OSTST meeting 2016, la Rochelle

Accounting for observation error correlations in the assimilation of data from the future SWOT High-Resolution altimeter mission

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Summary

- We use the portable ocean SWOT simulator[1] to quantify spatial correlations of errors in the future SWOT observations;
- We develop and implement a method **to account for these correlations** in the assimilation of (reduced-resolution) SWOT data;
- We conclude that accounting for error correlations is essential to accurately assimilation SWOT observations.

[1] *Gaultier et al, 2016, https://github.com/SWOTsimulator*

Why observation error correlations matter for data assimilation?

Because we need the <u>observation error covariance matrix</u> to assimilate the observations.

An assimilation algorithm seeks the best compromise between a prior estimate and the observations by minimizing a cost function:

$$\mathcal{J}(\mathbf{x}) = \mathrm{SomeNorm}(\mathbf{x} - \mathbf{x}^{\mathrm{prior}}) + [\underbrace{\mathbf{y} - \mathcal{H}(\mathbf{x})}_{\text{Observations-model difference}}]^T \, \mathbf{R}^{-1} \, [\mathbf{y} - \mathcal{H}(\mathbf{x})]$$

observation error covariance matrix

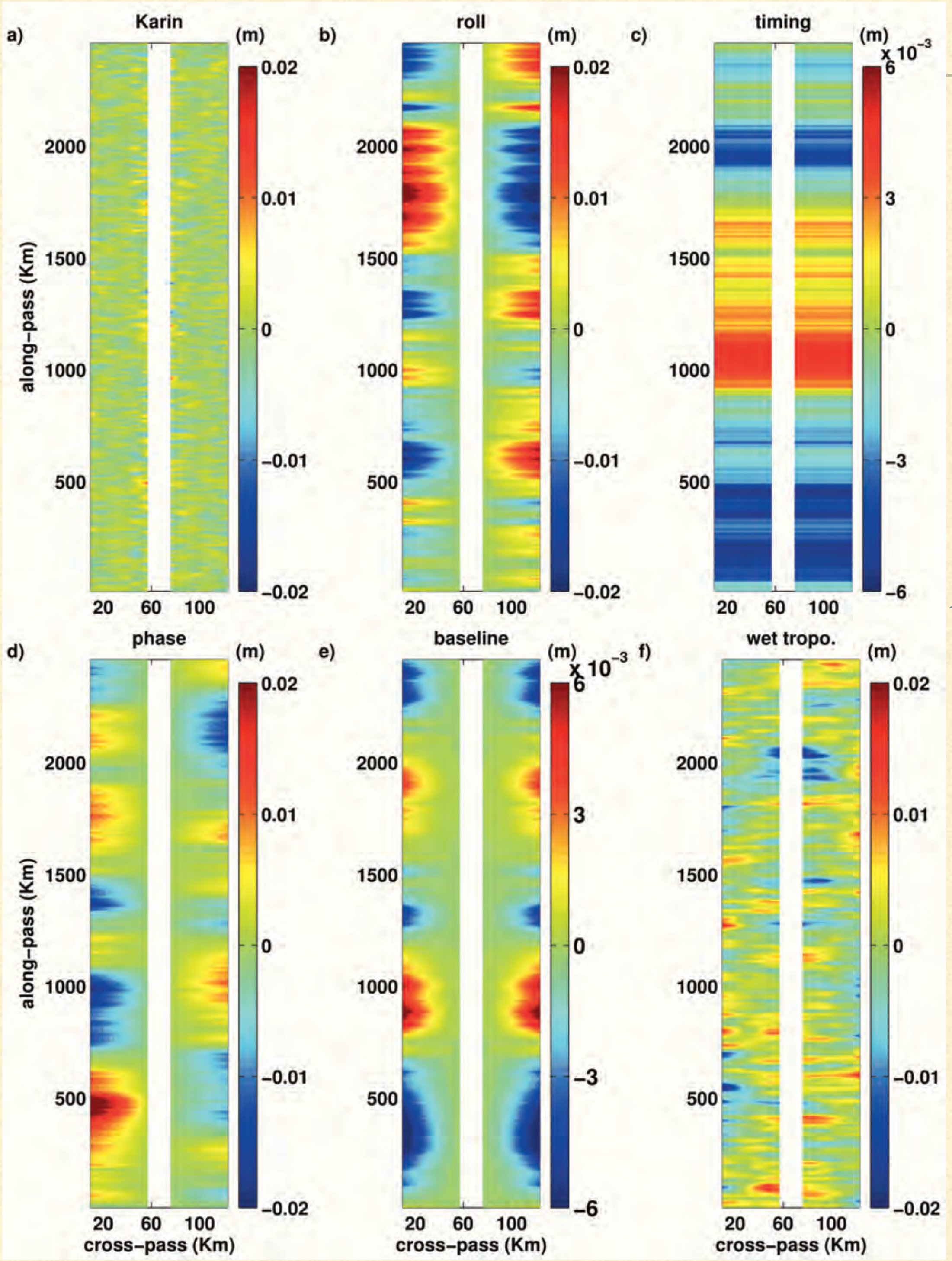
Challenges

1. We must estimate the observation error covariance matrix.
2. What we actually need is the **inverse** of the observation error covariance matrix.

$$\mathcal{J}(\mathbf{x}) = \mathrm{SomeNorm}(\mathbf{x} - \mathbf{x}^{\mathrm{prior}}) + \underbrace{[\mathbf{y} - \mathcal{H}(\mathbf{x})]}_{\text{Observations-model difference}}{}^{T}\, \mathbf{R}^{-1}\, [\mathbf{y} - \mathcal{H}(\mathbf{x})]$$

observation error covariance matrix

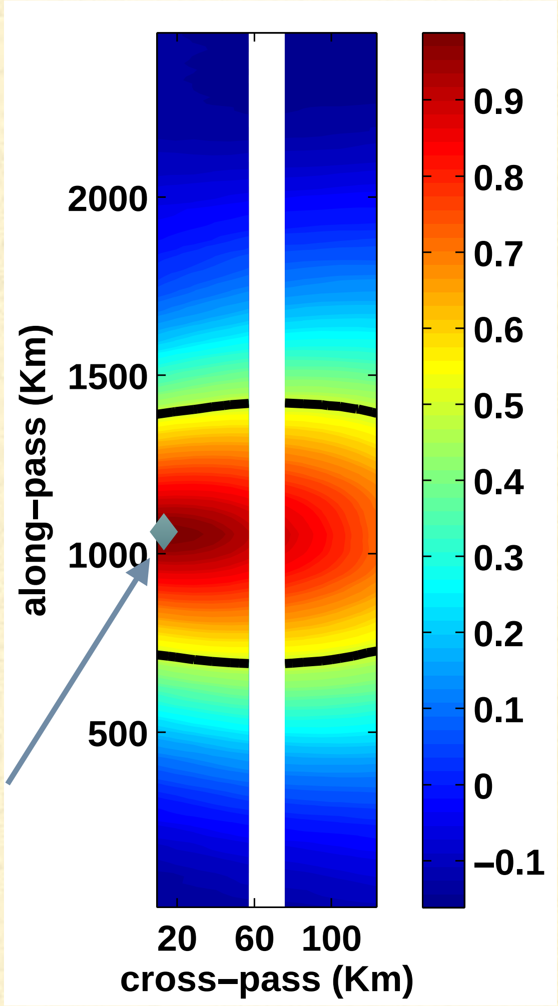
Challenge 1: estimating the matrix



We perform 5000 realizations of SWOT errors with the simulator.

A realization of SWOT errors

Correlations with the error at this point



Challenge 2: using the matrix in the assimilation algorithm

The observation error covariance matrix is **too big to be inverted** numerically.

In large systems (meteorology, oceanography), it is considered **diagonal**. Actually, the design of usual data assimilation systems is based on this approximation.

To alleviate the detrimental effects of this approximation, common (but not satisfactory) solutions are:

- to rule out observations when they are suspected of correlated errors,
- inflating the error variances (diagonal of the matrix).

Challenge 2: what we propose

Introduce a transformation of the observations:

$$\mathbf{y}^+ = \mathbf{T}\mathbf{y} \qquad \mathcal{H}^+ = \mathbf{T}\mathcal{H}$$

Note the error covariance matrix $\mathbf{R}^+$

Then

$$\left[\mathbf{y}^+ - \mathcal{H}^+(\mathbf{x})\right]^T \mathbf{R}^{+^{-1}} \left[\mathbf{y}^+ - \mathcal{H}^+(\mathbf{x})\right] = \left[\mathbf{y} - \mathcal{H}(\mathbf{x})\right]^T \mathbf{R}^{-1} \left[\mathbf{y} - \mathcal{H}(\mathbf{x})\right]$$

If

$$\mathbf{T}^T \mathbf{R}^{+^{-1}} \mathbf{T} = \mathbf{R}^{-1}$$

Brankart et al, 2009

Challenge 2: what we propose

We introduce

$$\mathbf{T} = \begin{pmatrix} \mathbf{I} \\ \delta_a \\ \delta_c \\ \delta_a^2 \\ \delta_c^2 \end{pmatrix}$$

— Identity

— Derivative along-track and across-track

— Second order derivatives

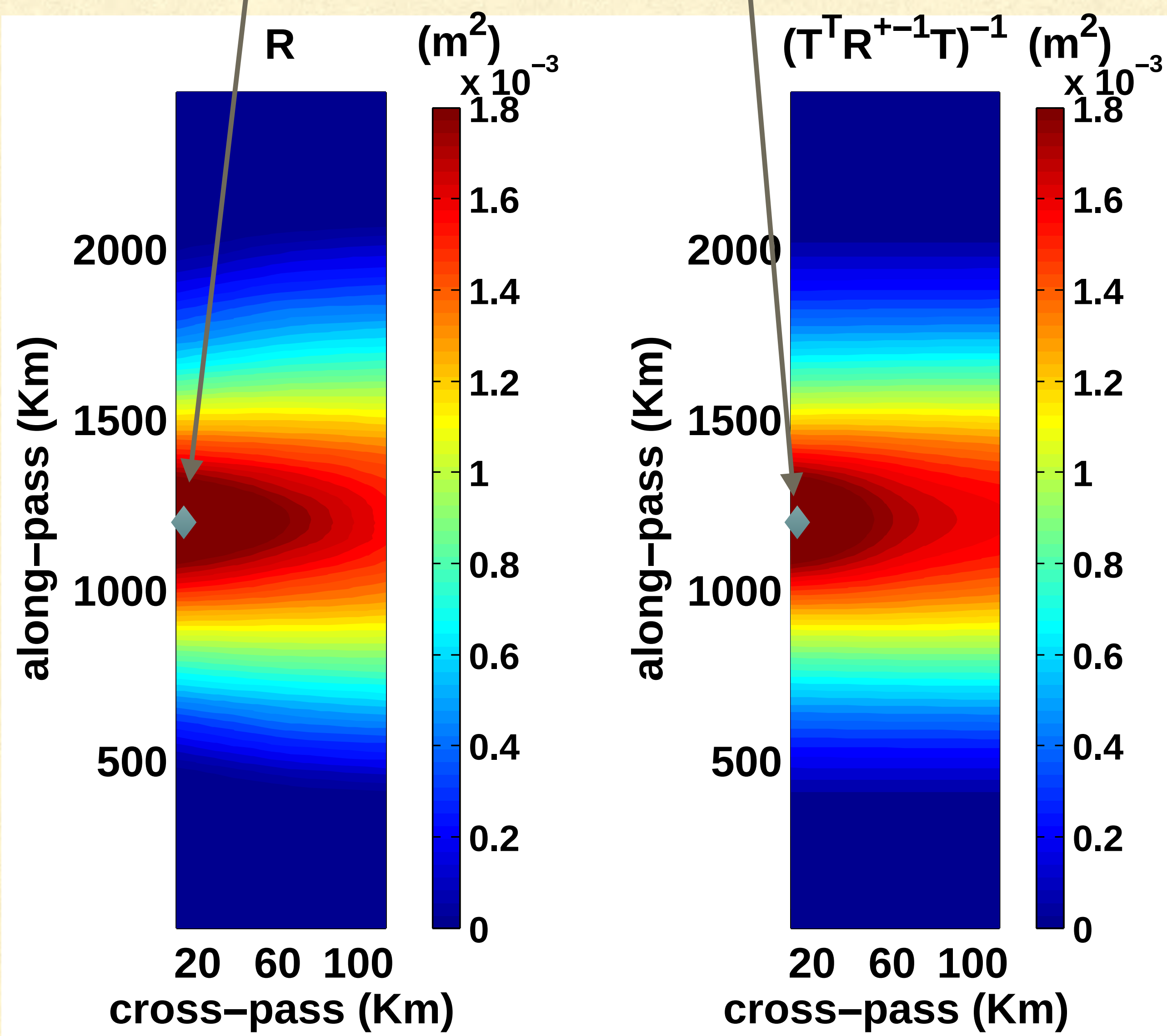
and find $\mathbf{R}^+$ (diagonal) that minimizes the matrix norm

$$\left\| \mathbf{R}(\mathbf{T}^T {\mathbf{R}^+}^{-1} \mathbf{T}) - \mathbf{I} \right\|_F^2$$

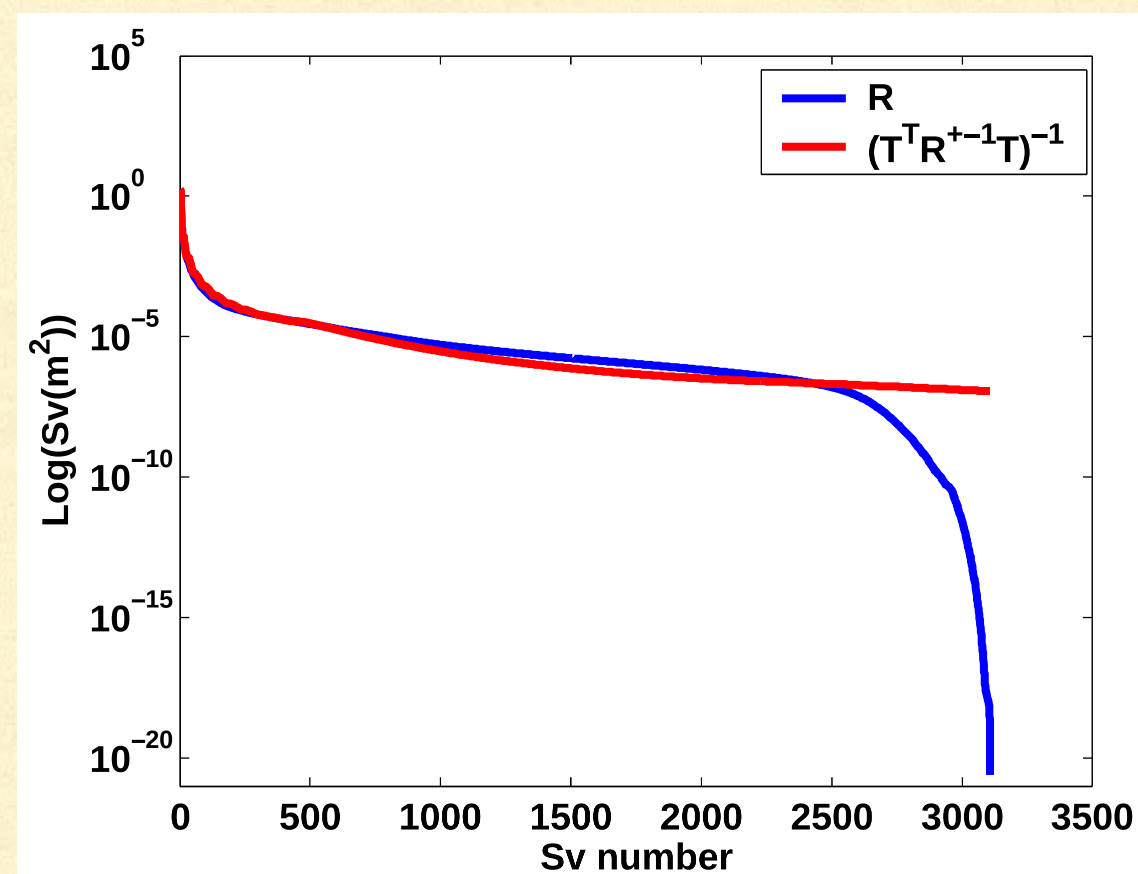
Ruggiero et al, 2016

Results

Correlations with this point



Singular values

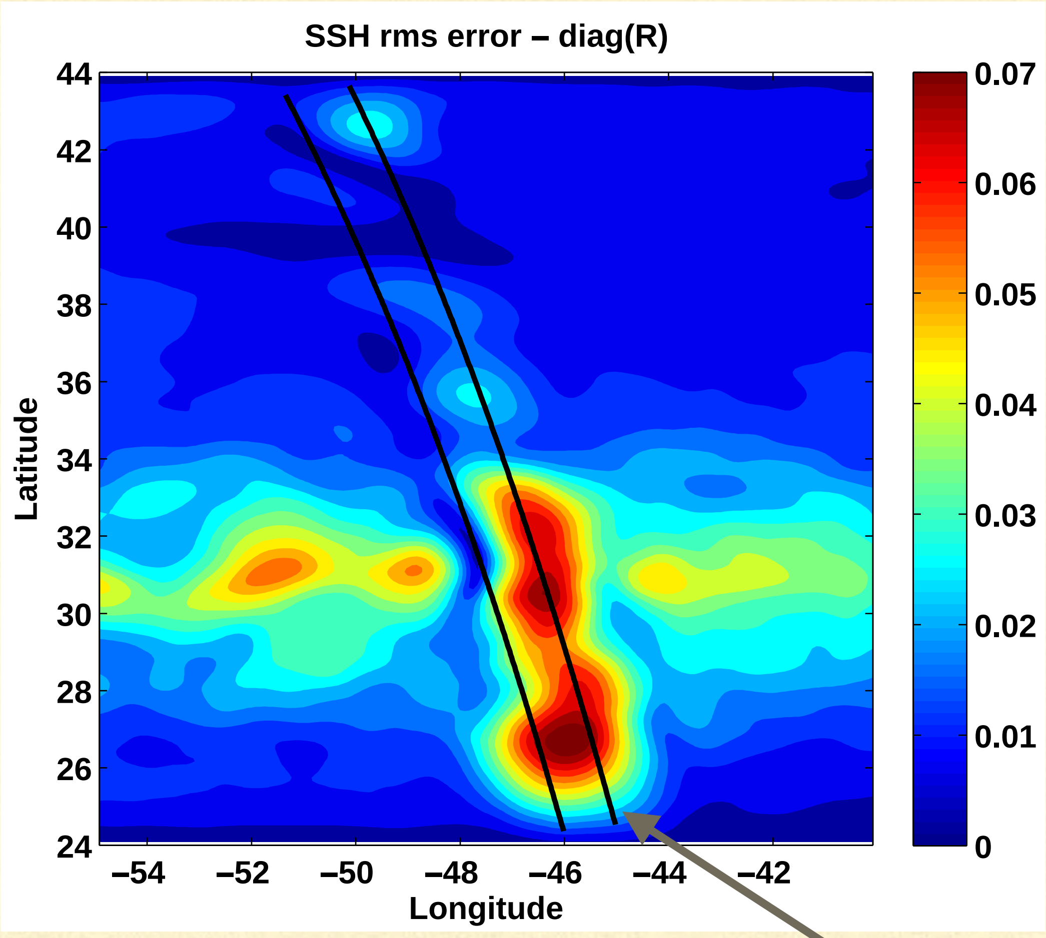


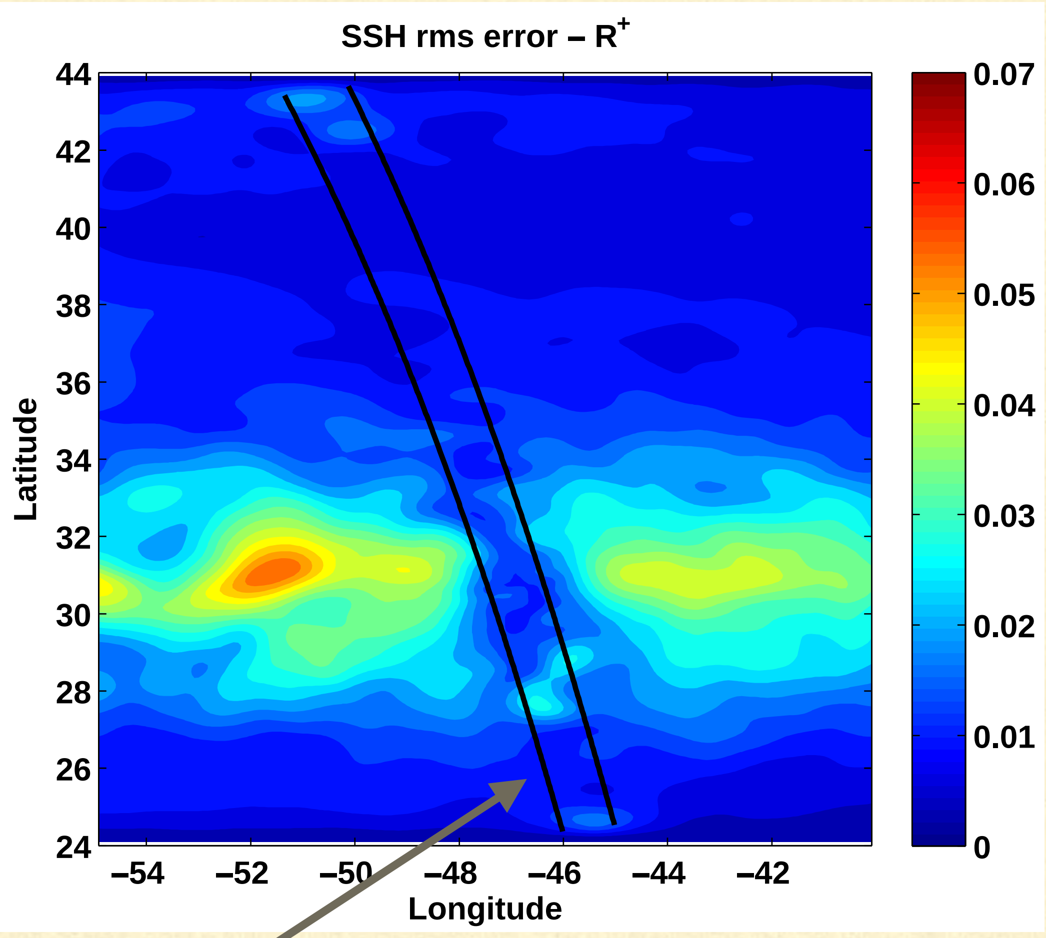
Results

Residual error after analysis (based on 180 analyses)

With diagonal R

Simulating the correlations





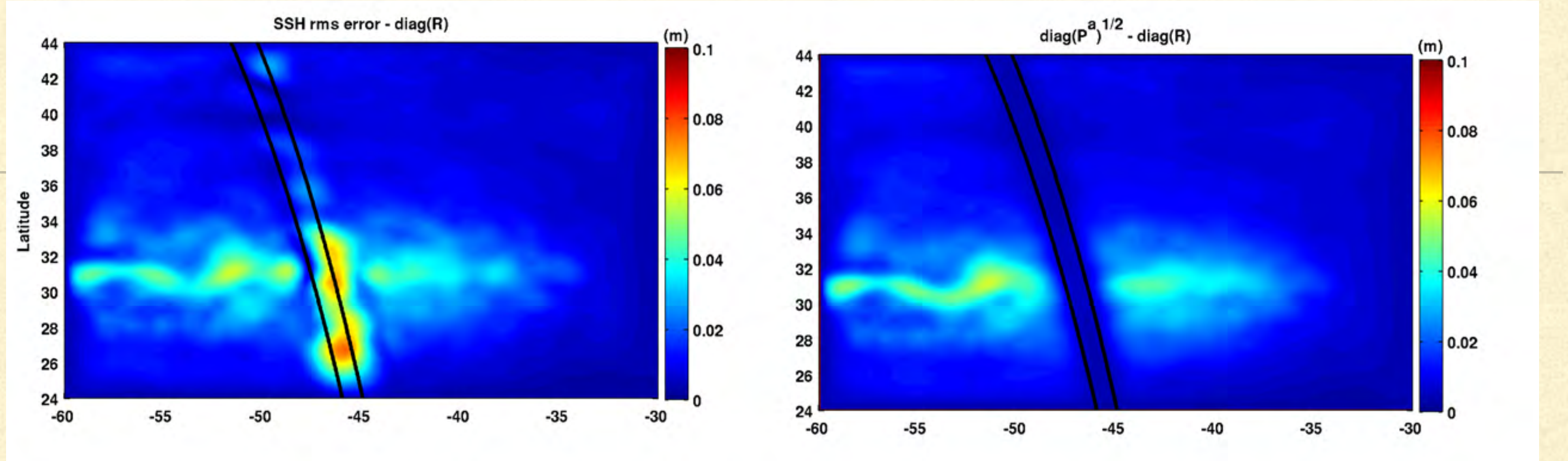
SWOT observations

Results

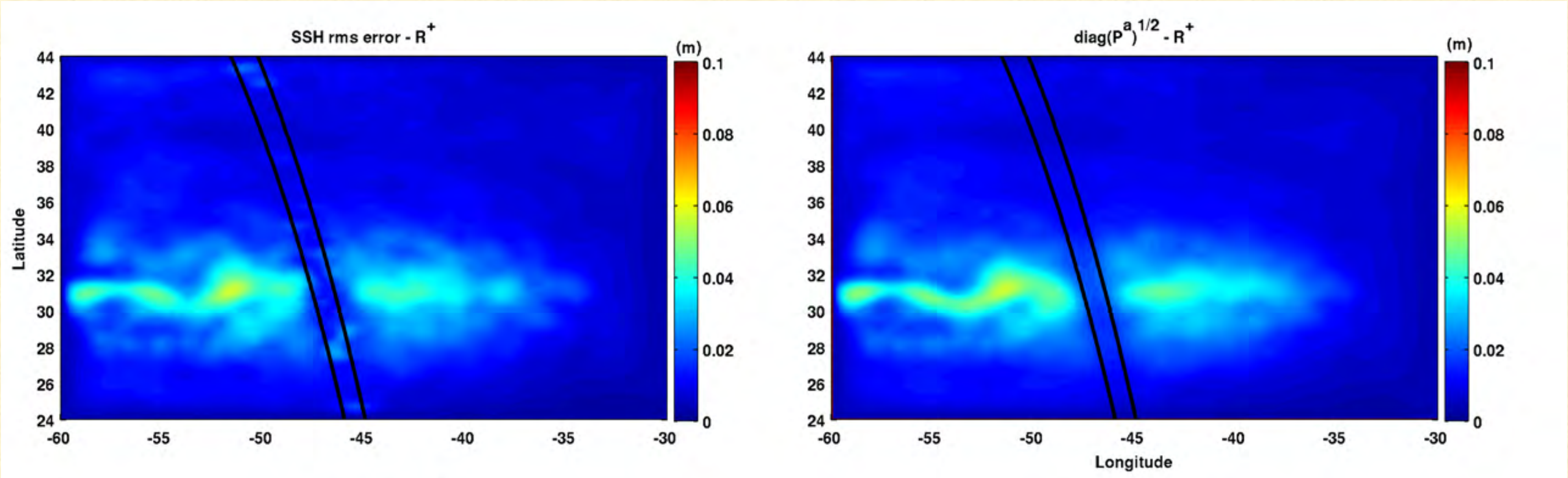
Residual error after analysis

What we have | What we should have

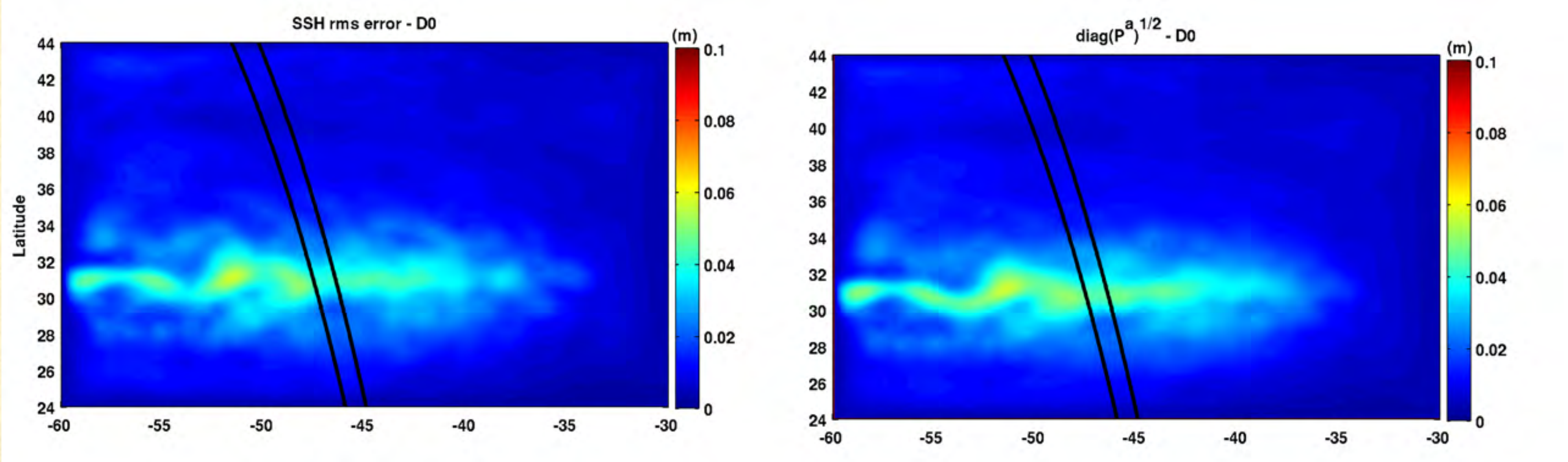
With diagonal R



Simulating the correlations



With diagonal R, inflated variances



Conclusions and discussions

- **Accounting for error correlations is essential to accurately assimilate SWOT observations, and we propose a method to do so (Ruggiero et al, JTECH, in press).**

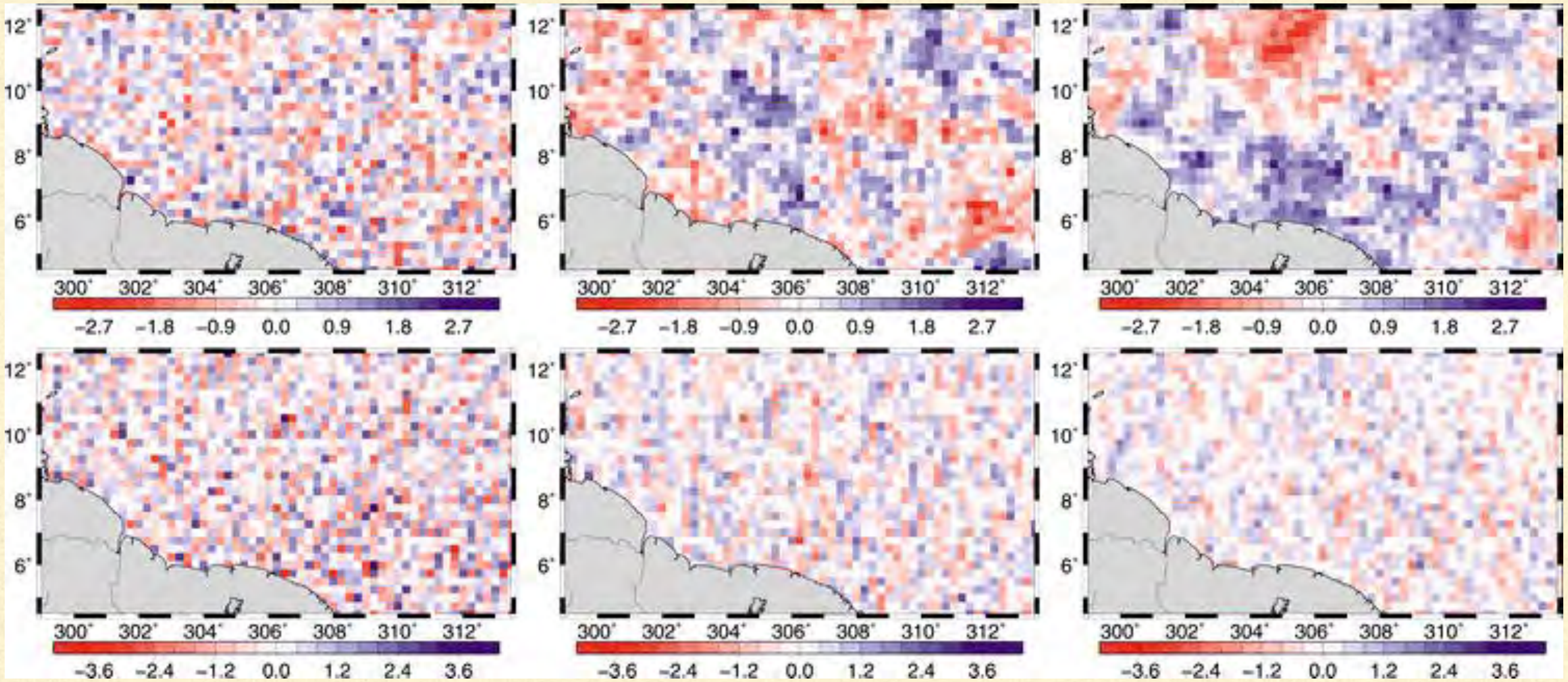
- Need to get rid of the uncorrelated KaRIn instrumental error to use the full resolution of SWOT (we are developing denoting techniques);
- The method is applicable to nadir altimetry (using along-track derivatives). Useful?
- The method can be complemented with online diagnostics (Desroziers et al, 2005) to improve the representation of the observation error covariance matrix.

why error correlations matter?

No correlations | Short-range correlations | Long-range correlations

Errors in SSH

Errors in SSH gradients



Brankart et al, 2009