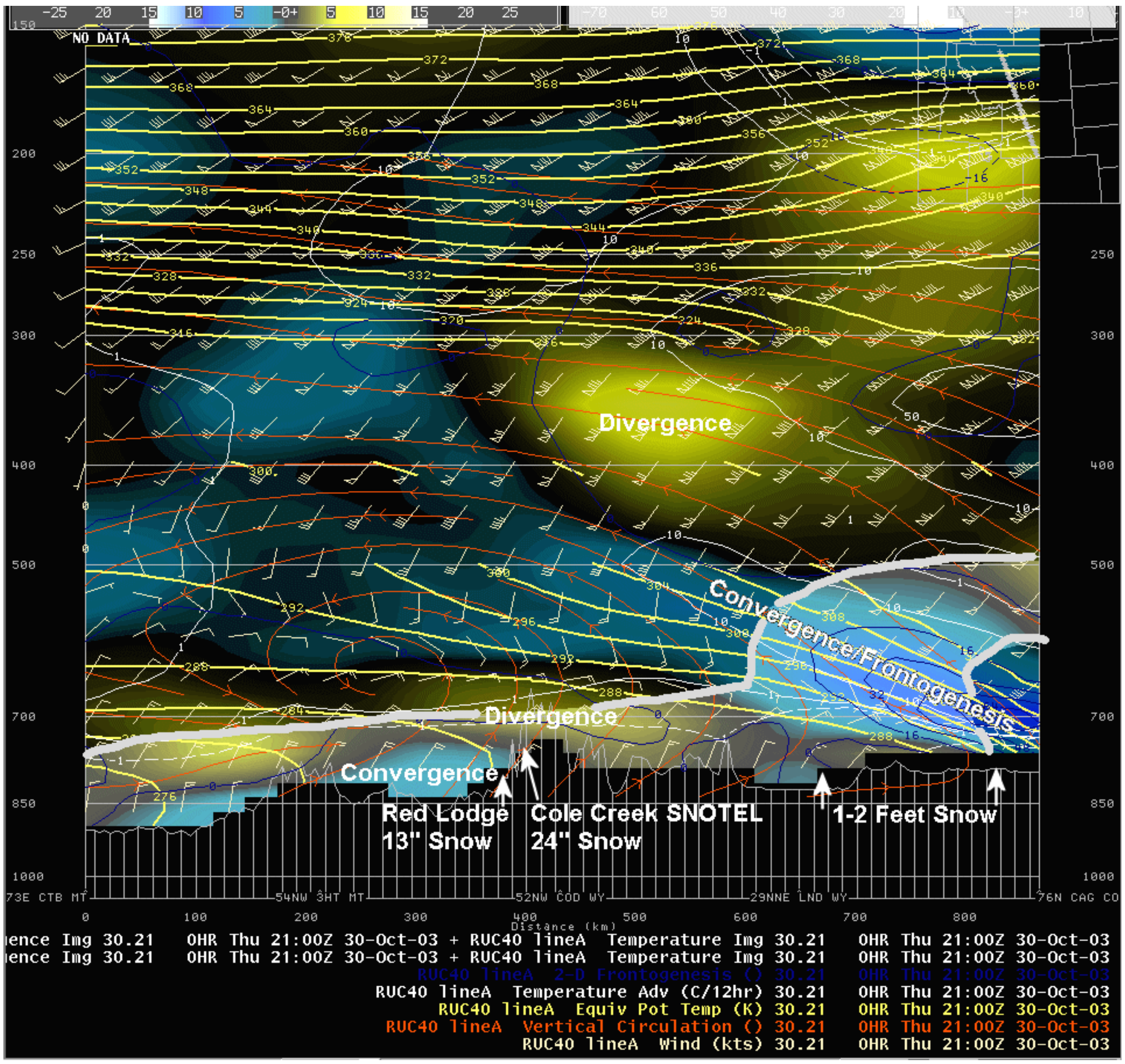


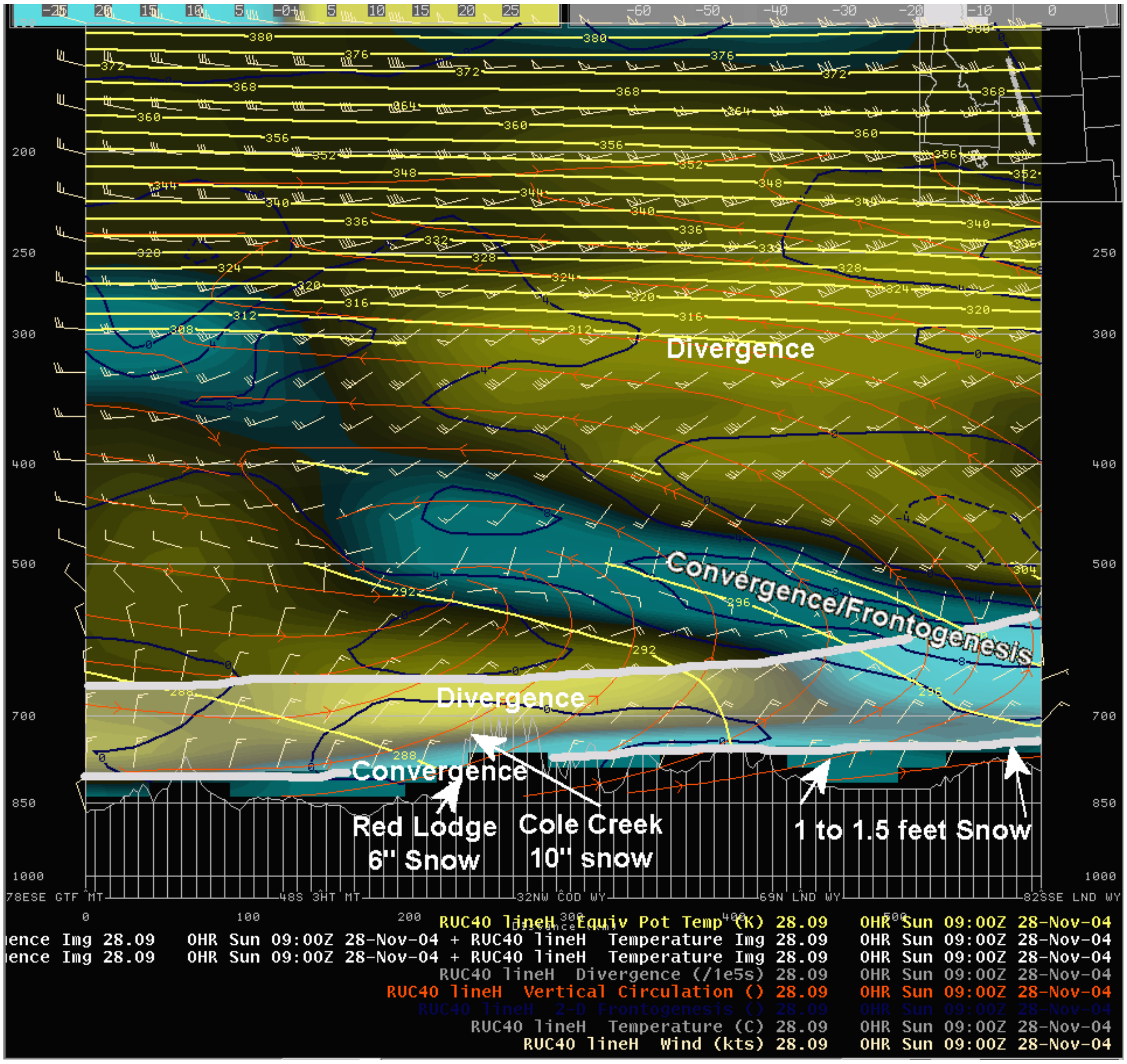
The Eta depicts synoptic scale divergence moving into south central Montana associated with the 700mb low and region of higher pressure to the north. Later Eta forecasts indicated even stronger divergence at 700mb for both events, which often is associated with light snowfall events in the area. The divergence at 700mb and near surface convergence (not shown) enhanced the lift below 700mb for good ascent in the dendritic layer. If the convergence was occurring near 700mb with divergence in a higher layer, the ascent would have been in a layer (colder than -22C) where slower growing ice crystals in the shape of columns and snow to liquid ratios around 10:1 would have been favored. This would have minimized the snowfall potential.

Despite the lift forecast by the Eta and GFS (omega not presented), model QPF indicated just half the observed liquid in the October event and a quarter of the observed liquid in the November event. Later model runs similarly under forecast QPF. While more similar cases need to be examined, there seems to be a clear bias of the models to under forecast the QPF despite having a reasonable performance in forcing.

To give a better indication of the forcing likely occurring when the heaviest snow was falling, a 00 hour forecast RUC cross section from south central Wyoming to north central Montana is shown below for both events (October event shown first). The main image shown is the convergence (blue) and divergence (yellow). The equivalent potential temperature lines are shown in yellow, frontogeneis is contoured blue, wind shown by the barbs, and vertical circulation by the red arrows. A second overlaying image is also shown to denote temperatures between -12C and -20C by transparent grey shading outlined with a thick gray line.

In both cases, near surface convergence with divergence around 700mb are indicated over the Beartooth Mountains. Jet level divergence above 400mb is also shown, which is likely providing some lift to the area. However as the vertical circulation shows, the majority of the ascent is below 600mb where temperatures maximize dendritic ice crystal growth with snow to liquid ratios typically around 20:1.





Summary

The snow events presented brought significant snowfall to the mountains near Red Lodge in a very short time. Since a strong cold front was well south of the area in both events with unstable low level environments, temperatures were very cold over Montana. Low level ascent where ice crystal growth through deposition is maximized was a key factor to the amount of snow observed in the mountains. One parameter that was present in both events was the movement of synoptic scale divergence just above mountain top into the area. As this divergence moved into the region, snowfall intensified dramatically while moisture content and upslope conditions remained fairly steady.

Model QPF was well underdone and future cases similar in nature could easily have the same bias. Thus forecasters may best deal with these type of events through pattern recognition. Knowing the upper level pattern suggests the potential for a significant snow event. Once the snow pattern is identified, parameters below 600mb should be scrutinized to determine if temperatures are favorable and if sufficient low level forcing, instability, and moisture are present for heavy snow. Comparisons between the two cases presented and future ones may serve as a better method to provide snow forecasts than model QPF.