P6.10 NEW TECHNIQUES FOR INTEGRATING ENVIRONMENTAL INFORMATION WITH RADAR BASE DATA ANALYSIS IN NATIONAL WEATHER SERVICE WARNING DECISION MAKING

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1. INTRODUCTION

In summer of 2008, a new capability called “integrated radar sampling” was released with Operational Build 8.3 of the Advanced Weather Interactive Processing System (AWIPS). The integrated radar sampling was designed to improve integrating environmental information with radar base data analysis for National Weather Service (NWS) warning decision making. The new capability builds off the exisiting radar cursor sampling by adding environmental data such as temperature, relative humidity, wind, etc from soundings, model forecasts, or objective analysis like the Local Analysis and Prediction System (LAPS). The capability is further enhanced by linking the cursor sampling output to a popup SkewT and displaying environmental data in the planes of the radar tilts (Fig. 1). The flexibility of the design also fundamentally improves the analysis of numerical model data and other four-dimensional gridded datasets.

In addition to improving forecasters’ situation awareness of the environment, the integrated radar sampling supports a fundamental shift from traditional height-based analysis to a more environment-based analysis. In previous builds of AWIPS, forecasters would have to relate the height of the radar observations to the environment through a multi-step process that was difficult to accomplish in the pressure of real time warning decision making. Now forecasters can directly relate the radar data to the environment for tasks like evaluating precipitation qualities in the hail growth zone for severe hail forecasting. The new capability supports a wide variety of current warning decision making practices, and it should be particularly helpful in analyzing Dual Polarization radar data when the NWS begins upgrading the Weather Surveillance Radar 88 Doppler (WSR-88D) radars in 2010 (Istok *et al.* 2009).

In this paper we will first review AWIPS radar analysis tools and their use in warning decision

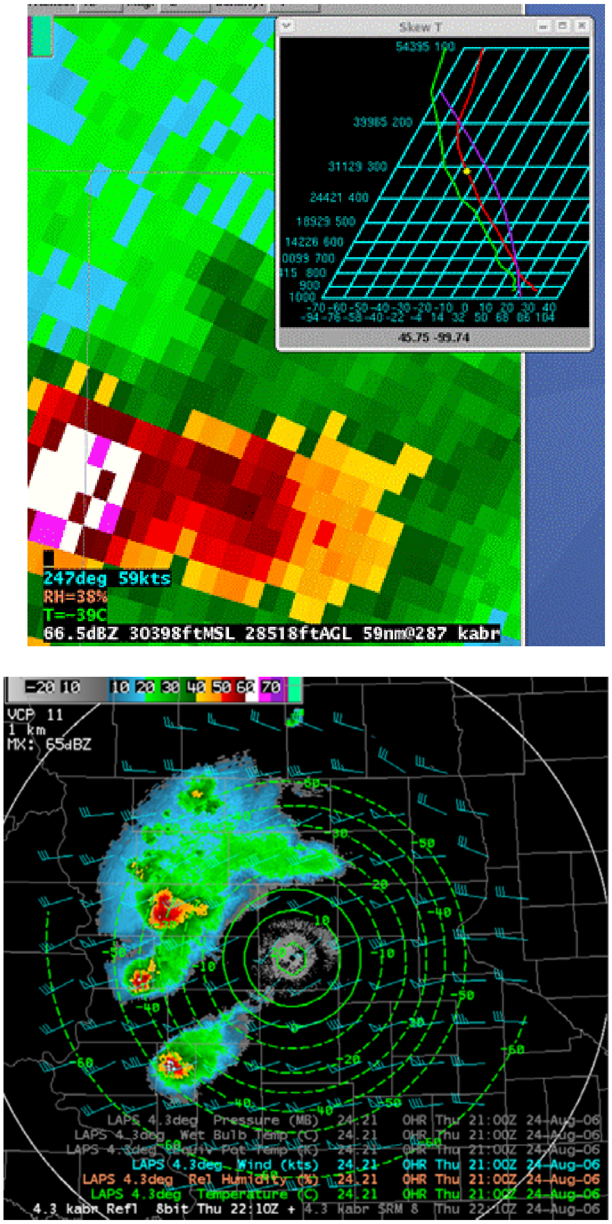

Figure 1. Radar and environmental cursor readout on a radar reflectivity image with linked Popup SkewT (top). The yellow dot on the SkewT is the height of the radar beam. Environmental data is from LAPS. Isotherms and wind barbs plotted in the plane of the radar tilt (bottom).

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Figure 2. Principal User Processor. The 1980s predecessor to today's radar analysis in AWIPS.

making. Then we will discuss how the new integrated radar sampling enhances current decision making and future decision making in the upcoming Dual Polarization era. We will conclude by discussing the opportunities for future development and collaboration using the next generation of NWS software, AWIPS-II (Tuell *et al.* 2008).

2. REVIEW OF AWIPS RADAR BASE DATA ANALYSIS TOOLS AND THEIR USE IN WARNING DECISION MAKING

When the WSR-88D radars were released in the late 1980s and early 1990s, radar analysis was limited to a stand alone radar-only display called the Principal User Processor (PUP; Andra *et al.* 1994). The PUP provided for basic display and looping of base products and algorithms in a single panel or four panel (Fig 2).

Radar displays began to change significantly with the development of AWIPS, "the centerpiece of NWS Modernization" (Friday 1994). AWIPS provided for a more integrated analysis of observations. In AWIPS, multiple observations (radar, satellite, surface observations, etc) are analyzed in a software display called the Display in 2 Dimensions (D2D). D2D supports five panes of data. Initially, the AWIPS radar displays essentially provided a faster version of the PUP with more control over display characteristics such as color tables and toggling between reflectivity and velocity data.

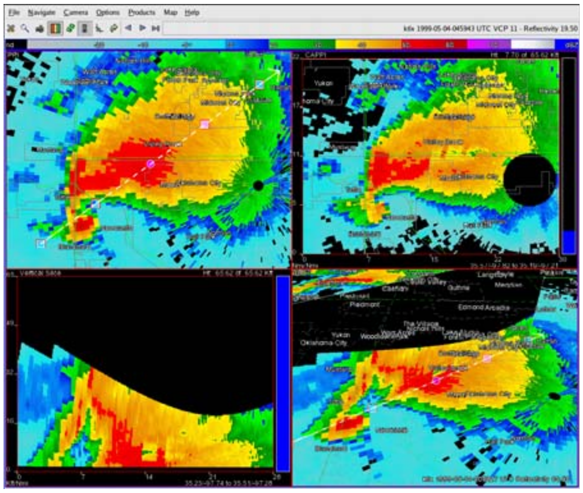

Figure 3. The recent addition of the Four-Dimensional Stormcell Investigator (FSI) to AWIPS in 2007. Shown is the standard radar tilt display (upper left), the horizontal cross section (upper right), vertical cross section (lower left), and 3D perspective of 2D displays (lower right).

One of the major improvements in AWIPS radar base data analysis was the subsequent development of the "all-tilts" application. All-tilts provided for a rapid way to step through a sequence of radar tilts of reflectivity and velocity data from a single radar. This was an effective tool for forecasters to develop a 3D mental model of storm structure. The rapid access to the latest base data was effective in detecting changes in storm evolution, a key to increasing lead time in warnings. Relatively small frame counts and time-centric image navigation limited the effectiveness of all-tilts to mostly the latest volume scan or two.

Since the inception of the WSR-88D, the Warning Decision Training Branch has promoted the use of the radar base data analysis tools, like all-tilts, throughout the NWS. In a major severe weather training initiative called Advanced Warning Operations Course (Ferree *et al.* 2004), all NWS warning forecasters were trained on leveraging radar base data analysis tools in concert with a more wholistic approach to warning decision making. WDTB's radar training has focused on fundamental base data analysis and using the algorithms as decision aids or as a safety net.

Over time, further improvements were made to all-tilts by increasing the frame count to handle up to 64 frames (3 or 4 full volume scans of data). Keyboard navigation shortcuts were also added for space navigation. These additions made it easier to interrogate radar base data in its native polar coordinates in both time and space.

A more recent major change in radar analysis tools in AWIPS occurred with the delivery of the

Four-Dimensional Stormcell Investigator (FSI) in 2007 (Stumpf *et al.* 2006). FSI contains a separate display from D2D, and it provides linked dynamic displays of standard radar tilts (i.e. all-tilts capability), horizontal cross sections, vertical cross sections, and a three dimensional perspective of the 2D displays (Fig. 3). While FSI was a significant improvement to radar base data analysis, it did not provide access to environmental data, and it did not contain visualization of 3D isosurfaces. Many forecast offices have obtained the commercial software, GRLevel2 Analyst Edition (http://www.grlevelx.com/gr2analyst/), for 3D isosurfacing. GRLevel2 Analyst Edition is a Windows-based application that runs outside of AWIPS using high-resolution radar data streams available through the internet.

The improvements in radar base data analysis tools have significantly enhanced forecaster's ability to quickly evaluate radar data in time-critical situations. Forecasters now use D2D and FSI to identify qualitative signatures such as storm tilt, inflow notches, bounded weak echo regions, etc. These fundamentals of radar analysis were described by the Lemon Technique (Lemon 1977) in the 1970s, and they continue to be useful today.

In terms of quantitative analysis, forecasters use cursor sampling in D2D and FSI to analyze base radar data in numerous ways. The magnitude of the reflectivity can be used to infer the presence of large hail, particularly at high heights where cold temperatures prohibit liquid water. The presence of significant reflectivity at high heights in the hail growth zone can also indicate a favorable configuration for the growth of large hail.

Velocity data is sampled to calculate low-level and mid-level radial convergence as well as upper-level radial divergence to aid in assessing updraft strength. Radial velocity data is also quantitatively sampled to calculate rotational velocities and gate-to-gate shear to determine tornado potential. Velocity data is also quantitatively sampled to identify areas of strong ground-relative wind that can cause severe wind damage.

Lastly, spectrum width data is used in conjunction with reflectivity data to detect three body scatter spikes which indicate the direct measurement of large hail.

Much of the quantitative analysis of radar base data relies on relating the height of the observation to the environment for effective interpretation. Prior to the development of the integrated radar sampling, this had to be done using multiple steps and separate display panes in AWIPS. In the time pressures of warning decision making this can be particularly challenging. The integrated radar sampling addresses the need to maintain situation awareness of the environement during radar analysis.

3. INTEGRATED RADAR SAMPLING: CURSOR READOUT AND CONTOURING

The integrated radar sampling interpolates the environmental data to the planes of the radar tilts to provide cursor readout and plotting of the environmental data. To enable cursor sampling of the environmental data, the user first loads a height-based radar product like a 0.5 degree reflectivity product or an all-tilts reflectivity product. Then the user loads a "standard environmental data package" for a desired source including upper air soundings, objective analysis such as LAPS, and model forecasts. The standard environmental data package is a fixed set of five parameters (temperature, relative humidity, wind, theta-e, wet bulb temperature, and pressure (Fig 4). As the data is sampled the cursor readout updates the radar product's value, height, location, and the associated environmental parameter. Any of the five parameters can be toggled on or off by clicking on the respective legend or using a keyboard shortcut.

For those with expertise in customizing AWIPS, it is possible to define different environmental data packages for 3D or 2D environmental data. For instance, someone may wish to monitor particular 2D fields like surface-based Convective Available Potential Energy or 0-1km shear while analyzing the radar data. In this instance the cursor readout would display the value at that location regardless of height of the radar product.

Since operational gridded datasets don't adequately resolve the small scale thermodynamic and kinematic variability inside thunderstorms, the environmental values in the cursor readout most often represent the base state surrounding the storm. The base state information can be used to interpret the influence of the environment on the dynamics and evolution of the convection.

There are a number of ways the environmental cursor readout can be used to improve warning decision making. Knowing the temperature at the height of the beam can be particularly useful in identifying elevated hail cores (in regions too cold to support supercooled water) as well as identifying large amounts of supercooled water in the hail growth zone. This

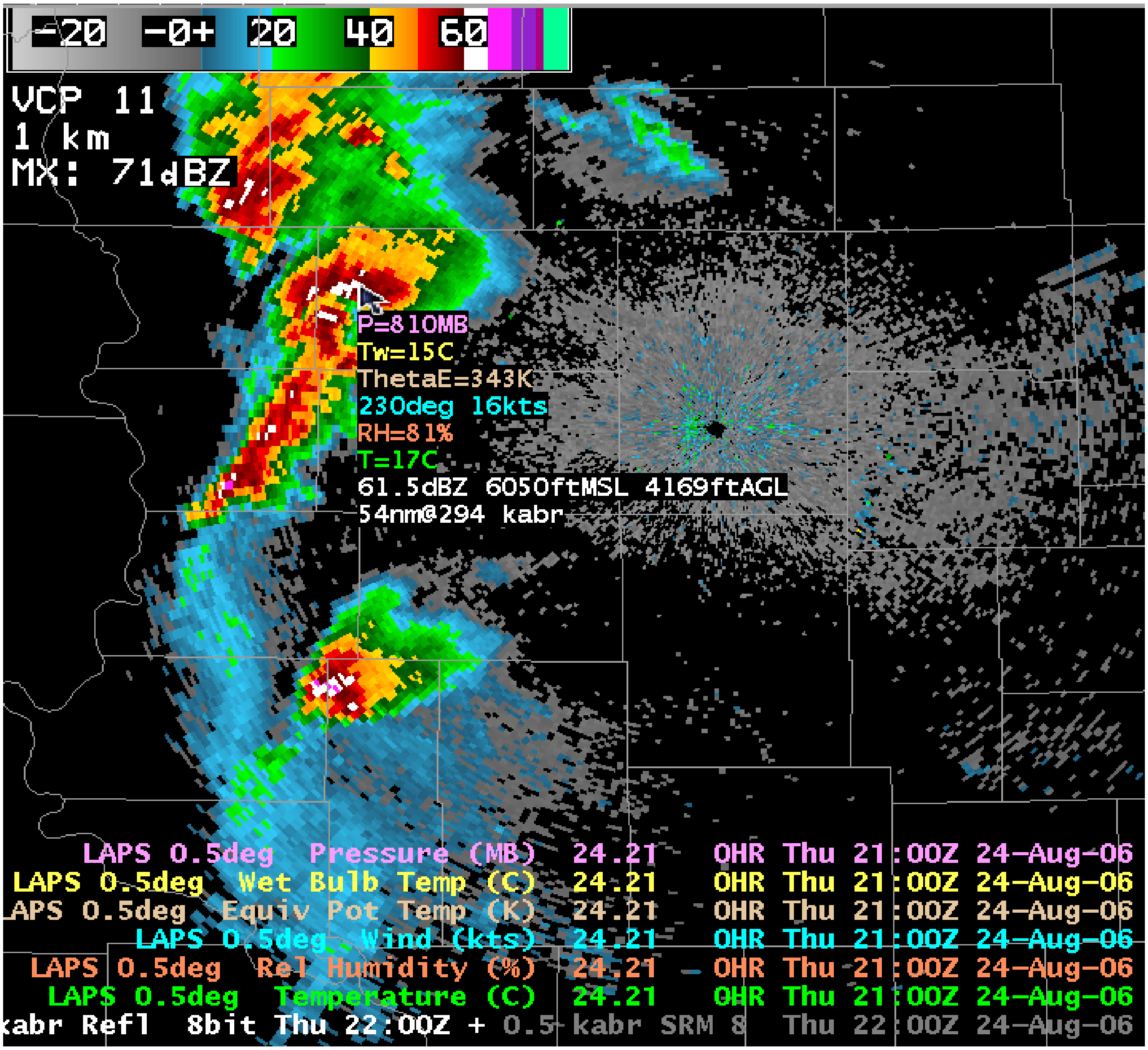

Figure 4. Integrated radar sampling standard environmental data package with temperature, relative humidity, wind, theta-e, wet bulb temperature, and pressure integrated into the cursor readout.

can also be used to identify the melting level which has applications in both severe and winter weather environments. The relative humidity and theta-e changes with height can also provide some indication of downdraft potential.

In addition to cursor readout, the standard environmental data packages support contouring of the fields in the native radar polar coordinates. When the standard environmental data package is first loaded, the fields are loaded into memory with the default drawing/contour density set to zero. By right clicking on the product name in the display, the user can change the density of the display field and effectively enable the display (Fig. 5).

Because radar beams are not horizontal, the environment along a radar beam can vary significantly from one side of a storm to the other. Having the ability to display the environmental data in the plane of the radar data allows forecasters to see how the base-state environment (e.g. temperature) varies across common radar structures. This can lead to forecasters having more complete conceptual models of severe storms. Overlaying environmental wind vectors on radar data in all-tilts is particularly enlightening in identifying vertical wind shear and its correlation with echo shapes and storm morphology.

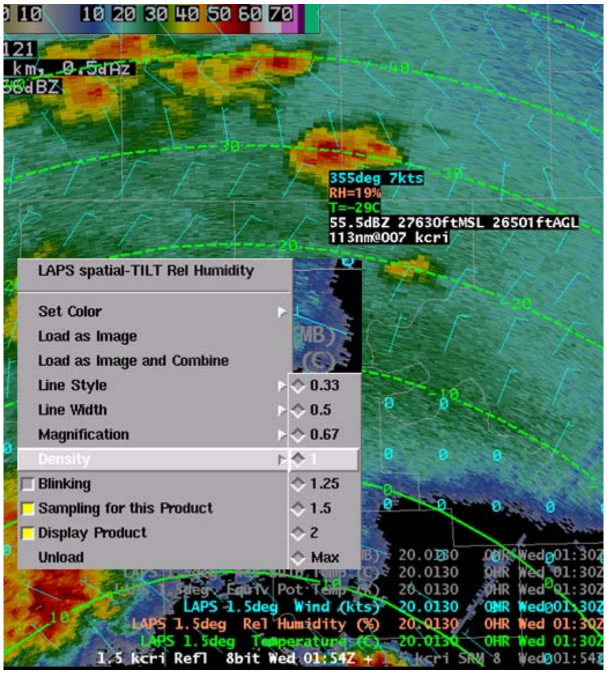

Figure 5. Adjusting the density of the product to something non-zero effectively turns on the field overlay. In this example temperature and wind vectors from LAPS have been plotted in the plane of the 1.5 degree radar tilt.

4. INTEGRATED RADAR SAMPLING: POPUP SKEWT

The integrated radar sampling popup SkewT uses the location of the cursor position to obtain the nearest vertical profile of temperature and dewpoint. A saturated parcel curve is also displayed (Fig 1). The popup SkewT is separate from the standard environmental data package (section 3), though it is beneficial to use them together. If a height-based product is loaded prior to launching the popup SkewT, then a yellow dot is plotted on the SkewT to identify the height of the beam centerline as provided in the cursor readout (Fig. 1).

The first step in loading the popup SkewT is to load a product like a 0.5 degree reflectivity product or an all-tilts product. Next, the user loads the popup SkewT, and selects a source. As with the standard environmental data packages (section 3), the user may choose to view the local sounding or the nearest gridpoint sounding from an objective analysis or model forecast.

Prior to the popup SkewT, launching SkewT profiles from many locations across a county warning area was time consuming, requiring separate panes in the display. Now the user can quickly roam from storm to storm across a large area and in a short period of time be able to identify the changes in buoyancy, lapse rates, lifted condensation level (LCL), level of free convection (LFC), and equilibrium level (EL). This aids in maintaining situation awareness of the environment.

The popup SkewT can be used to better comprehend radar sampling limitations. Viewing the height of the lowest radar tilt relative to the LCL and LFC is an effective way to visualize poor radar sampling at longer ranges (Fig. 6). When looking for upper-level reflectivity cores and upper-level divergence, the popup SkewT can illustrate the height of the observations relative to the equilibrium level. This allows the forecaster to better anticipate where to find these features, and it can illustrate how gaps between beams can affect detection (Fig 6).

The popup SkewT also complements the cursor readout capability in analyzing reflectivity structure in the hail growth zone. The lifted parcel curve can be used to better understand how the maximum potential buoyancy in the updraft could shift the height of the hail growth zone.

In winter weather situations the popup SkewT is particularly effective in identifying the location of warm air above the surface where bright banding can occur at the melting level. This can aid in anticipating precipitation phase near the ground.

The popup SkewT can also be used to improve general environmental analysis. If a popup SkewT is loaded over a mandatory pressure level plot of upper air data (e.g. 500mb plot), the upper air profiles for the whole country can be accessed dynamically by roaming the map with sampling on.

The popup SkewT also improves numerical model analysis. If the popup SkewT is loaded over a model forecast, the user can roam around the forecast in time and space with sampling on, and the SkewT updates continuously (Fig. 7). This dynamic blending of vertical and horizontal perspectives of model forecasts allows the forecaster to quickly develop a more complete conceptual model of the model forecast, and it encourages more detailed analysis in critical areas.

5. INTEGRATED RADAR SAMPLING: LIMITATIONS

While the integrated radar sampling can benefit warning decisions, there are a number of limitations that need to be considered. The first is that the environment from the top of the beam to the bottom of the beam can vary significantly at

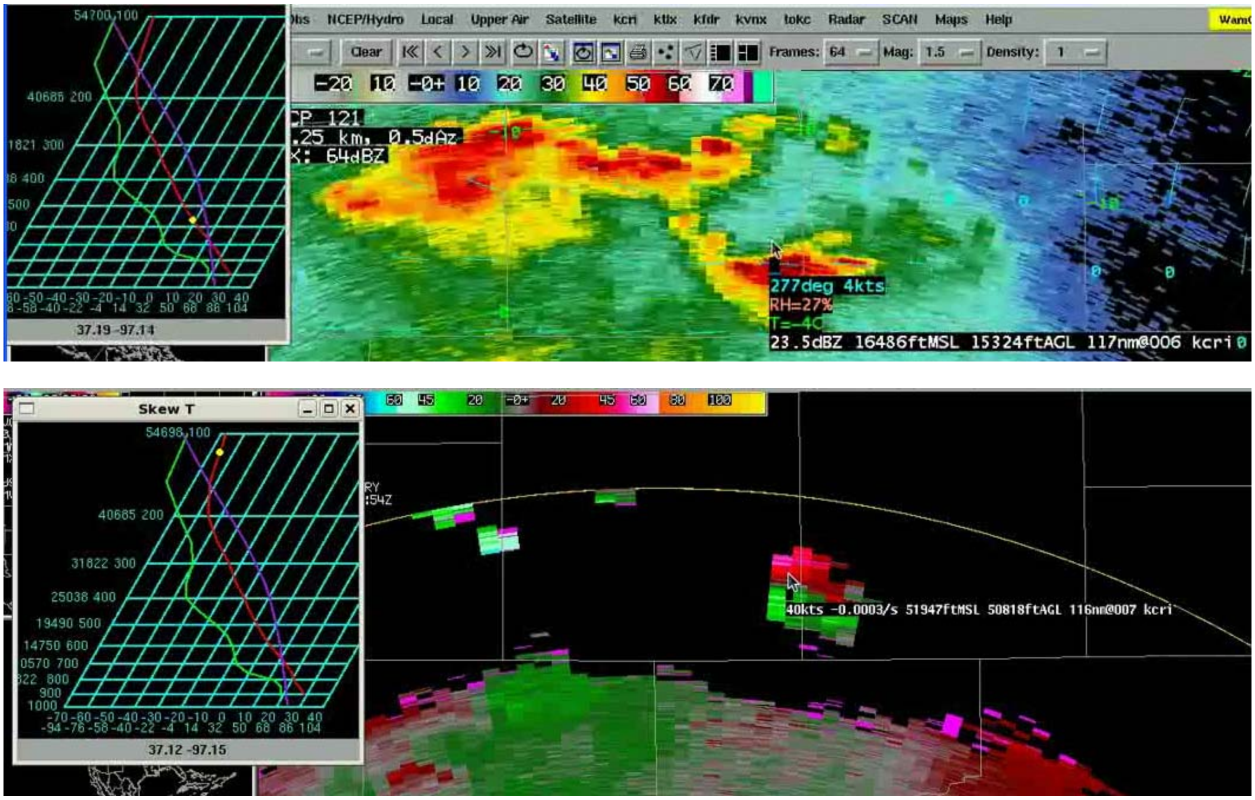

Figure 6. Popup SkewT illustrating lowest beam height at long range (top) and upper level divergence in the overshooting top (bottom).

longer ranges from the radar where beam volumes are large (Fig. 8). The value at the beam centerline provided can therefore be misleading. When using the integrated radar sampling it is prudent to watch for large environmental changes over small distances or from tilt to tilt which can indicate significant sampling limitations (Fig. 8).

Another limitation is that the forecaster has no control over the display of the popup SkewT. The SkewT would be greatly improved with the addition of wind vectors and control over the contents of the display. One other limitation with the first release is that there were some problems with the application's stability, and the dot on the SkewT would sometimes not update. The integrated radar sampling strengths and limitations have been incorporated into the routine AWIPS build training WDTB provides all forecasters.

All known problems with the first release have been fixed in the Operational Build 9.0 version that is currently targeted to be released in early 2009, prior to the spring severe weather season.

6. INTEGRATED RADAR SAMPLING: FUTURE OPPORTUNITIES

Another motivation behind the design of the integrated radar sampling is to develop more advanced tools to interrogate radar base data in the upcoming Dual Polarization era. With the fielding of Dual Polarization capabilities to the WSR-88D network (currently planned for 2010), forecasters will have twice as many base data products to analyze. Since many of the base data moments of Dual Polarization data are sensitive to precipitation phase and shape, it is particularly useful to have thermodynamic information integrated into the base data displays.

Other new tools have recently been developed in AWIPS to support Dual Polarization analysis. A four-panel all-tilts allows forecasters to use four linked all-tilts applications including up to eight products. Special keyboard shortcuts have been defined to allow toggling between all base data. The multiple product toggling supports visual spatial correlation which is particularly important in Dual Polarization data due to the strong gradients and relationship between base data. New sampling capabilities have also been designed to support cursor sampling all base data products from any one of the product's display. This allows for a more rapid quantitative multi-parameter

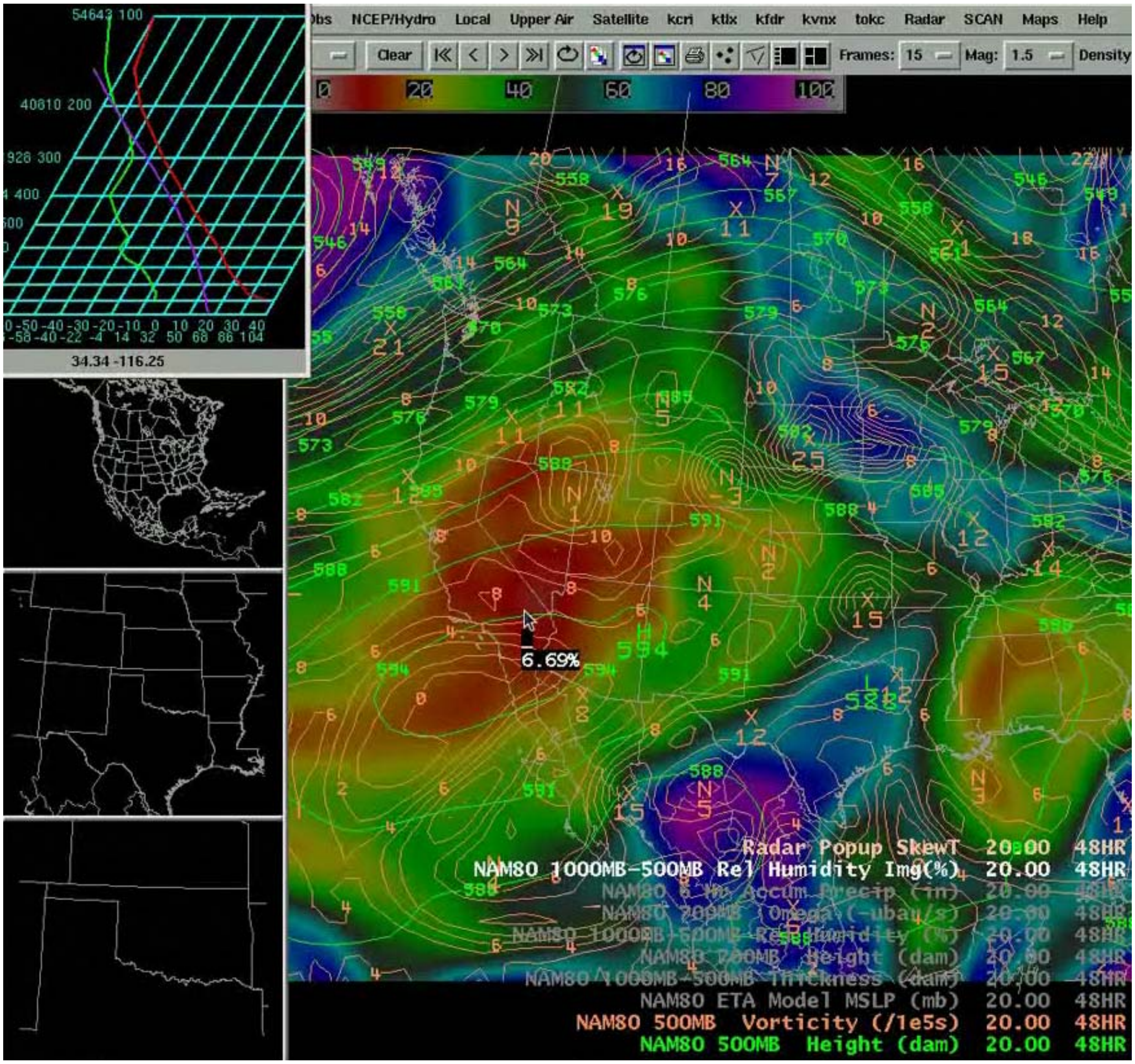

Figure 7. Popup SkewT integrated with the cursor readout of a numerical model forecast. Image shows a 48 hour NAM forecast of 500mb height (green contours), vorticity (red contours), 1000-500mb relative humidity (shaded). Cursor is placed over the desert southwest, and the popup SkewT show the corresponding dry atmosphere.

synthesis that is required to understand Dual Polarization base data.

After over a decade of use, the operational AWIPS software is being redesigned and replaced by AWIPS-II (Tuell *et al.* 2008). AWIPS-II is currently planned for release in 2010. AWIPS-II is a “black-box port” of existing AWIPS-I technology to a new Java-based architecture. AWIPS-II will come with an Application Development Environment (ADE) that is designed for collaborative development. Forecast offices, development laboratories, Universities, and other NWS partners will be able to access these new tools to collaborative and prototype improved forecast and warning tools.

7. CONCLUSIONS

The new integrated radar sampling capabilities are an important step toward improved radar analysis in NWS warning decision making. Among the notable improvements are:

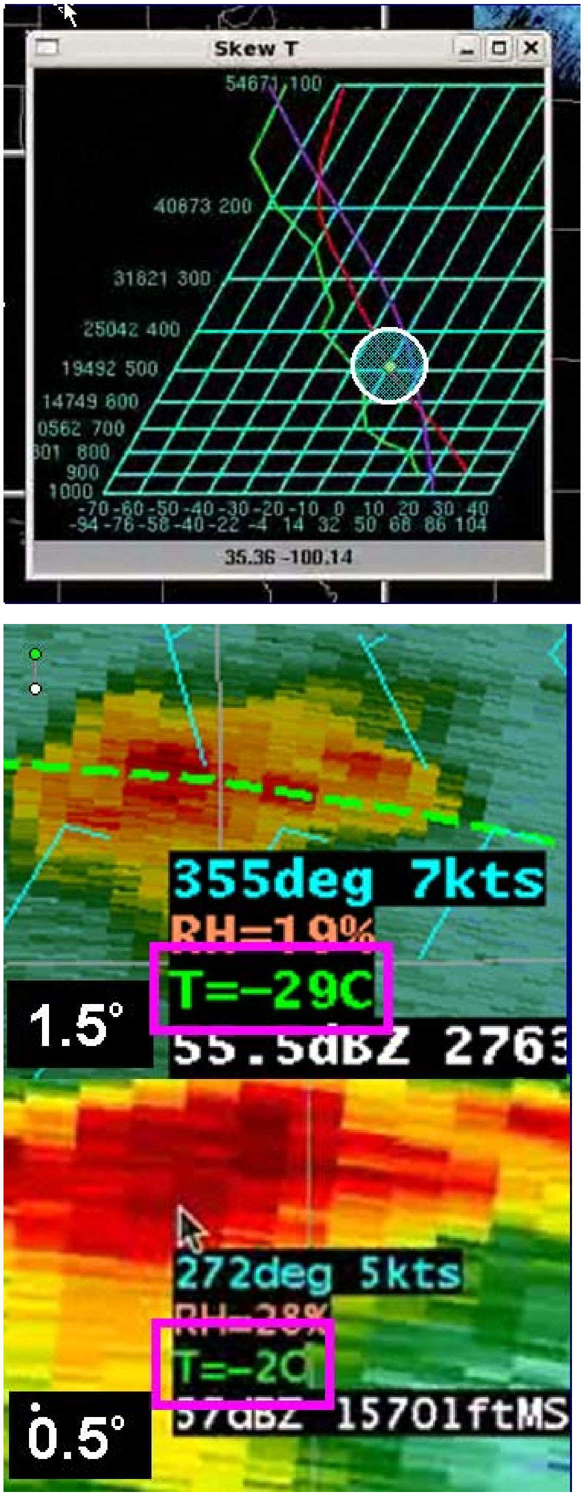

Figure 8. Popup SkewT (top) annotated with the beam size to illustrate ambiguity of beam centerline output. Cursor sampling of the 1.5 degree tilt (middle) and 0.5 degree tilt (bottom) illustrating large changes of temperature from successive tilts.

- environmental information included with the radar cursor readouts
- displaying environmental data fields interpolated to the planes of the radar tilts
- linking the radar data to a popup SkewT through the radar cursor readout with the height of the radar beam plotted on the SkewT
- a popup SkewT that allows rapid interrogation of upper air soundings and a dynamic blending of horizontal and vertical analysis of model data

While these capabilities can improve current warning decision making, they also have the potential to significantly improve warning decision making in the upcoming Dual Polarization era. As the existing AWIPS-I is replaced with AWIPS-II in 2010, there will be a new opportunity for collaboration on the next generation of warning decision making tools, including the integrated radar sampling. The application development environment of AWIPS-II presents a unique opportunity for the severe storms community to work together to transition research to operations and improve NWS warnings and services.

If you are interested in collaborating on future improvements to the integrated radar sampling capability, contact the author. He was the head of the integrated work team responsible for identifying the requirements and shepherding this through the development process. He intends to continue contributing to its evolution in concert with other NWS requirements groups.

8. ACKNOWLEDGEMENTS

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