Analysis of the 2nd February 2003 Utah Winter Storm: A Forecast Drill Using the Weather Event Simulator (WES)

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Introduction

Winter weather events present a significant challenge to forecasters at the Salt Lake City (SLC), Utah, Weather Forecast Office (WFO). One such challenging event occurred over Utah on 2-3 February, 2003, and was chosen as a Weather Event Simulator drill administered to forecasters at the SLC WFO. Snowfall amounts for this event were considered moderate for Utah winter storms, ranging from nearly 2 feet in the Wasatch Mountains east of Salt Lake City to as low as an inch reported across some nearby valleys. Mountain and valley areas of southwest Utah also received snowfall - heavier in the mountains, though valley areas on the nearby windward slopes also reported moderate to heavy amounts. This system exhibited several common attributes of a Utah winter storm. Key ingredients to winter storms in Utah include: Upward Vertical Velocity (UVV), either attributed to dynamic forcing, orographic forcing, or a combination of both; instability, which can also enhance the orographic lift; and a vertical tilt westward of the storm that produces mid- and upper-level dynamics above (ideally) unstable orographic lift. This latter factor is especially important to heavy snow along the urban Wasatch Front (north-south from Ogden to Salt Lake City to Provo). Moisture, as it turns out, is not a limiting factor since many Great Basin storms will produce moisture in place through intense Great Basin cyclogenesis. A moderate to strong baraclinic zone (and its associated low-level lift) pushing cold air into the Wasatch is also important. Finally, a key determining factor of snowfall amount is simply the storm's duration. Pacific storms that move onshore in the western United States often split, sending one portion of its energy southeast into the desert southwest, while the northern branch will slide east across the northern tier states. This can create drastic differences in snowfall across Utah. A system that is just beginning to split as it approaches Utah can actually be favorable for heavy snow across a broad extent of Utah, primarily either side of the Wasatch mountains that run north-southwest through the area. As the system splits it may slow down, thus allowing for a longer period of snow.

For this drill, forecasters were placed in the simulated forecast decision point of 00 UTC 2 February 2003 (500 PM MST, 1 February) with data available on the AWIPS Weather Event Simulator (WES) up to that point. Forecasters were also provided surface time series data - via a web point-and-click interface - from the Cooperative Institute for Regional Prediction (CIRP) MesoWest mesonet data up to the current simulated time. Forecasters were asked to fill out a 24-hr snow accumulation matrix for nine stations across the SLC County Warning Area (CWA, Fig 1, includes forecast points denoted with X's). The 24-hr period started at 600 PM MST 1 February, and ended at 600 PM MST 2 February. Forecasters were also asked to predict the start and end times of snowfall (if any received) at the SLC International Airport and the Alta ski area. This paper will be organized in a manner simulating what forecasters saw as they completed the drill, whereby the synoptic and mesoscale situation is described, forecast models shown, then a description of what actually happened presented. A short discussion on the event will conclude the paper.

Synoptic and Mesoscale Overview Facing Forecasters

Forecasters were encouraged to first examine the current situation rather than stepping immediately into the numerical models. This is a critical step to the forecast process. As such, a deep, progressive tough was located just off the U.S. west coast at the last raob analysis time available at the forecast decision point. At 1200 UTC 2 February, the trough exhibited a slight positive tilt and was characterized by a moderately cold core at 500 mb (Fig. 2). The 700 mb cold front appeared to just enter the Oregon coast at this time (Fig. 3). Note the very warm 700 mb temperatures at SLC at this time (+6 deg C). Meanwhile at jet level (250 mb), the jet with this system was analyzed on the lee side of this trough, implying little if any additional trough movement to the southeast (Fig. 4). By 2300 UTC, the surface cold front was located across central Nevada, then extended northeast into southern Idaho (Fig. 5). Again, very warm surface temperatures were reported across Utah with numerous record high temperatures set for the day. These high temperatures factored into the rain-snow consideration across the lower Utah valleys. However, the front was strong, with temperature falls behind the front of 15-20 deg F. Another view of the surface front is provided by a MAPS Surface Assimilation System (MSAS) analysis at 2300 UTC (Fig. 6), depicting a strong rise-fall couplet along the surface front, with the cold air trailing the surface trough that at 2300 UTC was lined from northern Utah southwest into southern Nevada. By 2300 UTC, the upper level trough appeared to be located just north of Reno, Nevada (Fig. 7), and moving mainly east. Some ridging was taking place upstream over the east Pacific, though not significant. Strong ridging upstream will act to dig a downstream system further, and was a consideration for forecasters at this time of the drill.

Model Forecasts

Both the GFS and Eta models handled this system nearly equally, with the GFS sending slightly more energy southeast into Arizona. Comparison of the ETA surface forecasts to those of the GFS showed the GFS was slightly more accurate in the timing of the front (not shown). GFS forecast plots will hence be shown here. Recall the key aspects of winter storms in Utah. Forecasters must first determine areas, intensity, and timing of UVV as created by dynamic or orographic lift, each of which can be enhanced by an unstable atmosphere. An effective method of determining the degree of dynamic lift within Utah winter storms is obtained by viewing model forecast upper level divergence (ULD) and positive differential vorticity advection (DVA). Figure 8 shows the 12-hr GFS forecast 250-mb divergence, wind, and isotachs, valid at 0600 UTC 2 February. A significant area of moderate ULD is located on a general axis from southern Nevada into western Utah. Likewise at this time, the upper level vorticity center was forecast to move into western Nevada and resulting in strong positive DVA across Nevada and east into northwest Utah (Fig 9). This trend continued into 1200 UTC (Fig. 10, Fig 11), thus showing this system had what appeared to be adequate upper-level dynamics associated with it.

As described earlier, systems that produce moderate to heavy snowfall along the urban Wasatch Front are often tilting westward with height. This allows unstable orographic flow into the Wasatch below dynamic forcing at mid- and upper-levels. Figure 12 is a time-height cross section for SLC derived from the GFS, showing equivalent potential temperature, relative humidity, omega (mbar/s), and wind through the forecast period of concern. Several favorable factors are depicted in this figure. First is the deep instability as shown by the nearly vertical equivalent potential temperature lines. Secondly, is the deep UVV, and third is its westward tilt with height (denoted by winds shifting to the northwest to the upper left of the figure). Combined with the deep moisture, these factors all appeared favorable for moderate to heavy snow beginning around 06Z and extending to at least 00Z 3 February. On a plan view, further favorable factors were still apparent. A 4-panel depiction of key GFS fields of the 12-hr forecast valid at 06 UTZ, (Fig. 13; upper left is 300 mb height, windspeed and vorticity; upper right is 500 mb temperature, relative humidity and wind; lower left is 700 mb temperature, relative humidity and wind; lower right is Mean Sea Level Pressure, surface wind, and 6-hr QPF) shows the 700 mb front has entered northern Utah, appearing to be near the Wasatch Front. Meanwhile, the 500 mb thermal trough lagged behind (favorable for snow) in western Nevada. The MSLP panel also indicated that the surface front and pressure trough through the Wasatch Front at this time. The GFS also produced quite a bit of precipitation for this time period. A big question, however, is when the airmass would be cold enough to snow on the valley floors in the north (e.g., SLC). Subjective correlation has shown locally that valley (SLC) snow will generally occur with 700 mb temperatures of -8 deg C. At the time of this forecast (06 UTC), 700 mb temperatures appeared to be only as low as -2 deg C over SLC. Thus precipitation would likely begin as rain. By 1200 UTC (18-hr forecast), the 4-panel GFS (Fig.14) showed the 700 mb front well through most of Utah, with moist orographic flow into the mountains and nearby favorable northwest flow valleys at that time. Again, the mid-level trough and cold air still lagged behind in Nevada. At this time, then, there are strong orographics into the Wasatch, with dynamics streaming overhead in southwest flow aloft - all favorable ingredients for moderate to heavy snow in Utah. However, temperatures still appeared to be too warm for snow in the valley floors. Also note the southern extent of this system into southwest Utah. This pattern is typically favorable for heavy snow in the windward slopes and nearby valleys of southwest Utah. Finally, by 0000 UTC 3 February (30-hr forecast, Fig. 15) , the upper level cold core moved overhead in northern Utah, which usually signifies a stabilizing atmosphere, minimal dynamics, and the end of the event. Nonetheless, the flow remained northwesterly at the surface, although exhibiting too much of a northerly component for optimally strong orographic flow into the Wasatch Mountains.

Regarding the issue of rain versus snow in the valley floors across the north, an ETA BUFR sounding from the 1800 UTC 1 February ETA model run (Fig. 16), and valid for 0600 UTC 2 February, shows model surface temperatures well into the 40's deg F an hour or so behind the front. The University of Utah's MM5 model forecast valid at the same time is slightly colder, yet still in the upper 30's deg F. Considering the cold air behind this system, is the ETA accurately depicting the cooling of the lower column of the atmosphere for this time? This question is critical to determining when rain will turn to snow and begin accumulating. (Many forecasters completing the drill determined accumulating snowfall would not begin until at least around 1200 UTC.)

What Actually Happened?

As was implied by the GFS, this system did indeed split enough to A) slow in its eastward movement, B) produce heavy snowfall across the southwest mountains and nearby windward valleys, and C), wrap up so much that it brought strong northerly flow just off the surface over northern Utah - even bringing a wrap-around-like flow pattern across the northern Wasatch and limiting the amount of orographic lift on slopes typically favored by northwest flow. Figure 17 depicts the 24-hr snowfall amounts (ending 0100 UTC 3 February) reported at the nine drill forecast points. The majority of the forecasters completing the drill underforecast the amount at Salt Lake City, likely due to the later-than-expected change to snow. In fact, SLC reported moderate rain for approximately 1.5 hrs before turning over to all snow. The 0600 UTC KMTX radar 0.5 deg reflectivity depicts moderate to heavy precipitation along the front just prior to moving through the Salt Lake area (Figure 18). At 0630 UTC (Fig 19), the cold front had moved through northern Utah and the Salt Lake area. Precipitation at this time was rain in the valleys, with significant snowfall in the nearby Wasatch mountains. Again, SLC reported moderate rain at this time. By 0930 UTC (Fig 20), valley rain turned over to snow, including at SLC where the temperature fell to 32 deg F by this time. Recall according to model forecasts near this time, the airmass was forecast to be too warm for snow. The intense lift along the front, combined with the dynamic lift overhead, produced strong precipitation rates that brought surface temperatures down cold enough for snow. Precipitation aerial coverage was reduced by 1200 UTC (Fig 21) to mainly orographically forced areas along the mountains, with instability showers behind the front. Light to moderate snow continued in the Salt Lake area through the rest of the mornng to nearly midday before the system moved east of the area (See 2130 UTC IR satellite image, Fig. 22), recording a storm total of 4.3 inches by the time the snow ended the afternoon of the 2nd. A link to archived MesoWest data at CIRP MesoWest database shows the 24-hr time series at SLC, ending at 0000 UTC 3 February. Note the periods of moderate snow, as well as the fast change over to snow just behind the front. Later in the day on the 2nd, snow had wrapped around the system from the east while surface flow was northwest enough to produce orographic lift on and near northwest slopes. However, a curious pattern was present by 2300 UTC, whereby northwest flow into the Oquirrh and Stansbury Mountains to the west of Salt Lake City was producing significant orographic lift (Fig. 23). The Tooele forecast point received 10 inches in this event, in large part due to this stationary band that established towards the end of the event. The two bands near these two ranges are even more prominent at 0100 UTC 3 February (Fig. 24; see arrows pointing to these areas).

Summary

This was a deep system moving through the Intermountain West that wrapped up at the end of the forecast period as it moved into southern Colorado. The upper low was diving into southwest Utah, with strong dynamics ahead of it across most of Utah, then into Colorado. Strong cyclogenesis took place as a result near the four corners area, which as it did, pulled a strong surface front through Utah. Mid-level southwest flow dynamically supported low-level north-northwest (orographical) flow in northern Utah - a common recipe for heavy snow in the northern mountains and nearby valley areas (i.e. "benches"). A model time-height at SLC showed good system tilt to the west with height. Though models were showing mainly northerly flow at 700 mb, there was enough of a westerly upslope component to support orographic precipitation (the 1200 UTC 2 February 700 mb wind at SLC was actually about 340 deg - more of a northwesterly component than models were forecasting). Precipitation was confined to along and just behind the front across the valleys - outside of snow squalls and showers post-frontal - with precipitation basically ending as the mid-level trough moved through. Mountain and some valley snowfall continued in the system's wrap-around and orographic flow. Instabilities, though not great, were strong enough to enhance orographics. Tooele received warning-level snow from this event from the system's wrap around and enough orographics off the Oquirrh Mountains (a similar band was present on the westward slope of the Stansbury Mountains to the west). Always a concern with winter storms over northern Utah are intense snows off the Great Salt Lake. Pure lake bands never formed with this particular event, likely due to the strong low-level shear and the less than optimal time of day (ideal lake events initiate overnight). In southern and southwest Utah, favorable upper-level dynamics and low-level orographics produced heavy snow along the western slope of the southern and central mountains. An upper low track similar to this is typically very favorable for heavy snow in those southwest areas.

Figure 1

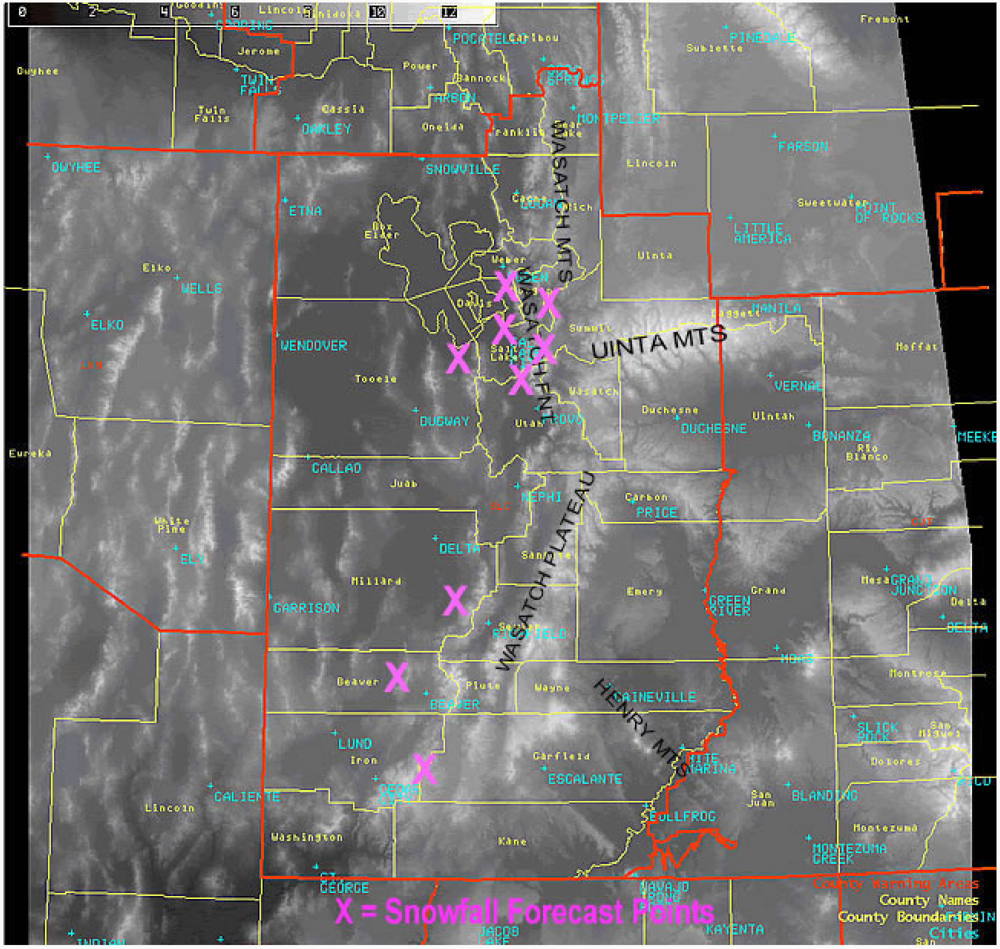
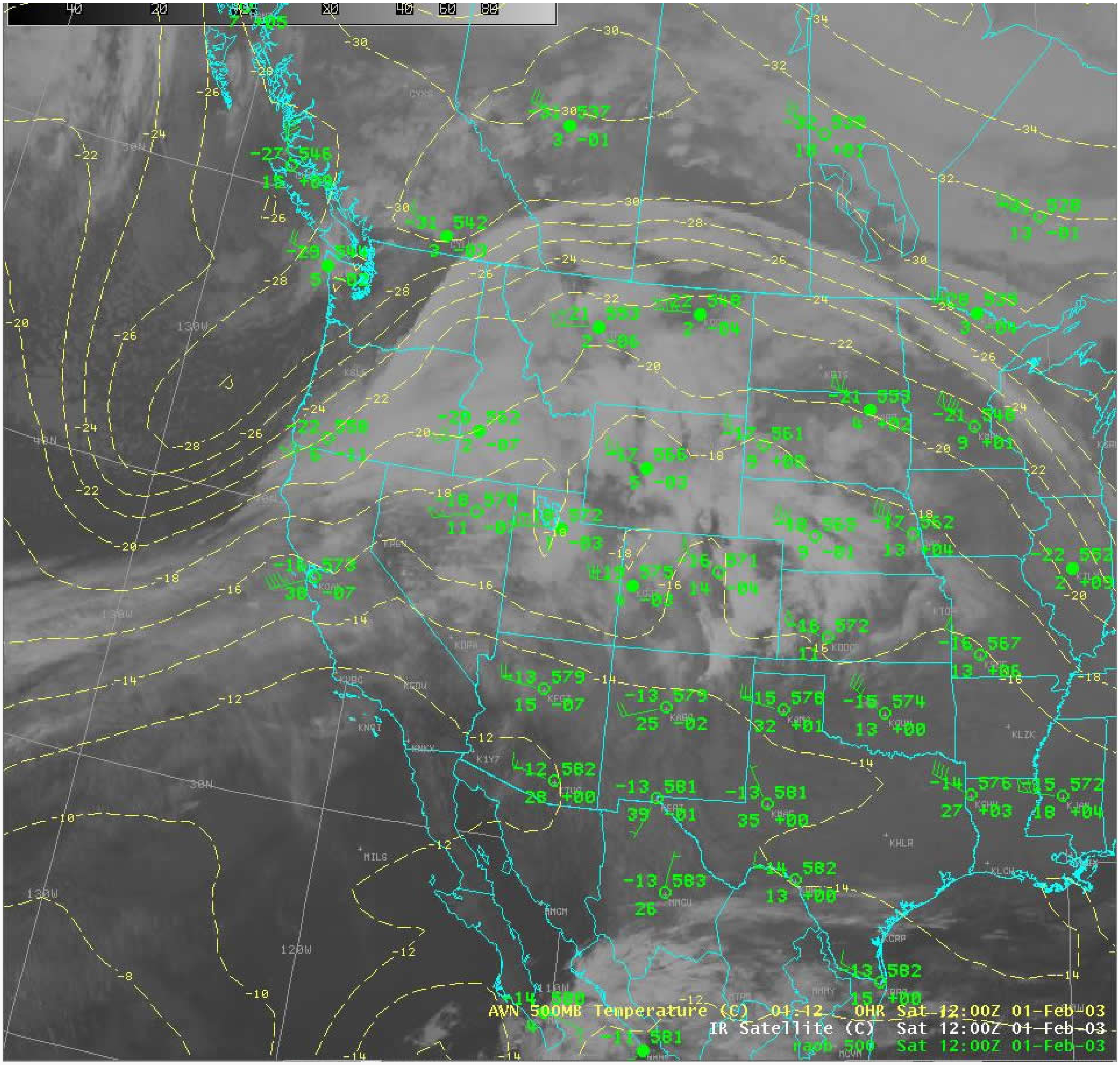


Figure 2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raob 500 Sat 12:00Z 01-Feb-03

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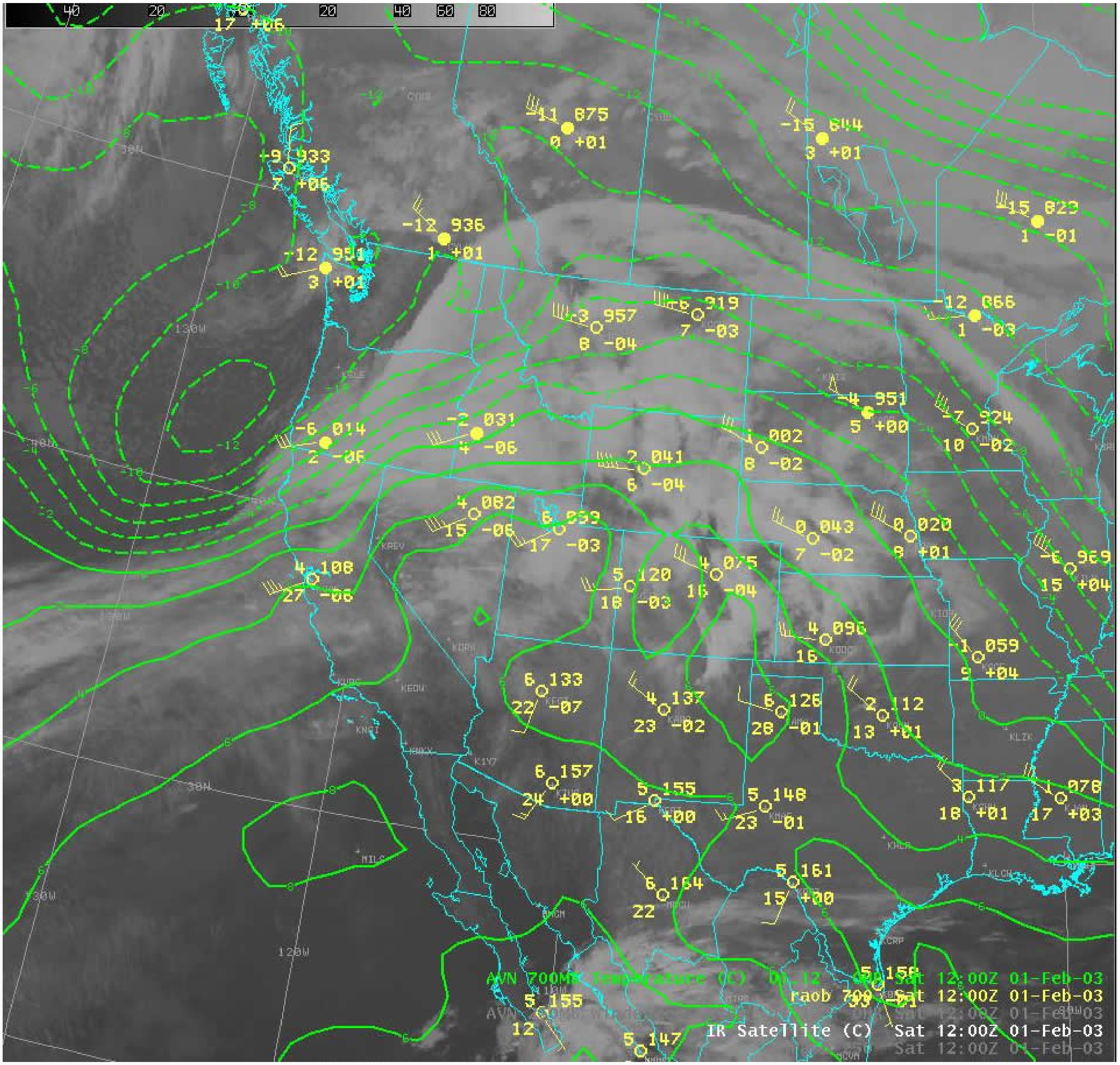
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Figure 4

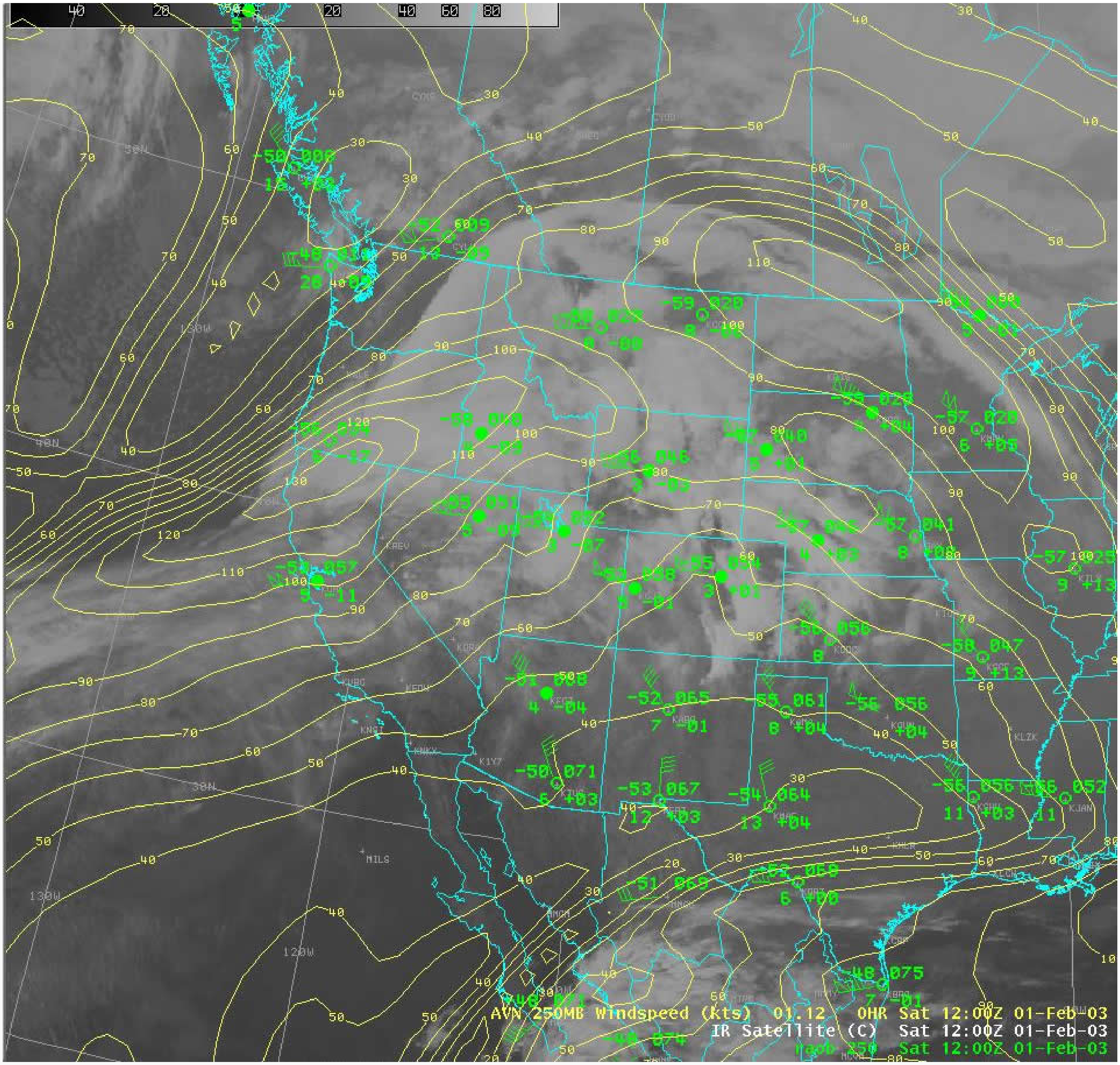
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Figure 5

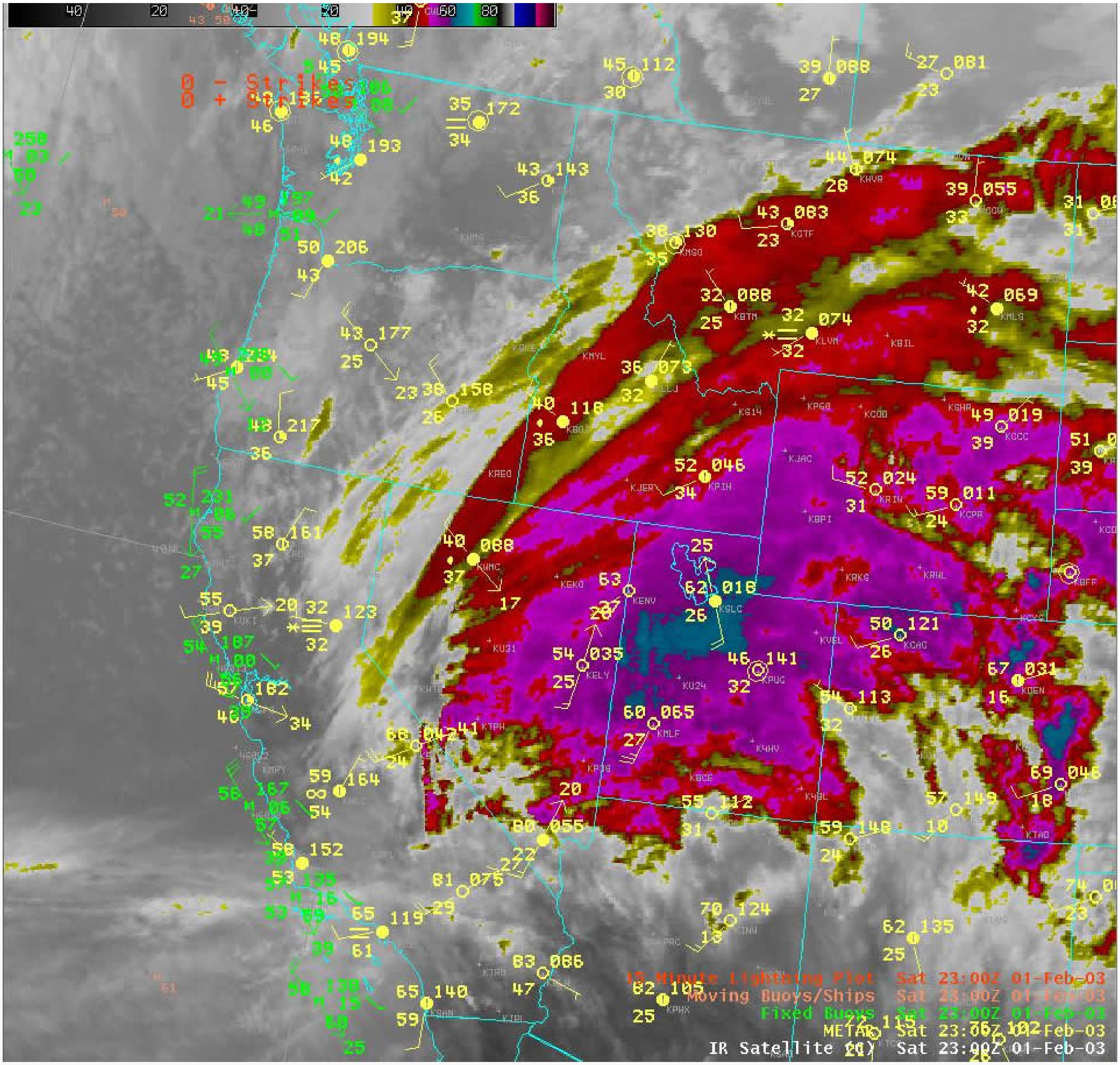
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Figure 6

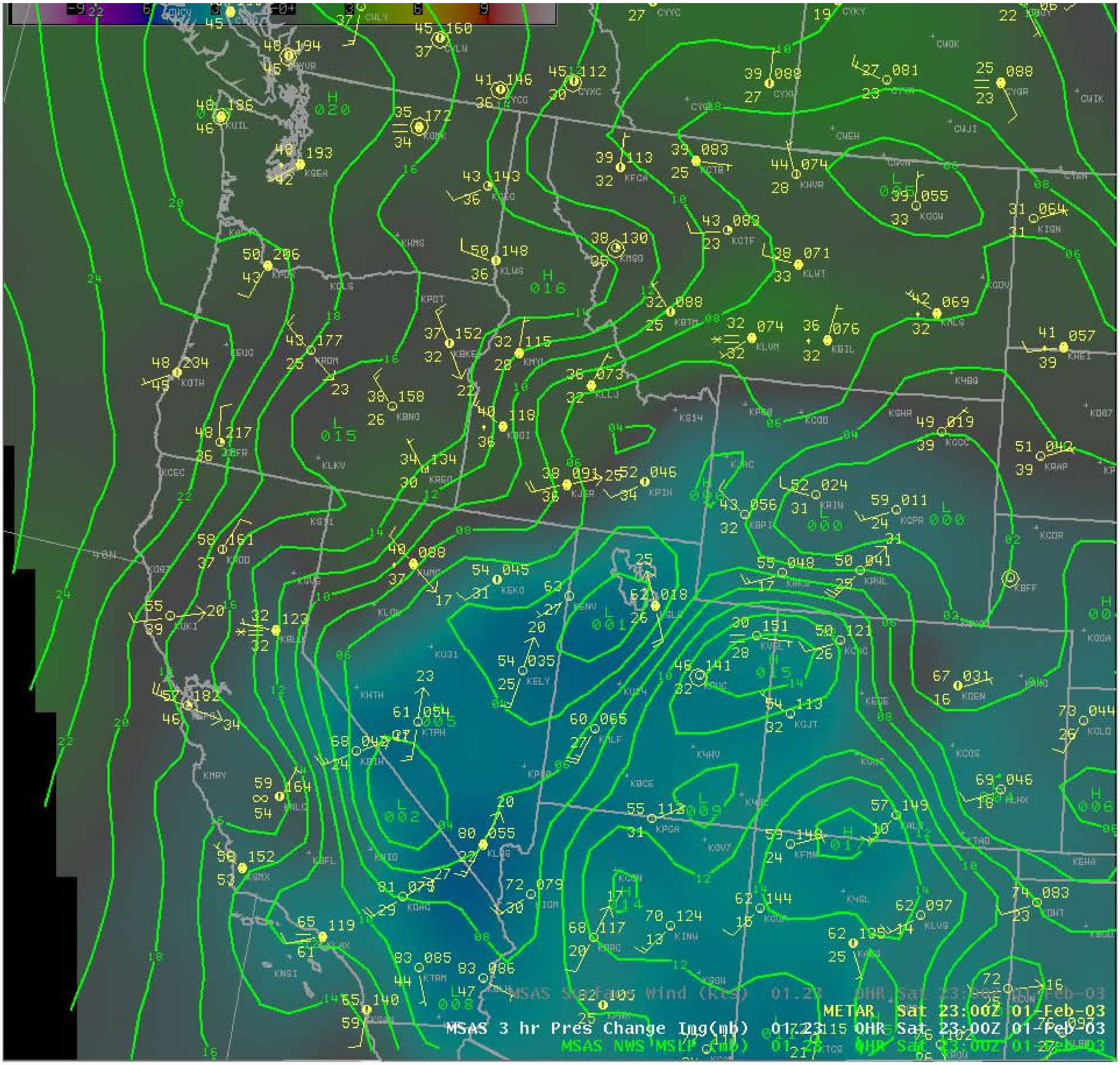
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Figure 7

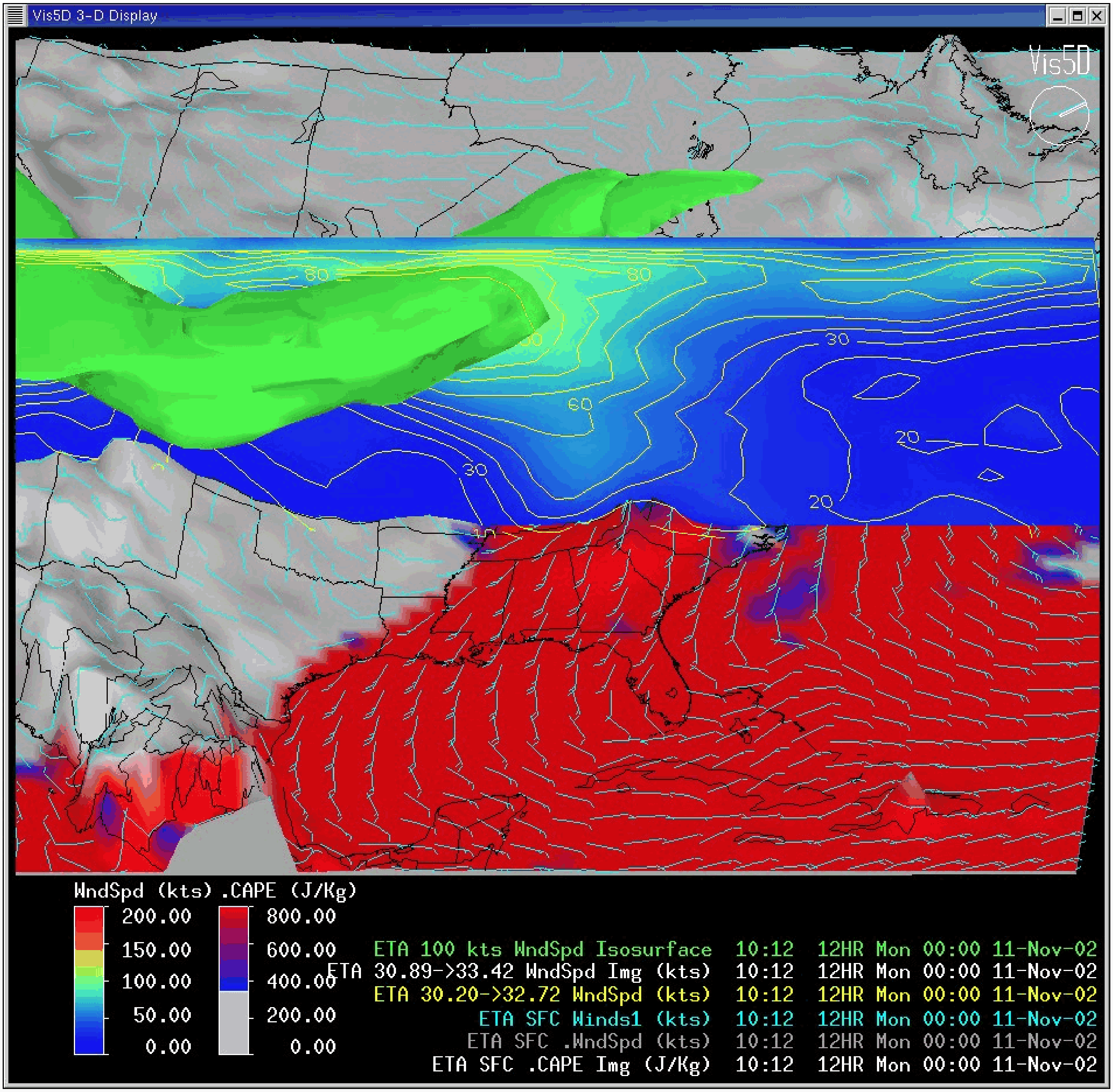
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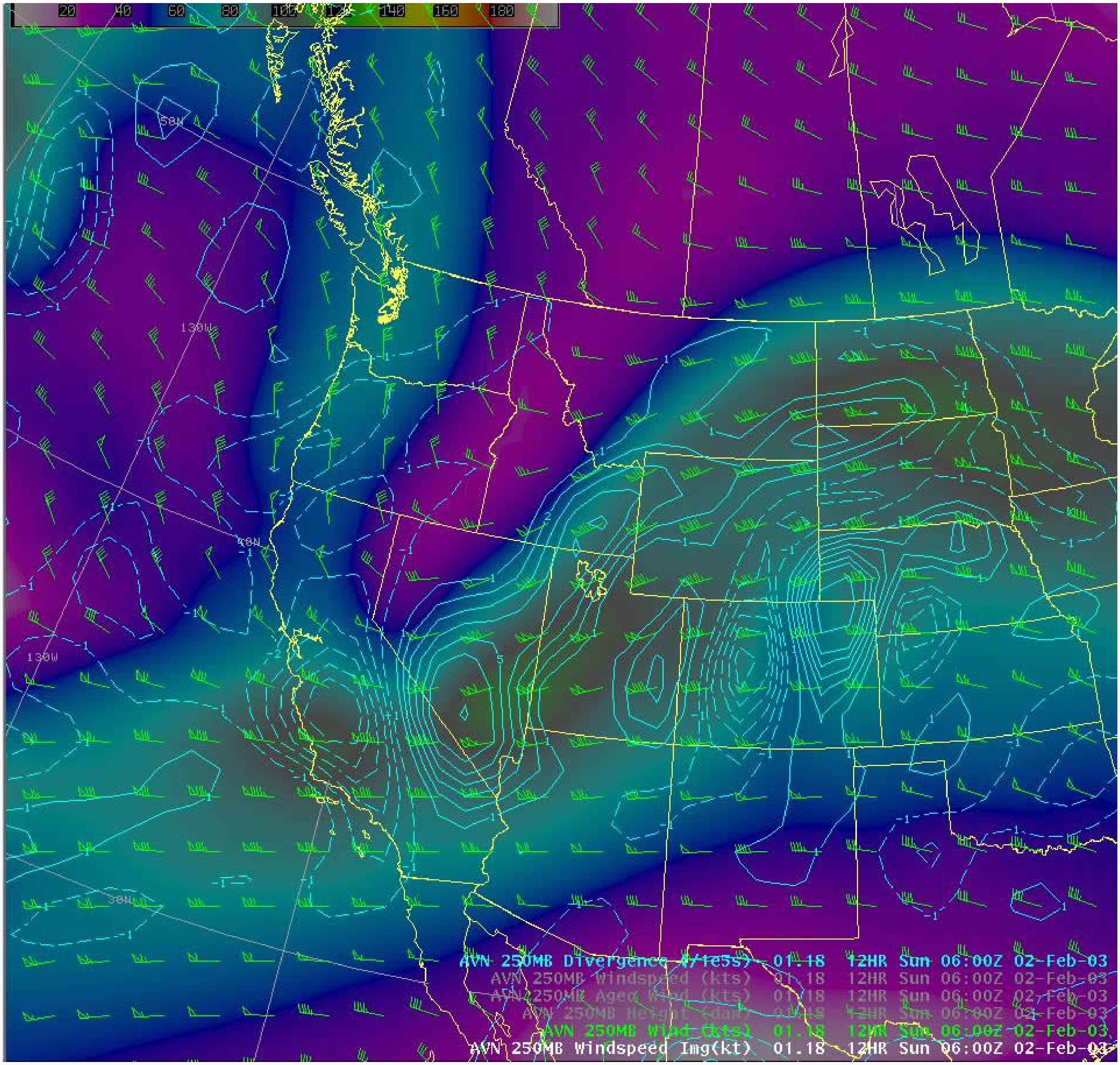
Figure 8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AVN 250MB Aged Wind (kts) 01.18 12HR Sun 06:00Z 02-Feb-03
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AVN 250MB Windspeed Img(kt) 01.18 12HR Sun 06:00Z 02-Feb-03

Figure 9

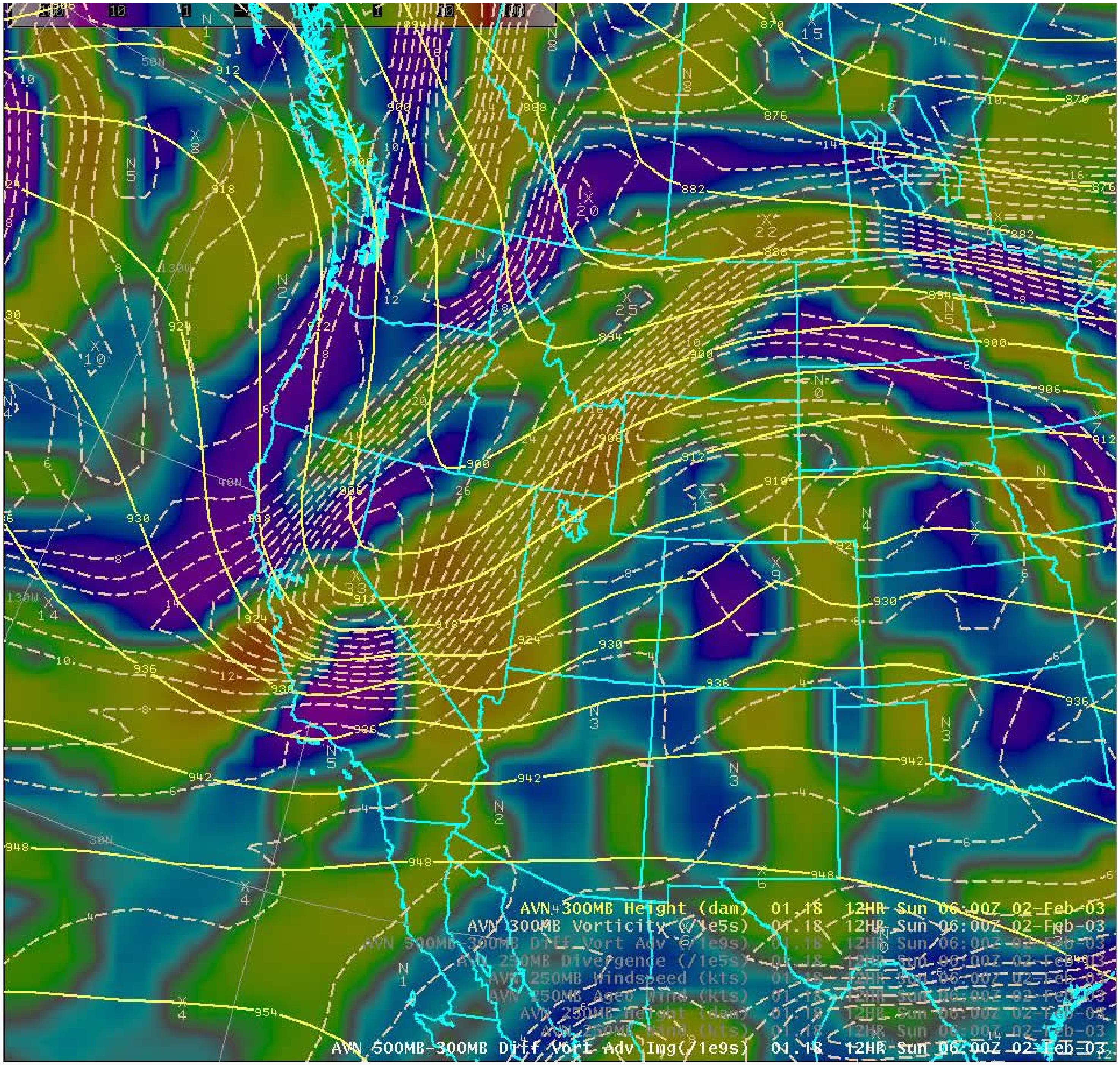
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Figure 10

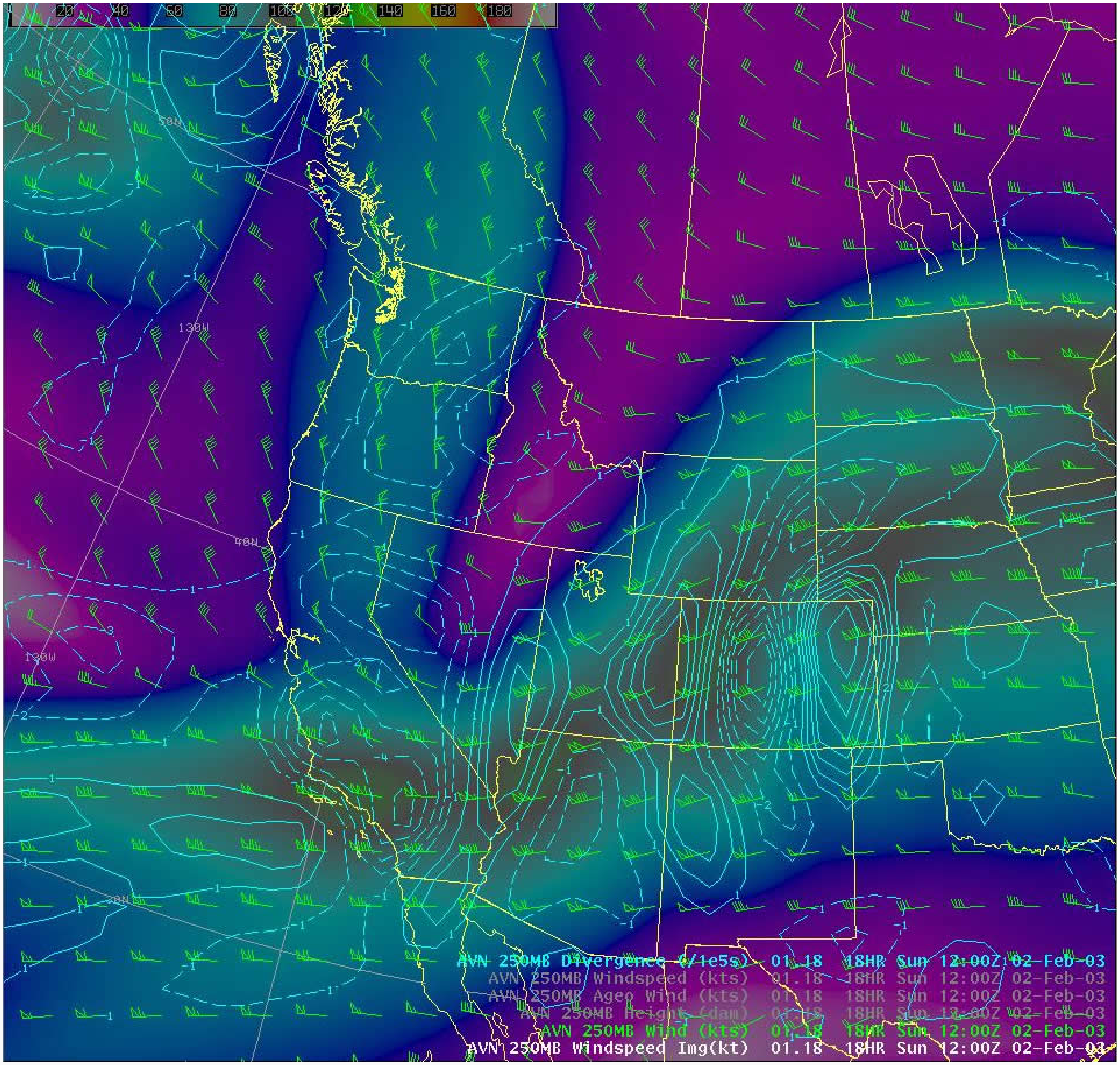
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Figure 11

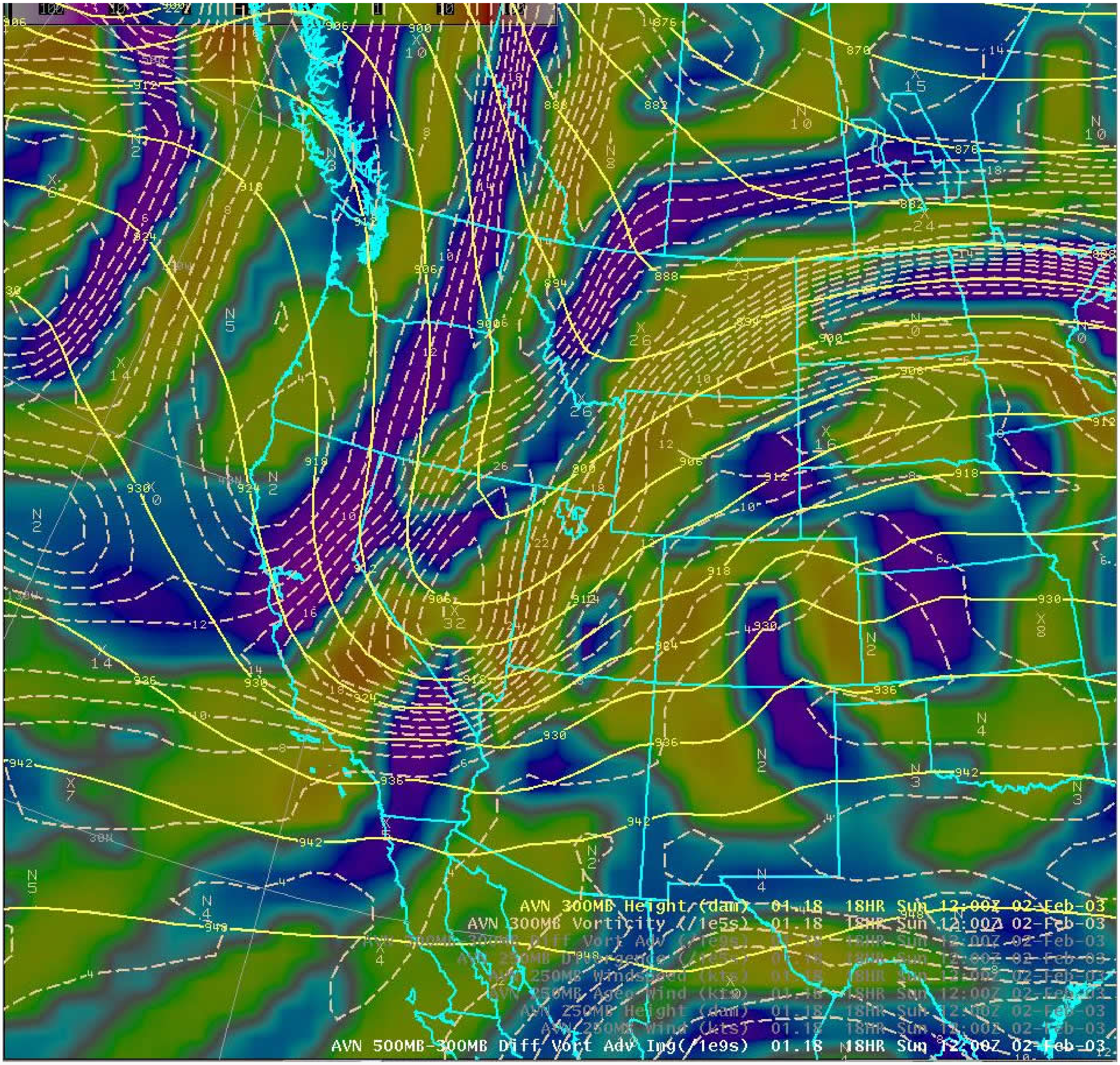
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Figure 11

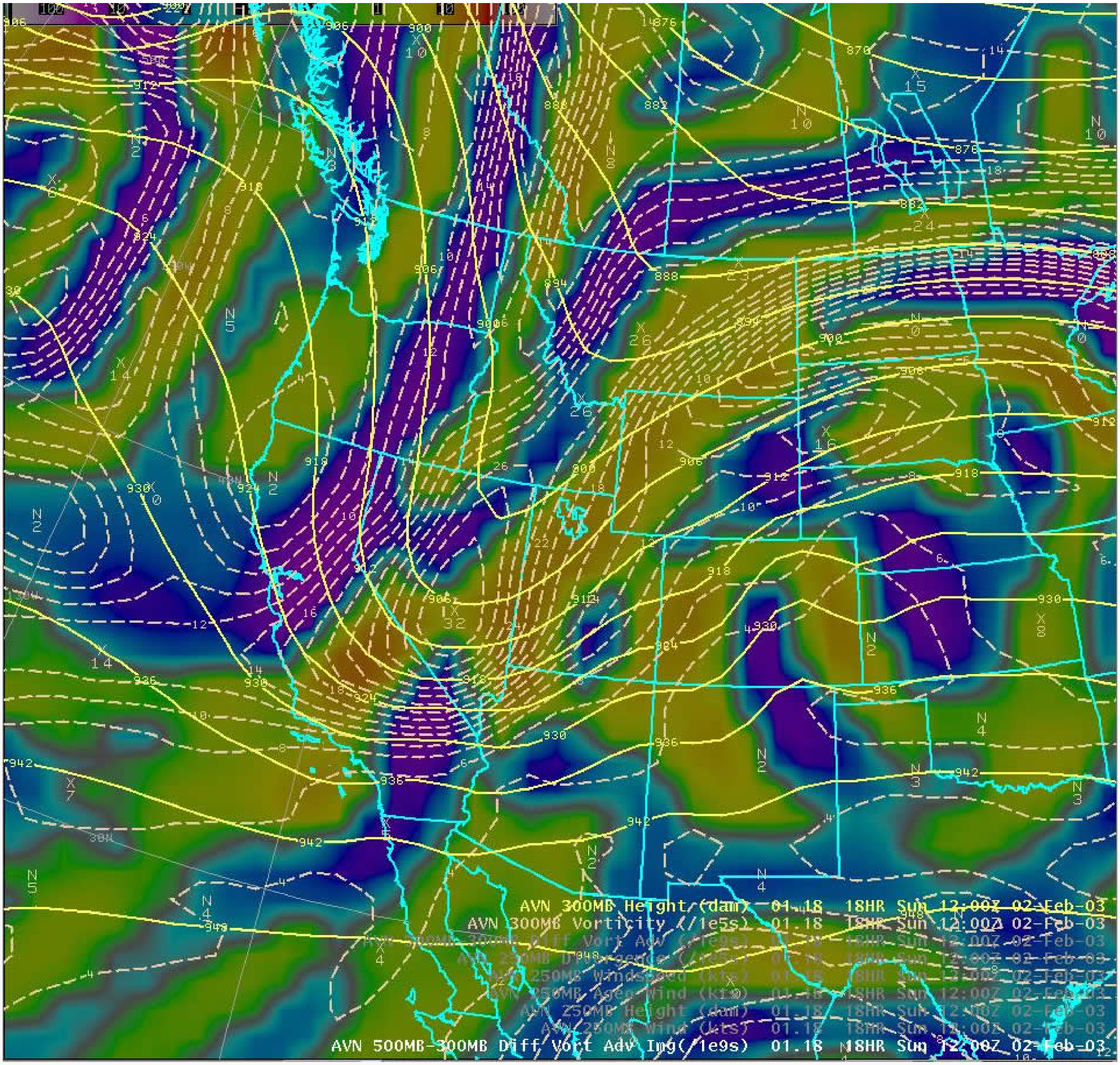
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Figure 12

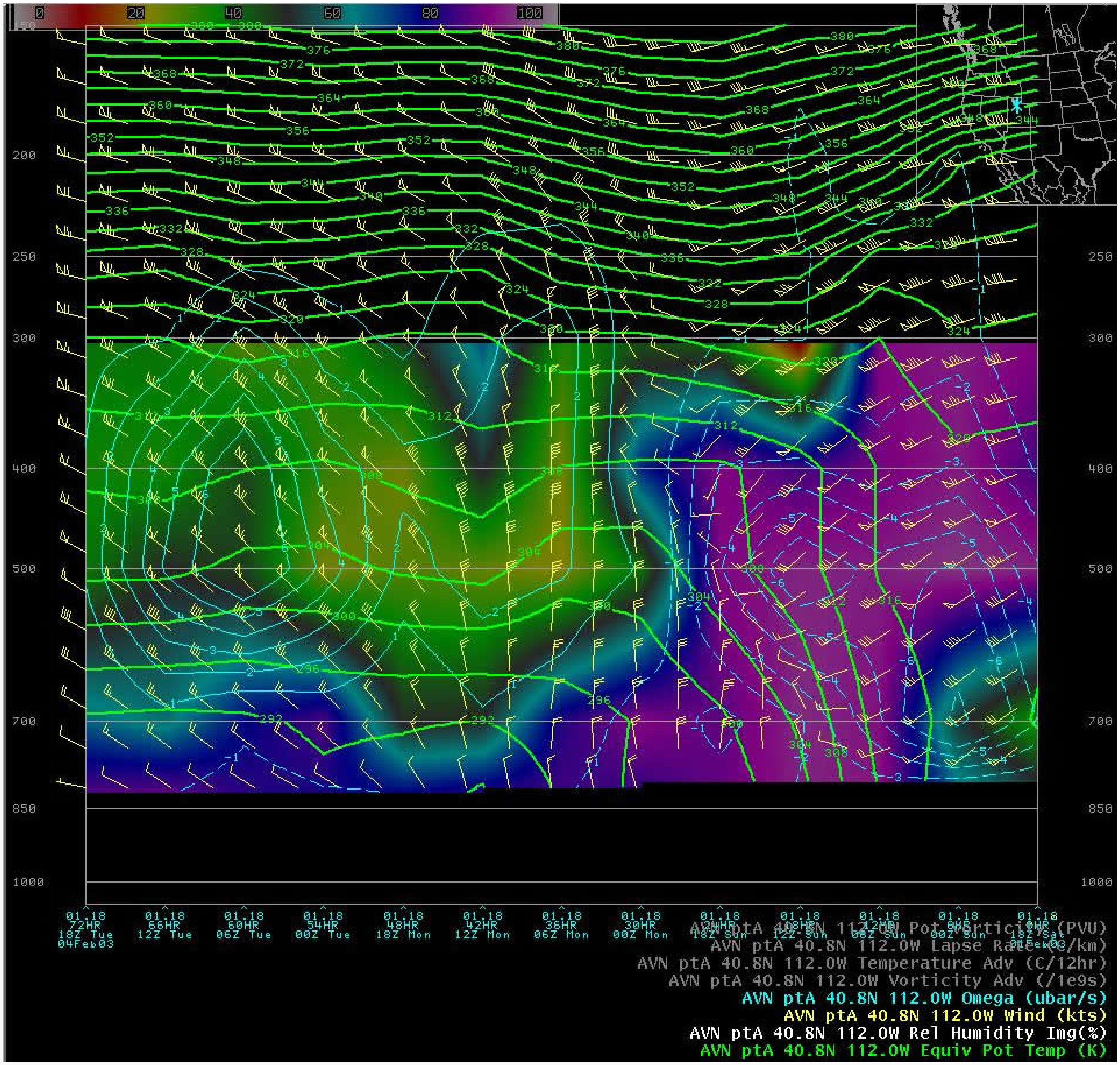
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Figure 13

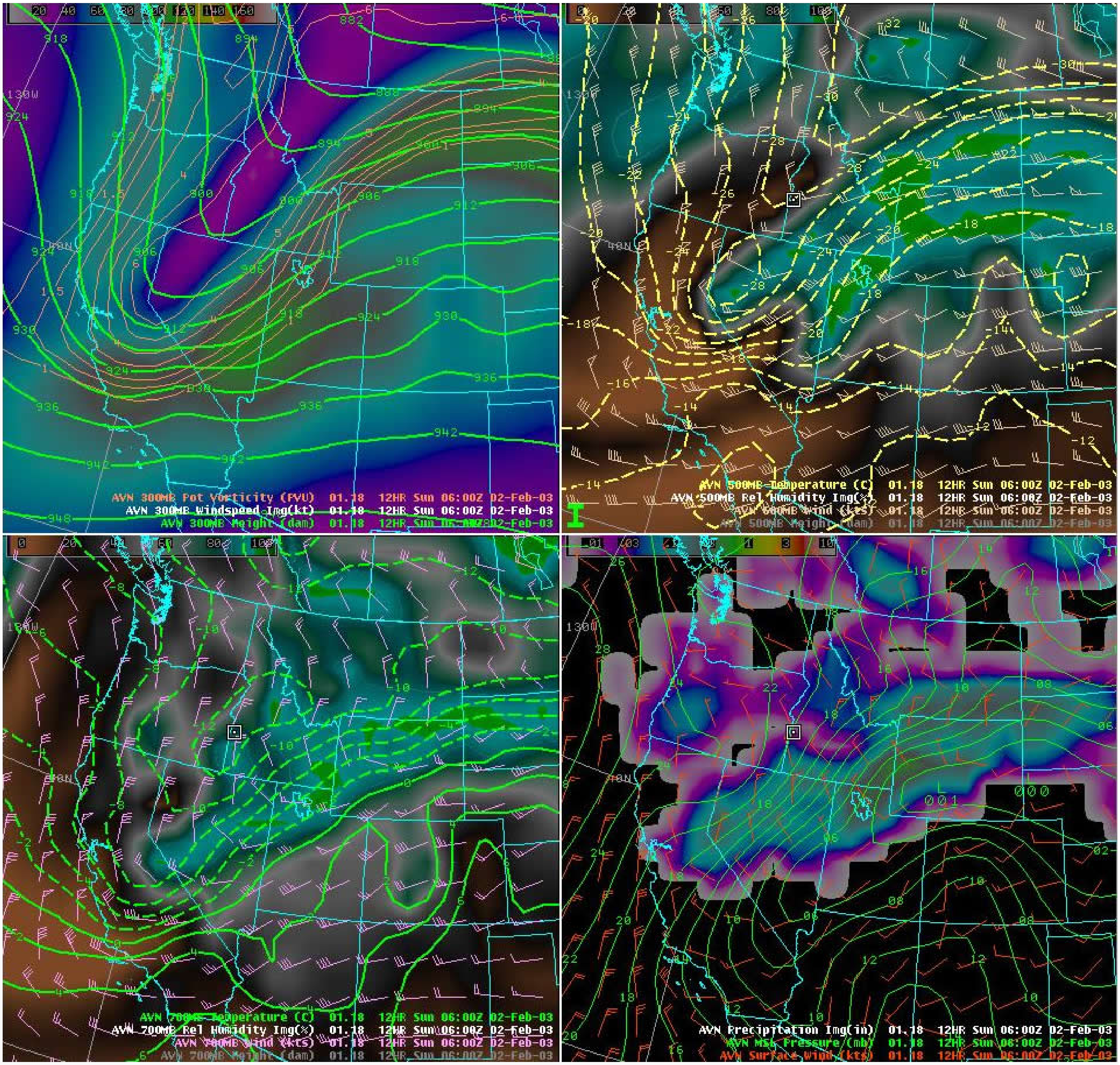
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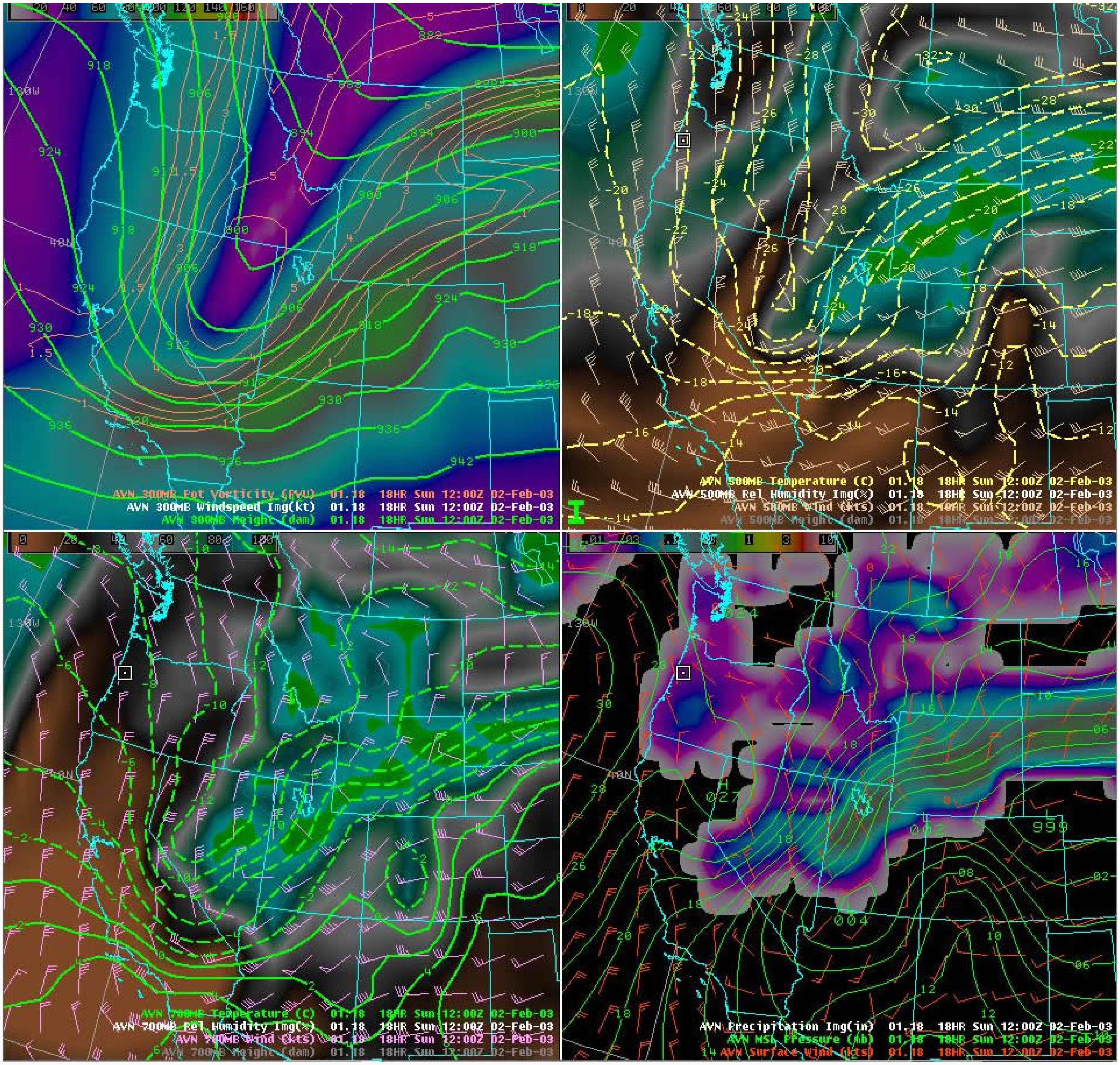
Figure 14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AVN Precipitation Img(in) 01.18 18HR Sun 12:00Z 02-Feb-03
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AVN Surface Wind (kts) 01.18 18HR Sun 12:00Z 02-Feb-03
130W
40N

Figure 15

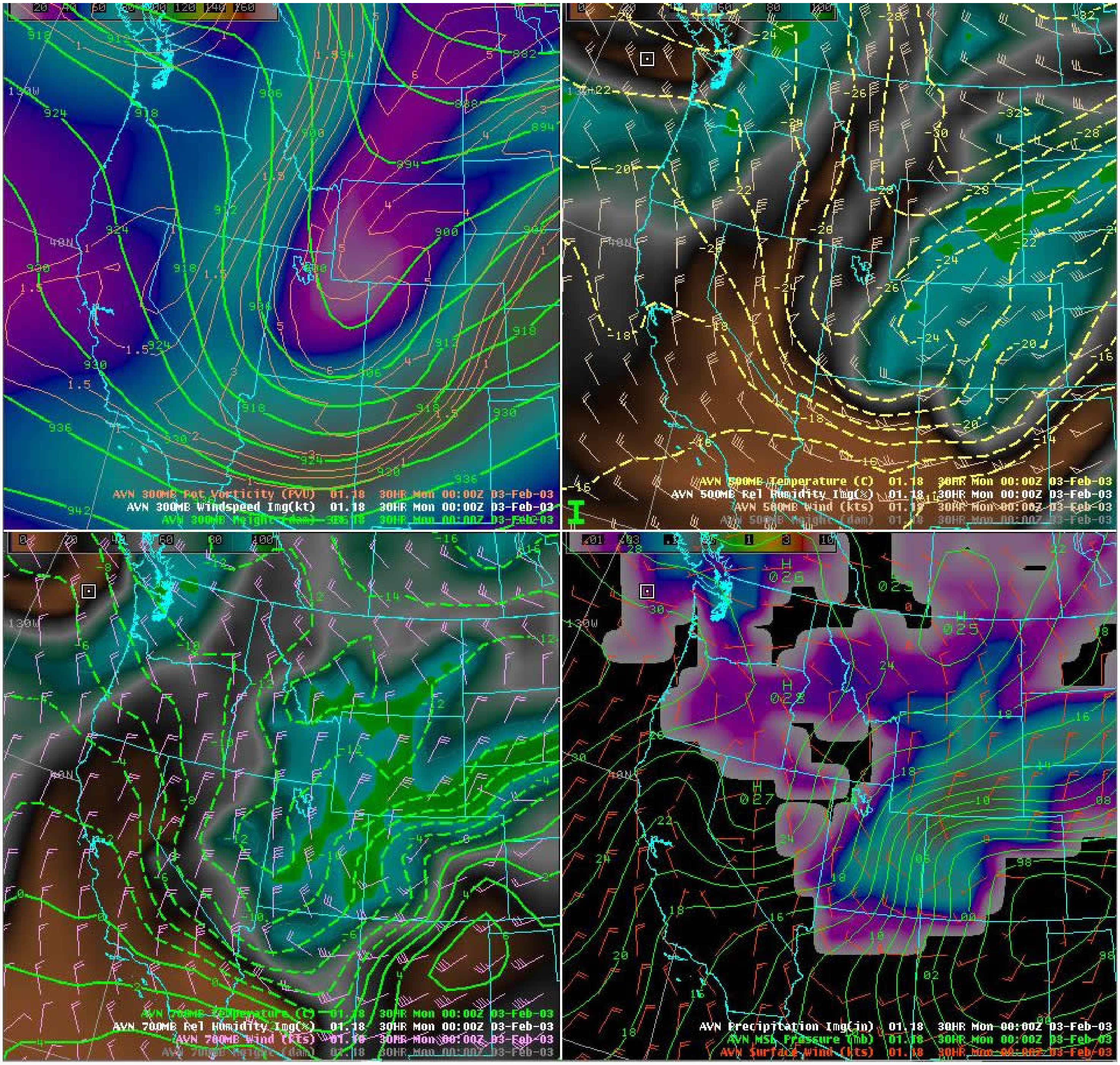
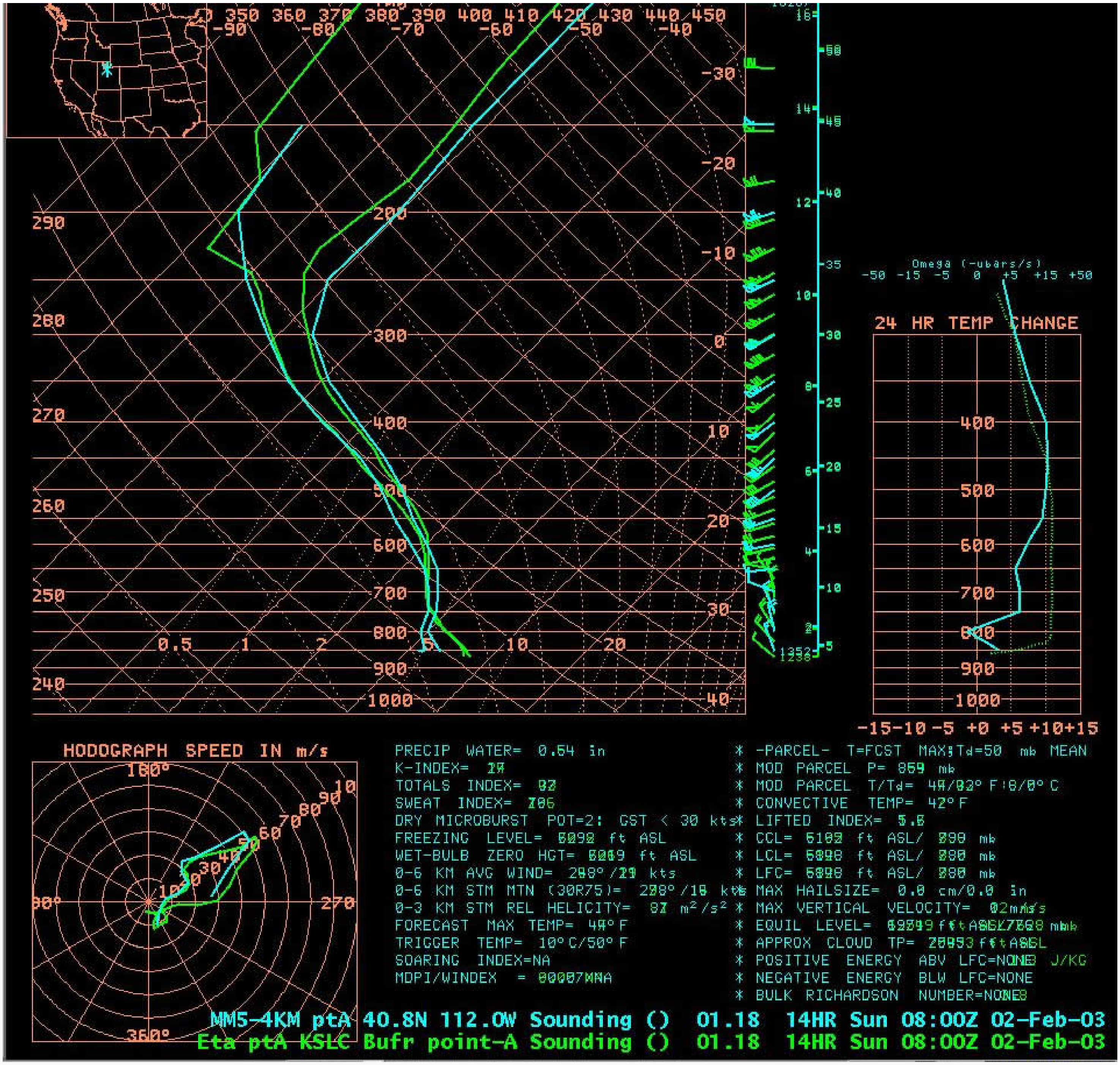

AVN 300MB Pot Vorticity (PVU) 01.18 30HR Mon 00:00Z 03-Feb-03
AVN 300MB Windspeed Img(kt) 01.18 30HR Mon 00:00Z 03-Feb-03
AVN 300MB Height (dam) 01.18 30HR Mon 00:00Z 03-Feb-03
AVN 500MB Temperature (C) 01.18 30HR Mon 00:00Z 03-Feb-03
AVN 500MB Rel Humidity Img(%) 01.18 30HR Mon 00:00Z 03-Feb-03
AVN 500MB Wind (kts) 01.18 30HR Mon 00:00Z 03-Feb-03
AVN 500MB Height (dam) 01.18 30HR Mon 00:00Z 03-Feb-03
AVN 700MB Temperature (C) 01.18 30HR Mon 00:00Z 03-Feb-03
AVN 700MB Rel Humidity Img(%) 01.18 30HR Mon 00:00Z 03-Feb-03
AVN 700MB Wind (kts) 01.18 30HR Mon 00:00Z 03-Feb-03
AVN 700MB Height (dam) 01.18 30HR Mon 00:00Z 03-Feb-03
AVN Precipitation Img(in) 01.18 30HR Mon 00:00Z 03-Feb-03
AVN MSL Pressure (mb) 01.18 30HR Mon 00:00Z 03-Feb-03
AVN Surface Wind (kts) 01.18 30HR Mon 00:00Z 03-Feb-03

Figure 16



```
PRECIP  WATER=  0.54  in                  *  -PARCEL-  T=FCST  MAX;Td=50  mb  MEAN
K-INDEX=  17                              *  MOD  PARCEL  P=  859  mb
TOTALS  INDEX=  92                        *  MOD  PARCEL  T/Td=  49/32° F:8/0° C
SWEAT  INDEX=  106                        *  CONVECTIVE  TEMP=  42° F
DRY  MICROBURST  POT=2:  GST  <  30  kts  *  LIFTED  INDEX=  5.6
FREEZING  LEVEL=  6092  ft  ASL           *  CCL=  5102  ft  ASL/  890  mb
WET-BULB  ZERO  HGT=  6069  ft  ASL       *  LCL=  5898  ft  ASL/  880  mb
0-6  KM  AVG  WIND=  288°/29  kts         *  LFC=  5898  ft  ASL/  880  mb
0-6  KM  STM  MTN  (30R75)=  278°/18  kts *  MAX  HAILSIZE=  0.0  cm/0.0  in
0-3  KM  STM  REL  HELICITY=  87  m²/s²   *  MAX  VERTICAL  VELOCITY=  02m/s
FORECAST  MAX  TEMP=  49° F               *  EQUIL  LEVEL=  62599 ft ASL/768 mb
TRIGGER  TEMP=  10° C/50° F               *  APPROX  CLOUD  TP=  20553 ft ASL
SOARING  INDEX=NA                         *  POSITIVE  ENERGY  ABV  LFC=NONE  J/KG
MDPI/WINDEX  =  00007MNA                  *  NEGATIVE  ENERGY  BLW  LFC=NONE
                                          *  BULK  RICHARDSON  NUMBER=NONE
```

MM5-4KM ptA 40.8N 112.0W Sounding () 01.18 14HR Sun 08:00Z 02-Feb-03
Eta ptA KSLC Bufr point-A Sounding () 01.18 14HR Sun 08:00Z 02-Feb-03

Figure 17

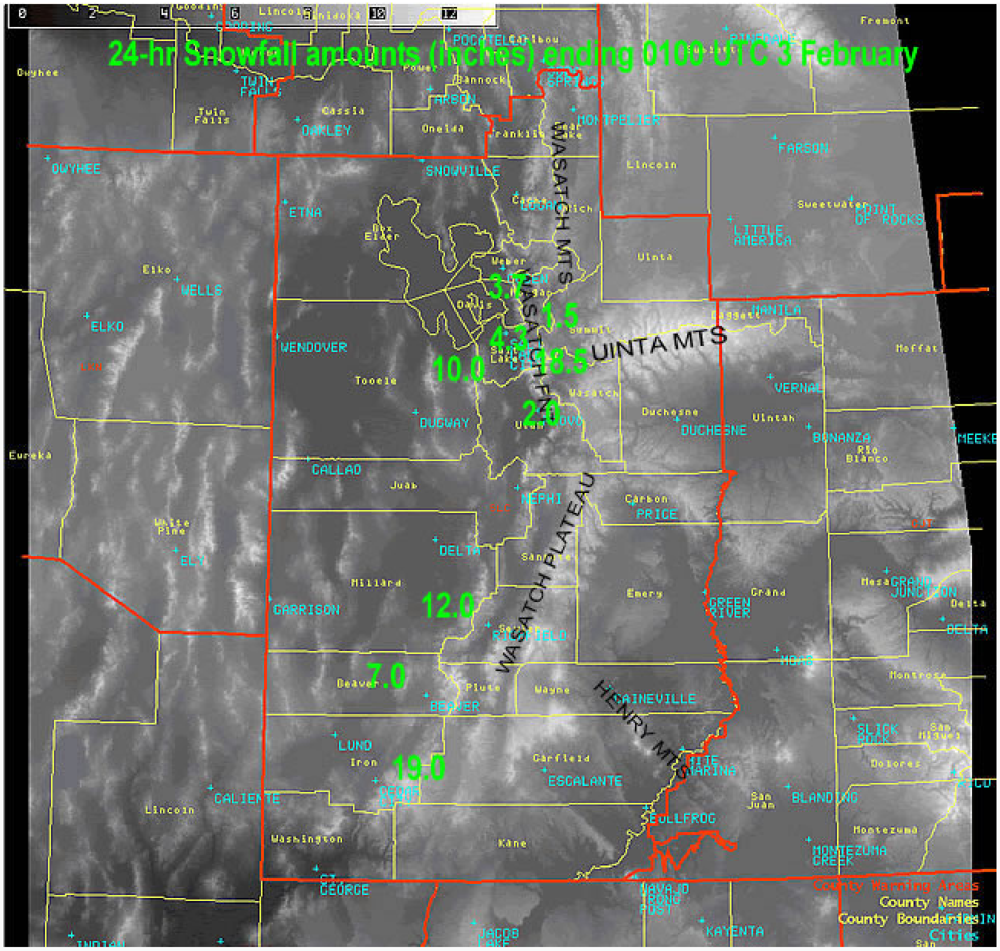

24-hr Snowfall amounts (inches) ending 0100 UTC 3 February
WASATCH MTS
UINTA MTS
WASATCH FN
WASATCH PLATEAU
HENRY MTS
3.7
1.5
4.3
10.0
18.5
2.0
12.0
7.0
19.0
SNOWVILLE
LOGAN
OGDEN
WENDOVER
DUGWAY
PROVO
NEPHI
DELTA
RICHFIELD
BEAVER
CEDAR
ST. GEORGE
PRICE
VERNAL
DUCHESNE
GREEN RIVER
MOAB
HANKSVILLE
BLANDING
County Warning Areas
County Names
County Boundaries
Cities

Figure 18

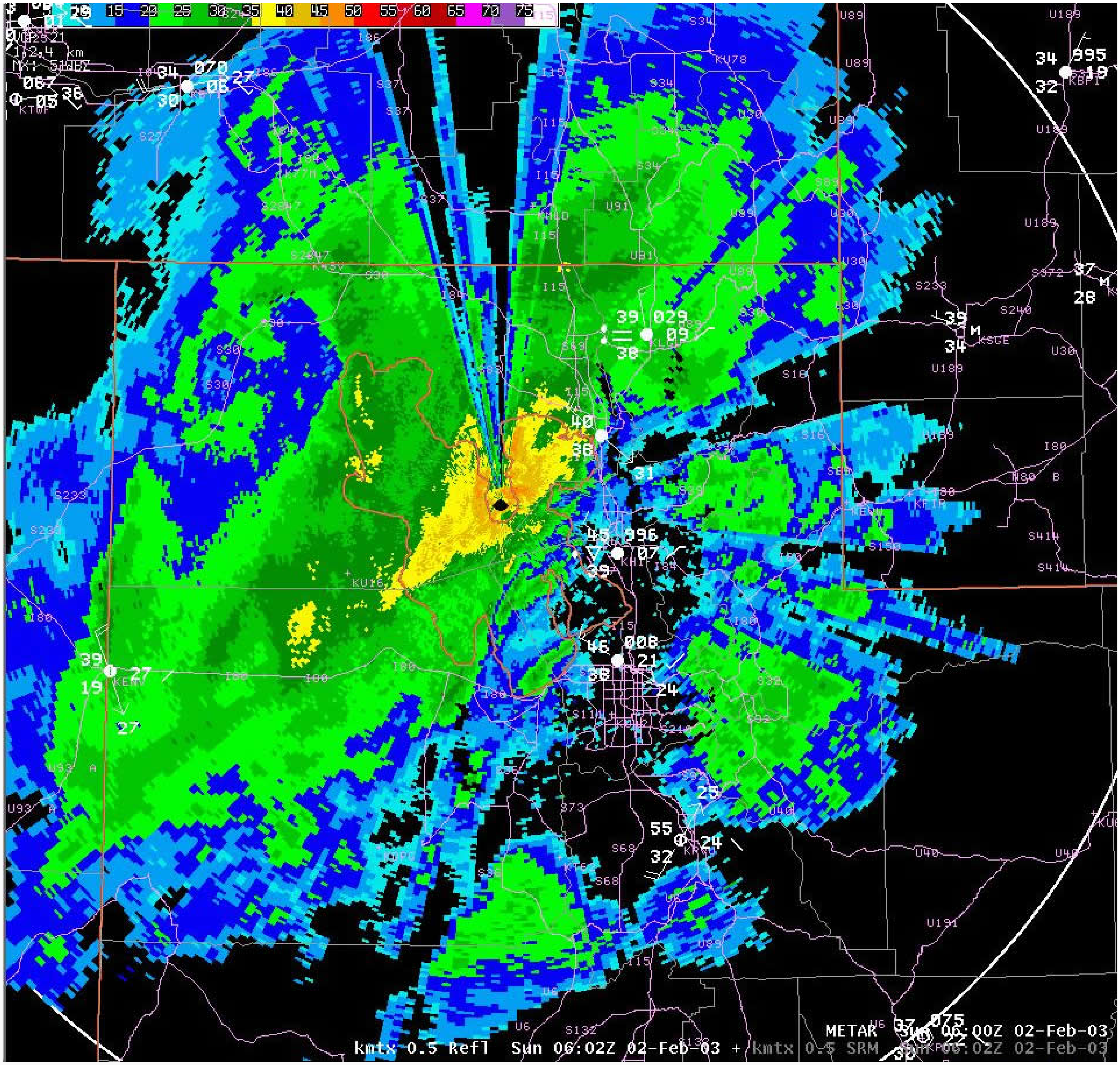

10
15
20
25
30
35
40
45
50
55
60
65
70
75
112.4 km
METAR Sun 06:00Z 02-Feb-03
kmtx 0.5 Refl Sun 06:02Z 02-Feb-03 + kmtx 0.5 SRM Sun 06:02Z 02-Feb-03
I15
I80
I84
U89
U91
U189
U30
U40
U6
U191
KSLC
KHIF
KEVW
KFIR
KSGE
KBPI

Figure 19

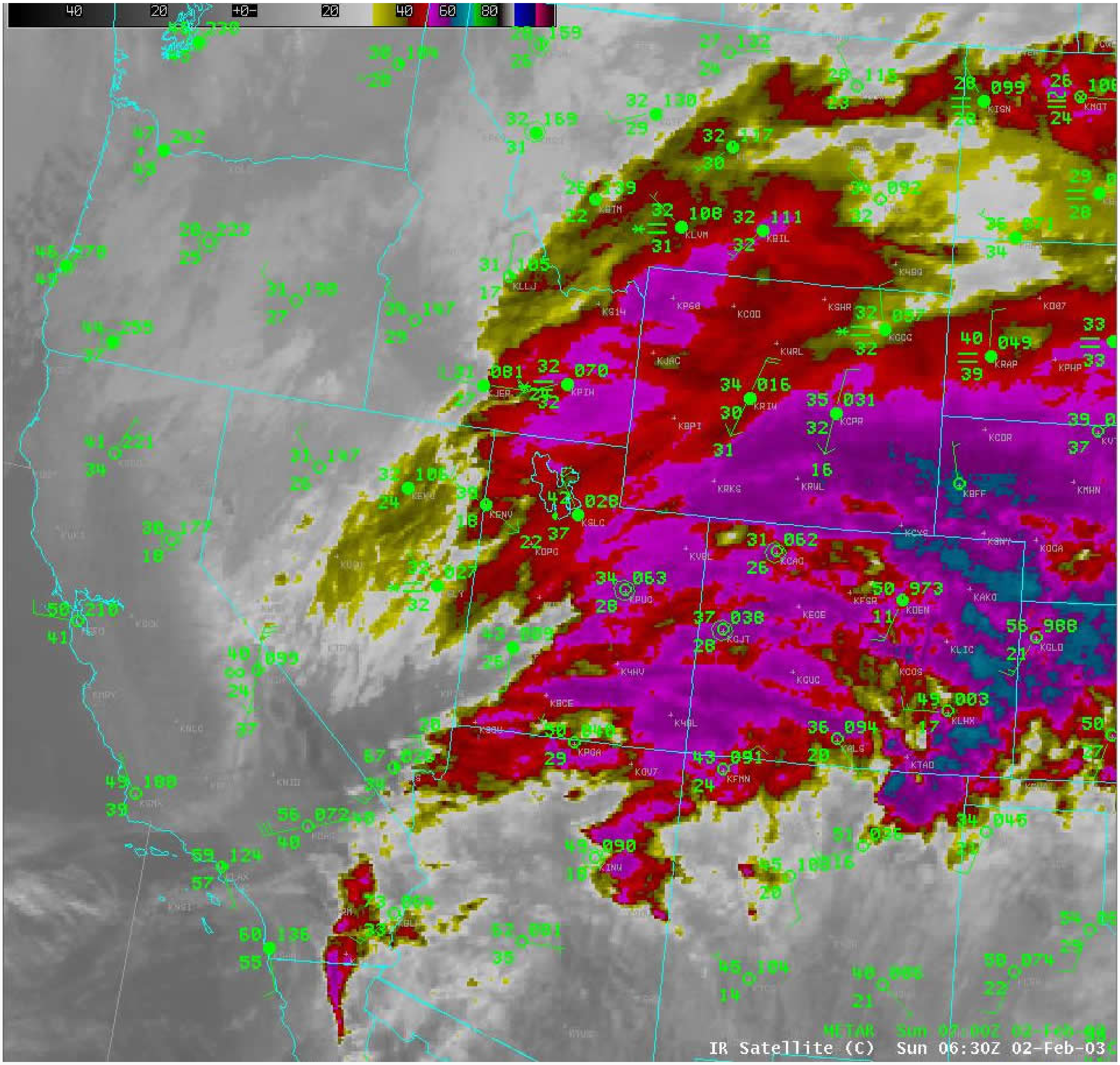

40
20
+0-
20
40
60
80
METAR Sun 07:00Z 02-Feb-03
IR Satellite (C) Sun 06:30Z 02-Feb-03

Figure 20

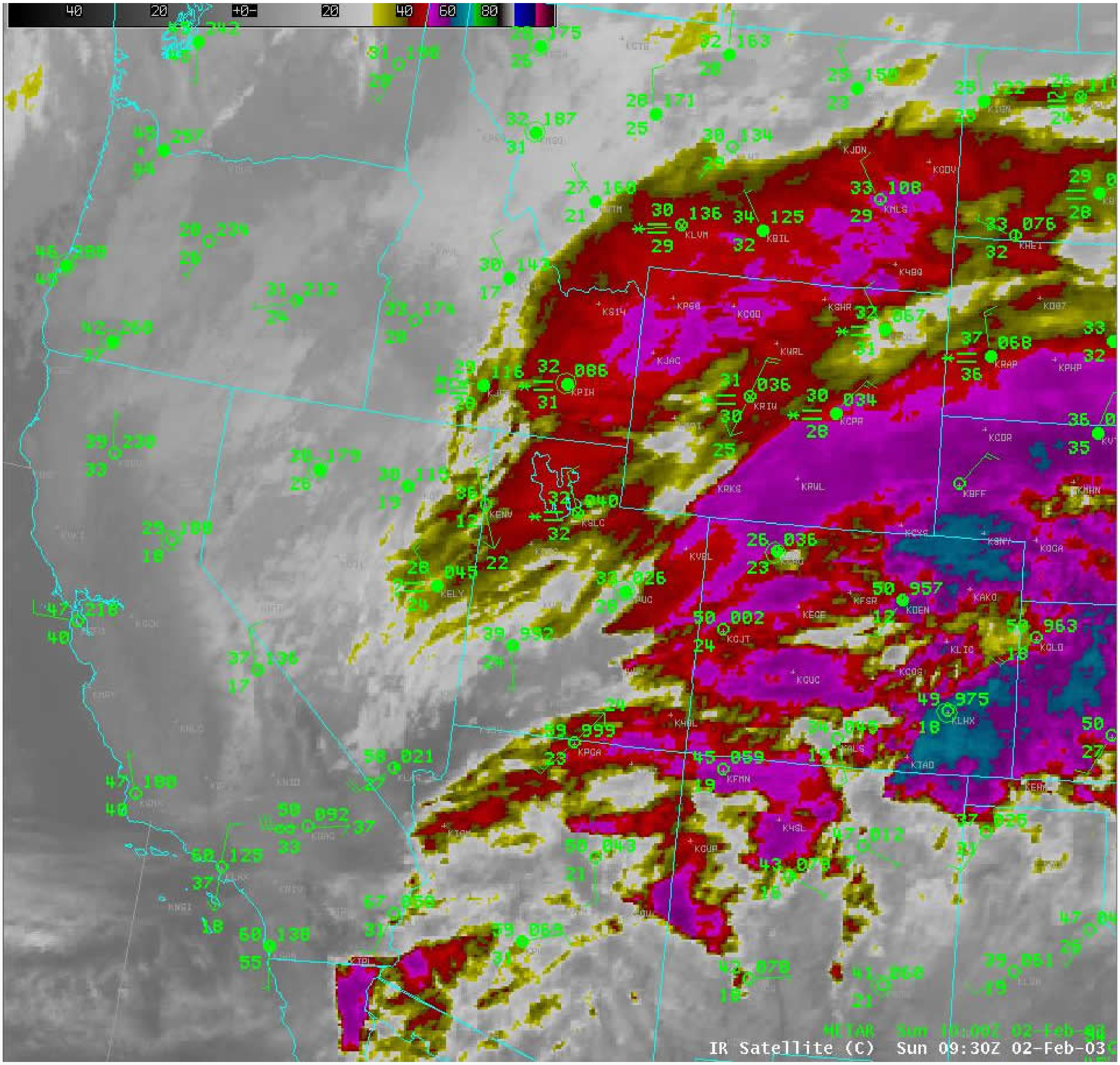


Figure 21

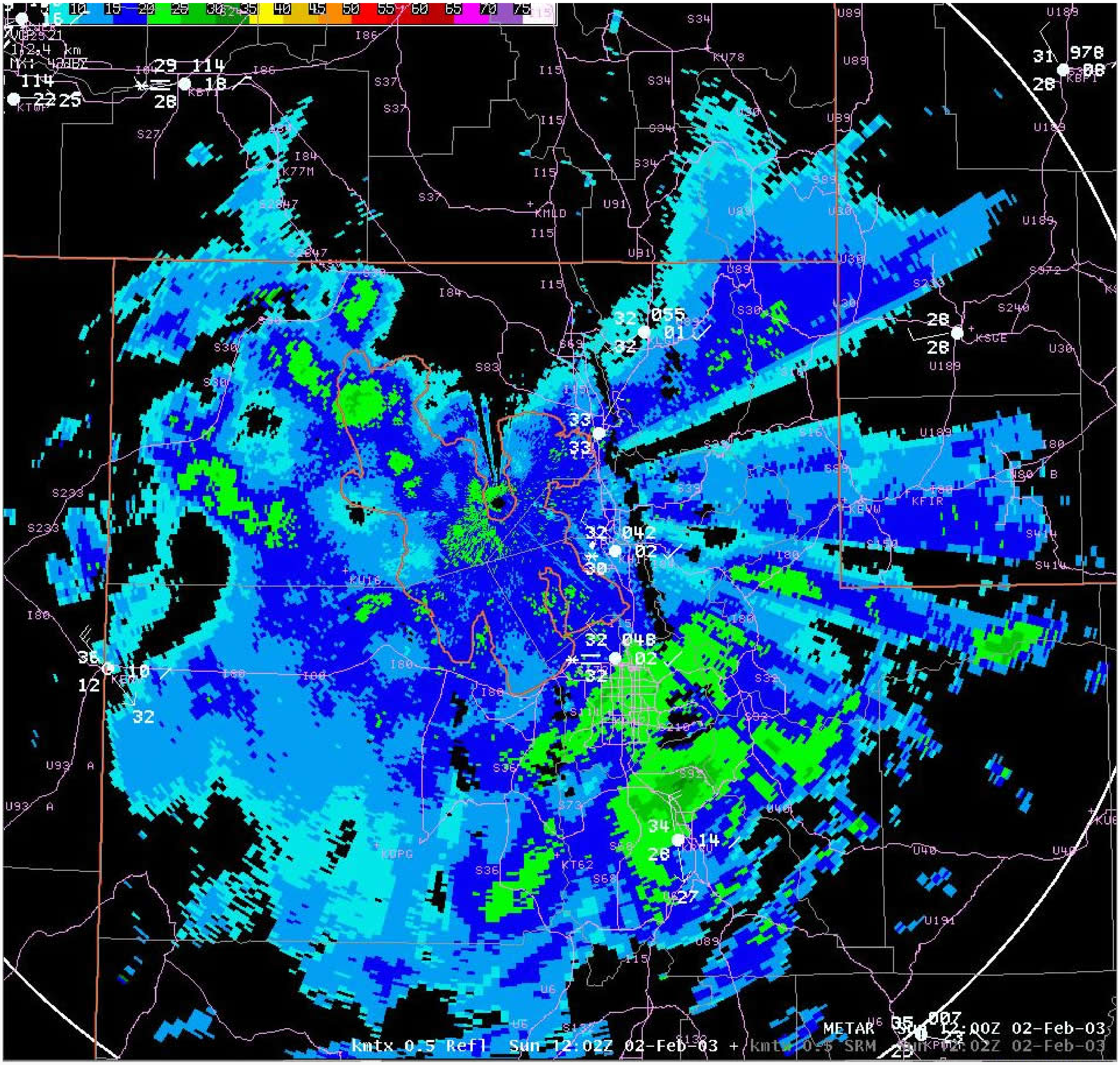

10
15
20
25
30
35
40
45
50
55
60
65
70
75
METAR Sun 12:00Z 02-Feb-03
kmtx 0.5 Refl Sun 12:02Z 02-Feb-03 + kmtx 0.5 SRM Sun 12:02Z 02-Feb-03
I15
I80
I84
U89
U189
U40
U6
KMLD
KDPG
KT62

Figure 22

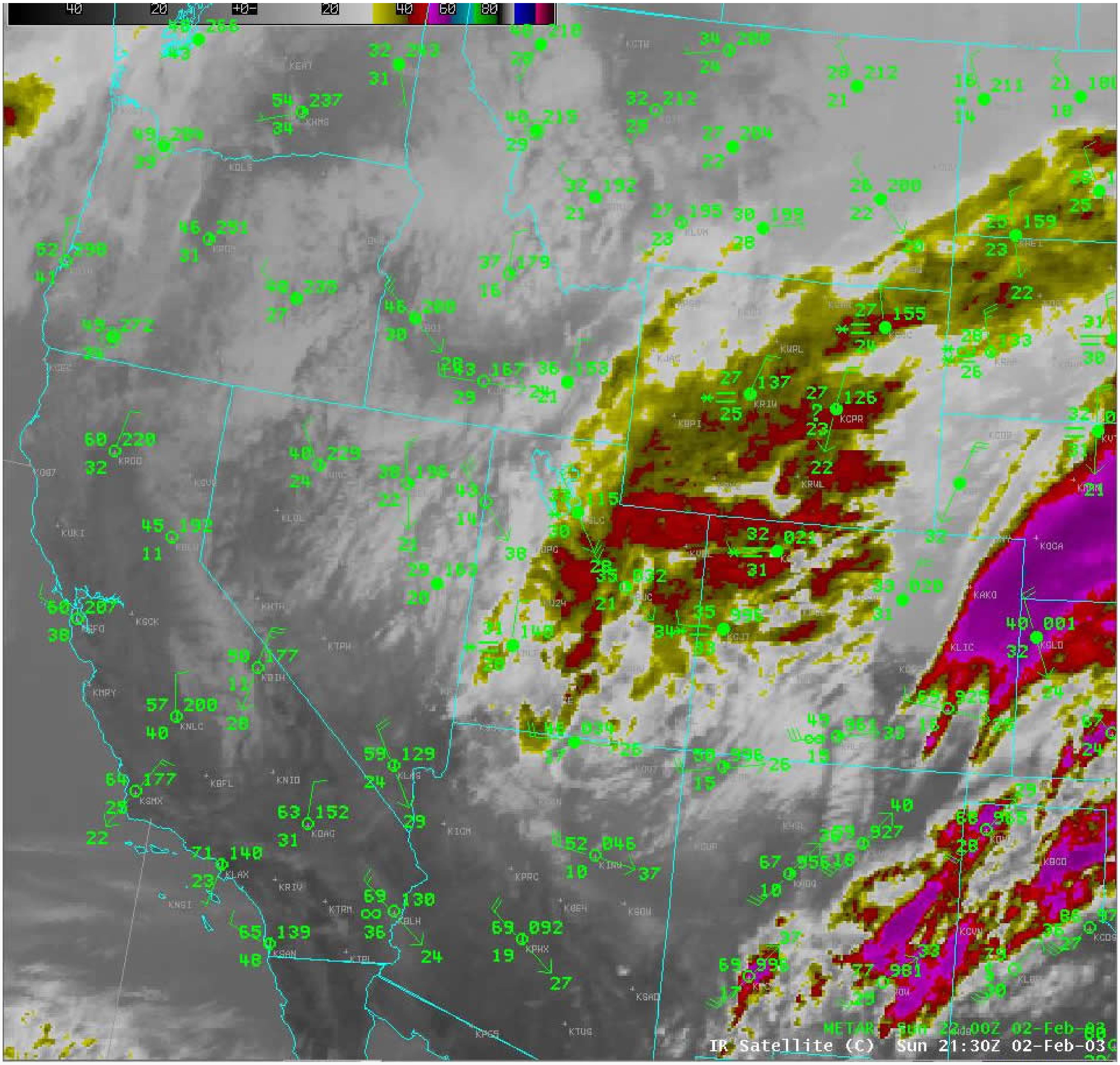
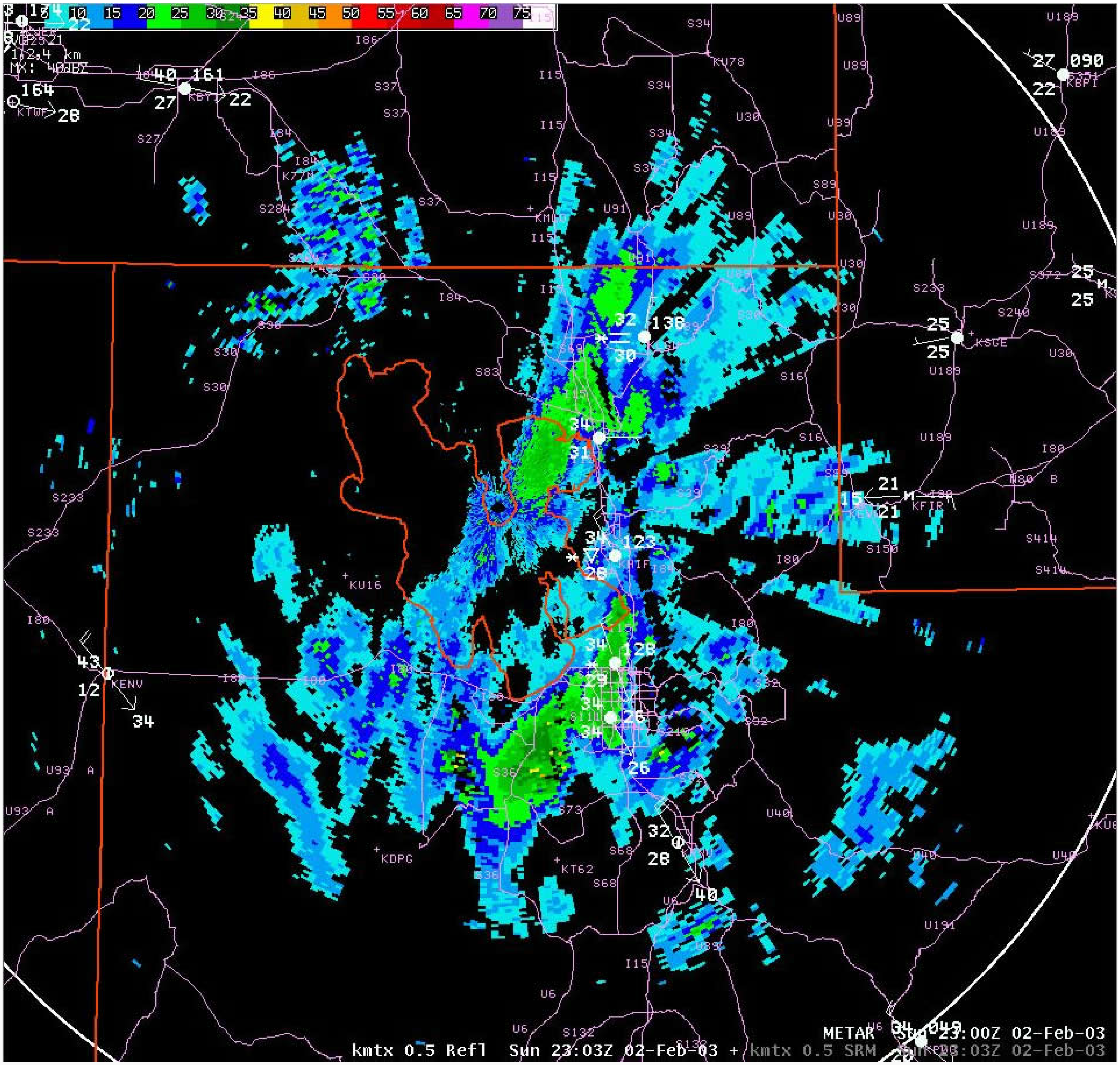
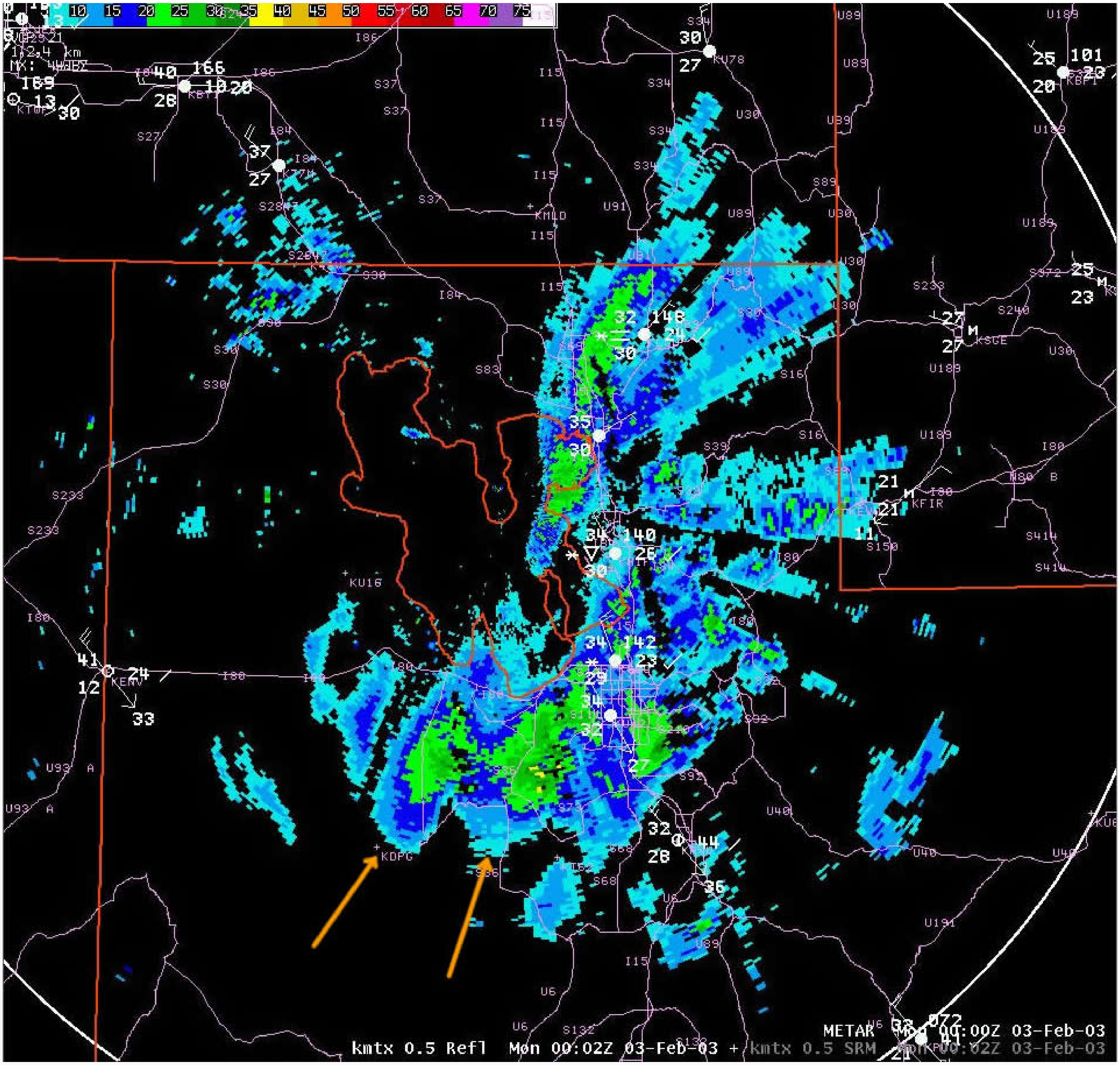


Figure 23



10 15 20 25 30 35 40 45 50 55 60 65 70 75
METAR Sun 23:00Z 02-Feb-03
kmtx 0.5 Refl Sun 23:03Z 02-Feb-03 + kmtx 0.5 SRM Sun 23:03Z 02-Feb-03
KBYI
KTWF
KBPI
KSGE
KFIR
KEVW
KHIF
KENV
KDPG
KT62
KU16
KMLD
K77M
I15
I80
I84
I86
U89
U30
U40
U6
U189
U191
U93

Figure 24


10 15 20 25 30 35 40 45 50 55 60 65 70 75
KDPG
I80
I15
I84
U89
U6
KMLD
KENV
KFIR
KSGE
METAR Mon 00:00Z 03-Feb-03
kmtx 0.5 Refl Mon 00:02Z 03-Feb-03 + kmtx 0.5 SRM Mon 00:02Z 03-Feb-03