U.S. NAVAL RESEARCH LABORATORY

THE UNIVERSITY of NEW ORLEANS

Multi-Scale Assimilation of Simulated SWOT observations

Joseph M. D'Addezio[1]

Innocent Souopgui[2], Clark D. Rowley[1], Scott R. Smith[1], Gregg A. Jacobs[1], Robert W. Helber[1], Max Yaremchuk[1], and John J. Osborne[1]

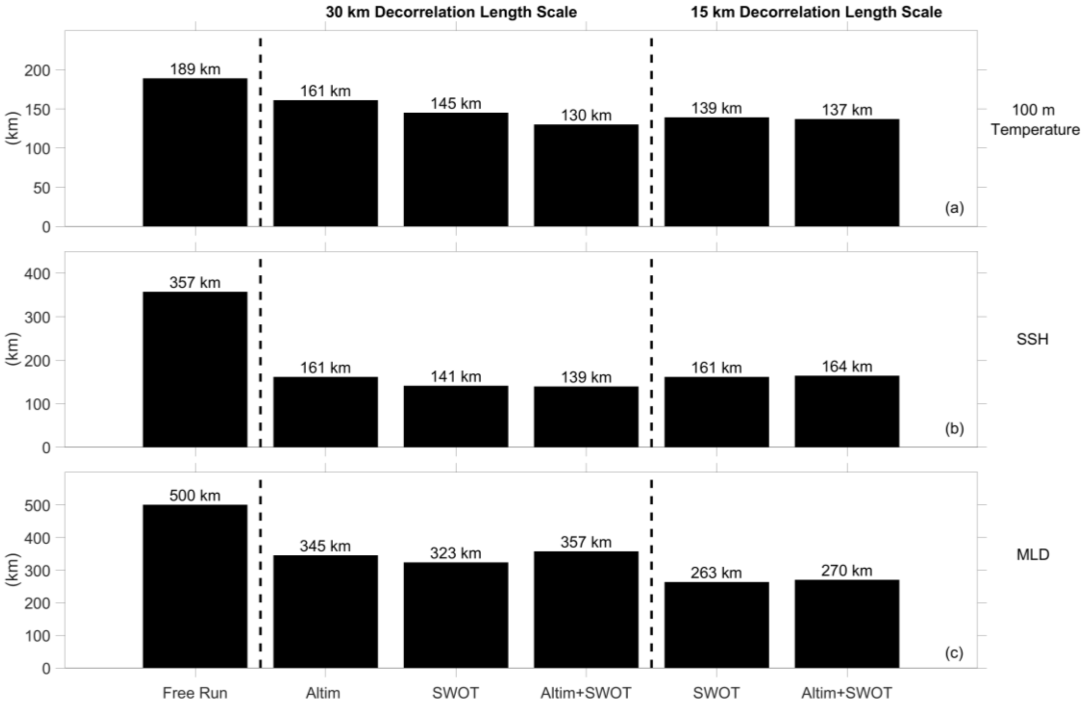
[1]Naval Research Laboratory, Ocean Dynamics and Prediction, MS, USA

[2]University of New Orleans, Department of Physics, LA, USA

Multi-Scale Assimilation of Simulated SWOT observations

Motivation & Objectives

U.S. NAVAL RESEARCH LABORATORY



Minimum constrained wavelength = smallest wavelength the model has skill

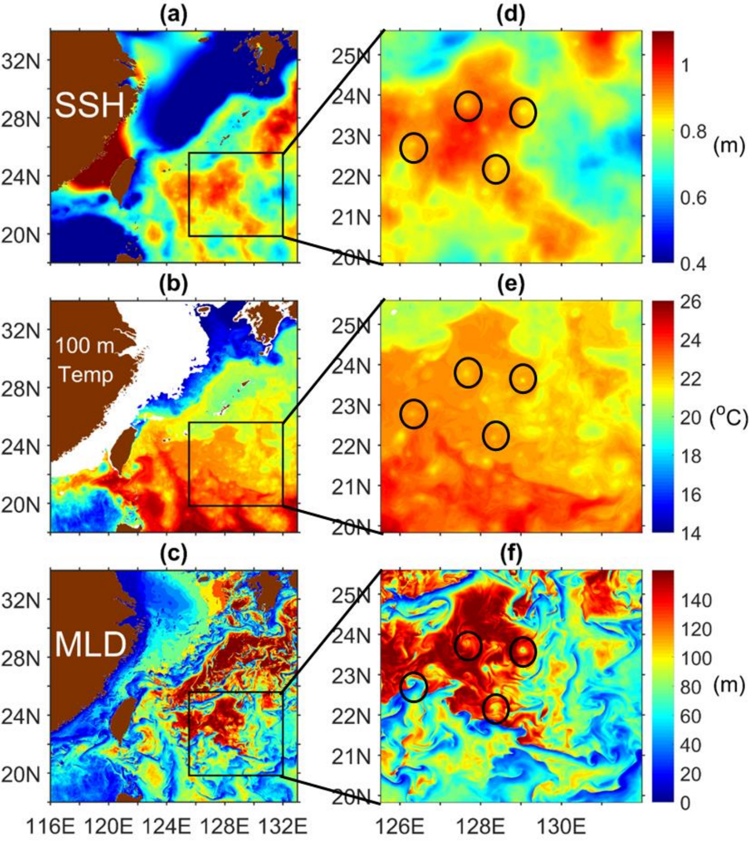
smaller = better

Single-scale assimilation of SWOT observations cannot constrained wavelengths below 100 km (D’Addezio et al., 2019)

Hypothesis: A multi-scale assimilation is required to fully utilize SWOT observations

Methods - OSSE

U.S. NAVAL RESEARCH LABORATORY



High-resolution model (1 km) can produce sub-mesoscale features.

The current regular observations cannot constrain their true position in the real ocean.

Can't test SWOT data yet. Need to use an Observing System Simulation Experiment (OSSE).

Western Pacific ocean is modeled. Simulated observations are extracted at real observation times and locations. JPL SWOT simulator is used to make simulated SWOT data.

U.S. NAVAL RESEARCH LABORATORY

Methods – Multi-scale formulation

Multi-scale NCODA-3DVAR

Background

3DVAR Analysis (1)
Large-Scale Observations
Large Decorrelation Length Scale
Increments (1) to **Background**

3DVAR Analysis (2)
Small-Scale Observations
Smaller Decorrelation Length Scale
Increments (2) to **Analysis (1)**

Background + Increments (1) + Increments (2)

Forecast

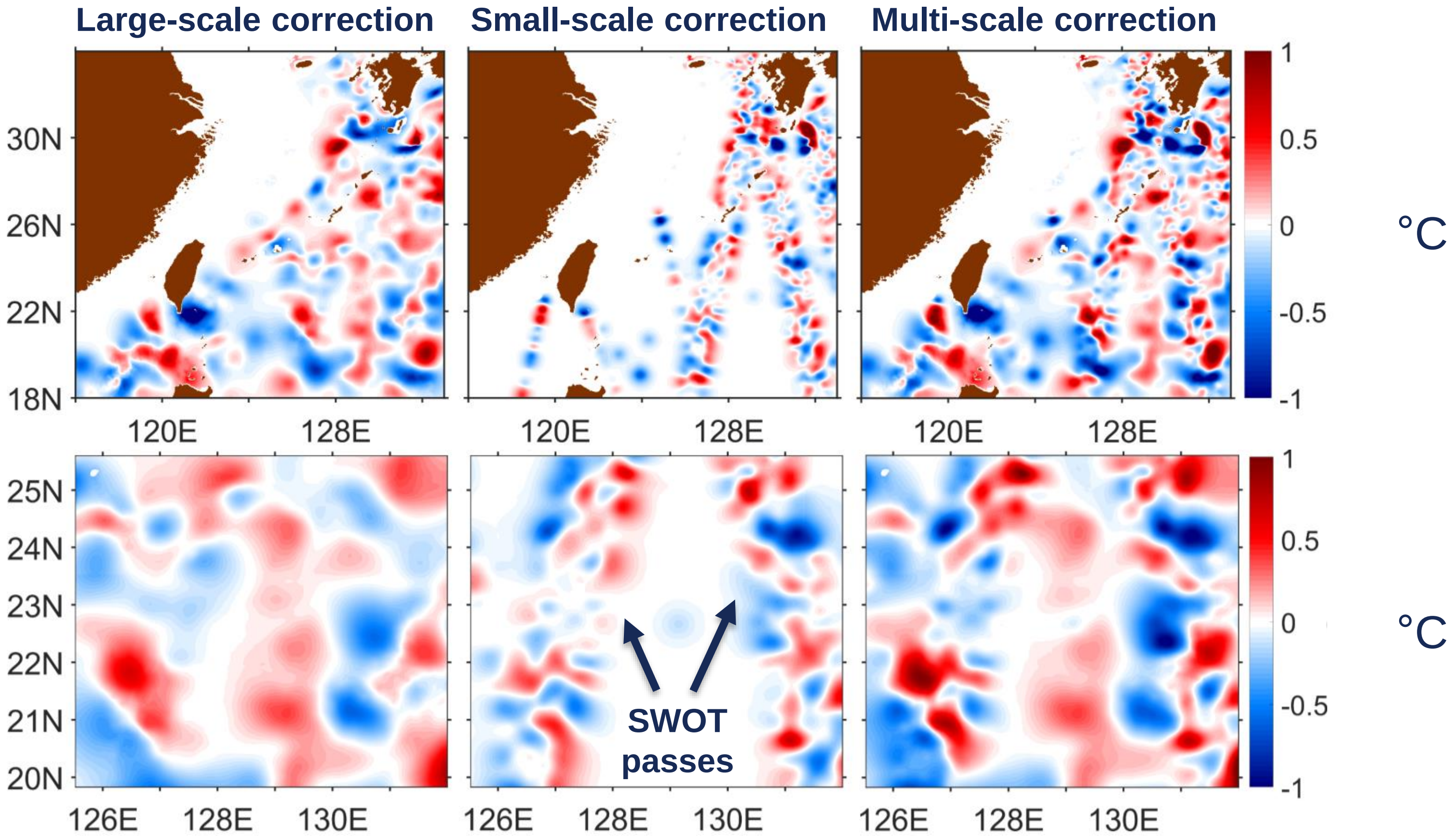
$$\delta\mathbf{x} = \mathbf{P}_L\delta\mathbf{x} + \mathbf{P}_S\delta\mathbf{x} = \delta\mathbf{x}_\mathrm{L} + \delta\mathbf{x}_S$$

$$J(\delta\mathbf{x}_L) = \frac{1}{2}\delta\mathbf{x}_L^\mathrm{T}\mathbf{B}_\mathrm{L}^{-1}\delta\mathbf{x}_L + \frac{1}{2}(\mathbf{H}\delta\mathbf{x}_L - \mathbf{d})^\mathrm{T}\left(\mathbf{R} + \mathbf{H}\mathbf{B}_S\mathbf{H}^\mathrm{T}\right)^{-1}(\mathbf{H}\delta\mathbf{x}_L - \mathbf{d})$$

$$J(\delta\mathbf{x}_S) = \frac{1}{2}\delta\mathbf{x}_S^\mathrm{T}\mathbf{B}_S^{-1}\delta\mathbf{x}_S + \frac{1}{2}(\mathbf{H}\delta\mathbf{x}_S - \mathbf{d})^\mathrm{T}\left(\mathbf{R} + \mathbf{H}\mathbf{B}_L\mathbf{H}^\mathrm{T}\right)^{-1}(\mathbf{H}\delta\mathbf{x}_S - \mathbf{d})$$

Methods – Increment visualization

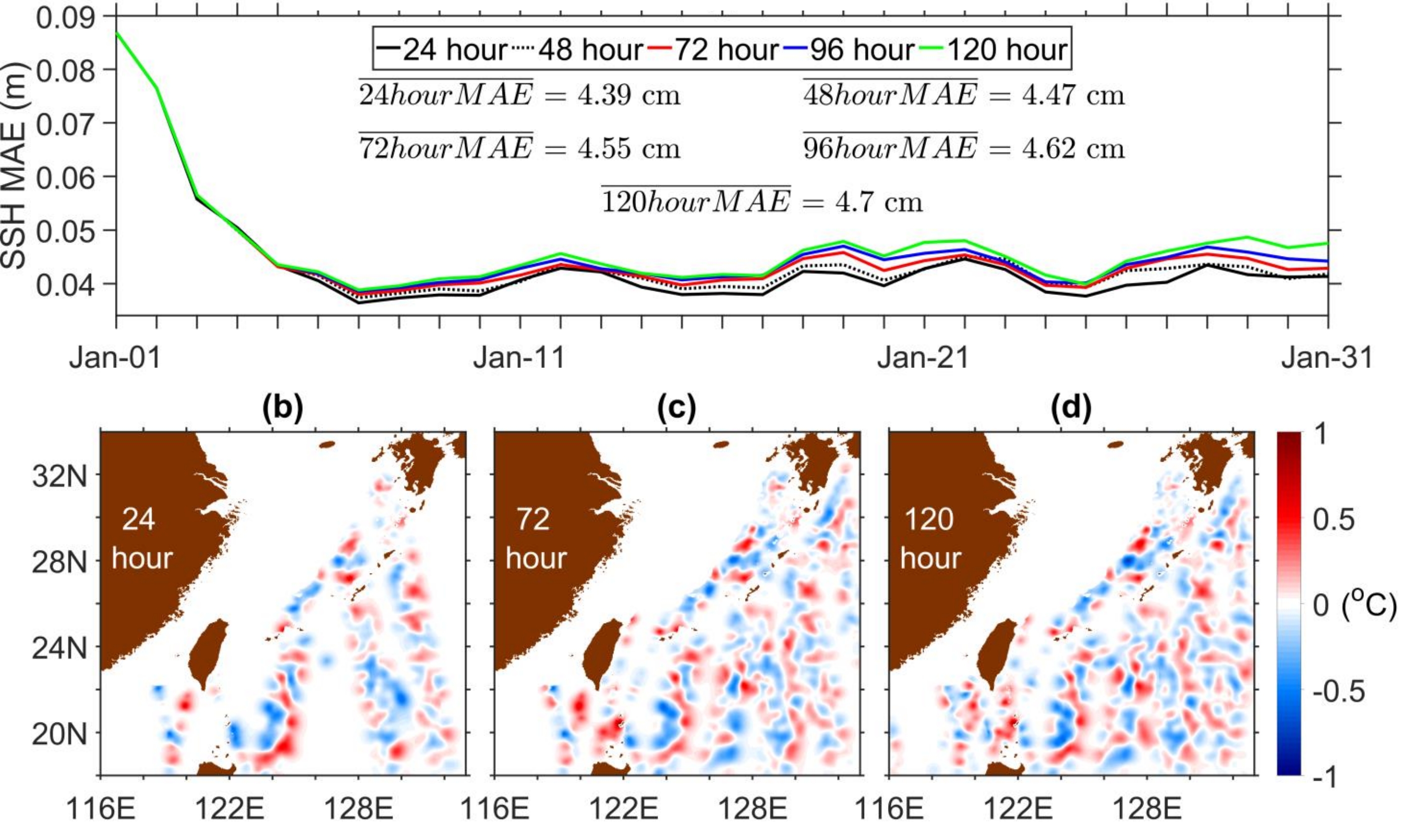
100 m temperature increments



Multi-Scale Assimilation of Simulated SWOT observations

Methods – Temporal component

Observation window of the small-scale update



Temporal component observed

Small-scale update requires a shorter observation window (i.e. time window over which observations are gathered for assimilation)

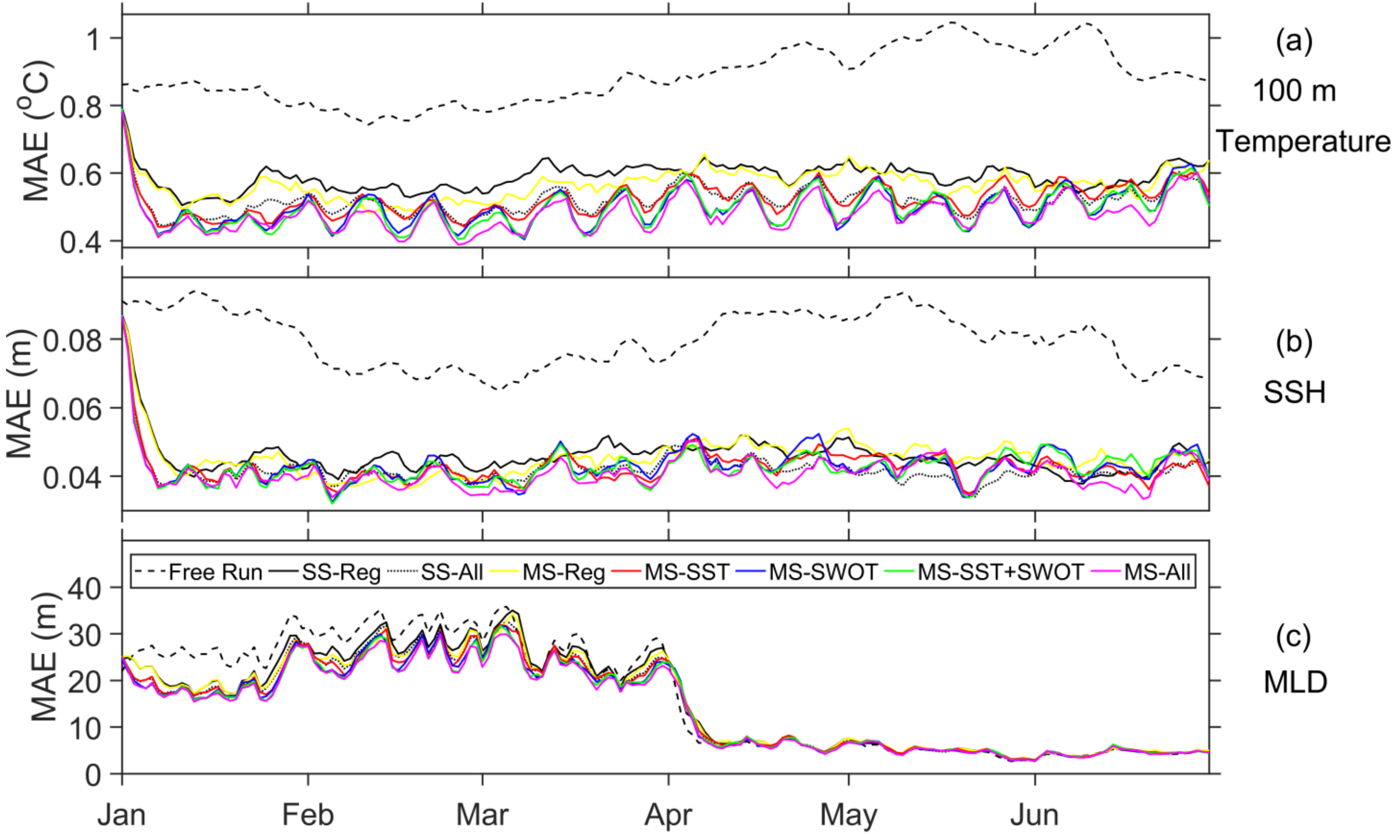
Smaller-scale features are transient

Methods - Experiments

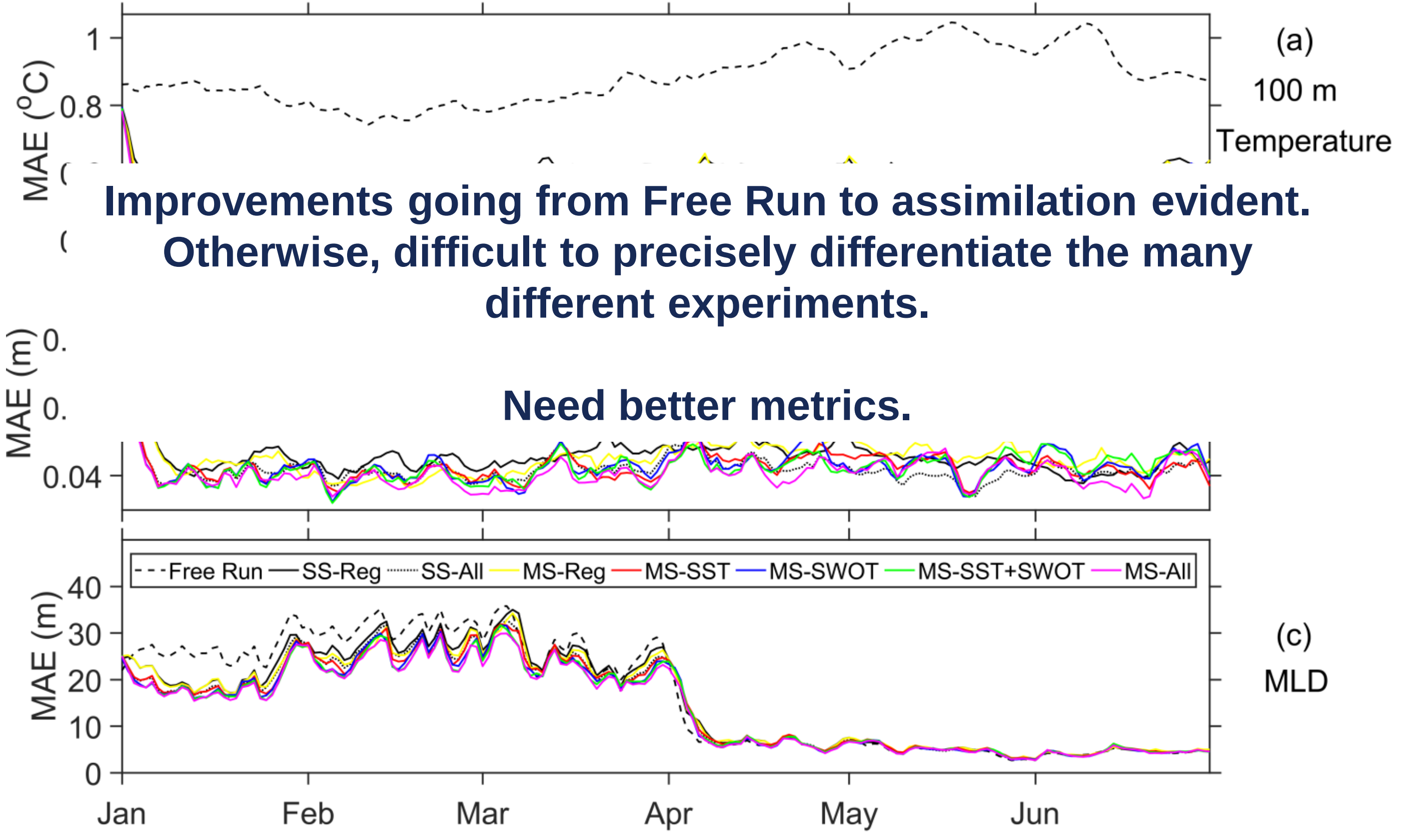
	Profiles		SST		Altimeters		SWOT	
Analysis Step	1	2	1	2	1	2	1	2
Free Run								
SS-Reg	Yes		Yes		Yes		No	
SS-All	Yes		Yes		Yes		Yes	
MS-Reg	Yes	Yes	Yes	Yes	Yes	Yes	No	No
MS-SST	Yes	Yes	Yes	Yes	Yes	No	Yes	No
MS-SWOT	Yes	No	Yes	No	Yes	No	Yes	Yes
MS-SST-SWOT	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
MS-All	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Multi-Scale Assimilation of Simulated SWOT observations

Results – Time series



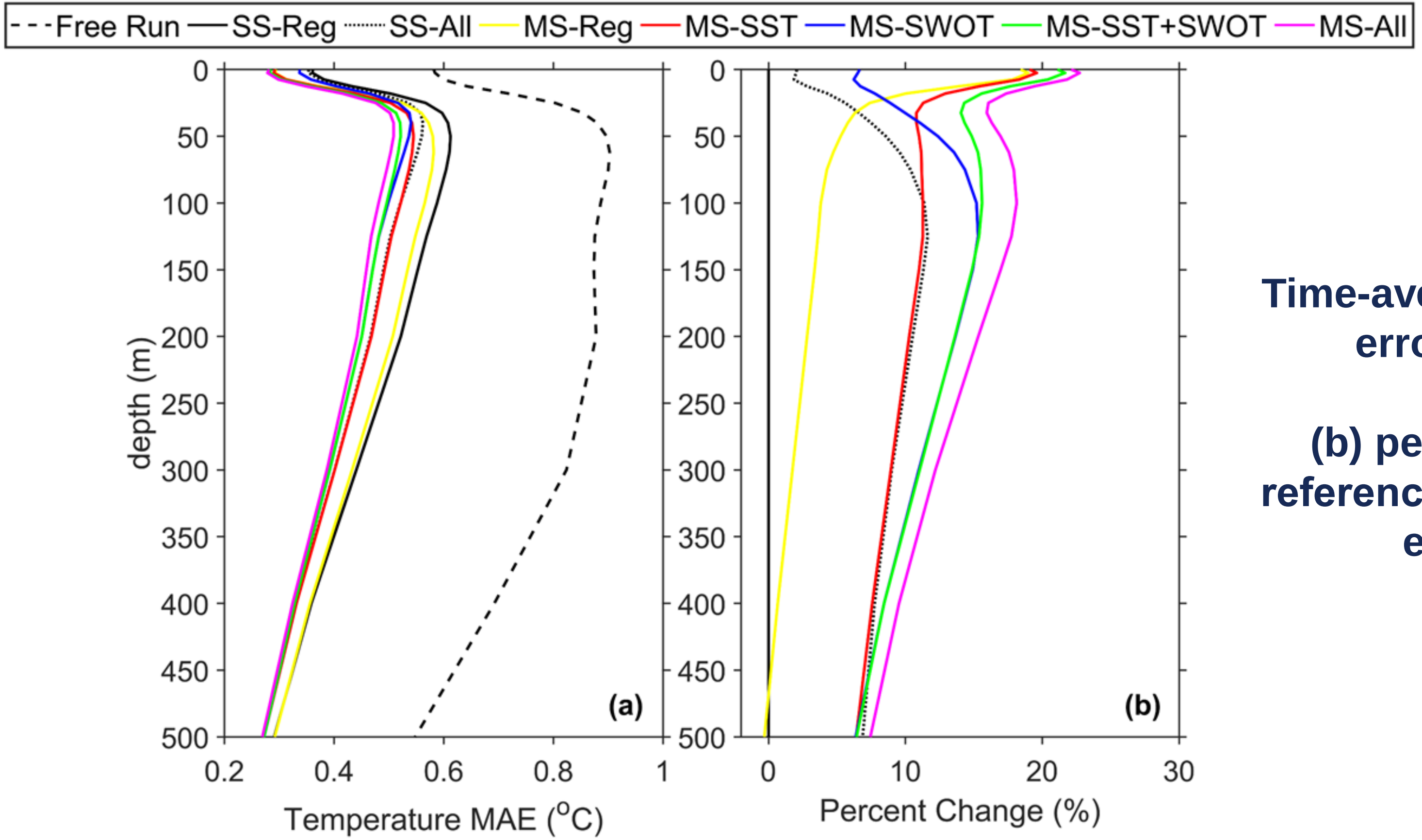
Results – Time series



Improvements going from Free Run to assimilation evident. Otherwise, difficult to precisely differentiate the many different experiments.

Need better metrics.

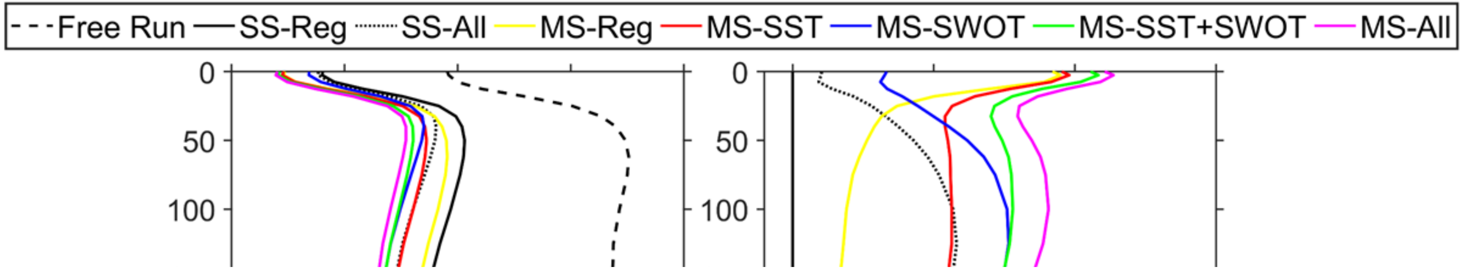
Results – Time-depth errors



Time-averaged (6 months) error with depth.

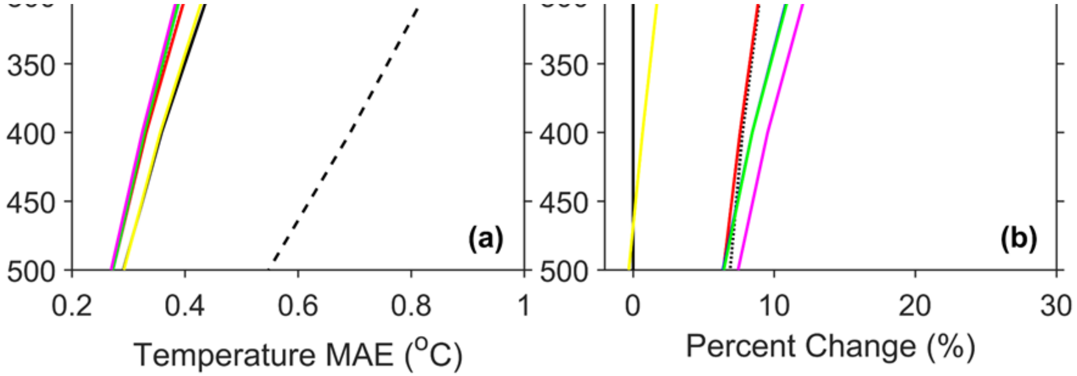
(b) percent change is referenced to the 'SS-Reg' experiment.

Results – Time-depth errors

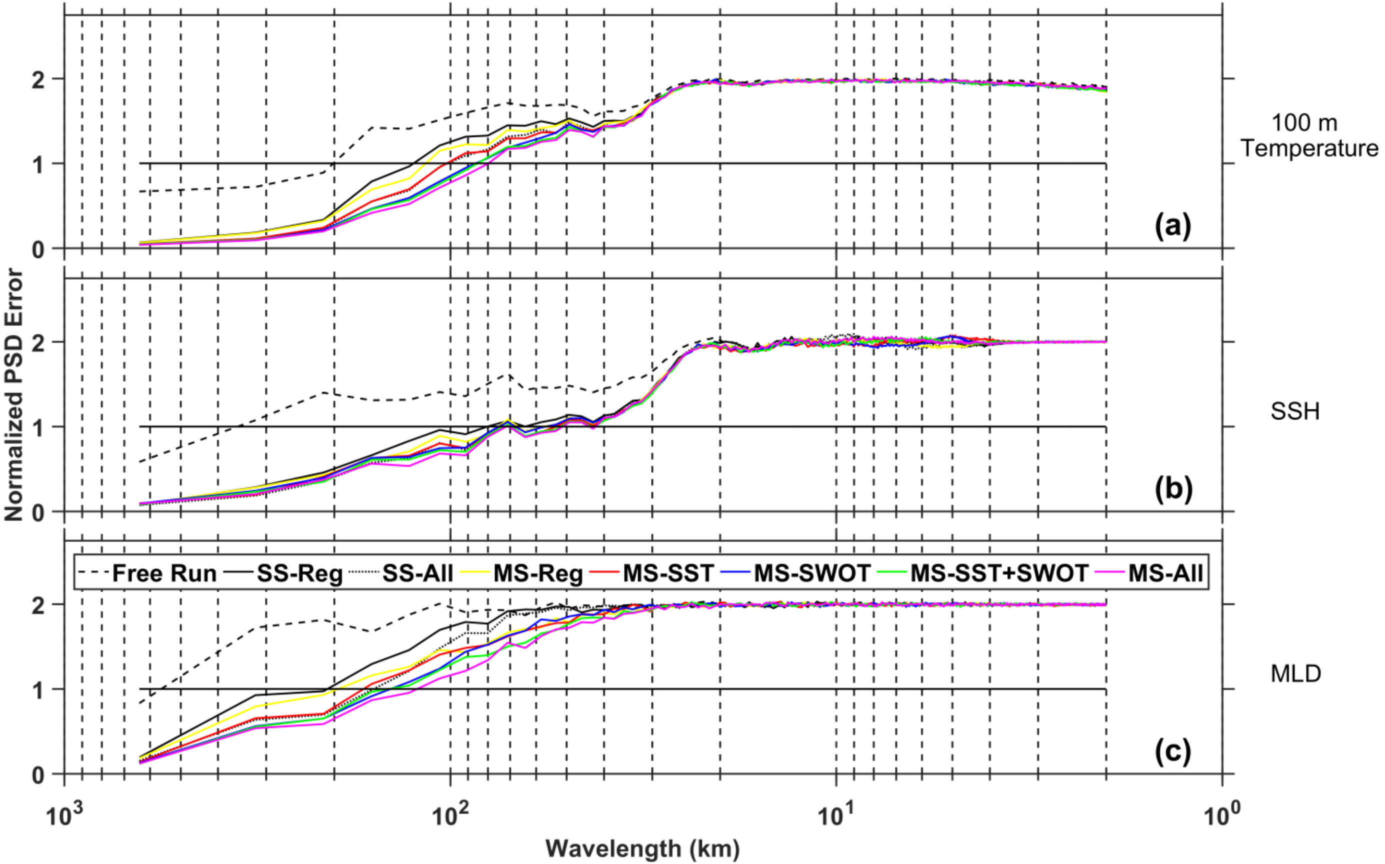


Better. Now we can see a clear progression of increased skill from no-SWOT to SWOT and single-scale to multi-scale.

One more trick.



Results – Constrained wavelengths

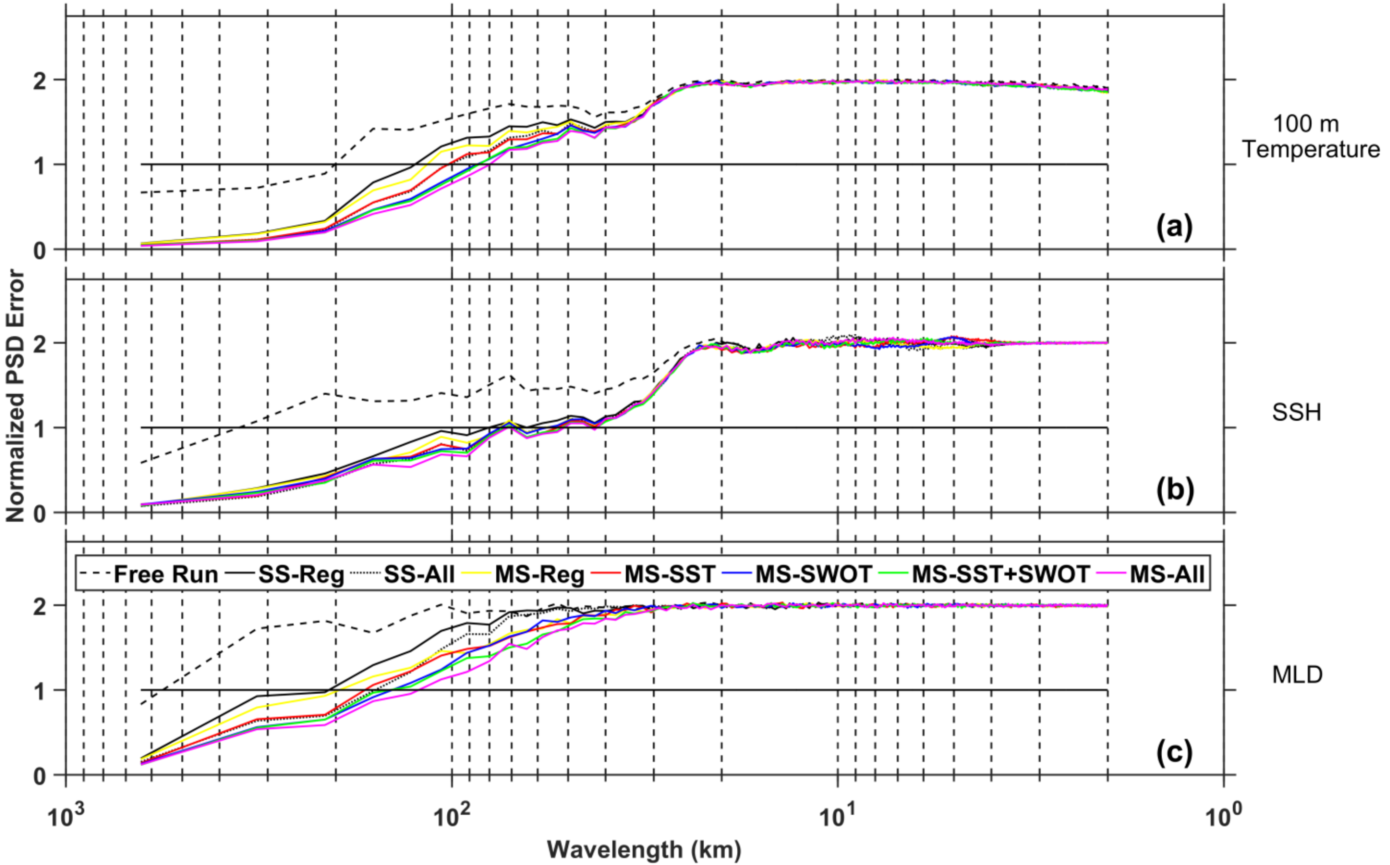


$$\frac{\varepsilon_{OSSE}}{\langle \gamma_{NATURE}, \gamma_{OSSE} \rangle}$$

ε_{OSSE} is the PSD of the OSSE error (NATURE minus OSSE), γ_{NATURE} is the PSD of the Nature Run, γ_{OSSE} is the PSD of the OSSE, and the brackets denote the mean of the two spectra.

Multi-Scale Assimilation of Simulated SWOT observations

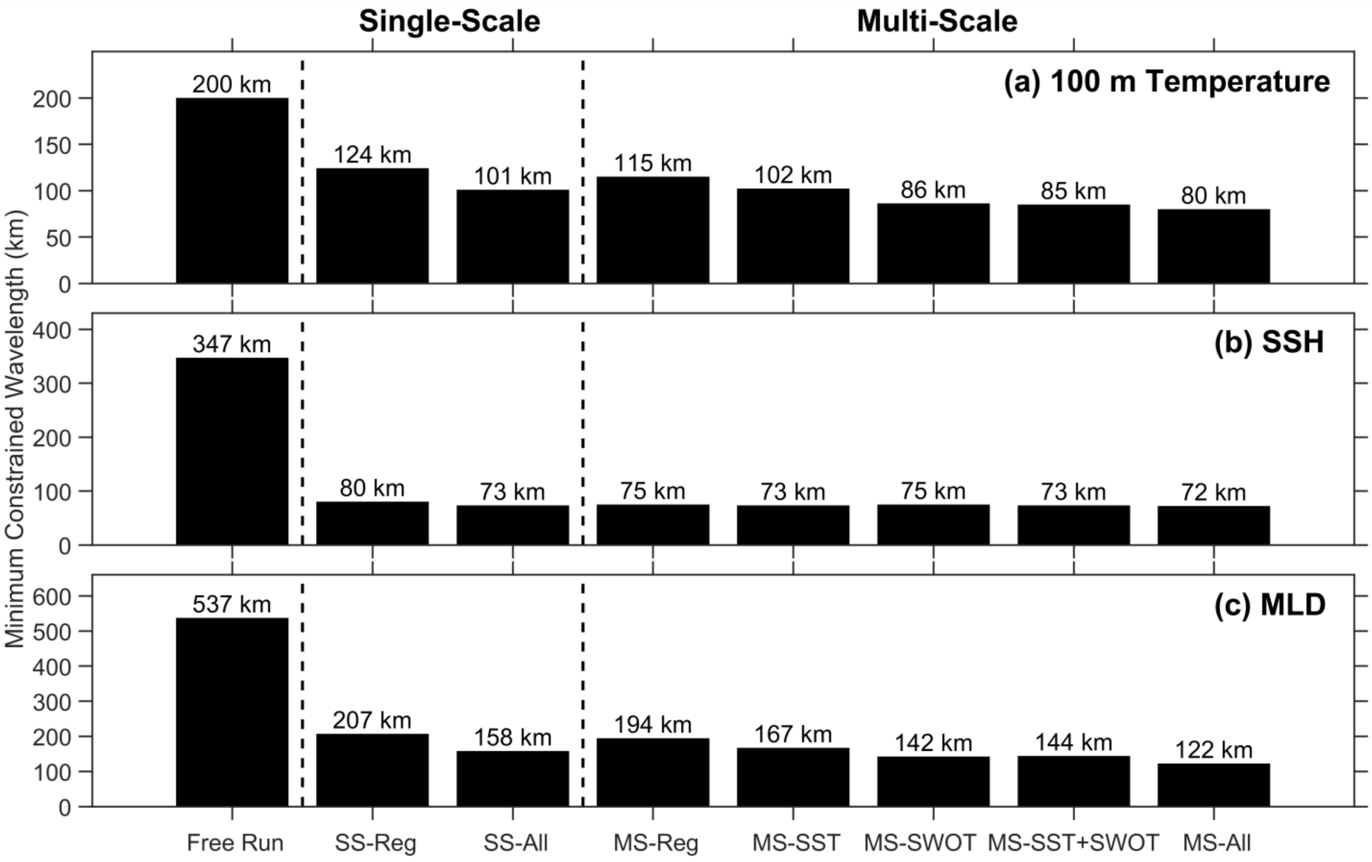
Results – Constrained wavelengths



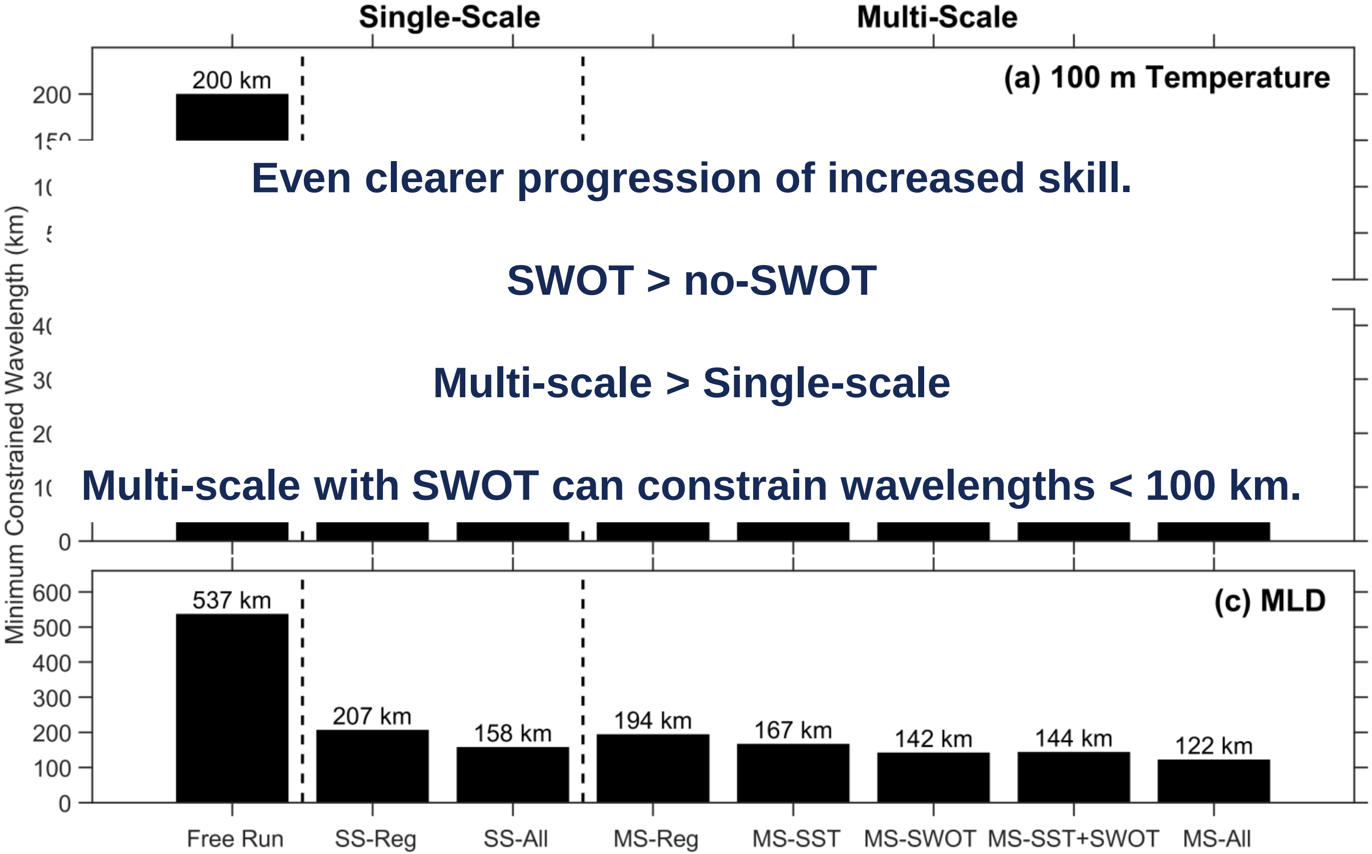
$$\frac{\varepsilon_{OSSE}}{\langle \gamma_{NATURE}, \gamma_{OSSE} \rangle}$$

Skill is defined at a value of 1 = 'minimum constrained wavelength'

Results – Constrained wavelengths



Results – Constrained wavelengths



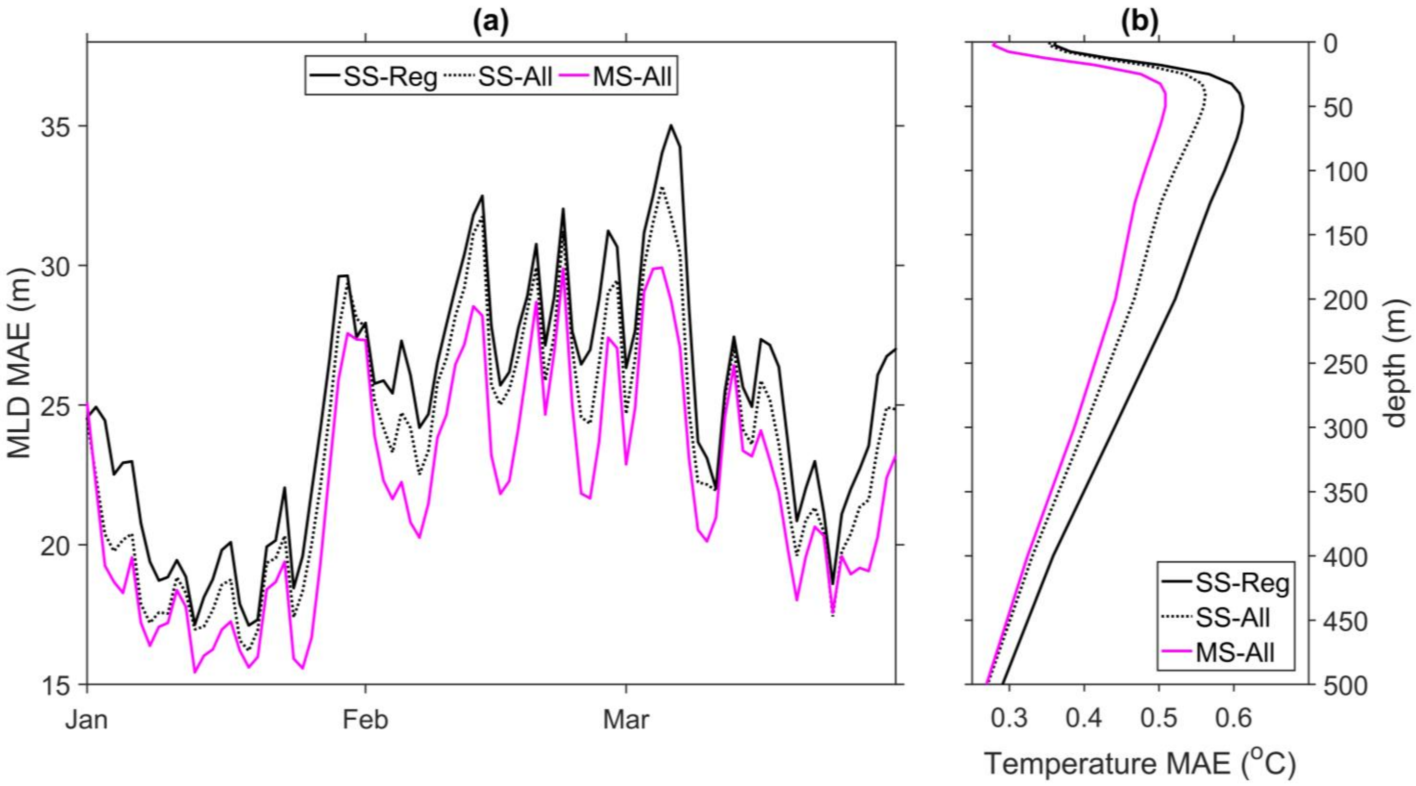
Even clearer progression of increased skill.

SWOT > no-SWOT

Multi-scale > Single-scale

Multi-scale with SWOT can constrain wavelengths < 100 km.

Summary and Conclusions



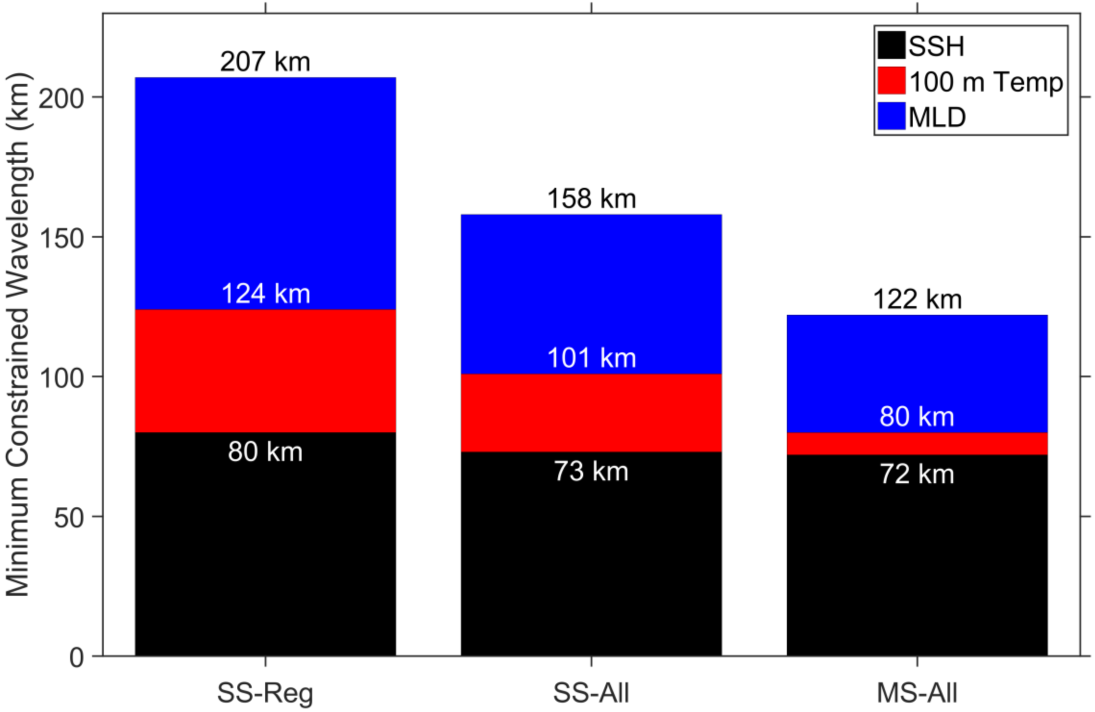
SS-Reg = Skill we have today

SS-All = Single-scale skill we will have with SWOT

MS-All = Multi-scale skill we will have with SWOT

Summary and Conclusions

U.S. NAVAL RESEARCH LABORATORY



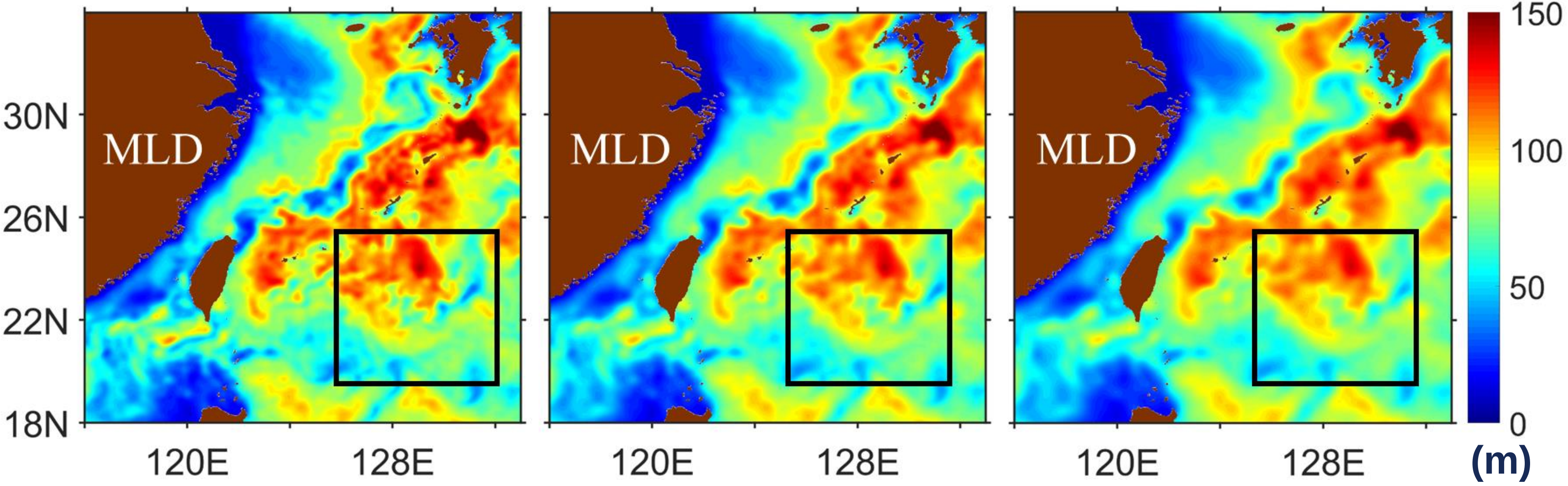
SS-Reg = Skill we have today

SS-All = Single-scale skill we will have with SWOT

MS-All = Multi-scale skill we will have with SWOT

Summary and Conclusions

What do these improvements in ‘constrained wavelength’ look like?



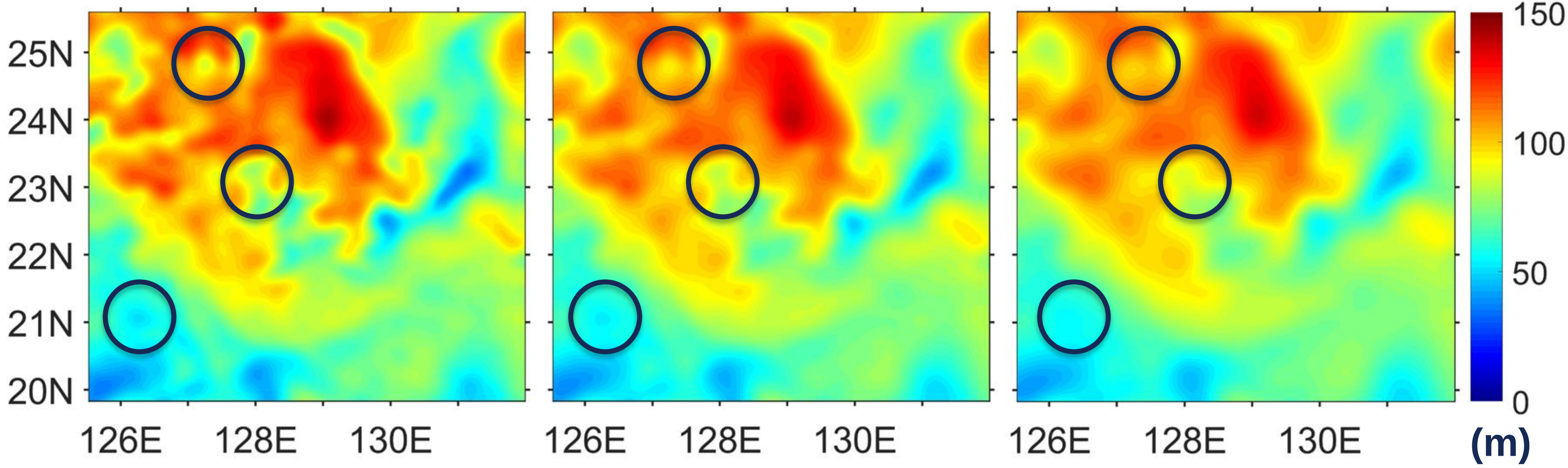
120 km filter
MS-All

160 km filter
SS-All

200 km filter
SS-Reg

Summary and Conclusions

What do these improvements in ‘constrained wavelength’ look like?



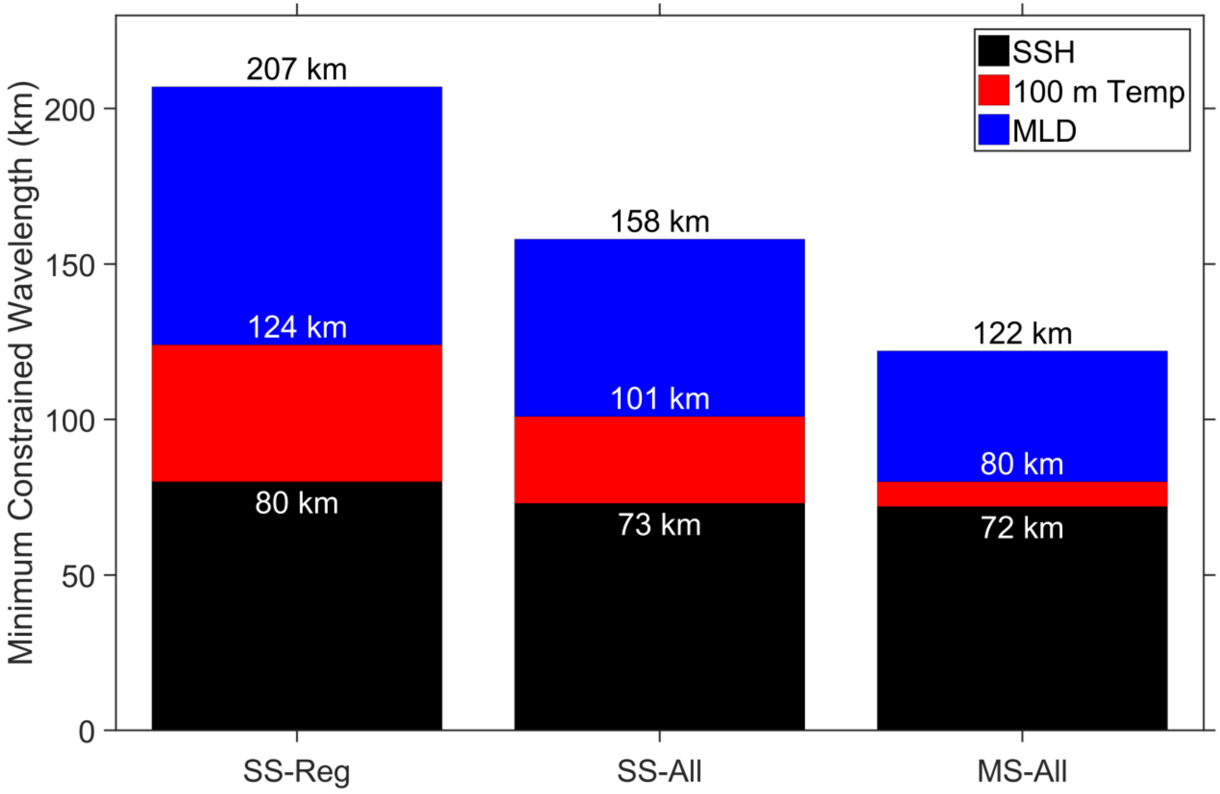
120 km filter
MS-All

160 km filter
SS-All

200 km filter
SS-Reg

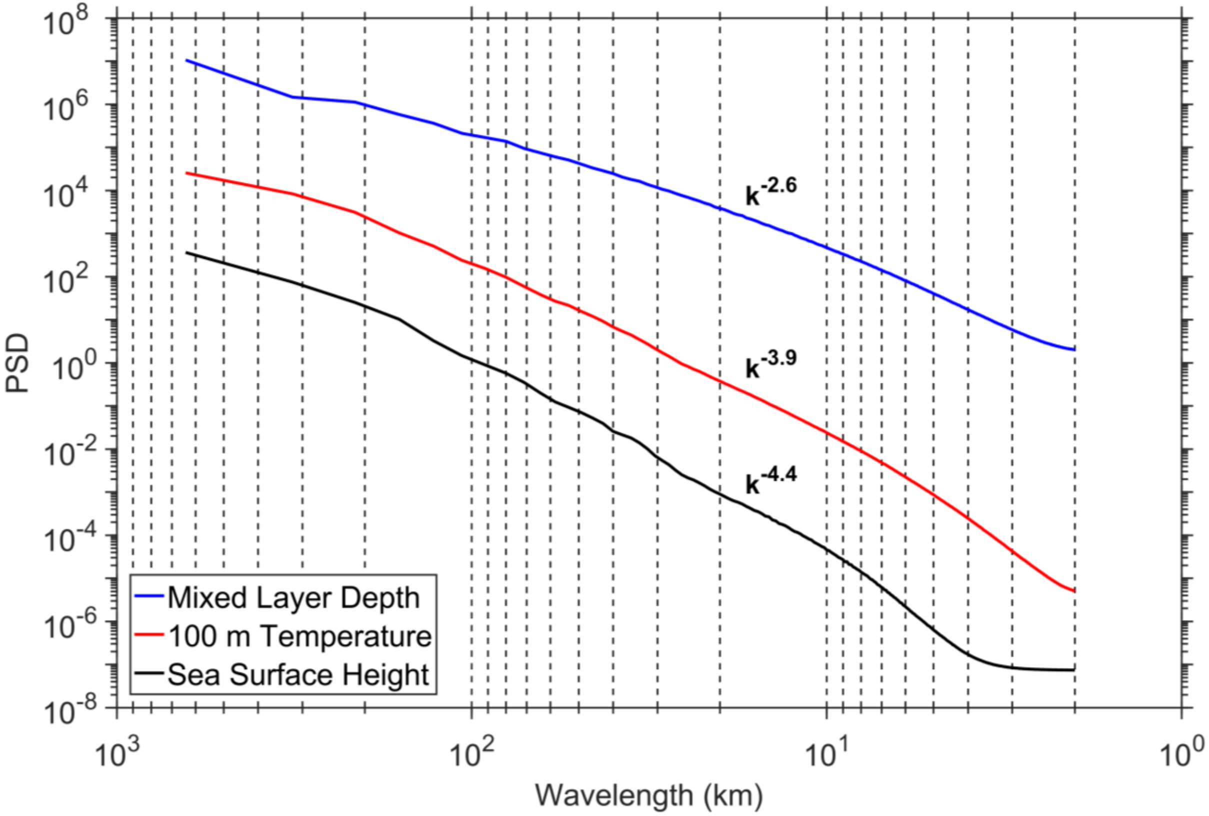
Summary and Conclusions

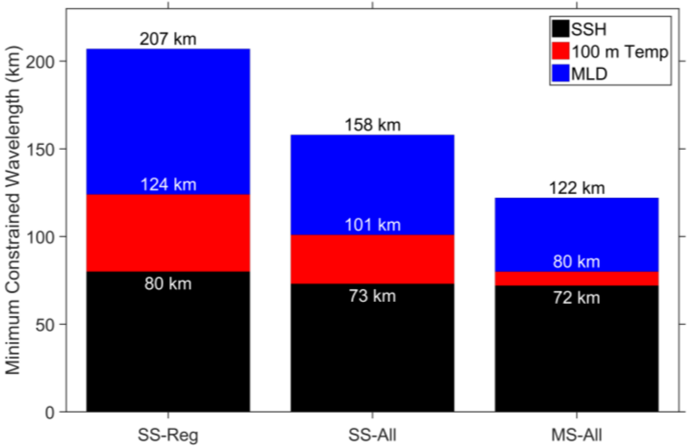
U.S. NAVAL RESEARCH LABORATORY



Why does MLD improve so much and SSH so little?

Summary and Conclusions



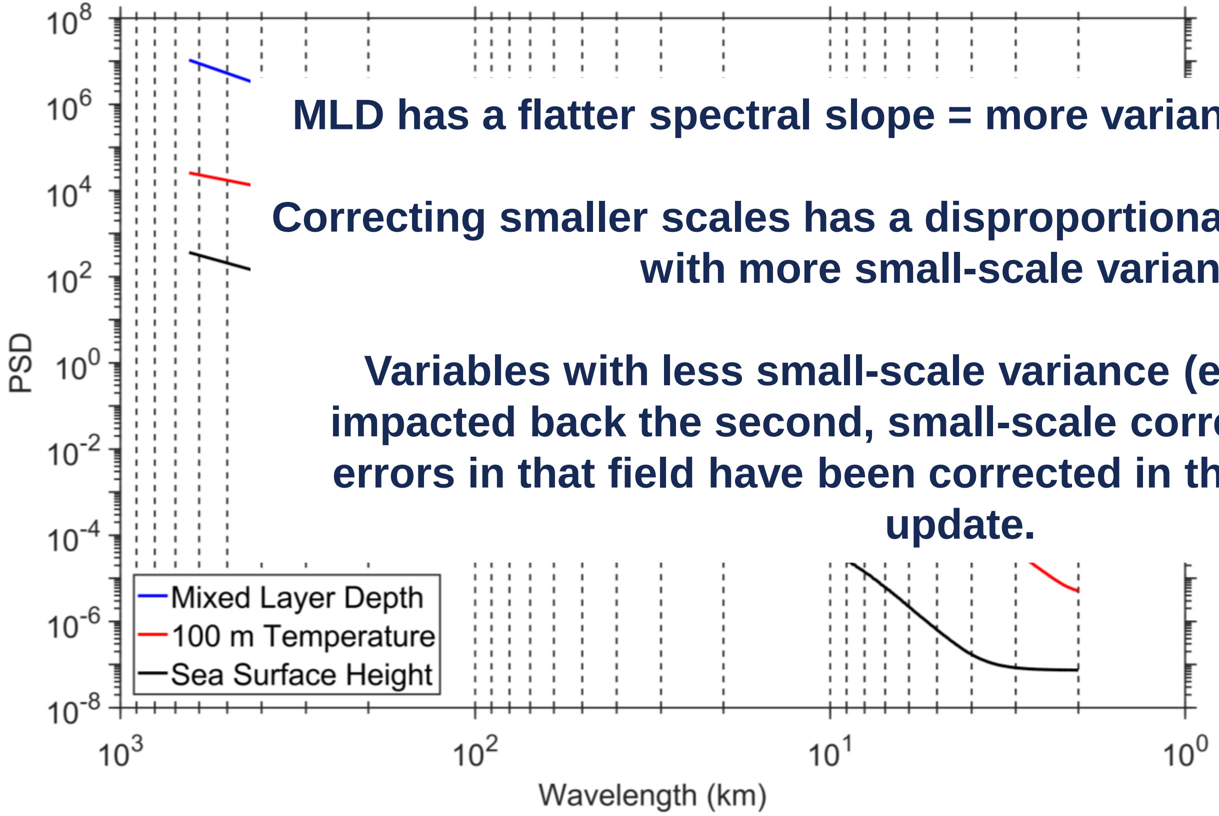


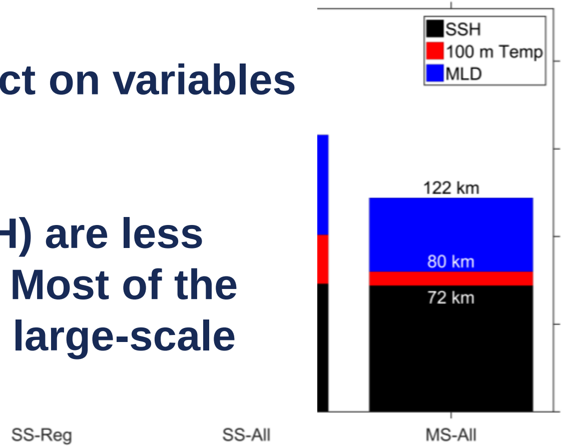
Summary and Conclusions

MLD has a flatter spectral slope = more variance at smaller scales

Correcting smaller scales has a disproportionate effect on variables with more small-scale variance.

Variables with less small-scale variance (e.g. SSH) are less impacted back the second, small-scale correction. Most of the errors in that field have been corrected in the first, large-scale update.





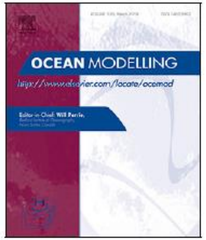
Summary and Conclusions

Ocean Modelling 154 (2020) 101683

Contents lists available at ScienceDirect

Ocean Modelling

journal homepage: www.elsevier.com/locate/ocemod



Multi-scale assimilation of simulated SWOT observations

Innocent Souopgui [a], Joseph M. D'Addezio [b,*], Clark D. Rowley [b], Scott R. Smith [b], Gregg A. Jacobs [b], Robert W. Helber [b], Max Yaremchuk [b], John J. Osborne [b]

[a] University of New Orleans, Department of Physics, LA, USA
[b] Naval Research Laboratory, Ocean Dynamics and Prediction, MS, USA

Multi-Scale Assimilation of Simulated SWOT observations

Future Work