The computational aspect of the SCLAE-LETKF data assimilation system for rapid-update-cycle, high-resolution radar data assimilation

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Introduction

- We have developed the **SCALE-LETKF** (Lien et al. 2017) regional data assimilation (DA) system for research.
  - It utilizes the Scalable Computing for Advanced Library and Environment-Regional Model (SCALE-RM; Nishizawa et al. 2015; Sato et al. 2015) model and the Local Ensemble Transform Kalman Filter (LETKF; Hunt et al. 2007).
  - https://github.com/gylien/scale-letkf

Comparison of community DA code for research

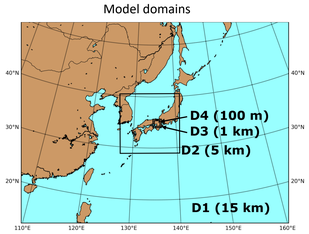
		WRFDA	Community GSI/EnKF	DART	SCALE-LETKF
Developer team		Mesoscale and Microscale Meteorology (MMM) Laboratory/ NCAR (U.S.)	Developmental Testbed Center (DTC)/ NCEP (U.S.)	Data Assimilation Research Section (DAReS)/ NCAR (U.S.)	RIKEN AICS
Assimilation algorithm		3DVar, 4DVar, Hybrid 3D/4DEnVar	3DVar, EnSRF, Hybrid 3D/4DEnVar	EAKF, EnSRF, Particle filter, … etc.	**LETKF**
Supported models	Global	--	GFS	MPAS, CESM, … etc.	--
	Regional	WRF	WRF	WRF, … etc.	**SCALE**
Supported observations		Conventional, satellite radiance, radar, GPSRO, … etc.	Conventional, satellite radiance, radar, GPSRO, … etc.	Conventional, radar, GPSRO, … etc.	Conventional, radar, satellite radiance (partial)

- We aim to use the SCALE-LETKF to conduct real-time, rapid-update-cycle, high-resolution assimilation of Phased Array Weather Radar (PAWR) data.
  - This requires very careful design in every part of the code to achieve high computational efficiency.

Targeted problem

- 30-second update cycle, 100-m model resolution, 100-member radar DA covering the radar observing range.

Model domains



Highest resolution domain (D4)	
Model resolution	100 meters
Cycle length	30 seconds
Grid numbers	1200 x 1200 x 100
Meteorological variables	11
Ensemble members	100
Total data dimension (number of variables)	**1.6 x 10^{11}**
Total data size (Assume double-precision variables)	**1.3 TB**

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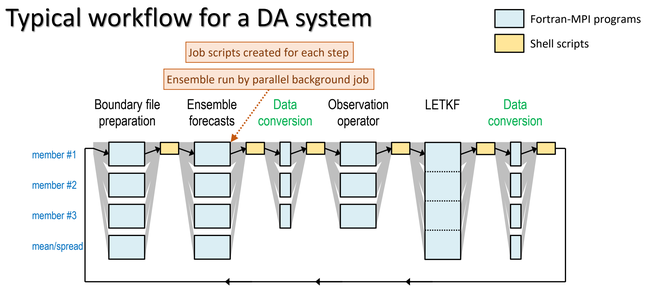
Total nodes	82,944
Cores / node	8
Memory / node	16 GB
Maximum disk space / node	29 GB

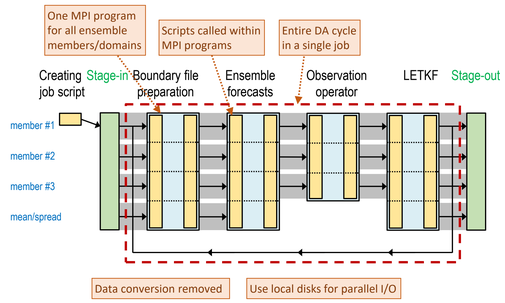
Observation	
Platform	Phased-Array Weather Radar (PAWR)
Highest resolution	100 meters
Frequency	30 seconds

Improvements in the workflow

Typical workflow for a DA system

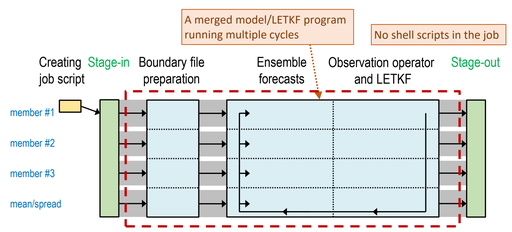


Improved workflow in the SCALE-LETKF

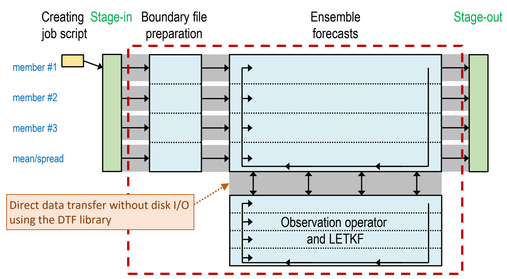


Specialized versions for real-time radar DA

A) Merged SCALE/LETKF program

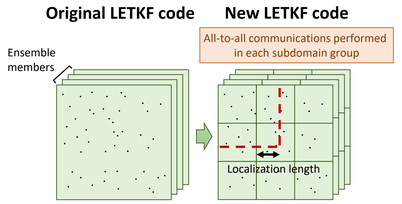


B) Direct data transfer between SCALE and LETKF using the DTF library *(in progress)*



Improvements in the LETKF program

- Employ domain splitting in the LETKF (similar to that usually done in the model):
  - Reduce the amount of all-to-all communications by maintaining the data locality, and also reduce the memory usage.
  - Similar to that done in Yashiro et al. (2016) for NICAM-LETKF.



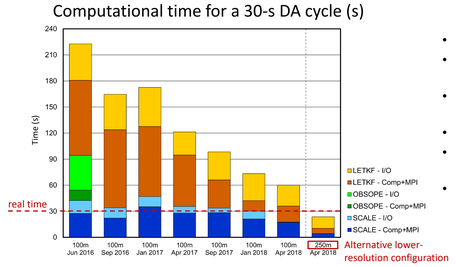
(One process is in charge of one subdomain for one or more member)

- Optimize the use of OpenMP.
- Implement MPI parallelization also in the observation operator calculation.
- Improve observation sorting and implement a fast observation number limit (Hamrud et al. 2015) scheme.
- Implement online, fast superobing in the LETKF. *(in progress)*

Results: Computational time

Progress we've made for the targeted problem

Computational time for a 30-s DA cycle (s)

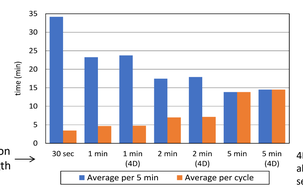


- Jun 2016 → Sep 2016: Merge OBSOPE and LETKF into a single program.
- Sep 2016 → Jan 2017: In LETKF, use QUICKSELECT algorithm for observation selection for the number limit.
- Jan 2017 → Apr 2017: Implement deterministic run (Schraff et al. 2016) and distribute the I/O of mean/spread files in a more parallel way.
- Apr 2017 → Sep 2017: Optimize the OpenMP directives.
- Sep 2017 → Jan 2018: Remove most run-time shell scripts and improve the observation processing code
- Jan 2018 → April 2018: Run multiple cycle using a merged SCALE/LETKF program and thus use direct memory copy to exchange data between the SCALE model and LETKF.

Computational time and forecast skill with respect to different cycle lengths

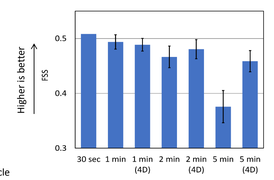
(1-km resolution; 208 nodes on the K computer)

Computational time (model + DA)



4D: 4D-LETKF assimilating all asynchronous (every-30-second) observations in a cycle

Forecast skill: Mean FSS in the 10- to 30-min forecasts



(18-fcst average)
Error bars: 95% confidence interval compared to 30-sec

Summary

- We have made remarkable progress in the code development to improve the computational efficiency and speed towards the goal of real-time experiments.
  - The 100-m resolution, 30-second-update configuration is still slower than the real time, while the 250-m resolution configuration can meet the goal.
- We believe that the SCALE-LEKTF system has become a useful research tool for broad mesoscale data assimilation studies.

Data Assimilation Team
RIKEN R-CCS 理化学研究所 計算科学研究センター RIKEN Center for Computational Science

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