1A.2 **REAL-TIME HIGH RESOLUTION NUMERICAL WEATHER PREDICTION FORECASTS FOR INCIDENT METEOROLOGISTS**

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1. INTRODUCTION

During the summer of 2008 the National Weather Service (NWS) Forecast Office in Salt Lake City, Utah, ran an experimental, nested, high-resolution numerical weather prediction model on a Linux cluster (8 nodes and 1 server). The goal of the project was to provide real-time high resolution model forecasts for use by Incident Meteorologists (IMET) at wildfires across the complex terrain of Utah. An IMET could access this information on a website and obtain unique detail for their site of interest. Specific site information is critical for IMET briefings and this can be obtained from mesoscale models and knowing the micro-scale meteorology. For this project, the Environmental Modeling System (EMS) was configured to run a version of the Weather Research and Forecasting (WRF) model [online at http://strc.comet.ucar.edu], known as the NCAR Advanced Research WRF (ARW).

It was discovered that the high resolution model output, such as composite reflectivity, proved useful for the short-term temporal and spatial depiction of convection across the complex terrain of southern Utah during the monsoon. Model forecasts of the movement and intensity of convection proved useful as an aid in the forecast and warning process (i.e., prior to and with radar reflectivity). Although the ability to issue warnings based solely on ensemble or deterministic numerical model forecasts is in its early stages (Stensrud, 2008), this study offered promise for applying short-term model forecasts in an operational setting.

The NWS has provided short-term forecasts for a variety of weather events, but most commonly precipitation. These forecasts typically are created by a meteorologist using the most recent Weather Surveillance Radar-1988 Doppler (WSR-88D) imagery. The forecaster may add a projected movement of the observed precipitation through extrapolation or by use of algorithms, but it is much less common to provide information on future development unless obvious boundary interaction is anticipated. Similarly to the prediction of lake-effect snow convection, forecasters may not be able to add specific location and timing information until radar reflectivity is present. This study will present several examples of using model data to improve short-term predictions.

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2. ARW MODEL

On a Linux cluster system the ARW model was set up to use initial and boundary conditions from the National Center for Environmental Prediction's (NCEP) North American Mesoscale Model (NAM). There were two 3-km nests defined across northern and southern Utah, respectively (Fig 1). Depending on expected weather conditions or deployment of IMET's the desired nested domain would be operated. Computing power allowed the model to

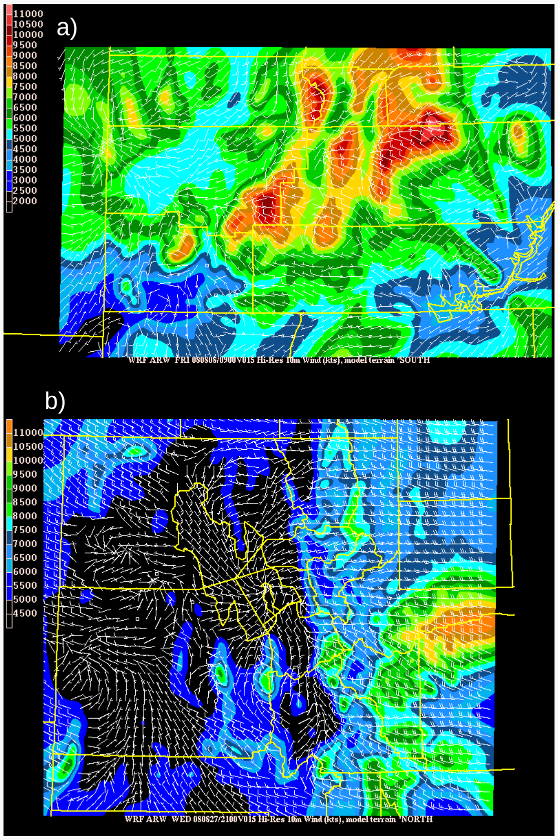

Fig. 1. Model domain and topography (color shaded) for southern Utah (a) and northern Utah (b). Color scale ranging from 4,000 ft to 11,000 ft MSL.

run at a 3-km resolution out to 24 hours for at least once a day. Given the horizontal resolution the use of model generated precipitation (explicit convection) was chosen in place of a convective scheme.

Post-processed products were made available on the Internet and included; hourly Binary Universal Form for Representation of Meteorological Data (BUFR) for all Remote Automated Weather Stations (RAWS) locations which are viewable using BUFKIT software, and full resolution plan-view graphics created with GEMPAK software. Hourly BUFR points and graphical output at a 3-h temporal resolution were available in real-time for evaluating the potential for moist convection such as convective available potential energy (CAPE) and composite reflectivity, and for following changes in 2-m humidity and 10-m wind for up to 18 hours from the time of model availability.

3. MODEL DATA AND EVALUATION

Unlike the 2007 season**,** the fire activity during the experiment in 2008 was limited, therefore IMET deployment and use of the data was infrequent. However, other uses of the data became apparent during the experiment and specifically with the onset of the monsoon. The location and timing of convective development and its movement is critical to wind forecasts in and near any fire. Such forecasts can also be of significant value for any outdoor recreationalist (e.g., thousands of visitors at the national parks annually). The purpose of this research was to identify particular model data which operational forecasters could use to improve meso or micro-scale forecasts. This study included an analysis of the events in which forecast composite reflectivity was used to anticipate the initiation and evolution of convection both before and while reflectivity was observed on radar. The reflectivity and 10-m winds forecast by the local model provided greater detail than the national scale models, and were valuable for short-term forecasts and warning decisions. In this study, composite reflectivity forecast by the model was chosen to compare with base reflectivity. In general, the radar composite reflectivity was tainted by high-based showers and virga, which are common over the Great Basin in summer. It should be noted that such light precipitation can be just as critical to wind forecasts due to the dry microburst potential.

Several recent studies have demonstrated the utility of model simulated reflectivity and the prediction of storm type (Stratman et al, 2009; Weiss et al., 2007 and 2008; Coniglio et al., 2008; Kain et al., 2006; Koch et al., 2005). Other studies have indicated that the use of 1-km AGL simulated reflectivity may be the best choice when comparing to mosaic base reflectivity data (Koch et al., 2005). This study focused on small areas or within the radar umbrella so comparison was limited to individual radars rather than mosaics.

4. EVENTS AND RESULTS

Several convective precipitation events were examined during the summer of 2008. Overall, the WRF-ARW model had a tendency to develop moist convection in the correct area, but the intensity and timing forecasts were inconsistent. Some of these issues may be associated with the model initial conditions (Weiss et al., 2008). In other cases, the complex terrain and the model generated outflow boundaries may make it nearly impossible to accurately depict given the current technology. However, the use of simulated radar reflectivity is only in the early stages of a potential warn-on-forecast approach, and this paper only suggests the use of this guidance to aid short-term weather forecasting.

4.1 Early results of wind and convective output

Early in the experiment it was not surprising that a 3-km model would provide very detailed wind patterns across complex terrain. Most of the common wind patterns that might present challenges to a forecaster were indentified in the wind fields including: blocked and redirected flow, divergence, convergence, upslope, drainage (i.e., downslope), channel enhanced or accelerated wind and convective outflow (see Fig. 1). The details in the 2-m relative humidity forecasts were clearly apparent for a case in Figure 2 with the very dry air (less than 10 percent) across the deserts and locally much higher moisture levels over small bodies of water (e.g., Utah Lake).

Since wind and humidity can be greatly affected by moist convective development the model's ability to depict convection was monitored. If a critical parameter such as convection could be accurately modeled a forecaster could then use these detailed temporal and spatial predictions for advanced anticipation of conditions that could greatly impact fire behavior. The ARW model was run with explicit convection (i.e., convection allowing) and early results were similar to other studies by Weiss et al. and Kain et al. (2008 and 2006) which demonstrated a utility for anticipating storm structure for the forecast process. The first event in this study forecast a broken line of thunderstorms across southwest Utah (Fig. 3). The corresponding base reflectivity image depicted a similar structure, but only one main broken line of convection and a much smaller trailing line segment (Fig. 4).

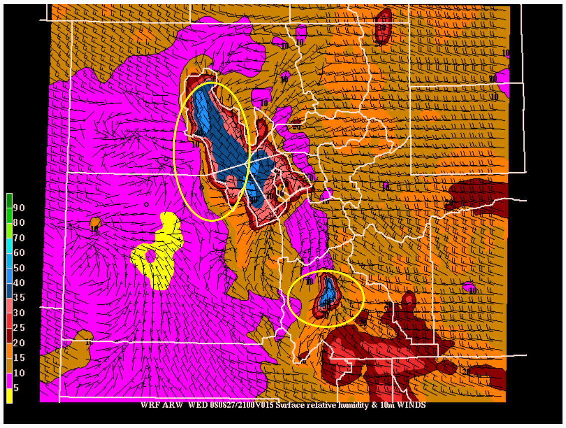

Fig. 2. ARW relative humidity and wind depiction across northern Utah. The small Utah Lake and lake breeze along the Great Salt Lake shores are depicted (circled).

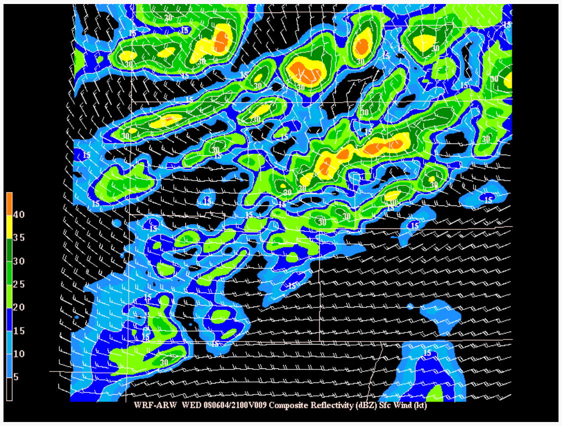

Fig. 3. 1200 UTC 4 June 2008 ARW composite reflectivity forecast at 2100 UTC 4 June. 3 broken lines of convection were predicted.

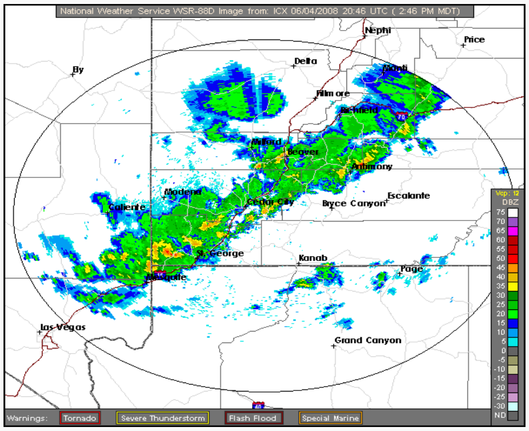

Fig. 4. KICX WSR-88D base reflectivity at 2046 UTC 4 June 2009.

4.2 Air mass monsoon thunderstorms

When sub-tropical moisture is in place across the Great Basin the development of moist convection is common and favored locations exist given a specific prevailing wind flow (e.g., southeast flow and the underlying opposing terrain driven flows). However, the location is often dependent on the magnitude of local low-level convergence with any mean wind flow and/or upper level short-wave troughs. Figure 5 displays the ARW depicting upslope regions and therefore it was anticipated that the model could reasonably predict thunderstorm formation across complex terrain. This was further demonstrated on 12 July 2008 when weak easterly flow tracked scattered thunderstorms across southern Utah. The thunderstorms were sustained and became severe just northwest of St. George Utah. WRF-ARW surface-based CAPE depicted this region to have the highest instability which would support additional or stronger moist convection (Fig. 6).

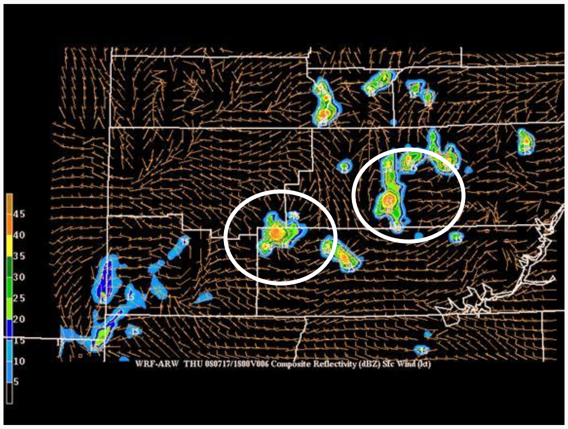

Fig. 5. 1200 UTC 17 July 2008 ARW composite reflectivity forecast at 1800 UTC 17 July. Local upslope flow created low-level convergence and initial moist convection (circled).

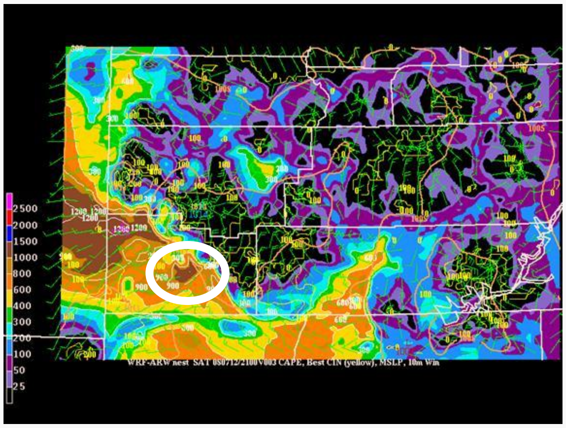

Fig.6. 1800 UTC 12 July 2008 WRF-ARW surface-based CAPE (shaded) at 2100 UTC 12 July. Location of severe thunderstorm circled.

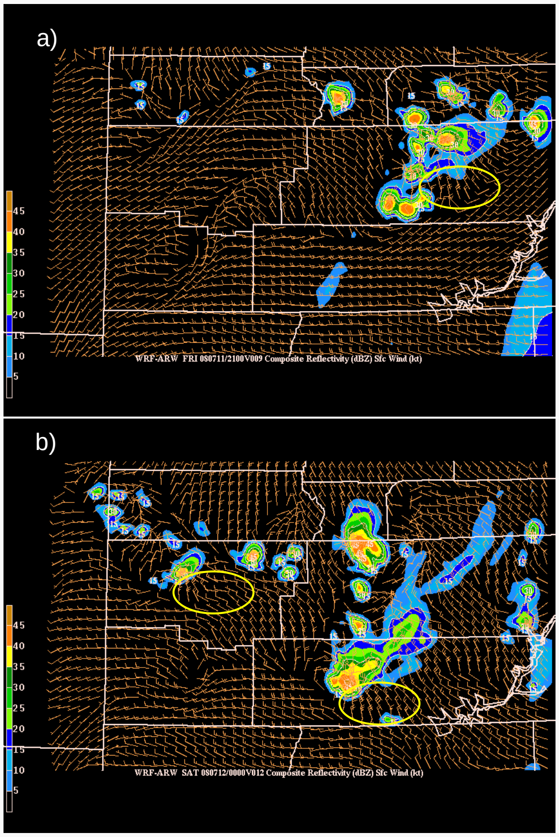

Fig 7. 1200 UTC 11 July 2008 WRF-ARW valid at 2100 UTC (a) and 0000 UTC 12 July (b). Model thunderstorm outflow areas are circled.

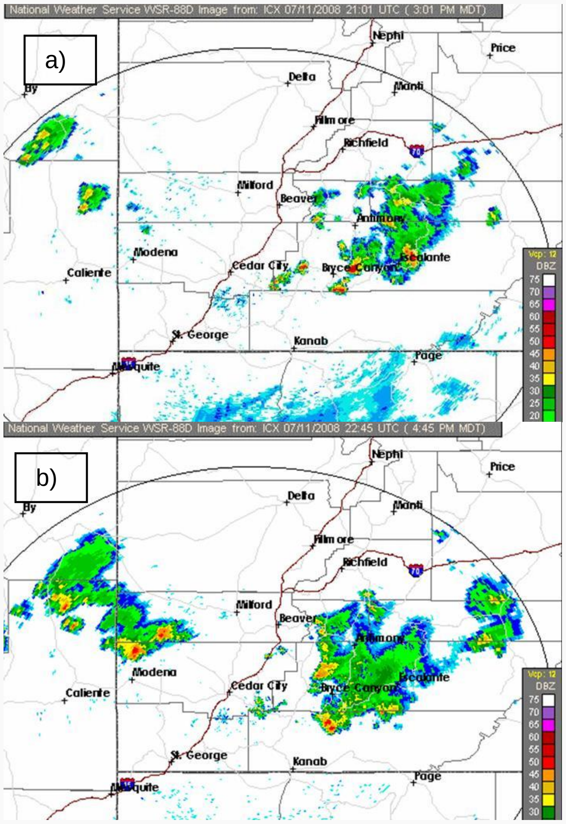

Fig. 8. KICX base reflectivity at 2101 UTC 11 July (a) and 2245 UTC 11 July 2008 (b). Simulated reflectivity forecasts verified well with the timing, location and intensity of moist convection.

An event on 11 July 2008 demonstrated the accuracy of a high resolution convection allowing model for predicting the location and timing of moist convection. The reflectivity and associated outflow generated areas were also vividly illustrated in the model output, and its ability to generate new convective cells from these outflow interactions across complex terrain (Fig. 7). When compared to Figure 8 the results were encouraging but whether this information could be regularly used by a meteorologist to enhance short-term weather predictions or accessible in a remote location remains the challenge. Because of the large potential for error with the detail provided by such high resolution models a forecaster may be reluctant to apply the information. Only through frequent exposure to high resolution data and research will the potentially beneficial detail be expressed in operational products.

4.3 Movement and propagation of thunderstorms

On 17 July 2008 the subtropical moisture and weak steering wind flow resulted in numerous thunderstorms forecast by the WRF-ARW (Fig. 9). The model's depiction was suggesting little organization and almost random development with some southwestward movement. KICX base reflectivity data confirmed this type of development and movement (Fig. 10). A forecaster could have used this information to anticipate the type and coverage of the moist convection as well as its potential slow movement. Air mass type thunderstorms are inherently challenging to forecast but have a high impact on wind and fire behavior. In the operational field it would be beneficially to provide any additional lead-time for such events beyond simple radar extrapolation. Current modeling may limit this to only providing information containing a higher probability of occurrence at a specific location.

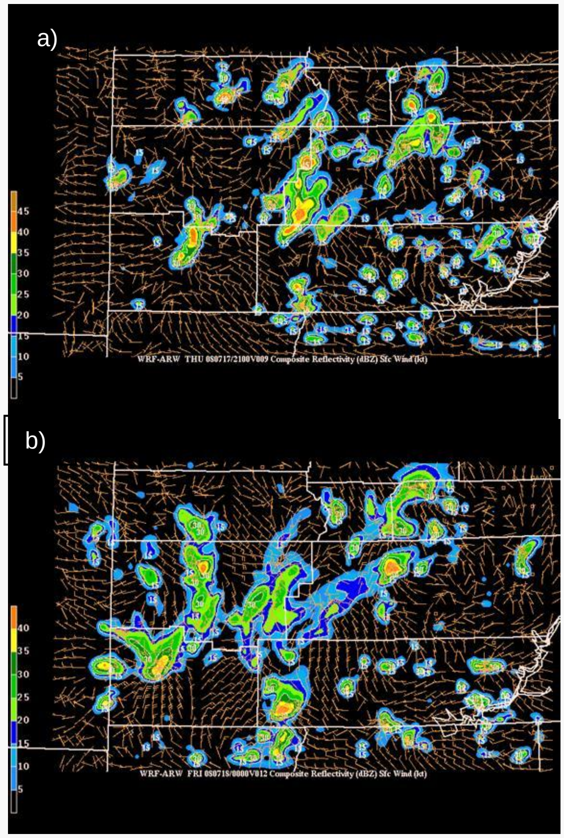

Fig. 9.1200 UTC 17 July 2008 WRF-ARW composite reflectivity at 2100 UTC (a) and 0000 UTC 18 July 2008 (b).

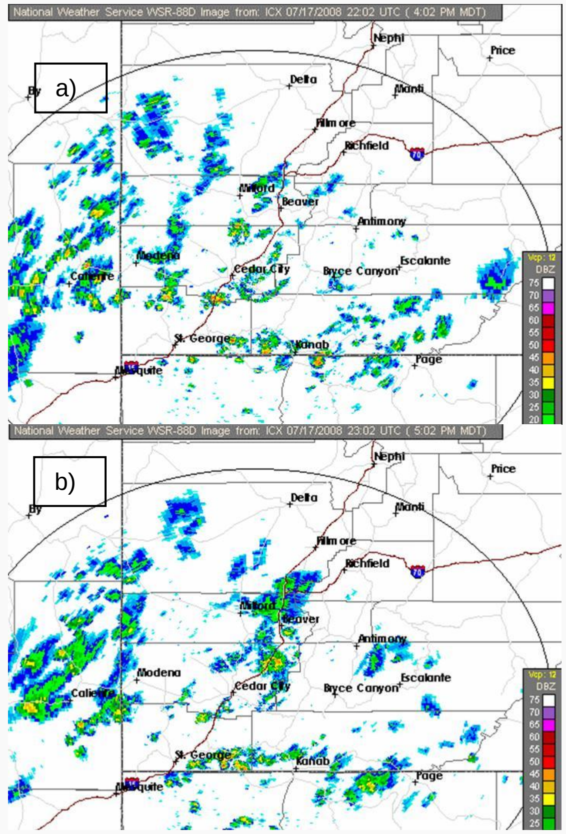

Fig.10. 2202 (a) and 2302 UTC (b) 17 July 2008 KICX base reflectivity imagery.

This case also illustrated the need for higher temporal resolution similar to 1-h BUFR information. In order to simplify the experiment the data was limited in the study and the author chose to use 3-h model output for plan view graphics. However, the 2009 Hazardous Weather Testbed Experiment involved radar and storm-scale modeling such as the Center for Analysis and Prediction (CAPS) which ran an ARW run with 1-km horizontal resolution and 5 minute output [on-line at http://www.caps.ou.edu/]. This model data appears well suited to provide storm structure, type and coverage from individual to multi-cellular thunderstorms but not nearly as accurate for timing and location. Improvement in the later may occur with better data assimilation (e.g., initialized with radar data) and fully resolving the boundary layer processes.

In addition, it is noteworthy in this event that the ARW model rapidly dissipated moist convection after 0000 UTC (not shown). The null events and the correct forecast of dissipation can be of significant value to the forecaster particularly when attempting to predict nocturnal convection and outflow generated storms. The issues associated with falsely generated convection when outflow boundaries were not observed or poorly modeled boundary layers (e.g., contaminated with effects from convection) when compared to the real atmosphere were documented by Weiss et al. (2008).

4.4 Using the model data for intensity forecasts

A considerable forecast challenge during the convective season, in addition to location and timing of thunderstorms, involves the intensity or persistence of the activity. The final case in this study demonstrated a model forecast of organized, strong and persistent thunderstorms (Fig. 11). Radar imagery at 2045 UTC 7 August 2008 verified an organized area of strong moist convection in a location similar to the model simulation (Fig. 12). Shortly after 2100 UTC 7 August there were 2 flash flood warnings issued. This model forecast may have given the forecaster a greater confidence that organized and strong thunderstorms would occur in or near flash flood prone regions of southern Utah.

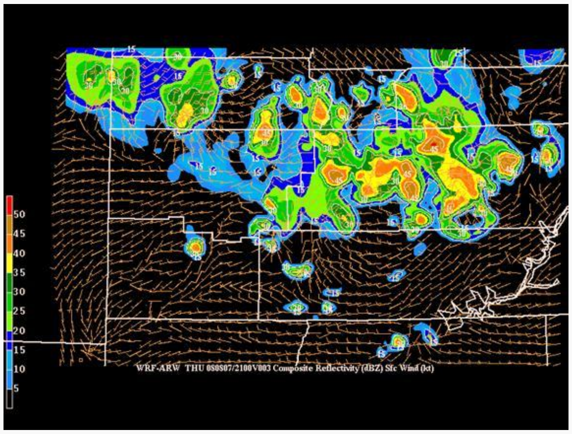

Fig. 11. 1800 UTC 7 August 2009 WRF-ARW composite reflectivity at 2100 UTC 7 August.

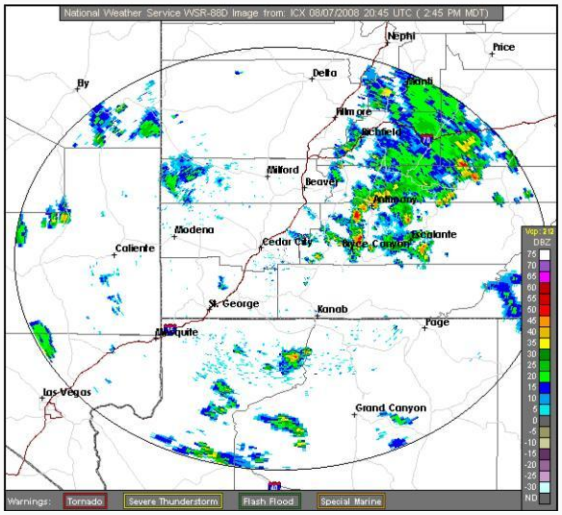

Fig.12. KICX base reflectivity at 2045 UTC 7 August 2009.

5. CONCLUSIONS

This study demonstrated the use of a high resolution model data for applications involving short-term weather forecasting. Model output parameters such as 10-wind, 2-m relative humidity and simulated composite reflectivity were particularly useful in the experiment. The original goal of the project was to provide high resolution data for site specific locations and to support IMET's. However, such model data proved to be useful for the temporal and spatial prediction of moist convection and the subsequent outflow and precipitation.

A similar EMS ARW model core nested to a 3-km resolution as used in this project could be configured and operated for any location given limited resources. This study was conducted across complex terrain but similar results should occur along coastlines and flat terrain. It is hope that this local study will demonstrate the need for further local modeling efforts. Future studies would evaluate more cases and different model output. Only through sharing the results from the efforts of experimental model evaluation will such technology and research be applied to operational forecasting.

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