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Implementation and Application of LETKF Data Assimilation System to KIAPS Global NWP Model

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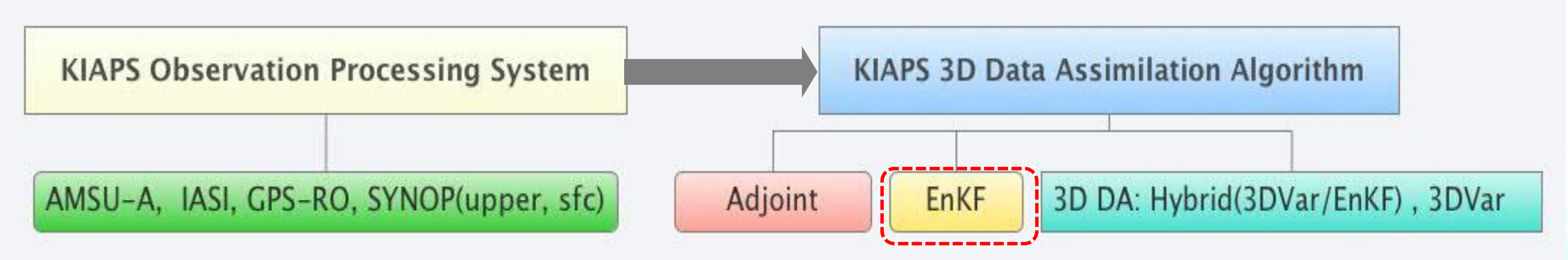
Introduction

- **Korea Institute of Atmospheric Prediction Systems (KIAPS)**
  - KIAPS was founded by Korea Meteorological Administration
  - **Goal:** To develop Global NWP system optimized to the topographic & meteorological features of Korea peninsula
  - Website: **http://www.kiaps.org**
- **KIAPS 3D Data Assimilation Algorithm**



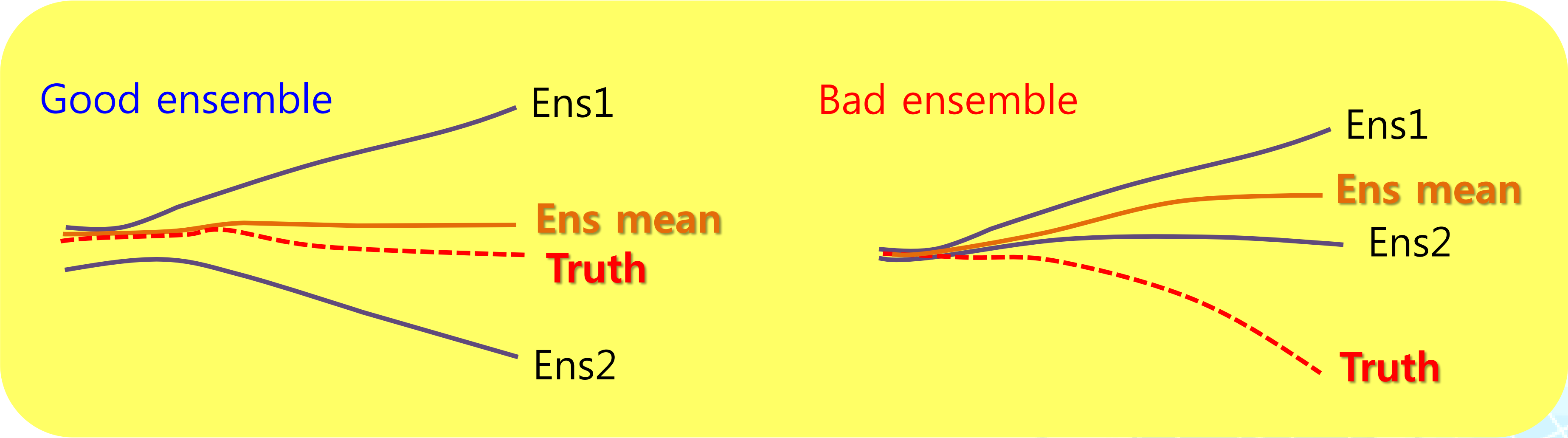
- ***Plans for KIAPS Data Assimilation System***
  - **Ensemble Data Assimilation**
    - Local Ensemble Transform Kalman Filter (LETKF, developed in the Univ. of Maryland, Hunt *et al*. 2007) would be the first system to be constructed as an operational system

LETKF-SPEEDY

- **LETKF-SPEEDY**
  - As a test bed, **LETKF** data assimilation has been implemented to an intermediate-complexity **general circulation model SPEEDY(Simplified PrimitivE-Equation DYnamics)** (Molteni, 2003)
  - SPEEDY can reduced computation time due to simplification of physics parameterization and low resolution
  - Many recently developed techniques of ensemble Kalman filter data assimilation have been examined (e.g. Kalnay et al., 2007; Miyoshi 2011; Kang et al. 2011, 2012) within LETKF-SPEEDY system

Test Experiments using LETKF-SPEEDY

- Covariance inflation methods
  - Background uncertainty tends to be underestimated with a limited ensemble size due to the imperfection of the model and nonlinearity of the system.



  - To avoid filter divergence, EnKF needs "covariance inflation" in which the prior or posterior ensemble state is increased by using inflation method.

Covariance Inflation methods

- Fixed Multiplicative Inflation (Anderson and Anderson, 1999)
  - **multiplies fixed inflation factor** which is **bigger than 1** (1.0+α) to the background ensemble variance

$$\mathrm{x}_i^b(t+1) \leftarrow r[\mathrm{x}_i^b(t+1) - \overline{\mathrm{x}^b}(t+1)] + \overline{\mathrm{x}^b}(t+1)$$

- Additive Inflation (Hamill et al. 2005, Whitaker et al. 2008)
  - **adds perturbations** which is **6hr forecast tendency** to the analysis state

$$\mathrm{x}_i^b(t+1) \leftarrow \mathrm{x}_i^b(t+1) + \eta_i$$

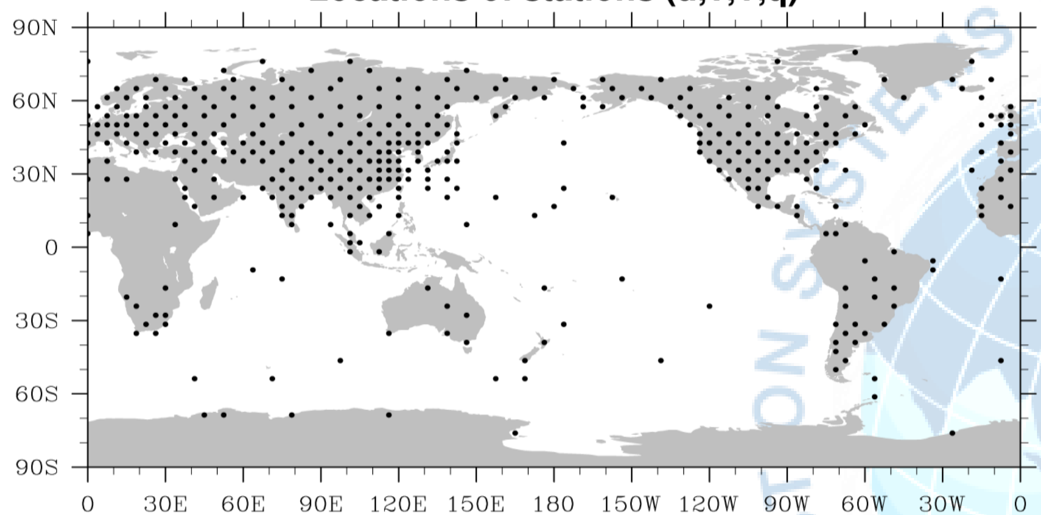
  - **6hr forecast tendencies**, $\eta_i = s[\mathbf{x}(t) - \mathbf{x}(t-6hr)]$

- Adaptive Multiplicative Inflation (Anderson, 2007, 2009; Li et al. 2009; Miyoshi 2011)
  - **Using innovation statistics(OMB^2)** to update inflation factor
  - **Inflation factor has spatially and temporally varying**

$$<\mathbf{d}_{\text{o-b}}\mathbf{d}_{\text{o-b}}{}^{\mathrm{T}}> = \mathbf{HP}^{\mathrm{b}}\mathbf{H}^{\mathrm{T}} + \mathbf{R}$$

LETKF-SPEEDY

- **Observing System Simulation Experiments (OSSEs)**
  - The system will be utilized for validating data assimilation techniques
  - Sensitivity experiments about covariance inflation can be done with simulated observations
- **SPEEDY**
  - Spectral model with T30L7
  - Prognostic variables : U, V, T, q, Ps
- **Example of simulated observations: radiosonde**



- Observation interval : 00Z, 12Z, but Ps every 6hour
- Observation error: U and V (1 m/s), T (1 K), q (0.001 kg), Ps(1 hPa)

OSSEs : Experiments Design

- Configuration of OSSEs
  - True state is generated by a simulation of the SPEEDY
  - Observations are simulated which are generated from the true state(nature run)
  - Forecast starts from random initial guess
  - Ensemble size : 20

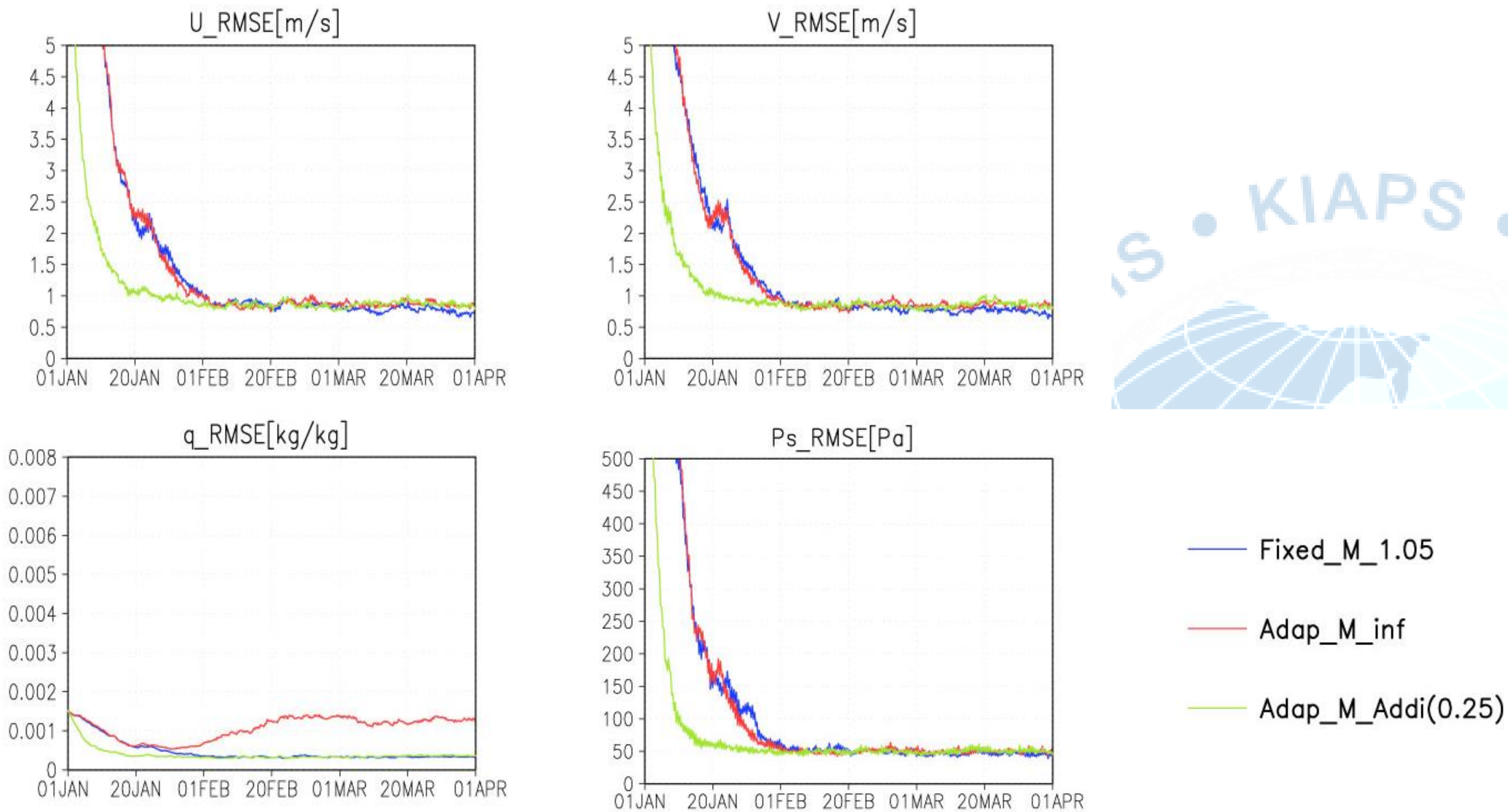
- Configuration of Experiments

Experiment	Inflation method	Scale factor	Inflation factor
Fixed_M_1.05	Fixed Multiplicative		5%
Adap_M_inf	Adaptive Multiplicative		Varying in time & space
Adap_M_Addi_inf	Adaptive Multiplicative + Additive	0.25	

OSSEs Results : RMS error

- Adap_M_Addi(0.25) has smaller RMS error than other experiments, also spin-up time is reduced significantly.
- **Why, they are fast convergence?**

Time series of RMSE, Z=1



OSSEs Results : RMS error, ensemble spread

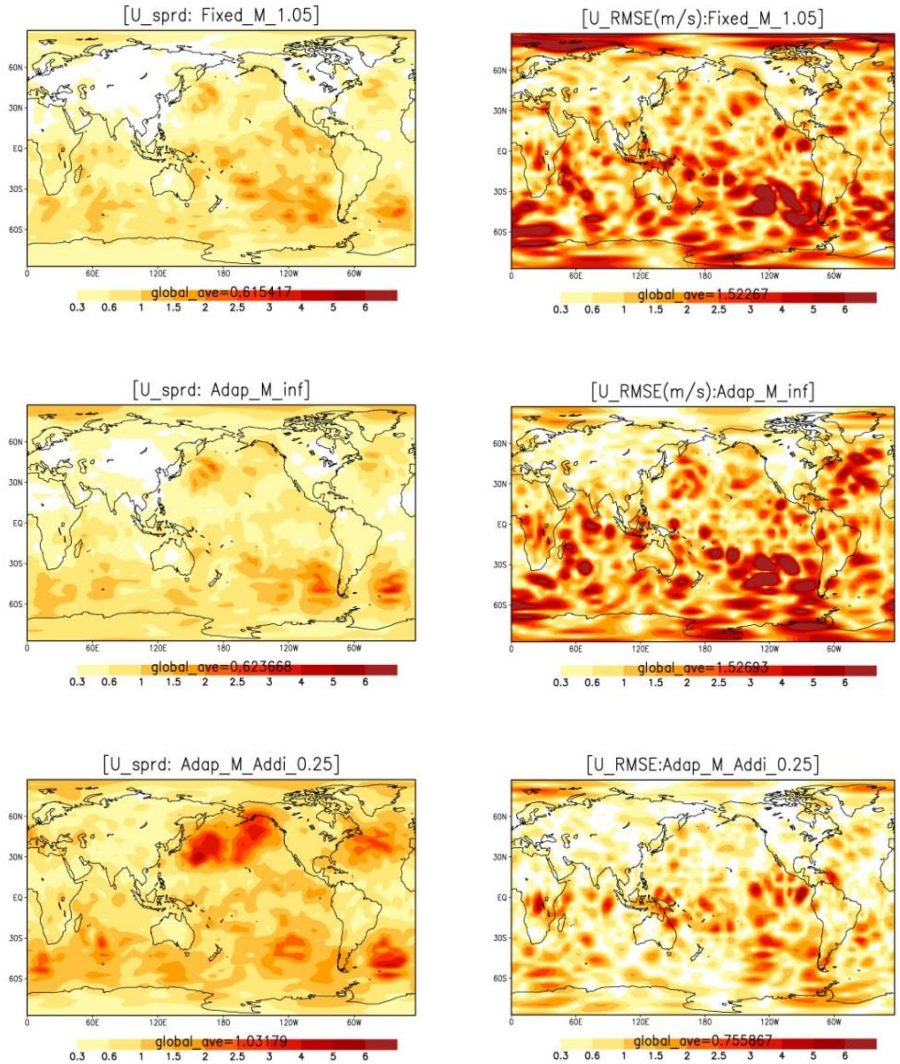
- **Much shorter spin-up in Adap_M_Addi_inf than the others**

Background ensemble spread | RMS error

Fixed_M_1.05

Adap_M_inf

Adap_M_Addi_inf



Still spin-up

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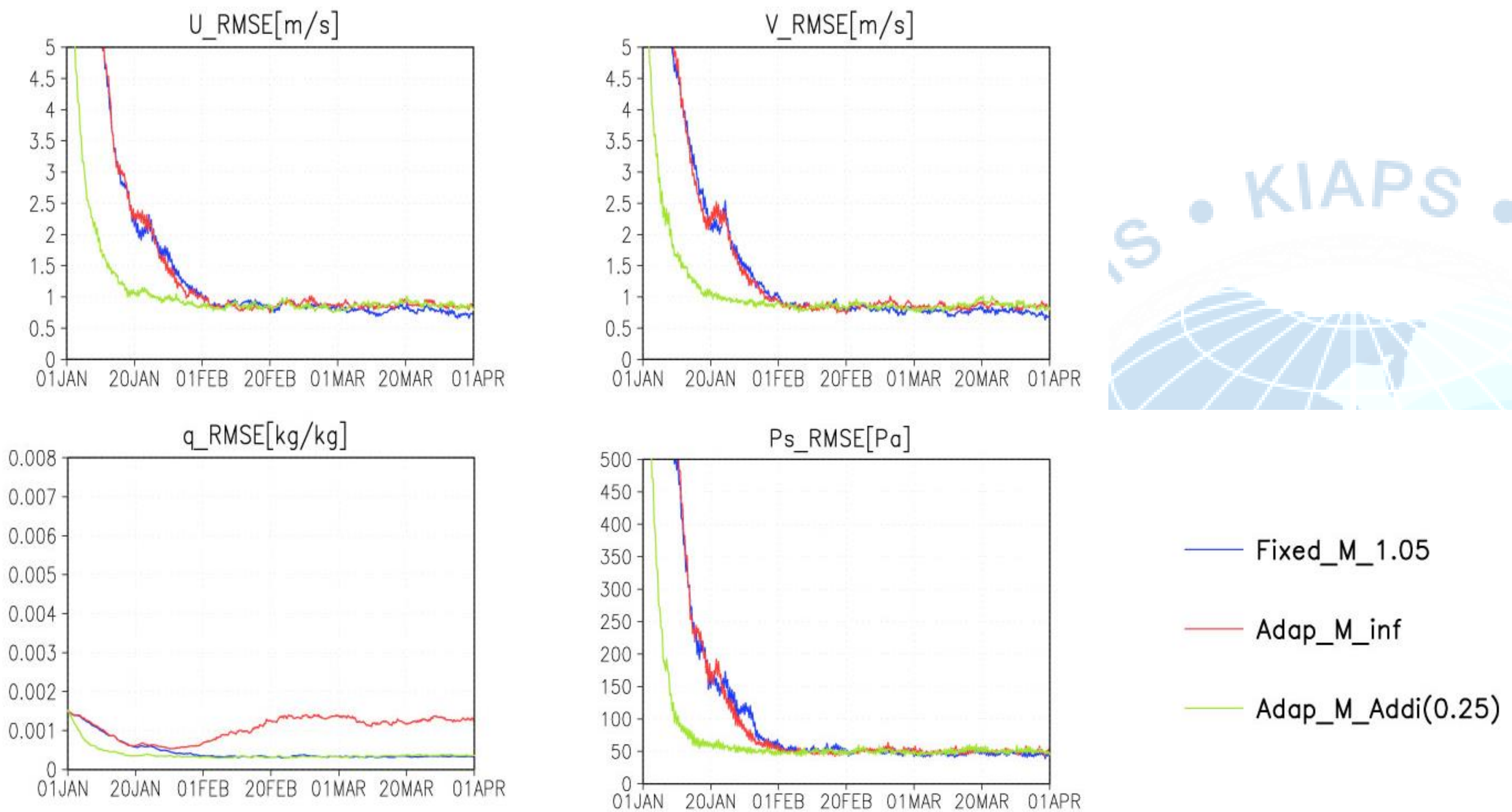
OSSEs Results : RMS error

- In the Adap_M_inf, RMS error of variable q is increasing gradually after a convergence
- **Why is it ?**

Time series of RMSE, Z=1



OSSEs Results : Adap_M_inf vs. Adap_M_Addi_inf

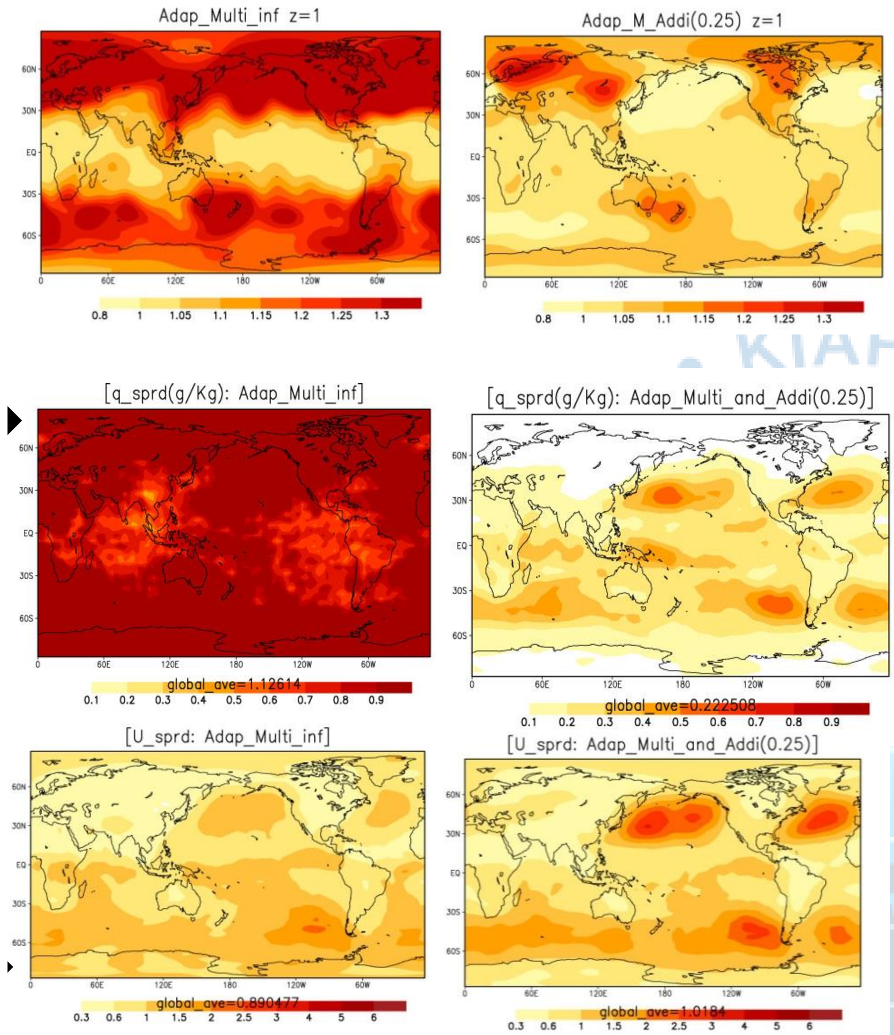
- **Why RMS error of variable q was increased in the Adap_M_inf?**

- Inflation factor of Adap_M_inf is very large from the middle latitude, **but variable q is close to zero there in general.**

- **Due to other variables such as wind, however, this area needs large inflation factor** that gives overestimation of background error for variable q

- The signal to noise might be occurred.

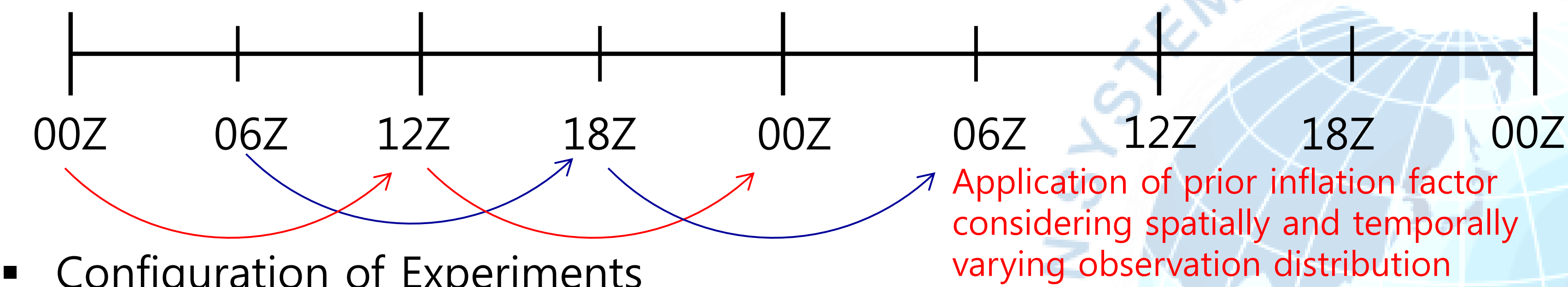
Adap_M_inf | **Adap_M_Addi_inf**



"Leap-frogging" Adaptive Multiplicative inflation

- Motivation of **"leap-frogging"** adaptive multiplicative inflation
  - **Inflation factor depends on observation density**: larger inflation factor tends to be estimated over observation-rich areas.
  - Estimated inflation factor can be useful when we have a similar observation coverage at the next analysis step.
  - If we do have remarkably different observation distribution in time, we need some modification in a standard adaptive multiplicative inflation, which **considers observation distribution cycle**

- **Leap frogging of inflation factor (Miyoshi 2011, Kang et al. 2012)**



- Configuration of Experiments

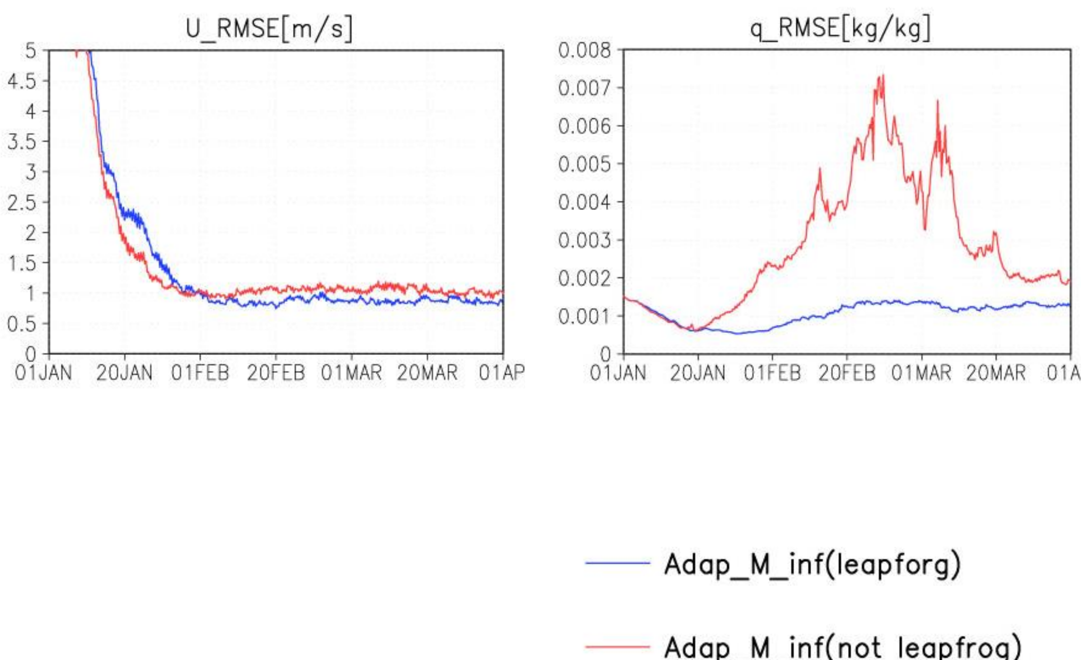
Experiment	Inflation method	Leap frogging	Inflation factor
NO_LF_Adap_Multi_inf	Adaptive Multiplicative	no	OMB X OMB
LF_Adap_Multi_inf	Adaptive Multiplicative	yes	OMB X OMB

OSSEs Results: leap-frogging Adaptive Multiplicative inflation

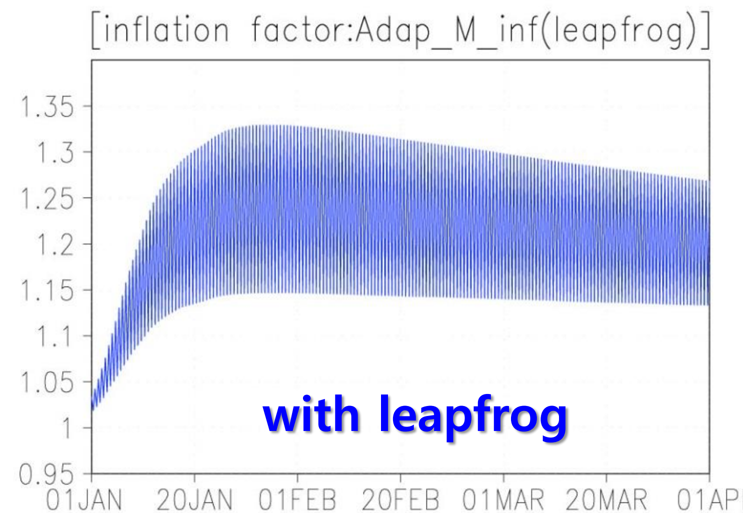
- **Impact of leap-frogging**

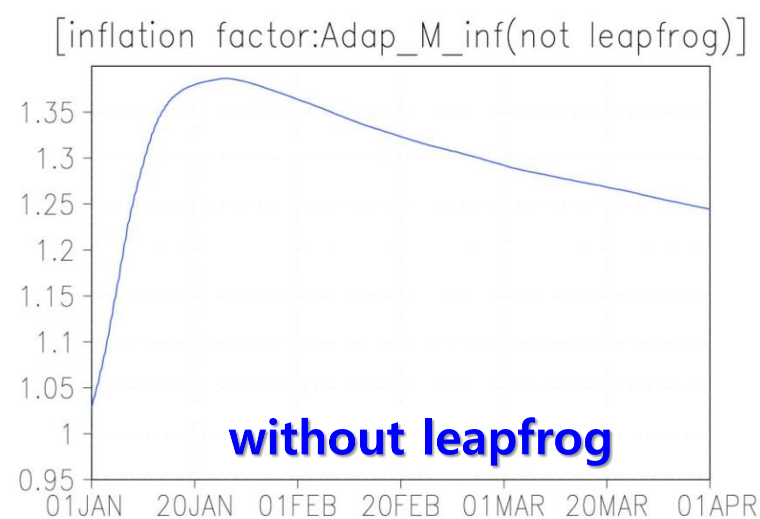
- Inflation factor has large fluctuation over the time with leapfrogging because we consider observation distribution
- The spin-up time seems to be reduced, but RMS error is increasing according to integrated time without leap frogging
- Also, inflation factor value is higher

Time series of RMSE, Z=1



Inflation factor, Z=1





Summary

- **For testing our implementation of LETKF-SPEEDY system**, various experiments have been performed using SPEEDY-LETKF under observing system simulation experiments in addition to what I've shown at this talk

- What I've learned from those test experiments:

  - Considering both adaptive multiplicative and additive inflation are more effective
    - **Shortened spin-up** and **smaller RMS errors**

  - We need to be careful about the observation coverage changing in time when using an adaptive multiplicative inflation method
    - It may **need a leap-frogging cycle for using appropriate inflation parameters.**

Future Plan

- LETKF-SPEEDY will be tested including satellite data(AMSU-A, IASI) and GPS radio occultation data through Observation System Simulation Experiments(OSSEs).

- LETKF for NCAR Community Atmospheric Model-Spectral Element model (LETKF-CAM) has been developed at KIAPS (Dr. Kang)

- **I will examine the system**, LETKF-CAM, in the future. Also we plan to test many useful techniques in EnKF such **as forecast sensitivity to observations**(Kalnay et al., 2012), **adaptive observation** (Liu et al., 2008) ,etc

Thank You

www.kiaps.org