The Front

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Model Output Statistics Provide Essential Data for Small Airports

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Terminal Aerodrome Forecasts (TAF) are hourly and highly detailed forecast for the weather conditions expected at airports. Many pilots complain that TAFs are not issued for enough airports. Typically, TAFs are issued at towered airports served by commercial air carrier operations. TAFs also are issued from a few larger general aviation airports and military airports.

From a legal perspective, if there is no TAF, you must use the Area Forecast (FA). The FA is one of the products read by an Automated Flight Service Station (AFSS) specialist when a pilot gets a standard weather briefing. The FA is also included as part of a Direct User Access Terminal (DUATS) computer briefing via the Internet.

While the FA does a fair job addressing some adverse weather elements such as ceiling and visibilities, it is not as detailed—and therefore as useful to a pilot—as a terminal forecast. Wouldn't it be helpful to see a weather product as detailed as a TAF for any airport in the country? Model Output Statistics (MOS) provides at least a partial solution to the problem.

As the name suggests, MOS is derived from weather forecasting model output. Numerical Weather Prediction (NWP) models are run on a scheduled basis. Models such as the North American Mesoscale (NAM) or Global Forecast System (GFS) are run every 6 hours.

The models give forecasters long and short range guidance in the form of charts and diagrams at various pressure levels (altitudes) and at the surface. They do not automatically produce a point forecast for a specific town or airport. MOS takes the raw model forecast and attempts to produce an objective and more useful *site-specific* forecast.

MOS is a statistical post-processing scheme applied to the output of a numerical weather prediction model. There is a version of MOS for each underlying NWP model. While it may not fulfill the legal role, it does provide much needed detail that isn't found using the FA alone (see **Figure 1**).

To make the original model forecast better, MOS takes into account a historical record of observations at forecast points such as airports, corrects for certain systematic model biases and quantifies uncertainty into probability forecasts. In addition, MOS transforms the data into weather elements the model does not directly forecast. This data includes weather elements basic to aviation such as ceiling height, visibility and the probability of thunderstorms for a specific airport.

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The Front

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Mission Statement

To enhance aviation safety by increasing the pilot's knowledge of weather systems and processes and National Weather Service products and services.

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CADILLAC/WEXFORD CO
 KCAD   ETA MOS GUIDANCE    1/24/2006  1200 UTC
 DT /JAN  24/JAN  25                /JAN  26                /JAN  27
 HR   18 21 00 03 06 09 12 15 18 21 00 03 06 09 12 15 18 21 00 06 12
 N/X                     25          29          18          39    33
 TMP  30 29 28 29 29 28 27 27 28 27 26 24 22 21 21 27 35 39 35 34 37
 DPT  30 29 26 24 23 23 22 22 22 22 21 20 19 18 18 22 24 24 25 28 33
 CLD  OV OV OV OV OV OV OV OV OV OV OV OV OV OV OV OV BK SC CL CL OV
 WDR  26 28 30 30 30 31 31 31 31 31 31 30 29 29 00 21 21 21 19 20 20
 WSP  12 14 14 17 17 15 14 12 13 12 07 04 03 01 00 04 07 08 04 08 05
 P06        67    59    44    22     6     1     0     0     0  0  3
 P12                     66          28           5           3     3
 Q06         1     1     1     0     0     0     0     0     0  0  0
 Q12                     1           0           0           0     0
 T06      0/ 8  0/ 2  0/ 1  0/ 0  0/ 4  0/ 0  0/ 1  0/ 0  0/ 0999/99
 T12            0/14        0/ 2        0/ 7        0/ 1   999/99
 SNW                     2                           0                 0
 CIG   3  2  4  4  4  4  4  4  4  5  5  5  6  4  3  4  8  8  8  8  8
 VIS   3  3  4  5  4  5  5  3  5  5  7  5  6  5  5  4  5  5  7  5  5
 OBV   N BR  N  N  N  N  N  N  N  N  N  N  N BR BR BR BR HZ  N  N BR
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Figure 1. *A text bulletin is one way to view MOS data. Here is an example of a complete MOS text bulletin for Wexford County Airport in Cadillac, MI, generated from the NAM (Eta) model.*

Here's the way MOS works. First, the underlying NWP model (NAM, GFS, NGM, etc.) runs on the computers at the National Centers for Environmental Prediction (NCEP). Once the model has completed the forecast, specific data is collected from model fields and the MOS equations are evaluated. Before sending out the product, the MOS output is post-processed to check for meteorological and statistical consistency; then categorical forecasts are generated.

These MOS forecasts predict the "sensible" weather elements. The predicted elements can be categorical and continuous data. For example, continuous data includes, but is not limited to, temperature, dew point temperature, wind direction and wind speed. For some predicted elements, forecasters use categories. For instance, instead of providing a cloud height forecast of 500 feet AGL, the MOS system assigns a category of "3" representing a range of cloud heights from 500 feet AGL to 900 feet AGL (**Figure 1**). On the other hand, precipitation is not always presented as a probability of a ceiling height (**Figure 2**).

MOS is output in a tabular format (called FOUSnn where nn is the bulletin number), but also may be depicted graphically. For example, MOS is frequently illustrated in a meteogram. Each bulletin contains multiple sites. These sites are usually airports but may include other locations, normally with an NWS official weather observation. Currently, there are nearly 1,700 MOS locations in the United States, including Alaska, Hawaii, Puerto Rico and the Virgin Islands as well as U.S. coastal waters using buoys and in Cuba.

MOS is not just for pilots. Forecasters at NWS Forecast Offices use MOS to help generate TAFs. Forecasters sometimes use MOS as the starting point for constructing the TAF, but MOS is rarely the only forecast guidance used, and for obvious reasons it may be superseded by more timely observational data.

MOS does have a few important limitations. For example, while it provides another view of the weather conditions expected at an airport, it does not substitute for the official forecast, nor should it be the only source of weather data a pilot uses. Here are four points to consider.

- MOS will correct many known systematic biases in the NWP model, but it will not "fix" a bad forecast. Forecasters have the experience to recognize these cases and produce forecasts accordingly. A faulty model forecast does happen occasionally so don't become complacent. Always verify the current output against observations, satellite and radar data to ensure that the MOS guidance appears on track. Use other forecast guidance or other models' MOS output as a check and balance.
- Due to degraded model accuracy, MOS guidance tends to less accurate for extended forecasts. From an aviation perspective, a MOS forecast beyond 72 hours is not much better than using climatology (averages). Using MOS forecasts up to and including 60 hours will provide the pilot with the most useful guidance.
- Local terrain effects are sometimes a problem for MOS. One well known example is the prediction of cold-air damming along the Appalachian Mountains. MOS tends to forecast warmer temperatures at the surface and may even miss a freezing rain event.

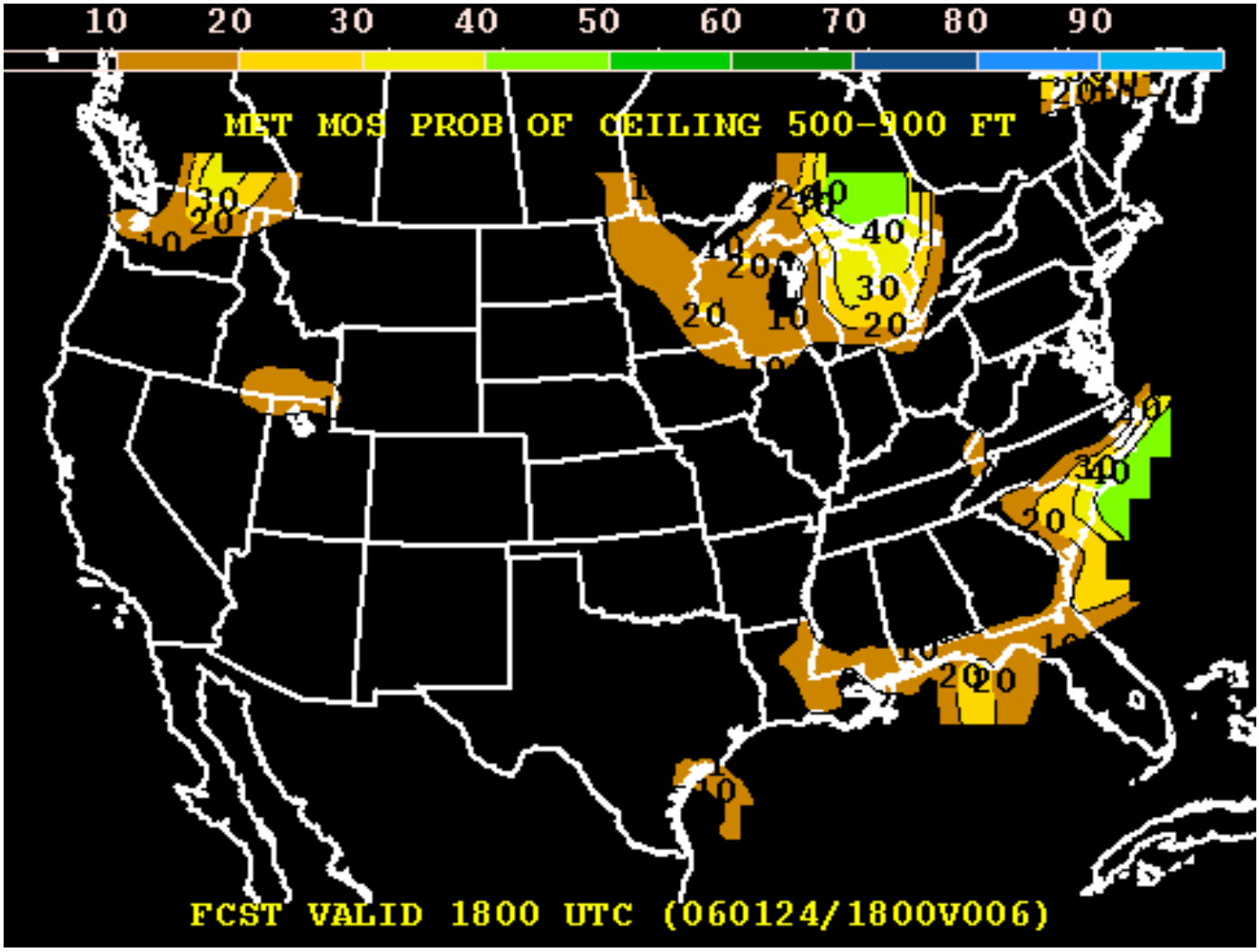

Figure 2. *MOS also can be viewed graphically in many ways, including this chart which indicates the probability of a ceiling of 500 ft to 900 ft AGL valid at 1800 UTC on January 24.*

Cloud Height Categories (AGL)		Visibility Categories	
1	Less than 200 ft	1	Less than 1/2 mile
2	200 to 400 ft	2	1/2 to < 1 mile
3	500 to 900 ft	3	1 to < 2 miles
4	1000 to 1900 ft	4	2 to < 3 miles
5	2000 to 3000 ft	5	3 to 5 miles
6	3100 to 6500 ft	6	6 miles
7	6600 to 12000 ft	7	Greater than 6 miles
8	Greater than 12000 ft or unlimited	8	

Figure 3: *Many MOS bulletins include a categorical representation of cloud height and visibility. These categories can be decoded using these two tables.*

- MOS may be inaccurate if conditions are highly irregular. This is not to say that record high and record low temperatures can't be predicted by MOS; however, when adverse weather is at its worst, don't depend on MOS to predict the extreme conditions.

For planning, a graphical MOS representation is normally sufficient. Keep in mind, graphical representations created for the public may only depict a subset of weather elements. Therefore, it may not show those critical to aviation. There are usually more weather elements in the text bulletin than depicted graphically. Some pilots find it easier to scan the tabular text when looking at a dozen or more sites along their planned flight route.

From a pilot's perspective, MOS is best used for generalizations and trends. For example, assume a pilot is flying to Hagerstown, MD (KHGR). A scheduled TAF is not issued for Hagerstown. The closest site with a TAF is 22 nautical miles southwest at Martinsburg, WV (KMRB). Can a pilot simply use the TAF out of Martinsburg?

Legally, the pilot must use the Area Forecast since the TAF is only valid 5 statute miles from the center of the airport's runway complex. On the other hand, the area forecast may not be detailed enough for you to feel comfortable about the actual weather at Hagerstown. How do you obtain a more accurate outlook?

This is a scenario where MOS can help. Assume from the example above, you check the latest MOS bulletin for Hagerstown (see below) and notice a trend toward lower ceilings (CIG) and lower visibility (VIS) around the estimated time of arrival (0600 UTC). The MOS product will provide the general magnitude and timing of the adverse weather they might face.

```
KHGR   ETA MOS GUIDANCE    1/12/2006  1200 UTC
DT /JAN  12/JAN  13                /JAN  14                /JAN  15
 HR   18 21 00 03 06 09 12 15 18 21 00 03 06 09 12 15 18 21 00 06 12
 CLD  FW SC CL SC BK BK OV OV OV OV OV OV OV OV OV OV OV OV OV OV CL
 CIG   8  8  8  8  1  2  1  1  8  6  5  4  3  3  2  4  4  4  3  6  8
 VIS   7  7  7  7  3  3  4  4  7  7  7  5  2  4  4  3  6  7  5  7  7
 OBV   N  N  N  N  N  N BR HZ  N  N  N BR BR BR BR BR  N  N BR  N  N
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For example, from the NAM (Eta) MOS guidance above, a quick scan of the ceiling forecast for Hagerstown shows a rapid change from VFR conditions (category 8) to very low broken (BK) to overcast (OV) IFR ceiling (category 1) beginning before 0600 UTC Jan 13 through 1500 UTC. From this data, it is likely there will be an overnight and morning low IFR event at Hagerstown.

While MOS isn't a legal substitute for the official terminal and area forecasts, it may help provide the pilot with some assurance that there won't be any surprises. For more information on MOS go to: http://www.weather.gov/mdl/synop/products.shtml and http://www.weather.gov/mdl/forecast/graphics/MET/index.html ✈

Microburst Recognition Makes Navigating West and Southwest Safer and More Accurate

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Pilots navigating the mountainous terrain of the western United States, in particular the intermountain region and interior Southwest, generally enjoy from 250 to 300 plus VFR days per year with unlimited visibility and ceilings above 12,000 ft. Many of these excellent flying days occur between May and October; however, if you are flying during the southwest monsoon season from early July through mid-September, you need to watch for afternoon thunderstorms. Fortunately, the monsoon season is interspersed with drier periods. Pilots often find good flying conditions in these drier periods with only minimal convection.

Transitions from dry to moist periods, or vice versa, however, can be dangerous for an unsuspecting pilot. The dangers come from variability in amount and strength of convection despite a

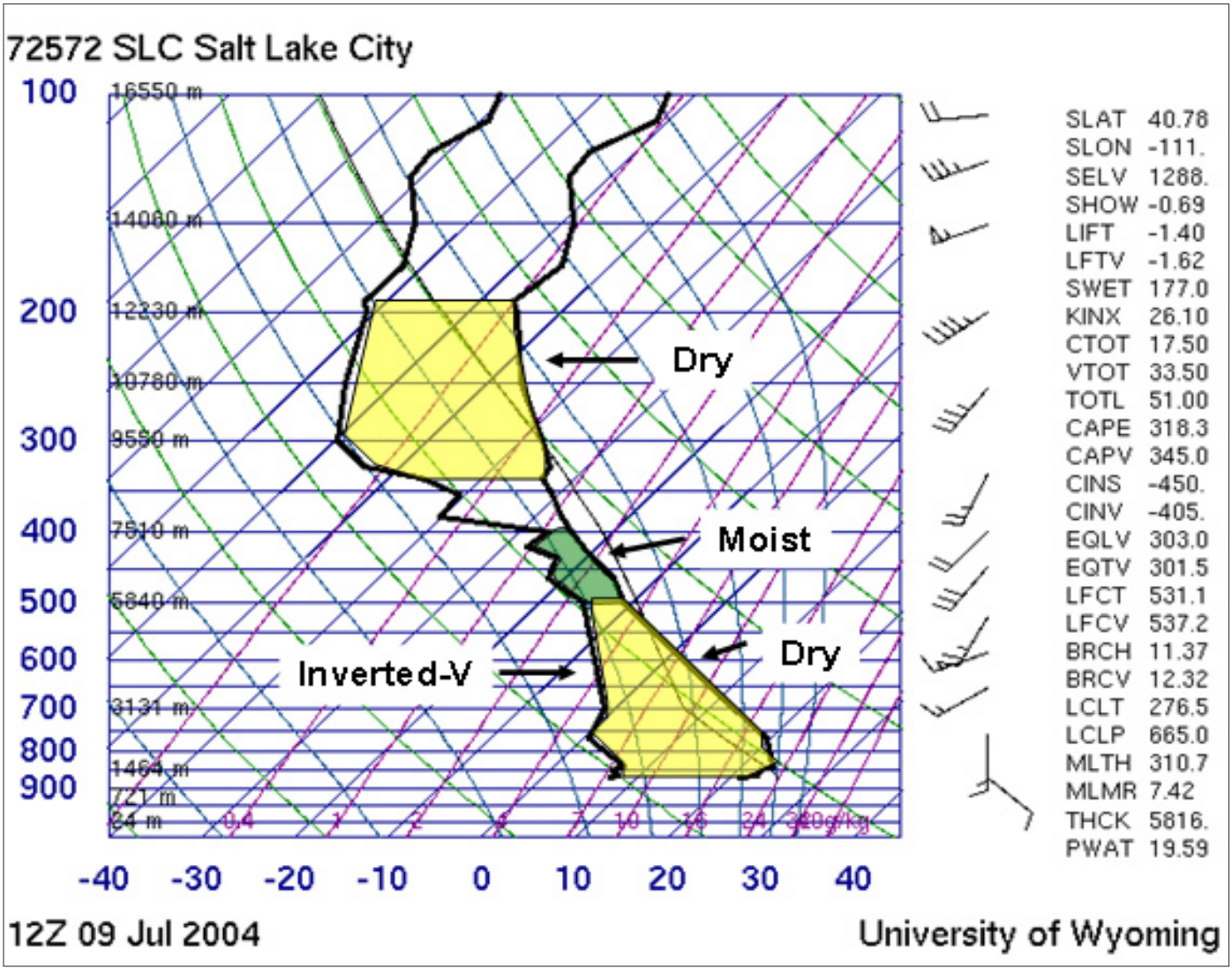

Figure 1. *Skew T-logp plot of temperature and dewpoint profiles (°C) at SLC valid 12 UTC 09 July 2004. Dry adiabats are indicated by green lines and moist adiabats are blue. Horizontal wind profile is displayed along the right side (pennant, full barb, and half barb denote 10, and 5 kt, respectively).*

seemingly tranquil weather pattern. Although the speed with which monsoon surges move north across the intermountain region varies, they usually spread much faster than forecast by numerical weather prediction models.

Typically, mid- or high-levels gain moisture first, followed by lower levels a day or two later. Strong afternoon surface heating often causes this thin layer of mid-level moisture to bubble up into shallow convection over the mountains. The moisture then dissipates rapidly at sunset. This type of convection can be easily navigable. Under certain conditions, however, this shallow convection can become deceivingly strong and produce widespread microburst events. As a pilot, you need to understand the subtle differences in the atmosphere's vertical structure that indicate shallow convection may become severe. Analyzing the morning sounding and checking regional conditions at the surface and aloft are key in understanding the weather concerns of the day.

Figure 1, recorded in July 2004, is an excellent example of a shallow convection day in which Salt Lake City observed severe microburst winds. Once the afternoon convection developed, examining the radar signatures helped discern between severe convection and run of the mill storms.

Synoptic Pattern

Dry low levels and a shallow layer of moisture at mid levels (classic inverted-V signature sounding) were the precursor conditions across northern Utah at 1200 UTC 09 July 2004 (**Figure 1**). You can obtain these charts through http://rucsoundings.noaa.gov/ Just enter a 4 letter ICAO, then click on (java based plots). For more information on utilizing these plots, see the Feb2004 edition of the Front by Craig Sanders at (http://aviationweather.gov/general/pubs/front/docs/feb-04.pdf)

A close look at this sounding shows the atmosphere was unstable in the mid levels from about 500 mb to near 300 mb. This inverted-V profile alerts you to the fact that conditions are favorable for convection and strong winds; however, you do not have sufficient information to decide if conditions will become severe by afternoon. To make that call, you need to glance at the big picture—synoptic pattern—across the West.

Transitions from dry to moist periods, or vice versa, however, can be dangerous for an unsuspecting pilot. The dangers come from variability in amount and strength of convection despite a seemingly tranquil weather pattern.

The 500 mb ridge axis on 1200 UTC 09 July 04 (**Figure 2**) was sitting over the front range of the Rockies from central Colorado southward across eastern New Mexico. This ridge placed the intermountain region under a broad anticyclonic southerly flow. Also, note the 20 kt and 15 kt winds at San Diego and Flagstaff, respectively, corresponding with 30 kt winds at Salt Lake. This increase in wind speed from south to north supports an increase in vertical lift. These conditions, added to favorable destabilizing attributes of the afternoon due to solar heating, meant the atmosphere was ripe for at least shallow elevated convection.

Although you need both the 1200 UTC sounding and 500 mb charts to understand current and future conditions, you should also review a 12 h forecast from these meteorological tools. For ease of comparison, both the actual 0000 UTC SLC sounding and 500 mb charts are used as a 12 h forecast. The 0000 UTC 10 July 2004 SLC sounding (**Figure 3**) shows the classic inverted-V sounding had attained full maturity with very dry surface conditions below a moist mid-level layer, signaling the potential for strong elevated convection.

Note that the winds in the mid-level region—between 500 mb and 300 mb—increased by 15-25 kt between 1200 UTC and 000 UTC. The increased difference between the low-level winds (850-700 mb) and the mid-level winds (500 mb) likely resulted in greater tilt to any convection, making it stronger and more self-sustaining.

At 500 mb, the winds increased over western Montana, Idaho and northern Nevada, signaling a strengthening jet in this region at 0000 UTC on 10 July 2004 (**Figure 4**). This configuration placed northern Utah under what meteorologists call the "right rear quadrant (RRQ) of a jet." The RRQ

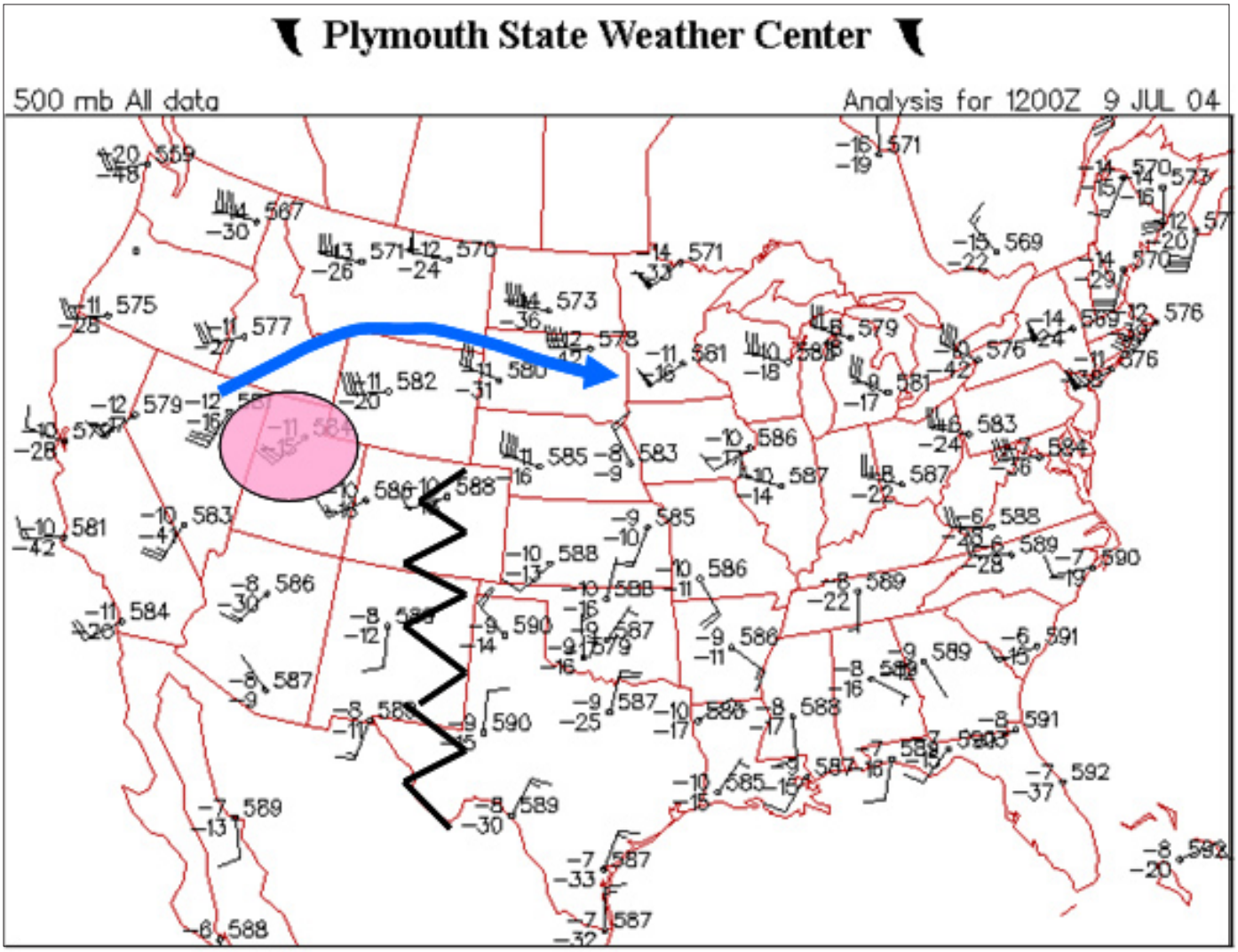

Figure 2. *500 mb chart valid 12 UTC 09 July 2004. Station plots contain the following data: temperature (°C) top left, dewpoint (°C) bottom left, geopotential height (decameters) and winds (pennant, full barb, and half barb denote 10, and 5 kts, respectively). Blue arrow (500 mb jet axis), pink oval (right rear quadrant of jet) and black zig-zag is the 500 mb ridge axis.*

is an area of upper-level divergence that can enhance convection. This combined with winds that were 5-10 kt lighter at Las Vegas and Flagstaff than at 1200 UTC 09 July 2004, which created a stronger relative difference between northern Utah and the jet axis over Idaho. As a result, stronger lift was induced over Utah.

Radar

Both radar and satellite showed shallow convection over northwest Utah by early afternoon, but due to a more stable region above this layer of mid-level moisture, significant vertical cloud development never materialized. The cells that formed were pulse-type storms (short lived) with general movement of about 35-40 kt from the southwest to northeast. Strict interpretation of these radar signatures—without situational awareness of the atmosphere's vertical profile—typically would not alert pilots to strong microburst potential. Consequently, you might not anticipate severe wind in excess of 70 mph at 2230 UTC 09 July 2004 in the Cache Valley (65 miles north of Salt Lake).

These winds would not be as much of a surprise, however, if you understood the inverted-V type vertical profile in the North American Model (NAM) forecast for that afternoon (not shown,

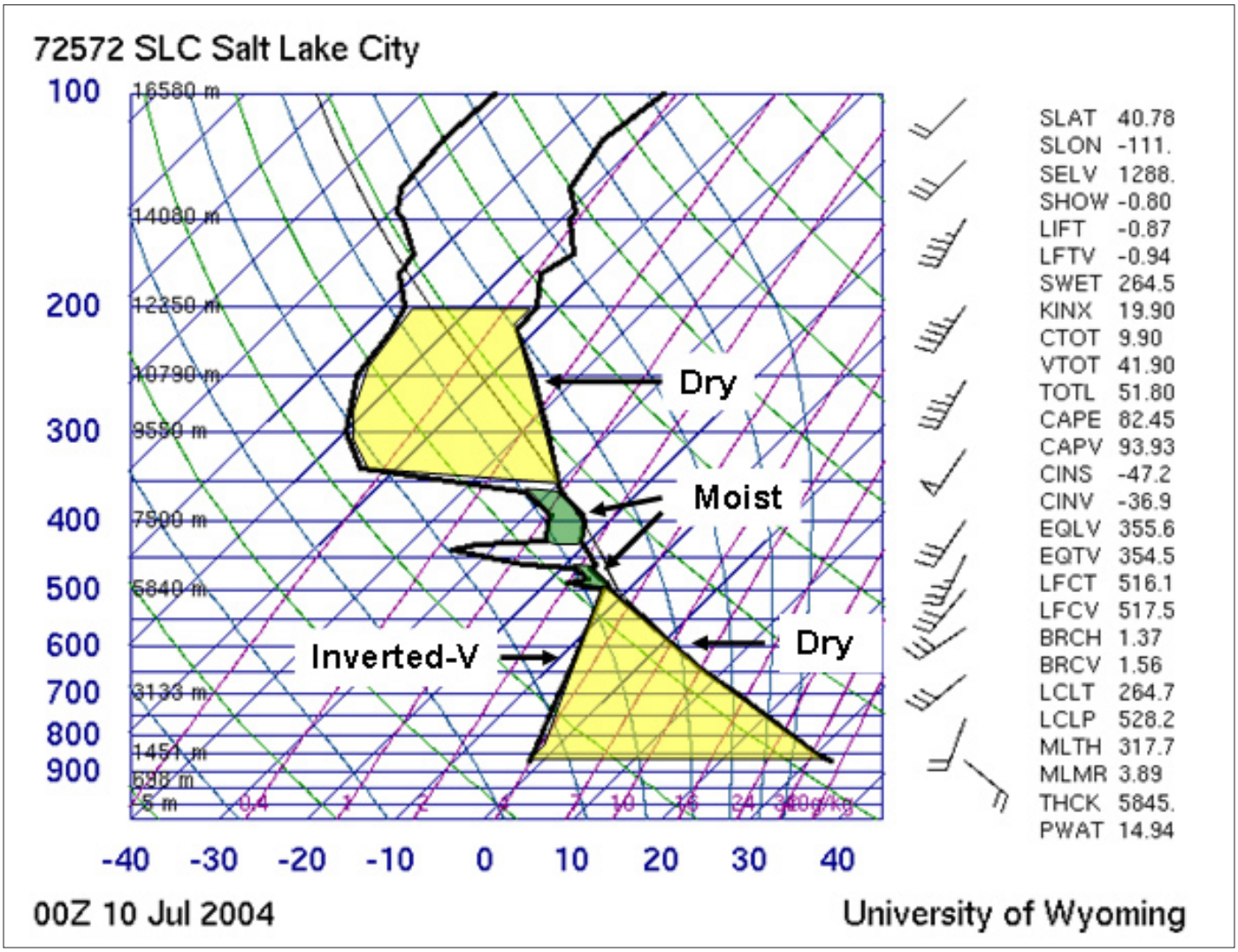

Figure 3. *Same as* ***Figure 1****, except valid 0000 UTC 10 July 2004. Note a parcel lifted moist adiabatically from the lifted condensation level (LCL) (bottom of the green highlighted moist layer) near 500 mb (14,000 ft AGL) would reach a maximum height of about 355 mb (24,000 ft AGL), top of highlighted moist layer. Therefore, the moist (unstable) layer thickness was about 10,000 ft.*

but nearly identical to **Figure 3**). Quick inspection of the SLC WSR-88D KMTX radar indicated this severe wind was the result of a collapsing 35 dBZ echo. In general, the majority of the echoes were in the 20-30 dBZ range, with only isolated echoes over 30 dBZ, which is far less than what is normally associated with severe winds.

Radar echoes, however, can be broken into two separate components: reflectivity and velocity. In this case, velocity strength was more representative of the weather that resulted from these echoes. As a result, forecasters and pilots equipped with more advanced technology should monitor echo velocity in addition to echo reflectivity from their perspective radars.

Another issue is the radar's effectiveness in capturing the entire vertical component of the storm. If the storm data is from a high-elevation radar, which most are in the intermountain region, there is a distinct probability that radar is missing critical near-surface conditions. You need to look at Terminal Doppler Weather Radar (TDWR) as a backup. The weather on 09 July 2004 shows the potential use of the TDWR data.

At 2301 UTC, the KMTX radar (6574 ft MSL) depicted very weak velocity returns in an area about 30 miles southwest of Salt Lake. At that time, the FAA TDWR (4220 ft MSL) depicted an area of slightly enhanced velocities that correlated well with the reflectivities greater than 30 dBZ in this area (**Figure 5**). The difference in velocity returns over this portion of the valley was due to

KMTX's minimum beam height being at 9600 ft MSL, 5400 feet above ground level (AGL), versus the TDWR, 12 miles north of Salt Lake, with a minimum beam height of only 870 ft AGL.

By 2338 UTC, the TDWR velocity intensities had increased to greater than 50 kt. NWS issued a severe thunderstorm warning with high winds for north of Salt Lake (**Figure 6**). Winds gusted to more than 60 mph at several locations within the warning area.

Based on these observations, the radar echoes velocity component was much more representative of the weather than its reflectivity. There was no lightning associated with this storm or any other on that day.

Summary

This review covered two important aspects of summertime convection. First, analyze morning soundings as well as making a regional check of conditions. Second, once convection forms, use both the reflectivity and velocity components of the radar.

In the intermountain region and the desert Southwest, many summer days start dry and sunny, giving pilots a false sense of security. You can glean vital data from morning soundings and weather patterns to better understand how the stability of the atmosphere will evolve by afternoon. For

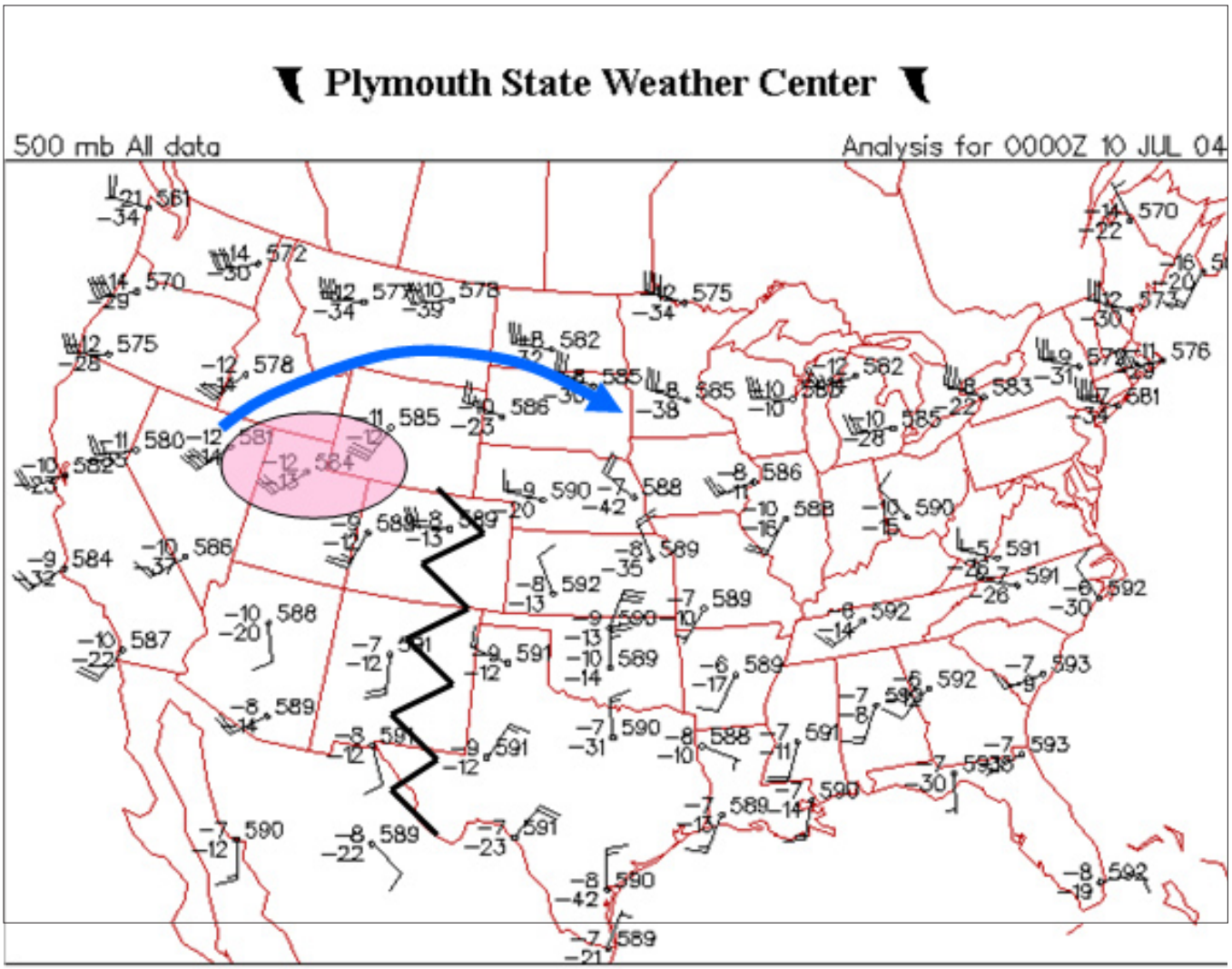

Figure 4. *Same as Figure 2 except valid 0000 UTC 10 July 2004. Wind strength over northern Great Basin changed little from 1200 UTC 09 July 2004, while there was a 10 kt decreased at Desert Rock in southern Nevada. Blue arrow (500 mb jet axis), pink oval (right rear quadrant of jet) and black zig-zag is the 500 mb ridge axis.*

example, the 1200 UTC synoptic and mesoscale pattern on July 9, 2004, consisted of three main components capable of producing microbursts:

- Mid-level moisture
- Dry low levels of the sounding
- Right rear quadrant of a moderately strong anticyclonic 50 kt jet aloft.

The more stable atmospheric conditions above 300 mb capped conditions that otherwise would have allowed deep convection. But, despite this cap, shallow elevated convection was able to develop and become severe across portions of northern Utah. One important contributor to this convection was the strengthening jetstream over Idaho and Montana, which placed Utah under the favorable right rear quadrant—an area of the jetstream associated with good upward vertical motion.

Satellite images of the clouds as well as radar signatures, depicted by the KMTX mountain

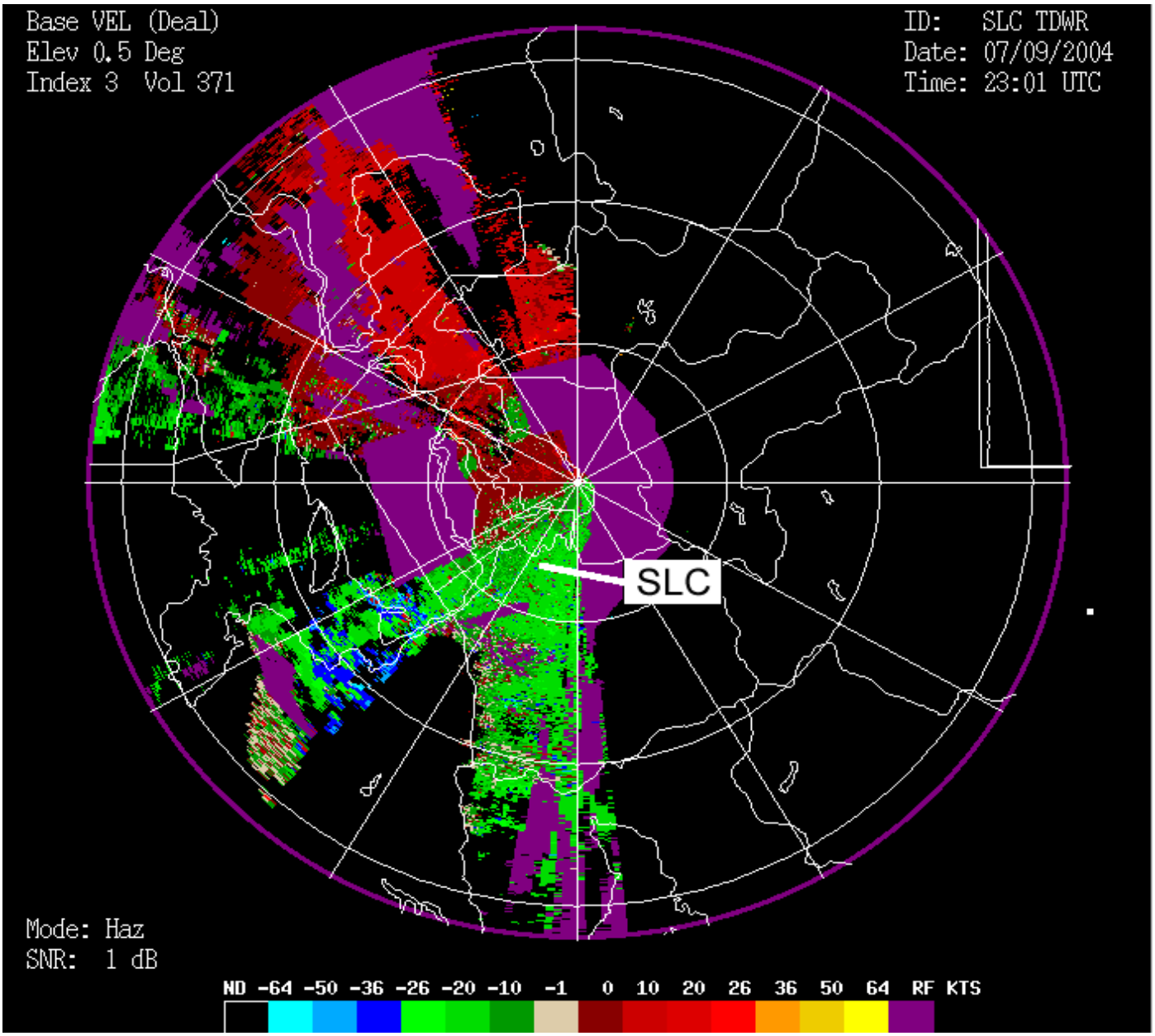

Figure 5. *TDWR image valid at 2301 UTC 09 July 2004. Inbound velocities are cool colors and outbound are warm. Strongest inbounds (>50 kt) are 25-35 miles west southwest of SLC.*

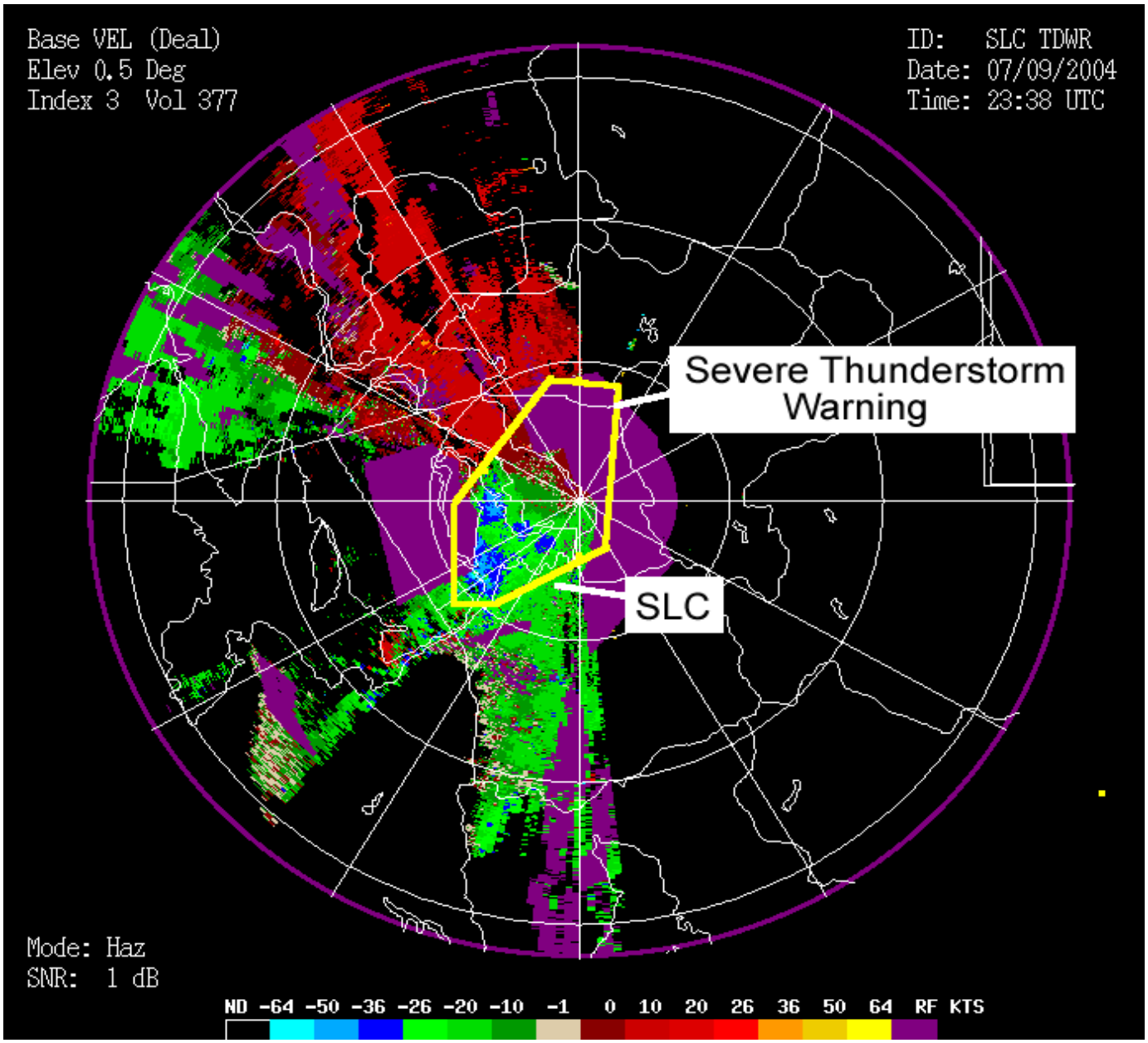

Figure 6. *TDWR image valid at 2338 UTC 09 July 2004. Severe Thunderstorm Warning valid through 0030 UTC was issued 3 minutes after this time for the area surrounded by the yellow border.*

top radar in northern Utah, did not adequately reveal the strength of this convection. The general reflectivity strength was only 25-30 dBZ with isolated 35 dBZ, reflectivities typically not associated with severe convection.

Fortunately, radars depict echo reflectivity and velocity. The velocity display showed the strength of these otherwise innocuous appearing areas of reflectivity, areas that produced wind gusts in excess of 60 mph. Although KMTX depicted these velocities well within a 30-50 mile radius, the TDWR radar on the valley floor portrayed the true potential of these microbursts with improved display of low-level velocities. For all of these reasons, only monitoring reflectivity is not a good practice. You can glean important information from the velocity display as well. One final note, don't rely on lightning data alone to identify severe weather. Lightning was not observed in Utah on this day. ✈