Multi-Scale Assimilation of Simulated SWOT observations

Joseph M. D’Addezio\textsuperscript{1}
Innocent Souopgui\textsuperscript{2}, Clark D. Rowley\textsuperscript{1}, Scott R. Smith\textsuperscript{1}, Gregg A. Jacobs\textsuperscript{1}, Robert W. Helber\textsuperscript{1}, Max Yaremchuk\textsuperscript{1}, and John J. Osborne\textsuperscript{1}

\textsuperscript{1}Naval Research Laboratory, Ocean Dynamics and Prediction, MS, USA
\textsuperscript{2}University of New Orleans, Department of Physics, LA, USA
Motivation & Objectives

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

Minimum constrained wavelength = smallest wavelength the model has skill

going smaller = better

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

Multi-scale NCODA-3DVAR

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

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

- **Forecast**
  - \[ \delta x = P_L \delta x + P_S \delta x = \delta x_L + \delta x_S \]
  - \[ J(\delta x_L) = \frac{1}{2} \delta x_L^T B_L^{-1} \delta x_L + \frac{1}{2} (H \delta x_L - d)^T (R + H B_S H^T)^{-1} (H \delta x_L - d) \]
  - \[ J(\delta x_S) = \frac{1}{2} \delta x_S^T B_S^{-1} \delta x_S + \frac{1}{2} (H \delta x_S - d)^T (R + H B_L H^T)^{-1} (H \delta x_S - d) \]
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Methods – Increment visualization

Large-scale correction  Small-scale correction  Multi-scale correction

100 m temperature increments

°C

100 m temperature increments
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Methods – Temporal component

Observation window of the small-scale update

- 24 hour MAE = 4.39 cm
- 48 hour MAE = 4.47 cm
- 72 hour MAE = 4.55 cm
- 96 hour MAE = 4.62 cm
- 120 hour MAE = 4.7 cm

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

### Multi-Scale Assimilation of Simulated SWOT observations

<table>
<thead>
<tr>
<th>Analysis Step</th>
<th>Profiles</th>
<th>SST</th>
<th>Altimeters</th>
<th>SWOT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free Run</td>
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<tr>
<td>SS-Reg</td>
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<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>SS-All</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>MS-Reg</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>MS-SST</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
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<tr>
<td>MS-SWOT</td>
<td>Yes</td>
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<td>MS-SST-SWOT</td>
<td>Yes</td>
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</tbody>
</table>
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Results – Time series

(a) 100 m Temperature

(b) SSH

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

Need better metrics.
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Results – Time-depth errors

Time-averaged (6 months) error with depth.

(b) percent change is referenced to the ‘SS-Reg’ experiment.
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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.
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Results – Constrained wavelengths

\[ \epsilon_{OSSE} \]

\[ \langle \gamma_{NATURE}, \gamma_{OSSE} \rangle \]

\( \epsilon_{OSSE} \) is the PSD of the OSSE error (NATURE minus OSSE), \( \gamma_{NATURE} \) is the PSD of the Nature Run, \( \gamma_{OSSE} \) is the PSD of the OSSE, and the brackets denote the mean of the two spectra.
Skill is defined at a value of 1 = ‘minimum constrained wavelength’
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Results – Constrained wavelengths

(a) 100 m Temperature

- Single-Scale
  - 200 km
  - 124 km
  - 101 km
  - 115 km
  - 102 km
  - 86 km
  - 85 km
  - 80 km

- Multi-Scale
  - Constrained Wavelength (km)

(b) SSH

- 347 km
  - 80 km
  - 73 km
  - 75 km
  - 73 km
  - 75 km
  - 73 km
  - 72 km

(c) MLD

- 537 km
  - 207 km
  - 158 km
  - 194 km
  - 167 km
  - 142 km
  - 144 km
  - 122 km

Free Run, SS-Reg, SS-All, MS-Reg, MS-SST, MS-SWOT, MS-SST+SWOT, MS-All
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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.

(a) 100 m Temperature

(c) MLD
Summary and Conclusions

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(a)  
MLD MAE (m)

(b)  
Temperature MAE (°C)

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

120 km filter MS-AII

160 km filter SS-AII

200 km filter SS-Reg
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

Why does MLD improve so much and SSH so little?
Summary and Conclusions

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- Mixed Layer Depth
- 100 m Temperature
- Sea Surface Height

Wavelength (km)

PSD

$P \propto \frac{1}{k^2}$
$P \propto \frac{1}{k^3.9}$
$P \propto \frac{1}{k^{4.4}}$
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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

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Future Work

Using mesoscale covariances in both steps (only horizontal scale changes from step 1 to 2)

Using submesoscale covariances in step 2 (horizontal scale and physics change from step 1 to step 2)