# Improving EnKF spin-up for typhoon assimilation and prediction

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## 1. Background

To initialize the mesoscale EnKF for a regional model, it is common to use initial conditions from the global (re)analysis products and initial ensemble perturbations constructed based on the 3D-Var background covariance. Such initial conditions don't have enough mesoscale information and the perturbations are less than optimal due to the lack of mesoscale flow-dependency. Therefore, mesoscale EnKF requires a spin-up period to reach its asymptotic level of accuracy.

To accelerate the spin-up, the "running in place" method proposed by Kalnay and Yang (2010) is implemented based on the framework of Local Ensemble Transform Kalman Filter (LETKF) with the Weather Research and Forecasting model (WRF ).

## 2. Running-in-place with LETKF

The LETKF scheme (Hunt et al. 2007) performs an analysis locally in space using local information, including the background ensemble and observations. The analysis corrections ($\overline{\mathbf{x}}_a - \overline{\mathbf{x}}_b$) and ensemble perturbations ($\mathbf{X}_a$) obtained by the LETKF is represented within a space spanned by the local ensemble. The formula to update the ensemble mean and perturbations at $t_n$ are:

$$\overline{\mathbf{x}}_n^a = \overline{\mathbf{x}}_n^b + \mathbf{X}_n^b \overline{\mathbf{w}}_n \text{, where } \overline{\mathbf{w}}_n = \hat{\mathbf{P}}_n^a \mathbf{Y}_n^{bT} \mathbf{R}^{-1}(\mathbf{y}_n^o - \overline{\mathbf{y}}_n^b)$$

$$\mathbf{X}_n^a = \mathbf{X}_n^b \mathbf{W}_n \text{, where } \mathbf{W}_n = [(K-1)\hat{\mathbf{P}}_n^a]^{\frac{1}{2}} \text{ and } \hat{\mathbf{P}}_n^a = [(K-1)\mathbf{I} + \mathbf{Y}_n^b \mathbf{R}^{-1} \mathbf{Y}_n^b]^{-1}$$

*Definition*: $\mathbf{y}_n^o$ is the observations at $t_n$. And, $\overline{\mathbf{y}}_n^b$ and $\mathbf{Y}_n^b$ are the background mean and ensemble perturbations in the observational space.

- **Running in place (Kalnay and Yang, 2010):** The no-cost smoother (Kalnay et al. 2007, Yang et al. 2009) + a iteration scheme to accelerate the ensemble states toward the true dynamics provided by the observations.

1)At $t_n$, perform the LETKF and derive the weight coefficients ($\overline{\mathbf{w}}_n$, $\mathbf{W}_n$)
2)use the no-cost smoother to smooth, $\overline{\mathbf{x}}_m^a$ and $\mathbf{X}_m^a$ (at $t_m$ and $t_m < t_n$)
3)perturb $\mathbf{X}_m^a$ with random Gaussian perturbations
4)evolve the analysis ensemble to $t_n$
5)If $\dfrac{\left|\mathbf{RMS}(\mathbf{y}_n^o - \overline{\mathbf{x}}_{n,itr-1}^b) - \mathbf{RMS}(\mathbf{y}_{obs} - \overline{\mathbf{x}}_{n,itr}^b)\right|}{\mathbf{RMS}(\mathbf{y}_n^o - \overline{\mathbf{x}}_{n,itr-1}^b)} > \varepsilon$, repeat (1)-(4).

## References and Acknowledgement

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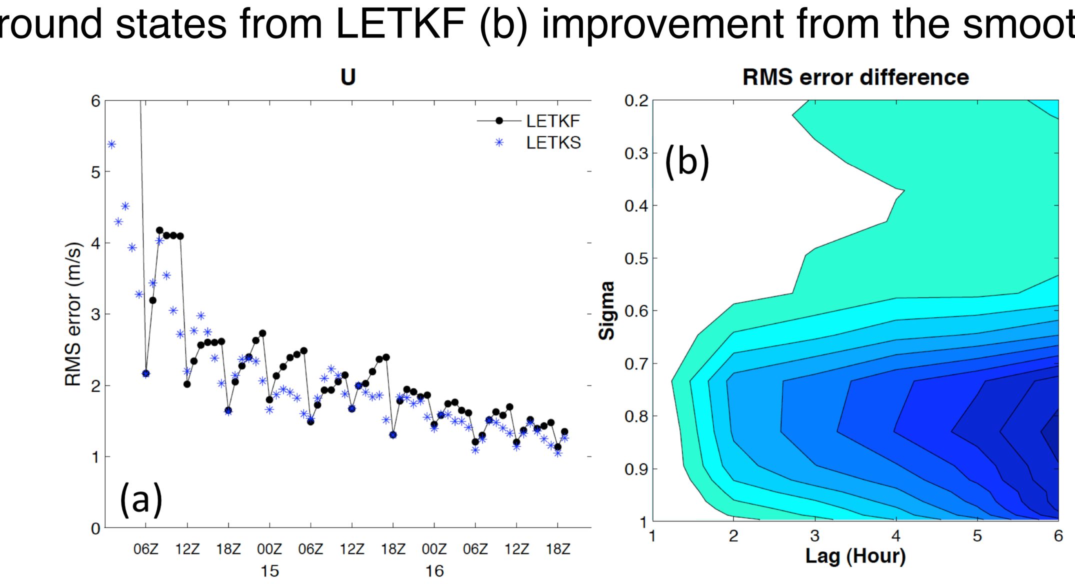
## 3. OSSE Experiment setup

- **WRF model domain**: The grid dimension is 150×150×27 layers, centered at (125°E, 21°N) and the resolution is 25 Km.
- **Truth run**: Among a set of ensemble simulations, select a typhoon that approaches Taiwan with rapid intensification.
- **Analysis variables**: velocity, potential temperature and water vapor mixing ratio, geopotential height and mass perturbation
- **Observations**: add Gaussian noises to the true evolution
  - 11 soundings locate at the realistic stations (available every 6 hour)
  - Ocean surface wind: locations from QuikSCAT wind (available every 12 hour)
- The WRF-LETKF is performed with 36 ensemble members with an analysis cycle of 6-hour. Localization procedures are done in horizontal and vertical.

- **Local Ensemble Kalman smoother (LETKS) vs. LETKF**

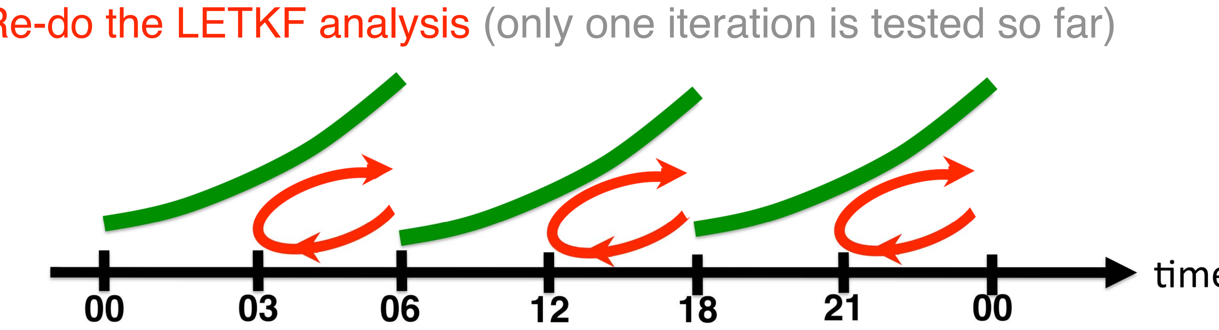
**Fig.** 1 (a) averaged RMS error of the model states from LETKS and analysis/ background states from LETKF (b) improvement from the smoothed model states




The information from the later observations provides effective corrections for the model states evolving within the 6-hr assimilation window. Even with the surface wind, the improvement can extend to the upper levels for a lag with 3 hour.

- **Setup for the LETKF-RIP experiment**

1)Computed the LETKF weights at analysis time (00,06,12,18Z)
2)Use these weight to reconstruct the analysis ensemble (U, V, T) at the chosen time (e.g. 03,09,15,21Z)
3)Perturb the new analysis ensemble with random perturbations
4)perform the 3-hr forecasts
5)Re-do the LETKF analysis (only one iteration is tested so far)

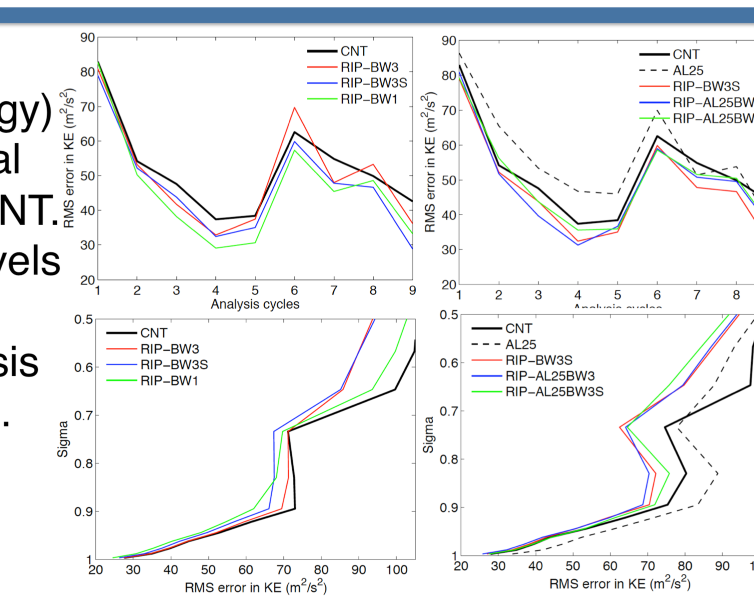



| EXP name | Horizontal localization (km) | | Window of Loop B |
|---|---|---|---|
| | Loop A | Loop B | |
| CNT | 150 | | N/A |
| AL25 | 250 | | N/A |
| RIP-BW3 | 150 | 150 | 3 |
| RIP-BW1 | 150 | 150 | 1 |
| RIP-AL25BW3 | 250 | 150 | 3 |
| RIP-AL25BW1 | 250 | 150 | 1 |

## 4. Impact on the analysis

**Fig.** 2 RMS analysis error (in term of kinetic energy) (a,b) averaged for lower levels and (c,d) in vertical

1. All the RIP-related experiments improve the CNT. But the wind structure is better at mid- high levels when loop B uses longer nonlinear integration
2. With a larger horizontal localization, the analysis accuracy is much improved during the spin-up.



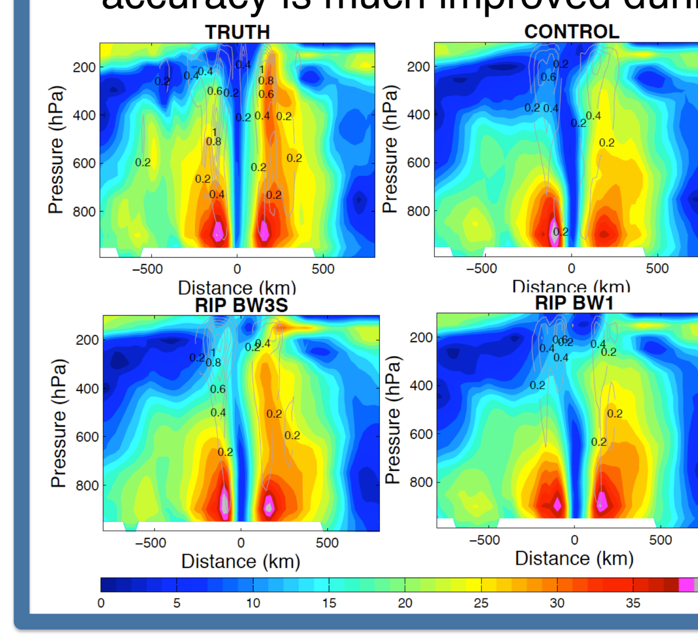




**Fig. 3** Vertical wind structure of the typhoon from the truth, CNT, RIP-BW3 and RIP-BW1 at 09/15 06Z (shading: wind speed, contour: vertical velocity)

The loop B in RIP plays an important role in adjusting the dynamical structure of typhoon

## 5. Impact on typhoon prediction

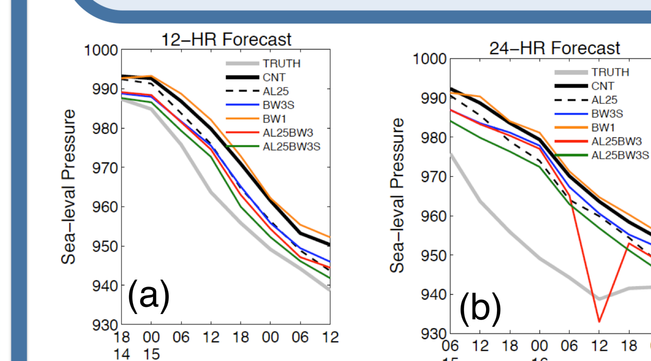
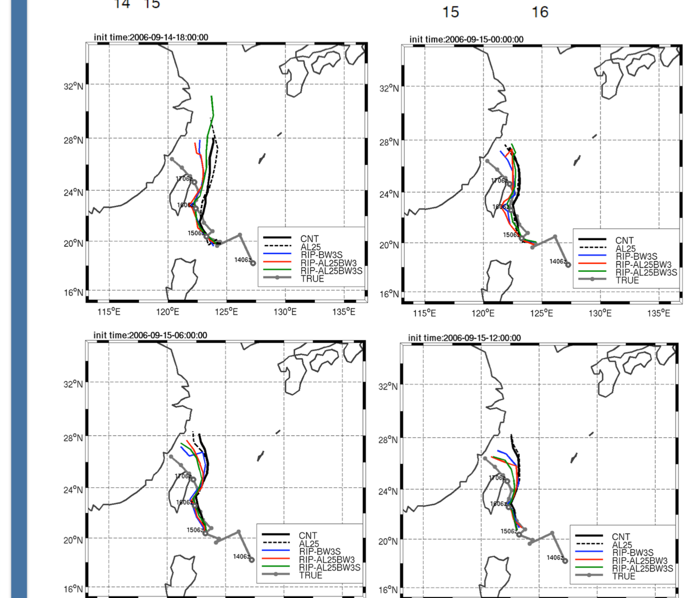



**Fig. 4** Typhoon intensity from (a) 12-hour and (b) 24-hour forecasts initialized from the LETKF and RIP analysis



The improvements on the LETKF-RIP analysis can lead to better prediction of typhoon intensity and track.

- Forecasts initialized from RIP with 3-hour nonlinear integration are always better than CNT forecast.
- The impact of the RIP on forecasting is limited with 1-hour nonlinear integration.
- Further improvement could be obtained by using a larger horizontal localization in loop A.

**Fig. 5** Typhoon track predictions initialized at (a) 09/14 18Z, (b) 09/15 00Z (c) 09/15 06Z and (d) 09-15 12Z

## 6. Summary and future work

- The running in place method is implemented in the WRF-LETKF system and tested with only one iteration to investigate its potential impact. Results suggest better strategies are:
  - take advantage of the fully nonlinear model with long enough integration
  - use different localization scales to capture both the synoptic and meso scale features
- Results suggested that the ocean surface wind can provide more positive impact with the LETKF-RIP during the spin-up period, resulting a better dynamical structure of the typhoon.
- Positive influence is also identified with the LETKF-RIP for the track and intensity prediction.
- Considered the computational cost that the LETKF-RIP would require, a quasi outer-loop (Yang and Kalnay, 2010) , the simplified version of RIP, will be tested in the future.