Feature Calibration Alignment for the WRF model

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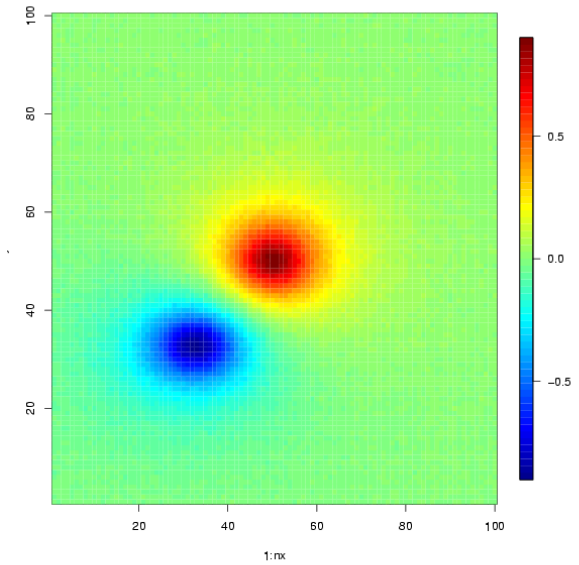
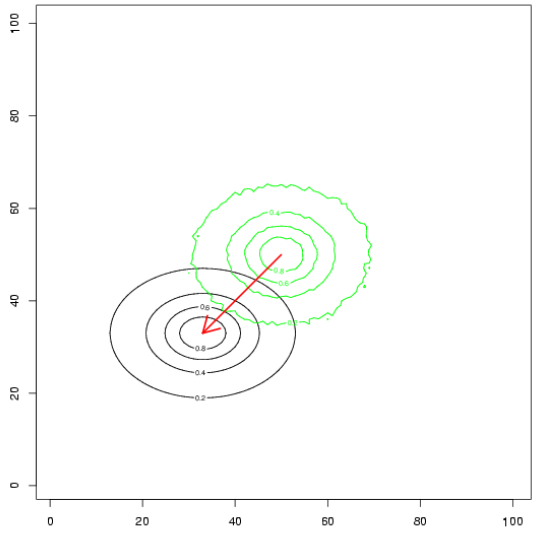
Motivation/Background

- Background errors are sometimes caused by mis-placement (phase errors) of coherent features
- This can result in non-Gaussian error statistics
- Feature Calibration and Adjustment: partition errors into displacements and additive (residual) errors



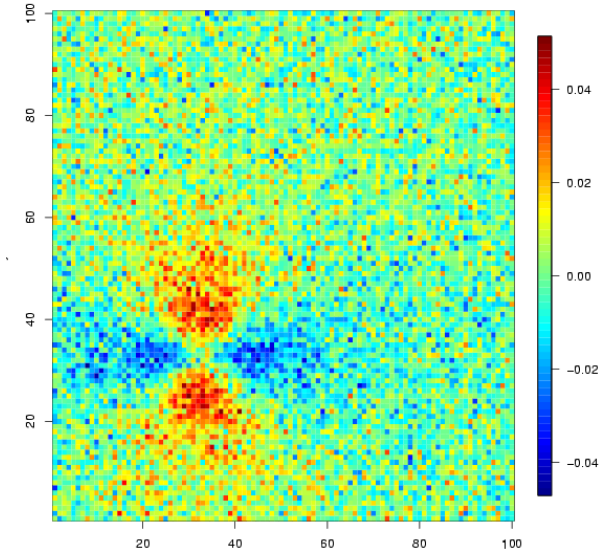
background error

=>



displacements of coherent features

+



additive (residual) error

FCA Formulation

- **Non-linear minimization of an objective function**
  - based on feature calibration and alignment implementation by Grassotti et al. (1999)
  - derive displacement vectors by minimizing an objective function:

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

  - residual errors after adjustment of the background:

$$J_{res} = \sum w_{obs}(y^{obs}(x,y) - y^{bg}(x+\delta x, y+\delta y))^2$$

  - penalty function implements constraints on the displacements

$$J_{pen}\left(\delta x, \delta y\right) = \sum_i \lambda_i J_i$$

FCA Formulation

- Use a truncated spectral representation of the displacement vectors
  - retain only largest scales
  - few degrees of freedom for minimization
- Choice of penalty functions/constraints:
  - Displacements normalized by a length scale S_x

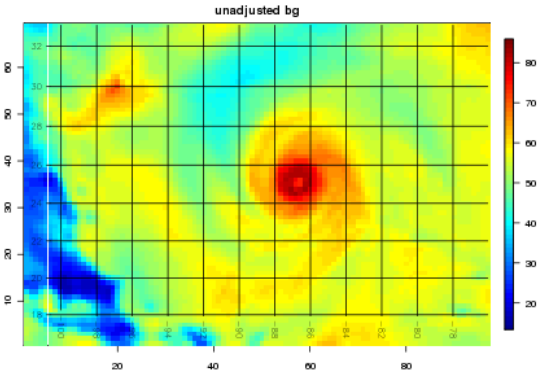
Constraint	**Abbrev**	**Formula**	**gp/spec**
Smoothness	d	$\sum S_x^{-2}\left(\nabla^2(\delta x,\delta y)\right)^2$	spec
Magnitude	m	$\sum S_x^{-2}\delta x^2$	spec
Barrier (gp)	gpa	$\sum(\delta x/S_x)^{20}$	gp
Divergence	gpdiv	$\sum(\partial\delta x/\partial x+\partial\delta y/\partial y)^2$	gp

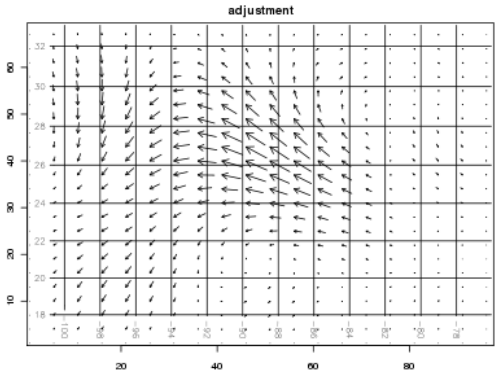
Application to identical twin OSSE

- Katrina case, time-lagged
- Control:
  - 6-hr Forecast initiated at 00 UTC 2005/08/28
  - dx=30 km, GFS IC/LBC
- Truth/Observations:
  - 12-hr Forecast initiated at 00 UTC 2005/08/28
- Tested using
  - lowest-level perturbation pressure (P),
  - integrated water vapor (IWV), or
  - both (P+IWV)
- IWV results in almost identical displacements as P+IWV

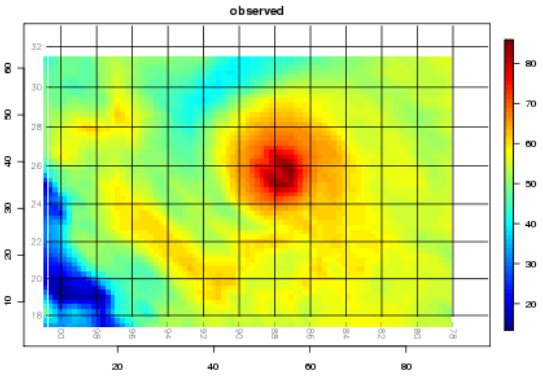
Displacement Solution: Katrina

Control

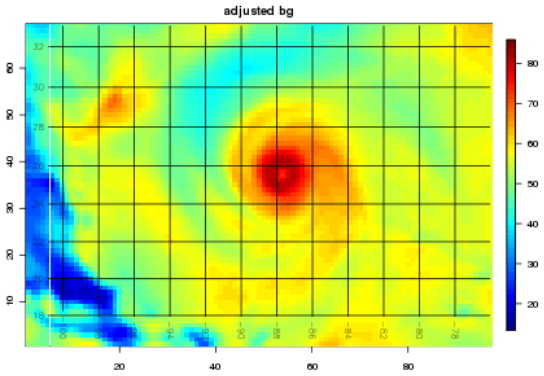




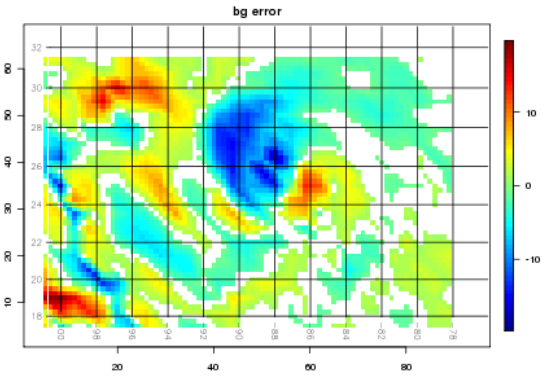
Observed



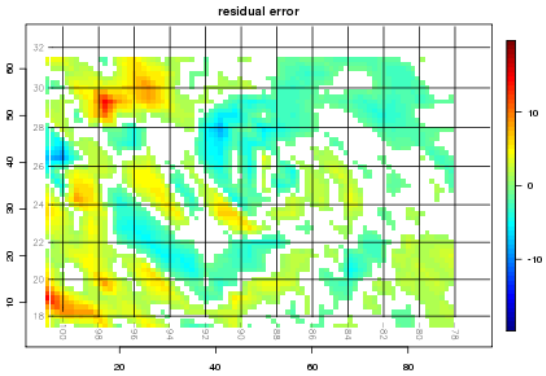
Adjusted



Original Errors



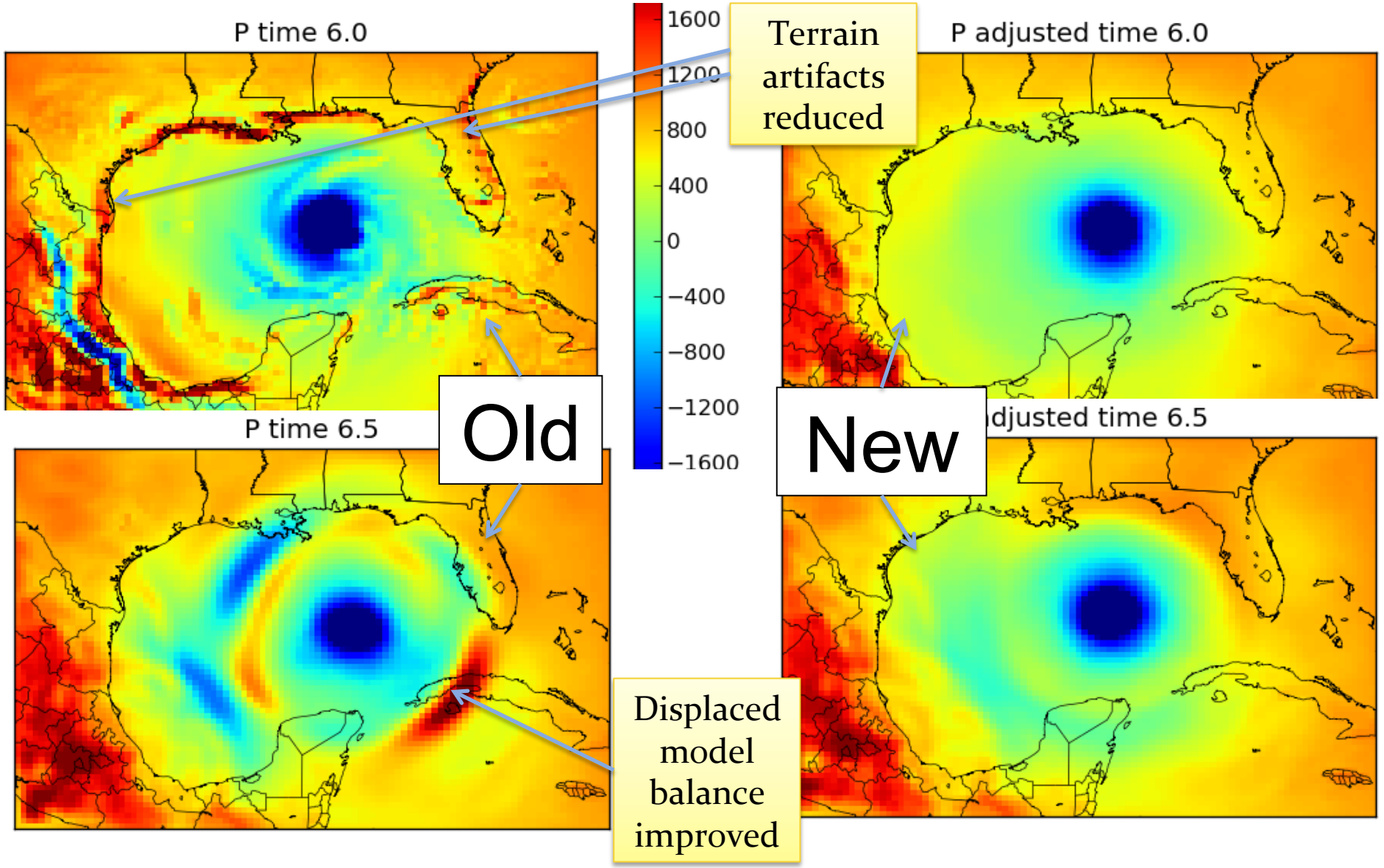
Residual Errors



Displacements: apply to 3D model state

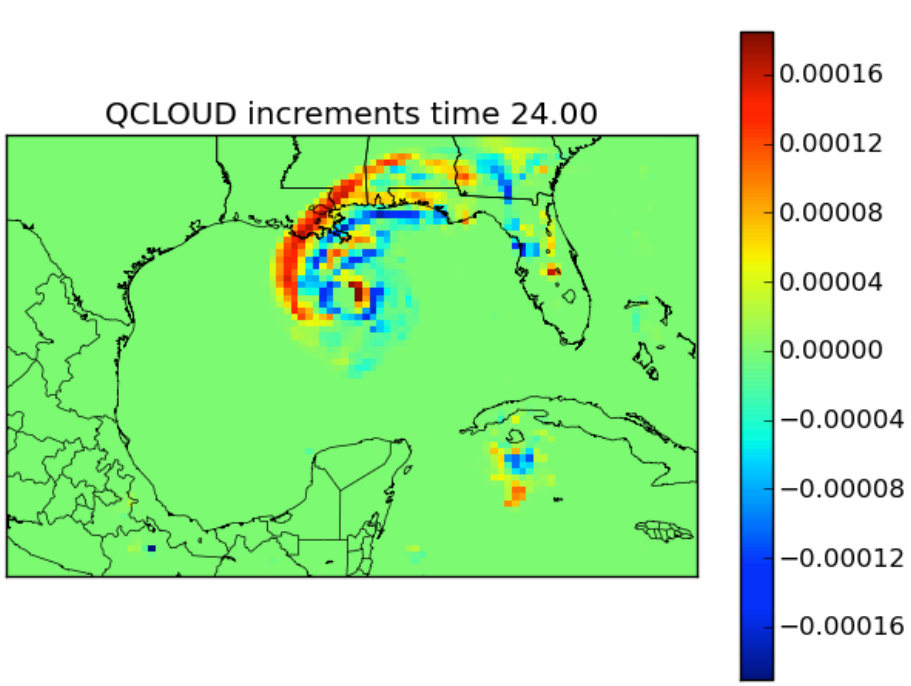
- Initial tests:
  - simple 2d displacements of all model fields
  - Imbalances lead to substantial adjustments during spin-up
- Modified algorithm (Hsiao et al.,2010):
  - Displace some fields: wind components, sea level pressure, relative humidity, hydrometeor mixing ratios, potential temperature
  - Re-derive others: pressure, specific humidity, temperature, hydrostatic geopotential, dry air mass
  - Displace relative humidity instead of water vapor mixing ratio
    → avoid artificial creation of super-saturation
  - Displace potential temperature along constant altitude instead model sigma coordinate
    → avoid changes to static stability

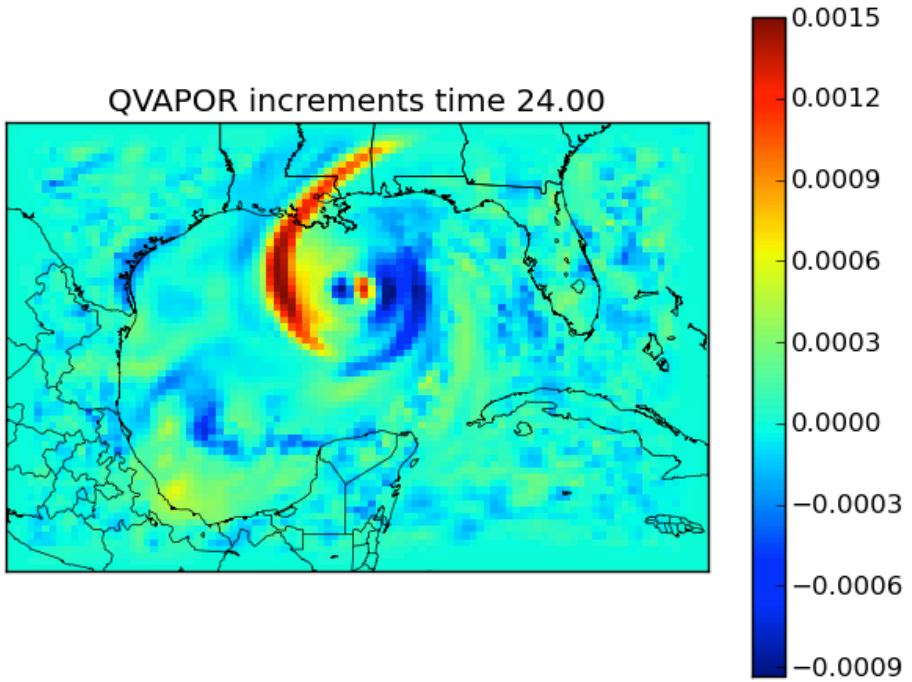
Application of displacements to 3d model fields



Katrina case: Displaced – Control Forecasts after 18 hours

Displaced forecasts (t+18h) run stably and result in changes in cloud mixing ratios

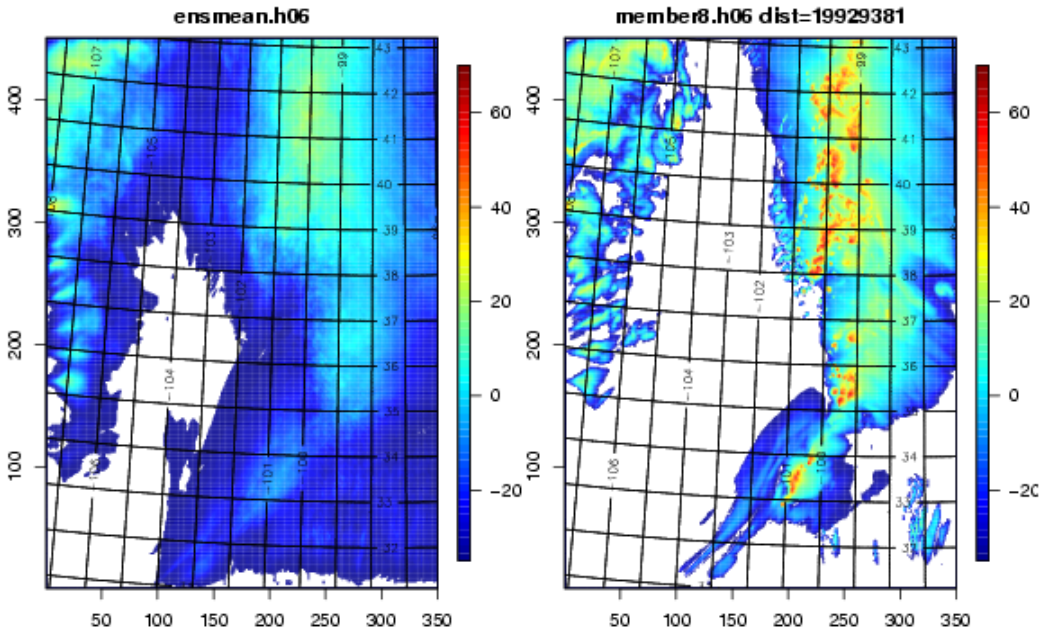




Application to ensemble forecast

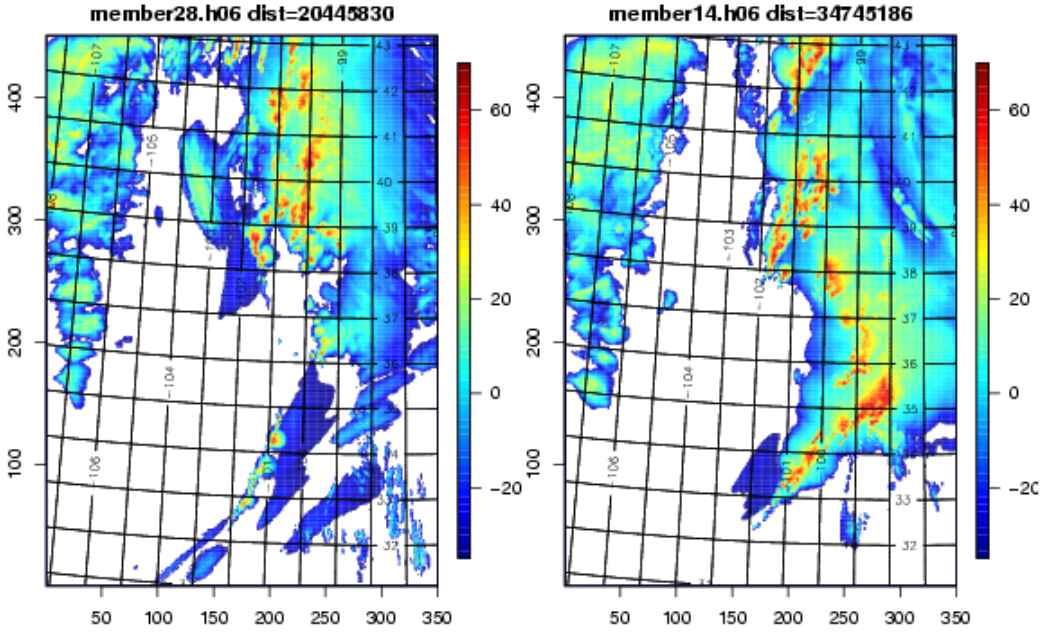
- **applied to an ensemble forecast of deep convection**
  - 30-member ensemble of 6-hour forecasts of deep convection (dx=3km)
  - consider 2d field of maximum dbZ in model column
  - characterize ensemble spread in terms of displacements
  - Define an ensemble "centroid": ensemble member closest to the ensemble mean
  - Distance defined by sum of squared difference in dbZ
  - Derive displacement between each ensemble member and the centroid

ensemble mean



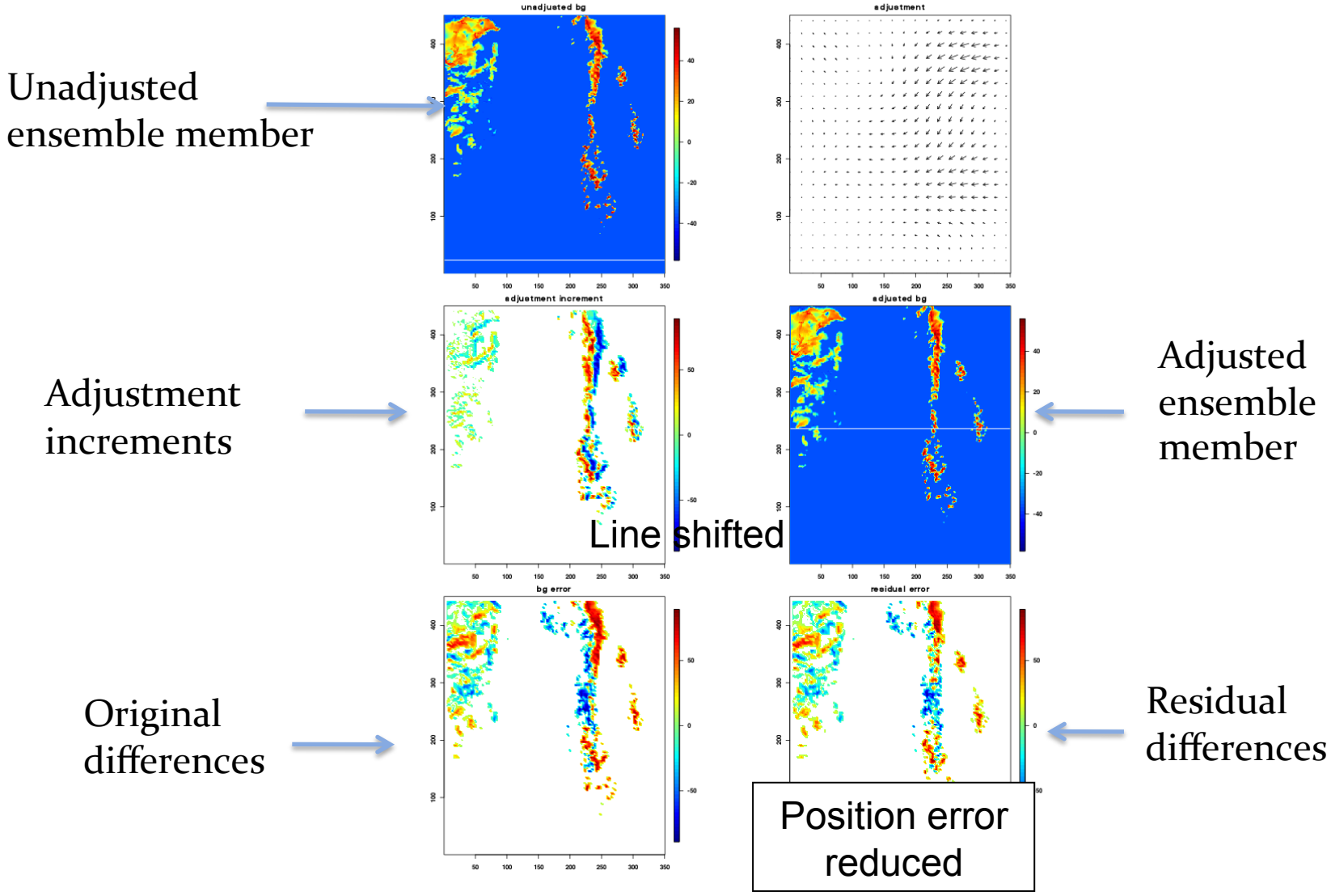
centroid (member closest to mean)

next closest member

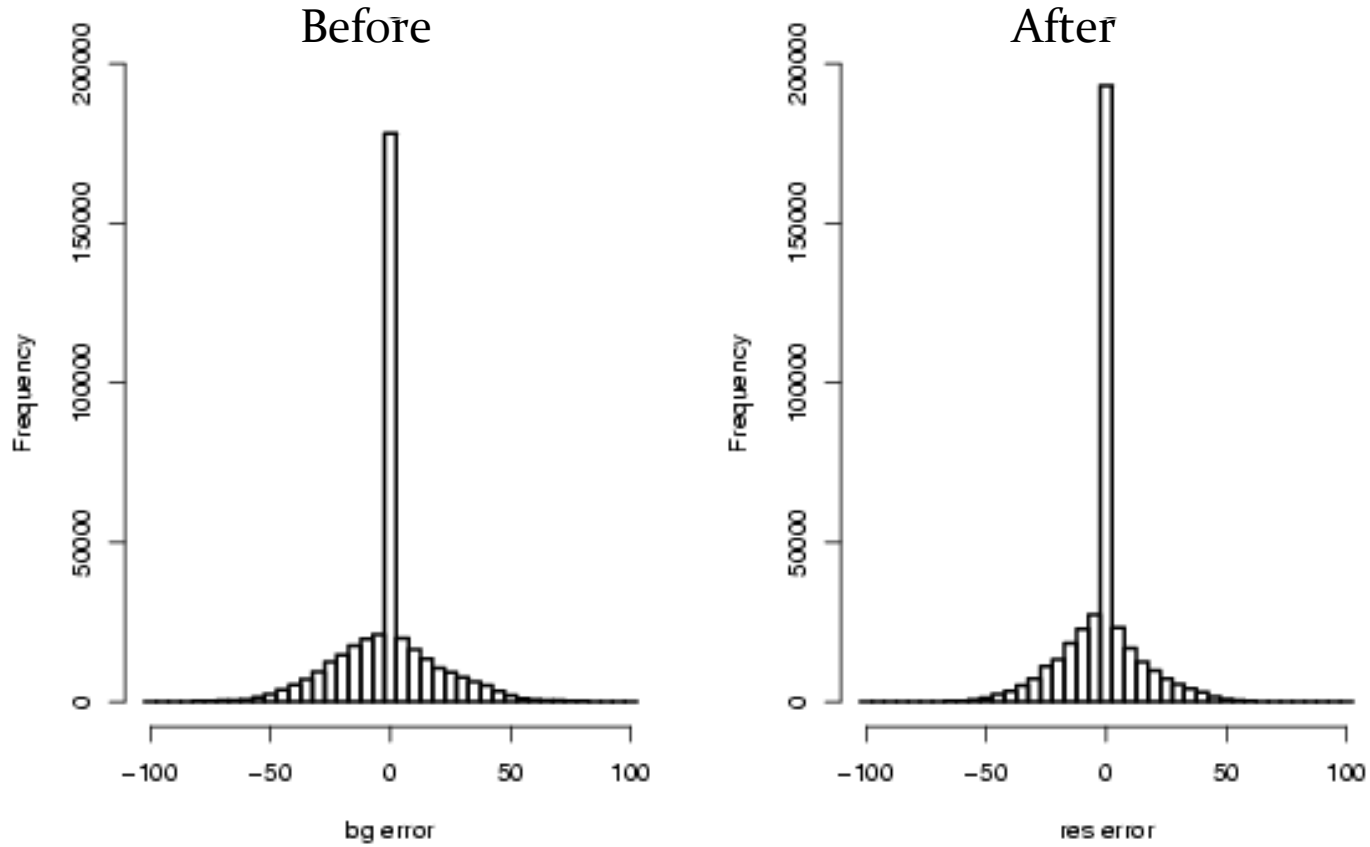


member furthest from the mean

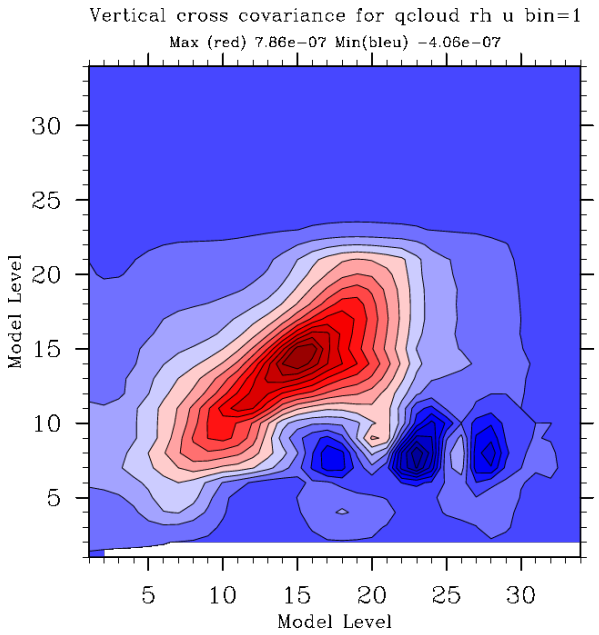
Example: squall line position differences between ensemble member and centroid



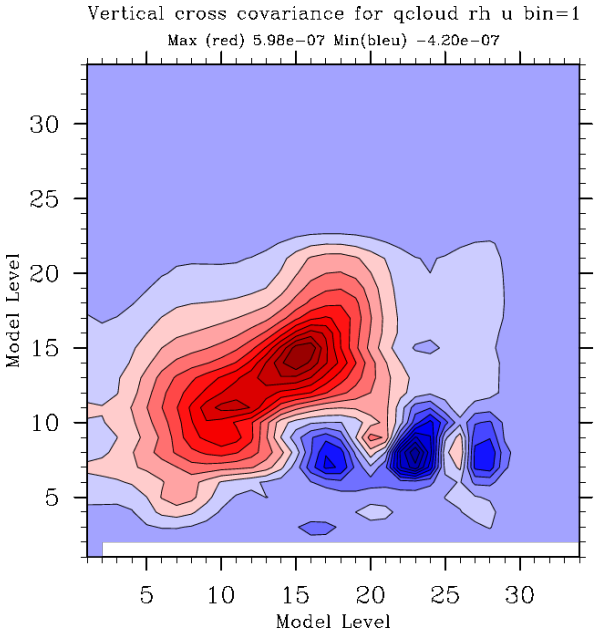
Ensemble Spread (dbZ) before and after displacements



GEN_BE: Cross-Covariances for Original and Displaced Ensemble



CONTROL



DISPLACED

rh-qcloud

Conclusions / Future Work

- Horizontal displacement vectors
  - obtained by comparison of simulated and observed 2D quantities
  - used to adjust 3d WRF model fields
- Results
  - Idealized example shows large potential impact in some situations
  - Mesoscale ensemble and real-data application show small, but positive impacts
- Future work
  - Examine forecast impacts
  - Improve model dynamic balance
  - Refine adjustment algorithm
    - formulation of constraints