Processing and Assimilation of Radar Data

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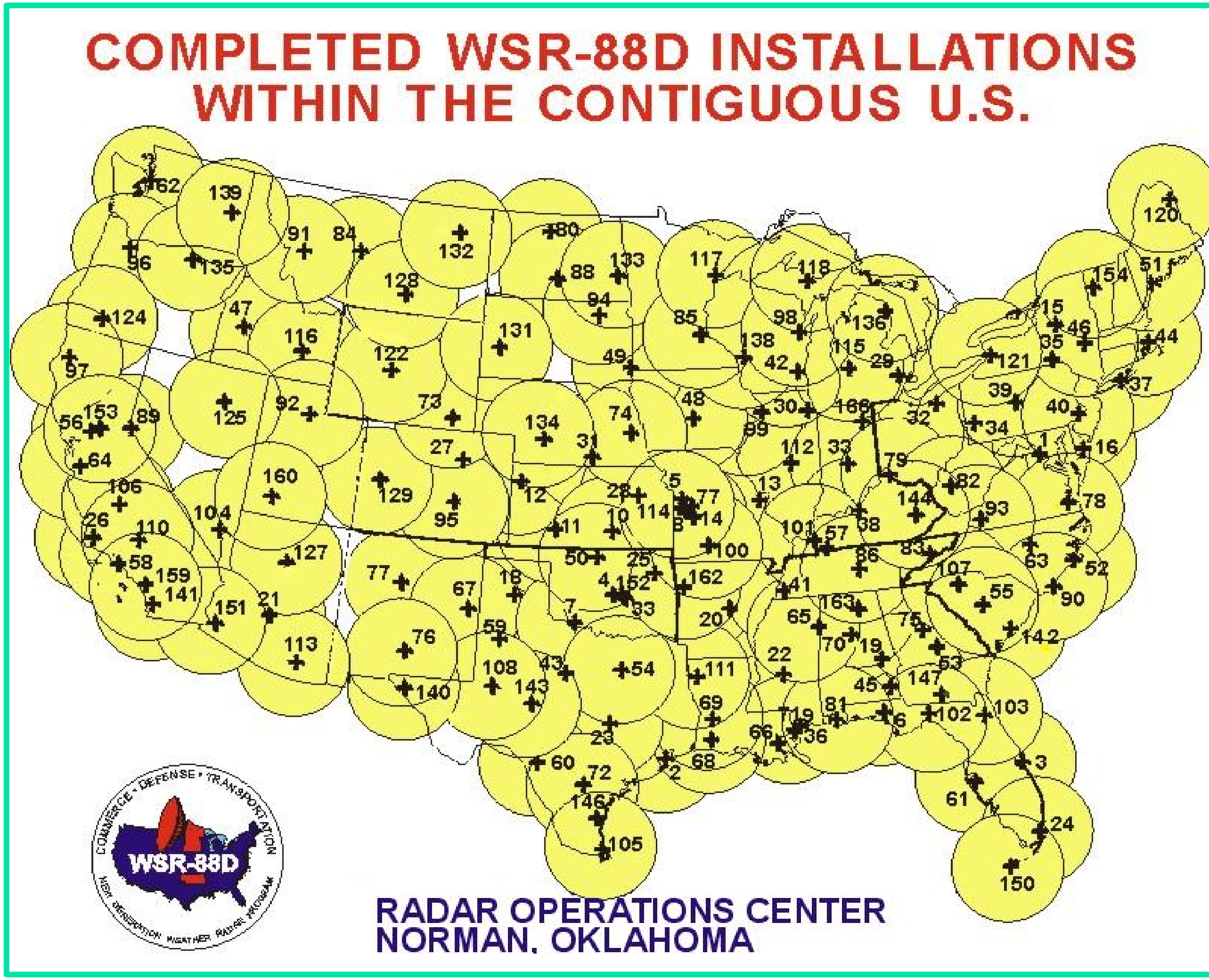
Workshop on

Shaping the Development of EarthCube to Enable Advances in Data Assimilation and Ensemble Prediction

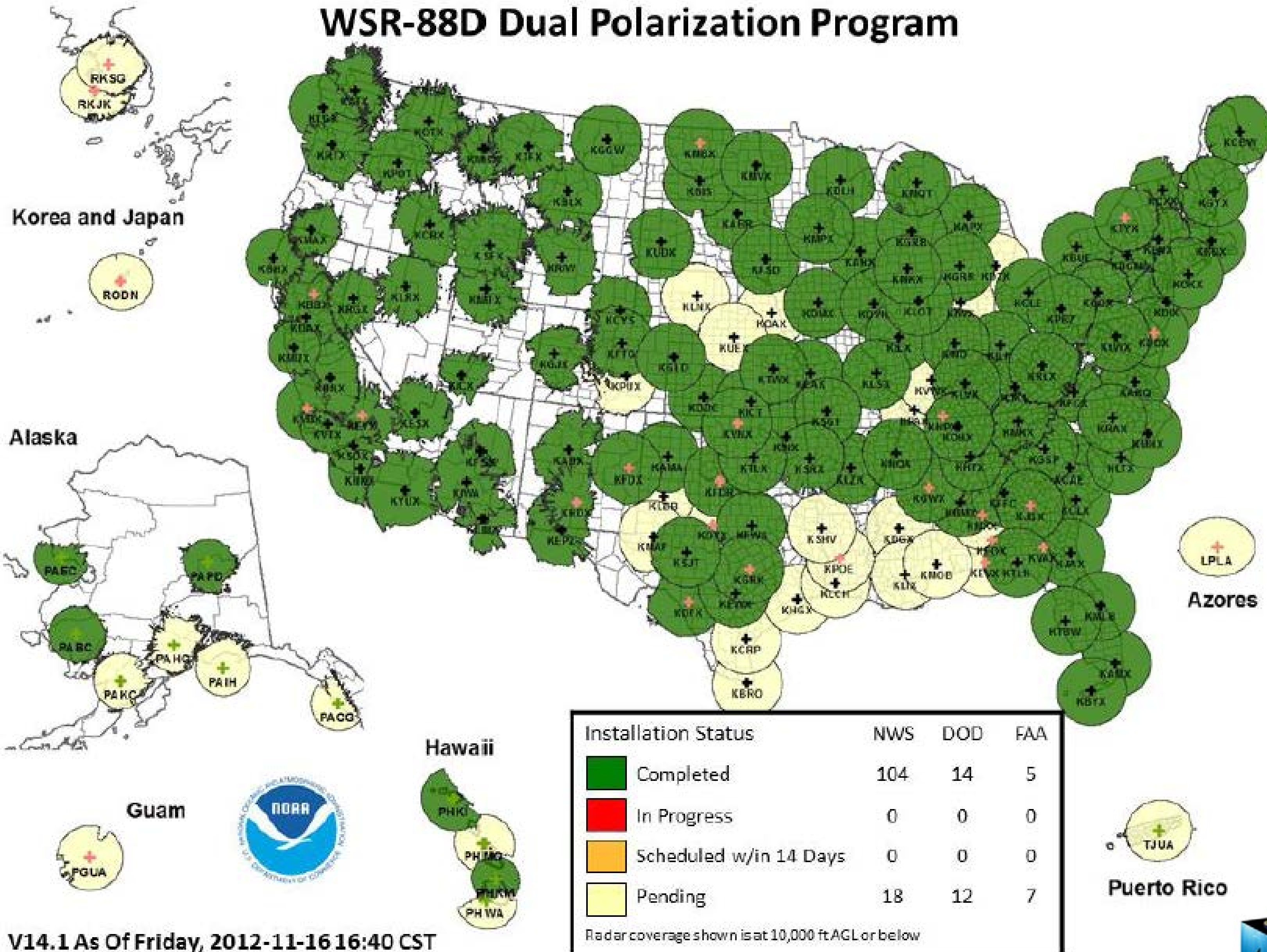
Boulder CO, 17-18, Dec 2012

US Operational WSR-88D Radar Network

- 160 radars (NWS, DoD and FAA)
- Vr, Z and spectrum width
- Dual-pol adds Z_{DR}, CC and K_{DP}



Dual-Pol Upgrade – 123 radars completed



(Source: Radar Operations Center – ROC)

Scanning Modes/ Data Volume

- Clear air mode: 5 elevations (0.5-4.5°) /10 min
- Precipitation modes: 14 elevations (0.5-19.5°) /5 mins
- Maximum data volume: Z 250m in range up to 460 km, Vr 250 m in range up to 300 km, 0.5° in azimuth, up to 14 elevations, 1 volume scan/5 min → 30 million observations/5 min for Vr and Z/radar.
- Adding spectrum width, Zdr, CC, Kdp → 90 million obs/5 min/radar.
- 160 radars → 14 billion observations/5 min!
- 4 TB of data with 4:1 compression
- The above is the worst case scenario – in reality, most radars run in clear air mode, and compression can be higher – 1 order of magnitude less.

Data Processing for Assimilation

- Data processing approaches:
  - Map the data from radar coordinates to model grid points (e.g., ARPS 3DVAR)
  - Map data in horizontal to model grid, but keep on elevations in the vertical (EnKF DA studies)
  - Keep data in radar coordinates (e.g., airborne radar)
  - Further thinning to below grid resolution
- QC critical, including velocity dealiasing.
- For large grids, parallel processing required.

Remapping/Data Thinning

- Least square fitting on elevations for horizontal interpolation (88d2arps at in ARPS)
- Cressman interpolation (VDRAS, etc.)
- Data selection based on variances (PSU?)
- Data every a few grid intervals

Main Methods of Radar Data Assimilation

- 3D variational (3DVAR) method
- 4D variational (4DVAR) method
- Ensemble Kalman filter (EnKF) methods
- Ensemble/Var hybrid methods
- Semi-empirical methods, e.g., complex cloud analysis
- Multi-step retrieval/analysis methods, e.g., Single-Doppler Velocity Retrieval (SDVR), thermodynamic retrieval techniques

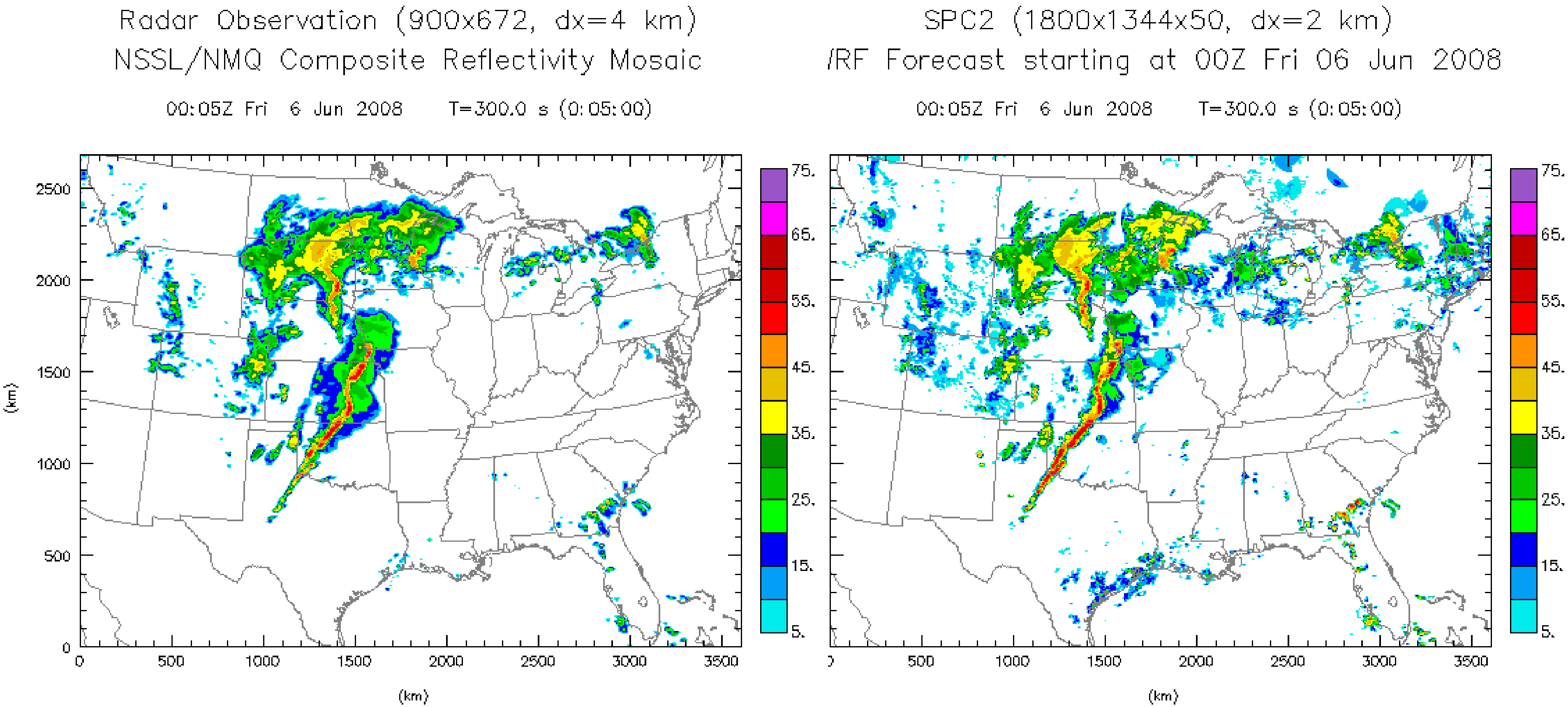
Realtime Radar DA as Part of the CAPS Storm-Scale Ensemble Forecasting (SSEF) for NOAA Hazardous Weather Test

- CAPS has been assimilating Level-2 Vr and Z data from all WSR-88D radars into CONUS 1-4 km models using ARPS 3DVAR/Cloud analysis in realtime for HWT Spring Experiments since 2008.

- The perturbed 3DVAR analyses were used to initialize up to 50 members of multi-model (4 models), multi-physics, multi-IC/LBC, storm-scale ensemble forecasts (SSEF) on a 4 km CONUS grid

CAPS 2 km WRF-ARW forecast v.s. observations

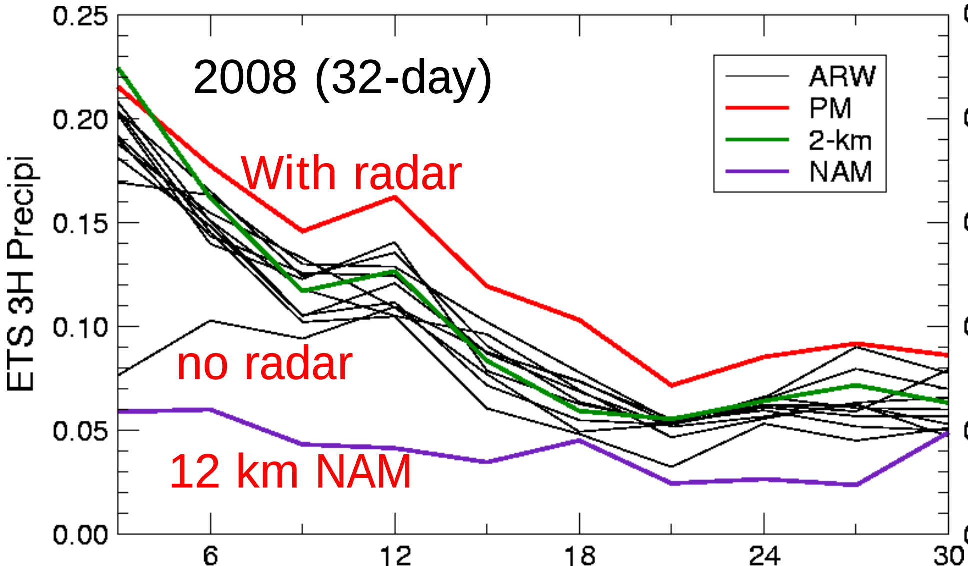
5 minute time intervals

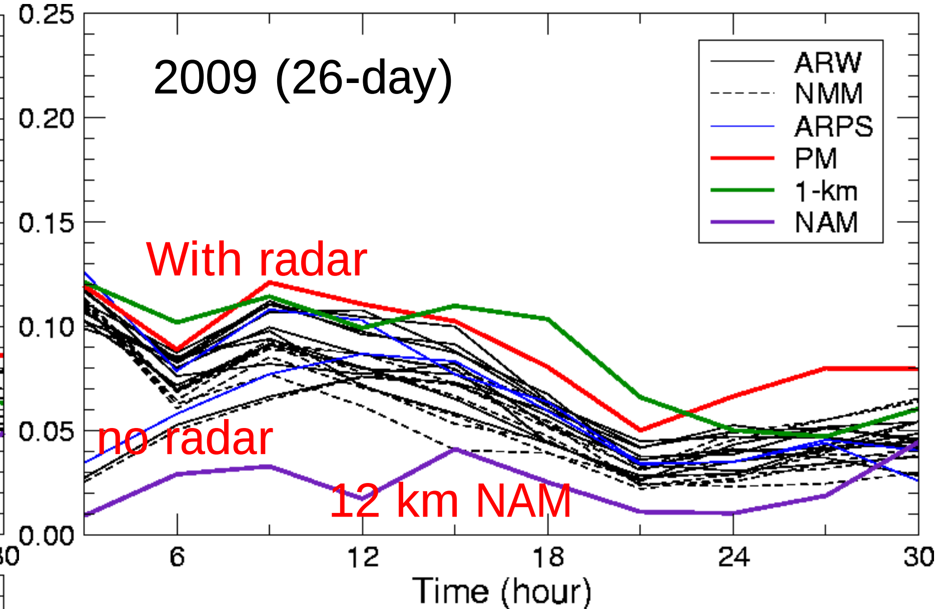


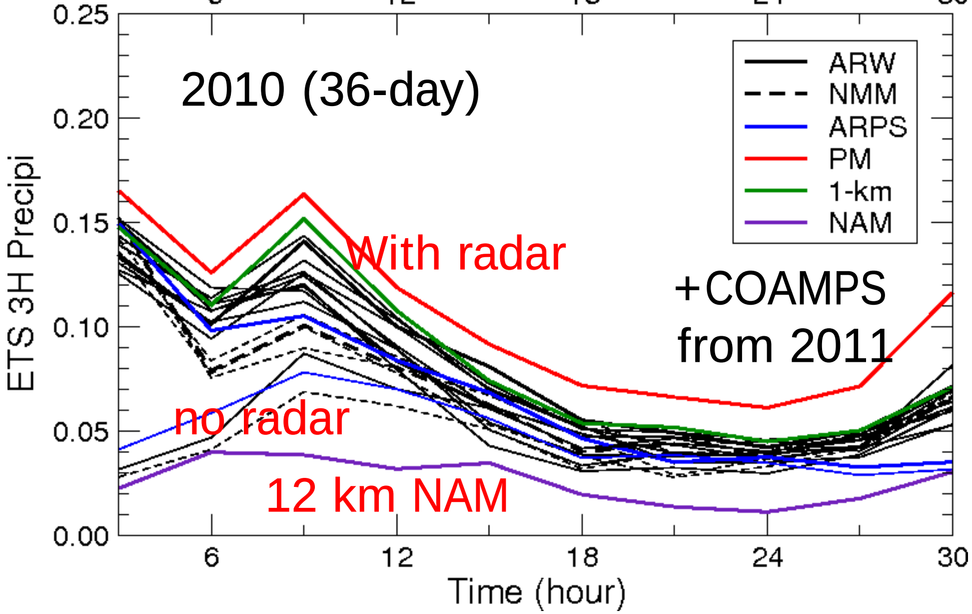
Initial condition with radar data

2008 – first year to assimilate radar data

Euitable Threat Scores for 3-hourly Precip. ≥ 0.5 in







Radar data impact lasts up to in 12 hours

All high-res models outperform 12km NAM

Probability-matched score generally better than any ensemble member

2 km score no-better than the best 4-km ensemble member – may be due to physics

1-km score better than any 4-km member and than the 4 km PM score in 2009.

WRF 4DVAR Radar DA

1. Radar reflectivity assimilation

   Assimilating retrieved rainwater from Z;

2. New control variables and background error covariance

   Cloud water (*qc*), rain water (*qr*);

3. Microphysics scheme

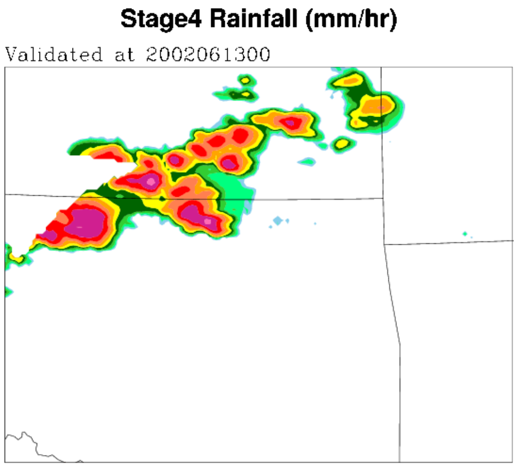
   Linear/adjoint of a Kessler warm-rain scheme

(Wang et al. 2012a,b)

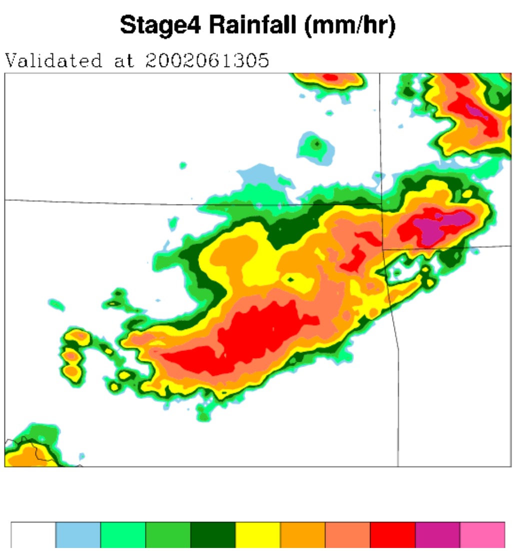
Courtney of Junny Sun of NCAR

Mid-west squall line (IHOP) experiments

0000 UTC



0600 UTC



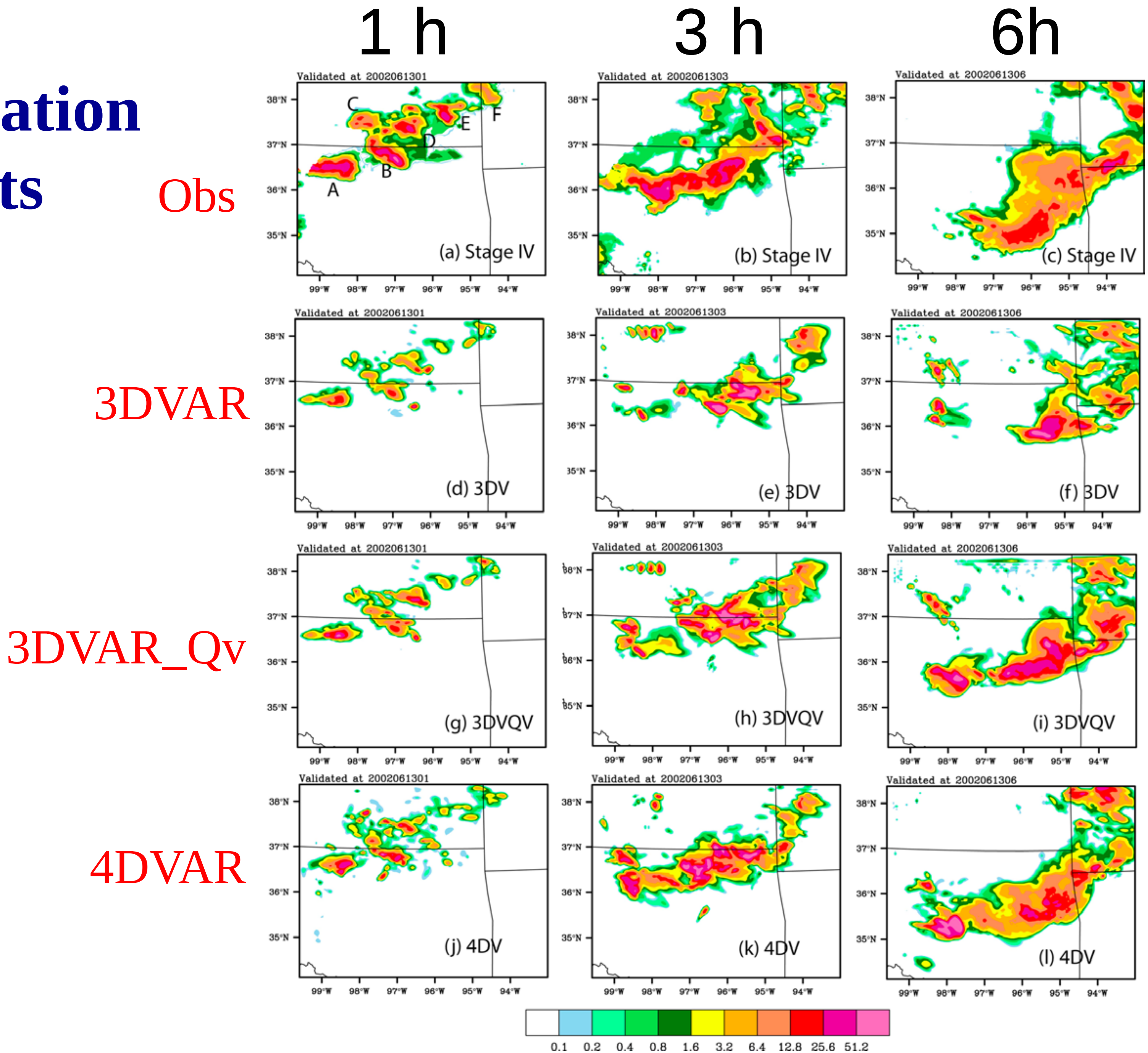
Compare 3 experiments:

3DVAR
Assimilate RV and RF from 6 radars at 0000 UTC with WRF 3DVAR

3DVAR_Qv
Same as 3DVAR, but also Assimilate derived in-cloud humidity

4DVAR
Assimilate RV and RF between 0000 UTC and 0030 UTC with WRF 4DVAR

Hourly Precipitation Forecasts



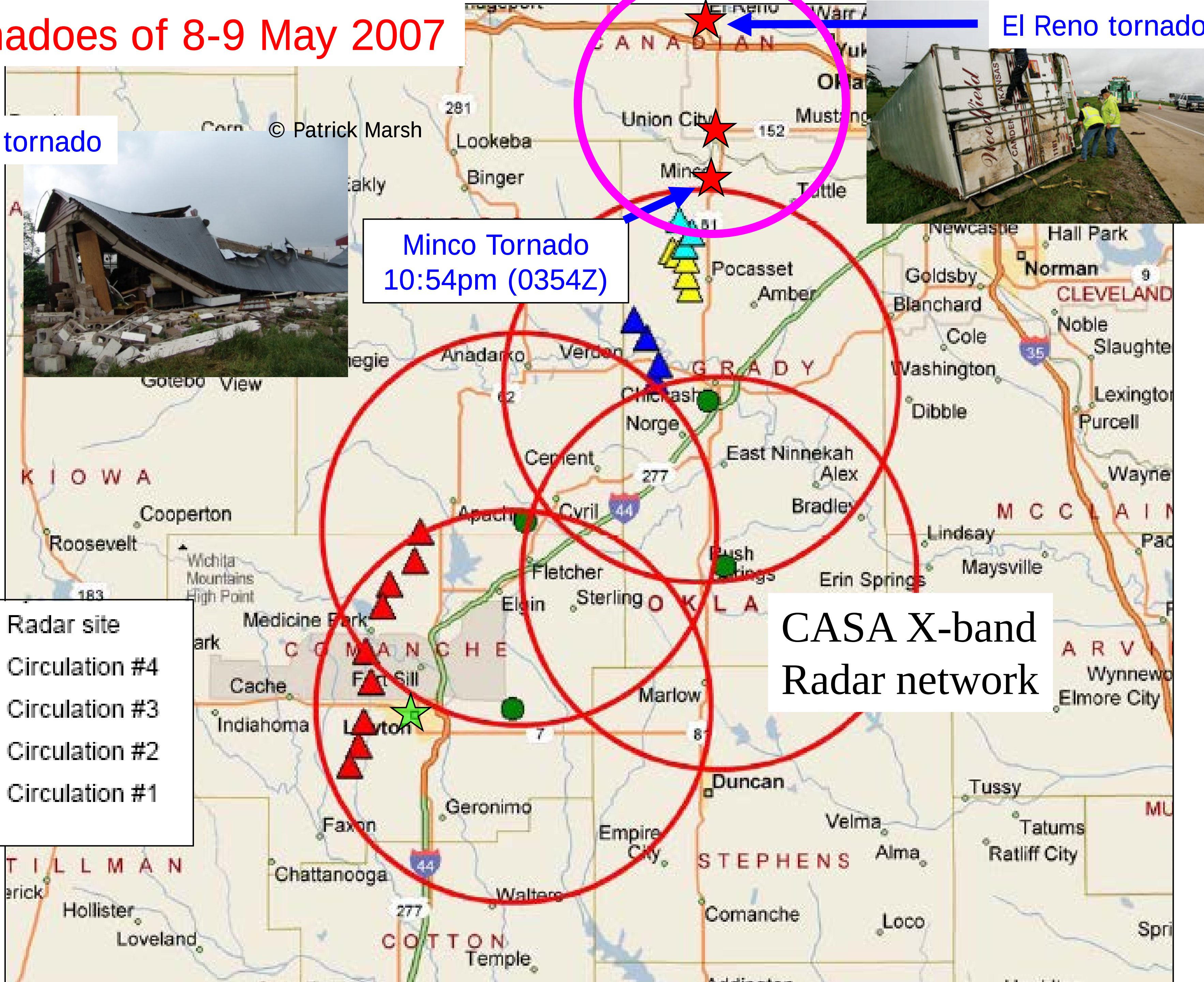
EnKF Radar DA Examples

A Mesoscale Convective System that Spawned Several Tornadoes in Oklahoma

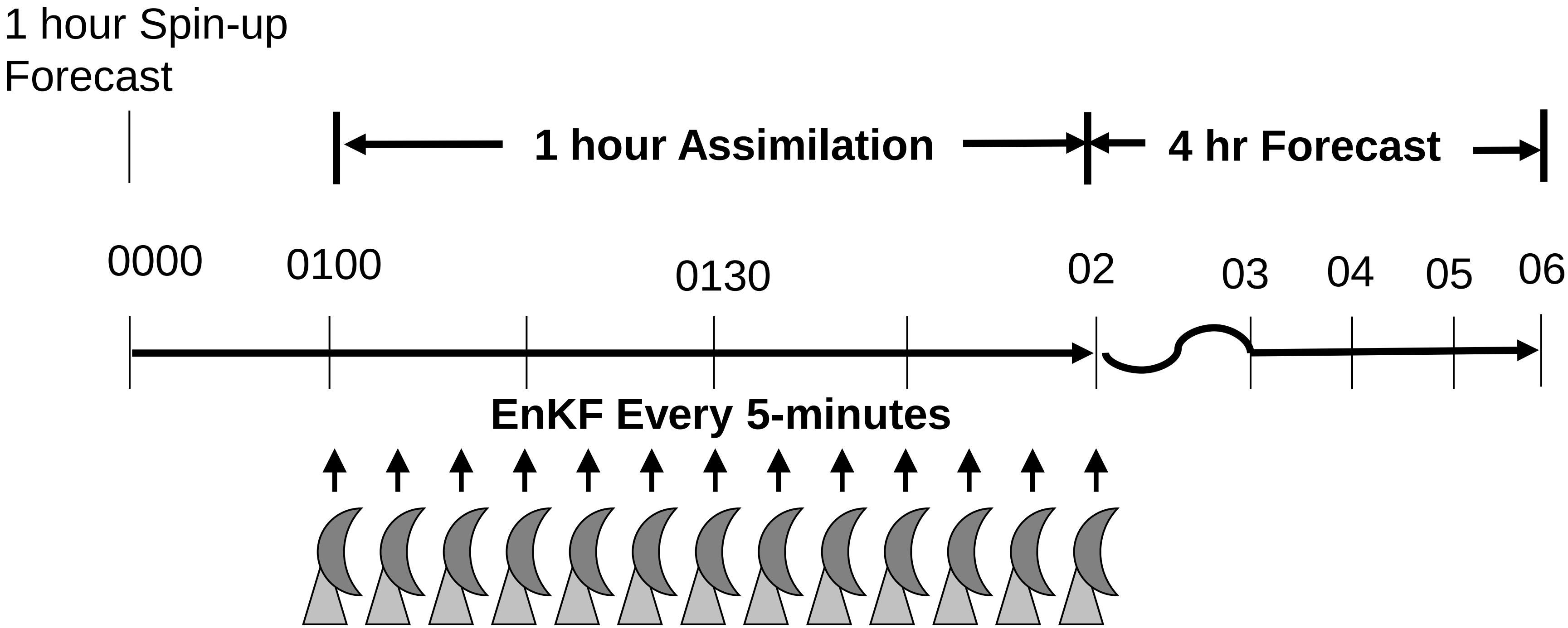
Tornadoes of 8-9 May 2007

Minco tornado

El Reno tornado

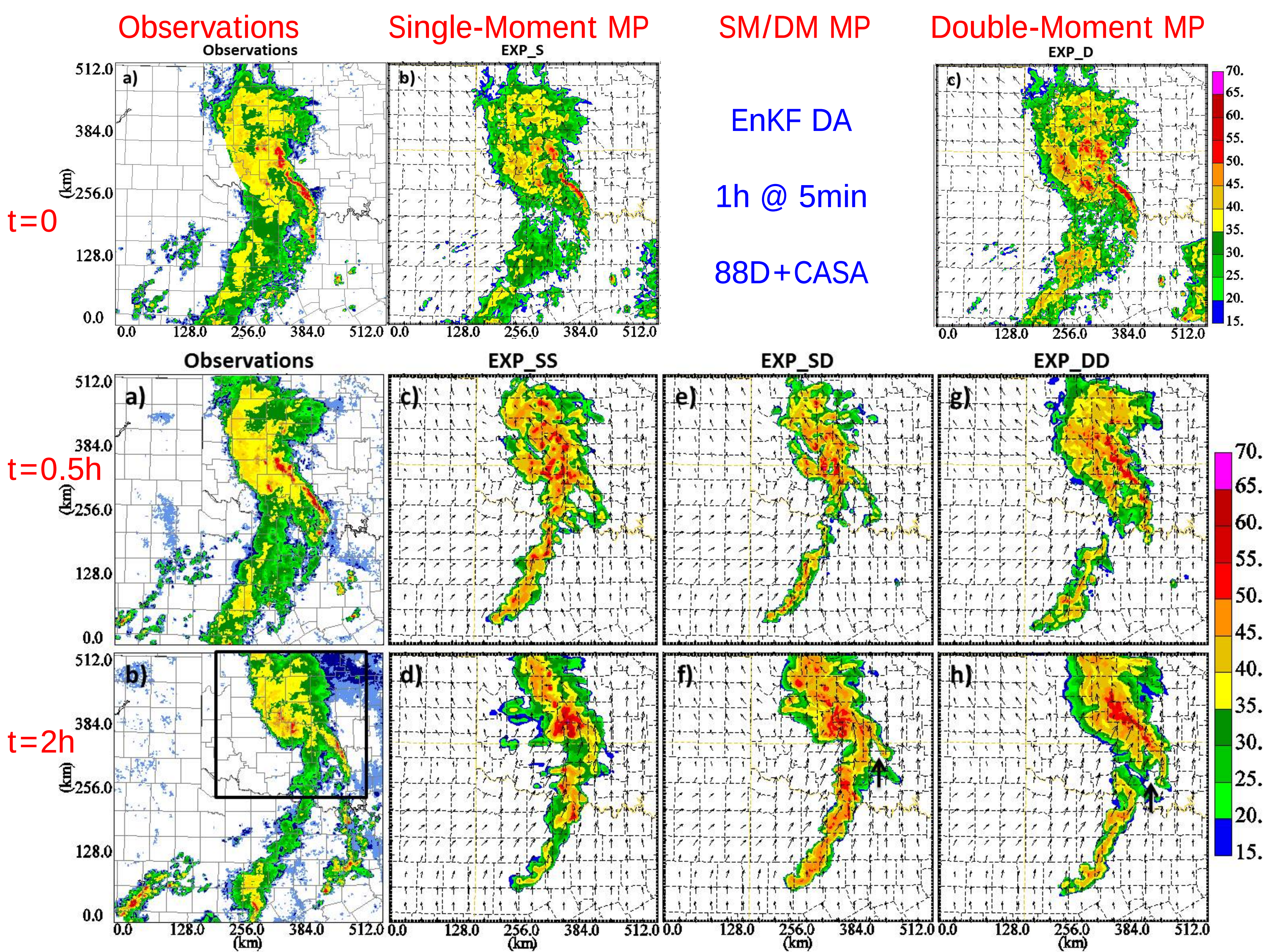


EnKF Data Assimilation Experiments



EnKF DA at 5-min intervals for 1 hour
at 2 km resolution

(Snook et al. 2011, 2012, Putnam et al. 2013)



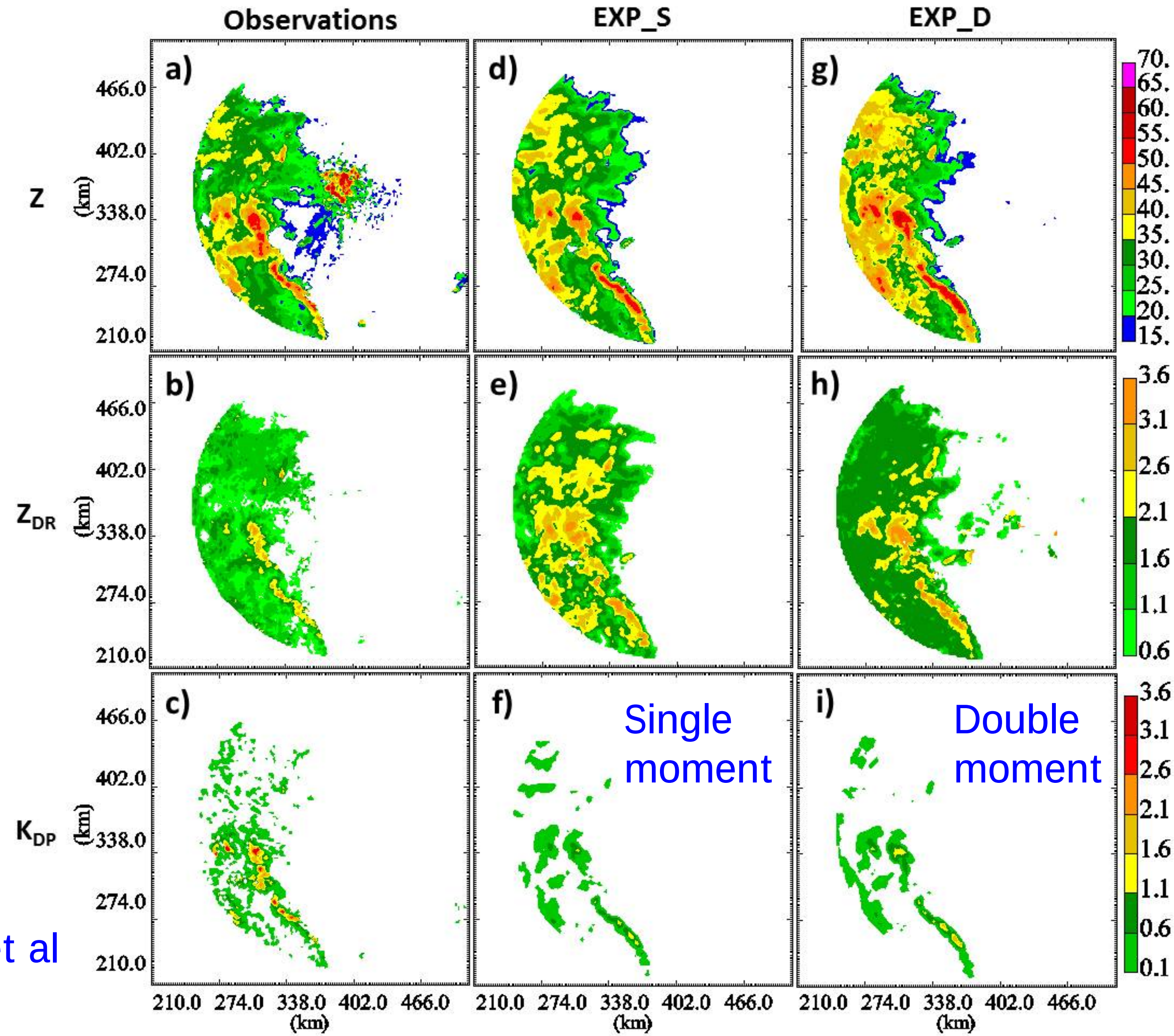
Observations
Single-Moment MP
SM/DM MP
Double-Moment MP
EXP_S
EXP_D
EnKF DA
1h @ 5min
88D+CASA
t=0
t=0.5h
t=2h
EXP_SS
EXP_SD
EXP_DD
(km)

EnKF Analysis of Dual-Pol Variables

Z

Z_{DR}

K_{DP}



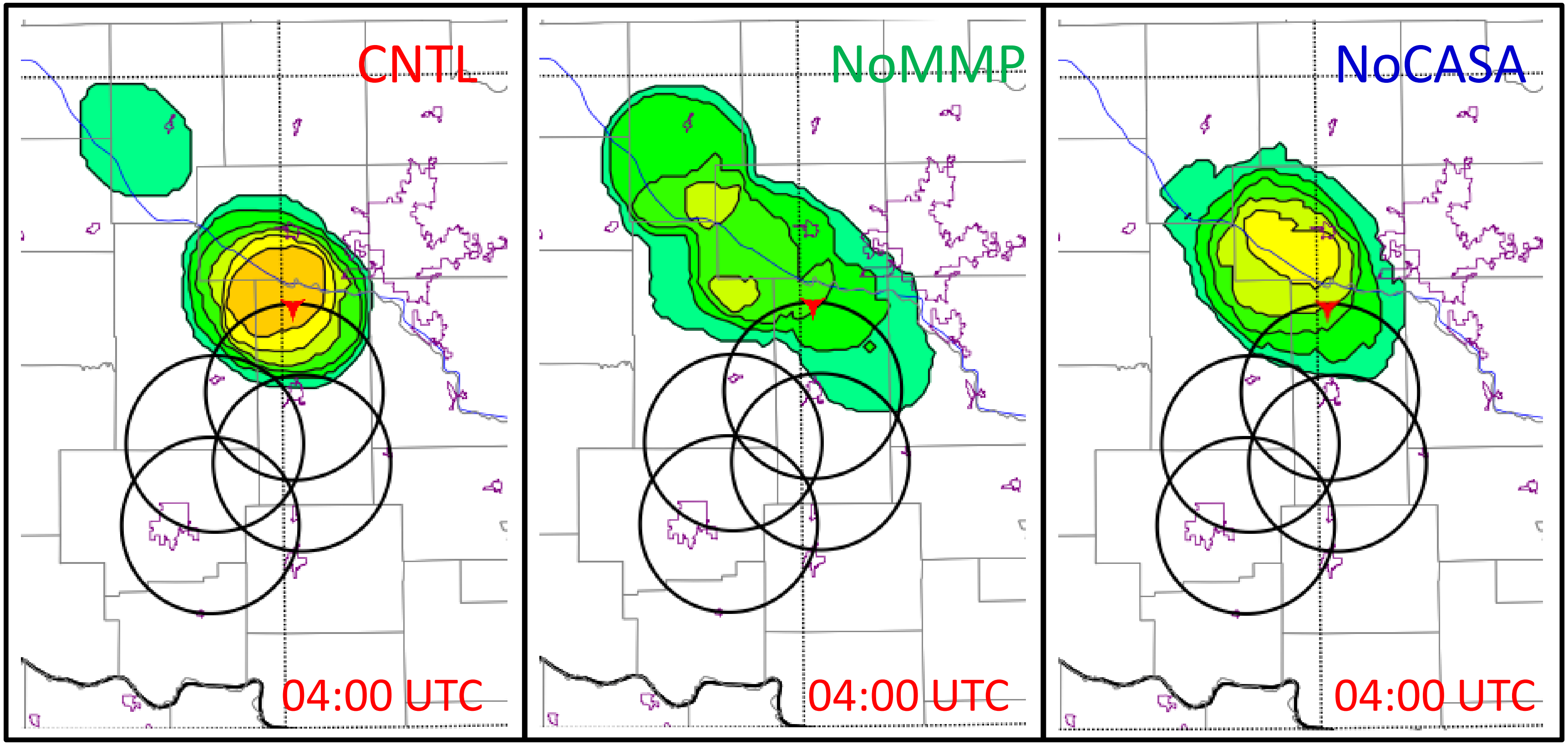
Single moment

Double moment

Putnam et al (2013)

Effects of Assimilating CASA data and Mixed-microphysics Ensemble

2h Probabilistic Forecasts of Near-surface Vortices



CNTL: 0.65 NoMMP: 0.35 NoCASA: 0.43

Snook et al (MWR 2012)

Parallel EnKF Algorithms

- Dense Radar data on large high-res domains require effective parallelization
- Radar DA has so far exclusively used serial EnSRF/EnAF algorithms
- LETKF easier to parallelize, but algorithm itself more expensive
- DART and GSI-based EnSRF parallelize on state vector level but still process one observation after another – hard to scale to high data volumes

EnSRF v.s. LETKF

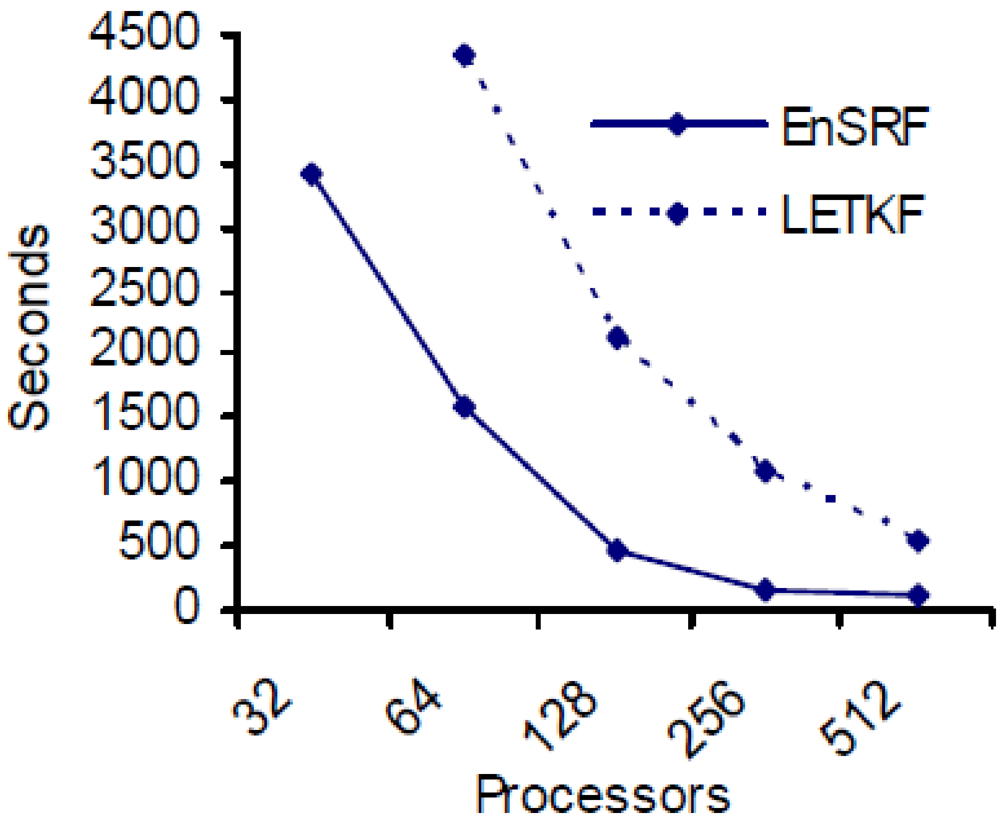
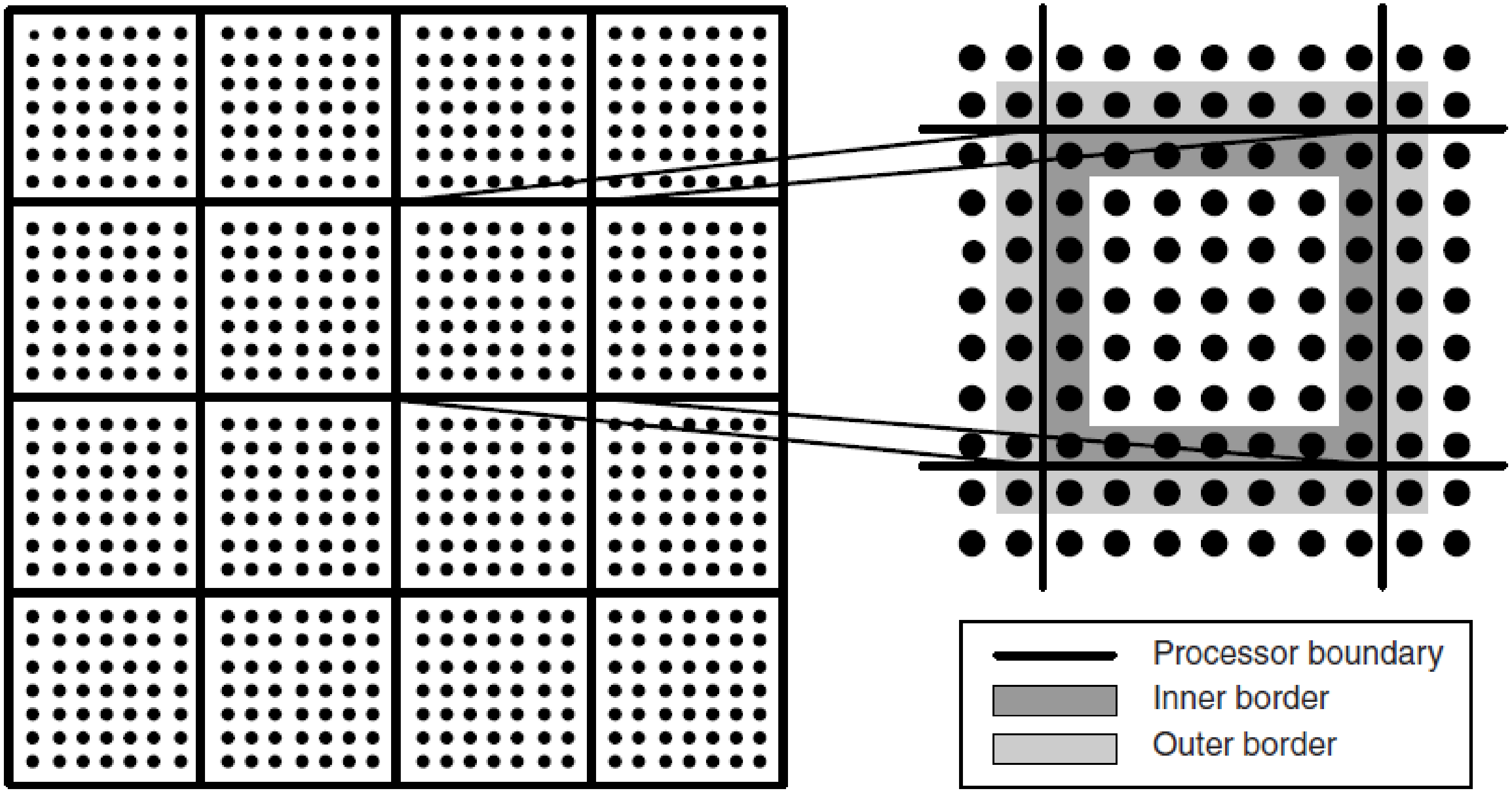


Fig. 5. Timing statistics of parallel EnSRF and LETKF algorithms for a global model test problem of moderate resolution (courtesy of Jeffrey Whitaker).

Domain Decomposition Strategy used by most models (WRF, ARPS, NAM, etc)



Parallel EnSRF algorithm suitable for dense radar data via domain decomposition

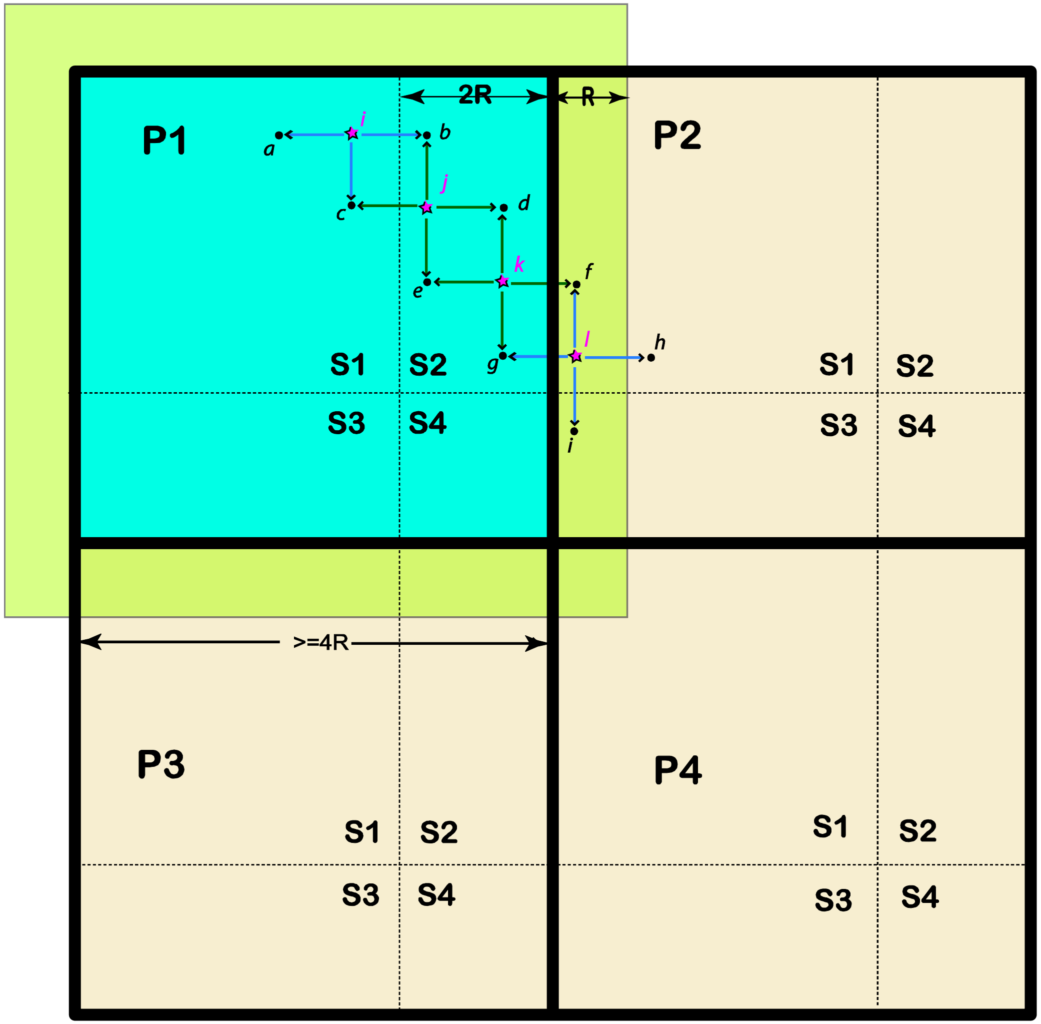
R is maximum localization radius

Grid is decomposed into sub-domains, each domain is assigned to a shared-memory node

Each sub-domain is further divided into S1-S4 sub-patches

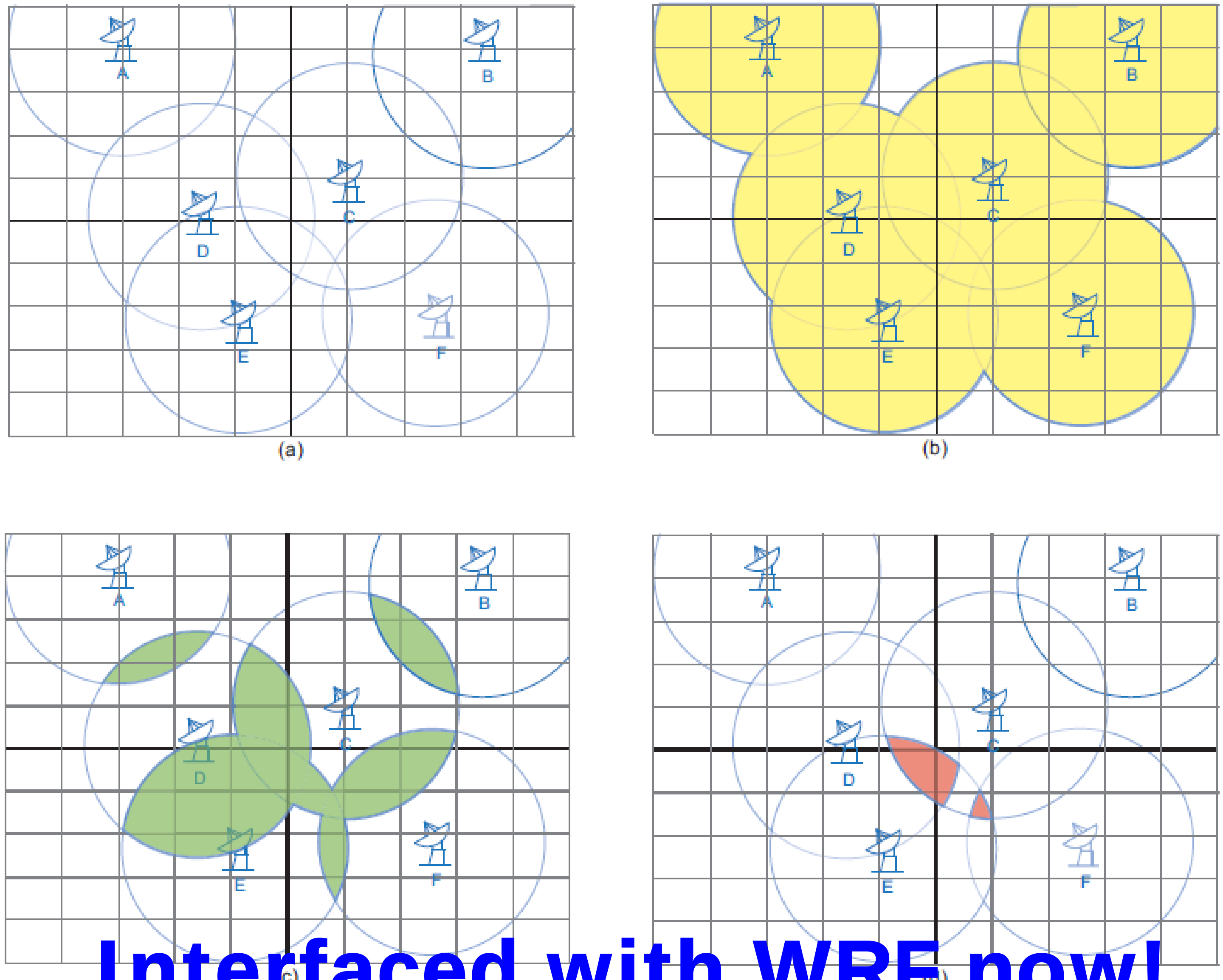
Sub-patches with the same label must be at least 2R apart so that obs within them don't affect common grid points and can be processed simultaneous

Loop through S1-S4 to complete obs assimilation



OpenMP/MPI hybrid Parallel EnKF Algorithm (Wang et al. 2013 JTech)

NSF PetaApps Support

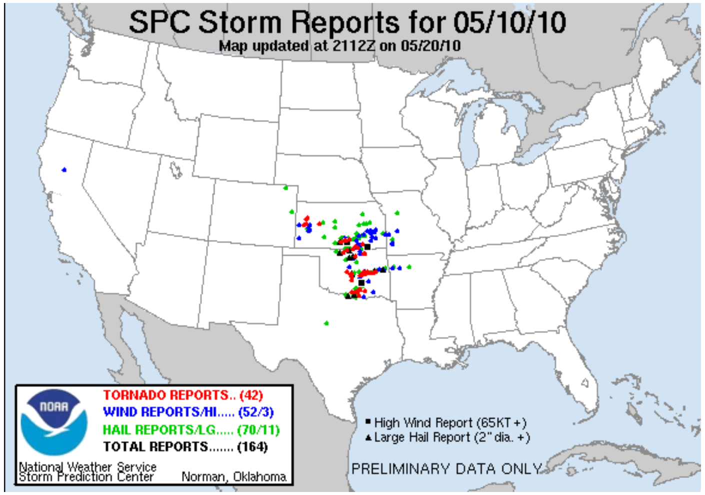


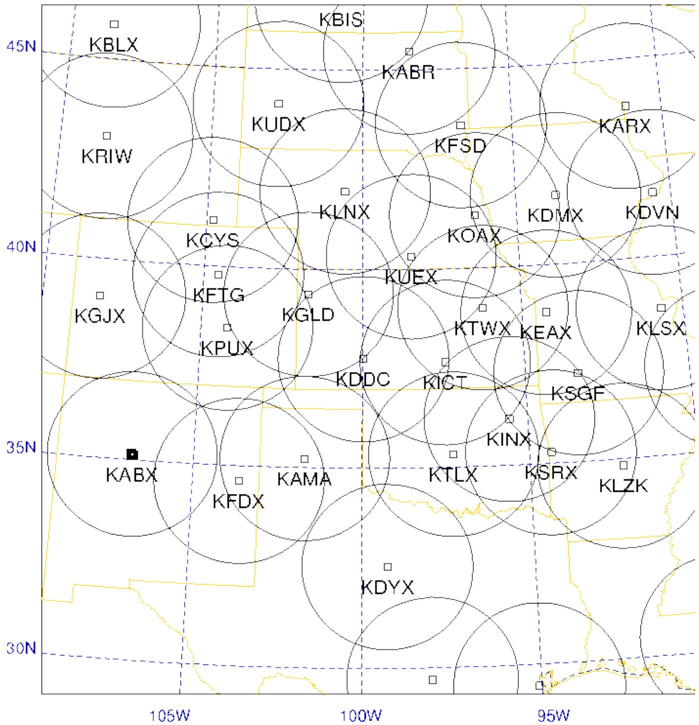
Interfaced with WRF now!

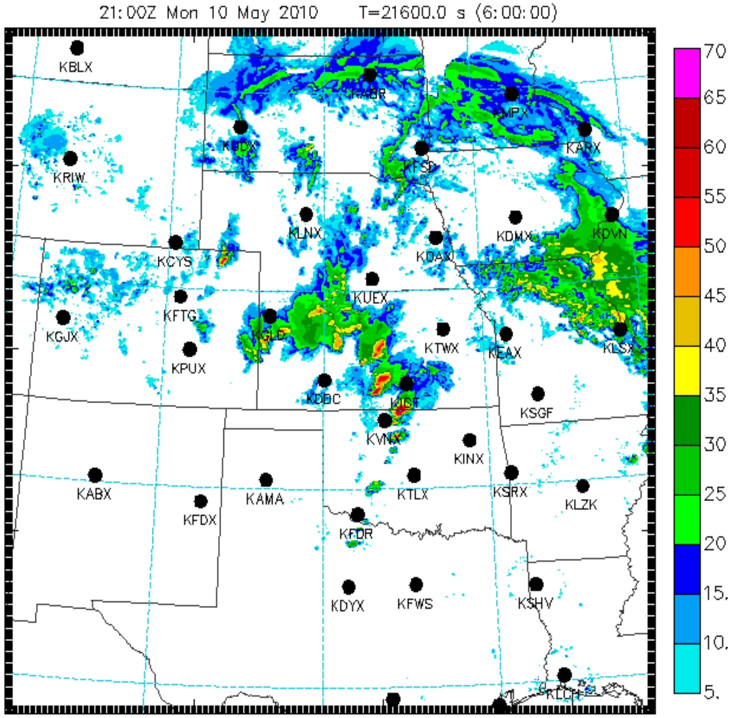
Data on elevations organized into batches, each batch contain no overlapping

EnKF Analysis of Many Radars

10 May 2010 OK-KS tornado outbreak







443x483x53 grid

1760 x 1920 km

~40 radars:

Vr and Z

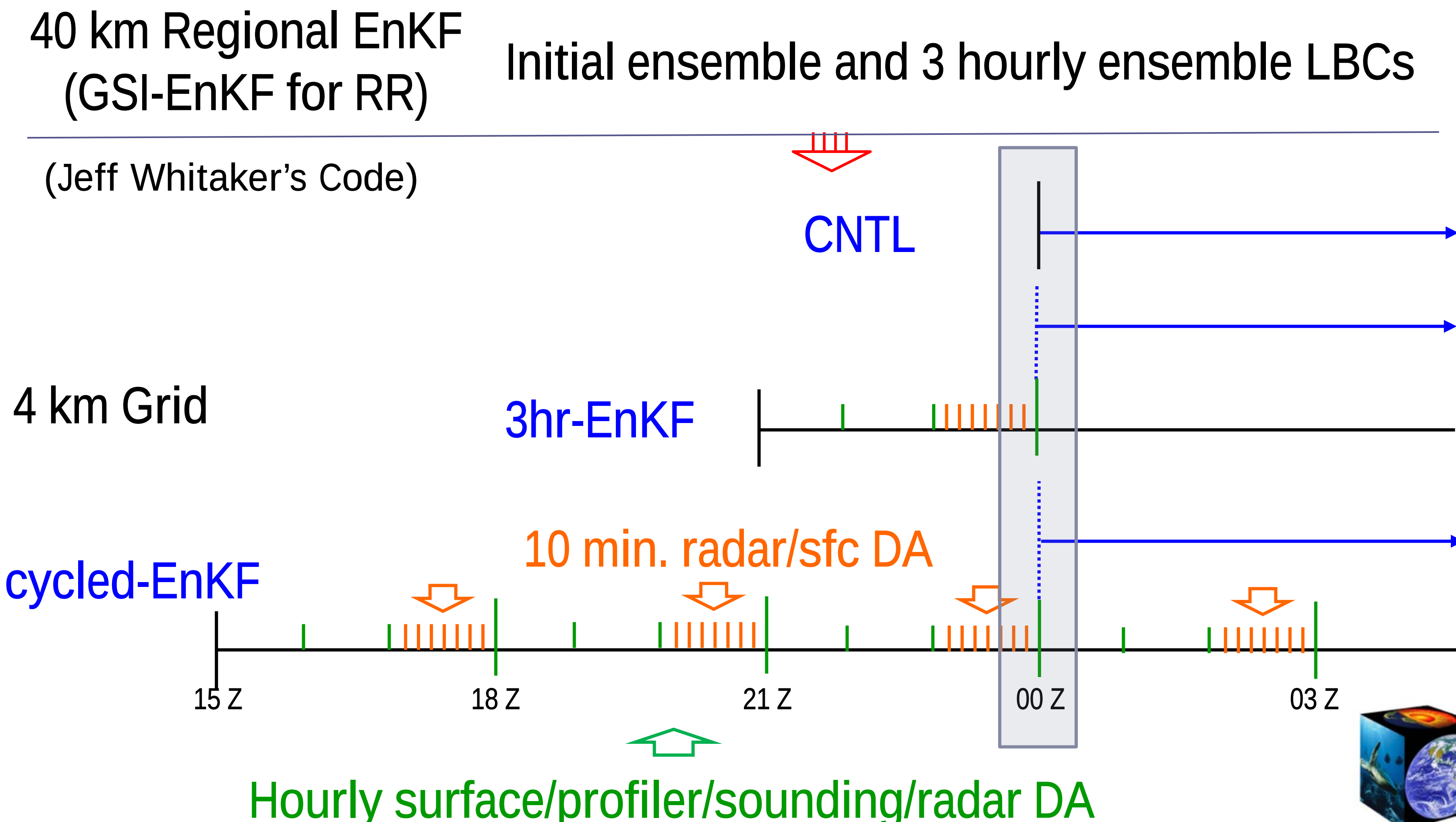
Surface obs,

Soundings

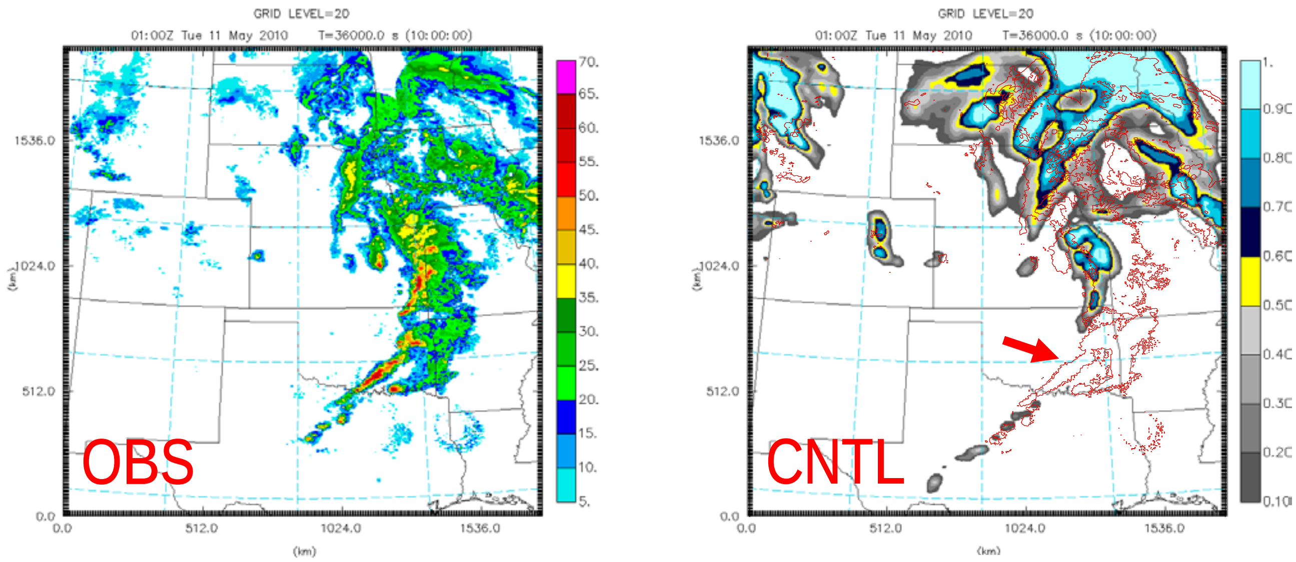
Profilers

Parallel multi-scale EnKF Algorithm (Wang et al. 2012)

Ensemble forecasts initialized at 0000 UTC

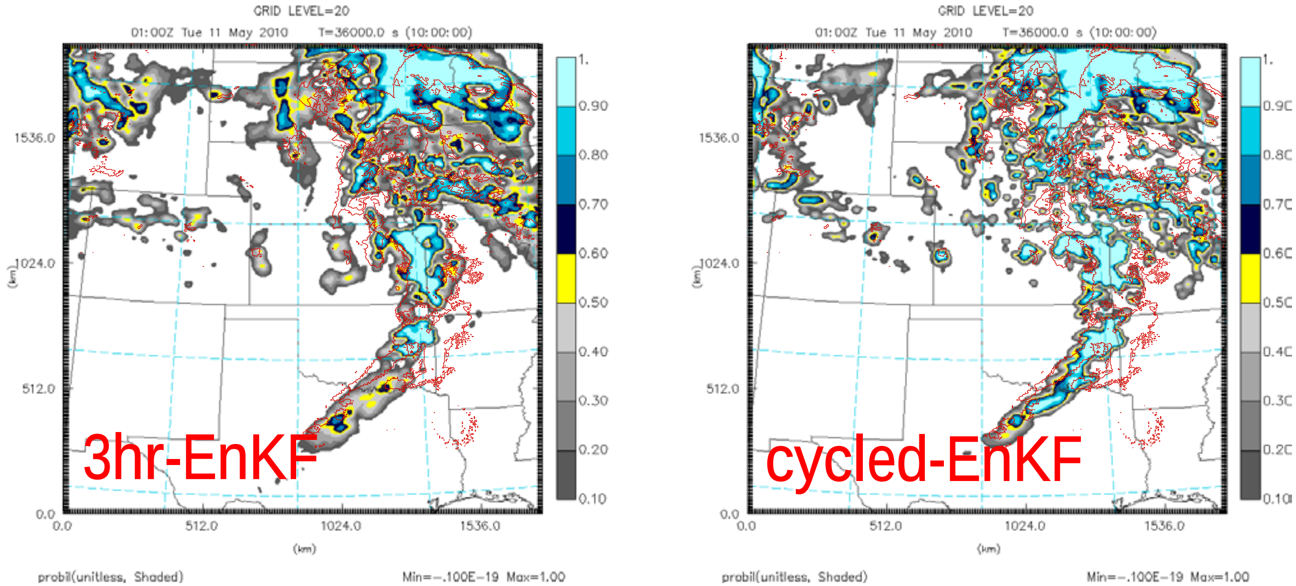


Probabilistic forecast (valid at 0100 UTC, 1h)

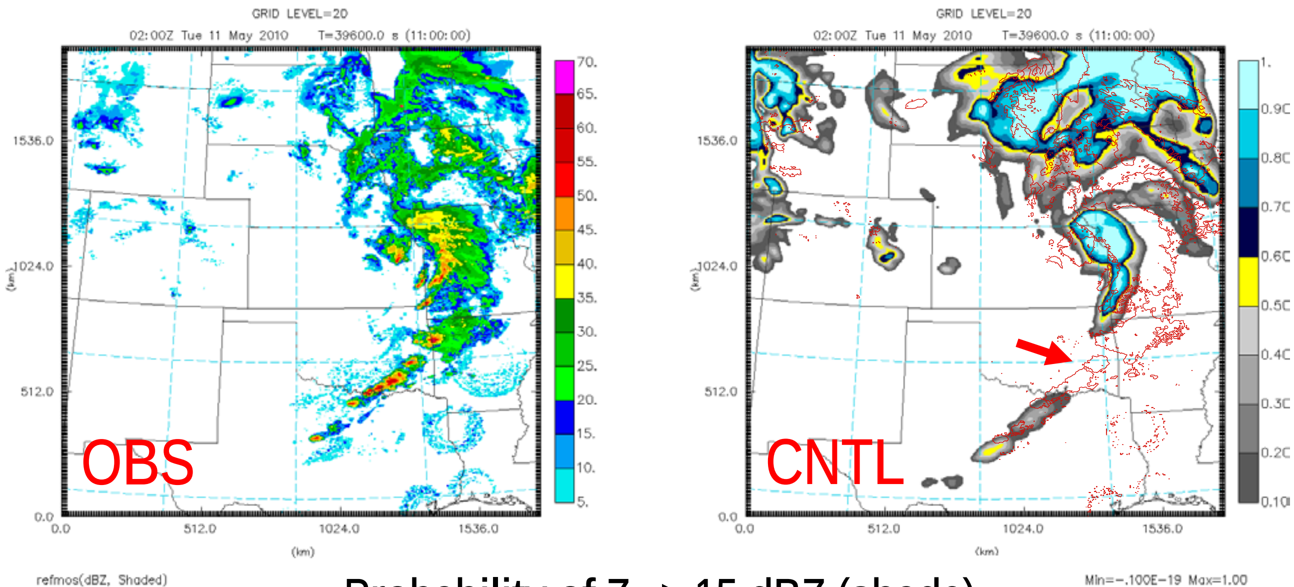


Probability of Z_H > 15 dBZ (shade)

Observed Z = 15 dBZ contours

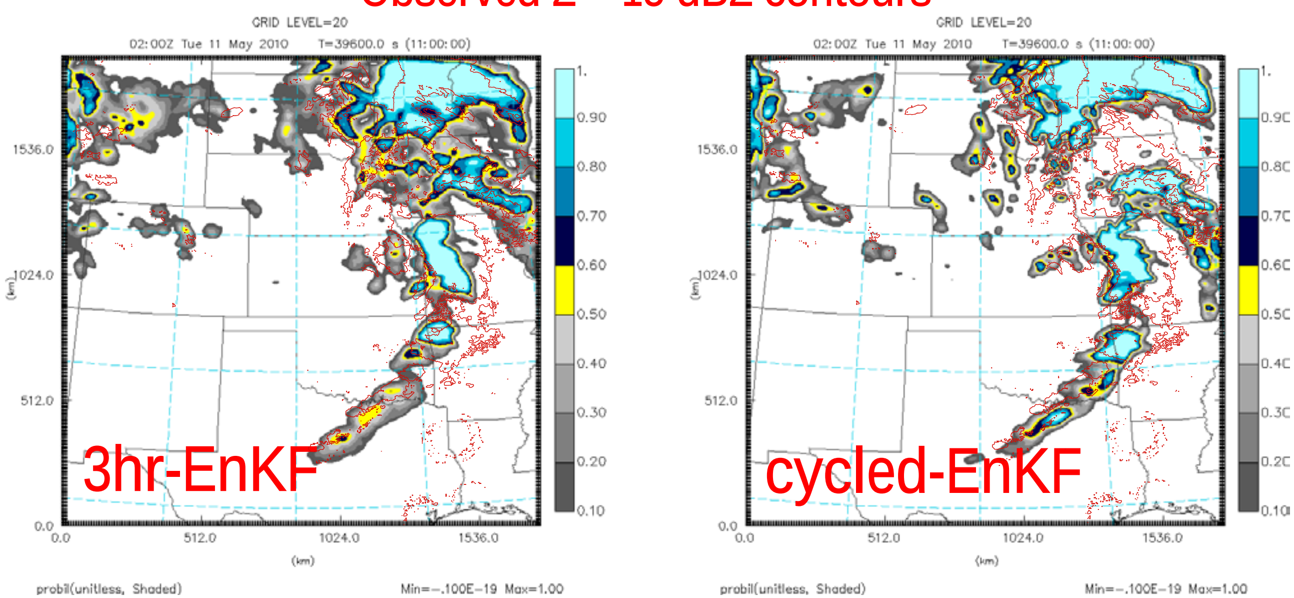


Probabilistic forecast (valid at 0200 UTC, 2h)

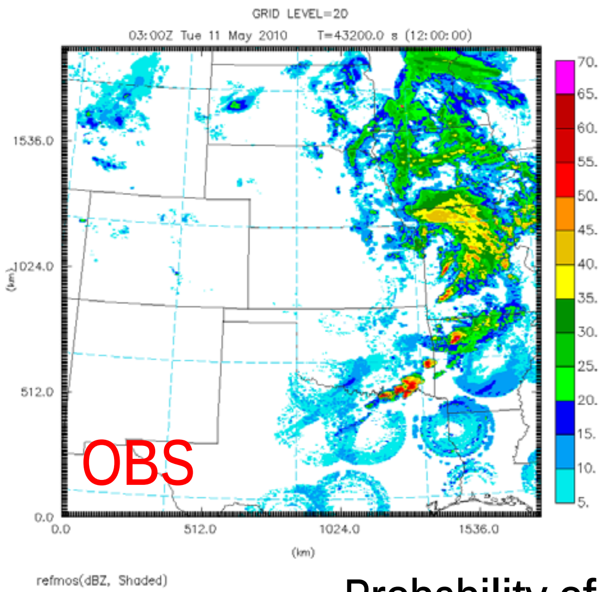


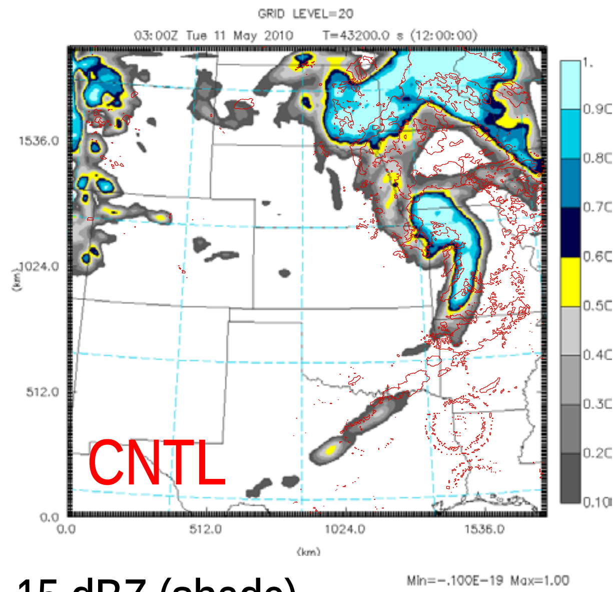
Probability of Z_H > 15 dBZ (shade)

Observed Z = 15 dBZ contours



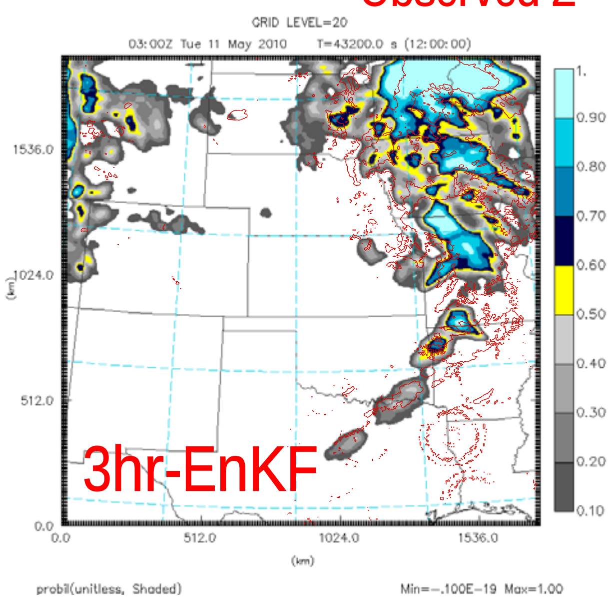
Probabilistic forecast (valid at 0300 UTC, 3h)

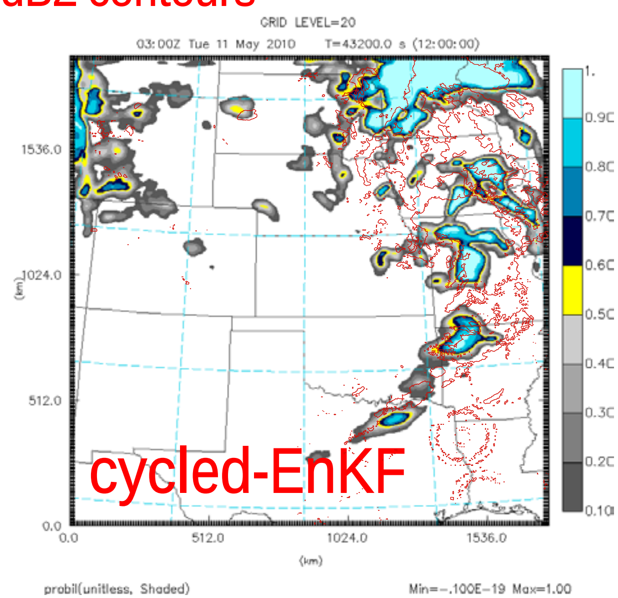




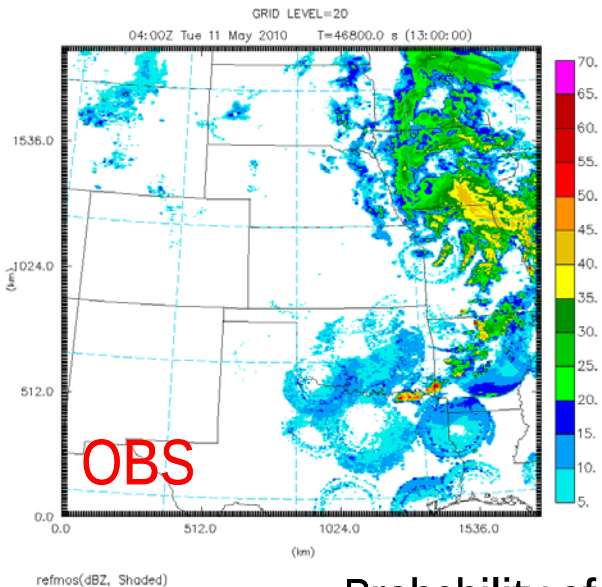
Probability of Z_H > 15 dBZ (shade)

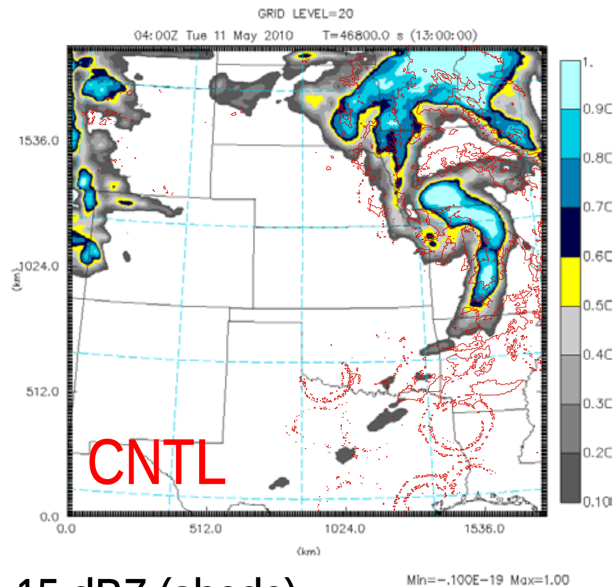
Observed Z = 15 dBZ contours





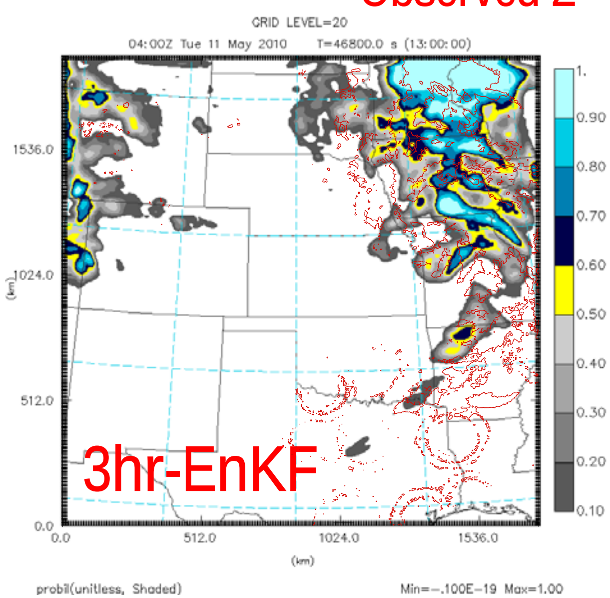
Probabilistic forecast (valid at 0400 UTC, 4h)

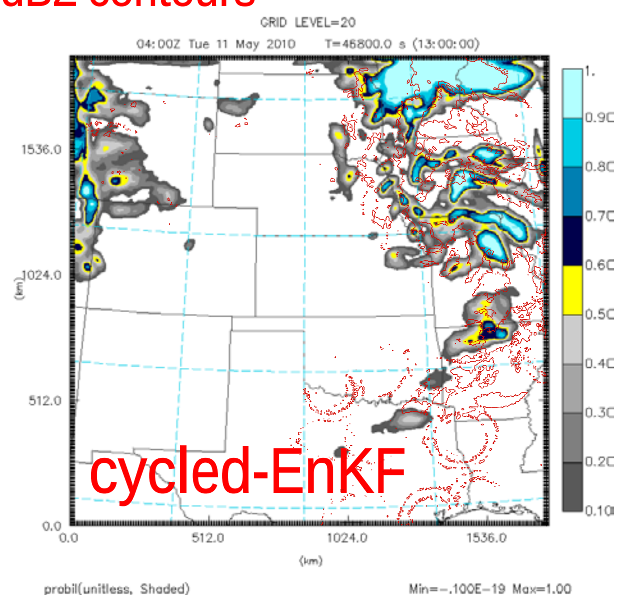




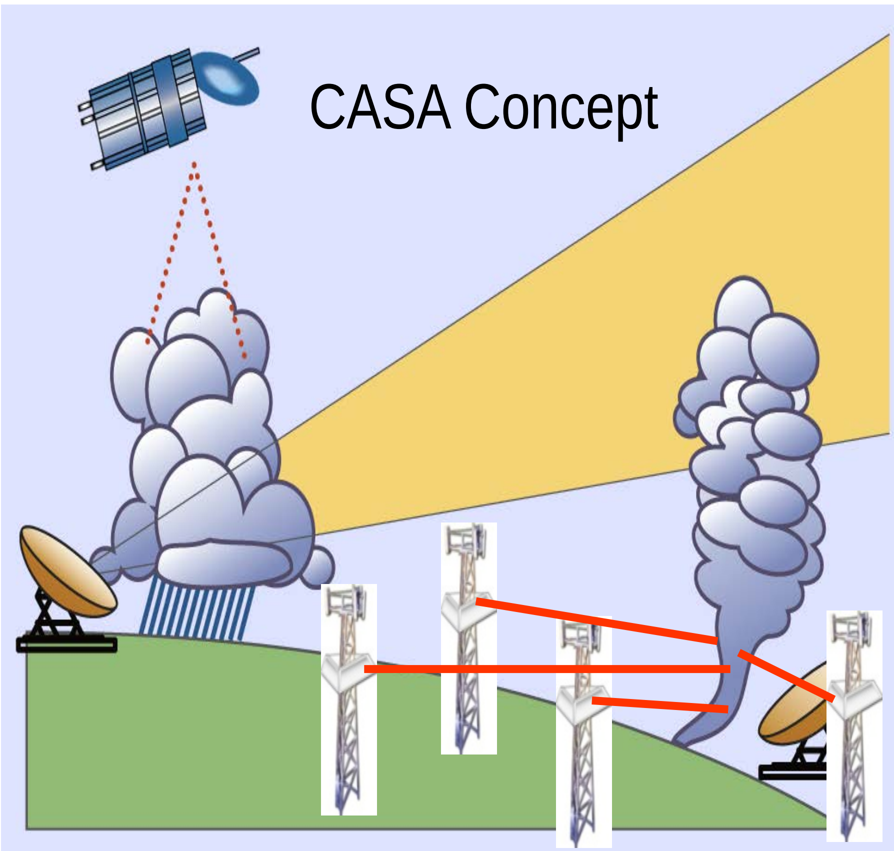
Probability of Z_H > 15 dBZ (shade)

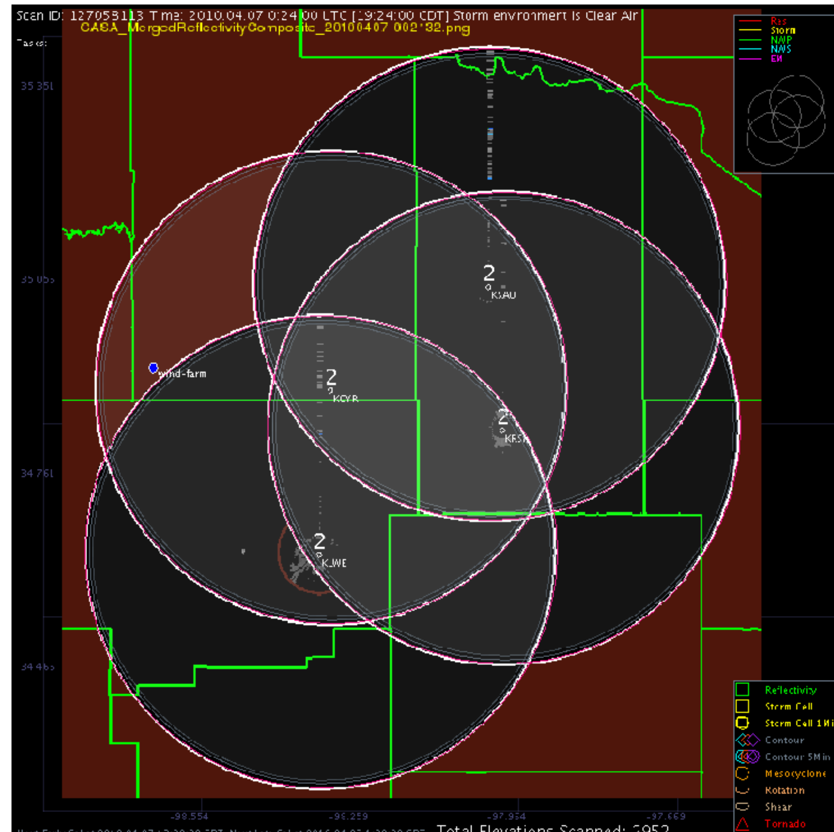
Observed Z = 15 dBZ contours



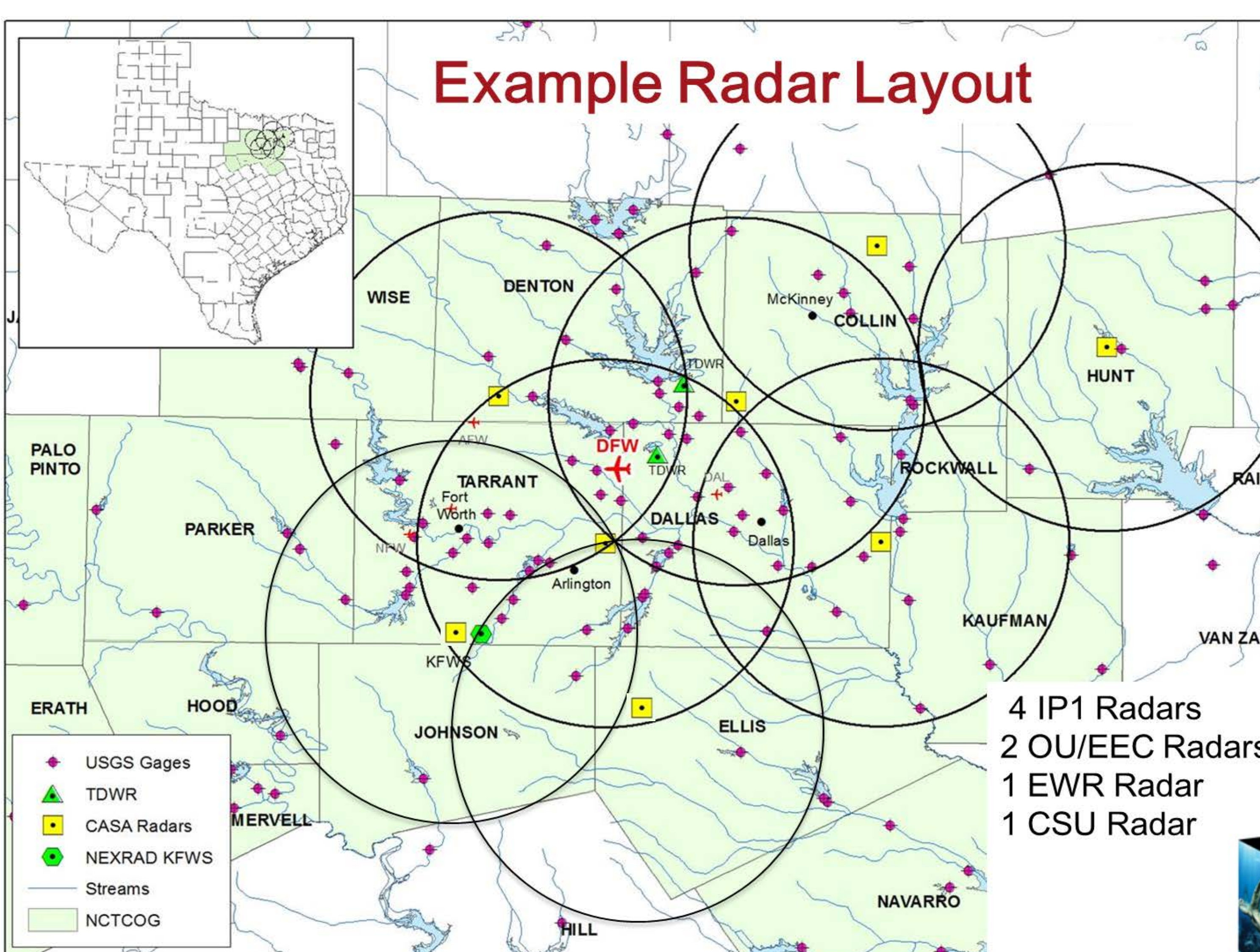


Future: Small, Dense, Inexpensive Radars to Fill Low-level Data Gaps and Scan Adaptively?





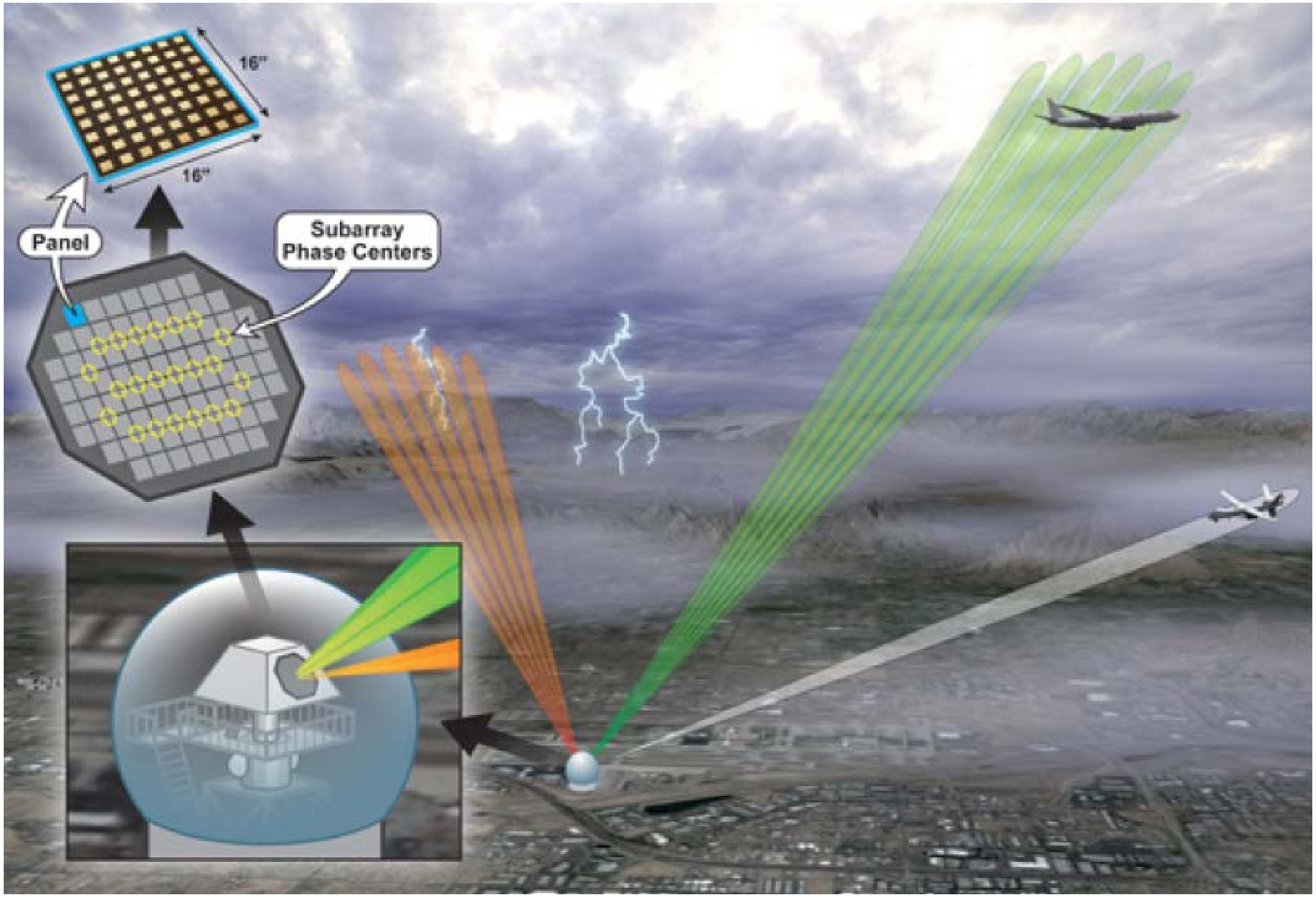
Regional Testbed Data (DFW, NoN Concept)



4 IP1 Radars
2 OU/EEC Radars
1 EWR Radar
1 CSU Radar

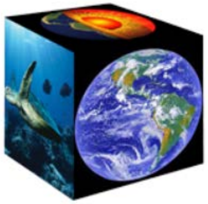
Future Radars and Forecasting Systems

- Volume scan down to ~1 min intervals → even higher data volume



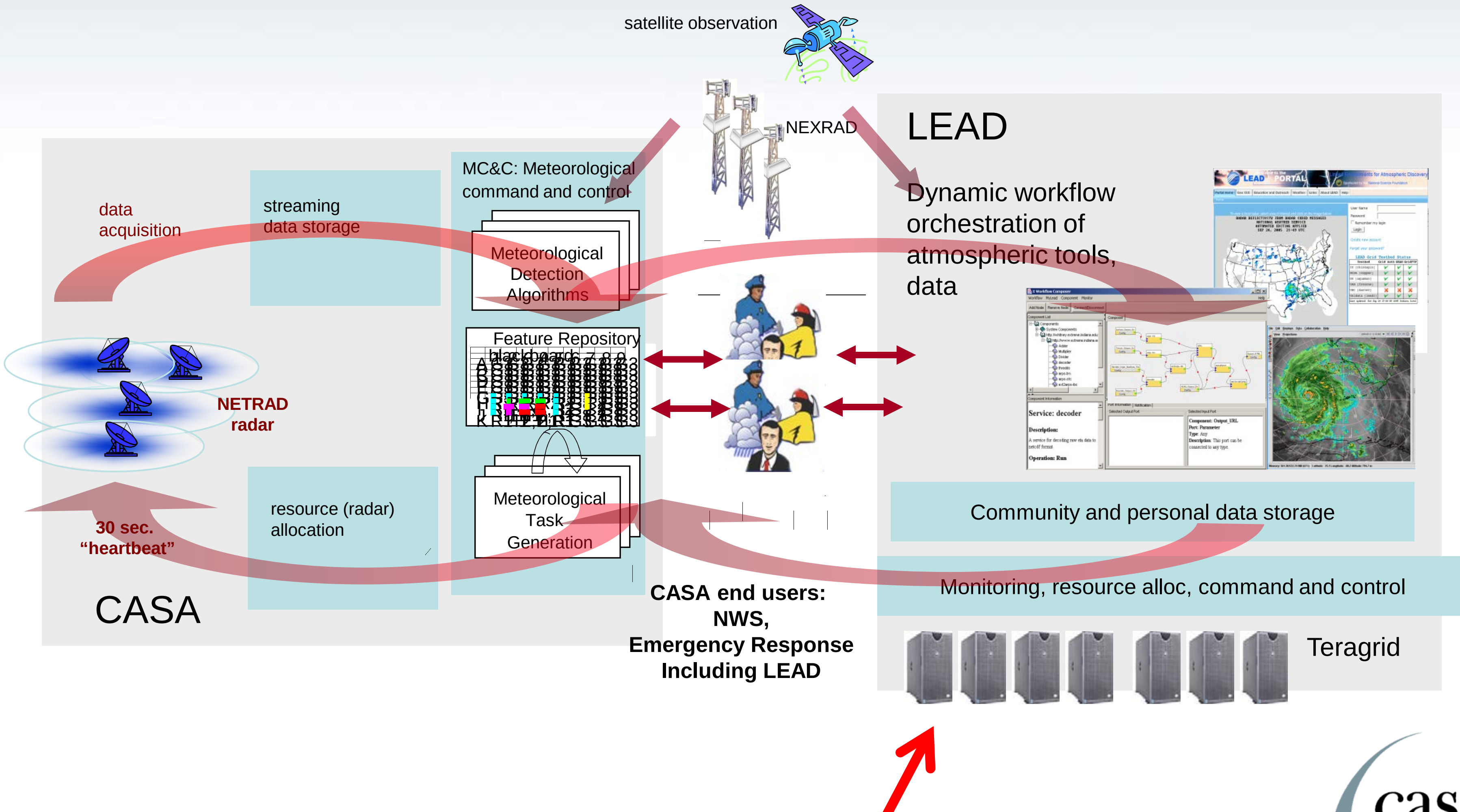
Convection-Resolving Ensemble DA and Forecasting

- Need to integrate radar with all other data sources (conventional, satellite, other remote sensing platforms) – multi-scale problem!
- Continuously cycled EnKF/Hybrid DA @ 5 min intervals @ 1-4 km grid spacing
- CONUS+ domain 1-4 km ensemble forecasts updated every hour (not ECMWF problem)
- Data ingest, processing, storage, distribution, analysis and visualization all very challenging, more so for fast severe weather.
- Many research questions – Fuqing gave a very good list.
  - QC, model error, multi-scale issues
- CAPS alone has produced several PB of data over the past 6 years – sitting inside mass storage systems – need something like Earthcube to liberate them!
- Need orders of magnitude more resources and infrastructures to achieve the above goals.



Real-time Targeted Observing & Modeling Systems

(CASA – LEAD Examples)



Lead: Linked Environment for Atmospheric Discovery

Thanks!