CERFACS

EUROPEAN CENTRE FOR RESEARCH AND ADVANCED TRAINING IN SCIENTIFIC COMPUTING

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

Synobs Kickoff, 2022

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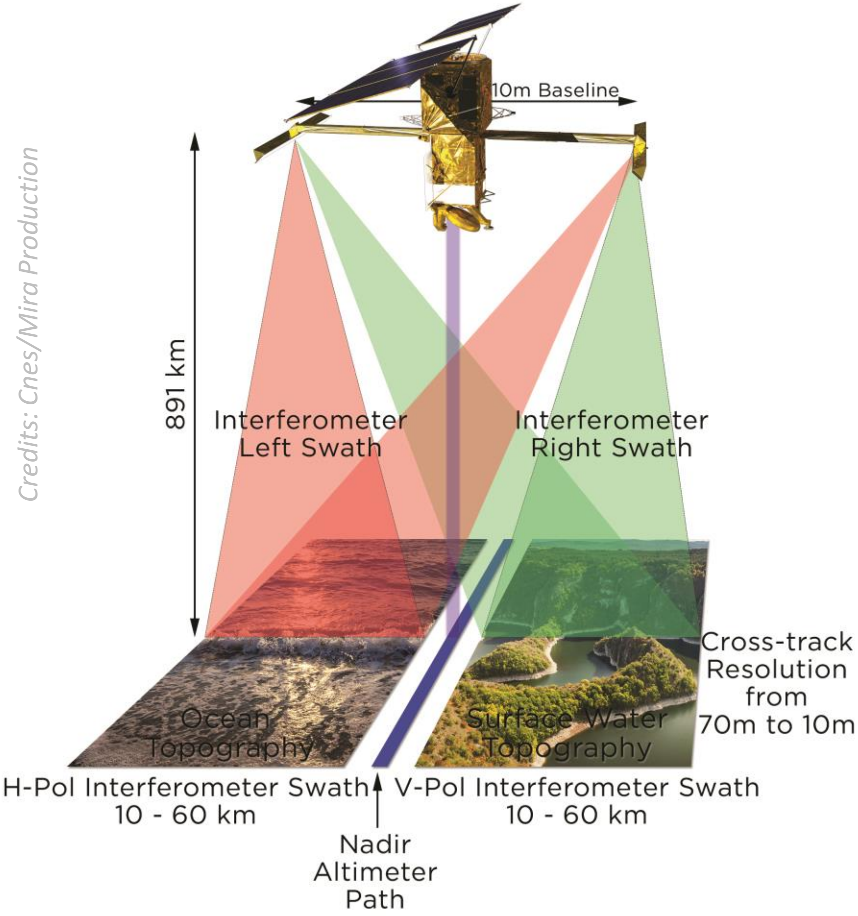
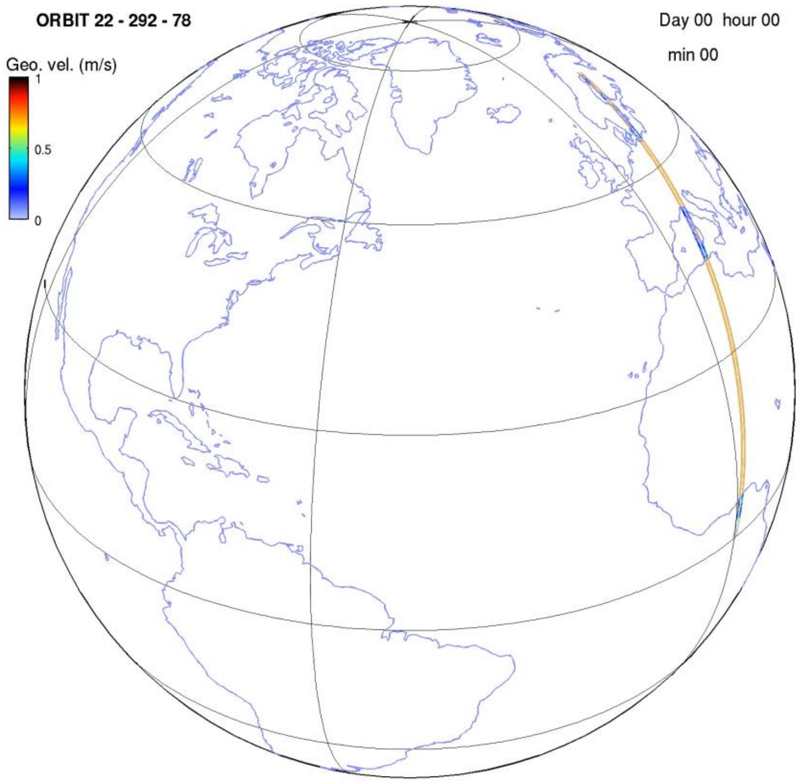
Application: wide swath altimetry

A simulator of SWOT data has been developed by JPL and CNES.

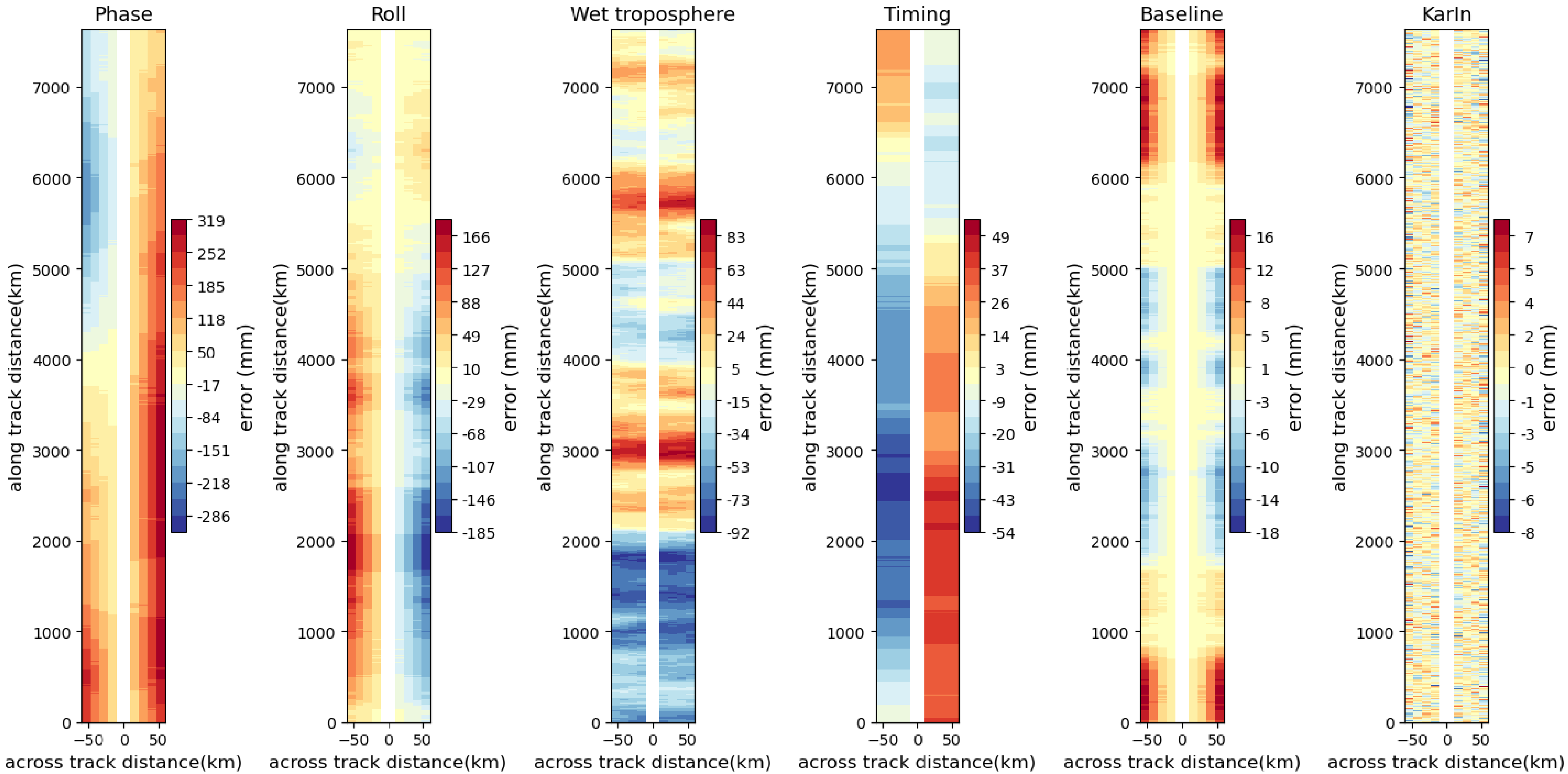


Credits: Cnes/Mira Production

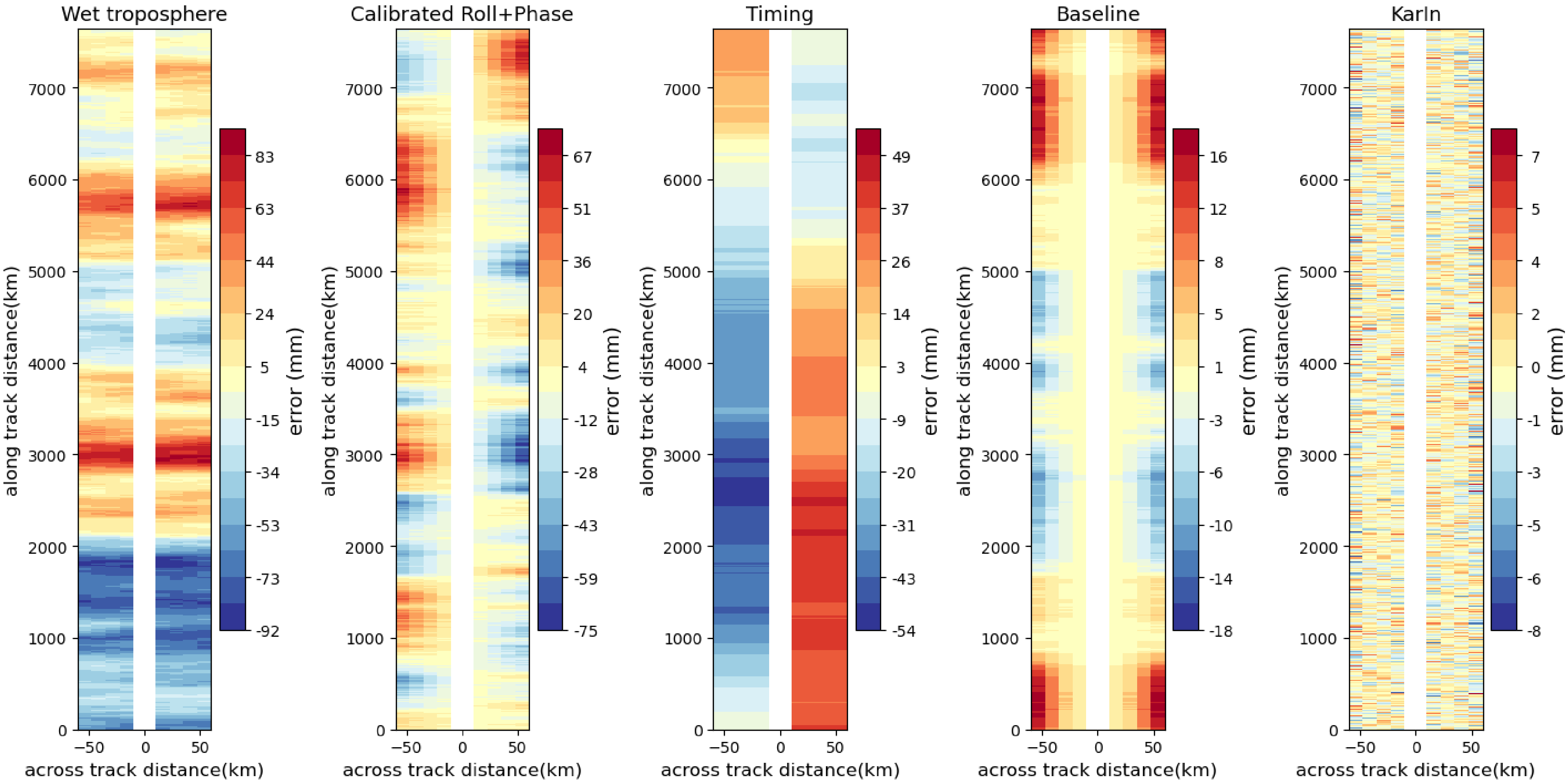


Credits: JPL/C.Ubelmann

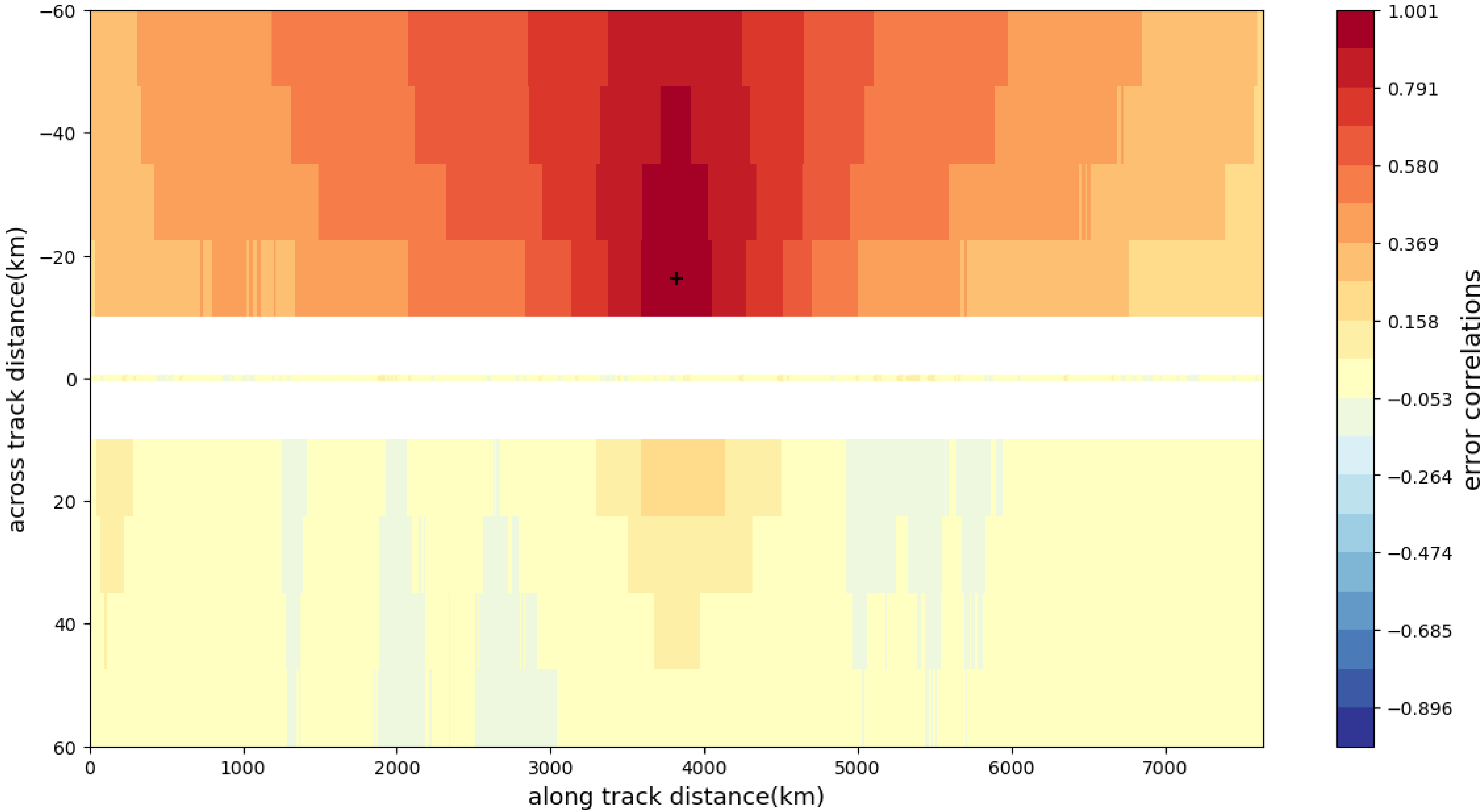
Uncalibrated error sample



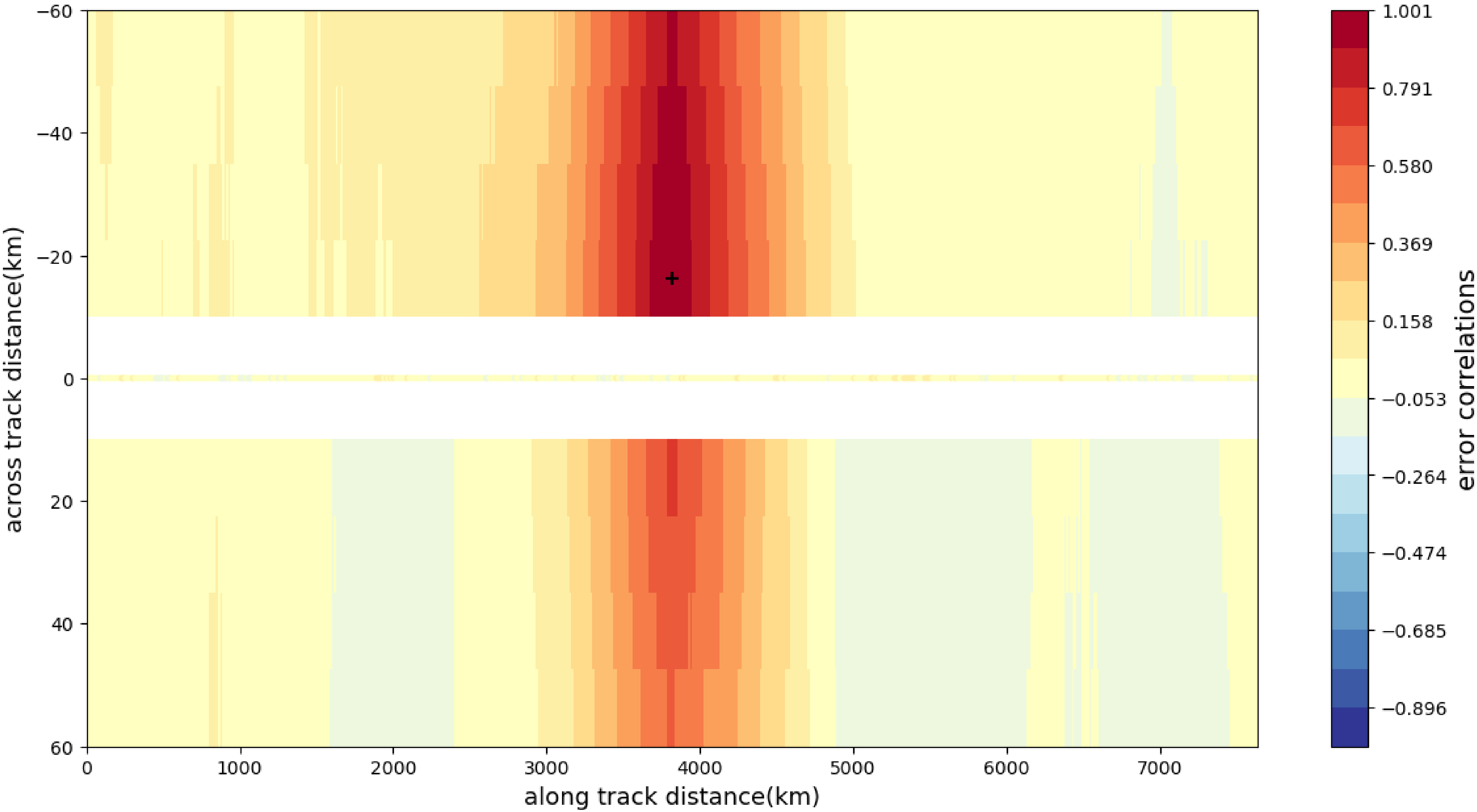
Calibrated error sample



Uncalibrated error correlations

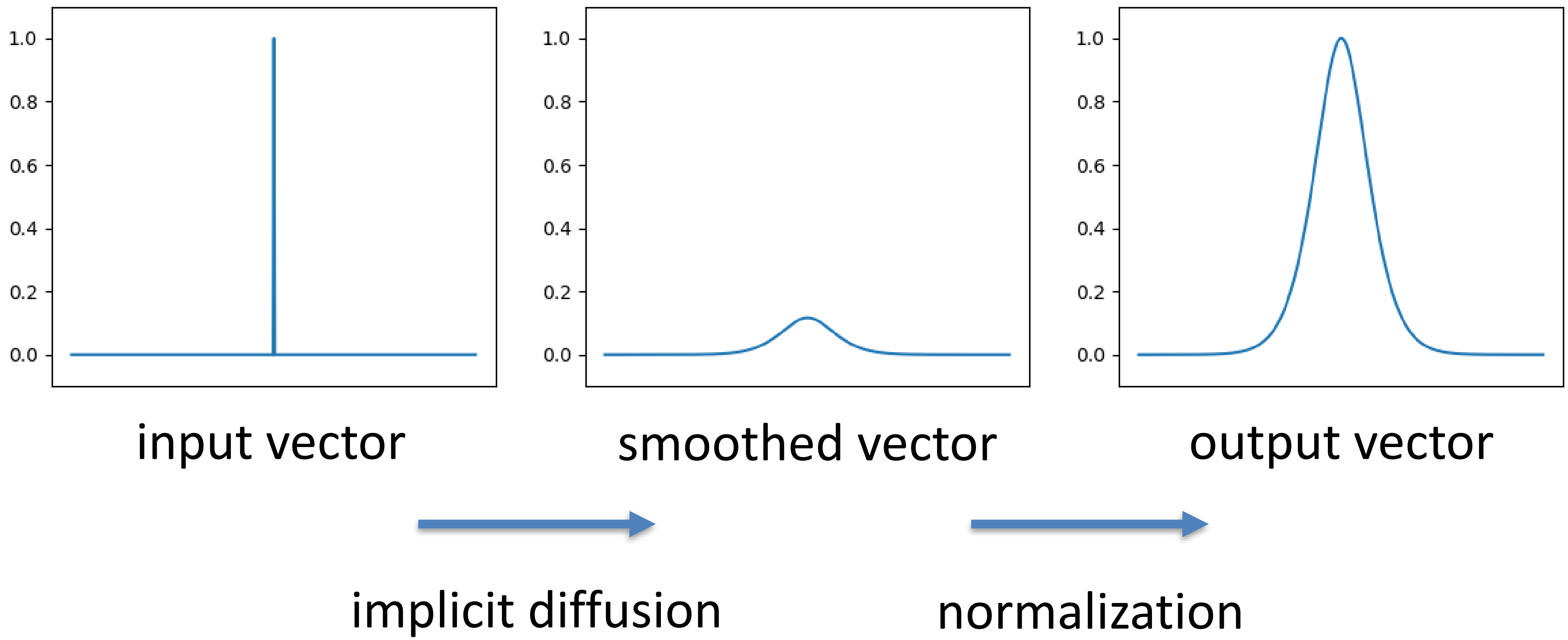


Calibrated error correlations



Diffusion-modelled correlation operators

Diffusion operators can be used to create inexpensive, flexible models of R



Both steps are easy to invert, and the inverse operator of R is even less expensive than the direct operator

Diffusion operators for correlation modelling

Diffusion-modelled correlation operators can be represented by a sequence of operators:

$$\boldsymbol{C} = \boxed{\boldsymbol{\Gamma}} \times \underbrace{\boldsymbol{A}^{-1} \times \cdots \times \boxed{\boldsymbol{A}}^{-1}}_{M/2} \times \boxed{\boldsymbol{W}}^{-1} \times \underbrace{\boldsymbol{A}^{-\mathrm{T}} \cdots \times \boldsymbol{A}^{-\mathrm{T}}}_{M/2} \times \boldsymbol{\Gamma}$$

Normalization (diagonal)

Mass matrix (diagonal)

$$\boldsymbol{I} - \boldsymbol{W}^{-1}\boxed{\boldsymbol{K}}$$

Stiffness matrix (sparse)

In variational data assmiliation, we only need the inverse operator, which is inexpensive, scalable and compatible with unstructured data:

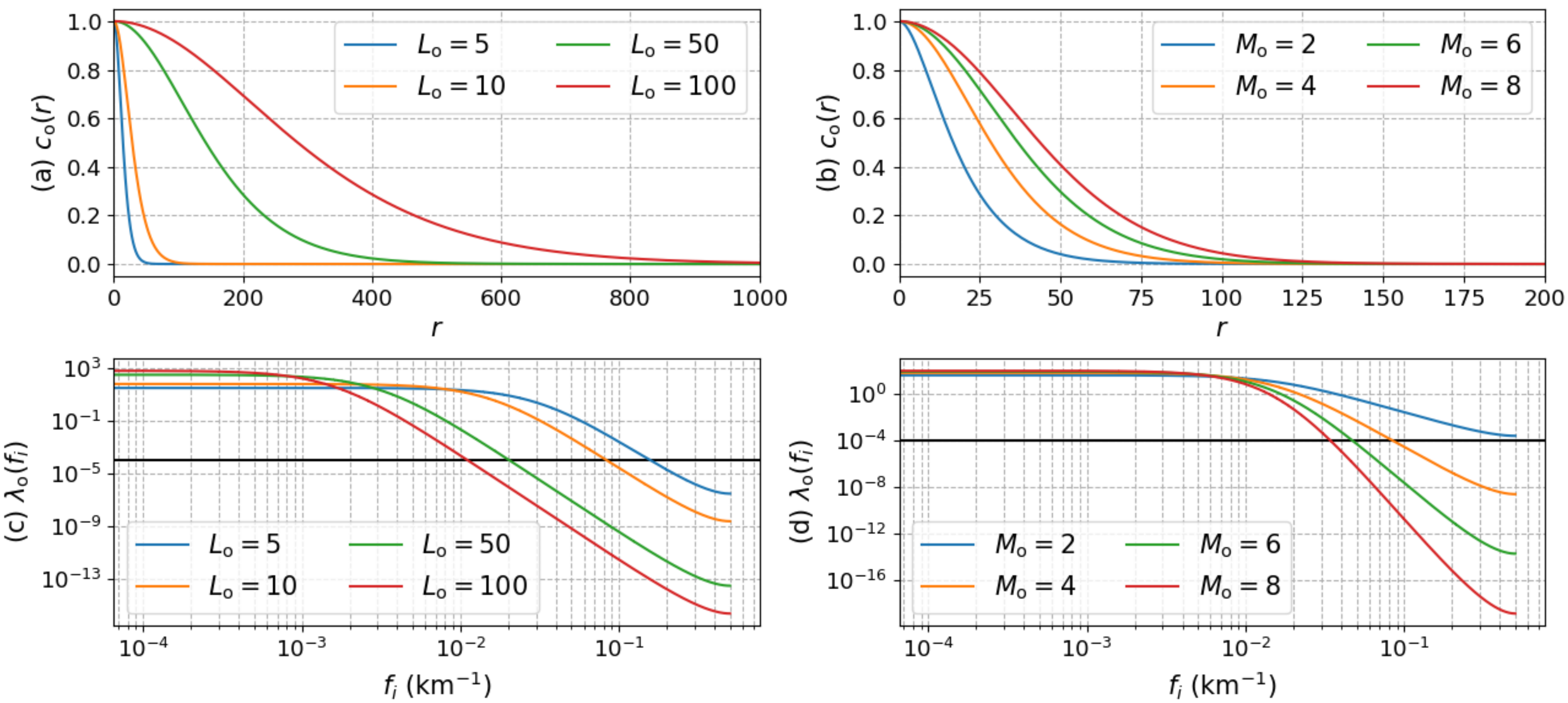
$$\boldsymbol{C}^{-1} = \boldsymbol{\Gamma}^{-1} \times \underbrace{\boldsymbol{A} \times \cdots \times \boldsymbol{A}}_{M/2} \times \boldsymbol{W} \times \underbrace{\boldsymbol{A}^{\mathrm{T}} \cdots \times \boldsymbol{A}^{\mathrm{T}}}_{M/2} \times \boldsymbol{\Gamma}^{-1}$$

Diffusion operators

It can be interpreted as a parametric model that represents correlation functions from the Matérn class.
It depends on a length-scale parameter L and an integer (smoothness) parameter M

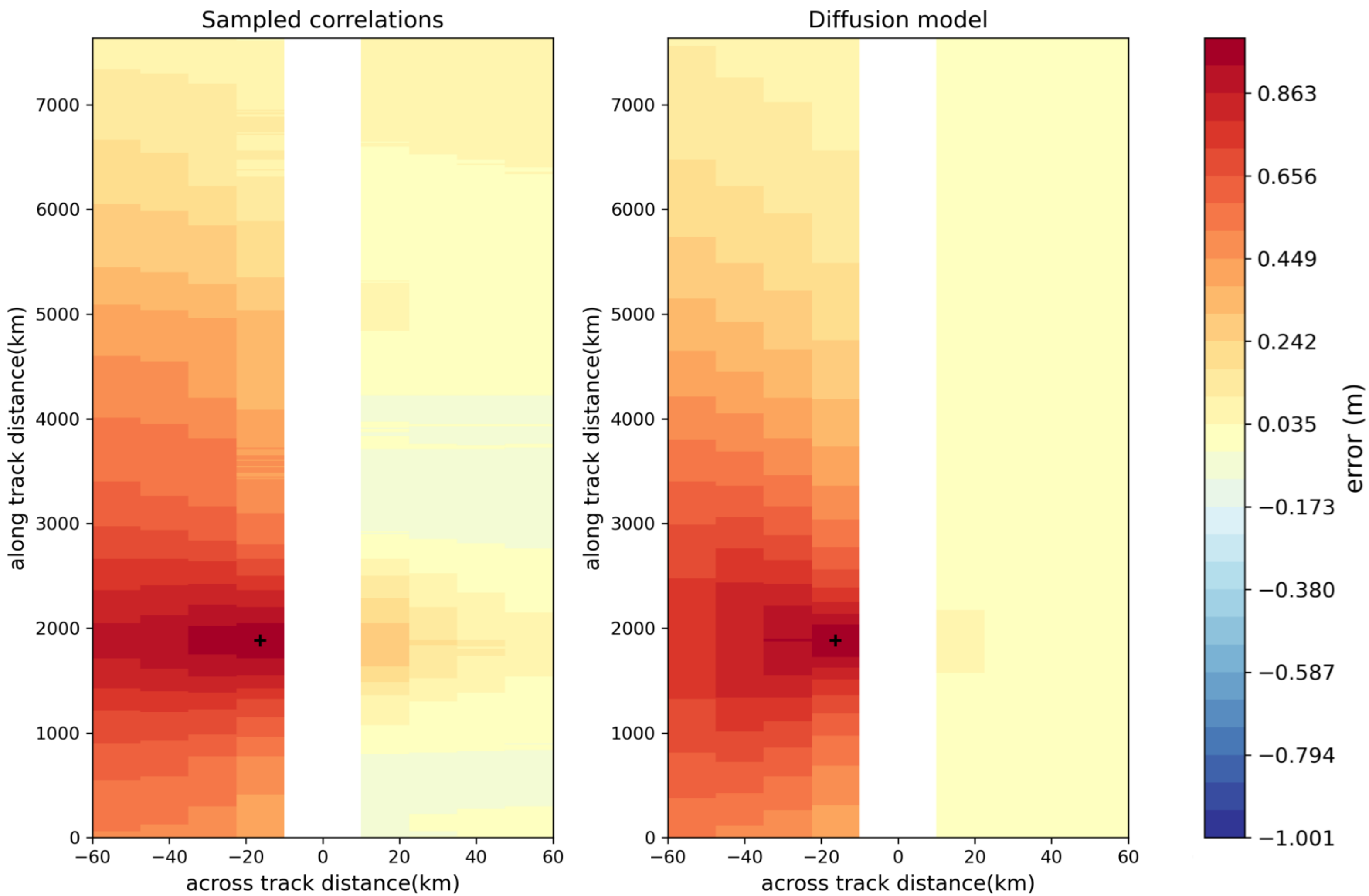
Correlation functions

Power spectra

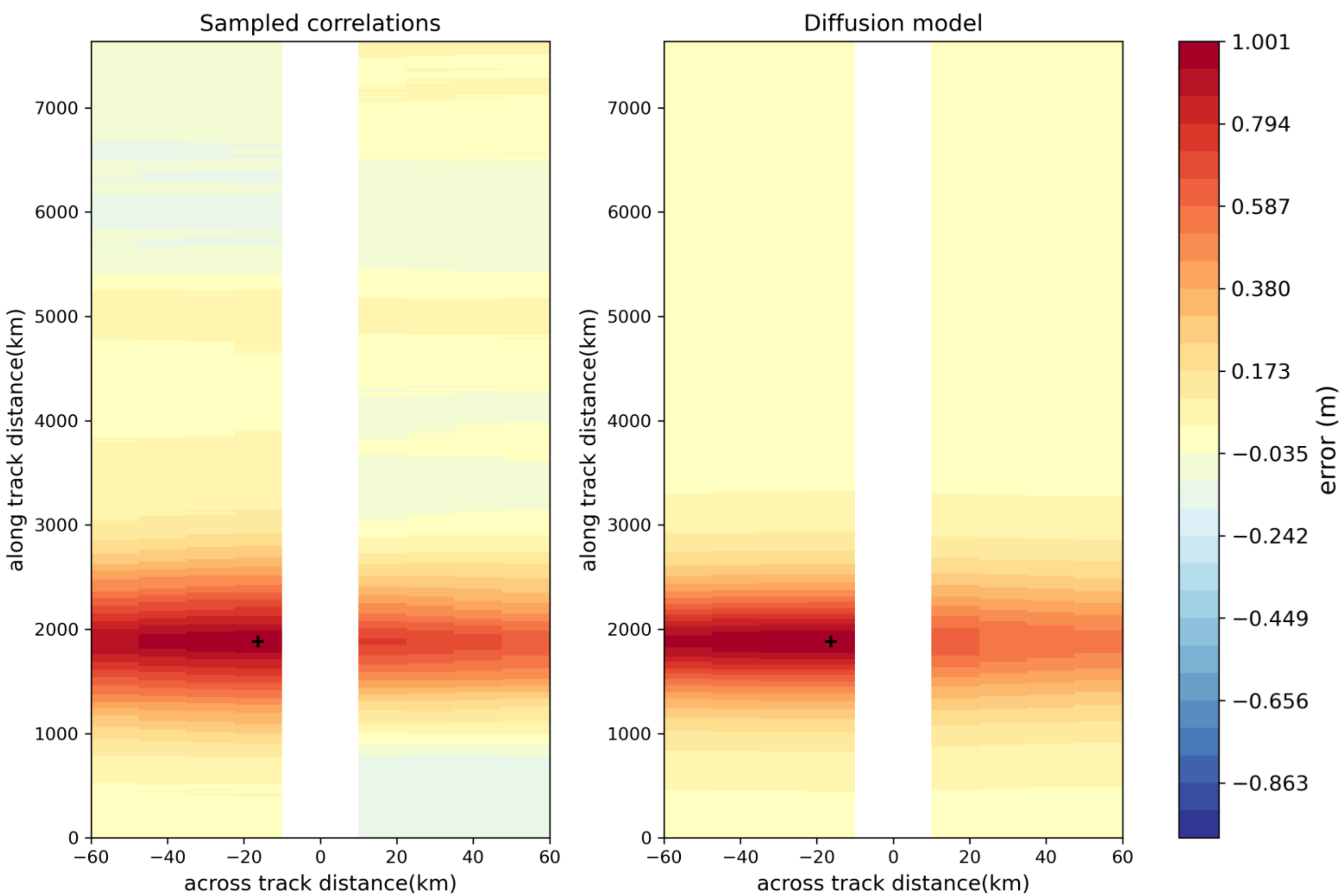


In practice, L can be spatially variable and direction dependent

Uncalibrated error correlation diffusion model

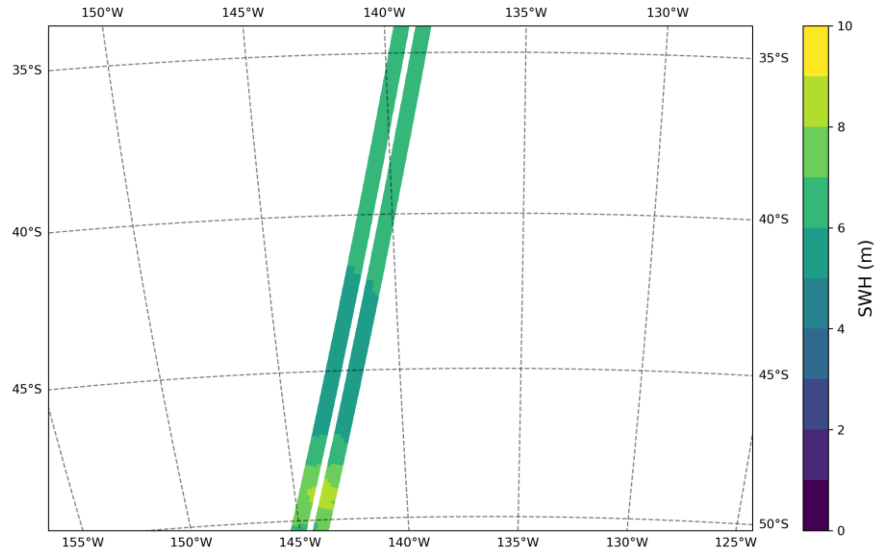


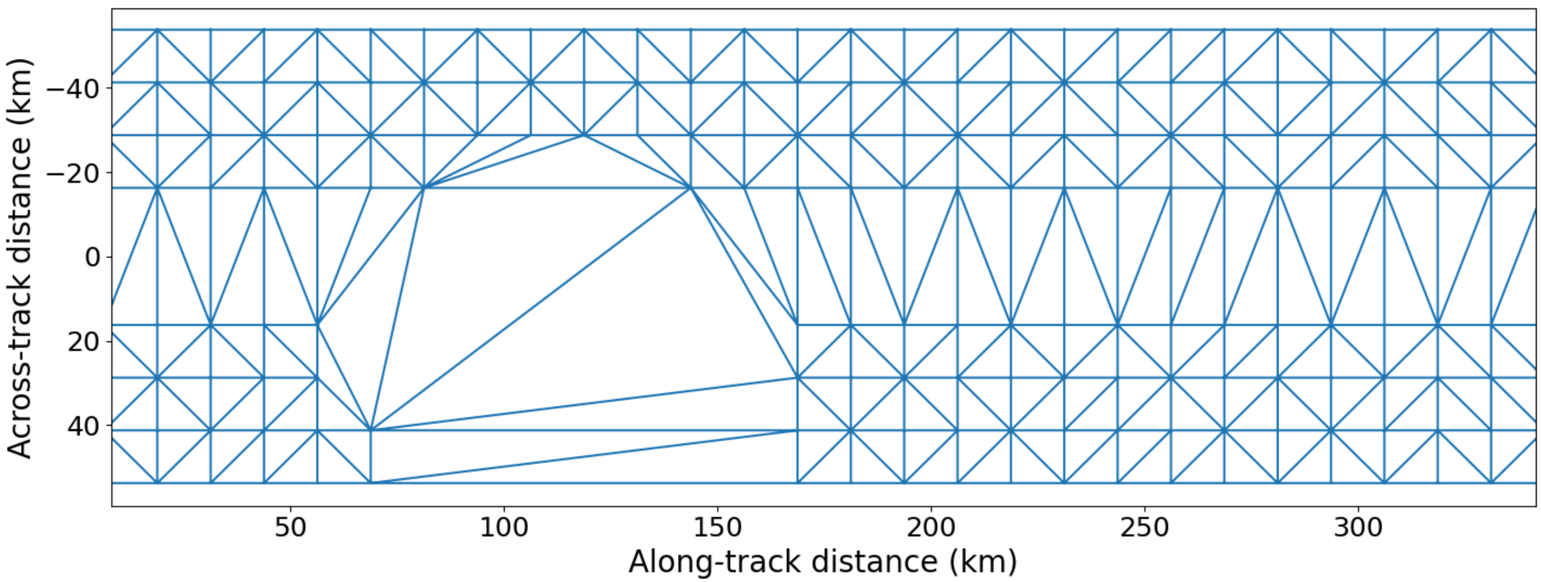
Calibrated error correlation diffusion model



Diffusion on an unstructured mesh

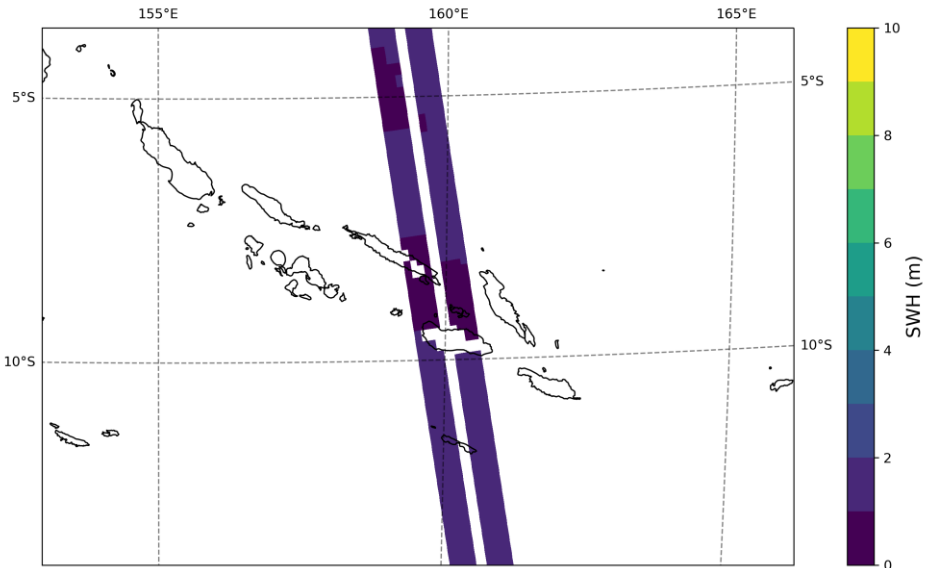
Observations with a large SWH might be removed by the quality control.

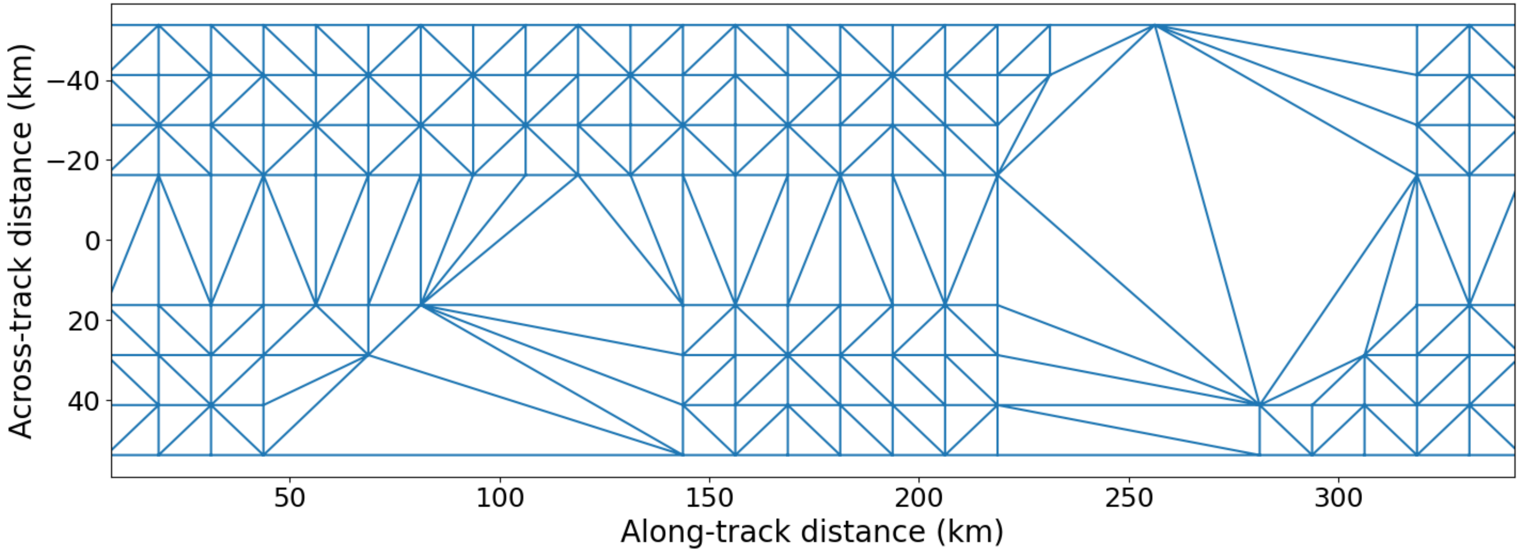




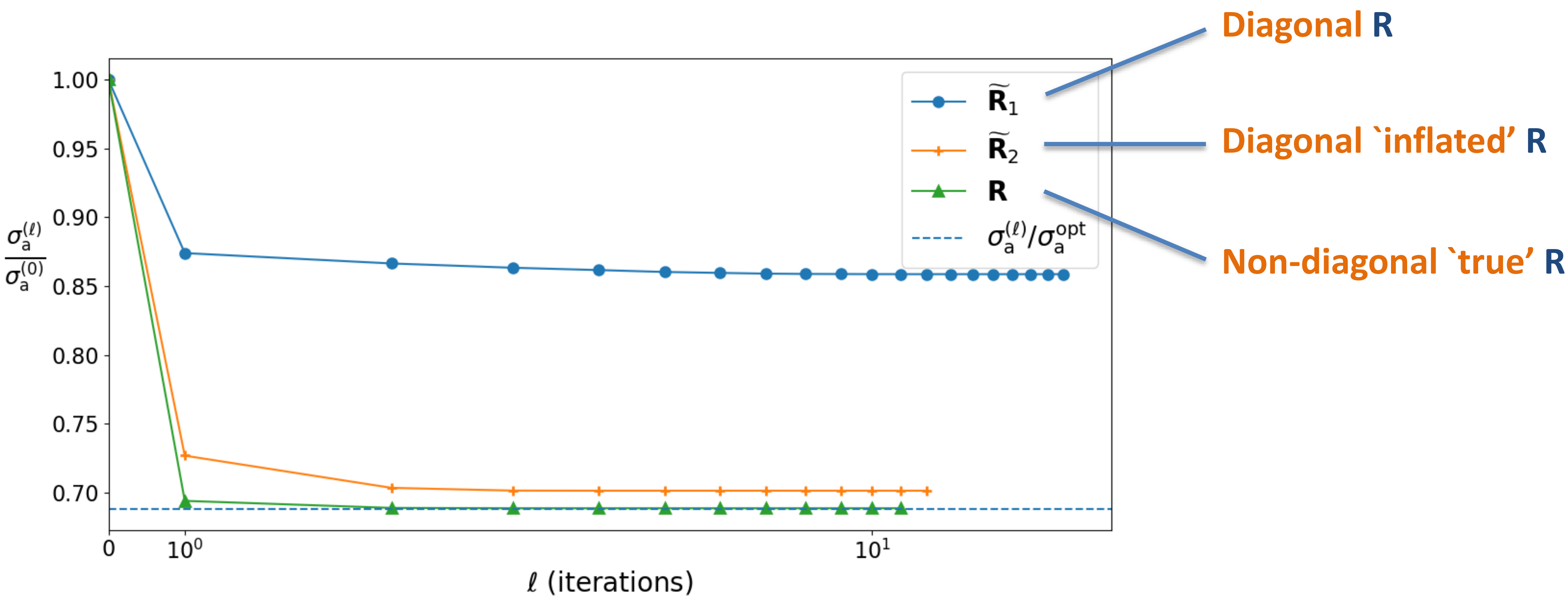
Diffusion on an unstructured mesh

Islands create gaps through which there should be correlations.



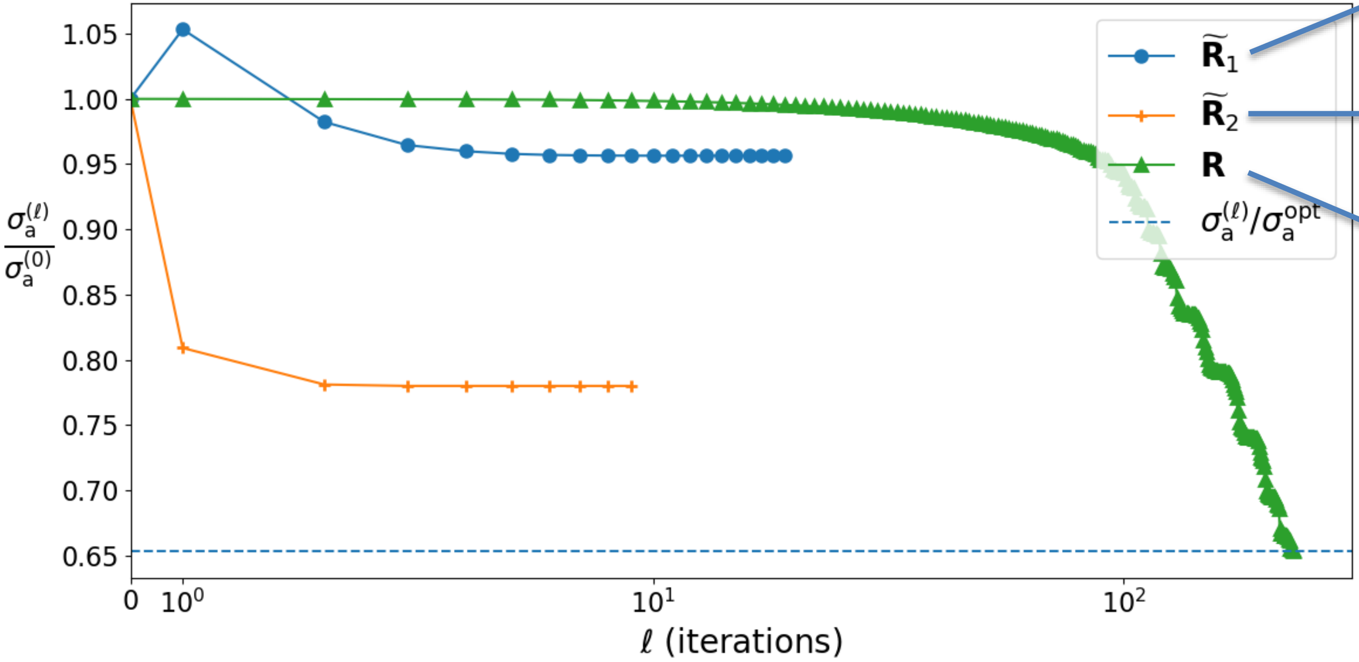


- How will a non-diagonal R impact the convergence of iterative solvers in variational DA ?
- Can a degradation in conditioning outweigh the improvement brought by a more accurate observation error model ?
- Can we adjust the parameters of the observation error correlation model such that the convergence rate of the solvers is improved while staying close to diagnosed correlations ?



Preliminary studies

- How will a non-diagonal R impact the convergence of iterative solvers ?
- Can an increase in conditioning outbalance the improvement associated to a more accurate observation error model ?
- Can we adjust the parameters of the observation error correlation model such that the convergence rate of the solvers is improved while staying close to diagnosed correlations ?



Diagonal R

Diagonal `inflated' R

Non-diagonal `true' R

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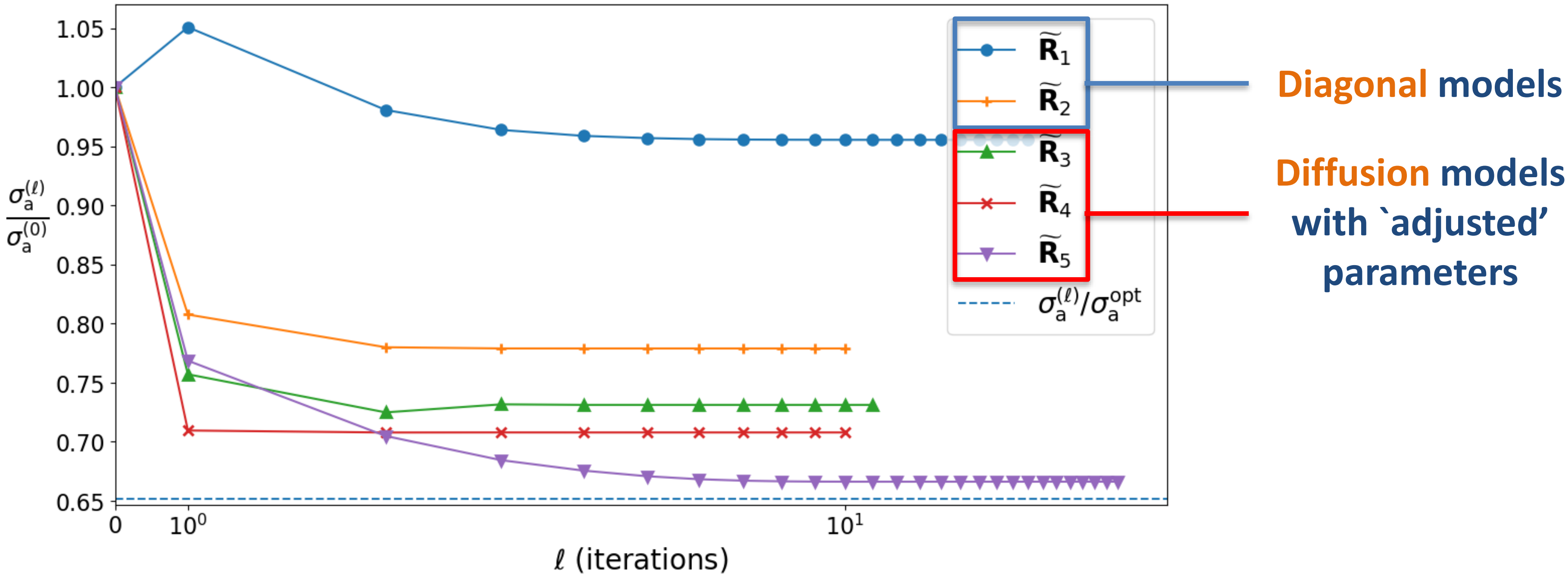

Conclusion

Summary:

- The assumption of uncorrelated observation error is not realistic for many observation types, including the soon-to-be-launched SWOT mission.
- Diffusion operators can be used to model a correlation operator, its inverse or its square root, and can be applied at a low computational cost with unstructured data.
- Using a non-diagonal R in variational DA has a substantial impact on the convergence of iterative solvers. If the parameters of the correlation model are chosen wisely, this impact does not have to be negative, and can even speed up the convergence.

Perspectives:

- Implementation in the NEMOVAR ocean DA system.
- Use this method to account for correlated errors in altimeter data (nadir as well as wide-swath).

References

Diffusion operators for data assimilation:

Mirouze, I., & Weaver, A. T. (2010). Representation of correlation functions in variational assimilation using an implicit diffusion operator. *Q. J. R. Meteorol. Soc.*, 136(651), 1421–1443. doi: 10.1002/qj.643

Extension to unstructured data:

Guillet, O., Weaver, A. T., Vasseur, X., Michel, Y., Gratton, S., & Gürol, S. (2019). Modelling spatially correlated observation errors in variational data assimilation using a diffusion operator on an unstructured mesh. *Q. J. R. Meteorol. Soc.*, 145(722), 1947–1967. doi: 10.1002/qj.3537

Convergence of the B-PCG:

Goux, O., Gürol, S., Weaver, A. T., Diouane, Y., Guillet, O. (2022) Impact of correlated observation errors on the convergence of the conjugate gradient algorithm in variational data assimilation. *Submitted to Numerical Linear Algebra with Applications.*