Doppler Radar Observations of Boundary Layer Winds over Houston and Dallas-Fort Worth in Support of TexAQS II

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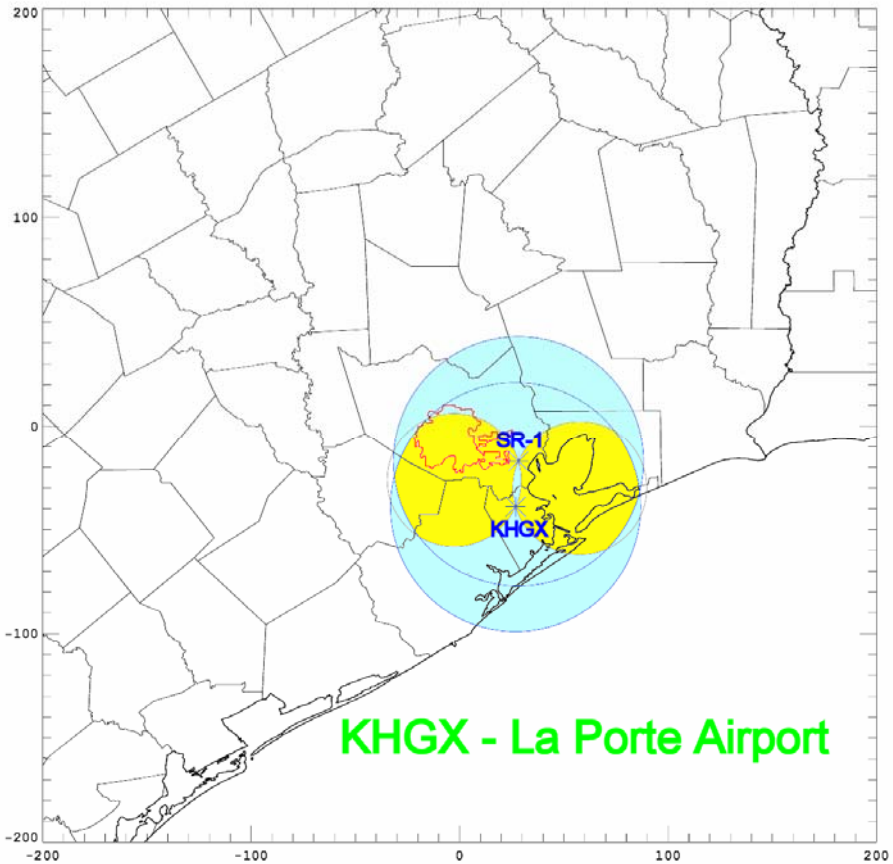
- Two (2) mobile self-contained scanning radars
- Truck mounted – flexible
- C-band (λ = 5.5 cm)
- Doppler capable
  - Sensitive to "clear-air" (i.e., non-precipitation) winds in the boundary layer
  - Flexible scanning
  - Doppler radial velocity (V_r), spectral width (σ), and radar reflectivity (Z)

SMART Radar

Shared Mobile Atmospheric Research & Teaching Radar



Houston-Galveston-Brazoria Deployment

SMART Radar #1 (SR1)

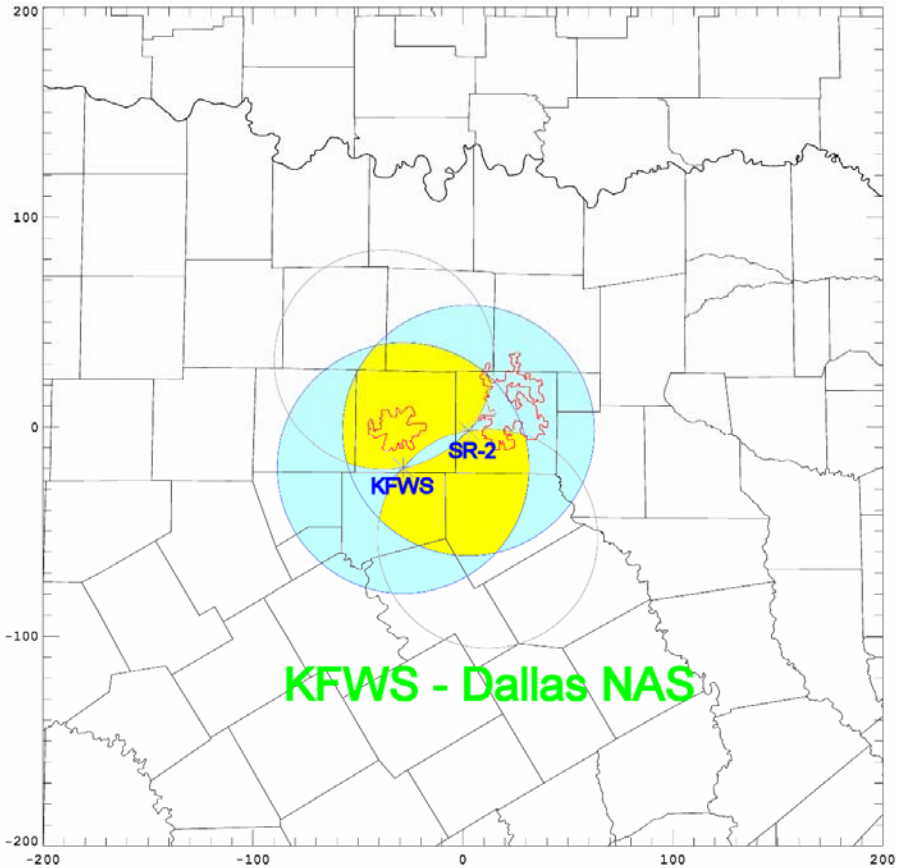
Boundary Layer Domain

(Range ≈ 60 km)

Dual-Doppler

(SR1 was 22 km north of KHGX radar)

Single-Doppler



Dallas-Fort Worth Deployment

SMART Radar #2 (SR2)

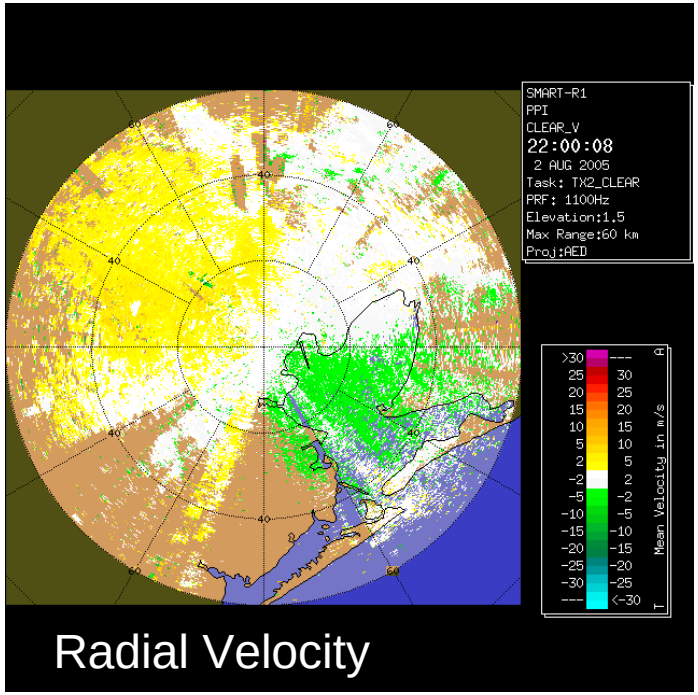
Boundary Layer Domain

(Range ≈ 60 km)

Dual-Doppler

(SR2 was 37 km northeast of KFWS radar)

Single-Doppler

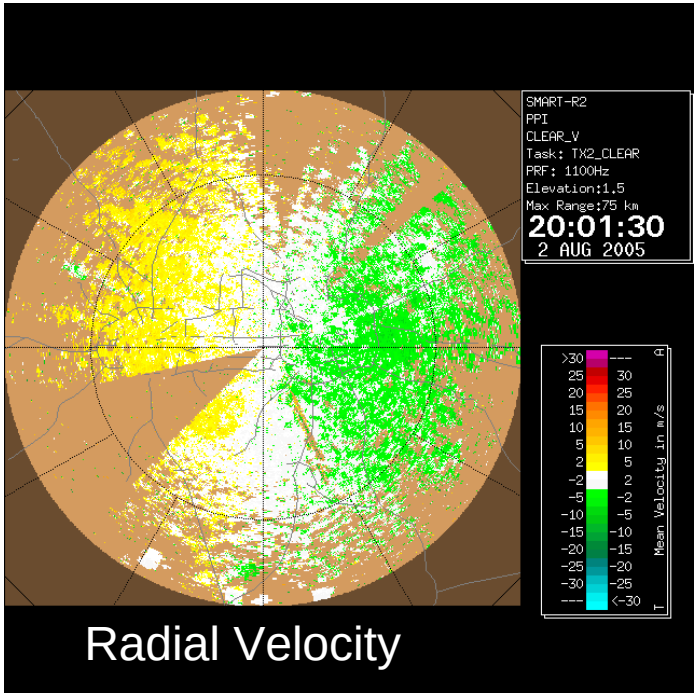


Period: July 11, 2005 – September 21, 2005

UP time: 94% (down time due to major/minor repairs, routine maintenance, land power conversion, DSL installation, re-fueling early on, radar shutdowns)

Doppler Radar Data ≈ 1,624 hours or 186 GBytes

Clear Air Signal Range: 40 – 60 km



Period: July 17, 2005 – September 22, 2005

UP Time: 97% (down time due to minor repairs, routine maintenance, re-fueling, radar shutdowns)

Doppler Radar Data ≈ 1,560 hours or 194 GBytes

Clear Air Signal Range: 40 – 75 km

Clear-Air Radar Observations: What are measured?

(Wilson et al. 1994)

- Clear-air echoes mixed Boundary layer primarily come from insects/birds are most commonly observed over land from spring to autumn. Doppler radar velocities measured the winds if the insects and birds are not migrating.
- Typical clear-air data for WSR-88D:
  - 0-3km, 50-100km radius, ev4-10min, 1 m s^{-1} error in |Vr|
- Typical clear-air data for SMART Radar:
  - 0-3km, 40-75km radius, ev3-10min, 1 m s-1 error in |Vr|

Background of the Current Study

- As part of the TEXAQS II air quality field campaign, one SMART radar (C-band) is deployed 22 km away from the KHGX WSR-88D radar (S-band) which collected data nearly continuously from July 11 to August 31, 2005

- Dual Doppler analysis is feasible with Vr observations from both radars

- A WRF-based EnKF to simulate clear-air observations from one or both radars

Dual-Doppler Radar Inferred Winds

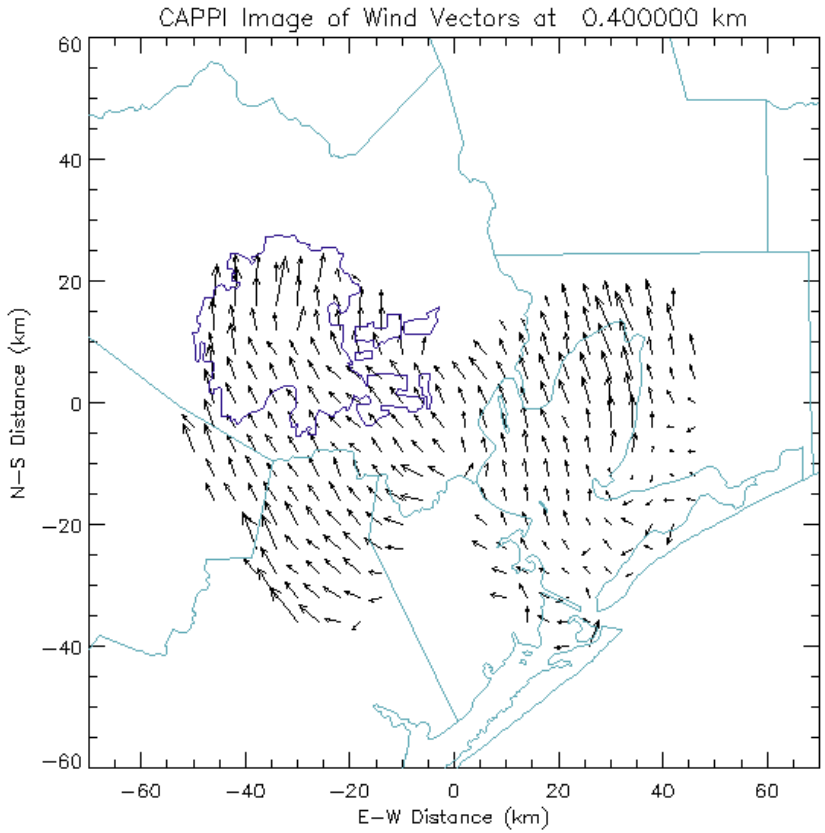
- Create and modified programs to run a Dual-Doppler synthesis from the TEXAQSII study from summer 2005 in order to create netCDF files and gif images.

  This involved:

  - Matching the radars scans, SR1 and KHGX, SR2 and KFWS, to within 3 minutes, resulting in grids about every 10 minutes.

  - Creating a method to remove ground clutter. We ultimately settled on a threshold using velocity (greater than 0.25 m/s) and spectral width (greater than 0.7).

  - Deciding on the best grid spacing, grid radius, and height levels. 2 km was used as the x and y spacing and 0.2 km as the z spacing. Grid radius was 2 km in the horizontal and a radius of 0.4 km in the vertical.



Dual-Doppler winds over Houston from August 3rd, 2005 at 2020 Z.

Data Processing/Storage: TAMU LINUX Workstation/RAID

SMART-R IRIS Binary

DSL Internet or CD Delivery

WSR-88D LVL II Binary

T1 Internet via LDM

Data Format Conversion
(IRIS/LVL II → NCAR SWEEP → UF)

PERL Script – automated data flow

Quality Control
(GPS heading, time, calibration corrections using custom software)

Clean-up/Artifact Removal
(de-speckle velocity to remove noise, thresholding of velocity on spectral width and |velocity| to remove ground clutter using custom software)

Interpolation/Cartesian Gridding and Local Radial Velocity Unfolding
(using NCAR reorder software)

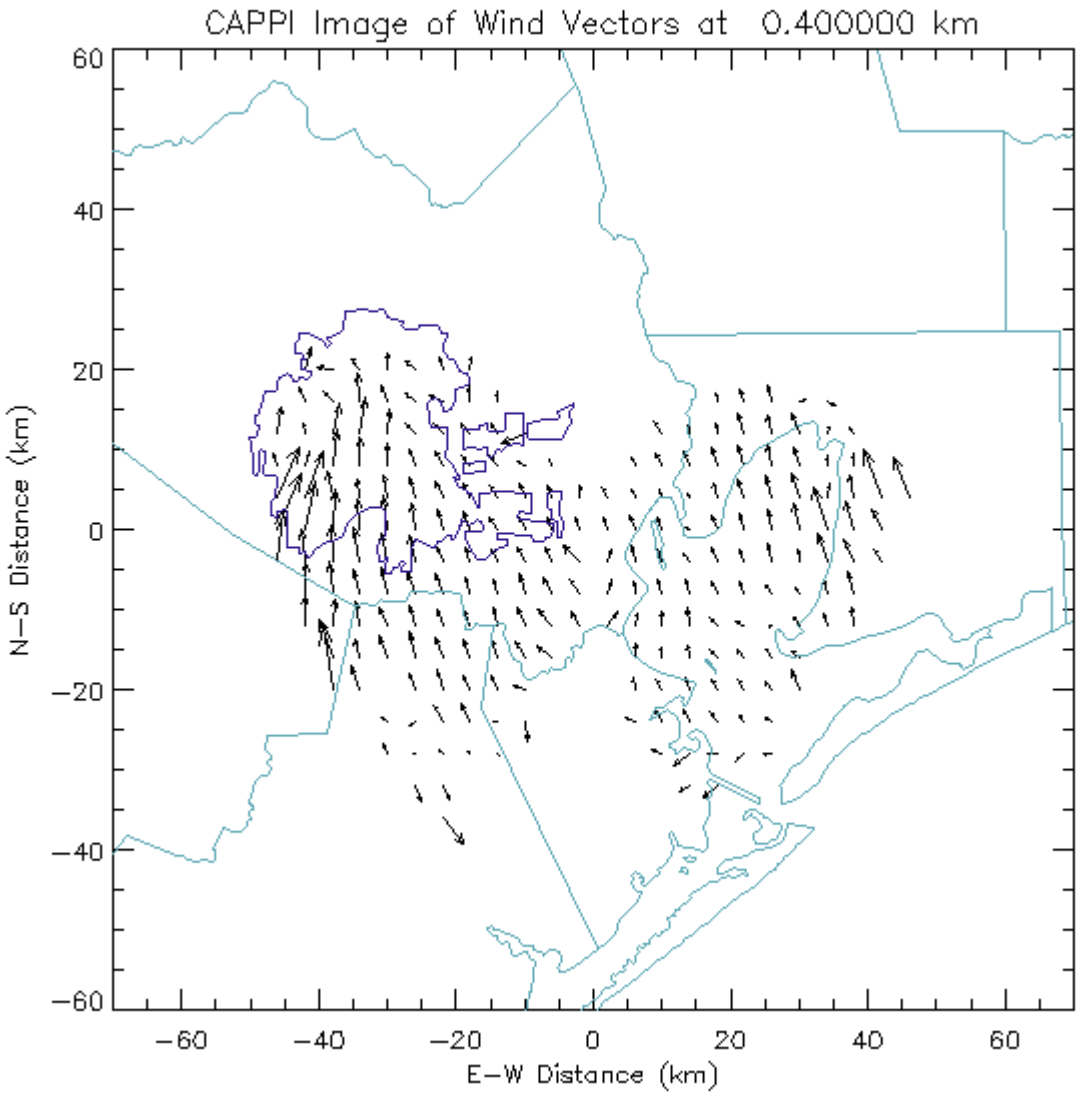
Global Radial Velocity Unfolding and Dual-Doppler Synthesis to Generate 3-D Winds (using NCAR CEDRIC software)

GIF Image Generation of Cartesian Winds (using IDL)

Houston Dual-Doppler Radar Derived Wind Field

23:58 UTC

August 2, 2005



Validation Data and Methods

- Collect Surface data- Meteorological Assimilation Data Ingest System (MADIS) (http://www.madis-fsl.org/public/sfcdumpguest.html)
- Determine the wind speed and direction for each data point in the dual-Doppler grid
- Given the latitude and longitude of each station, find the closest grid point to each station. Stations had to be within 3 km of a grid point to be considered.
- Compare the winds at the surface station versus the winds at the closest grid point

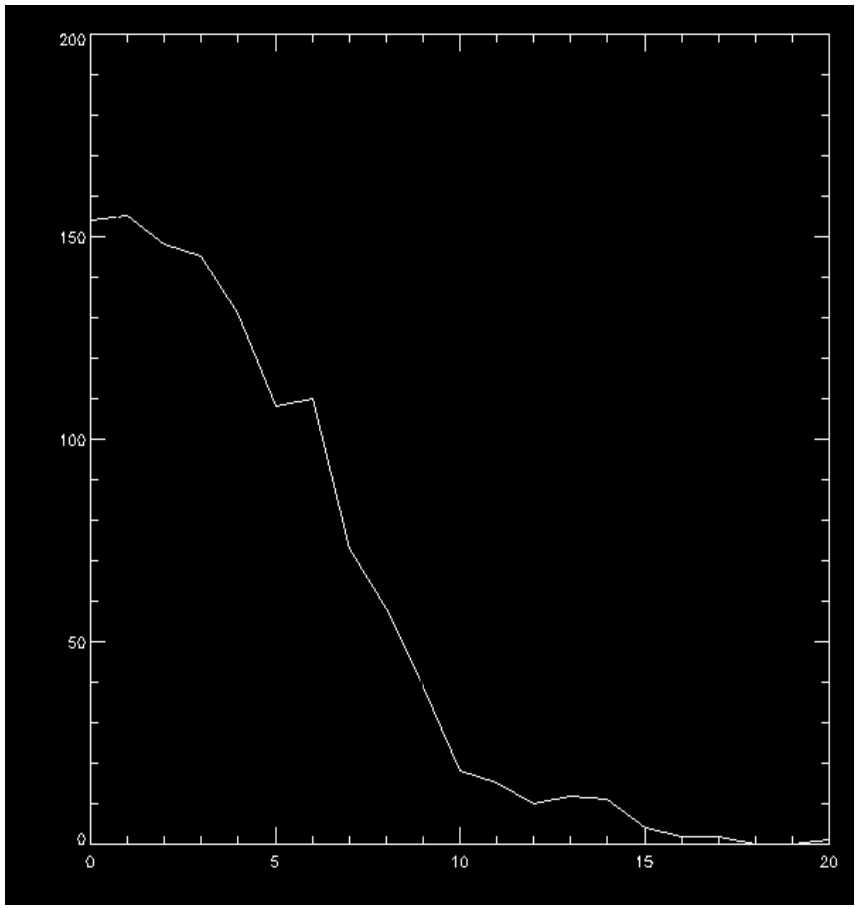
- Houston-Galveston-Brazoria (HGB)
  - Eighteen 3-hour chunks at 15 minute resolution were randomly selected
    - 54 hours sampled on 17 different days (July: 4; August: 8; Sept: 5)
    - 29 hours before noon and 25 hours after noon
  - There are 1196 (986) data points for wind speed (direction)
    - For surface observations with no wind (i.e., zero wind speed), no wind direction was recorded
- Dallas Fort Worth (DFW)
  - Ten 3-hour chunks at 15 minute resolution were randomly selected
    - 30 hours sampled on 10 different days (July: 4; August: 3; September: 3)
    - 15 hours before noon and 15 hours after noon
  - There are 1173 (1082) data points for wind speed (direction)

Validation of Radar Winds with Surface Observations

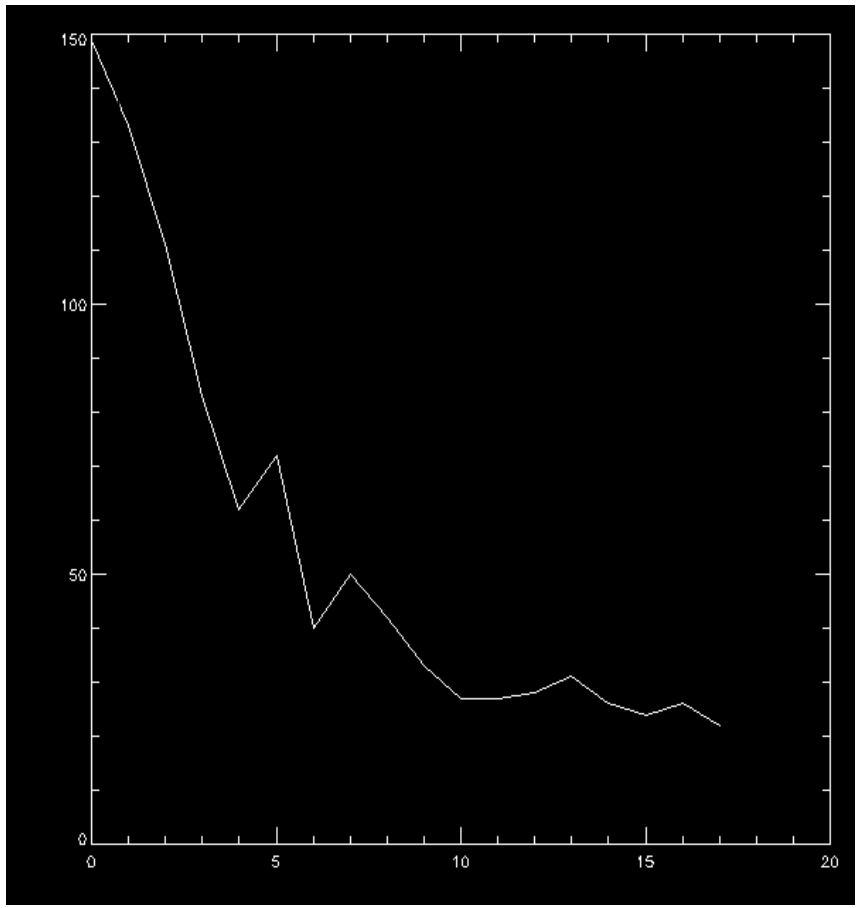
Summary of Wind Speed and Direction Differences between **Surface Station Observations** and the Gridded Dual-Doppler Radar Inferred Winds over Houston-Galveston-Brazoria (HGB) and Dallas-Fort Worth (DFW) during July – September 2005

Category	Sample Size	Median Difference	Mean Difference	Standard Deviation of Difference
HGB Wind Speed	1196	4.0 m s^{-1}	4.6 m s^{-1}	3.3 m s^{-1}
HGB Wind Direction	986	43°	58°	50°
DFW Wind Speed	1173	3.4 m s^{-1}	4.5 m s^{-1}	3.6 m s^{-1}
DFW Wind Direction	1082	35°	49°	44°

HGB Area Frequency Histograms Wind Difference: |Radar-SFC|



Histogram of Difference in Speed ($m\ s^{-1}$)

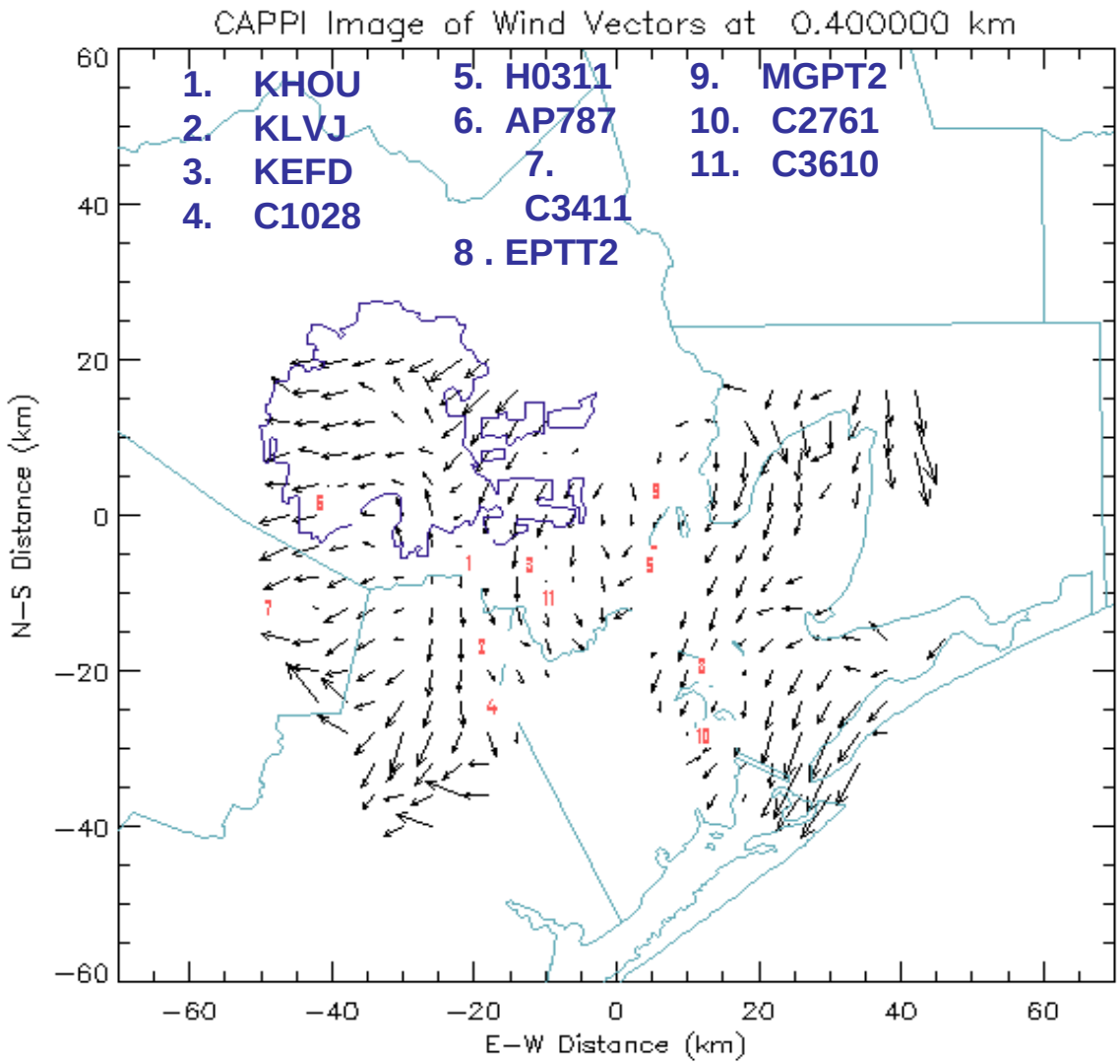


Histogram of Difference in Direction (°/10)

Worst Performers

- Speed (>8.9m/s)
  - AP787
  - C2761
  - C3610*
  - C3411*
- Direction (>140°)
  - KHOU
  - KEFD
  - KLVJ
  - C3411*

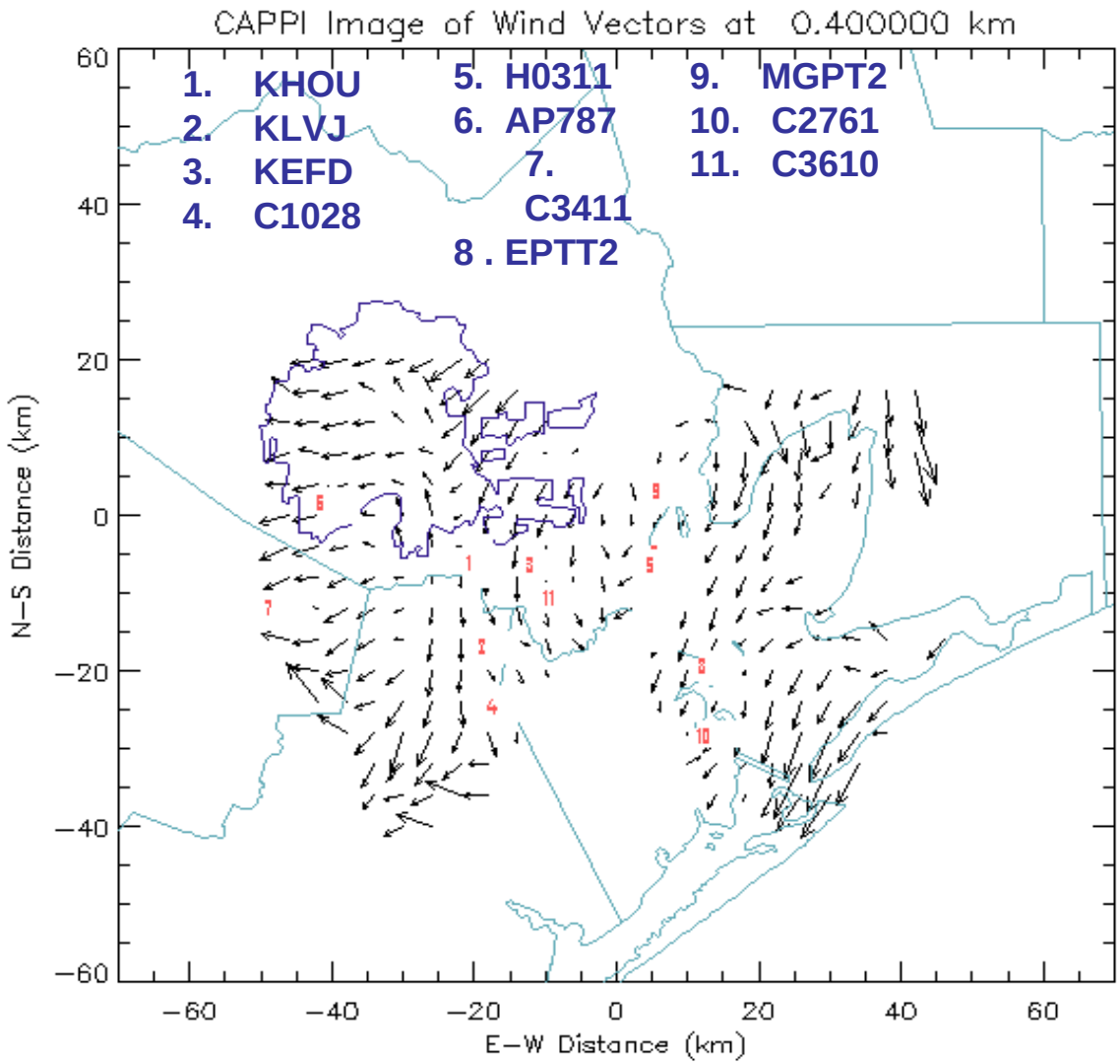
*contributed small amount of data points



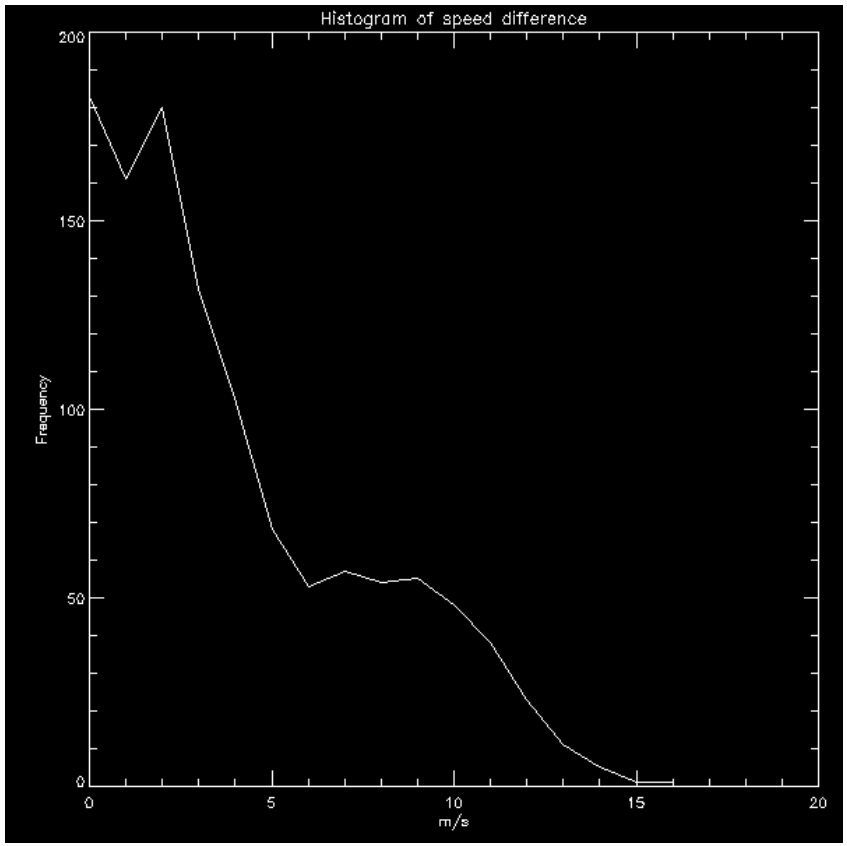
Best Performers

- Speed (<.8 m/s)
  - MGPT2
  - EPTT2
  - KHOU
  - KLVJ
- Direction (<7°)
  - H0311
  - C2761
  - C1028
  - MGPT2

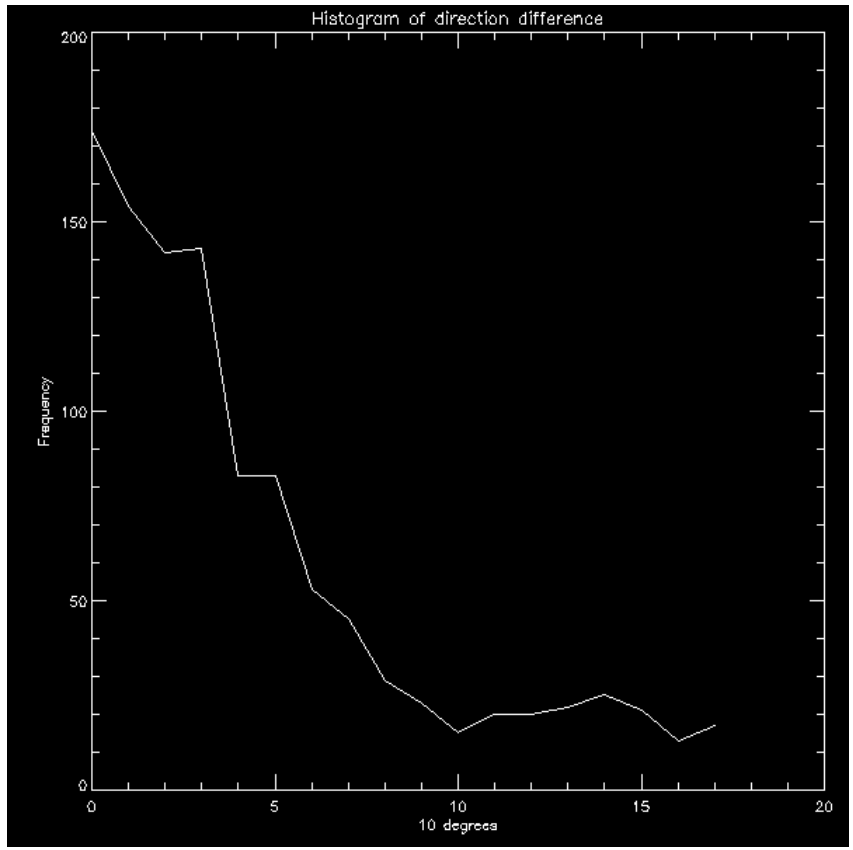
*contributed small amount of data points



DFW Area Frequency Histograms Wind Difference: |Radar-SFC|



Histogram of Difference in Speed ($m\ s^{-1}$)



Histogram of Difference in Direction (°/10)

Validation with Rawinsonde Winds Over DFW

- KFWD rawinsonde sounding winds within ±100 m of the 600 m radar grid level in the vertical was compared to closest radar grid box in the horizontal.

- Rawinsondes typically launched at 12z and 00z by NWS with special soundings occasionally launched at other times (e.g., 18z, 06z).

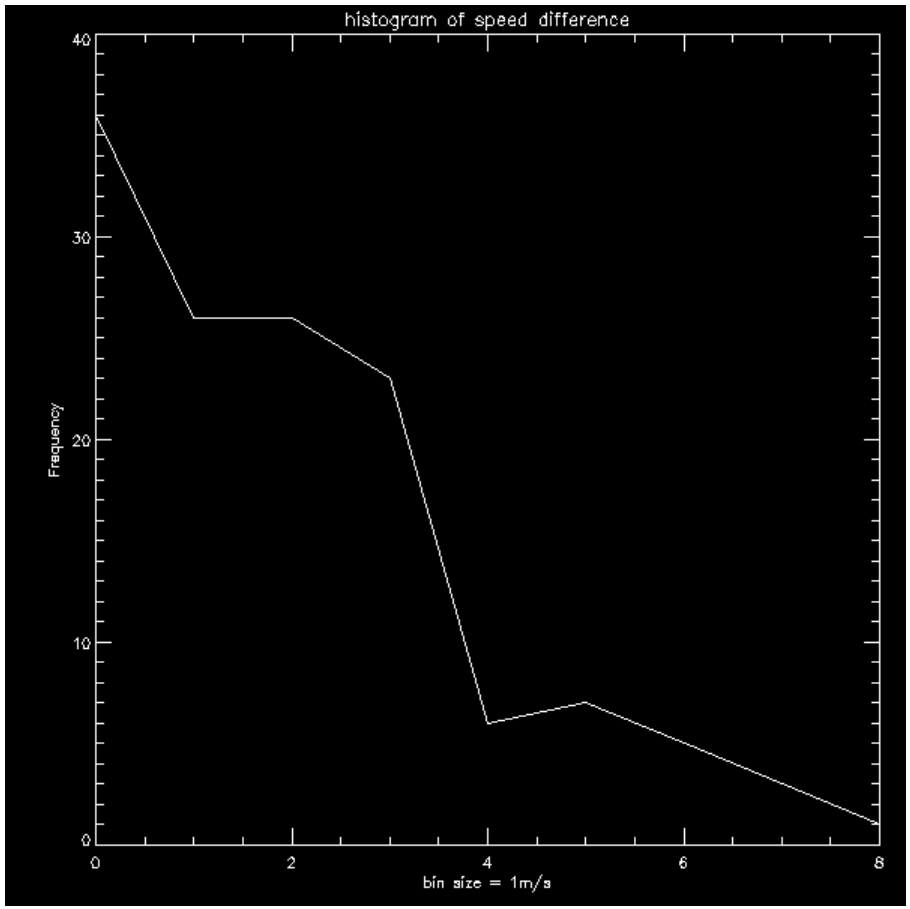
- All available rawinsondes were used, resulting in 133 data points for comparison.

Summary of Wind Speed and Direction Differences between **KFWD Rawinsonde Sounding** and the Gridded Dual-Doppler Radar Inferred Winds at 600 m over Dallas-Fort Worth (DFW) during July – September 2005

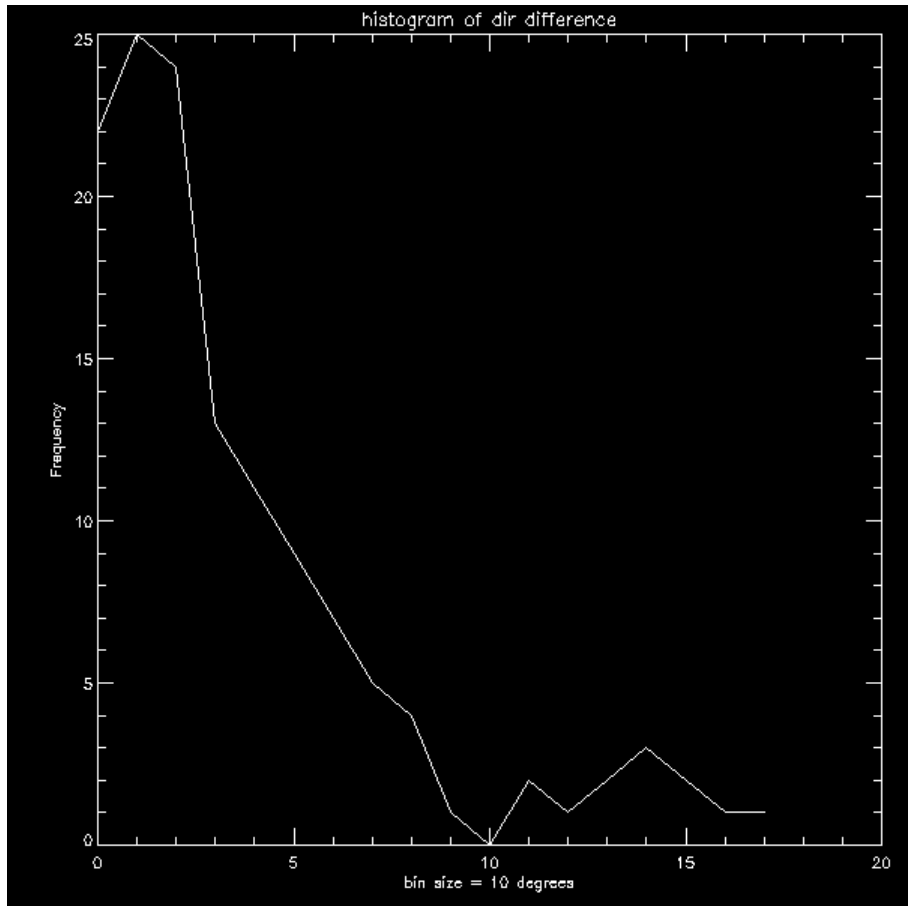
Category	Sample Size	Median Difference	Mean Difference	Standard Deviation of Difference
DFW Wind Speed	133	2.3 m s^{-1}	2.5 m s^{-1}	1.9 m s^{-1}
DFW Wind Direction	133	29°	42°	39°

* Note: Rawinsonde data was unavailable over HGB.

DFW Area Frequency Histograms Wind Difference: |Radar-Sounding| at 600 m

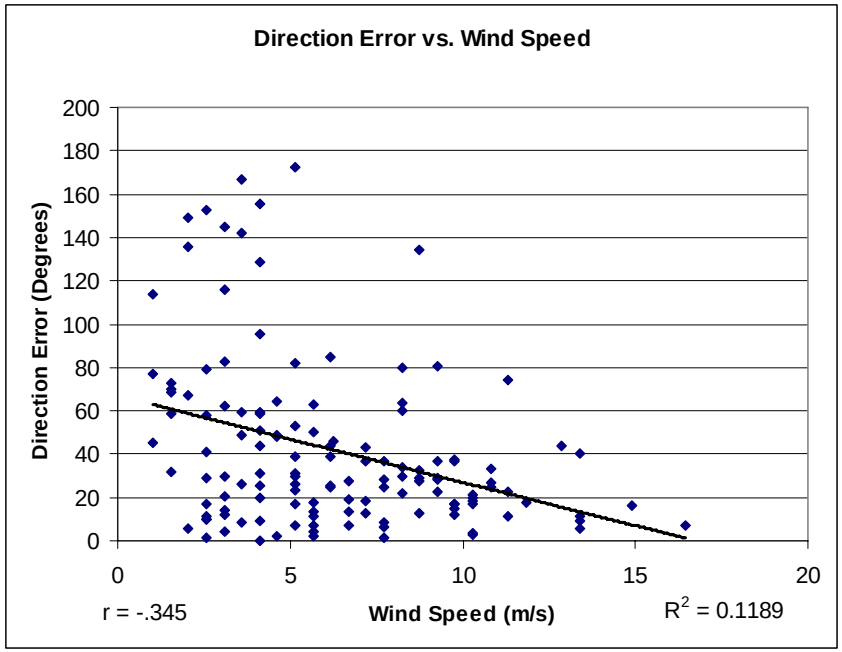


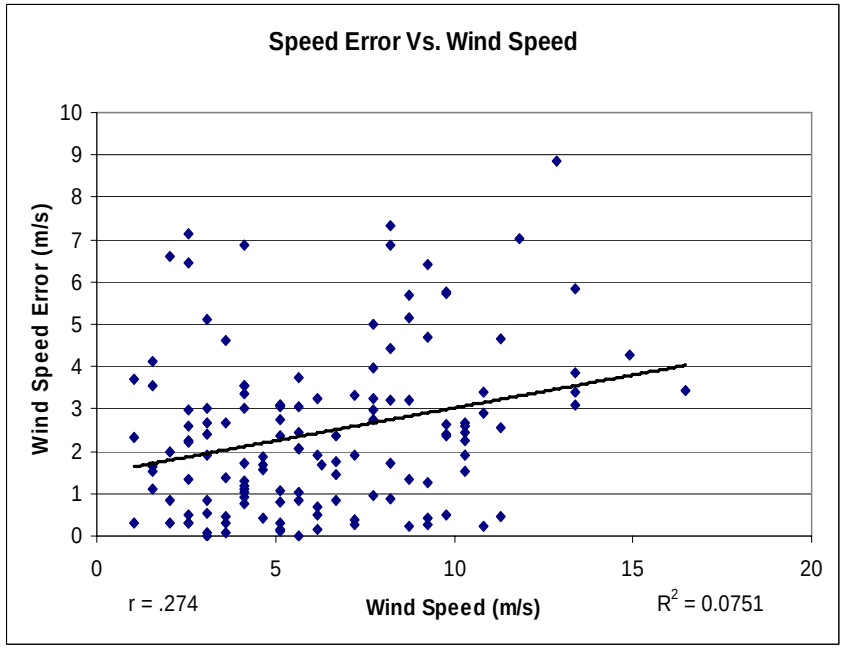
Histogram of Difference in Speed ($m\ s^{-1}$)



Histogram of Difference in Direction (°/10)

Correlation of Direction and Speed Error to KFWD Sounding Wind Speed

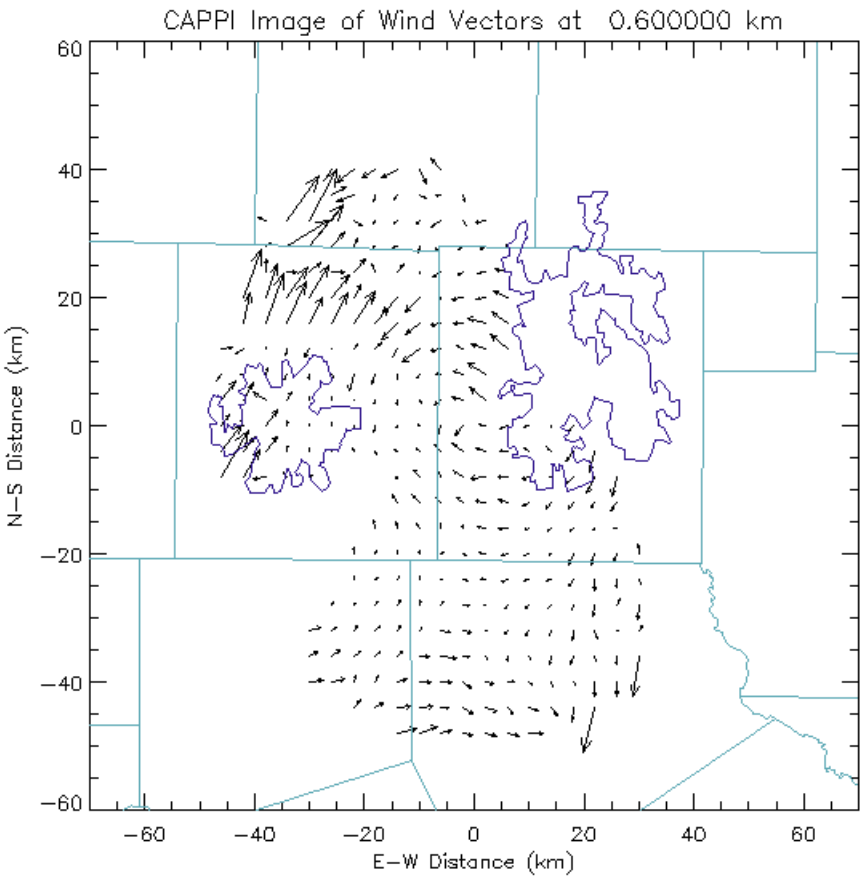




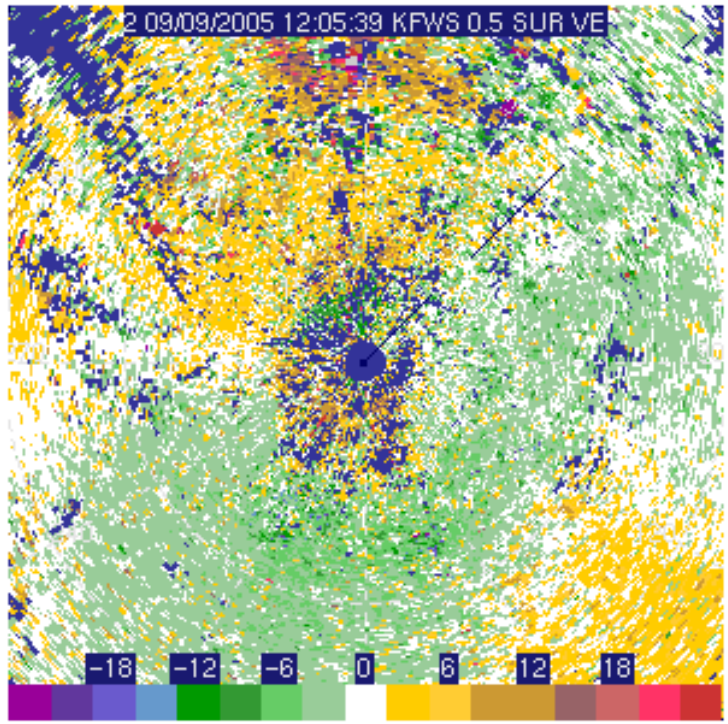
- Tendency for increasing directional error with decreasing actual (sounding) wind speed.
- Consistent with past dual-Doppler radar research.

- Weak Tendency for increasing speed error with increasing actual (sounding) wind speed.
- Possible sample size issue at larger wind speeds and no correlation.

Outlier Example for KFWD Rawinsonde vs. DFW Radar Winds



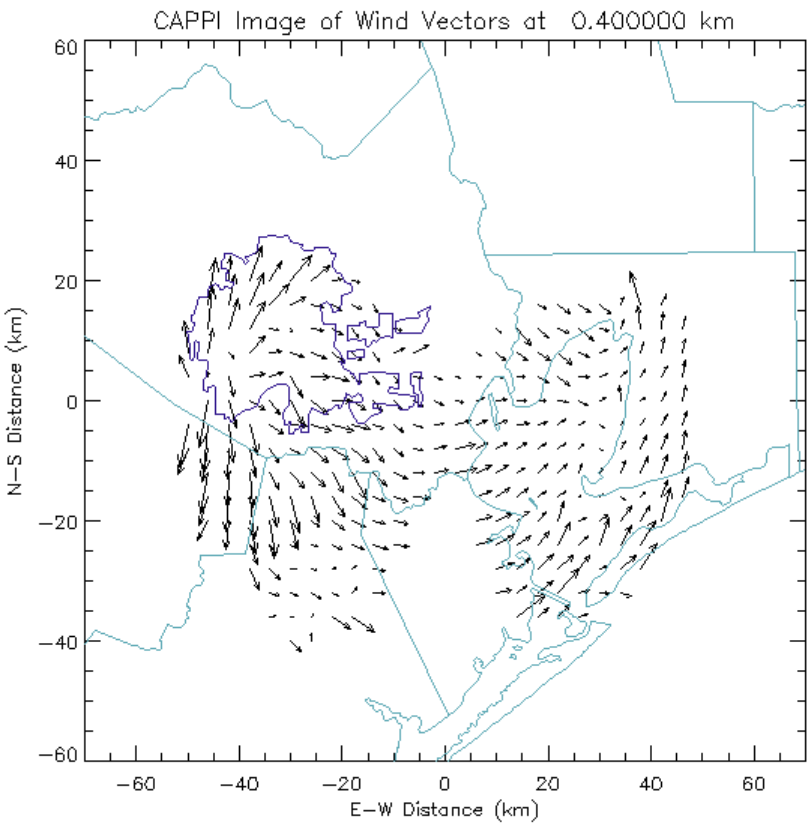
Dual-Doppler Derived Winds at 600m
September 9, 2005, 1206 UTC

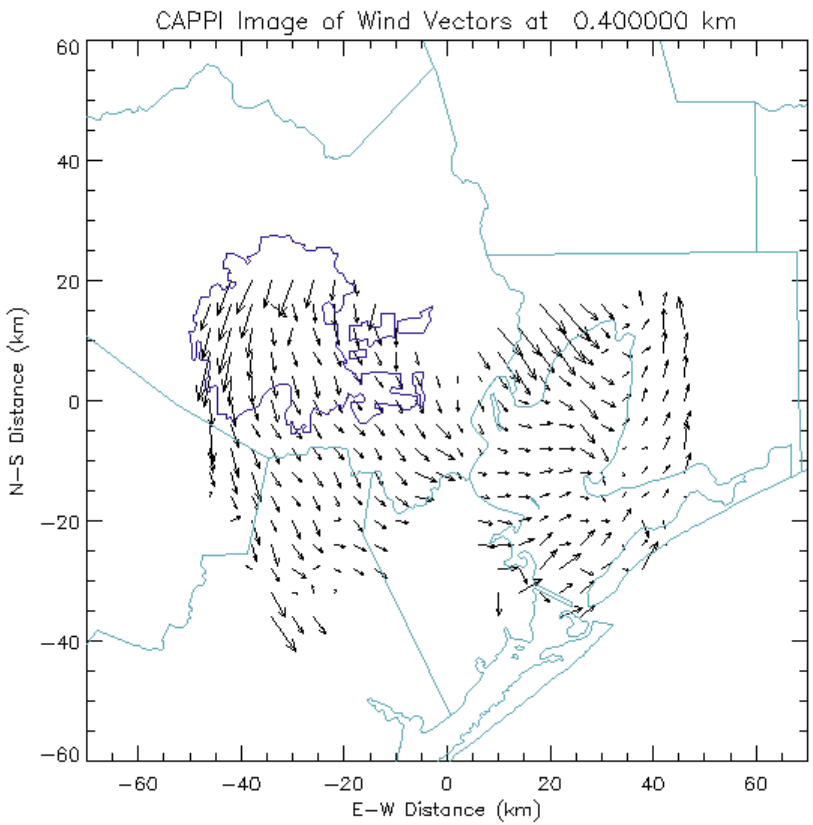


KFWS radial velocities

- unusually noisy after thresholding, especially to northwest through north
- likely migrating/feeding birds since 12z near sunrise

Houston: Migrating Birds at Sunrise (about 12 UTC)



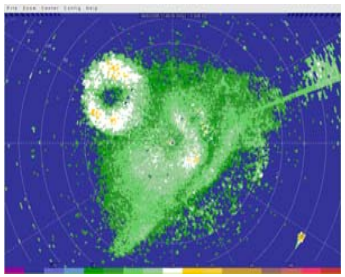


- Near sunrise: 1156 UTC
- Migrating birds appear as a strong divergence signature over SW Houston in background flow
- from about -30 min to +30 min relative to sunrise

- After sunrise: 1302 UTC
- Migrating bird feature is gone and background flow of land breeze is apparent over Houston.

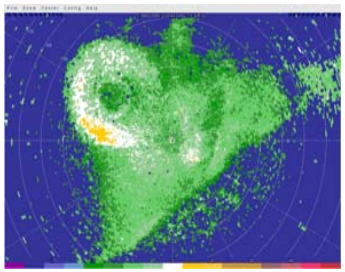
Sunrise Bird Migration in Raw SR-1 Radar Reflectivity Data over Houston

1.



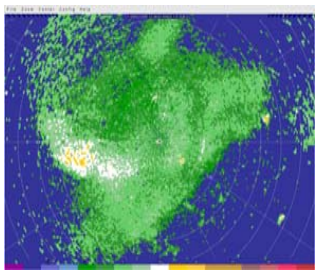
1148 UTC

2.



1220 UTC

3.

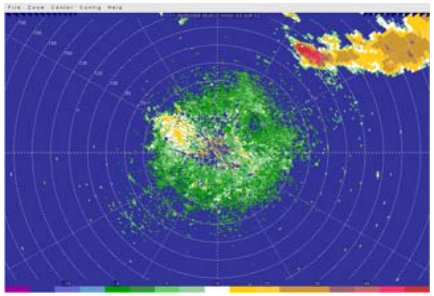


1233 UTC

- Early AM Bird migration is visible as a growing donut shaped ring on the SR1 radar
- Diverging donut from roosting location in SW Houston.
- Up to 100,000 Purple Martins roost just south of I-10, between Gessner and Sam Houston Toll way from June-August, leaving the roost at about sunrise each day
    - *Source*: Houston Audubon Society

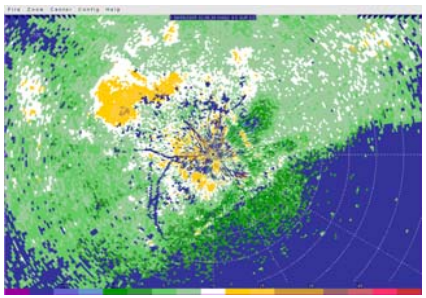
Late PM Bird Migration in Raw SR-1 Radar Reflectivity Data over Houston?

4.



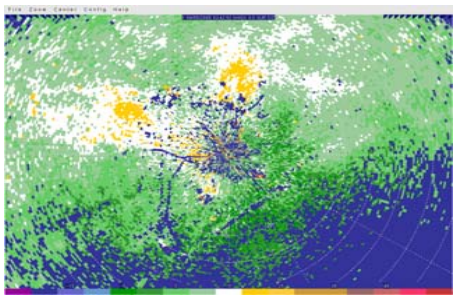
0040 Z

5.



0151 Z

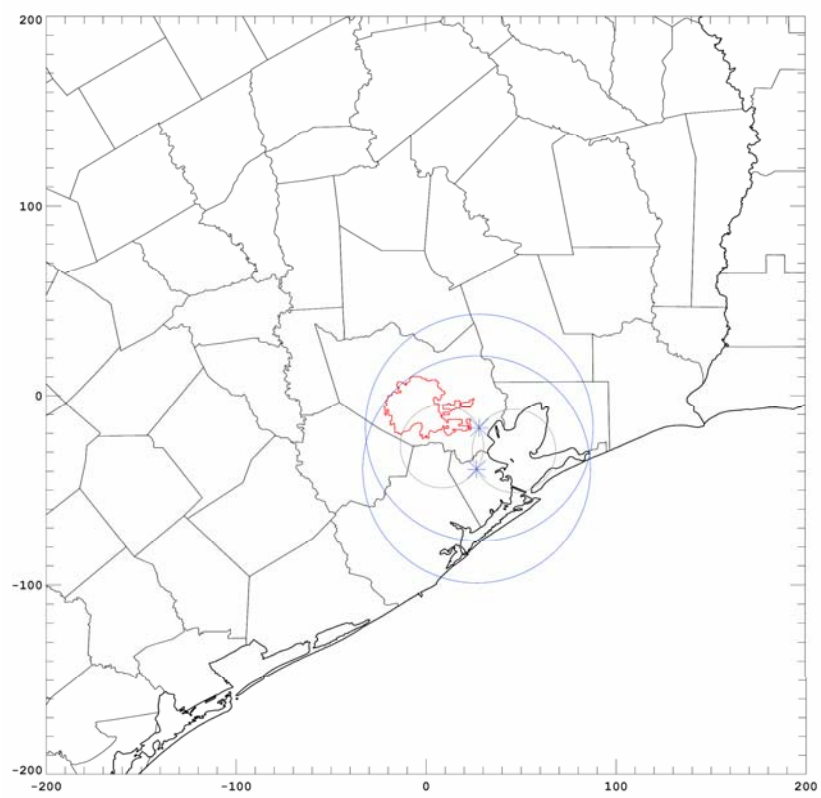
6.



0342Z

- Birds are also likely present near sundown.
- The birds tend to appear as a “cloud” of enhanced reflectivity at approximately the same location in SW Houston.
- In a study in Russel (1998), they found that nighttime flocks are more sporadic and are not often picked up by radar because of lower flight levels.
    - (Russel, Kevin R. Gauthreaux Jr., Sidney A. “Use of Weather Radar to Characterize Movements of Roosting Purple Martins”. Wildlife Society Bulletin. 1998 26(1). Pg 5-16.)
- From our images, it appears like night flights last longer over all, and would be more likely to be interpreted as meteorological due to more subtle nature.

Dual-Doppler radar beam-crossing angle, error variance, and analysis domain



$\beta = 30°$

Error variances

$$\frac{\sigma_u^{\ 2} + \sigma_v^{\ 2}}{\sigma_1^{\ 2} + \sigma_2^{\ 2}} = \csc^2 \beta \equiv b$$

Area of analysis domain

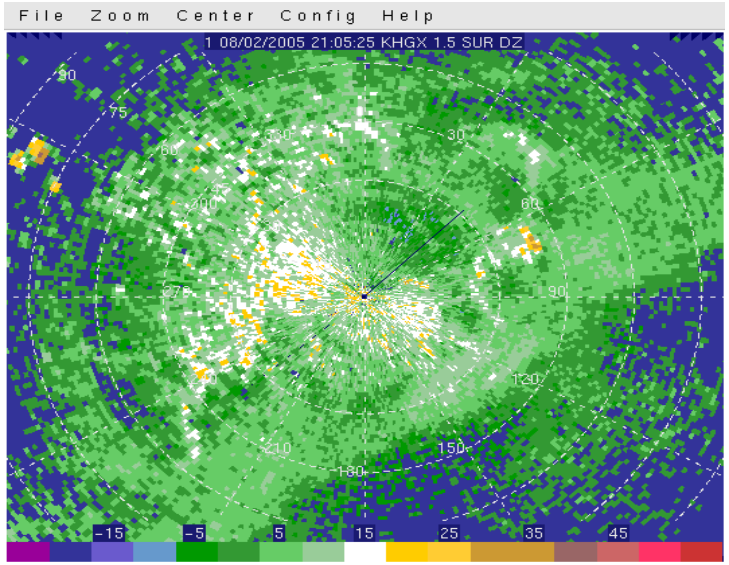
$$A_1(\beta) = 2(d \csc \beta)^2 \left(\pi - 2\beta + 2\sin 2\beta\right),$$

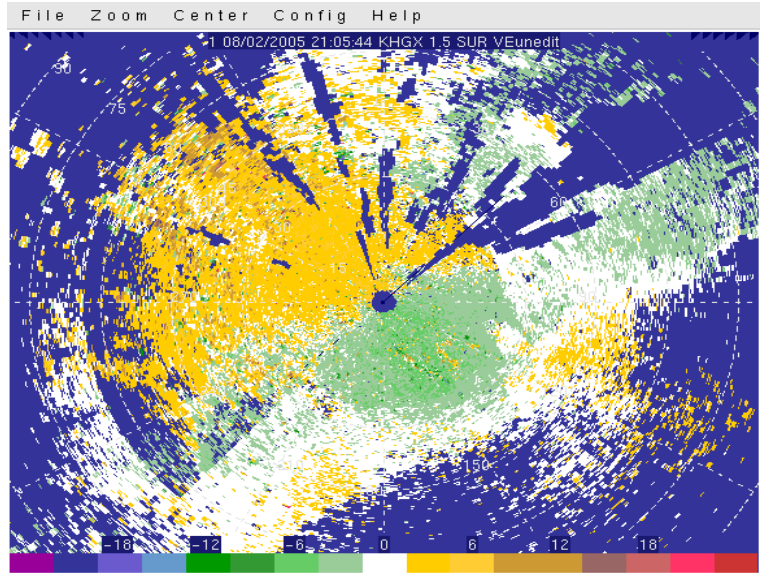
$\beta \uparrow \rightarrow \sigma_u^{\ 2} + \sigma_v^{\ 2} \downarrow$ "good"

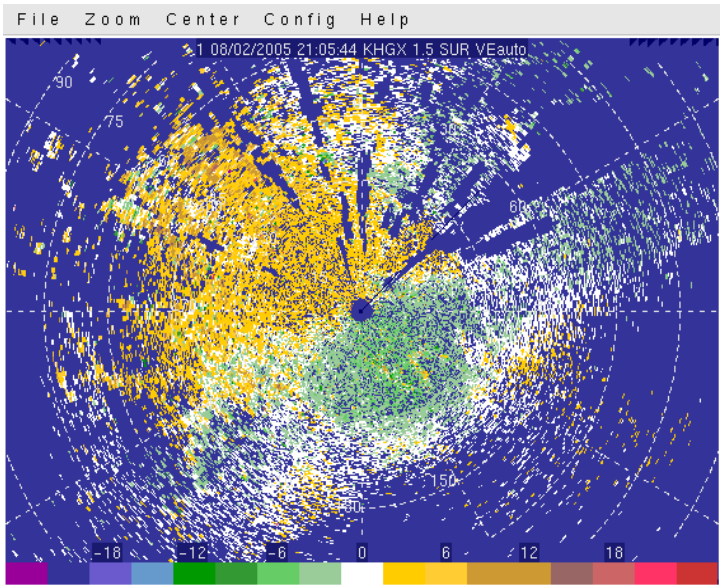
$\beta \uparrow \rightarrow A_1 \downarrow$ "bad"

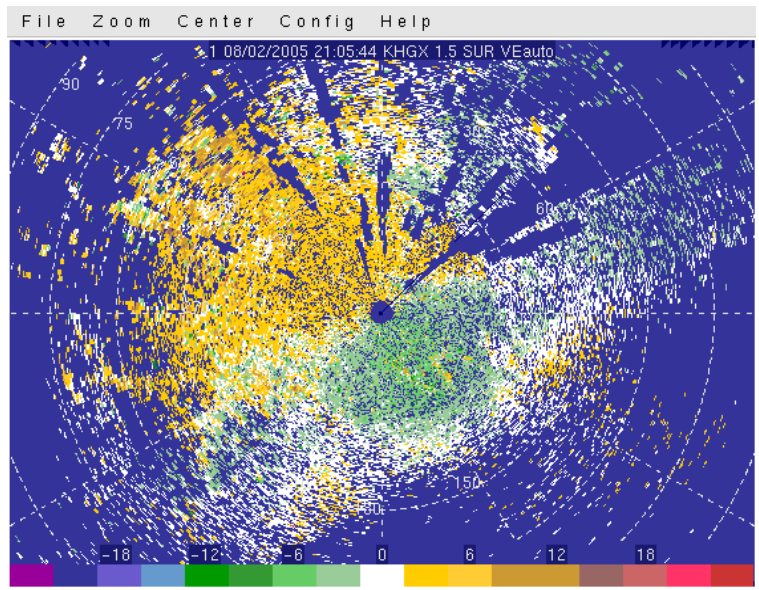
WSR-88D of KHGX at 2105UTC and Vr Editing

Top Left: DZ, Top Right, Unedited VR, Bottom Left: AutoVR, Bottom Right: AutoManualVR



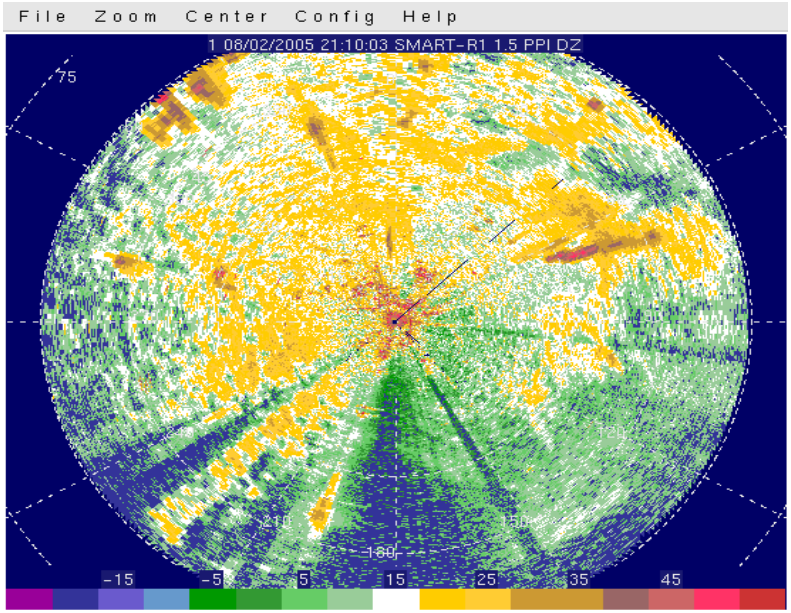


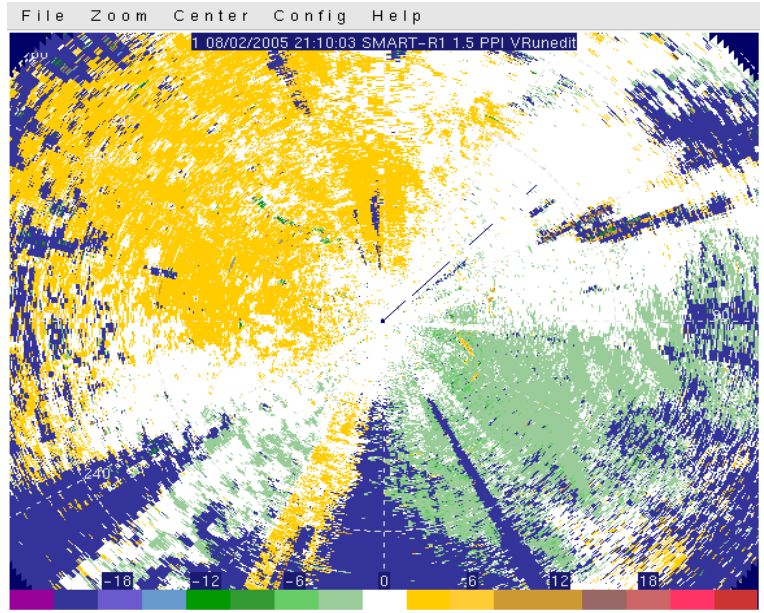


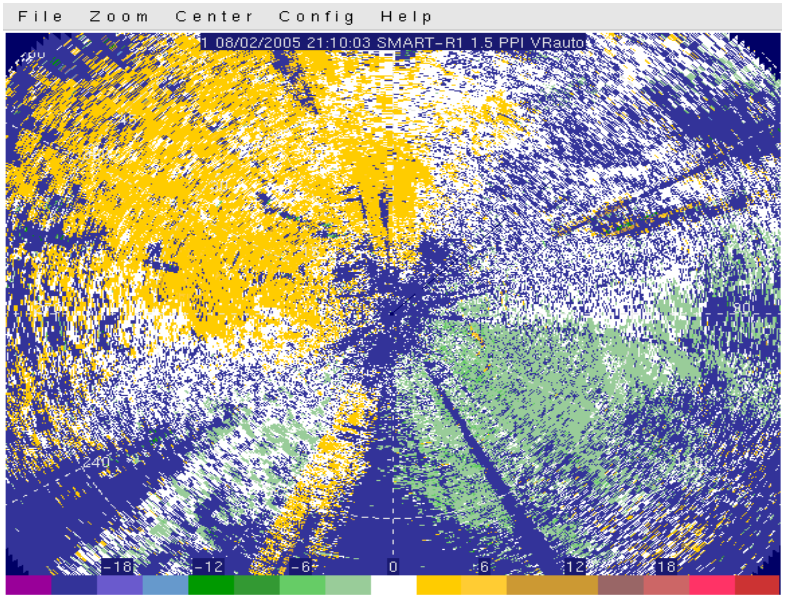


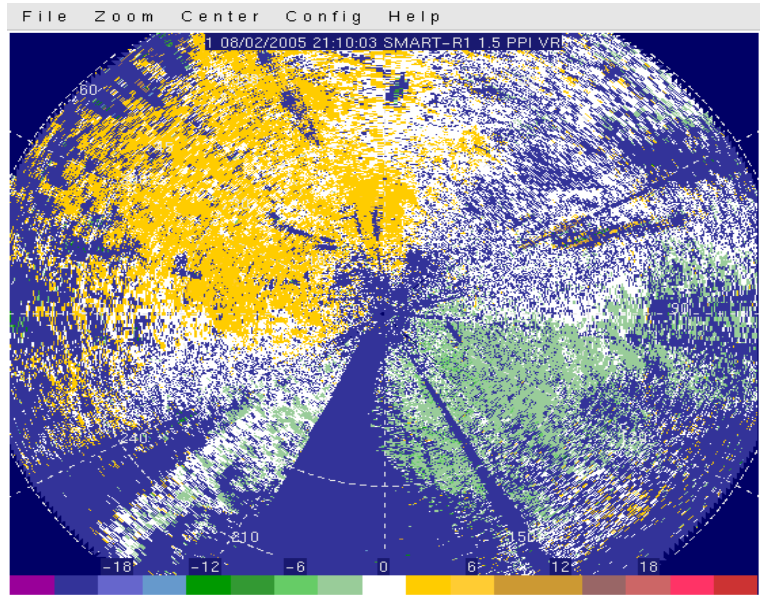
SMART Radar at 2110UTC and Vr Editing

Top Left: DZ, Top Right: Unedited VR, Bottom Left: AutoVR, Bottom Right: AutoManualVR









Summary and Conclusions

- Completed generation of dual-Doppler radar derived wind maps over Houston-Galveston-Brazoria and Dallas-Fort Worth regions for operational period from 11 July - 22 September 2005. Call this version 1 maps.
  - Binary (netCDF) and image (gif) files
  - 2 km x 2 km x 0.2 km
  - Typically every 10 minutes or better temporal resolution
- Validation with surface and upper air wind data near completion
  - Comparison with surface observations over HGB and DFW suggests median errors of about 3.4 to 4.0 m s^{-1} in speed and 35° to 43° in direction.
    - Part of this error is likely due to difference in observation heights (1-10 m vs. 400-600 m)
  - Comparison with Dallas rawinsonde data (KFWD) at 600 m suggests median wind speed (direction) error of 2.3 m s^{-1} (29°).
    - Comparison of Houston data to wind profiler and/or ACARS data underway although results will likely be less representative than above due to location mismatch and potential wind errors in the validation source.
- Preliminary analysis of outliers suggests that large wind speed and direction errors are typically associated with
  - Migrating birds near sunrise or sunset
  - Proximity to edge of dual-Doppler domain
    - Larger range – lower resolution and higher beam height
    - Larger inherent dual-Doppler retrieval error due to smaller beam crossing angle
  - Residual clutter or other data artifacts
- Fixing remaining outliers is somewhat problematic
  - As we delete more outlier radial velocities (i.e., noise) from birds, edge effects, clutter, and other radial velocity artifacts, we will also delete more real winds (i.e., insect signal).
  - We could make Version 2 maps with less noise (i.e., increased confidence) but also less winds (i.e., decreased coverage)
- Absolute wind speed errors are weakly positively correlated to wind speed while absolute direction errors are negatively correlated to wind speed.

Towards Assimilating Clear-Air Radar Observations with an WRF-Based EnKF

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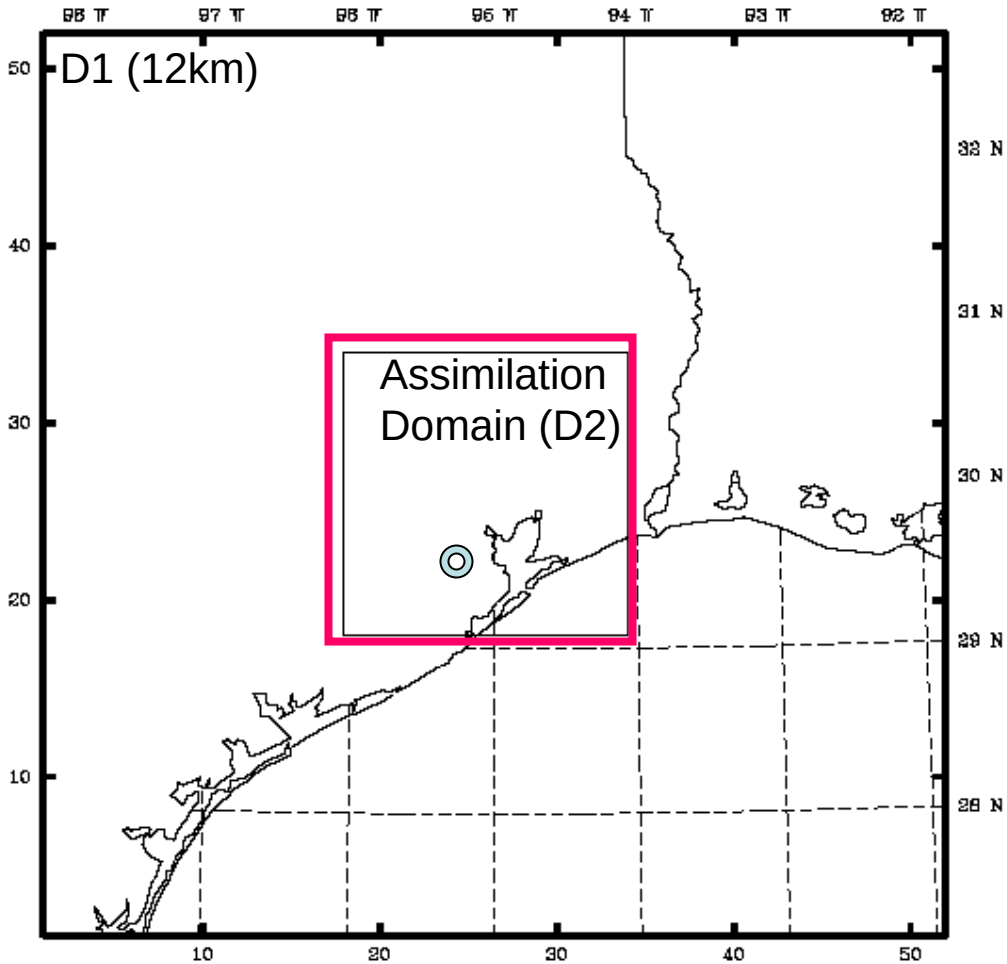
Experimental Design: OSSE with EnKF

- **Forecast model**: WRF, 12-km (and 4-km) grids of 51x51 centered over Houston
- **Case in study**: TEXAQS II of 2 August 2005
- **A 30-member ensemble**: initiated at 00Z 2 August with random but balanced perturbations using WRF 3Dvar background error statistics (Barker et al. 2003)
- **Perfect-model OSSE**: truth as one of the ensemble members; no model error
- **OBS type**: boundary layer (0-4km) clear-air radar obs of Vr from truth run centered on KHGX radar site and at $(24\ km)^2$ spacing, every 1 h
- **OBS error**: 3 m/s for Vr; uncorrelated
- **Square-root sequential EnKF**: OBS assimilated one by one; OBS not perturbed
- **Radius of influence**: 12 grid points each direction (Gaspari and Cohn 1999)
- **Variance relaxation**: mixing prior and posterior variances (Zhang, Snyder and Sun 2004)

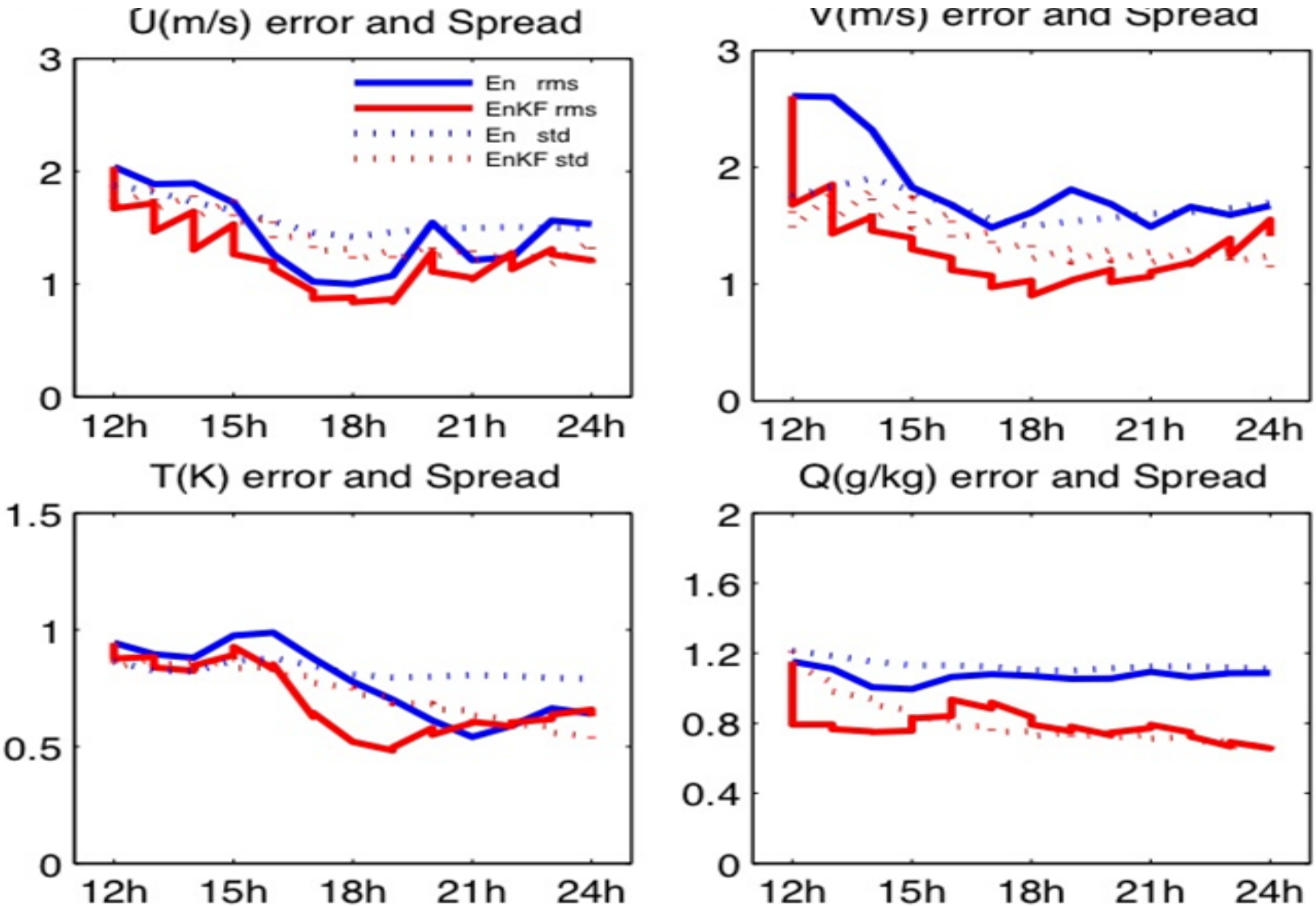
WRF Model Domains and Configurations



Model Physics: Grell CPS, 6-class WSM microphysics & YSU PBL

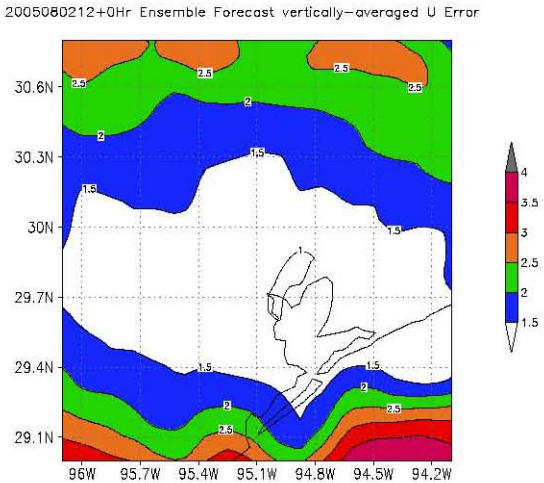
Ensemble generation: WRF/3DVAR covariance; size 30

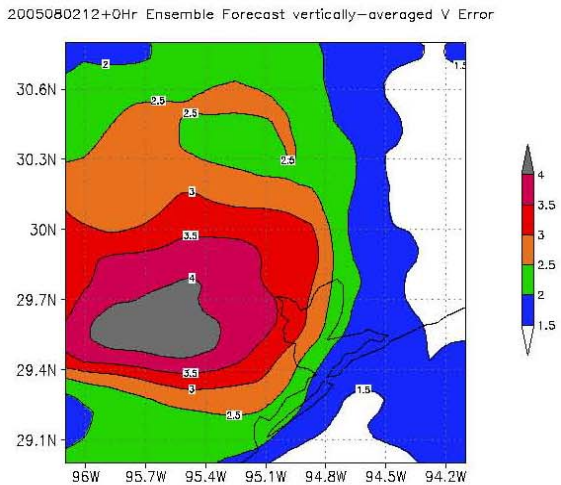
EnKF Performance: Analysis vs. Forecast



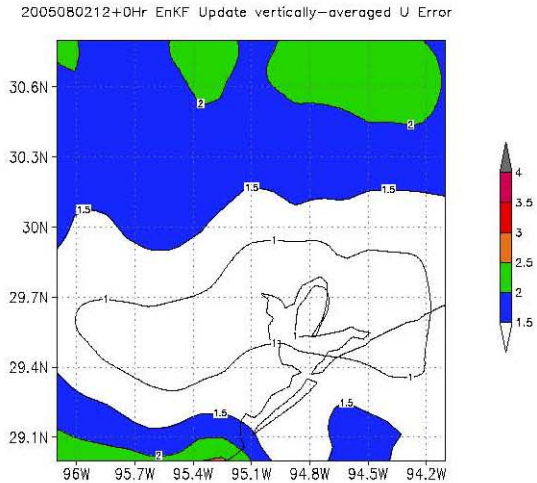
Horizontal RMS Error Distribution at 12h: u,v

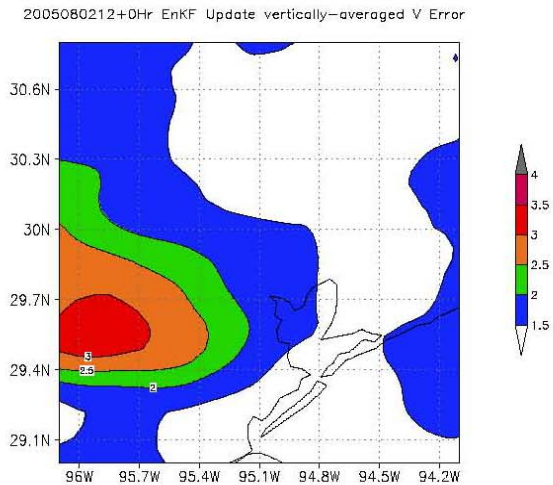
Pure EF





EnKF





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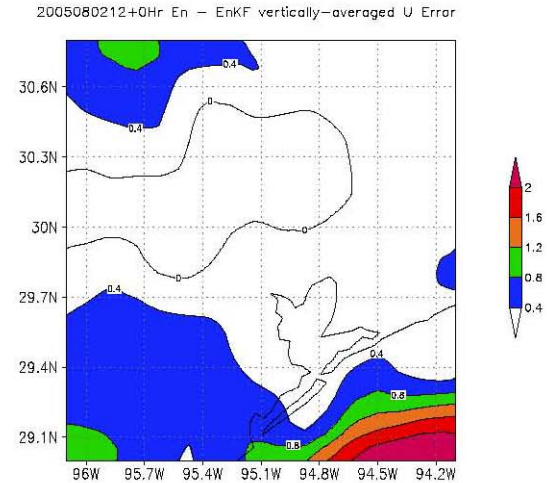
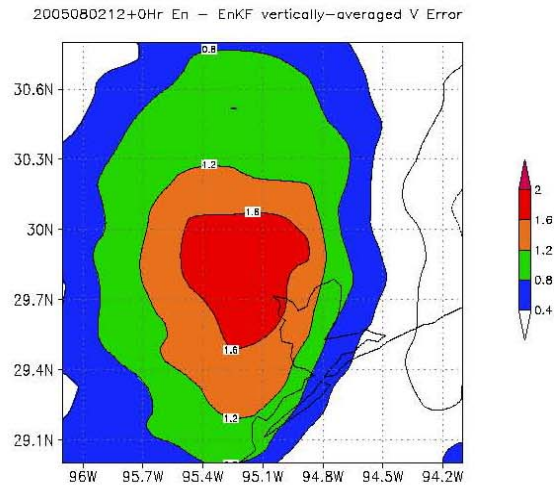


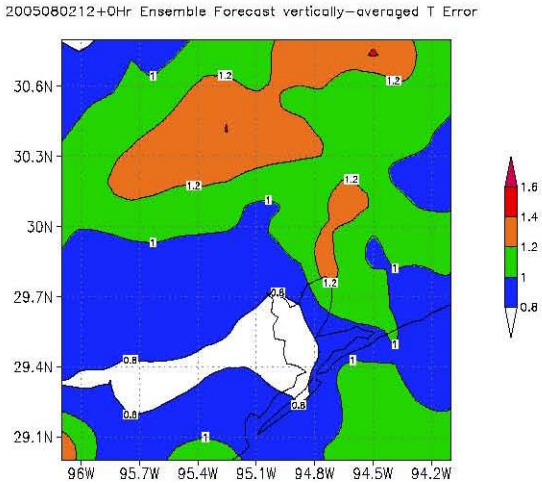


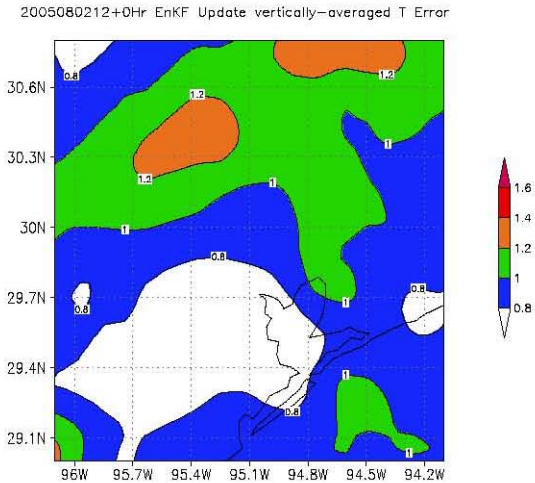
Horizontal RMS Error Distribution at 12h: T,Q

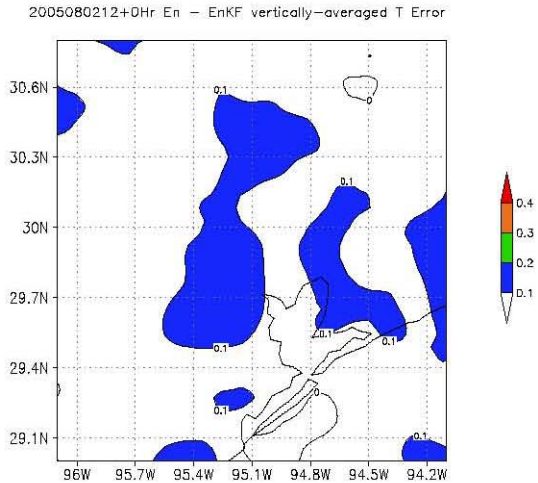
Pure EF

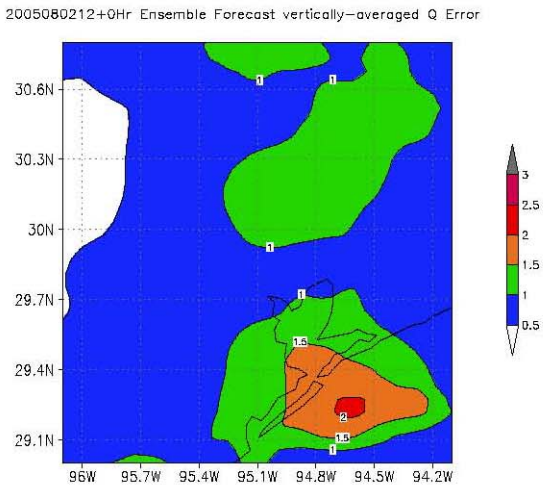
EnKF

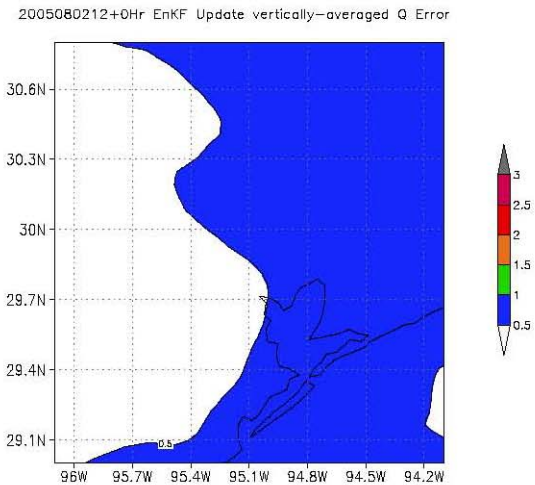
Difference

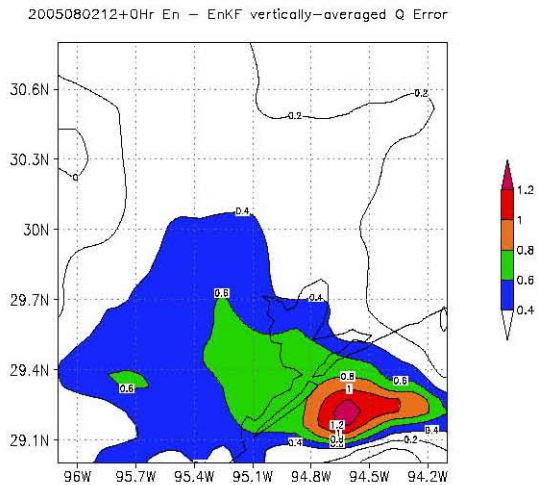










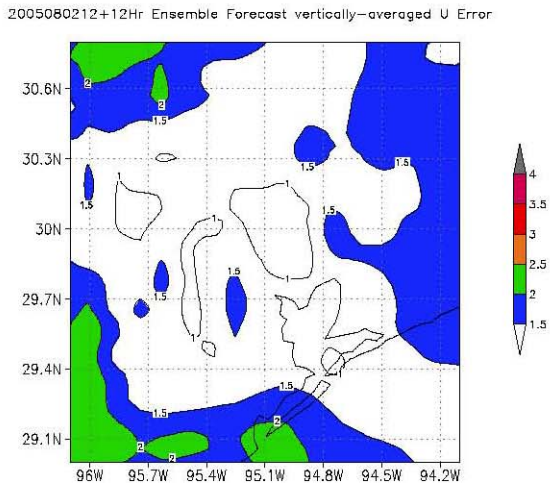


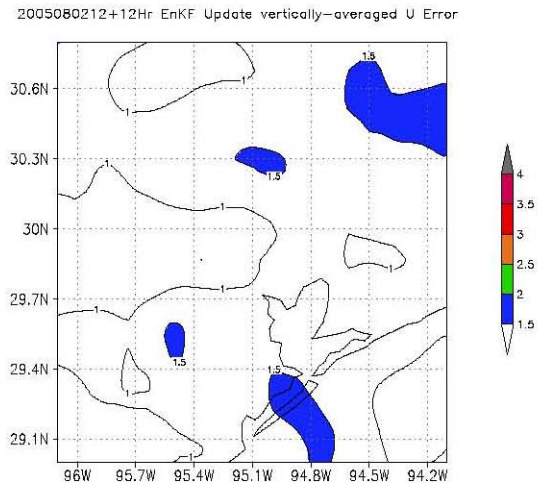
Horizontal RMS Error Distribution at 24h: u,v

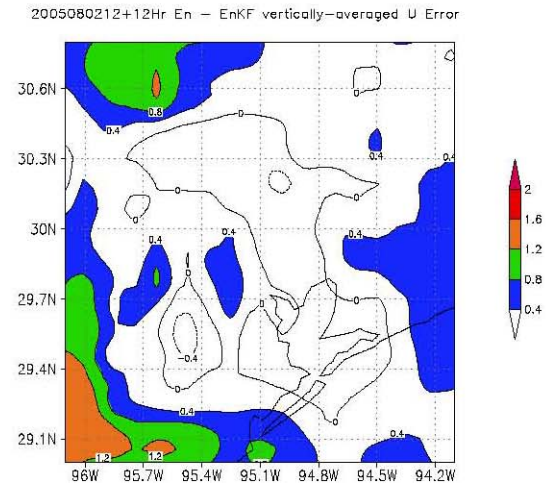
Pure EF

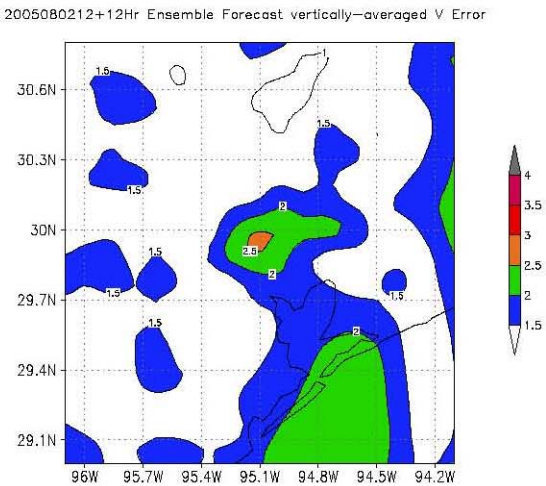
EnKF

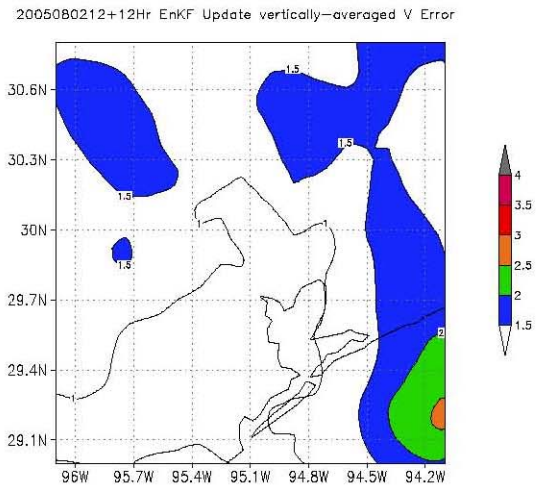
Difference

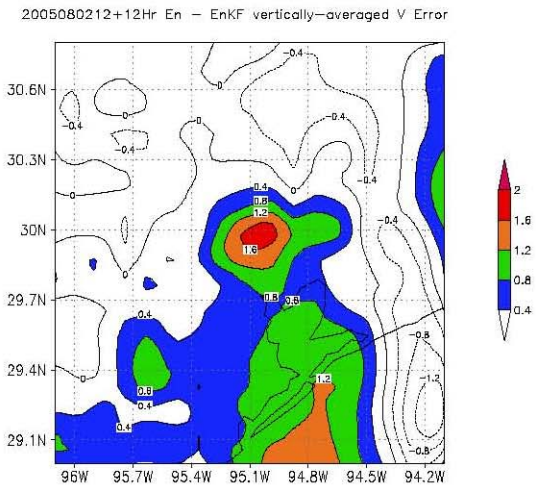






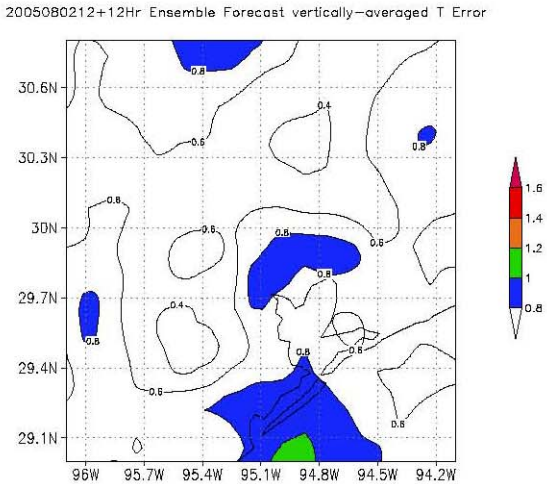


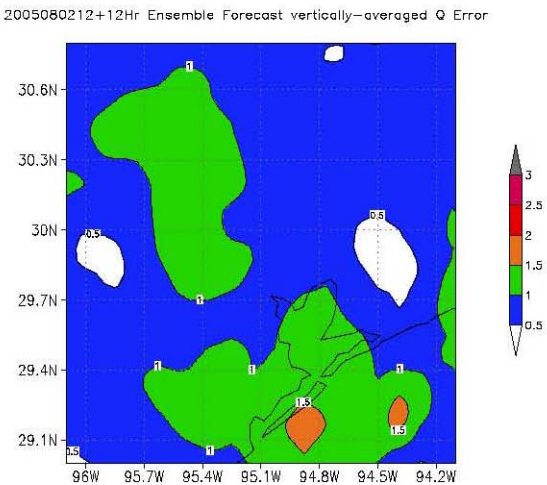




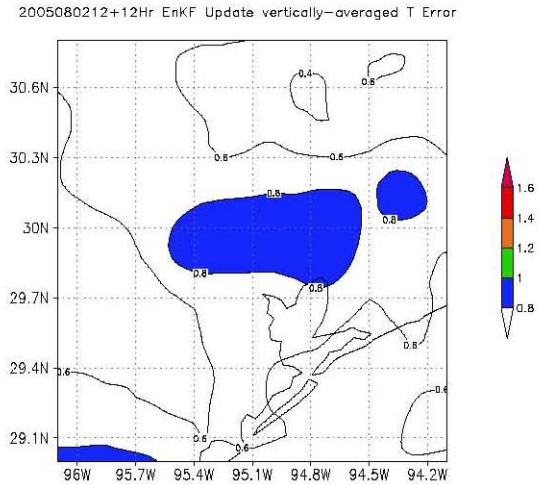
Horizontal RMS Error Distribution at 24h: T,Q

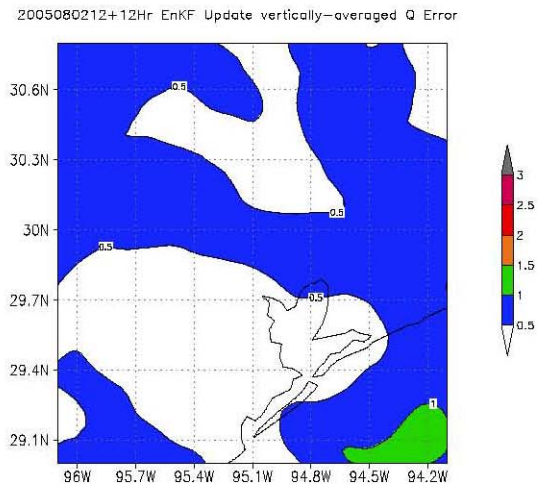
Pure EF





EnKF





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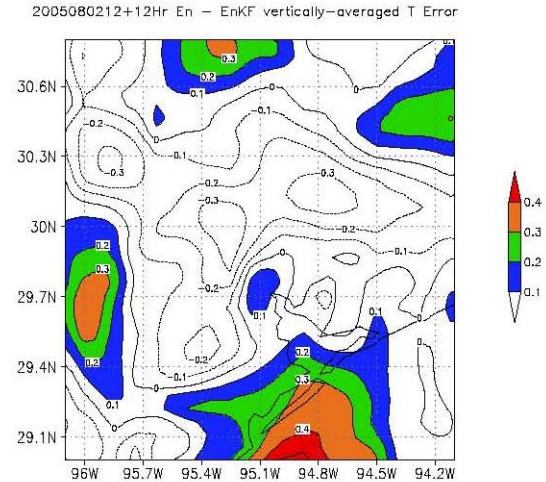
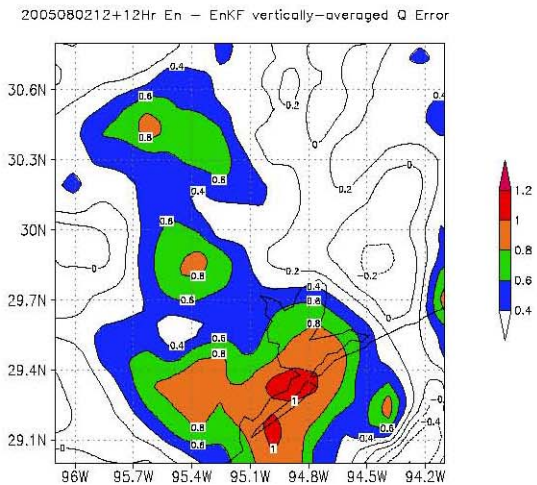




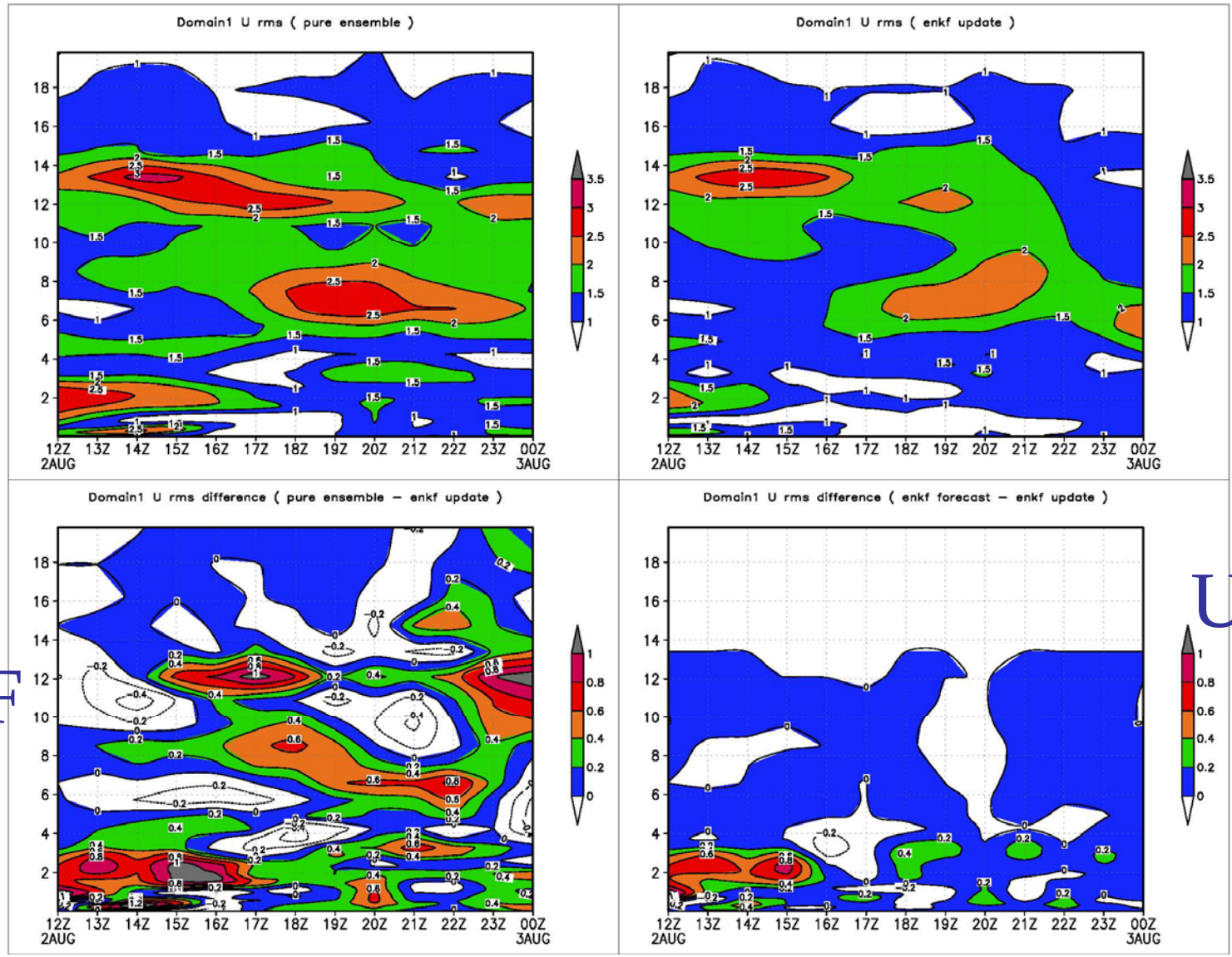
Time Evolution of Vertical RMS Error : u

Pure EF

EnKF

EF-EnKF

Update



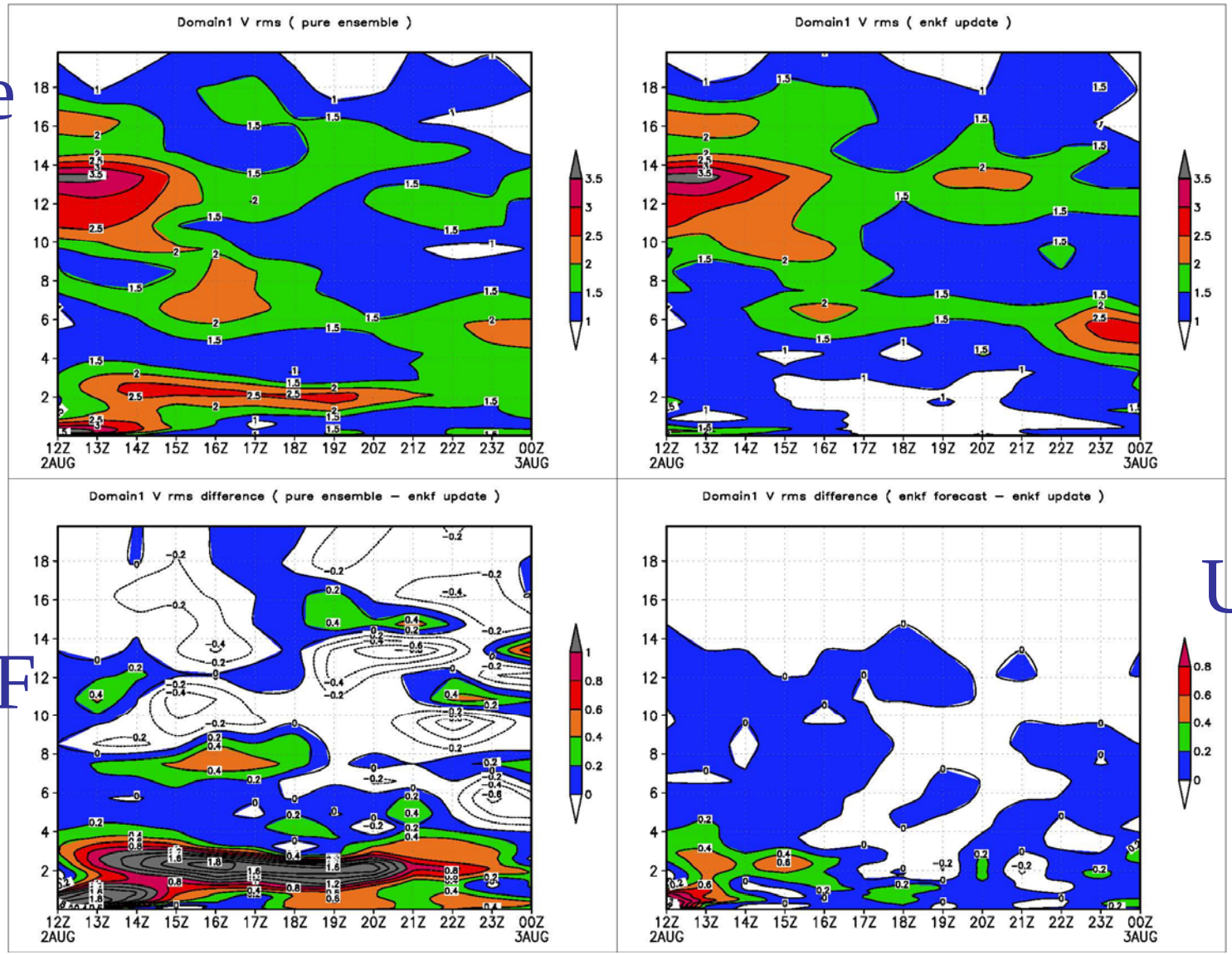
Time Evolution of Vertical RMS Error : v

Pure EF

EnKF

EF-EnKF

Update



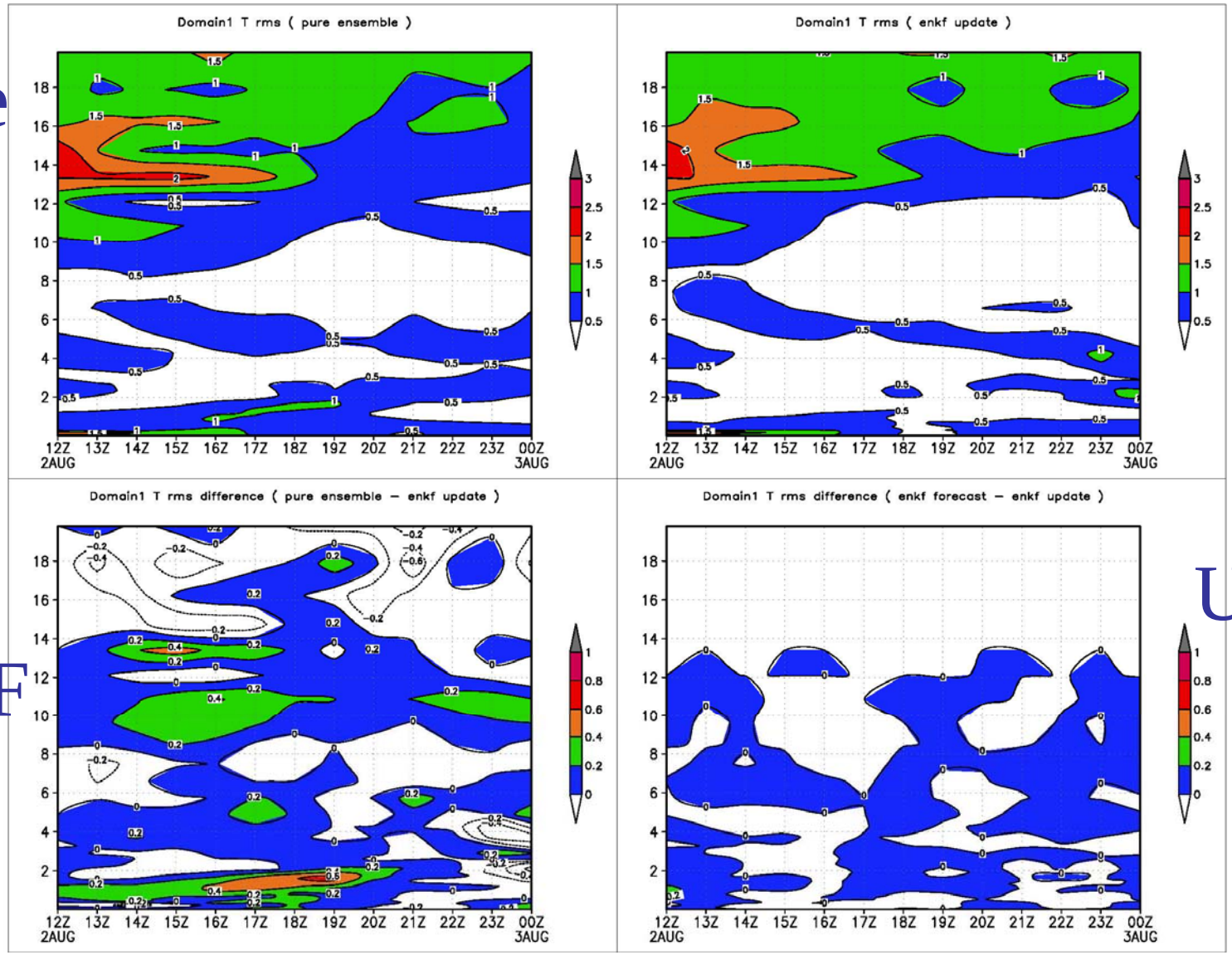
Time Evolution of Vertical RMS Error : T

Pure EF

EnKF

EF-EnKF

Update



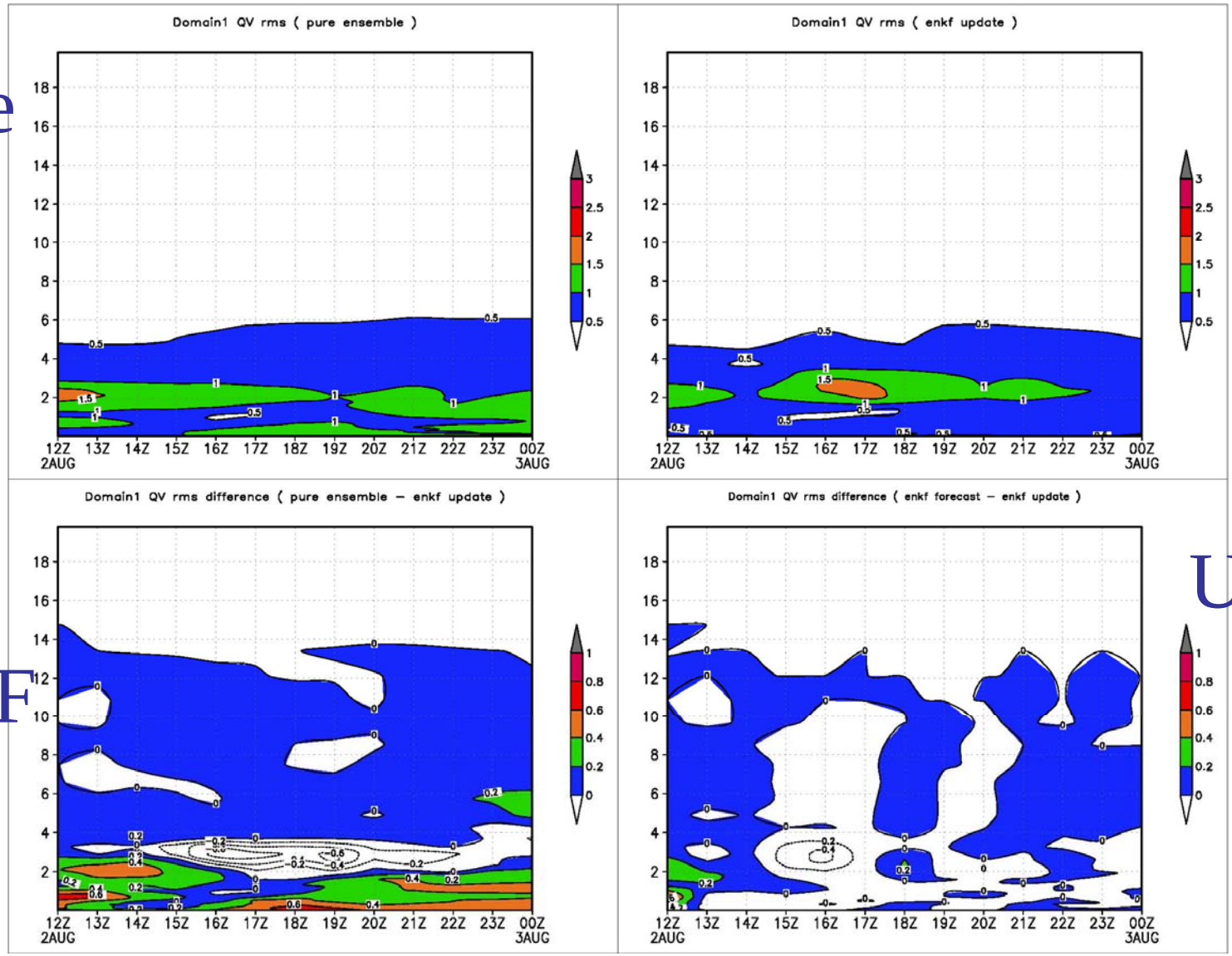
Time Evolution of Vertical RMS Error : Q

Pure EF

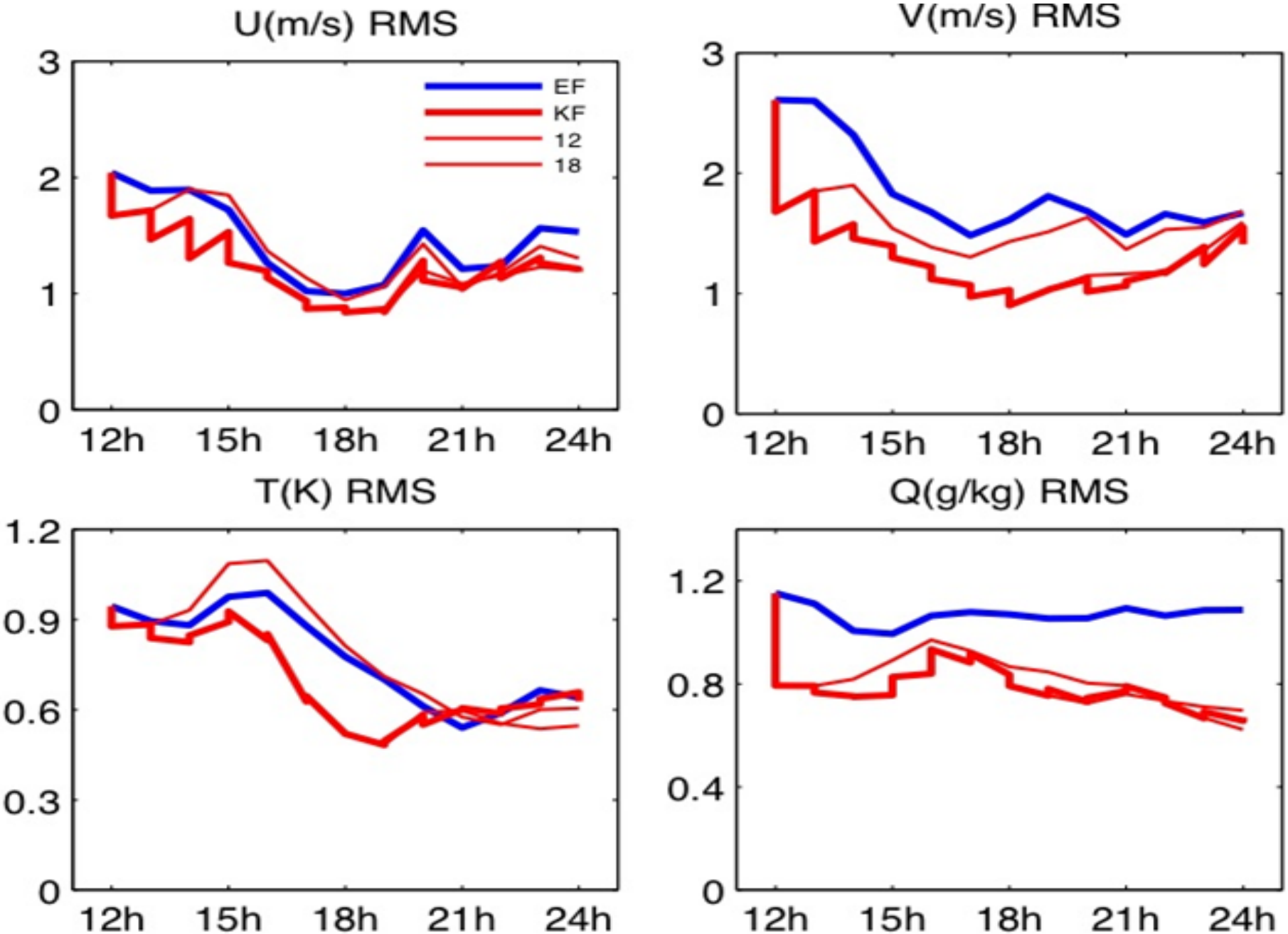
EnKF

EF-EnKF

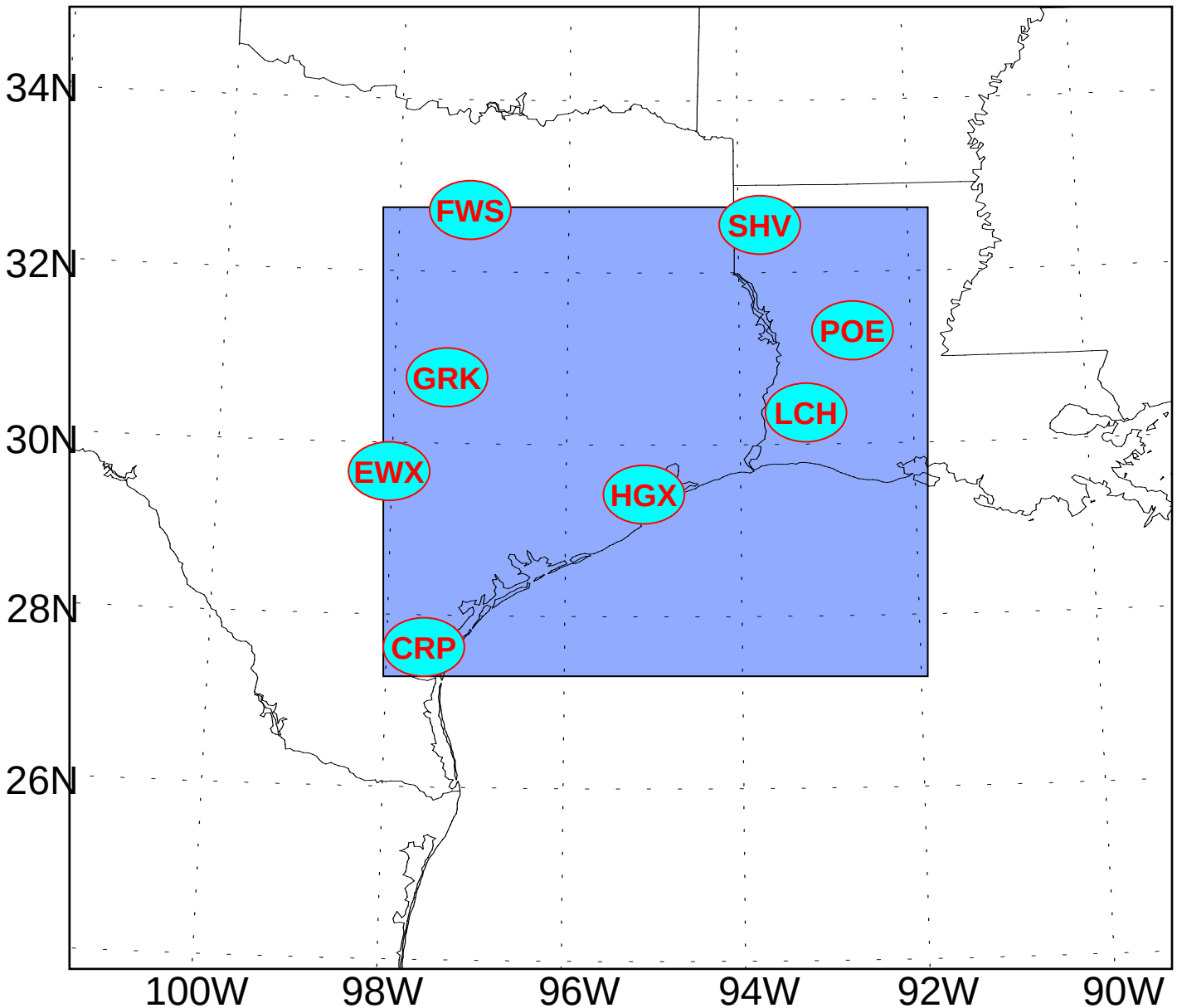
Update



EnKF Performance: Analysis vs. Forecast



Concluding Remarks

- **ISSUES:**
  - Quality control of clear-air observations is harder
  - Resolution and frequency of the obs to be assimilated
  - Observational error covariance; correlated obs error
  - Model error: boundary layer parameterizations and surface (external) forcing
  - Lack of error growth could mean slow redevelopment of meaningful covariance
- **Promises**
  - Abundant WSR-88D clear-air observations
  - Good for boundary layer profiling; convective initiation
  - Complementary to (and potentially better) than Vr than in precipitation mode for mesoscale NWP because of the larger characteristic spatial scales in clear-air mode vs. precipitation mode
- **Ongoing and future work**
  - Ready to assimilate the real data of clear-air Vr
  - Compared to Dual Doppler and subsequent nudging
  - Assimilated obs from multiple radars over large domains; both clear-air and precip

WSR-88D Network: for mesoscale NWP, clear-air obs