ISDA-Online

June 02, 2023, 07 – 09 UTC

"Topic: Parameter Estimation & Inverse Modelling"

Organizers: *Yvonne Ruckstuhl (W2W, LMU Munich, Germany)*
Yuefei Zeng (NUIST, Nanjing, China)
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Tobias Necker (U. Vienna, Austria)

Estimating uncertain model parameters during data assimilation bears great potential for improving numerical predictions. In recent years, parameter estimation gained increasing popularity in climate and numerical weather prediction applications. This ISDA-online session is devoted to all aspects of parameter estimation and inverse modeling, including research beyond geosciences.

Program: *Time slots 18min each (15 min presentation + 3min Q&A)*

07:00 – 07:03	**Welcome**
	Inverse Modelling
07:03 – 07:21	**Combining Data Assimilation and Data-driven Sparse Sensing Placement Method For Designing Better Observation Locations** *(invited)* Shunji Kotsuki, Takumi Saito, Mao Ouyang, Daiya Shiojiri
07:22 – 07:40	**Critical remarks on inverse modeling techniques** *(invited)* Martin Vojta, Andreas Plach, Rona L. Thompson, Andreas Stohl
07:41 – 07:59	**Data assimilation developments for a new emission inversion system at ECMWF** Luca Cantarello, Nicolas Bousserez, Panagiotis Kountouris, Massimo Bonavita, Richard Engelen
	Parameter Estimation
08:00 – 08:18	**Simultaneous inference of sea ice state and surface emissivity model using machine learning and data assimilation** Alan Geer
08:19 – 08:37	**An Efficient Estimation of Time-Varying Parameters of Dynamic Models by Combining Offline Batch Optimization and Online Data Assimilation** Yohei Sawada, Le Duc
08:38 – 08:56	**Parameter estimations in Land Surface Model** Sujeong Lim, Seon Ki Park, Claudio Cassardo
08:57 – 09:00	**Closing: Outlook on ISDA in Bologna**

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**
  08 – 10 am BST (London) | 09 – 11 am CEST (Berlin)
  03 – 05 pm CST (Shanghai) | 04 – 06 pm JST (Tokyo) | 05 – 07 pm AEDT (Sydney)
  00 – 02 am PDT (San Fran.) | 01 – 03 am MDT (Denver) | 03 – 05 am EDT (New York)

Combining Data Assimilation and Data-driven Sparse Sensing Placement Method For Designing Better Observation Locations

Shunji Kotsuki[1], Takumi Saito[1], Mao Ouyang[1], Daiya Shiojiri[1]

[1]Chiba University, Japan

Data assimilation (DA) plays an important role in numerical weather prediction (NWP) to provide optimal initial conditions by combining forecasted state and observation data. There have been various DA studies to "evaluate" impacts of assimilated observations such as by forecast sensitivity to observation. However, there have been few studies yet that try to optimize the placement of observations for NWP to "increase" impacts of observations.

This study aims at designing better observation networks using the data-driven sparse sensor placement (SSP) method explored in informatics science. This method determines the optimal sensor locations so that the selected sensors effectively determine coefficients of proper orthogonal decomposition (POD) modes. The original SSP method reconstructs the spatial patterns of data from the selected sensors by solving a linear inverse problem using the POD modes. This study combined the SSP and DA so that we can accurately estimate the spatial patterns owing to Tikhonov regularization.

We applied the combined approach to two problems: static and mobile observations. Firstly, the proposed method was applied for the placements of rain-gauge observations over Hokkaido Island in Japan. The optimized rain-gauge locations by the SSP reconstruct more accurate spatial patterns of precipitation than the fields reconstructed by operational stations known as AMeDAS. The second problem aims to optimize the locations of additional mobile stations for NWP. We implemented the SSP into an intermediate global atmospheric model coupled with the local ensemble Kalman filter (a.k.a. SPEEDY-LETKF) to optimize observing placement over the ocean. Our preliminary experiment was promising, showing that the SSP-based placement provides more accurate analyses than an ensemble spread-based placement.

Critical remarks on inverse modeling techniques

Martin Vojta[1], Andreas Plach[1], Rona L. Thompson[2], Andreas Stohl[1]

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Inverse modeling provides a powerful tool to verify national greenhouse gas (GHG) emission inventories by using atmospheric observations to optimize an a priori emission estimate. Often, inversions are based on Lagrangian Particle Dispersion Model simulations, where virtual particles are released from observation sites and traced backwards in time to establish a relationship between atmospheric concentrations and emission sources within the simulation period. The fact, that this simulation period is limited due to computational costs, raises two essential questions: (i) How to best define a baseline, that accounts for all emissions that occur prior to the simulation period? (ii) Which period length should be chosen for the backward-simulation?
We show that often used statistical baseline methods have large problems and present a superior global-distribution-based (GDB) approach, that is consistent with the backward-simulation period, accounts for meteorological variability, and leads to inversion results that agree well with known global emission estimates. Our results further show, that longer backward-simulation periods beyond the often used 5 to 10 days increase the correlation between modeled and observed concentrations, and lead to more robust inversion results. Furthermore, they can help to better constrain emissions in regions poorly covered by the observation network.

Data assimilation developments for a new emission inversion system at ECMWF

Luca Cantarello[1], Nicolas Bousserez[1], Panagiotis Kountouris[1], Massimo Bonavita[2], Richard Engelen[2]

[1]ECMWF, Bonn, Germany
[2]ECMWF, Reading, United Kingdom

The European Centre for Medium-Range Weather Forecasts (ECMWF) is working towards a new Copernicus monitoring and verification service for anthropogenic CO2 emissions (CO2MVS). The global component of the new system will be based on the Integrated Forecasting System (IFS) and is expected to enter operations in 2026. A prototype system is expected to be delivered within the CoCO2 project (coordinated by ECMWF) already by the end of 2023.
As part of the research activities for the new CO2MVS, a new emission inversion capability based on the already operational IFS 4D-Var data assimilation scheme has been developed. The new system allows to jointly optimise the emissions (or fluxes) and the concentrations of several atmospheric composition species together with the meteorological fields. In addition, the Ensemble of Data Assimilation (EDA) method already in use for NWP at ECMWF has been extended so that multi-member emission inversions can be run in parallel (by perturbing the model physics, the observations and the prior fluxes) to provide an estimate of the posterior distribution of emissions and concentrations.
A preliminary evaluation of the system will be presented, including verification against independent observations. Furthermore, the results of a number of Observing System Simulation Experiments (OSSEs) based on the EDA and used to perform sensitivity analyses for various parameter of the system will be discussed.

Simultaneous inference of sea ice state and surface emissivity model using machine learning and data assimilation

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Satellite microwave radiance observations are strongly sensitive to sea ice, but physical descriptions of the radiative transfer of sea ice and snow are incomplete. Further, the radiative transfer is controlled by poorly-known microstructural properties that vary strongly in time and space. A consequence is that surface-sensitive microwave observations are not assimilated over sea ice areas, and sea ice retrievals use heuristic rather than physical methods. One way forward would be to create an empirical model for sea ice radiative transfer, but this cannot be trained using standard machine learning techniques because the model's inputs are mostly unknown. Even the sea ice concentration is not well-known enough to use in training. The solution is to simultaneously train the empirical model and a set of empirical inputs: an "empirical state" method. This is implemented here using a mix of machine learning and data assimilation. A hybrid physical-empirical network describes the known and unknown physics of sea ice and atmospheric radiative transfer. The network is then trained to fit a year of radiance observations from AMSR2. This process estimates maps of the daily sea ice concentration whilst also learning an empirical model for the sea ice emissivity. The model learns to define its own empirical input space along with daily maps of these empirical inputs. These maps represent the otherwise unknown microstructural properties of the sea ice and snow that affect the radiative transfer. The trained empirical model is then transferred into an atmospheric data assimilation framework, where it is used to assimilate microwave observations over sea ice. This approach improves polar weather forecasts and also provides sea ice retrievals for use in coupled data assimilation. The "empirical state" approach could be used to solve other problems of earth system data assimilation, such as directly inferring soil moisture or vegetation from radiances.

An Efficient Estimation of Time-Varying Parameters of Dynamic Models by Combining Offline Batch Optimization and Online Data Assimilation

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It is crucially important to estimate unknown parameters in process-based models by integrating observation and numerical simulation. For many applications in earth system sciences, a parameter estimation method which allows parameters to temporally change is required. In the present paper, an efficient and practical method to estimate time-varying parameters of relatively low dimensional models is presented. In the newly proposed method, called Hybrid Offline Online Parameter Estimation with Particle Filtering (HOOPE-PF), an inflation method to maintain the spread of ensemble members in a Sampling-Importance-Resampling Particle Filter (SIRPF) is improved using a non-parametric posterior probabilistic distribution of time-invariant parameters obtained by comparing simulated and observed climatology. HOOPE-PF outperforms the original SIRPF in synthetic experiments with toy models and a real-data experiment with a conceptual hydrological model when an ensemble size is small. The advantage of HOOPE-PF is that its performance is not greatly affected by the size of perturbation to be added to ensemble members to maintain their spread while it is important to get the optimal performance in the original particle filter. Since HOOPE-PF is the extension of the existing particle filter which has been extensively applied to many models in earth system sciences such as land, ecosystem, hydrology, and paleoclimate reconstruction, HOOPE-PF can be applied to improve the simulation of these process-based models by considering time-varying model parameters. Lastly, the recent progress to incorporate this idea into ensemble Kalman filter (HOOPE-EnKF) will also be presented.

Parameter estimations in Land Surface Model

Sujeong Lim[1], Seon Ki Park[1], Claudio Cassardo[2]

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Land surface models (LSMs) provide surface fluxes as the lower boundary conditions for regional numerical weather prediction (NWP) and climate models. However, LSMs contain uncertain parameters based on empirical relations, as well as an unreasonable representation of the spatiotemporal surface heterogeneity. Therefore, we implemented a global optimization algorithm, the micro-genetic algorithm (micro-GA), which is based on natural selection and fitness for survival, into LSMs to find the best parameters. In this study, we introduce studies of parameter estimation using the micro-GA to improve soil temperature, soil moisture, or snow variables. For example, the random forcing tuning parameters to perturb the soil temperature and soil moisture, snow-related parameters involved in the calculation of snow processes, and the percentage of sand, silt, and clay determining the soil texture can be the object of parameter estimation. Results indicated that parameter estimation leads to improvements in LSMs.