Observations of submesoscale eddies using high-frequency radar-derived kinematic and dynamic quantities

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Observations of submesoscale eddies using high-frequency radar-derived kinematic and dynamic quantities

- Submesoscale processes
  - $O(1)$ Rossby number
    \[ \text{Ro} = \frac{U}{fL} = \frac{\zeta}{f} \]
  - A horizontal scale smaller than the first baroclinic Rossby deformation radius; $O(1-10)$ km
  - Frequently observed as fronts, eddies, and filaments

Simulations on mesoscale and submesoscale grids (SST)

From Klein et al (Capet et al, JPO, 2009a)
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  - O(1) Rossby number \( [\text{Ro} = U/(fL) = \zeta/f] \)
  - A horizontal scale smaller than the first baroclinic Rossby deformation radius; O(1-10) km
  - Frequently observed as fronts, eddies, and filaments
  - Contribute to the vertical transport of oceanic tracers, mass, and buoyancy and rectify the mixed-layer structure and upper-ocean stratification

(Williams and Follows, 2003)

\( \text{e.g., vertical frontal scale secondary circulation} \)
Observations of submesoscale eddies using **high-frequency radar**-derived kinematic and dynamic quantities

- An observational sensor using **electromagnetic waves**
  - 3-30 MHz frequency (HFR)
  - Using Doppler shift of backscattered signals of surface gravity waves **to estimate the background currents**
- Upper 1 m depth-averaged currents
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  - Hourly and O(1) km scale surface current maps
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- Velocity potential and stream function
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- Divergence and normalized vorticity
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- Velocity potential and stream function
- Divergence and normalized vorticity
- Stretching and shearing deformation rates, and strain rate

\[ \vartheta = \frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}, \]
\[ \zeta = \frac{\partial u}{\partial x} - \frac{\partial v}{\partial y}, \]
\[ \kappa = \sqrt{\vartheta^2 + \zeta^2}. \]

(a) divergence; (b) stretching deformation; (c) vorticity; (d) shearing deformation.
Observations of submesoscale eddies using high-frequency radar-derived kinematic and dynamic quantities

- **Surface**
  - Hourly and $O(1)$ km resolution surface current maps
  - Their kinematic and dynamic quantities

- **Subsurface**
  - ADCP – current profiles
  - Temperature profiles – vertical movement of thermoclines
• Eddy detection using surface current maps
  • Geometry-based technique
• Interpretation of submesoscale eddies
  • Statistics of diameters and Rossby numbers
  • Verification with circulation
  • Horizontal structure of identified eddies
  • Secondary circulation due to drifting submesoscale eddies
• Summary
Eddy detection using HFR surface currents

- Streamlines (nearly closed polygons) are identified with winding angle method.
- Co-centered streamlines are fitted into an ellipse.
- If the centers of ellipses in consecutive time steps are 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

- Based on 2-year hourly observations.
- About 700 eddies are identified for each rotation.
- $O(0.5-1)$ Rossby number at the center of eddies.
- 5 – 20 km size diameter ($L$) eddies.

(Kim, CSR 2010)
Horizontal structure

- $V_\Theta$: Tangential velocity
- $V_r$: Radial velocity
- $\zeta/f_c$: Rossby number

$r/a$: Relative distance on the major axis

- $V_\Theta$ and $\zeta/f_c$ have similar shapes to the Taylor eddy.

(Kim, CSR 2010)
Frontal-scale secondary circulation: Expectation

(Williams and Follows, 2003)
Paired eddies (a front) move to ‘a’, thermoclines fluctuate up- and down-ward.
• Paired eddies (a front) move to ‘a’, thermoclines fluctuate up- and down-ward.

• On the other hand, due to moving paired eddies (front) to ‘b’, the thermoclines fluctuate down- and up-ward.

(Williams and Follows, 2003)
Frontal-scale secondary circulation: Data-derived indicator

- **Surface**
  - Stream function, velocity potential
  - Divergence and vorticity,
  - Shearing and stretching deformation rates, and strain rate

\[
\delta = \nabla_H \cdot \mathbf{u} = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y},
\]

\[
\zeta = \nabla_H \times \mathbf{u} = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y},
\]

\[
Q = \frac{\partial v}{\partial x} + \frac{\partial u}{\partial y},
\]

\[
\zeta = \frac{\partial u}{\partial x} - \frac{\partial v}{\partial y},
\]

\[
\kappa = \sqrt{Q^2 + \zeta^2}.
\]

- **Subsurface**
  - ADCP Current profiles \([\mathbf{u} = \mathbf{u}(z, t)]\)
  - Rotational tendency of the whole water column: Vertical rotary coefficients

\[
\alpha(t) = \frac{- \sum_{m < 0} S(m,t) + \sum_{m > 0} S(m,t)}{\sum_{m < 0} S(m,t) + \sum_{m > 0} S(m,t)},
\]

- Vertical movements of thermoclines [T-string data]
Frontal-scale secondary circulation: Surface & Temp.

(Kim, CSR 2010)
Frontal-scale secondary circulation: Subsurface & Temp

\[ \alpha(t) = \frac{-\sum_{m<0} S(m,t) + \sum_{m>0} S(m,t)}{\sum_{m<0} S(m,t) + \sum_{m>0} S(m,t)} \]

(Kim, CSR 2010)
Two events of submesoscale eddies approaching ADCP/T-string (Kim, CSR 2010).
Summary

- **Submesoscale eddies** off southern San Diego detected from direct estimate of kinematic and dynamic quantities of HFR observations and ADCP: Rossby number of \( O(0.5-1) \) and 5-25 km diameter

- **Frontal-scale vertical circulation due to drifting eddies undulates thermoclines.**

- Available submesoscale observational resources are very sparse and few, but they may enhance our understanding on the submesoscale process studies including biological interactions.