Regional 4DEnVar with global ensemble at NCEP

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GSI Hybrid Variational-Ensemble

Incorporate ensemble perturbations directly into variational cost function through extended control variable Lorenc (2003)

$$J(\mathbf{x}_f', \boldsymbol{\alpha}) = \beta_f \frac{1}{2}(\mathbf{x}_f')^T \mathbf{B}^{-1}(\mathbf{x}_f') + \beta_e \frac{1}{2}\sum_{n=1}^{N} (\boldsymbol{\alpha}^n)^T \mathbf{L}^{-1}(\boldsymbol{\alpha}^n) + \frac{1}{2}\sum_{t=1}^{T} (\mathbf{y}_t' - \mathbf{H}\mathbf{x}_t')^T \mathbf{R}^{-1}(\mathbf{y}_t' - \mathbf{H}\mathbf{x}_t')$$

$$\mathbf{x}_t' = \mathbf{x}_f' + \sum_{n=1}^{N} \boldsymbol{\alpha}^n \circ \mathbf{x}_{et}'^n \qquad \frac{1}{\beta_f} + \frac{1}{\beta_e} = 1$$

$\mathbf{x}_f'$ is the increment associated with the static covariance

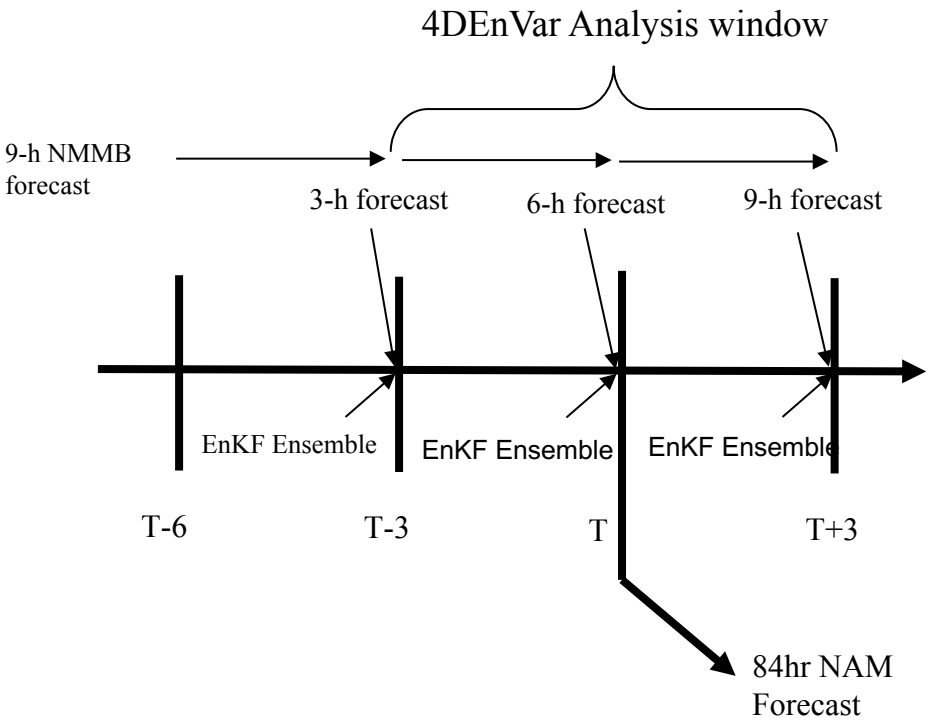
β_f & β_e: weighting coefficients for fixed and ensemble covariance respectively

$\mathbf{X}_t$': (total increment) sum of $\mathbf{x}_f'$ increment from fixed/static **B** ($\mathbf{x}_f$) and ensemble **B**

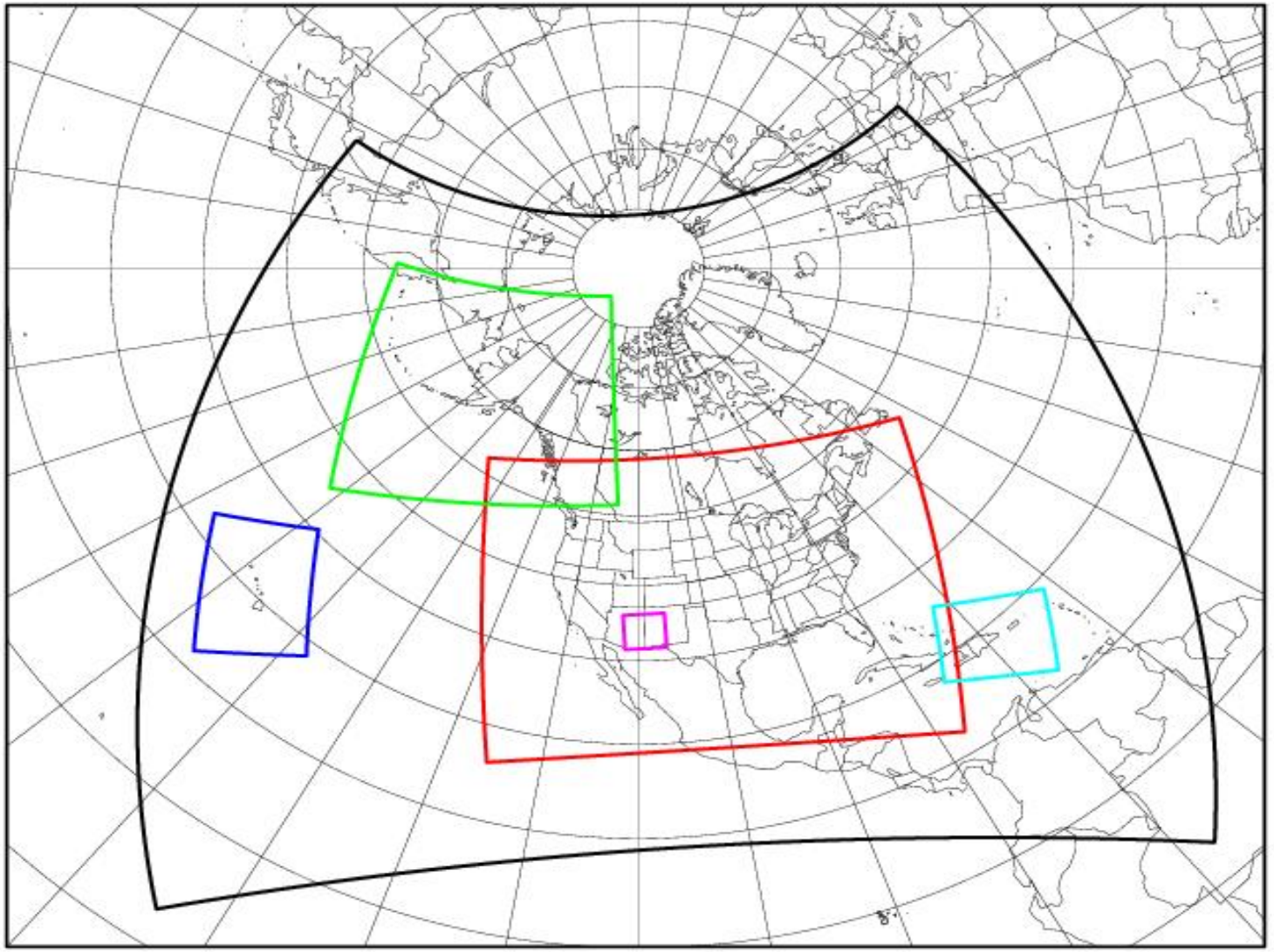
α_k: extended control variable; x_e : ensemble perturbation

L: correlation matrix (localization on ensemble perturbations)

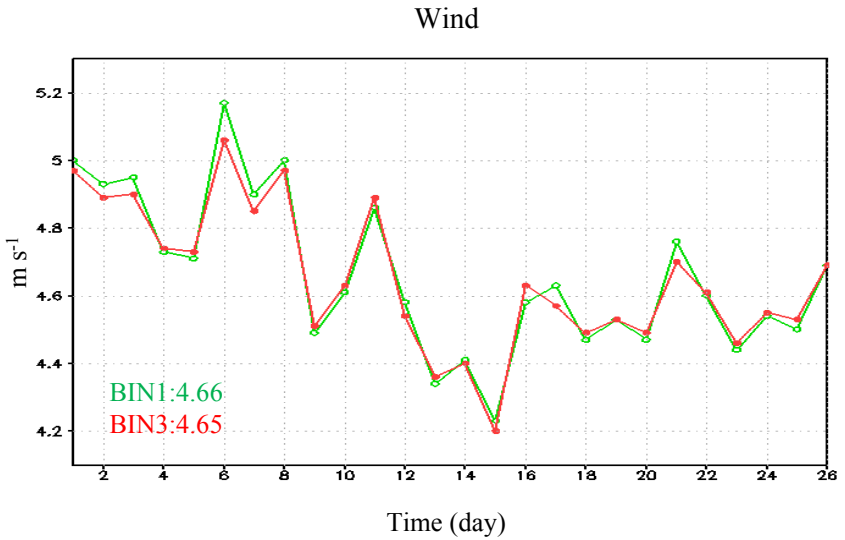
NDAS 4DEnVar

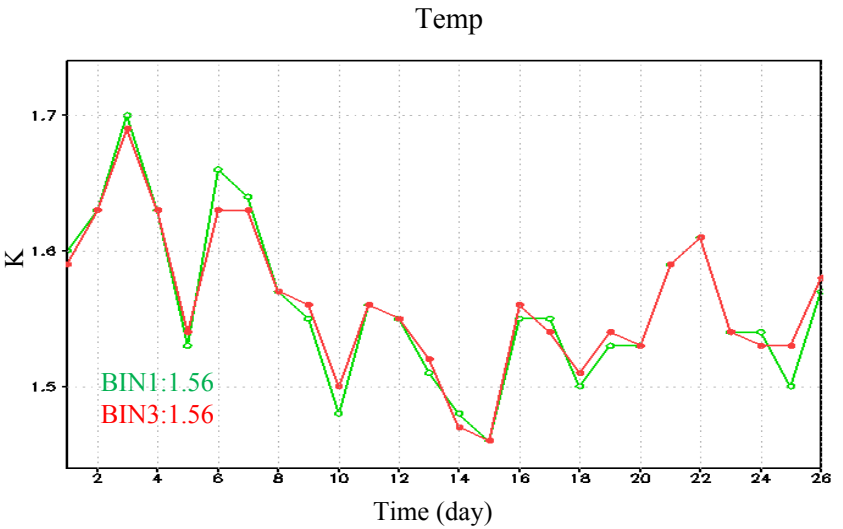


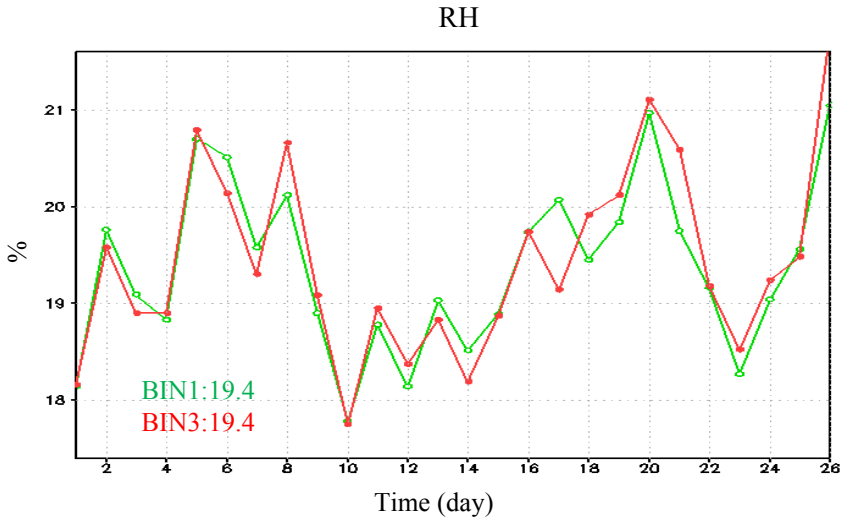
NAM integration domain

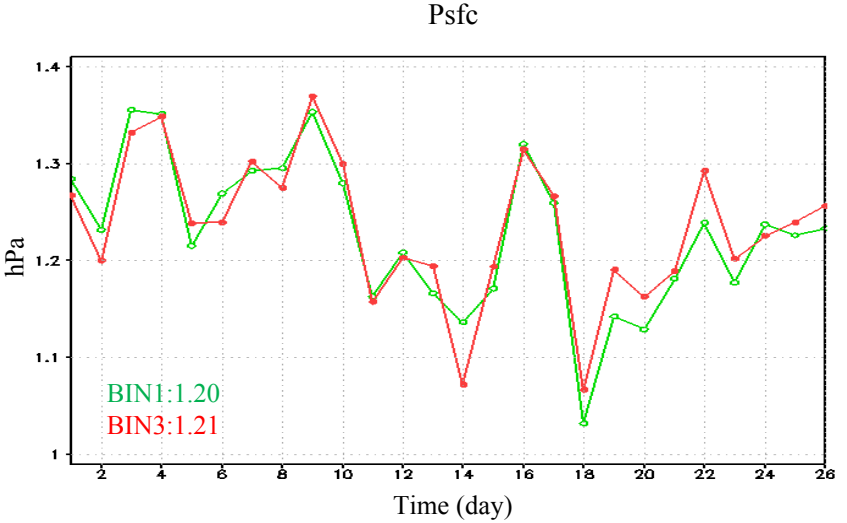


Sensitivity of hourly and 3-hourly bins









Impact of time bin

- less interpolation error with smaller time bin; more computational costs
- with 4DVar where all observations used when integrating the TL model
- with 4DEnVar best ensemble member identified with the observations in each bin

  data density may be a problem when bin width become small.

  (extreme example: 1 observation in the bin, similar weight to all members)

4DEnVar & TC

EnVar: use only ensemble perturbations

ensemble mean disregarded

Goal: initiate from the best of the 2 systems according to fit to observations

Option: **Trajectory Correction**

add an option to correct model/mean trajectories.

at each time bin, add 1 extra ensemble member to existing 80:

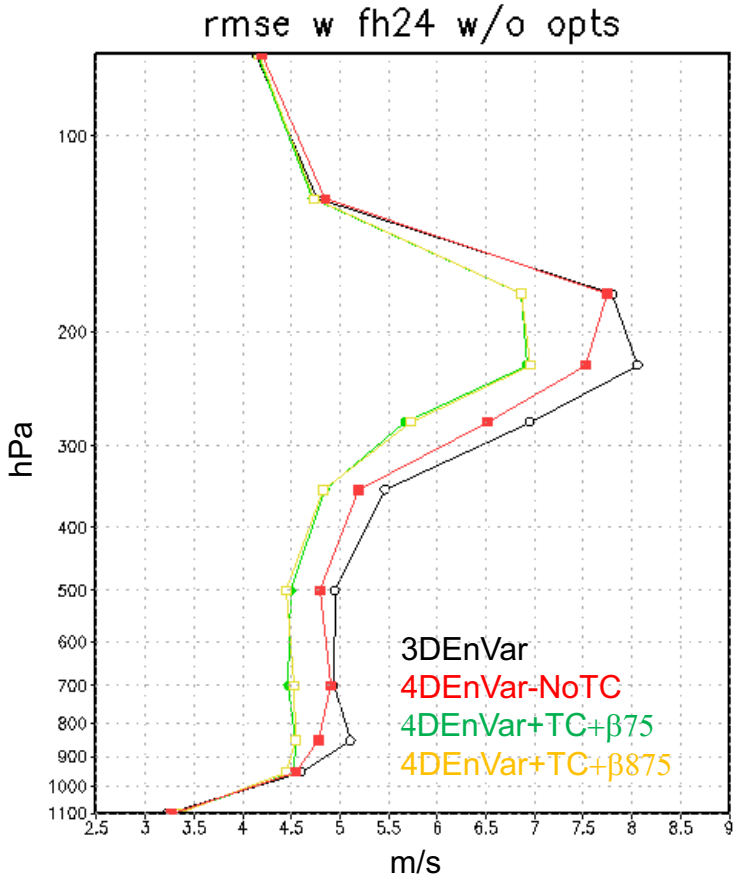
differences of the global ensemble mean(En_m) and the regional first guess (X_g)

from $\mathbf{x}'_t = \mathbf{x}'_f + \sum_{n=1}^{N} \boldsymbol{\alpha}^n \circ \mathbf{x}'^n_{et}$

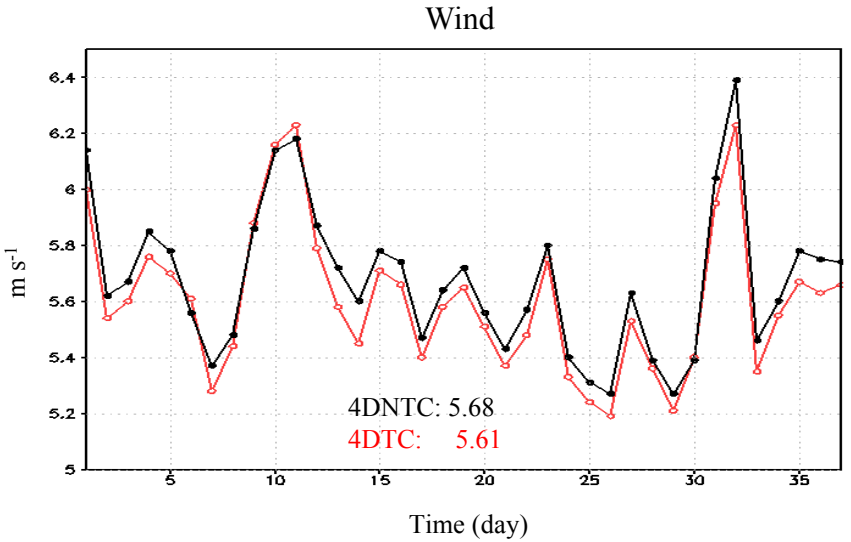
$X_a = X_g + \alpha\,(En_m - X_g) + \ldots \rightarrow En_m$

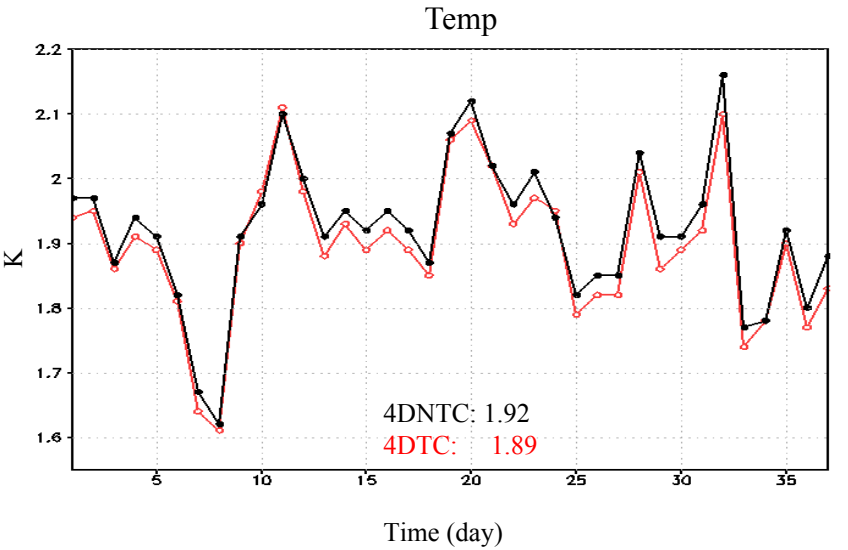
ability to locally bias correct first guess trajectory toward ensemble mean.

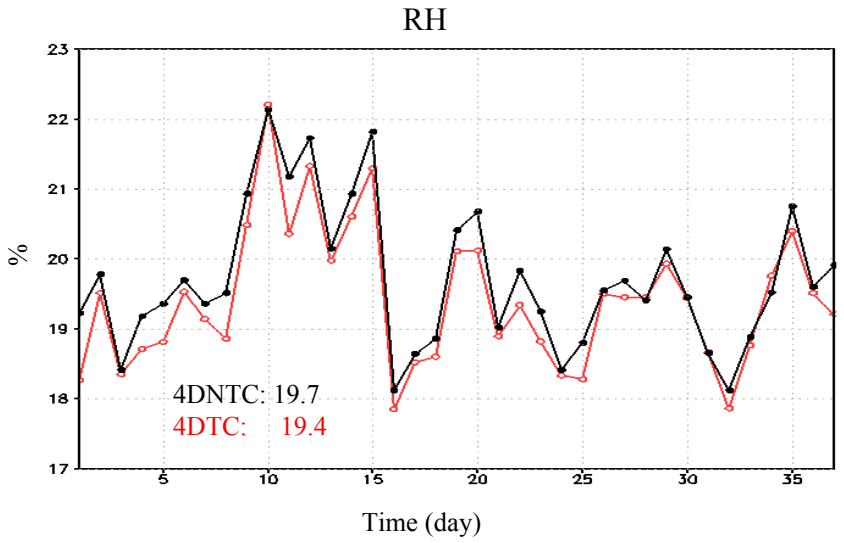
4DEnVar: Magnitude of impact from trajectory correction

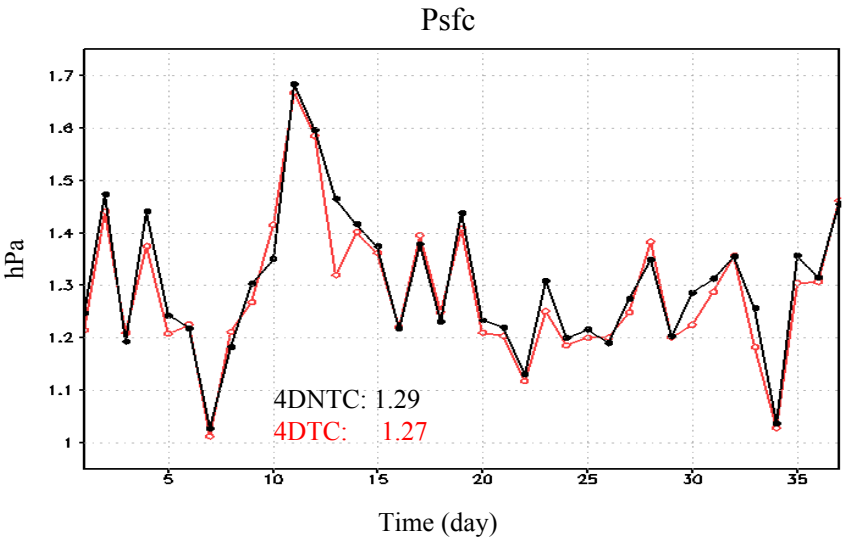


Impact of Trajectory Correction

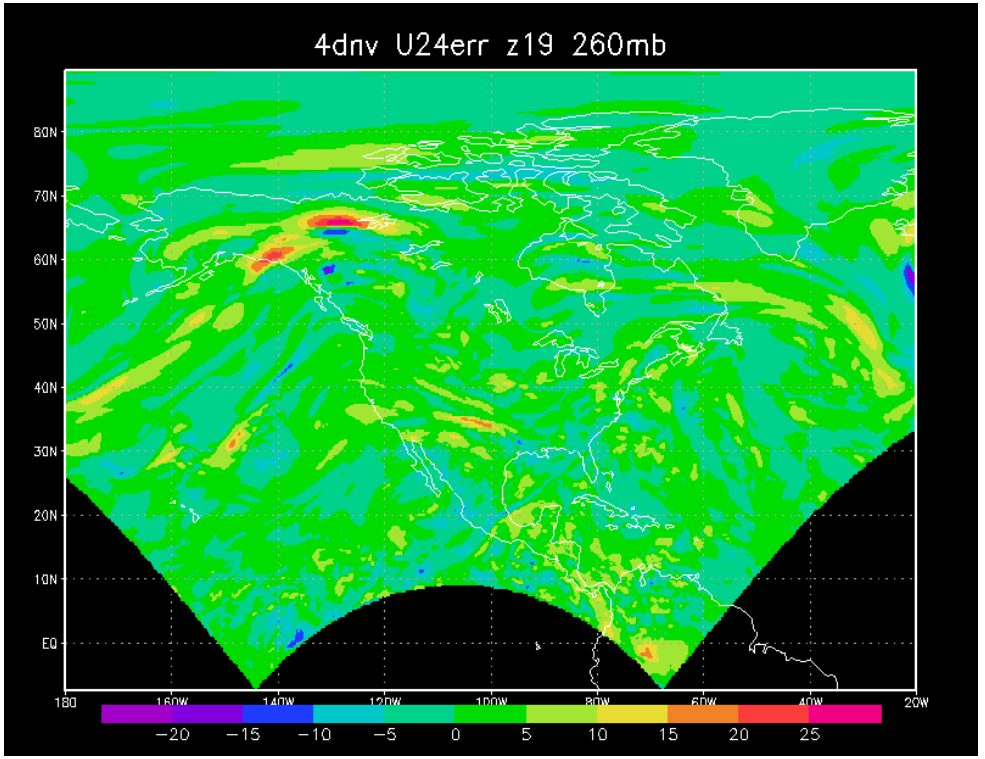


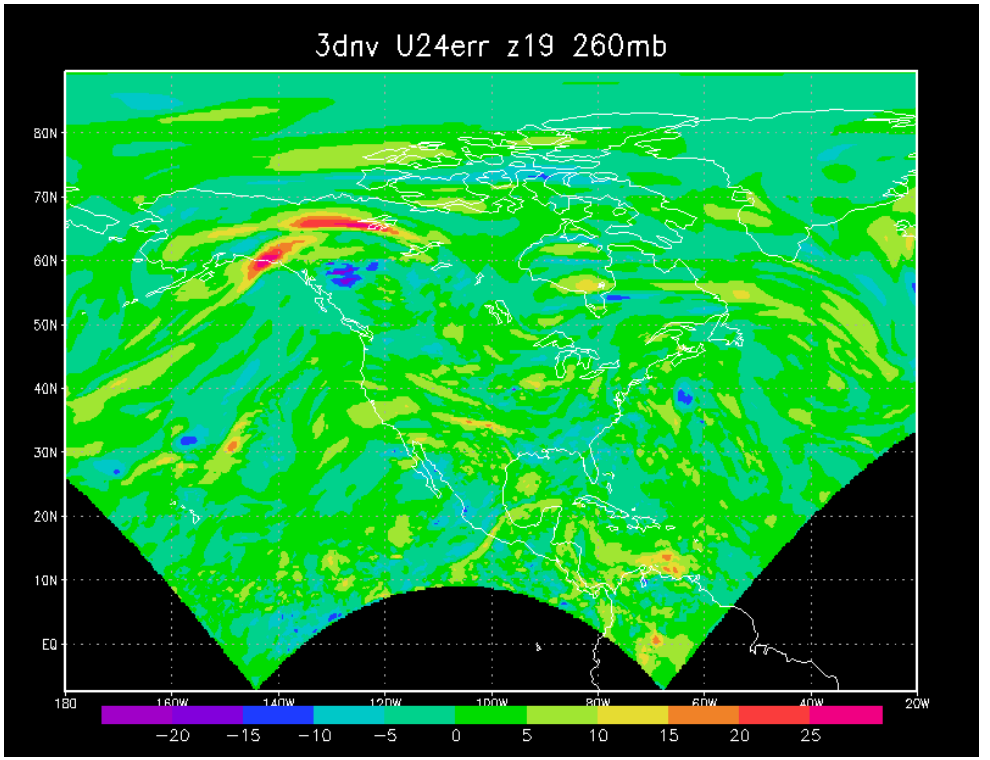




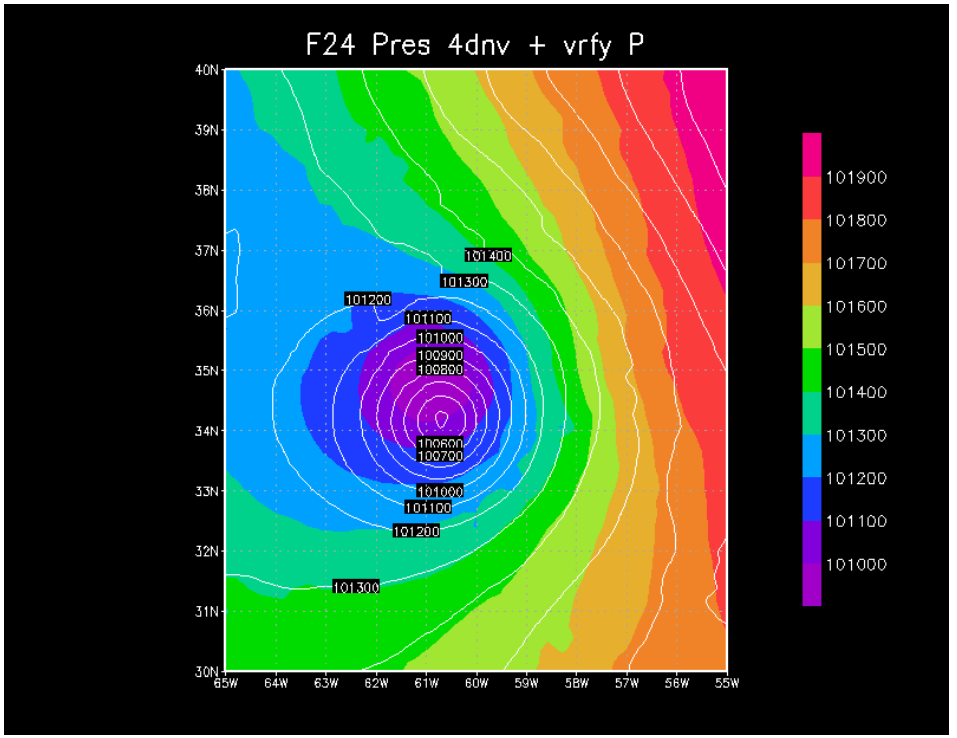


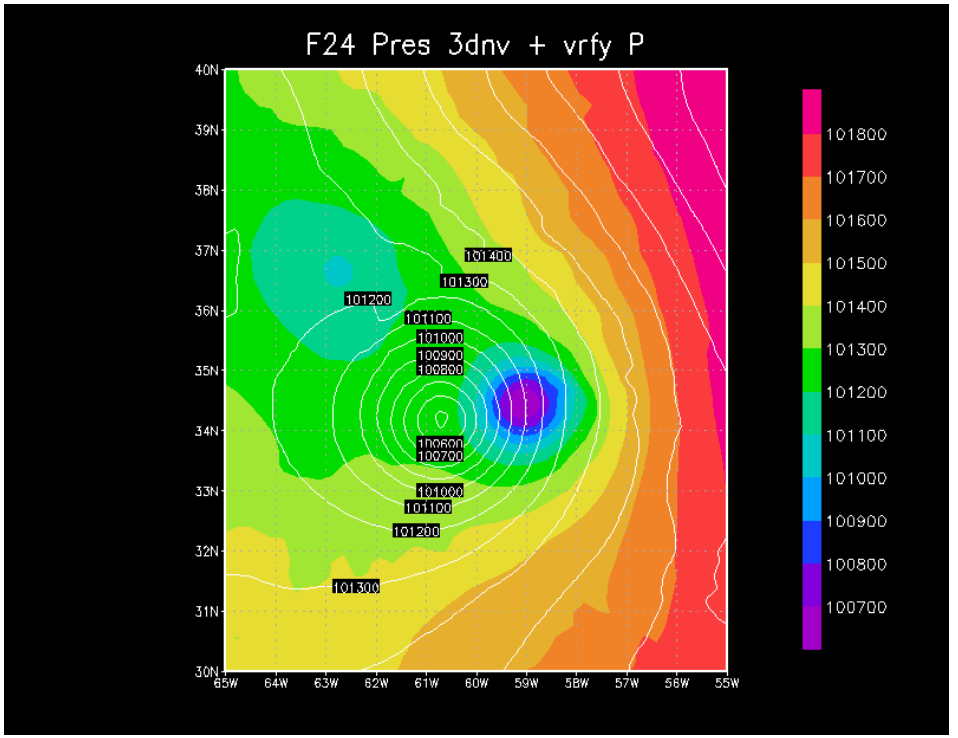
3D/4DEnVar u24err 260mb





3D/4DEnVar F24 P error
tropical cyclone





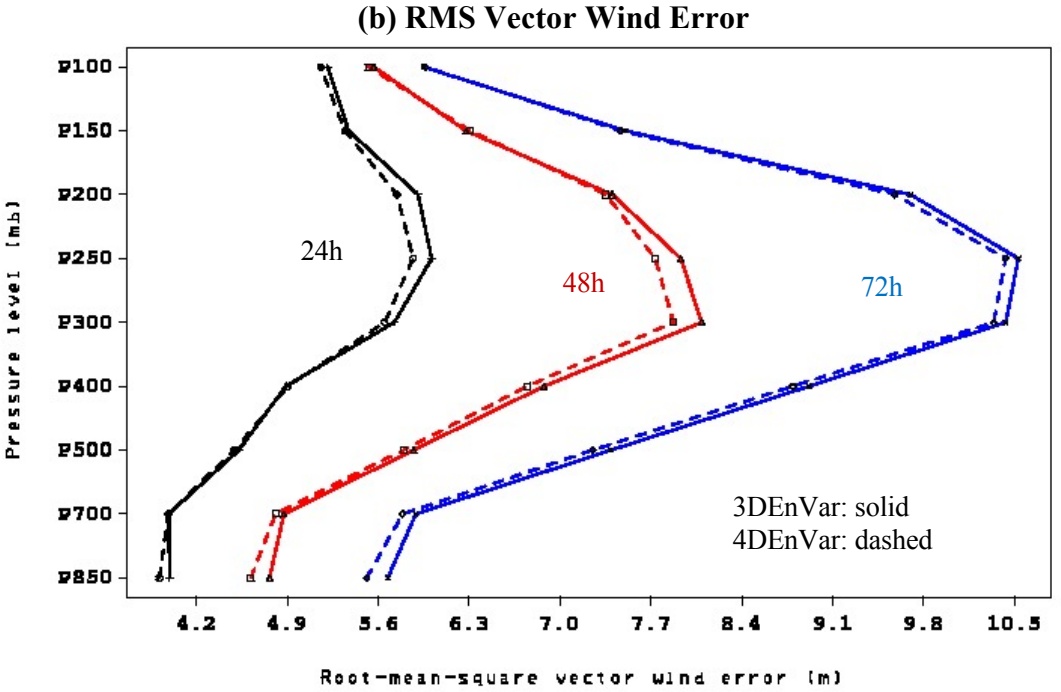
F24 with 4DEnVar smaller position and size error

Testing 4DEnVar in NDAS parallel

Results from NDAS parallel by

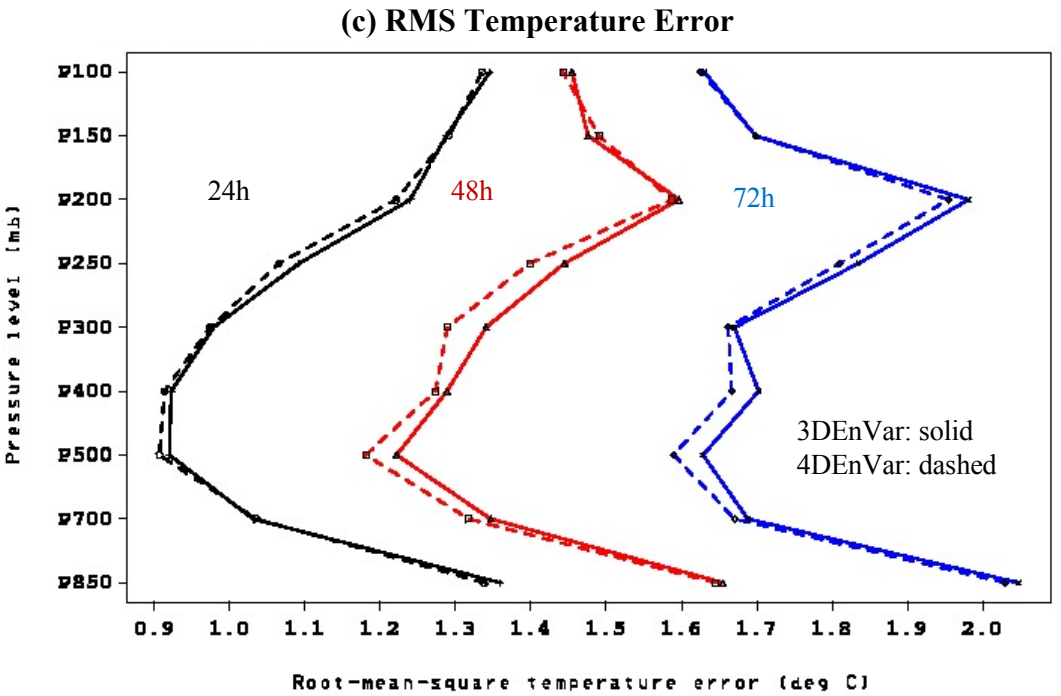
1) Eric Rogers: upper air statistics
2) Ying Lin: precipitation scores
3) Quang Ping Lou: Hurricane tracks

NDAS parallel results



Cumulative RMSE over the continental US for 15 September 2015 to 15 November 2015.
(Eric Rogers EMC)

NDAS parallel results



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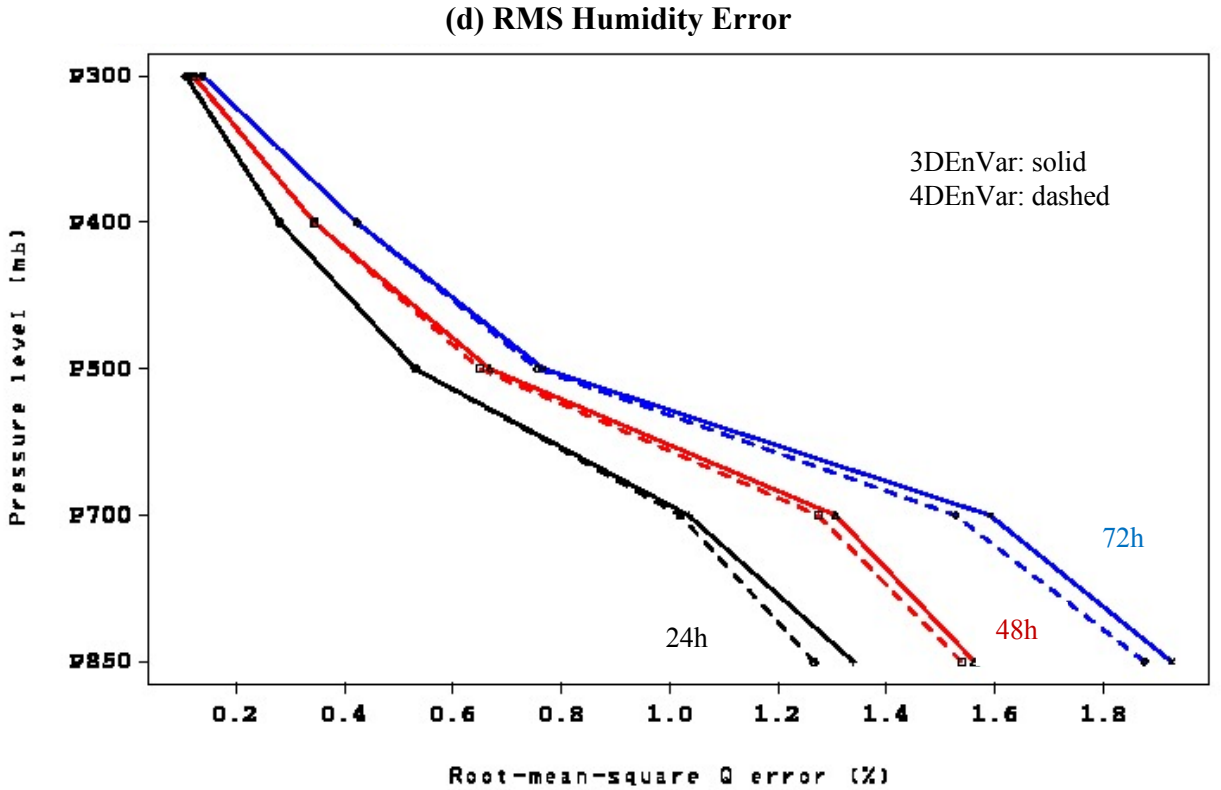
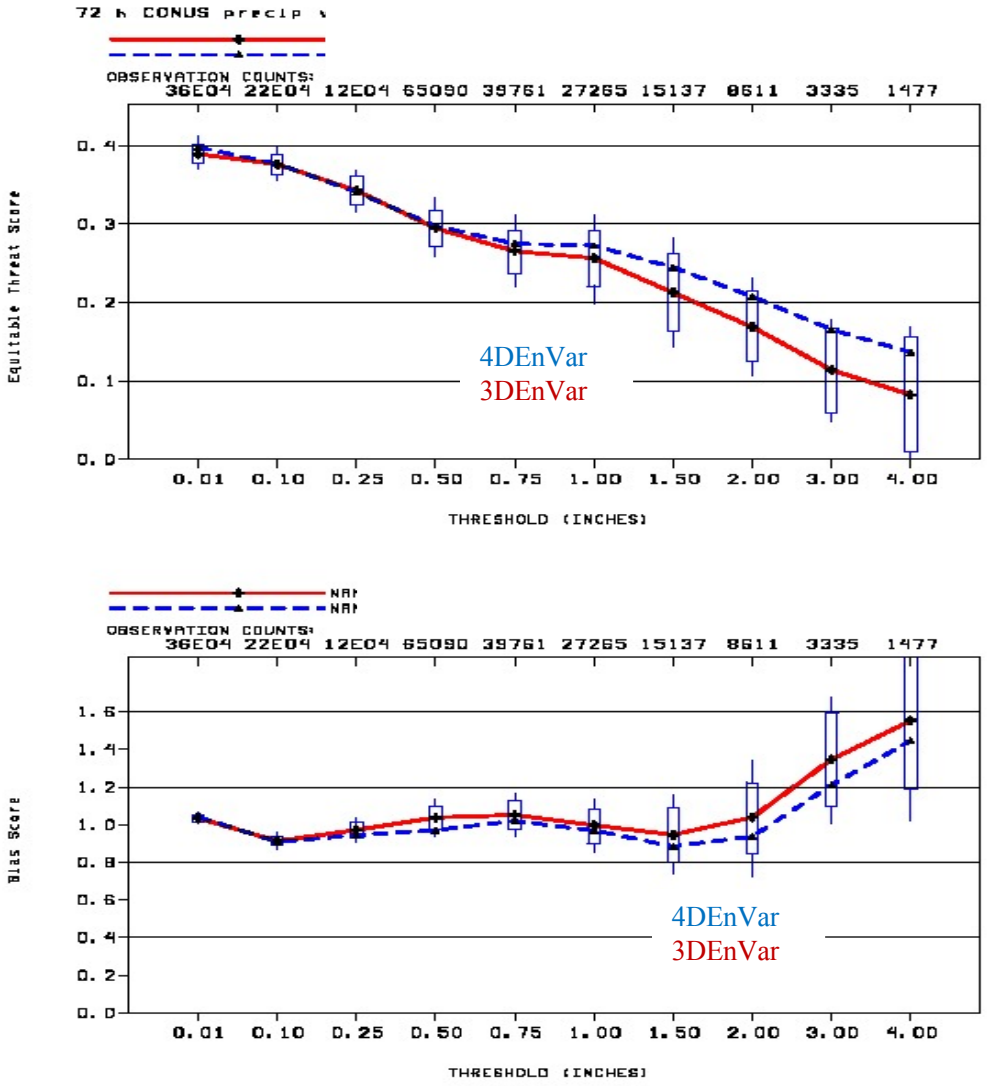
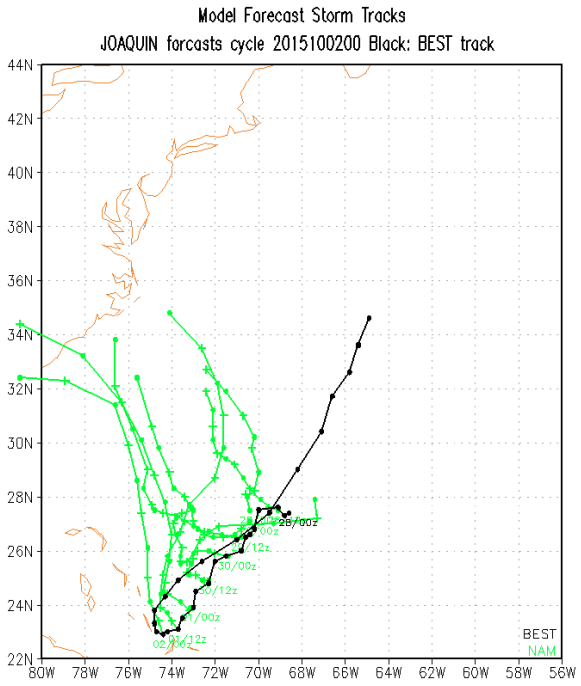


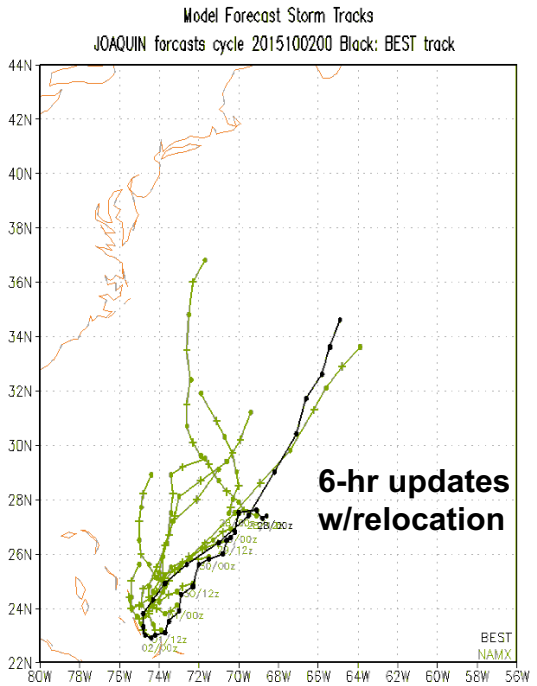
Cumulative RMSE over the continental US for 15 September 2015 to 15 November 2015.
(Eric Rogers EMC)

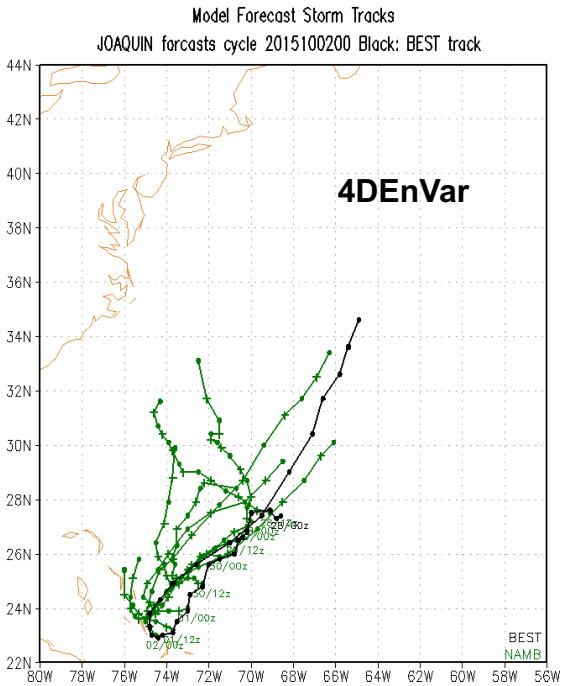
12-36hr forecasts ETS/bias

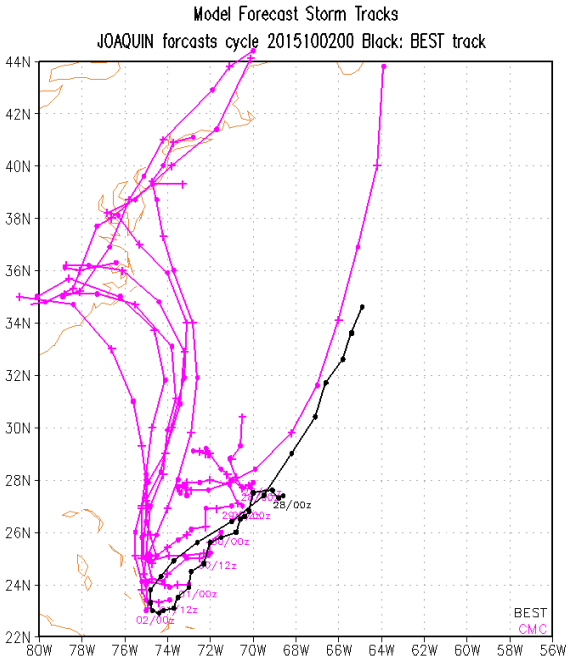


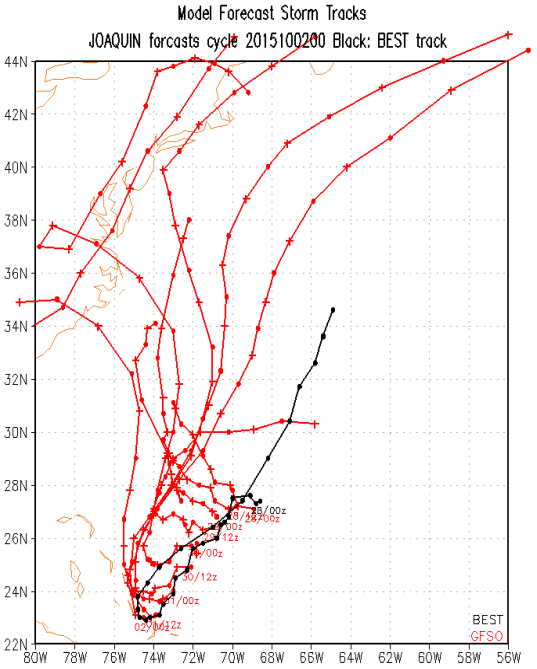
Equitable threat scores and bias scores over the continental US for 15 September 2015 to 15 November 2015. (Ying Lin EMC)

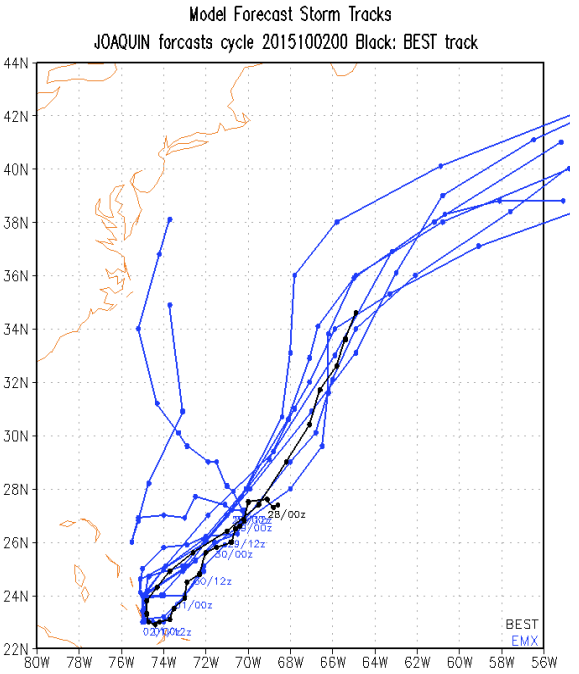












00Z 20150928 – 00Z 20151002 (Quang Ping Lou, EMC)

conclusions

- Global ensemble used in regional 4DEnVar with trajectory correction
- TC enriches the ensemble by improving the coverage in phase space
- TC allows the ensemble mean to be used in the analysis with EnVar
- Positive impact from 4DEnVar; advantages on
  - atmospheric statistics
  - precipitation scores
  - hurricane track prediction

extension of the work

- Apply EnVar with TC to combine a super ensemble

- Add regional ensemble (and its mean) beside global ensemble to help define the smaller-scale part of the background error covariance.