Data Assimilation Research Team

1. Team members

Takemasa Miyoshi (Team Leader)

Shigenori Otsuka (Postdoctoral Researcher)

Koji Terasaki (Postdoctoral Researcher)

Shunji Kotsuki (Postdoctoral Researcher)

Hazuki Arakida (Technical Staff)

Juan J. Ruiz (Visiting Scientist)

Shinichiro Shima (Visiting Scientist)

Masahiro Sawada (Visiting Scientist)

Shu-Chih Yang (Visiting Scientist)

Stephen G. Penny (Visiting Scientist)

Keiichi Kondo (Student Trainee)

Marimo Ohhigashi (Research Assistant)

Yukie Komori (Assistant)

Rie Deguchi (Assistant)

2. Research Activities

Data Assimilation Research Team (DA Team) was launched in October 2012 and is composed of 12 research and technical staff including 5 visiting members as of March 2014. Data assimilation is a cross-disciplinary science to synergize numerical simulations and observational data, using statistical methods and applied mathematics. As computers become more powerful and enable more precise simulations, it will become more important to compare the simulations with actual observations. DA Team performs cutting-edge research and development on advanced data assimilation methods and their wide applications, aiming to integrate computer simulations and observational data in the wisest way. Particularly, DA Team will tackle challenging problems of developing efficient and accurate data assimilation systems for high-dimensional simulations with large amount of data. The specific areas include 1) research on parallel-efficient algorithms for data assimilation with the super-parallel K computer, 2) research on data assimilation methods and applications by taking advantage of the world-leading K computer, and 3) development of most advanced data assimilation software optimized for the K computer.

In FY2013, we focused on data assimilation research in the following aspects: 1) theoretical research on challenging problems, 2) leading research on meteorological applications, 3) optimization of computational algorithms, and 4) exploratory research on wider applications.

We also explored close collaborations with several research teams within the AICS Research Division. We have made substantial progress on the following research items:

[Theoretical research]

1. A discrete Bayesian optimization approach to find optimal ensemble sizes in a multi-model ensemble Kalman filter (EnKF) was explored.
2. The approach to multi-scale covariance localization invented and investigated in FY2012 was further explored (2 papers published).
3. The role of observation error correlations in data assimilation was explored.
4. Potential impact of assimilation order of observations in serial EnKF was investigated.
5. Particle filter methods to treat non-Gaussian PDF were explored.

[Leading research on meteorological applications]

6. A Local Ensemble Transform Kalman Filter (LETKF) experiment with large ensemble up to 10240 members was performed to investigate the probability density function (PDF) of atmospheric flows more precisely. PDF plays an essential role in data assimilation.
7. The LETKF system with a global Nonhydrostatic ICosahedral Atmospheric Model (NICAM) was developed and tested with the real conventional observations, in collaboration with Computational Climate Science Research Team.
8. "Big Data Assimilation" to take advantage of Big Data from both high-resolution simulations and advanced sensors was explored. As a first step, next-generation phased array weather radar data were considered for assimilation.

[Computational optimization]

9. The high-performance eigenvalue solver "EigenExa" was applied to the LETKF in close collaboration with Large-scale Parallel Numerical Computing Technology Research Team.
10. The KMR (K Map Reduce) was applied to the LETKF workflow to maximize the efficiency with the K computer, in close collaboration with HPC Programming Framework Research Team.

[Wider applications]

11. A potential application of data assimilation to ecosystem simulations was explored.

Among the achievements, three achievements are selected and highlighted in the next section.

3. Research Results and Achievements

3.1. A discrete Bayesian optimization approach to multi-model EnKF

No simulation can be perfect, and data assimilation fills the gap between the imperfect simulations and real phenomena. Multi-model ensemble may account for uncertainties of simulation models, and previous studies in meteorological data assimilation showed advantage of multi-model ensemble Kalman filter (EnKF) in reducing the impact of the model errors.

In the previous studies, the ensemble sizes for each model are prescribed subjectively, for example, uniformly distributed to each model (Fig. 1 left). In this study, we adopt a Bayesian filter approach to a multi-model EnKF to find the optimal combination of ensemble sizes for each model (Fig. 1 right). We developed an effective inflation method to make the Bayesian filter work without converging to a single imperfect model.

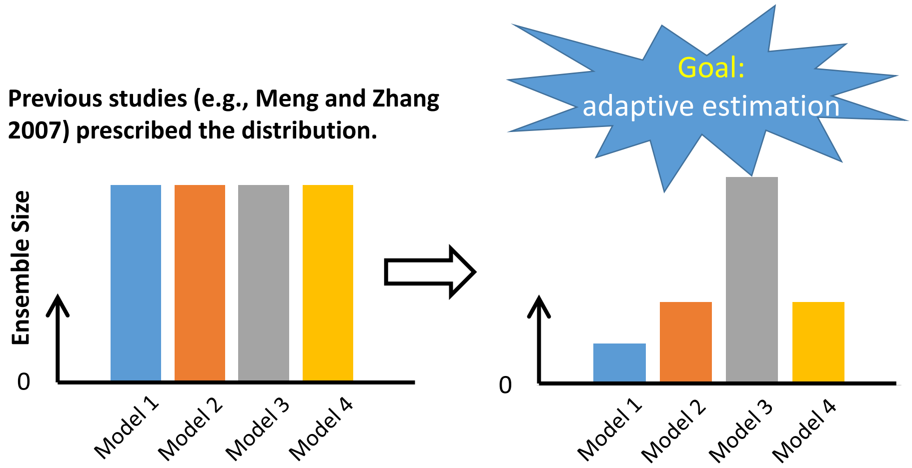

Figure 1. Schematic showing the motivation for the Bayesian optimization approach to multi-model EnKF. Four models (Model 1-4) are considered.

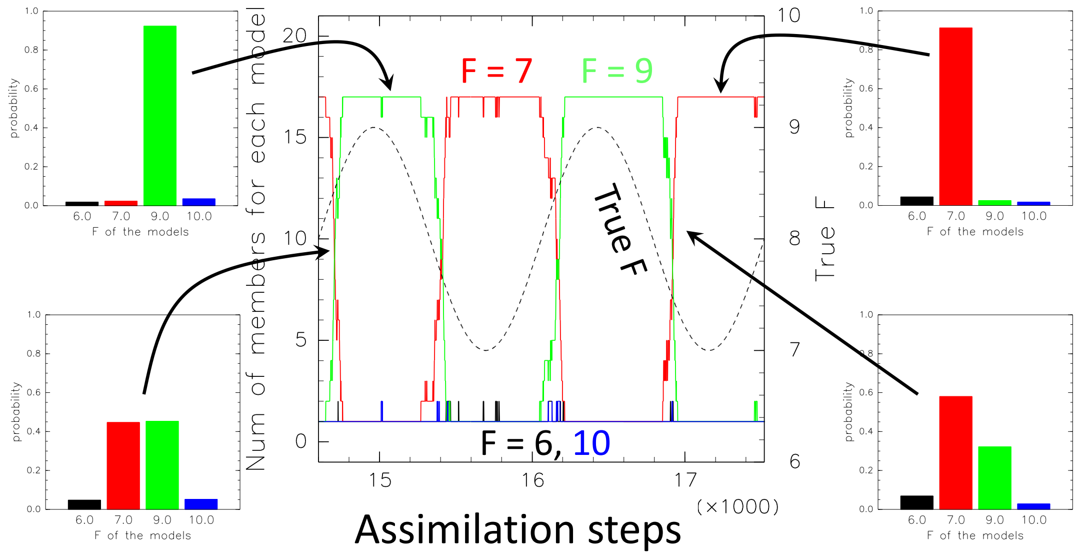

Figure 2. Results of the Bayesian optimization approach to multi-model EnKF. The largest center figure shows time series of true F (black dashed, right axis) and the estimated ensemble sizes (solid lines, left axis) for F=6 (black), 7 (red), 9 (green), and 10 (blue). The smaller four panels on both sides show the snapshot of PDF of each model at chosen instances (shown by arrows).

As a first step, we tested the proposed approach with the 40-variable Lorenz-96 model. Four different values of the model parameter *F* (*F* = 6, 7, 9, 10) were used to mimic the multi-model ensemble. When the true *F* had temporal variations *F* = 8 + sin(*t*), the proposed system followed the temporal change successfully (Fig. 2), and the RMSE was improved.

3.2. Multi-scale covariance localization

Following the theoretical development of the dual-localization approach in FY2012, in FY2013 a number of experiments were performed using an Atmospheric General Circulation Model (AGCM) with intermediate complexity known as the SPEEDY model, having led to two publications (Miyoshi and Kondo 2013; Kondo et al. 2013). The main findings are highlighted in this report.

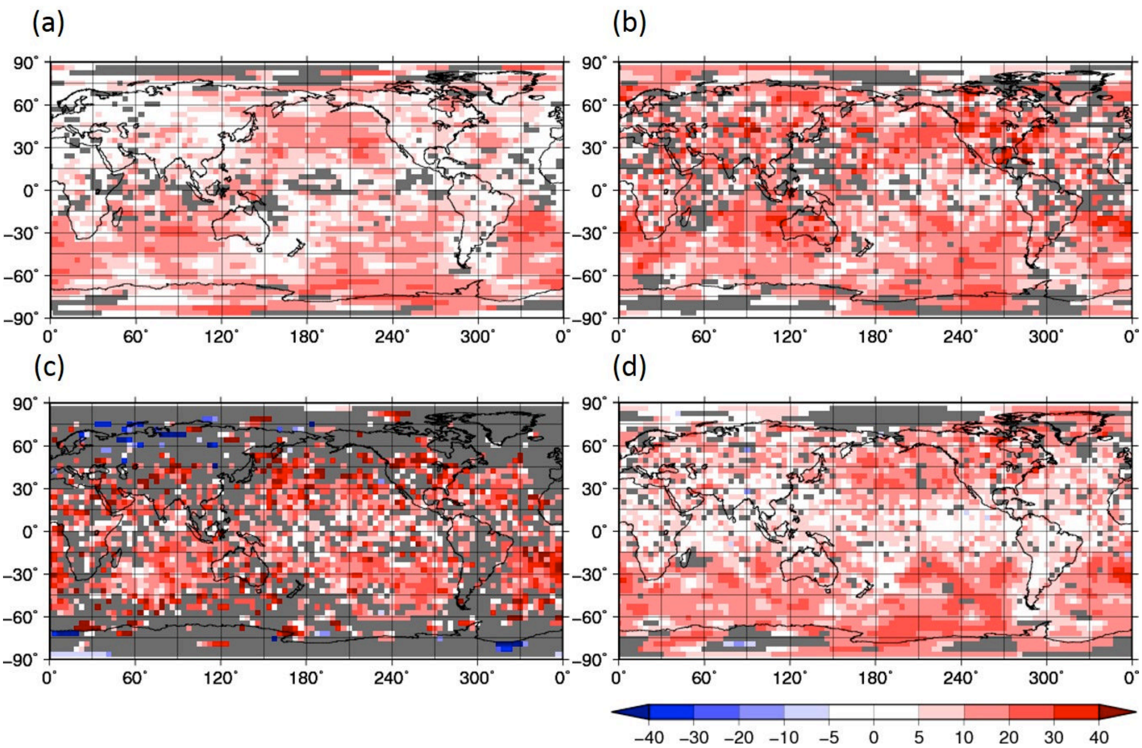

Figure 3. Improvements (%) of 1-year-average analysis RMSE of DLOC over CTRL for (a) zonal wind at the 4th model level (~500 hPa), (b) temperature (K) at the 2nd model level (~850 hPa), (c) specific humidity at the lowest level (~950 hPa), and (d) surface pressure. Red (blue) indicates advantage (disadvantage) of DLOC. Adapted from Fig. 6 of Miyoshi and Kondo (2013).

The newly proposed dual-localization method (DLOC) indicates astonishing improvements for all variables compared with the regular single localization (CTRL) (Fig. 3). DLOC uses two localization parameters, and the sensitivity to the two localization parameters is investigated. The results show that the dual-localization approach outperforms traditional single localization with relatively wide choices of the two localization scales by about 400-km ranges (Fig. 4). This suggests that we could avoid fine tuning of the two localization parameters. We started adapting DLOC to a real typhoon case using the WRF-LETKF system and obtained improved representation of heavy rainfalls at meso-convective scales. Here, WRF stands for the Weather and Research Forecasting model, a widely-used community numerical weather prediction model.

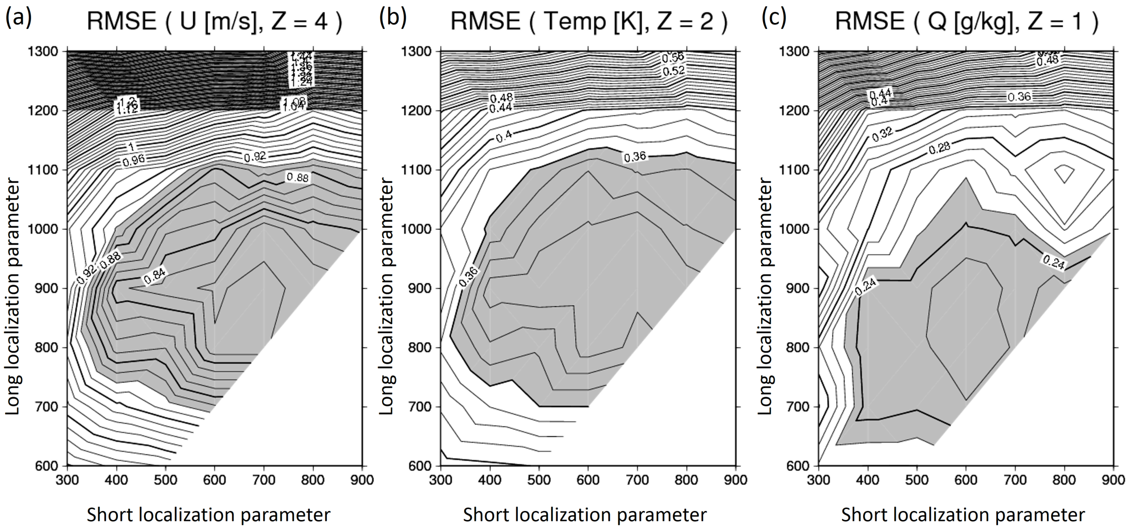

Figure 4. Analysis RMSEs of dual localization with various localization scale parameters, averaged for a year from 0000 UTC 1 February 1982 to 0000 UTC 1 February 1983 for (a) zonal wind (m s^{-1}) at the 4th model level, (b) temperature (K) at the second model level and (c) specific humidity (g kg^{-1}) at the lowest model level. The RMSEs of CTRL are 0.900 m s^{-1}, 0.366 K and 0.258 g kg^{-1}, respectively. The shaded areas indicate improvements of DLOC over CTRL. Adapted from Fig. 5 of Kondo et al. (2013).

3.3. Developing the NICAM-LETKF system

The local ensemble transform Kalman filter (LETKF) was applied to the Nonhydrostatic ICosahedral Atmospheric Model (NICAM). Taking advantage of the existing LETKF code for efficient development, our first version of the NICAM-LETKF prototype system (Fig. 5) has the LL-to-ICO grid conversion and its inverse, where LL and ICO represent Longitude-Latitude and ICOsahedral grid structures for the existing LETKF code and NICAM, respectively. Without making substantial changes to the existing codes, the grid conversions act as adapters between the existing NICAM and LETKF. With this prototype, we assimilated successfully the National Centers for Environmental Prediction (NCEP) PREPBUFR observational data, a dataset from the NCEP operational Global Data Assimilation System (GDAS) containing global conventional observations such as reports from surface stations, ships, ocean buoys, weather balloons and aircrafts, and satellite-based winds.

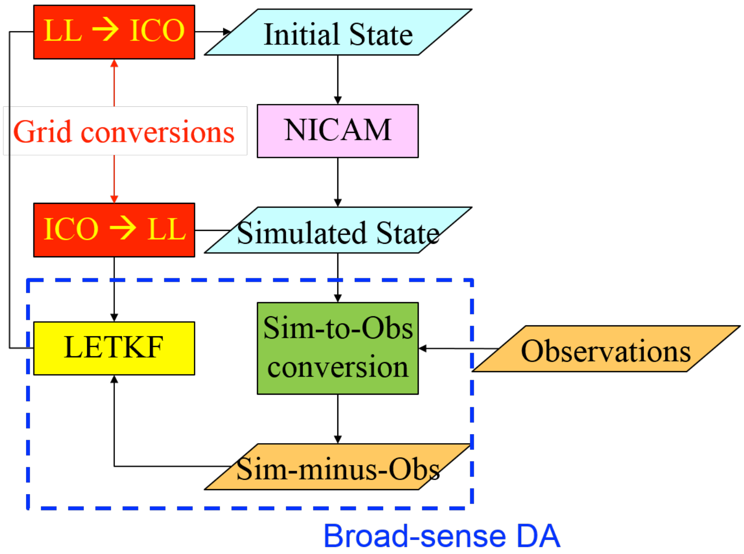

Figure 5. Flow-chart of the NICAM-LETKF prototype system.

After 5 days of data assimilation, the NICAM-LETKF produced the analysis with high correlation with other analysis data from operational numerical weather prediction centers (Fig. 6). This confirms the successful implementation of the NICAM-LETKF data assimilation system.

We also started making substantial changes to the LETKF interface, so that the LL-ICO grid conversions are no longer needed. This will reduce the significant I/O and interpolation errors due to the grid conversions. We developed a preliminary version of the NICAM-LETKF without LL-ICO conversions, and confirmed that the computer time was reduced by about 40% (Fig. 7).

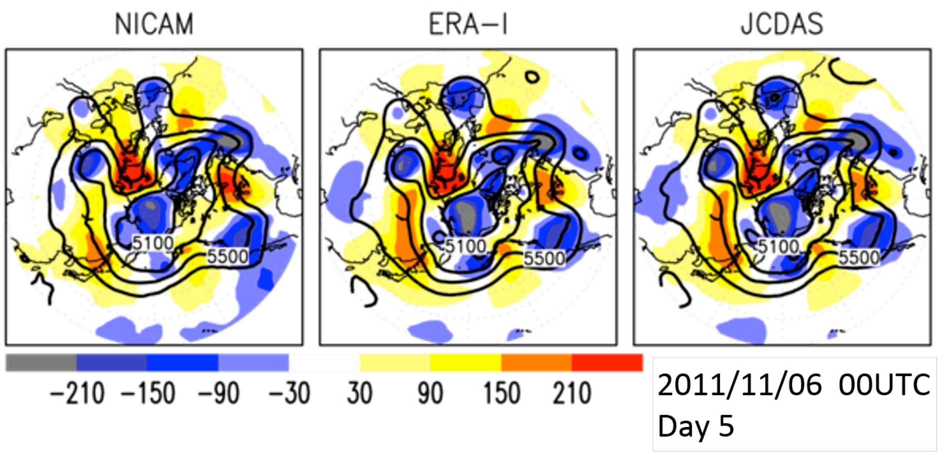

Figure 6. 500-hPa geopotential height analysis on 0000 UTC 6 November 2011 from the NICAM-LETKF (left, the 5th day of data assimilation), European Reanalysis ERA Interim (middle), and Japanese Climate Data Assimilation System (right).

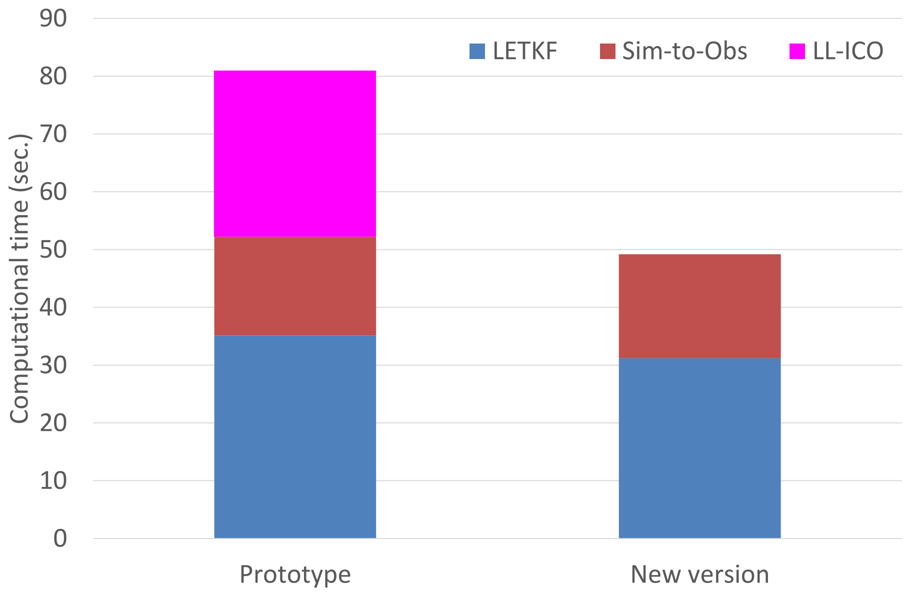

Figure 7. Computational time of the two versions of NICAM-LETKF at a G-level 6 (112 km) resolution using 200 nodes of the K computer. Left: prototype version with LL-ICO grid conversions, Right: new version without grid conversion.

3.4. Application of KMR (K Map Reduce) to LETKF workflow

The LETKF workflow had a large number of small jobs, and we applied KMR (K Map Reduce) to optimize the workflow. KMR is developed and maintained by HPC Programming Framework Research Team, and this work is a good example of interdisciplinary collaborations between computer science and computational science within AICS Research Division.

The WRF-LETKF system has *N* separate jobs for ensemble forecasting, where *N* is the ensemble size (Fig. 8). We have a single job for the LETKF. Here, we consider WRF-LETKF as an example, but the results and discussions can be generalized to any model. When $N = 41$, it took about 2 hours to complete the 41-member ensemble forecasts (Fig. 9). For robustness, we measured the timing 4 times and took the median. The median of the run time of the WRF forecast was about 2 minutes, and the submitted job had a size of 15 nodes for an hour. An hour may sound too long, but occasionally, it could take up to an hour, so we had to assign an hour to avoid unexpected failure. Due to the limit of the number of simultaneous job submissions in the K computer, we could submit either 15 or 20 jobs simultaneously. Therefore, we had almost 2 hours of the wait time to compete all 41 WRF forecasting jobs (Fig. 9).

This situation may be ameliorated by applying the KMR. "Map Reduce" fits very well with the LETKF workflow (Fig. 8), and can easily combine the *N* forecasting jobs into one. We applied the KMR and combined the 41 small jobs (15 nodes for an hour) into a single large job (630 nodes for an hour). The total computational request is very similar (630 node-by-hour product), but the number of jobs is different (41 vs. 1). As a result, we could accelerate the total wall-clock time to be about 8 minutes (compared with 120 minutes!) (Fig. 10). For robustness, we measured the timing 9 times and took the median. What is different is the wait time. The K computer wait time in the queue turned out to be much smaller for 630 nodes for an hour, rather than submitting 15 or 20 jobs simultaneously for 15 nodes for an hour.

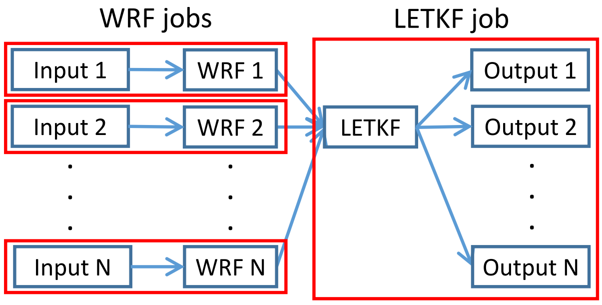

Figure 8. Schematic showing LETKF workflow. Blue and red boxes indicate each process and job, respectively. “Input” processes generate input data to the WRF forecast, “WRF” processes compute the forecast, “LETKF” process is data assimilation, and “Output” processes convert the file formats.

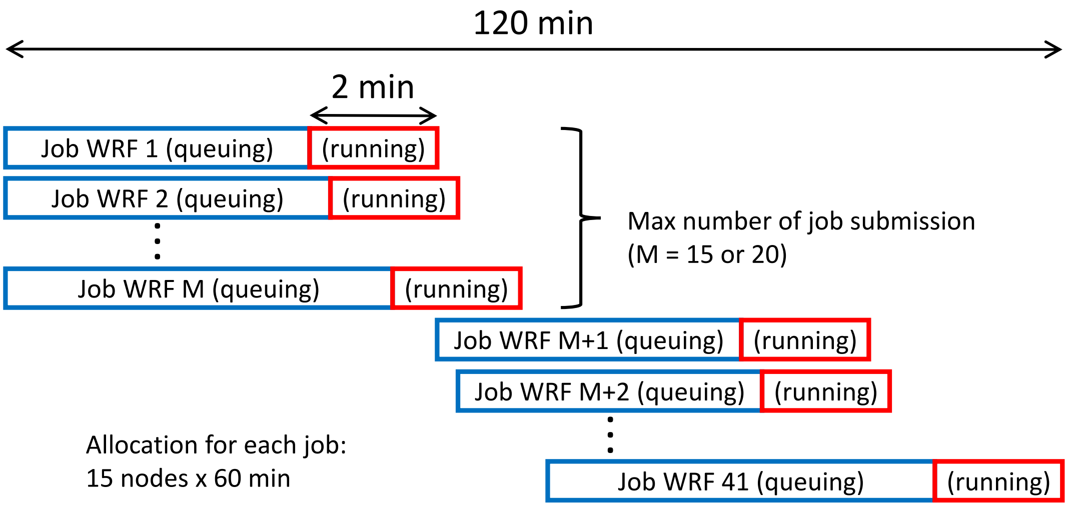

Figure 9. Wall-clock time for computations of the 41-member WRF ensemble forecasts.

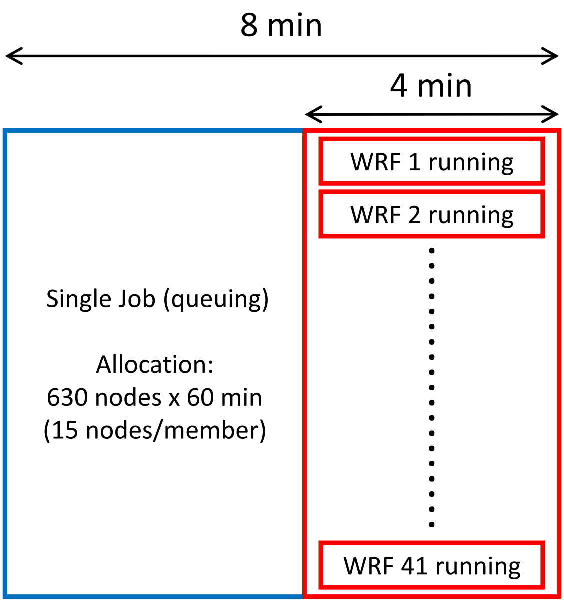

Figure 10. Wall-clock time for the same WRF ensemble forecasts as Fig. 9, but with KMR combining the 41 separate jobs into one.

4. Schedule and Future Plan

In FY2013, Team had three additional full-time research and technical staff and accepted visiting researchers, leading to a substantial growth. We started working on a wide range of data assimilation research on theoretical explorations, leading meteorological applications, algorithmic optimization, and wider applications. Our active research efforts started making impact on the scientific communities, and we are in a good shape in making progress on the research items of the AICS road-map. In FY2014, we will further extend and strengthen what we have achieved so far, and also will keep seeking new challenges. Making the most use of Big Data is an important emerging direction, and we are taking the lead in what we call the "Big Data Assimilation" concept. We will keep updating ourselves with the most recent movements and trends in the scientific community and society, while making substantial progress on traditional research.

Team will have a few more additional research staff in FY2014. Team is still young and spinning up, but will keep the consistent and competitive level of productivity, aiming to be one of the world's leaders in the field of data assimilation.

5. Publication, Presentation and Deliverables

(1) Journal Papers

[1] Onogi, K., Y. Harada, S. Kobayashi, H. Kamahori, C. Kobayashi, K. Endo, T. Ishibashi, M.

Kubota, K. Yoshimura, **T. Miyoshi**, N. Komori, and K. Oshima, 2012: Report on WCRP International Reanalysis Conference. *Tenki*, **59**, 1007-1016. (in Japanese)

[2] Kobayashi, K., **S. Otsuka**, K. Takara, S. Origuchi, and K. Saito, 2013: Ensemble prediction of heavy rainfalls and floods around small- to medium-size rivers. *Annual J. Hydraulic Engineering*, **57**, 1597-1602. (in Japanese)

[3] Yoshimura, K., **T. Miyoshi**, and M. Kanamitsu, 2013: Idealized experiments of water isotopes using an ensemble Kalman filter. *J. Japan Society of Civil Engineers B1 (Hydraulic Engineering)*, **69**, 1795-1800. (in Japanese)

[4] Iwasaki, T., K. Ito, H. Miura, **S. Otsuka**, Y. Baba, A. Hashimoto, K. Saito, T. Hara, A. Noda, and **M. Sawada**, 2013: Report on the Second International Workshop on Nonhydrostatic Numerical Models. *Tenki*, **60**, 209-215. (in Japanese)

[5] **Ruiz, J. J.**, M. Pulido, and **T. Miyoshi**, 2013: Estimating model parameters with ensemble-based data assimilation: A review. *J. Meteorol. Soc. Japan*, **91**, 79-99. doi:10.2151/jmsj.2013-201

[6] Enomoto, T., **T. Miyoshi**, Q. Moteki, J. Inoue, M. Hattori, A. Kuwano-Yoshida, N. Komori, and S. Yamane, 2013: Observing-system research and ensemble data assimilation at JAMSTEC. *Data Assimilation for Atmospheric, Oceanic and Hydrologic Applications (Vol. II)*, ed. by S. K. Park and L. Xu, chap. 21, 509-526, Springer, doi:10.1007/978-3-642-35088-7_21.

[7] Norwood, A., E. Kalnay, K. Ide, **S.-C.Yang**, and C. Wolfe, 2013: Lyapunov, singular and bred vectors in a multi-scale system: an empirical exploration of vectors related to instabilities. *Journal of Physics A, special issue of Lyapunov vectors*, **46**, 20.pp.1. doi:10.1088/1751-8113/46/25/254021

[8] Ushiyama, T., T. Sayama, S. Fujioka, Y. Tatebe, K. Fukami, and T. Miyoshi, 2013: Rain-runoff prediction experiments of 12th and 15th Typhoon in 2011 using ensemble Kalman filtering. *J. River Technology*, **18**, 319-324. (in Japanese)

[9] Lien, G.-Y., E. Kalnay, and **T. Miyoshi**, 2013: Effective Assimilation of Global Precipitation: Simulation Experiments. *Tellus*, **65A**, 11915. doi:10.3402/tellusa.v65i0.19915

[10] Arabas, S. and **S. Shima**, 2013: Large Eddy Simulations of Trade-Wind Cumuli using Particle-Based Microphysics with Monte-Carlo Coalescence. *J. Atmos. Sci.*, **70**, 2768-2777. doi: 10.1175/JAS-D-12-0295.1

[11] Ota, Y., J. C. Derber, E. Kalnay, and **T. Miyoshi**, 2013: Ensemble-based observation impact estimates using the NCEP GFS. *Tellus*, **65A**, 20038. doi:10.3402/tellusa.v65i0.20038

[12] **Ruiz, J. J.**, M. Pulido, and **T. Miyoshi**, 2013: Estimating model parameters with ensemble-based data assimilation: Parameter covariance treatment. *J. Meteorol. Soc. Japan*, **91**, 453-469. doi:10.2151/jmsj.2013-403

[13] **Miyoshi, T., S. Otsuka**, N. Komori, T. Tsuyuki, T. Enomoto, 2013: Report on AICS International Workshop on Data Assimilation. *Tenki*, **60**, 731-735. (in Japanese)

[14] **Yang, S.-C.**, K.-J. Lin, **T. Miyoshi**, and E. Kalnay, 2013: Improving the spin-up of regional EnKF for typhoon assimilation and forecasting with Typhoon Sinlaku (2008). *Tellus*, **65A**, 20804. doi:10.3402/tellusa.v65i0.20804

[15] **Kondo, K.**, **T. Miyoshi** and H. L. Tanaka, 2013: Parameter sensitivities of the dual-localization approach in the local ensemble transform Kalman filter. *SOLA*, **9**, 174-177. doi:10.2151/sola.2013-039

[16] **Penny, S. G.**, E. Kalnay, J. A. Carton, B. R. Hunt, K. Ide, **T. Miyoshi**, and G. A. Chepurin, 2013: The local ensemble transform Kalman filter and the running-in-place algorithm applied to a global ocean general circulation model. *Nonlin. Processes Geophys.*, **20**, 1031-1046. doi:10.5194/npg-20-1031-2013

[17] **Miyoshi, T**. and **K. Kondo**, 2013: A multi-scale localization approach to an ensemble Kalman filter. *SOLA*, **9**, 170-173. doi:10.2151/sola.2013-038

[18] **Kotsuki, S.**, K. Tanaka., and S. Watanabe, 2014: Projected hydrological changes and their consistency under future climate in the Chao Phraya River Basin using multi-model and multi-scenario of CMIP5 dataset. *Hydrological Research Letters*, **8**, 27-32. doi:10.3178/hrl.8.27

[19] Watanabe, S., Y. Hirabayashi., **S. Kotsuki.**, N. Hanasaki., K Tanaka., C.M.R. Mateo., M. Kiguchi., E. Ikoma., S. Kanae., T. Oki., 2014: Application of performance metrics to climate models for projecting future river discharge in the Chao Phraya River basin, *Hydrological Research Letters*, **8**, 33-38. doi:10.3178/hrl.8.33

[20] **Kotsuki, S.** and K. Tanaka, 2014: Improvement of global crop calendar product using satellite-sensed vegetation indexes. *J. Japan Society of Civil Engineers B1 (Hydraulic Engineering)*, **70**, 259-264. (in Japanese)

(2) Conference Papers

[21] **Kostuki, S.** and K. Tanaka, 2014: Comparison of soil moisture derived from AMSR-E and land surface model in West African arid regions. *Proceedings of the Soil Moisture Workshop 2013*, 33-36. (in Japanese)

(3) Invited Talks

[22] **Yang, S.-C.**, K.-J. Lin, **T. Miyoshi** and E. Kalnay: Improving the spin-up of the regional EnKF for typhoon assimilation and forecast. AICS International Workshop on Data Assimilation, RIKEN, Japan, Feb, 2013.

[23] **Yang, S.-C.**, S.-Y. Chen, S.-H. Chen, C.-Y. Huang and C.-S. Chen: Evaluating the impact of the COSMIC-RO bending angle data on predicting the heavy precipitation episode on 16 June 2008 during SoWMEX-IOP8. Seminar at Korea Institute of Atmospheric Prediction Systems, Korea, 19th Aug, 2013.

[24] **Otsuka, S.**, M. Takeshita, and S. Yoden: Numerical experiments on formation of tropopause

inversion layer associated with extratropical cyclone. WCRP regional workshop on stratosphere-troposphere processes and their role in climate, Kyoto, 2nd Apr, 2013.

[25] **Shima, S.**: Super-Droplet Approach to Simulate Precipitating Trade-Wind Cumuli - Comparison of Model Results with RICO Aircraft Observations. International Workshop on Numerical Simulations of Particle/Droplet/Bubble-laden Multiphase Flows, JAMSTEC Tokyo office, Japan, 24th May, 2013.

[26] **Miyoshi, T.**: Computational Challenges in Big Data Assimilation with Extreme-scale Simulations. Big Data and Extreme-Scale Computing (BDEC) Workshop, Charleston, SC, USA, 1st May, 2013.

[27] **Miyoshi, T.**: "Data Assimilation Research on Typhoons. Biannual Meeting of the Meteorological Society of Japan, Tokyo, Japan, May, 2013.

[28] **Miyoshi, T.**: Exploring multi-scale and model-error treatments in ensemble data assimilation. Davos Atmosphere and Cryosphere Assembly DACA-13, Davos, Switzerland, 9th July, 2013.

[29] **Miyoshi, T.**: “Special Lecture Numerical Weather Prediction I/Ⅱ: Numerical Weather Prediction Chaos, Predictability, and Data Assimilation”, "Lecture: Localization and Inflation techniques in ensemble data assimilation", Summer School/Creative Workshop on Data Assimilation & Inverse Problems, Reading, UK, 25th July, 2013.

[30] **Miyoshi, T.**: Exploring Multi-scale and Model-error Treatments in Ensemble Data Assimilation. Sixth WMO Symposium on Data Assimilation, College Park, MD, USA, 8th Oct, 2013.

[31] **Miyoshi, T.**: Advances and challenges in ensemble data assimilation. RIMS International Conference on Theoretical Aspects of Variability and Predictability of Weather and Climate Systems, Kyoto, Japan, 25th Oct, 2013.

[32] **Yang, S.-C.**: Improving severe weather prediction in Taiwan using an advanced regional data assimilation system, National Cheng-Jung University, Taiwan. November, 2013.

[33] **Miyoshi, T.**: IMA Hot Topics Workshop : Exploring Multi-scale and Model-error Treatments in Ensemble Data Assimilation. Predictability in Earth System Processes, IMA, University of Minnesota, Minneapolis, MN, USA, 18th November, 2013.

[34] **Miyoshi, T.**: Toward severe-weather forecasting through "Big Data Assimilation". Second International Symposium on Watercourse Sensing and Operational Monitoring, Kyoto, Japan, 27th Novemver, 2013.

[35] **Miyoshi, T.**: Predicting sudden severe rainstorm using observational data and simulations. 9^{th} workshop on information technology for safe life, The Institute of Image Electronics Engineers of Japan, Tokyo, 31 January, 2014. (in Japanese)

[36] **Miyoshi, T.**: Exploring Multi-scale and Model-error Treatments in Ensemble Data Assimilation. International Symposium on Data Assimilation 2014, Munich, Germany, 26th Feb, 2014.

[37] **Miyoshi, T.**: Innovating "Big Data Assimilation" technology for revolutionizing very-short-range severe weather prediction. International movement of Big Data application, Tokyo, 4 March, 2014. (in Japanese)

[38] **Miyoshi, T.**: Predict Sudden Severe Rainstorm with Data Assimilation. TEDxSannomya, Kobe, 9 March 2014. (in Japanese)

[39] **Miyoshi, T.**: Big Data Assimilation. Workshop on Earth fluids data analysis and numerical computation, Kobe, 11 March 2014. (in Japanese)

[40] **Miyoshi, T.**: Ensemble Kalman Filter in Meteorology and "Big Data Assimilation". Mathematical Science on Big Data Assimilation in Meteorology, Kyoto, Japan, 19th Mar, 2014.

(4) Posters and Presentations (selected English presentations)

[41] **Yang, S.-C.**, S.-Y. Chen, S.-H. Chen, C.-Y. Huang and C.-S. Chen: Evaluating the impact of the COSMIC-RO bending angle data on predicting the heavy precipitation episode on 16 June 2008 during SoWMEX-IOP8, 93rd AMS Annual Meeting.

[42] **Yang, S.-C.**, K.-J. Lin, **T. Miyoshi** and E. Kalnay: Improving the spin-up of the regional EnKF for typhoon assimilation and forecast with the 2008 Typhoon Sinlaku, 93rd AMS Annual Meeting.

[43] **Yang, S.-C.**, S.-Y. Chen, S.-H. Chen, C.-Y. Huang and C.-S. Chen: Evaluating the impact of the COSMIC-RO bending angle data on predicting the heavy precipitation episode on 16 June 2008 during SoWMEX-IOP8, International conference for GPS Radio Occultation, Taiwan (English)

[44] **Otsuka, S.**, M. Takeshita, S. Yoden: Numerical Simulation on the Formation of Tropopause nversion Layer by Gravity Waves Associated with an Extratropical Cyclone. AOGS, Brisbane, AS07-D5-PM1-P7-004, 28th Jun, 2013.

[45] **Otsuka, S.**, M. Takeshita, S. Yoden: A Numerical Experiment on the Formation of Tropopause Inversion Layer by Gravity Waves Associated with an Extratropical Cyclone. Davos Atmosphere and Cryosphere Assembly 2013, Davos, #415, 11th Jul, 2013.

[46] **Otsuka, S.**, N.J. Trilaksono, S Yoden: Statistical Analysis on the Size Distributions of Tropical Convective Systems during the Jakarta Flood Event in 2007 Simulated by JMA-NHM. Davos Atmosphere and Cryosphere Assembly 2013, Davos, #417, 12th Jul, 2013.

[47] **Yang, S.-C.** and E. Kalnay: Application of Ensemble Sensitivity to Data Assimilation. 6th WMO data assimilation workshop, USA

[48] Dillon M.E., **J.J. Ruiz**, E.A. Collini, Y. Garcia-Skabar, E. Kalnay, **T. Miyoshi**, M. Kunii: Application of the WRF-LETKF system over Argentina: A Case Study. Sixth WMO Symposium on Data Assimilation, College Park, MD, USA, 8th Oct, 2013.

[49] Chang, C.-C., **S.-C. Yang** and C. Keppenne: Applications of the mean re-recentering scheme

to improve typhoon track prediction: A case study of typhoon Nanmadol (2011). 2013 APEC Typhoon Symposium, Taiwan.

[50] Tsai, C.-C., **S.-C. Yang**, and Y.-C. Liou, 2013b: Improving Short-Term QPFs with a WRF-LETKF Radar Data assimilation system: real case study with Typhoon Morakot. 2013 APEC Typhoon Symposium, Taiwan.

[51] Chang, C.-C., **S.-C. Yang** and C. Keppenne, 2013: Applications of the mean re-recentering scheme to improve typhoon track prediction: A case study of typhoon Nanmadol (2011). RIMS International Conference on Theoretical Aspects of Variability and Predictability in Weather and Climate Systems, Kyoto, 23rd Oct, 2013.

[52] **Yang, S.-C.**, E. Kalnay and E. Enomoto: Application of Ensemble Sensitivity to Data Assimilation, RIMS International Conference on Theoretical Aspects of Variability and Predictability in Weather and Climate Systems, Kyoto, 23rd Oct, 2013.

[53] **Otsuka, S.** and **T. Miyoshi**: A Bayesian optimization approach to multi-model ensemble data assimilation. RIMS International Conference on Theoretical Aspects of Variability and Predictability in Weather and Climate Systems, Kyoto, 22nd Oct, 2013.

[54] **Kondo, K.** and **T. Miyoshi**: Parameter sensitivities of the dual-localization approach in the SPEEDY-LETKF. RIMS International Conference on Theoretical Aspects of Variability and Predictability in Weather and Climate Systems, Kyoto, 25 Oct, 2013.

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(5) Patents and Deliverables

[66] The LETKF code is updated as needed and available at https://code.google.com/p/miyoshi/.