1B.1 HIGH RESOLUTION ASSIMILATION OF CASA X-BAND AND NEXRAD RADAR DATA FOR THUNDERSTORM FORECASTING

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1. INTRODUCTION

Recently the NSF Engineering Research Center for Collaborative Adaptive Sensing of the Atmosphere (CASA, McLaughlin et al. 2005) deployed a network of four X-band dual-polarization Doppler radars in southwestern Oklahoma. This CASA NetRad network was deployed as CASA's first integrated project (IP1, Brotzge et al. 2007, Junyent et al. 2005).

During the spring of 2007 the CASA NetRad and NWS/FAA/DoD WSR-88D NEXRAD radar data were combined with other data, including surface observations and satellite imagery, in a high resolution data assimilation experiment as part of the CASA IP1 Spring Experiment-2007 (CSET-2007). A series of 6-hour assimilated forecasts at 1-km resolution were produced in near-real time using different combinations of radar data to evaluate this first-generation application of the CASA radar data in NWP and to establish a baseline for enhancements of the analysis and assimilation techniques to be made in the coming months.

This paper will describe the CASA IP1 radar network, the methods used to insert radar data in the model, describe a sample case, and report on ongoing enhancements to the radar processing and the planned verification.

2. CASA NETRAD IP1 RADAR NETWORK

The CASA IP1 radar network consists of four dual-polarization X-band Doppler radars separated by about 25 km and is situated in southwest Oklahoma, midway between the Oklahoma City (KTLX) and Frederick (KFDR), Oklahoma WSR-88D radars of the NEXRAD operational radar network (Fig. 1). Specifically, the four CASA radars are located in Chickasha (KSAO), Rush Springs (KRSP), Cyril (KCYR) and east of Lawton (KLWE).

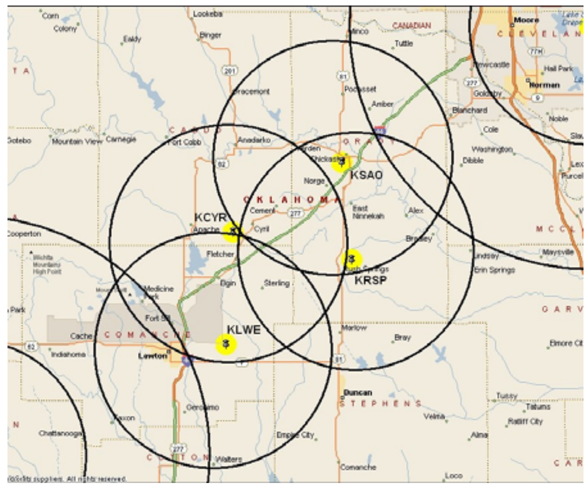

Fig 1. *Location of CASA NetRad IP1 radars in southwestern Oklahoma, 30 km range rings in center, and 30 and 60 km range rings from the Frederick and Oklahoma City NEXRAD radars.*

The radars were sited to maximize the dual-Doppler coverage areas while utilizing existing high speed communications facilities of the Oklahoma OneNet (Brewster et al. 2005b). Each CASA radar has a nominal maximum range of 30 km (efforts are currently being made to increase that to 40 km).

The radars scan in a coordinated fashion, using Distributed Collaborative Adaptive Sensing (DCAS) to maximize end-user utility depending on observed weather features (Zink et al. 2005). This is accomplished, for example, by adapting the sector scanning to scan identified thunderstorm cells with more vertical scans than nearby echo-free regions. The end-users include the National Weather Service, the emergency man-

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agers in the area, weather researchers, and the numerical weather prediction models.

The radars operate at X-band (3 cm) and thus are subject to attenuation by precipitation, which is corrected in real-time by a dual-polarization method (Park et al. 2005a, 2005b, Liu et al. 2006). The radars are operated at low elevation angles to scan below the radar horizon of the adjacent NEXRAD radars. Ground clutter is mitigated using a Gaussian model adaptive processing technique (GMAP, Siggia and Passarelli 2004), and velocity dealiasing is achieved using a dual-PRF waveform. Additional details about the radar system are reported by Junyent et al. (2005).

The radar moment data are stored in NetCDF formatted files and are transmitted within seconds to the CASA Systems Operations Control Center (SOCC) at CAPS, in the National Weather Center in Norman.

3. SPRING 2007 DATA ASSIMILATION

For the CSET-2007 data assimilation effort the CAPS ADAS analysis program (Brewster 1996), including a complex cloud analysis with latent heating adjustment was used to generate analysis increments on a 1-km resolution grid (Fig. 2) to be assimilated in the CAPS Advanced Regional Prediction System (ARPS) non-hydrostatic model (Xue et al. 2000, 2001) using incremental analysis updating (IAU, Bloom et al. 1996). IAU was applied with a triangular time-weighting function in four consecutive 10-minute cycles (Fig. 3). Previous research (Hu et al. 2006a,b) suggested that 10 min cycling of reflectivity using the ADAS cloud analysis was effective at initializing and sustaining ongoing convection. In this application of the IAU, the vertical velocity and pressure increments are not applied, so those variables may freely adjust to increments in horizontal winds, latent heating and hydrometeors.

This experiment represents the first real-time, automated use of the CASA data in NWP, the first real-time use of the IAU assimilation in cycling at CAPS, and the first use of ADAS as updated for massively parallel computations using the Message Passing Interface library (MPI).

The initial time of the assimilation for each day was adapted to the weather, beginning at the hour of first echo development in the CASA

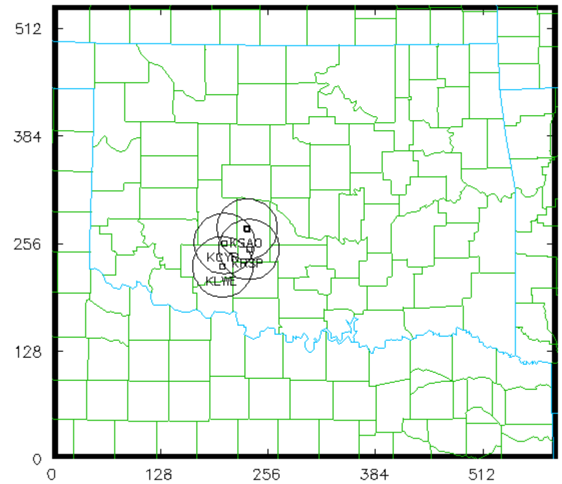

Fig. 2. 1-km assimilation and forecast domain covering most of Oklahoma and neighboring parts of North Texas and southern Kansas. CASA radars with 30 km range rings in black Distance scale in km.

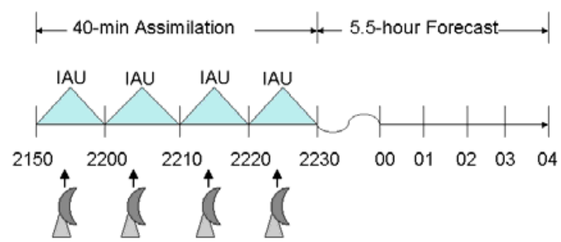

Fig 3 Schematic of data assimilation and forecast for a sample nominal start time of 22 UTC.

network, or at the time of arrival in the network for ongoing convection moving into the network. A 5.5-hour forward forecast was made following the 40-minute data assimilation period. This forecast will be compared to actual radar echoes from the CASA and NEXRAD networks.

On days without precipitation in the CASA network, the model was not run as the CASA radars were not designed for clear-air detection, and for the 2007 real-time runs only the reflectivity data were assimilated.

The radar remapping, analyses and model forecasts were done on 150 processors of a Pentium4 Xeon EM64T Linux Cluster at the OU Supercomputing Center for Education and Research (OSCER). When run in pairs (75 processors per forecast), each pair of 6h assimilation and forecast takes about 8 hours wall clock time in this configuration.

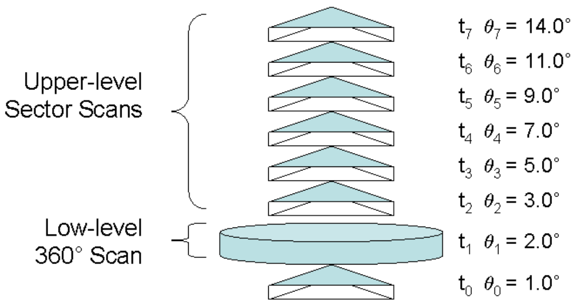

Fig 4. *Construction of pseudo-volume from scans of a CASA NetRad radar*.

4. PROCESSING OF THE RADAR DATA

For these experiments the radar data from all sources are processed through the ADAS Cloud Analysis, that combines the radar data satellite and surface data.. The cloud analysis was initially adapted from the cloud analysis of LAPS (Albers et al. 1996) with several upgrades for ARPS (Zhang et al. 1998, Brewster 2002, Hu et al. 2006a).

Some cloud information comes from the hourly surface aviation observations taken between 50 and 55 minutes after the hour. Starting the assimilation cycling with the 50-00 minute time window thus allows these data to anchor the first analysis. Cloud information from any specials that may be taken other times are also used in the appropriate data assimilation window.

The radar processing is done in terms of radar volumes. The CASA radar data are collected in terms of sectors, typically covering the most intense convection, with a 360 surveillance scan at the 2° tilt, as illustrated in Figure 4. In the sequence of processing employed during CSET-2007 each sector scan decision is made in 1-minute intervals, the interval known as the Meteorological Command and Control (MC&C) heartbeat. From the collection of scans taken in the 10-minute window, the search for an appropriate radar scan sequence begins with the heartbeat that ends at the 6 minute point of the window, and continues backward in time to find a set of tilts that meets the minimum conditions of one complete 360 scan and having at least a total of 950 azimuthal degrees coverage as summed over all tilts in the vertical sequence. The pseudo-volume selection decision is made independently for each radar, but, in general, the radar scans among CASA radars are coincident in time because the CASA NetRad scanning is synchronized by the MC&C.

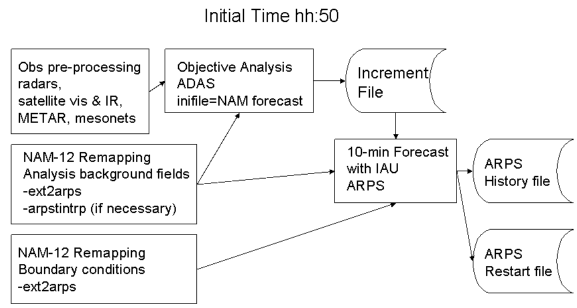

Fig 5. *Assimilation flowchart at initial time*.

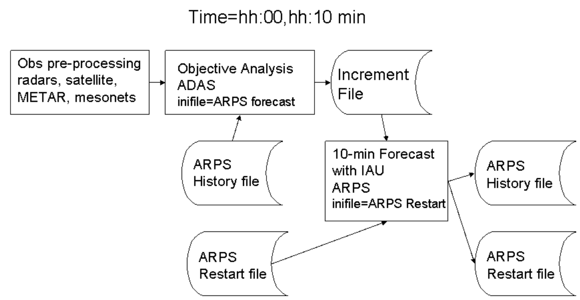

Fig 6. *Assimilation flowchart during the cycling period.*

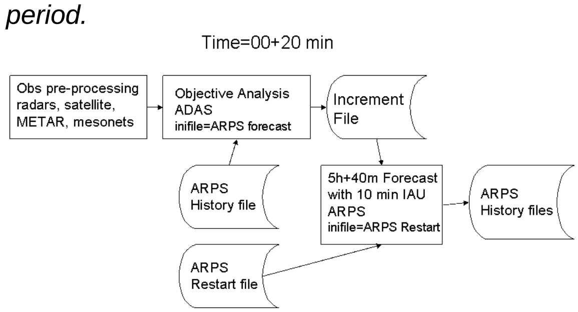

Fig 7. *Flowchart for the final cycle and forward model forecast.*

For NEXRAD, the first complete volume that begins after the beginning of the data assimilation window is selected, except in those cases where 10-minute clear-air mode scanning is done. In that case, a scan covering the data assimilation window beginning at most two minutes before the data window is selected. Level-2 data from 14 NEXRAD radars in and around the forecast domain are used. NIDS (Level-3) data are used if the Level-2 NEXRAD data are not available.

The data from each radar are remapped to the model grid points, after screening for clutter and anomalous propagation. The remapping is accomplished using a local least squares fit to a function is quadratic in the horizontal and linear in the vertical (Brewster et al. 2005b). The remapped reflectivities from all radars are combined in a 3D radar mosaic using the maximum reflectivity from all sources at each point.

Latent heat adjustment is made for columns where clouds are added in the analysis at each cycle. A moist adiabatic ascent with entrainment is calculated and any excess in this temperature over the analyzed temperature is then added to the analyzed value. The same ascent profile is used to derive the mixing ratios of cloud water and cloud ice, which form increments to the background variables. Because of scavenging by precipitating hydrometeors, the cloud water and ice are reduced to 10 percent of the analyzed mixing ratio where precipitating hydrometeors are also diagnosed. This is a heuristic adjustment based on testing for a few cases, and more work is needed to find the most accurate accounting for the scavenging.

As indicated by the flowcharts in Figs 5-7, the first background field comes from the 12-km NAM forecast (interpolated in time from 3-hourly output grids). Thereafter the background is the ARPS model forecast valid at the beginning of the cycle.

5. PRELIMINARY RESULTS

At the time of this writing CSET-2007 is still underway, so it is too early for quantitative verification of these baseline runs, but some sample results are shown here to provide a sense of the overall performance of the assimilation and modeling system.

Figure 8, a vertical cross-section of reflectivity from the first analysis time for 01 UTC, 9 May 2007, demonstrates how the CASA NetRad data fill-in the reflectivity below the NEXRAD data coverage, below about 1.2 km in this cross-section. Figure 9 shows the fifth model level (about 250 m AGL) where the NEXRAD covers only the area close to the KTLX and KFDR radars, while the addition of the NetRad radar data fills the domain within the range of the NetRad radars.

Figure 10 shows the reflectivity field at the lowest model level (10 m AGL) at the end of the assimilation period (0130 UTC) compared to the radar display from KTLX (a) and from the NetRad radar at this time. The characteristics of the ongoing convection, including details of the storm outlines are generally well replicated, though the observed reflectivites are a little stronger than the model's 1-km resolved values.

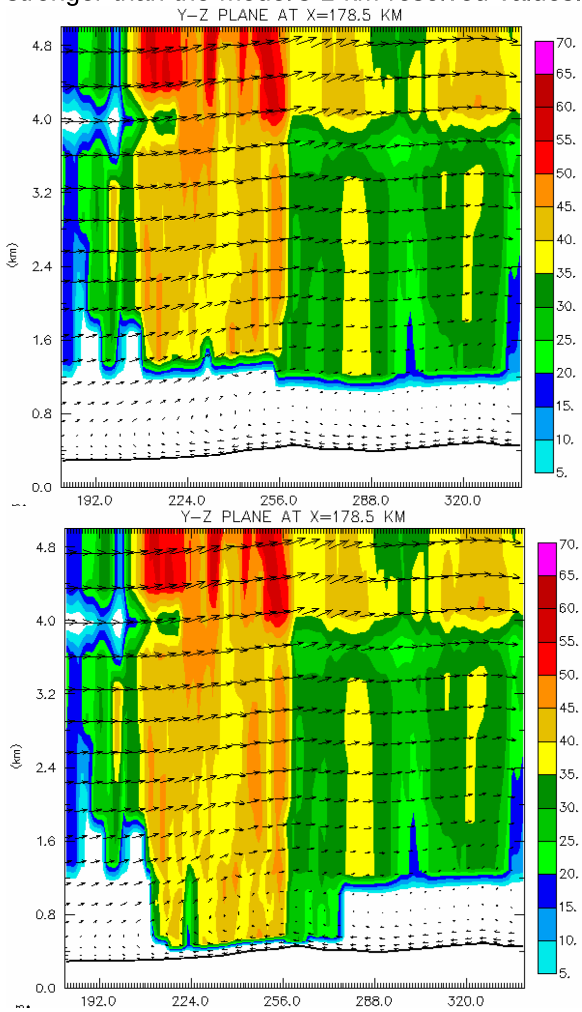

Fig. 8 Vertical cross-section of reflectivity from model hydrometeors in the analysis at 0050 UTC for the 01 UTC 9 May 2007 assimilation. a) Using only NEXRAD reflectivity data, b) with the addition of CASA reflectivity data.

The CASA NetRad only run has a limited horizontal extent to the echoes compared to the observed, not surprisingly, but is otherwise well behaved. As in the combined run, the forecast tends to produce a maximum in low-level vorticity on the eastern edge of the cells.

Figure 11 shows the forecasted fields at 0300 UTC. At this time a circulation was noted in the KSAO CASA radar at the location shown by the brown triangle. Subsequent to this a tornado developed that produced damage in the town of Minco, Oklahoma. The forecast model has produced a circulation indicated by the vertical

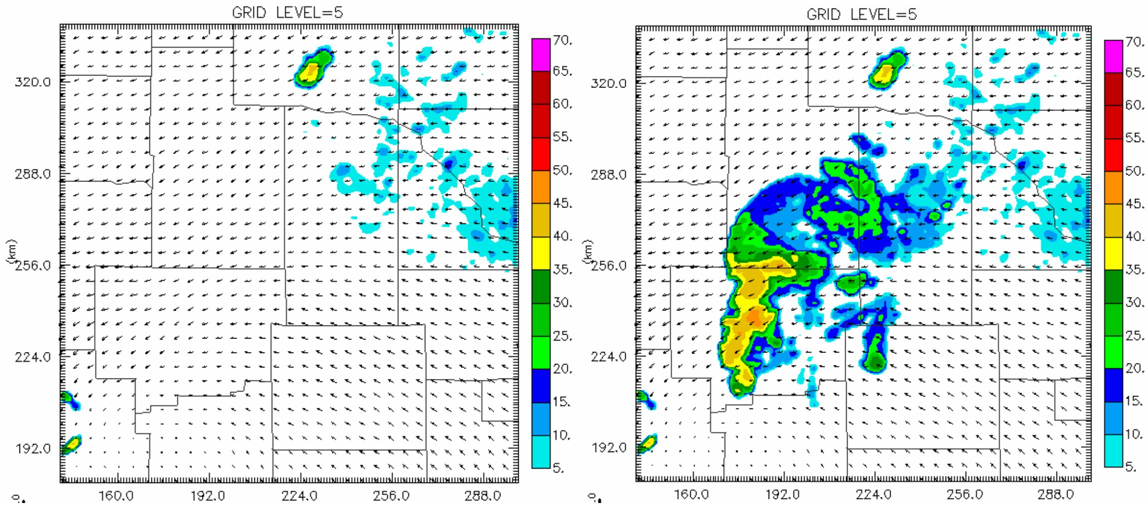

Fig 9. Horizontal cross-section at the k=5 model level (about 250 m AGL). a) NEXRAD only, b) NEXRAD combined with CASA NetRad.

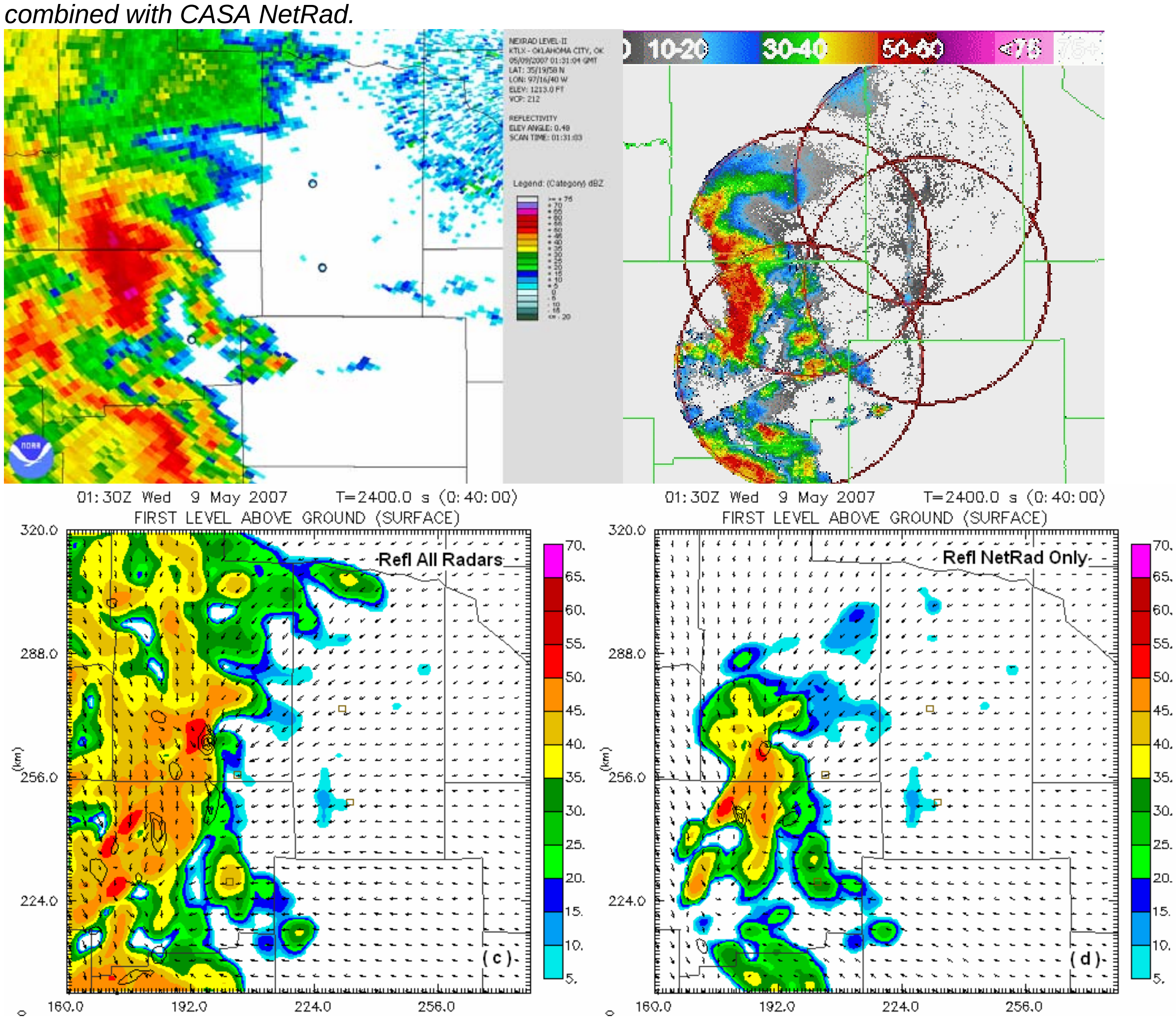

Fig 10. Forecast comparison at 0130 UTC, model reflectivity (dBZ) and vertical vorticity contours. a) KTLX 0.5 degree scan at 0129 b) CASA NetRad Composite at 0129, c) forecast including reflectivities from all radars d) forecast with just CASA NetRad reflectivity data.

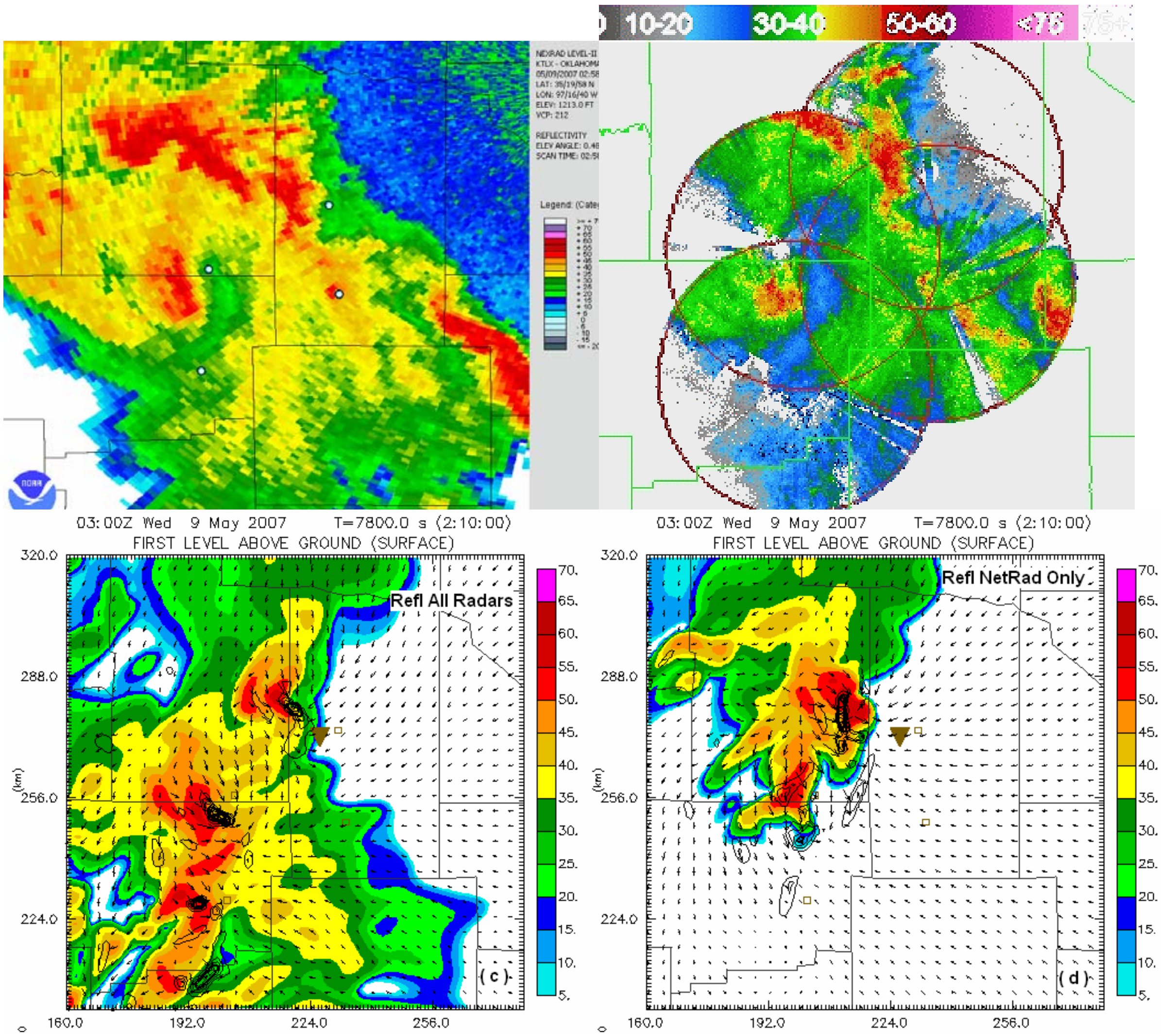

Fig 11. *Forecast comparison at 0300 UTC as in Fig 10. a) KTLX 0.5 degree scan at 0259 b) CASA NetRad Composite at 0259, c) forecast including reflectivities from all radars d) forecast with just CASA NetRad reflectivity data.*

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vorticity contours. Another circulation indicated is associated with the evolving mesoscale convective vortex, some indication of which is seen in the spiral shape of the observed reflectivity. The model is a little slow in the eastward progress and strength of the cells in the southeast quadrant of this figure.

6. DISCUSSION AND ONGOING WORK

Some qualitative results have been shown that demonstrate that the data assimilation system with cycled IAU performs well at ingesting reflectivity data from combined NEXRAD and CASA NetRad radars for springtime convection in the Southern Plains.

In the coming months quantitative verification will be performed to judge precipitation forecasting skill. Cases with low-level circulations will be compared to observed circulations and scored for position error and skill in predicting trends. Forecasts with and without the CASA radar data will be compared.

The MPI version of ADAS including a velocity correction from radial velocity is being developed and will be applied to these data. The effect of the addition of CASA radial velocity data will be measured, particularly in cases where low-level circulations were observed.

In preparation for CSET-2008 the ARPS 3DVAR program will be updated for MPI and compared to the results produced by ADAS.

7. ACKNOWLEGMENTS

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