WRF-LETKF
The Present and Beyond

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With many thanks to
B. Hunt, J.-S. Kang, S. Greybush, S. Penny, and UMD Weather-Chaos group
I am moving to Kobe, Japan.

Data Assimilation Research Team was launched at RIKEN Advanced Institute for Computational Science (AICS) in October 2012. I was appointed as the lab head, and will move to Kobe permanently at the end of December.

AICS operates the 10-Peta-Flops K computer; my group will work with this monster computer.
The whole building is floating in case of earthquakes.
WRF-LETKF studies at UMD

Goal: Improve TC forecasts by improving the initial conditions

- WRF-LETKF system (Miyoshi and Kunii 2012)
  - LETKF: Local Ensemble Transform Kalman Filter (Hunt et al. 2007)
  - Adaptive inflation method (Miyoshi 2011)

- Several techniques to improve TC forecasts have been explored.
  - Running-In-Place method (Yang, Miyoshi and Kalnay 2012)
  - Including SST uncertainties (Kunii and Miyoshi 2012)
  - Assimilating AIRS retrievals (Miyoshi and Kunii 2012)
  - Estimating observation impact using the ensemble-based method (Kunii, Miyoshi and Kalnay 2012)
    - Based on the ensemble sensitivity method of Liu and Kalnay (2008)
  - Two-way nested WRF-LETKF for higher-resolution experiments
Studies on methods: towards optimal use of available observations

**RUNNING-IN-PLACE (RIP)**

Yang, Kalnay, and Hunt (2012, in press)
Yang, Miyoshi and Kalnay (2012, in press)
Yang, Lin, Miyoshi, and Kalnay (in progress)
Running-In-Place (RIP, Kalnay and Yang 2008)

4D-LETKF: Ensemble Kalman Smoother

\[ \mathbf{x}_a(t_{n-1}) = \mathbf{x}_a(t_{n-1}) + \mathbf{X}_a(t_{n-1}) \mathbf{w}_a(t_n) \]
\[ \mathbf{X}_a(t_{n-1}) = \mathbf{X}_a(t_{n-1}) \mathbf{W}_a(t_n) \]
\[ \mathbf{w}_a = \mathbf{P}_a \mathbf{Y}_b \mathbf{R}^{-1} (\mathbf{y} - H(\mathbf{x})) \]
\[ \mathbf{W}_a = [(K-1)\mathbf{P}_a]^{\frac{1}{2}} \]

Running-In-Place (RIP) method:
1. Update the state (★) at \( t_{n-1} \) using observations up to \( t_n \) (smoother)
2. Assimilate the same observations again (dealing with nonlinearity)
3. Repeat as long as we can extract information from the same obs.
In OSSE, RIP is very promising. Realistic observing systems are assumed, including dropsondes near the TC. Vortex strength and structure are clearly improved.

Yang, Miyoshi and Kalnay (2012)
Typhoon Sinlaku (2008)

Track

MSLP
RIP impact on Sinlaku track forecast

This is the real case.

RIP better use the “limited observations”!

S.-C. Yang (2012)
WRF-LETKF: including additional sources of uncertainties

SST UNCERTAINTIES
Kunii and Miyoshi (2012, Weather and Forecasting)
SST ensemble perturbations

SST is randomly perturbed around the SST analysis in the WRF-LETKF cycle.

The SST perturbations are the differences between SST analyses on randomly chosen dates. The perturbation fields are fixed in time.
6-h forecast fields

The location and intensity are the best with the SST perturbation.

NOTE: There is no SST perturbation in the forecast, but only in the DA cycle.
Improvement in TC forecasts

1. TC intensity and track forecasts are greatly improved.
   (NO SST perturbations in the forecast)

2. Improvement is not only in the single case.
   (NO SST perturbations in the forecast)
WRF-LETKF: using satellite data

ASSIMILATION OF AIRS DATA

Miyoshi and Kunii (2012, *Tellus*)
Larger inflation is estimated due to the AIRS data.

- August-September 2008, focusing on Typhoon Sinlaku
72-h forecast fit shows general improvements

Relative to radiosondes  Relative to NCEP FNL

1-week average over September 8-14, 2008
AIRS impact on TC forecasts

➢ TC track forecasts for Typhoon Sinlaku (2008) were significantly better, particularly in longer leads.

Too deep to resolve by 60-km WRF
WRF-LETKF: towards optimizing observing systems

ENSEMBLE-BASED OBS IMPACT

Kunii, Miyoshi, Kalnay and Black (in progress)
Forecast sensitivity to observations

- **Observation impact** is calculated without an adjoint model. *(Liu and Kalnay 2008, Li et al. 2009)*

- We applied the above method to **real observations for the first time!** *(Kunii, Miyoshi, and Kalnay 2011)*
Impact of dropsondes on a Typhoon

Estimated observation impact

Degrading

Improving
Denying negative impact data improves forecast!

Estimated observation impact

DOTSTAR  00Z11SEP2008

Typhoon track forecast is actually improved!!

Improved forecast

36-h forecasts

Observed track

Original forecast
Impact of NRL P-3 dropsondes

NRL P-3 RF10 Flight Track
Start of Mission: 2008/09/10 2019 UTC
End of Mission: 2008/09/11 0602 UTC
Impact of WC-130J dropsondes
Impact of DLR Falcon dropsondes
Overall impacts of dropsondes (T-PARC/ITOP2010)

**T-PARC 2008**

- **Level (hPa):** 100-200, 200-300, 300-400, 400-500, 500-700, 700-850, >850
- **Forecast error contribution (J kg⁻¹):**
  - **U**: improving, degrading
  - **V**: improving, degrading
  - **T**: improving, degrading

**ITOP 2010**

- **Level (hPa):** 100-200, 200-300, 300-400, 400-500, 500-700, 700-850, >850
- **Forecast error contribution (J kg⁻¹):**
  - **U**: improving, degrading
  - **V**: improving, degrading
  - **T**: improving, degrading

**OBS count**

- **Level (hPa):** 100-200, 200-300, 300-400, 400-500, 500-700, 700-850, >850
- **OBS count:** 0, 500, 1000, 1500, 2000, 2500
Composite of dropsonde impact over many TCs

Dropsonde impact (J kg\(^{-1}\)) per observation count
Location relative to the TC center

T-PARC 2008

ITOP 2010

Further statistical investigations are currently in progress.
WRF-LETKF: towards efficient experiments at a higher resolution

TWO-WAY NESTED LETKF

Miyoshi and Kunii (in preparation)
Motivation for higher resolution DA

60-km analysis

60/20-km 2-way nested analysis
An example of heterogeneous grids
The existing LETKF can deal with the homogeneous grid.

Multiple domain forecasts are treated in the single LETKF analysis step.

Observation operators are not affected.
Efficient implementation

Taking advantage of the independence of each grid point in the LETKF, having a simple mask file enables skipping unnecessary computations.

Additional I/O could be a significant drawback.
Enhanced localization

- We can define different localization scales at each grid point.
- We may want to have tighter localization in the higher-resolution region(s).
Covariance structure near Sinlaku

2WAY CORR U05-U05

60-km grid spacing
400-km localization

2WAY-LOC CORR U05-U05

20-km grid spacing
200-km localization

20-km grid spacing
400-km localization
Analysis increments and analysis

CTRL

60-km resolution increments

2WAY-LOC

20-km resolution increments

0600 UTC, September 9, 2008: Best track 985hPa
A single case intensity forecast

Initial time: 0000UTC September 10, 2008

Dropsonde data played an important role in higher-resolution data assimilation in this case.
Future research ideas

- Regional ocean coupling
  - Considering flow-dependent SST perturbations.

- Higher-resolution runs, multi-scale considerations
  - We need more localization with higher resolution, but tight localization only allows using data for high-frequency components.

- Model parameter estimation

- Expanding to WRF-Chem
  - Aerosols, air-quality, lidar data assimilation
2-D air-sea coupling parameter estimation

Sensitivity to the model parameters (a real TC case)

Ruiz and Miyoshi (2012)

We estimated the air-sea moisture exchange parameters as a 2-D variable, but did not get good results yet.
We succeeded in CALIPSO lidar assimilation with a GCM (not WRF).

Surface dust distribution and station obs

- **NO DA**
  - Blue stations: no dust observed
- **WITH DA**
  - Red stations: dust observed

Assimilating CALIPSO data clearly improves horizontal surface-dust distribution.

(Sekiyama et al. 2010)
We are hiring researchers.

Contact me for details. Short visits are also welcome.

Seeking Research Scientist, Postdoctoral Researcher, or Technical Staff

Laboratory
Data Assimilation Research Team, RIKEN Advanced Institute for Computational Science
(Team Leader: Dr. Takemasa Miyoshi)

Research Field
The Advanced Institute for Computational Science (AICS) is operating the world’s leading K computer, and also has a strong Research Division. AICS takes the lead in advancing the computational science and aims to be an international center of excellence for computational science in collaboration with a wide range of research organizations. AICS integrates the computer science and computational science to conduct most advanced research and development of a wide range of applied scientific computation, as well as of high performance computing technologies.

The Data Assimilation Research Team (“DA team”) performs cutting-edge research and development on advanced data assimilation methods and their wide applications, aiming at integrating computer simulations and observational data in the wisest way. Particularly, the 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.
Thank you very much!!