ISDA-Online

Friday, February 2, 2024, 08-10h UTC (***SPECIAL TIME*****)**

"Advancements in Variational Data Assimilation"

Organizers and Conveners: Massimo Bonavita *(ECMWF)*, Ross Bannister (*U. Reading, UK*), James Taylor *(RIKEN, Japan)*, Ting-Chi Wu *(Central Weather Administration, Taiwan)*

Join us in a deep dive into the world of Variational Data Assimilation. This session is dedicated to exploring new frontiers in variational methods, crucial for the advancement of data assimilation across diverse domains. We welcome contributions that shed light on recent developments, tackle complex challenges, and demonstrate the wide-ranging applications of variational data assimilation, pushing the boundaries and efficiency in predictive modeling.

Program: (UTC)

08:00 – 08:05	**Welcome**
08:05 – 08:30 (22'+3')	**Bridging classical variational data assimilation and optimal transport** *Marc Bocquet (CEREA, France)*
08:30 – 08:50 (17'+3')	**Accounting for correlated observation error in variational ocean data assimilation** *Olivier Goux (CERFACS/CECI, France)*
08:50 – 09:10 (17'+3')	**Data assimilation as variational inference. Full posterior estimation using the 4DVAR cost** *Arthur Filoche (U. Western Australia)*
09:10 – 09:30 (17'+3')	**Deviation of skin increments using all-sky microwave observation for use in a coupled atmosphere-ocean system** *Tracy Scanlon (ECMWF)*
09:30 – 09:50 (17'+3')	**Towards higher resolution data assimilation in ECMWF IFS** *Ziga Zaplotnik (ECMWF)*
09:50 – 10:00	**Closing: Information on upcoming sessions**

Please note:

- When you login to the session before 08:00 UTC, and everything is quiet, this is most likely because we muted the microphones.
- The times in UTC are approximate. In case of technical problems, we might have to change the order of the presentations.
- **Time Zones**: 08 – 10 UTC
- *Europe: 08 – 10 am GMT (London) | 09 – 11 am CET (Berlin)*
  Asia/Australia: 04 – 06 pm CST (Shanghai) | 05 – 07 pm JST (Tokyo) | 07 – 09 pm AEDT (Sydney)
  Americas: 00 – 02 am PDT (San Fran.) | 01 – 03 am MDT (Denver) | 03 – 05 am EDT (New York)

Bridging classical variational data assimilation and optimal transport

Marc Bocquet (CEREA, France)
Pierre J. Vanderbecken (CEREA, France)
Alban Farchi (CEREA, France)
Joffrey Dumont Le Brazidec (CEREA, France)
Yelva Roustan (CEREA, France)

Because optimal transport acts as displacement interpolation in physical space rather than as interpolation in value space, it can potentially avoid double penalty errors. As such it provides a very attractive metric for non-negative physical fields comparison --- the Wasserstein distance --- which could further be used in data assimilation for the geosciences. The algorithmic and numerical implementations of such distance are, however, not straightforward. Moreover, its theoretical formulation within typical variational data assimilation problems face conceptual challenges, resulting in scarce contributions on the topic in the literature.

We formulate the problem in a way that offers a unified view on both classical variational data assimilation and optimal transport. The resulting OTDA framework accounts for both the classical source of prior errors, background and observation, together with a Wasserstein barycentre in between states that stand for these background and observation. We show that the hybrid OTDA analysis can be decomposed as a simpler OTDA problem involving a single Wasserstein distance, followed by a Wasserstein barycentre problem which ignores the prior errors and can be seen as a McCann interpolant. We also propose a less enlightening but straightforward solution to the full OTDA problem, which includes the derivation of its analysis error covariance matrix. Thanks to these theoretical developments, we are able to extend the classical 3D-Var paradigm at the core of most classical data assimilation schemes. The resulting formalism is very flexible and can account for sparse, noisy observations and non-Gaussian error statistics. I will illustrate this talk with simple one-- and two--dimensional examples that show the richness of the new types of analysis offered by this unification.

Accounting for correlated observation error in variational ocean data assimilation

Olivier Goux (CERFACS/CECI)
Anthony Weaver (CERFACS/CECI)
Selime Gürol (CERFACS/CECI)
Oliver Guillet (Météo-France)

In variational data assimilation, the assumption of uncorrelated observation errors is commonly made to simplify access to the inverse correlation operator. However, this assumption becomes problematic when dealing with certain observation types, notably high-resolution satellite data. Neglecting observation error correlations during assimilation often results in suboptimal analyses, wherein observations tend to be overfitted at larger spatial scales and underfitted at smaller scales. Conventional mitigation strategies include thinning — assimilating only a subset of spatially separated observations — and inflating variances to mitigate overfitting at large scales. Both methods impair the extraction of small-scale features from observations and thus constrain the potential of high-resolution data.

To address this issue, we have implemented a correlation observation operator based on a diffusion operator within the ocean data assimilation system NEMOVAR. Diffusion operators — initially designed for modelling correlations in background error — offer a cost-effective and flexible framework for modelling the inverse observation error correlation operator with unstructured data.

While accounting for observation-error correlations should improve the quality of the solution, it also affects the convergence rate of the minimization algorithms used to approximate the solution. In operational applications, where the minimization process is usually truncated before achieving full convergence, even correctly accounted for observation-error correlations might therefore compromise the quality of the analysis. Through analytical and numerical results, we explore the influence of the observation-error correlations on both the sensitivity and convergence rate of variational data assimilation algorithms. In particular, we aim to provide insights into how the choice of an observation error correlation model must reflect a balance between computational efficiency and solution accuracy.

Data Assimilation as Variational Inference. Full posterior estimation using the 4DVAR cost

Arthur Filoche (University of Western Australia)
Dominique Bereziat (Sorbonne University, LIP6)

Variational data assimilation in its most widely used form seek maximum a posteriori estimation, realizing a compromise between the likelihood of the observation and a prior knowledge in the form of a background and a physics-based dynamics. Even though such prior models have meaningful regularizing effect, the fact that maximum a posteriori is a point estimate has two major drawbacks: it is prone to overfit noisy data and discard uncertainty quantification. Variational inference, which is widely used to solve inverse problems in diverse communities, aims at overcoming both issues by fitting a specified shape for the posterior. The main objective of this work is to apply the method in a data assimilation context, allowing full posterior estimation of the initial condition knowing the observations, in one optimization run still by backpropagating gradient through the 4DVAR forward model.

We first detail the framework in a general manner. It starts with setting a parametrized distribution used to approximate the desired posterior probability. The objective function to minimize is then the Kullback-Leibler divergence between these two distribution. As the minimization involves expectation, we use Monte Carlo sampling associated with the reparameterization trick, ensuring correct backpropagation of gradient through random nodes.

We test the proposed method in two synthetic experiments. The first is a Gaussian and linear case where the posterior has a closed form solution, making evaluation straight forward. The second is based on the Lorenz96 dynamics, in which we use a sampling intensive approximate Bayesian computation to have a grasp on the the ground truth. In both cases we show that fitting a multivariate Gaussian posterior leads to informative uncertainty quantification.

Finally, we give perspectives of potential improvement to save computation or to use non-Gaussian posterior, drawing connections with the machine learning literature.

Derivation of skin temperature increments using all-sky microwave observation for use in a coupled atmosphere-ocean system

Tracy Scanlon (ECMWF)
Alan Geer (ECMWF)
Niels Bormann (ECMWF)
Philip Browne (ECMWF)
Tony McNally (ECMWF)

Skin temperature increments can be derived within the ECMWF Integrated Forecast System (IFS) using a sink variable approach. This is implemented operationally for data processed under the clear-sky route (IR and one microwave sounder), however it has not yet been used for all-sky (clear plus cloudy) observations.

In this presentation we will show the results of activating this approach for two microwave imagers: AMSR2 and GMI. These sensors have been chosen as they carry lower frequency channels, i.e. 6 and 10 GHz which are more sensitive to surface parameters and thereby help to constrain the skin temperature increments. These channels have never before been implemented in the ECMWF-IFS and require robust quality control including sun-glint, coastline and RFI screening.

The skin temperature increments generated for these microwave imager help to account for known deficiencies in the background skin temperature used within the ECMWF-IFS without compromising the atmospheric analysis and hence this approach is considered suitable for these sensors.

The aim is to now use these increments within the new experimental coupled ocean-atmosphere data assimilation system at ECMWF to constrain the 3D ocean via the bulk sea surface temperature (SST). This has already been demonstrated to provide benefit to the ocean when used with the IR skin temperature increments (ECMWF Newsletter 172) and the all-sky data is expected to enhance this further as it allows a much greater spatial coverage.

Towards higher resolution data assimilation in ECMWF IFS

Ziga Zaplotnik (ECMWF)
Massimo Bonavita (ECMWF)
Elias Holm (ECMWF)

The Integrated Forecast System (IFS) of ECMWF comprises an Earth-system model coupled with an advanced data assimilation system, which was recently experimentally rescaled to higher resolution. The higher resolution initial conditions were achieved through higher resolution (4.4 km) 4D-Var first guess trajectory, higher resolution (20 km) 4D-Var minimizations (utilizing tangent linear model and its adjoint) or their combination. We demonstrate significant improvements of large-scale skill scores and better use of observations in higher resolution 4D-Var minimization, and an added benefit of using higher resolution 4D-Var together with the higher resolution observations from multispectral imager instrument on board the Himawari satellite. The impact of the higher resolution DA system is evaluated on specific test cases of extreme events where the increased spatial resolution allows to improve the fidelity of simulations. For example, the tropical cyclone Otis, which made landfall as a Category 5 tropical cyclone, was only predicted to reach the tropical storm intensity by most of the global (and regional) NWP models. Employing higher resolution trajectory and higher resolution 4D-Var, we were able to emulate the observed rapid intensification of TC Otis.