Assimilating observations of deformation to improve short-term ensemble forecasts of sea ice features

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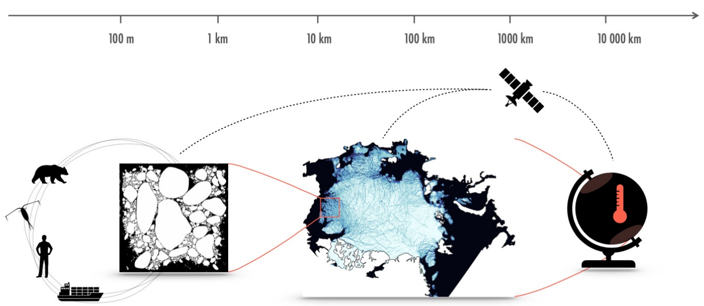

**SASIP, *ACCIBERG*
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Motivation

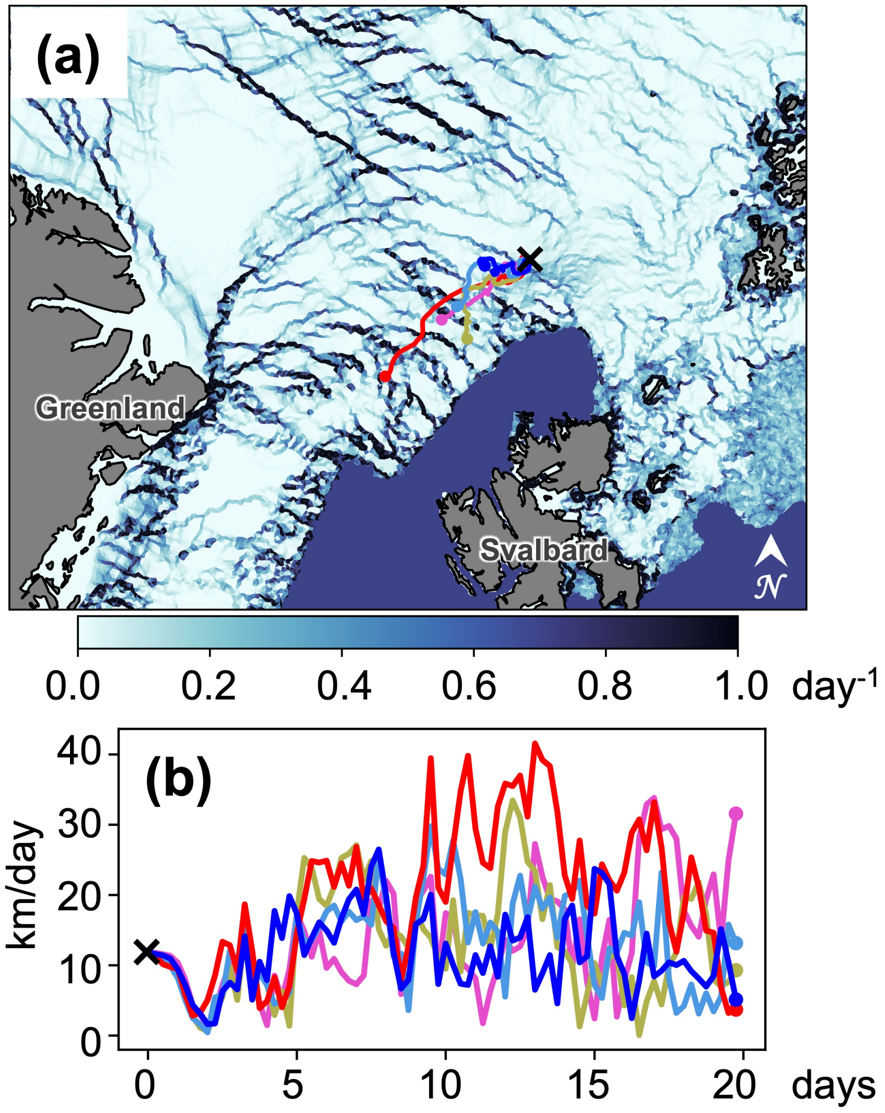
Deformation is important features for short-term sea ice forecasts: both large-scale **wind forcing** and small-scale ice **rheology** influences.

Challenging **multifractal** and **nonlinear** problems!

Part 1: some visual example of sea ice deformation

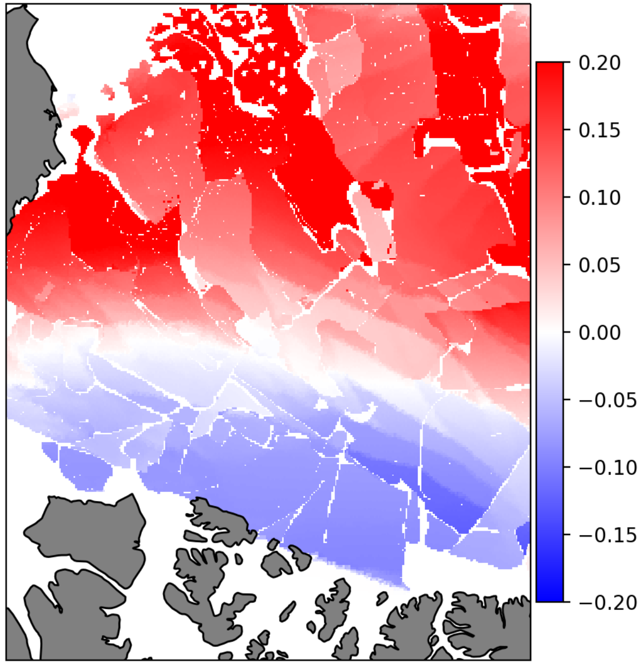
Part 2: a 1-D illustration of the assimilation problem

Part 3: Bayesian formulation for the multiscale filter

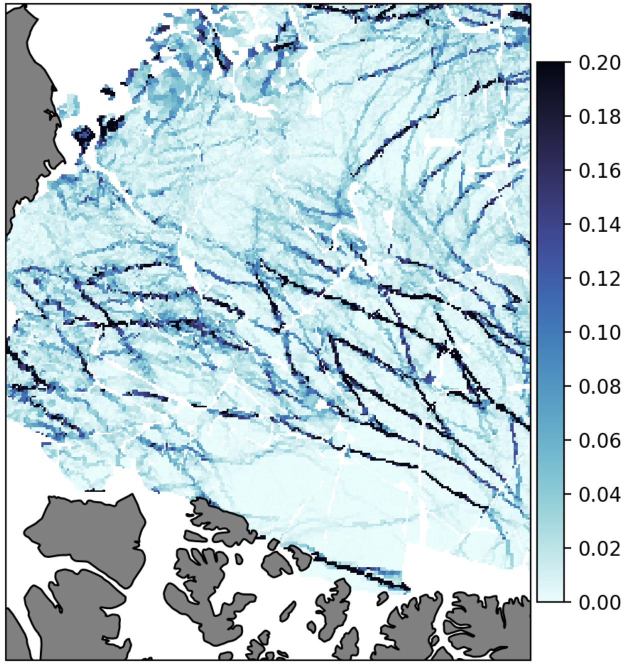


Part 1: Sea ice drift and deformation

ice drift u (m/s)



ice shear deformation (1/day)



RGPS SAR imagery
(Synthetic Aperture Radar)

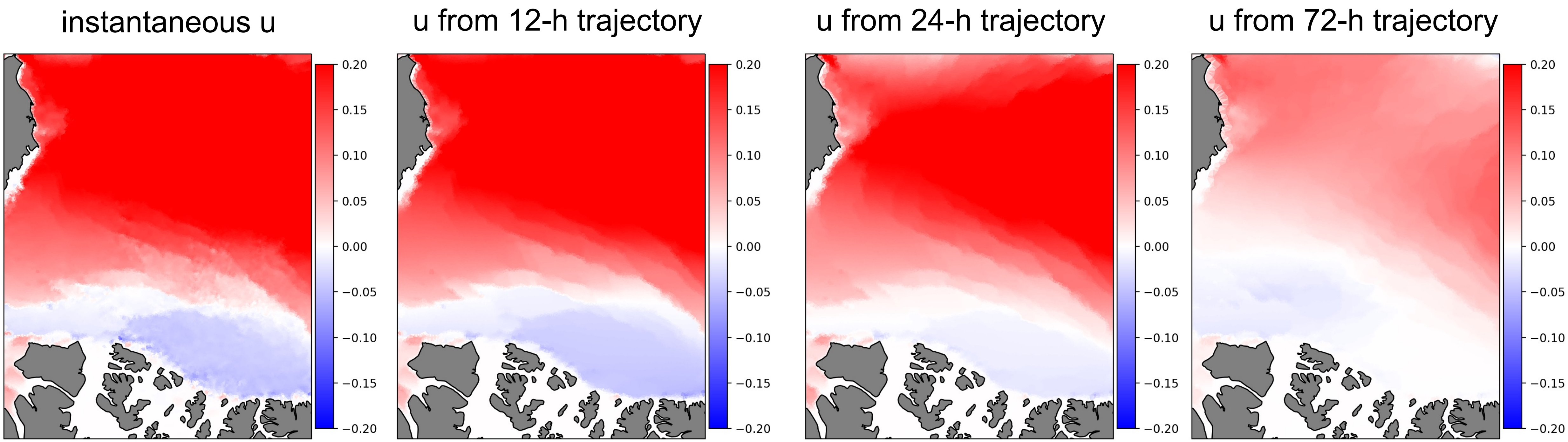
Tracking ice image pairs for coherent features: ice drift

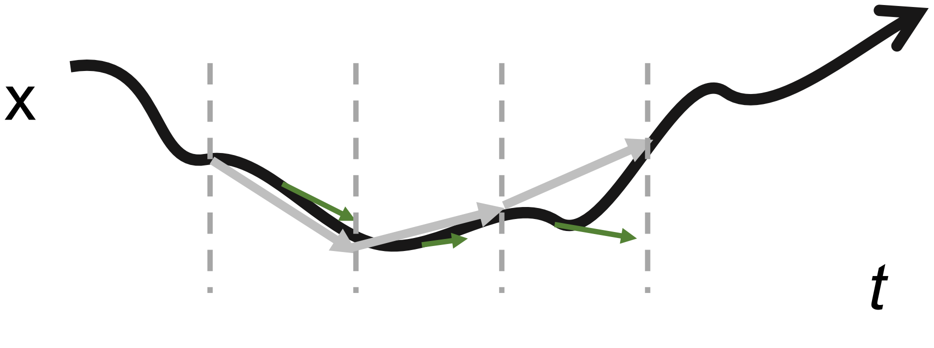
$$(u, v) = \left(\frac{x(t+\delta t) - x(t))}{\delta t}, \frac{y(t+\delta t) - y(t))}{\delta t} \right)$$

$$\dot{\varepsilon}_{\text{shear}} = \sqrt{(u_x - v_y)^2 + (u_y + v_x)^2},$$

as $\delta t \rightarrow 0$, (u, v) is the instantaneous velocity in model restart files

Sea ice drift definition

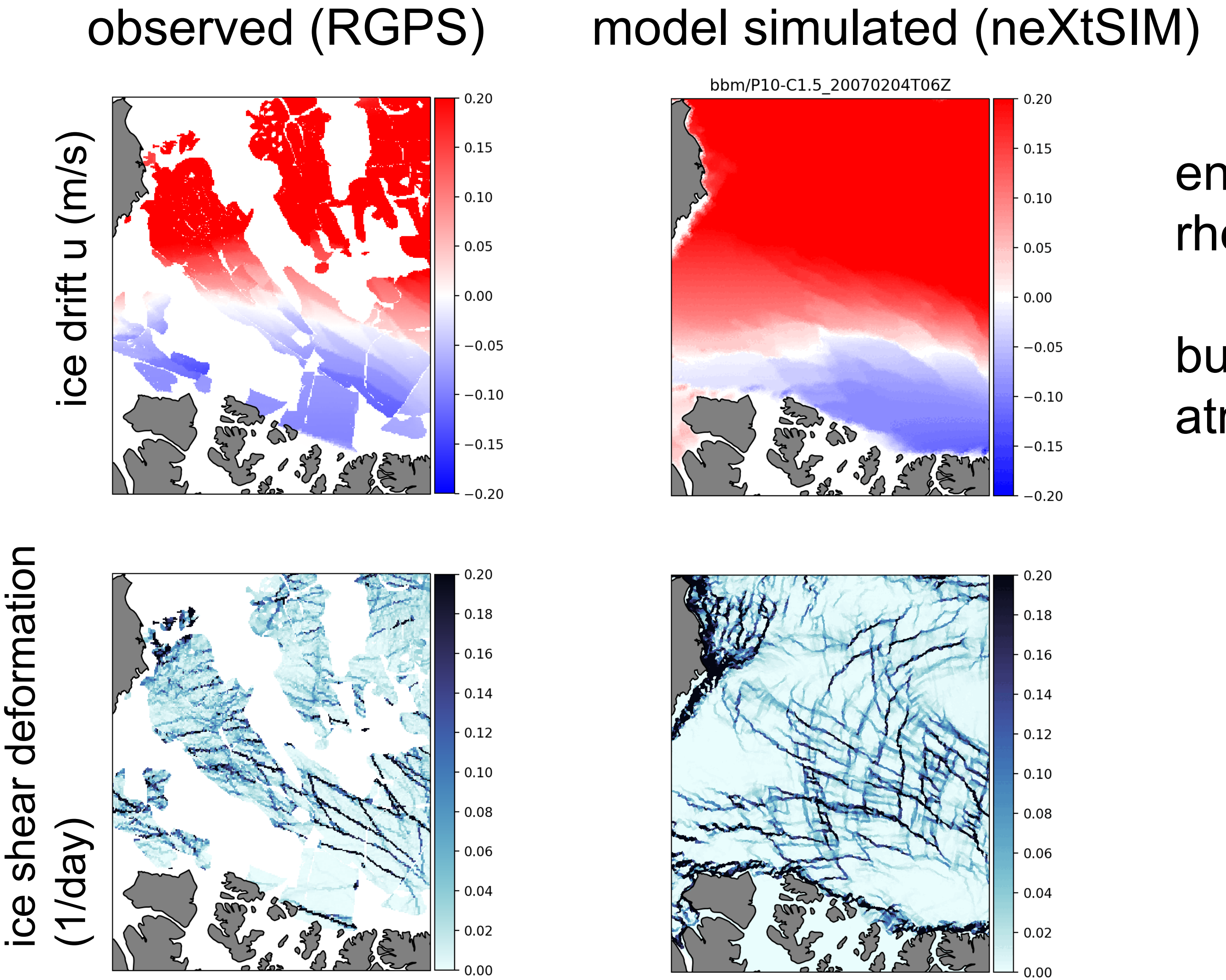




we need:

- enough temporal resolution
- asynchronous assimilation

neXtSIM ensemble simulation of sea ice deformation



ensemble using different rheology parameters (P, C)

but using the same atmospheric forcing

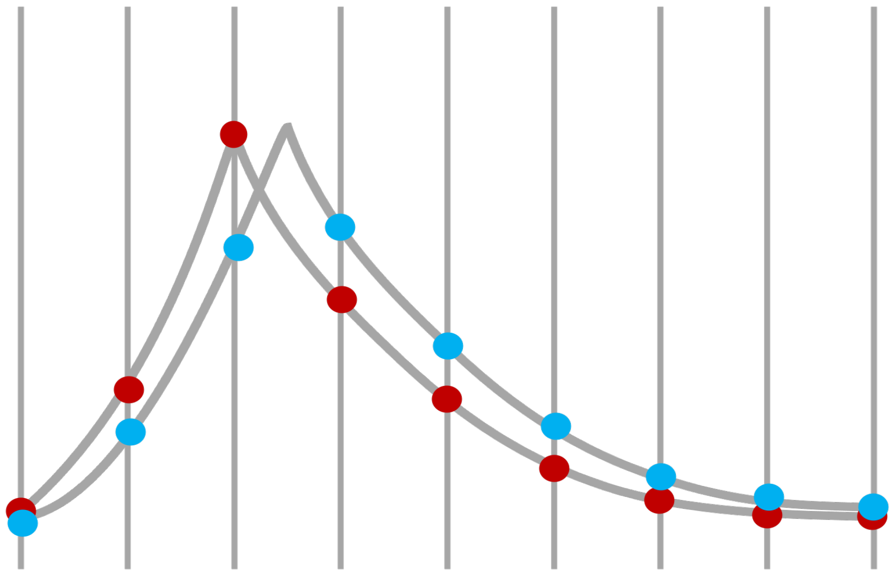
Challenges in assimilating small-scale features

- **irregular triangular mesh**: members have different mesh positions

Interpolation to a common analysis grid:

at higher resolution, it's costly

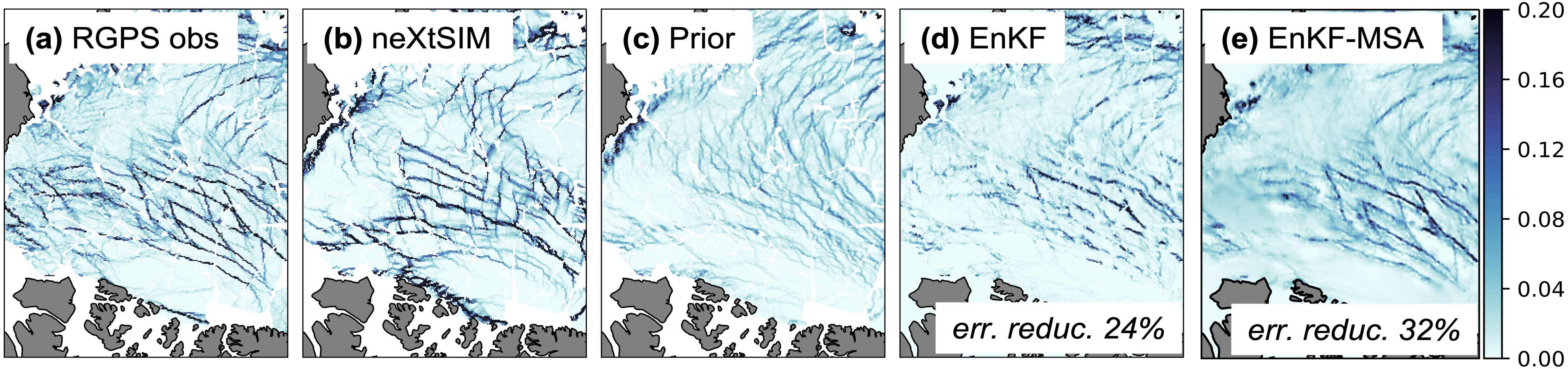
at the same resolution, interpolation is diffusive



Challenges in assimilating small-scale features

- **irregular triangular mesh**: members have different mesh positions
- **deformation is fractal**: hierarchy of features with position errors

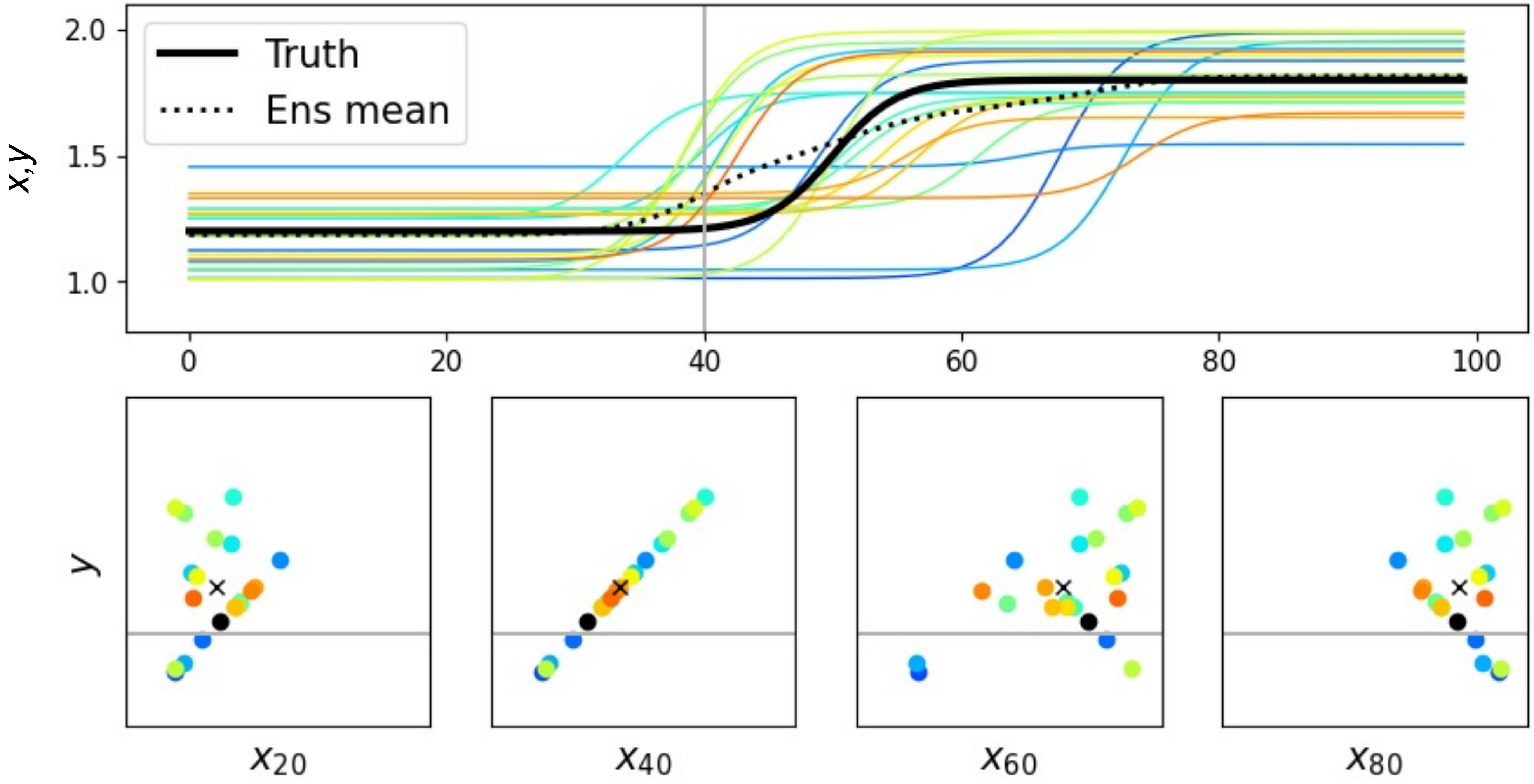
Using multiscale alignment method, we can better assimilate deformation:



How to update the model states (drift, concentration, damage…)?

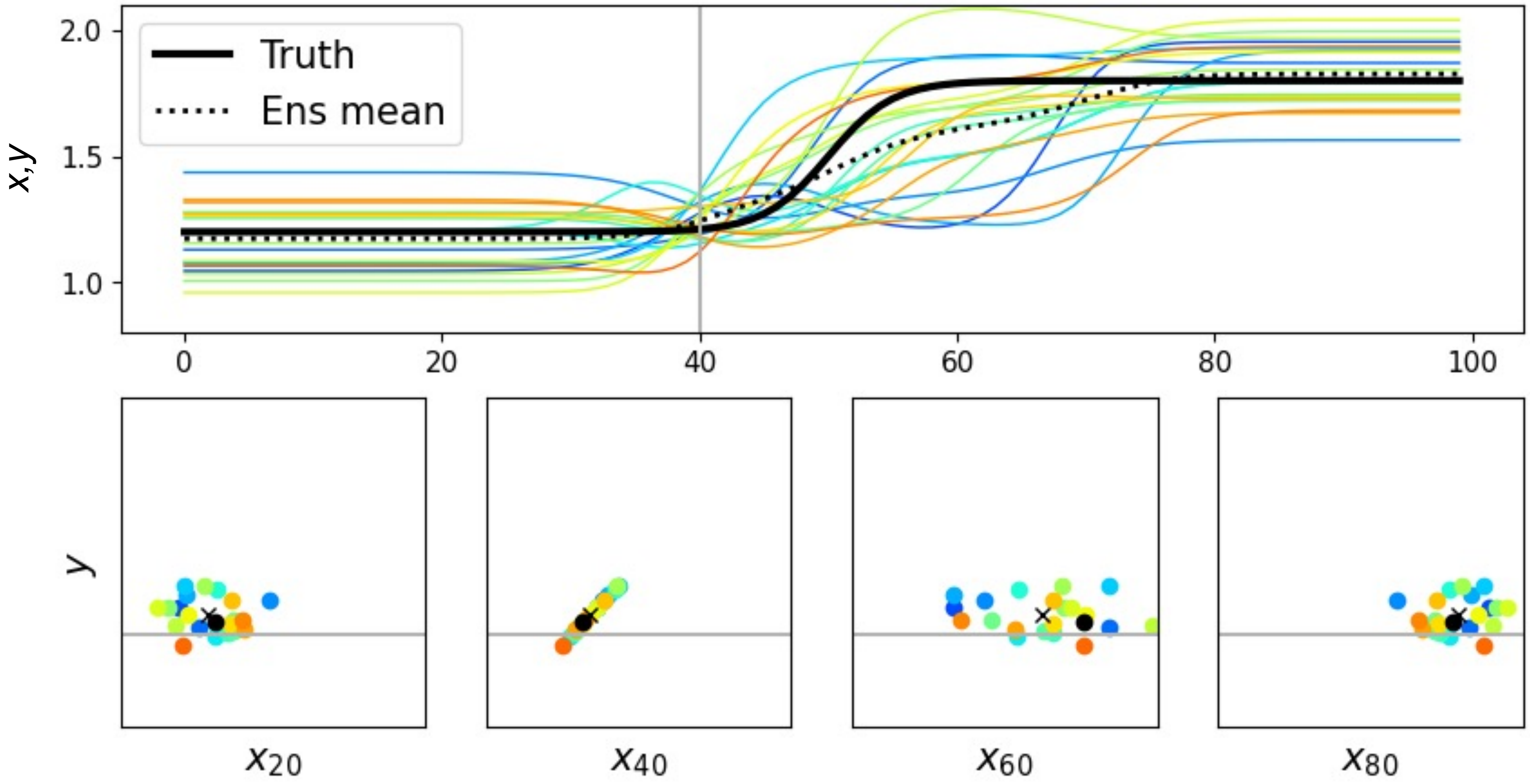
Part 2: 1-D illustration of the problem

Prior

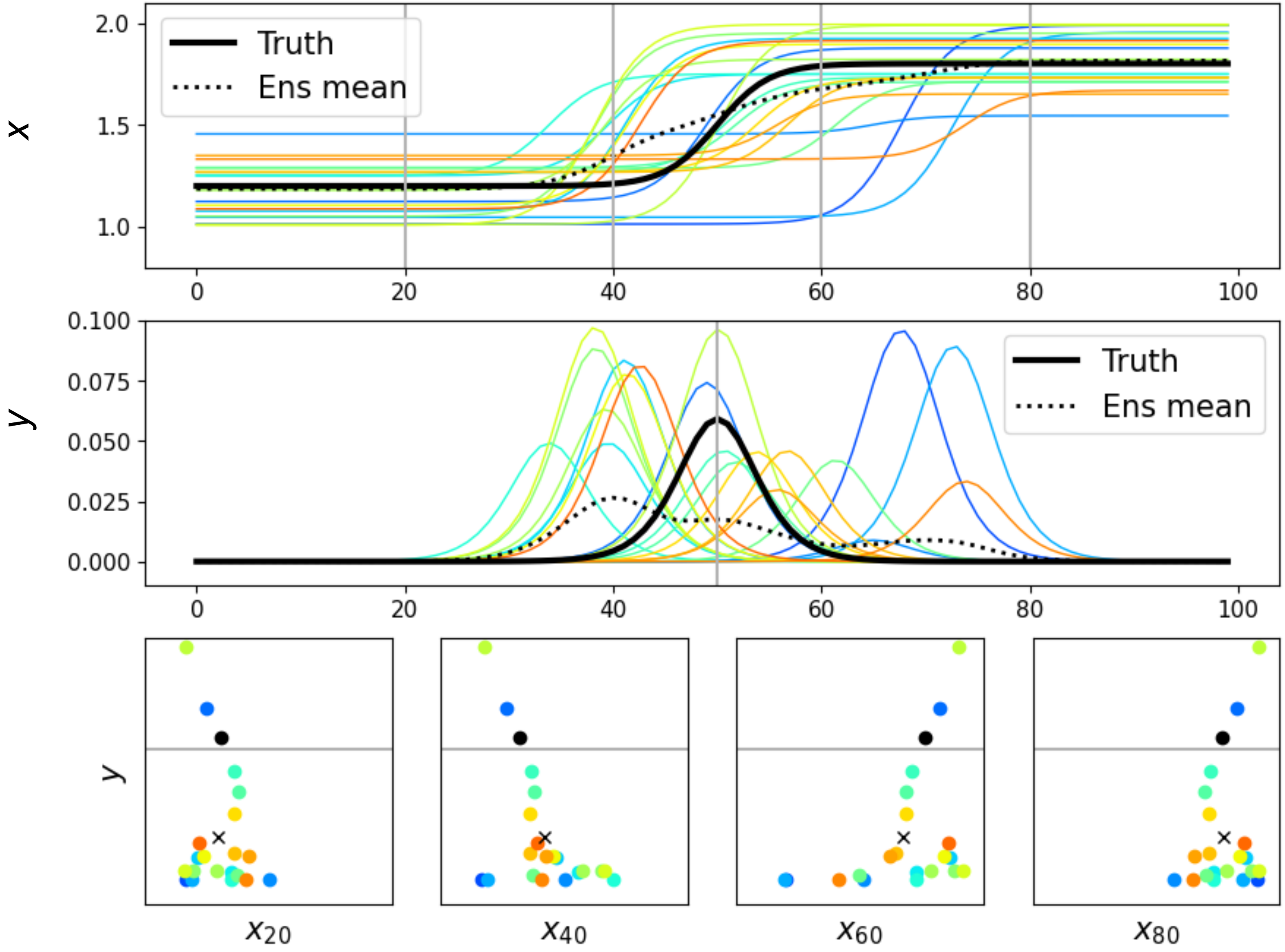


Part 2: 1-D illustration of the problem

Posterior, assimilating drift to update drift



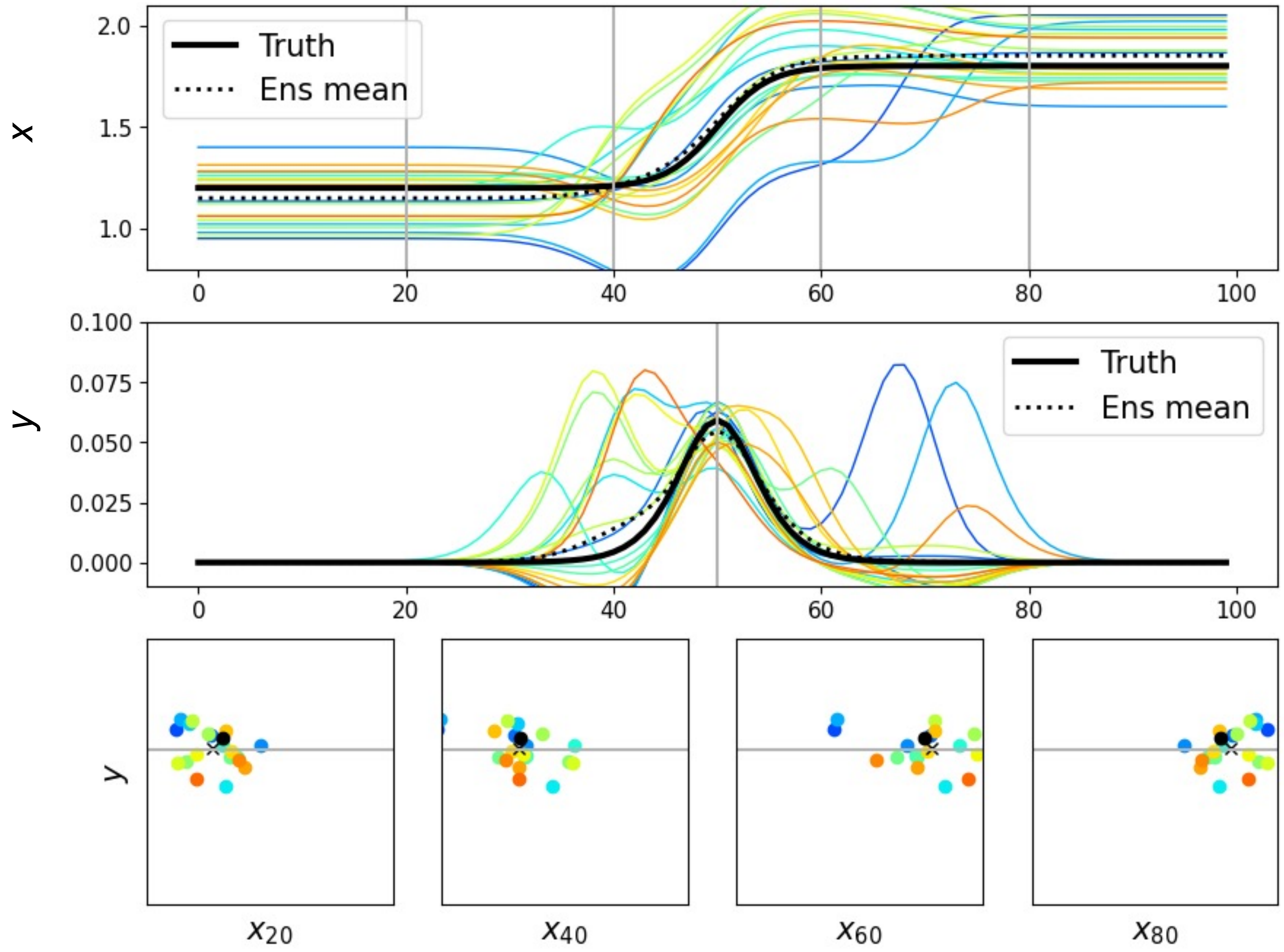
Advantage of assimilating deformation



x: drift u

y: deform, grad(u)

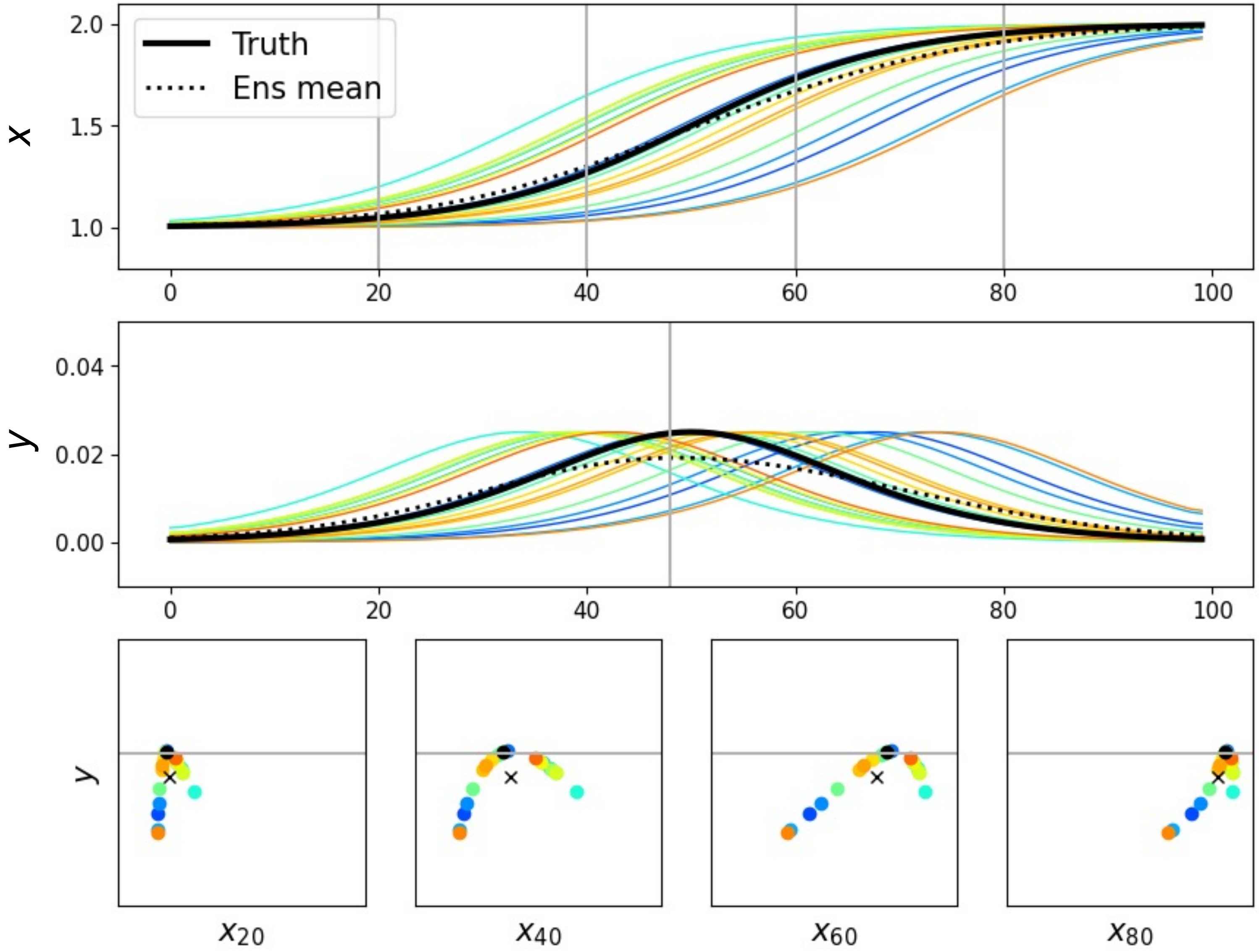
Advantage of assimilating deformation



x: drift u

y: deform, grad(u)

Effect of nonlinear position errors

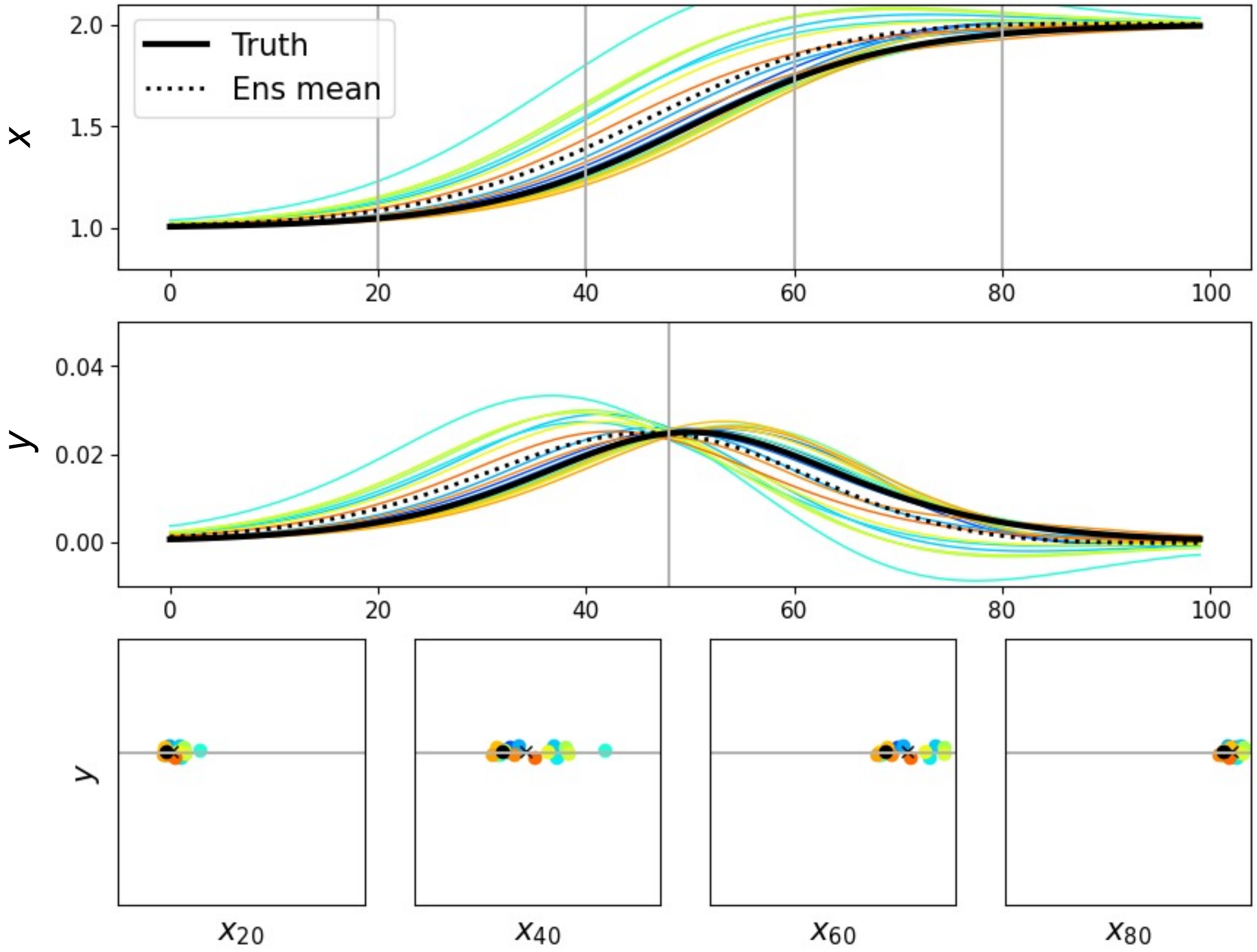


x: drift u
y: deform, grad(u)

only position errors

nonlinearity is shown

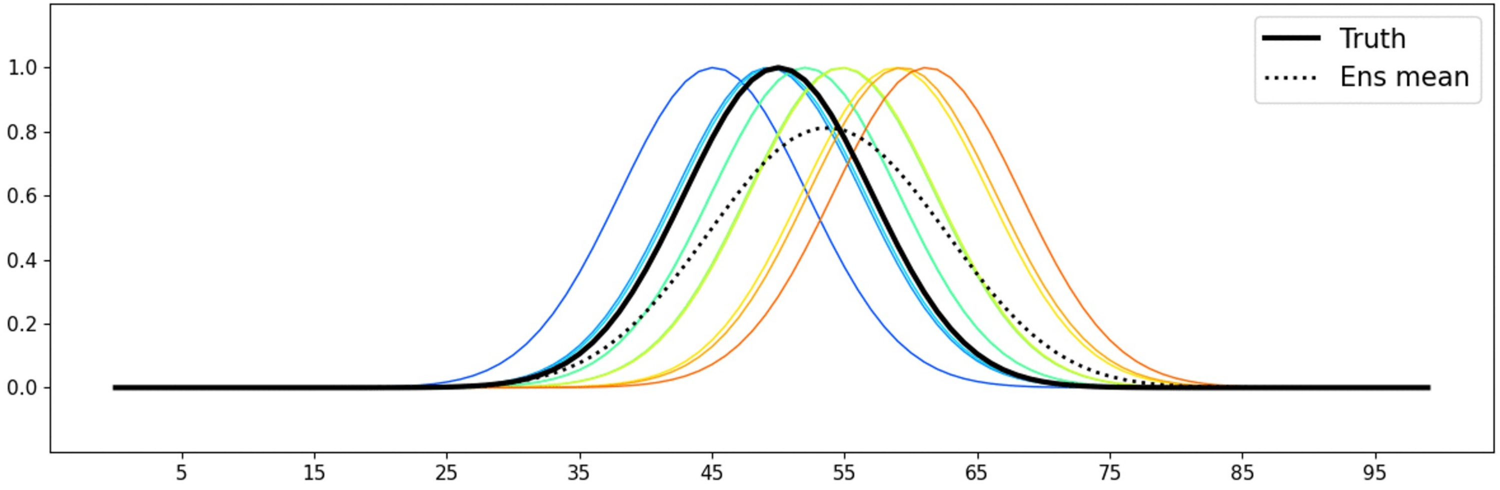
Effect of nonlinear position errors

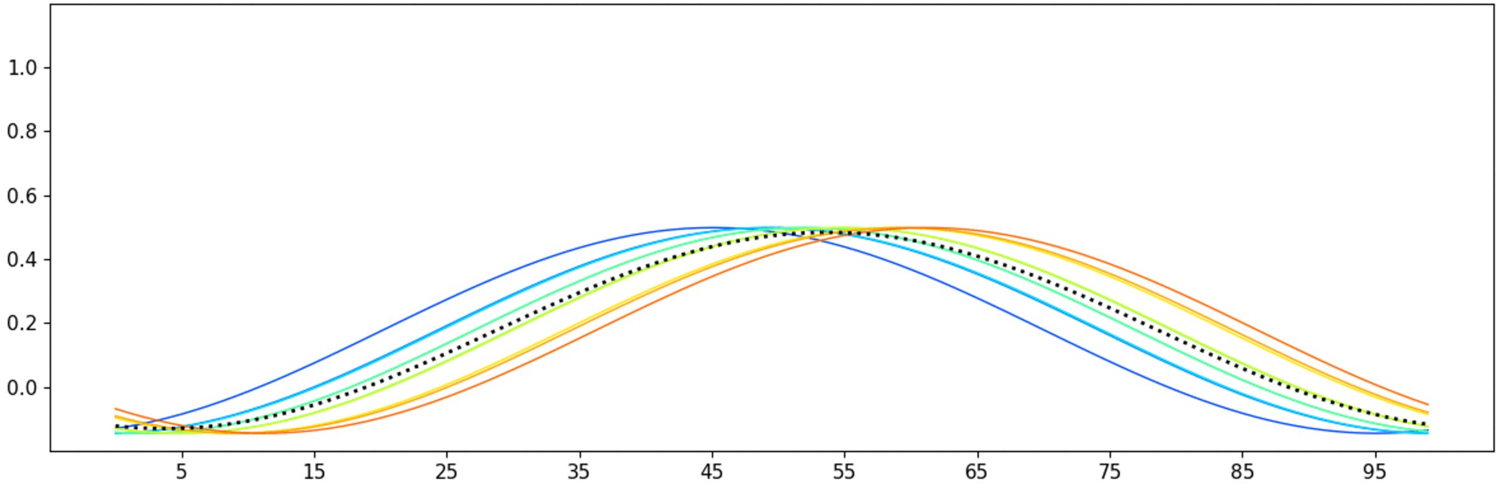


x: drift u
y: deform, grad(u)

assimilation corrects some position errors, but introduced bias in drift speed

Remedy: multiscale alignment





Run filter at coarse resolution

Find displacement vectors and warp the fields

(optional) run filter again for higher resolution …

This is also useful for irregular mesh problems, to preserve sharp gradients!

Part 3: Bayesian framework for multiscale filtering

The underlying idea for multiscale alignment:

Decompose state into sum of scale component s = 1, 2 … Ns

$$x^b = x_1^b + x_2^b + \ldots + x_{N_s}^b$$

At each scale, the error is further separated into phase and amplitude:

$$x_s^b(r) = x_s^t(r + q_s) + x_s'$$

e.g., Fourier transform $x(r) \rightleftharpoons \hat{x}(k)e^{ikr}$

The new cost function

$$p(x, q|y) \propto p(y|x, q)p(x|q)p(q)$$

$$J(x, q) = \|y - h[x(q)]\|_R^2 + \left\|x(q) - x^b(q)\right\|_{B(q)}^2 + ln[B(q)] + L(q)$$

two-step solution:

1. filter update $J(x)|_{q=0} = \|y - h[x]\|_R^2 + \left\|x - x^b\right\|_B^2 \rightarrow x^a$

2. alignment $J(q)|_{x^a} = \left\|x^a - x^b(q)\right\|^2 + L(q) \rightarrow q$

Relation between large- and small-scale components

Ying 2019 assumed that small-scale displacement inherits the large-scale ones

$$x_s^b(q_1 + q_2 + \ldots + q_{s-1})$$

Ying et al. 2023: large- and small-scale position errors can be incoherent, making this a bad assumption

Instead, maybe using covariance to update $q_s^b \to q_s^a$?

Summary and ongoing work

Sea ice deformation has fractal features, which are important information for models to maintain prediction skill

Traditional EnKF has limitation when assimilating sea ice observation

- Assimilating deformation in additional to drift
- Treatment of irregular lagrangian mesh
- Nonlinear position errors tackled by alignment techniques
- Rethinking the large- and small-scale relationship