Using the WES to Mitigate Model Difficulties in Forecasting the Movement of an Arctic Front through Western Montana

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Introduction

On February 23rd, 2002 an arctic frontal boundary moved through Western Montana from the north and northeast. As is often the case, the numerical models did not capture important details on the strength and movement of the arctic air through the complex terrain of the region. Reasons for the poor model performance in this particular event and a few simple techniques that may aid in forecasting the movement of these fronts will be discussed.

Synoptic Discussion and Model Assessment

Water Vapor imagery overlayed with 500 mb heights from the AVN at 23/00Z Feb 2003(fig 1) shows two separate jet streams; a southern branch with a closed low off the Oregon Coast and a northern branch extending southeast from British Columbia. These two streams converge over Washington and southern British Columbia. At 23/00Z very warm air in the low levels ahead of the pacific frontal system has spread into Montana with widespread record high temperatures in the 50s and 60s. The arctic front has just crossed the border into north central Montana (fig 2 -blue line).

The 23/00Z runs of the AVN and Eta were very similar and accurately forecast the progression of the large scale features through the next 48 hours. The closed low off the Oregon Coast fills and moves inland spreading warm moist Pacific air into western Montana (fig 3), followed by a northern branch shortwave which moves southeast through Montana beyond 36 hours (fig 4).

The models are also consistent in moving the arctic air mass south and southeast through 48 hours into most of western Montana resulting in strong isentropic ascent of the moist pacific air with widespread significant snows. The 23/00Z MesoEta brings the front strongly through Kalispell about 23/10Z (fig 5 and fig 6, frontal passage noted by red line). The front holds just north of Missoula until around 24/00Z, and then weakly moves into the Missoula area between 24/03Z and 24/06Z (fig 7 and fig8, frontal passage noted by red line). It is difficult to determine the precise frontal passage as the passage is quite weak and shallow with little to no wind shift until well after 09Z. Also during the evening, theta is decreasing near the surface due to radiational cooling. It appears that in the model data a very weak frontal passage possibly occurs at Butte around 24/21Z (fig 9 and fig 10, frontal passage noted by red line). In the model data, the arctic boundary never appears to pass through Hamilton or Dillon in extreme southwest Montana.

In reality, the arctic front quickly moved through Kalispell by 23/07Z, Missoula, 23/15Z, Butte 23/16Z, Dillon 23/18Z, and Hamilton at 23/20Z. This was 3 hours faster than the MesoEta forecast at Kalispell, 15 to 18 hours faster at Missoula, and 30 hours faster at Butte. Similar to the MesoEta, the AVN also had slower frontal timing. Note the position of the front at 23/23Z (fig 11) compared with the MesoEta forecast from 24/21Z (fig 9). The frontal position is already farther south than where the MesoEta was forecasting the front 22 hours later. In this event, an accurate forecast of the frontal position and timing was critical to the success of the snowfall forecast. South of the front only scattered valley rain would occur. While north of the front widespread significant snow with enhanced isentropic ascent over the frontal surface would occur. Since the front moved south through western Montana much more quickly than forecast, snow developed much earlier and persisted much longer over portions of the forecast area than the models indicated.

The models performed quite well with the overall synoptic pattern, depth of the arctic air in eastern Montana, and the timing and movement of the modified arctic air dropping into Washington and northern Idaho. A comparison of the model sounding from the 23/00Z MesoEta for Great Falls at 24/00Z (in brown) compared with the Great Falls RAOB at 24/00Z (in green) (fig 12) indicates the MesoEta did a good job in forecasting the depth of the cold air. The poor performance of the models with the arctic airmass in western Montana seems to be directly related to the poorly resolved terrain in the region by the models. Comparing the actual terrain (Fig 13) with the model terrain of the MesoEta (Fig 14), it is easy to see how poorly the valley systems are resolved in the model with the model surface in some cases several thousand feet above the valley bottoms. The valleys provide conduits for the cold dense air to travel. We did not have access to the high resolution Eta native grid output to determine if the unfiltered model output properly handled the arctic air. However, this is unlikely as even with a grid spacing of 12 km the terrain in this area is still not well resolved. In both the Eta 12 and MesoEta, cold air less than 6500' MSL (1950m MSL) deep is blocked from progressing south of a line from north of Missoula to north of Butte. Overlaying 850 mb temperatures from the MesoEta on MesoEta terrain (fig 15) it is easy to see this blocking. Note the wedge shape feature in the temperature field north of Missoula and the axis of higher terrain. In reality, the deep valleys that allow the cold air to move south are not resolved in the models.

Discussion

Due in large part to the poorly resolved terrain, the models often do a poor job in predicting the timing and strength of arctic fronts moving into western Montana. In an effort to improve forecasts of these events, a better understanding of how the arctic air masses move into the region is being investigated through WES case studies of previous events. Based on the few cases investigated to date, the following is a list of factors that the forecaster should consider if an arctic intrusion is possible.

1. ***Know the model terrain***. It is important that the forecasters know what the model terrain looks like and how it differs from the actual terrain and understand how this will affect the dynamics of the cold air crossing the divide.

2. ***An accurate forecast of the depth of the cold air east of the divide is critical***. If the cold air is not as deep as the lowest gaps, the cold air will not cross the divide, regardless of the MSLP pressure gradient. Air cannot go through mountains nor can cold dense air move over mountains. The critical element to the movement of the cold air across the divide is the pressure gradient at and above

mountain gap level across the divide. To a lesser degree the direction and speed of the winds in the cold air can play a factor. The best source for this information are model derived soundings, and the Great Falls RAOB. The deeper the cold air, the more quickly it will rush across the divide. Often, this arctic intrusion will occur much more quickly than the models indicate, as the models do not resolve the gaps and low areas along the divide. In the event discussed, the arctic inversion was above 10,000' MSL east of the divide (fig 12), well above the mean ridge height.

3. ***Knowing the stability of the warm air ahead of the arctic front and the stability of the air below the arctic inversion is also very important***. It is commonly thought that southwest to west winds in the warm air moving over an arctic airmass would shallow out the airmass slowing or preventing the progress of the arctic air south and southwest across the divide. This does not necessarily seem to be the case and appears dependent on the stability of the air ahead of and within the arctic inversion and to a lesser degree the winds in the warm air and in the cold air dome. If the warmer air impinging on the top of the cold air dome is unstable, the warm air will tend to rise more easily over the arctic dome without much erosion of cold air, particularly if the winds in the warm air are not too strong. Conversely, in situations where the warm air is more stable, such as in a moist subtropical feed, the top of the cold air dome may be more likely to erode.

One method that might show some promise to measure the potential for the warm air to rise over the cold air dome as opposed to erode the dome is by use of a Froude number analysis. The Froude number provides a ratio of kinetic energy to potential energy; giving a measure of how easily flow is blocked by an obstacle.

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Froude Number = Fr = U/Nh

U = Mean wind in layer

N = $(g*Theta*(dTheta/dz))^{1/2}$ = Buoyancy Frequency

h = height or depth of flow - or depth of cold air in our case

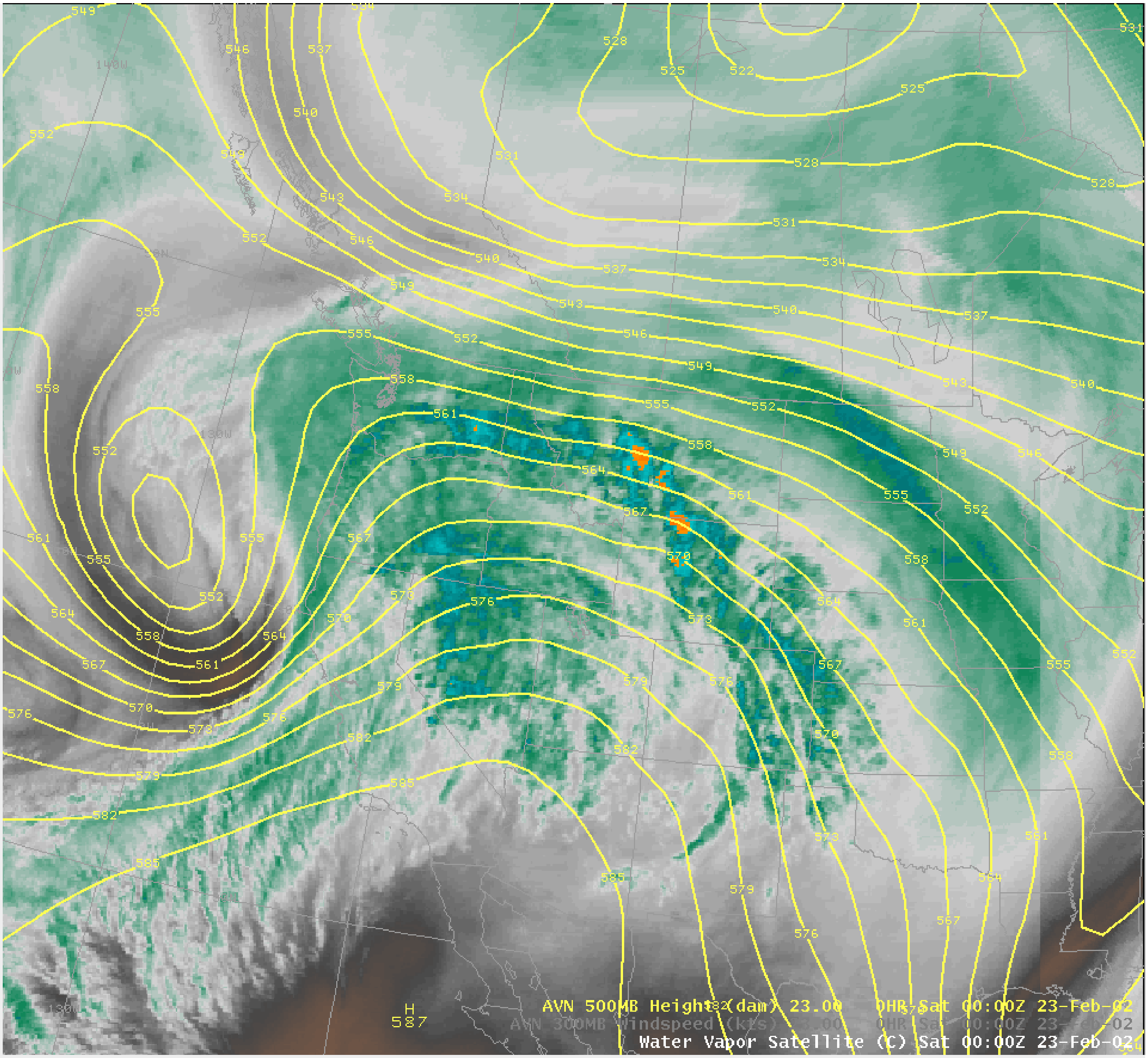
Given 2 cross sections from the event discussed; the first from near Lewiston, ID to south of Lethbridge, Alberta through Kaslipell (fig 16), the second from extreme northeast Oregon to near Shelby, Montana through Missoula (fig 17) (note the smoothness of the model terrain in the cross section versus the actual terrain, and the lack of data in the deeper valleys); the estimated Froude number in the warm air is about 1.8. In the cold air it is about 0.3. When the Froude number is greater than 1, the flow can more readily rise over the obstacle. If less then 1, the flow is more likely to be blocked and forced around an obstacle; particularly if it is less than 0.5. This indicates that in the case discussed, the unstable warm air may more readily rise over the cold air dome rather than erode it. Typical uses of Froude number analysis deal with blocking by mountains, so a direct comparison to blocking by a cold air dome cannot be made. In addition, this type of analysis may be unpractical in an operational setting. However, by investigating this technique on several cases, some variation of a Froude number analysis might show some promise for use in operations.

A less rigorous more subjective method to determine the blocking potential of the cold air dome is to look at the lapse rate within the arctic inversion and in the warm air impinging on the cold air dome. From (fig 6 and fig 8), the 700-500 mb lapse rate in the warm air is about 6 to 7 C/km, while in the arctic inversion it is about -5 C/km. A preliminary result from four other cases investigated indicates that if the difference in lapse rates is greater than 8 to 10 C/km, the cold air dome is less likely to erode. In addition, if cold air advection continues east of the Divide or the winds in the cold air have a component normal to the mountains the cold air dome will erode more slowly.

4. ***The surface pressure field ahead of the arctic front can also play a role***. If arctic air has already started to move across the divide, it's movement across the remainder of the region will be accelerated if a surface low or low pressure trough exists just south or west of the region. The models are often too slow with the movement of the arctic air in this situation. In the case discussed, a surface low was present in eastern Washington (fig 5), which progressed to central Idaho (fig 7).

This list will be refined as more arctic intrusion cases are investigated with the use of the Weather Event Simulator with the hope of finding more objective methods to forecast the movement of the arctic air across the Continental Divide and through the valleys of Western Montana.

Figure 1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AVN 300MB Windspeed (kts) 23.00 0HR Sat 00:00Z 23-Feb-02
Water Vapor Satellite (C) Sat 00:00Z 23-Feb-02

Figure 2

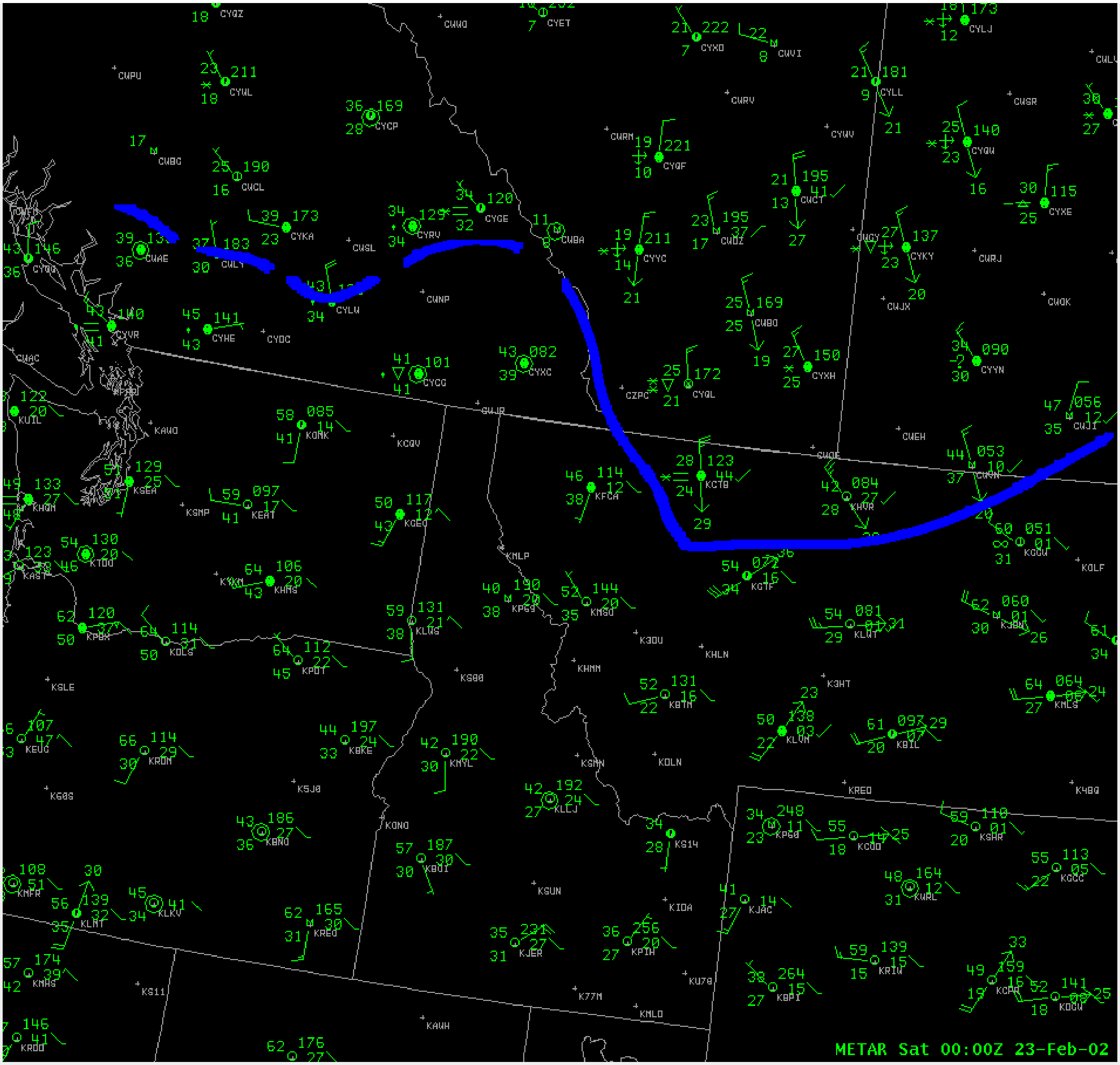

Figure 3

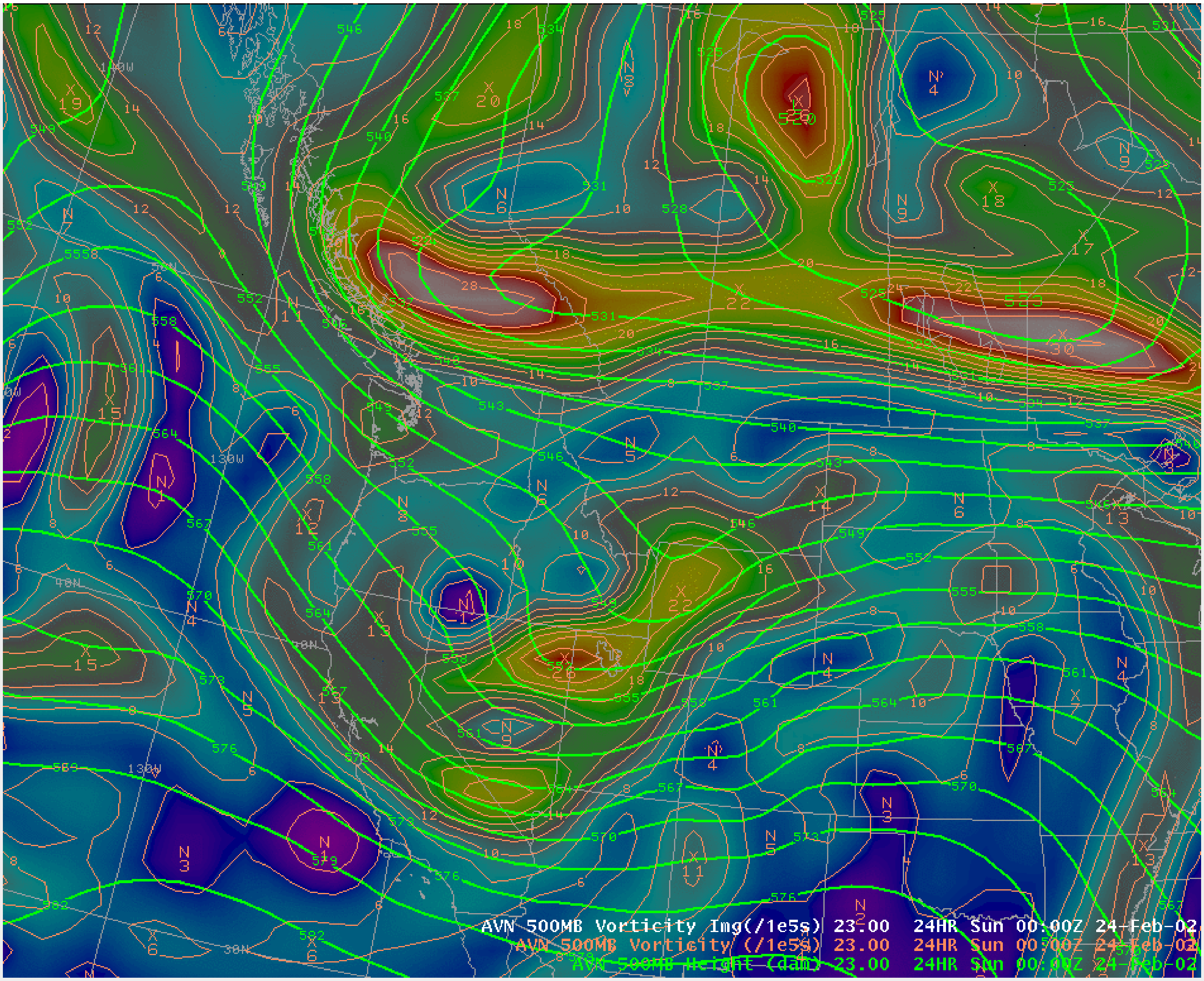
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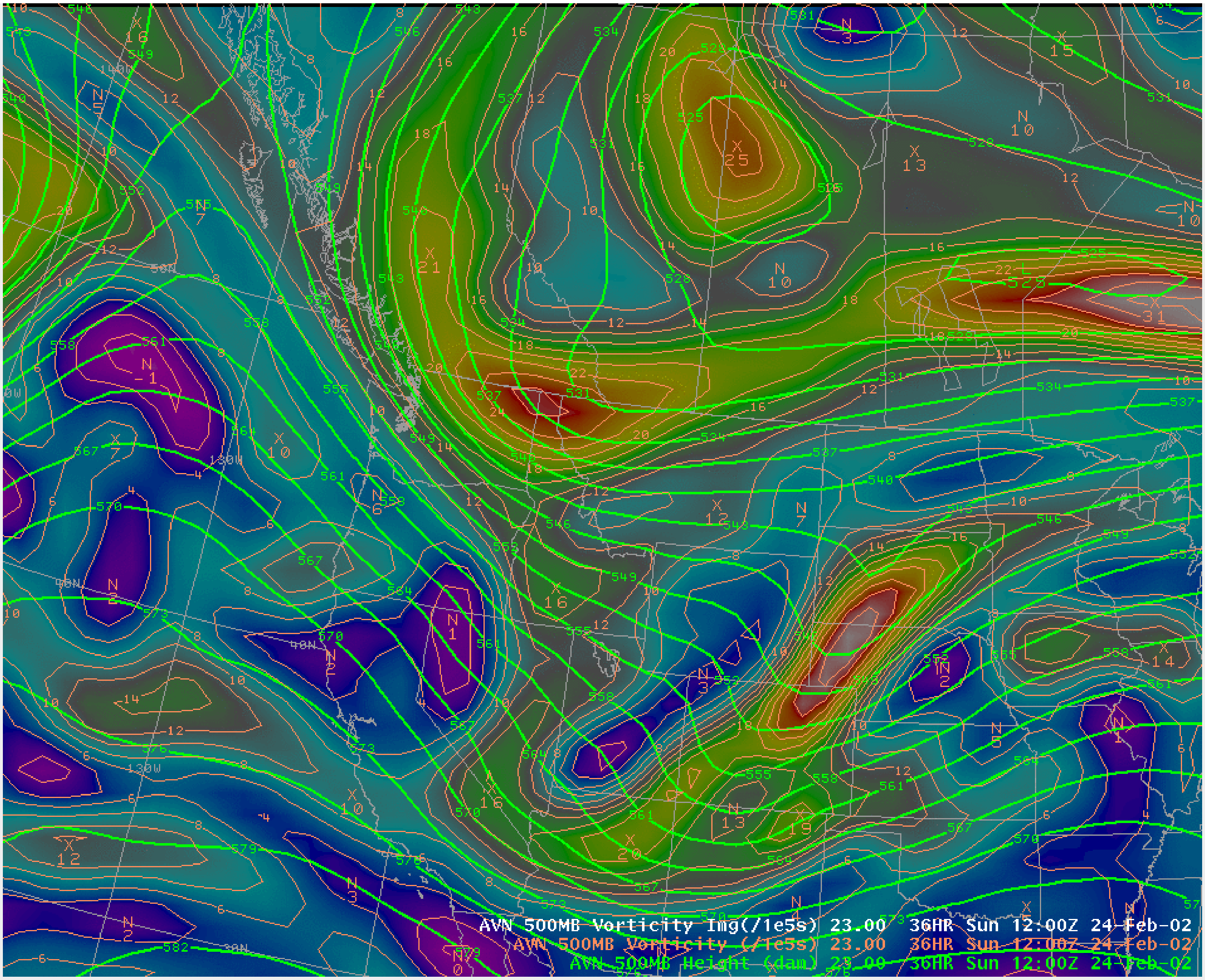
Figure 4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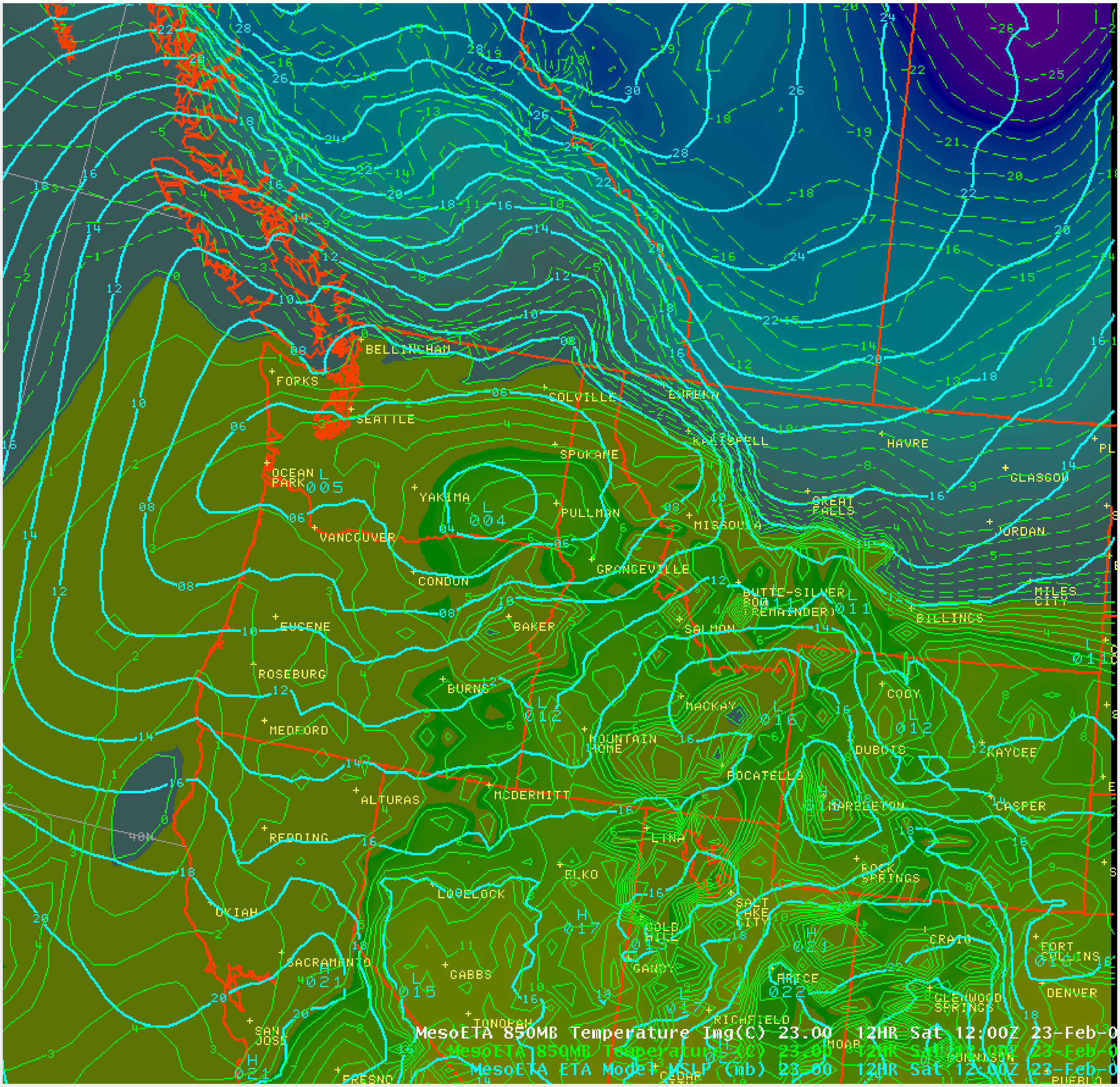
AVN 500MB Height (dam) 23.00 36HR Sun 12:00Z 24-Feb-02

Figure 5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MesoETA ETA Model MSLP (mb) 23.00 12HR Sat 12:00Z 23-Feb-0
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FORKS
SEATTLE
COLVILLE
EUREKA
KALISPELL
HAVRE
SPOKANE
GLASGOW
OCEAN PARK
YAKIMA
PULLMAN
MISSOULA
GREAT FALLS
JORDAN
VANCOUVER
GRANGEVILLE
CONDON
MILES CITY
BILLINGS
EUGENE
BAKER
SALMON
ROSEBURG
BURNS
MACKAY
CODY
MEDFORD
MOUNTAIN HOME
DUBOIS
KAYCEE
POCATELLO
ALTURAS
MCDERMITT
CASPER
REDDING
ELKO
ROCK SPRINGS
LOVELOCK
SALT LAKE CITY
UKIAH
CRAIG
SACRAMENTO
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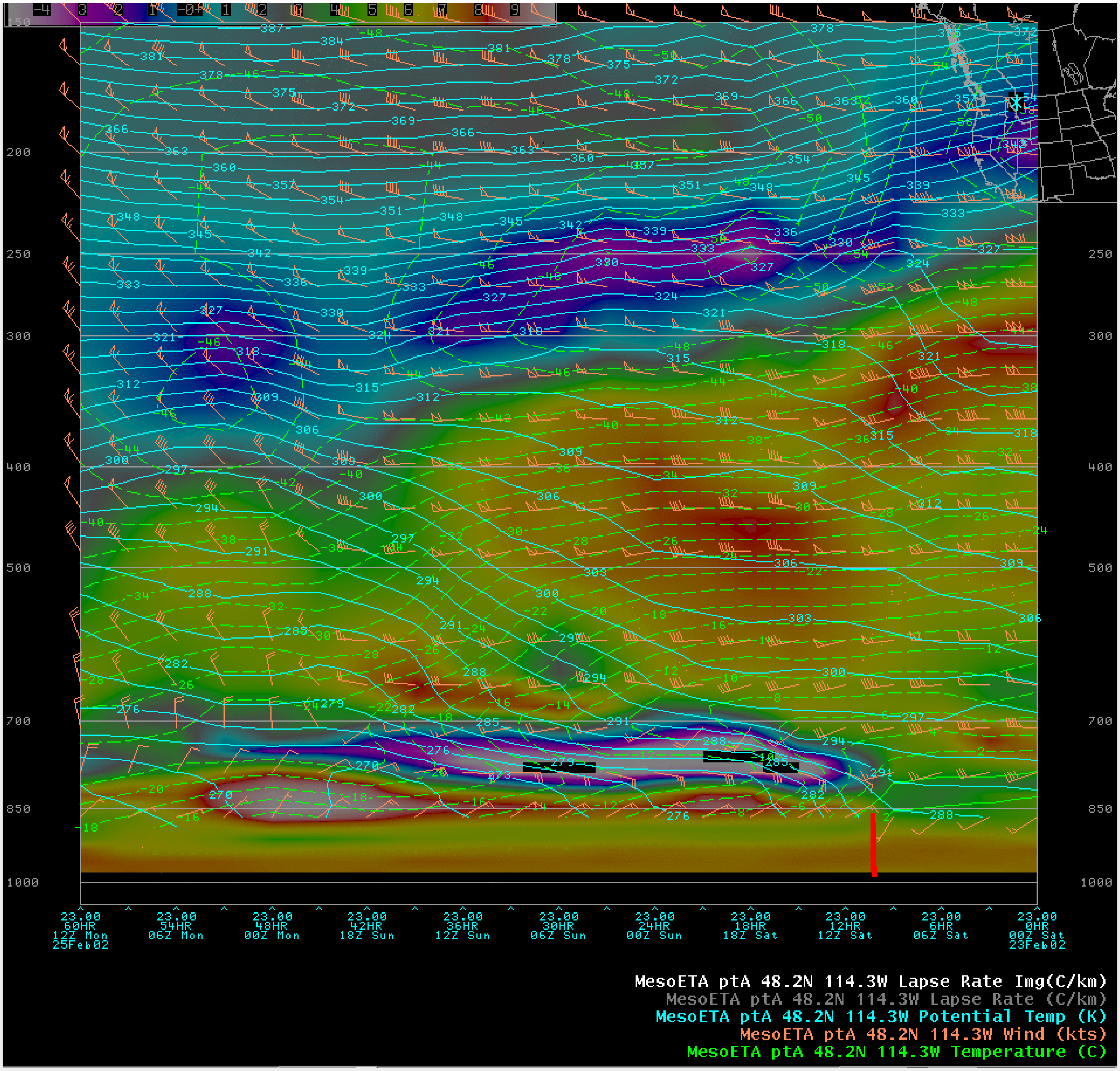
FORT COLLINS
DENVER
TONOPAH
RICHFIELD
SAN JOSE
FRESNO

Figure 6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MesoETA ptA 48.2N 114.3W Lapse Rate (C/km)
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MesoETA ptA 48.2N 114.3W Wind (kts)
MesoETA ptA 48.2N 114.3W Temperature (C)
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23.00 54HR 06Z Mon
23.00 48HR 00Z Mon
23.00 42HR 18Z Sun
23.00 36HR 12Z Sun
23.00 30HR 06Z Sun
23.00 24HR 00Z Sun
23.00 18HR 18Z Sat
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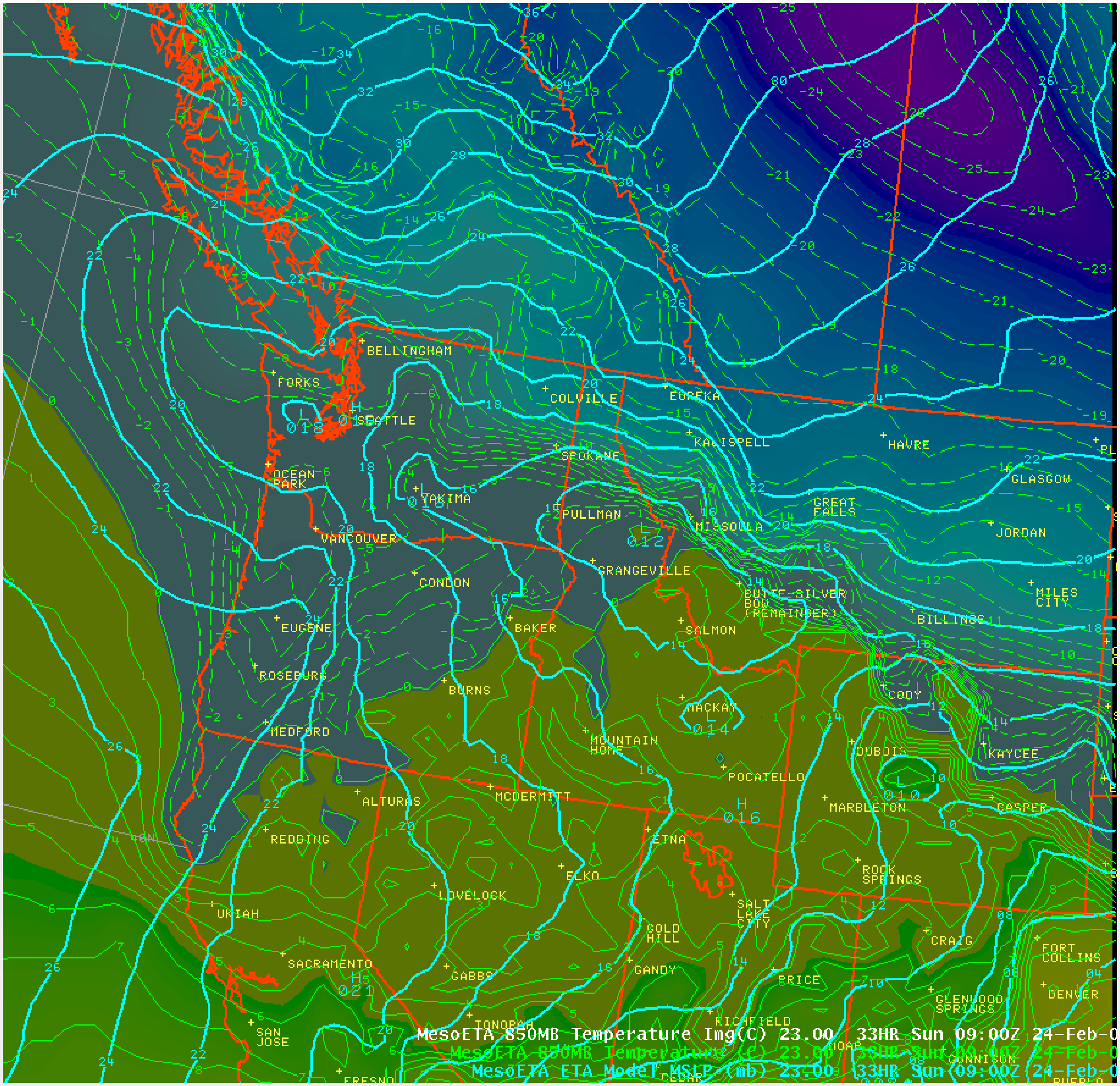
400
500
700
850
1000

Figure 7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FORKS
SEATTLE
OCEAN PARK
YAKIMA
VANCOUVER
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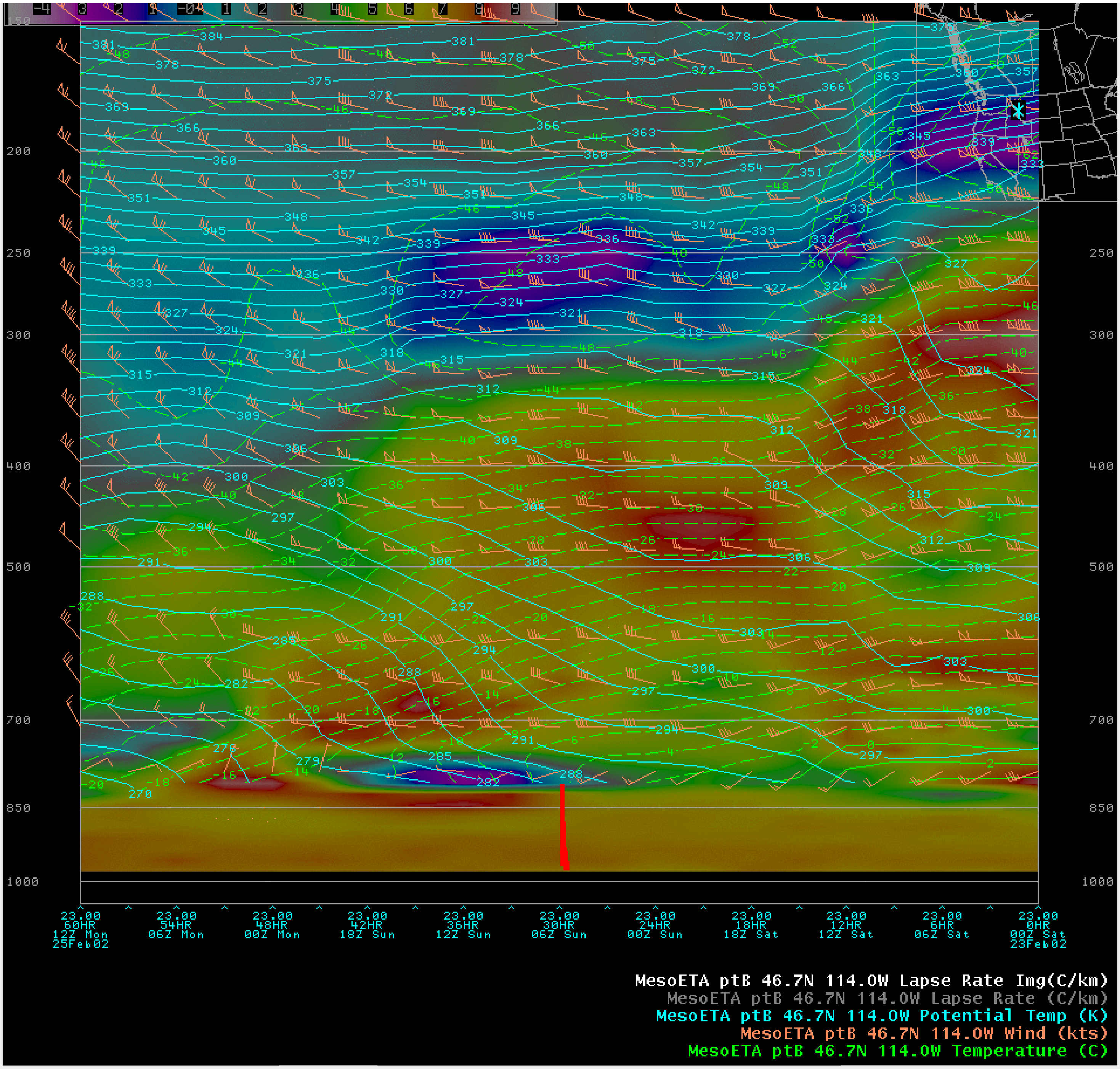
SPOKANE
PULLMAN
MISSOULA
GREAT FALLS
GLASGOW
JORDAN
CONDON
GRANGEVILLE
BUTTE-SILVER BOW (REMAINDER)
MILES CITY
EUGENE
BAKER
SALMON
BILLINGS
ROSEBURG
BURNS
CODY
MACKAY
MEDFORD
MOUNTAIN HOME
DUBOIS
KAYCEE
POCATELLO
ALTURAS
MCDERMITT
MARBLETON
CASPER
REDDING
ETNA
ELKO
ROCK SPRINGS
LOVELOCK
UKIAH
SALT LAKE CITY
GOLD HILL
CRAIG
FORT COLLINS
SACRAMENTO
GABBS
GANDY
PRICE
DENVER
GLENWOOD SPRINGS
SAN JOSE
TONOPAH
RICHFIELD
FRESNO
MesoETA 850MB Temperature Img(C) 23.00 33HR Sun 09:00Z 24-Feb-0
MesoETA 850MB Temperature (C) 23.00 33HR Sun 09:00Z 24-Feb-0
MesoETA ETA Model MSLP (mb) 23.00 33HR Sun 09:00Z 24-Feb-0

Figure 8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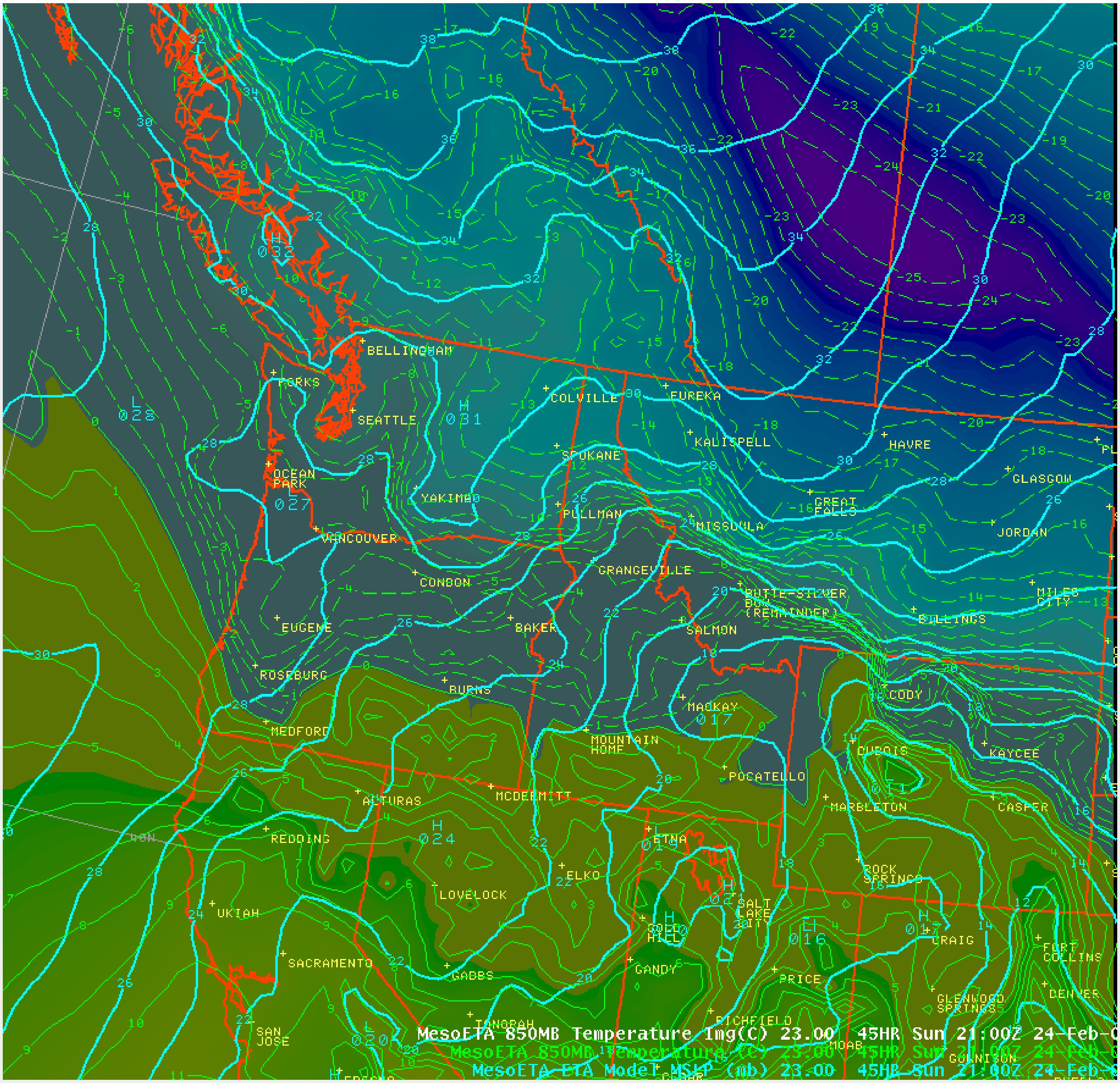
MesoETA ptB 46.7N 114.0W Lapse Rate (C/km)
MesoETA ptB 46.7N 114.0W Potential Temp (K)
MesoETA ptB 46.7N 114.0W Wind (kts)
MesoETA ptB 46.7N 114.0W Temperature (C)

Figure 9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BELLINGHAM
FORKS
SEATTLE
COLVILLE
EUREKA
KALISPELL
HAVRE
SPOKANE
OCEAN PARK
YAKIMA
PULLMAN
MISSOULA
GREAT FALLS
GLASGOW
JORDAN
VANCOUVER
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BUTTE-SILVER BOW (REMAINDER)
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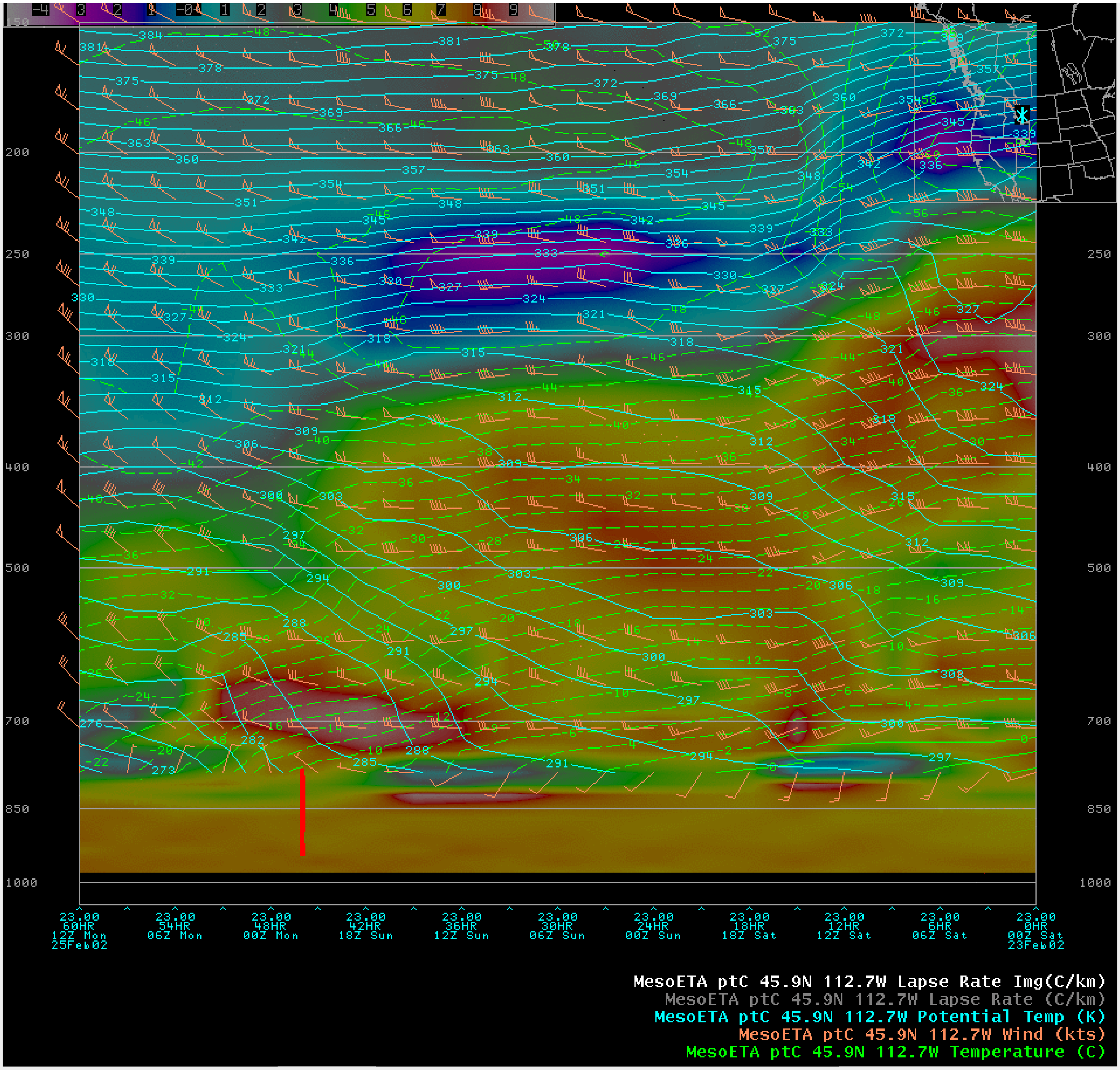
CRAIG
FORT COLLINS
SACRAMENTO
GABBS
GANDY
PRICE
DENVER
GLENWOOD SPRINGS
SAN JOSE
TONOPAH
RICHFIELD
MOAB
GUNNISON

Figure 10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MesoETA ptC 45.9N 112.7W Lapse Rate (C/km)
MesoETA ptC 45.9N 112.7W Potential Temp (K)
MesoETA ptC 45.9N 112.7W Wind (kts)
MesoETA ptC 45.9N 112.7W Temperature (C)

Figure 11

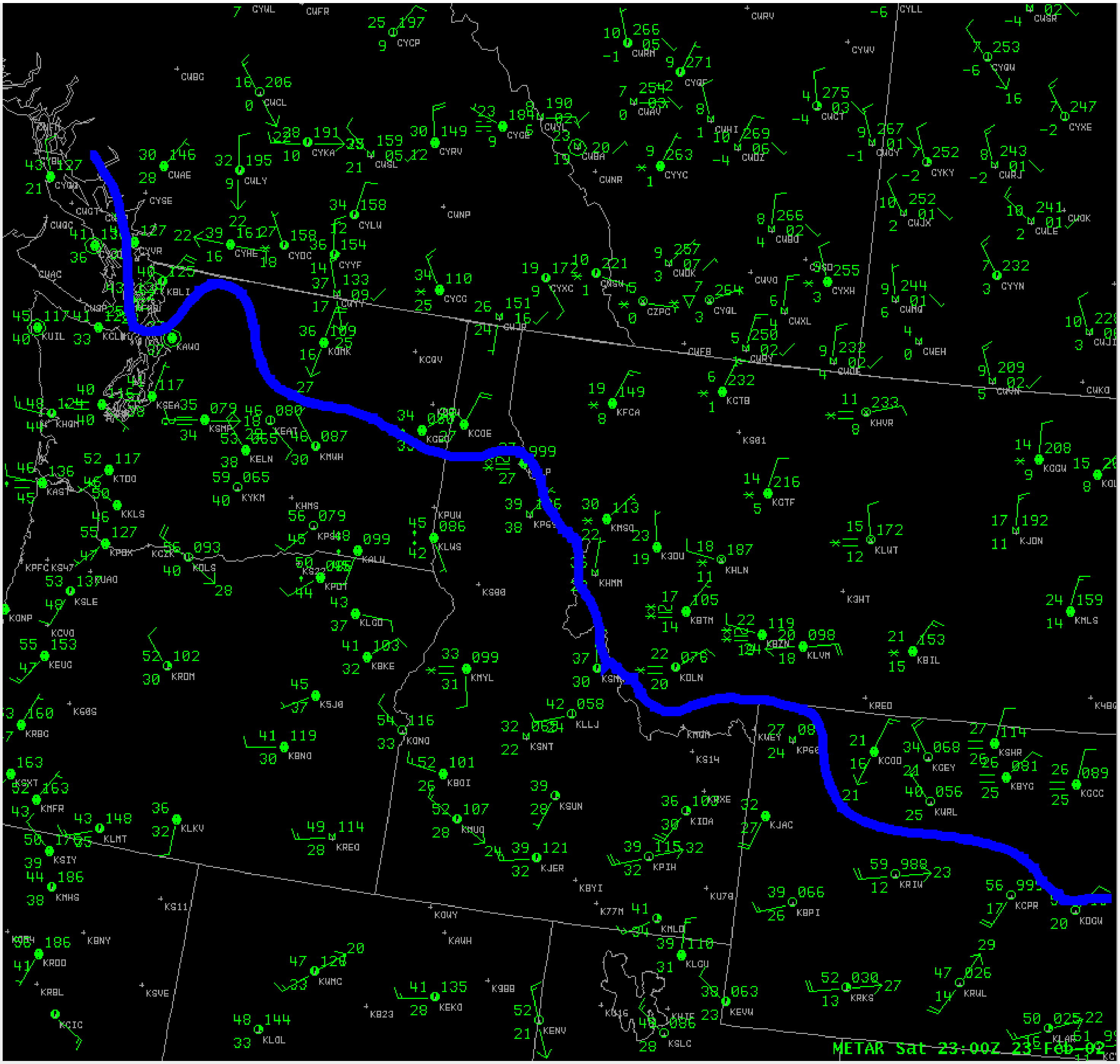


Figure 12

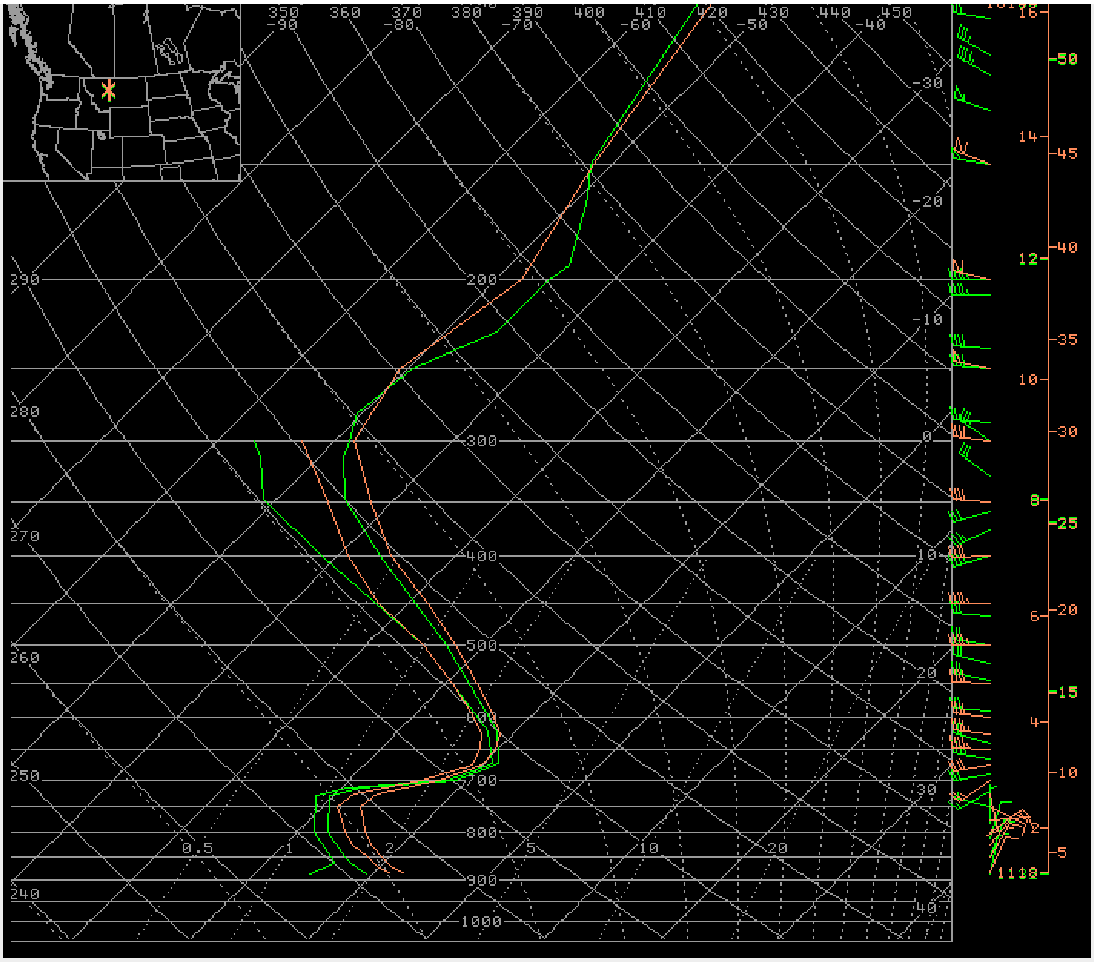


Figure 13

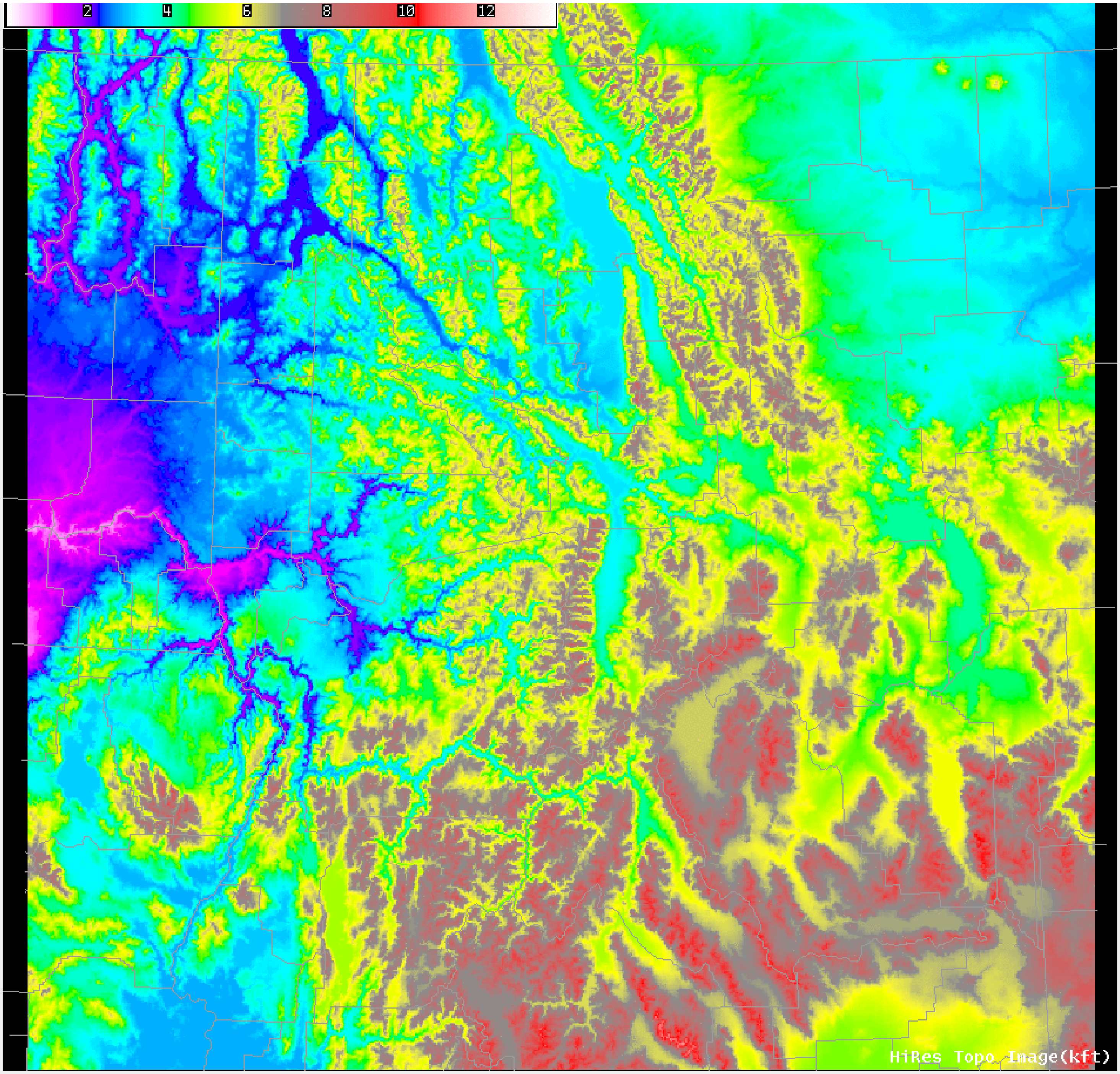
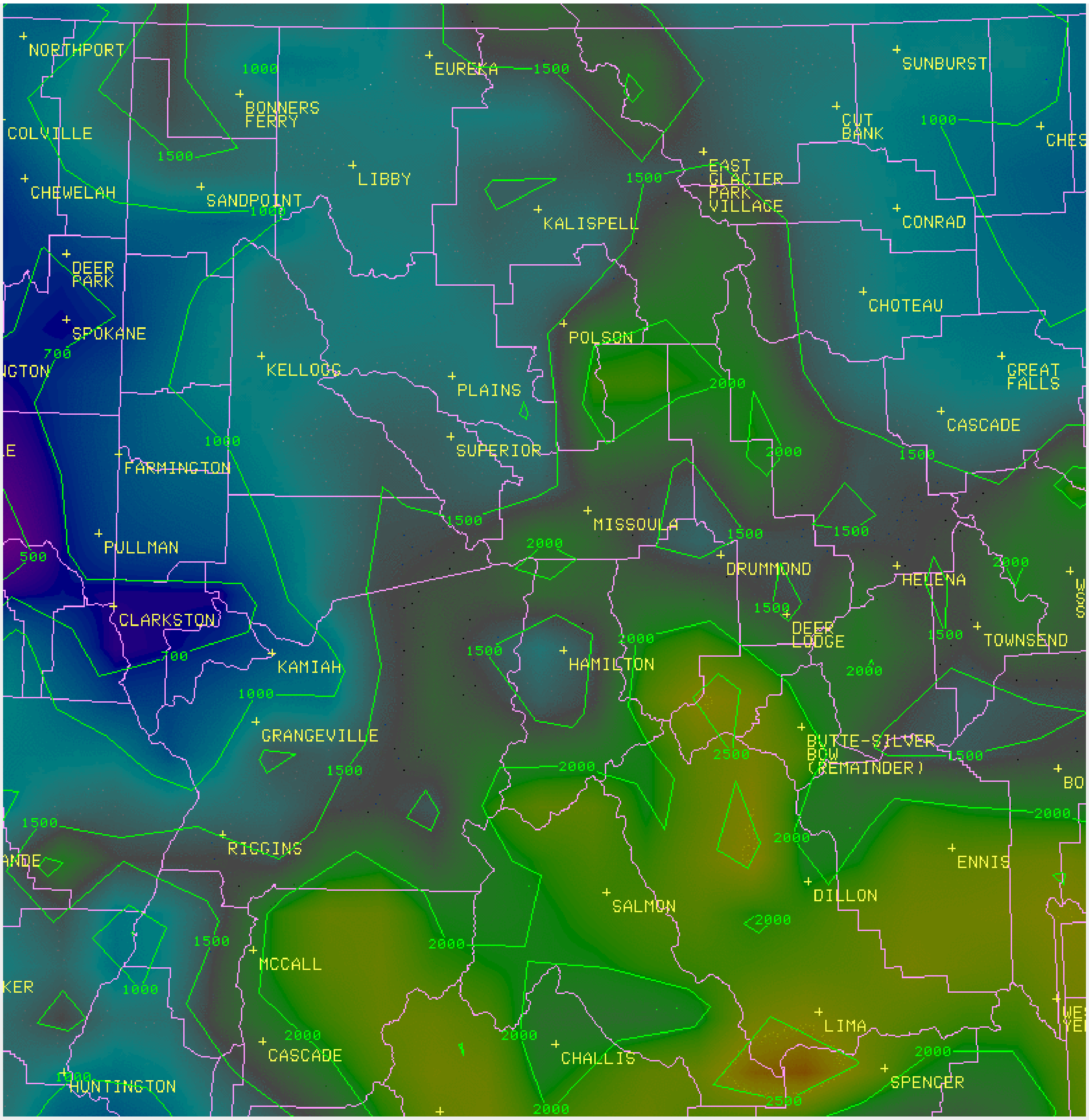


Figure 14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LIBBY
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SANDPOINT
EAST GLACIER PARK VILLAGE
KALISPELL
CONRAD
DEER PARK
CHOTEAU
SPOKANE
POLSON
KELLOGG
PLAINS
GREAT FALLS
CASCADE
SUPERIOR
FARMINGTON
MISSOULA
PULLMAN
DRUMMOND
HELENA
CLARKSTON
DEER LODGE
TOWNSEND
HAMILTON
KAMIAH
GRANGEVILLE
BUTTE-SILVER BOW (REMAINDER)
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ENNIS
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DILLON
MCCALL
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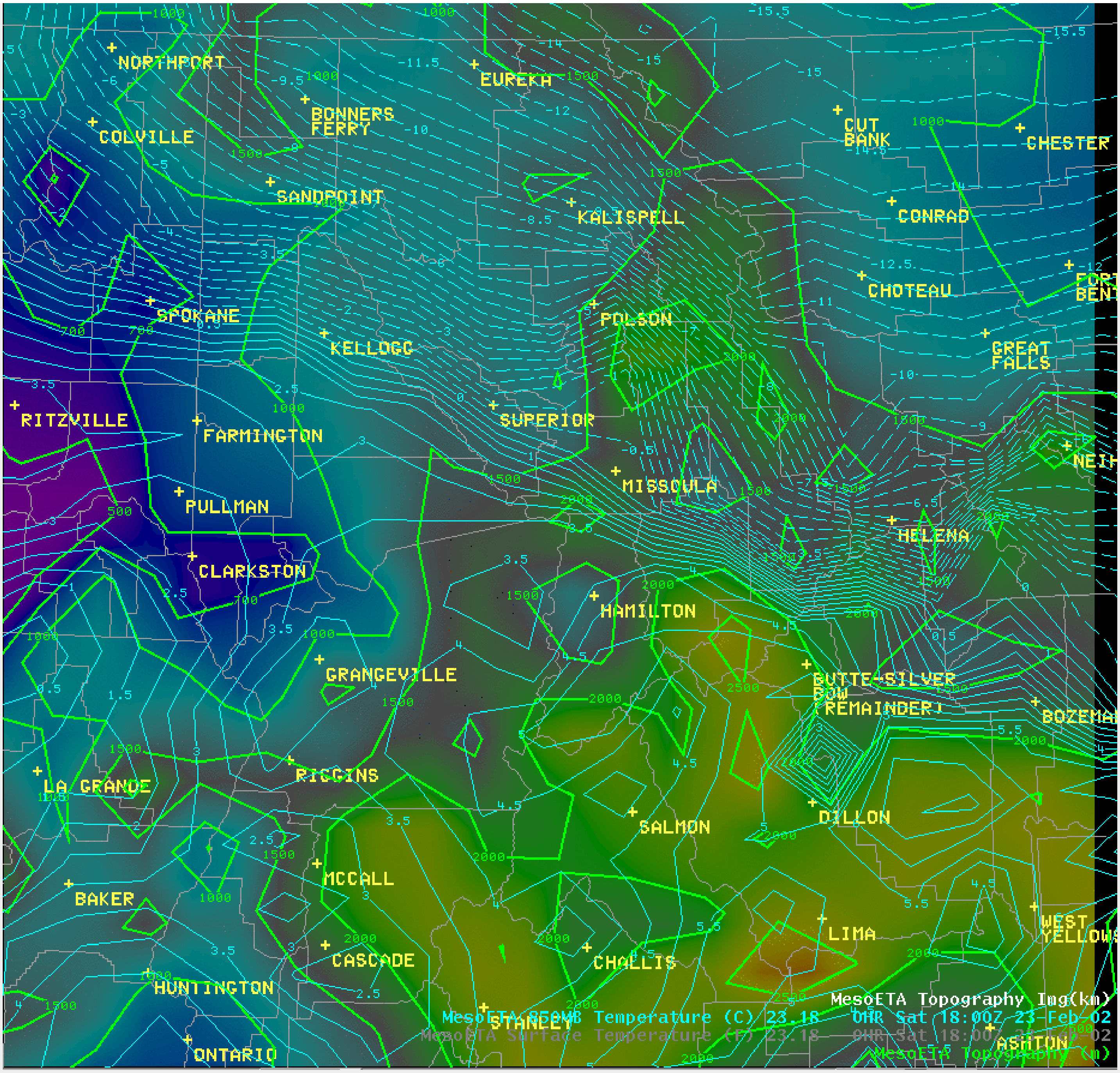
CASCADE
CHALLIS
SPENCER
HUNTINGTON

Figure 15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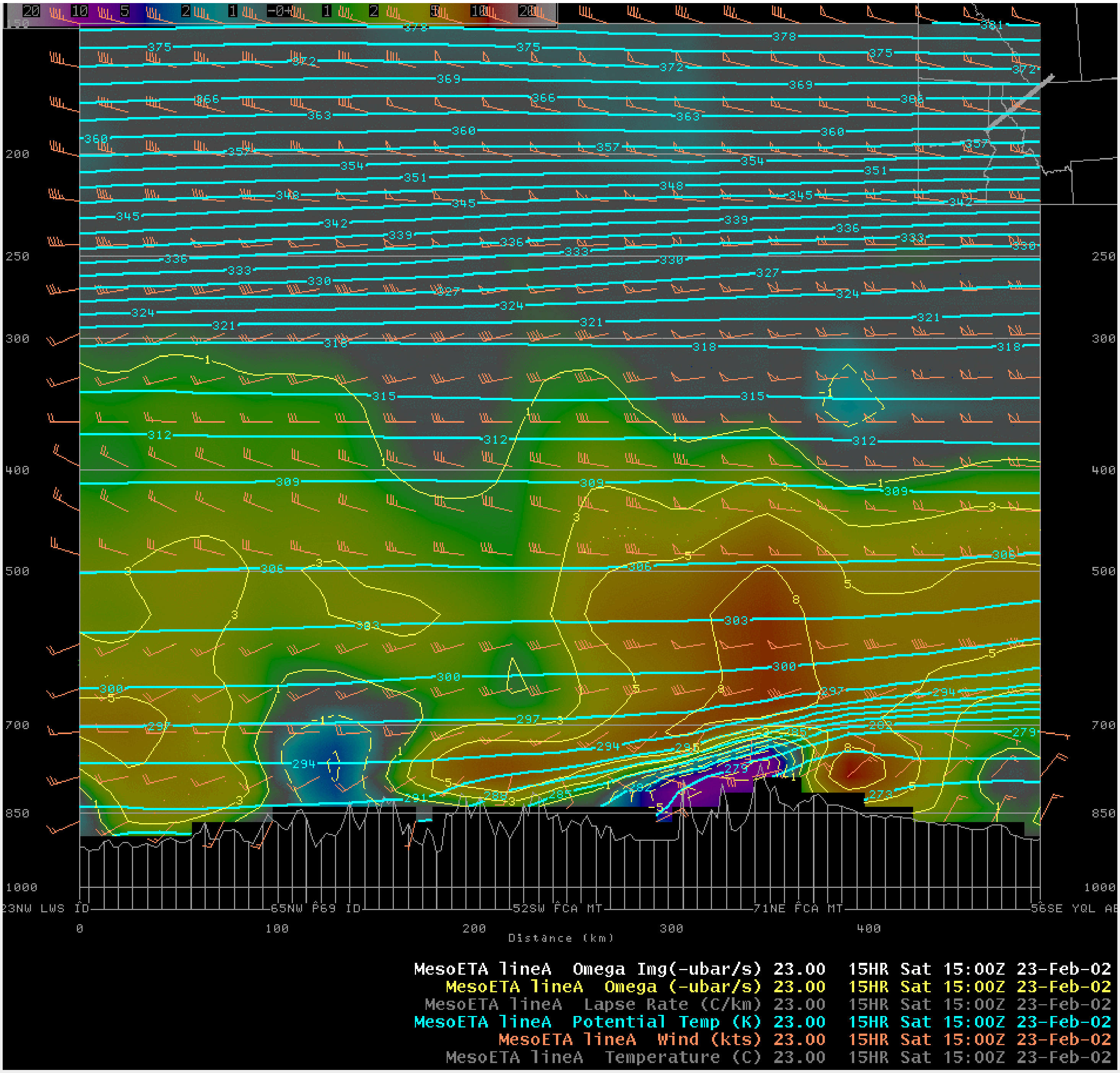
KELLOGG
GREAT FALLS
RITZVILLE
FARMINGTON
SUPERIOR
MISSOULA
PULLMAN
HELENA
CLARKSTON
HAMILTON
GRANGEVILLE
BUTTE-SILVER BOW (REMAINDER)
RIGGINS
LA GRANDE
SALMON
DILLON
MCCALL
BAKER
CASCADE
CHALLIS
LIMA
HUNTINGTON
STANLEY
ONTARIO
ASHTON
MesoETA Topography Img(km)
MesoETA 850MB Temperature (C) 23.18 0HR Sat 18:00Z 23-Feb-02
MesoETA Surface Temperature (F) 23.18 0HR Sat 18:00Z 23-Feb-02
MesoETA Topography (m)

Figure 16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MesoETA lineA Potential Temp (K) 23.00 15HR Sat 15:00Z 23-Feb-02
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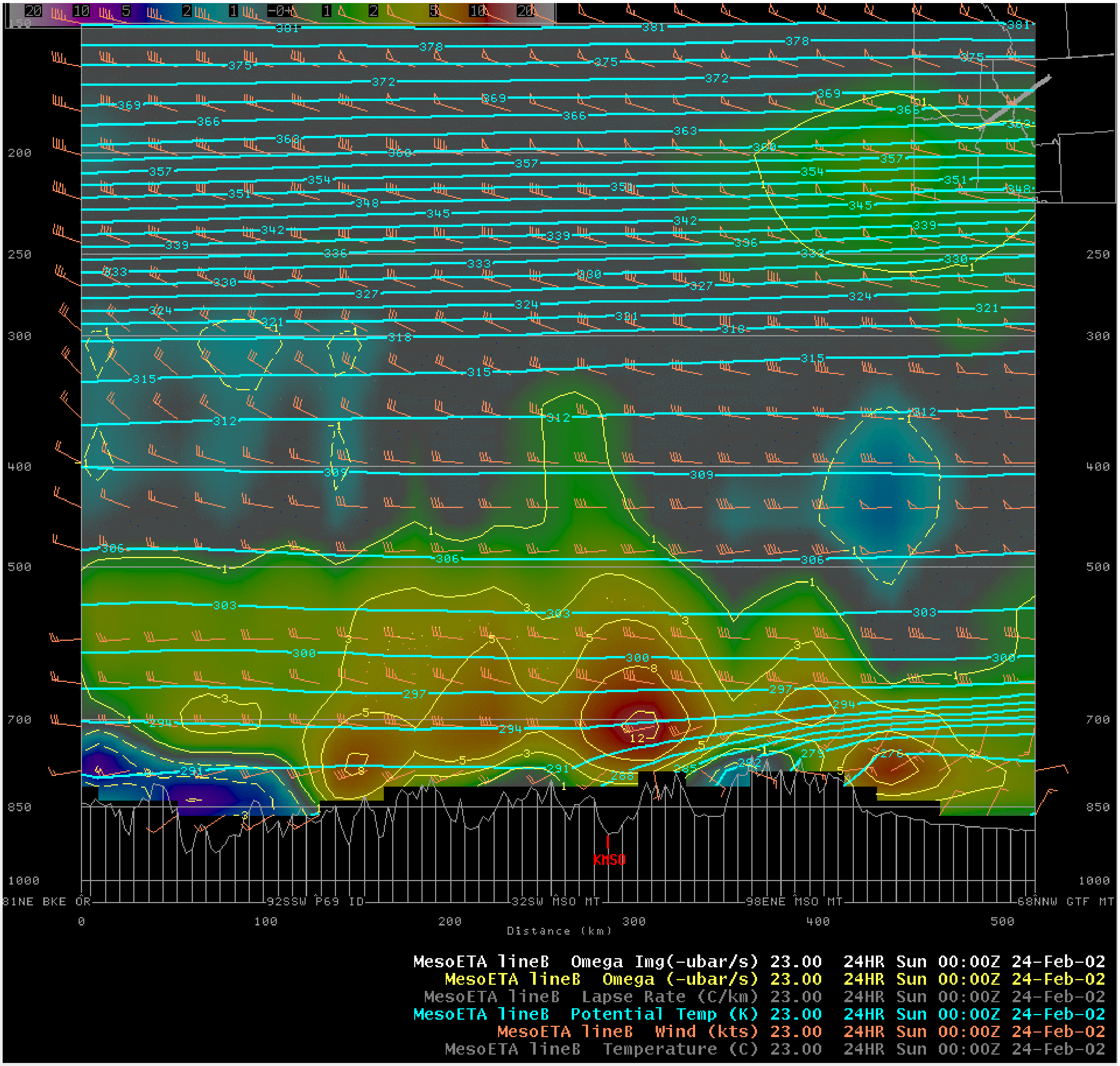
Figure 17



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KMSO
Distance (km)
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MesoETA lineB Omega (-ubar/s) 23.00 24HR Sun 00:00Z 24-Feb-02
MesoETA lineB Lapse Rate (C/km) 23.00 24HR Sun 00:00Z 24-Feb-02
MesoETA lineB Potential Temp (K) 23.00 24HR Sun 00:00Z 24-Feb-02
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