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A Modified Total Totals Index for Thunderstorm Potential Over the Intermountain West

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I: Introduction:

The Total Totals (TT) Index was first used by Miller (1972) as an aid to forecasting severe thunderstorms over the Great Plains. The TT Index is comprised of two values: the Vertical Totals (VT) and the Cross Totals (CT). The VT is a measure of the vertical stability without regard to moisture and is found by subtracting the 500 mb temperature from the 850 mb temperature. The CT is a measure of the stability that includes moisture and is found by subtracting the 500 mb temperature from the 850 mb dew point temperature. The TT is simply the sum of the two and is combined to give (1):

$$1) \qquad 850T + 850Td + (500T \times 2) = TT$$

TT values of 44 suggest isolated thunderstorms should be forecasted, while values over 50 favor the development of scattered to numerous thunderstorms along with a better chance of severe weather. The 850 mb level was used to highlight the amount of moisture several thousand feet off the surface and was developed as an aid to predicting severe weather in the plains where the surface is well below 850 mb. However, over the Intermountain West, the calculation of the TT index is not sufficient as the surface is almost always above 850 mb.

For this investigation, the TT index was modified in hopes of finding a better and more reliable thunderstorm index for the Intermountain West. To account for the higher topography of the western U.S., the TT calculation was adjusted to account for temperature and moisture at 700 mb rather than 850 mb and was appropriately termed the High Level Total Totals (HLTT) index. The HLTT index was evaluated during the summer months, June to September, for 9 years spanning 1995-2003. The values of the HLTT index necessary for thunderstorm potential was calibrated from thunderstorm days over Reno, NV during the 9 year sample period. Reno was chosen due to the continuous hourly weather observations from the airport and the release of twice daily radiosondes which provided real time sampling of the atmospheric state. Reno lies immediately to the lee of the Sierra Nevada mountains at an elevation of 4,400 feet and experiences a desert climate typical of most valley locations in the Great Basin.

The results of the HLTT index during the analysis period showed positive results when correlated with thunderstorm development. Since the TT was initially designed to help forecast the occurrence of severe weather, the HLTT was also evaluated as an aid for severe thunderstorm development over the Intermountain West. To achieve this, the HLTT index was compared to severe thunderstorm and tornado warnings issued by WFO-Reno. Finally, the value of the HLTT was compared to precipitation occurrences at the Reno airport. A strong relationship was found with high value of the HLTT and the probability of precipitation.

The methodology of the study is presented in section II, results in section III, a detailed case study employing the HLTT index during a widespread thunderstorm outbreak over the Intermountain West is described in section IV. Finally, a summary and conclusion is presented in section V.

II: Methodology:

The HLTT index was calculated from radiosondes launched at 00Z from the NWS office in Reno during the summer months, June 1st through September 31st, from 1995 through 2003. The 00Z radiosondes were used as they represented the late afternoon environment when thunderstorm development was most widespread due to maximum daytime heating. The HLTT values were calculated every summer day during the 9 year period and compared to weather observations, precipitation amounts, and a limited lightning data set in hopes of finding correlations. This method does introduce the possibility of errors as the radiosondes did not always sample the environment closest to the period when precipitation or thunderstorms were observed at the Reno airport. Often RA, TS, or TSRA occurred several hours prior to or after the radiosonde launch, while on a few occasions occurred during the early morning hours.

The issuance of Severe Thunderstorm and Tornado Warnings from WFO-Reno were evaluated for the summer months during the sample period and compared to the values of the HLTT to see if correlations existed. Due to the paucity of observations and spotters over the western Nevada deserts and mountains of eastern California, it was not required for the warning to have verified. Only on rare occasions do thunderstorms pass over a populated area or an observing site to verify warnings.

The values of the HLTT index, as calculated from the radiosondes, were also compared to observed RA, TS, and TSRA reports from Reno, yielding the probability of precipitation or thunderstorm occurrence based on a given HLTT value. The probability of precipitation or thunderstorms was found by dividing the number of days precipitation or thunderstorms occurred with a given HLTT value by the total number of days with the same HLTT value. The HLTT was also calculated from numerical model output from the ETA and GFS during the 2003 summer season for subjective evaluation.

III: Results:

The value of the HLTT index on days when rain or thunderstorms were observed at Reno for the 9 year analysis period is presented in Figure 1. There is a substantial increase in the number days where RA, TS, or TSRA was reported when the HLTT index gets above 27. Precipitation was found to occur less than 15% of the time when the HLTT was below 28. The percentage is likely lower as many of these days were found to have precipitation occurring in the early morning prior to air mass stabilization like frontal passages or a transformation from monsoonal flow to drier westerly flow. The occurrence of RA, TS, or TSRA days at Reno peaks when the HLTT is between 29 and 33 and represents over 63% of the sampled days. It should be noted there were many days when the HLTT was at least 29 but no precipitation was observed at RNO. This is not to say that thunderstorms were not in the area, they may have been isolated or scattered but did not pass over the Reno airport.

Based on the results of the distribution of precipitation at Reno, a general guideline for using the HLTT index was developed and is presented in Table 1. The higher the value of the HLTT index, the better chance of thunderstorm development, especially if conditions are warm and moist at or near the 700 mb level. Caution should be used with this index under unseasonably cool upper lows, which were occasionally observed in early June or late September. With cold upper lows, the 500 mb temperatures can be at least -18C, causing an overestimation of thunderstorm potential in low topped convection. Due to the overestimation of the HLTT index with cold upper lows the HLTT is often above 34. Under this synoptic pattern, thunderstorms are isolated and snow levels are quite low, usually below 7000 or 8000 feet in an atmosphere dominated by low topped scattered to widespread convection.

Forecast	**High Level TT**
Isolated thunderstorm possible	28-29
Isolated thunderstorms	29-30
Isolated to scattered thunderstorms	31-32
Scattered to numerous thunderstorms	>= 33

Table 1.

The probability of rain or thunderstorms occurring in Reno based on values of the HLTT index was then evaluated. To determine the probability of precipitation based on a given value of the HLTT index, the total number of days of the HLTT index at a specific value was compared to the number of occurrences of rain or thunderstorms with the same value to yield a probability of precipitation percentage. For example, a HLTT index of 30 was found to occur in 61 days of the study, while 24 of these days had RA, TS, or TSRA observed, yielding a probability of precipitation of 39%. A strong correlation was found to exist between the likelihood of rain or thunderstorms and the increasing value of the HLTT. Rain or thunderstorms were observed in 26% of the days when the HLTT index was 28 (figure 2). The probability of precipitation jumps to 32% with a HLTT index of 29, and to 39% with a HLTT index of 30. The chance of precipitation significantly jumps when the HLTT is 31 or greater. With a HLTT of 35 or greater the likelihood of precipitation is at least 80%, although the sample size is small compared to the more numerous occurrences of a HLTT index of 34 or less.

The HLTT was compared with the number of days that severe thunderstorm (SVR) or tornado warnings (TOR) were issued from WFO-Reno to see if the index could be applied to severe weather forecasting. A SVR or TOR was only counted in the statistics if the county where the warning was issued was within a reasonable distance to the radiosonde and subjectively determined to be within 75 miles. A strong correlation was found to exist between the value of the HLTT index and the frequency of SVR or TOR warnings (figure 3). When the HLTT index was observed to be 30, the occurrence of SVR’s or TOR’s Warnings issued was only found to be 6.4% of the time. That is to say, Whenever the HLTT index is 30, SVR’s or TOR’s are issued on 6.4% of those days. The percentage steadily increases until the HLTT reaches 34, which was found to have a 50% probability of SVR or TOR Warning being issued with this value.

IV: Case Study:
To show the effectiveness of the HLTT index, a detailed case study is presented during an active thunderstorm day which occurred on July 20th, 2003 over the Intermountain West. At 18Z on July 20th a strong upper level pressure ridge was centered over Utah with the ridge axis extending into northern Idaho and western Montana (figure 4). Numerous vorticity maxima were analyzed by the GFS rotating around the ridge and provided a focus for convective development.

The 700 mb equivalent potential temperatures analysis from the GFS shows very high values across Colorado, northwestern New Mexico, and eastern Arizona (figure 5). Equivalent potential temperatures are lower, yet still impressive, over Utah, north-eastern Nevada and extending down the Sierra of extreme eastern California and western Nevada. The high equivalent potential temperature values at 700 mb and the numerous vorticity maxima rotating around the upper high, combined with topographically induced forcing, provided the necessary dynamics for thunderstorm development.

Precipitable water values of over 0.75" encompassed a majority of the Intermountain west in this "monsoonal" type pattern (figure 6). The values were analyzed to be highest over Utah, northwestern New Mexico, and portions of eastern Arizona with values exceeding 1.25". The lowest precipitable water values are located over the southern Sierra extending into western and southern Nevada and northern Colorado. The HLTT index analyzed at 00Z July 21st is depicted in Figure 7 with infrared satellite imagery and 1 hourly accumulated lightning beginning at 23Z July 20th overlayed. The greatest values of the HTLL index are located over southern Colorado, northern and western New Mexico, eastern Arizona, Utah, the northern Rockies, and northern Nevada extending southward down the Sierra Nevada. The most numerous lightning strikes were found to occur in the same regions. Analyzing the HLTT index, a sharp demarcation in the number of lightning strikes exists as the values drop below 30. Over western and southern Nevada, and extending into western Arizona a large gradient in the HLTT index is observed which matches very well with the transition of lightning from being numerous to scattered to non-existent.

To better depict the number of lightning strikes around the 00Z July 21st HLTT index, lightning for a 6 hour period, from 21Z July 20th through 03Z July 21st is presented in Figure 8 with HLTT values equal to or greater than 30 shaded. The most numerous lightning strikes are very well correlated with the highest values of the HLTT index, especially when values are above 30. When the HLTT index falls below 30 almost no lightning strikes were observed.

To further illustrate the effectiveness of the HLTT index, lightning for a 6 hour period, from 21Z to 03Z, was compared to values of the HLTT index were analyzed from the GFS for 00Z July 22nd and 00Z July 23rd. Values of the HLTT index equal to or greater than 30 are once again shaded to highlight locations where thunderstorm development would be most likely. On July 22nd at 00Z, as analyzed by the GFS, values of the HLTT index above 30 encompass almost all of the lightning strikes over the Intermountain West (figure 9). The exception would be a few lightning strikes over southern Oregon and southern Nevada. Comparing the HLTT index for July 23rd with actual lightning observations again shows almost all the strikes occurred where the GFS had the HLTT index 30 or greater (figure 10). The highest values of the HLTT index are found over north-central Arizona and northern New Mexico extending into central Colorado. This region shows the highest density of lightning strikes match the highest values of the HLTT index.

V: Summary

The Total Totals Index, which is used to predict the occurrence and severity of thunderstorms in the plains, was modified for the higher elevations of the Intermountain West. The 850mb level is often at or below the surface in the western United States and therefore fails to account for the necessary moisture needed for thunderstorm development. Instead of employing the 850mb layer, the level typically used in lower elevation topography of the central and eastern United States, the 700 mb level was substituted into the calculation Total Totals Index and was renamed the High Level Total Totals Index.

The HLTT index was evaluated over Reno in hopes of finding correlations between values from the HLTT index and thunderstorm development. Strong correlations were found between the HLTT index and thunderstorm development, the severity of thunderstorms, and the probability of precipitation. The most likely chances for thunderstorm development occur with the highest values of the HLTT index. A minimum values of 28 or 29 is required for the development of isolated thunderstorms while a value of 32 or higher yields a high probability of scattered to numerous thunderstorm development. Severe thunderstorm or tornado warnings issued from WFO-Reno were found to most frequently occur when the HLTT index was 32 or higher. Almost no severe thunderstorm or tornado warnings were issued when the HLTT index fell below 30.

The results suggest the higher the value of the HLTT index, the better probability of receiving measurable precipitation. A HLTT of 29 was found to give a 32% chance of precipitation at the Reno airport with the likelihood of precipitation occurring jumped sharply to 58% when the HLTT index was 31 and up to an 80% likelihood with a value of 35 or higher.

The HLTT index should be used with caution when an unseasonably cold upper lows move through the Intermountain West as the 500 mb temperature can lead to an overestimated value of the HLTT index. Comparing the HLTT values of the GFS and the ETA with actual radiosondes shows numerical models slightly overestimate the values. The overestimated values are likely the result of convective feedback due to excessive latent heat release with cumulus development or providing too much moisture at the 700 mb level compared to reality. The HLTT index should primarily be used during the summer season when 500 mb temperatures are usually below -15EC. A more thorough investigation into the cause of the overestimation is needed.

VI: Reference

Miller, **R. C., 1972: Notes on analysis and severe storm forecasting procedures of the Air Force Global Weather Central. Tech. Rept. 200(R), Headquarters, Air Weather Service, USAF, 190 pp.**

Figures

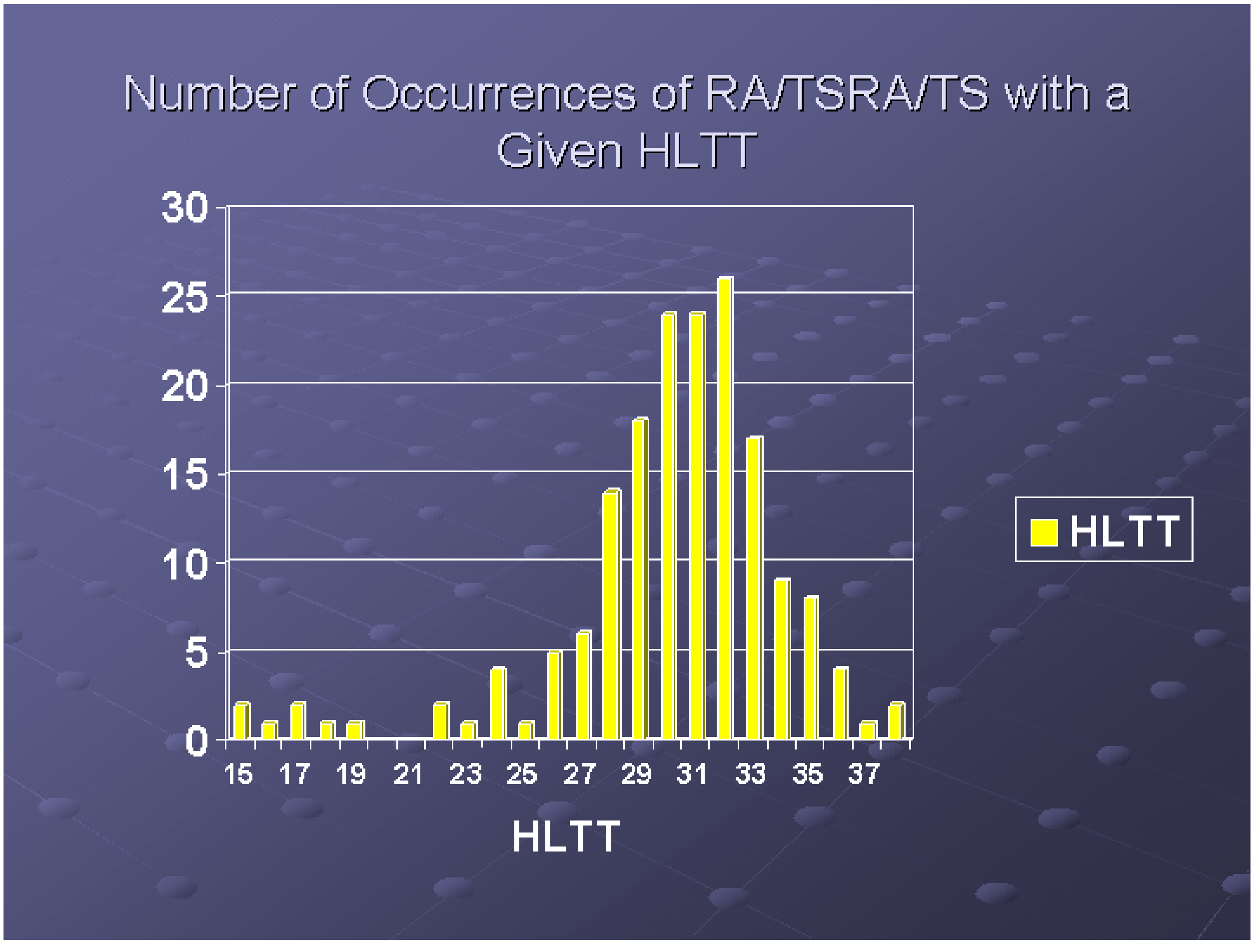


Figure 1

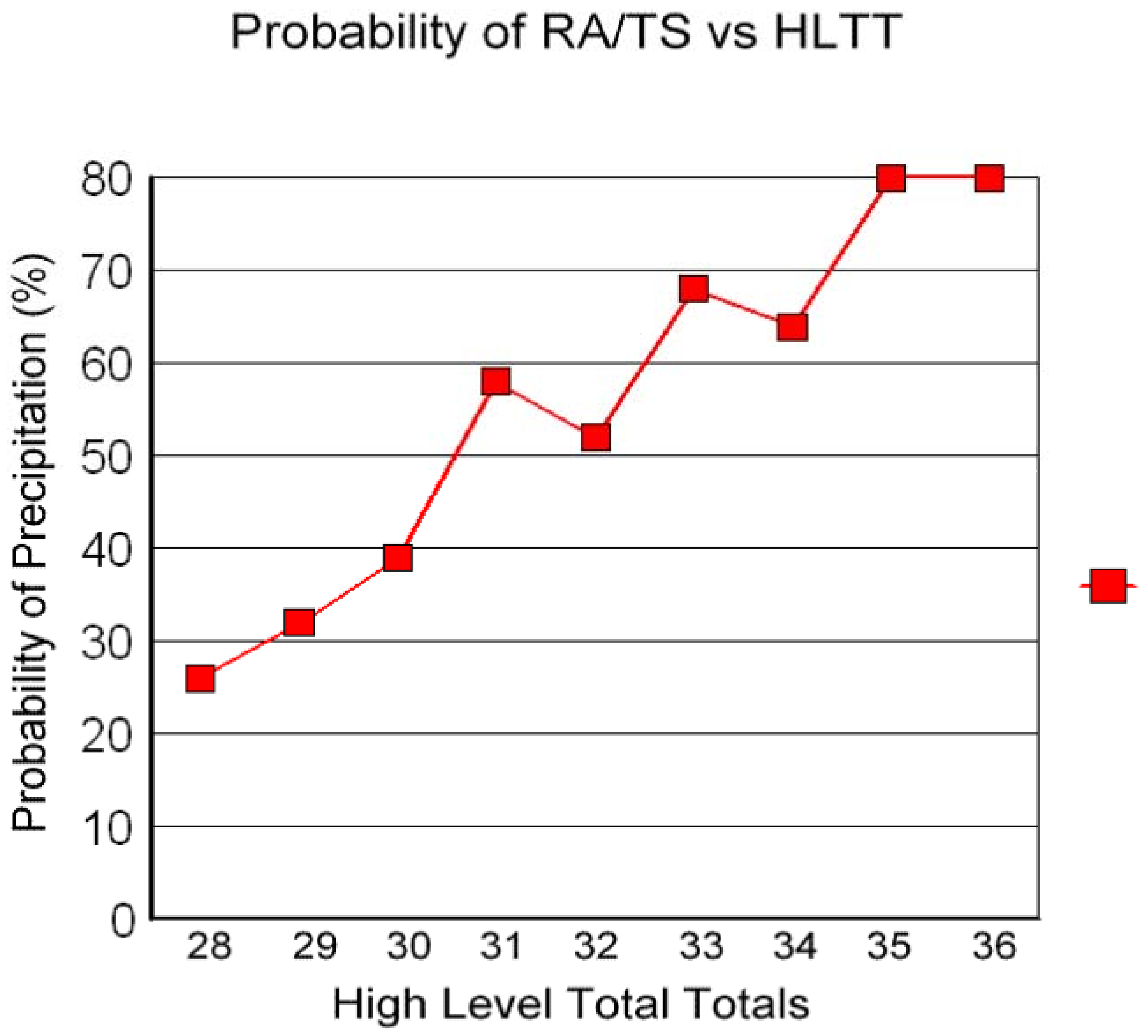

Probability of RA/TS vs HLTT
Probability of Precipitation (%)
80
70
60
50
40
30
20
10
0
28
29
30
31
32
33
34
35
36
High Level Total Totals

Figure 2

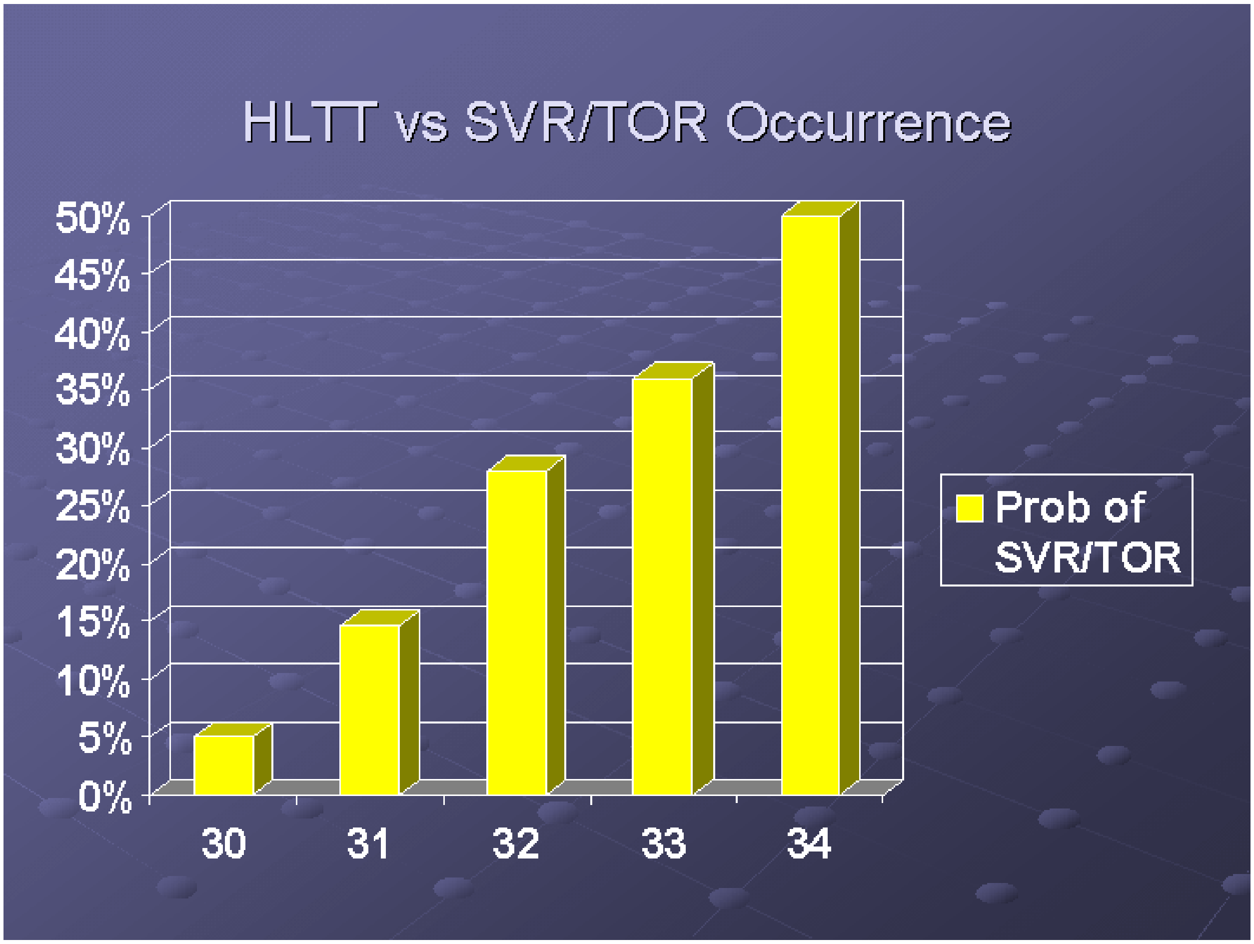

HLTT vs SVR/TOR Occurrence
50%
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
30
31
32
33
34
Prob of SVR/TOR

Figure 3

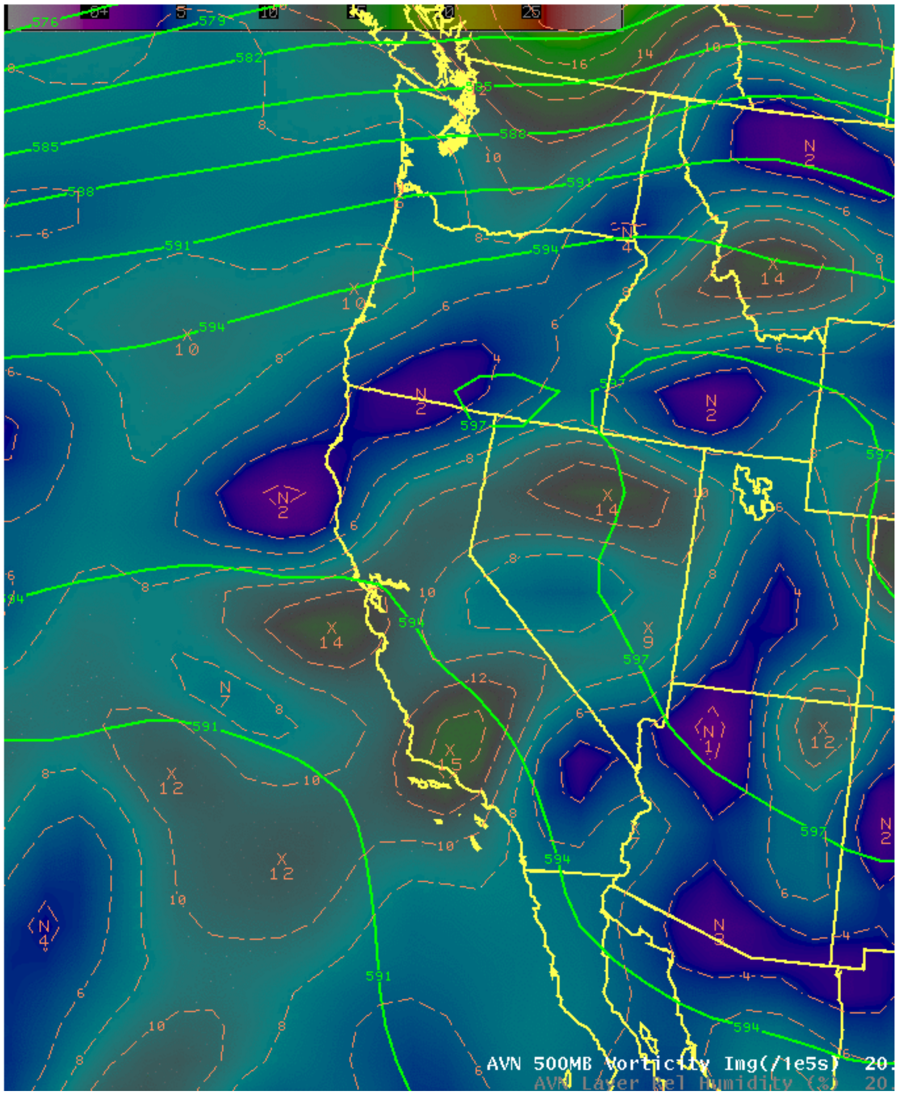


Figure 4

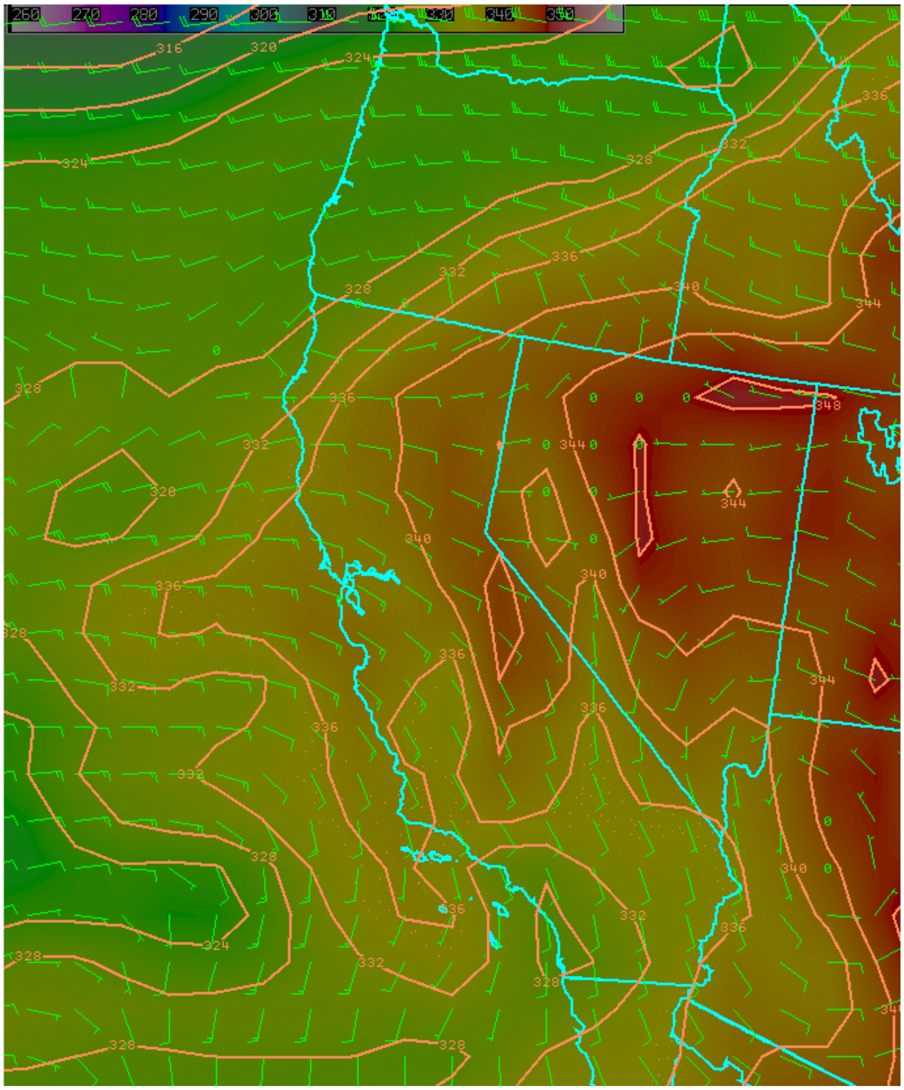


Figure 5

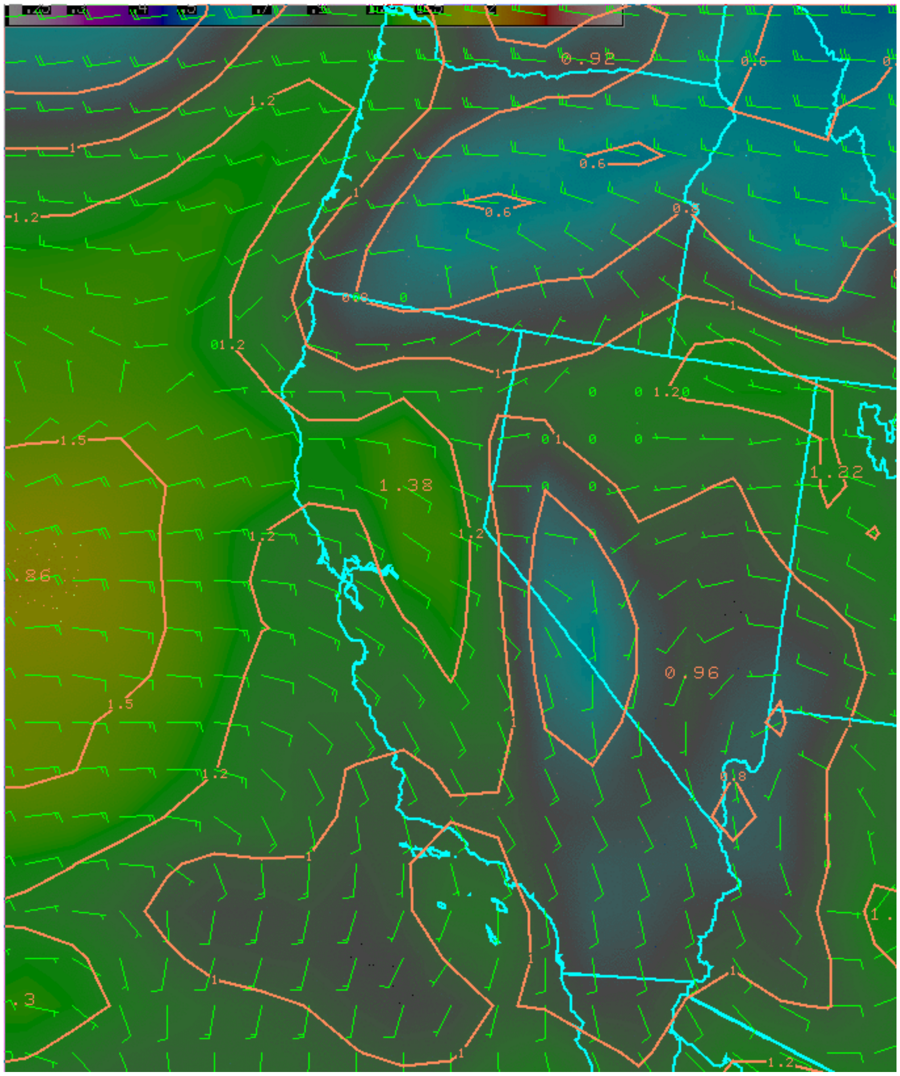


Figure 6

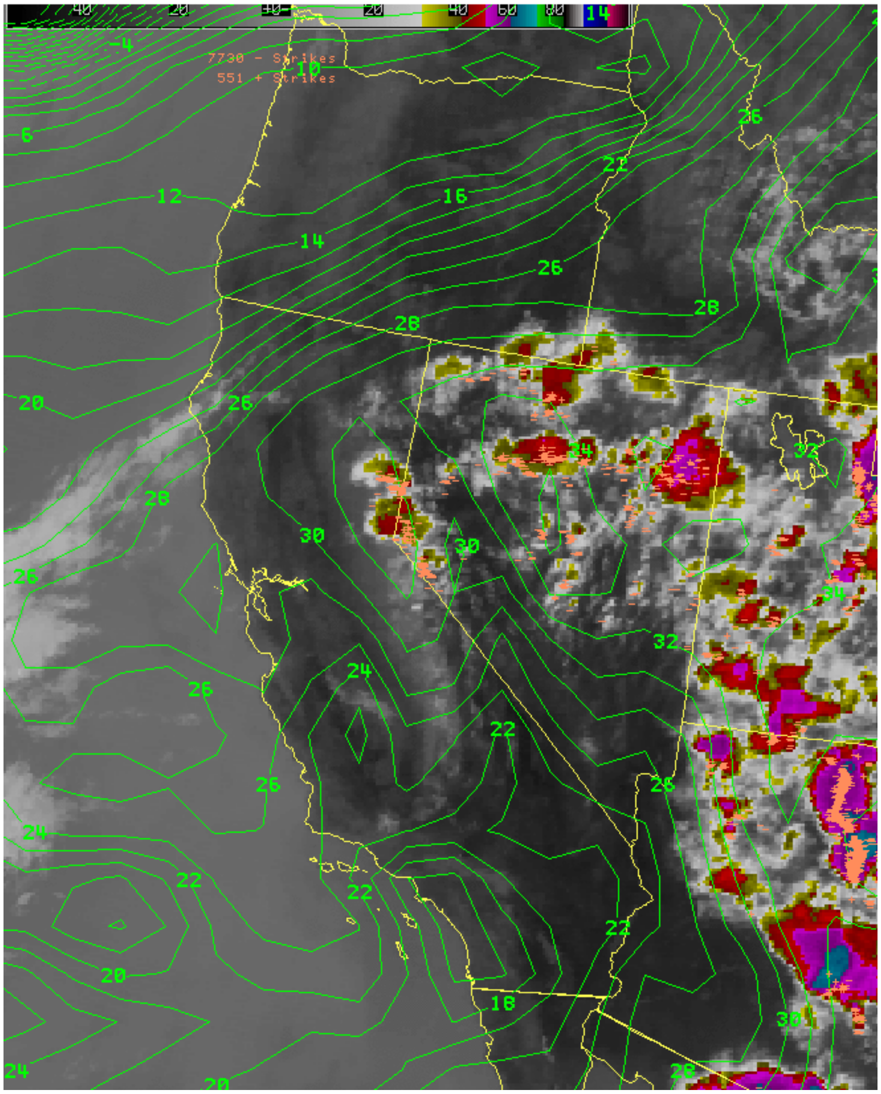


Figure 7

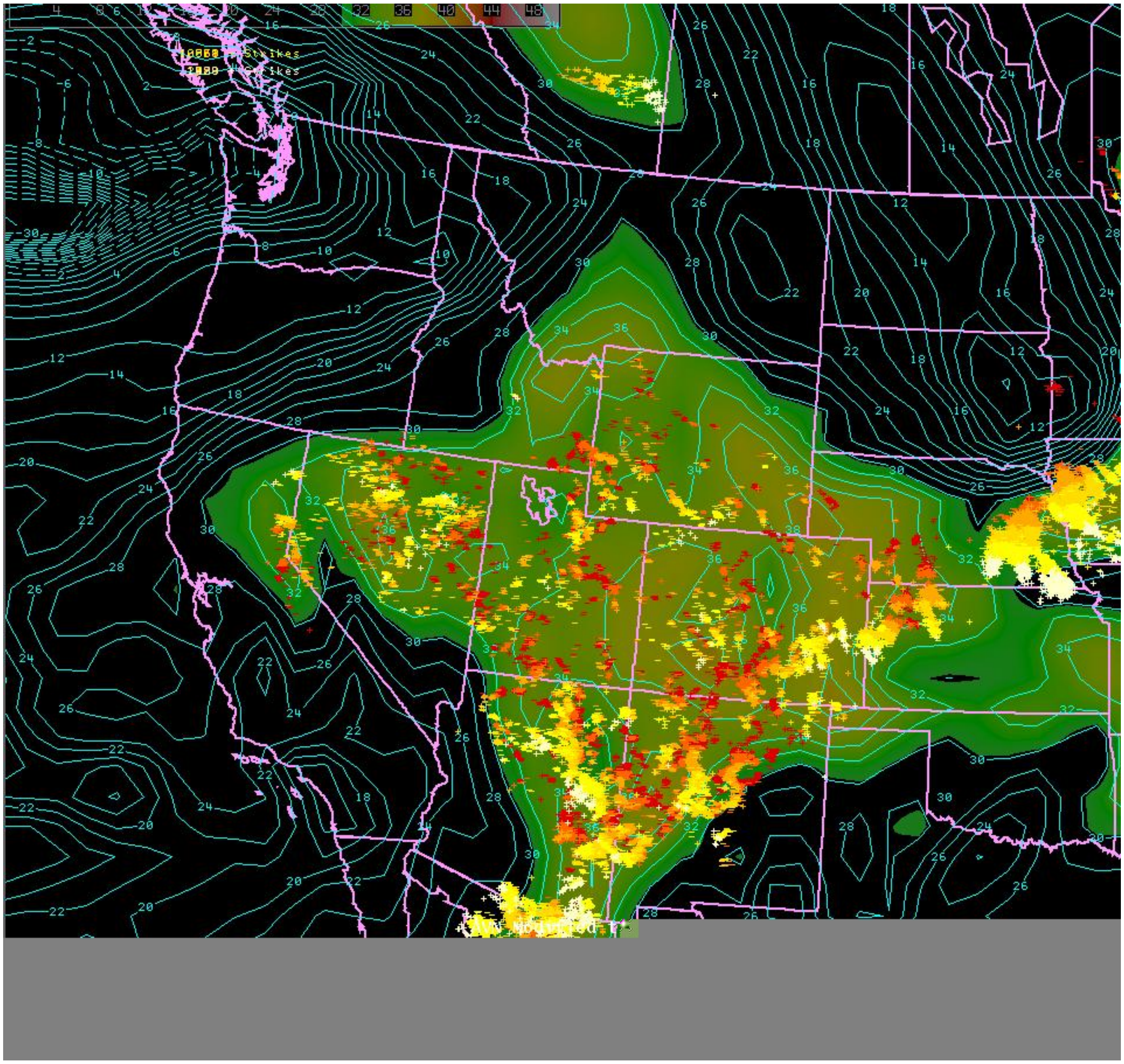


Figure 8

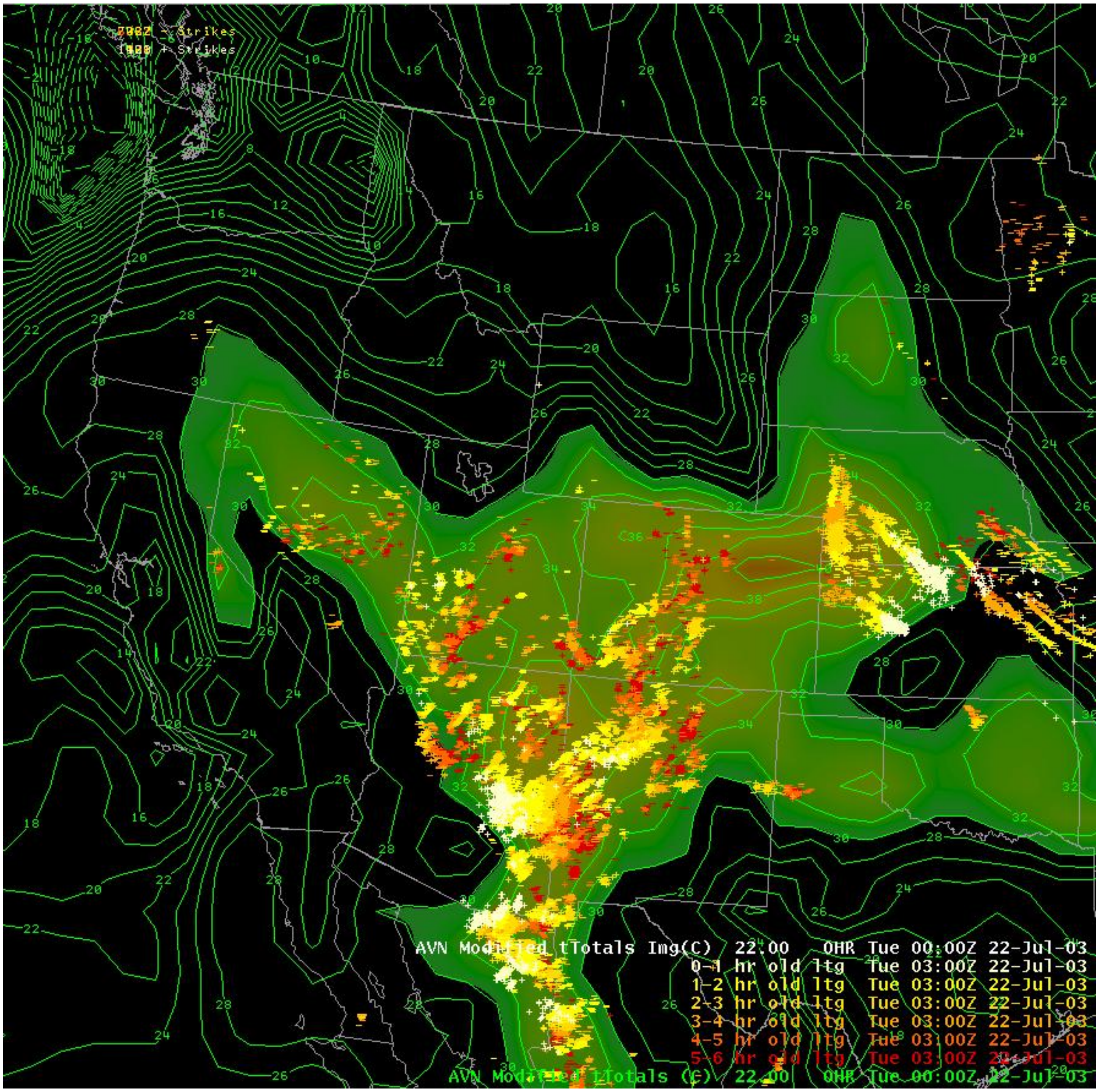
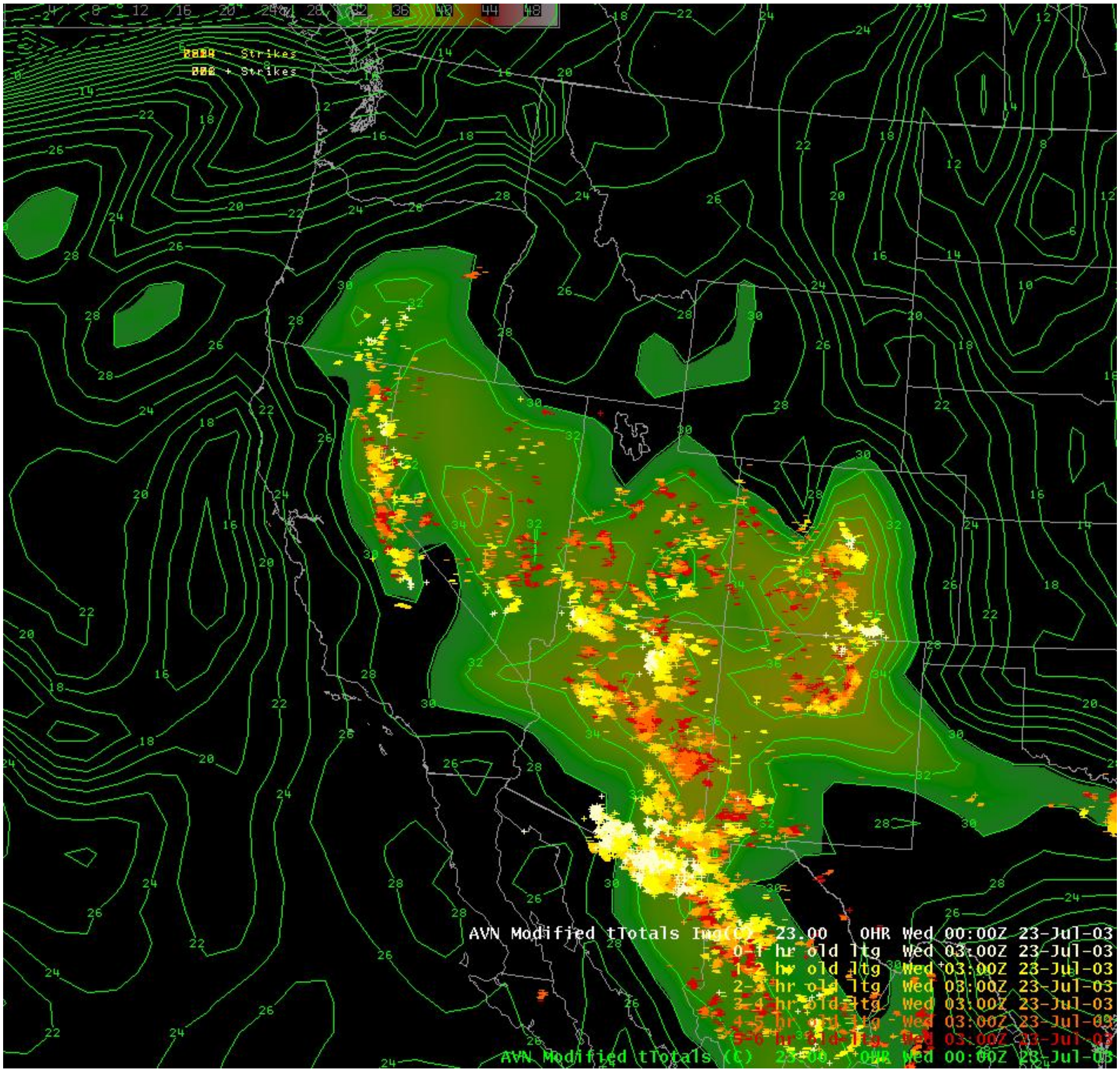

AVN Modified tTotals Img(C) 22.00 0HR Tue 00:00Z 22-Jul-03
0-1 hr old ltg Tue 03:00Z 22-Jul-03
1-2 hr old ltg Tue 03:00Z 22-Jul-03
2-3 hr old ltg Tue 03:00Z 22-Jul-03
3-4 hr old ltg Tue 03:00Z 22-Jul-03
4-5 hr old ltg Tue 03:00Z 22-Jul-03
5-6 hr old ltg Tue 03:00Z 22-Jul-03
AVN Modified tTotals (C) 22.00 0HR Tue 00:00Z 22-Jul-03

Figure 9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0-1 hr old ltg Wed 03:00Z 23-Jul-03
1-2 hr old ltg Wed 03:00Z 23-Jul-03
2-3 hr old ltg Wed 03:00Z 23-Jul-03
3-4 hr old ltg Wed 03:00Z 23-Jul-03
4-5 hr old ltg Wed 03:00Z 23-Jul-03
5-6 hr old ltg Wed 03:00Z 23-Jul-03
AVN Modified tTotals (C) 23.00 OHR Wed 00:00Z 23-Jul-03

Figure 10