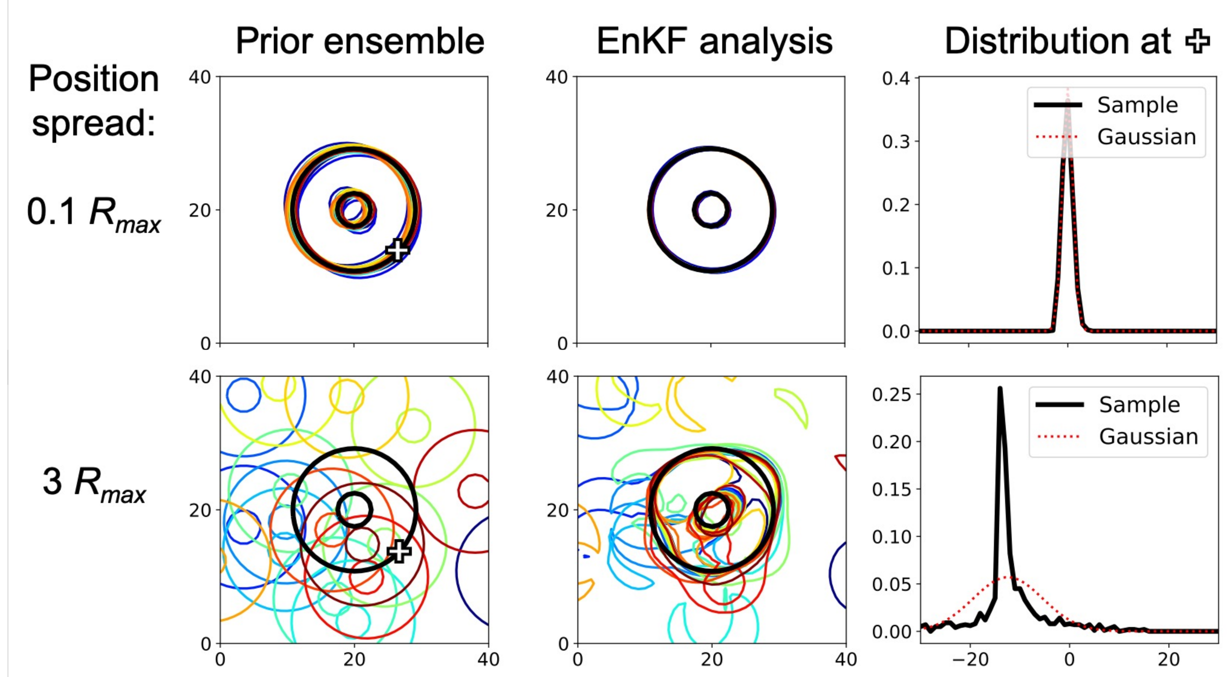
Improving vortex position accuracy with a new multiscale alignment ensemble filter

Yue Ying* (NERSC), Jeffrey Anderson (NCAR), Laurent Bertino (NERSC)

NERSC NCAR

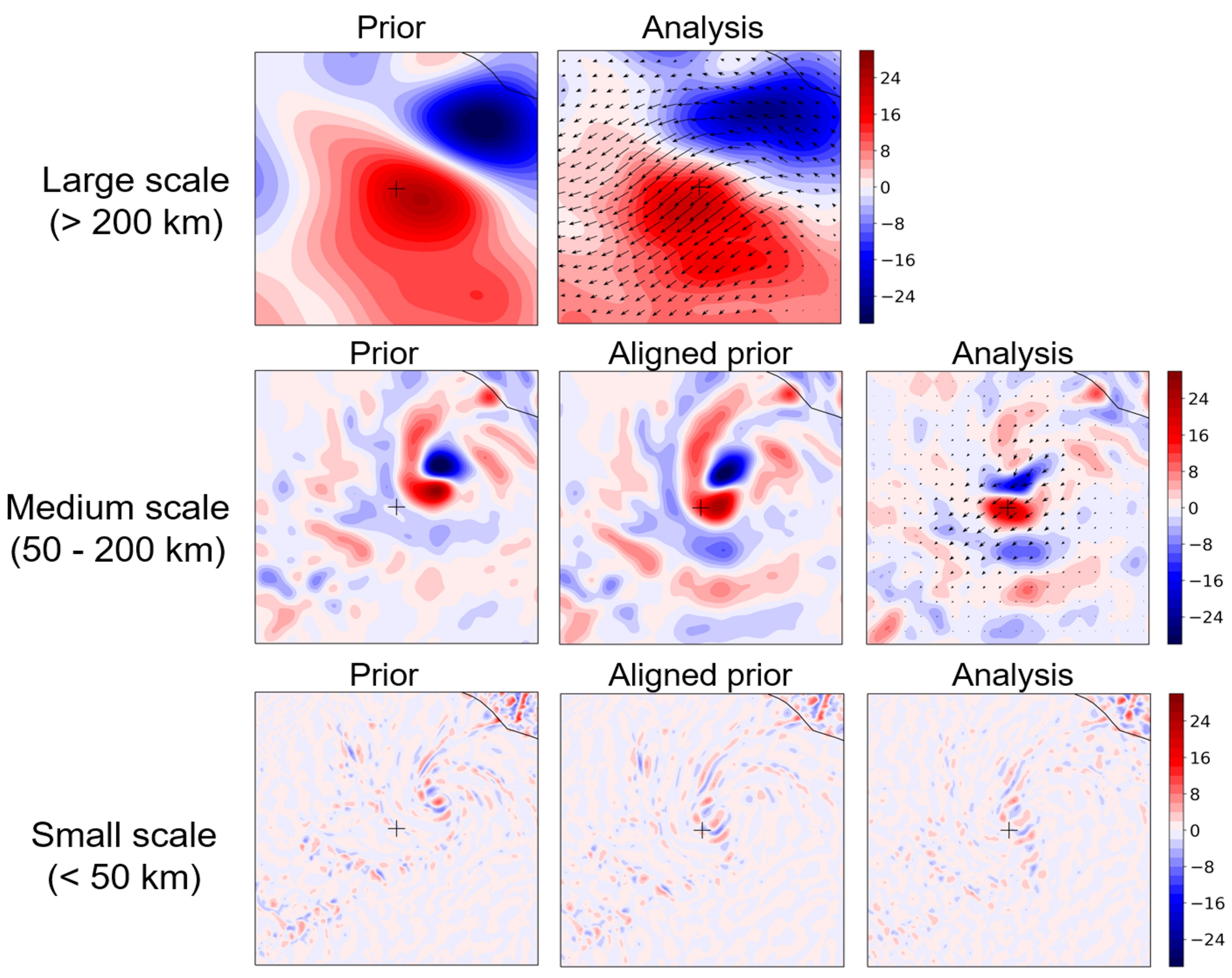
Motivation

Position errors introduce nonlinearity in assimilation problems. The figures below compares the EnKF analysis in a quasi-linear (top row) and a nonlinear (bottom row) scenario, demonstrating how nonlinear position errors degrade EnKF analysis.

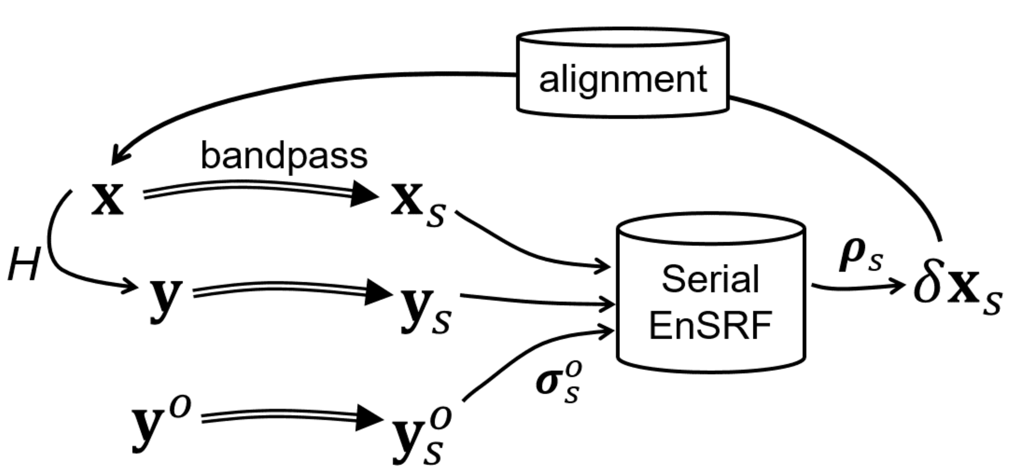


Multiscale alignment (MSA)

To provide a remedy for nonlinear position errors, Ying (2019) introduced MSA based on the idea of some feature alignment techniques (e.g. Ravela et al. 2007; Nehrkorn et al. 2014). The following figures illustrate in a hurricane example how the MSA updates the zonal wind field iteratively from large to small scales, using "optical flows" derived from large-scale analysis increments to reduce position errors at the smaller scale prior to its analysis.



The following diagram is the work flow of a multiscale ensemble data assimilation system.



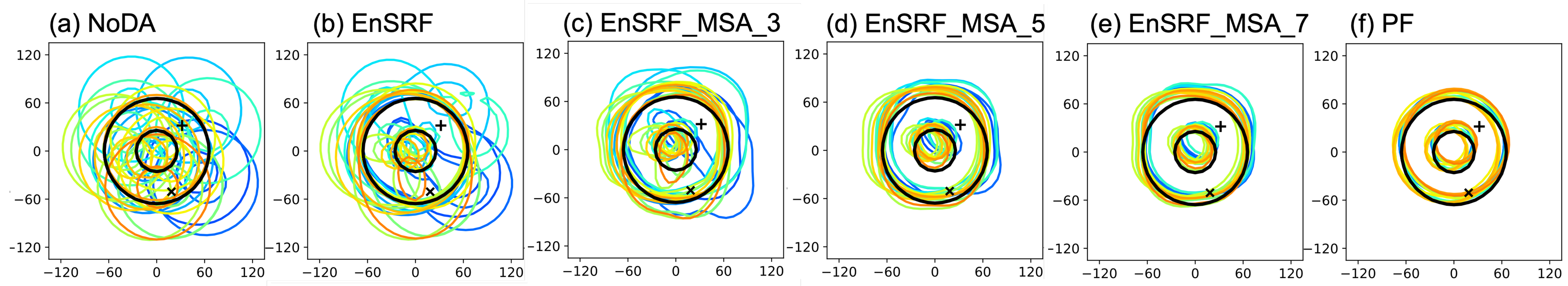
While the traditional EnKF (serial EnSRF, a variant) takes the prior states ($\mathbf{x}$) and observation ($\mathbf{y}^o$) directly as input and output the analysis increment ($\boldsymbol{\delta}\mathbf{x}$), the multiscale framework adds some pre- and post-processing steps, the bandpass filter for obtaining scale component ($\mathbf{x}_s$), the alignment step using optical flows, and an iterative outer loop over the number of scales ($s = 1, \ldots, N_s$).

A new option is introduced (MSA-O) where the observations and obs priors are also decomposed into scale components ($\mathbf{y}_s$), making the EnKF update suffer less from scale mismatches.

See Ying et al. 2023, MWR for more details
Visit my webpage: https://myying.github.io
***Correspondance:** yue.ying@nersc.no

Stress test in a single observation experiment

We tested how the MSA method performs as N_s goes from 1 to 7. A single wind observation at "+" is assimilated to update the entire wind field for 20 members. As expected, the MSA solution starts to resemble a nonlinear solution (from a particle filter) as N_s increases.



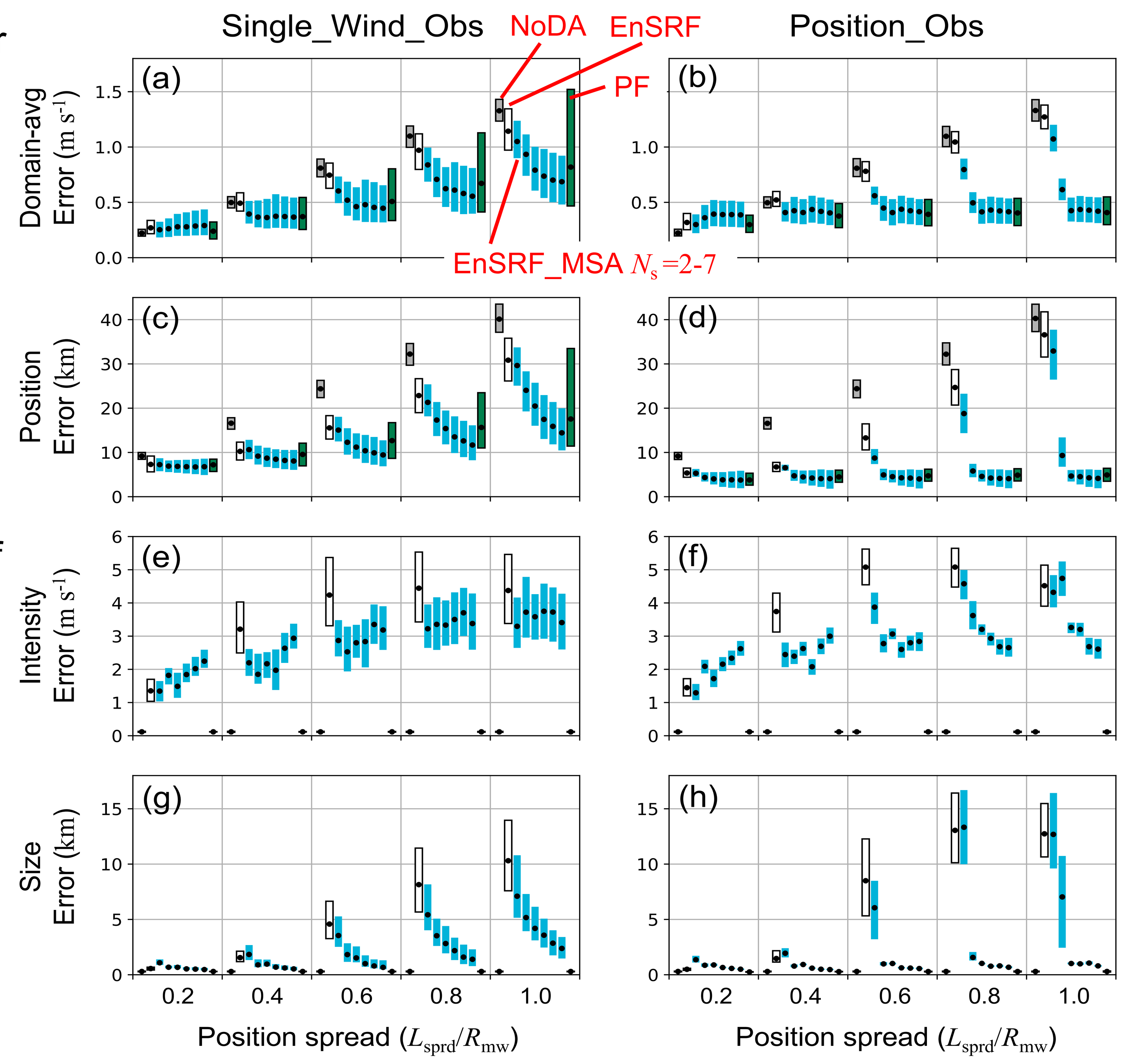
Then 1000 trials with random prior position errors and observation location are done for this assimilation and results are shown as boxplots.

5 different scenarios are tested from low to high prior position spread (increasing nonlinearity).

In linear regime, MSA has slight degradation over the optimal EnKF performance. Weakening of pixel-wise intensity after alignment is the cause.

In nonlinear regimes, the MSA consistently outperforms the traditional EnKF.

With position observations, MSA can reach the same performance no matter how nonlinear the position errors are.

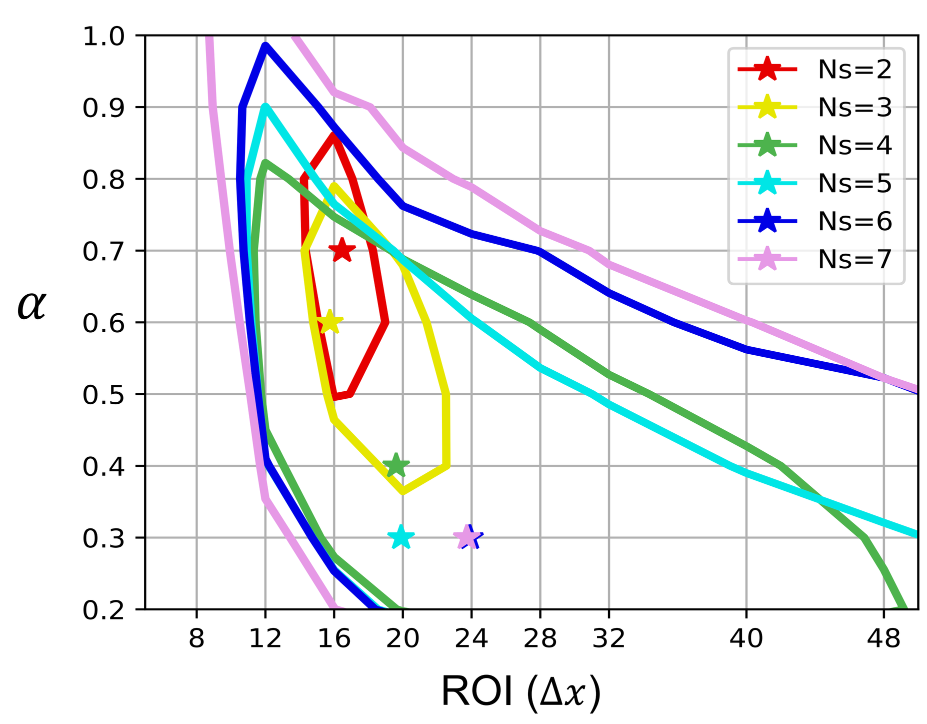


Tuning of localization and inflation

The localization function $\boldsymbol{\rho}_s$ has two tunable parameters: radius of influence (ROI) and a multiplicative factor (α). The question is whether the multiscale framework requires more tuning efforts for these parameters.

Here, manual tuning of ROI and α is done for $s = 1$ with increasing N_s, contours indicate the range of parameters that achieve an error within 1% of the best performance.

For larger-scale components, the method is less sensitive to exact parameter choices.

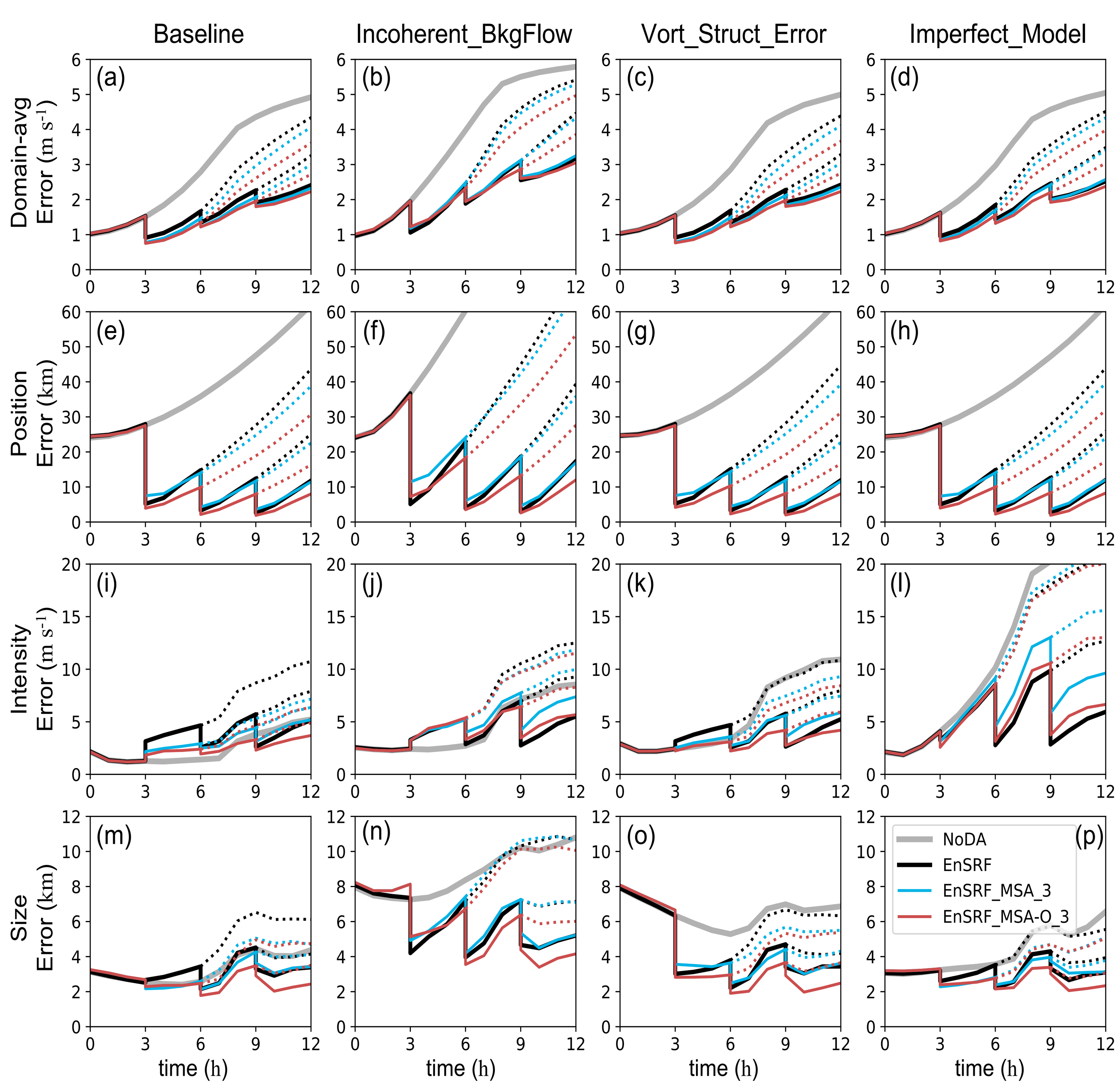


Test in cycling DA

The MSA-O and MSA methods are further tested and compared to the EnSRF in a cycling experiment using a 2D vortex model over 12 h period.

Tests are done in several scenarios: **Baseline** with initial position spread of 0.6; **Incoherent_BkgFlow** where the initial vortex position errors are incoherent with the background flow; **Vort_Struct_Error** where additional prior errors exists for vortex intensity and size; **Imperfect_Model** where the forecast models have biases in the vorticity generation term.

The MSA-O method consistently outperforms the EnSRF, showing lower forecast error growth rate as an indicator for better vortex features in the analysis.



Real applications

A new ensemble data assimilation system (NEDAS) has been developed at NERSC, where the MSA framework is implemented for the EnKF code at NERSC. Currently, we are using the neXtSIM ice model and HYCOM ocean model to test the impact of assimilating satellite-derived ice feature observations on short-term ice forecasts. We also hope to leverage the MSA method to improve the prediction skill for other systems, such as ocean eddies, biogeochemistry, and sun spots.