The 20 January 2002 Winter Storm in the Treasure Valley
A Weather Event Simulation

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Setup

On Friday, January 18th, 2002, forecasters at Boise were faced with model guidance indicating two pieces of storm energy will cross the Treasure Valley during the upcoming 3-day Martin Luther King Day weekend. The challenge is determining if you will issue any highlights for the weekend? For which time periods and for which areas?

Discussion

From a quick look at model guidance, it is apparent that two storms will cross the CWA during the weekend. One on Saturday the 19th , and another on Sunday the 20th. As with many winter storms, the initial challenge is determining which storm will bring the more significant precipitation. The 24-hour precipitation amounts from both the Eta (figs 1a and 1b) and AVN (figs 2a and 2b) are similar. In fact, almost all fields are similar between the models, so from here on out we will only show one model to keep things simple.

So, with the model precipitation fields between the two days being nearly equal, are there reasons to favor one storm more than the other? We can oversimplify a bit and say:

precipitation = lift + moisture

Lets then look at the lift available on both days and see if we see any differences.

First, lets look at the model omega fields themselves. A time-height cross section at Boise indicates two periods of lift (fig 3). The one on Saturday the 19th is stronger - but short-lived. The one starting on Sunday the 20th is a bit weaker - but lasts much longer.

However, could there be processes contributing toward lift that the models do not handle well?

Lets look at orographic lift. Strong winds impinging on our mountains causes lift. Basically, the stronger the low-level winds, the stronger the lift. (Stability, of course, modifies where, relative to the mountain, that lift takes place) The model shows stronger winds at 700mb at midday on the 20th than at midday on the 19th (figs 4a and 4b). This, alone, might be a good reason to favor the storm for Sunday over the storm for Saturday.

The model handles dynamical reasons for lift well - but lets investigate what is going on. How about jet dynamics. The 300mb winds for midday on the 19th and midday on the 20th, show that there might be some jet interaction on the 19th (figs 5a and 5b).

Rather than trying to infer the amount of divergence based on the 300mb wind field, lets look at the divergence fields directly (figs 6a and 6b). There is more organized upper-level divergence at midday on the 19th, rather than the 20th. However, it appears to be somewhat related to jet curvature (i.e., the stronger the curvature - the stronger the divergence aloft on the "downstream" side of the curve). Quadrant-type of jet dynamics (stronger divergence on the left-front and right-rear quadrants of a jet) does not appear to be involved (in fact, they may be opposing each other in this case - leaving the curvature terms to be more dominant.).

What about Quasi-geostrophic forcing? The models show strong 500mb vorticity advection at midday on the 19th, but very weak advection at midday on the 20th (Figs 7a and 7b). In these images, 500mb vorticity is the image, and the white contours depict the vorticity advection.

Better yet, in QG forcing, we are really looking for vorticity advection increasing with height. A time-height section at Boise shows very strong vertical increase in vorticity advection with the Saturday storm, but very little with the Sunday storm (fig 8).

But QG lift depends on TWO factors. Spatial Maximums of warm advection also act as forcings for vertical motion. The low-level warm advection at 700mb is MUCH stronger on Sunday than Saturday (fig 9):

So, on Saturday we have the vorticity advection term in QG tending to force rising motion, and on Sunday we have the warm advection term in QG tending to force rising motion.

One thing to keep in mind with QG theory is that the QG response is through the depth of the troposphere, and the STABILITY through the troposphere is important. With similar forcing, you will get bigger vertical motions with more unstable atmospheres. Look closely at a cross section of theta (fig 10). The stability is proportional to the distance between isentropes. The isentropes are more "widely spaced" on Sunday than they are on Saturday - indicating more instability and a larger QG vertical motion response to any QG forcing on Sunday.

If you don''t want to eyeball the spacing of isentropes, you can look at a deep-layer stability measure like the lapse rate. The model 700-300mb lapse rate is much larger on Sunday (indicating greater instability) (figs 11a and 11b).

Another way to look at rising motion that does not have the scale restrictions of QG theory is to look at isentropic surfaces. There are two difficulties with this approach: (1) finding the right level, and (2) the movement of the isentropic surfaces themselves. A time-height section of theta reveals that about a 290K surface will be near 700 mb both Saturday and Sunday (fig 12).

If an isentropic surface is stationary, and the wind is blowing toward higher pressure values, then there is sinking motion, and if it is blowing toward lower pressure values, then there is rising motion. Put another way, if the pressure advection is positive, then there is rising motion. On the 290K surface there is a BIG difference between Saturday and Sunday - with Sunday having STRONG rising motion, and Saturday having strong sinking motion (figs 13 a and 13b).

However, be careful! Look closely at the cross section of theta - and you see that the 290 surface itself it rising rapidly on Saturday - and is probably overcoming the sinking motion that you see if you just consider the isentropic surface stationary. Indeed, don''t forget that the model is showing rising motion on both days.

OK, so the model has rising motion on both days - both generating similar precipitation values. The QG forcings, while different, are present on both days - but the stability is less on Sunday, and the orographic lift should be stronger on Sunday. All these factors should lead us to expect the Sunday storm to be bigger. The presence of dynamic factors (i.e. QG forcing), not just orographic lift, might lead us to believe that the precipitation will NOT simply be confined to the mountainous areas - but may spread well into the nearby valleys.

So we have considered lift - now let us consider moisture.

If you look simply at the 700mb RH field at both times (figs 14a and 14b) - the model is nearly saturated in both cases.

However, we may want to look at a more "integrated" measure of moisture like precipitable water (figs 15a and 15b). This shows a slight, but distinguishable, increase between Saturday and Sunday.

However, it is difficult to interpret model precipitable water patterns - because so much of the precipitable water patterns are dominated by terrain. Since warmer air can potentially hold more water before saturating, places where the atmosphere goes down to sea-level will almost always have much more precipitable water than areas at higher elevations, where the lowest layers of the atmosphere are cooler.

One thing to keep in mind is that "closeness to saturation" is NOT a measure of the absolute amount of moisture. Cooler air holds much less moisture (before it saturates) than warm air. Thus, 90% RH at -20 degrees is much less "absolute moisture" than 90% RH at 20 degrees. One way to investigate this is to look at specific humidity - truly a measure of the amount of moisture (in grams per kilogram of air). A time-height cross section of this at Boise (fig 16) reveals a large difference between the moisture available on Saturday and Sunday. At any particular level, there is much more moisture available on Sunday than there is on Saturday. Also note how the specific humidity rises and falls in direct proportion to the temperature.

Actual observations also show that lots of moisture is being injected into the storm for Sunday. Water vapor satellite imagery (fig 17) shows a large plume of moisture originating west of Hawaii being entrained in the flow.

The polar orbiter satellite images of total precipitable water (fig 18) also show a huge difference in the moisture going into the storm west of Hawaii (which will arrive on Sunday) compared to the storm in the Gulf of Alaska (which will arrive on Saturday).

Lets go back to our oversimplified equation:

precipitation = lift + moisture

We now know that the lift component slightly favors the Sunday storm, and the moisture component strongly favors the Sunday storm. In both cases, the presence of synoptic-scale lift factors implies that significant precipitation "away from the mountains" is possible.

Keep in mind that precipitation depends on both intensity and duration. An intense, but short-lived storm, may produce less precipitation than a weak, but long-lived one. Lets look briefly at the duration of lift and precipitation. Look closely again at the model time-height section of omega at Boise (fig 19). The Saturday storm, while intense, is rather short-lived - with most of the omega occurring in a 6 hour time-period between 12 and 18Z. The Sunday storm, on the other hand, has omega that lasts from early Sunday into Tuesday.

Precipitation intensity is very difficult to forecast - since it depends on many factors, including many microphysical factors around each precipitation particle. One thing that may be important are "gross" factors of crystal growth habit. Ice crystals grow MUCH faster in a temperature range of about -12 to -18 than at other temperatures. If all other factors are equal, storms where vertical motion and moisture are concentrated near this temperature band, may be able to generate larger ice crystals more rapidly - leading to heavier precipitation rates.

In this case, the main low-level omega maximum near 700mb on Sunday is in this temperature range, while the omega maximum on Saturday (near 500mb) is at much cooler temperatures (fig 20). This might also contribute to more significant precipitation on Sunday.

Precipitation type is a little tricky for the second storm (the 20th). Model soundings indicate the warm-up due to low-level warm-advection on Sunday, but even by late in the day (00Z on the 21st), the Eta model sounding (figs 21a and 21b) are still well below freezing.

Several local studies have indicated the the models handle the boundary layer temperatures poorly. Looking at large-scale fields such as thickness values works better for rain/snow decisions. In particular, a 850-700mb thickness value of 1530m delineates snow/rain well (fig 22a and 22b). In this case, thickness values indicate that snow may change over to rain late on Sunday.

Southeasterly flow at the surface could bring in a little bit drier air from out ahead of the storm - which would then allow a little bit of cooling due to evaporative cooling and melting effects. This might offset some of the warming seen on the thickness charts - but it still seems that a changeover to rain is likely.

All of this supports the possibility of a significant snow event in the mountains on Sunday, and possibly spreading into the nearby valleys.

Wrapup:

The Sunday storm was a significant snowstorm for the Treasure valley, with most locations receiving six to eight inches of snow, with up to 14 inches in some valley locations. The snowfall differences between the mountains and valleys were much less than normal - indicating that dynamical factors, rather than orographic lift were dominating in this case. Precipitation remained snow for nearly all the precipitation event on Sunday, changing over to rain only at the very end of the event.

Figure 1a

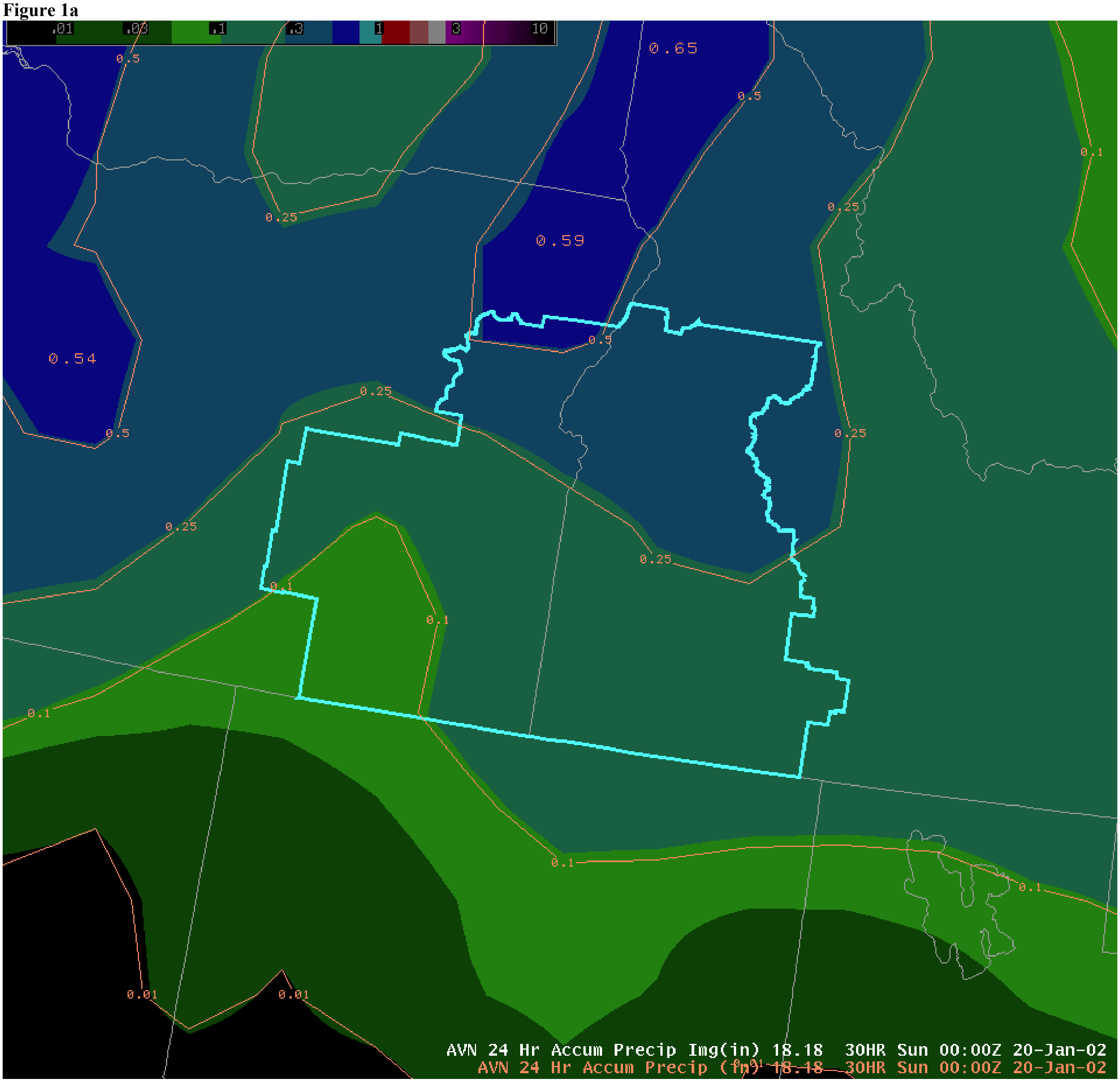
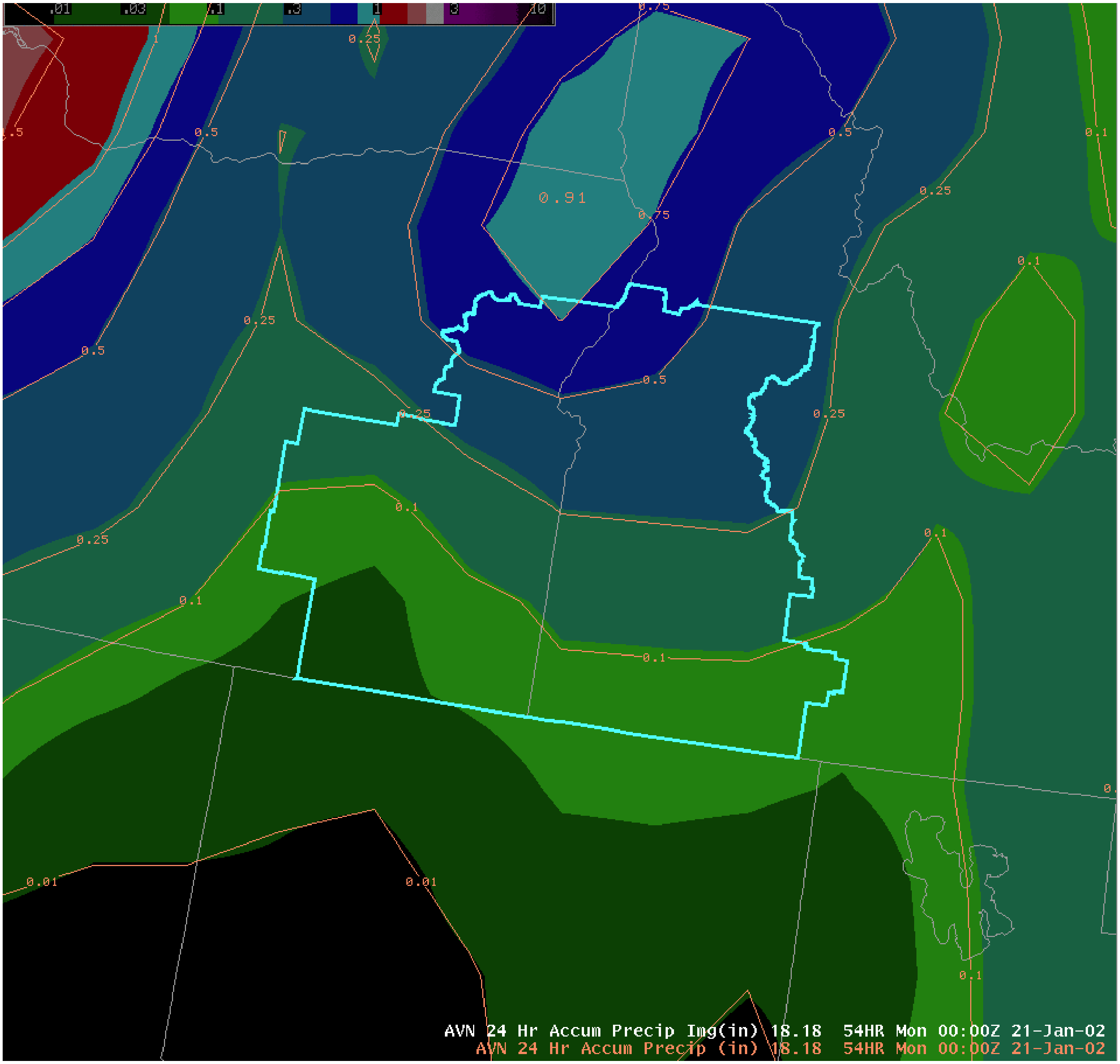


Figure 1b



.01 .03 .1 .3 1 3 10
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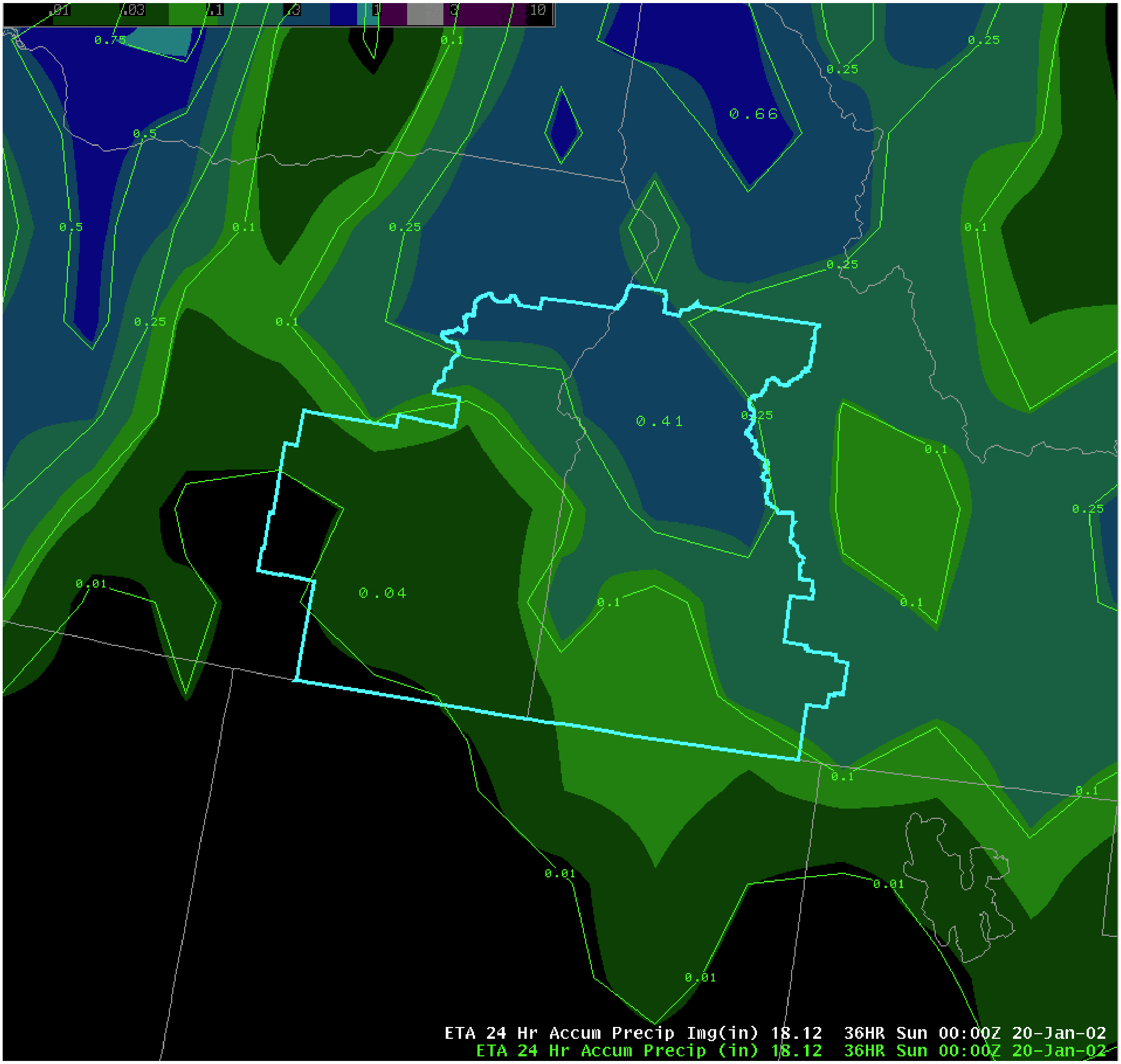
AVN 24 Hr Accum Precip Img(in) 18.18 54HR Mon 00:00Z 21-Jan-02
AVN 24 Hr Accum Precip (in) 18.18 54HR Mon 00:00Z 21-Jan-02

Figure 2a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ETA 24 Hr Accum Precip Img(in) 18.12 36HR Sun 00:00Z 20-Jan-02
ETA 24 Hr Accum Precip (in) 18.12 36HR Sun 00:00Z 20-Jan-02

Figure 2b

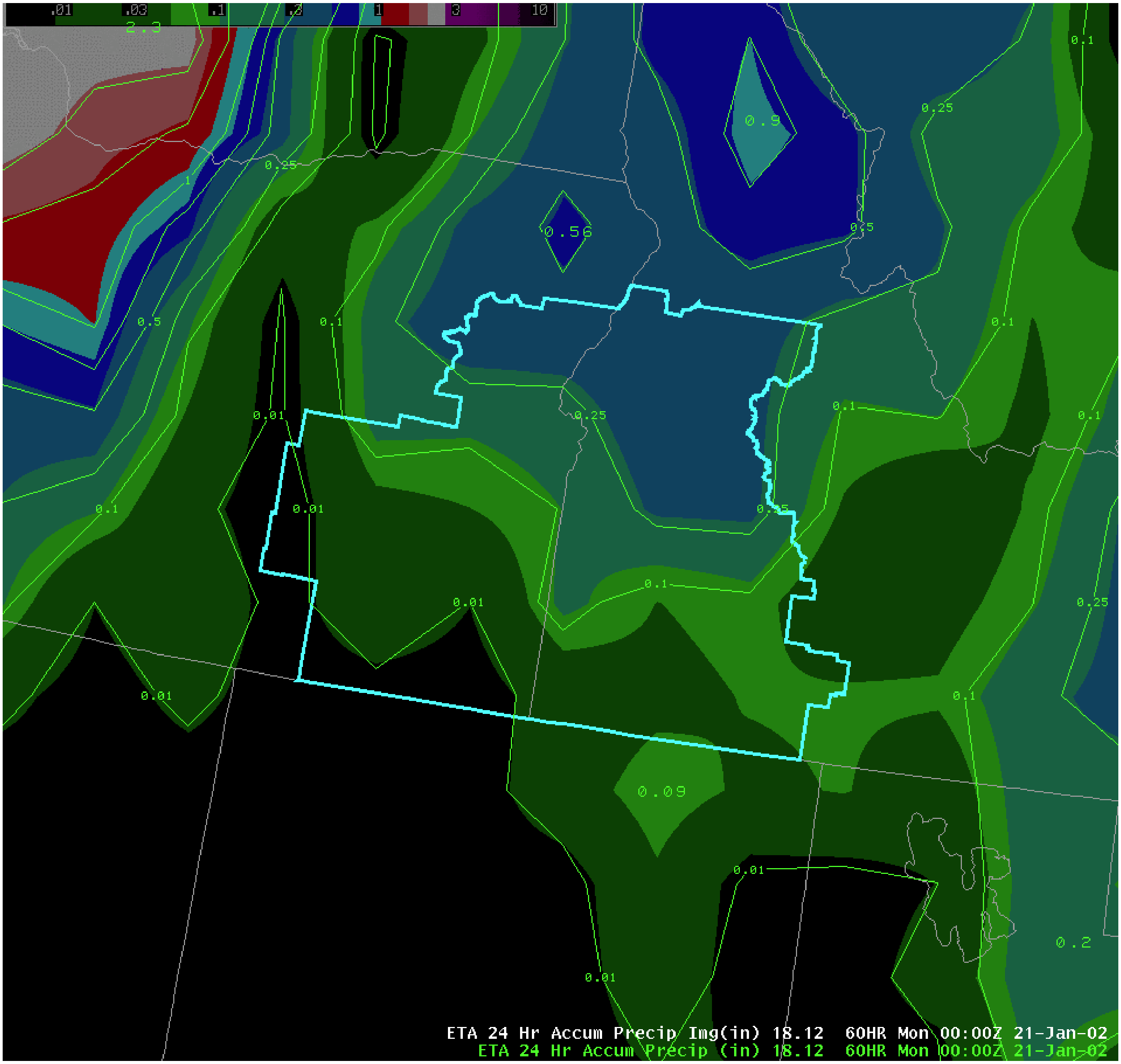
.01 .03 .1 .3 1 3 10
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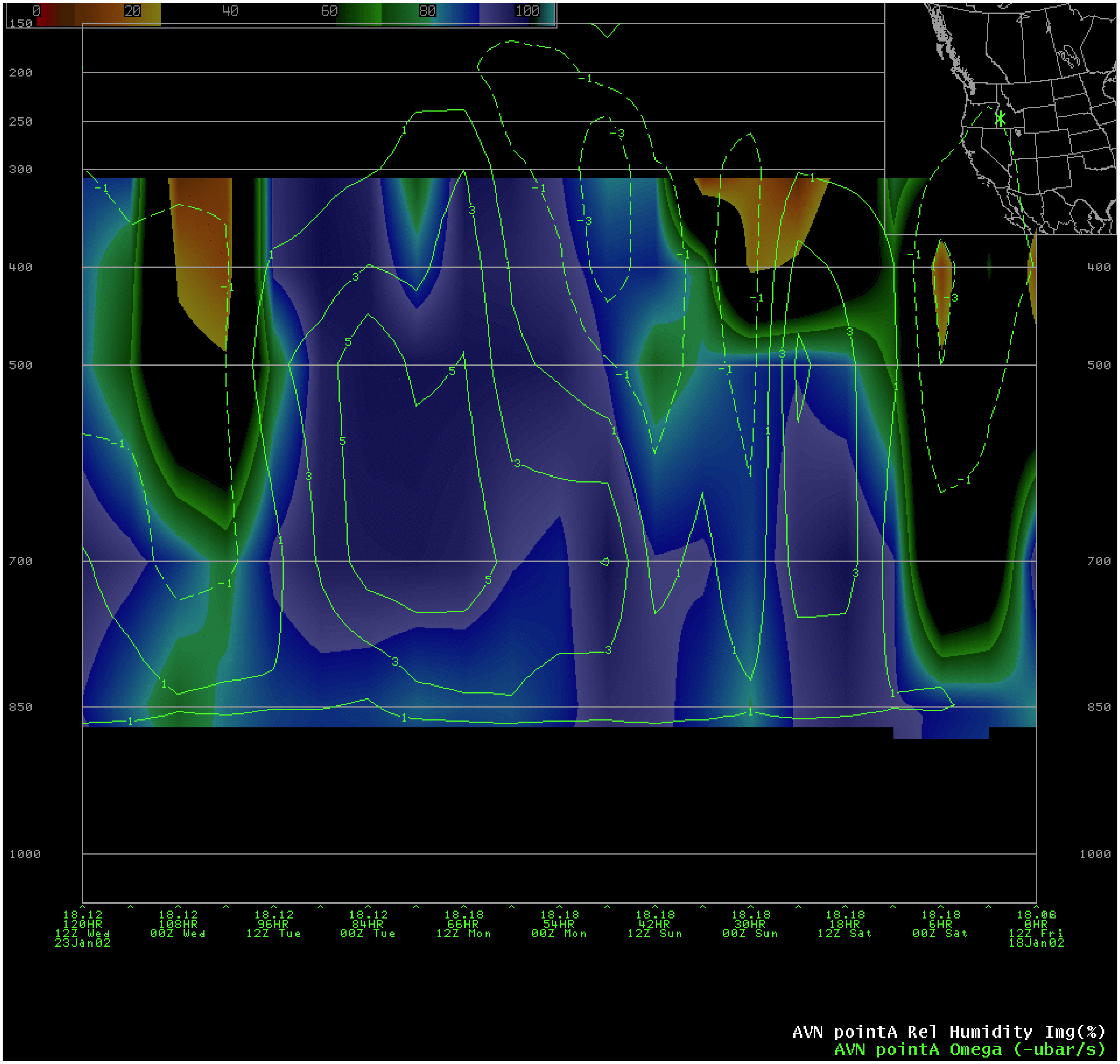
Figure 3



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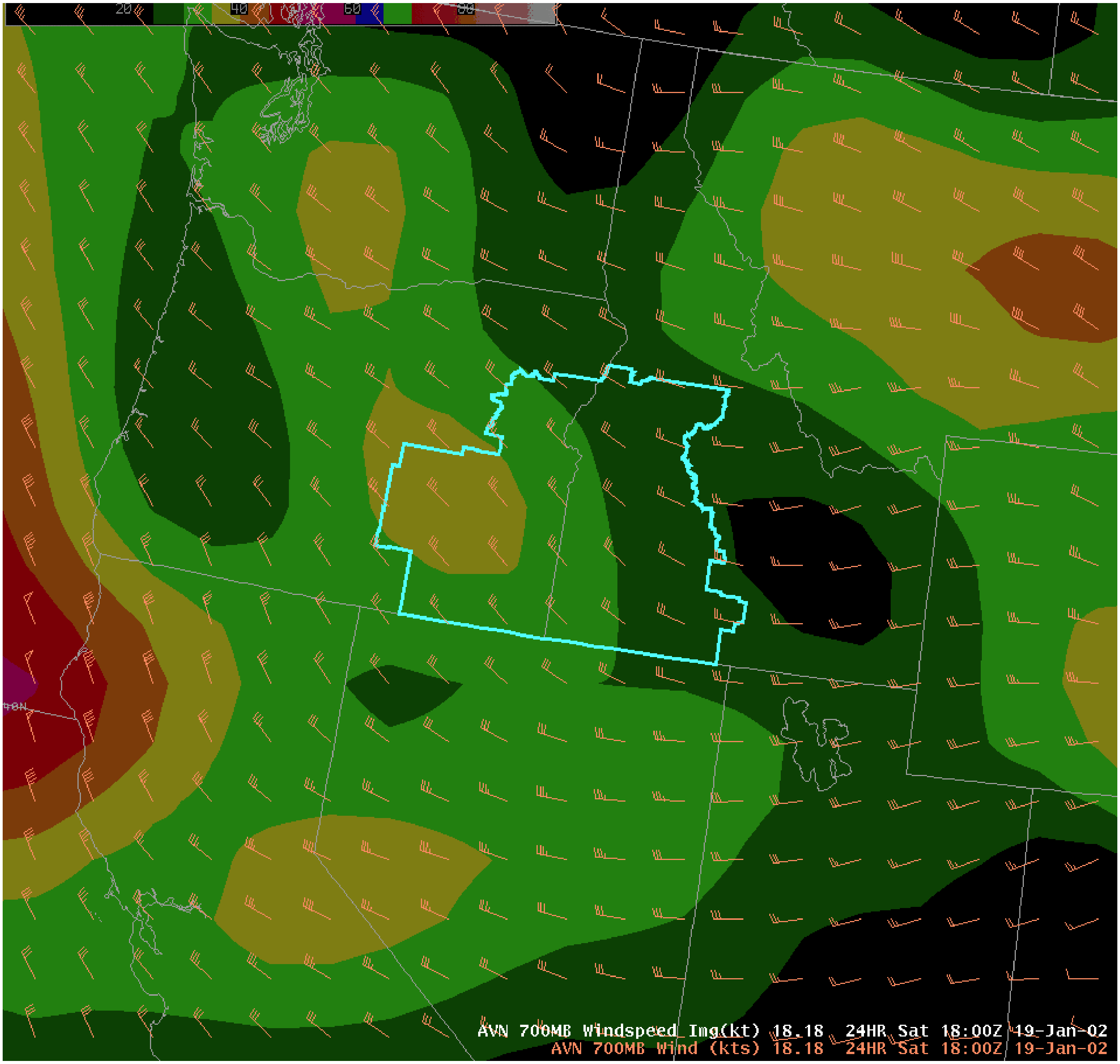
18.18 18HR 12Z Sat
18.18 6HR 00Z Sat
18.00 0HR 12Z Fri 18Jan02
AVN pointA Rel Humidity Img(%)
AVN pointA Omega (-ubar/s)

Figure 4a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AVN 700MB Wind (kts) 18.18 24HR Sat 18:00Z 19-Jan-02

Figure 4b

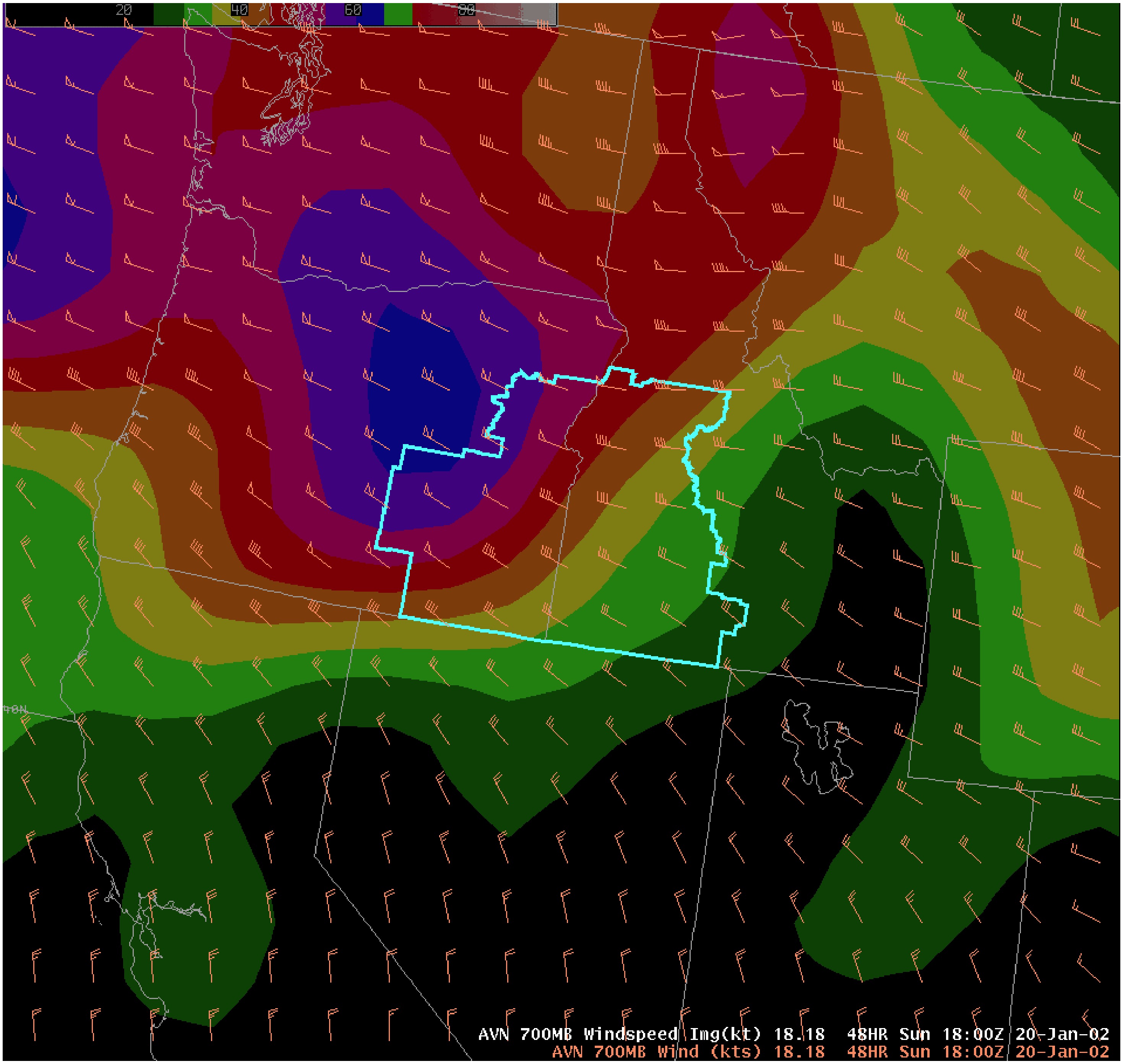
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Figure 5a

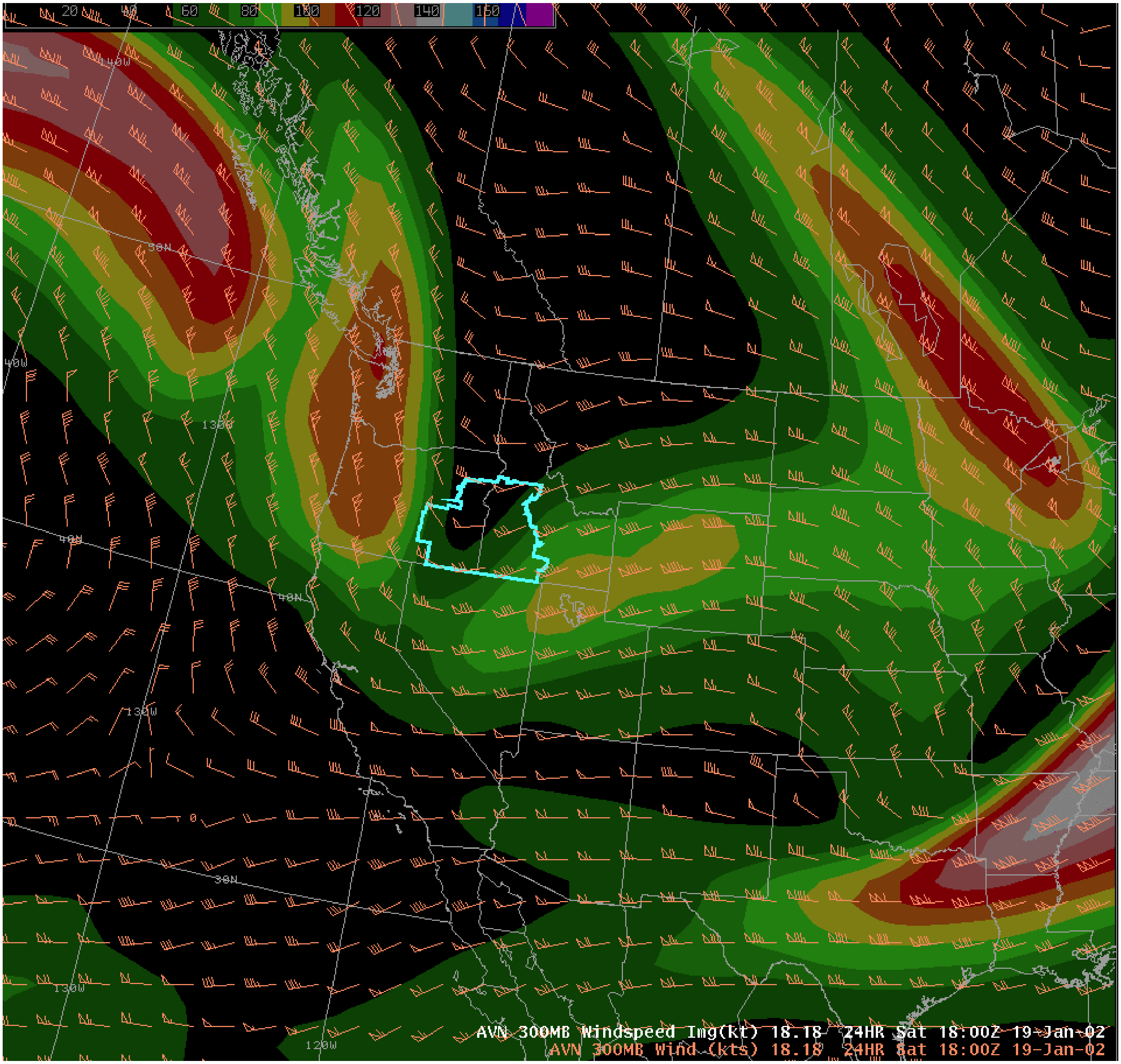
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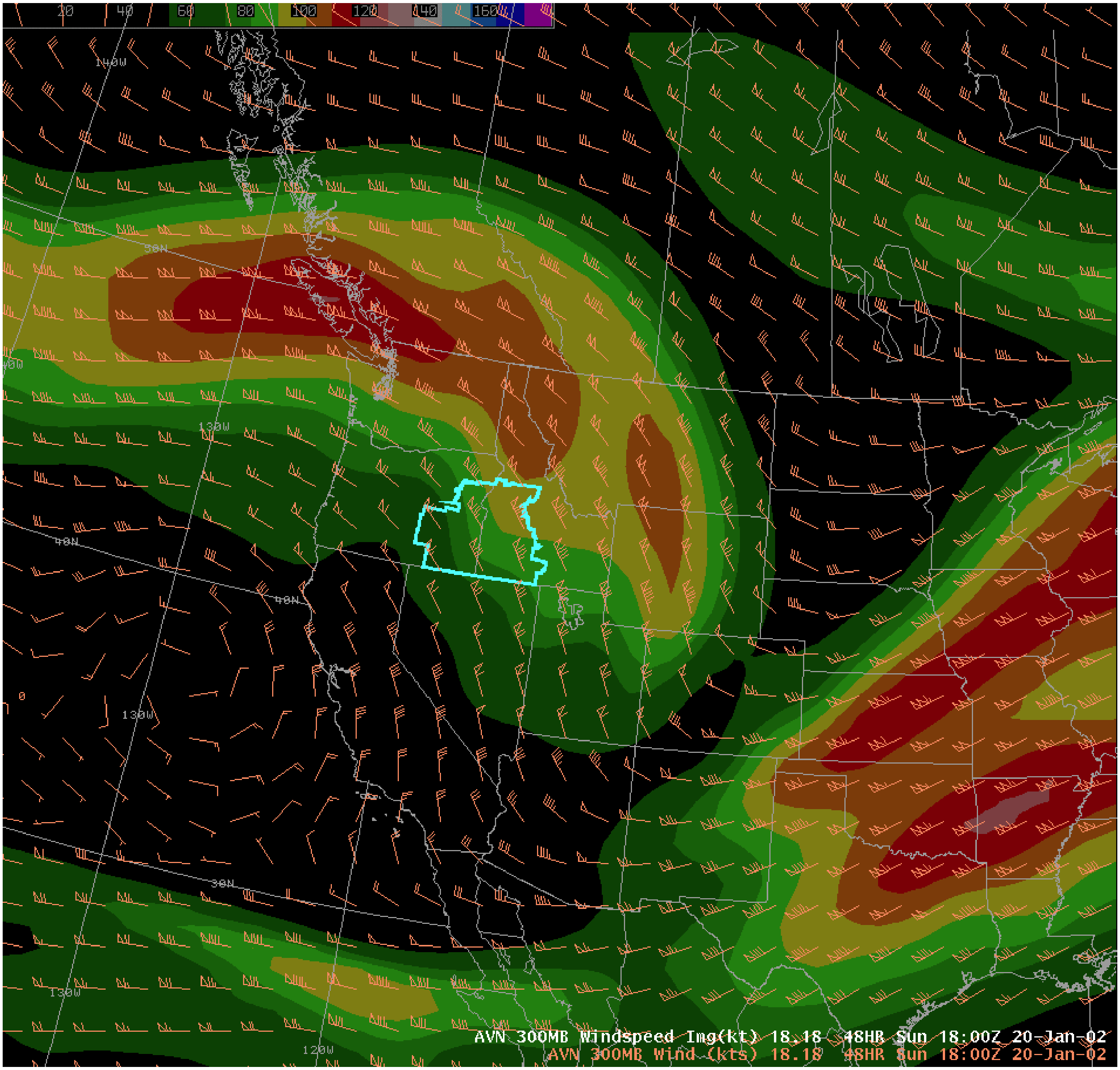
Figure 5b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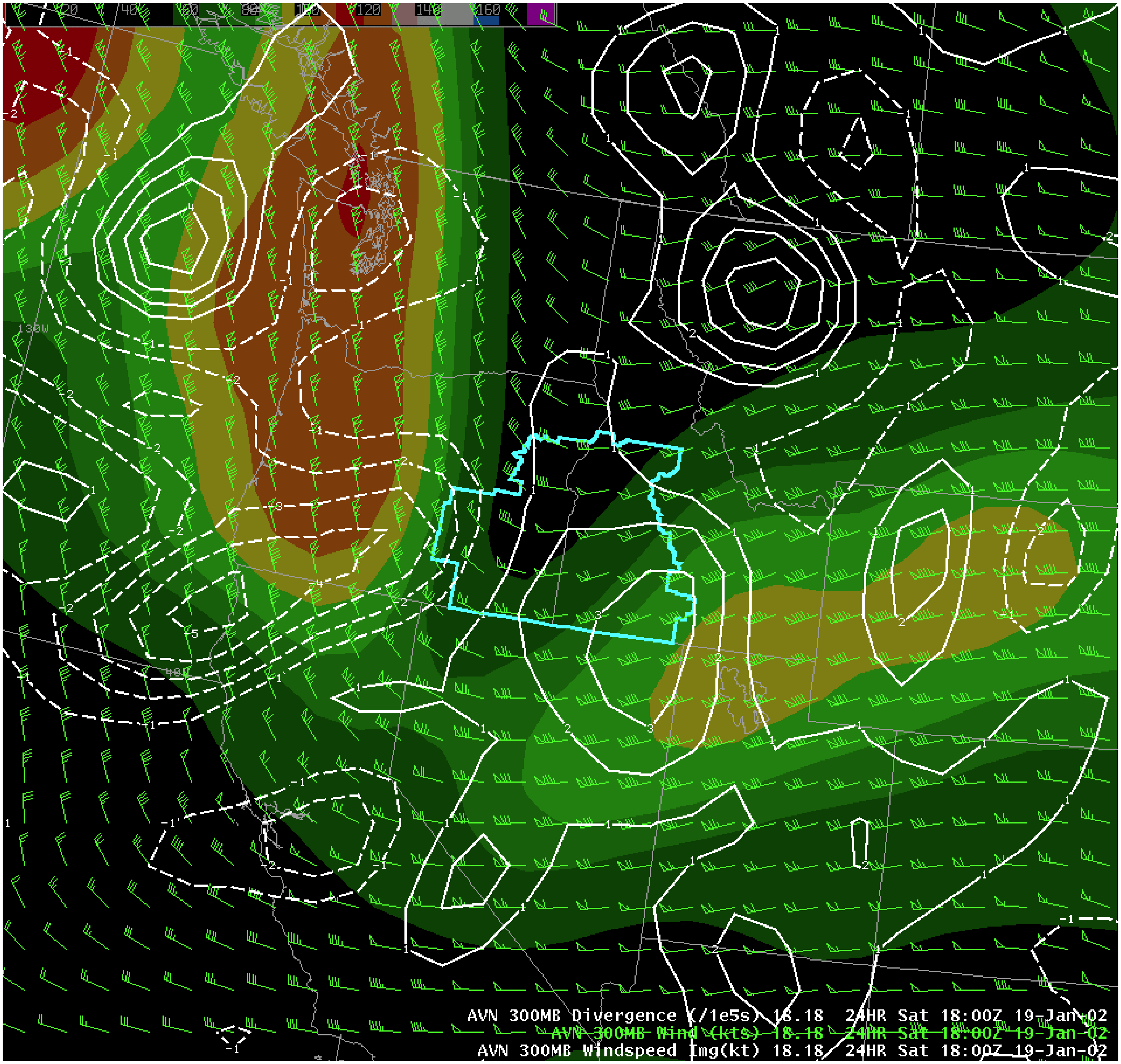
AVN 300MB Wind (kts) 18.18 48HR Sun 18:00Z 20-Jan-02

Figure 6a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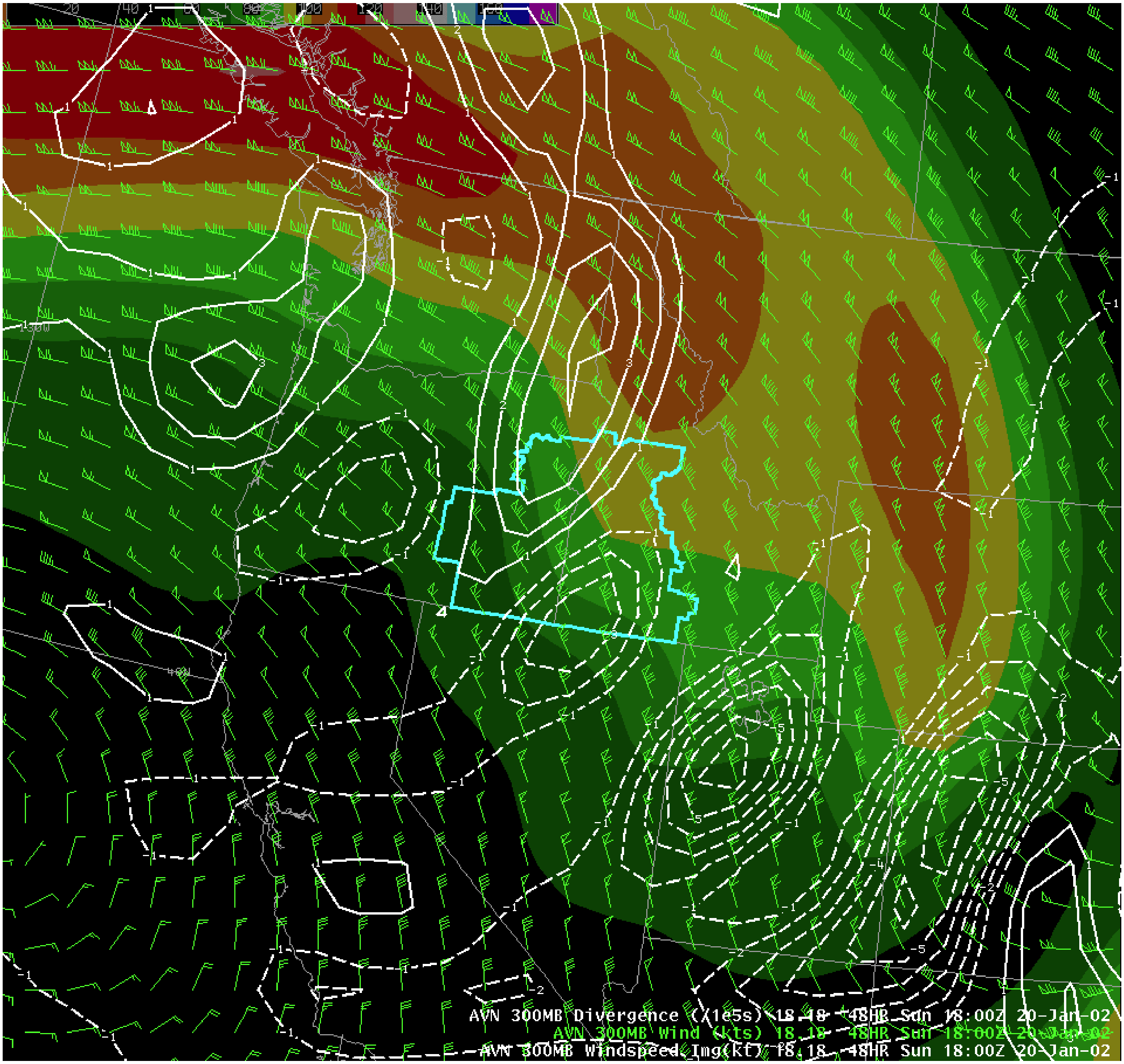
AVN 300MB Divergence (/1e5s) 18.18 24HR Sat 18:00Z 19-Jan-02
AVN 300MB Wind (kts) 18.18 24HR Sat 18:00Z 19-Jan-02
AVN 300MB Windspeed Img(kt) 18.18 24HR Sat 18:00Z 19-Jan-02

Figure 6b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AVN 300MB Wind (kts) 18.18 48HR Sun 18:00Z 20-Jan-02
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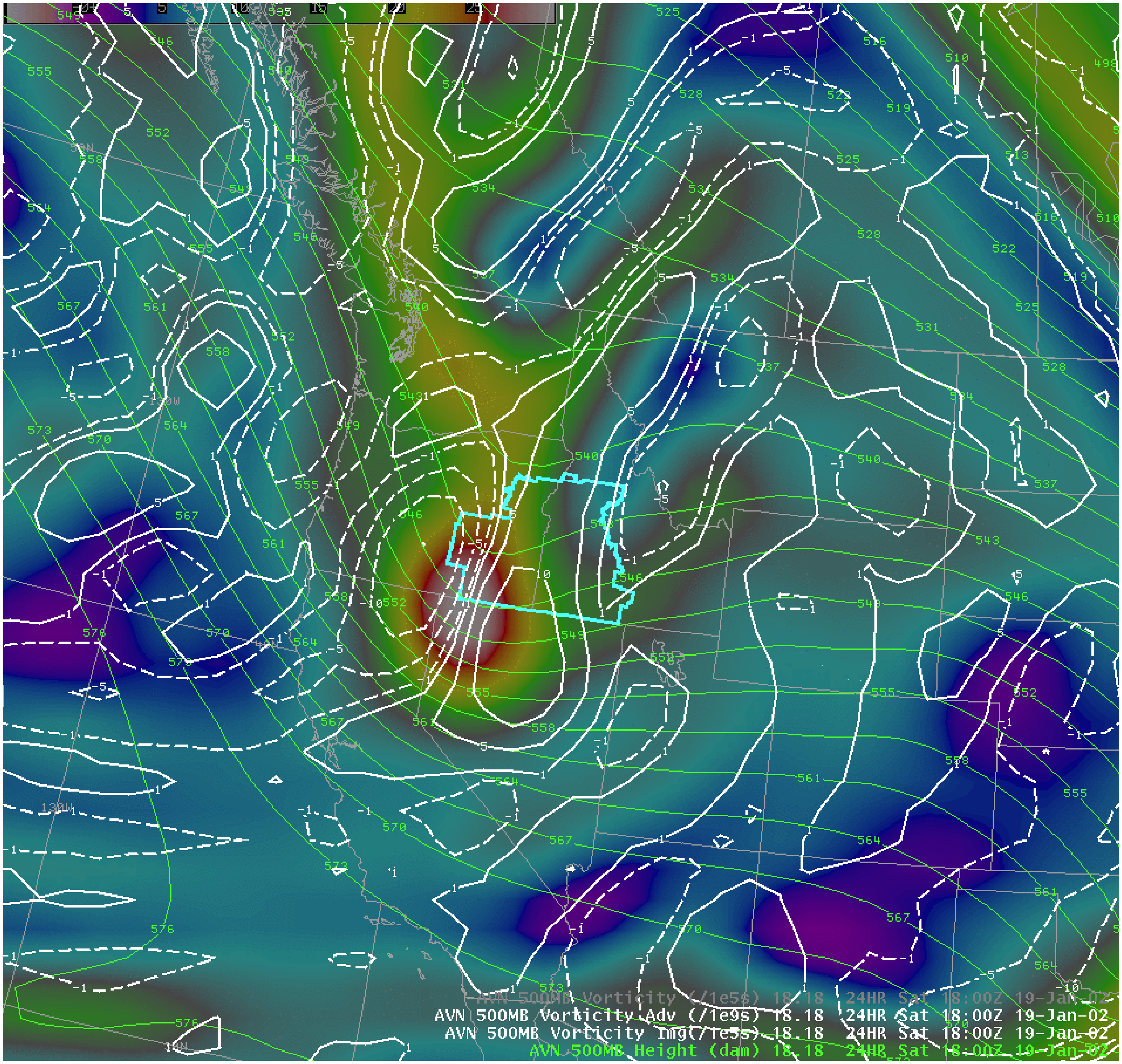
Figure 7a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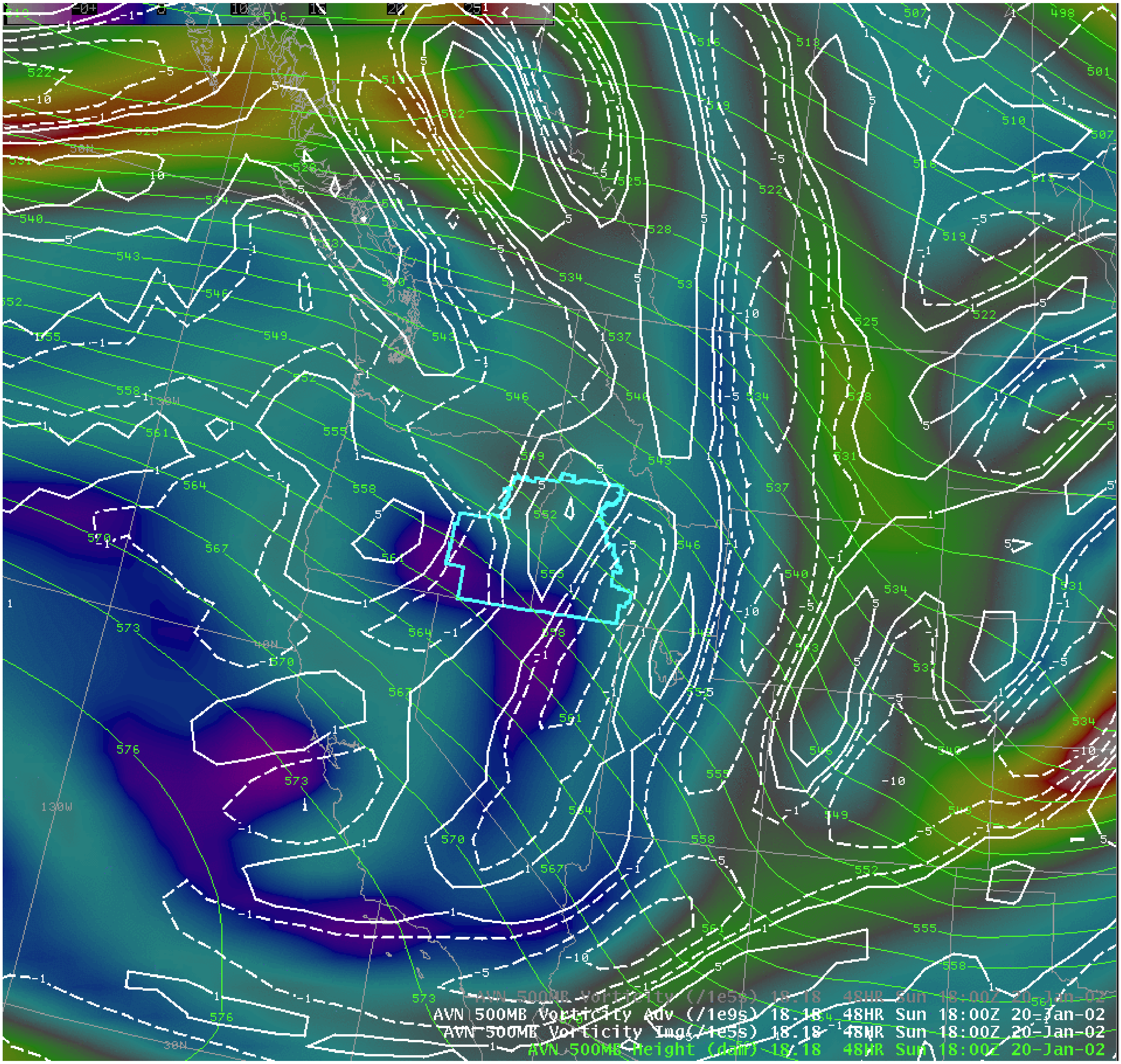
AVN 500MB Vorticity Adv (/1e9s) 18.18 24HR Sat 18:00Z 19-Jan-02
AVN 500MB Vorticity Img(/1e5s) 18.18 24HR Sat 18:00Z 19-Jan-02
AVN 500MB Height (dam) 18.18 24HR Sat 18:00Z 19-Jan-02

Figure 7b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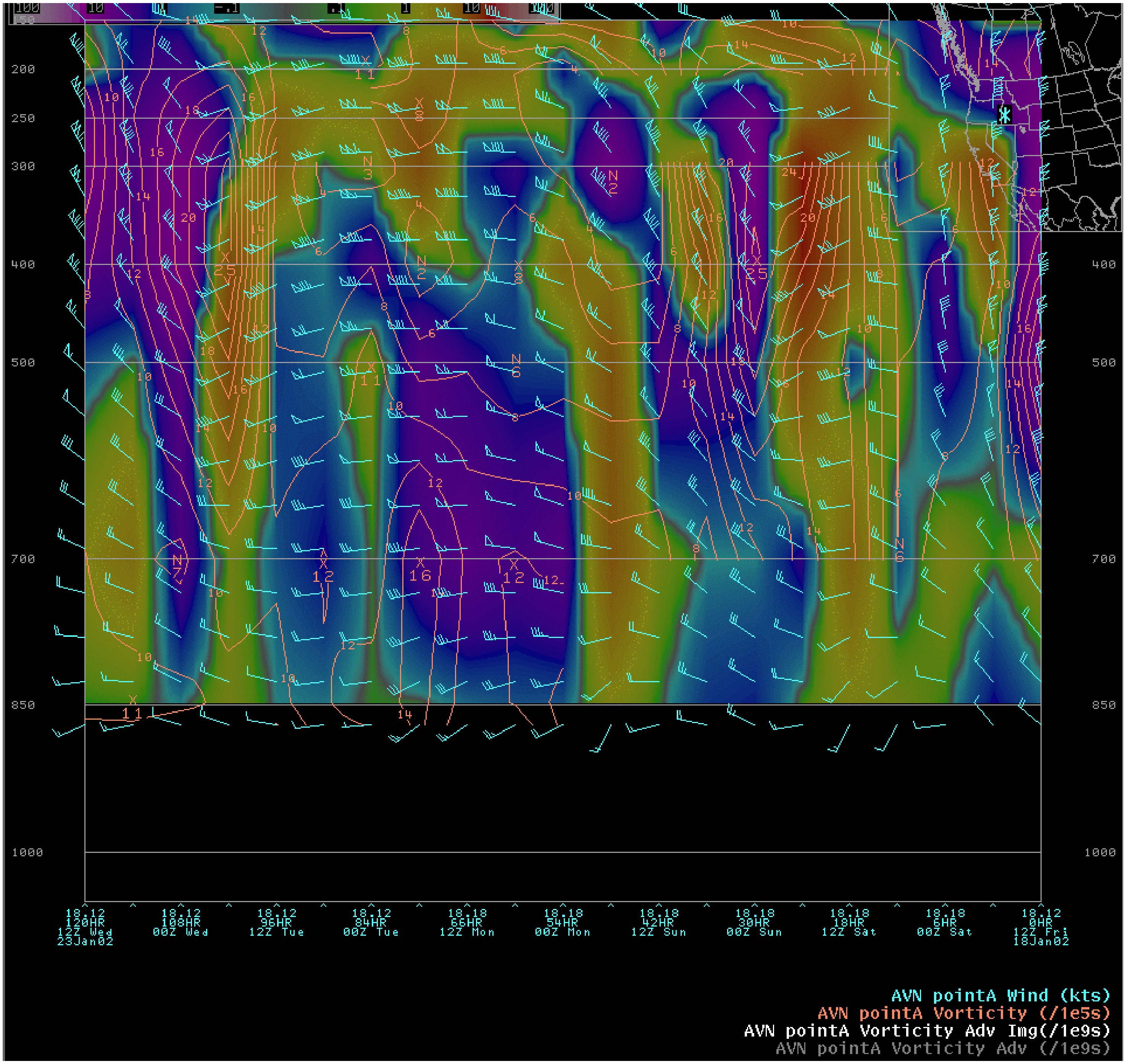
AVN 500MB Vorticity Adv (/1e9s) 18.18 48HR Sun 18:00Z 20-Jan-02
AVN 500MB Vorticity Img(/1e5s) 18.18 48HR Sun 18:00Z 20-Jan-02
AVN 500MB Height (dam) 18.18 48HR Sun 18:00Z 20-Jan-02

Figure 8



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18.18 18HR 12Z Sat
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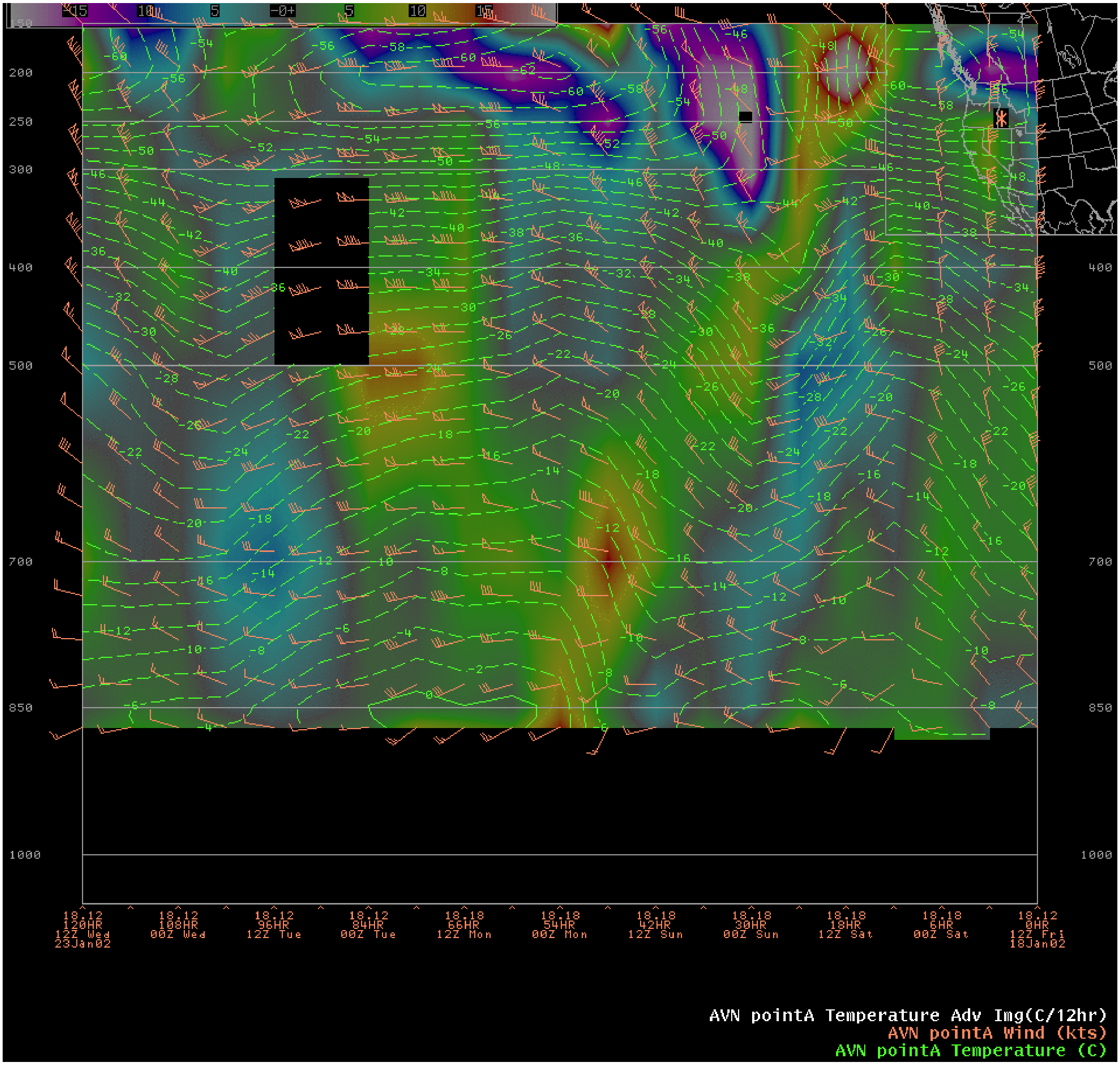
18.12 0HR 12Z Fri 18Jan02
AVN pointA Wind (kts)
AVN pointA Vorticity (/1e5s)
AVN pointA Vorticity Adv Img(/1e9s)
AVN pointA Vorticity Adv (/1e9s)

Figure 9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AVN pointA Wind (kts)
AVN pointA Temperature (C)
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18.12 84HR 00Z Tue
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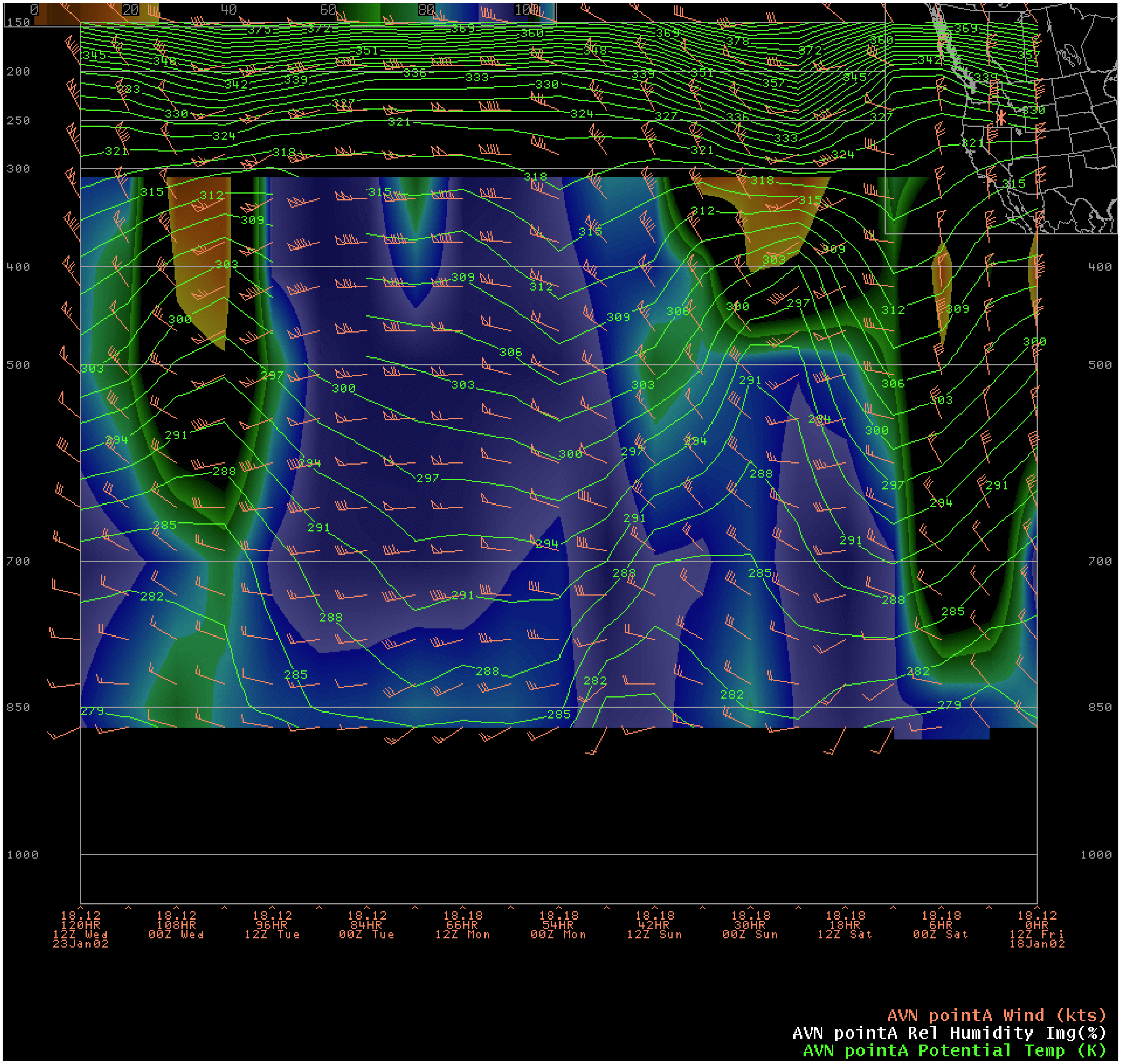
18.12 0HR 12Z Fri 18Jan02

Figure 10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AVN pointA Rel Humidity Img(%)
AVN pointA Potential Temp (K)
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18^12 108HR 00Z Wed
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18^18 6HR 00Z Sat
18^12 0HR 12Z Fri 18Jan02

Figure 11a

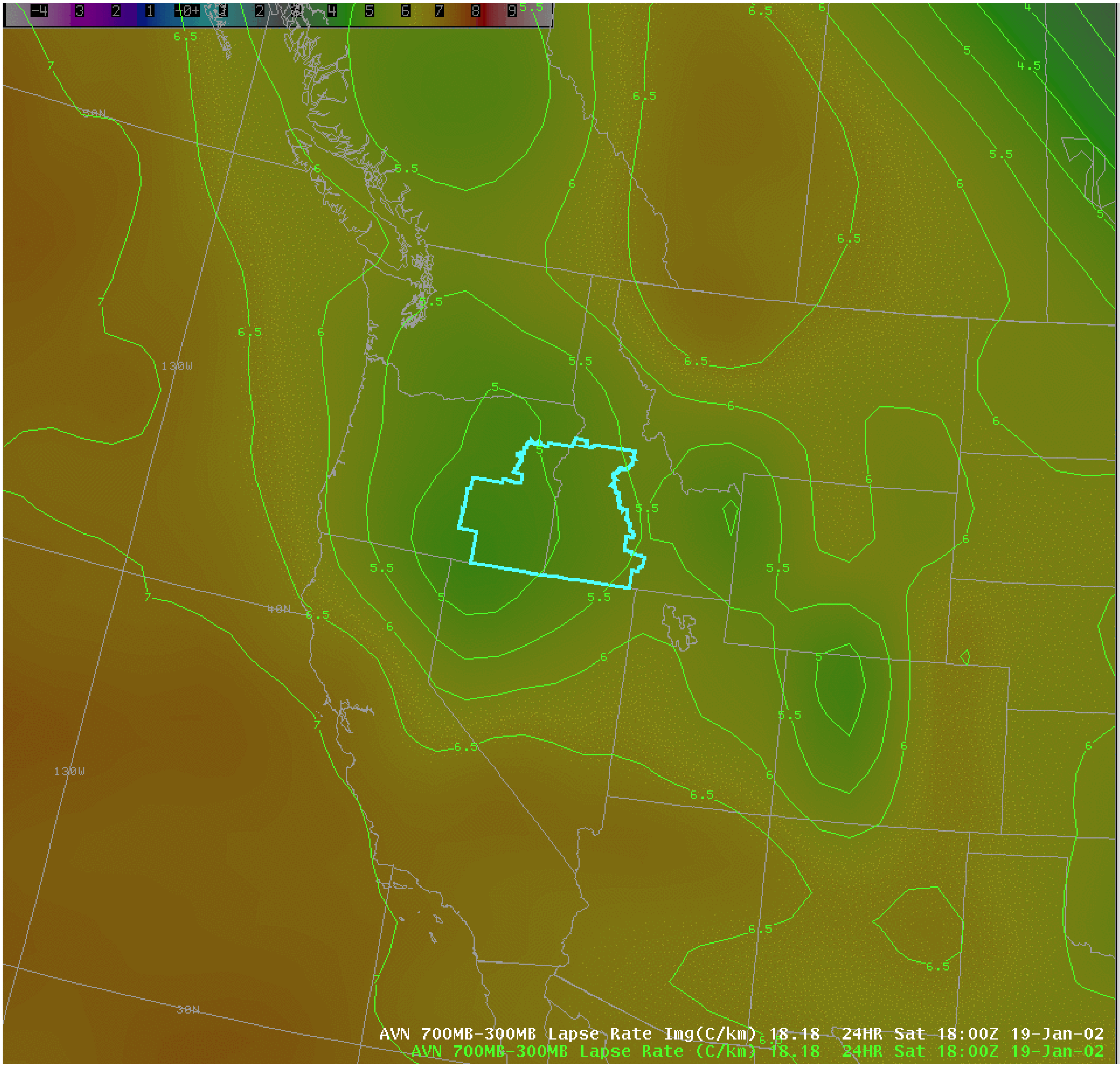
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Figure 11b

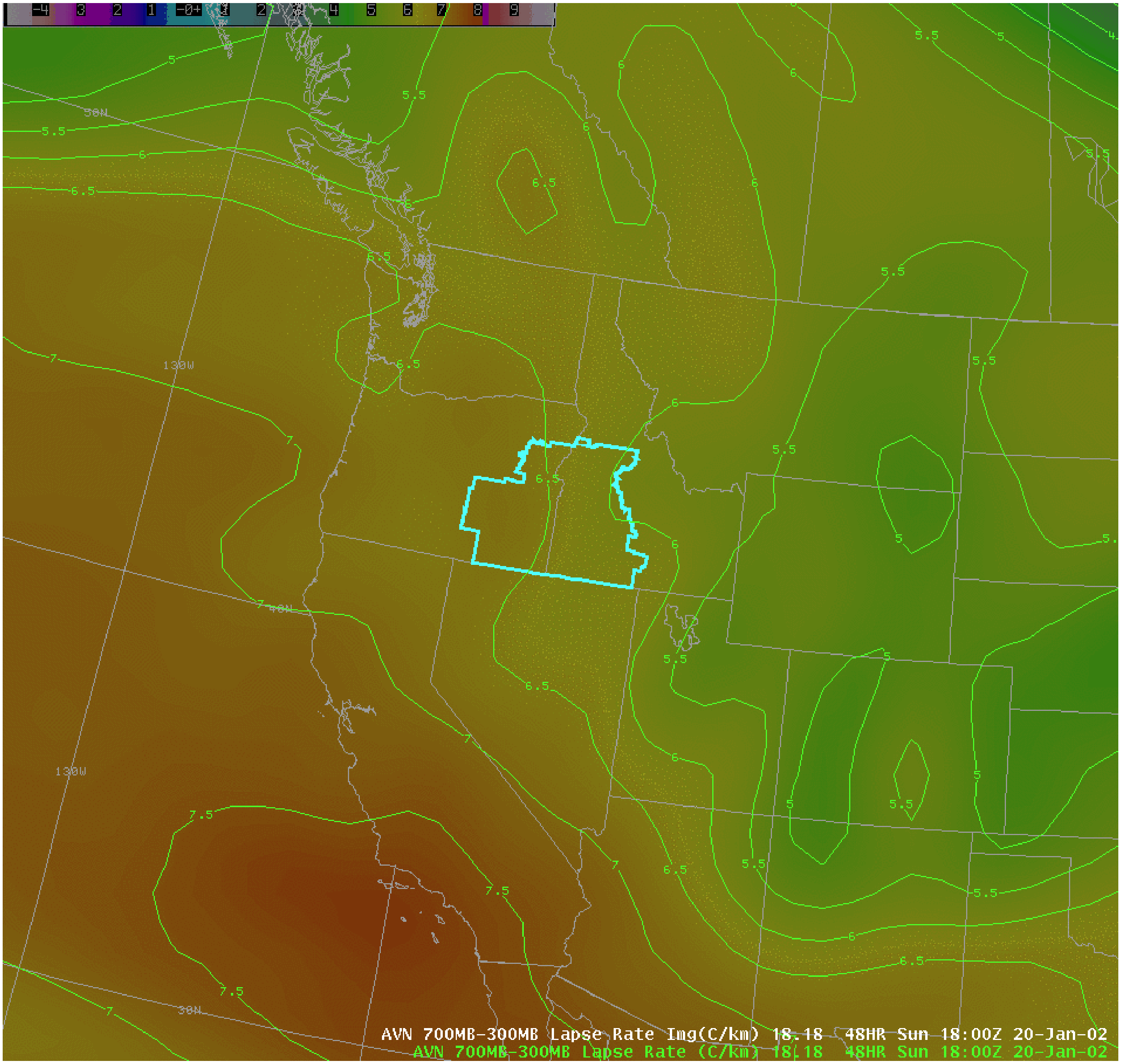
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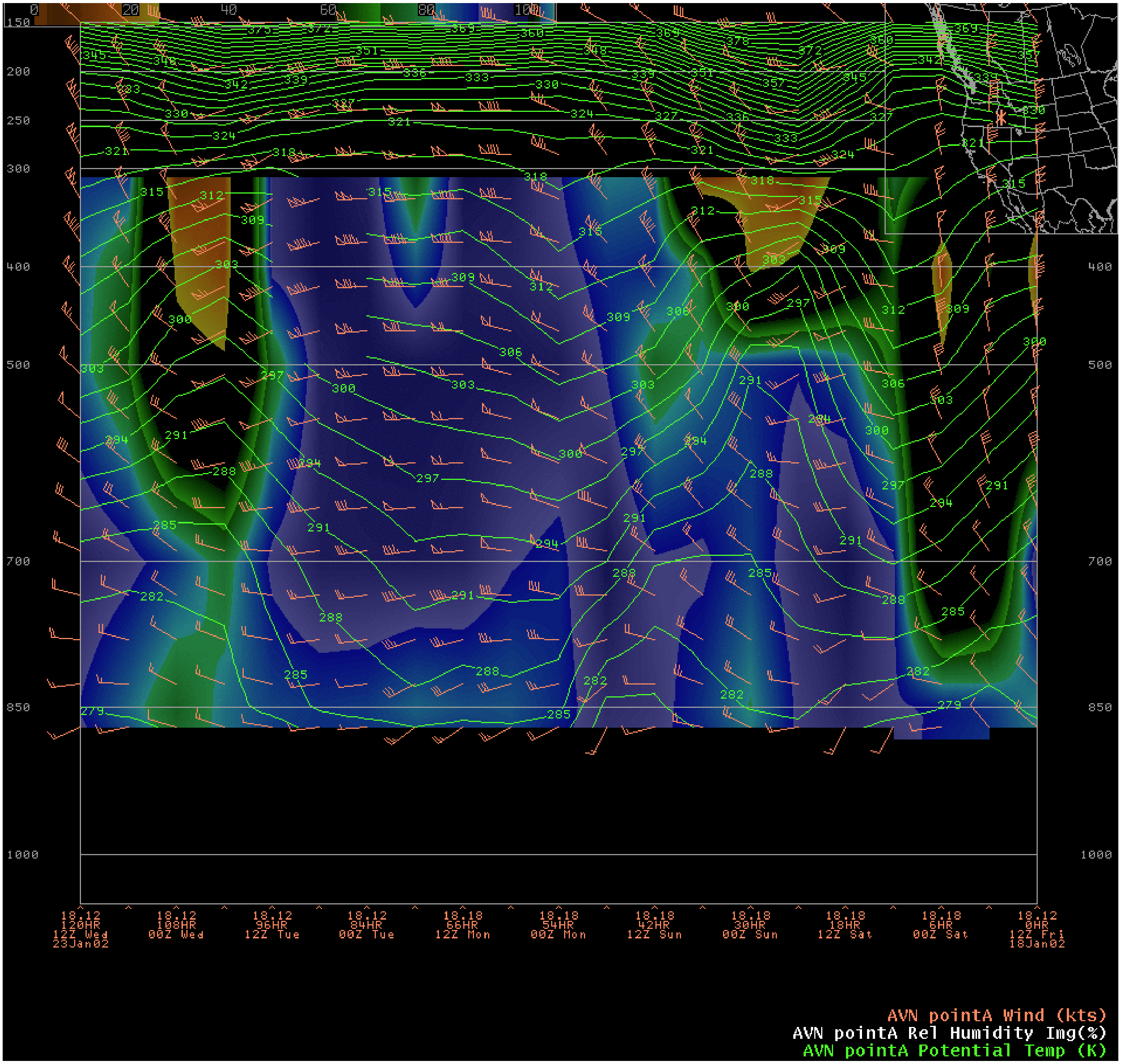
Figure 12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AVN pointA Potential Temp (K)
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Figure 13a

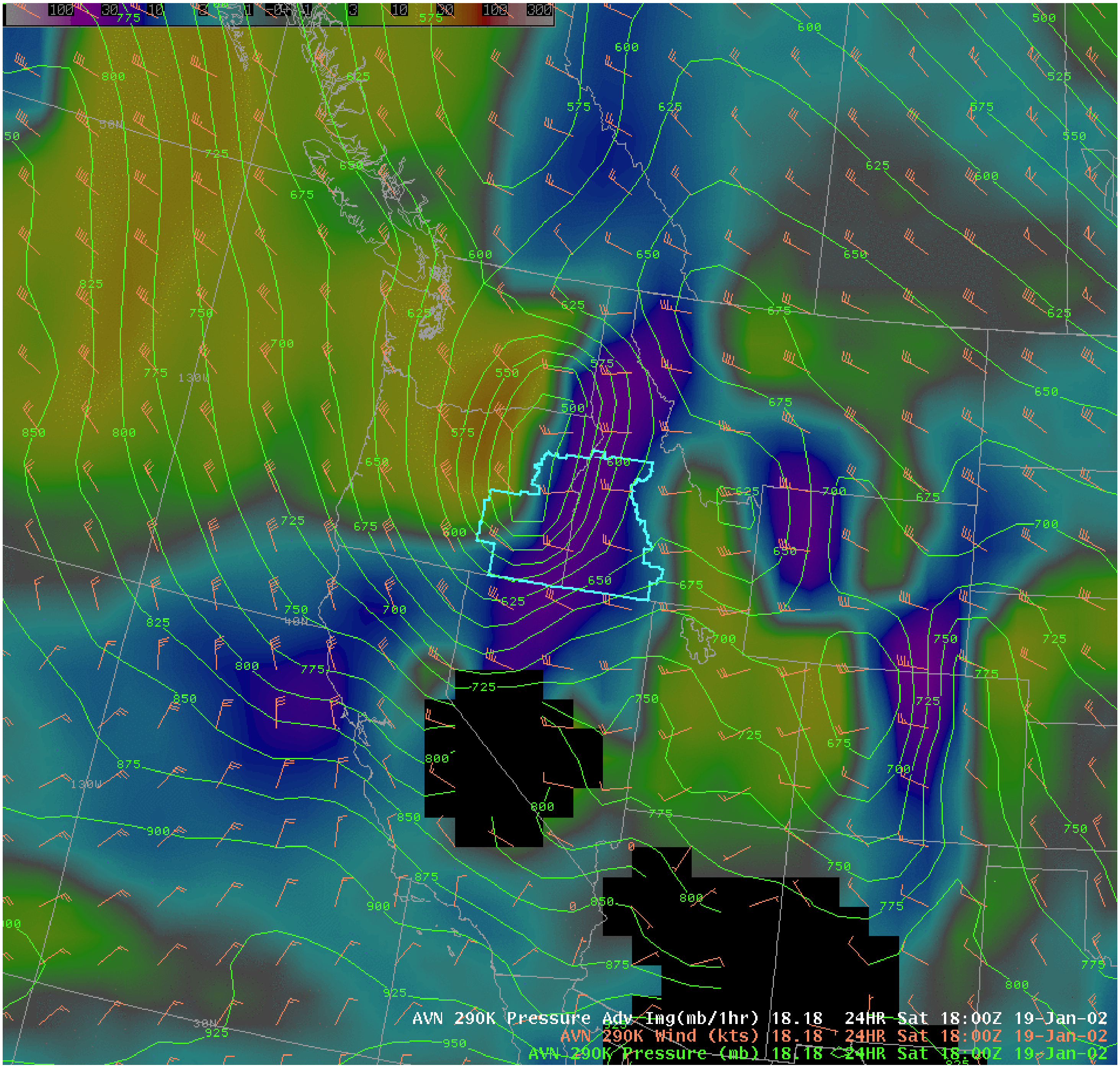
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Figure 13b

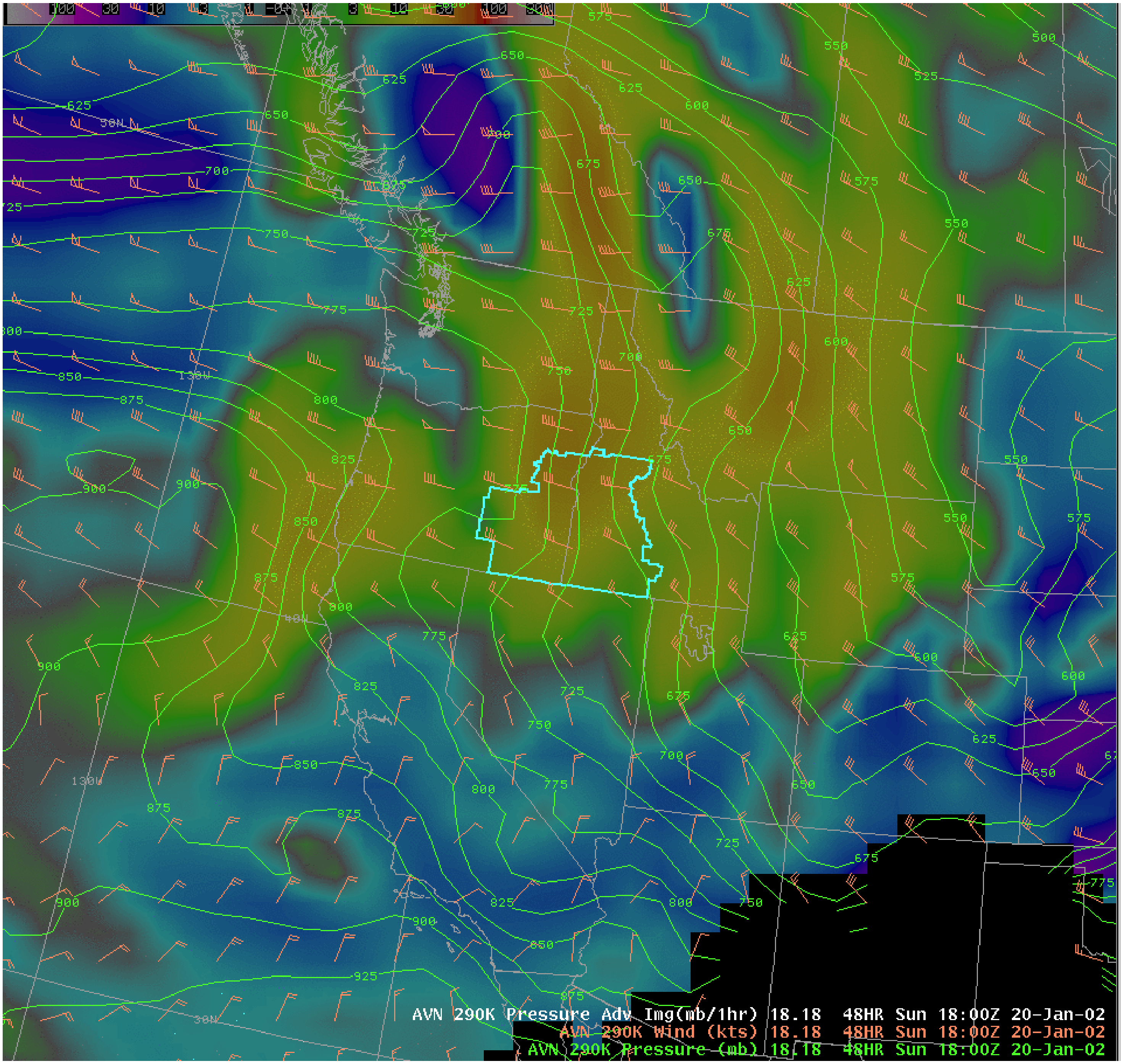
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Figure 14a

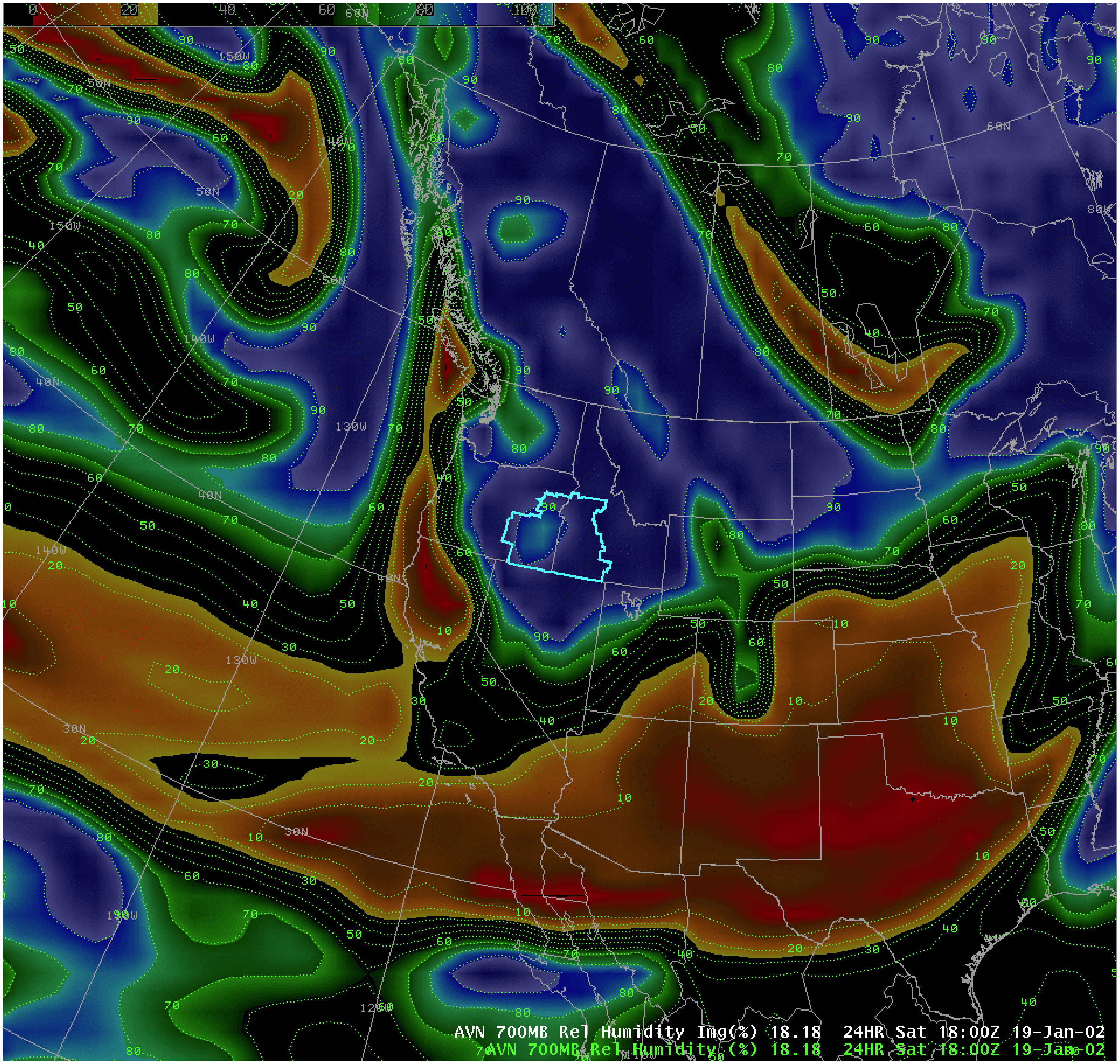
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Figure 14b

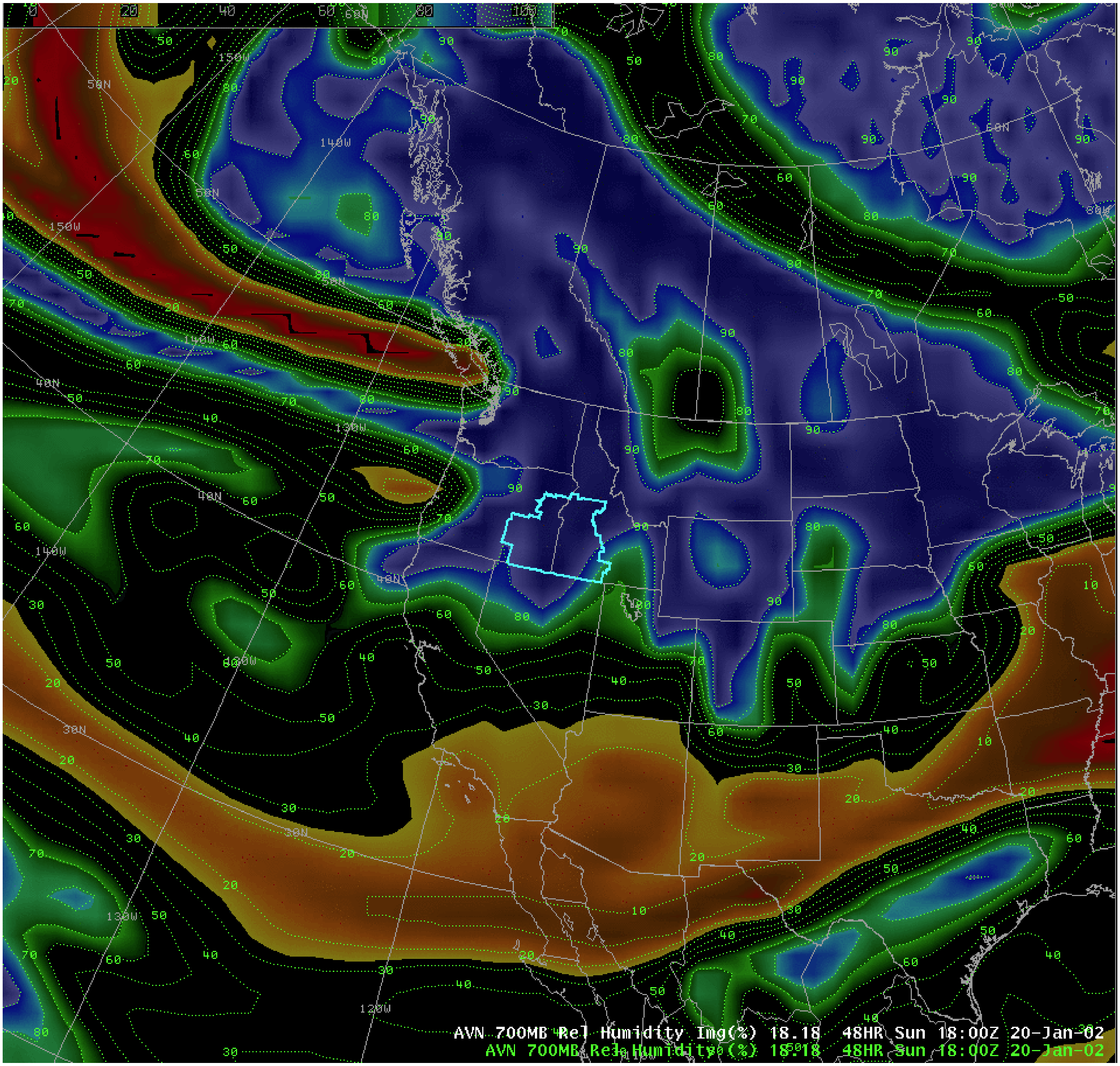
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Figure 15a

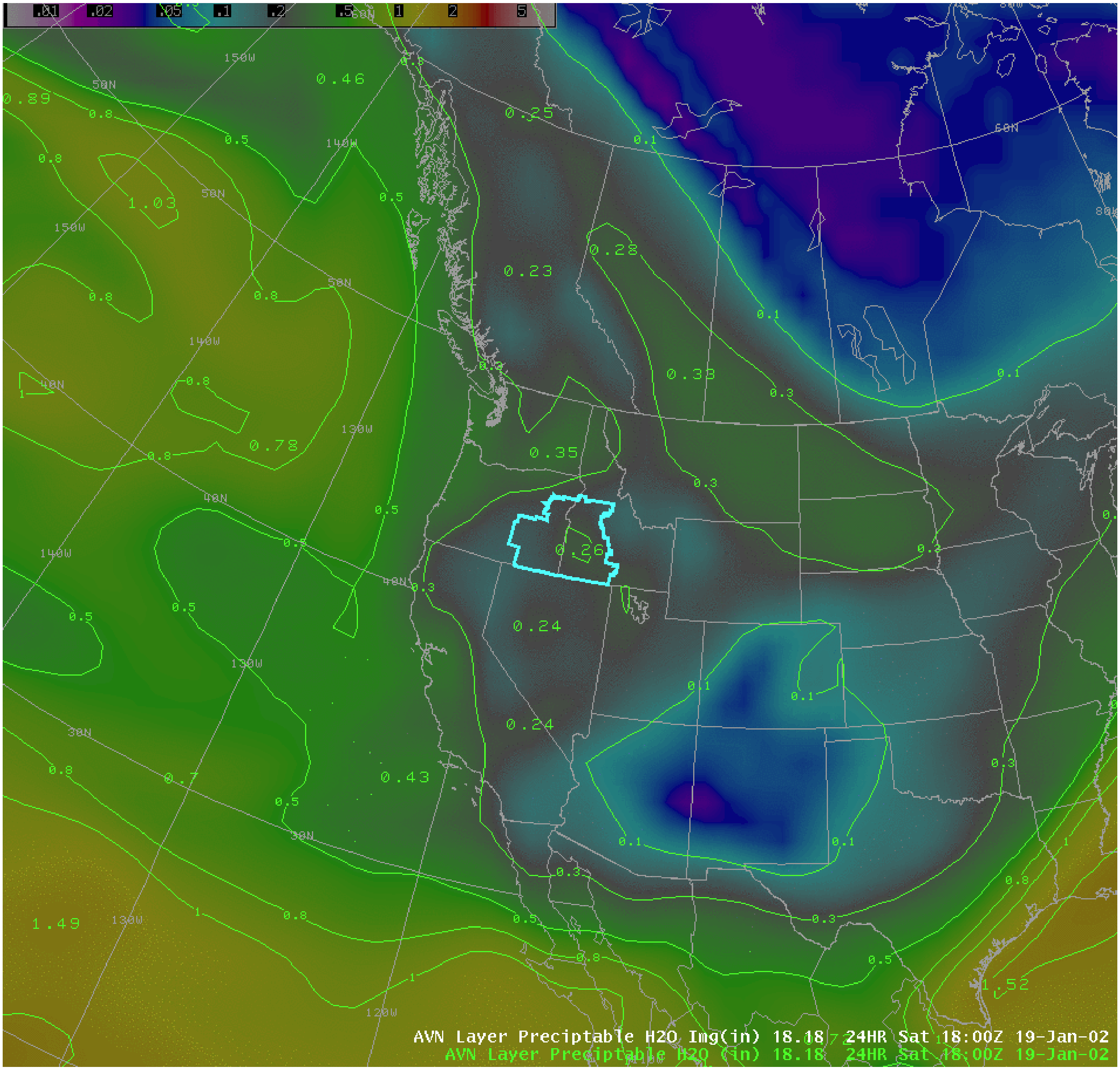
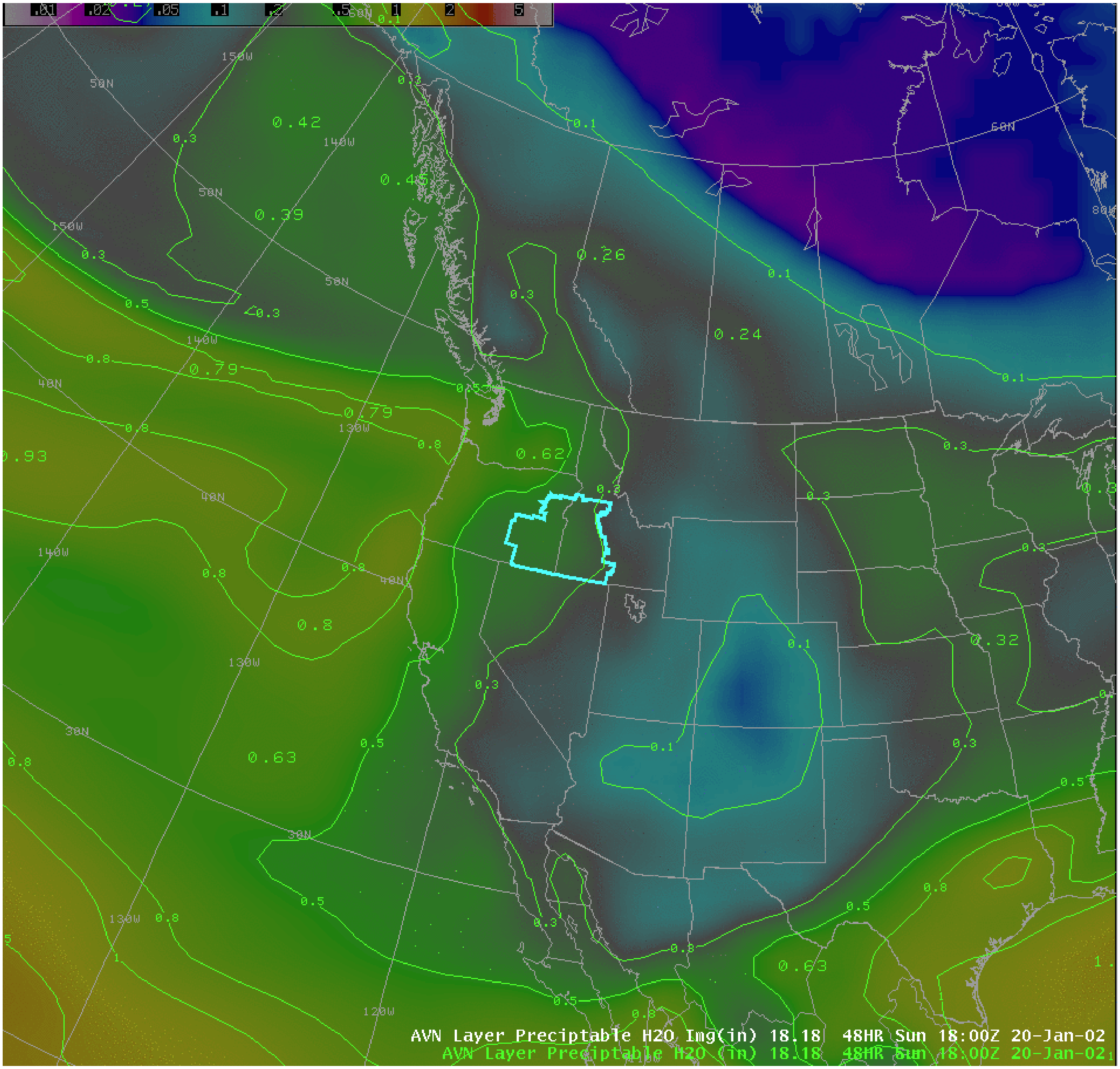

AVN Layer Preciptable H2O Img(in) 18.18 24HR Sat 18:00Z 19-Jan-02
AVN Layer Preciptable H2O (in) 18.18 24HR Sat 18:00Z 19-Jan-02

Figure 15b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AVN Layer Preciptable H2O (in) 18.18 48HR Sun 18:00Z 20-Jan-02

Figure 16

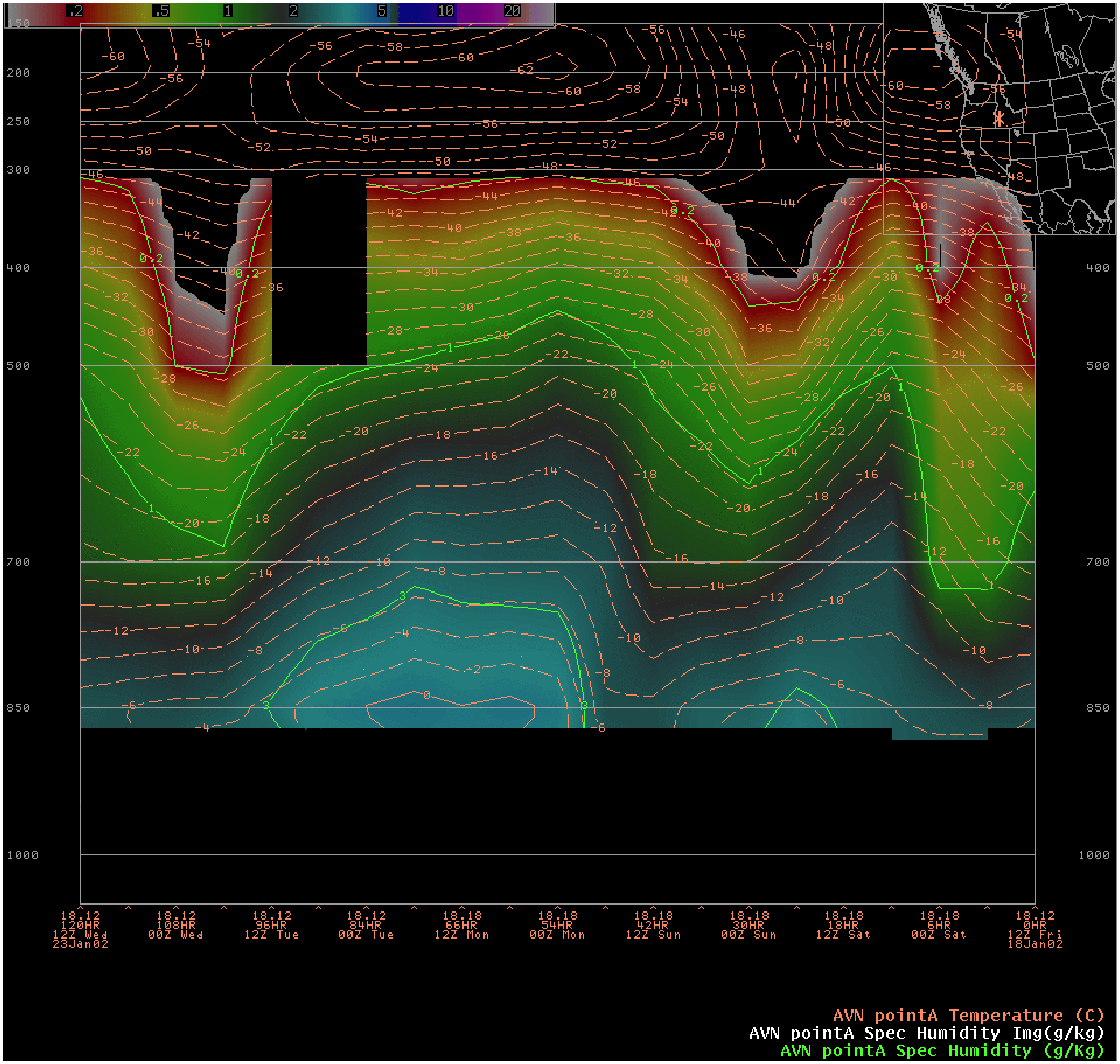

AVN pointA Temperature (C)
AVN pointA Spec Humidity Img(g/kg)
AVN pointA Spec Humidity (g/Kg)

Figure 17

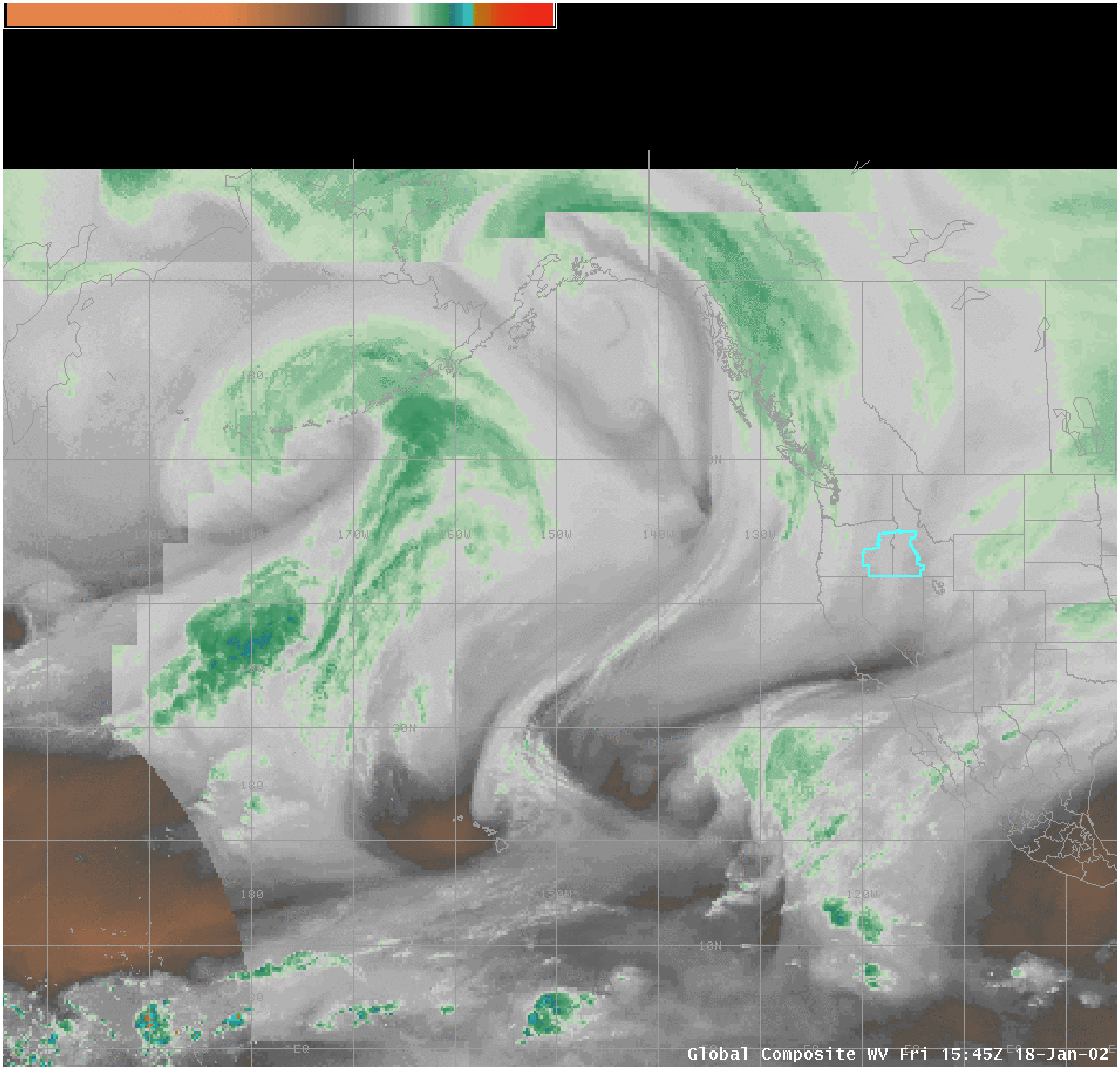


Figure 18

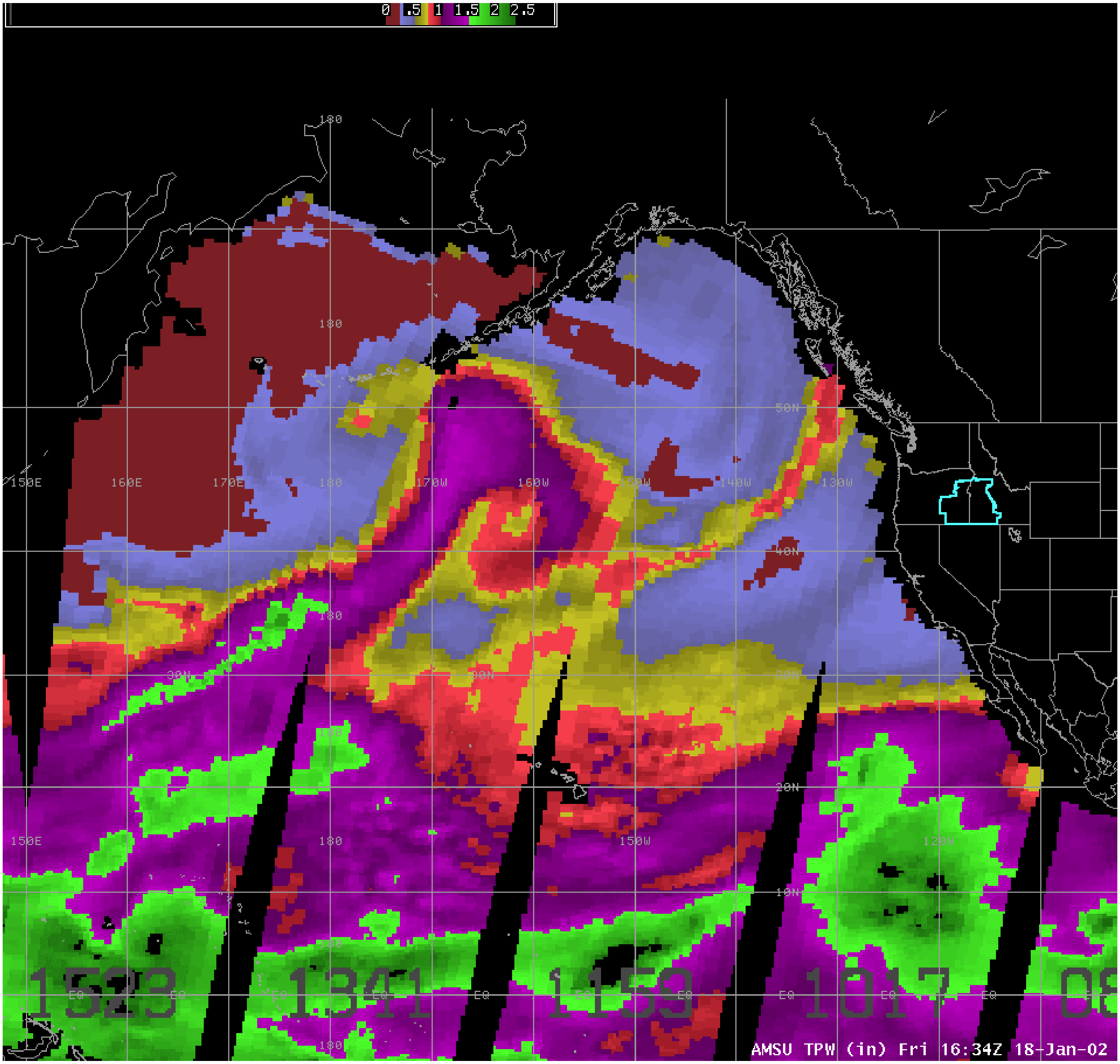


Figure 19

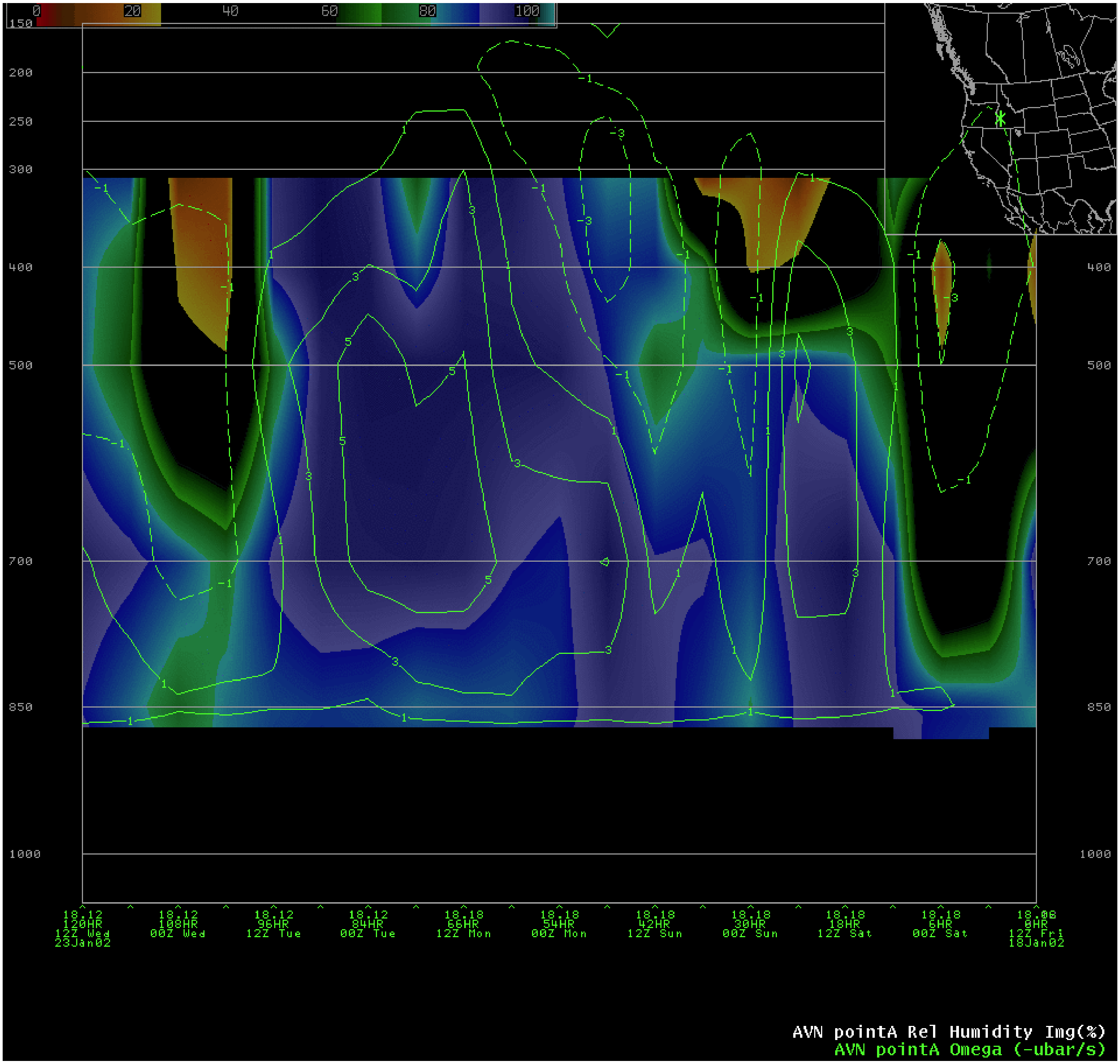
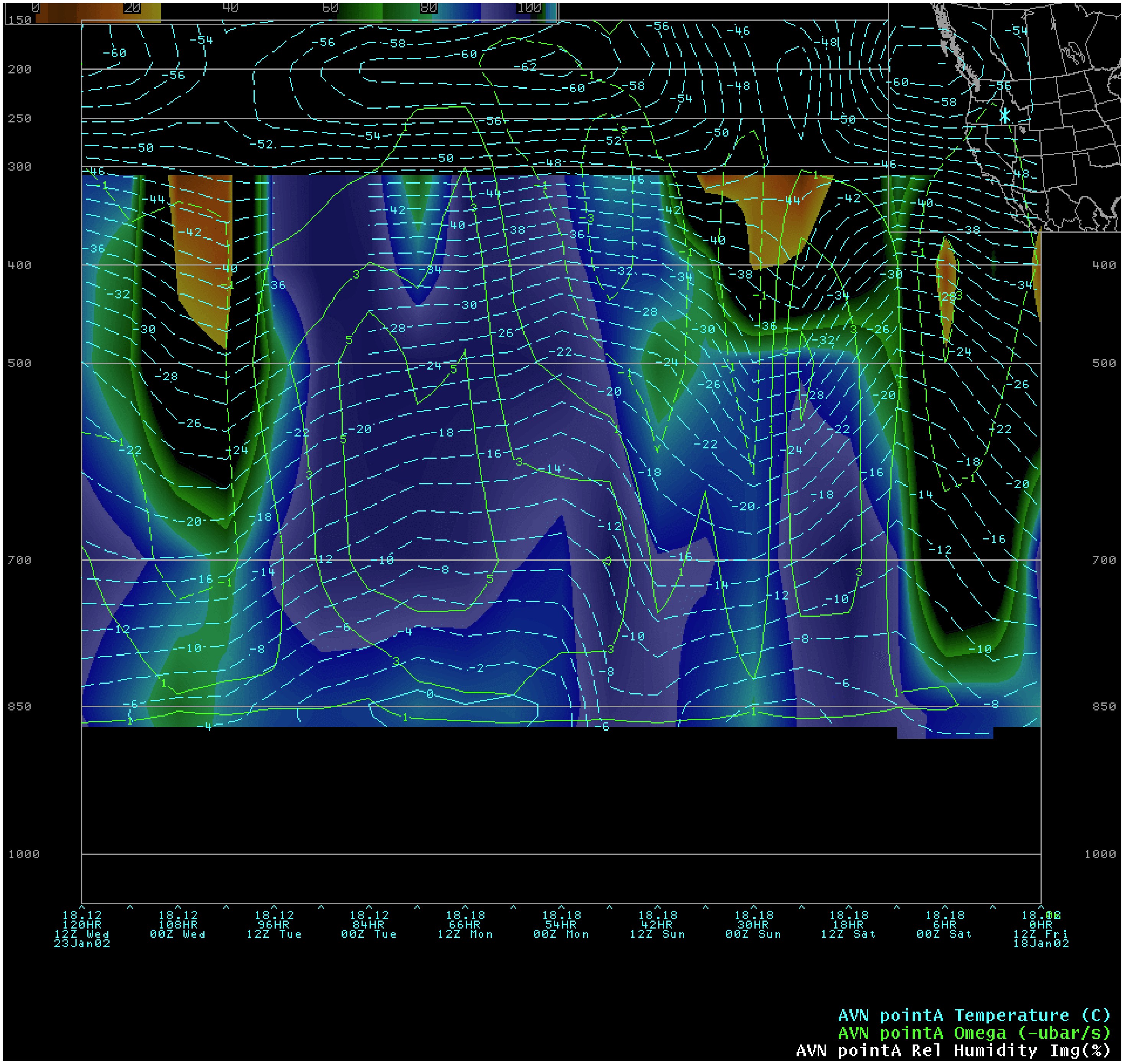

0
20
40
60
80
100
150
200
250
300
400
500
700
850
1000
18.12
120HR
12Z Wed
23Jan02
18.12
108HR
00Z Wed
18.12
96HR
12Z Tue
18.12
84HR
00Z Tue
18.18
66HR
12Z Mon
18.18
54HR
00Z Mon
18.18
42HR
12Z Sun
18.18
30HR
00Z Sun
18.18
18HR
12Z Sat
18.18
6HR
00Z Sat
18.00
0HR
12Z Fri
18Jan02
AVN pointA Rel Humidity Img(%)
AVN pointA Omega (-ubar/s)

Figure 20



AVN pointA Temperature (C)
AVN pointA Omega (-ubar/s)
AVN pointA Rel Humidity Img(%)

Figure 21a

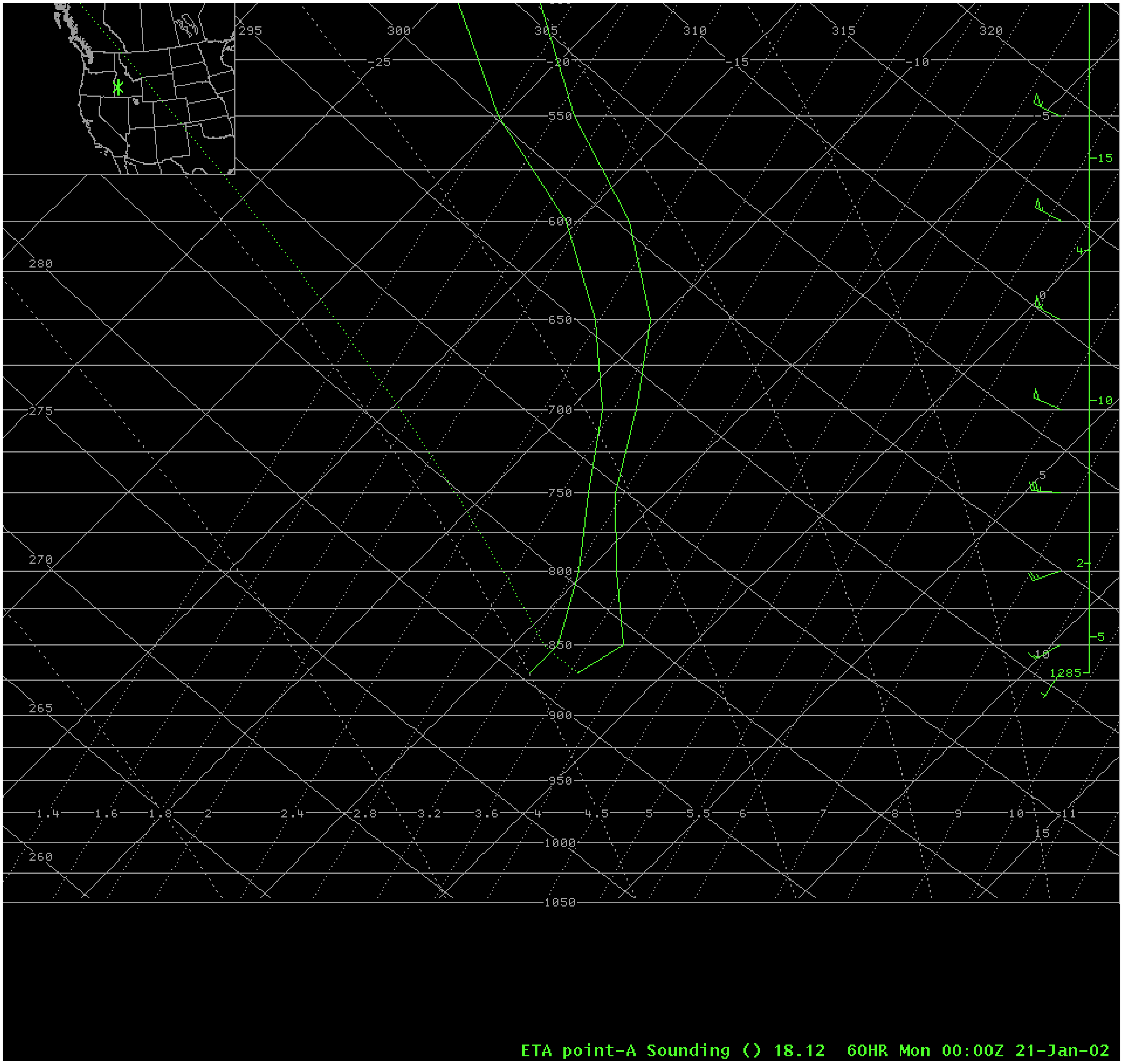


Figure 21b

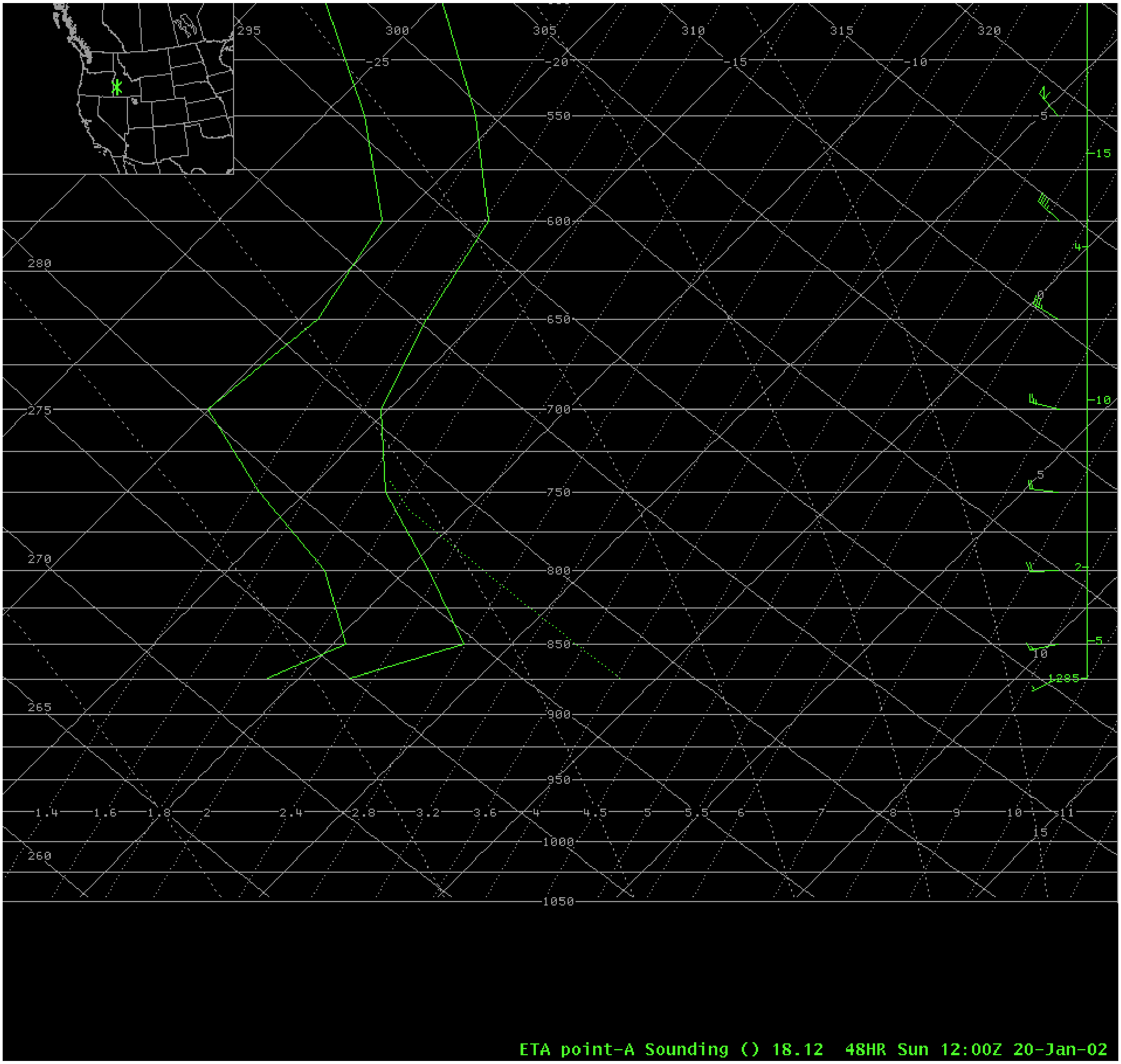


Figure 22a

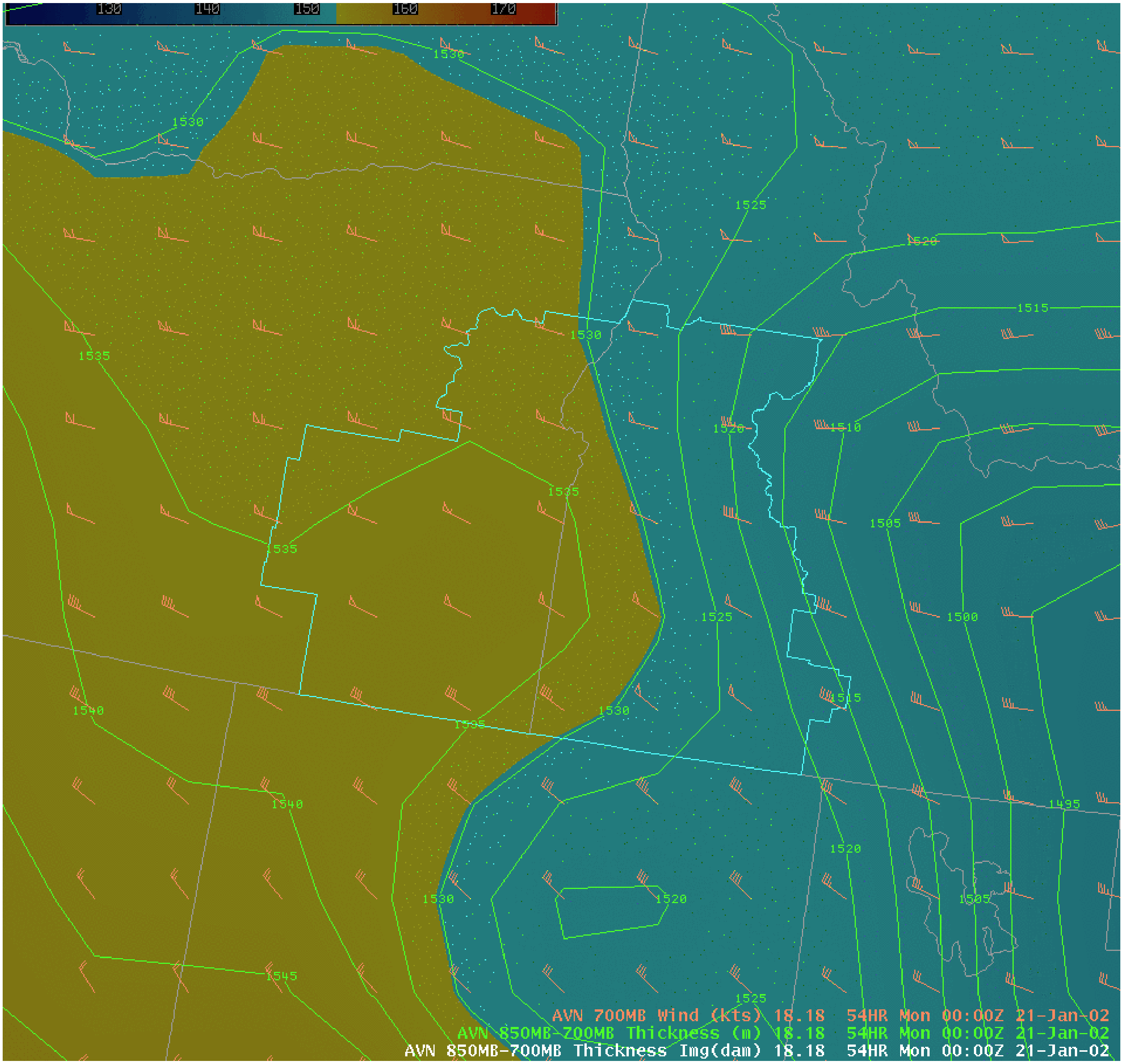
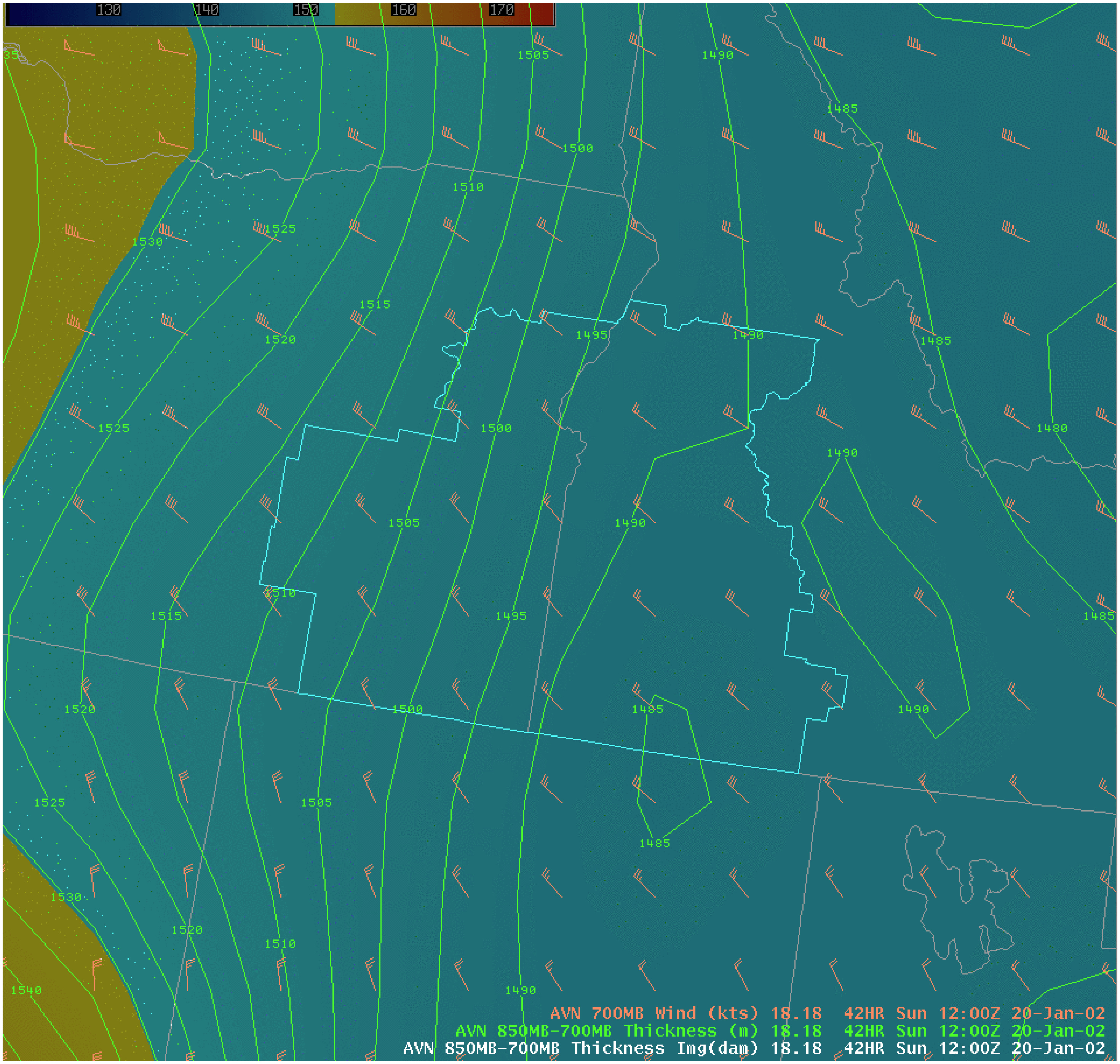

130
140
150
160
170
1530
1530
1525
1520
1515
1535
1530
1520
1510
1535
1505
1535
1525
1500
1540
1530
1515
1535
1540
1495
1520
1530
1520
1505
1545
1525
AVN 700MB Wind (kts) 18.18 54HR Mon 00:00Z 21-Jan-02
AVN 850MB-700MB Thickness (m) 18.18 54HR Mon 00:00Z 21-Jan-02
AVN 850MB-700MB Thickness Img(dam) 18.18 54HR Mon 00:00Z 21-Jan-02

Figure 22b


130
140
150
160
170
AVN 700MB Wind (kts) 18.18 42HR Sun 12:00Z 20-Jan-02
AVN 850MB-700MB Thickness (m) 18.18 42HR Sun 12:00Z 20-Jan-02
AVN 850MB-700MB Thickness Img(dam) 18.18 42HR Sun 12:00Z 20-Jan-02