Thursday, March 13, 2025, 07-09 UTC

Topic: Data Assimilation Methodology

Organizers: James Taylor *(RIKEN, Japan),*
Steven J Fletcher *(Colorado State University, USA)*

Program:

07:00 – 07:05 **Welcome**

07:05 – 07:25 **Are Ensemble-based Data Assimilation Methods Really Necessary for Accurate Filtering?**
Marc Bocquet, Alban Farchi, Tobias S. Finn, Charlotte Durand, Sibo Cheng, Yumeng Chen, Ivo Pasmans, Alberto Carrassi

07:25 – 07:45 **An Integral-Form Ensemble Square-Root Filter with Efficient and Precise Model-Space Localization**
Robin Armstrong, Ian Grooms, Chris Snyder

07:45 – 08:05 **Exploration of Tempering Data Assimilation Methods for using the Local Ensemble Transform Kalman Filter: Simple and Intermediate Experiments**
Jorge Gacitua, Juan Ruiz

08:05 – 08:25 **Flow-Dependent Large-Scale Blending for Limited-Area Ensemble Data Assimilation**
Saori Nakashita, Takeshi Enomoto

08:25 – 08:50 **[Invited] Quantum Data Assimilation: A New Approach to Solving Data Assimilation on Quantum Annealers**
Shunji Kotsuki, Fumitoshi Kawasaki, Masanao Ohashi, Tadashi Tsuyuki

08:50 – 09:00 **Closing**

Please note:

- The times in UTC are approximate.
  In case of technical problems, we might have to change the order of the presentations.
- **Time Zones**: **07 – 09 UTC**
  07 – 9 am BST (London) | 08 – 10 am CET (Berlin)
  03 – 05 pm CST (Shanghai) | 04 – 06 pm JST (Tokyo) | 06 – 08 pm AEDT (Sydney)
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Are ensemble-based data assimilation methods really necessary for accurate filtering?

Marc Bocquet[1], Alban Farchi[1], Tobias S. Finn[1], Charlotte Durand[1], Sibo Cheng[1], Yumeng Chen[2], Ivo Pasmans[2], Alberto Carrassi[3]

[1]CEREA, ENPC and EDF R&D, Institute Polytechnique de Paris, Île-de-France, France
[2]Department of Meteorology and National Centre for Earth Observation, University of Reading
[3]Department of Physics and Astronomy, University of Bologna,

We investigate the ability to discover data assimilation (DA) schemes meant for chaotic dynamics with deep learning. The focus is on learning the analysis step of sequential DA, from state trajectories and their observations, using a simple residual convolutional neural network, while assuming the dynamics to be known. Experiments are performed with low-order dynamics which display spatiotemporal chaos and for which solid benchmarks for DA performance exist. The accuracy of the states obtained from the learned analysis approaches that of the best possibly tuned ensemble Kalman filter, and is far better than that of variational DA alternatives. Critically, this can be achieved while propagating even just a single state in the forecast step. We investigate the reason for achieving ensemble filtering accuracy without an ensemble. We diagnose that the analysis scheme actually identifies key dynamical perturbations, mildly aligned with the unstable subspace, from the forecast state alone, without any ensemble-based covariances representation. This reveals that the analysis scheme has learned some multiplicative ergodic theorem associated to the DA process seen as a non-autonomous random dynamical system. This also suggests building a new class of efficient deep learning-based ensemble-free DA algorithms.

An Integral-Form Ensemble Square-Root Filter with Efficient and Precise Model-Space Localization

Robin Armstrong[1], Ian Grooms[2], Chris Snyder[3]

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[2] University of Colorado Boulder, Department of Applied Mathematics
[3] NSF NCAR, Mesoscale and Microscale Meteorology Laboratory

In ensemble data assimilation, covariance localization is critical for mitigating the harmful effects of spurious correlations between data and model variables, as well as for preventing ensemble collapse. Observations such as satellite radiance require localization to be done in model space, a computationally demanding task which involves various trade-offs between accuracy and efficiency. This talk introduces an ensemble square-root filter with model-space localization which achieves a favorable trade-off between these factors by combining modern techniques from numerical quadrature and Krylov subspace iteration. This algorithm is compatible with a wide variety of spatial and spectral covariance localization schemes, is parallelizable, and is built upon linear-algebraic primitives whose accuracy is backed up by strong error analyses. We will compare the performance of our algorithm to existing covariance localization techniques such as the gain-form ensemble transform Kalman filter (GETKF). We will also discuss recent efforts to implement this algorithm in the Joint Effort for Data Assimilation Integration (JEDI) for testing with the Model for Prediction Across Scales (MPAS).

Exploration of tempering data assimilation methods for using the LETKF: Simple and intermediate experiments

Jorge Gacitua[1], Juan Ruiz[2]

[1] CONICET
[2] Centro de Investigaciones del Mar y la Atmósfera (CIMA)

Extreme weather events associated with deep moist convection pose significant social risks, requiring advanced technologies for anticipatory measures. Numerical forecasting at convection-resolving scales relies heavily on high-quality initial conditions obtained through data assimilation. Incorporating remote sensing observations into these systems presents challenges due to the nonlinear relationships between observations and model variables. This research explores an iterative implementation of the Local Ensemble Transform Kalman Filter (LETKF) with tempering, designed to address such nonlinearities.
The study utilizes in an initial step the N-variable Lorenz model for its simplicity and low computational cost, enabling rapid experimentation. The experiments tested different ensemble sizes and varying degrees of tempering to assess their impact on the assimilation system's accuracy and stability under controlled conditions. Also intermediate simulations were performed prior to more complex setups to evaluate how single observations, with different degrees of error, impact forecasts in regional models in particular WRF.
The preliminary results in the simple experiments shows that tempering significantly improves the quality of initial condition estimates and enhances the stability of the data assimilation cycle, particularly when using smaller ensembles or higher tempering levels. These findings suggest that the tempered LETKF approach holds potential for mesoscale modeling systems, offering a promising avenue for improving predictions of severe weather events linked to deep moist convection.

Flow-dependent large-scale blending for limited-area ensemble data assimilation

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[1] Graduate School of Science, Kyoto University, Japan
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Limited-area models (LAMs) often suffer from degradation in their representation of large-scale features compared to that of global models (GMs) due to the restricted domain size and limited observational coverage. To address this, we propose a novel flow-dependent large-scale blending (LSB) method for LAM data assimilation (DA).
LSB methods incorporate large-scale information from a GM into the LAM DA system using scale-dependent weights. Our approach, termed as nested EnVar, extends the previously proposed static variational LSB method (nested 3DVar) to an ensemble-based framework. Unlike static LSB methods, nested EnVar simultaneously assimilates both observational and large-scale GM information into LAM forecasts with dynamically adjusting the weight given to GM information based on its estimated flow-dependent uncertainty.

Through idealized assimilation experiments using a nested system of simplified chaotic models with a single spatial dimension, we demonstrate that nested EnVar effectively reduces large-scale errors in LAM DA as existing LSB methods, and offers better forecasts than GM downscaling. Compared to both traditional DA and other LSB methods, nested EnVar provides more accurate analyses and forecasts when dealing with dense and unevenly distributed observations. By dynamically accounting for GM uncertainty, nested EnVar improves the stability and accuracy of the analysis across scales.

Our findings suggest that nested EnVar offers a promising alternative to traditional LSB methods for high-resolution simulations of complex, hierarchically structured phenomena.

This novel approach has the potential to enhance the effectiveness of high-resolution LAM DA for spatially localized convective-scale observations.

[Invited]

Quantum Data Assimilation: A new approach to solving data assimilation on quantum annealers

Shunji Kotsuki[1], Fumitoshi Kawasaki[1], Masanao Ohashi[1], Tadashi Tsuyuki[1]

[1]Chiba University

Data assimilation plays an important role in numerical weather prediction (NWP) to provide optimal initial conditions. Many operational NWP centers use variational or ensemble variational methods that iteratively reduce cost functions based on their gradients. In variational data assimilation methods, huge computational resources and time are consumed for the data assimilation in NWP systems due to the iterations.
We propose an alternative approach: solving data assimilation on quantum annealing machines. We reformulated the cost function of the data assimilation problem into the quadratic unconstrained binary optimization k.a. QUBO problem, which can be solved by quantum annealers. Our four-dimensional variational data assimilation experiments using the 40-variable Lorenz model were promising, showing that the quantum annealers yield analysis whose accuracy was comparable to the conventionally used quasi-Newton method. The D-Wave Advantage, D-Wave's physical quantum machine, solved the four-dimensional variational data assimilation with a much shorter time than the other gradient-based optimizations in our experiments. Recently, we have extended the quantum data assimilation for solving more complicated cost functions including local minima. Specifically, we propose combining quantum data assimilation with a second-order incremental approach to search for the global minimum in four-dimensional variational data assimilation. The presentation will include the most recent progress up to the seminar.