Exploring 3D Velocity Field Reconstructions using the SWOT Simulator and a Submesoscale-Resolving OGCM

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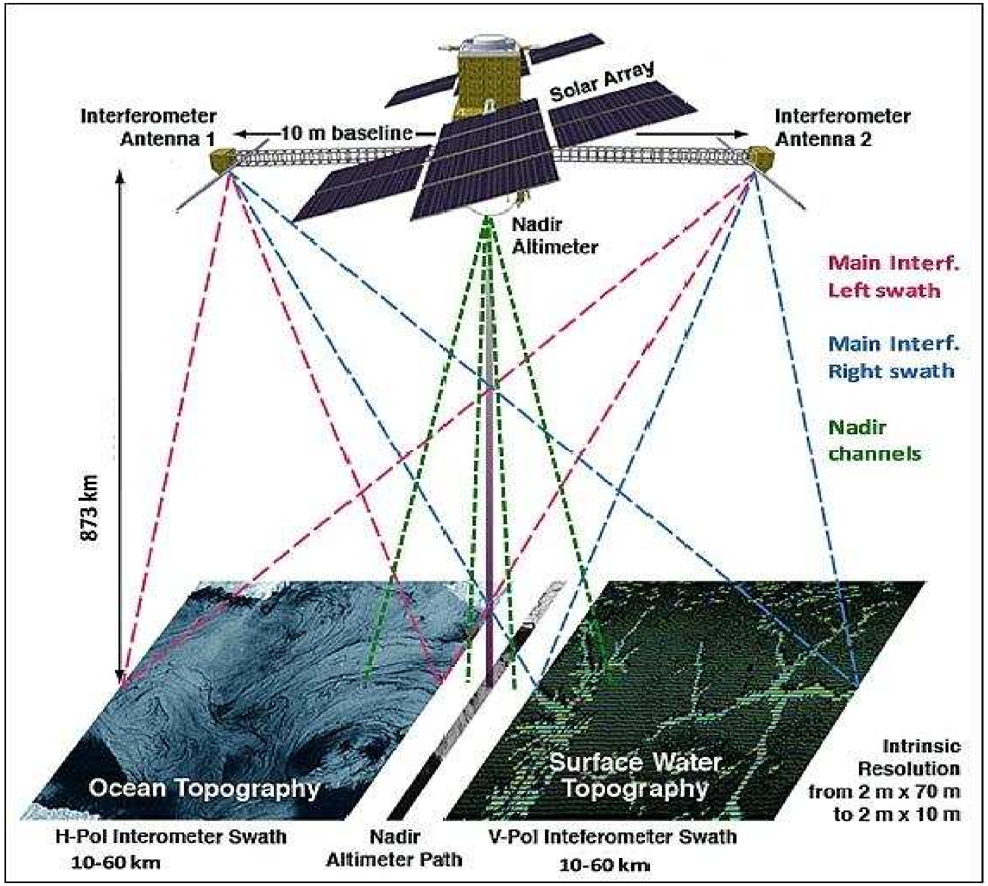

www.jpl.nasa.gov/missions/surface-water-and-ocean-topography-swot/

OSTST Meeting, Reston, VA
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Background:

- Instead of propagating westward dictated by β effect, submesoscale SSH signals tend to be advected by mesoscale circulation they imbedded in

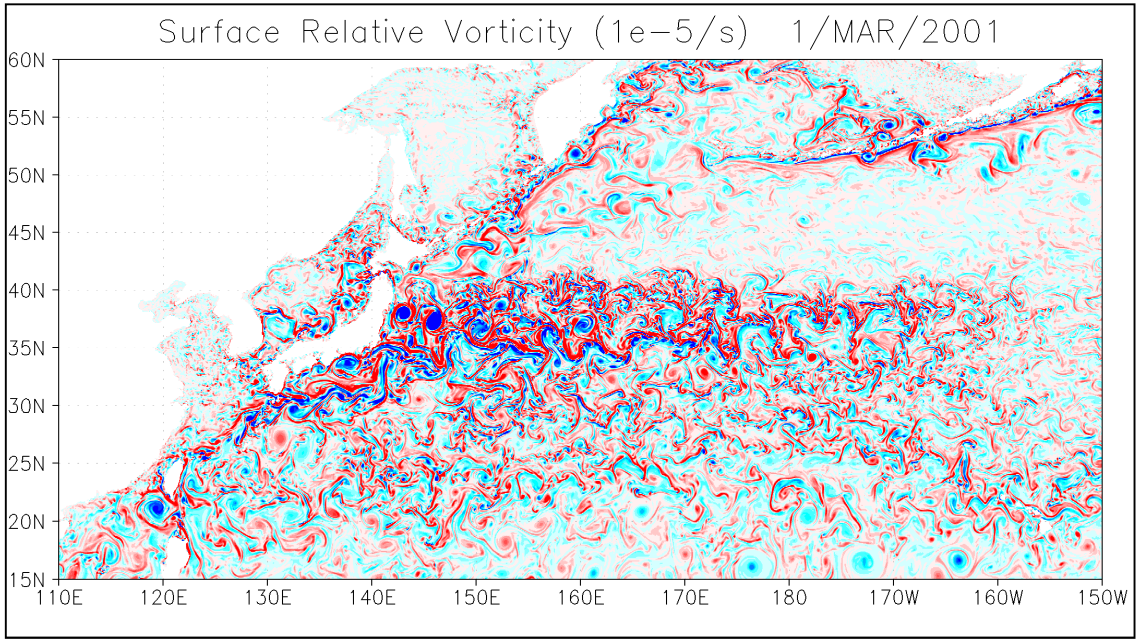
- This provides a “new” set of dynamical constraints, and the possibility of reconstructing 3D upper ocean circulation structures, including the vertical velocity field, based on high-resolution SSH data

- Can the 3D upper ocean structures be reliably reconstructed from the expected SWOT measurements?

- Addressed this issue using the SWOT simulator (with swath gaps and measurement errors) and the OFES 1/30° OGCM output

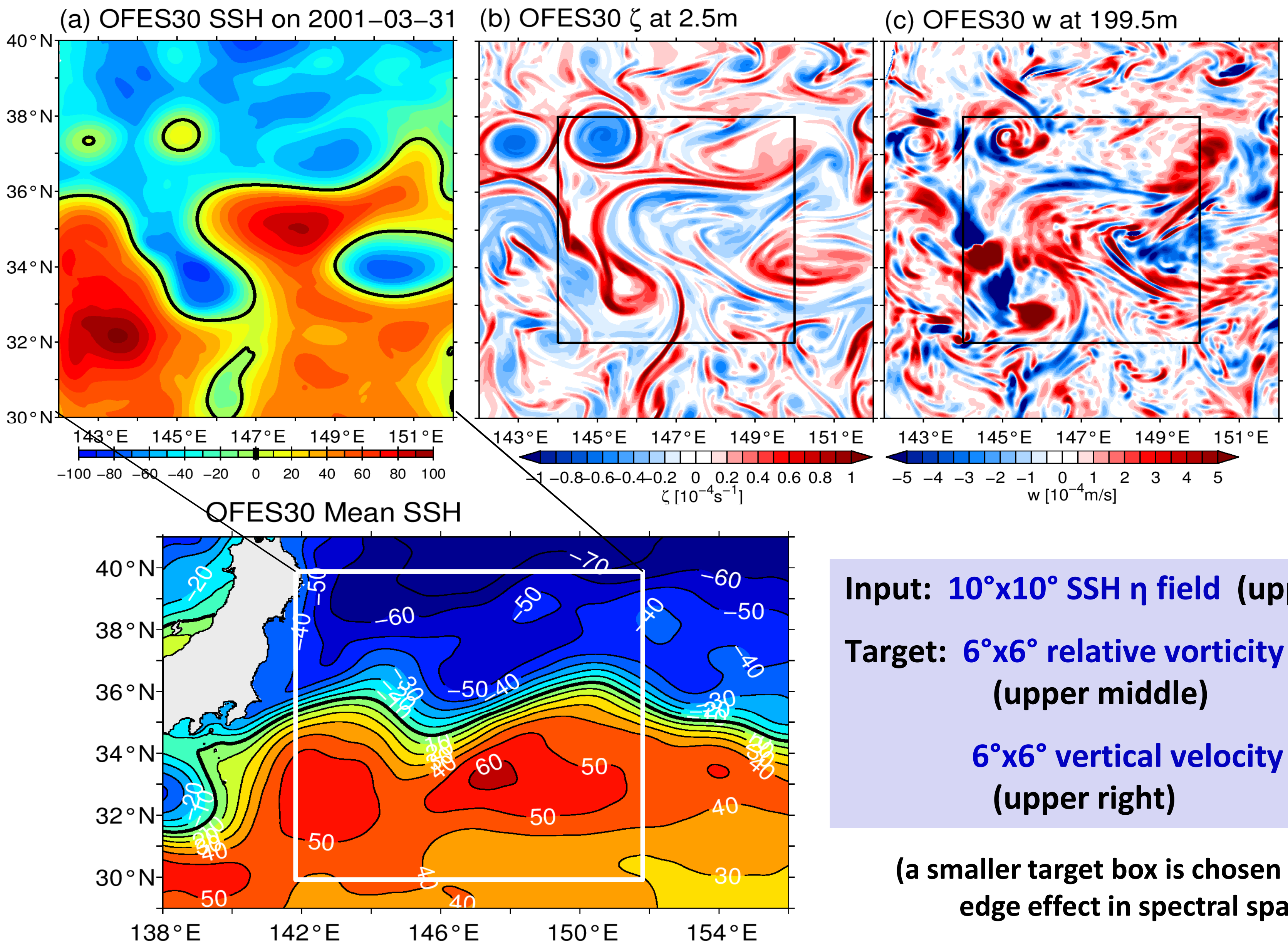
OFES 1/30° N Pacific OGCM Simulation:

- **SWOT-equivalent 3-km horizontal grid resolution; 100 vertical levels (60 in upper 500 m)**
- **Model domain 100°E-70°W, 20°S-66°N**
- **Initialized with T/S from output of the 1/10° North Pacific hindcast simulation on 1 January 2010**
- **Forced by JRA-25 6-hourly reanalysis data (1° resolution)**
- **Analysis of daily-mean η, u, v, w & ρ field of 2001-2002**



Sasaki, Klein, Qiu & Sasai (2014, Nature Comm.)

A specific example in the Kuroshio Extension region: March 31, 2001



OFES original

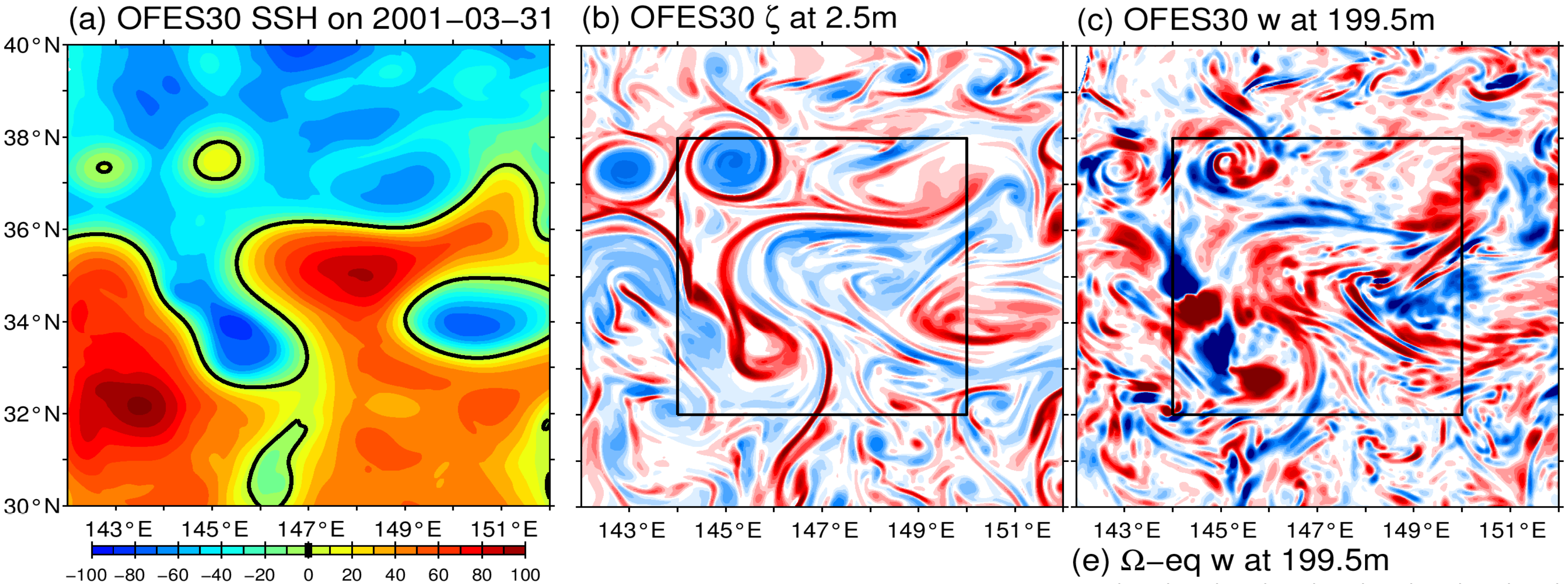
Input: 10°x10° SSH η field (upper left)

Target: 6°x6° relative vorticity ζ field (upper middle)

6°x6° vertical velocity w field (upper right)

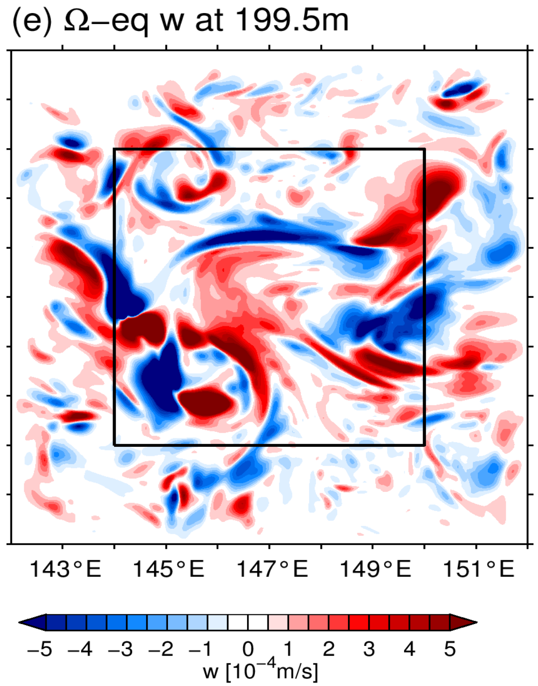
(a smaller target box is chosen to avoid edge effect in spectral space)

A specific example in the Kuroshio Extension region: March 31, 2001



OFES original

- **Interested in "balanced" vertical motion because it has longer Lagrangian timescales, thereby more relevant to upper ocean material transport**
- **Evaluated "balanced" vertical motion by the ω-equation using modeled 3D velocity/density fields**
- **Comparison is done between this balanced w and the eSQG-derived w**



OFES balanced w

Effective surface quasi-geostrophic (SQG) theory: Lapeyre and Klein (2006)

- **Under the assumption that interior upper ocean PV is correlated to surface PV, geostrophic streamfunction ψ becomes functionally related to the SSH η field:**

$$\hat{\psi}(\mathbf{k}, z) = \frac{g}{f_o}\hat{\eta}(\mathbf{k}) \exp\left(\frac{N_o}{f_o}kz\right)$$

where ^ : horizontal Fourier transform, k : horizontal wavenumber, and N_0 : effective buoyancy frequency.

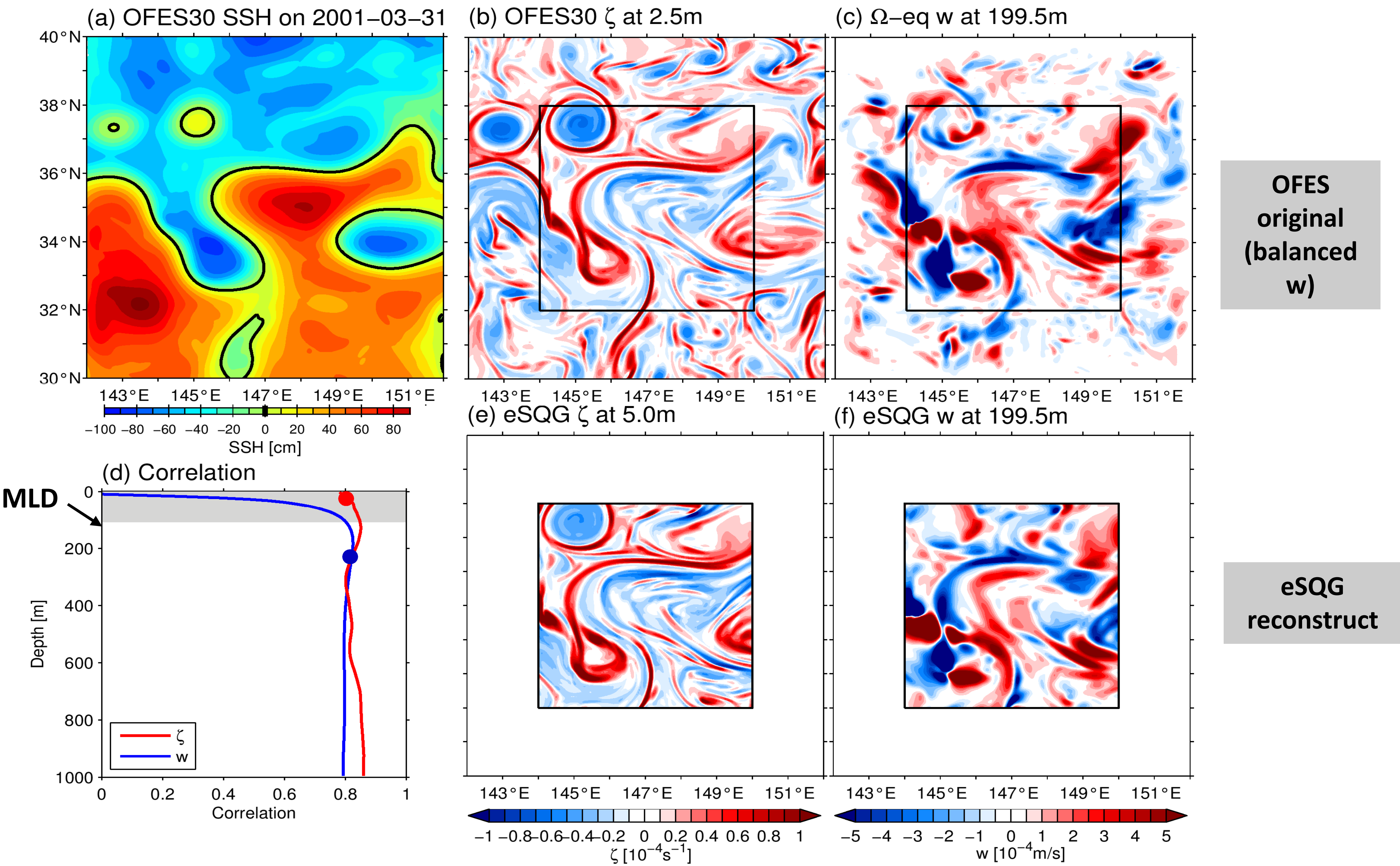
- **Once ψ is specified, 3-D relative vorticity, buoyancy, and vertical velocity fields can be deduced from geostrophy, hydrostaticity, and advective buoyancy equation, respectively :**

$$\hat{\zeta}(\mathbf{k}, z) = -k^2\hat{\psi}(\mathbf{k}, z),$$

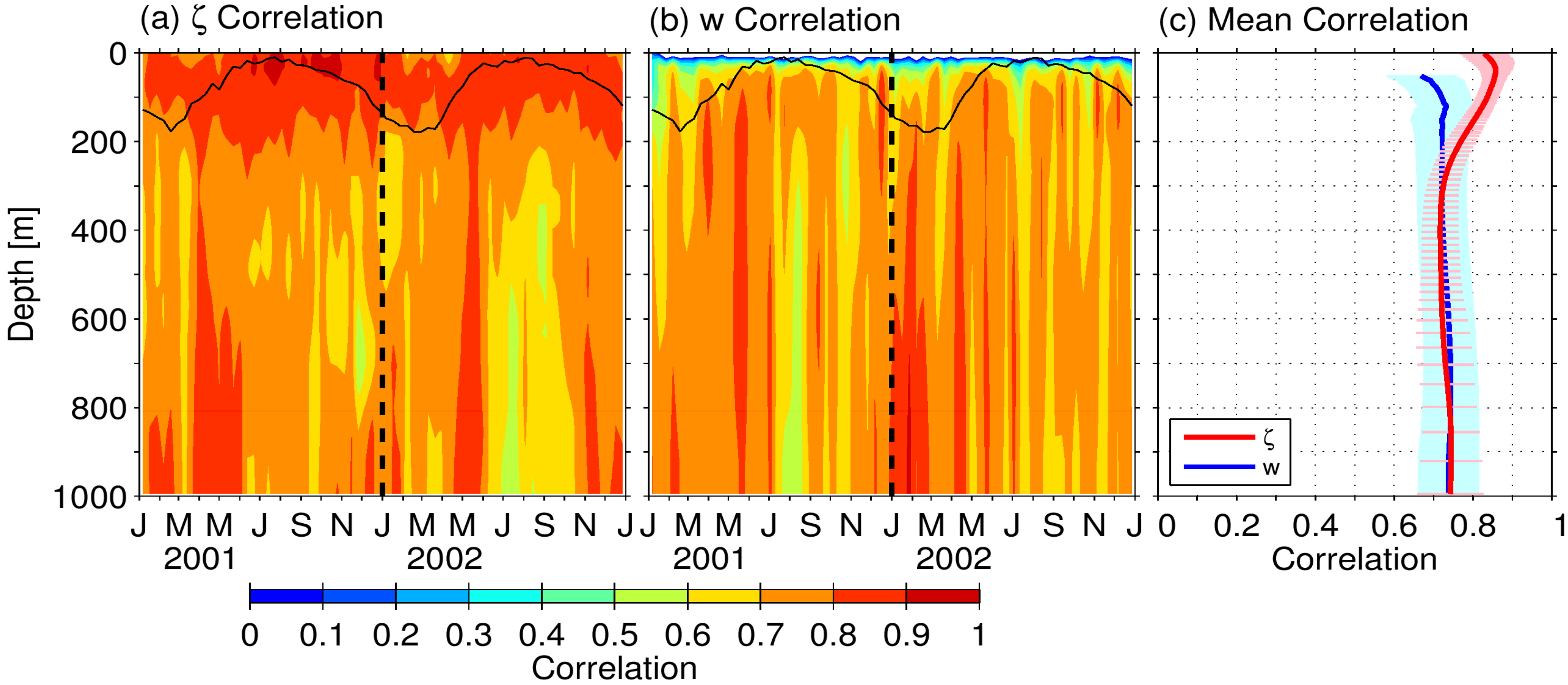
$$\hat{b}(\mathbf{k}, z) = \frac{N_o k}{c}\hat{\psi}(\mathbf{k}, z),$$

$$\hat{w}(\mathbf{k}, z) = -\frac{c^2}{N_o^2}\left[-\widehat{J(\psi_s, b_s)} \exp\left(\frac{N_o}{f_o}kz\right) + \widehat{J(\psi, b)}\right]$$

Best reconstruction: modeled η as input, no swath gaps/measurement errors

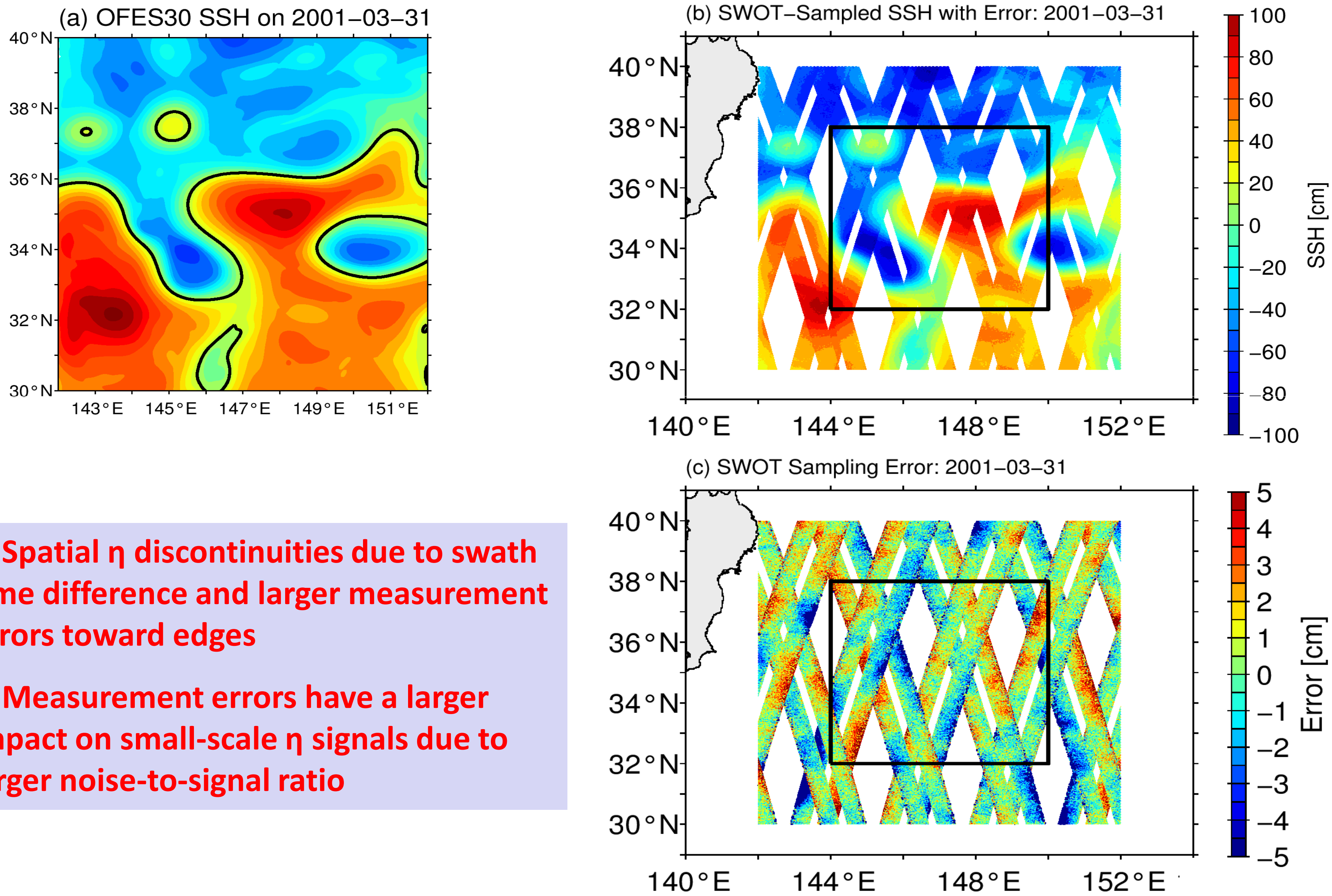


Best reconstruction: Statistics for ζ & w over the 2-yr OFES simulation



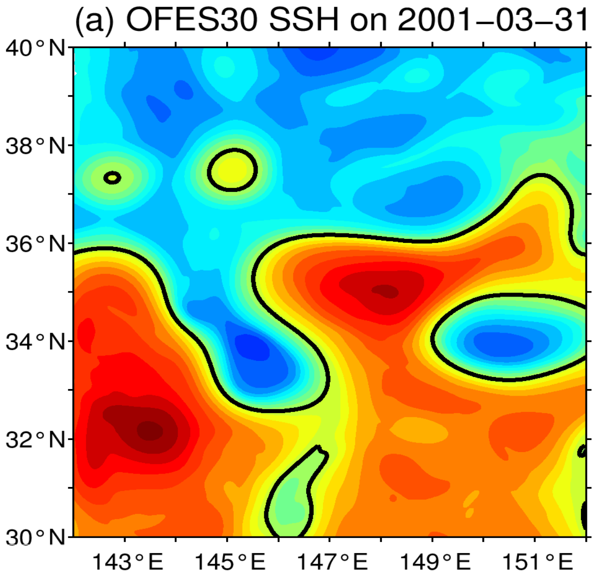
- **Good overall reconstructability:**
  0.7-0.9 for ζ and 0.7-0.8 for balanced w
- **eSQG fails to capture w in the shallow 50m layer**

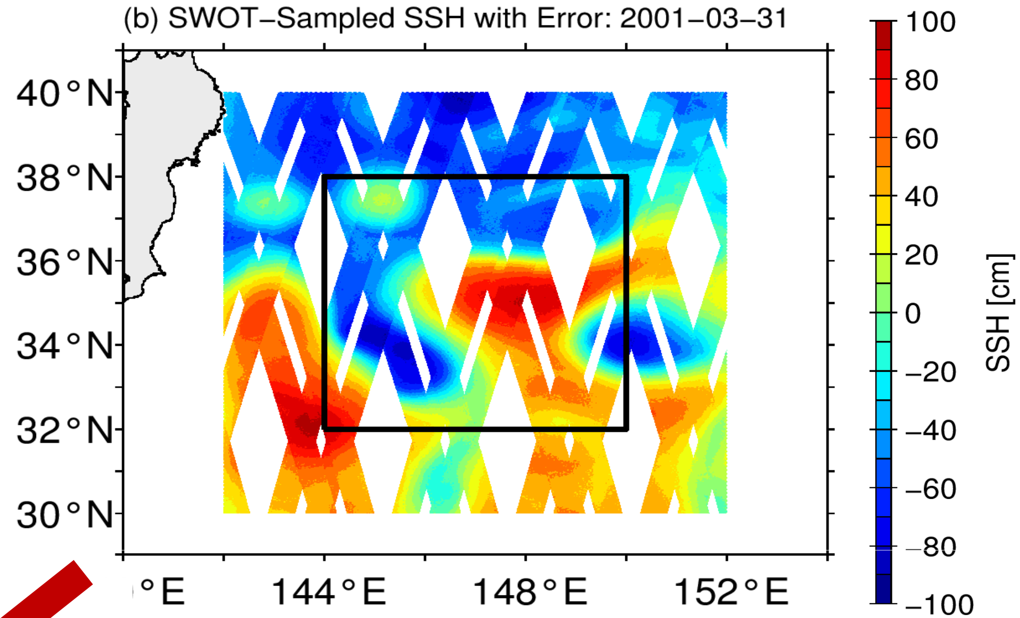
SWOT simulator-sampled SSH field in a sub-cycle centered on March 31

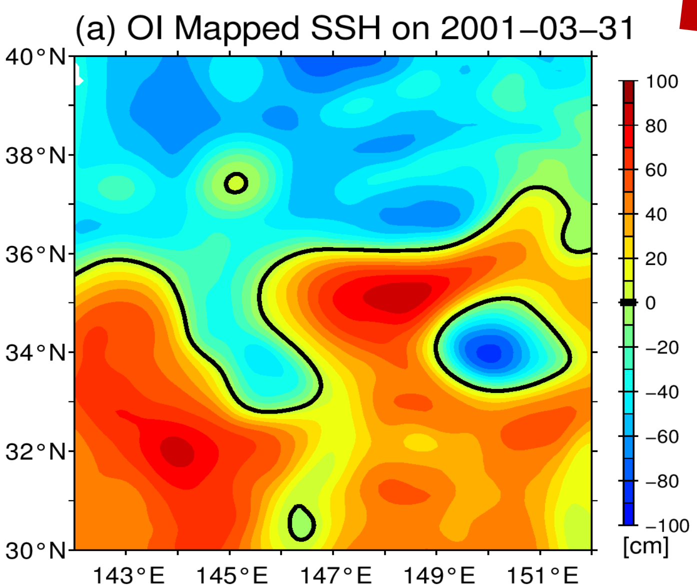


- **Spatial η discontinuities due to swath time difference and larger measurement errors toward edges**
- **Measurement errors have a larger impact on small-scale η signals due to larger noise-to-signal ratio**

Spatio-temporal objective mapping of the η field for reconstruction

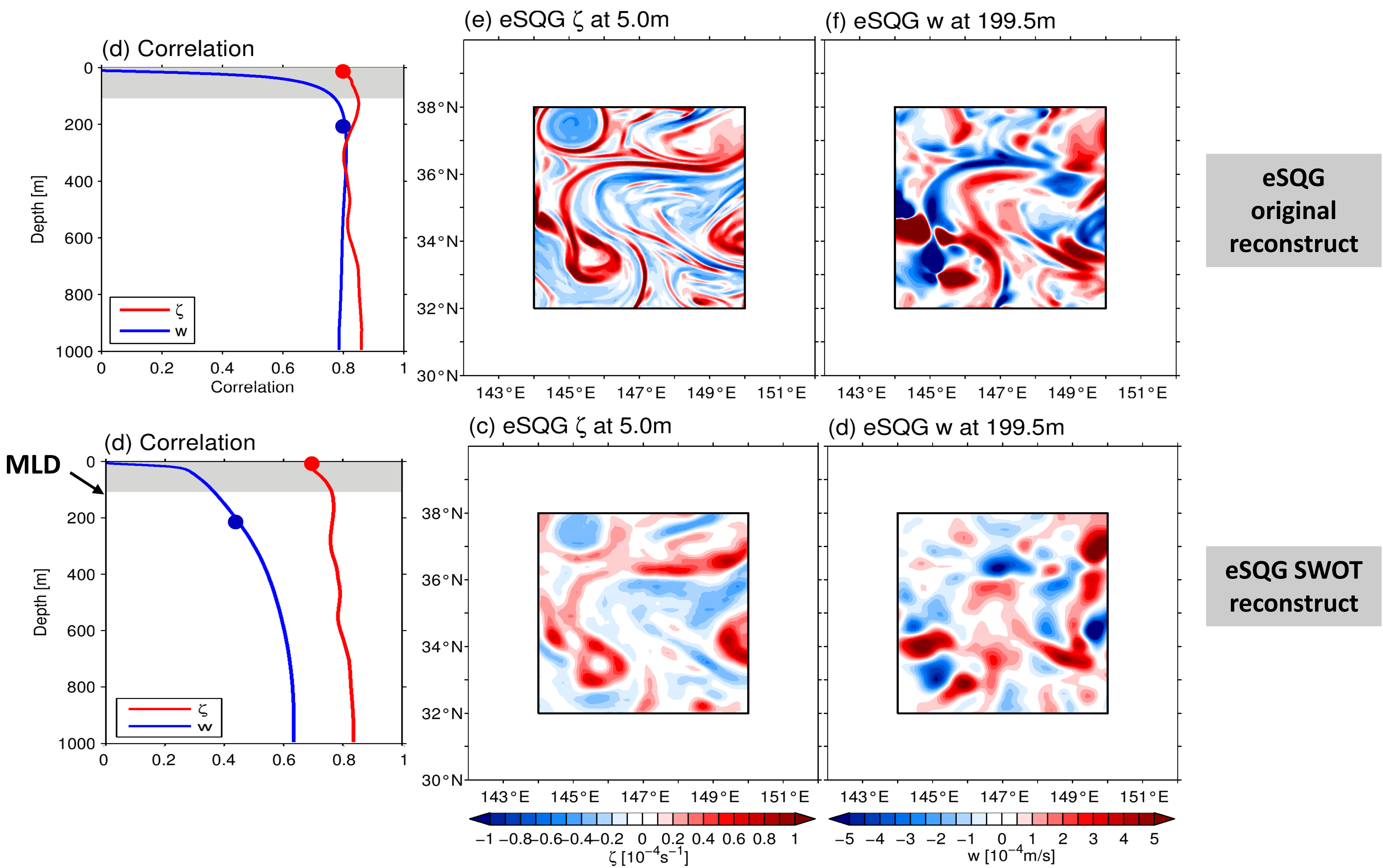




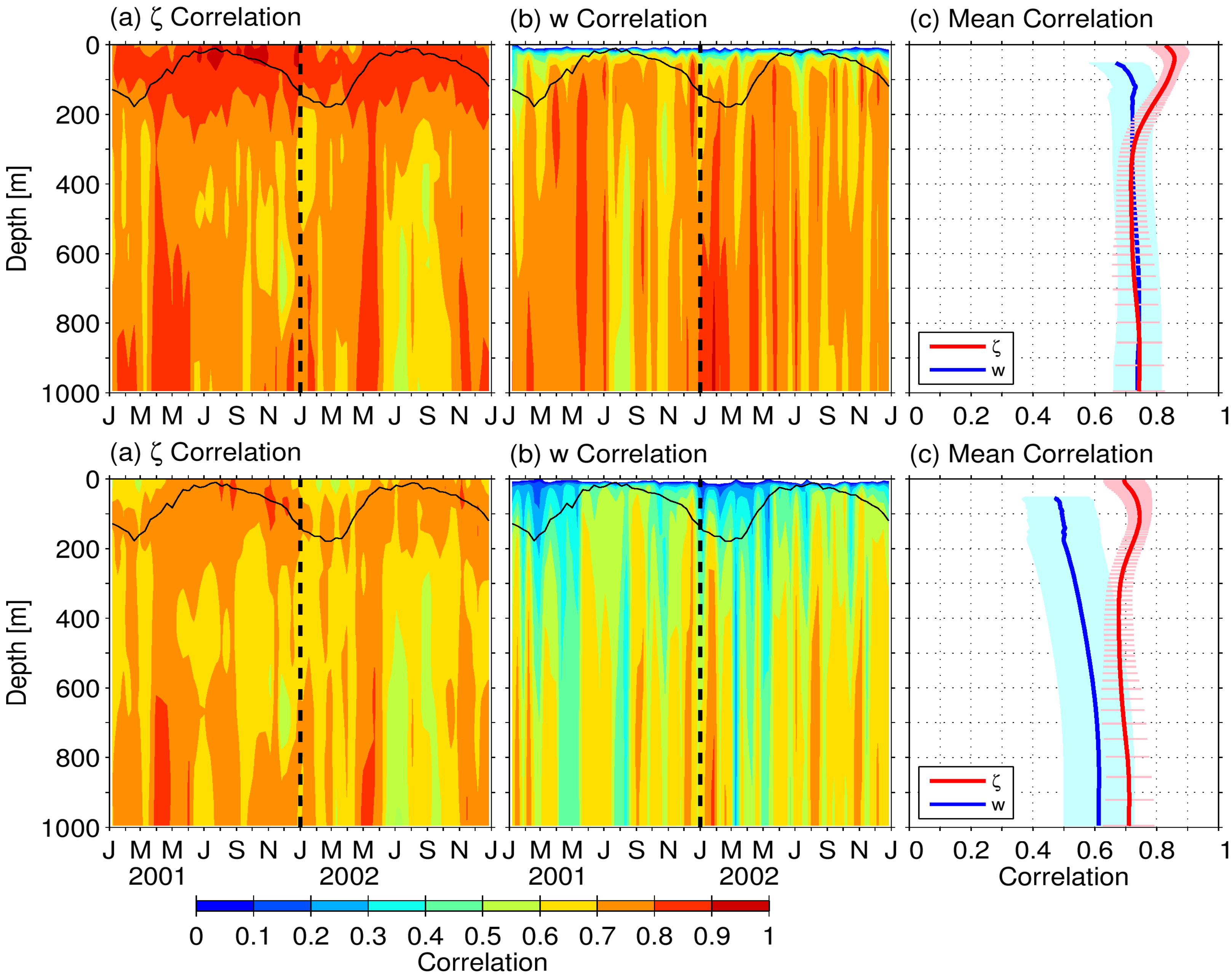


- The OI method preferentially smears out smaller-scale signals
- Reduction of SSH anomalies by 19.4%
- "Dynamical" interpolation method is called for

Reconstruction comparisons with simulated vs. mapped SSH field as input



Best vs. SWOT reconstructions: Statistics over the 2-yr OFES simulation

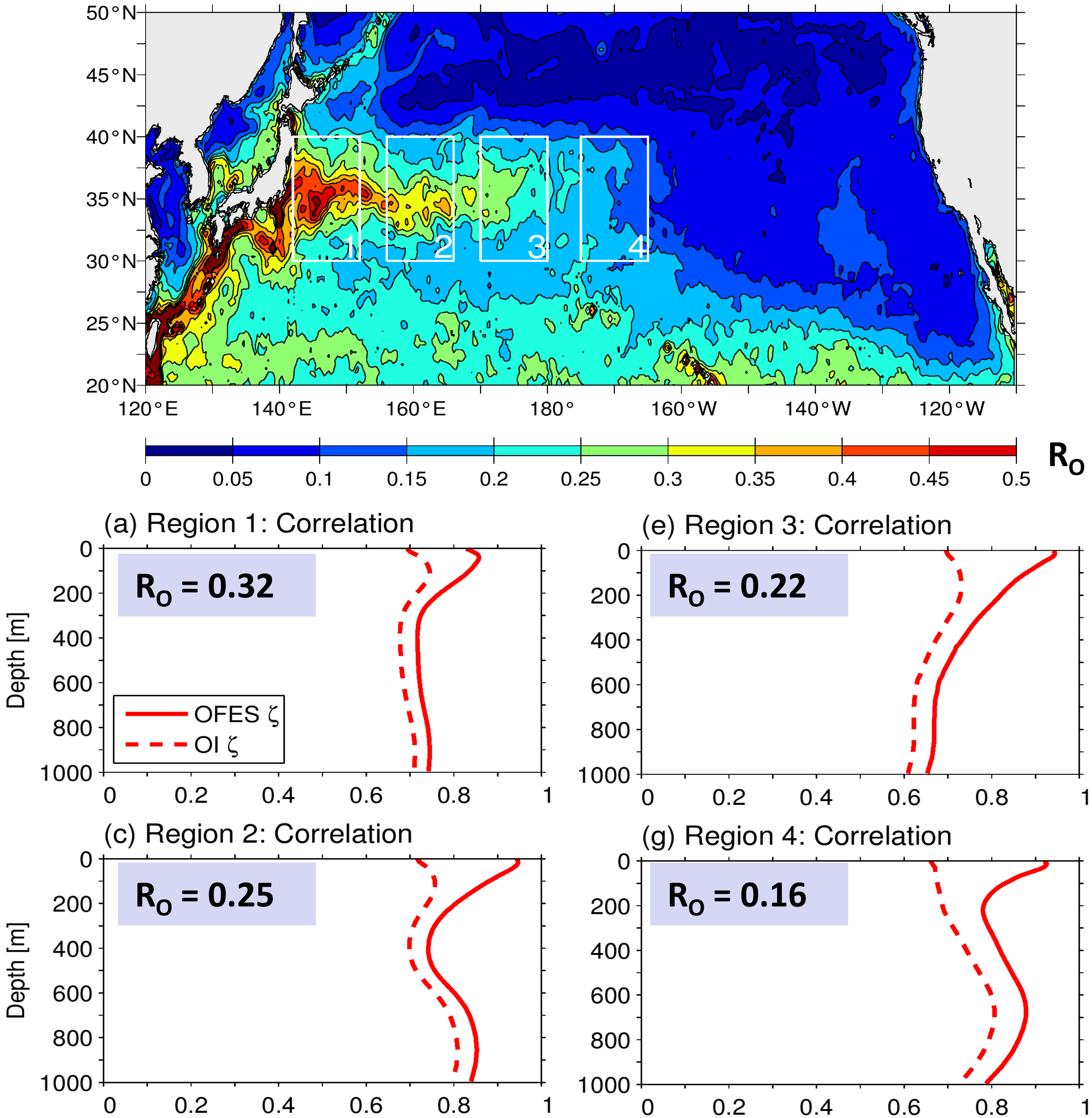


ζ : 0.7-0.9
w : 0.7-0.8

ζ : 0.7-0.8
w : 0.5-0.6

5-10% vs. 15-25% degradation

Reconstructability of ζ as a function of regional R_O # (= ζ_{rms}/f)

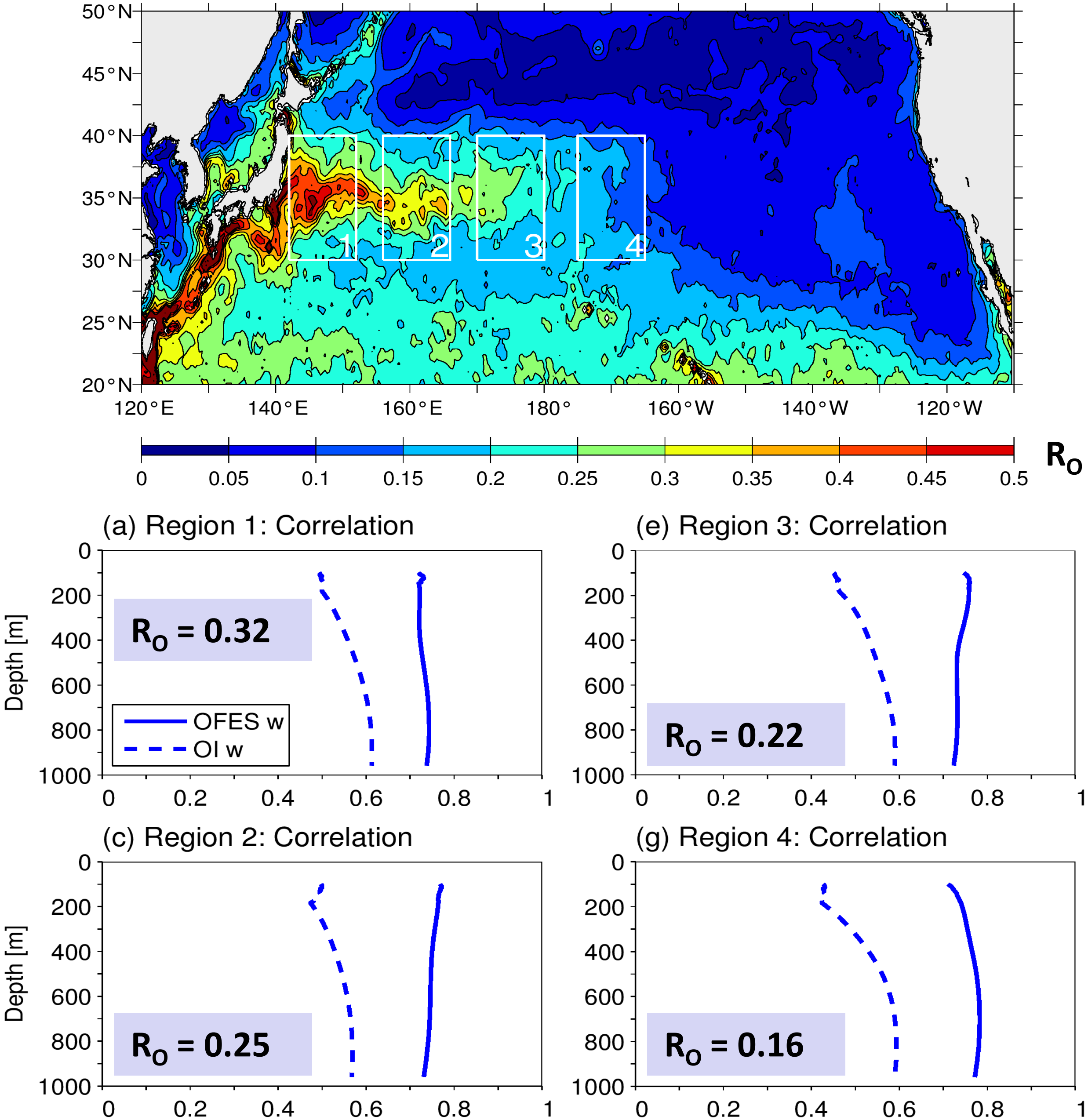


———— : reconstruction using modeled η

- - - - - - : reconstruction using SWOT-sampled η

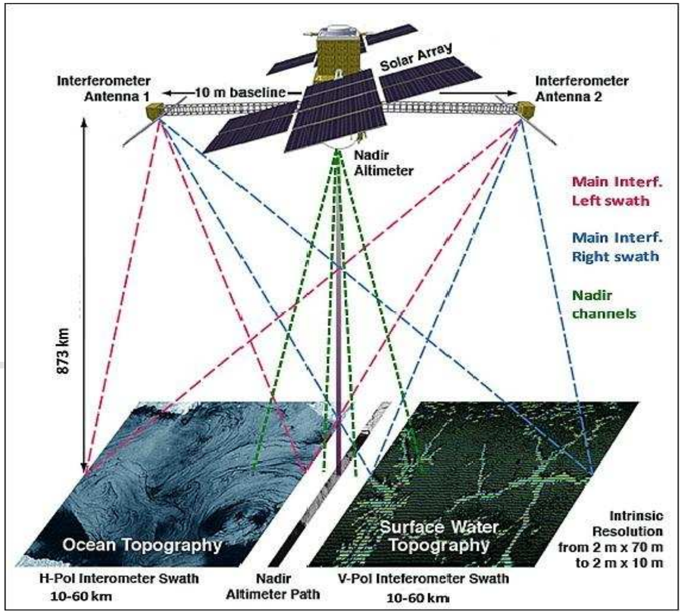
- **Correlation for ζ is not a sensitive function of R_O**
- **Degradation by SWOT errors is greater in smaller R_O regions (smaller signal/noise ratio)**

Reconstructability of balanced w as a function of regional R_O # (= ζ_{rms}/f)



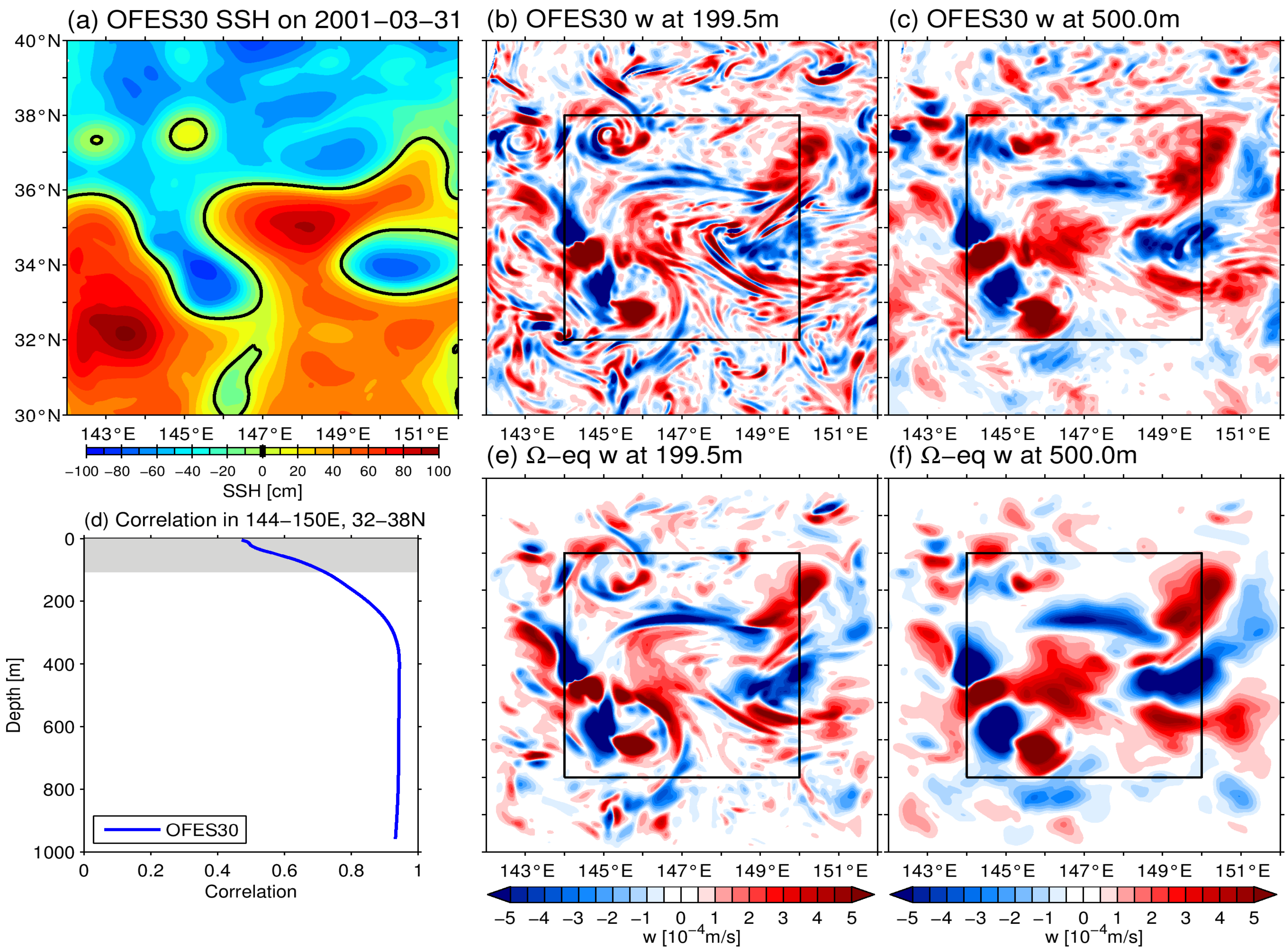
- Correlation for balanced w is also not a sensitive function of R_O
- Degradation by SWOT errors is greater in smaller R_O regions (smaller signal/noise ratio)

Concluding Remarks

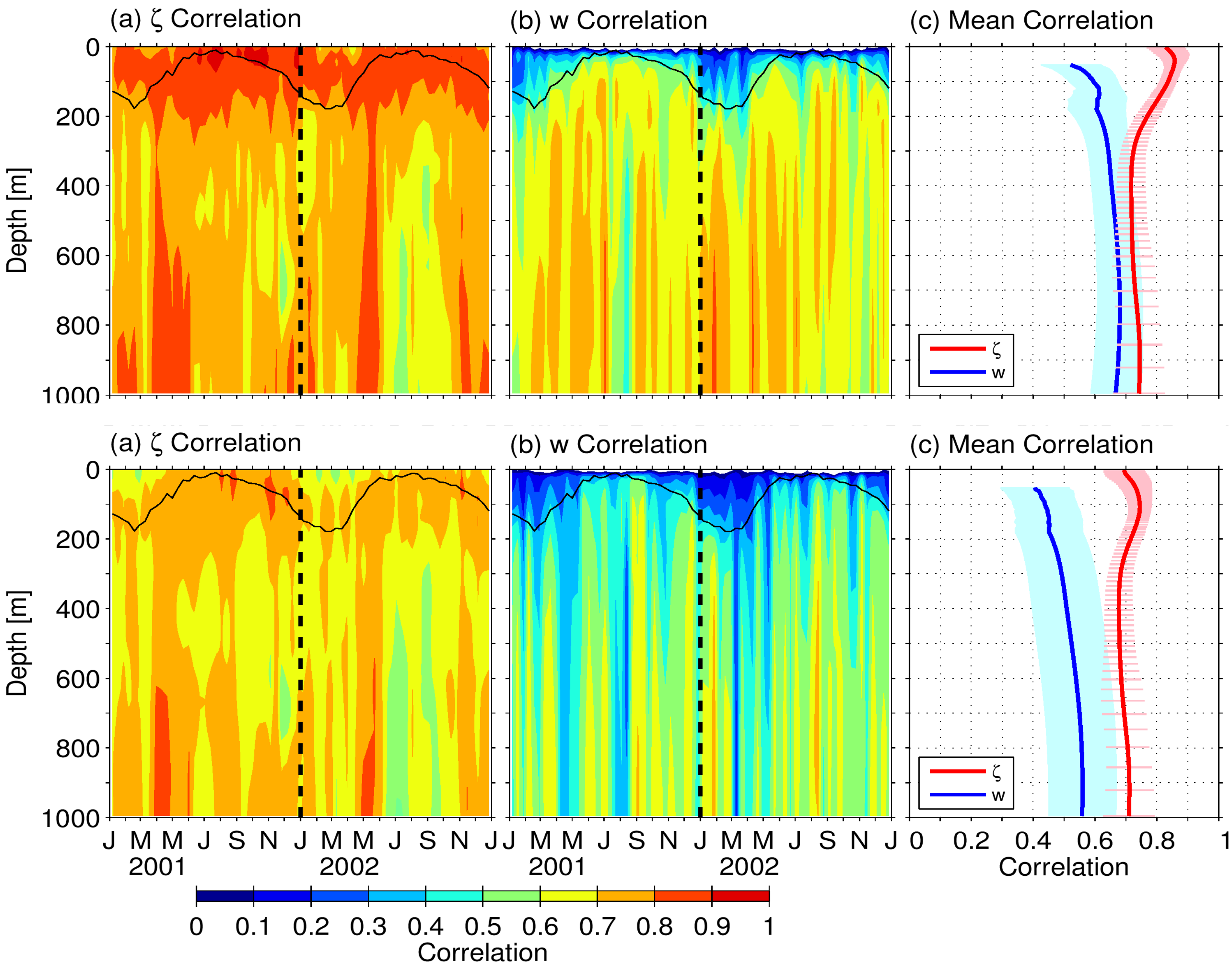


- **eSQG theory is a simple and effective formulism to reconstruct 3-D circulation field, including w, from the planned SWOT SSH measurements.**
- **Allowing for sampling & measurement errors, the 3D reconstructed ζ and w can reach c ≈ 0.7-0.8 and 0.5-0.6, respectively, when compared to the "true" field in broad Kuroshio Extension region.**
- **Better reconstruction theories (i.e., beyond eSQG; adding other high-res. data constraints) and interpolation methods (from OI to dynamical) are desired in future studies.**

Comparisons between simulated vs. “balanced” w fields



Best vs. SWOT reconstructions (original w): Statistics over the 2-yr OFES simulation

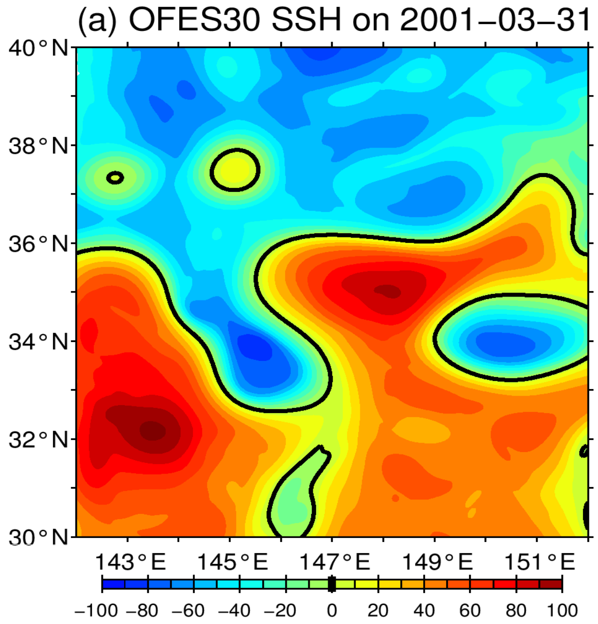


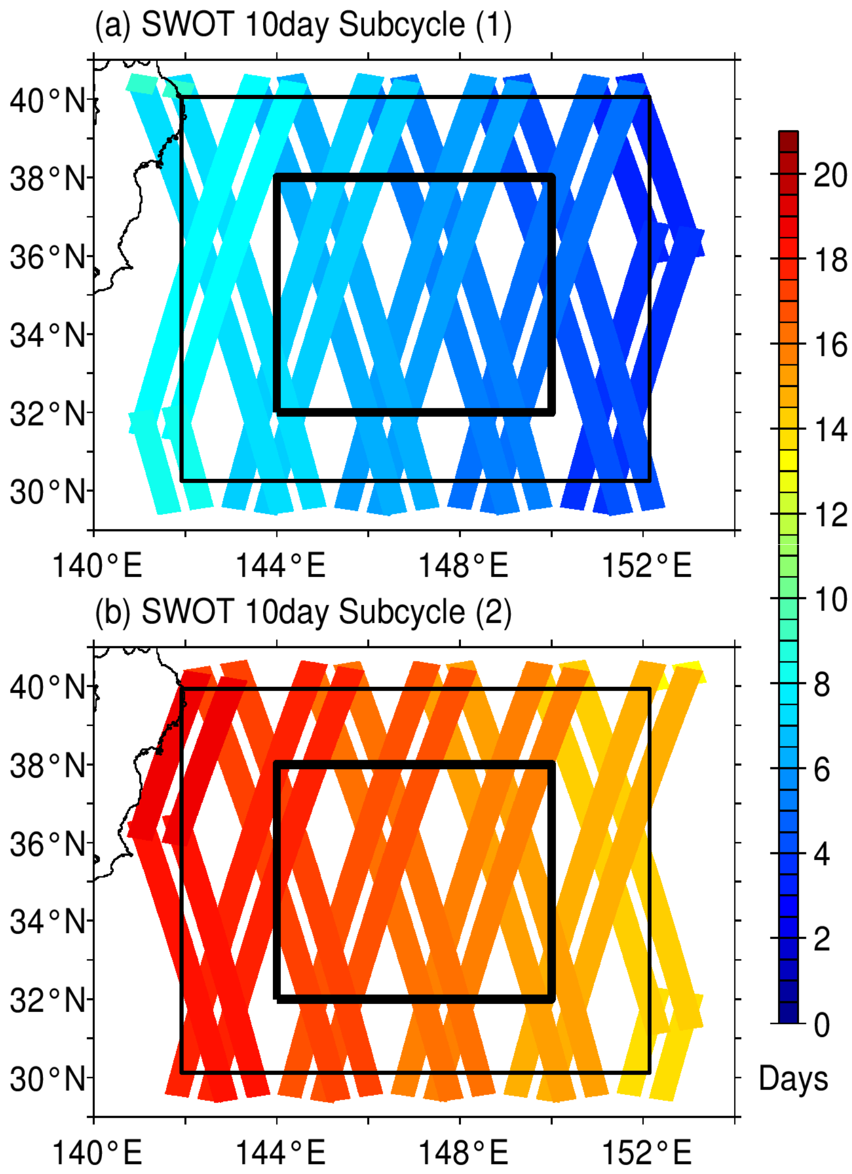
ζ : 0.7-0.9
w : 0.5-0.7

ζ : 0.7-0.8
w : 0.4-0.6

5-10% vs. 15-25% degradation

SWOT simulator: samples along-swath modeled SSH & adds expected errors





Two 10-day sub-cycles in each 20.86-day repeat cycle

For a 6° x 6° box, time difference of various swaths in one sub-cycle < 4 days