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31 A REAL-TIME HIGH-RESOLUTION ANALYSIS AND SHORT-TERM FORECAST SYSTEM FOR SEVERE WEATHER IN THE DALLAS/FORT WORTH TESTBED

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1. INTRODUCTION

The Dallas/Ft. Worth Testbed (D/FW Testbed) has been established as a region for testing real-time data analysis and short-term forecasting over an urban area. A number of high-density observing networks are being tested in the region, namely X-band Doppler radars, including those from the Collaborative Adaptive Sensing of the Atmosphere (CASA) project (McLaughlin et. al, 2009) and private companies, citizen weather observations, truck-mounted mobile sensors, and ground based profilers. Building on our experience from the CASA Integrated Project-1 (IP1) in Oklahoma we have configured a 3DVAR analysis system with 400-m grid spacing and a numerical weather prediction system for 0-to-2 hour forecasts with low latency. Besides providing real-time information for local governments and the National Weather Service Forecast Office in Fort Worth, the system can be used as a basis for the testing of observation system impacts, including those being integrated into the National Mesonet Program. This work describes the D/FW Testbed and the current real-time analysis forecasting system. Some cases of severe storms in the network during 2014 are presented as examples.

2. DALLAS-FORT WORTH TESTBED

In anticipation of the CASA radars being moved to North Texas from Oklahoma as a cornerstone of the D/FW Testbed, the domain for the CASA analysis and NWP system was relocated from Oklathoma to the D/FW area in the spring of 2012. At the same time, thanks to cooperation among the NOAA Radar Operations Center, NWS Southern Region Headquarters and the NOAA National Severe Storms Lab, CAPS gained real-time access to the Level-II TDWR data from the two D/FW radars.

As of November, 2014 there are four X-band radars deployed in the CASA D/FW Testbed (Fig 1), two relocated from the original CASA IP1 Network in southwestern Oklahoma, one Ridgeline Instruments radar and one Enterprise Electronics (EEC) radar. There are plans for four more, including the remaining IP1 radars and one from EWR Weather Radar Systems, and a second EEC radar. These are in addition to the three Federal radars in the immediate area, namely the NEXRAD (WSR-88D) at Fort Worth (KFWS) and two FAA Terminal Doppler Weather Radars serving DFW Airport (TDFW) and Dallas Love Field (TDAL). The forecast system also uses additional NEXRAD radars from adjacent sites having partial coverage in the domain.

In addition to the radars and conventional observation systems, a number of additional non-conventional instruments are in the region, or will soon be brought into the testbed, as listed in Table 1. To highlight a few, the standard suite of surface observations from the National Weather Service (NWS) and Federal Aviation Administration (FAA) are augmented with additional surface observations from the EarthNetworks WeatherBug network as well as the Citizen Weather Observer Program (CWOP), e.g. Fig 2. Additionally, mobile MoPED truck-mounted observations (Heppner, 2013) are being added from GST, Inc., SODARs from WeatherFlow, Inc., andt temporary deployments of low-level profiling units from the University of Oklahoma, etc.

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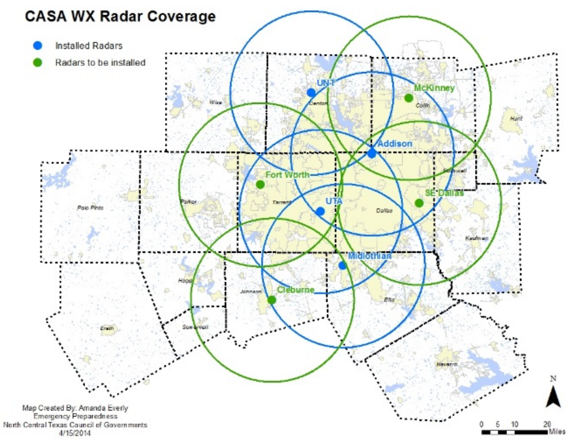
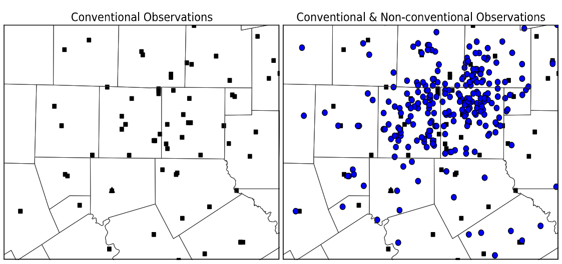


Fig 1. *Current status of CASA X-band Radar Network in Dallas-Ft. Worth Testbed. Blue circles indicate 40-km* … *reen* … *o be* … *ounty*



… *ns in* … *Left:* … *non-* … *and EarthNetworks* … *WxBug* … *sites.*

Table 1. *Observations in Dallas-Ft Worth Testbed*

Conventional Observations	Non-Conventional Observations
ASOS	EarthNetworks (WxBug)
AWOS	CWOP
West Texas Mesonet	GST MoPED
Oklahoma Mesonet	
S-band WSR-88D Radars	X-band Radars
	C-band TDWR Radars
Radiosondes	SODAR
	Radiometers

3. BUILDING THE X-BAND RADAR NETWORK

As the X-band radar network has been planned candidate sites are evaluated using principles and techniques used to build the IP-1 radar network in Oklahoma (Brewster et al., 2005). The primary goals being to have broad coverage areas, significant overlap of X-band radars, good dual-Doppler crossing angles and low-level coverage to supplement NEXRAD. Logistical concerns, such as the availability of affordable power and high-speed networking, and a suitable elevated structure (such as a rooftop) free of obstructions also played a role in the siting of the radars.

Figure 3 and the first column of Table 2 show results of an analysis of the low-level coverage of the Federal radar network in the D/FW Testbed. There is some dual-Doppler coverage provided by these three radars, but the alignment of the TDWR radars along nearly the same radial of the Fort Worth NEXRAD is not optimal for this purpose.

Considering the X-band network alone (Figure 4 and the second column of Table 2), it offers good coverage in the D/FW Testbed region with 48% of the coverage area having overlap of two or more radars, and 19% of the coverage area having coverage from three radars. 45% of the dual-Doppler area has 30° or better crossing angles allowing for excellent wind retrieval using dual-Doppler or 3DVAR methods. The mean height of the lowest beam in the X-band radar network is less than 500 m AGL. The combined radar network (Figure 5 and the third column of Table 2) has the coverage area of the Federal radar (120 km radius from KFWS was used for this analysis), but with improved minimum beam height and dual-Doppler crossing angles.

***Table 2** Features of Radar Networks*

	Federal Radars	CASA X-band	Combined
Coverage (km^2)	61 k	22 k	61 k
2-radar Overlap	46%	49%	48%
Mean Minimum Beam Height	1267 m	467 m	805 m
>30°dual Doppler	29%	45%	36%

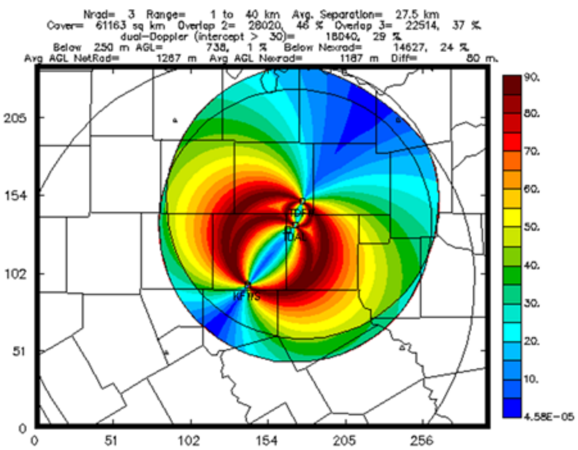


***Fig 3**.. Maximum dual-Doppler crossing angles (color, degrees, scale at right) for the Federal radars in the Dallas-Ft Worth Testbed, including the NEXRAD (120 km range ring) and TDWR radars (60 km range rings).*

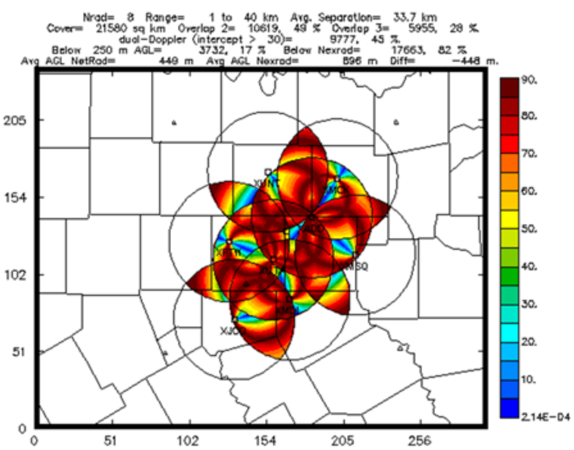


***Fig 4**. Maximum dual-Doppler crossing angles (color, scale at right) for planned CASA X-band radar network, including only the 8 X-band radars (40-km range rings).*

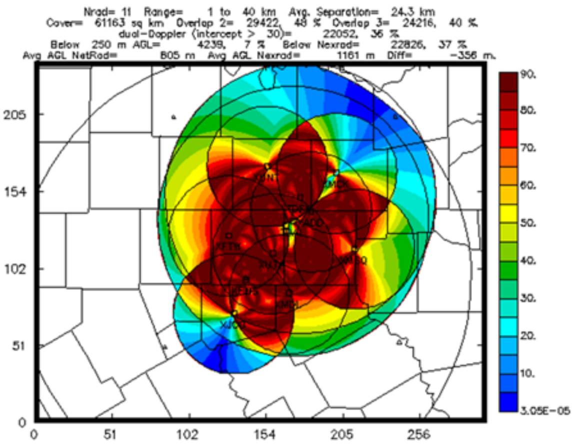


***Fig 5**. Maximum dual-Doppler crossing angles (color, scale at right) for combined Federal and CASA X-band network.*

4. REAL-TIME ANALYSES AND FORECASTS DESIGN

CAPS designed a 400-m grid resolution real-time analysis and 1-km real-time data assimilation, nowcasting and numerical weather prediction system (NWP) using the Advanced Regional Prediction System (ARPS, Xue et al., 2001; Xue et al., 2003), and the ARPS 3D-Variational (3DVAR) and cloud analysis (Gao et al., 2004; Brewster et al., 2005; Hu et al. 2006a,b) and ran the system in a domain covering central and southwest Oklahoma (Brewster et al., 2007 and 2010). The system as repositioned for the D/FW Testbed is described below with summary details for the analysis and forecast in Tables 3 and 4, respectively.

The analysis is performed every 5 minutes on a 160x160 km grid with 400 m resolution. The focus for the analysis on tracking low-level signatures of storms and precursors for convective initiation so the top of the analysis domain is 15 km AGL, using 28 vertical levels with an average spacing of 600 m, and minimum of 20 m near the ground. The analyses are run on 128 Xeon Sandy Bridge cores of the OU Supercomputing Center for Research and Education (OSCER) Boomer. The total time for the analyses, including image post processing is about 6 minutes so two sets of cores are used.

Data assimilation and short-term forecasting are run on a 353 x 320 km domain with 1-km grid spacing. 53 vertical grid levels are used with domain top at 20 km and enhanced vertical resolution near the ground (20 m minimum vertical grid spacing).

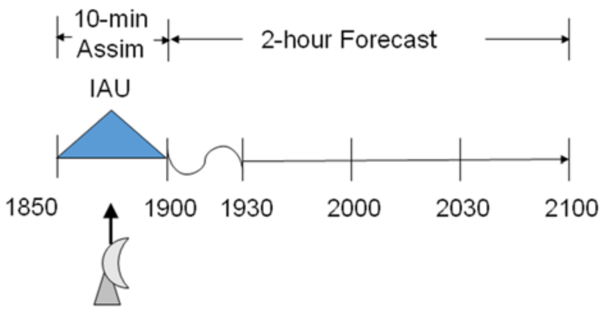


Fig 6. *Data assimilation time-line diagram for a sample 1900 UTC forecast initial time, showing observation insertion in pre-forecast IAU steps followed by 2-hour forecast.*

Table 3. *Features of Real-Time 400-m Analyses*

Method	3DVAR & Complex Cloud Analysis
Processors	128 Cores MPI
Interval	5 minutes
Typical Run Time	~6 minutes
Grid Spacing	400 m
Vertical Grid Spacing	600 m mean 20 m minimum
Grid Dimensions	403 x 403 x 28

Table 4 *Features of Real-Time NWP Forecasts*

Model	ARPS with IAU
Processors	192 Cores MPI
Interval	15 minutes
Forecast Time	0-2 hours
Typical Run Time	~20 minutes
Grid Spacing	1 km
Vertical Grid Spacing	400 m mean 20 m minimum
Grid Dimensions	353 x 323 x 53

Data are assimilated by calculating the increments from the most recent 12-km NAM background forecast valid at the 10-minutes before the nominal initial time using 3DVAR, then using them in an incremental analysis updating scheme (IAU, Bloom et al., 1996) over a 10 minute period with triangular weighting. Then, a 2-hour forecast is run, as shown in Figure 6. The IAU allows the model to ingest the observation information, including the cloud and precipitation variables and associated latent heating, while allowing the model to come into balance by the end of the assimilation window.

For the short-term forecast there is no cumulus parameterization, clouds and precipitation are modeled using the Lin 3-Ice scheme (Lin et al., 1983),. The model uses NASA Goddard atmospheric radiation transfer parameterization. Surface fluxes are calculated from stability-dependent surface drag coefficients using predicted surface temperature and volumetric water content. The model employs a two-layer force-store soil model based on Noilhan and Planton (1989).

The NWP model is run when there is significant precipitation in the D/FW Testbed area or when precipitation is expected and the X-band radars are activated. The model is run on 192 cores of OSCER Boomer every 15 minutes. The model, including image post-processing takes about 20-25 minutes to run so two sets of cores are used.

Interested readers can find the real-time analysis and forecast products on the Web during our operational periods at http://forecast.caps.ou.edu .

5. EXAMPLES FROM 2014

Two examples are presented from recent events in the Dallas-Ft. Worth Testbed. The first is a case of damaging winds from a brief tornado and subsequent mesoscale convective vortex (MCV) that passed through northern Dallas County on the afternoon of 8 May 2014. On 8 May two CASA X-band radars were operational, Arlington (XUTA) and Midlothian (XMDL).

Figure 7 shows a sequence of analysis output at 1-km AGL at 10-min intervals (every-other analysis) from 2020-2050 UTC showing the appearance of vertical vorticity and subsequent development of the MCV as the moderate squall line traversed northern Dallas Co. (highlighted with red boundary). The analyses show an area of rotation in western Dallas Co. at 2020 UTC that causes a wrap-up of rotation in central Dallas Co. at 2030 UTC that progresses northeast through the northern part of the county, exiting at the northeast corner at 2050 UTC.

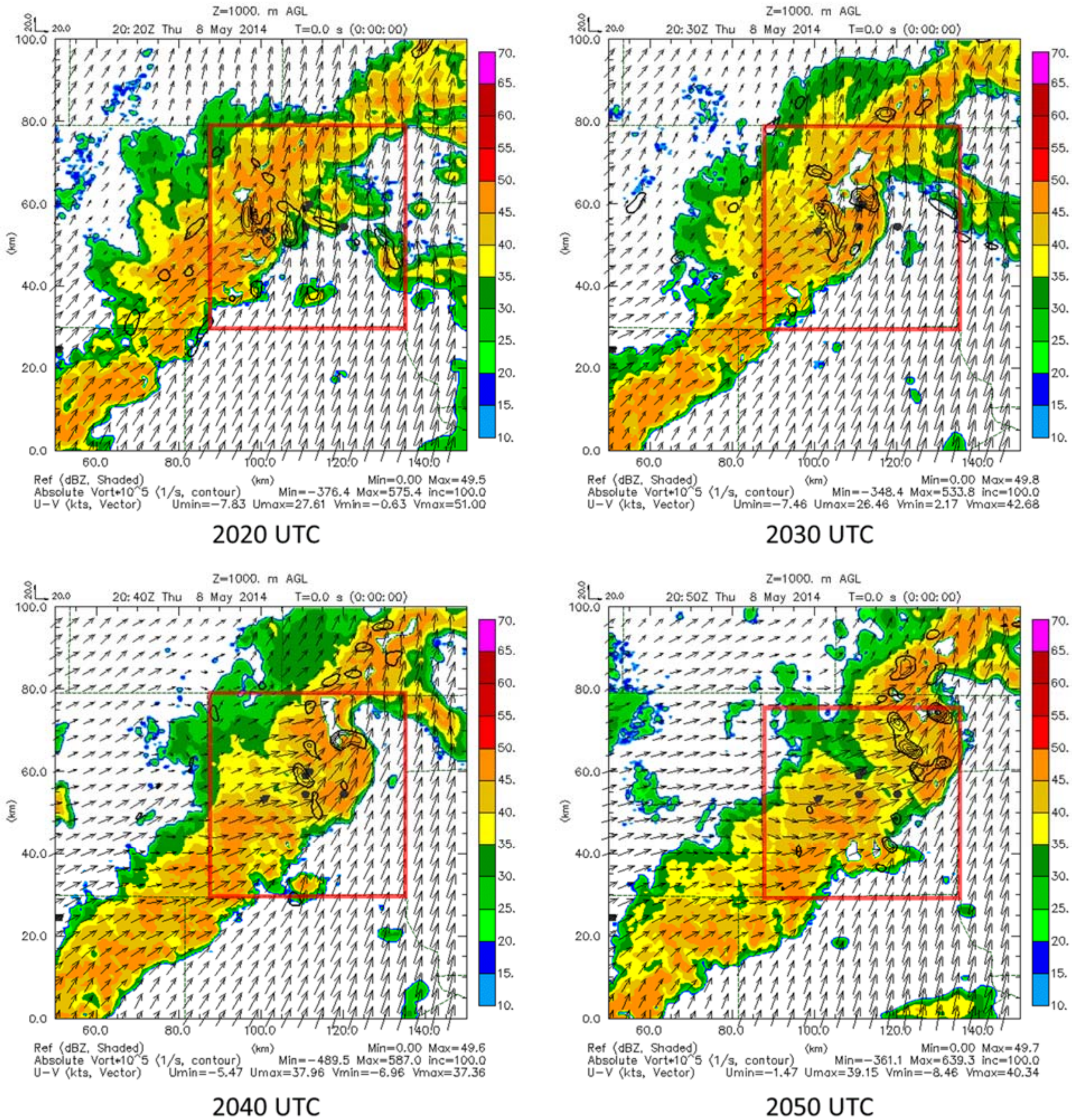


Fig 7. *Analyses 8 May 2014 at 1.0 km AGL for 2020 to 2050 UTC in 10-min intervals. Reflectivity (dBZ) in color, wind vectors and vertical vorticity > 100 x 10^{-5} sec^{-1} contours, Dallas County is highlighted in red.*

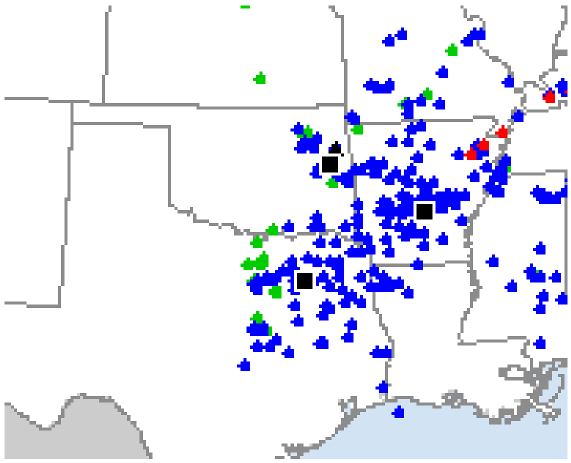


Fig 8. *Preliminary Severe Storm reports for 2 Oct 2014 in the south-central United States. Red: tornado reports, green hail reports, blue wind reports, black triangles hail > 5 cm, black squares wind > 33 ms^{-1}. From NOAA Storm Prediction Center.*

Regarding the forecasts we examine a sequence of forecasts produced during a severe weather outbreak on the afternoon of 2 Oct 2014. Two CASA radars were operational on 2 Oct 2014, at Arlington and Midlothian.

Figure 8 shows the severe weather reports in the Southern Plains for this date from the Storm Prediction Center preliminary storm reports. Severe weather in Texas was associated with a squall line that formed in, and just west of, the D/FW Testbed and propagated eastward during the late afternoon.

The top row of Figure 9 shows radar echoes from the Ft. Worth NEXRAD radar (KFWS) covering the period 2030 to 2130 UTC. Below each radar image is the sequence of forecasts valid at the time of the radar data, considering forecasts initialized from 1900 UTC to 2030 UTC (actual forecast interval was 15-min, every-other one is shown here for clarity). Scanning from bottom to top of each column one can see how the forecast for that time evolved with successive forecasts.

Considering the reflectivity forecasts, the forecast initialized at 1900 UTC had good skill in predicting the development and propagation of the squall line from Dallas-Ft Worth and northward, while missing the development of the tail of the squall line further south. The 1930 UTC forecast did a better job, and then by the 2000 UTC forecast the southward extent of the line was reasonably well forecasted.

At about 2050 UTC strong damaging wind gusts were observed in the Arlington area, just east of the marker for KFWS in the top row of Fig. 9. We consider the forecasted surface winds at this time, shown in the second column of Fig. 9. All forecasts showed a zone of higher winds along the leading edge of the squall line. The maximum wind speed at the lowest model level (10 m AGL) forecasted by the model at 2050 UTC was 25 ms^{-1} (initialized at 1900 UTC), 22 ms^{-1} (1930), and 20 ms^{-1} (2000), 19 ms^{-1} (2030). So, the forecast max speed was underforecasted by the model compared to winds estimated from damage of 25 ms^{-1} or more. Part of this may be due to the horizontal resolution not representing the strongest wind speeds as the model is forecasting the steady winds in a 1-lkm grid cell, not explicitly forecasting local gusts The reason the forecast closest to the verification time was the weakest may be a result of the latent heat adjustments in the cloud analysis cell initialization process intended to support a growing or steady-state cell, so it takes some time for the modeled cells to evolve to produce strong downdrafts and strong outflow. A longer pre-forecast adjustment period may help resolve this issue.

6. SUMMARY AND FUTURE WORK

A real-time high-resolution data analysis and short-term NWP system has been set-up for the D/FW Testbed. At the time of publication four X-band radars have been sited with locations for additional X-band radars identified considering needs for dual-Doppler analysis, low-level coverage and deployment logistics considerations. The X-band radar network is expected to be complete by mid-2015. Once the radar network is complete, formal quantitative evaluation will be done of precipitation forecasts using Equitable Threat Scores and object-based methods for tornadoes following recent work of Stratman and Brewster, 2014. Separately, training of forecasters and emergency managers in the use of these and other CASA tools will begin in early 2015, with subjective evaluation by stakeholders to follow, based on results from cases in 2014 and 2015.

The complex cloud analysis system is being updated and will include hydrometeor assignment specific to each available microphysics option, including the multi-moment schemes. This will allow better initialization of microphysics options other than Lin 3-ice, for possible future real-time implementation.

One objective of the D/FW Testbed, as part of the National Mesonet effort, is to identify the impact of the novel observation systems on the analyses and forecasts. This will be carried-out via OSSEs, data denial experiments and evaluation of analysis sensitivity to each data source.

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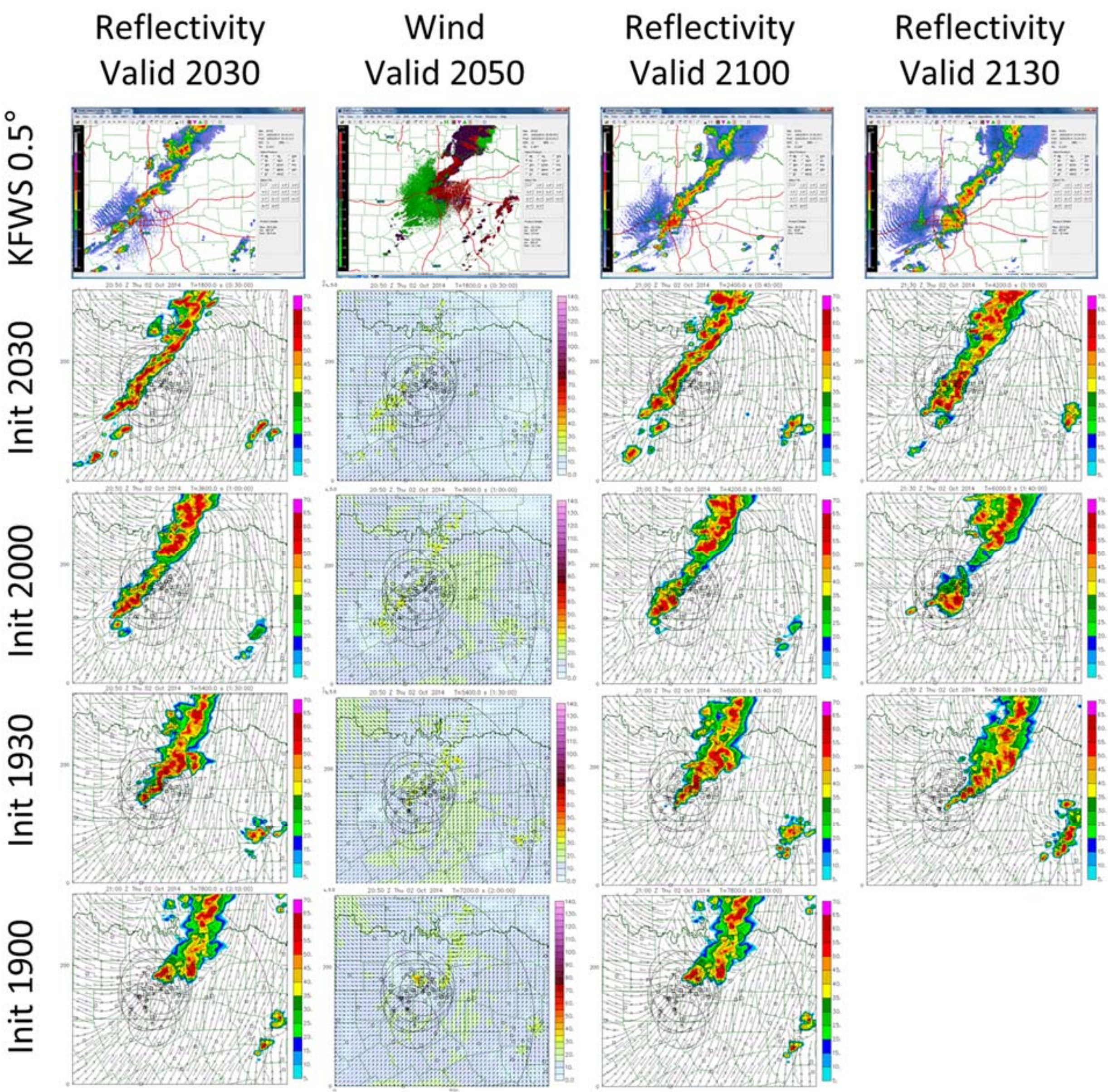

Fig 9. *Forecast results for 2 Oct 2014 2030-2130 UTC. First row: Verifying low-level radar scan (0.5 degree scan from KFWS), Second through fifth row: forecasts initialized at 2030 back to 1900 UTC in 30-min intervals. Forecasts are valid at the time at the top of the column. Columns 1,3 and 4 show simulated reflectivity at first model level (20 m AGL) and surface streamlines at valid time indicated at the top of each column. Second column shows wind speeds at time (2050 UTC) when damaging winds were occurring in the Arlington, Texas area.*