# Correcting for Position Errors in Variational Data Assimilation

Thomas Nehrkorn (AER); Bryan K. Woods (AER);
Thomas Auligné (NCAR); Ross N Hoffman (AER)

**JCSDA Seminar**
**Monday, November 10, 2014**


© Atmospheric and Environmental Research, Inc. (AER), 2014

# Outline

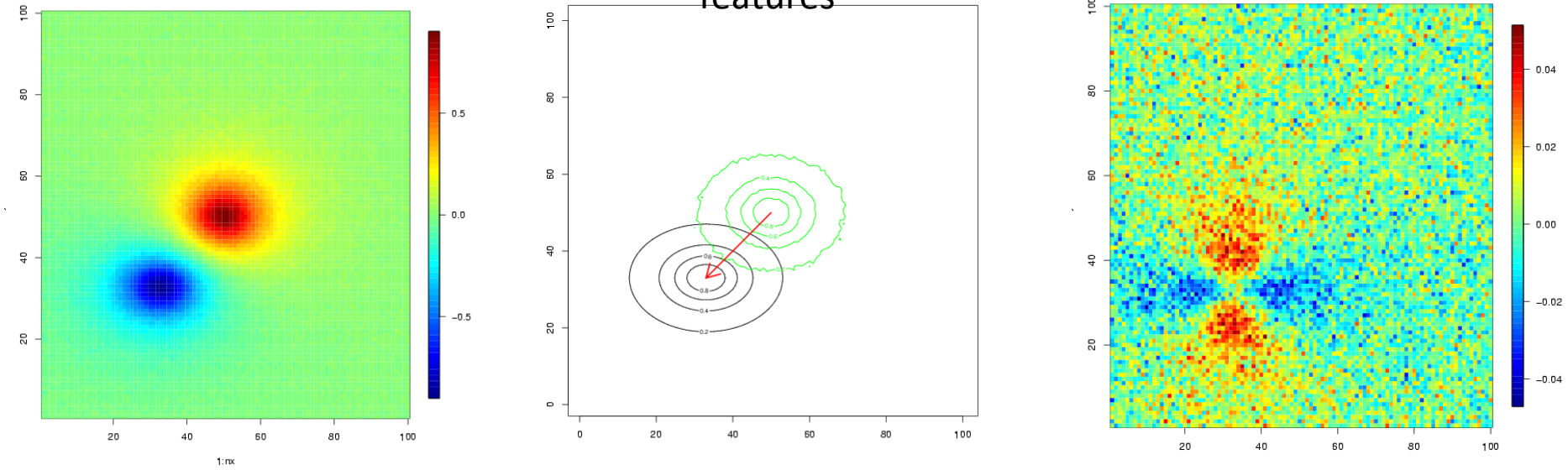
- Feature Calibration and Alignment (FCA):
  - Formulation as a stand-alone procedure
  - Katrina example
  - Other examples: characterization of ensemble spread
  - *2014 MWR article: 142, 2, 686-702*
- Displacements within variational DA
  - Displacement WRFDA (dWRF) formulation
  - Katrina example
  - *MWR article currently under review*
  - Other examples: GOES IR channels
- Conclusions, future work


© Atmospheric and Environmental Research, Inc. (AER), 2014

# Feature Calibration and Alignment (FCA)

- For cloud-related fields, position errors of features are both common and problematical
  - Non-Gaussian error statistics
  - Poor convergence of variational analysis schemes
- FCA represents errors (or differences) in terms of errors of alignment and errors of amplitude and "random" errors
  - Here we do not consider FCA amplitude errors

background error => displacements of coherent features + additive (residual) error





© Atmospheric and Environmental Research, Inc. (AER), 2014

# FCA Formulation

- Based on feature calibration and alignment implementation by Grassotti et al. (1999)
- Derive 2D displacement vectors s by nonlinear minimization of an objective function:

$$J = J_{res}\left(y^{obs}, y^{bg}, \mathbf{s}\right) + J_{pen}\left(\mathbf{s}\right)$$

- Residual errors after adjustment of the background:

$$J_{res} = \sum w_{obs}\left(y^{obs}(\mathbf{r}) - y^{bg}(\mathbf{r}-\mathbf{s})\right)^2$$


© Atmospheric and Environmental Research, Inc. (AER), 2014

# FCA Formulation

- Use a truncated spectral representation of displacements
- Regularization using tunable constraints (penalty functions):

| Constraint | Formula | Gridpoint / Spectral |
|---|---|---|
| Smoothness | $\sum S_x^{-2} \left(\nabla^2 \mathbf{s}\right)^2$ | Spectral |
| Magnitude | $\sum S_x^{-2} \lvert \mathbf{s} \rvert^2$ | Spectral |
| Barrier | $\sum \left(\lvert \mathbf{s} \rvert / S_x\right)^{20}$ | Gridpoint |
| Divergence | $\sum \left(\nabla \mathbf{s}\right)^2$ | Gridpoint |

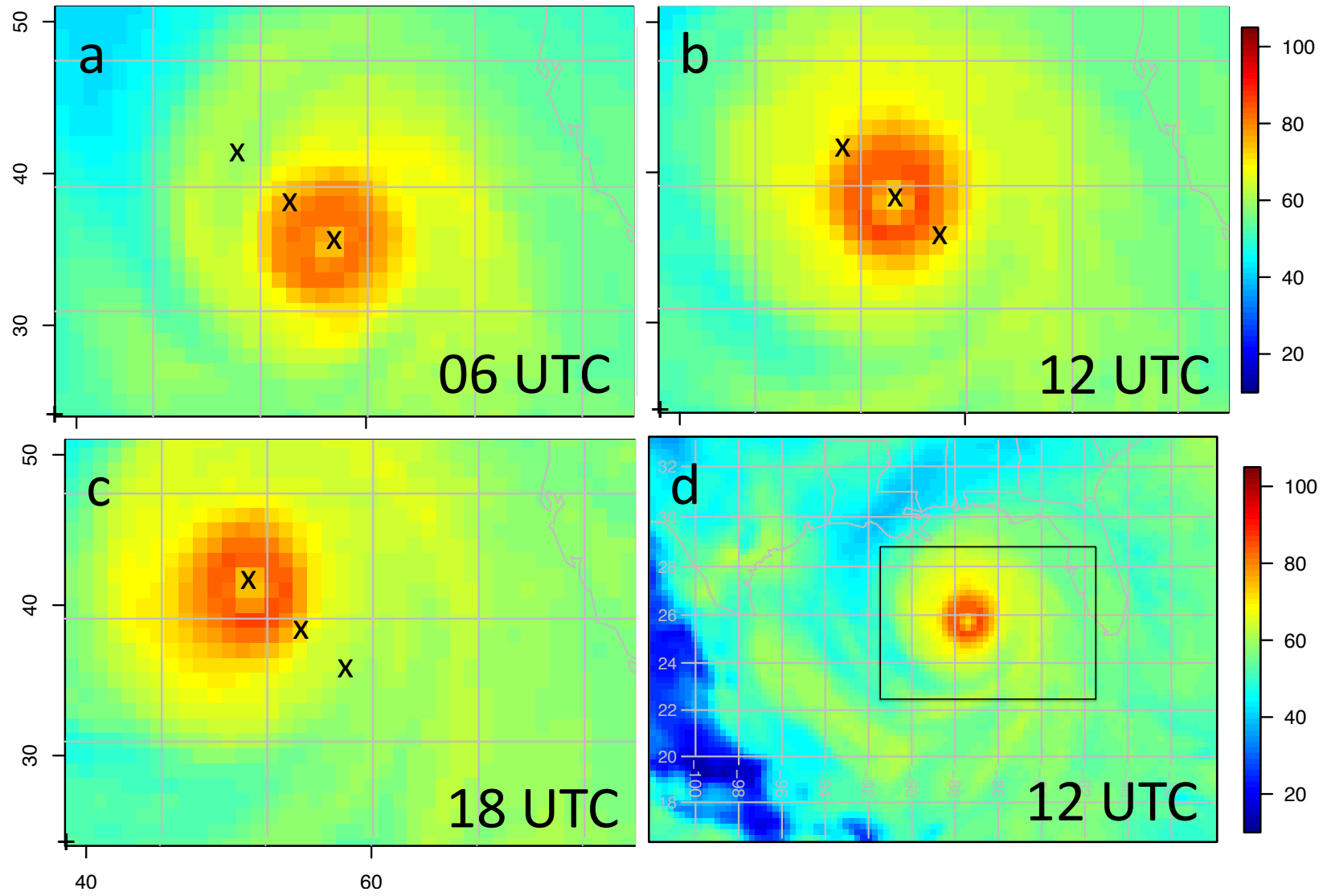

© Atmospheric and Environmental Research, Inc. (AER), 2014

# Katrina example

- Adjusting forecast IC in a perfect model case
  - Nature (Truth): control forecast at 12 UTC
  - Background (First guess): control forecast at 06 UTC
  - 2d fields: integrated water vapor (IWV) from Truth, subsampled (every 3rd grid point)


© Atmospheric and Environmental Research, Inc. (AER), 2014

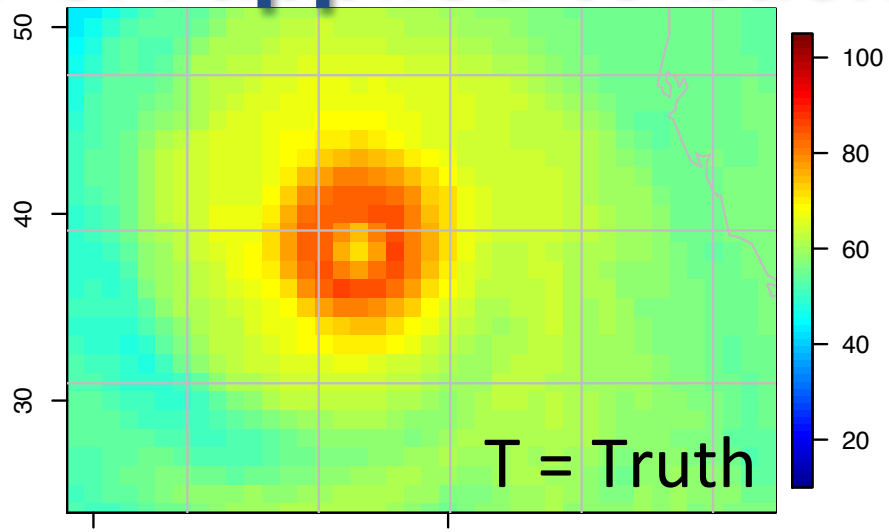
# Katrina simulation IWV (kg/m$^2$) 28 Aug 2005

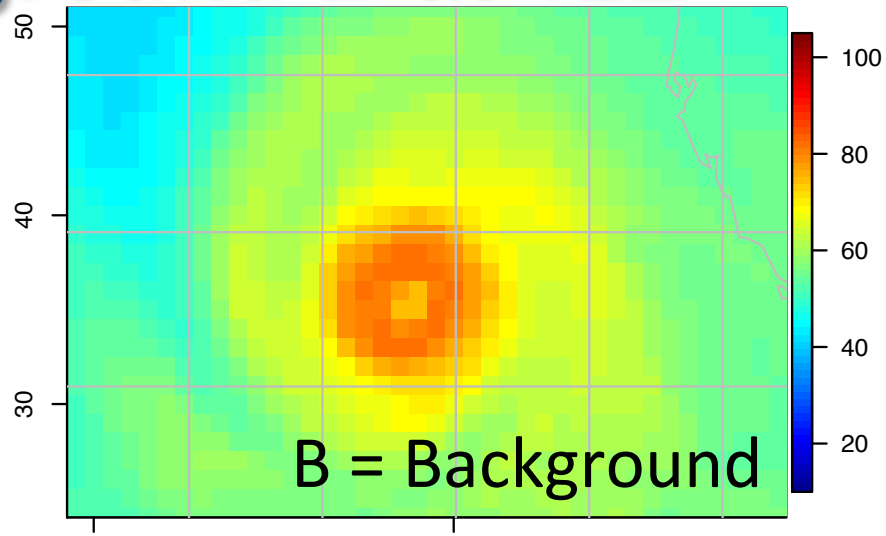


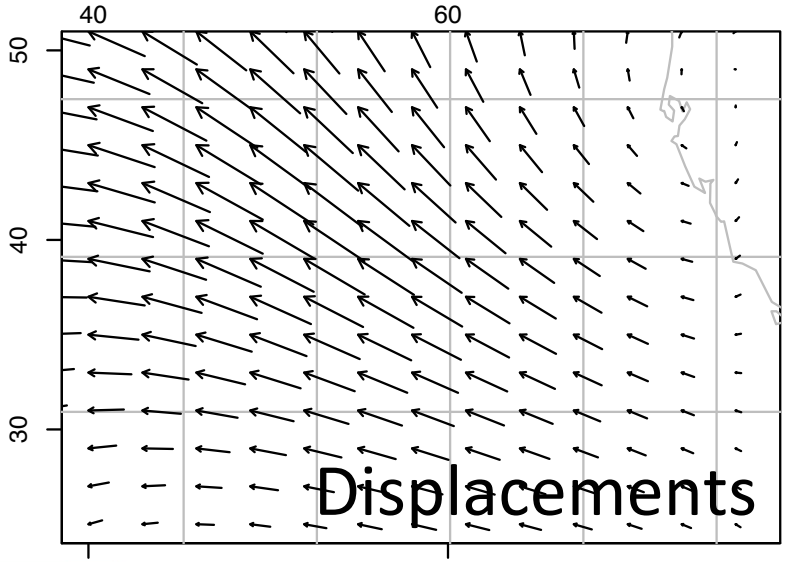

Atmospheric and Environmental Research

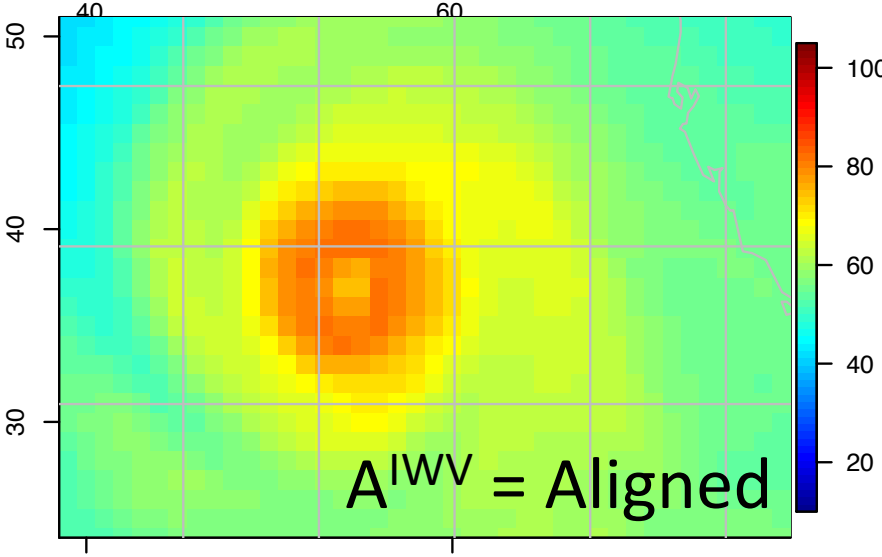
© Atmospheric and Environmental Research, Inc. (AER), 2014

# FCA applied to background B at 12Z



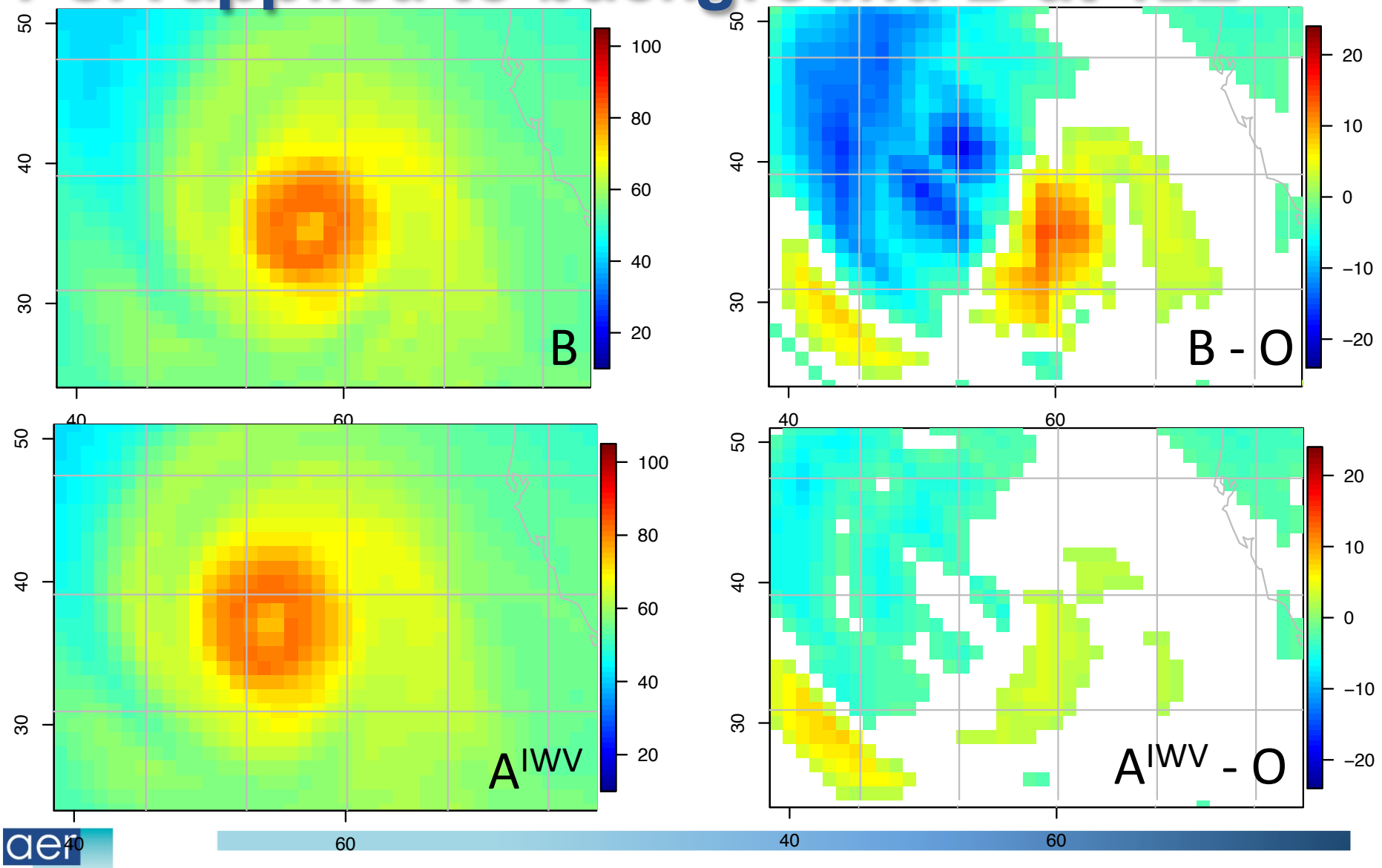





© Atmospheric and Environmental Research, Inc. (AER), 2014

# FCA applied to background B at 12Z





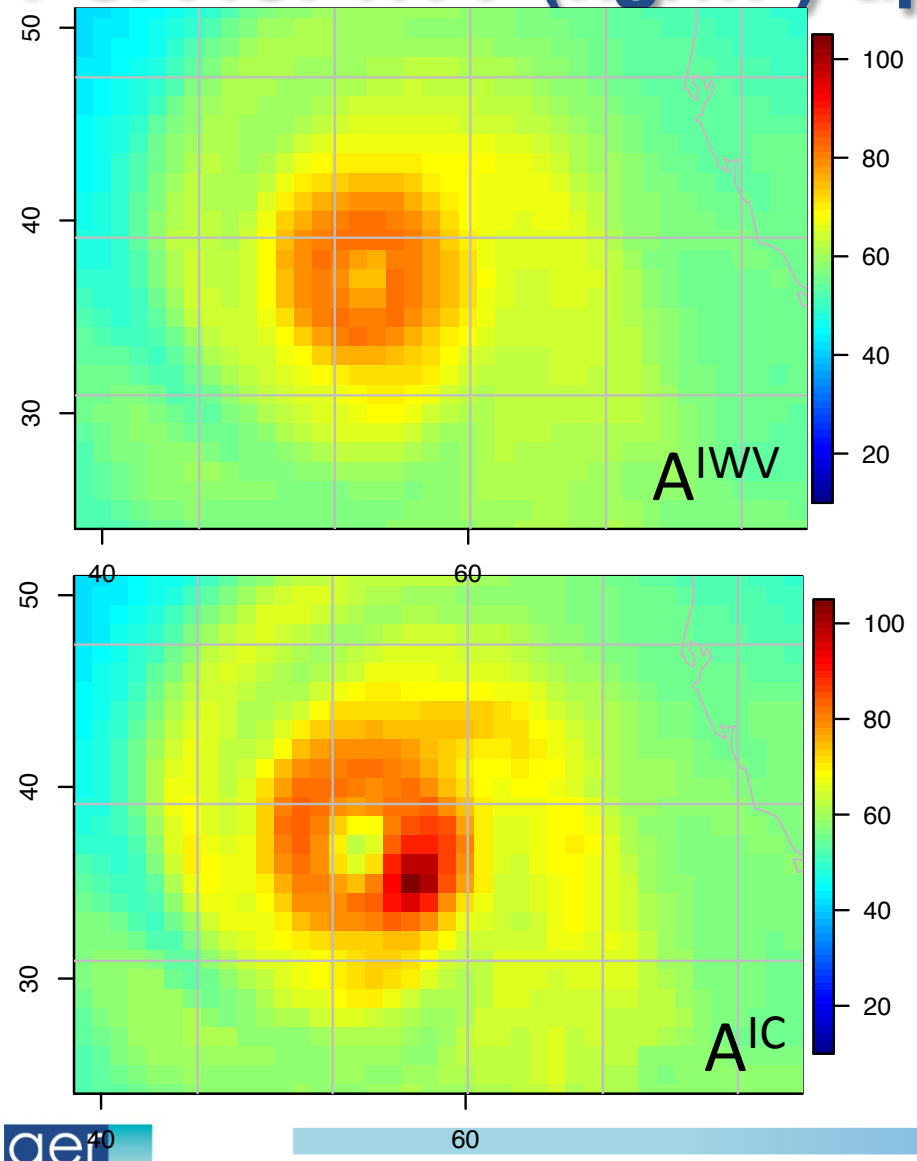
© Atmospheric and Environmental Research, Inc. (AER), 2014

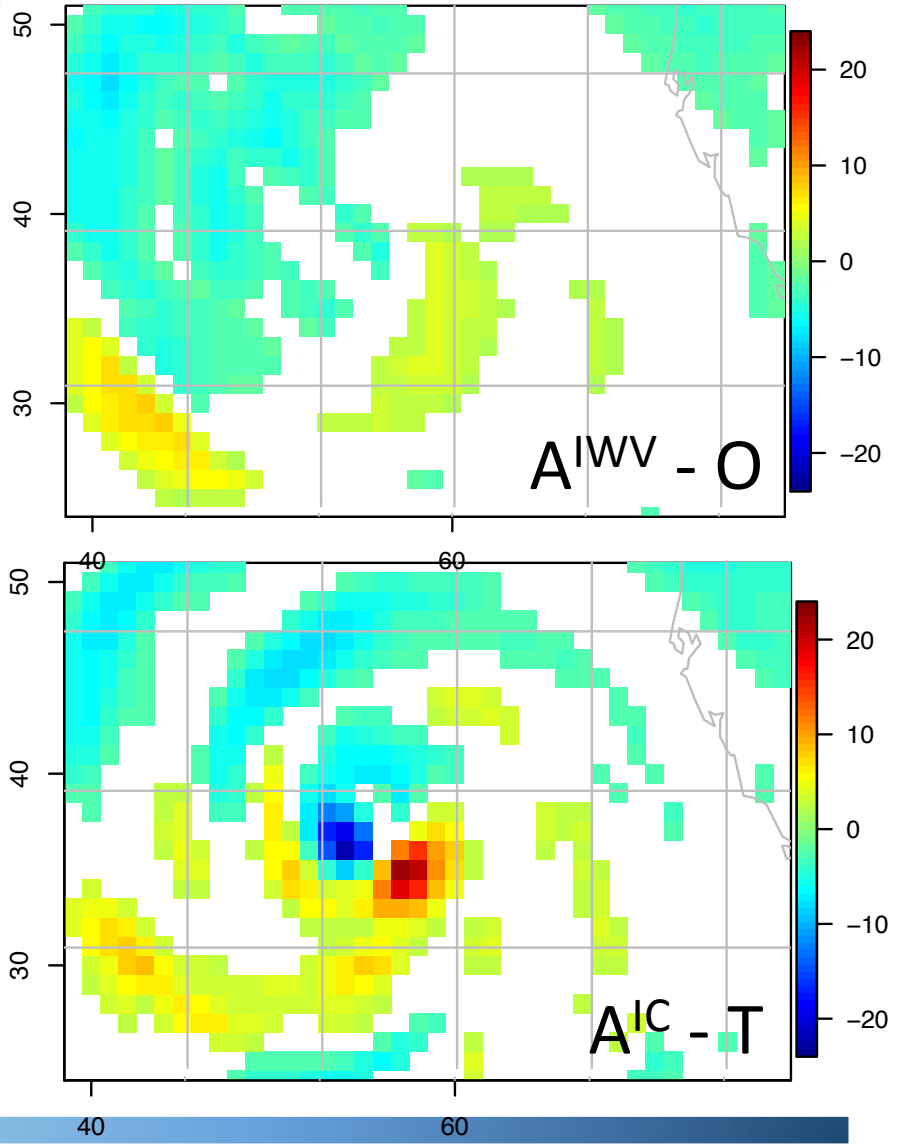
# Extend Hsiao et al. (2010) displacement algorithm for 3d model IC

- Goal is to apply 2d displacement vectors to 3d model fields without disturbing model balance
- Direct displacement of: winds (u,v,w), SLP, RH, hydrometeor mixing ratios, potential temperature
  - All along model surface, except
  - Potential temperature along constant height surfaces
- Recalculate derived quantities: pressure, specific humidity, temperature, hydrostatic geopotential, dry air mass
- Nonhydrostatic geopotential is not displaced


© Atmospheric and Environmental Research, Inc. (AER), 2014

# FCA for IWV (kg/m$^2$) applied to IWV and IC









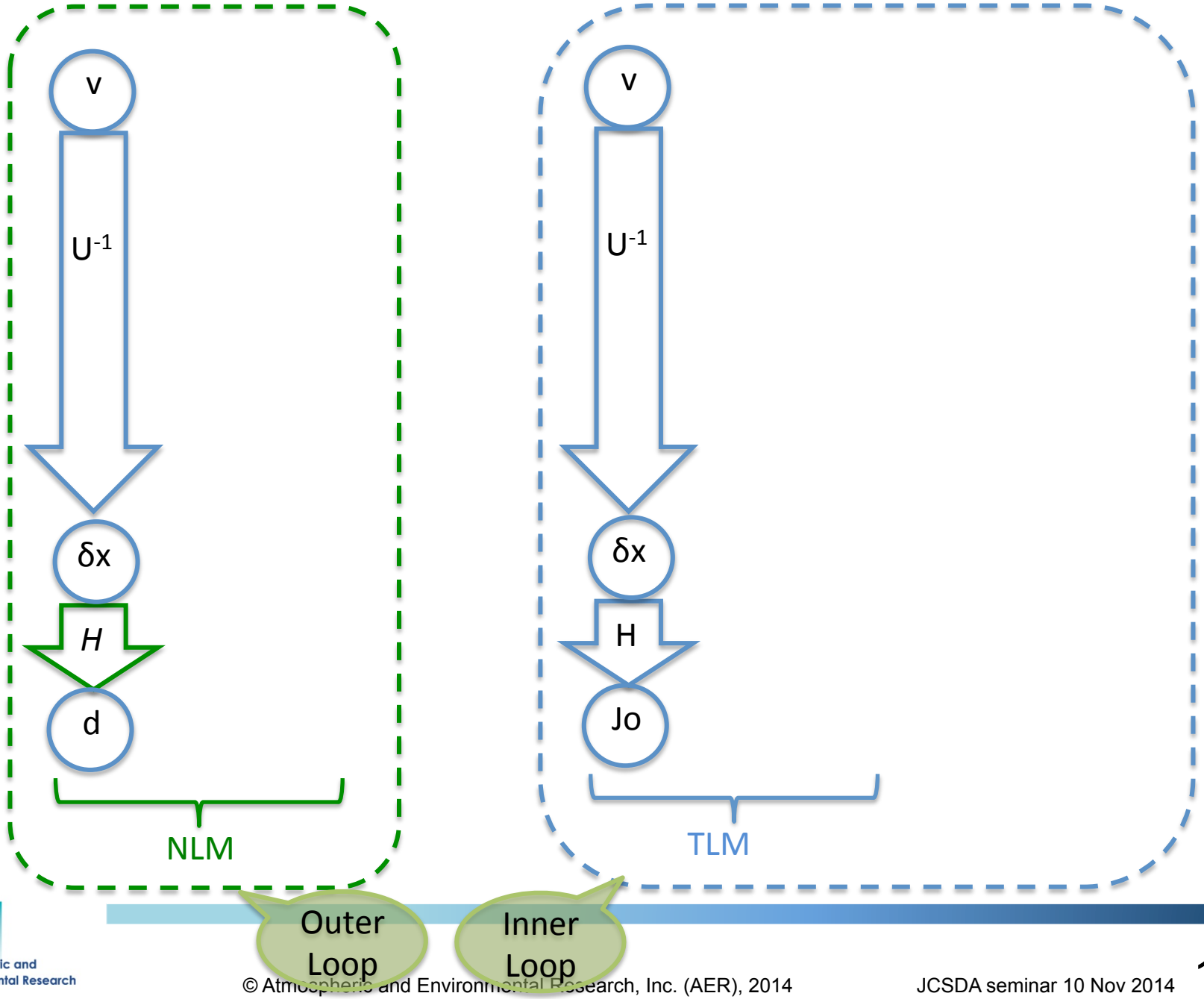

Atmospheric and Environmental Research

© Atmospheric and Environmental Research, Inc. (AER), 2014

# dWRF: Displacements added to WRFDA control vector

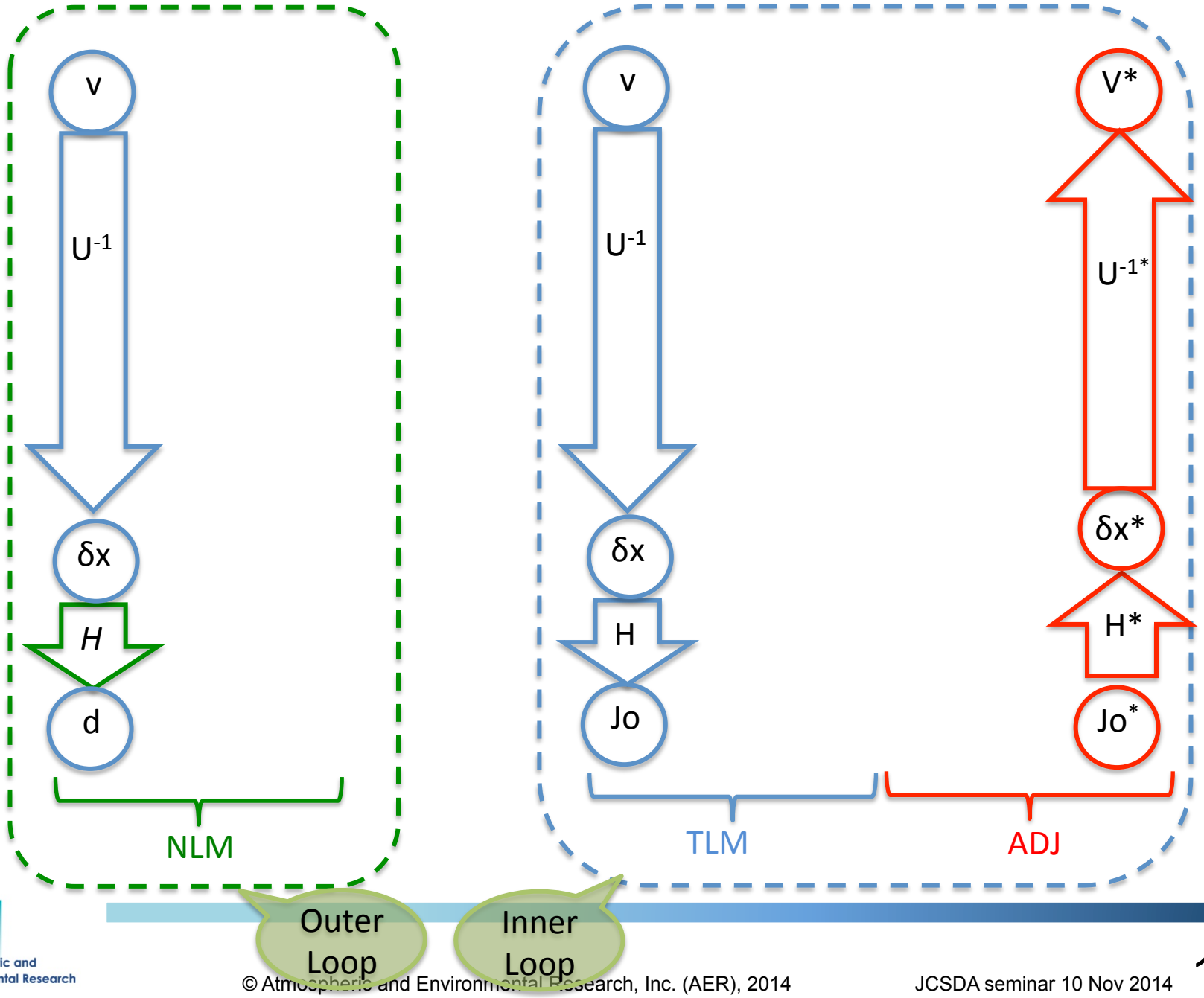
- Hijack u and v for displacements
  - Background function measures size of displacements
  - Examples shown use simple rescaling of error covariances for winds
- Apply displacement to 3-d model fields
  - Parallel implementation, inner loop linearized about current estimate of the displacements
- Otherwise standard 3dvar
  - Usual control variable, but only mid-level u, v are active
  - Existing minimization
    - Conjugate gradient in inner loop with linearized displacements; nonlinear adjustments in outer loop
  - Existing obs operators
    - Therefore this approach is applicable to all obs types supported by WRF Variational DA
    - Following example uses simulated GPS PW


© Atmospheric and Environmental Research, Inc. (AER), 2014



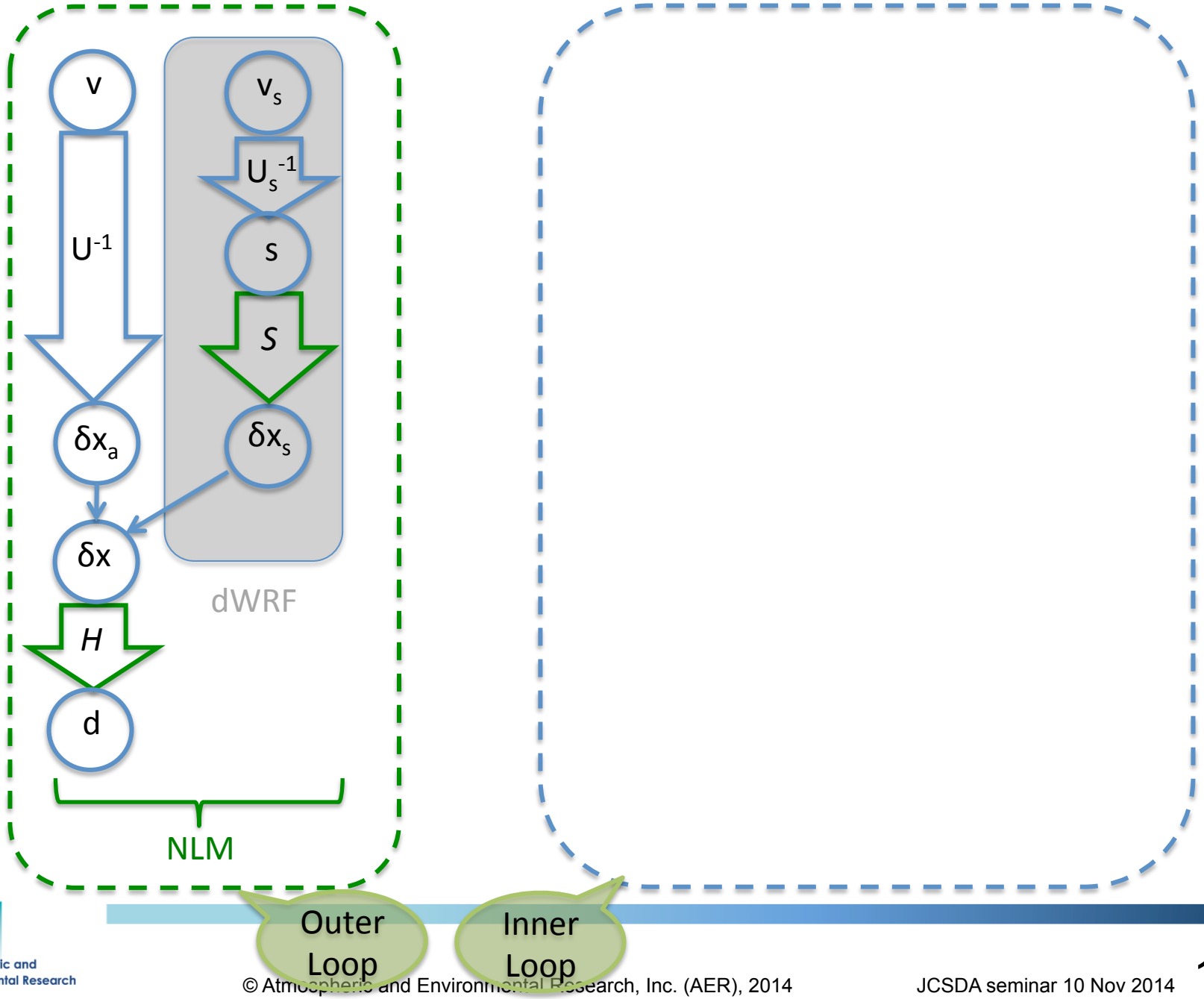


© Atmospheric and Environmental Research, Inc. (AER), 2014



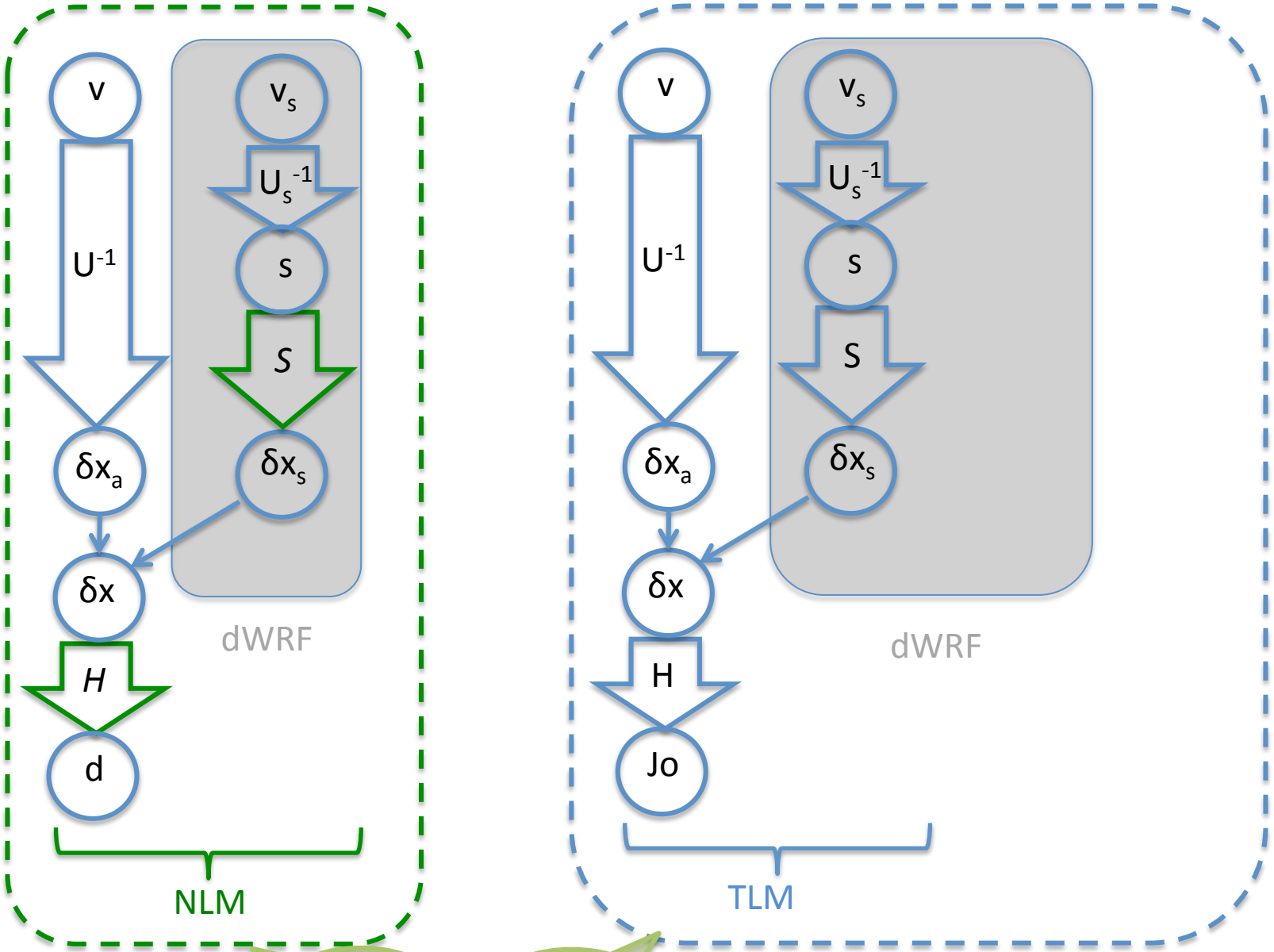


© Atmospheric and Environmental Research, Inc. (AER), 2014



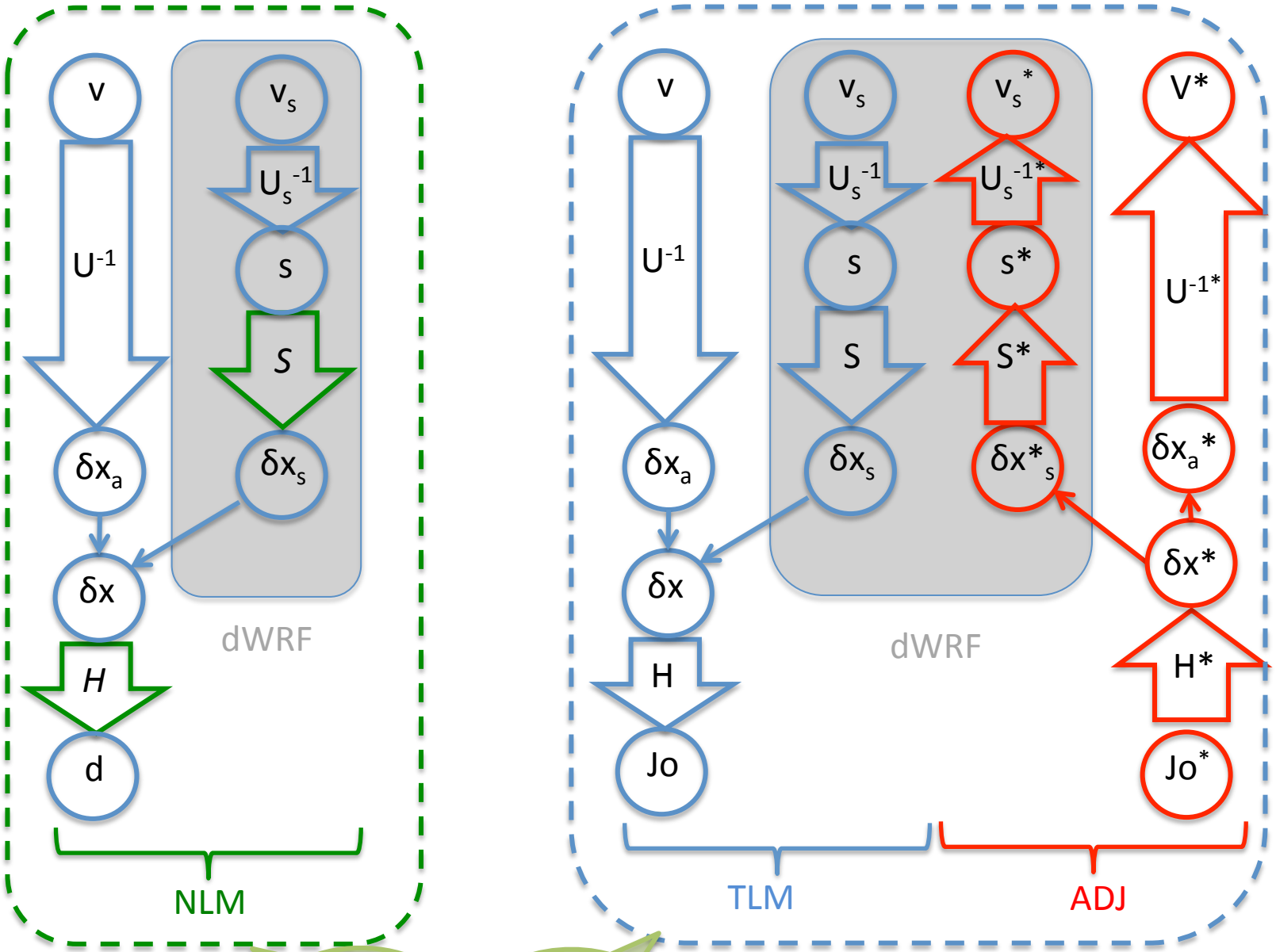


© Atmospheric and Environmental Research, Inc. (AER), 2014



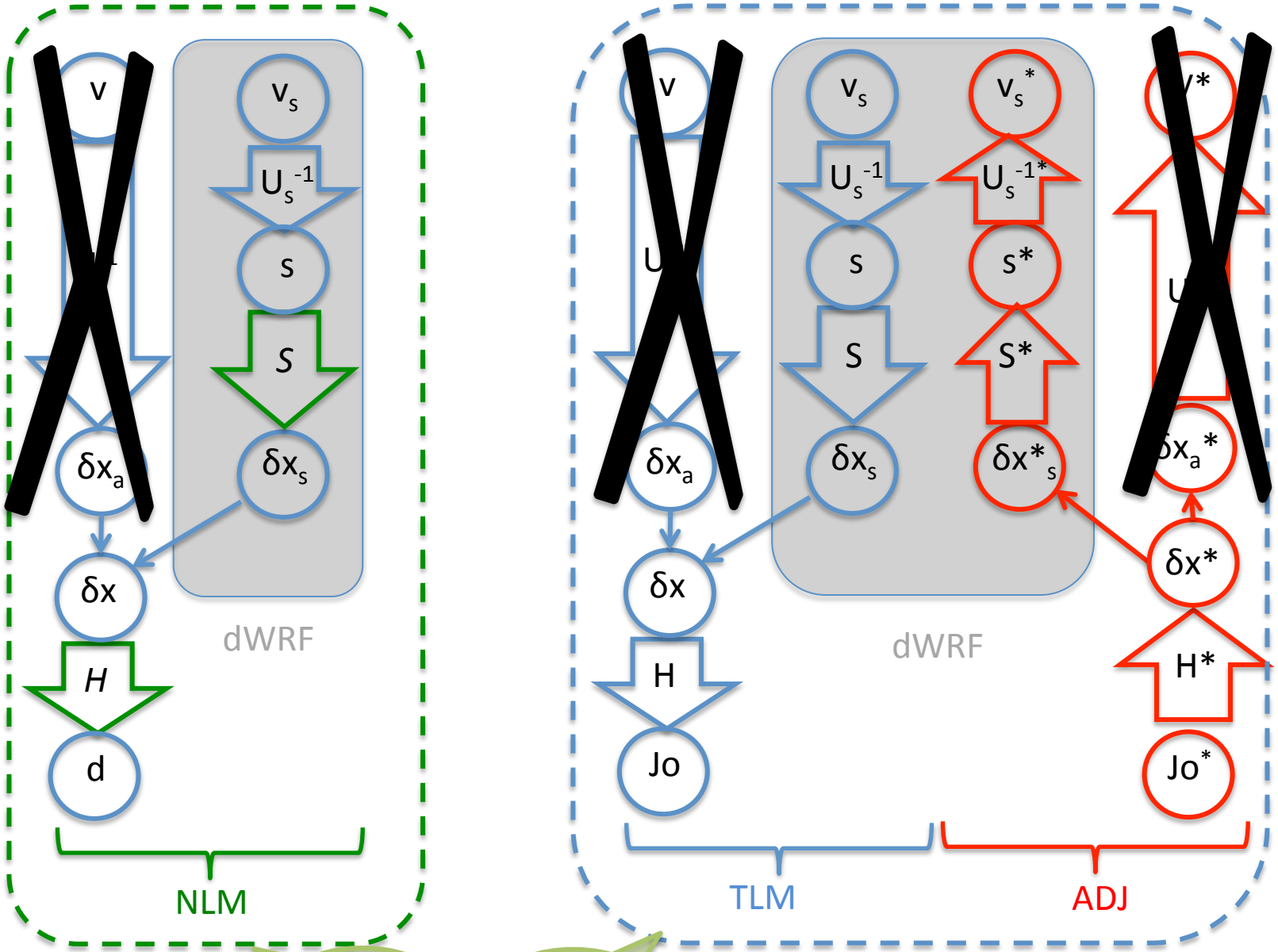


© Atmospheric and Environmental Research, Inc. (AER), 2014





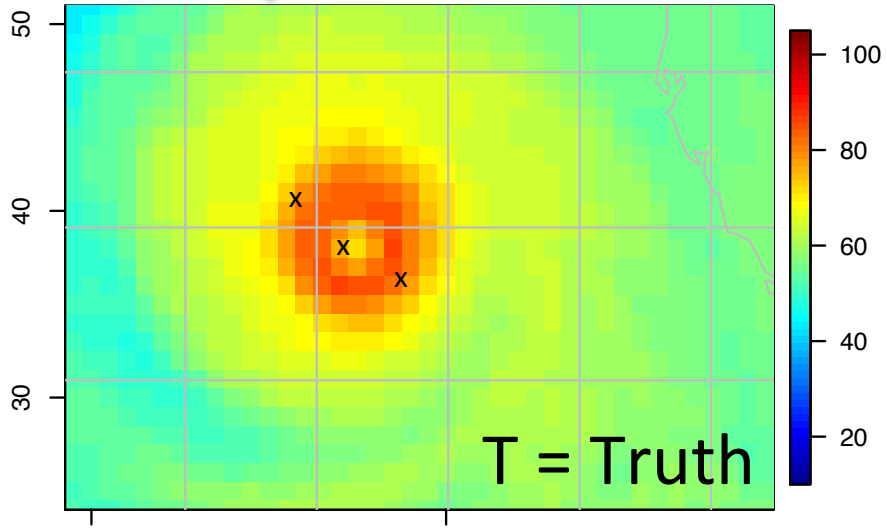
© Atmospheric and Environmental Research, Inc. (AER), 2014

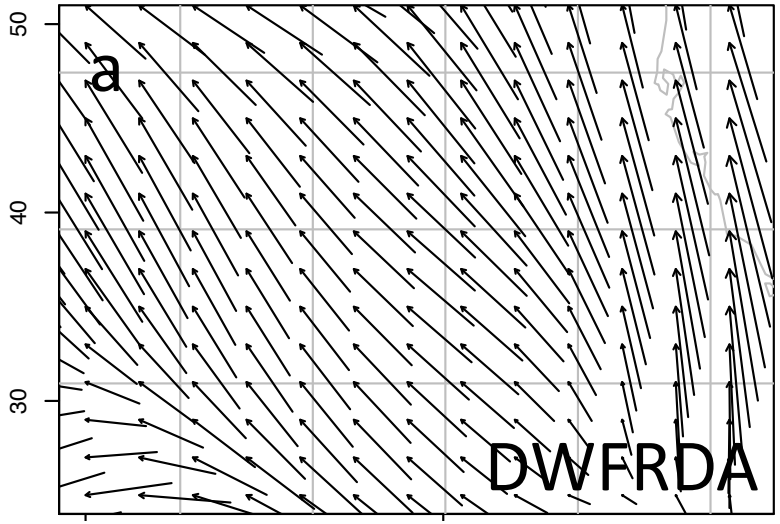


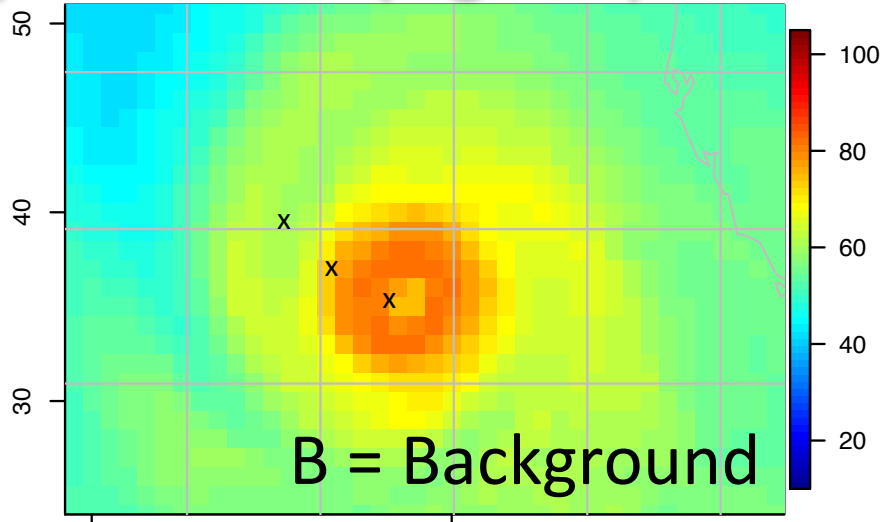


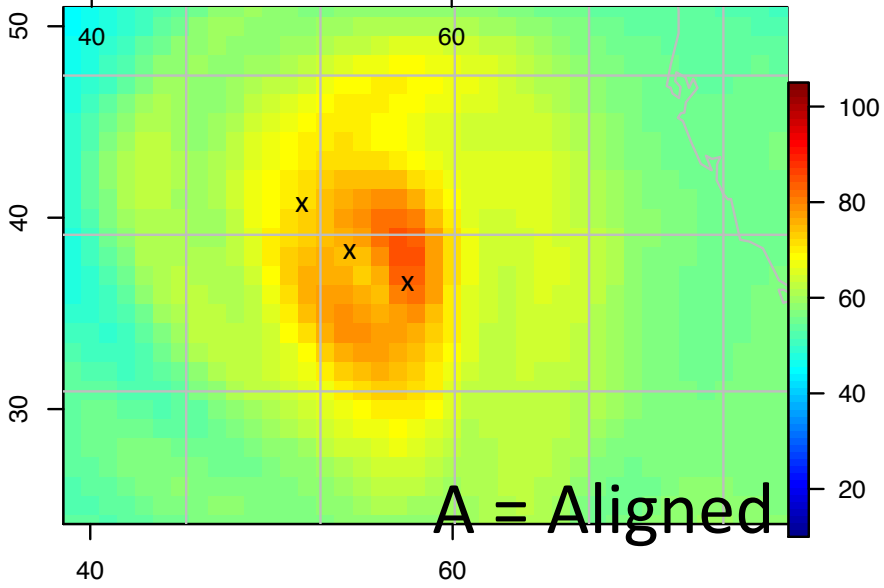
© Atmospheric and Environmental Research, Inc. (AER), 2014

# dWRF (FCA via WRFDA) for IWV (kg/m$^2$)



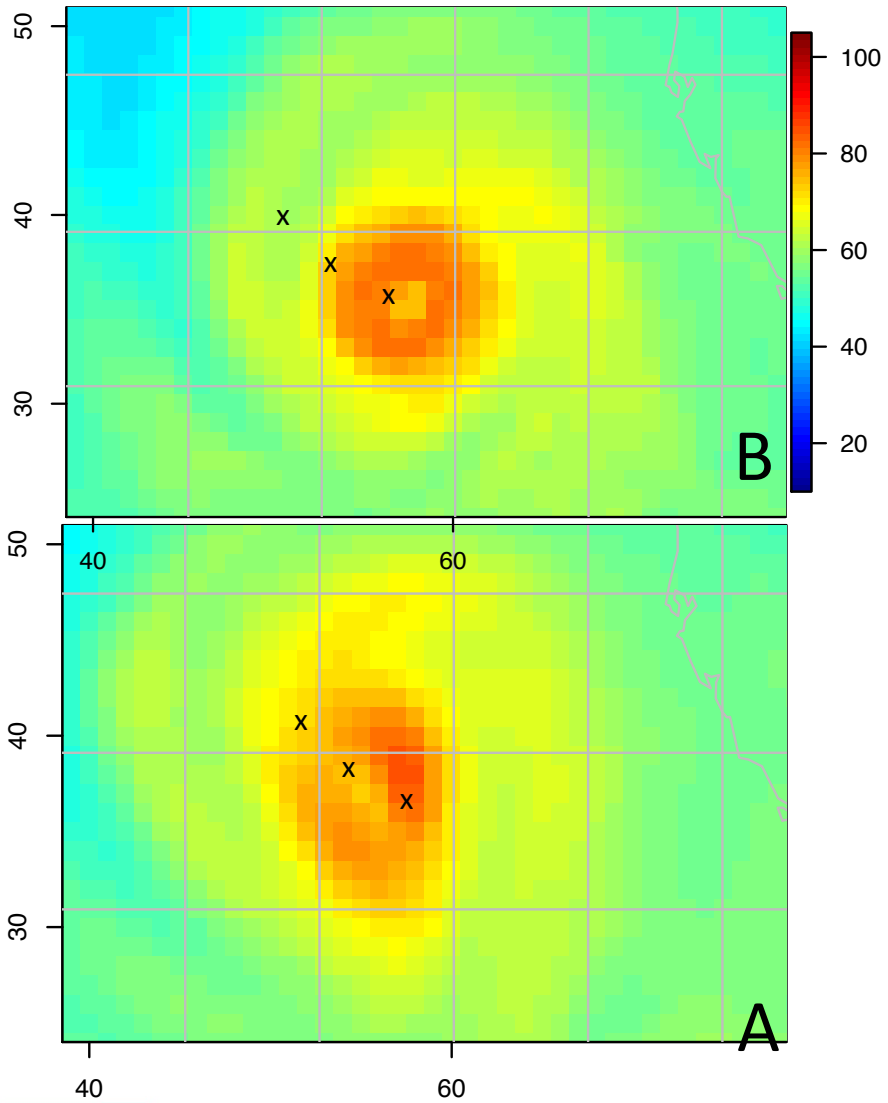



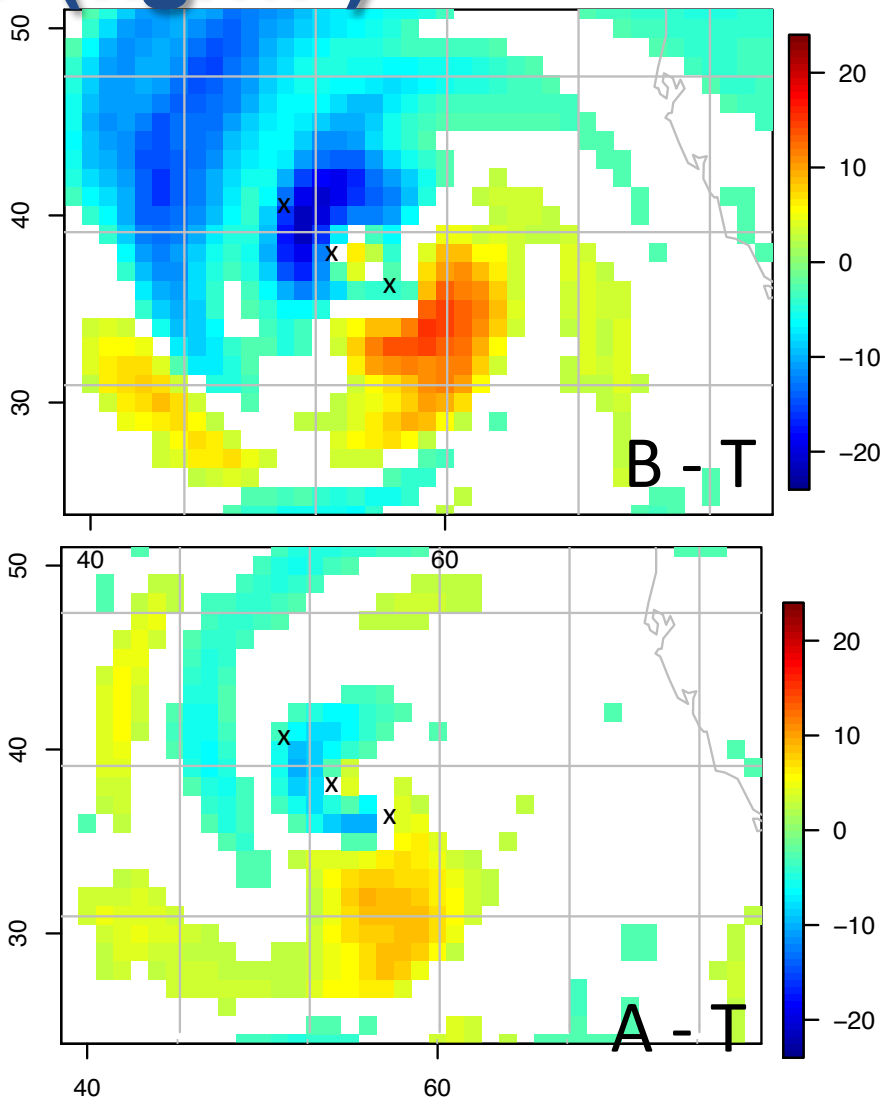





© Atmospheric and Environmental Research, Inc. (AER), 2014

# Katrina dWRF for IWV (kg/m$^2$)

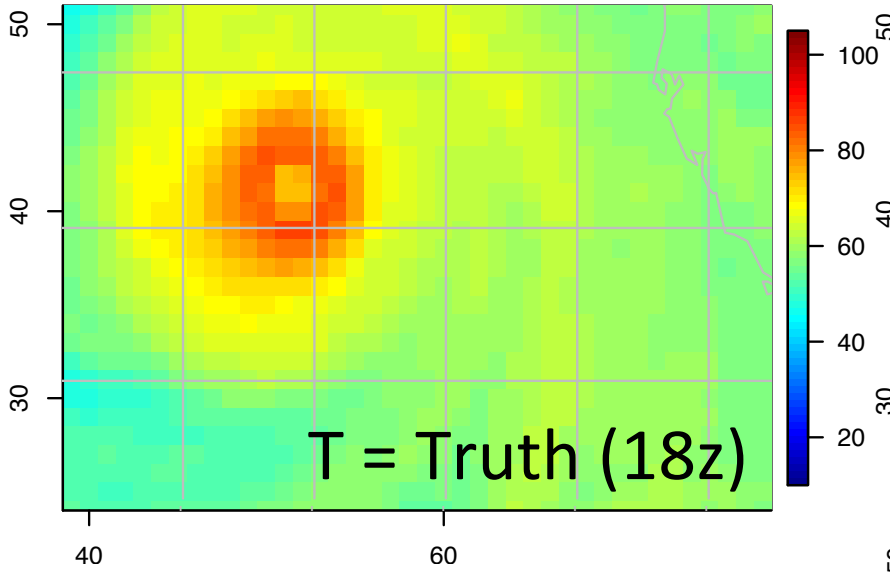


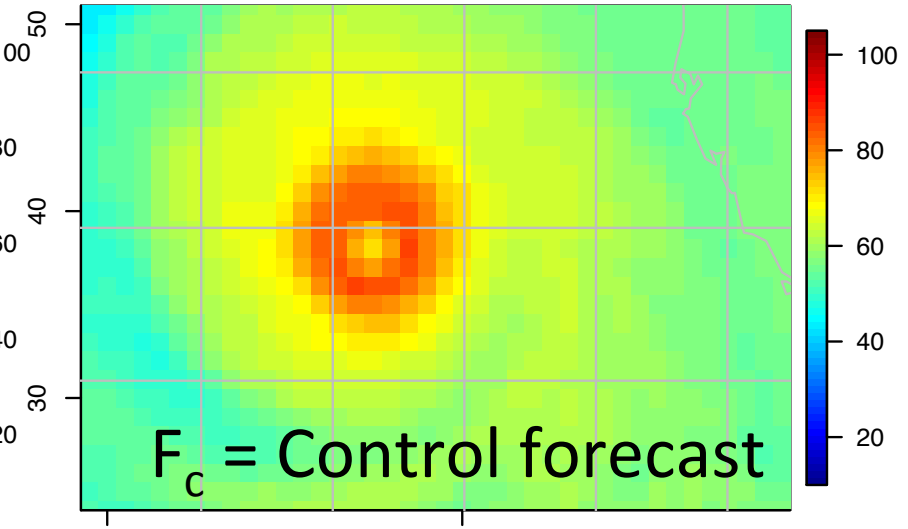



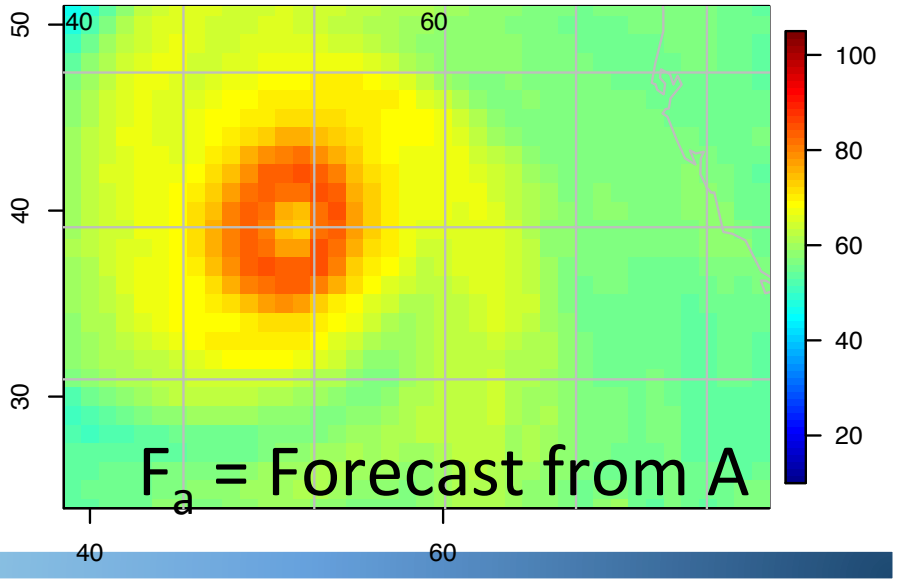



© Atmospheric and Environmental Research, Inc. (AER), 2014

# Katrina dWRF 6-h forecasts IWV (kg/m$^2$)



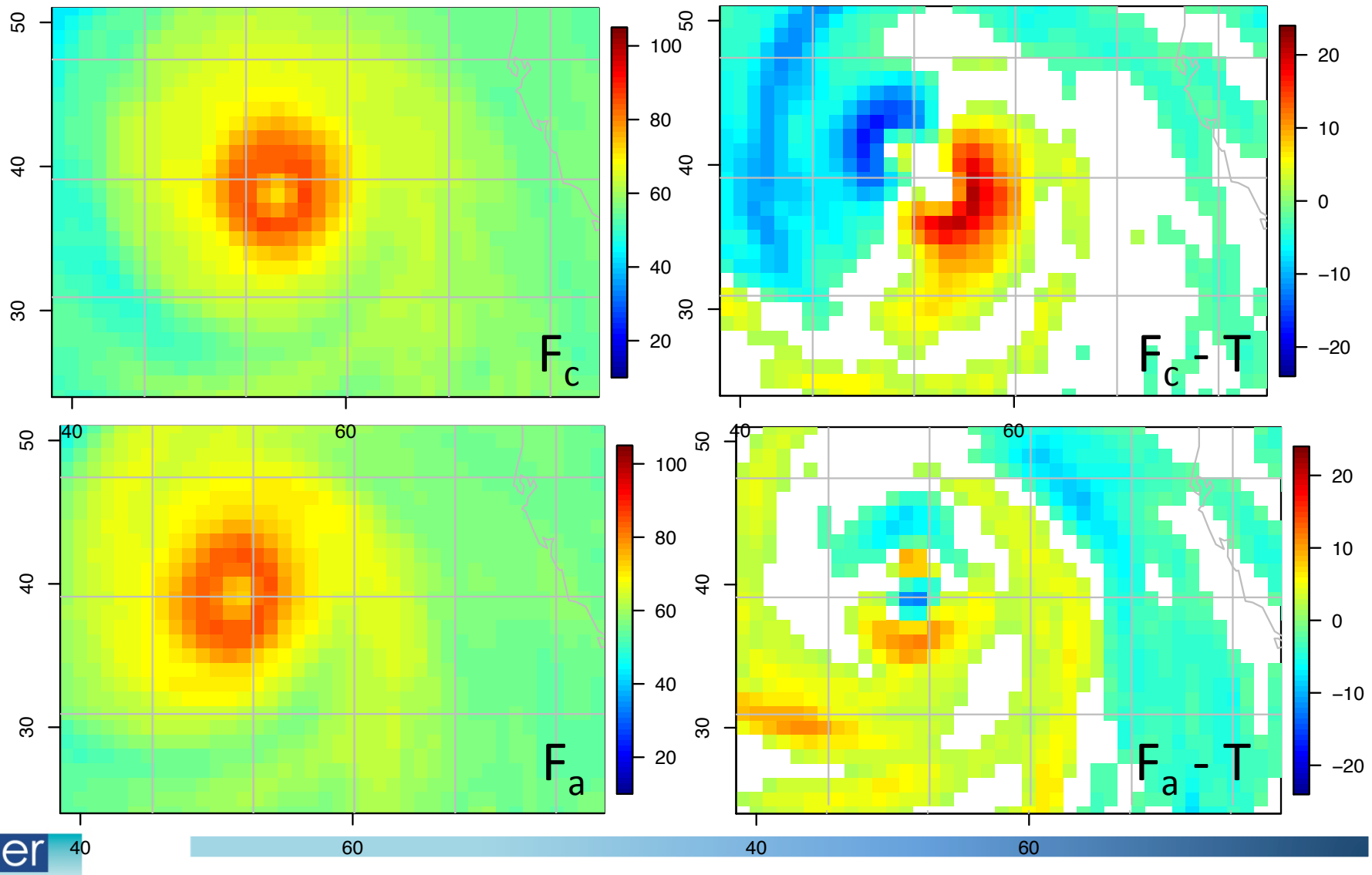





© Atmospheric and Environmental Research, Inc. (AER), 2014

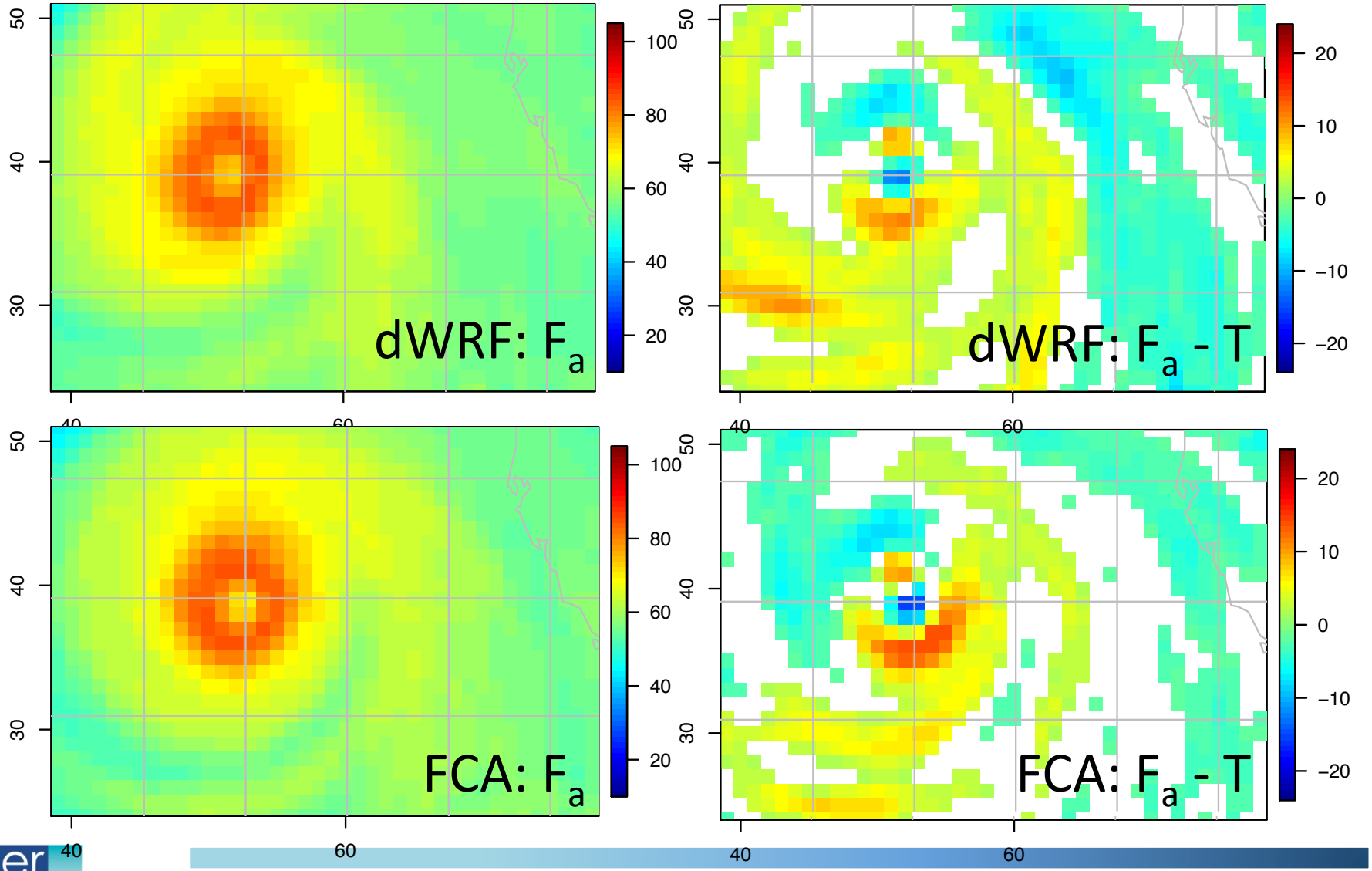
# Katrina dWRF 6-h forecasts IWV (kg/m$^2$)






© Atmospheric and Environmental Research, Inc. (AER), 2014

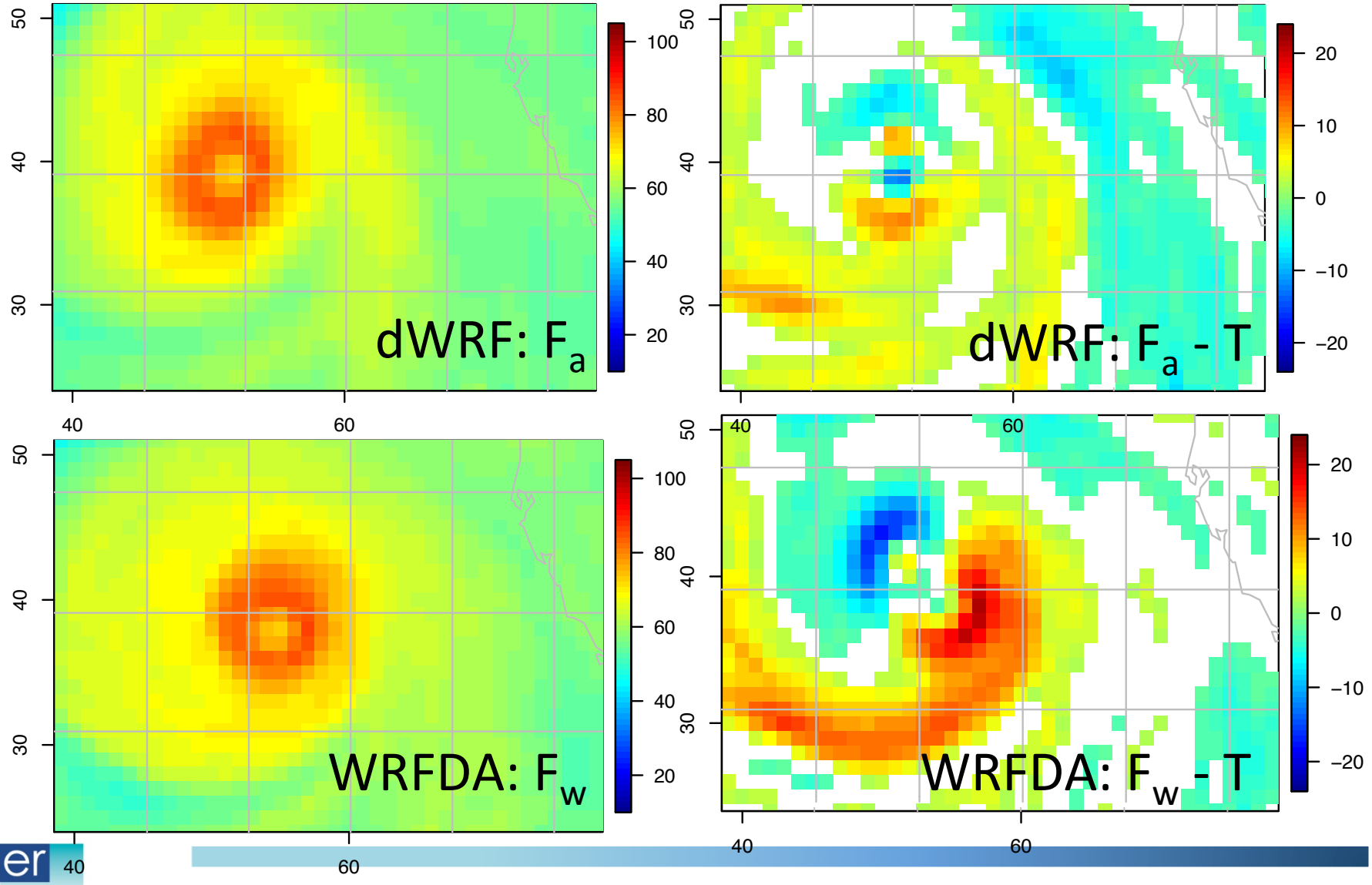
# Katrina dWRF/FCA 6-h forecasts IWV





© Atmospheric and Environmental Research, Inc. (AER), 2014

# Katrina dWRF/WRFDA 6-h forecasts IWV





© Atmospheric and Environmental Research, Inc. (AER), 2014

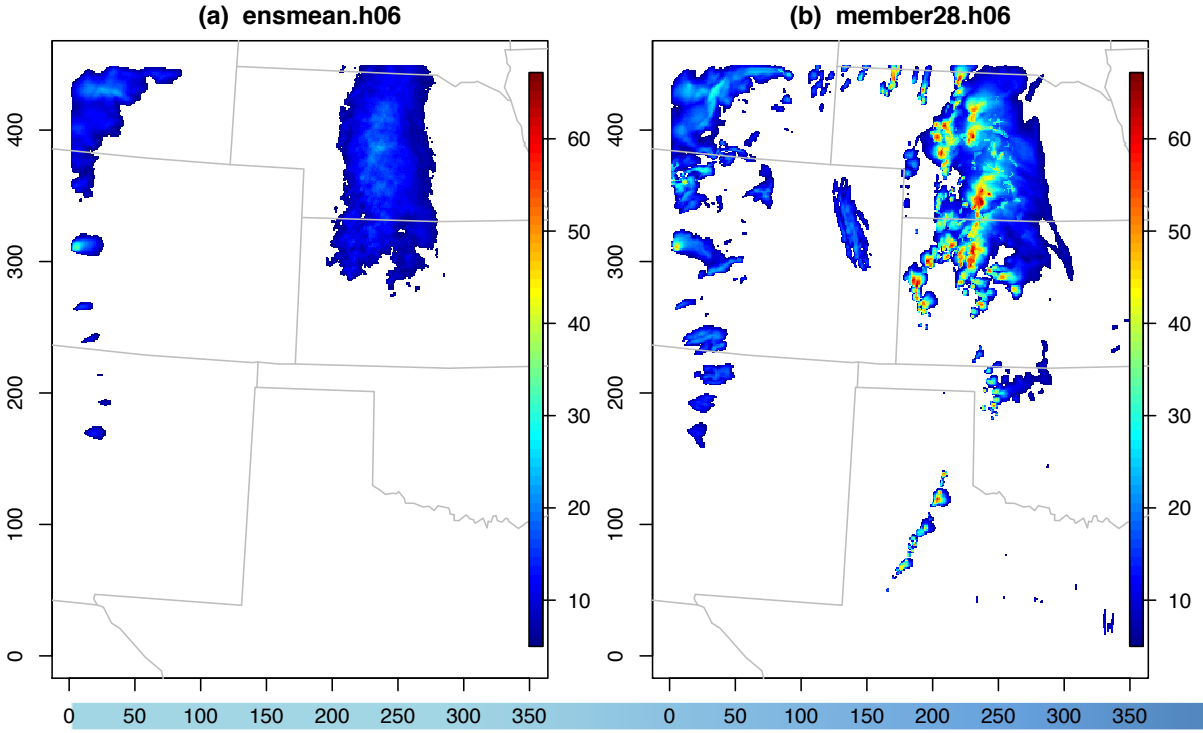
# Conclusions

- 2d FCA displacements can be applied to a full model state
- Standard 3dVAR of u and v can be hijacked to yield displacements
  - Nominal covariances for u and v are satisfactory in TC case
- Using GPS PW data in dWRF results in
  - comparable forecast improvement relative to using IWV in stand alone FCA
  - much better forecast improvement than using IWV in standard WRFDA 3dvar
- FCA can explain a sizeable fraction (>10%) of variance for a background ensemble of radar observations (dBZ)


© Atmospheric and Environmental Research, Inc. (AER), 2014

# FCA and ensemble errors for composite reflectivity (dBZ)

- FCA reduces variance and increases spatial scales of errors
- 30 member background ensemble of 6-h 3-km WRF forecasts valid 04 UTC 28 Mar 2007
- Use ensemble median in place of ensemble mean to preserve small scale detail

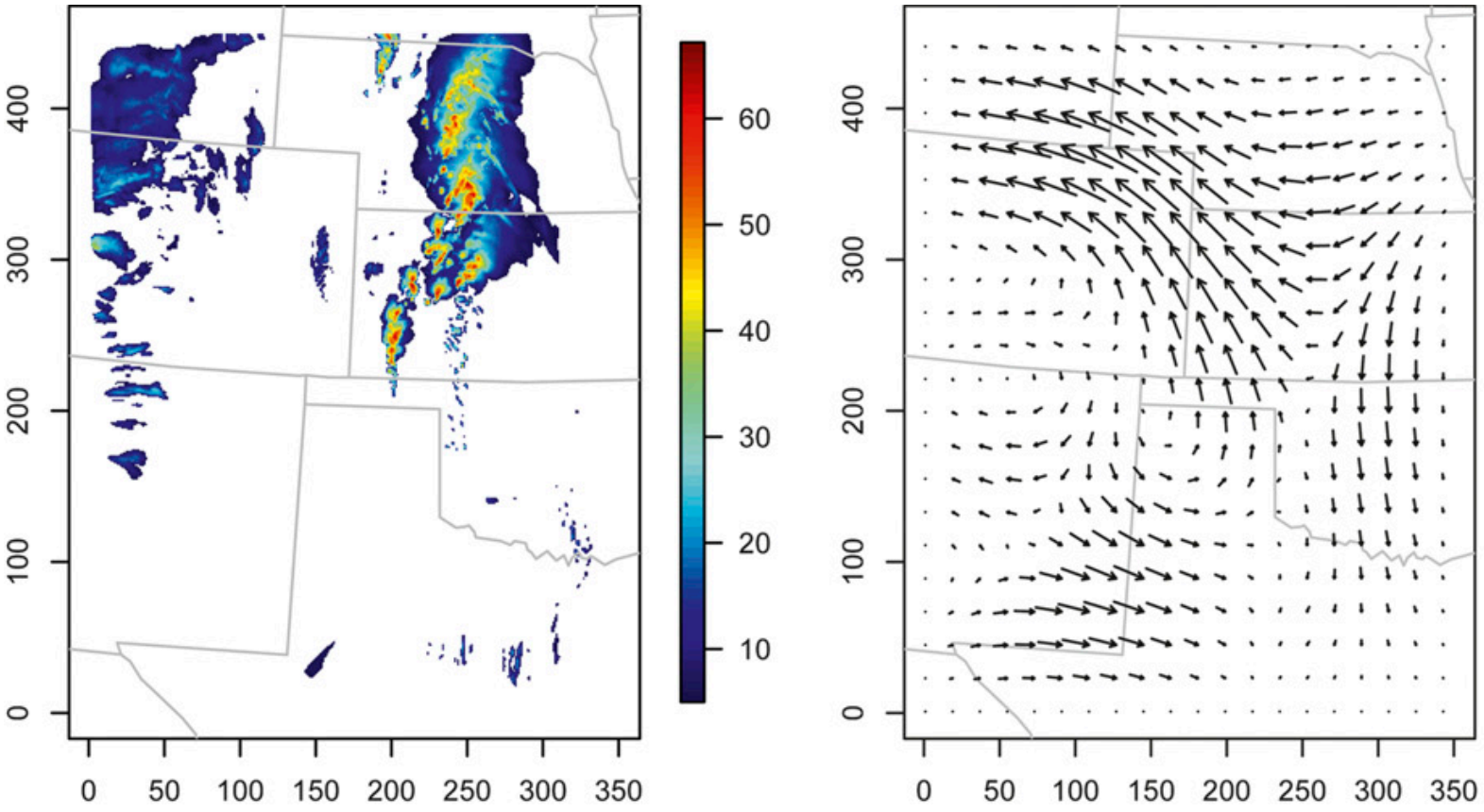




© Atmospheric and Environmental Research, Inc. (AER), 2014

# FCA and ensemble errors for composite reflectivity (dBZ)

- Use FCA to displace each ensemble member, using the ensemble median member as “truth”

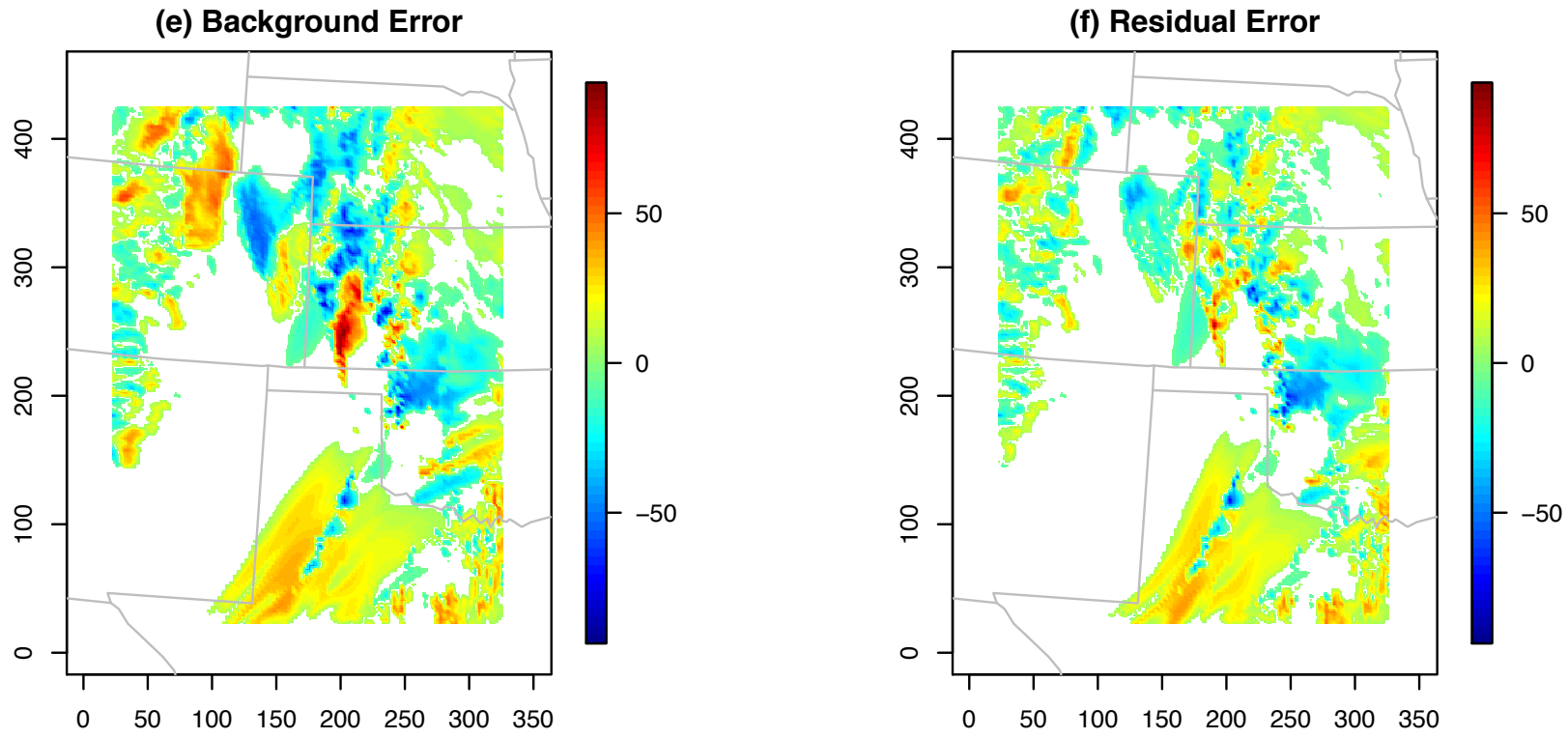




© Atmospheric and Environmental Research, Inc. (AER), 2014

# FCA and ensemble errors for composite reflectivity (dBZ)

- Use FCA to displace each ensemble member, using the ensemble median member as “truth”

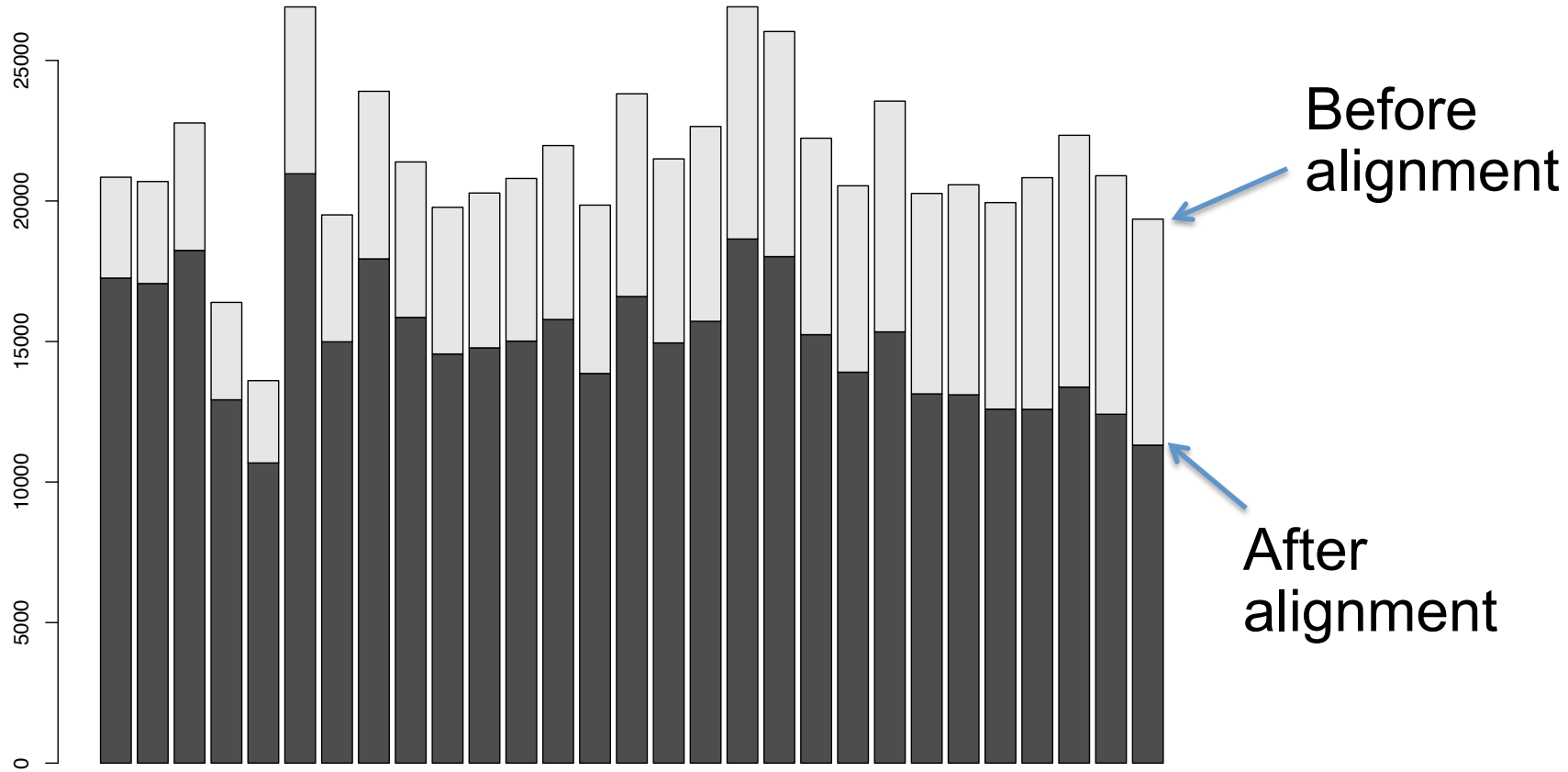




© Atmospheric and Environmental Research, Inc. (AER), 2014

# FCA and ensemble errors for composite reflectivity (dBZ)

- FCA reduces distance from median for each ensemble member (by varying degrees)

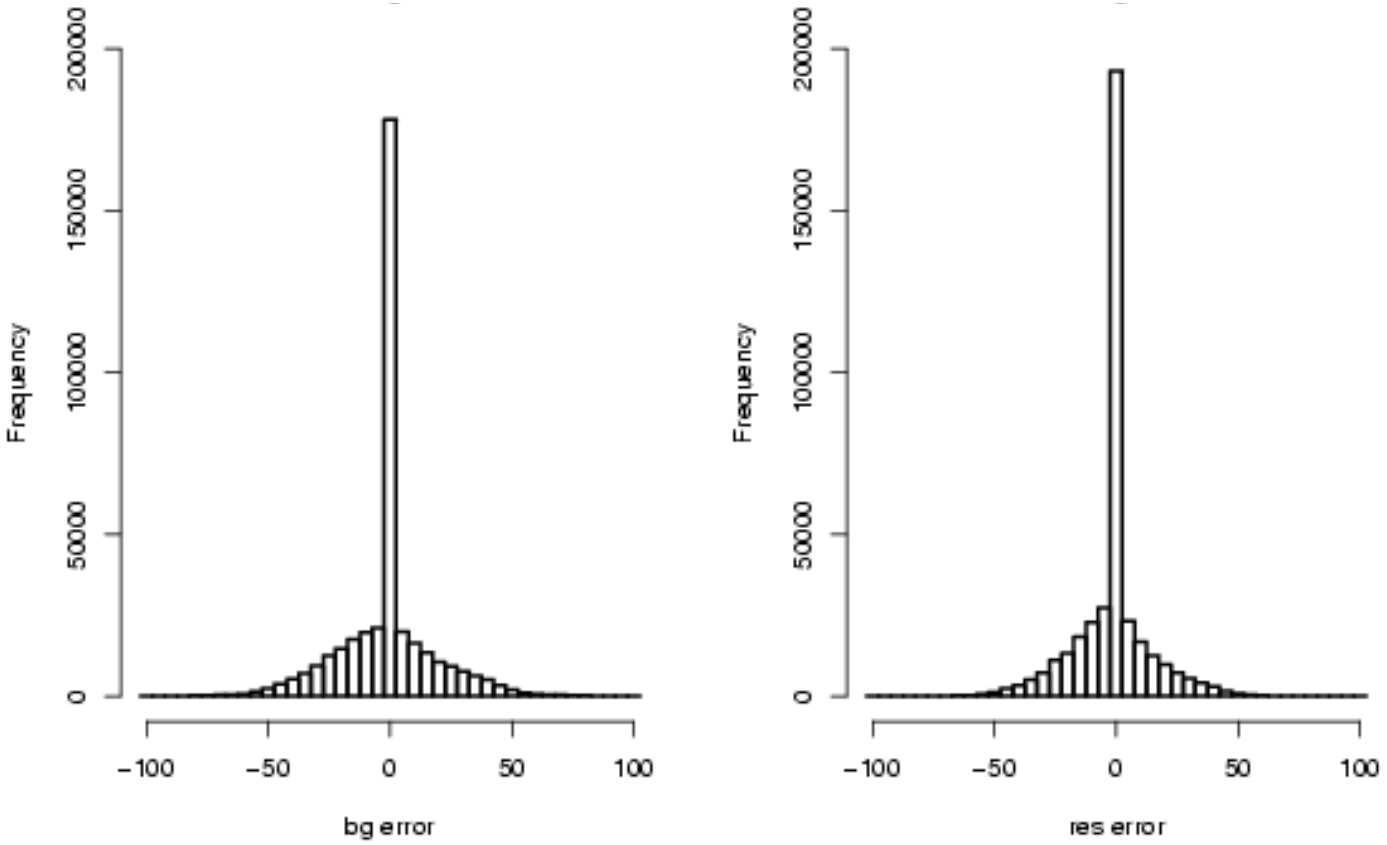




© Atmospheric and Environmental Research, Inc. (AER), 2014

# FCA and ensemble errors for composite reflectivity (dBZ)

- FCA reduces variance of dBZ:
  - thinner tails

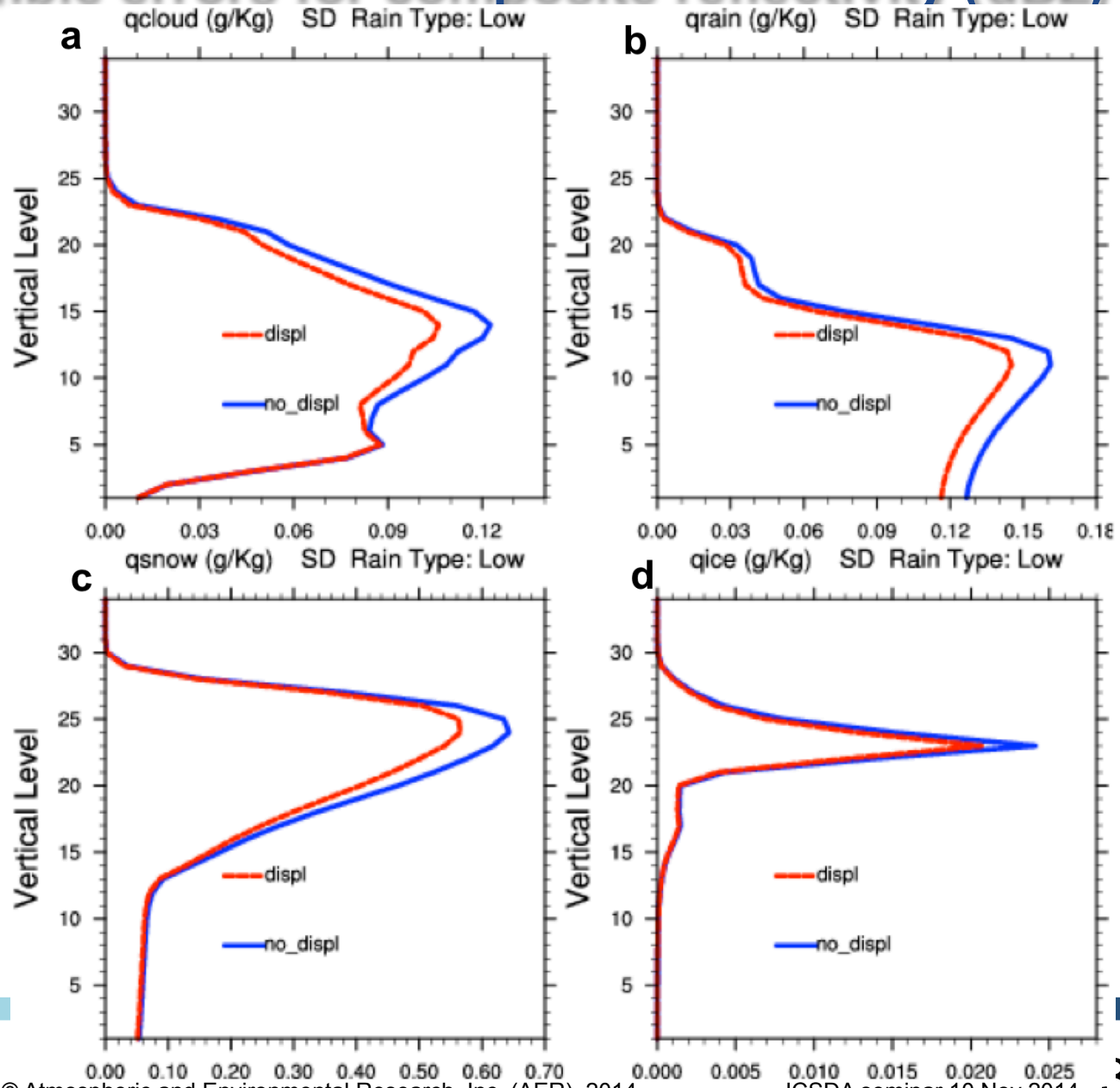




© Atmospheric and Environmental Research, Inc. (AER), 2014

# FCA and ensemble errors for composite reflectivity (dBZ)

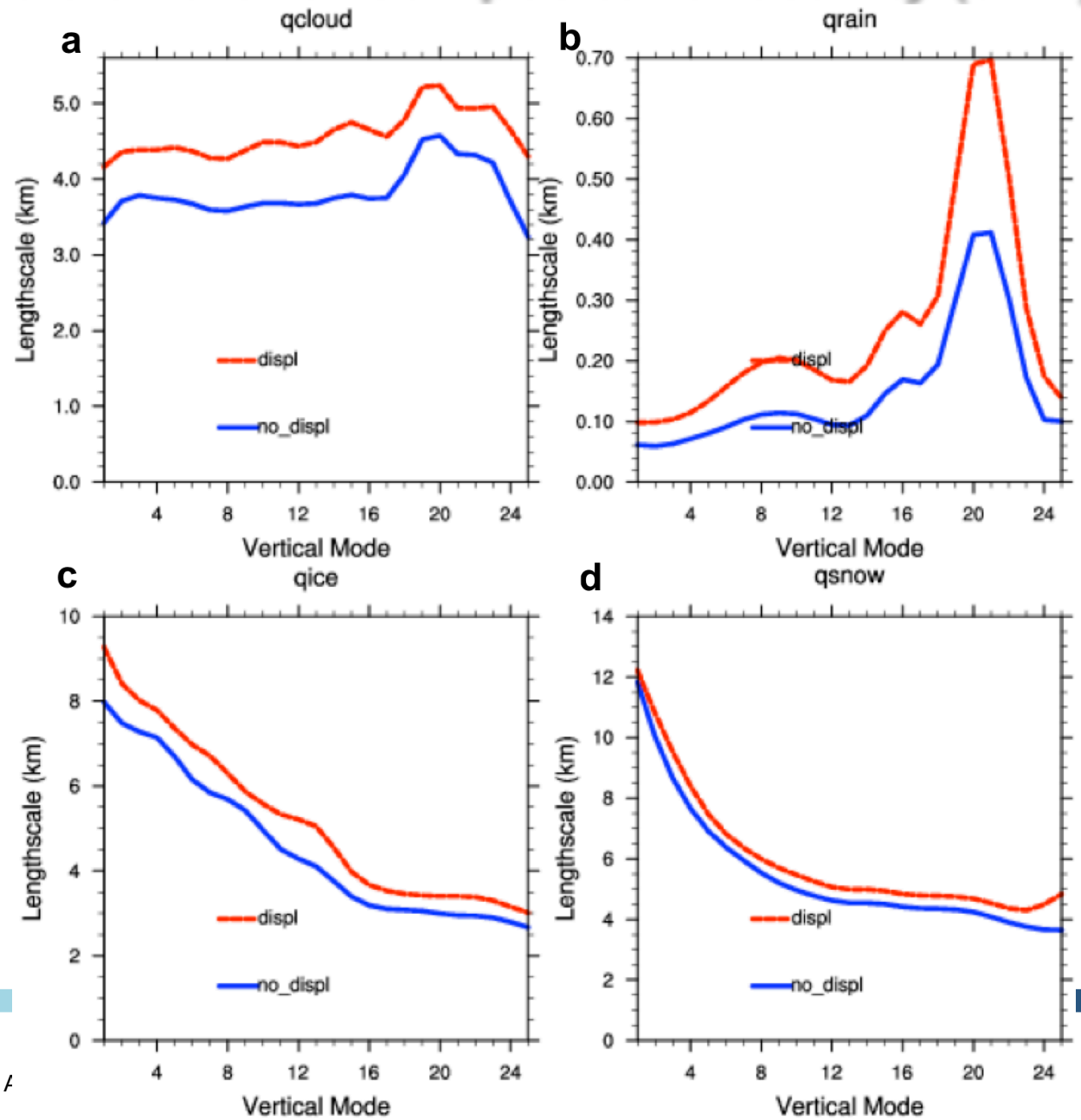
FCA reduces variance of cloud liquid, rain, ice, snow




© Atmospheric and Environmental Research, Inc. (AER), 2014

# FCA and ensemble errors for composite reflectivity (dBZ)

FCA increases correlation length scales



# Conclusions

- 2d FCA displacements can be applied to a full model state
- Standard 3dVAR of u and v can be hijacked to yield displacements
  - Nominal covariances for u and v are satisfactory in TC case
- Using GPS PW data in dWRF results in
  - comparable forecast improvement relative to using IWV in stand alone FCA
  - much better forecast improvement than using IWV in standard WRFDA 3dvar
- FCA can explain a sizeable fraction (>10%) of variance for a background ensemble of radar observations (dBZ)

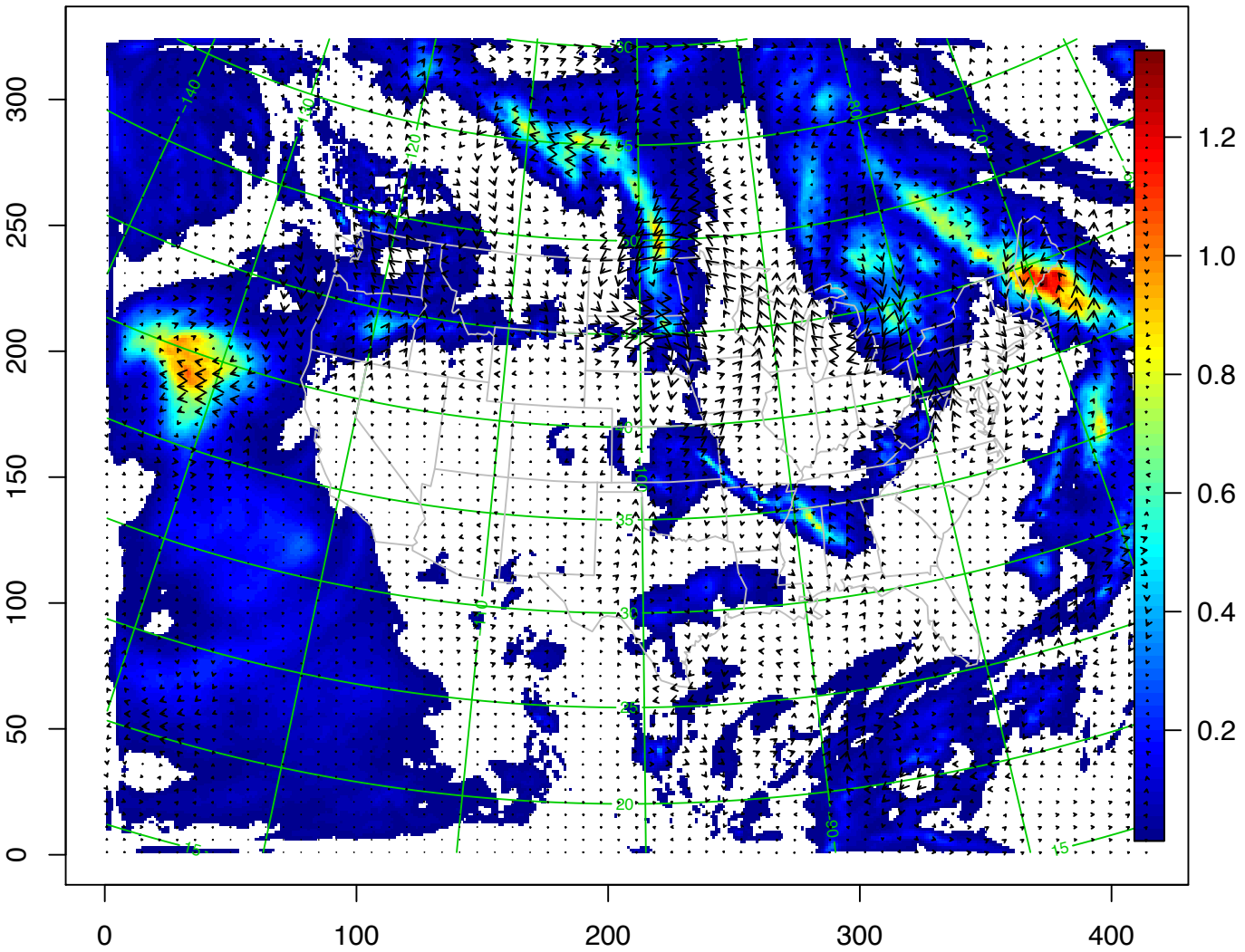

© Atmospheric and Environmental Research, Inc. (AER), 2014

# dWRF application to imagery data

- Uses a short-term, moderate resolution (15km) forecast over CONUS
- Example is from June 2006, using GOES-13 channels 2-5


© Atmospheric and Environmental Research, Inc. (AER), 2014

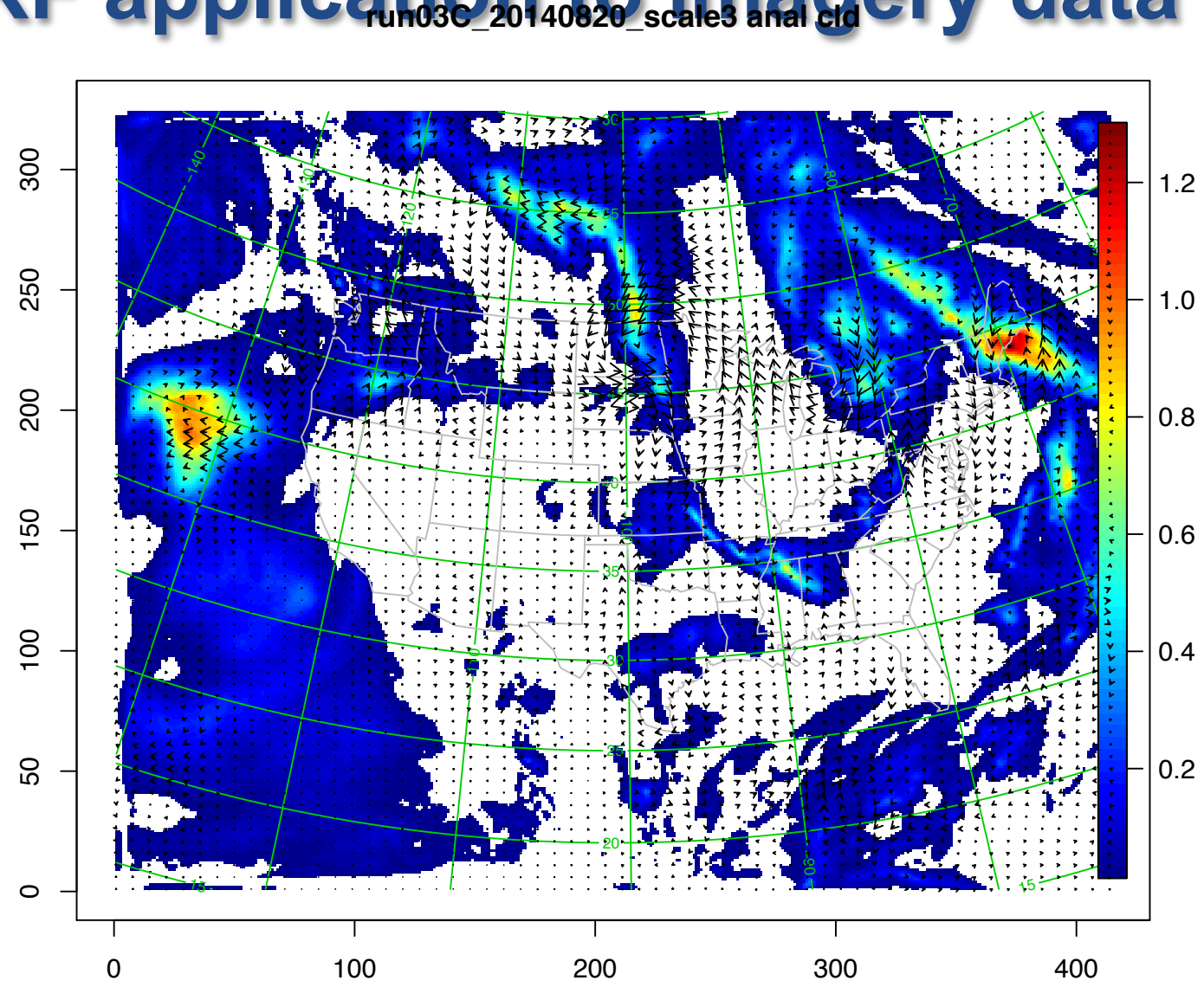
# dWRF application to imagery data





© Atmospheric and Environmental Research, Inc. (AER), 2014

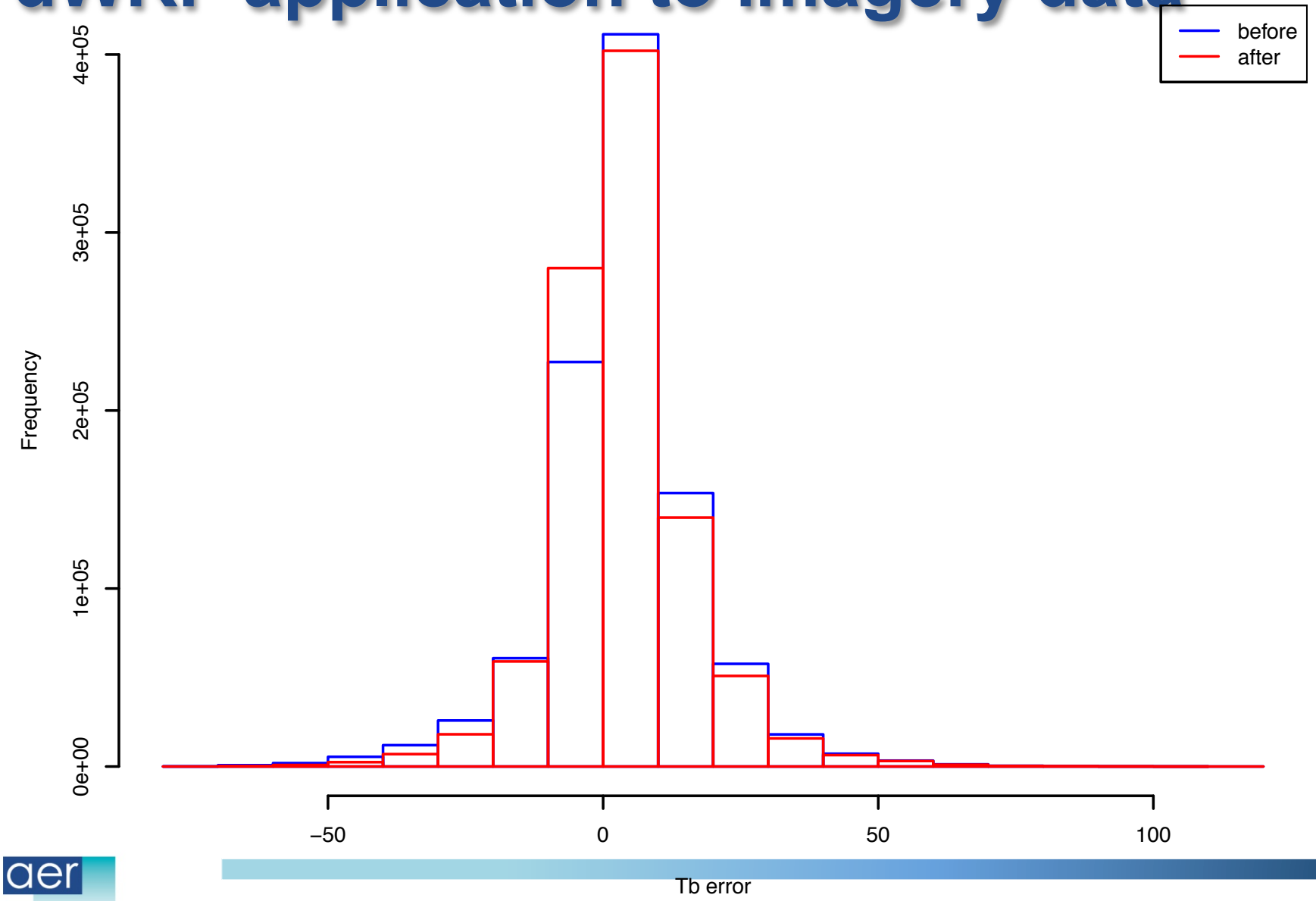
# dWRF application to imagery data





© Atmospheric and Environmental Research, Inc. (AER), 2014

# dWRF application to imagery data





© Atmospheric and Environmental Research, Inc. (AER), 2014

# Future work

- Tune / Derive background error covariances for displacement vectors
  - Explore “coalescence” (Ravela 2012)
- Extend control vector for simultaneous application of additive/displacement corrections
- Improve short-term cloud forecasting with 2-h cycle of WRFDA using GEO imagery in dWRF


© Atmospheric and Environmental Research, Inc. (AER), 2014

# Thank you


- Support from USAF as part of NCAR's advanced cloud analysis and forecast system (ACAPS)

- Grassotti et al., 1999, JAMC, doi:10/fprb35
- Hsiao et al., 2010, MWR, doi:10/bktnst
- Nehrkorn et al., 2014, MWR, doi:10/p5d

- tnehrkor@aer.com



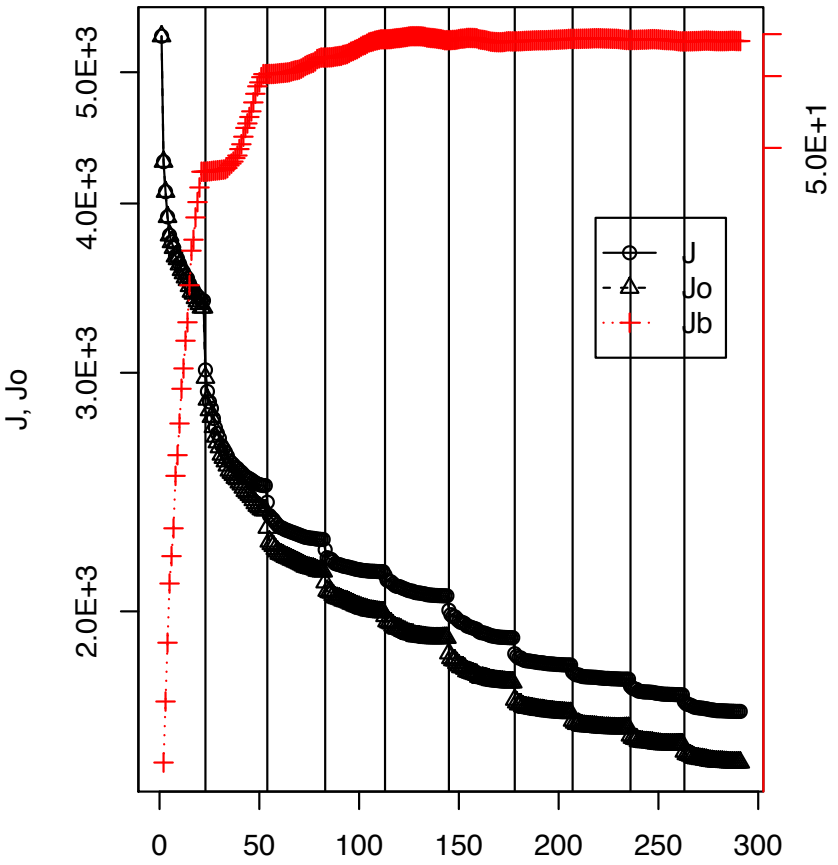

© Atmospheric and Environmental Research, Inc. (AER), 2014

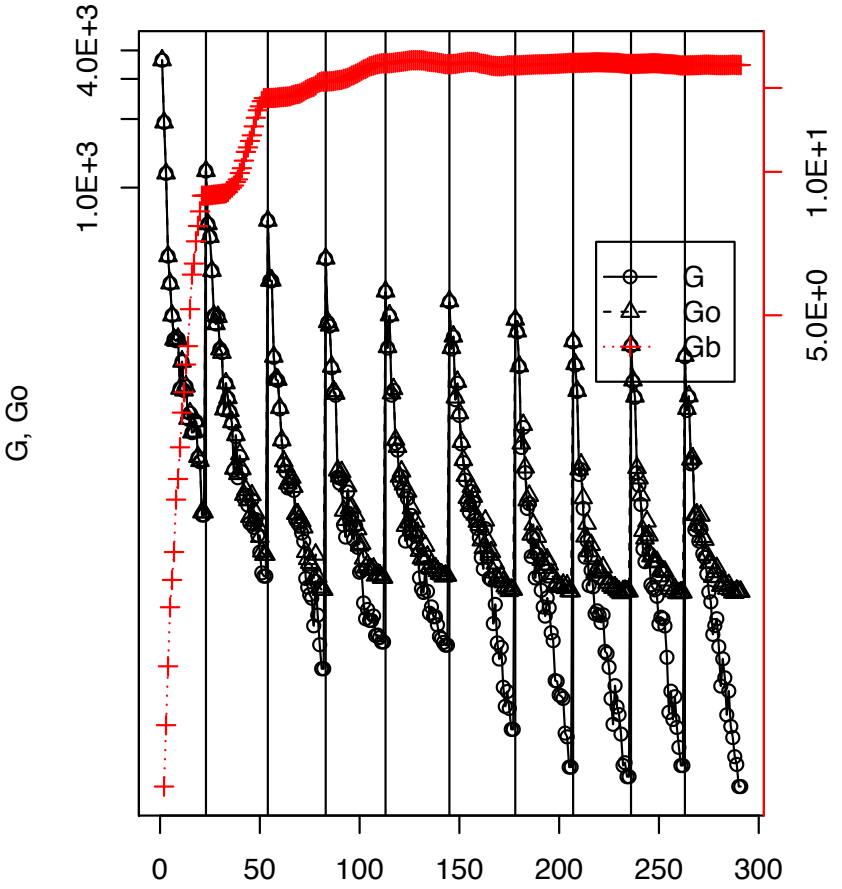
# Backup slides

- More results dWRF FCA


© Atmospheric and Environmental Research, Inc. (AER), 2014

# dWRF convergence behavior

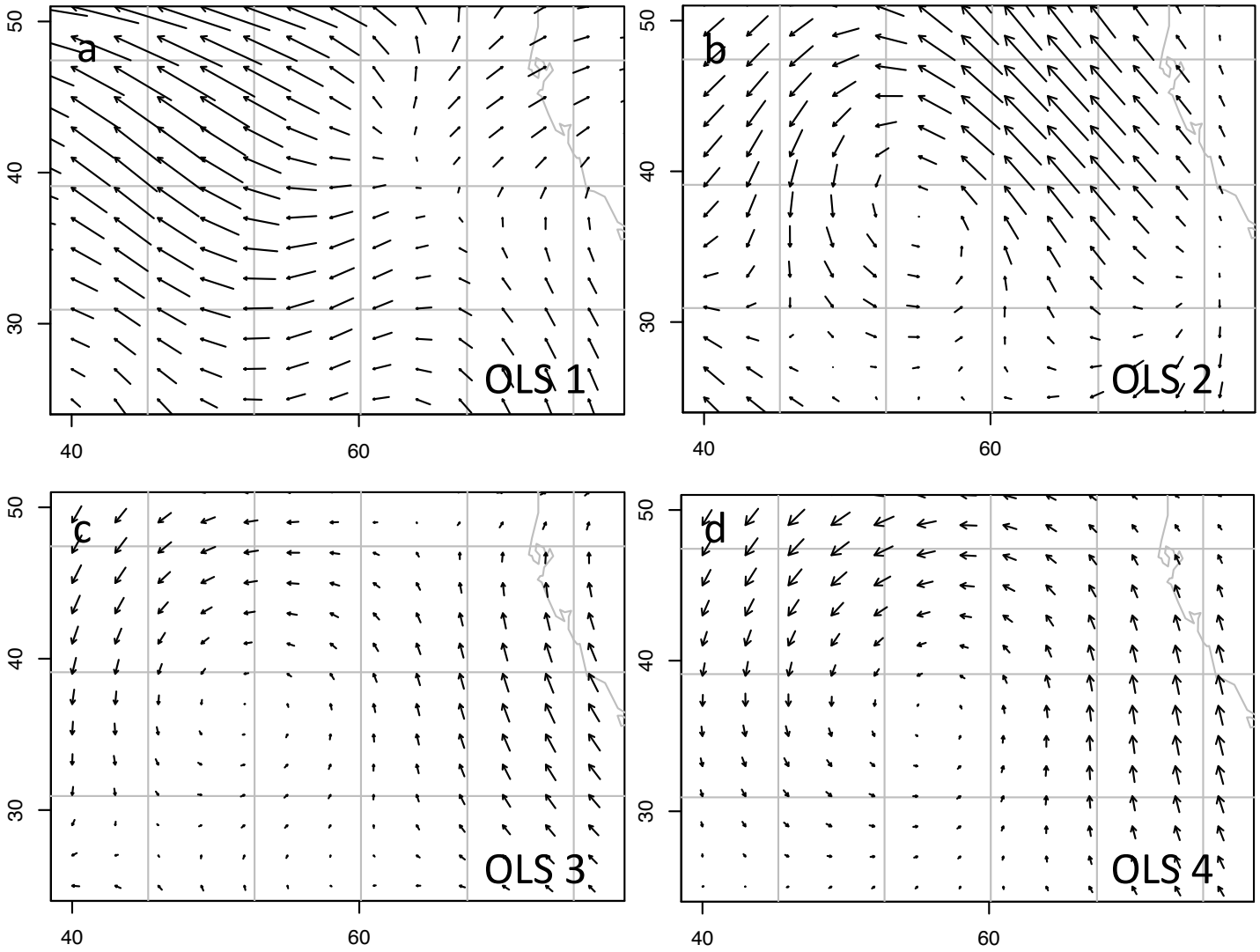




© Atmospheric and Environmental Research, Inc. (AER), 2014

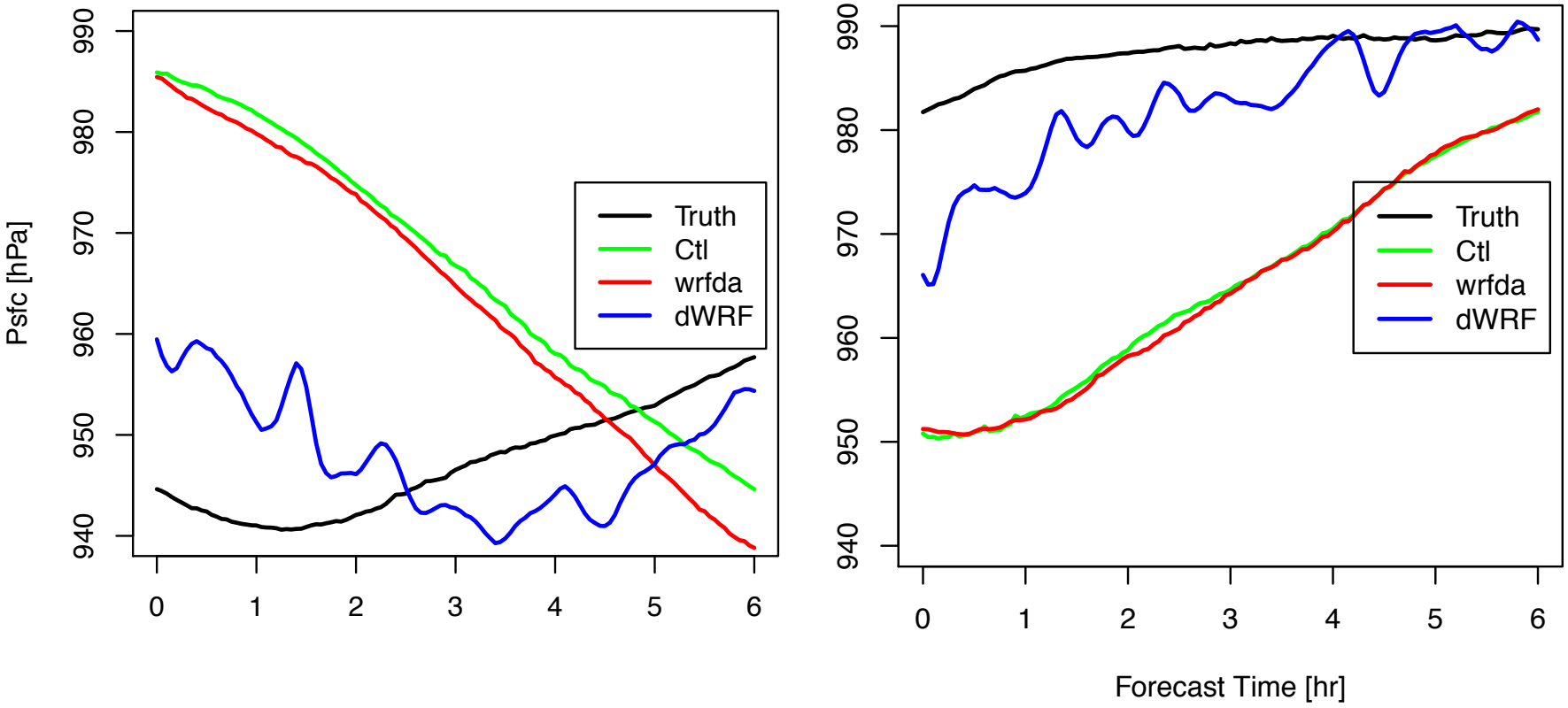
# Katrina dWRF incremental displacements





© Atmospheric and Environmental Research, Inc. (AER), 2014

# Katrina forecast evolution of Psfc





© Atmospheric and Environmental Research, Inc. (AER), 2014

# dWRF/WRFDA analysis/forecast errors

| Type | Dens | Bord | OLS | RMSE dWRF A | RMSE WRFDA $A_w$ | RMSE dWRF $F_A$ | RMSE WRFDA $F_w$ |
|---|---|---|---|---|---|---|---|
| IWV | 3 | 5 | | 2.95 | **1.88** | **3.84** | 5.81 |
| IWV | 3 | 10 | | 2.71 | **1.83** | **3.99** | 5.87 |
| IWV | 5 | 5 | | **3.23** | 3.79 | **3.41** | 5.35 |
| IWV | 5 | 10 | | **3.26** | 3.79 | **3.78** | 5.34 |
| IWV | 10 | 5 | | **4.81** | 6.15 | 5.50 | **5.49** |
| Raob | 3 | 5 | | 4.26 | **2.22** | 2.97 | **2.64** |
| Raob | 3 | 10 | | 4.23 | **2.23** | 2.95 | **2.94** |
| Raob | 5 | 5 | 8 | **3.82** | 3.83 | **3.04** | 3.35 |
| Raob | 5 | 10 | 8 | 3.87 | **3.82** | **3.10** | 3.31 |
| Raob | 10 | 5 | 1 | **3.72** | 6.22 | **3.17** | 6.48 |


© Atmospheric and Environmental Research, Inc. (AER), 2014