2013/3/21

The 3rd Research meeting of Ultrahigh Precision Meso-Scale Weather Prediction

Neighboring Ensemble-based variational assimilation scheme for a Cloud-Resolving Model

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EnVA: min. cost function in the Ensemble forecast error subspace

- Minimize the cost function with non-linear Obs. term.

$$J_x = 1/2(\vec{X} - \overline{X}_f)P_f^{-1}(\vec{X} - \overline{X}_f) + 1/2(Y - H(\vec{X}))R^{-1}(Y - H(\vec{X}))$$

- Assume the analysis error belongs to the Ensemble forecast error subspace （Lorenc, 2003):

$$\vec{X} - \overline{X}^f = \mathrm{P}_e^{f/2} \circ \Omega \qquad \Omega = [\vec{w}_1, \vec{w}_2, ,,,,, \vec{w}_N]$$

$$P_e^{f/2} = [\vec{X}_1^f - \overline{X}^f, \vec{X}_2^f - \overline{X}^f, ,,, \vec{X}_N^f - \overline{X}^f]$$

- Forecast error covariance is determined by localization $\quad \mathrm{P}^f = \mathrm{P}_e^f \circ \mathrm{S}$
- Cost function in the Ensemble forecast error subspace：

$$J(\Omega) = 1/2\, trace\{\Omega^t S^{-1} \Omega\} + 1/2\{H(\vec{X}(\Omega)) - Y\}^t R^{-1}\{H(\vec{X}(\Omega)) - Y\}$$

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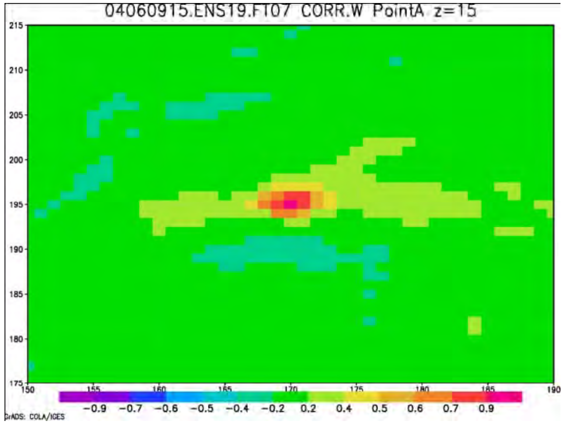
Problem in EnVA (2): Sampling error

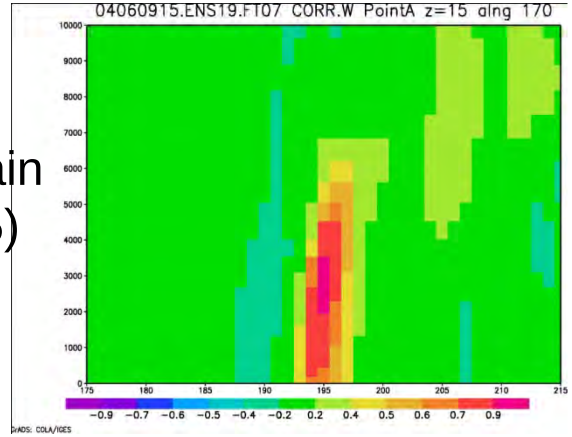
Forecast error corr. of W (04/6/9/15z 7h fcst)

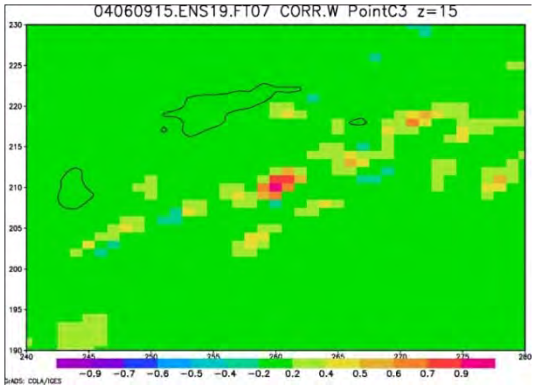
200 km

200 km

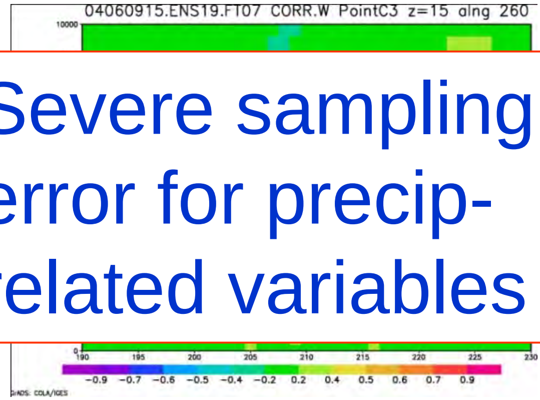


Heavy rain
(170,195)

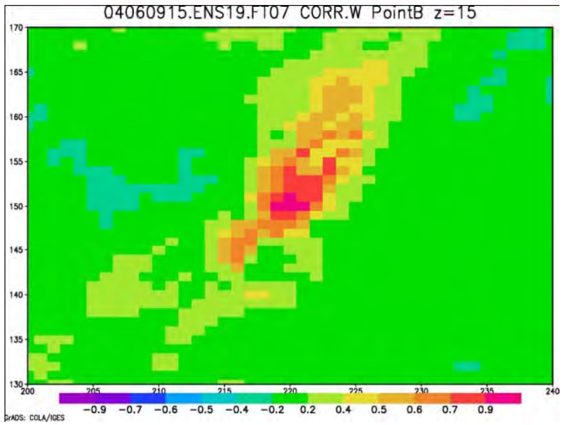




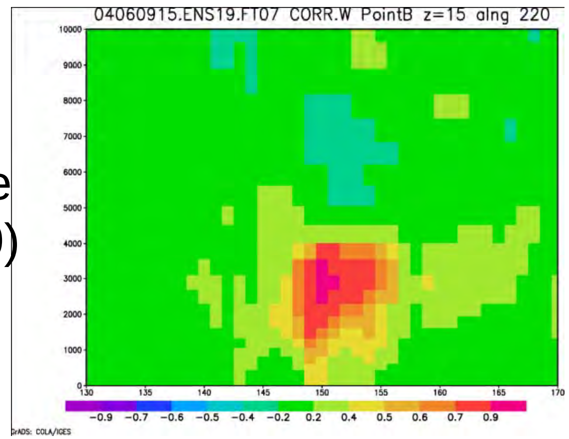
Weak ra
(260,21



Severe sampling error for precip-related variables



Rain-free
(220,150)



Sample error-damping methods of previous studies

- Spatial Localization (Lorenc, 2003)

$$C_{sp}(x1,x2)=C_{ENS}(x1,x2)\,S(\Delta_{1,2})$$

- Spectral Localization (Buehner and Charron, 2007)

$$\hat{C}_{sl}(k1,k2)=\hat{C}_{ENS}(k1,k2)\,\hat{L}_{sl}(k1,k2)$$

  – When transformed into spatial domain

$$C_{sl}(x1,x2)=\int C_{ENS}(x1+s,x2+s)L_{sl}(s)ds$$

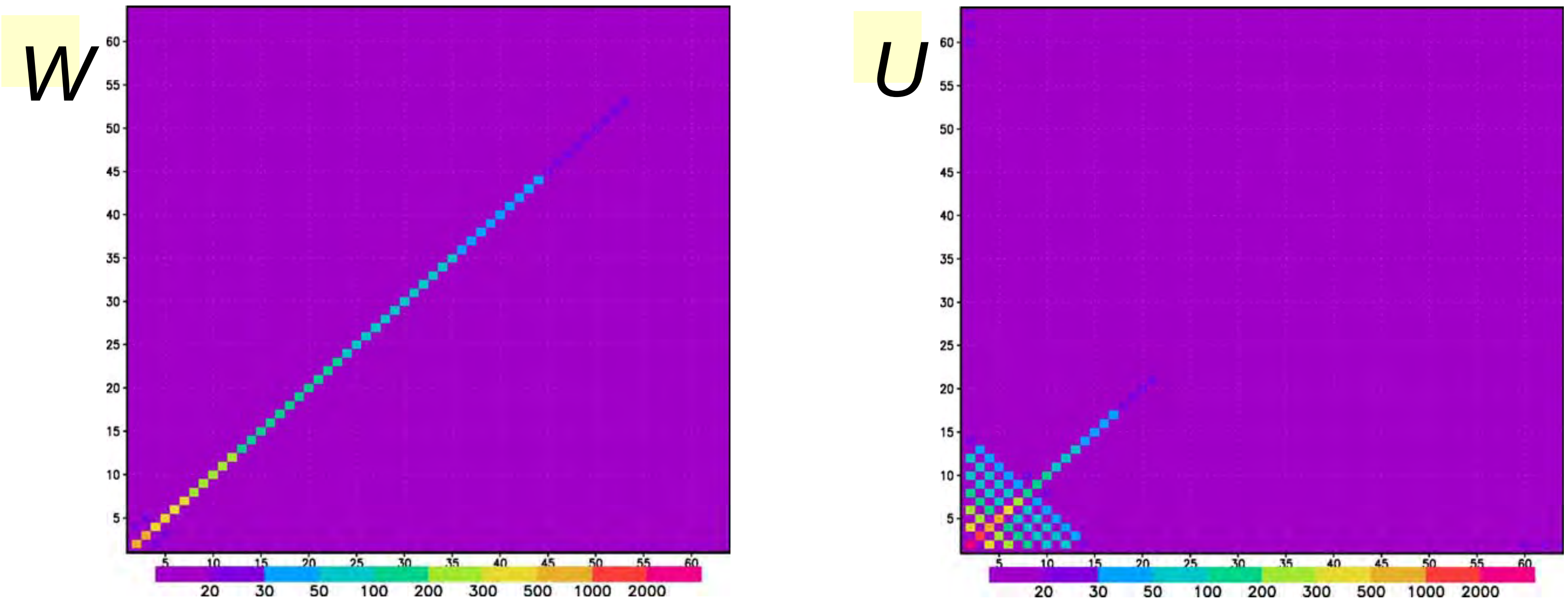
- Variable Localization (Kang, 2011)

$$C_{v}(v1,v2)=C_{ENS}(v1,v2)\,\delta(v1,v2)$$

Basic idea

- Sampling error damping method
  - Neighboring Ensemble
  - Separation of large-scale and local modes
- Space spanned by NE vertical SVD modes
- EnVA
  - Determination of cost function
  - Diagnolization of background term
  - Minimization of cost function
- Deriving the optimal for each member

Power spectral of horizontal ensemble forecast error (H~5000m) : Typhoon



1) Precip and W are diagonal, other had significant amplitudes for low-frequency, off-diagonal modes.

2) The presumption of the spectral localization "Correlations in spectral space decreases as the difference in wave number increases" is valid.

Neighboring ensemble

- Hypothesis of Buehner and Charron (2007)

  Correlations in spectral space decreases as the difference in wave number increases.

- Spectral Localization

$$\hat{C}_{sl}(k1,k2) = \hat{C}(k1,k2)\,\hat{L}_{sl}(k1,k2)$$

- When transformed into spatial domain

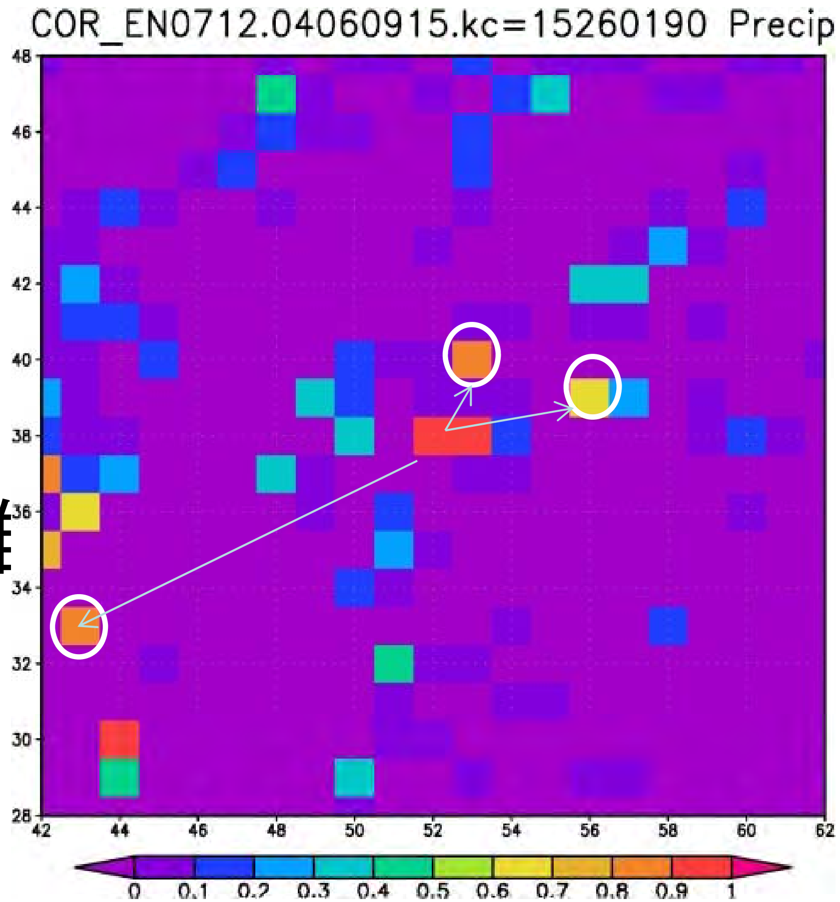
$$C_{sl}(x1,x2) = \int C(x1+s, x2+s) L_{sl}(s) ds$$

  Spectral-Localized correlation is a weighted, spatially-shifted average of correlation over the neighboring points.

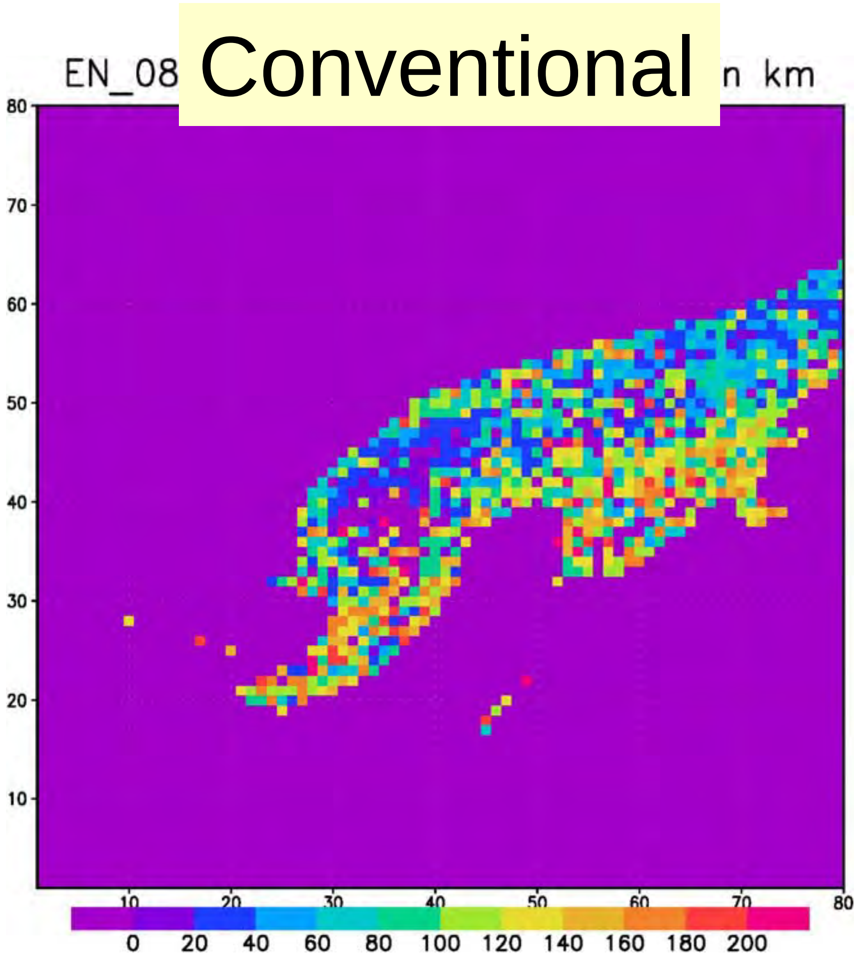
- we approximated the forecast error correlation using neighboring ensemble (NE) members of the target points (5 x 5 grids).

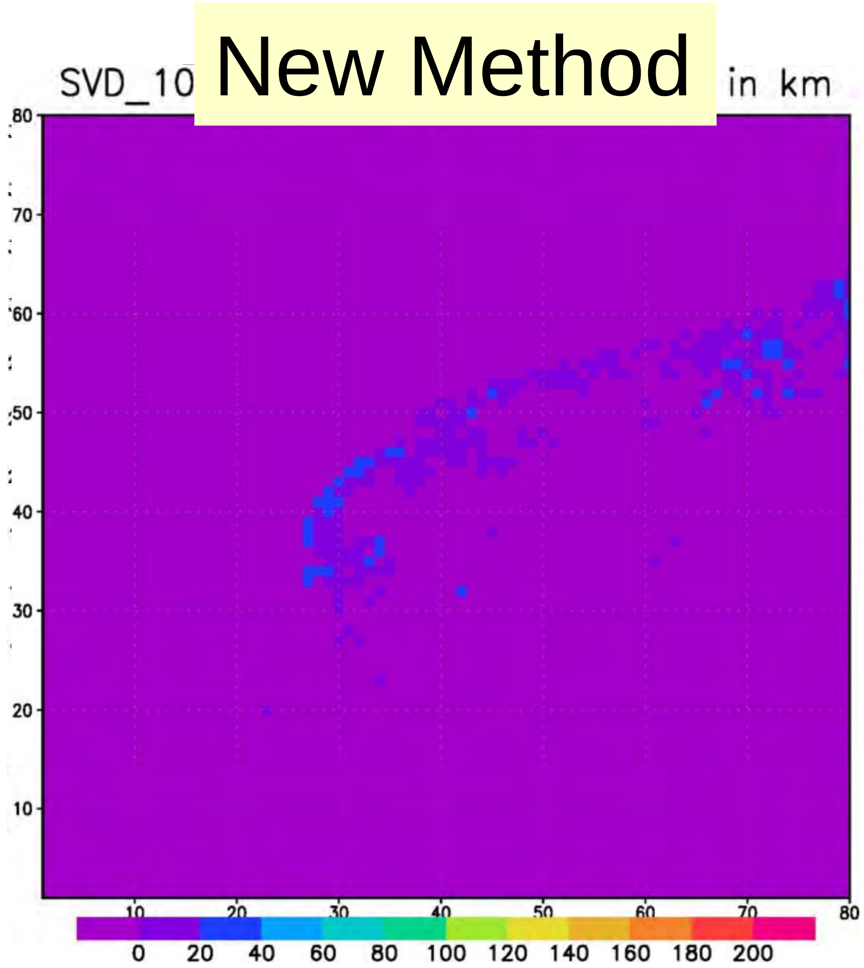
サンプリング誤差の指標

- 指標として、遠方の偽高相関域に着目
- 降水物理量の予報誤差の水平相関を計算した。
- 各粗格子点と0.5以上の相関を持つ格子点の距離の平均(DIST)を求めた。



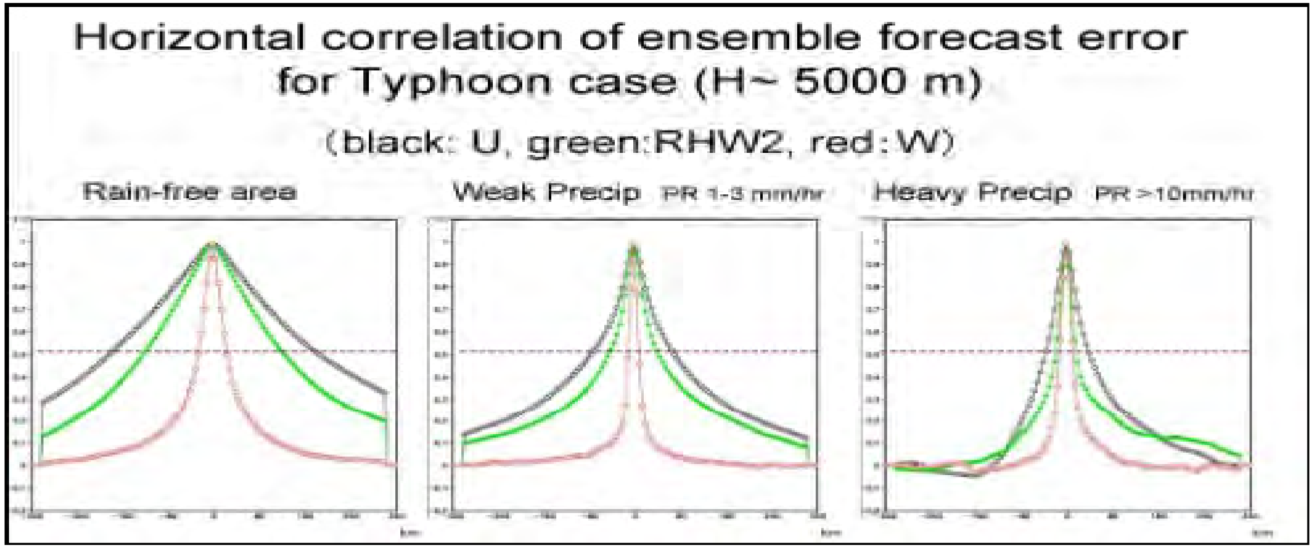
Averaged distance of area with horizontal correlation of precipitation over 0.5 (Typhoon case, H~3 km)





Separation of Large-scale and Local modes

- Scale differences between the precipitation-related variables and the other variables.
- We separated the other variables into large-scale modes (average over 65 km) and local modes (derivation from the average).



Space spanned by NE vertical SVD modes

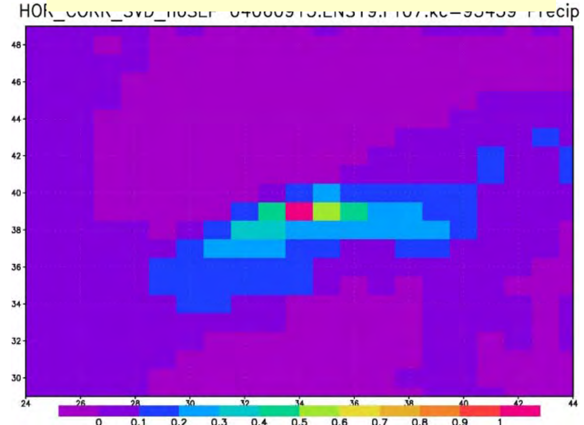
- NE member (~2500) =
  Ensemble (100 mem.) x Grid box（5x5)
- To reduce degree of freedom, we use SVD modes of vertical cross correlation of NE forecast error
- Space spanned by the NE vertical SVD modes:

$$U_{NE}{}^{f} = \frac{1}{\sqrt{K_h M - 1}} \begin{pmatrix} u_{G\ 1}(1) & u_{G\ N}(1) & & \\ u_{G\ 1}(K_h M) & u_{G\ N}(K_h M) & & \\ & & u_{g\ 1}(1) & u_{g\ N}(1) \\ & & u_{g\ 1}(K_h M) & u_{g\ N}(K_h M) \end{pmatrix}$$

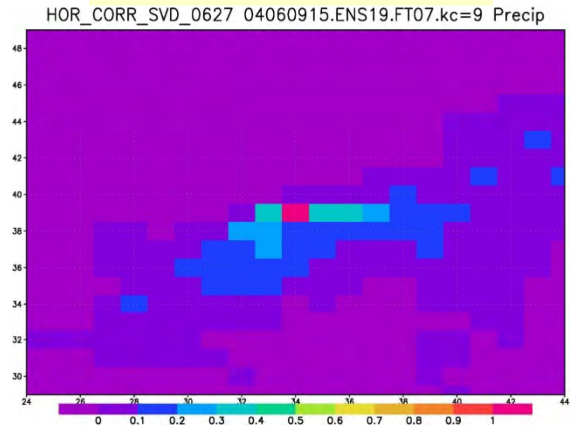
Horizontal correlation of Variables calculated from that of SVD modes at heavy rain area

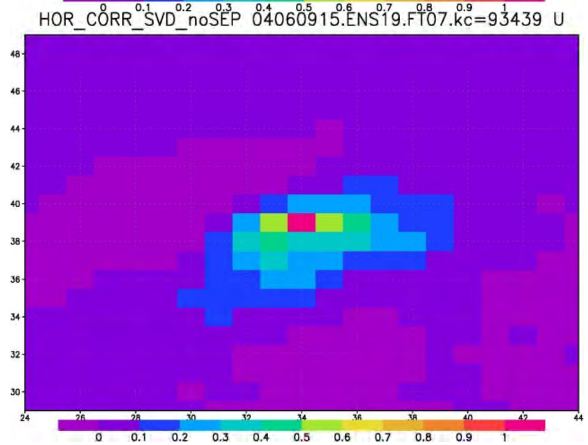
No separation

Separation

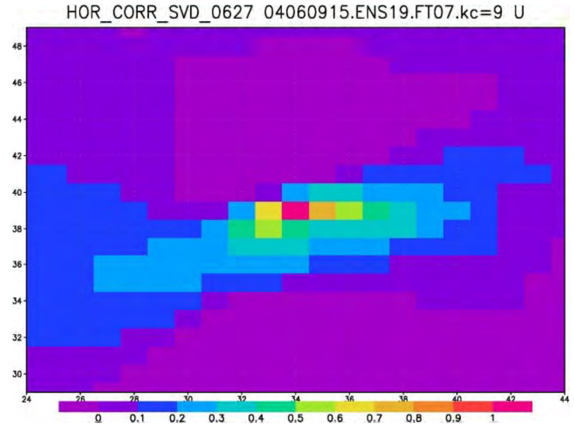


Precip





U



EnVA
Determination of cost function

- Cost function in the NE vertical SVD space

$$J_U = \frac{1}{2}(U^a - U^f)^t P_U^{-f}(U^a - U^f) + \frac{1}{2}\{H(U^a) - Y\}^t R^{-1}\{H(U^a) - Y\}$$

$$\delta U^a = U_{NE}{}^f \circ \Omega^a = \begin{pmatrix} U_G \circ \Omega_G & \\ & U_g \circ \Omega_g \end{pmatrix}$$

$$P_U{}^f = P_{U,NE}{}^f \circ S = \begin{pmatrix} (U_G U^t{}_G) \circ S_G & \\ & (U_g U^t{}_g) \circ S_g \end{pmatrix}$$

$$J_\Omega : 1/2\, trace\{\Omega^{at} S^{-1} \Omega^a\} + 1/2\{H(\Omega^a) - Y\}^t R^{-1}\{H(\Omega^a) - Y\}$$

$$= 1/2\, trace\{\Omega_G{}^t S_G{}^{-1} \Omega_G\} + 1/2\, trace\{\Omega_g{}^t S_g{}^{-1} \Omega_g\} + 1/2\{H(\Omega_G, \Omega_g) - Y\}^t R^{-1}\{H(\Omega_G, \Omega_g) - Y\}$$

EnVA
Determination of cost function

- Since vertical SVD modes are independent , cost function results in that of horizontal components:

$$J_{\Omega} -> J_{\Omega h}$$

$$: 1/2\, trace\{\Omega_h{}^{at} S_h{}^{-1} \Omega_h{}^{a}\} + 1/2\{H(\Omega_h{}^{a}) - Y\}^t R^{-1}\{H(\Omega_h{}^{a}) - Y\}$$

$$= 1/2\, trace\{\Omega_{Gh}{}^{t} S_{Gh}{}^{-1} \Omega_{Gh}\} + 1/2\{\vec{\chi}_g \vec{\chi}_g{}^{t}\}$$

$$+ 1/2\{H(\Omega_{Gh}, \vec{\chi}_g) - Y\}^t R^{-1}\{H(\Omega_{Gh}, \vec{\chi}_g) - Y\}$$

Summary

- Sampling error damping method
  - Neighboring Ensemble
  - Separation of large-scale and local modes
- Space spanned by NE vertical SVD modes
- EnVA
  - Determination of cost function