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Next Generation Ocean Prediction: Preparing for SWOT

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Motivation & Objectives

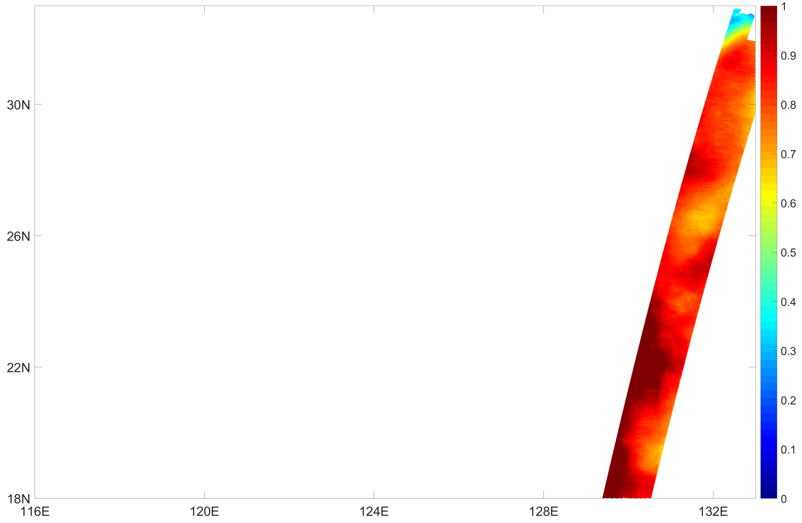
Motivation

- A convergence of modeling and observing capabilities is underway:

1. 1 km regional simulations, capable of resolving submesoscale eddies, are now readily producible.
2. The Surface Water Ocean Topography (SWOT) mission will provide the first global observations of sea surface height at horizontal resolutions capable of constraining the high resolution regional models.

- What impact will this new data provide in an operational setting?
- Using current operational technology, can submesoscale processes be constrained just by adding finer surface data?
- **What technology/assumptions need(s) to be superseded to best utilize this exciting new dataset?**

Simulated 21-day SWOT coverage



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Question 1

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How will SWOT improve ocean prediction skill when using the current operational settings?

Observing System Simulation Experiment (OSSE)

NATURE	
Dynamical Model	Navy Coastal Ocean Model (NCOM)
Horizontal Resolution	1 km
# σ/z Layers	50
Initial Condition	December 1, 2015 3 km NCOM
Boundary Conditions	8 km HYCOM -> 3 km NCOM -> 1 km NCOM
Surface Forcing	Navy Global Environmental Model (NAVGEM)

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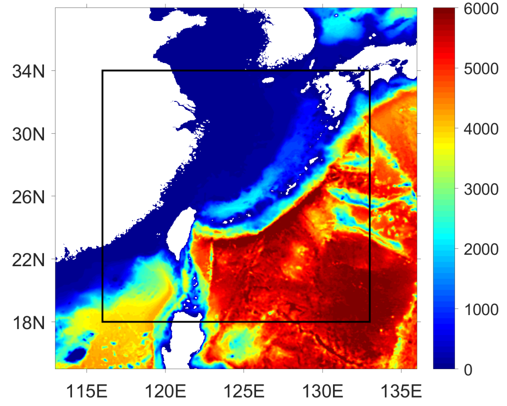

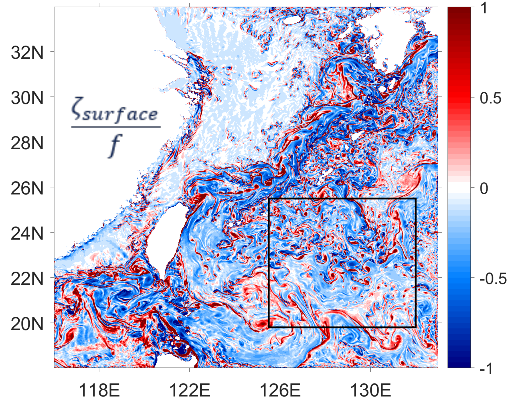

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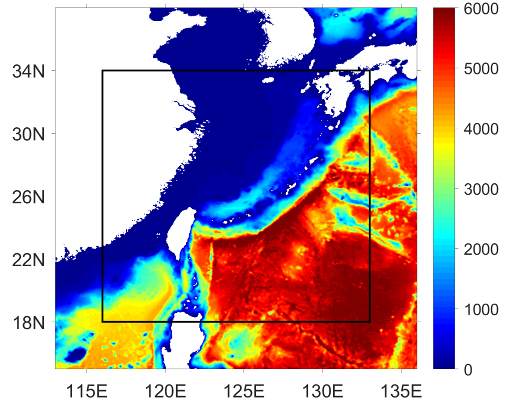

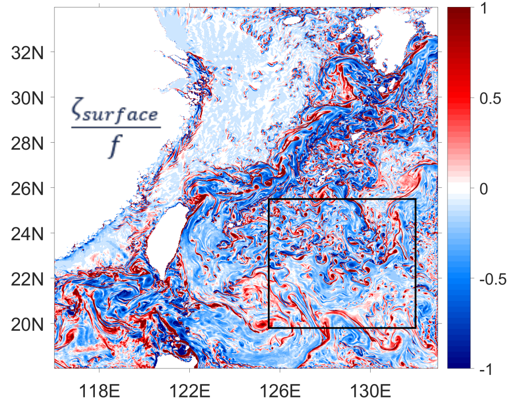

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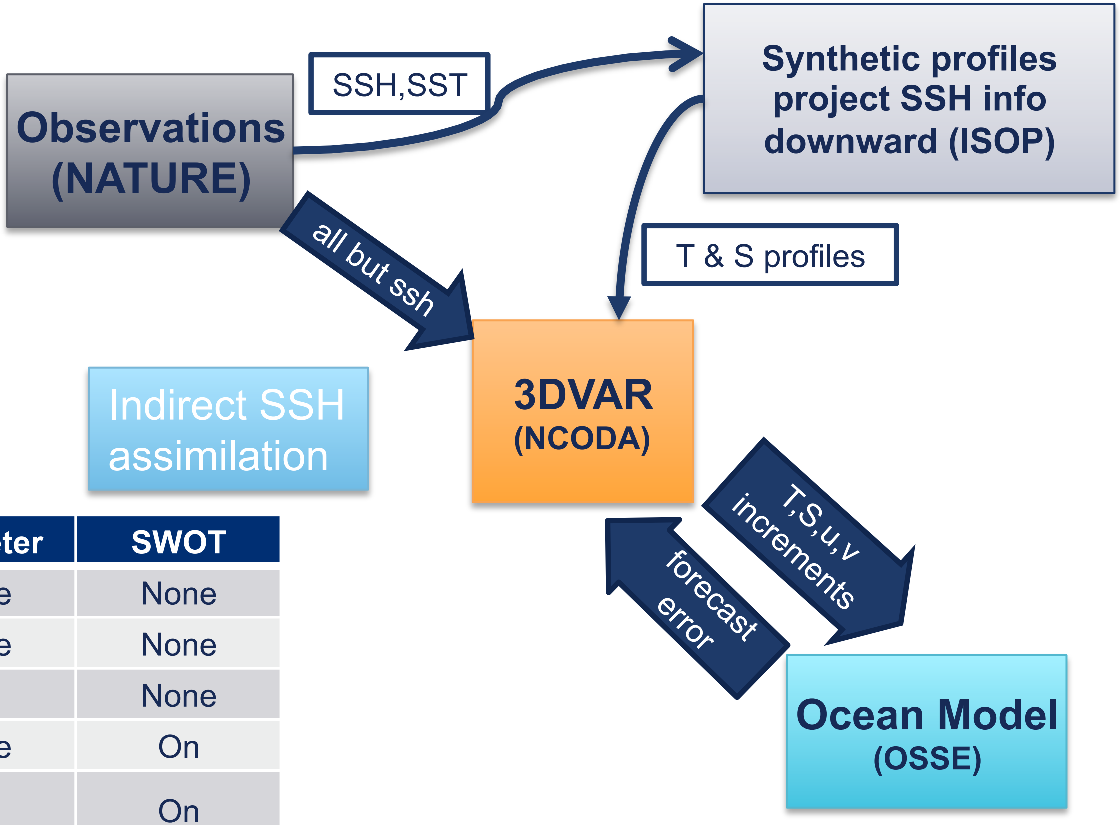
NCODA 3DVAR Data Assimilation

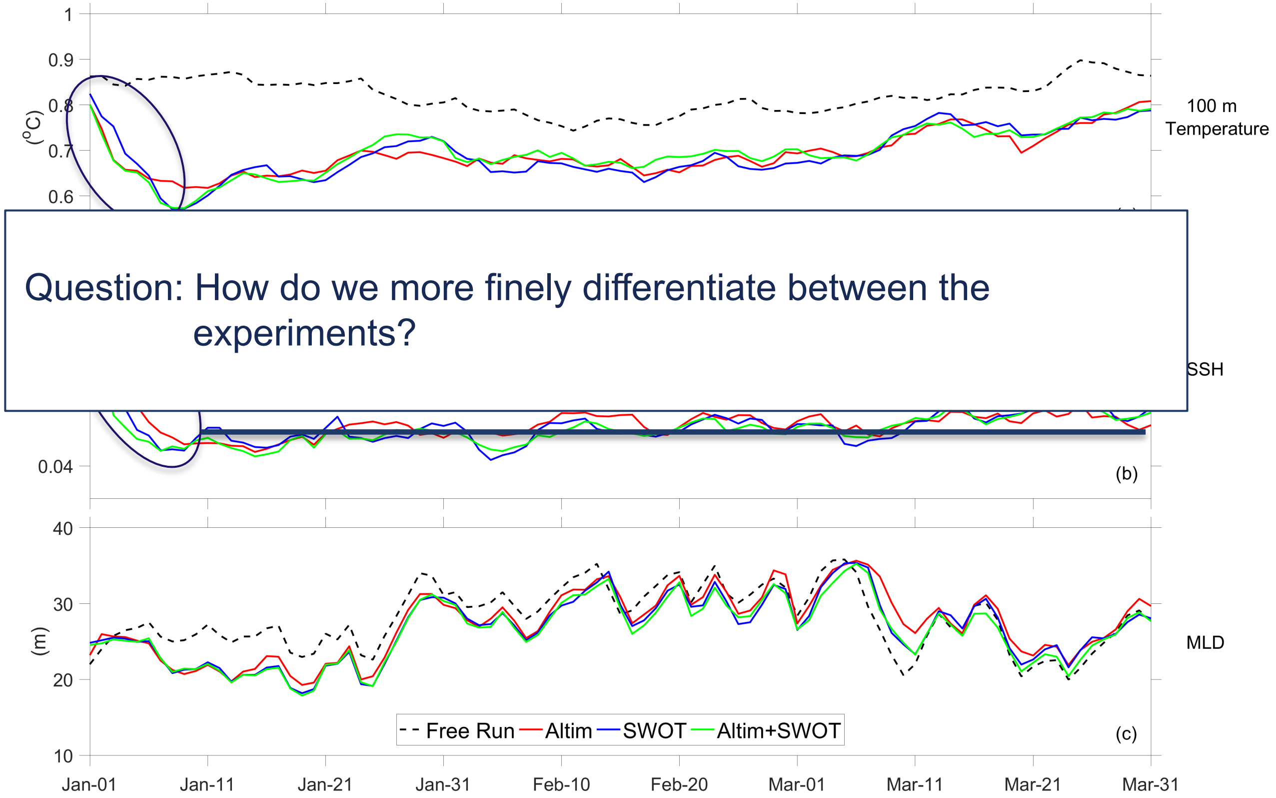
NCODA → Navy Coupled Ocean Data Assimilation
ISOP → Improved Synthetic Ocean Profile System
NCOM → Navy Coastal Ocean Model



	SST	*In Situ*	Altimeter	SWOT
NATURE	None	None	None	None
Free Run	None	None	None	None
Altim	On	On	On	None
SWOT	On	On	None	On
Altim + SWOT	On	On	On	On

Area-Averaged Errors

Mean Absolute Error (NATURE minus OSSE) in water depth > 1000 m



Question: How do we more finely differentiate between the experiments?

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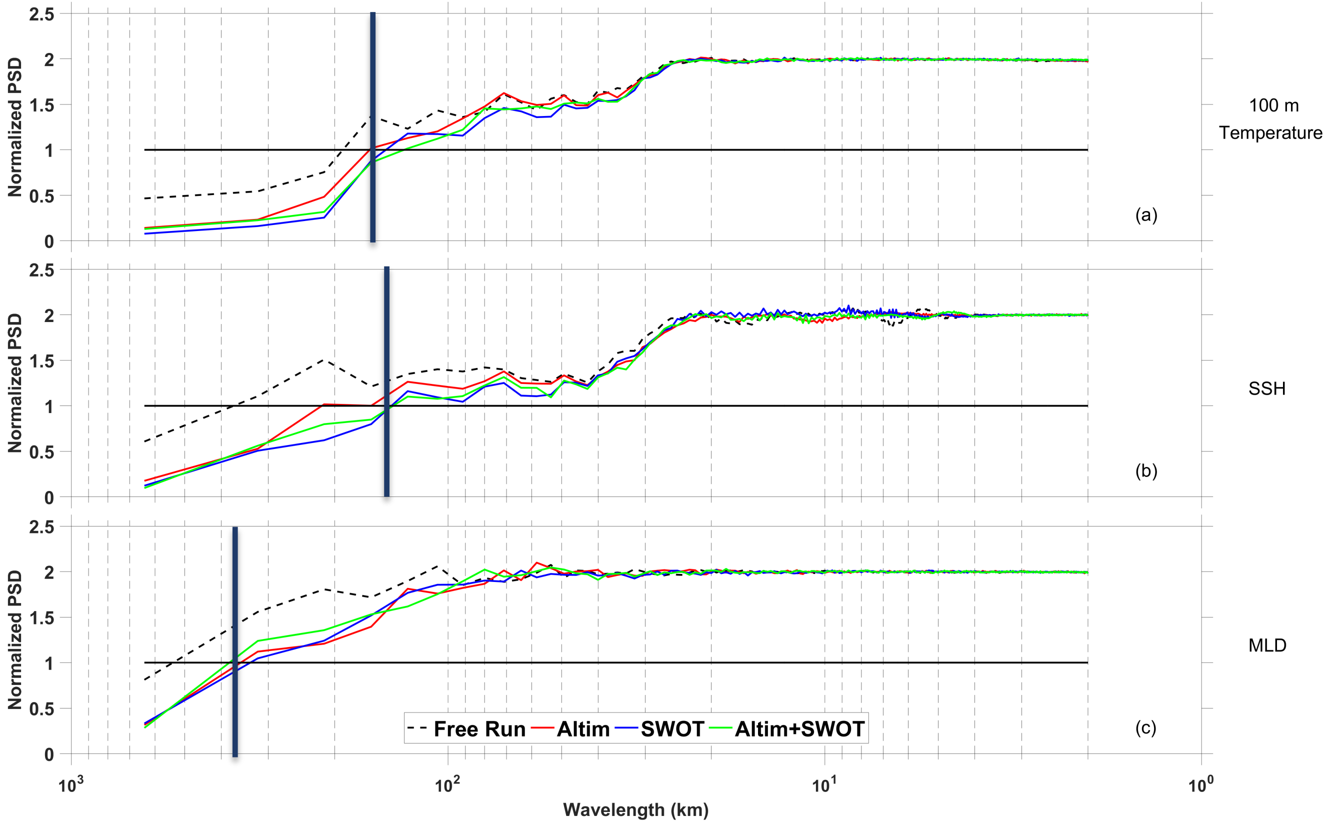
Wavenumber Spectra

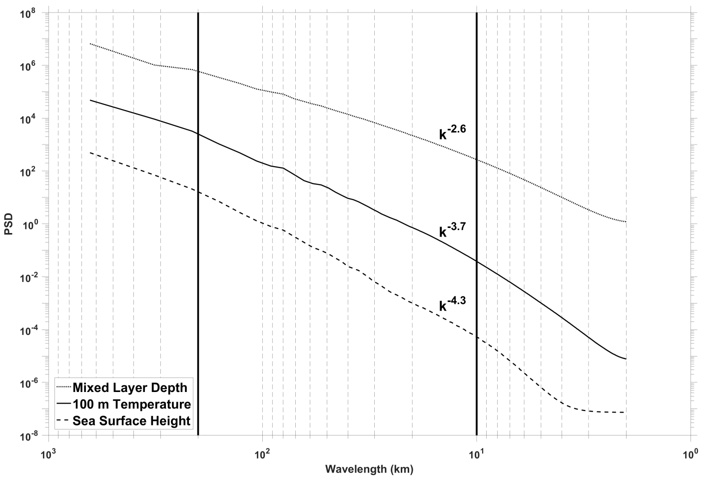
$$\frac{\varepsilon_{OSSE}}{\langle \gamma_{NATURE}, \gamma_{OSSE} \rangle}$$

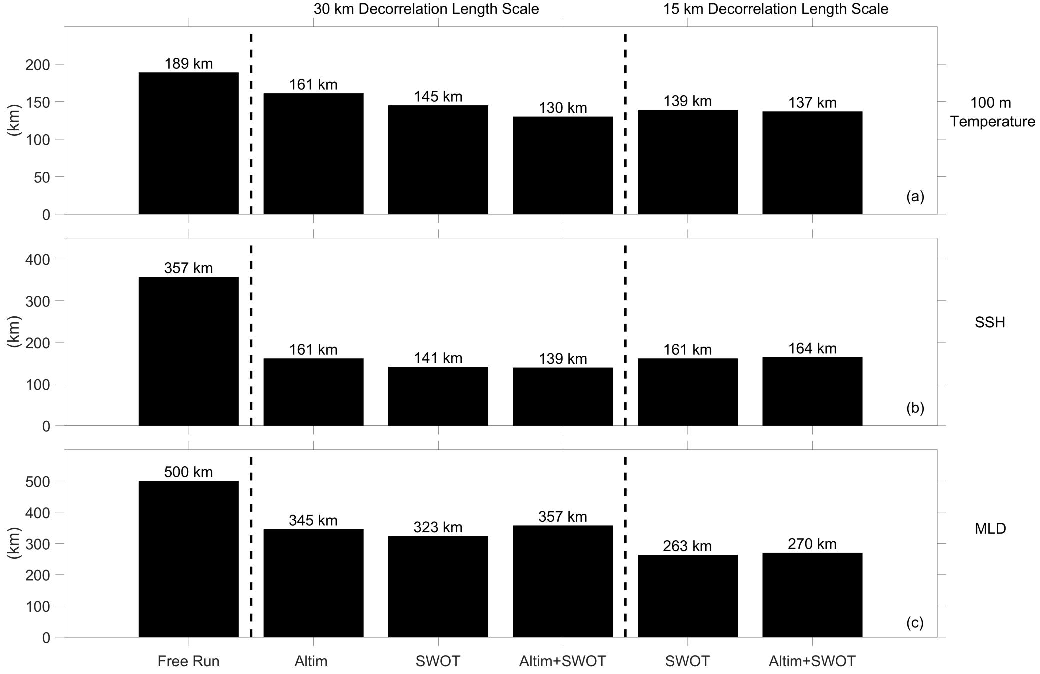
ε_{OSSE} =Spectrum of NATURE – OSSE
γ_{NATURE}=Spectrum of NATURE
γ_{OSSE}=Spectrum of OSSE
<> = Mean



Wavenumber Spectra

- Variables with relatively low energy at short wavelengths feature higher errors when reducing the decorrelation length scale.
- The reverse is true for variables with relatively higher energy at short wavelengths.





A multiscale solution is required

D'Addezio, J.M., et al., 2019. Quantifying wavelengths constrained by simulated SWOT observations in a submesoscale resolving ocean analysis/forecasting system. *Ocean Modelling*, 135, 40-55.

Question 2

How can we extract more information from the SWOT observations without introducing scale aliasing?

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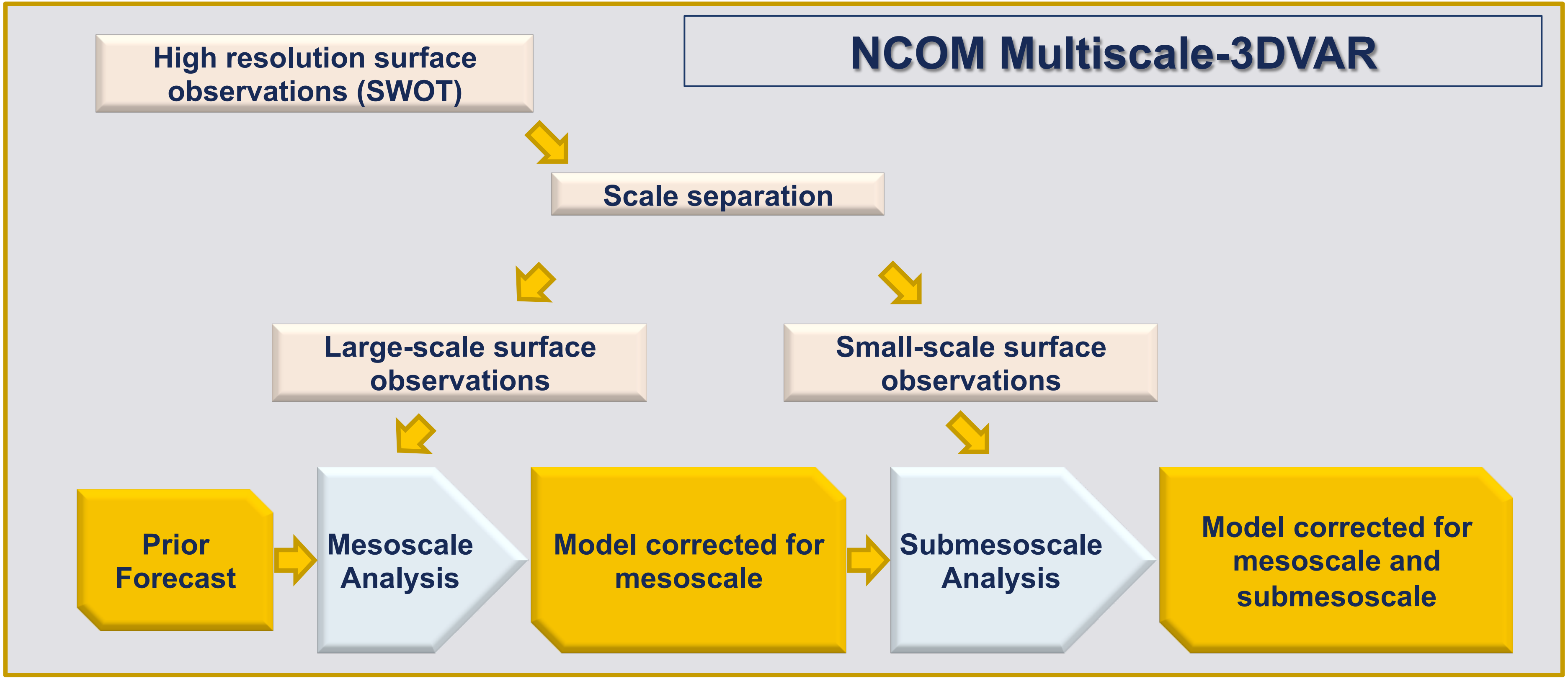
Multiscale Assimilation



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Multiscale Assimilation

Background

↓

Analysis (1)
Large-Scale Observations
Large Decorrelation Length Scale
Increments (1) to **Background**

↓

Analysis (2)
Small-Scale Observations
Smaller Decorrelation Length Scale
Increments (2) to **Analysis (1)**

↓

Background + Increments (1) + Increments (2)

↓

Forecast

$$\begin{aligned} J_L(\delta \mathbf{x}_L) &= \frac{1}{2}\delta \mathbf{x}_L^T \mathbf{B}_L{}^{-1}\delta \mathbf{x}_L \\ &+ \frac{1}{2}\left(\mathbf{H}^d \delta \mathbf{x}_L - \mathbf{d}_L^d\right)^T \left(\mathbf{R}_L^d\right)^{-1} \left(\mathbf{H}^d \delta \mathbf{x}_L - \mathbf{d}_L^d\right) \\ &+ \frac{1}{2}\left(\mathbf{H}^c \delta \mathbf{x}_L - \mathbf{d}^c\right)^T \left(\mathbf{R}^s + \mathbf{H}^c \mathbf{B}_S \mathbf{H}^{cT}\right)^{-1} \left(\mathbf{H}^c \delta \mathbf{x}_L - \mathbf{d}^c\right) \end{aligned}$$

$$\begin{aligned} J_S(\delta \mathbf{x}_S) &= \frac{1}{2}\delta \mathbf{x}_S^T \mathbf{B}_S^{-1}\delta \mathbf{x}_S \\ &+ \frac{1}{2}\left(\mathbf{H}^d \delta \mathbf{x}_S - \mathbf{d}_S^d\right)^T \left(\mathbf{R}_S^d\right)^{-1} \left(\mathbf{H}^d \delta \mathbf{x}_S - \mathbf{d}_S^d\right) \\ &+ \frac{1}{2}\left(\mathbf{H}^c \delta \mathbf{x}_S - \mathbf{d}^c\right)^T \left(\mathbf{R}^c + \mathbf{H}^c \mathbf{B}_L \mathbf{H}^{cT}\right)^{-1} \left(\mathbf{H}^c \delta \mathbf{x}_S - \mathbf{d}^c\right) \end{aligned}$$

Li et al. (2015)

Multiscale Assimilation

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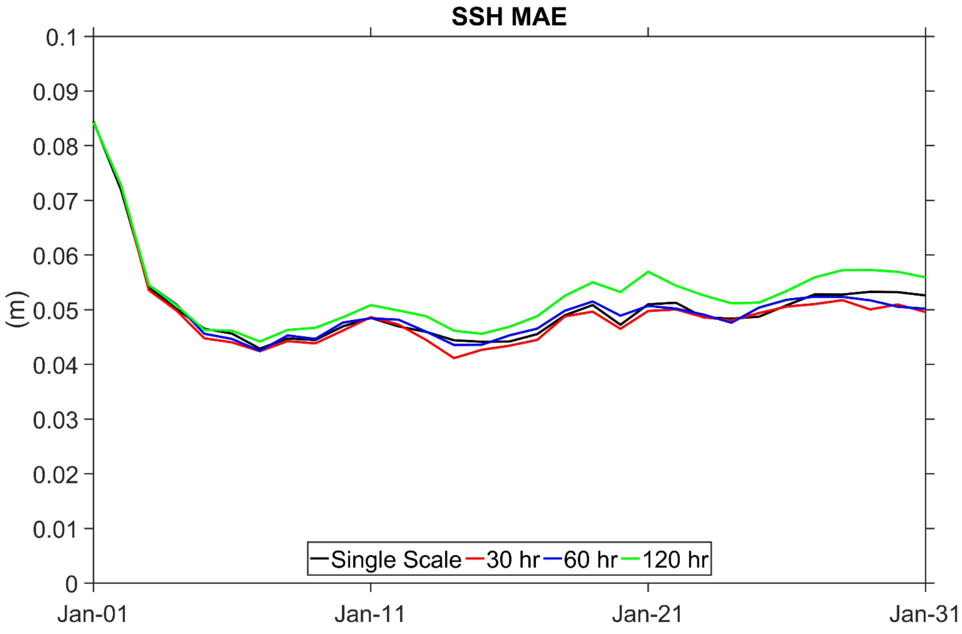
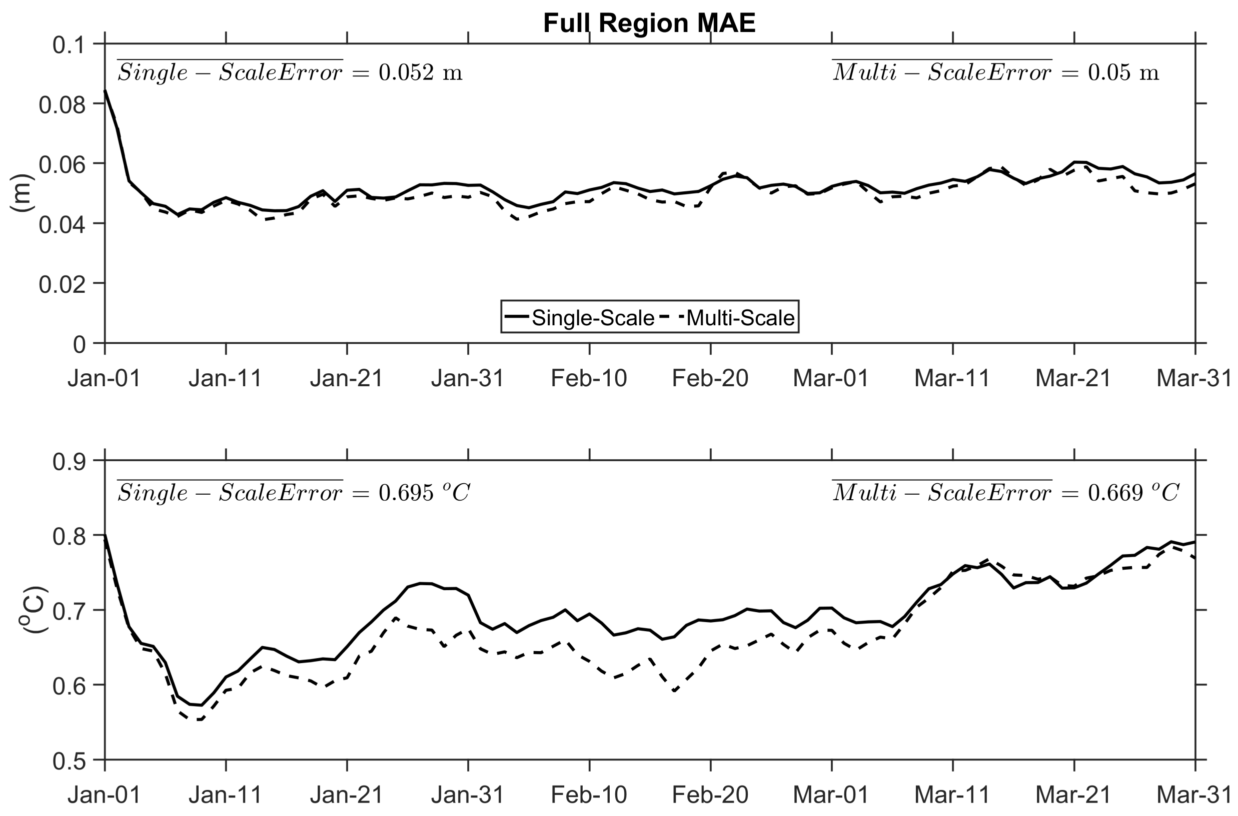


	MAE (cm)
Single Scale	5
Multi Scale (30 hr small-scale window)	4.94
Multi Scale (60 hr small-scale window)	5.04
Multi Scale (120 hr small-scale window)	5.3

Multiscale Assimilation



SSH

100 m temperature

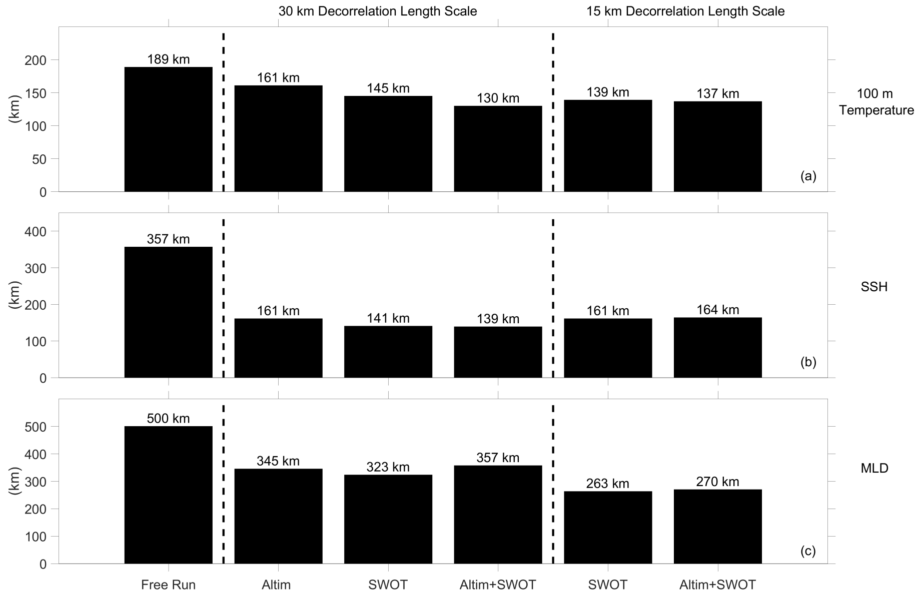
Summary and Conclusions

Conclusions

- SWOT data make a considerable improvement to both analysis and forecast skill when using the current system.
- A multi-scale analysis procedure extracts additional data from the high-resolution surface observations without biasing errors into one scale or another.
- Next steps:

1. We have taken length scales into account, but not differences in physics (i.e. we assume mesoscale dynamics in both scales).
2. Need to implement a system that accounts for the complex SWOT error budget.

How low can we go?

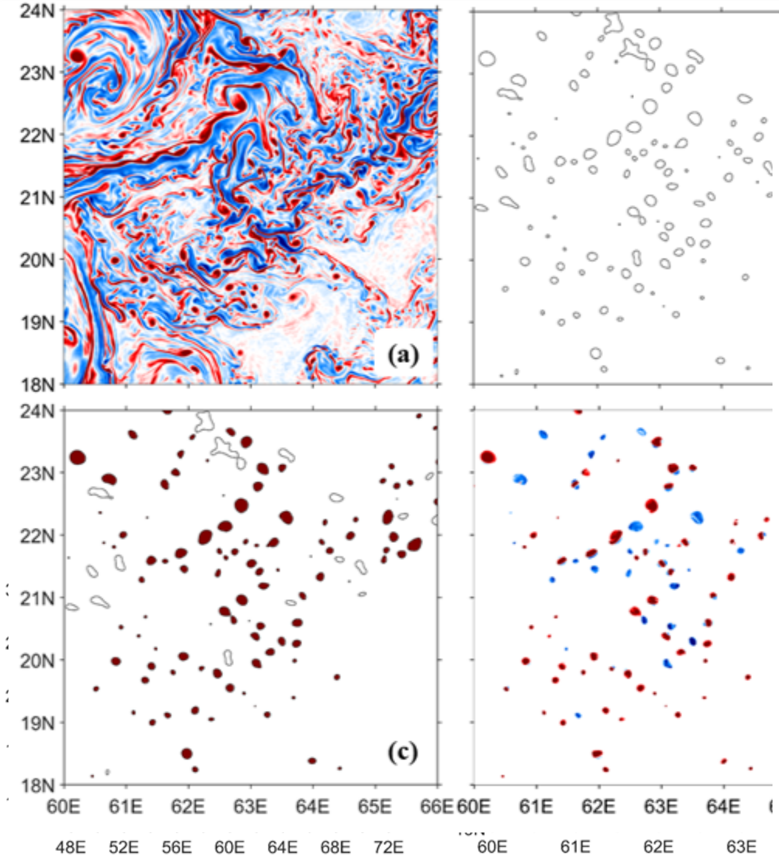


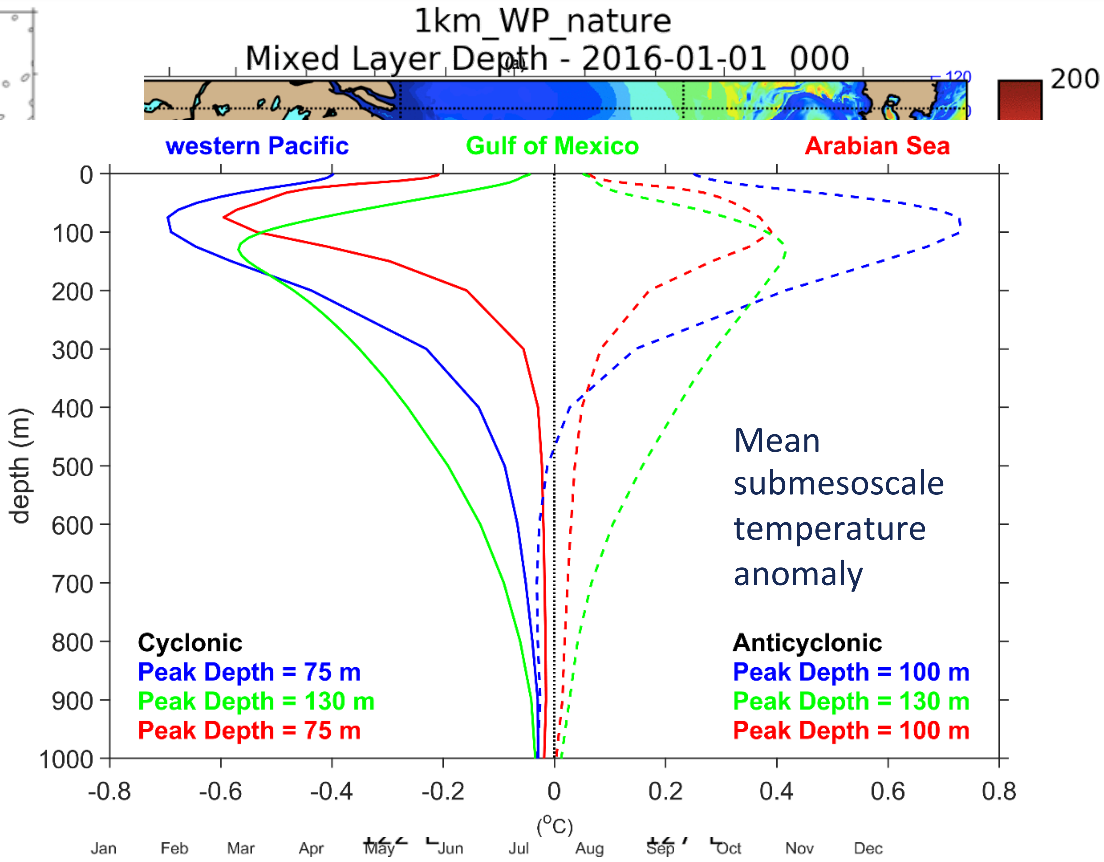
Extra Slides

Question 3

How do we account for the disparate physics found within each scale?

Submesoscale Dynamics





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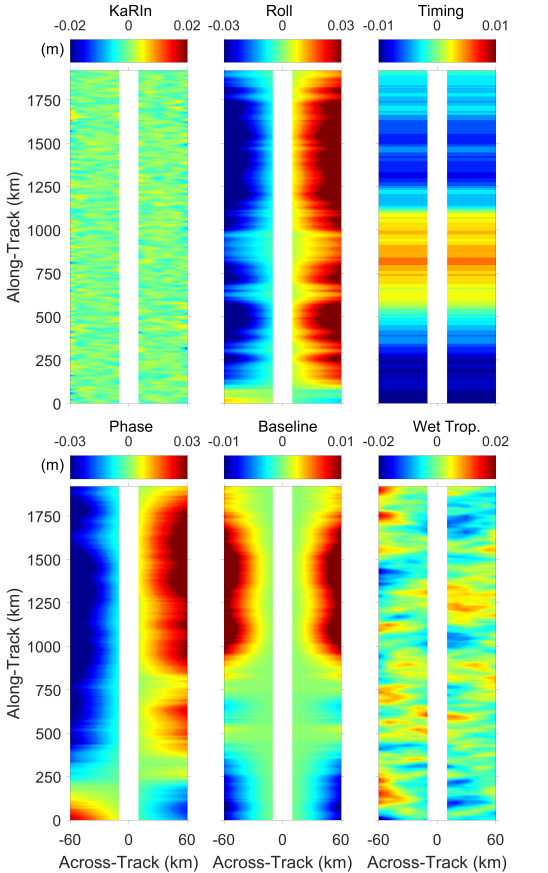
Question 4

How do we account for the complex SWOT error budget?



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SWOT Observation Error Covariance

$$\delta \mathbf{x}_m = \mathbf{B}_m \mathbf{H}^T \left(\mathbf{H} \mathbf{B}_m \mathbf{H}^T + \mathbf{R}_m \right)^{-1} \delta \mathbf{d}_m$$

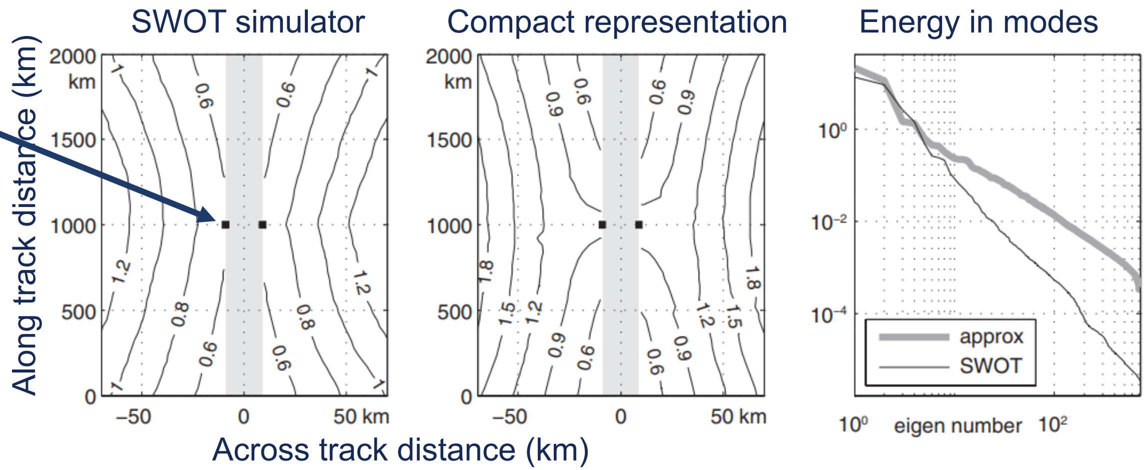
$$\delta \mathbf{x}_s = \mathbf{B}_s \mathbf{H}^T \left(\mathbf{H} \mathbf{B}_s \mathbf{H}^T + \mathbf{R}_s \right)^{-1} \delta \mathbf{d}_s$$

R errors contains representativeness and sensor errors

$\mathbf{R}_m$ Submesoscale, internal waves, unmodeled physics, sensor error - $\mathbf{R}_s + \mathbf{R}_i + \mathbf{R}_u + \mathbf{R}_o$

$\mathbf{R}_s$ Submesoscale, internal waves, unmodeled physics, sensor error - $\mathbf{R}_i + \mathbf{R}_u + \mathbf{R}_o$

Error covariance at this point



Units are 100 cm²

Yaremchuk, M., et al., 2018. On the approximation of the inverse error covariances of high-resolution satellite altimetry data. Quarterly Journal of the Royal Meteorological Society, 144(715), pp.1995-2000.