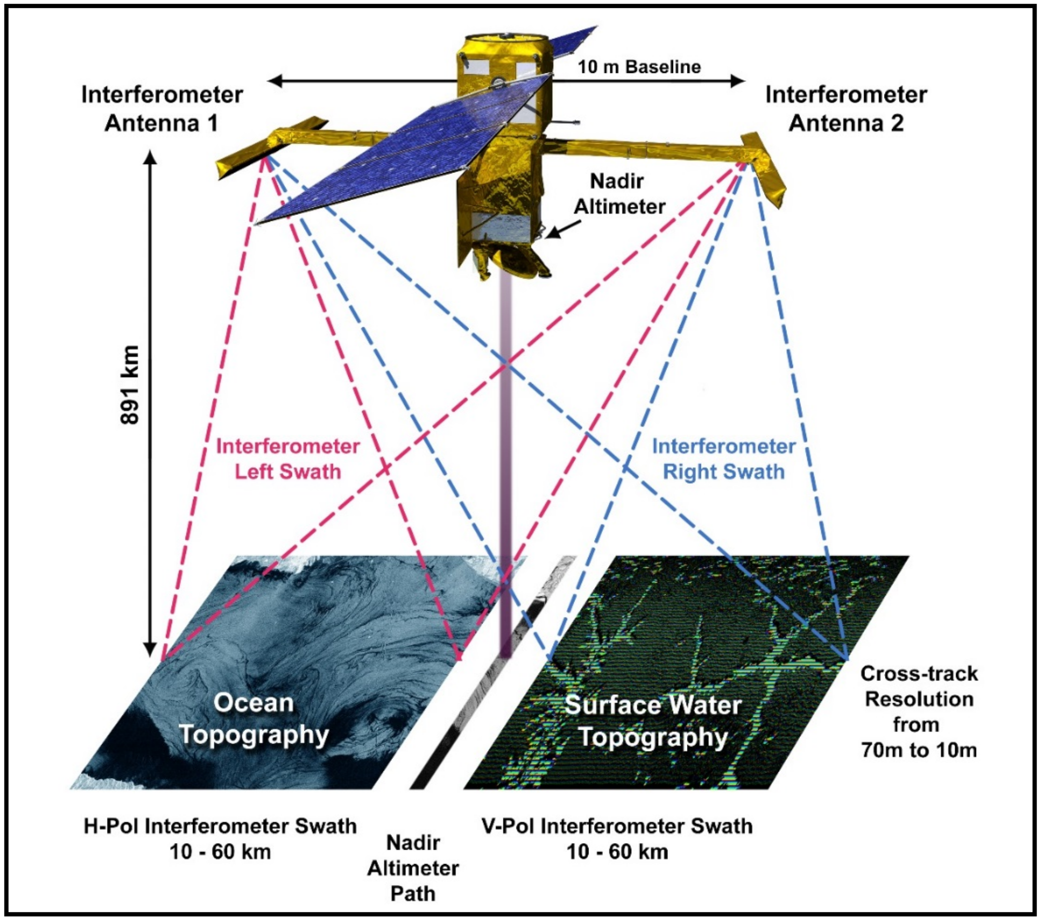
Reconstructing 3-D Upper Ocean Circulation Field in the Presence of Unbalanced Motions

Bo Qiu & Shuiming Chen

Dept of Oceanography, University of Hawaii

JPL collaborators: Jinbo Wang, Lee Fu & Patrice Klein

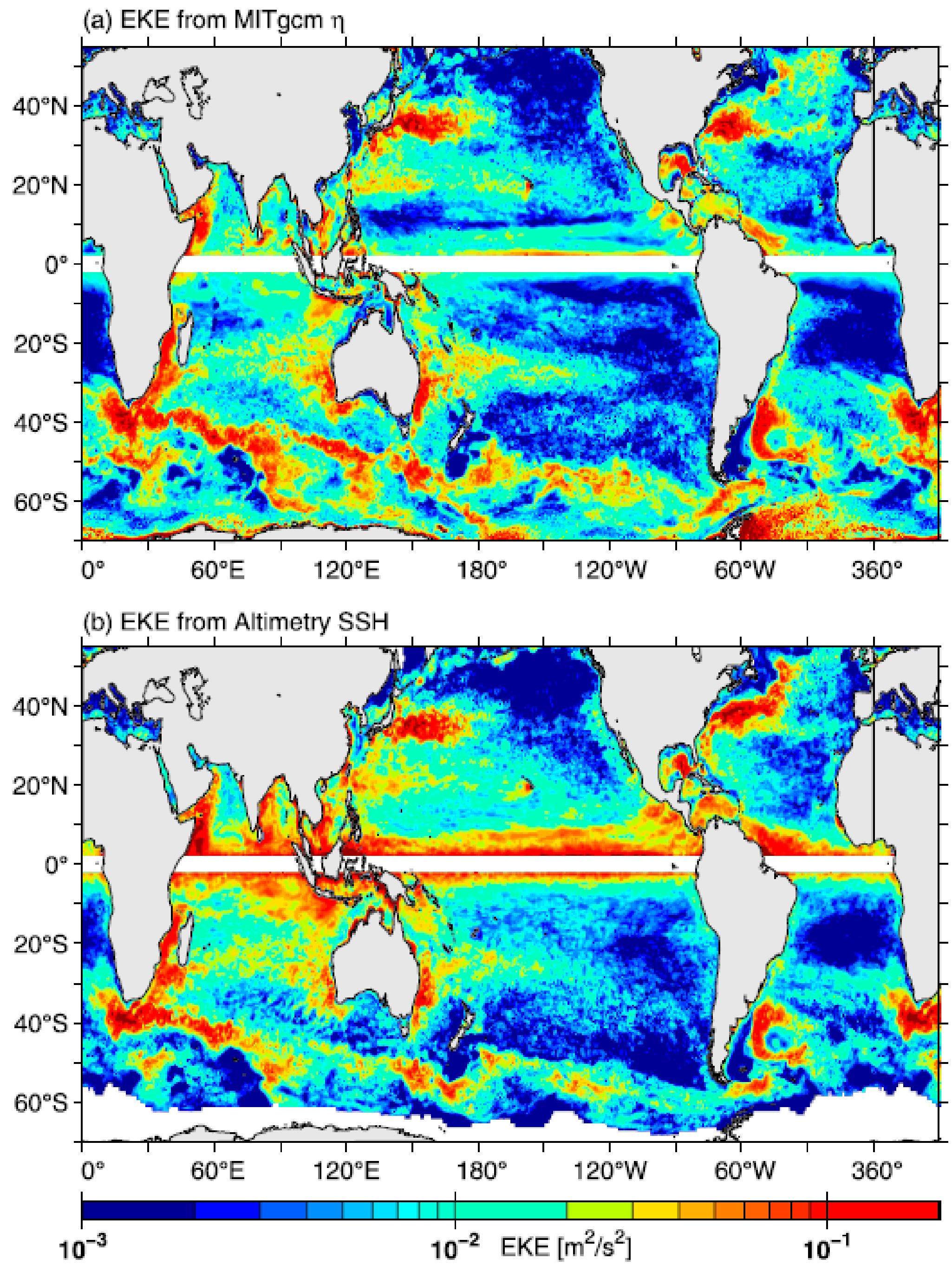


SWOT 3rd Science Team Meeting

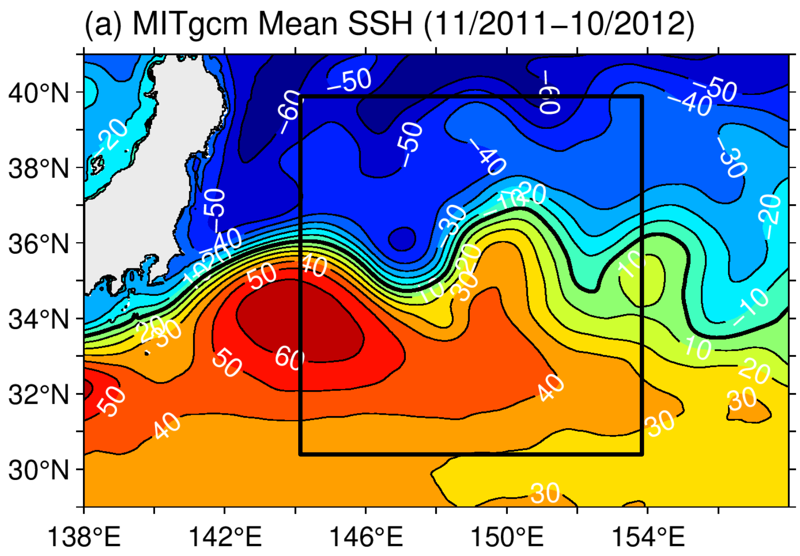
Montreal, Canada, 26-29 June 2018

Background:

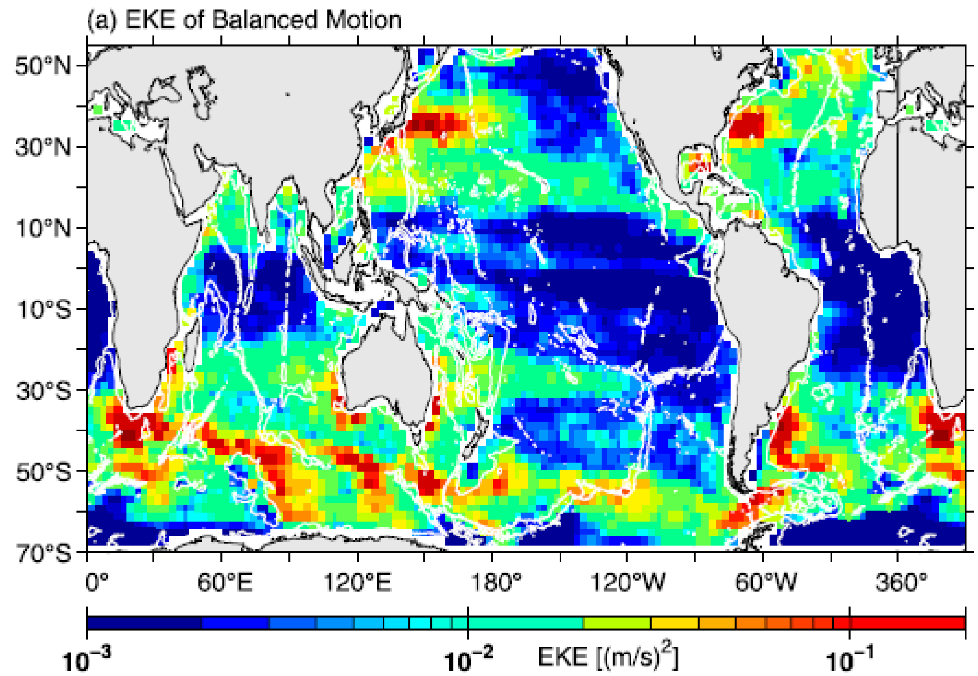
- Small mesoscale & submesoscale signals are mostly advected by circulation they're imbedded in
- From subtle phase changes, it allows us to reconstruct 3D balanced upper ocean circulation field, including w
- This talk assesses reconstructability using the SWOT simulator & MITgcm llc4320 in the context of eSQG framework (Lapeyre & Klein 2006)
- Our recent study shows that llc4320 simulates well the ADCP-measured balanced/unbalanced motions in the northwestern Pacific Ocean

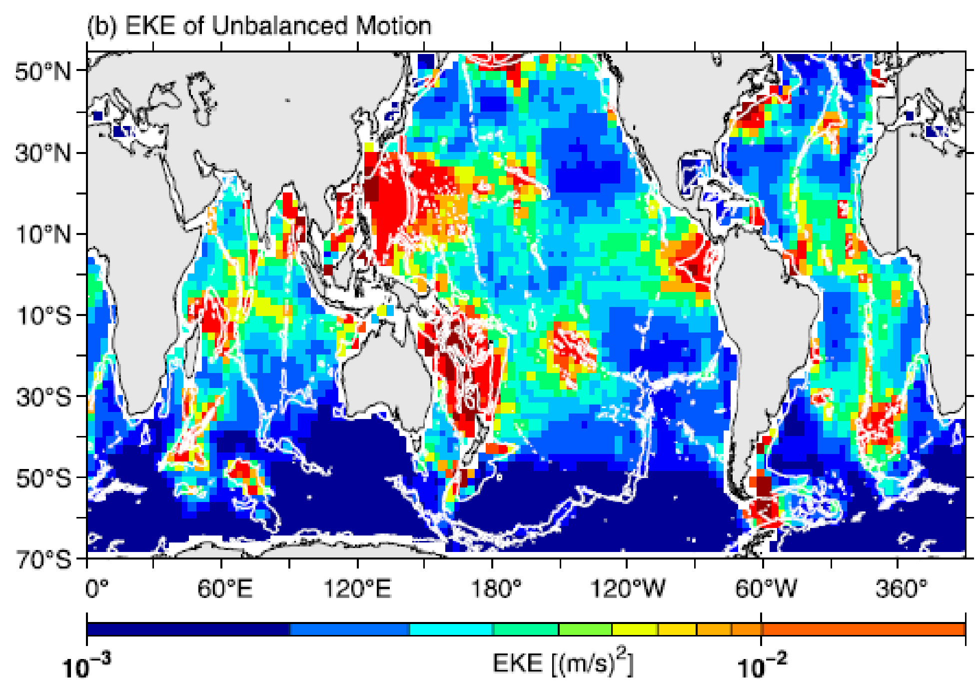


Qiu et al. (2018, JPO)



- Focus on a **Kuroshio Extension** box **30°–40°N, 144°–154°E**
- **The area has large balanced & moderate unbalanced signals (see right panels; different color scales)**





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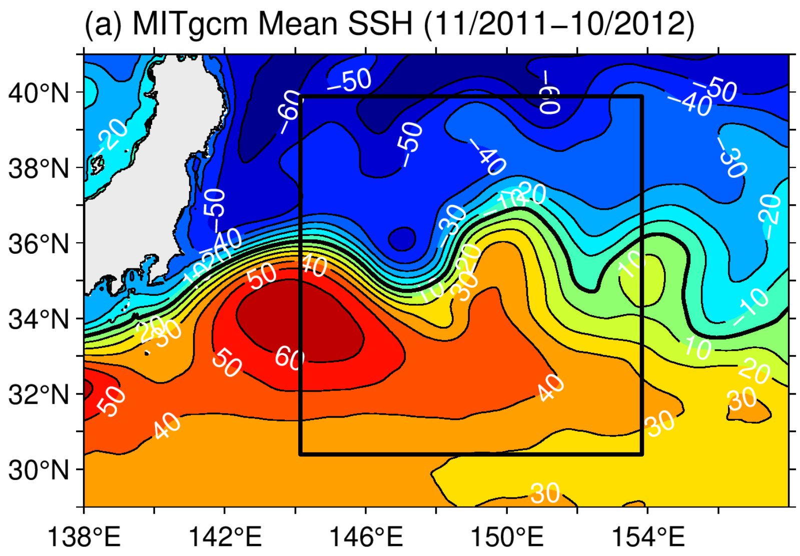
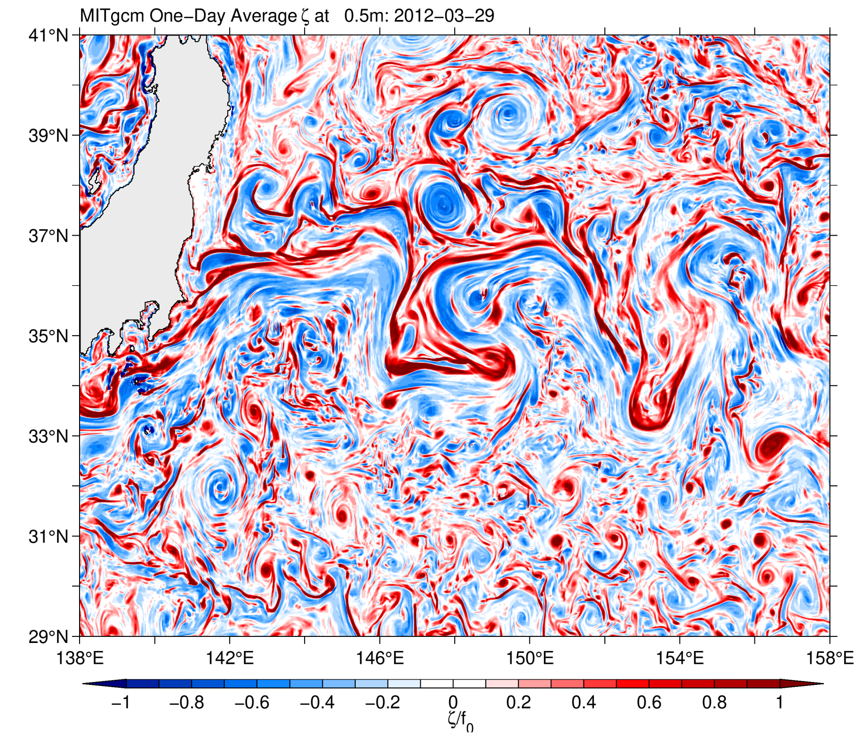
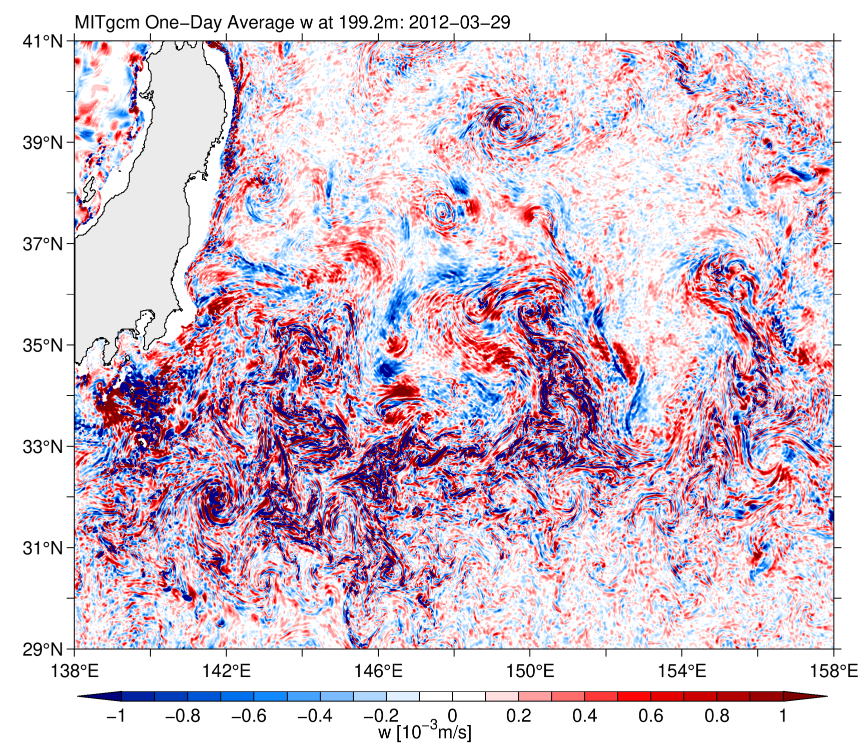


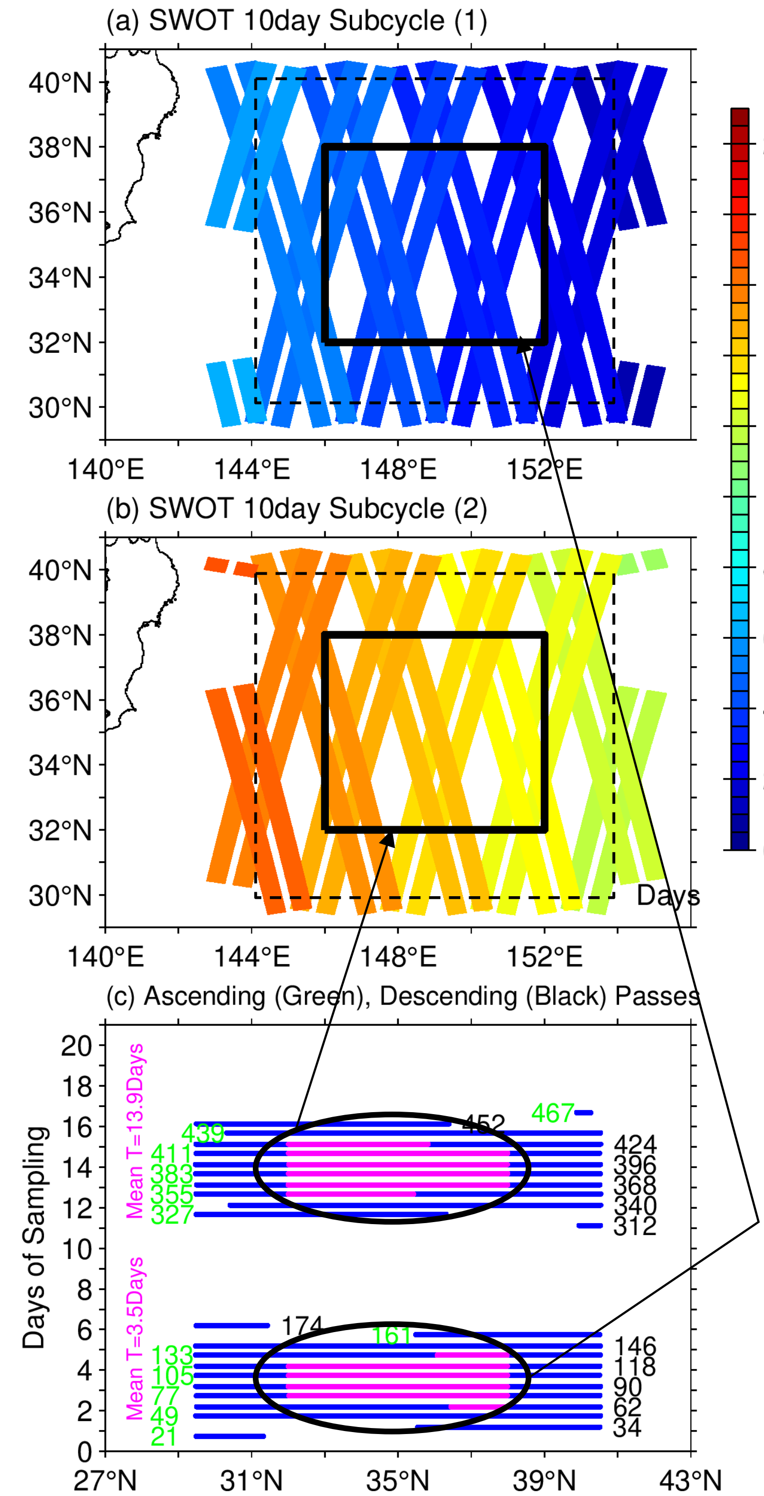
- Focus on a **Kuroshio Extension** box 30°–40°N, 144°–154°E
- The area has large balanced & moderate unbalanced signals
- This area is chosen because of enhanced regional submesoscale signals (right panels: typical daily-mean ζ & w field in winter)





Input: 10° x 10° hourly η field (in dashed box) or SWOT-simulator “measured” hourly η data within the 5-day sub-cycle + random measurement errors

Target: 6° x 6° 3-day-mean ζ & w field (in solid box); the smaller target box is chosen to avoid edge effect



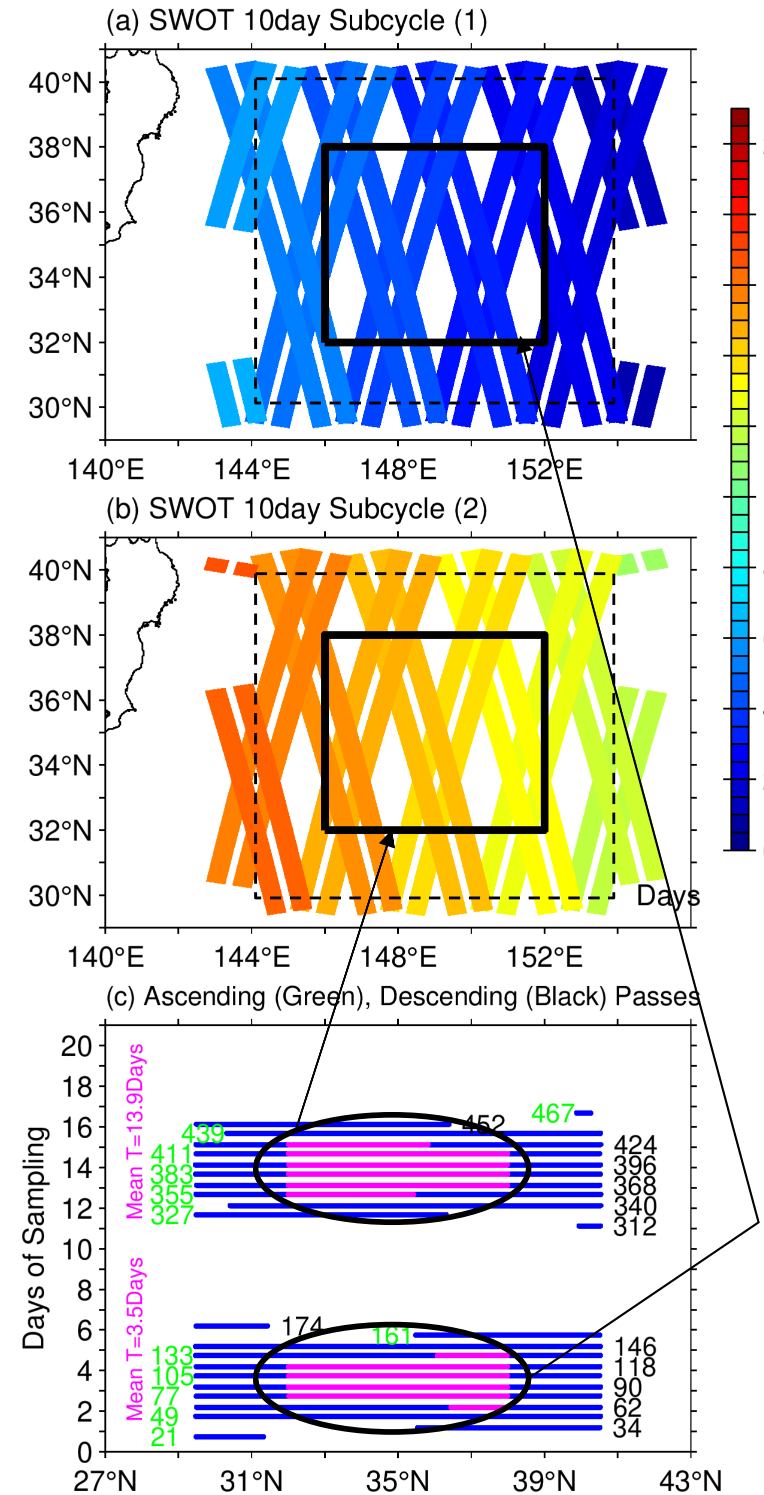
Two 5-day sub-cycles in each 20.86-day repeat cycle

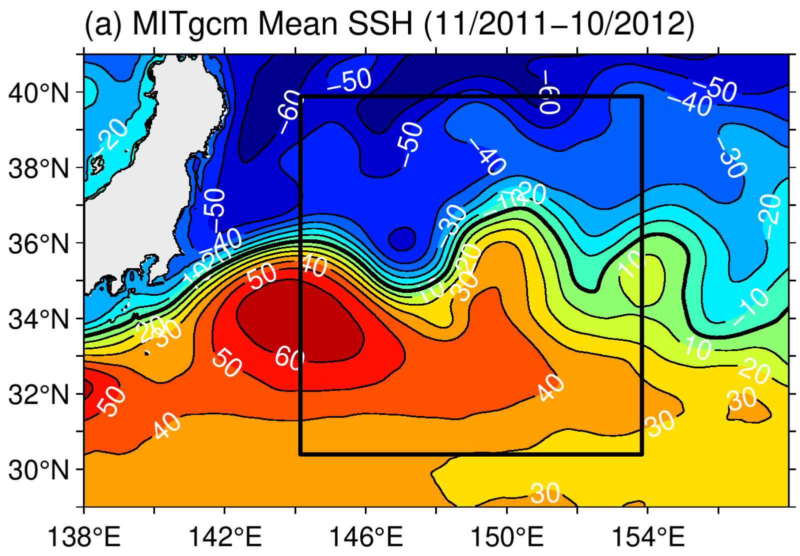
For a 6° x 6° box, time difference among various swaths in one sub-cycle < 4 days

Input: 10° x 10° hourly η field (in dashed box) or SWOT-simulator "measured" hourly η data within the 5-day sub-cycle + random measurement errors

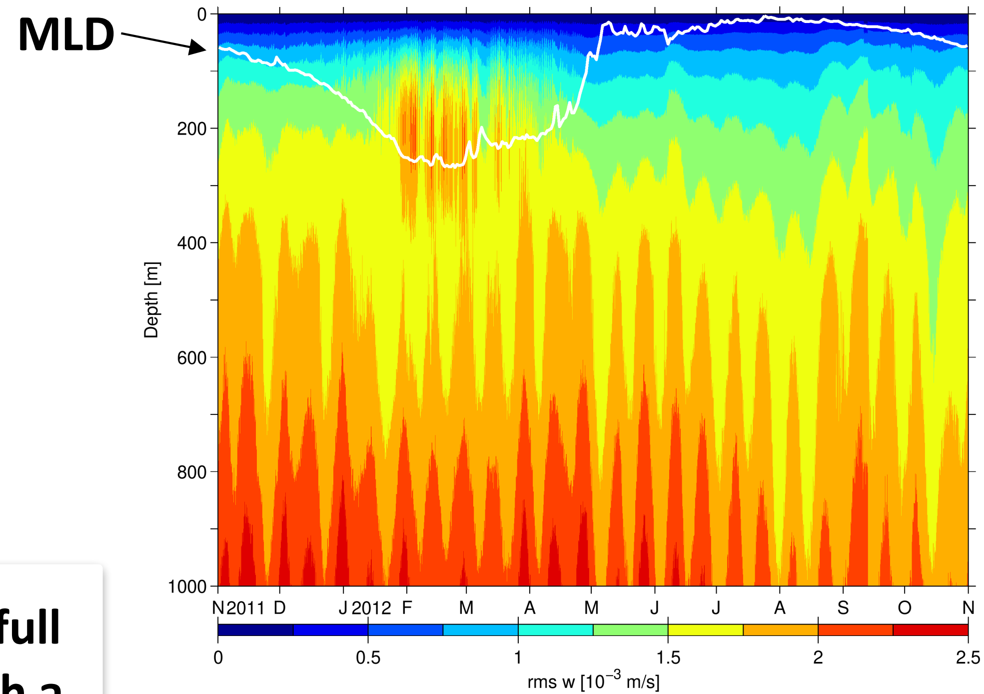
Target: 6° x 6° 3-day-mean ζ & w field (in solid box); the smaller target box is chosen to avoid edge effect

- For eSQG to work, a box encompassing full mesoscale features is required, even though a smaller target box gives better synopticity
- Because of fast evolution of meso-submeso-scale features, it does not help to bring in η data from neighboring sub-cycles (Qiu et al. 2016, JPO)
- With target being the 3-day-mean field, the reconstructed field captures "balanced" ζ & w signals

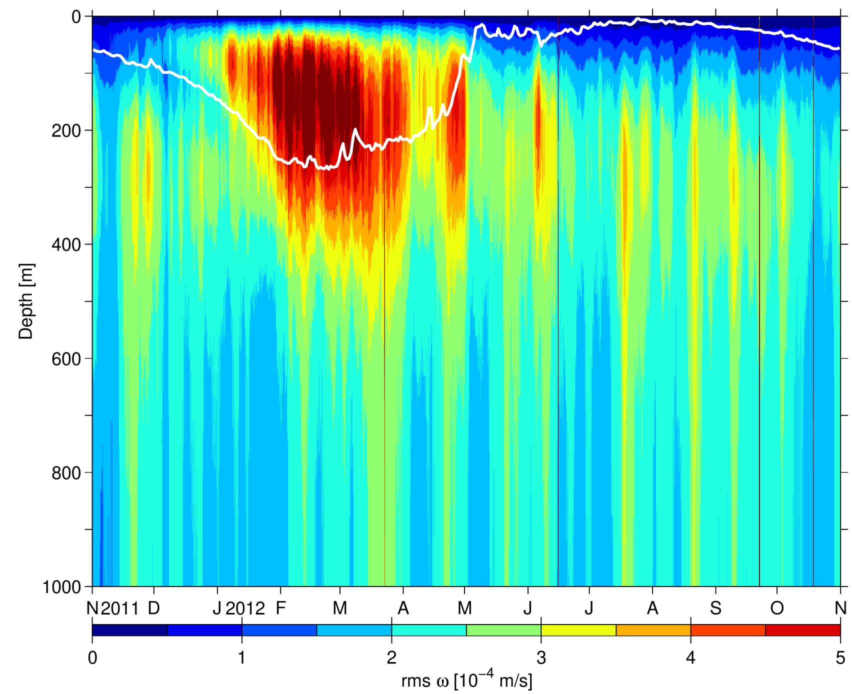




MITgcm rms original w



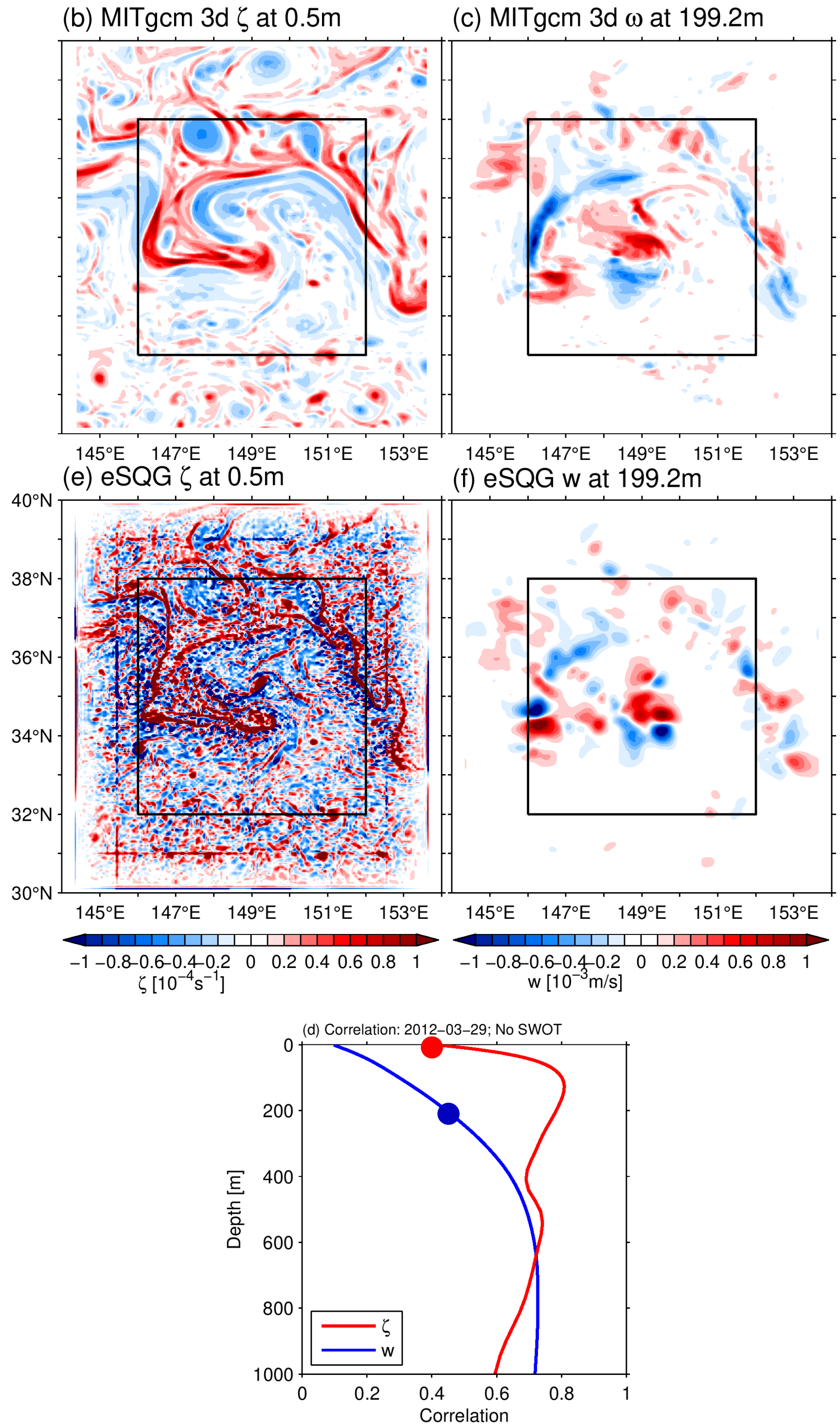
MITgcm rms balanced w



- **For eSQG to work, a box encompassing full mesoscale features is required, even though a smaller target box gives better synopticity**

- **Because of fast evolution of meso-submeso-scale features, it does <u>not</u> help to bring in η data from neighboring sub-cycles (Qiu et al. 2016, JPO)**

- **With target being the 3-day-mean field, the reconstructed field captures "balanced" ζ & w signals → dynamically more relevant**

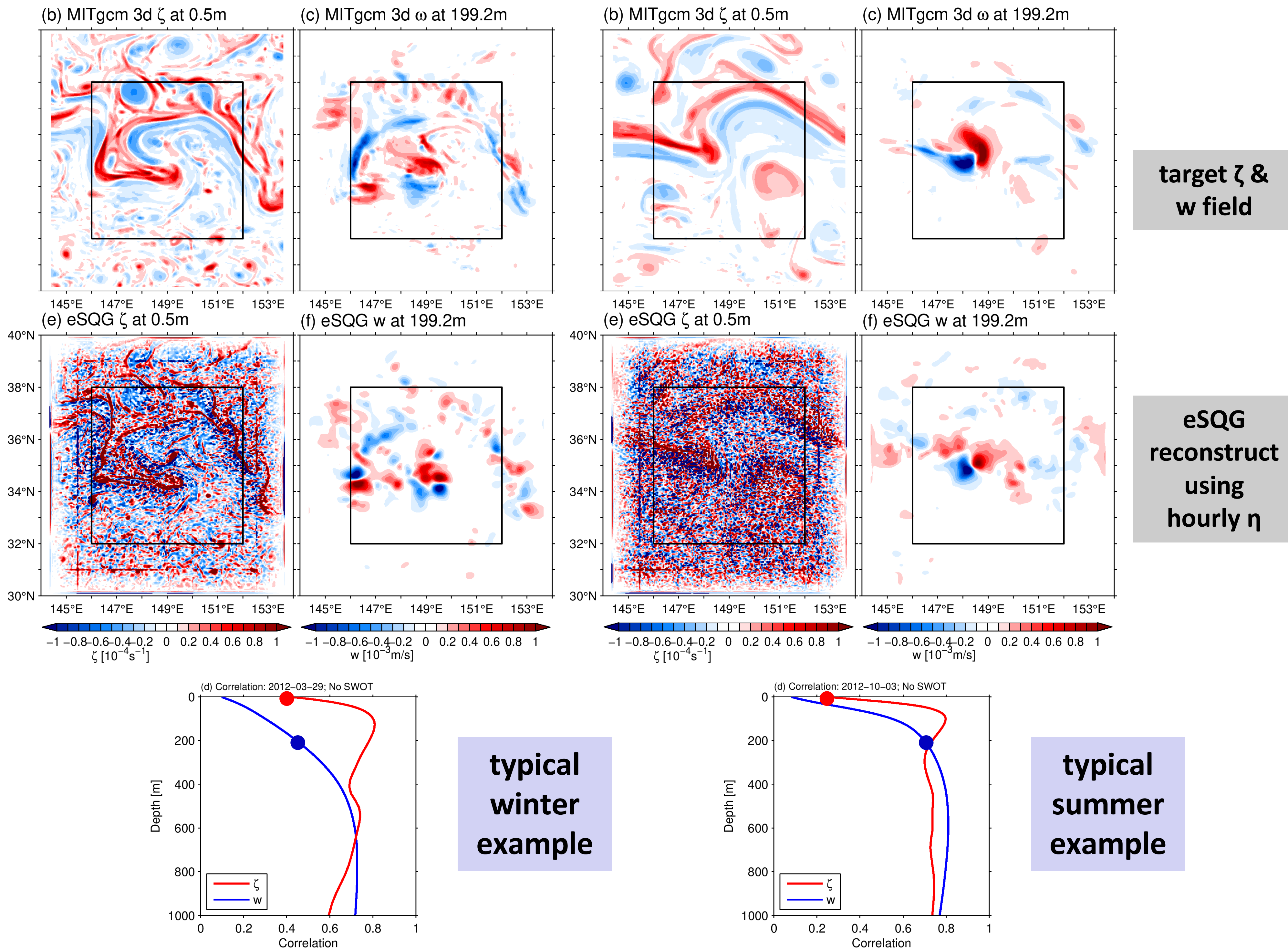


typical winter example

target ζ & w field

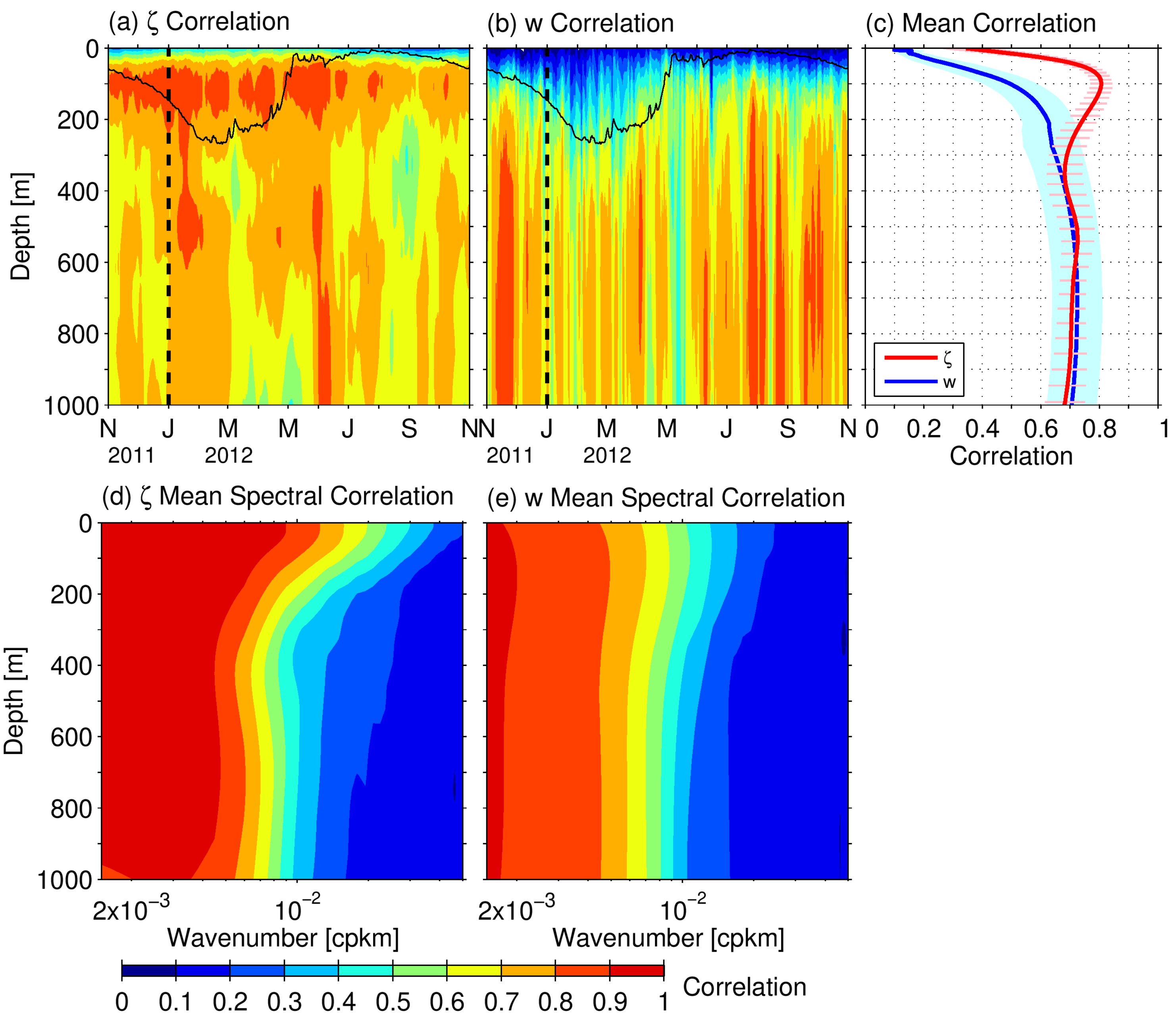
eSQG reconstruct using hourly η

- Hourly η field contains unbalanced signals that contaminate near-surface ζ & w ; reconstructed ζ & w improve in subsurface (z > 100m)
- The subsurface improvement is also due to reduction in submesoscale balanced motions



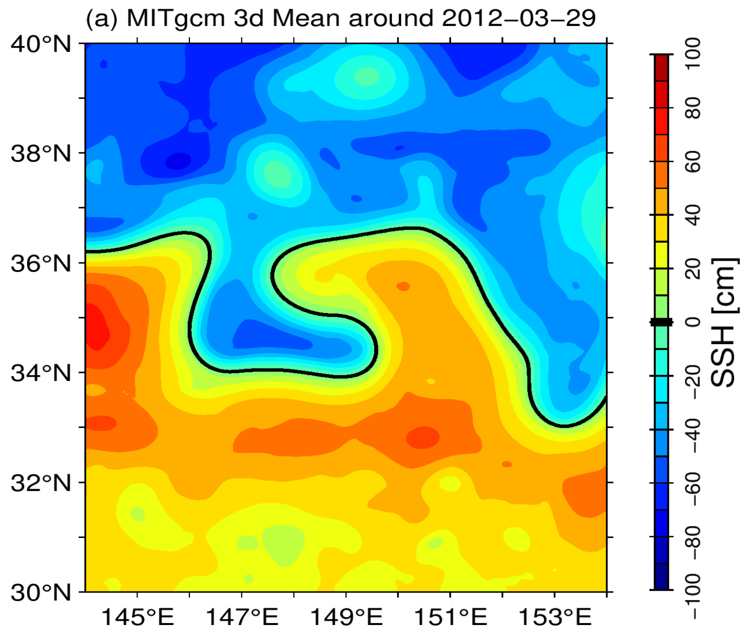
(b) MITgcm 3d ζ at 0.5m
(c) MITgcm 3d ω at 199.2m
(b) MITgcm 3d ζ at 0.5m
(c) MITgcm 3d ω at 199.2m
target ζ & w field
(e) eSQG ζ at 0.5m
(f) eSQG w at 199.2m
(e) eSQG ζ at 0.5m
(f) eSQG w at 199.2m
eSQG reconstruct using hourly η
145°E 147°E 149°E 151°E 153°E
40°N 38°N 36°N 34°N 32°N 30°N
−1 −0.8 −0.6 −0.4 −0.2 0 0.2 0.4 0.6 0.8 1
ζ [10−4s−1]
w [10−3m/s]
(d) Correlation: 2012−03−29; No SWOT
(d) Correlation: 2012−10−03; No SWOT
Depth [m]
Correlation
ζ
w
typical winter example
typical summer example

Reconstructed w & ζ correlations as a function of time



eSQG reconstruct using hourly η

target 3-day-mean η field



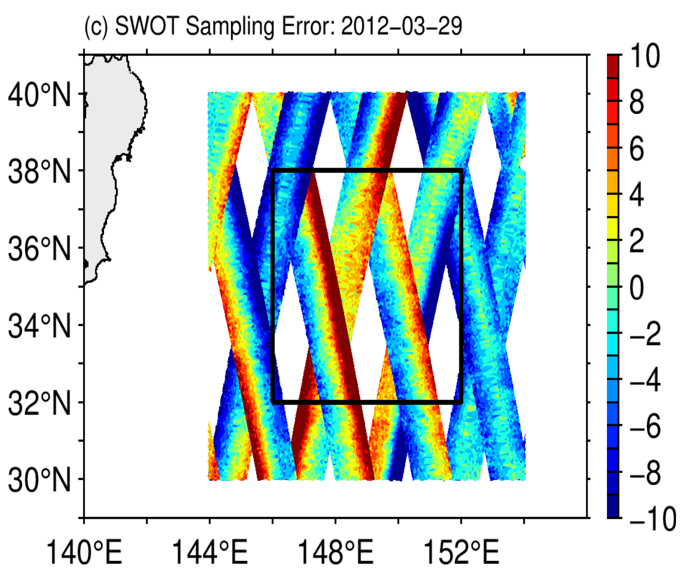
Comments on mapping of η field:

A non-trivial issue !!

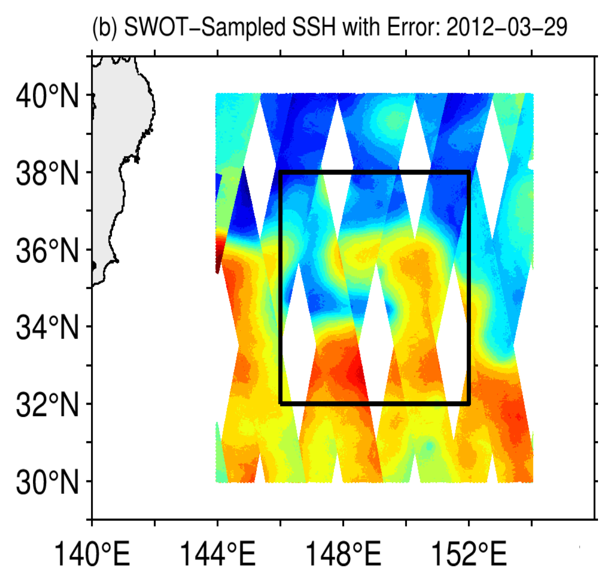
Used simulator-sampled η data within a sub-cycle (±2 days) only

Determined "optimal" spatial mapping scale by trial-and-error

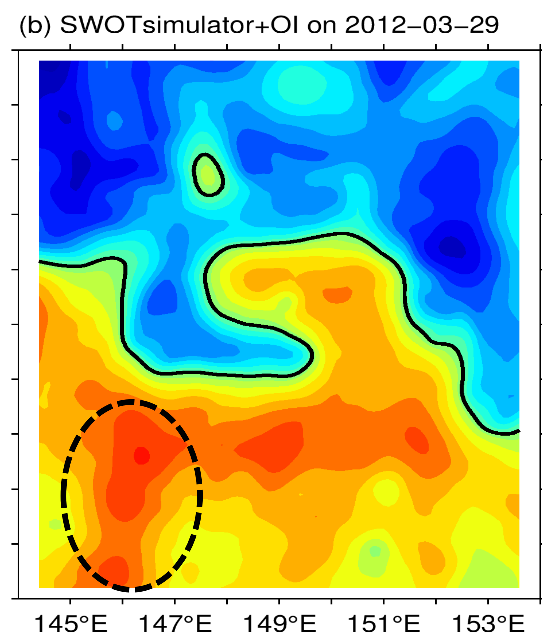
simulator-generated η errors

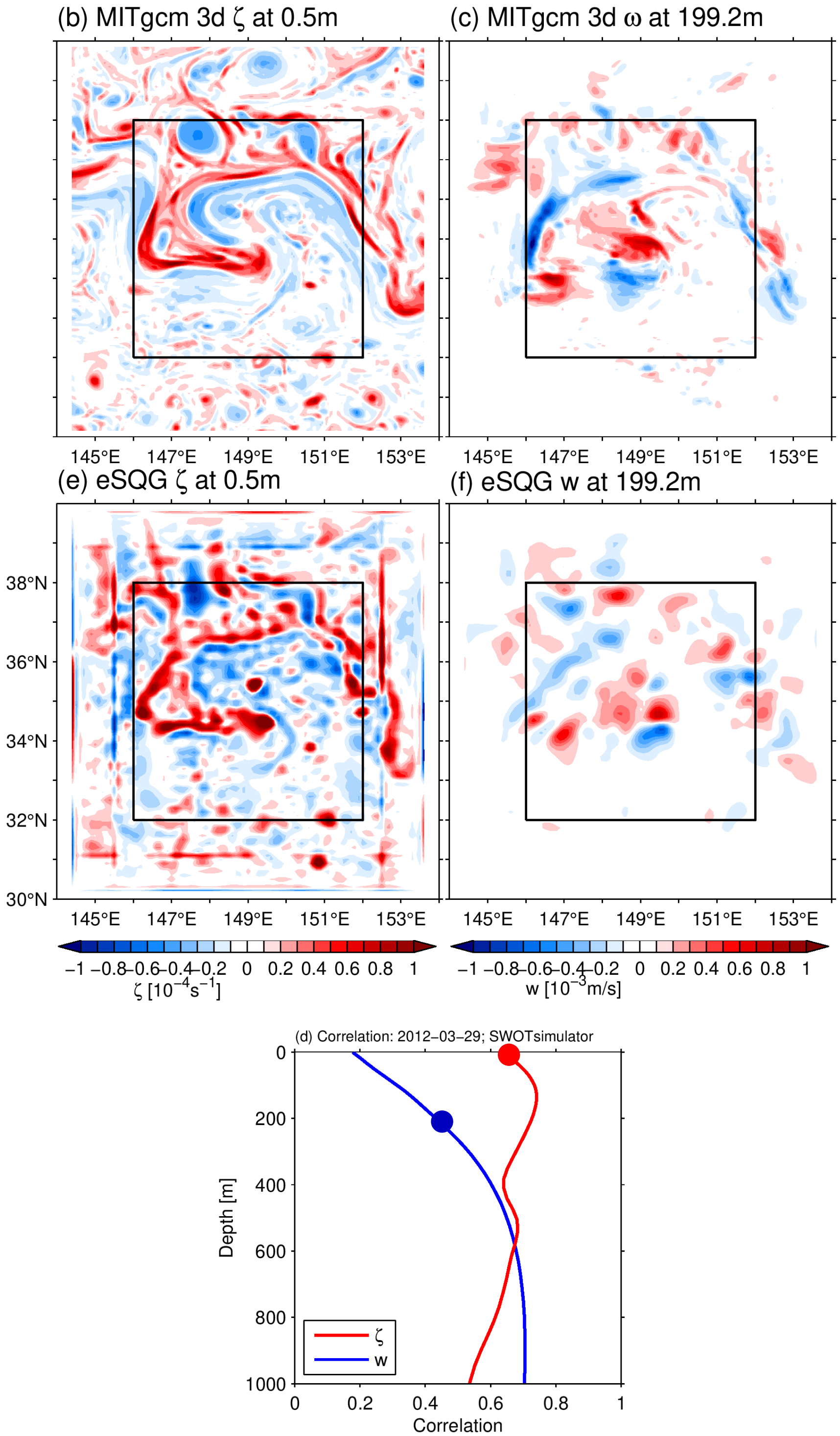


simulator-sampled hourly η field



mapped η with optimal scale



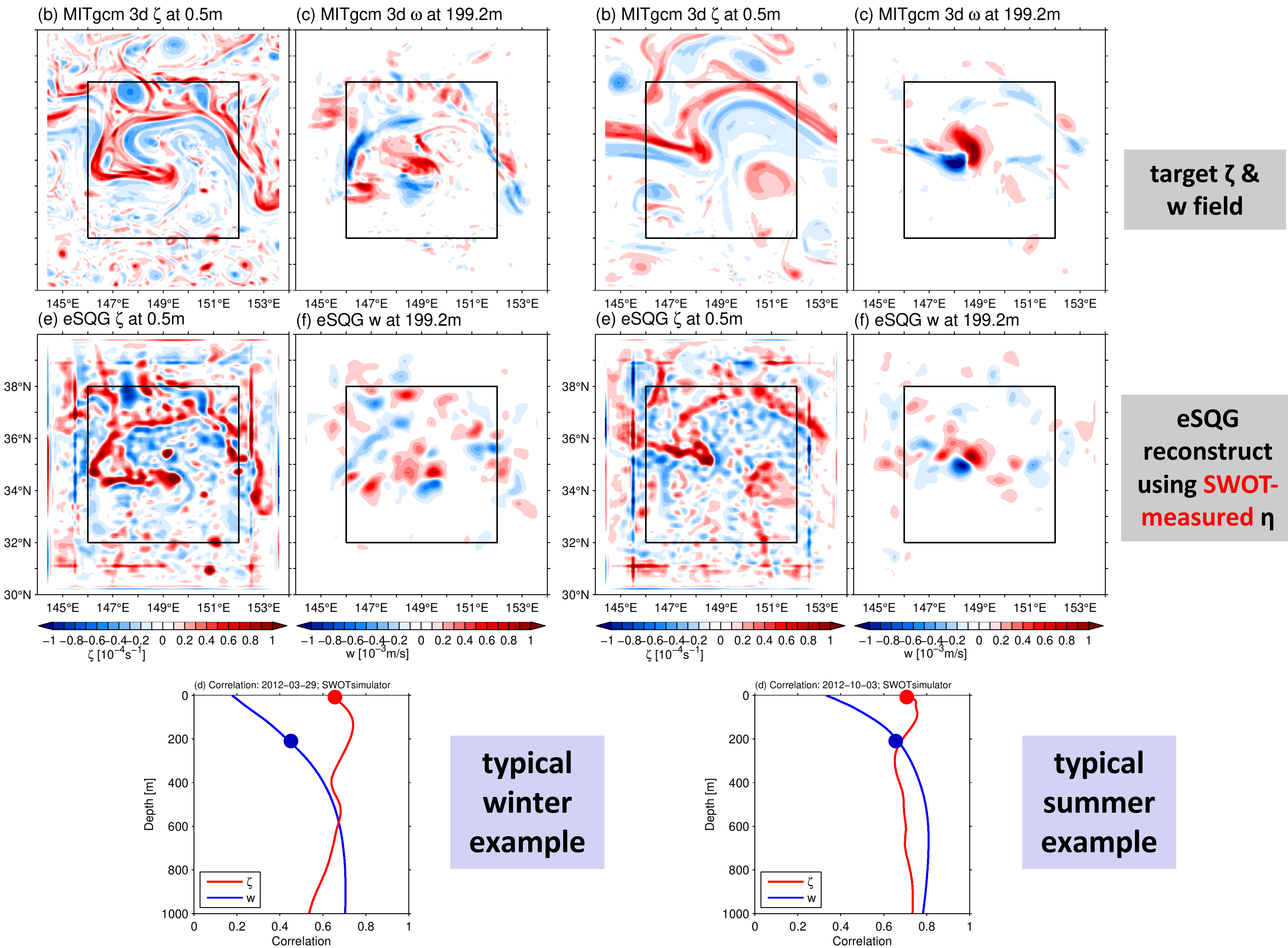


typical winter example

target ζ & w field

eSQG reconstruct using **SWOT-measured** η

- **OI-ed η field smears out unbalanced η signals that helps to "improve" near-surface ζ & w reconstruction (when compared to the use of original hourly η field)**
- **Subsurface reconstruction deteriorates due to smearing of mesoscale η signals**



(b) MITgcm 3d ζ at 0.5m
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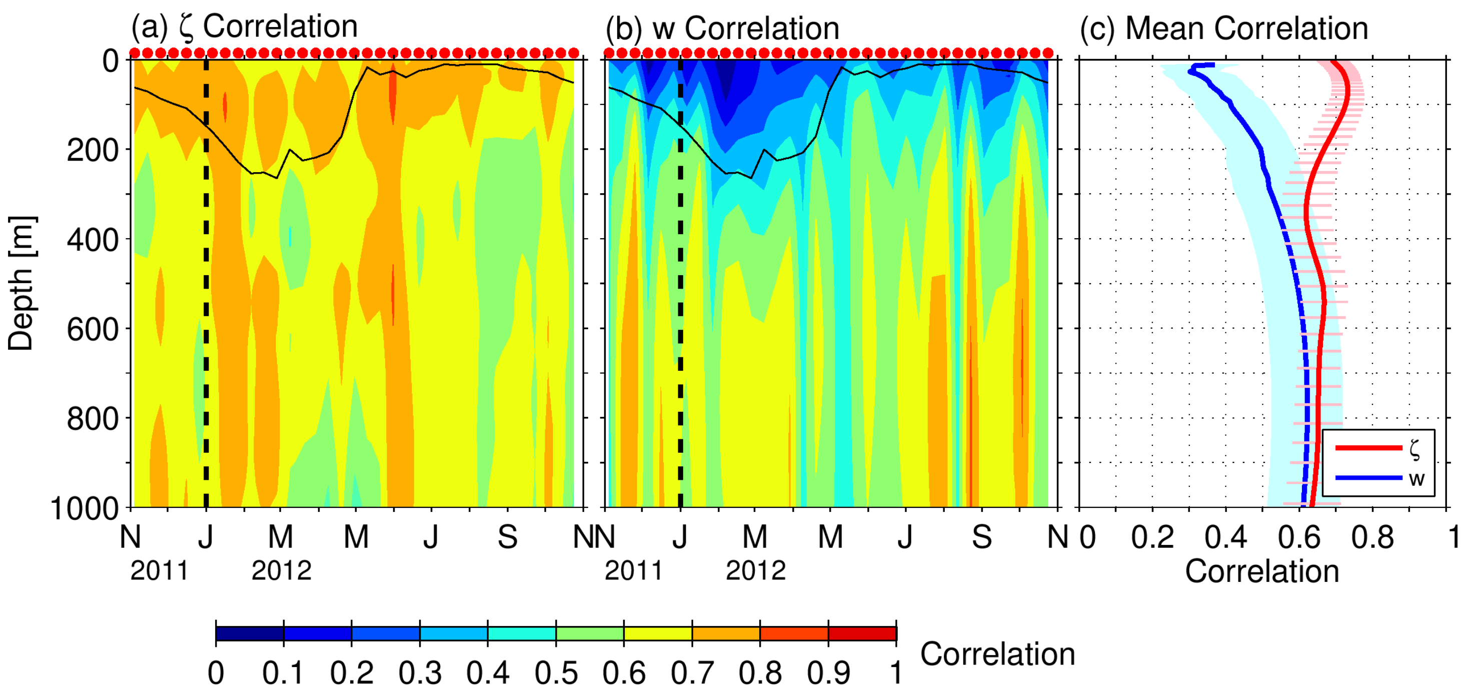
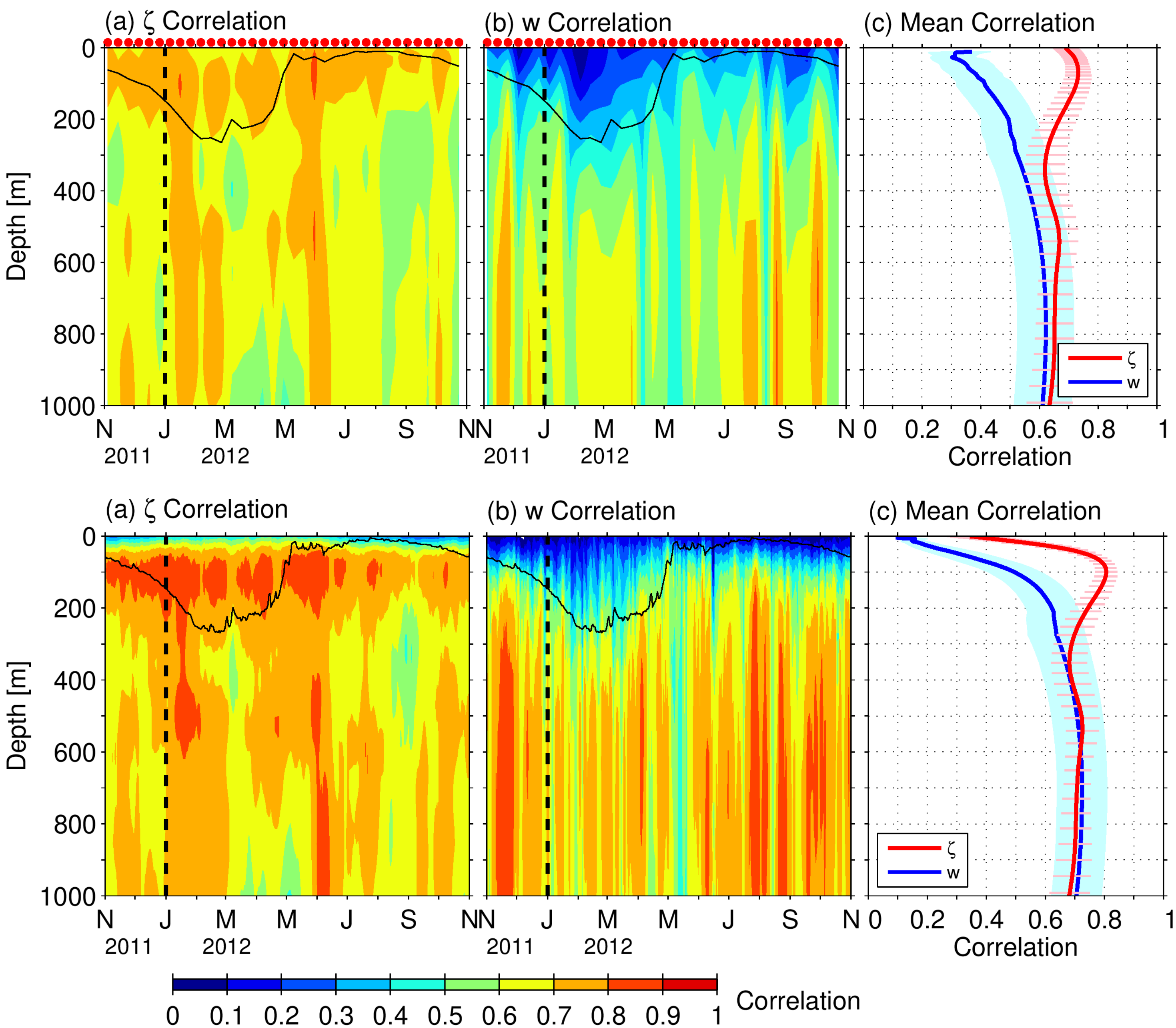
145°E 147°E 149°E 151°E 153°E
30°N 32°N 34°N 36°N 38°N
ζ [10−4s−1]
w [10−3m/s]
target ζ & w field
eSQG reconstruct using SWOT-measured η
(d) Correlation: 2012−03−29; SWOTsimulator
(d) Correlation: 2012−10−03; SWOTsimulator
Depth [m]
Correlation
ζ
w
typical winter example
typical summer example

Reconstructed w & ζ correlations as a function of time



eSQG reconstruct using SWOT-measured η

Reconstructed w & ζ correlations as a function of time



eSQG reconstruct using SWOT-measured η

eSQG reconstruct using hourly η

Concluding Remarks

- Effective SQG theory is a simple, but promising, formulation to reconstruct 3-D circulation field, including w, from the SWOT SSH measurements in high-EKE oceans

- With the need for interpolation, presence of unbalanced signals does not pose a significant problem for reconstruction

- Within a 3-day subcycle, the reconstructed ζ & w can reach c = 0.6–0.7 & 0.3–0.6, respectively, when compared to the 3-day mean field

  (analyses are being pursued in other regions of the world ocean to quantify the above 2 points)

- Better reconstruction theories (especially within the ML) & interpolation methods are needed in future studies

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

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

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

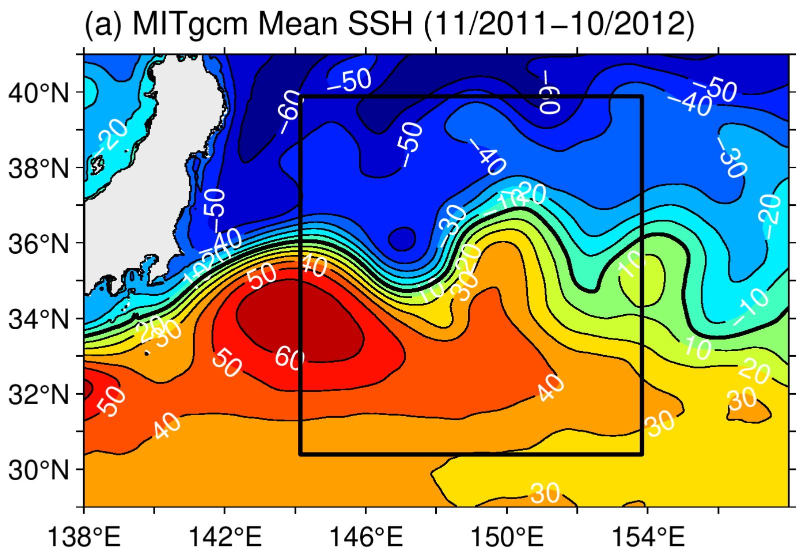
where ^ : horizontal Fourier transform, k : horizontal wavenumber, and N_0 : effective buoyancy frequency.

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

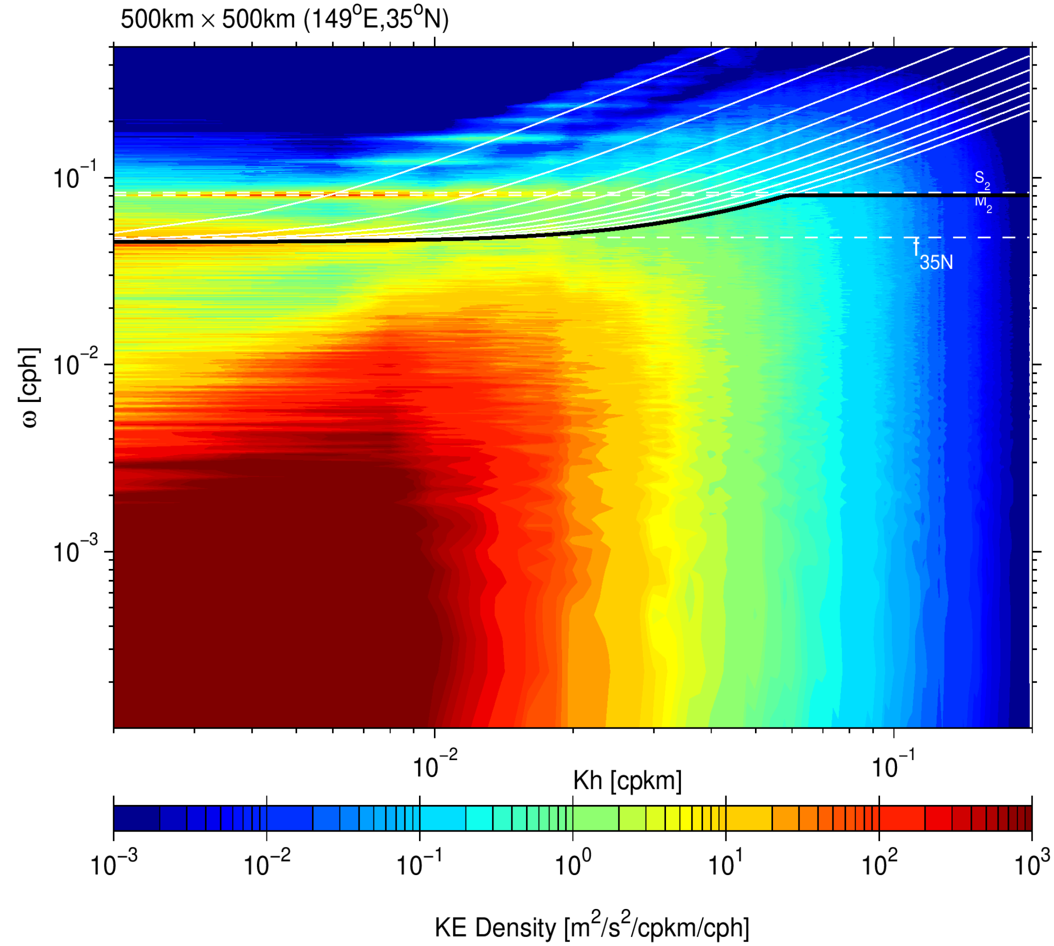
$$\hat{\zeta}(\mathbf{k}, z) = -k^2 \hat{\psi}(\mathbf{k}, z),$$

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

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



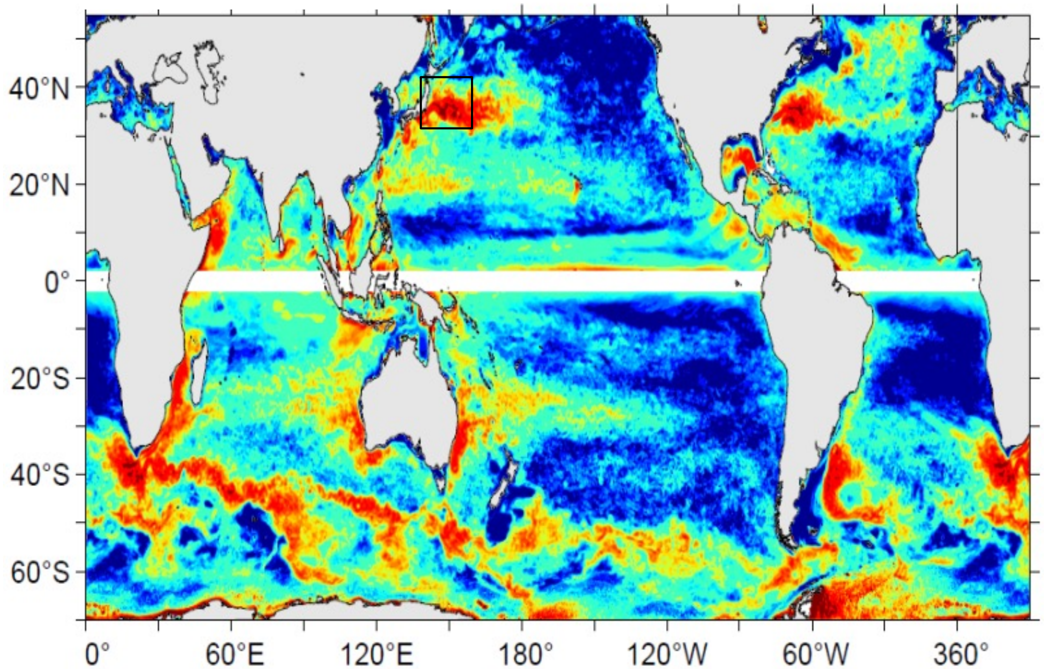
Wave frequency-wavenumber KE spectra

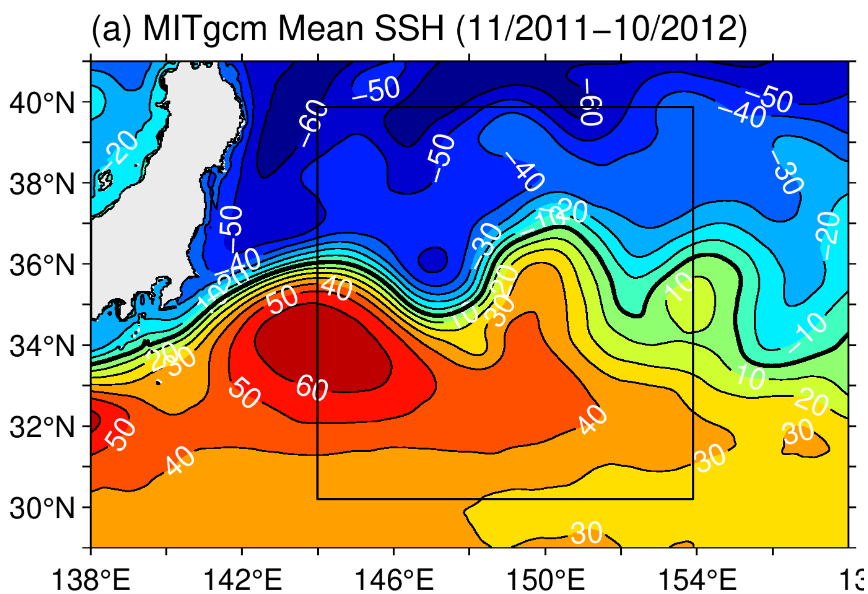


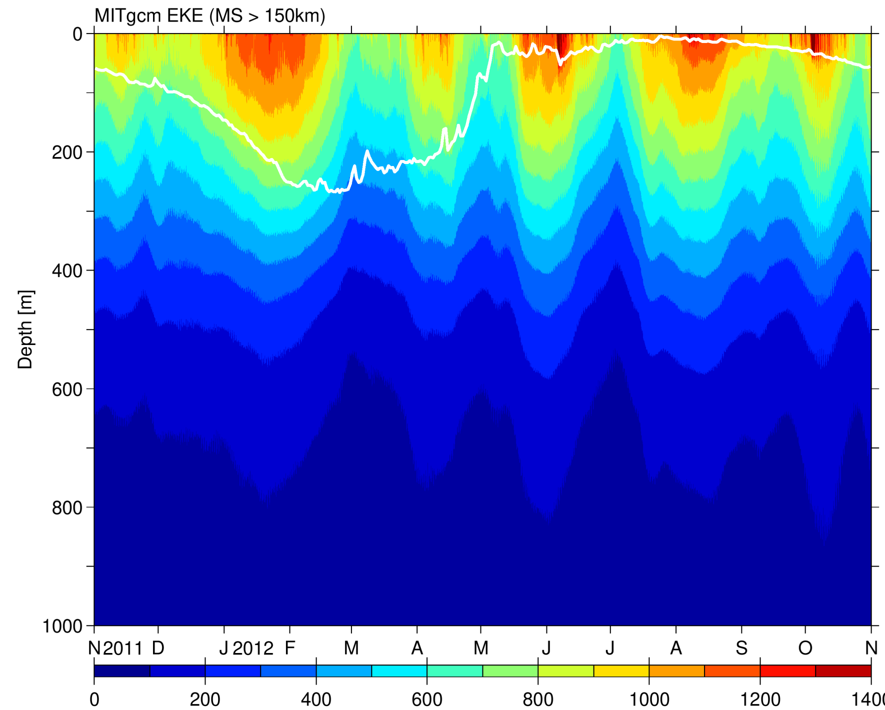
Balanced & unbalanced motions are delineated by the lower frequency boundary of either the local IGW dispersion curve or permissible tides

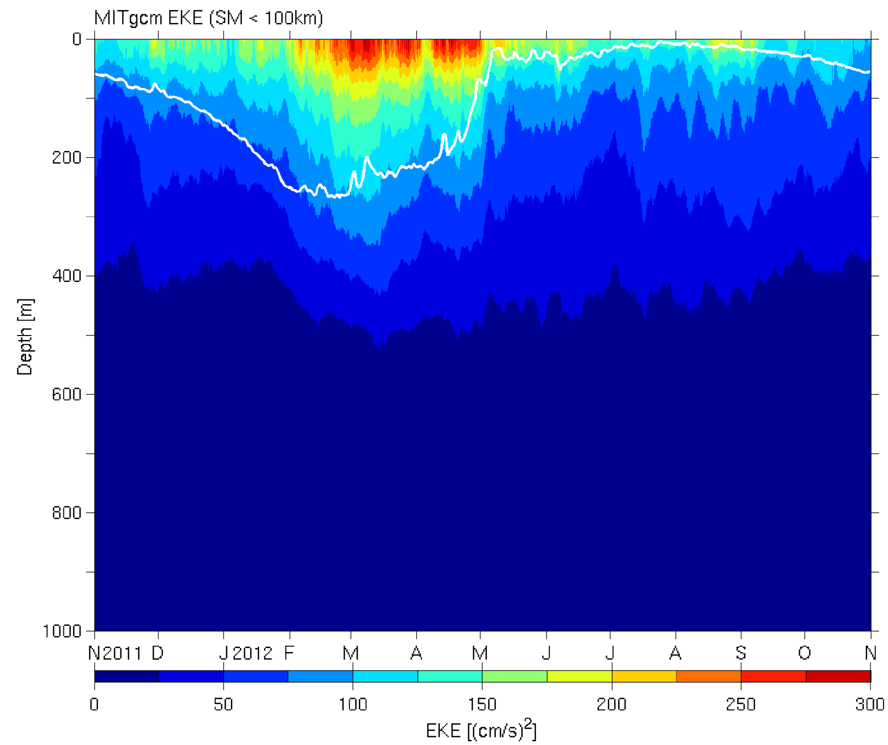
(Solid white lines denote dispersion curves for the first 10 IGW modes)

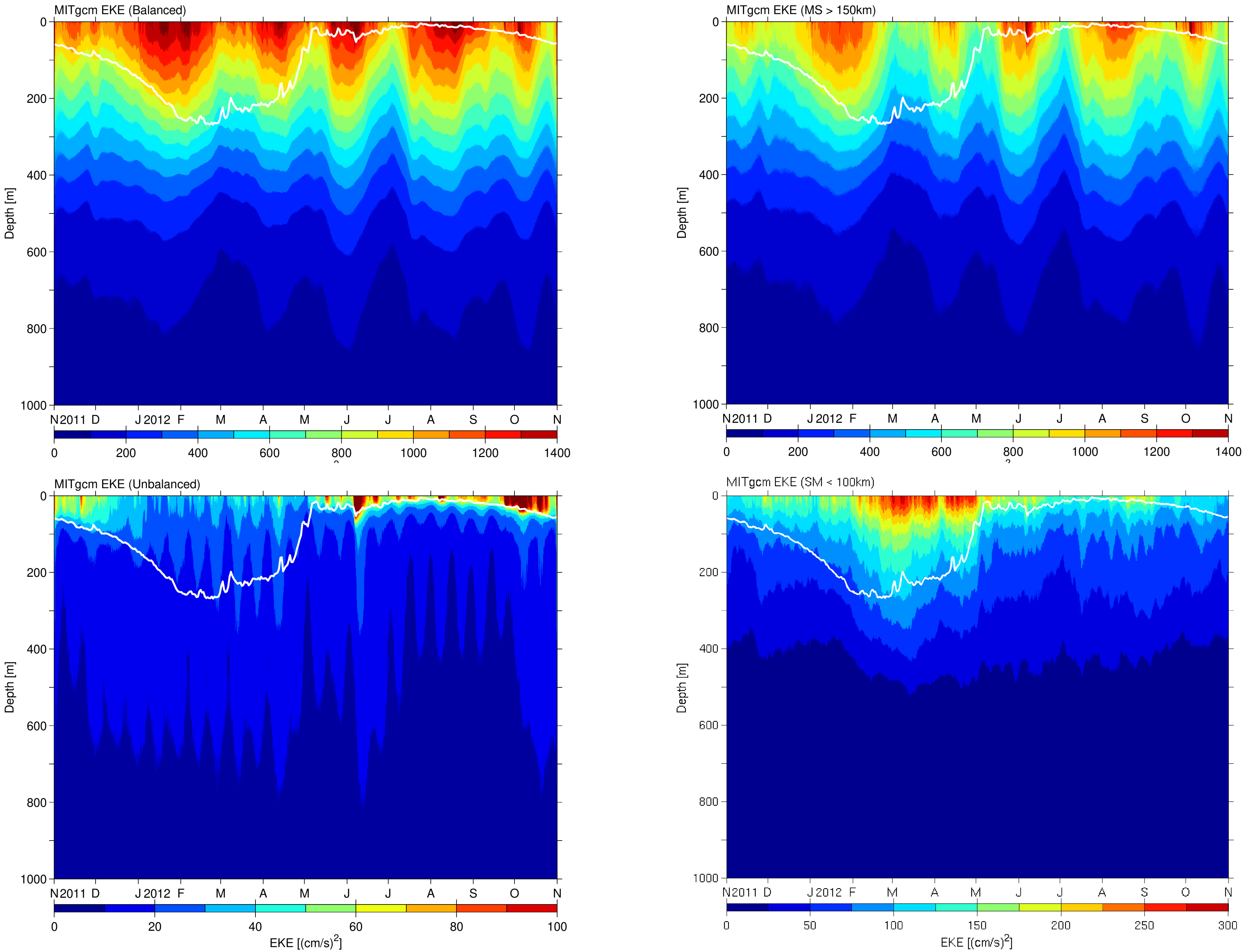
MITgcm mesoscale EKE



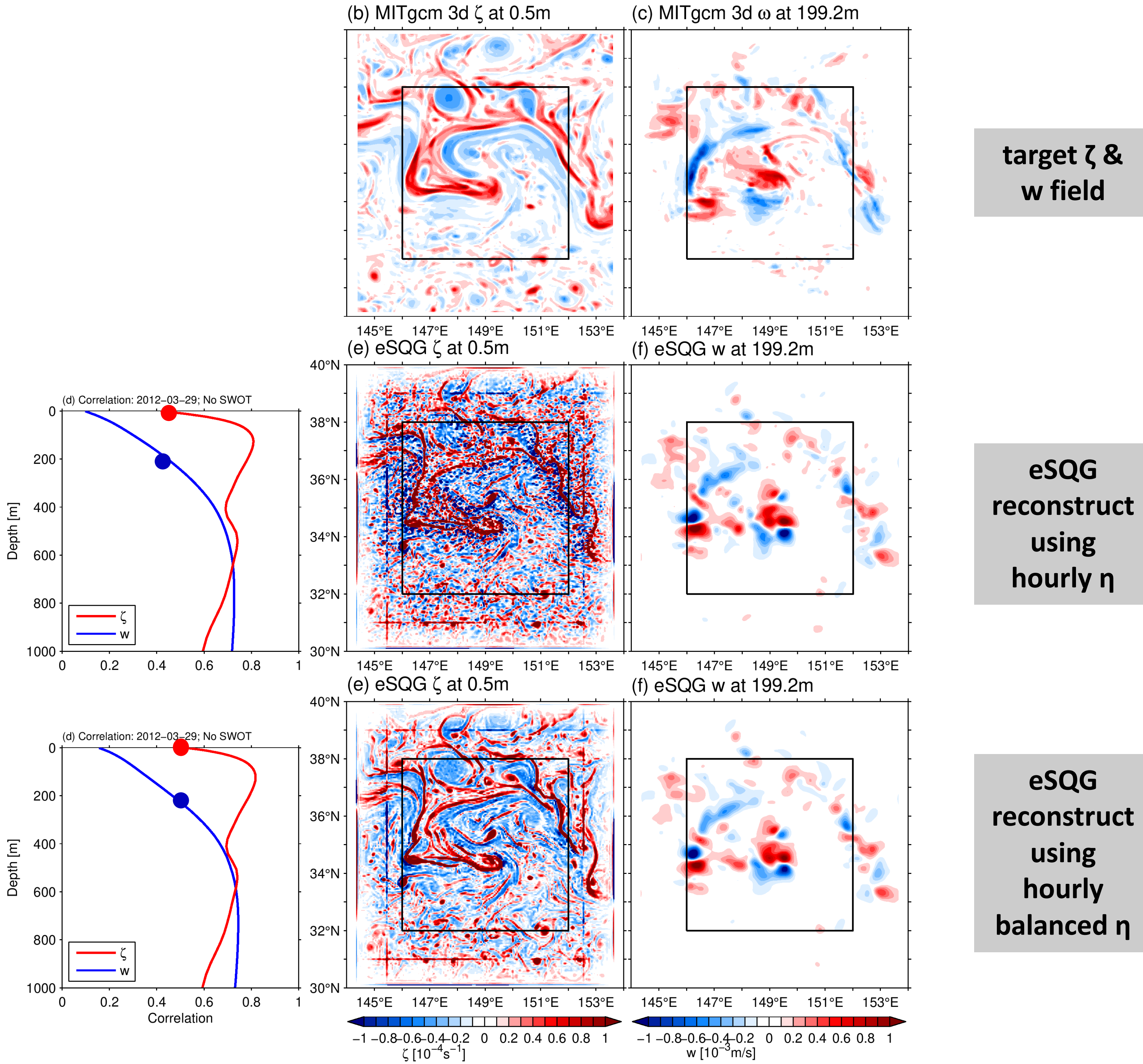








MITgcm EKE (Balanced)
MITgcm EKE (MS > 150km)
MITgcm EKE (Unbalanced)
MITgcm EKE (SM < 100km)
Depth [m]
0
200
400
600
800
1000
N 2011 D J 2012 F M A M J J A S O N
0 200 400 600 800 1000 1200 1400
0 20 40 60 80 100
0 50 100 150 200 250 300
EKE [(cm/s)^2]



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target ζ & w field
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eSQG reconstruct using hourly η
(d) Correlation: 2012–03–29; No SWOT
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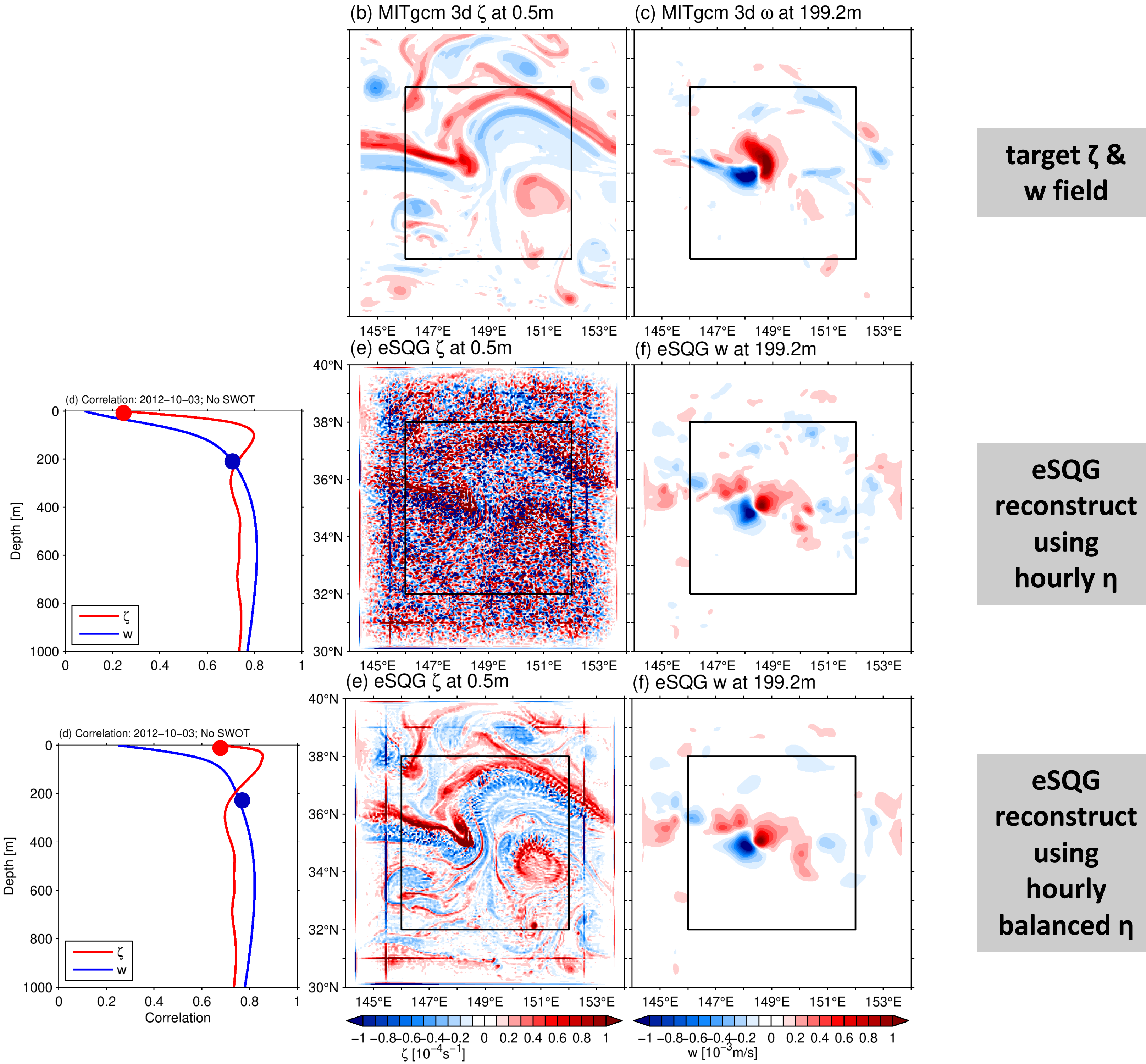
(f) eSQG w at 199.2m
eSQG reconstruct using hourly balanced η
Depth [m]
Correlation
ζ
w
145°E 147°E 149°E 151°E 153°E
30°N 32°N 34°N 36°N 38°N 40°N
ζ [10^{-4}s^{-1}]
w [10^{-3}m/s]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Depth [m]
Correlation
ζ [10^{-4}s^{-1}]
w [10^{-3}m/s]
145°E 147°E 149°E 151°E 153°E
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target ζ & w field
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