Feasibility of reconstructing sea surface height from surface current velocity fields

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2019 OVWST Meeting, Portland, Maine
Thursday, May 30, 2019

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Motivation

* At the May 2017 Ocean Vector Winds Science Team Meeting in La Jolla, Ross Hoffmann suggested that WaCM could make a good wide-swath altimeter
* This project essentially tests the feasibility of this idea
* If successful, WaCM could give information on surface winds, currents, and SSH over an 1800km wide swath!

Project Objective

* Can surface current observations from wide-swath Doppler Scatterometers such as the proposed WaCM give reasonable indirect estimates of dynamic sea surface height anomalies?
  * Develop the numerical inversion method
  * Space-time scales of coherence

Today's subject

  * Effects of observational noise and biases in surface currents
  * Sampling errors due to instrument coverage

Subject of ongoing work

Helmholtz Decomposition of surface currents

Non-divergent

Irrotational

$$u = -\frac{\partial \psi}{\partial y} + \frac{\partial \phi}{\partial x}$$

$$v = \frac{\partial \psi}{\partial x} + \frac{\partial \phi}{\partial y}$$

ψ is the streamfunction (non-divergent flow component)

ϕ is the velocity potential (irrotational flow component)

Streamfunction ψ to SSH η using geostrophic approximation

We hypothesize that the geostrophic flow can be approximated by the non-divergent flow component, and thus the streamfunction should be related to the dynamic SSH anomaly η :

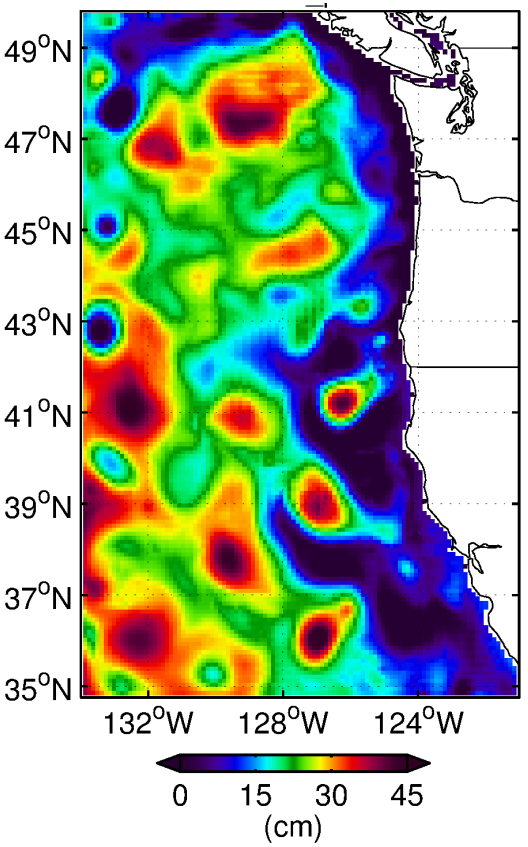
$$\eta = \frac{f}{g}\psi$$

SSH Streamfunction

Estimation of SSH from Surface Ocean Current Streamfunction

* Use high resolution ocean model simulations of near-surface ocean currents and SSH
  * Coupled WRF-ROMS simulation off the North American west coast
    * 2 km ocean, hourly output for 61 days (Aug 1-Sept 13 2009)
    * Averaged to 10-km for this analysis, commensurate with expected WaCM sampling

ROMS SSHA Snapshot



Helmholtz Decomposition in a Limited Domain

* How do we get streamfunction ψ from u and v?
* Finite difference the derivatives to second order accuracy, then form a matrix equation for the resulting set of linear equations:
* Solve for ψ and ϕ from this linear matrix equation using a QR decomposition of A

$$\begin{bmatrix} \boldsymbol{u} \\ \boldsymbol{v} \end{bmatrix} = A \begin{bmatrix} \boldsymbol{\psi} \\ \boldsymbol{\phi} \end{bmatrix}$$

$$\begin{bmatrix} \boldsymbol{\psi} \\ \boldsymbol{\phi} \end{bmatrix} = R^{-1} \left(Q \begin{bmatrix} \boldsymbol{u} \\ \boldsymbol{v} \end{bmatrix} \right)$$

Helmholtz Decomposition: Boundary Conditions

* Specify streamfunction via SSH two grid points deep into the boundary along the external domain and internal coastlines
  * These specify the scalar and normal and tangential derivatives for streamfunction
  * Automatically provides normal and tangential derivatives for velocity potential
* These BCs satisfy uniqueness conditions for the interior streamfunction and velocity potential solutions, to an arbitrary constant in velocity potential

On $\partial\Omega$:

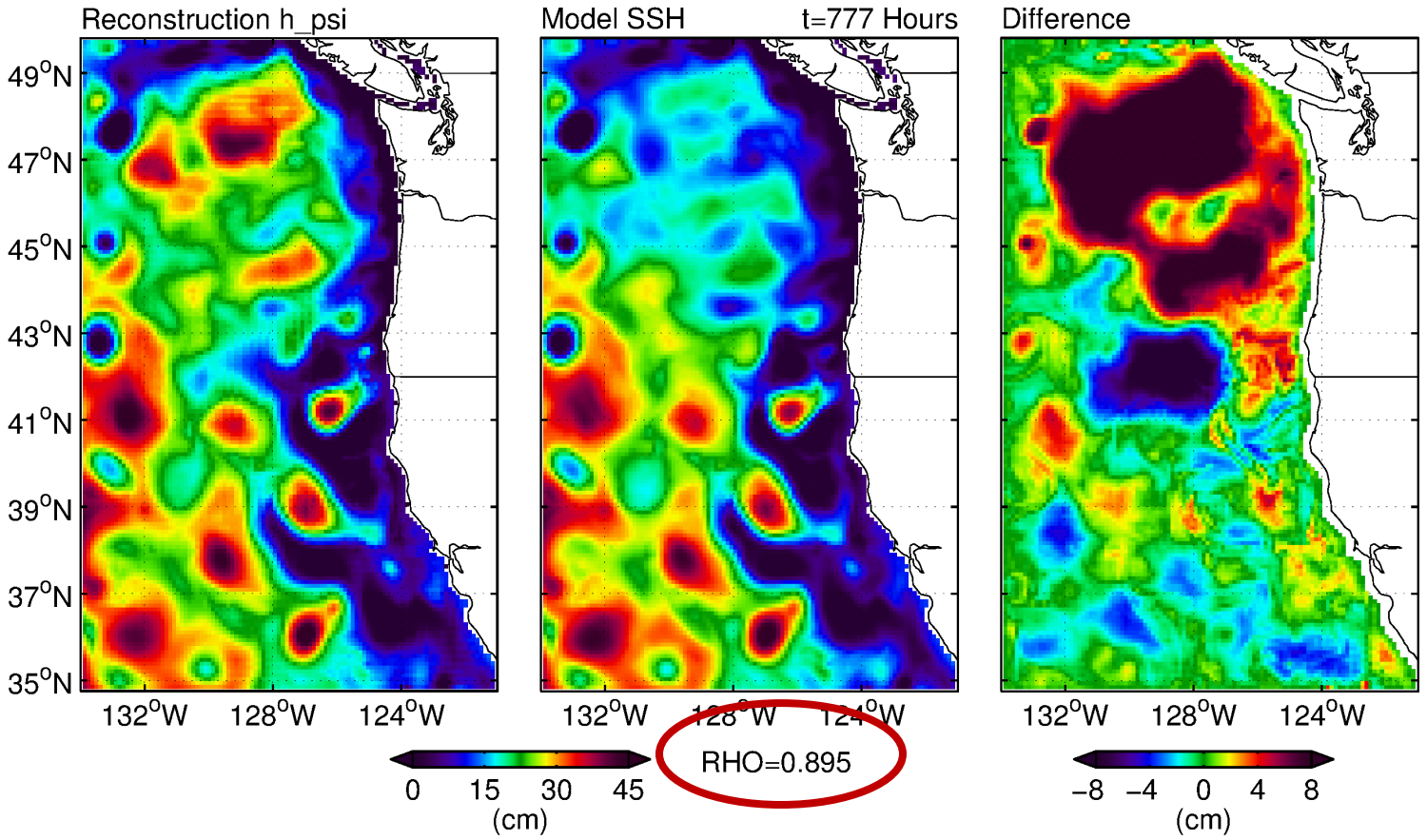
$$\boxed{\psi} = \frac{g}{f}\eta$$

$$\frac{\partial \phi}{\partial x} = u + \boxed{\frac{\partial \psi}{\partial y}}$$

$$\frac{\partial \phi}{\partial y} = v - \boxed{\frac{\partial \psi}{\partial x}}$$

Solution Snapshot

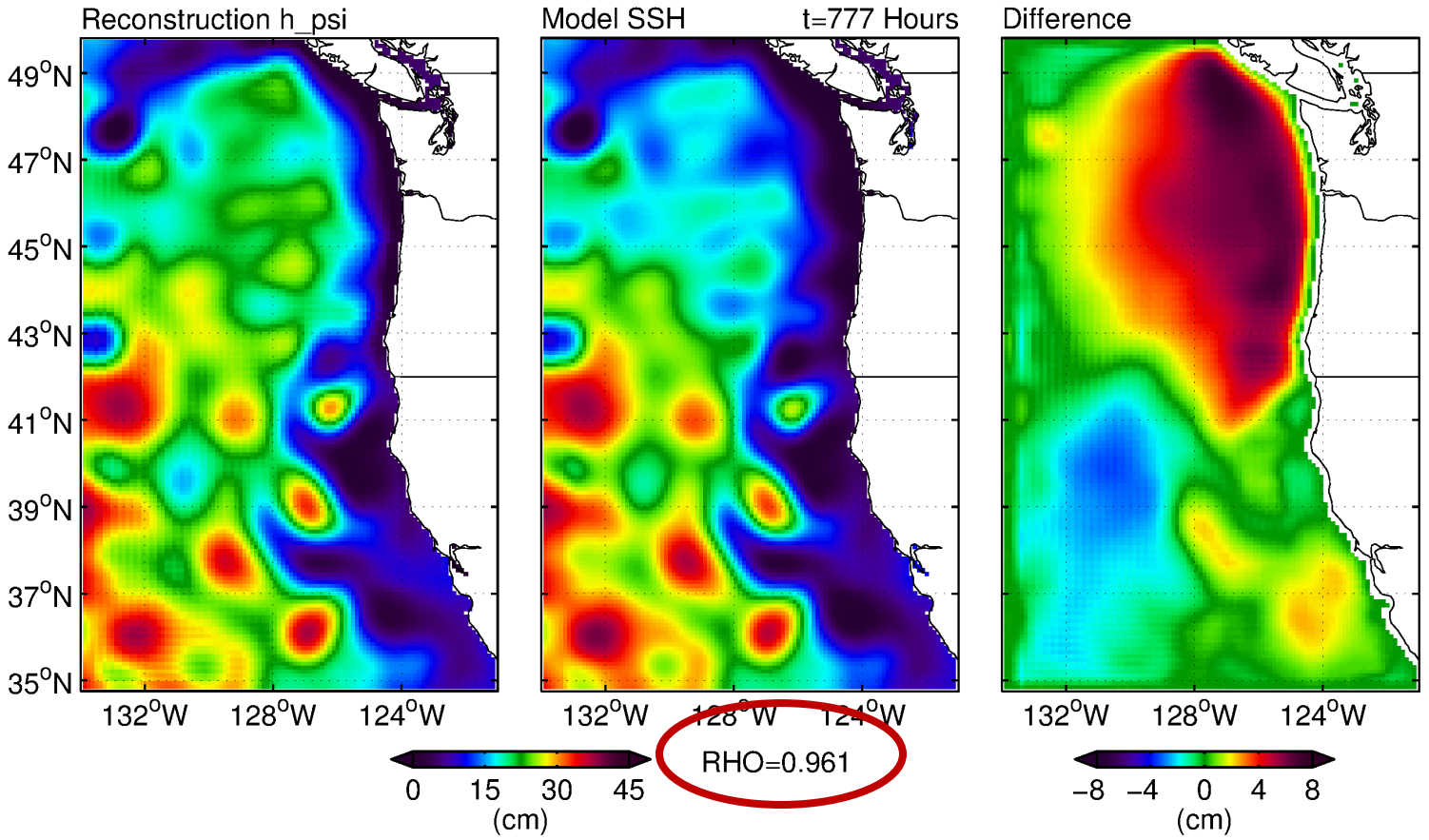
$$h_\psi = \frac{f}{g}\psi$$



No time or space smoothing

Solution snapshot with time and space smoothing

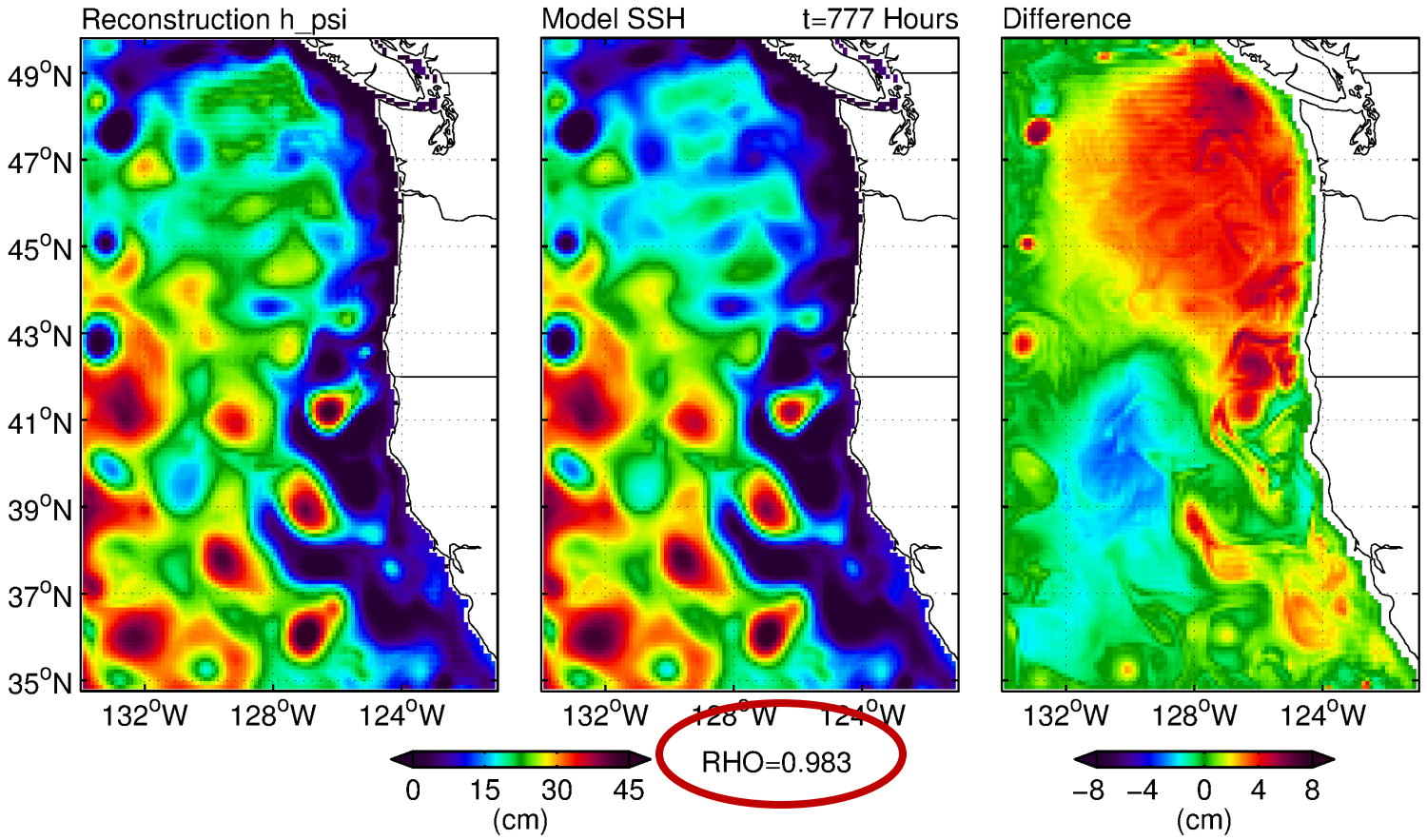
$$h_\psi = \frac{f}{g}\psi$$



100 km x/y by 60 hour block average

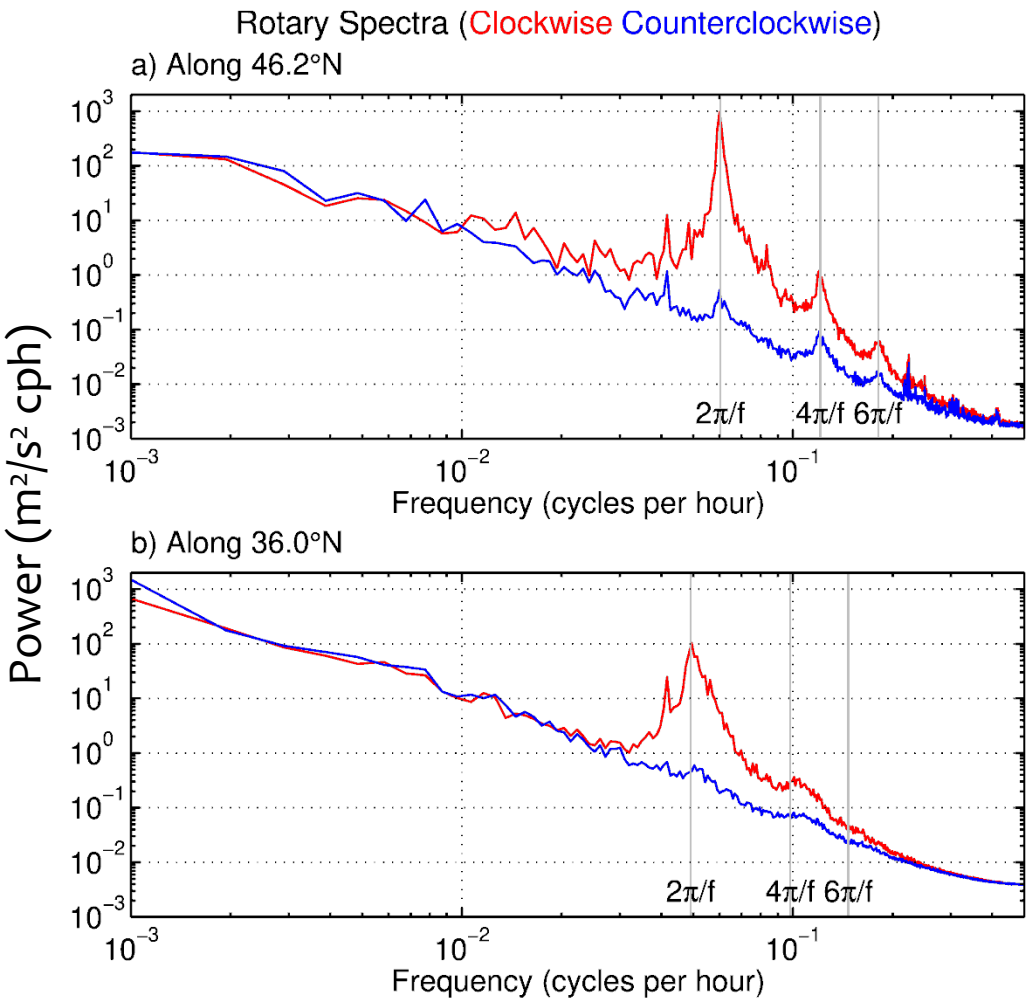
Solution snapshot with time smoothing only

$$h_\psi = \frac{f}{g}\psi$$



Variability with periods less than 120 hours attenuated

What temporal variability are we smoothing out?

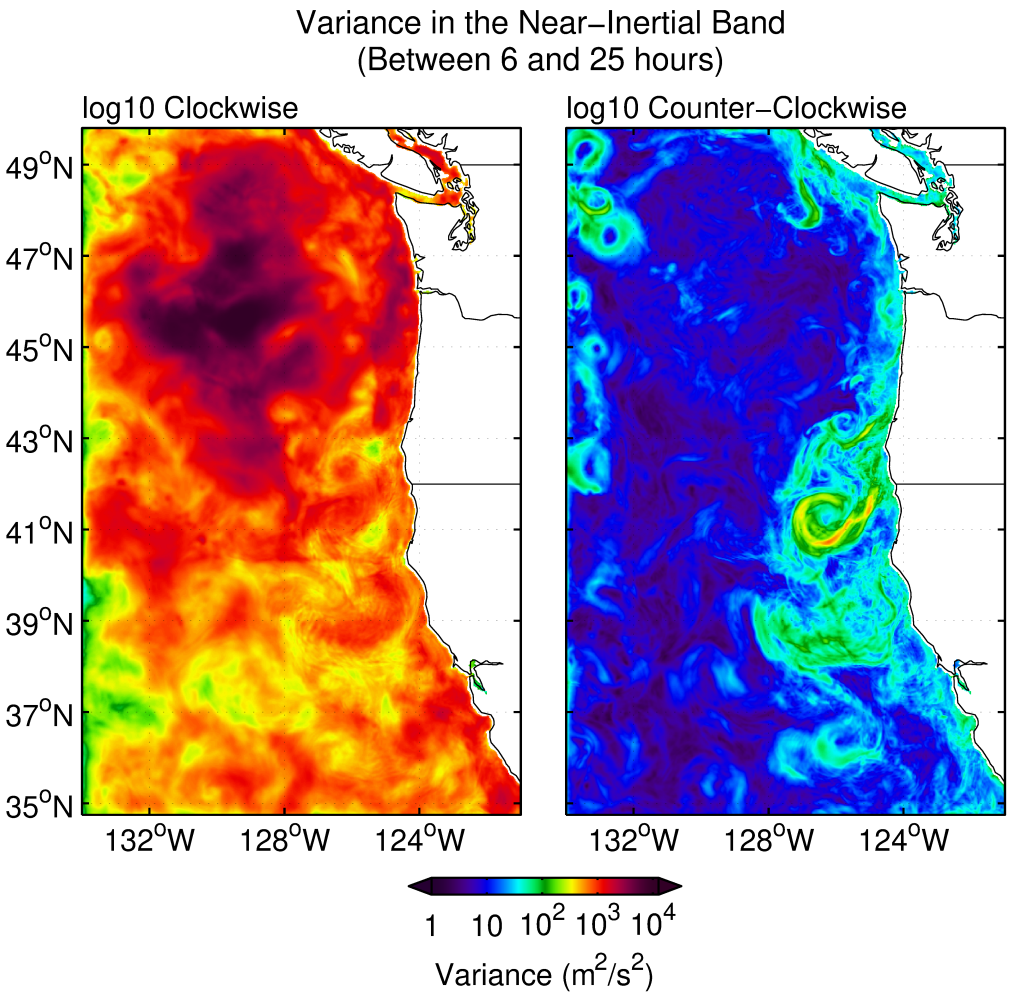


Answer: Near-inertial motions which are manifest in the surface currents

Clockwise motions are enhanced in the inertial band by several orders of magnitude in variance compared with CCW motions

The northern half of the domain experiences much more near-inertial variability

Clockwise motions more prevalent in the Northern half of the domain

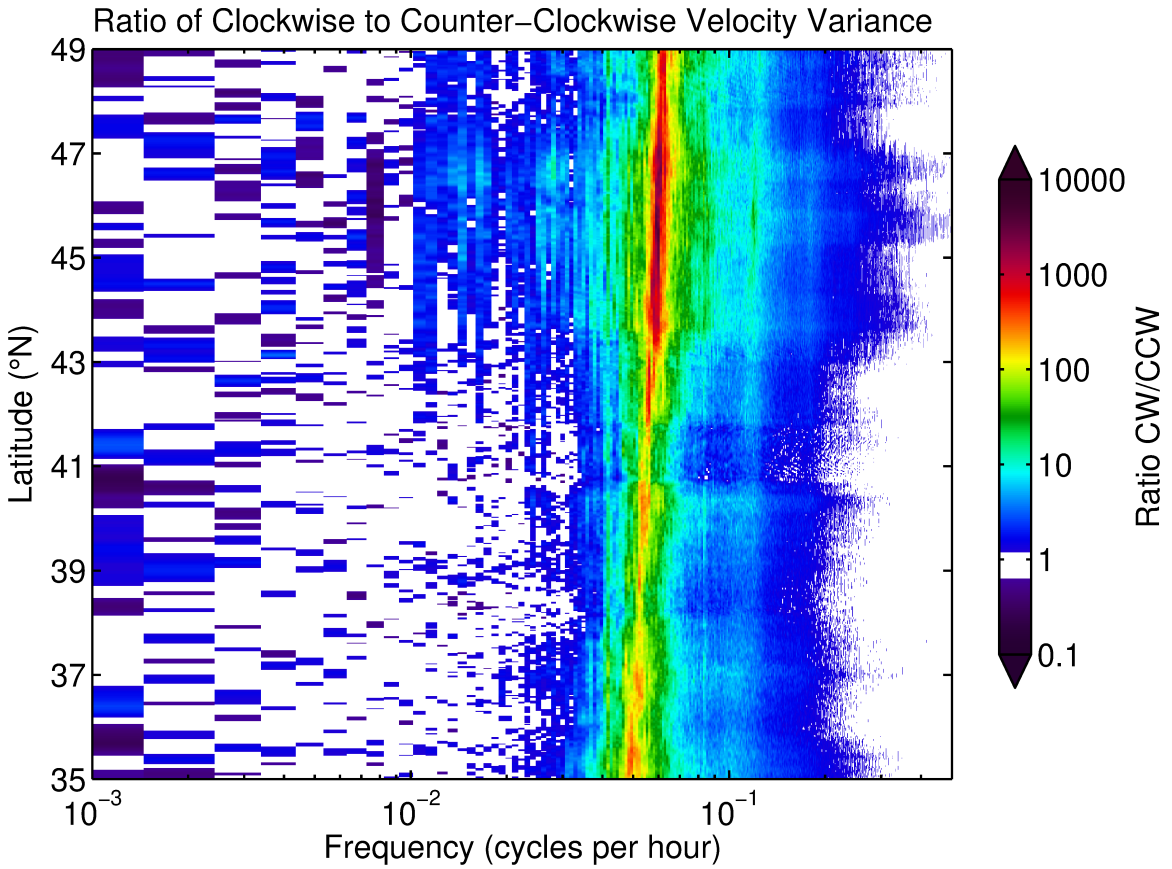


Motions in the inertial band are not geostrophically-balanced, but nonetheless project onto the streamfunction

This violates the dynamical balance equating streamfunction and SSH via geostrophy

$$\int_{f_1}^{f_2} S^{\mp}(f)\, df$$

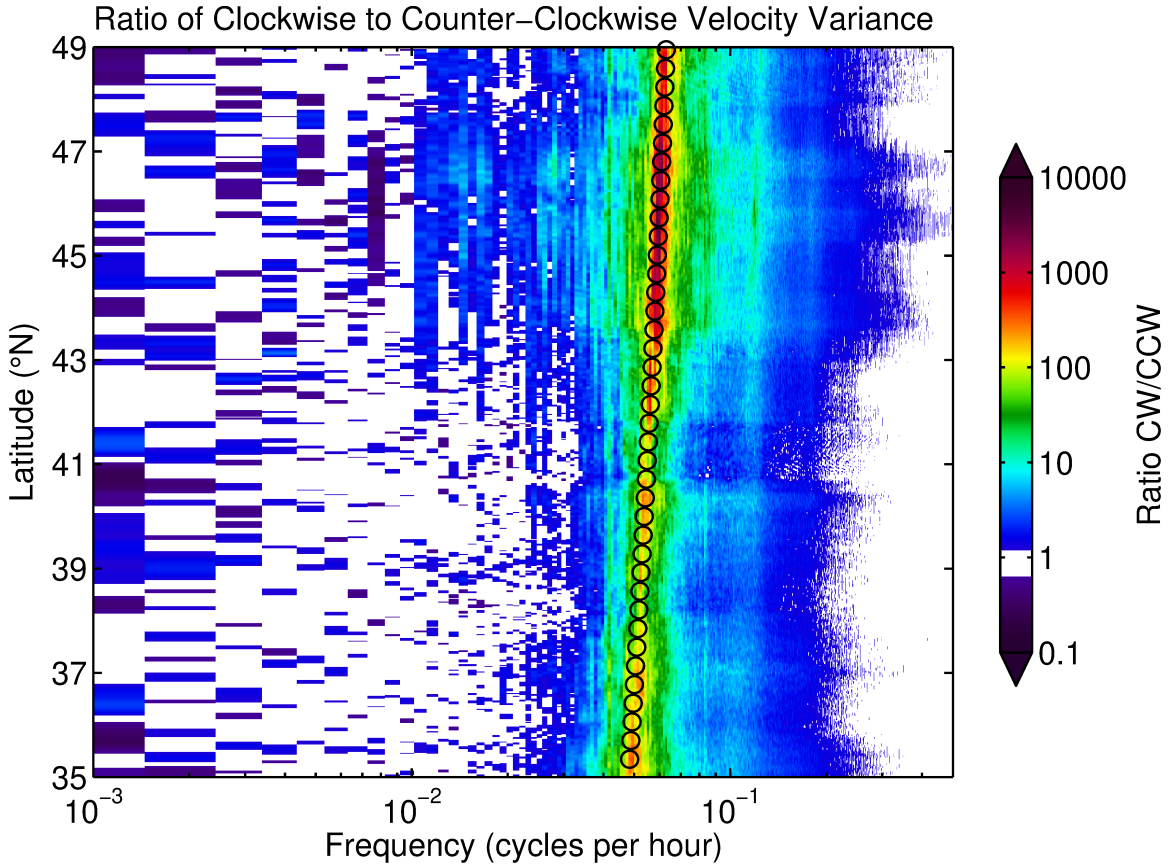
Rotary Spectra



Ratio of clockwise to counterclockwise variance in surface currents as a function of frequency and latitude

Clockwise rotation several orders of magnitude greater variance than counterclockwise rotations

Rotary Spectra

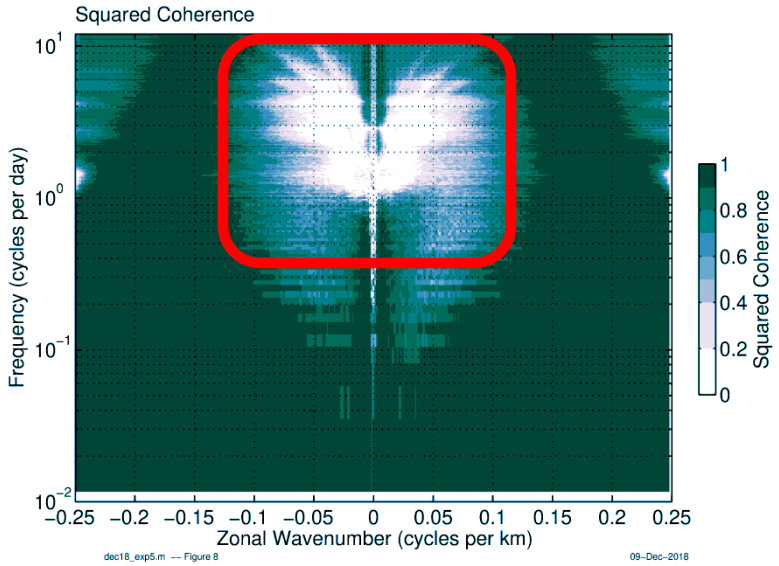


Ratio of clockwise to counterclockwise variance in surface currents as a function of frequency and latitude

Clockwise rotation several orders of magnitude greater variance than counterclockwise rotations

Cross-spectral wavenumber-frequency statistics

Squared Coherence

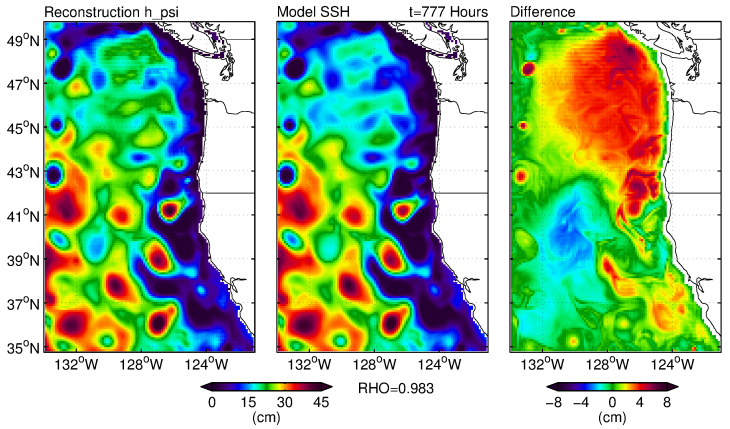


Coherence lower for high frequencies (periods less than about 5 days) at all wavenumbers

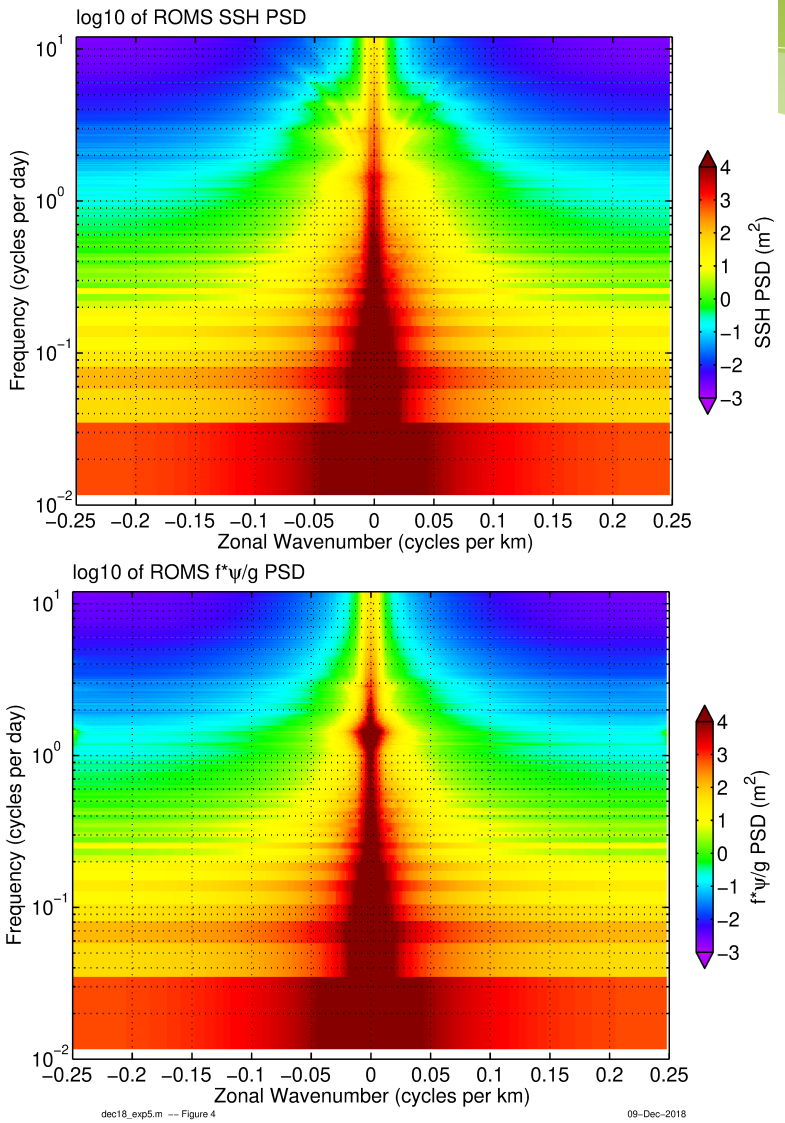
Low frequencies agree well at all wavenumbers

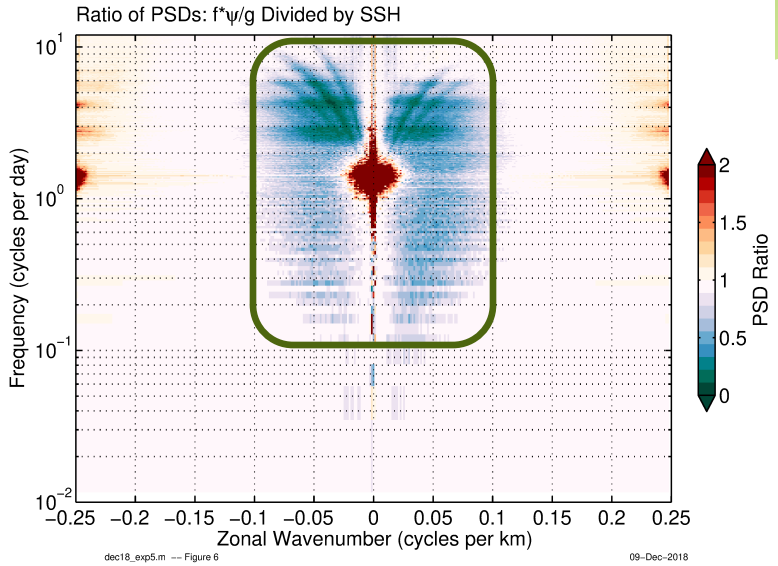
Summary

* Streamfunction estimates from surface currents and SSH boundary conditions on temporal scales greater than about 5 days
* Near-inertial variability in the surface currents need to be filtered out to obtain useful SSH from this method
* This method is promising to estimate SSH from surface currents, at least in the noise-free and well-sampled ROMS simulation
* This presents a best case scenario for WaCM
* The method of computing streamfunction and velocity potential will itself be valuable for studying variability in WaCM ocean currents



Wavenumber-Frequency Spectra

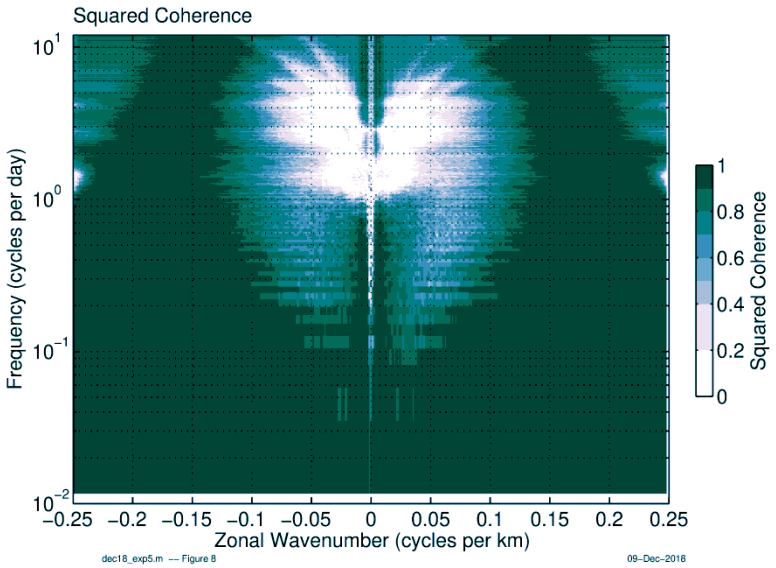


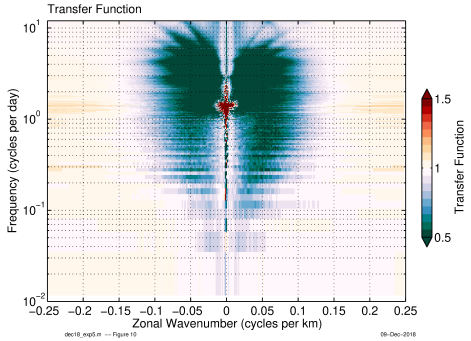


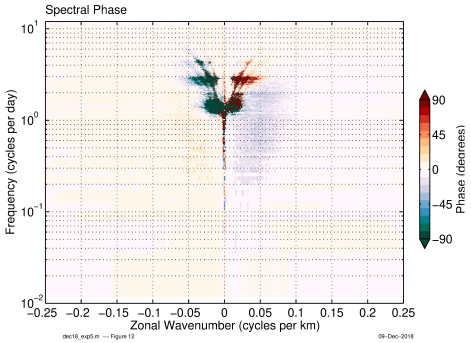
Disagreement on high frequencies and large scales

Near-inertial motions and surface signatures of internal gravity waves

Cross-spectral wavenumber-frequency statistics







Snapshot from coupled WRF-ROMS simulation off west of N. Amer.