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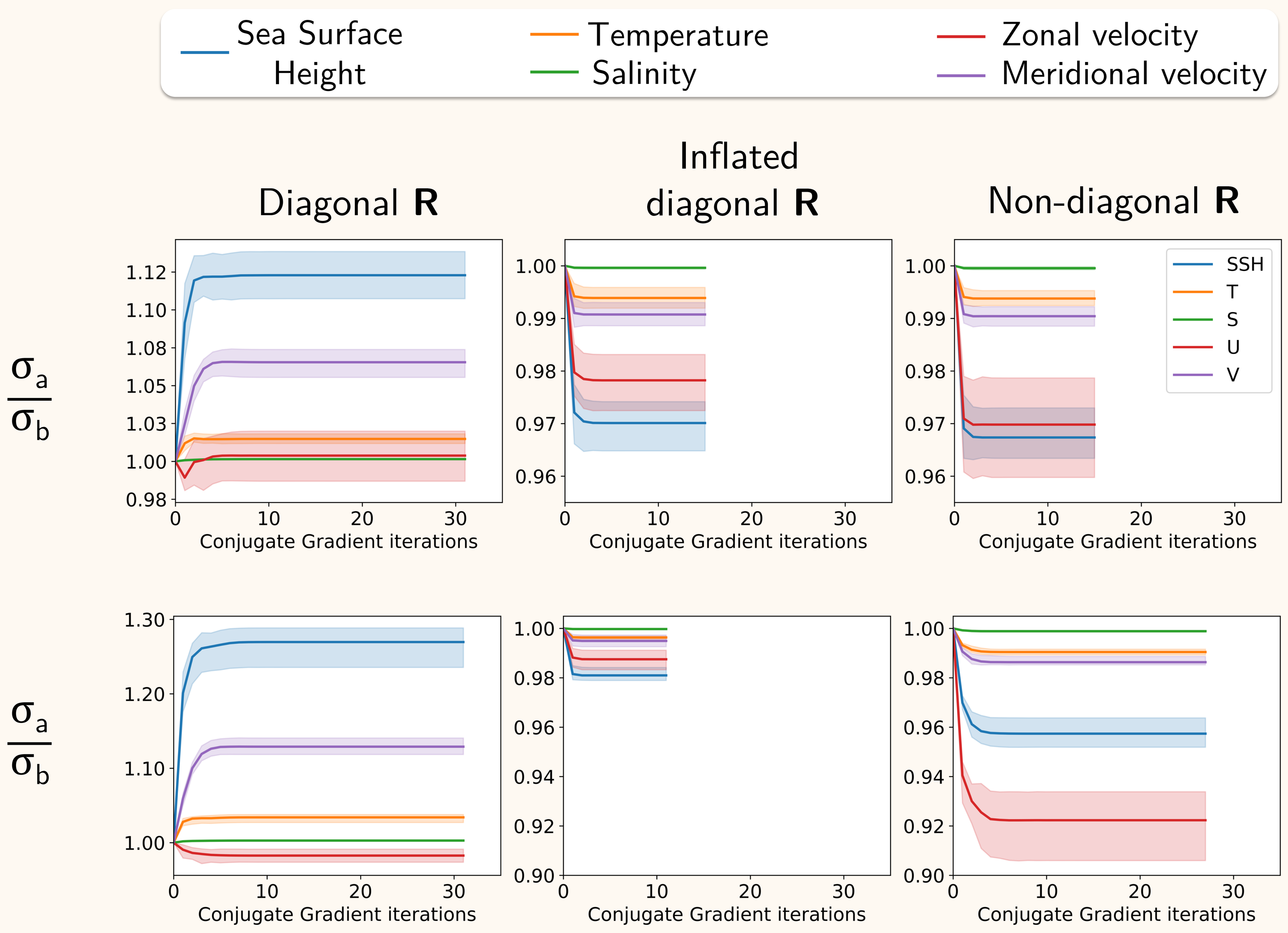
Accounting for correlated observation error in variational ocean data assimilation: application to altimeter data

- Many geophysical data assimilation systems are built around the assumption that **R** is diagonal, often to facilitate the access to $\mathbf{R}^{-1}$.
- This is equivalent to assuming that the observation error is **uncorrelated**.
- This not true for many modern datasets, especially satellite observations.
- Operational centres often have to reject valid data (up to 90%) to respect it.
- **We need to improve our ability to account for observation error correlations**.

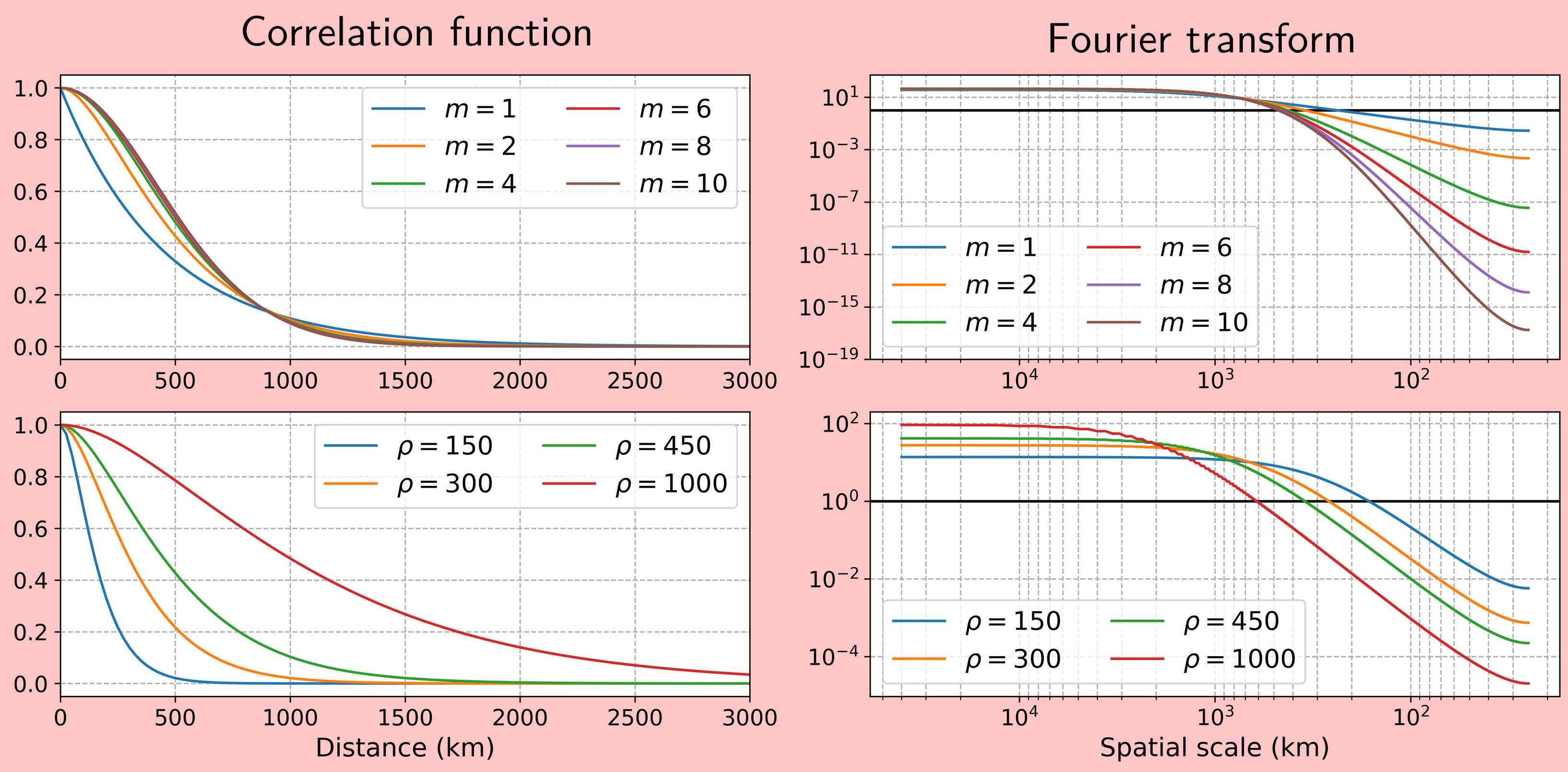
Experiments in NEMOVAR

- Using a **non-diagonal** R alters both the convergence rate of the minimisation [2] and the solution at full convergence.
- We assimilate simulated Sea Surface Height (SSH) observations of known error covariance in NEMOVAR We use real observations locations corresponding to one day of measurements from two altimeters.
- We compute, at each iteration of a **Conjugate Gradient** algorithm, the **analysis error variance** which would be obtained if the minimisation was stopped at this point.
- The **background** error correlation length scale ranges between **110 and 220 km in the meridional direction**, and ranges between **220 and 440 km in the zonal direction**. The background error correlation function is **Gaussian**.



Diffusion-based observation error correlation operators

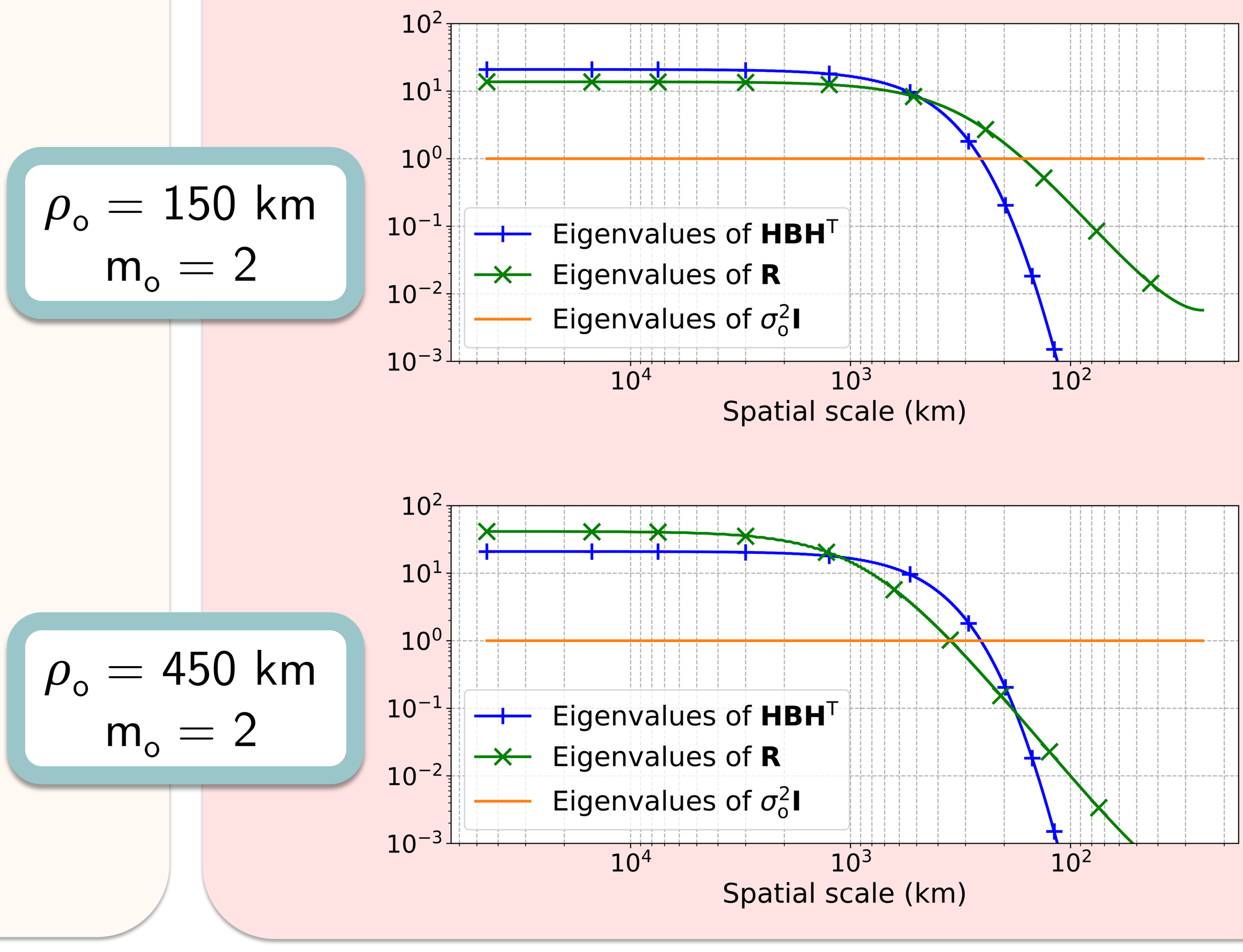
- Diffusion operators can be used to model observation error correlations as:
  - their **inverse** can be accessed easily to apply $\mathbf{R}^{-1}$.
  - they are compatible with **unstructured data**[1].
- The main parameters of diffusion operators are a **length scale** ρ and a **smoothness** parameter m.



- **We have implemented a diffusion operator to model observation error correlations in NEMOVAR in altimeter data. It is numerically efficient within a parallel computing environment[3].**

Spectral analysis in an idealized system

- Studying the **spectra** of **B** and **R** in an idealized framework (1D periodic domain, uniform grid and observation, constant covariances parameters) can help us understand our results in NEMOVAR.
- The **background** error correlation length scale is set to **200 km**. The background error correlation function is **Gaussian**.



In this idealized system, the **condition number** of the **B**-preconditioned Hessian matrix of the 3DVar cost function can be computed as:

$$1 + \max\left(\frac{\text{Eigenvalues of } \mathbf{HBH}^T}{\text{Eigenvalues of } \mathbf{R}}\right)$$

Impact of a non-diagonal R

When the observation error correlation legnth scale is **comparable to or smaller** than the background error correlation legnth scale:

- **A slightly more accurate** solution is reached due to a better retrieval of small scale features from the observations;
- Similarly to variance inflation, using a non-diagonal **R accelerates** the convergence.

When the observation error correlation length scale is **larger than the** background error correlation legnth scale:

- A **significantly more accurate** solution is reached as variance inflation does not allow the extraction of **relevant small scale features** while rejecting **error-prone large scales** from the observations;
- Using a non-diagonal **R** has a **neutral effect on the convergence**.

[1]: **Guillet, O, Weaver, AT, Vasseur, X, Michel, Y, Gratton, S, Gürol, S.** Modelling spatially correlated observation errors in variational data assimilation using a diffusion operator on an unstructured mesh. *Q J R Meteorol Soc* 2019
[2]: **Goux, O, Gürol, S, Weaver, AT, Diouane, Y, Guillet, O.** Impact of correlated observation errors on the conditioning of variational data assimilation problems. *Numer Linear Algebra Appl.* 2024
[3]: **Goux, O, Weaver, AT, Gürol, S, Guillet, O., Piacentini, A.** On the impact of observation error correlations in data assimilation, with application to along-track altimeter data. *Preprint available on Hal/ArXiv*

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