

Data Assimilation Methodology Developments at ECMWF

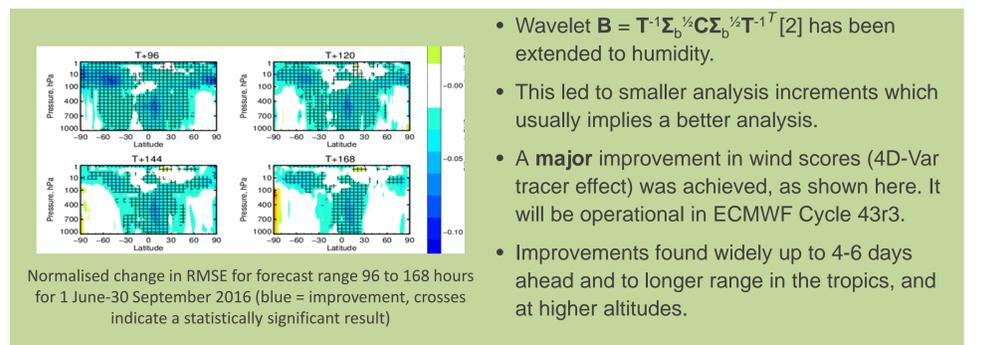
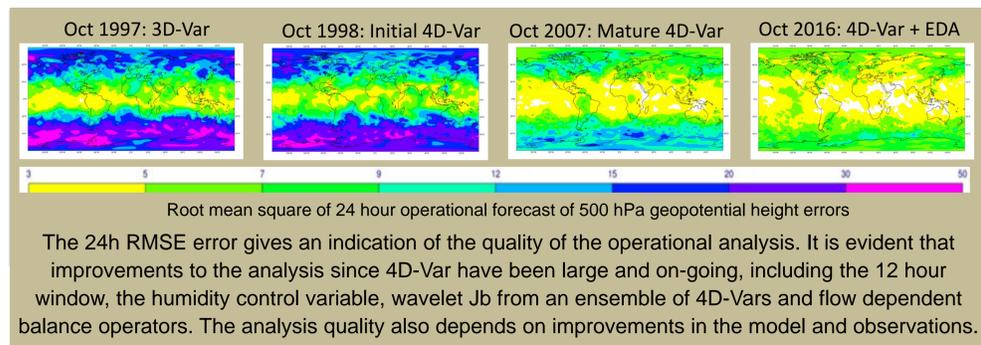


S.J. English, P. Browne, M. Bonavita, M. Chrust, P. de Rosnay, A. Geer, J. Goddard, M. Hamrud, E. Holm, S. Lang, P. Laloyaux, P. Lean, O. Marsden, L. Isaksen, S. Massart, D. Salmond, D. Schepers



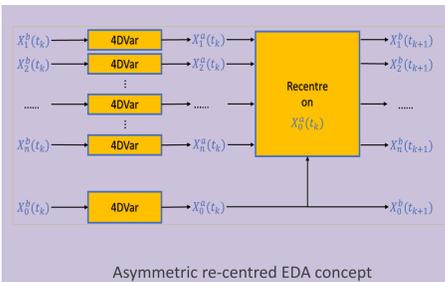
4D-Var: past, present and future

4D-Var has enabled satellite radiances to become critical observations for Numerical Weather Prediction leading to a huge reduction in analysis error since 1997, as shown below. ECMWF uses 4D-Var to generate both the high resolution analysis [1] and the ensemble covariances using an ensemble of 4D-Vars (EDA) [3]. The EDA 4D-Var approach continues regularly to give large skill improvements [3]. For example the extension of wavelet **B** to humidity, shown below. In this poster we show 4D-Var and EDA is still a developing concept with potential for further improvement. ECMWF are also making major code infrastructure changes to improve flexibility and scalability. Work also continues on weak constraint and longer windows, extending all-sky capability (Geer *et al.*, ITSC-21), the inner and outer loop resolution and configuration and the stability and quality of the tangent-linear model.



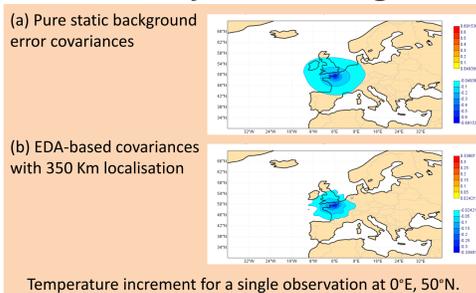
Current DA developments

EDA and Ensemble B



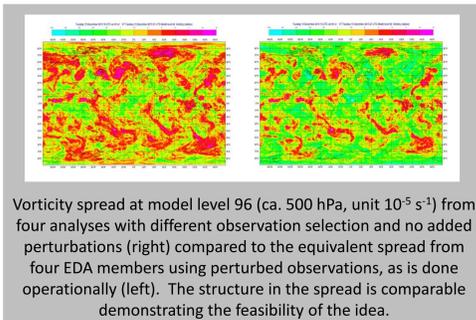
- The perturbed EDA members run with one outer loop whereas the unperturbed EDA control runs with three outer loops.
- We are investigating two re-centring options:
 - re-centring on the control analysis
 - “soft” re-centring using X_{fg} from the more accurate control member to “guide” minimization of perturbed members.
- Lower cost could enable a 50 member EDA.

Hybrid DA Augmented Control Variable



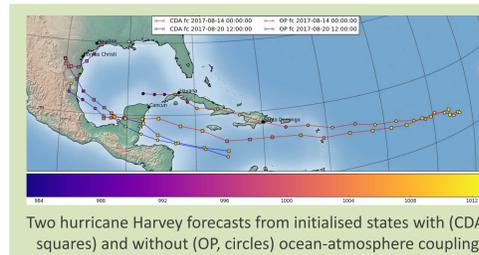
- Currently the **B** correlation matrix is 70% static + 30% flow-dependent at large scale and 7% static + 93% flow-dependent at small scale.
- New proposed hybrid B: Flow-dependent = Physical space B from EDA members with localisation.
- Implementation based on augmented control vector following [4] with a localisation length scale from [5].

Distributed use of observations in the EDA



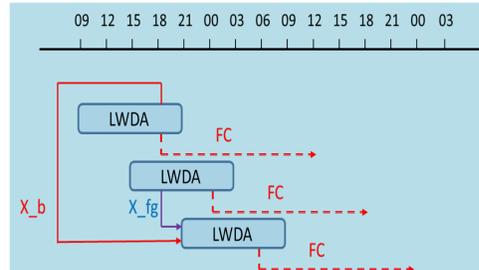
- EDA accounts for observation uncertainty by adding perturbations to the observations.
- An alternative, where possible, is to select different observations sets for each member.
- In the observation subset method the EDA members are more accurate as the observations are unperturbed.
- Allows fuller use of high density observations by using spread to estimate uncertainty.

Coupled DA



- The Coupled ECMWF Re-Analysis (CERA) system was developed under the EC FP7 ERA-CLIM2 project for 20th century re-analysis [6].
- Eresmaa *et al.* at ITSC-21 discuss CERA and the coupled re-analysis in the satellite era.
- CERA is being developed for an operational configuration. Left: a technical demonstration of coupled DA on forecasts for hurricane Harvey.

Overlapping 12-hour 4D-Var



- Currently the 12h DA windows are sequential.
- The overlapping configuration simplifies operations and allows for longer windows to be considered, e.g. 24 hours. Also more frequent updates will be possible, if affordable.
- The necessary separation of X_b and X_{fg} allows more flexibility, which enables the soft re-centring option to be tested in EDA.

Object Orientated Prediction System

The Object Orientated Prediction System (OOPS) was developed at ECMWF, principally by Yannick Trémolet and Mike Fisher. It has a C++ abstract layer that can run elements of the data assimilation system without needing to know what is being done inside each routine. ECMWF's Integrated Forecasting System (IFS) is now being developed to be called by OOPS. This has necessitated significant refactoring of the IFS Fortran code. ECMWF expect OOPS-IFS to be operational in 2019.

OOPS-IFS brings some significant benefits to the current IFS framework:

- Easier to develop and test alternative DA solvers;
- Enable approaches such as Saddlepoint to be tested with a full system;
- Potential for re-use of DA modules by different earth system components;
- Reduce interdependencies in the code;
- DA will be run as a single executable, reducing I/O costs;
- The OOPS code is open source under an Apache-2 license

OOPS is an international effort, involving ECMWF, Météo-France and the HIRLAM community. The Apache-2 license enables wider collaboration with other entities e.g. JCSDA, and the academic sector. Academic partners can benefit from the simplified models to test new DA approaches.

Conclusions

4D-Var has been a driving force behind analysis improvements in the last 20 years, in particular enabling effective use of radiances from infrared and microwave sounders. 4D-Var is continuing to improve through development and improvement of the core 4D-Var system as well as the ensemble hybrid **B** [3]. Significant science improvements, such as wavelet **B** for humidity, continue to regularly deliver large forecast accuracy improvements. Many new scientific improvements to the EDA 4D-Var configuration are currently underway. A major project, namely OOPS, is modernising the code to enable new science, increased flexibility and improved scalability of 4D-Var. A state of the art 4D-Var system with a hybrid ensemble component remains key to ECMWF's data assimilation strategy.

References

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- [2] Fisher, M., 2003, ECMWF seminar, September 2003. 45-63.
- [3] Bonavita M., *et al.* 2017: ECMWF Tech. Memo. 800.
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