Recent developments of the BUMP software

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What is B?

In the variational framework, the background error covariance matrix B describes the uncertainty of the background x^b:

$$\mathcal{J}\left(\mathrm{x}\right) = \boxed{\underbrace{\left(\mathrm{x}-\mathrm{x}^b\right)^{\mathrm{T}} \mathrm{B}^{-1} \left(\mathrm{x}-\mathrm{x}^b\right)}_{\mathcal{J}_b(\mathrm{x})}} + \underbrace{\left(\mathrm{y}^o - \mathcal{H}\left(\mathrm{x}\right)\right)^{\mathrm{T}} \mathrm{R}^{-1} \left(\mathrm{y}^o - \mathcal{H}\left(\mathrm{x}\right)\right)}_{\mathcal{J}_o(\mathrm{x})}$$

In the equivalent BLUE framework, B is the last operator applied to define the analysis increment:

$$\mathrm{x}^a = \mathrm{x}^b + \mathrm{B}\mathrm{H}^{\mathrm{T}} \left(\mathrm{H}\mathrm{B}\mathrm{H}^{\mathrm{T}} + \mathrm{R}\right)^{-1} \left(\mathrm{y}^o - \mathcal{H}\left(\mathrm{x}^b\right)\right)$$

B contains complex multivariate 3D structures (potentially 4D for the 4DEnVar algorithm).

Hybrid background error modeling

Hybrid background error covariance matrix:

$$\mathrm{B} = \underbrace{\beta^{e2}\, \mathrm{L} \circ \widetilde{\mathrm{B}}}_{\text{“ensemble” term}} + \underbrace{\beta^{s2}\, \mathrm{B}^s}_{\text{“static” term}}$$

where:

- $\widetilde{\mathrm{B}}$ is sampled from an ensemble of forecasts
- L is the localization matrix
- $\circ$ denotes a Schur product (element-by-element)
- β^e and β^s are scalar coefficients
- B^s is a “static” covariance matrix, usually modeled as:

$$\mathrm{B}^s = \mathrm{K}\boldsymbol{\Sigma}\mathrm{C}\boldsymbol{\Sigma}\mathrm{K}^{\mathrm{T}}$$

where:

- K is a balance operator
- $\boldsymbol{\Sigma}$ is the diagonal matrix of standard-deviations
- C is a correlation operator

BUMP overview

- **BUMP** stands for “Background error on an Unstructured Mesh Package”.
- **BUMP** is one of the background error covariance libraries of **SABER** (System Agnostic Background Error Representation), a component of the **JEDI** project.
- **BUMP** works with any model grid and is able to take complex boundaries into account (important for ocean or land models).
- Written in modern Fortran 90 ($\sim$ 25.000 lines), the code can be easily called through Fortran and C++ interfaces.
- Interfaces with **BUMP** are implemented for most of JEDI models, via OOPS.

BUMP functionalities

BUMP provides tools based on ensembles of forecasts to estimate:

- Horizontal and vertical localization length-scales of L and hybrid weights β^e and β^s, estimated locally using the theory of Ménétrier and Auligne (2015) [HDIAG].
- Vertical statistical regressions of the balance operator K estimated locally [VBAL].
- Standard-deviations Σ objectively filtered with the method of Ménétrier *et al.* (2015a,b) [VAR].
- Horizontal and vertical correlation length-scales of C estimated locally and simultaneously [HDIAG], or alternatively Local Correlation Tensors [LCT] for anisotropic functions.

A grid smoother is required to apply L and C in a variational framework: **BUMP** implements the **NICAS** method (Normalized Interpolated Convolution from an Adaptive Subgrid) [NICAS].

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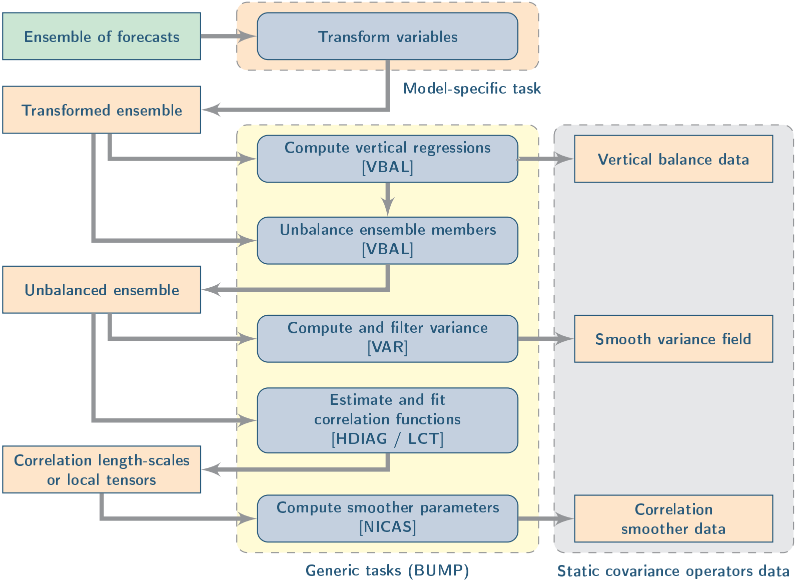
Static covariance training



Ensemble of forecasts

Transform variables

Model-specific task

Transformed ensemble

Compute vertical regressions [VBAL]

Vertical balance data

Unbalance ensemble members [VBAL]

Unbalanced ensemble

Compute and filter variance [VAR]

Smooth variance field

Estimate and fit correlation functions [HDIAG / LCT]

Correlation length-scales or local tensors

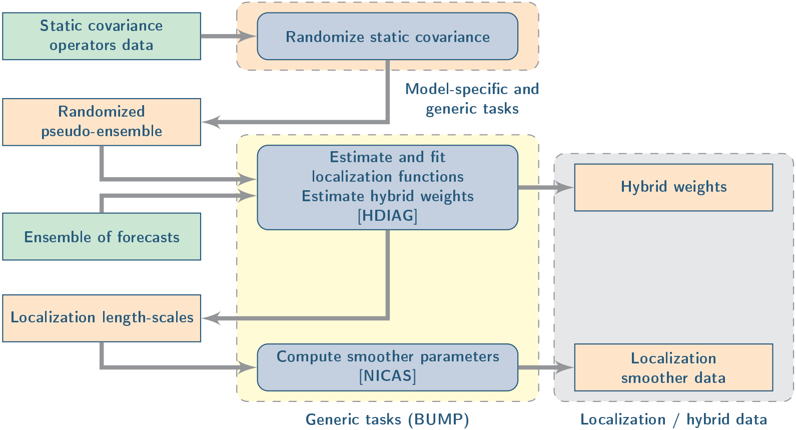
Compute smoother parameters [NICAS]

Correlation smoother data

Generic tasks (BUMP)

Static covariance operators data

Localization and hybrid weights training


Static covariance operators data
Randomize static covariance
Model-specific and generic tasks
Randomized pseudo-ensemble
Estimate and fit localization functions
Estimate hybrid weights
[HDIAG]
Hybrid weights
Ensemble of forecasts
Localization length-scales
Compute smoother parameters
[NICAS]
Localization smoother data
Generic tasks (BUMP)
Localization / hybrid data

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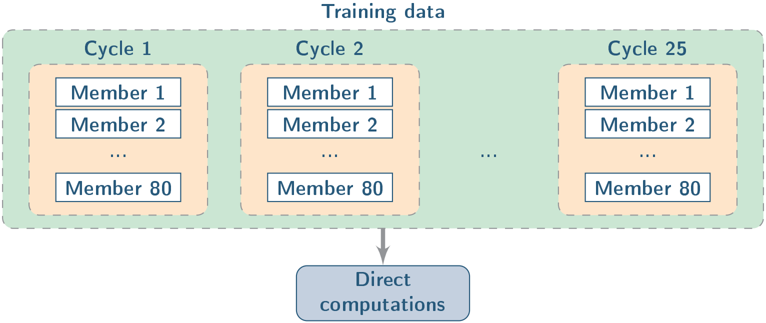
Critical memory issue

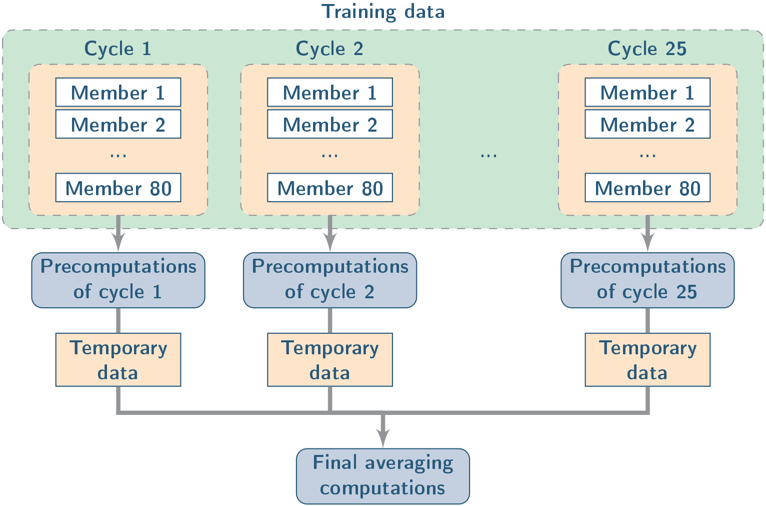


For FV3 at resolution C384:

- 1 member: $\sim$ 11 Gb
- 1 cycle of 80 members: $\sim$ 880 Gb
- 25 cycles of 80 members: $\sim$ 22 Tb

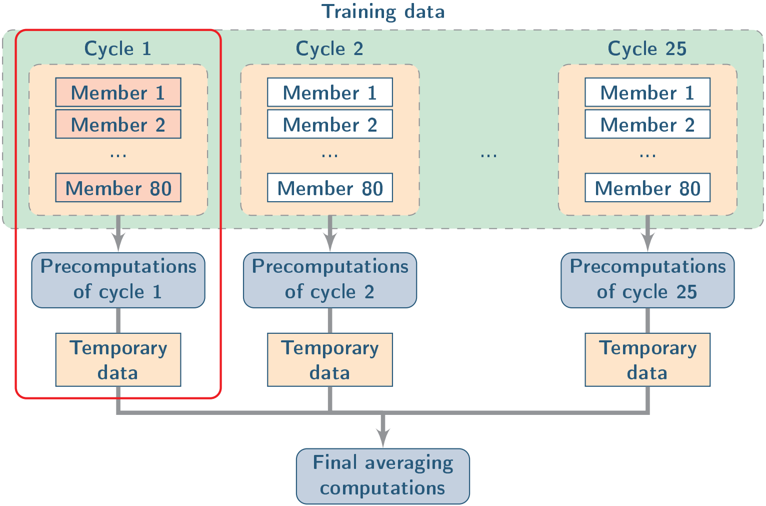
Difficult to load simulatneously on disk, not to say in memory...

BUMP solution: split the work



Easy to do for variance [VAR] and correlation [HDIAG / LCT], required theoretical developments for vertical regressions [VBAL].

BUMP solution: load members sequentially



Members are loaded sequentially to reduce the memory footprint.
No slow down, no precision loss.

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In the recent months, **BUMP** has been upgraded to improve the **B** components training:

- work split in cycle-based precomputations, with a final averaging step,
- reduced memory footprint, reading ensemble members sequentially.

Tests are underway on Orion for FV3-JEDI at full resolution (C384). Once the new branch is validated, it will be merged into `develop` and available for all users. A working example of a full static B training workflow will be provided.

Thanks for your attention!