

A hybrid ensemble transform Kalman filter (ETKF)-3DVAR data assimilation scheme for WRF

Hybrid Data Assimilation Theory

- Ensemble covariance is included in the 3DVAR cost function through augmentation of control variables (Lorenz 2003, QJ; Buehner 2005, QJ; Wang et al. 2007c, MWR)

Extra term associated with extended control variable

$$J = J_b + J_o + J_e = \beta_1 \frac{1}{2} \mathbf{x}'^T \mathbf{B}^{-1} \mathbf{x}' + \frac{1}{2} (\mathbf{y}^{o'} - \mathbf{H} \mathbf{x}')^T \mathbf{R}^{-1} (\mathbf{y}^{o'} - \mathbf{H} \mathbf{x}') + \beta_2 \frac{1}{2} \mathbf{\alpha}^T \mathbf{C}^{-1} \mathbf{\alpha}$$

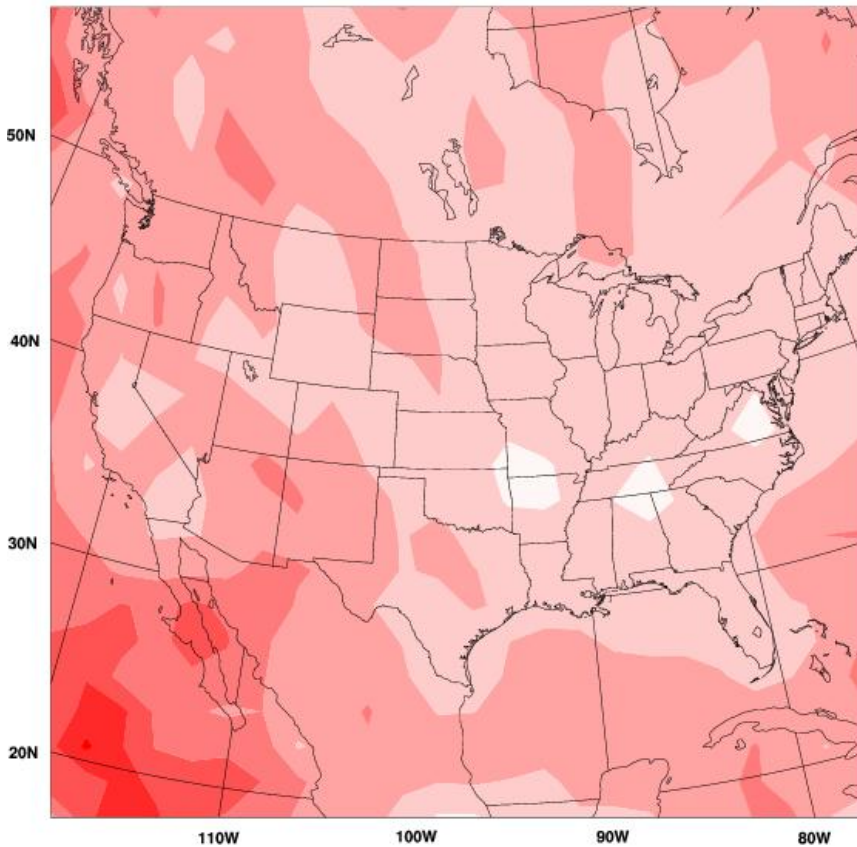
$$\mathbf{x}' = \mathbf{x}'_1 + \sum_{k=1}^K (\mathbf{\alpha}_k \circ \mathbf{x}_k^e)$$

← Extra increment associated with ensemble

B 3DVAR static covariance; **R** observation error covariance; *K* ensemble size;
C correlation matrix for ensemble covariance localization; \mathbf{x}_k^e *k*th ensemble perturbation;
 \mathbf{x}'_1 3DVAR increment; \mathbf{x}' total (hybrid) increment; $\mathbf{y}^{o'}$ innovation vector;
H linearized observation operator; β_1 weighting coefficient for static covariance;
 β_2 weighting coefficient for ensemble covariance; $\mathbf{\alpha}$ extended control variable.

OSSE: root mean square analysis error

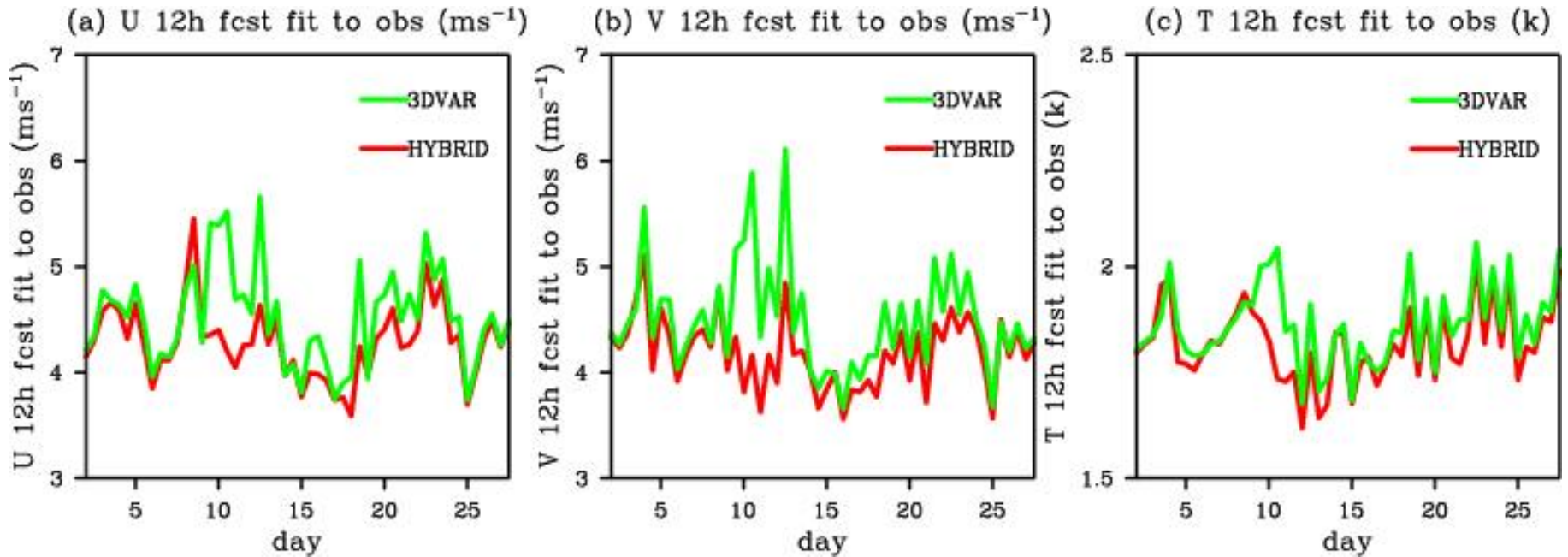
difference of V rms ana. error (ms^{-1})



- Hybrid has larger improvement over data sparse regions, e.g., ocean; Flow-dependent ensemble covariance has the largest impact where observation is sparse.

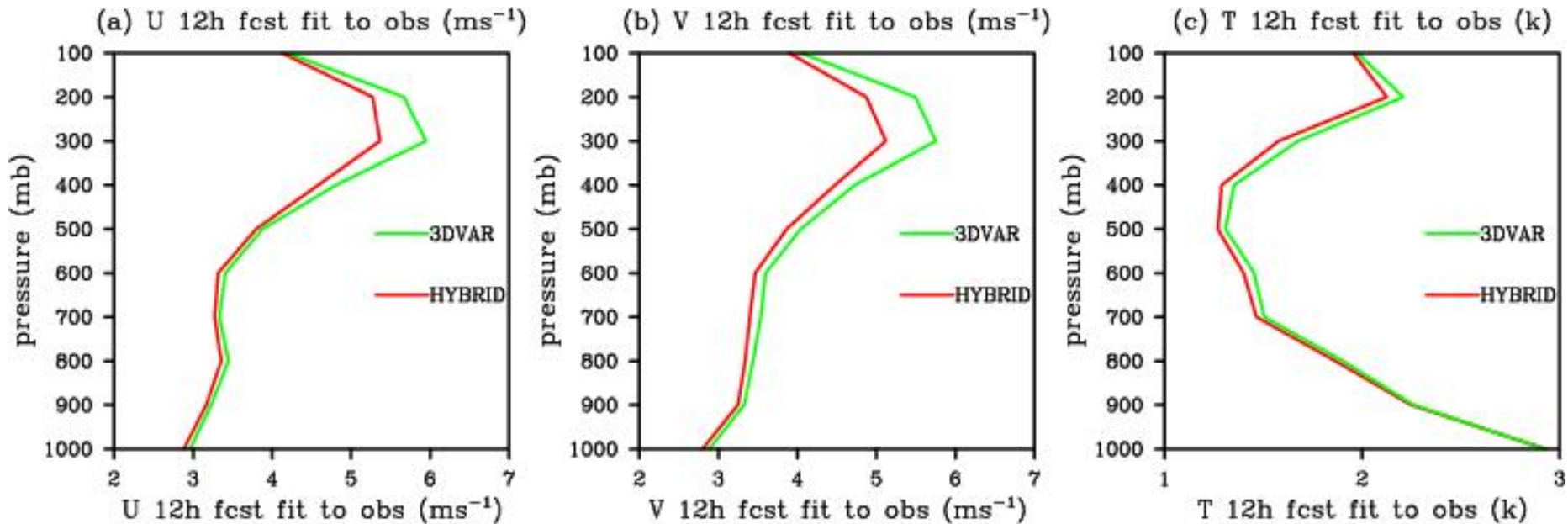
- Hybrid has larger improvement over western continent than the east; hybrid extrapolates observations info properly (flow dependently) to the upstream data void region.

Real obs. experiment: 12h forecast fit to obs.



- Hybrid 12h forecast is more accurate than the 3DVAR for most time.

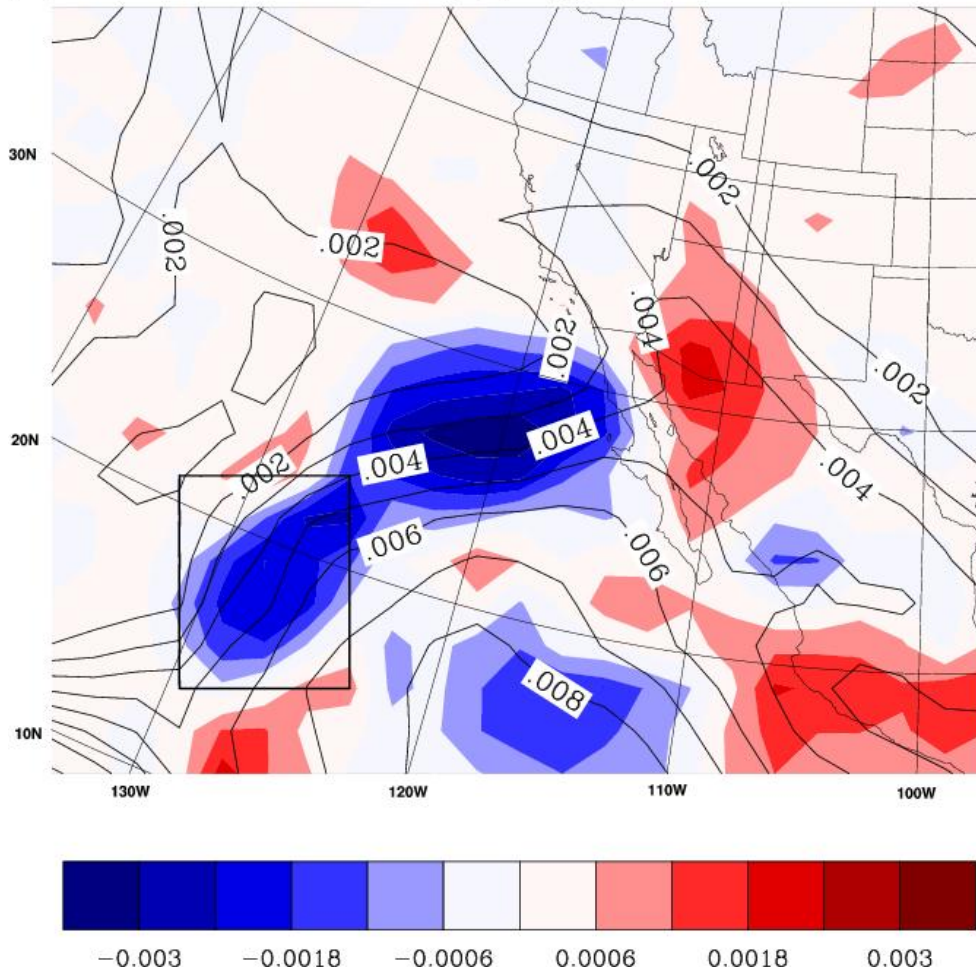
Real obs. experiment: 12h forecast fit to obs.



- **Wind:** Hybrid has the largest improvement at 200mb-300mb;
- **Temperature:** Hybrid is better than 3DVAR except lower troposphere. Significant bias at lower troposphere.

A case study: flow-dependent update of the data void upstream region by the hybrid

(a) HYBRID increment (kg/kg) qv 700mb 2003010812



- Hybrid corrected the moisture field over the data void upstream region using observations far in land. It dried the lower troposphere along the warm front, reaching the region where 3DVAR was raining.