Improving the spin-up of the regional EnKF for typhoon assimilation and forecast

Shu-Chih Yang[1], Eugenia Kalnay[2], Takemasa Miyoshi[3], and Kuan-Jen Lin[1]

1: National Central University, Taiwan

2: University of Maryland

3:RIKEN-AICS

2013/02/25@AICS

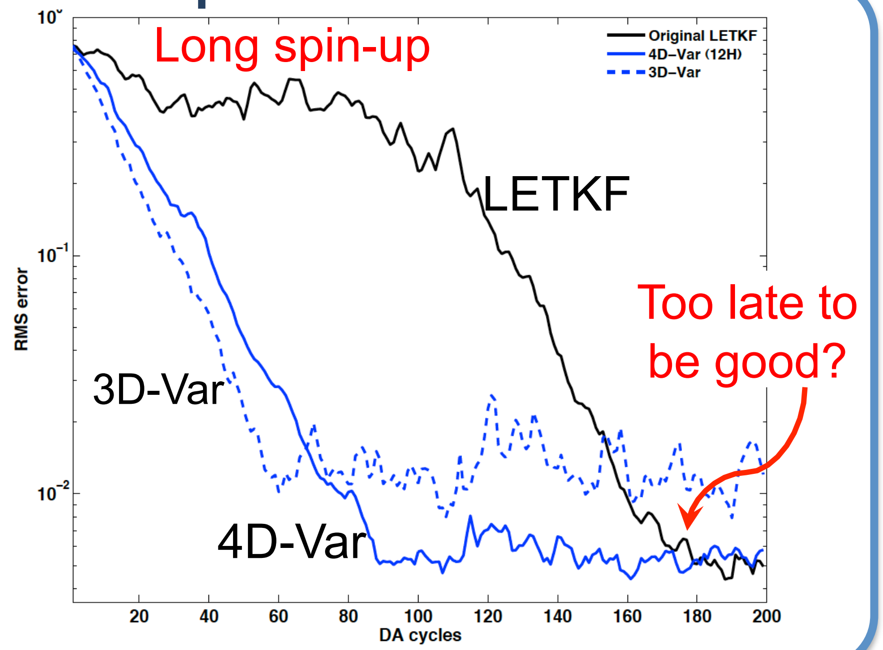
Outline

- Introduction
- **R**unning **I**n **P**lace method in the LETKF framework
- Results
  - OSSE experiments
  - Real case (Typhoon Sinlaku)
- Summary

Introduction

- Advantages of Ensemble Kalman Filters (EnKF)
  - Use the flow-dependent background error covariance
  - Naturally combine data assimilation and ensemble prediction (initial errors vs. ensemble perturbations)
- A reliable background error covariance is the key factor for good performance of EnKF
  - EnKFs needs a spin-up time to accumulate enough observations for building a reliable background error covariance
  - Strong nonlinearity limits EnKF's performance (nonlinear dynamics, poor initial ensemble, infrequent or sparse observations, …)

with poor initial conditions

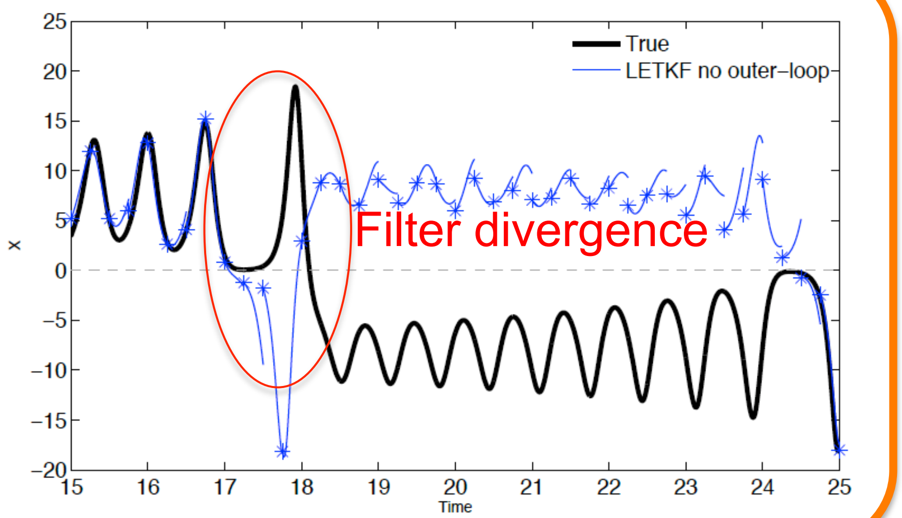


LETKF in a quasi-geostrophic channel model

Initial ensemble:
climatology mean + random perturbations

A long spin-up is required for LETKF to reach its asymptotic performance!

under strong nonlinearity



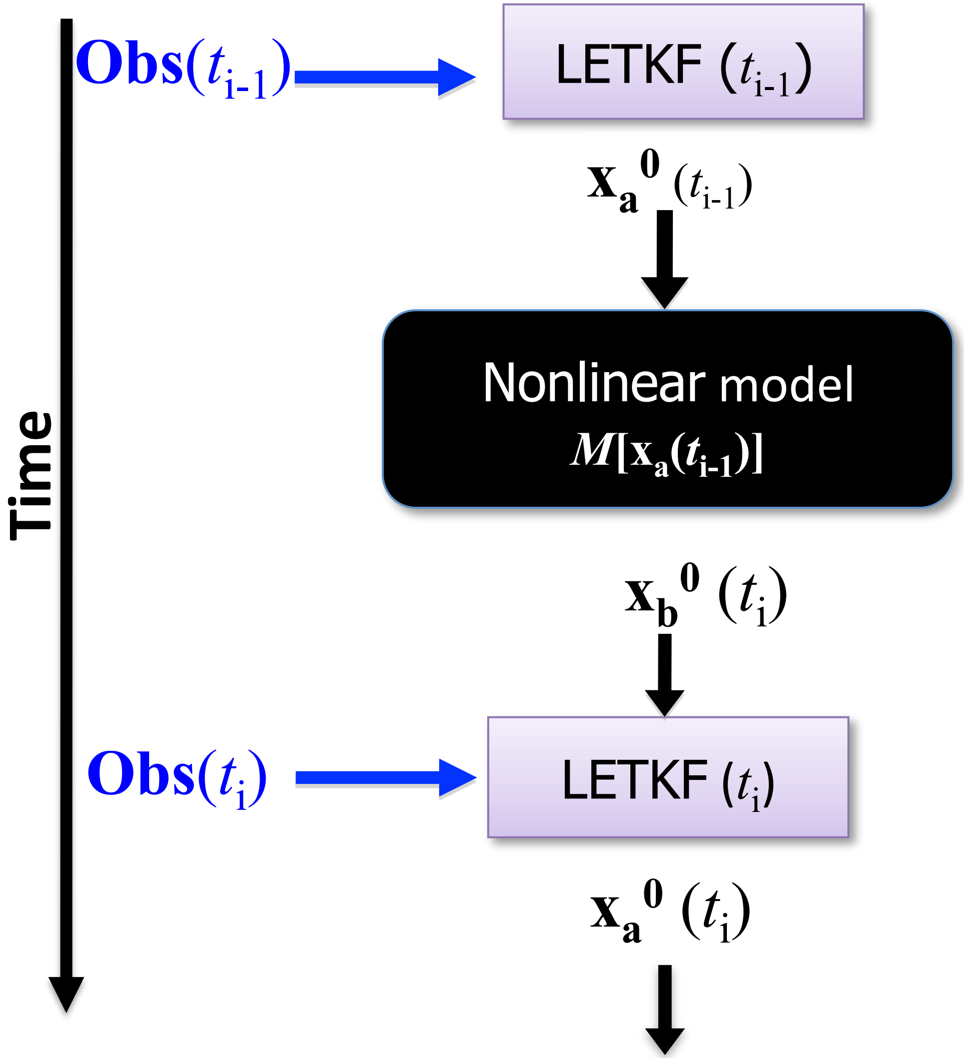
LETKF in the Lorenz 3-variable model

For cases with strong nonlinear growth, background ensemble can't represent the state uncertainty and <u>the most likely state is unlikely to happen!!</u>

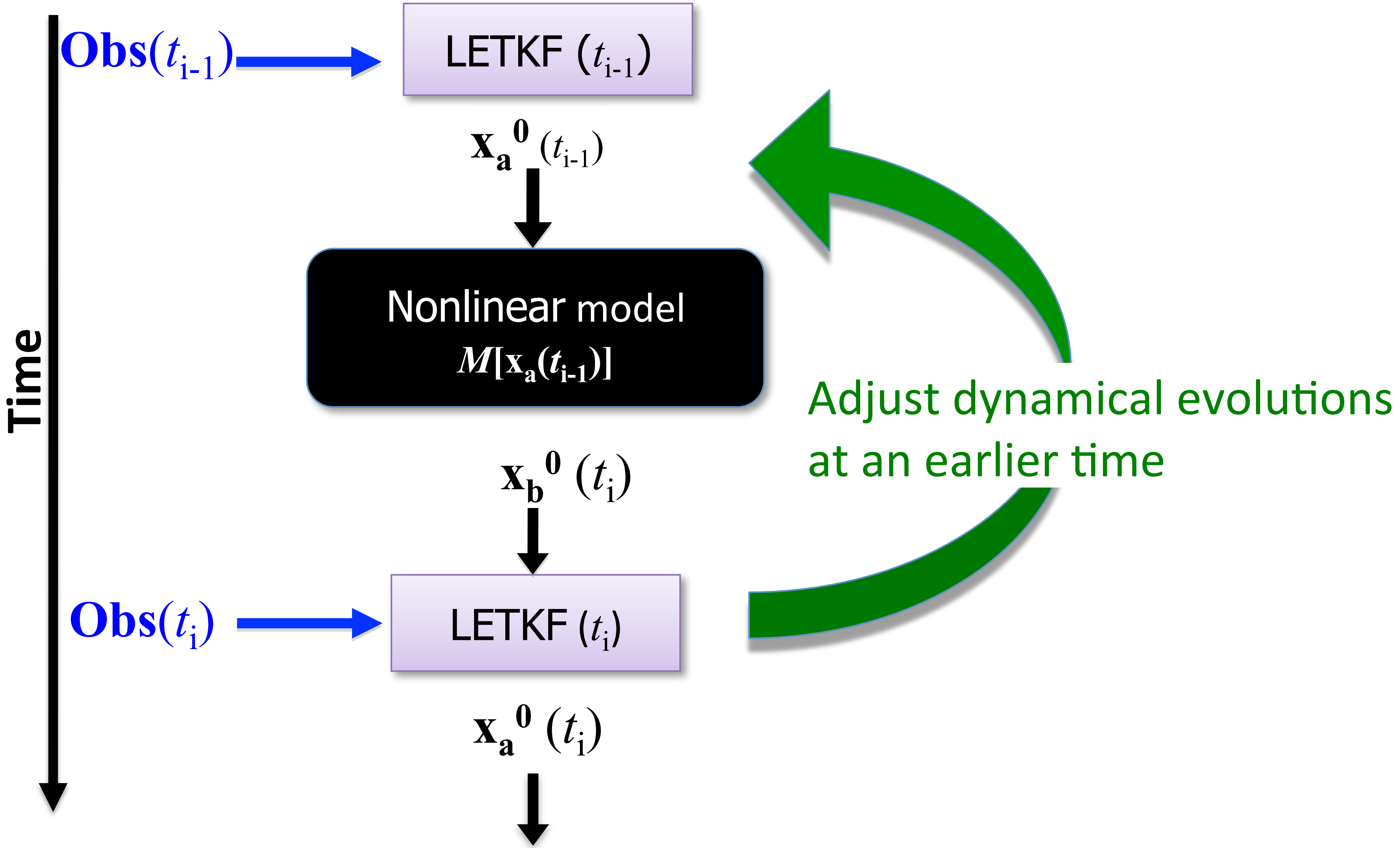
Implications on regional EnKFs

- The regional EnKF needs a spin-up period when cold-starting the ensemble with global analyses.
- For typhoon prediction, the EnKF's spin-up period becomes critical.
  - During the spin-up, TYs usually are developing on oceans, where limited observations are available.
  - During the spin-up, valuable observations (e.g. reconnaissance aircraft) can't be effectively used!!
  - Regional EnKF systems usually require a spin-up period of 2~3 day.
- The "Running In Place" method (Kalnay and Yang, 2008,2010) aims to improve both the accuracy of the mean state and structure of the ensemble-based covariance during the spin-up.
  - RIP is designed to re-evolve the whole ensemble to catch up the true dynamics, represented by observations.
  - RIP can serve as a generalized outer-loop for the EnKF framework to improve the nonlinear evolution of the ensemble (Yang et al., 2012a)

Standard LETKF framework

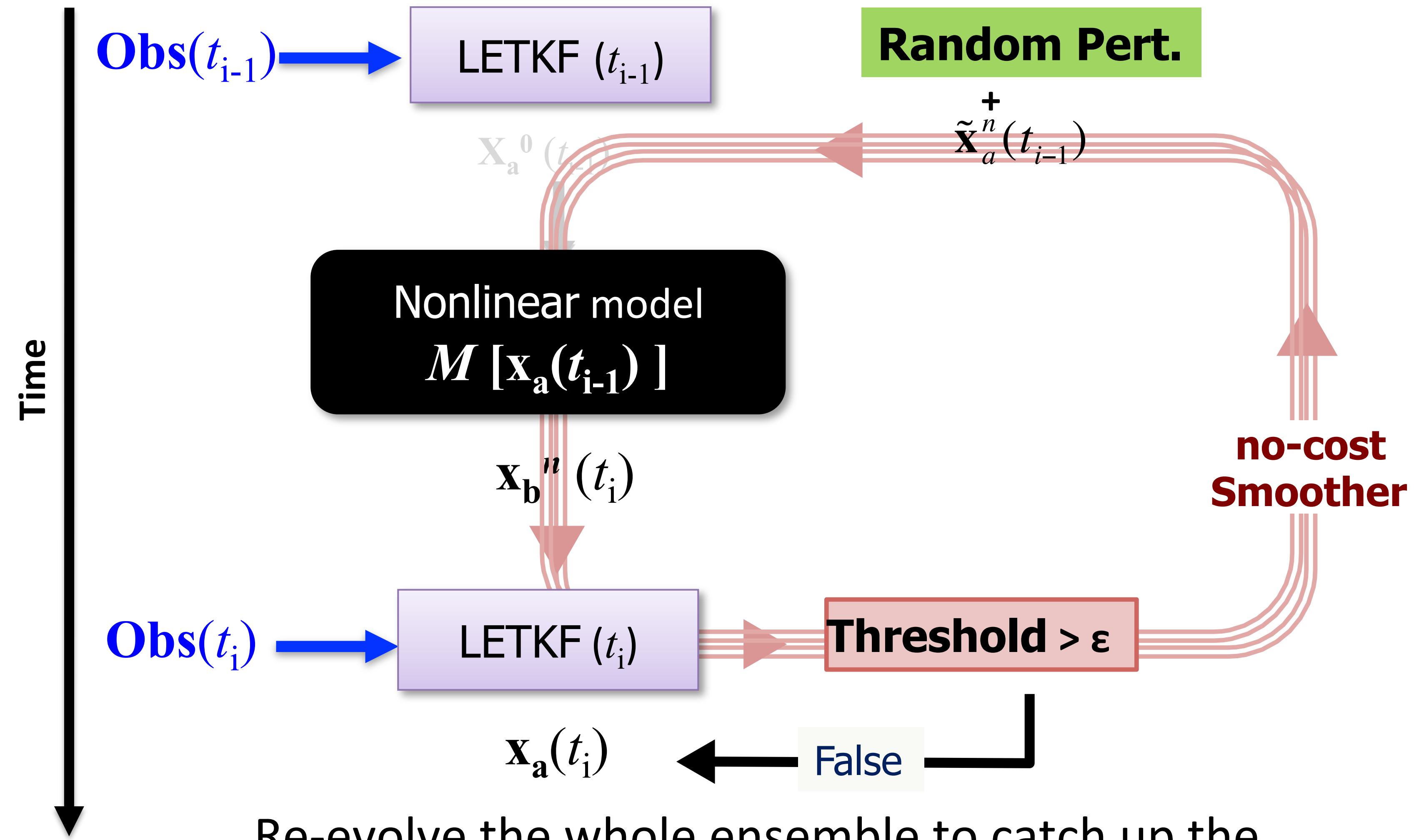


Standard LETKF framework



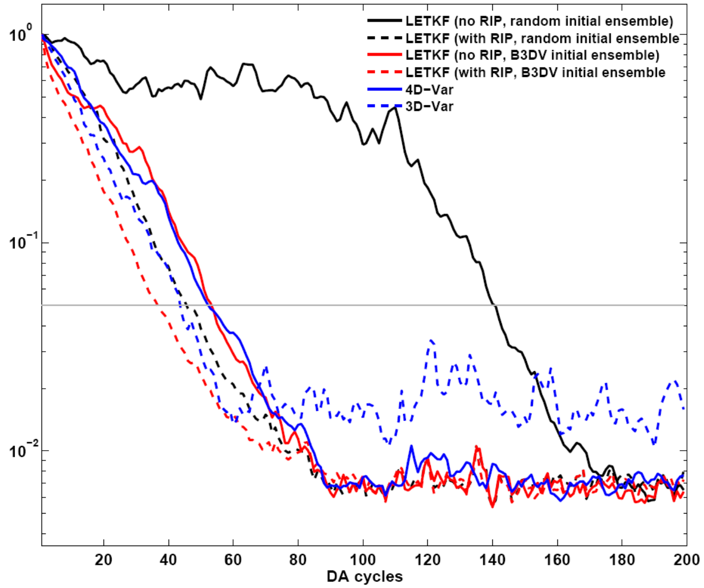
“Running in place” in the LETKF framework

(Kalnay and Yang, 2008, 2010)



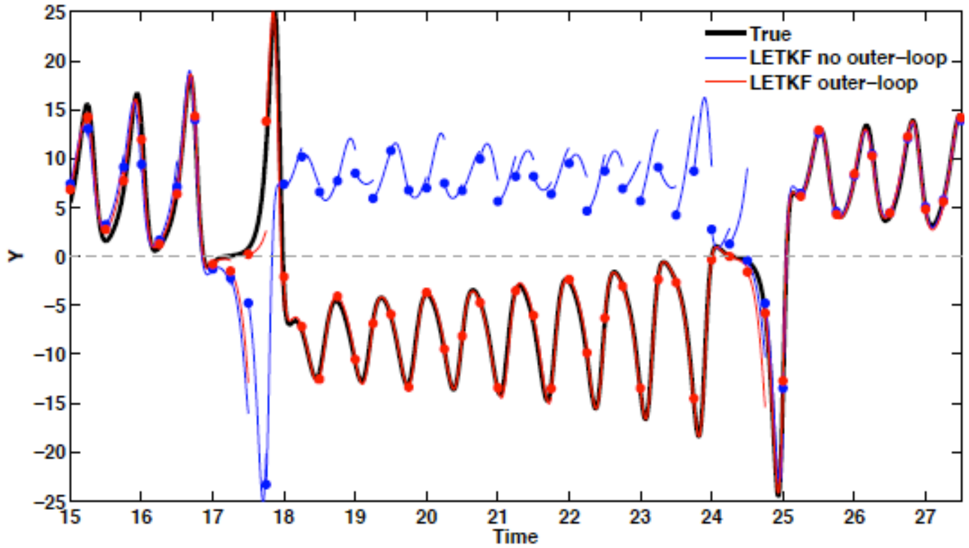
Re-evolve the whole ensemble to catch up the true dynamics, represented by observations.

Accelerating LETKF's spin-up



RIP significantly accelerates the LETKF's spin-up!

Deal with nonlinearity



RIP can serve as a generalized outer-loop to avoid filter divergence!

Goals

RIP is implemented in the WRF-LETKF system and has been applied to typhoon assimilation and prediction

- under the OSSE framework (Yang et al., 2012b)
- RIP's potential is further investigated with REAL cases
  - ✓ Improve the effectiveness of observations during the LETKF spin-up period
  - ✓ Use RIP as a generalized outer-loop (use it only when we need it!)

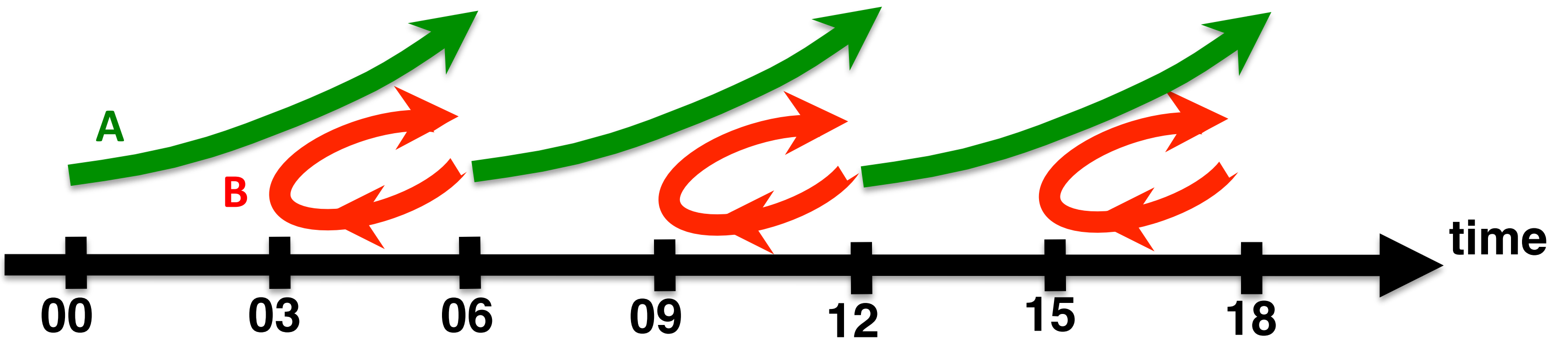
Applying RIP to the WRF-LETKF system for typhoon assimilation/prediction

Experiment setup:

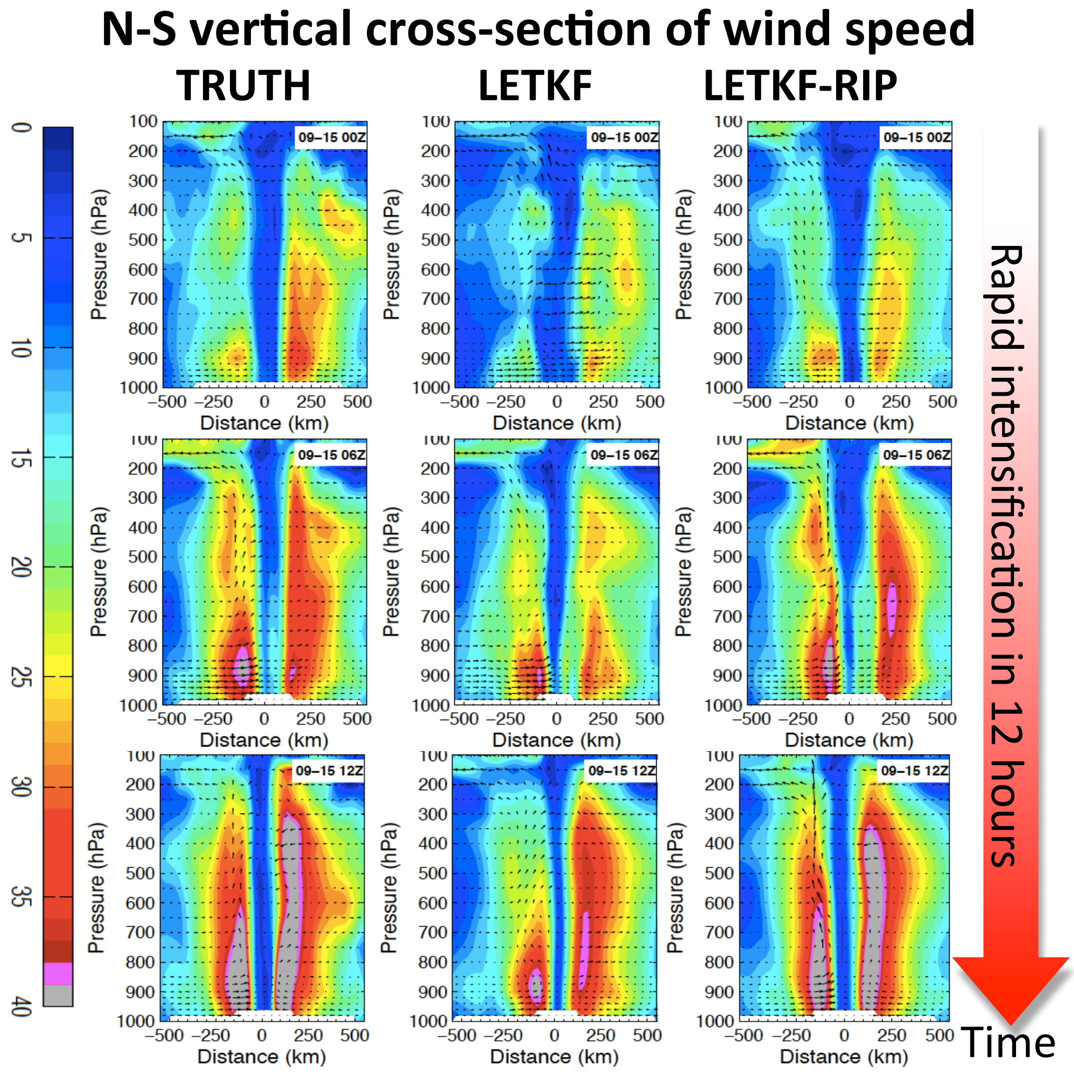
- Regional Model: Weather Research and Forecasting model (WRF, 25km)
- Assimilation schemes: LETKF/LETKF-RIP with 36 ensemble members

LETKF-RIP setup

1) Computed the LETKF weights at analysis time (00,06,12,18Z)
2) Use these weight to reconstruct the ensemble (U, V) at (03,09,15,21Z)
3) perform the 3-hr ensemble forecasts
4) Re-do the LETKF analysis (only one iteration is tested)

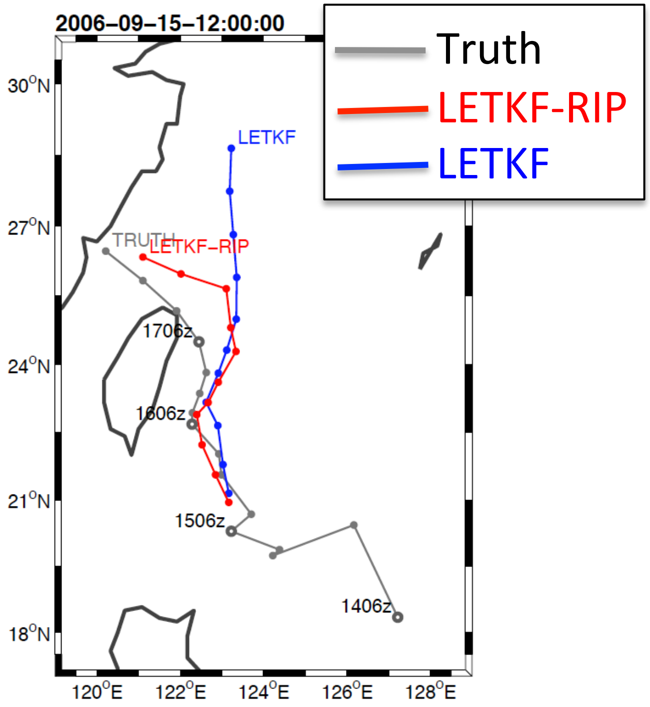


Impact from RIP on improving the mean state and error covariance (based on OSSE exps)



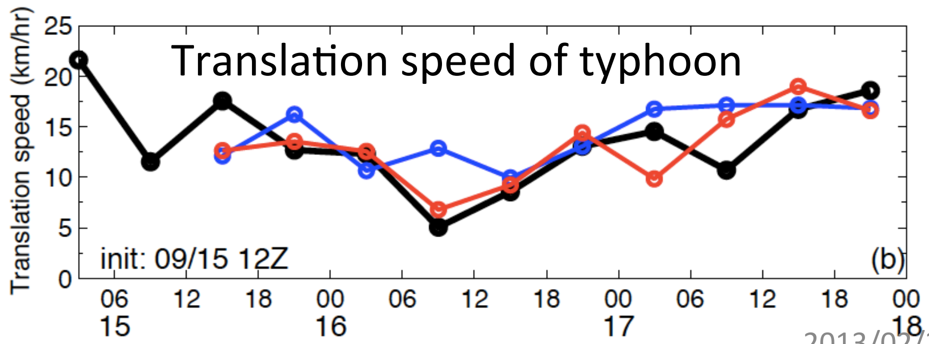
RIP Effectively spins up the dynamical structure of the typhoon!

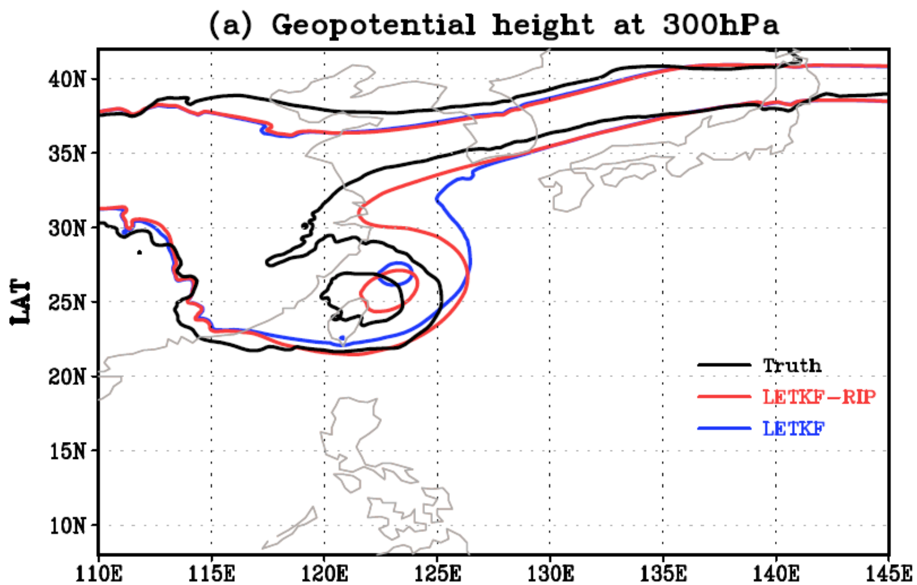
Typhoon prediction: the environmental condition



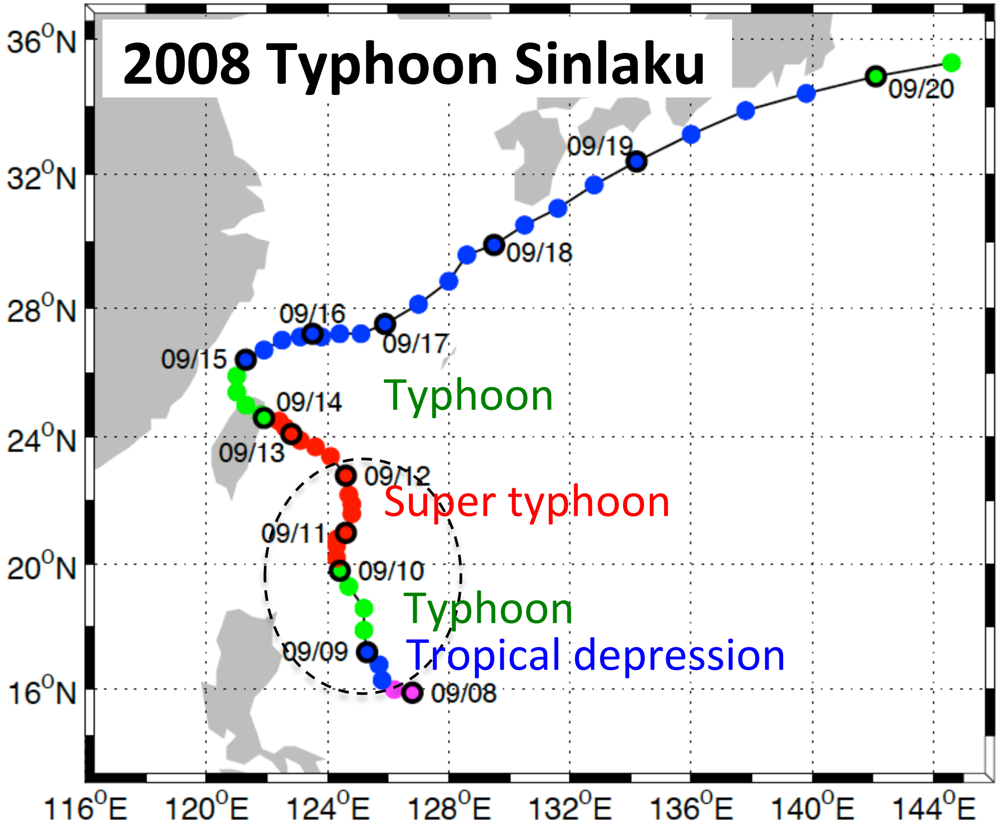
•No only the inner-core structure, LETKF-RIP is able to improve the environmental condition for typhoon movement:

•Improvements include: (1) capture the west-ward turning direction in the typhoon track and (2) capture the slow typhoon movement speed when approaching Taiwan





Real observations with 2008 Typhoon Sinlaku

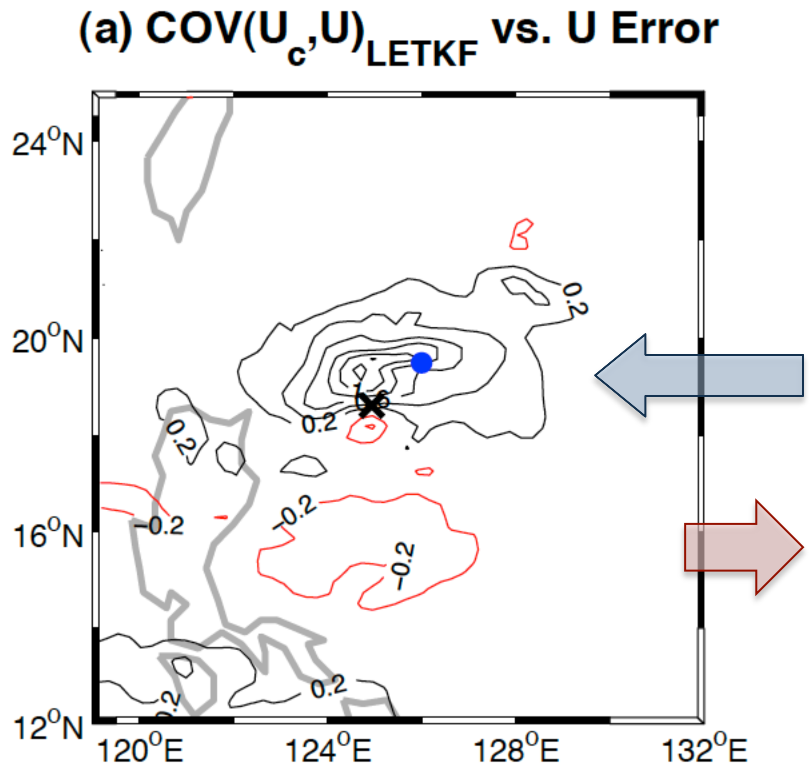


Observations:
Upper-air sounding, dropsonde, surface station

Experiment settings	
LETKF	Standard LETKF
LETKF-RIP	Apply RIP at all the analysis times (one iteration)
LETKF-RIP-TRS	Apply RIP with an iteration criterion (threshold)

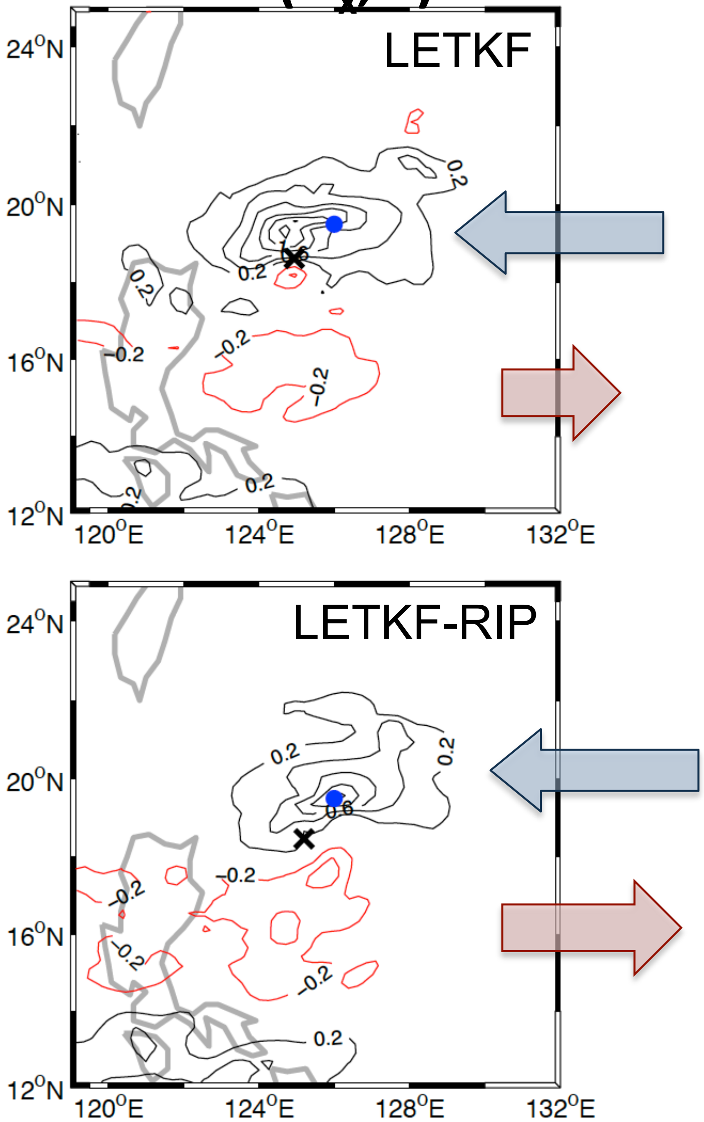
Error covariance during the spin-up

Flow-dependent error covariance reflects the features related to TY's circulation.



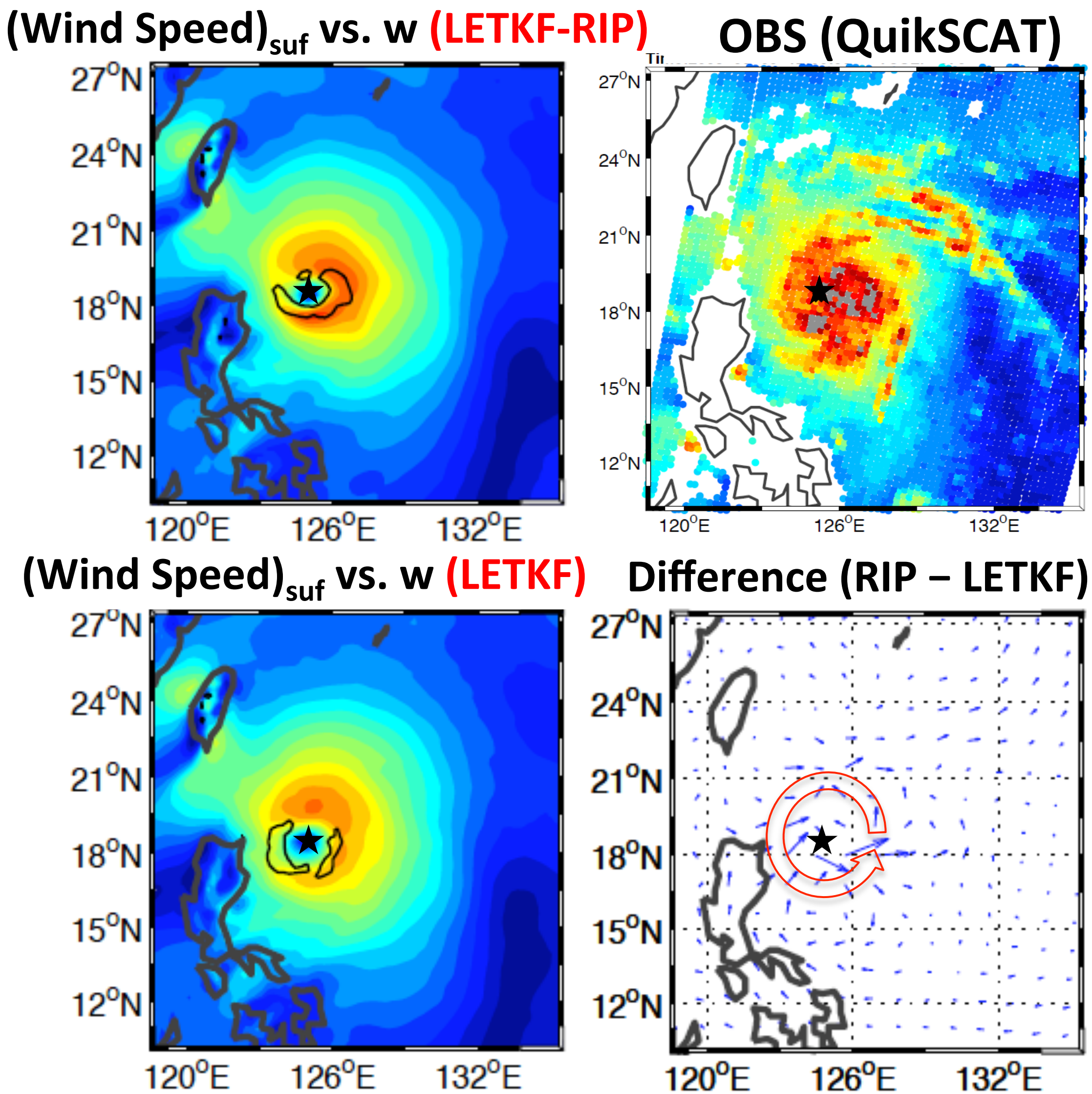
Error covariance during the spin-up

$COV(U_x, U)$



The feature related to the cyclonic circulation is enhanced with RIP.

Dynamical adjustment during the spin-up



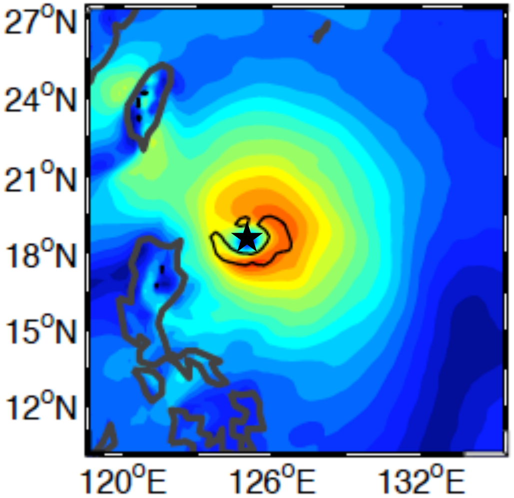
Time: 2008/09/09 12Z

- The asymmetric structure with the strong winds is captured in the LETKF-RIP analysis.
- The RIP scheme enhances the cyclonic flow and the vertical motion near the eyewall.

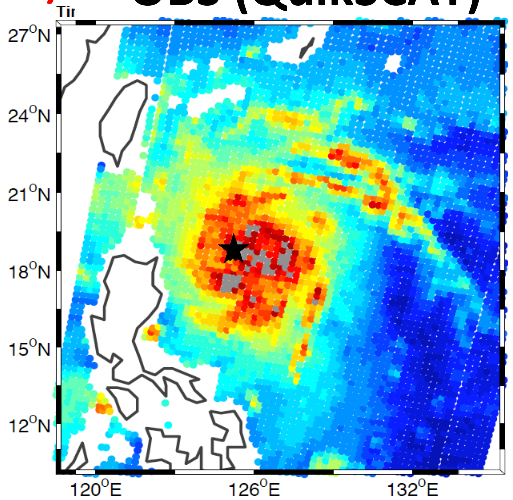
Dynamical adjustment during the spin-up

Time: 2008/09/09 12Z

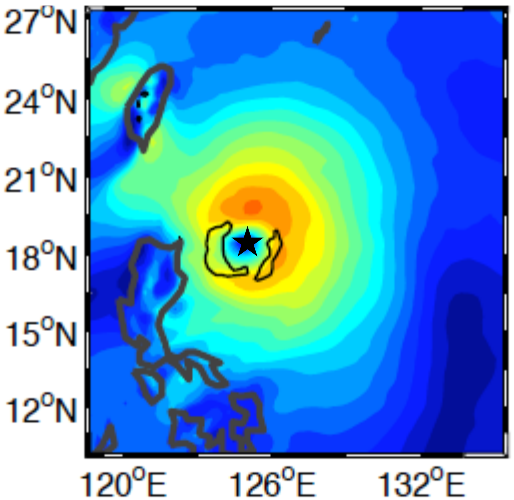
(Wind Speed)$_{suf}$ vs. w (LETKF-RIP)



OBS (QuikSCAT)

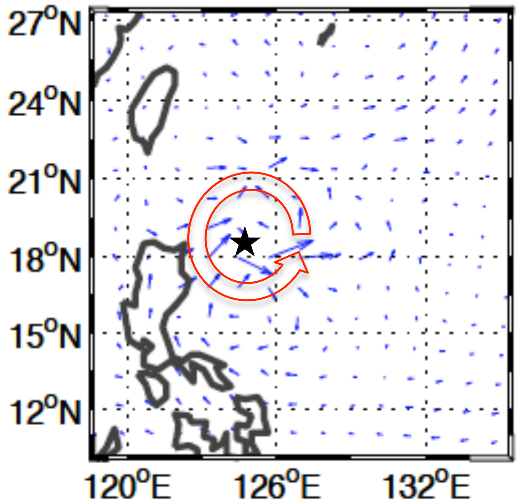


(Wind Speed)$_{suf}$ vs. w (LETKF)

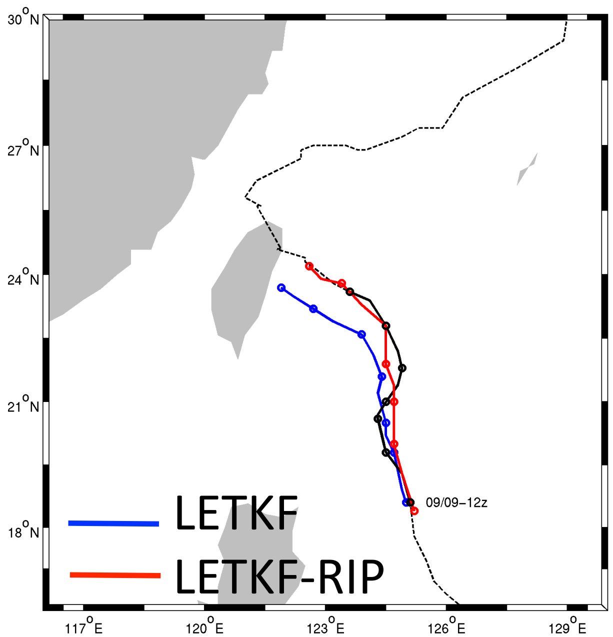


Color: wind speed
Contour: vertical motion

Difference (RIP – LETKF)

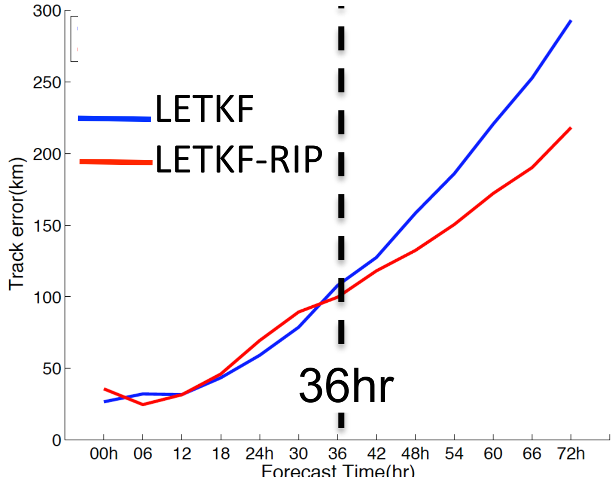


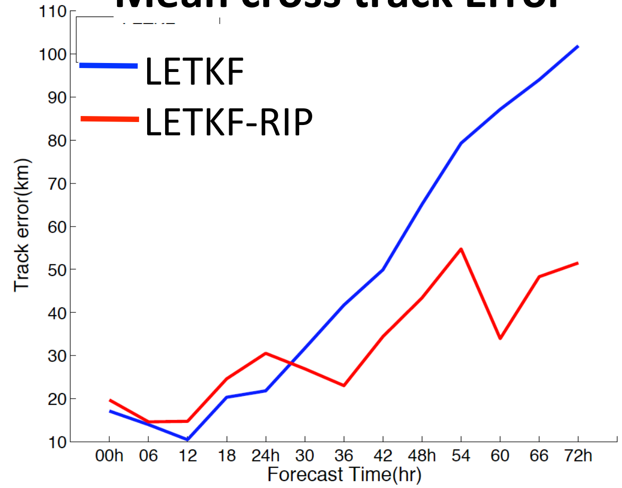
Lead to better track prediction!



Init time: 2008/09/09 12Z

Impact on Typhoon track prediction





- With RIP, the track prediction is significantly improved during the LETKF's spin-up period.
- RIP is especially useful for improving forecasts beyond 36 hours and the typhoon landfall location is better predicted.

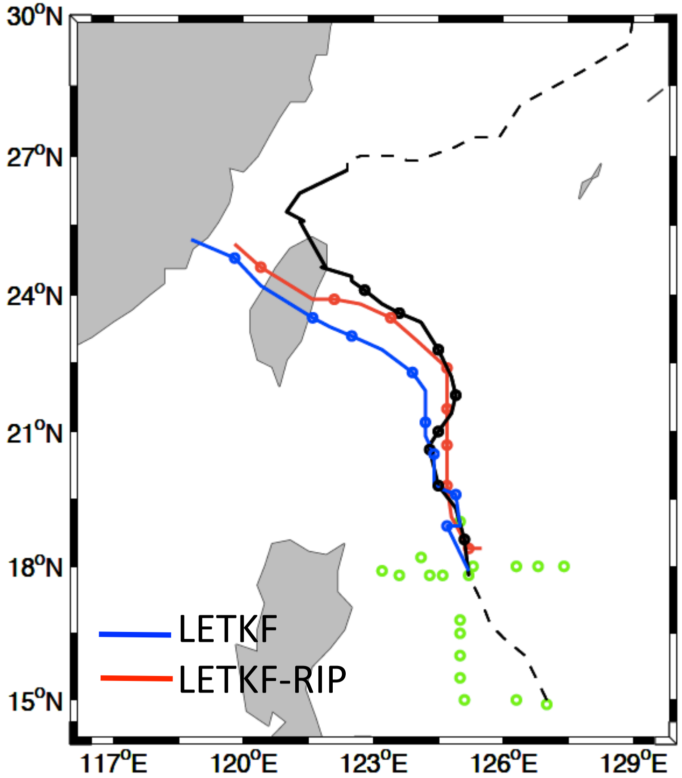
Fcst error of land fall location

Initial Time	LETKF	LETKF-RIP
09 06z	130	87
09 12z	87	43
09 18z	77	21
10 00z	13	11
10 06z	47	87
10 12z	47	32
10 18z	60	0

Averaged during the spin-up period (first two days)

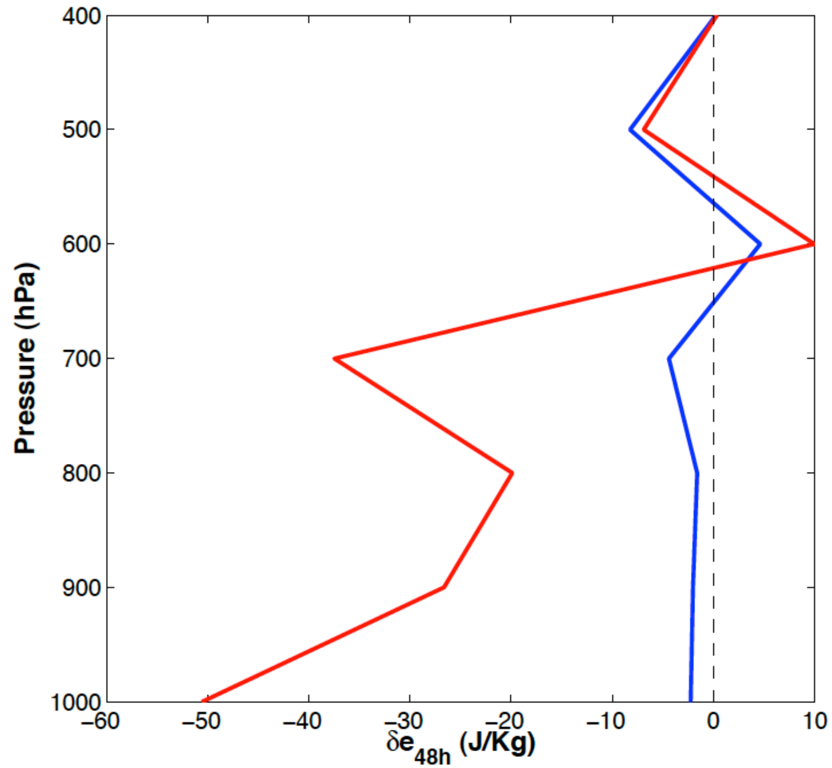
Observation Impact for the first set of dropsonde

4-Day track prediction initialized at 09/09 06Z



The effectiveness of the dropsonde data is greatly improved by RIP and the negative impact shown in the control LETKF run can be alleviated.

Mean observation impact with respect to dropsondes

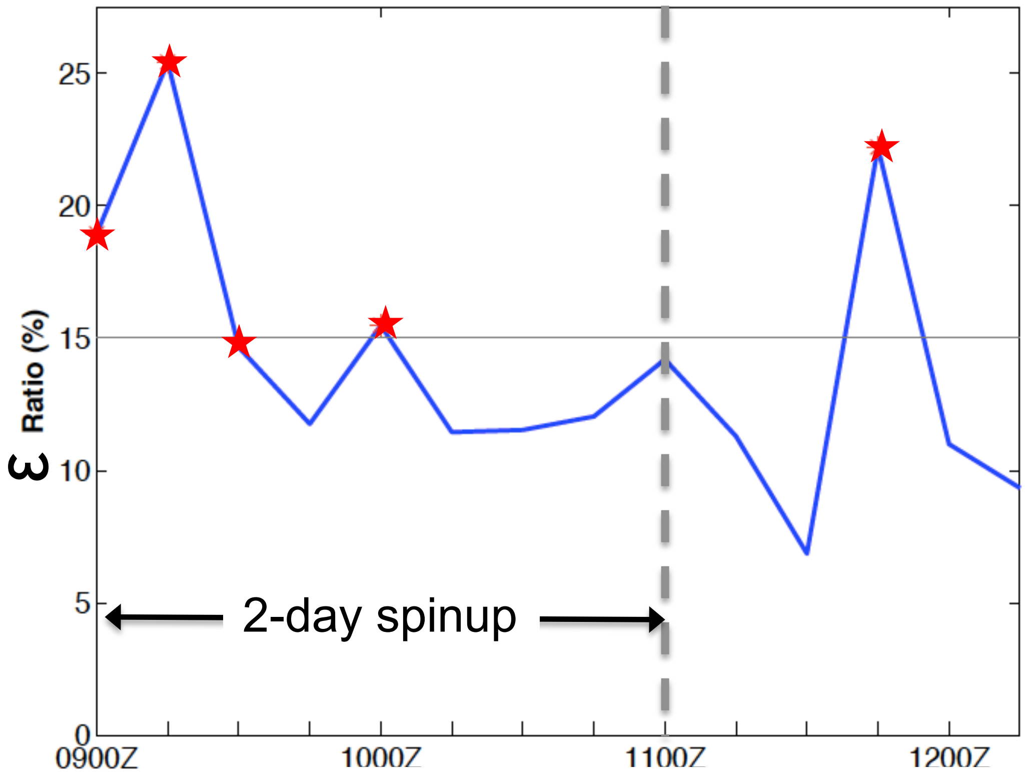


(Ensemble-based forecast sensitivity, Kalnay et al. 2012, Liu and Kalnay, 2008)

Should we always use RIP?

- Applying RIP at all the times may introduce over-fitting observations!!
- A threshold is required to automatically determine whether RIP should be switched on:

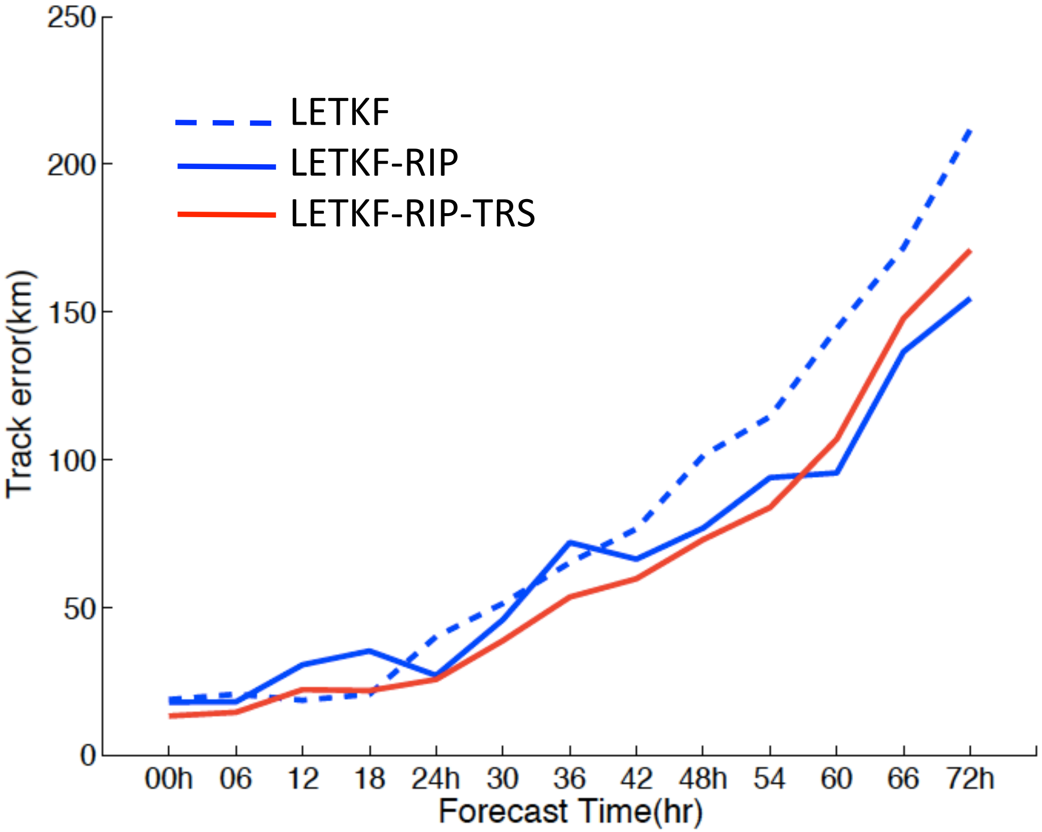
$$\varepsilon = \frac{RMS\_Innov_{itr} - RMS\_Innov_{itr+1}}{RMS\_Innov_{itr}} \times 100\%$$



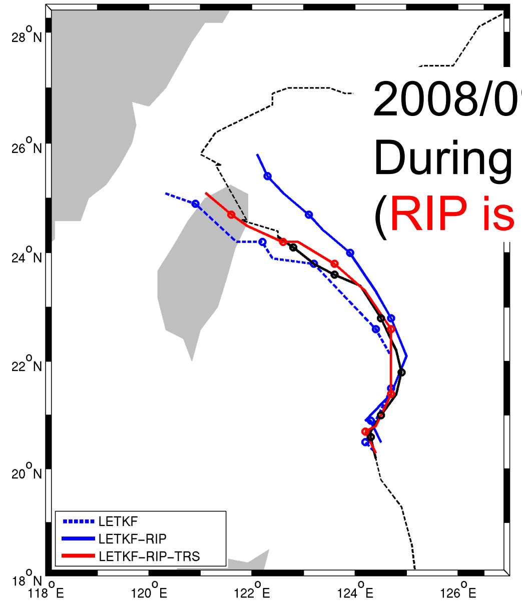
★: RIP is applied if ε > 15%

RIP vs. RIP with a threshold

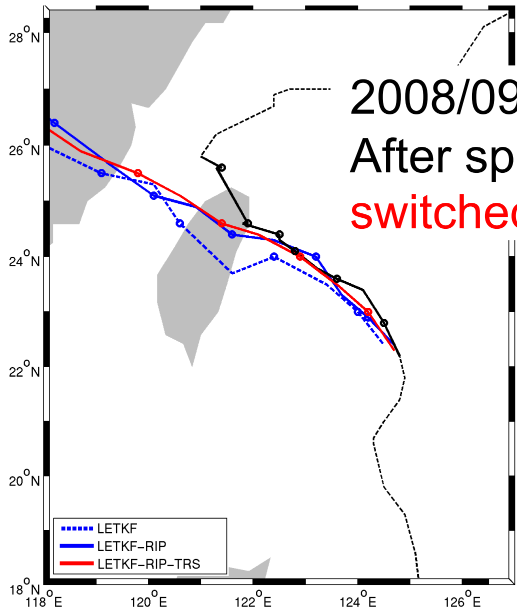
Mean cross-track error



Further improve early forecast



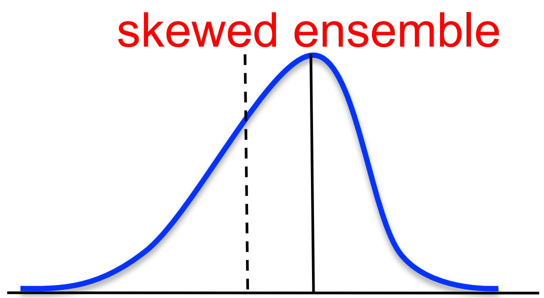
2008/09/10 06Z
During spinup
(RIP is turned off)

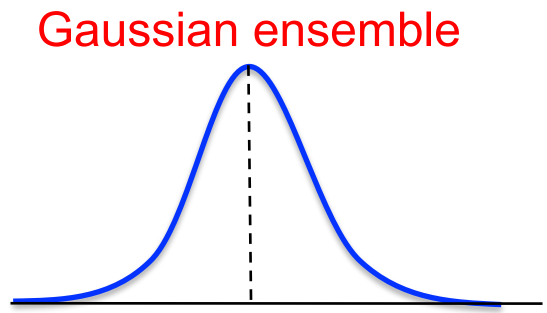


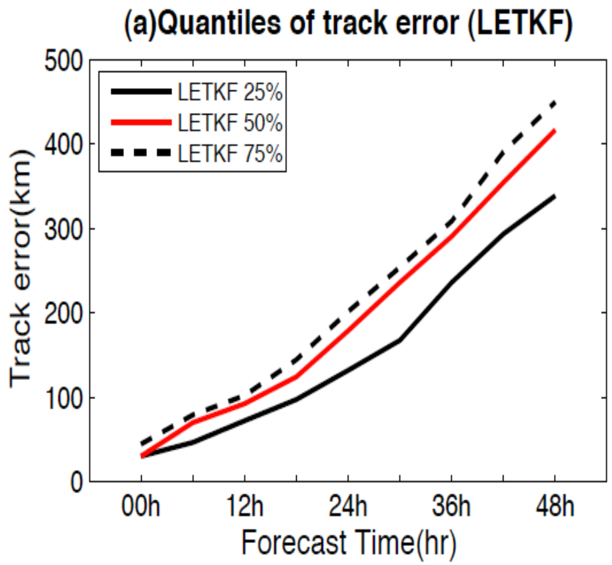
2008/09/11 18Z
After spinup (RIP switched on again)

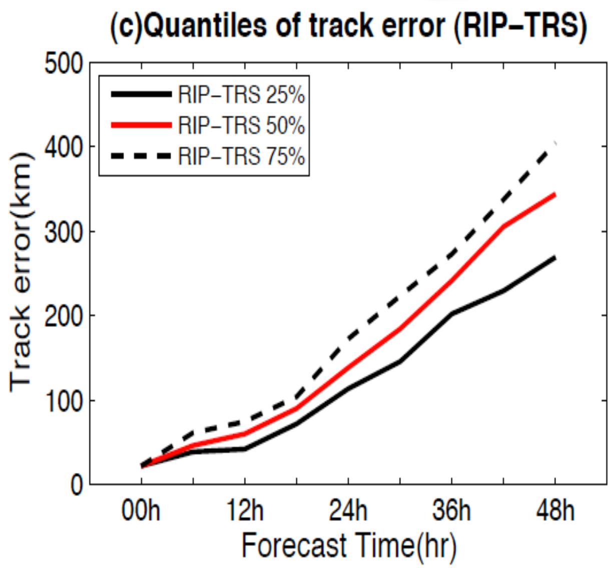
2013/02/25@AICS

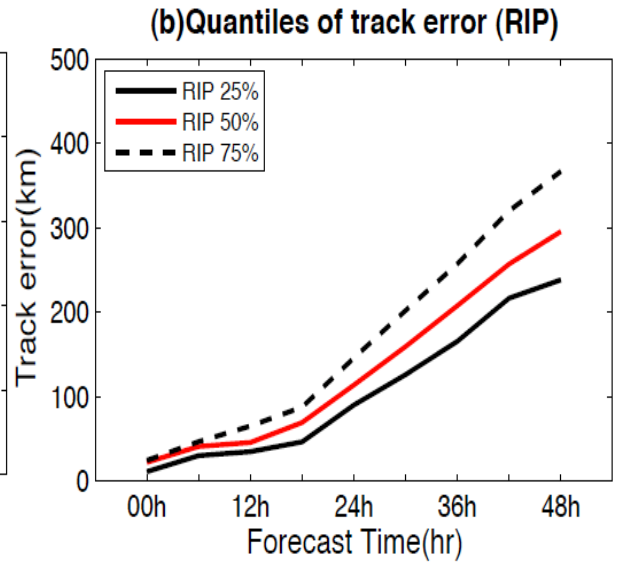
RIP for dealing with the nonlinearity











Switch on RIP helps to keep the Gaussianity of the ensemble!

Summary

- The RIP scheme accelerates the spin-up of the WRF-LETKF system and provides further adjustments for improving typhoon assimilation and prediction.
  - The flight dropsondes during the developing stage of typhoon can be more effectively used.
  - Better track prediction: the dynamical adjustments improves the environmental condition of the typhoon.
- With a threshold, RIP can be automatically turned off but on again when it is needed.
  - RIP can be used as a generalized outer-loop!

Reference

- Yang, S-C, K-J Lin, T. Miyoshi and E. Kalnay, 2012: Improving the spin-up of the regional EnKF for typhoon assimilation and forecast with the 2008 Typhoon Sinlaku (to be submitted).
- Yang, S-C, E. Kalnay and T. Miyoshi, 2012: Accelerating the EnKF Spinup for Typhoon Assimilation and Prediction, *Wea. Forecasting*, **27**, 878-897.
- Yang, S-C and E. Kalnay, 2012: Handling Nonlinearity in an Ensemble Kalman Filter: Experiments with the Three-Variable Lorenz Model, *Mon. Wea. Rev*., **140**, 2628-2646.
- Kalnay, E. and S-C Yang, 2010: Accelerating the spin up of Ensemble Kalman Filtering, *Q. J. R. Meteorol. Soc.*, **136,** 1644-1651.
- Yang, S-C, E. Kalnay, B. Hunt, N. Bowler, 2009: Weight interpolation for efficient data assimilation with the Local Ensemble Transform Kalman Filter. *Quar. Quart. J. Roy. Meteor. Soc.*, 135, 251-262. 2009
- Kalnay, E., S-C Yang, T. Miyoshi, H. Li and J. Liu, 2009: After Buenos Aires (2008): Ensemble Kalman Filter Potential, The 5TH WMO Symposium on Data Assimilation, Melbourne, Australia.
- Kalnay, E., and S.-C. Yang, 2008: Accelerating the spin-up of Ensemble Kalman Filtering. *Arxiv*: physics: Nonlinear/0806.0180v1.
- Kalnay, E., H. Li, T. Miyoshi, S-C Yang and J. Ballabrera-Poy, 2007: 4D-Var or Ensemble Kalman Filter? *Tellus-A*, **59**, 758-773, 2007