Can we partition IGWs and BMs from HFR observations? : Spectral contents in the HFR surface current observations

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• Observations of surface currents
  • Geophysical signals – frequency domain kinetic energy spectra along-shore and cross-shore directions
  • Tide-coherent surface currents
  • Near-inertial surface currents
  • Statistics of submesoscale eddies
  • Wavenumber domain kinetic energy spectra and fluxes

• Summary
HFR-derived surface current observations

- Hourly surface current maps (0.5, 1, 2, and 6 km resolution)
- Upper 1 m depth averaged currents
- From nearshore to 50 - 150 km offshore
- Near-near time reports via the web
- Due to low signal-to-noise ratio of satellite remote sensing near coastal regions, coastal surface current maps provide a useful resource to investigate the submesoscale processes in a view of statistics and dynamics.

Variance of surface currents (alongshore view) (Kim et al., JGR 2011)

- 60+ compact array HFR (CODAR) system
- Hourly surface current maps (0.5, 1, 2, and 6 km resolution)
- Upper 1 m depth averaged currents; From nearshore to 50 - 150 km offshore
- Variance coherent with tides, wind, low frequency signals, and Coriolis force.
- Regional noise levels
• Cross-shore variation of tide-, wind-, low frequency-forced energy
• Low frequency pressure setup against the coast
• Inertial variance gets narrow offshore
• Variance of tide-coherent currents decrease with offshore distance (Kim et al, JGR 2011)
Variance of surface currents (cross-shore view)

- Cross-shore variation of tide-, wind-, low frequency-forced energy
- Low frequency pressure setup against the coast
- Variance of tide-coherent currents decrease with offshore distance.
- Inertial variance gets narrow offshore

(Shallow depth & no-flow boundaries)

(Kim et al, JGR 2011)
Surface tides

Observation

ENPAC 2003

TPXO
Surface tidal currents

Harmonic analysis at K1 and M2.
Averaged cross-shore structure.
S1 = 1 cpd
SA1 = 0.0027 cpd
K1 = 1.0027 cpd
Variance at K1 can be shown with variance at S1 + SA1.

(Kim et al, JGR 2011)
Eddy detection on HFR surface currents

- Streamlines (nearly closed polygons) are identified with winding angle method.
- Co-centered streamlines are fitted into an ellipse.
- If the center of ellipses in consecutive time steps is within a drifting range (e.g., 1.5 km) with the same rotation, ellipses are considered as a part of an eddy time series. The length of time series is called as persistency.

(Kim, CSR 2011)
Rossby number and size

- About 700 eddies are identified for each rotation.
- $O(0.5-1)$ Rossby number at the center of eddies
- 5-20km diameter ($L$)
Two events of submesoscale eddies approaching ADCP/T-string (Kim, CSR 2010)
Demography of sub-mesoscale eddies

Using flow geometry of the stream functions.

A cluster of streamlines is fitted with an ellipse. (Kim CSR, 2010)

Vorticity at the center of eddies.

About 2200 eddies for each rotation are identified (at least two days persistence).

(Kim et al, JGR 2011)
KE spectra (USWC HFR; Altimeters; Shipboard ADCPs)

\[
S_{\mathbf{u}_\perp}(k_\parallel) = \left( \frac{g}{f_c} \right)^2 \left( 2\pi k_\parallel \right)^2 S_{\eta_\parallel}(k_\parallel),
\]

Power spectrum of cross-track geostrophic currents from along-track SSHAs

\(K^{-2}\) power law related to sub-mesoscale.

Robust estimate on \(k^{-2}\) spectra with data in other regions.

Two kinds of ALT data: Envisat and Jason-1
HFR data with three resolutions:
1 km and 6 km data are sampled from SoCAL, because minimum ageostropic components are expected.
20 km data are from the coastline axis.  

(Kim et al, JGR 2011)
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HFR data with three resolutions:
- 1 km and 6 km data are sampled from SoCAL, because minimum ageostropic components are expected.
- 20 km data are from the coastline axis.
Along-track altimeter data are binned in $2^\circ \times 2^\circ$ grid boxes and averaged in time (7-daily → 30 daily time series) to increase signal to noise ratio.
Scale-by-scale energy budget equation

\[ \frac{\partial}{\partial t} E(k^*) + \Pi(k^*) = -2\nu\Omega(k^*) + F(k^*), \quad \text{(Frisch 1995)} \]

where

\[ E(k^*) = \frac{1}{2} \sum_{|k|<k^*} |\hat{u}(k)|^2, \quad \text{Cumulative kinetic energy} \]

\[ \Pi(k^*) = \langle u_< \cdot (u \cdot \nabla u) \rangle, \quad \text{Cumulative advective kinetic energy flux} \]
\[ = \langle u_< \cdot (u_< \cdot \nabla u_> ) \rangle + \langle u_< \cdot (u_> \cdot \nabla u_> ) \rangle, \]

\[ \Omega(k^*) = \frac{1}{2} \sum_{|k|<k^*} k^2 |\hat{u}(k)|^2, \quad \text{Cumulative enstrophy} \]

\[ u(x) = u_<(x) + u_>(x), \]
\[ = \sum_{|k|<k^*} \hat{u}(k)e^{ikx} + \sum_{|k|>k^*} \hat{u}(k)e^{ikx}, \]
• Decay slopes of KE spectra range between $k^{-2}$ and $k^{-3}$
• Zero-crossings of KE fluxes appear O(10) km

(Soh and Kim 2018; in press)
Yearly-averaged KE spectra and temporal variability of spectral slopes
Helmholtz decomposition

\[ \mathbf{u} = \mathbf{u}_\psi + \mathbf{u}_\phi = \mathbf{k} \times \nabla_h \psi + \nabla_h \phi. \]
Helmholtz decomposition

\[ u = u_\psi + u_\phi = k \times \nabla_h \psi + \nabla_h \phi. \]
Summary

• Geophysical forcing’s responses in high-frequency radar-derived surface currents including baroclinic and barotropic tides, near-inertial variance, wind (pole-ward propagating signals; not shown), and submesoscale eddies.

• The kinetic energy spectra have decay slope of $k^{-2}$ and $k^{-3}$ and the potential injection scales are $O(10)\text{km}$ based on the scales where the slopes get steeper and the zero-crossing energy fluxes.

• The Helmholtz decomposition was applied to the surface currents and surface heights, but the stream function-derived current components still contain near-inertia and tidal variance.
Shifted near-inertial peak due to vorticity?

- Vorticity time series in a cross-shore direction contain seasonal circulation.
- Vorticity and normalized stream function (at a grid point) are consistent.
- Superinertial!
- A NI peak can be located using a least-squares fit with a set of trial frequencies.
Estimates of decorrelation time scales

• A NI peak of the power spectrum at each vector time series is fitted with a function, an exact Fourier transformed time series of NI motions.

\[
S(\sigma) = \frac{A^2 \lambda^2}{1 + \lambda^2 (\sigma + f_c^*)^2},
\]

\[
c(t) = Ae^{-if_c^*t}e^{-\frac{t}{\lambda}}, \quad t \geq 0
\]

• \(\lambda\) is the decay time scale.
• \(f_c^*\) is the local inertial frequency with a peak shifted.
Decorrelation time scales of NI surface currents

- Cross-shore variation of decay time scales of NI CW motions shows longer offshore [6 days] than nearshore [2 days], presenting the effects of bathymetry and coast (coastal inhibition).
- NI motions are restricted with coastline and bathymetry.
- NI CCW motions are limited (required more investigation)

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\[ c(t) = Ae^{-if_c^*t} e^{-\lambda t}, \quad t \geq 0 \]

(JGRC 2013, Kim and Kosro; JGRC 2014, Kim et al)
CW NI spatial coherence

(JGRC 2013, Kim and Kosro; JGRC 2014, Kim et al)
Sliced coherence in x- and y-directions

• Sliced coherence shows the exponentially decay spatial function.
• The local composite mean of coherence provides a smooth structure.
Decorrelation length scales of N1 surface currents