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

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(Kim, S. Y. 2010, *Cont. Shelf Res.* 30, 1639 -1655)

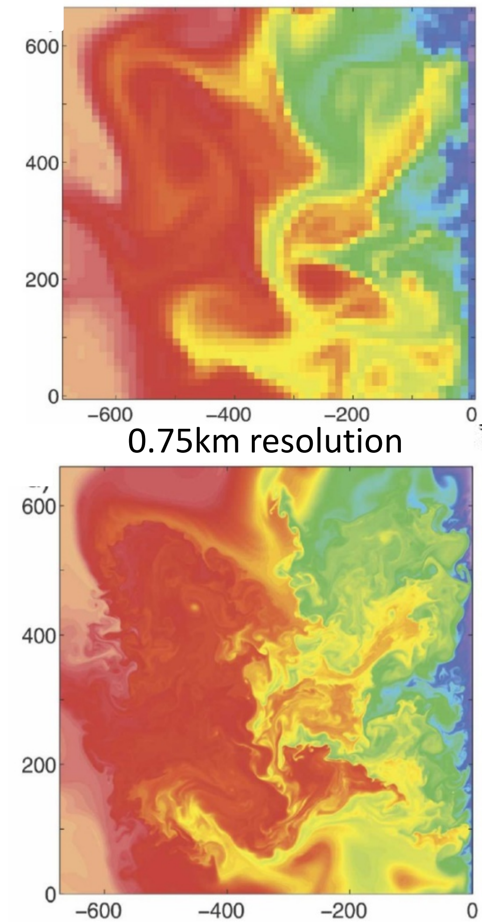
Acknowledgement: Eric Terrill and Bruce Cornuelle (SIO)

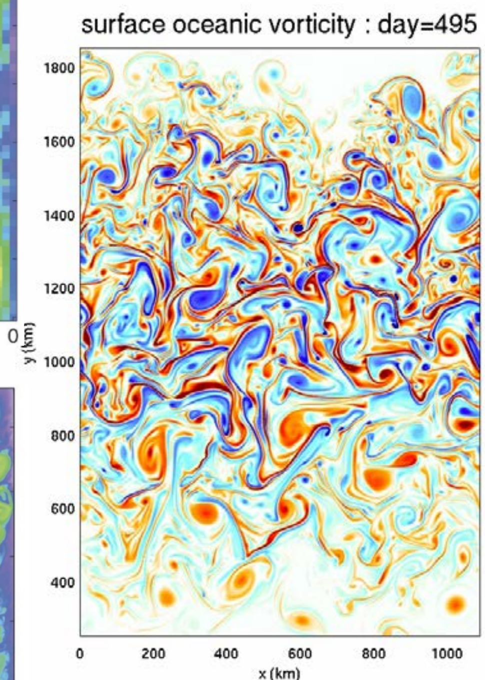
Observations of submesoscale eddies using high-frequency radar-derived kinematic and dynamic quantities

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

Simulations on mesoscale and submesoscale grids (SST)

12km resolution





From Klein et al

(Capet *et al*, JPO, 2009a)

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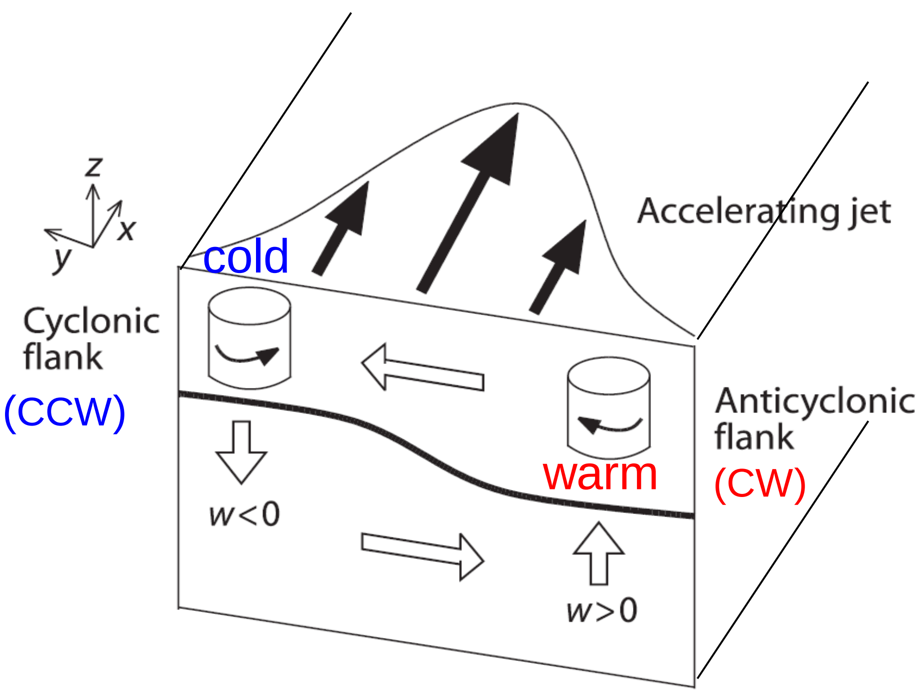
  - A horizontal scale smaller than the first baroclinic Rossby deformation radius; O(1-10) km
  - Frequently observed as fronts, eddies, and filaments
  - Contribute to the vertical transport of oceanic tracers, mass, and buoyancy and rectify the mixed-layer structure and upper-ocean stratification

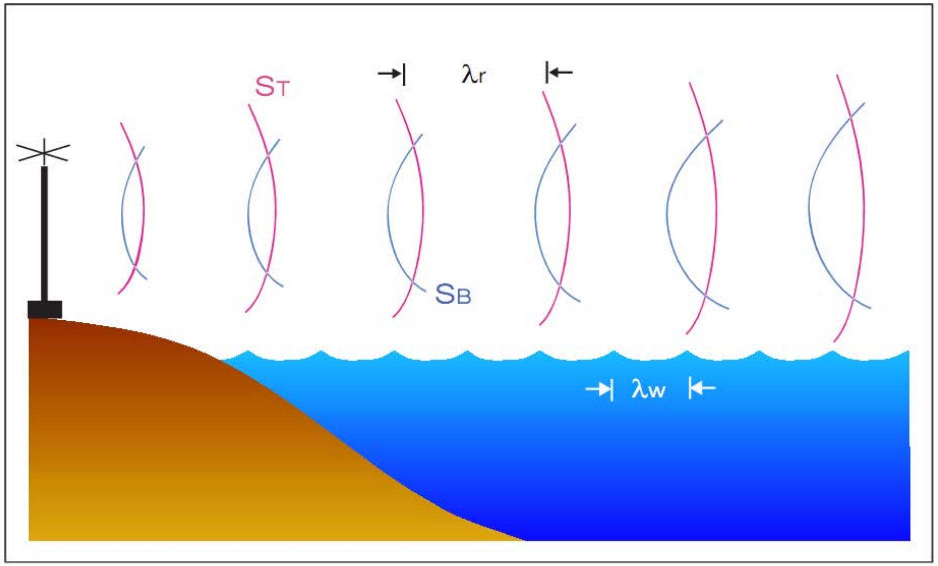


(Williams and Follows, 2003)

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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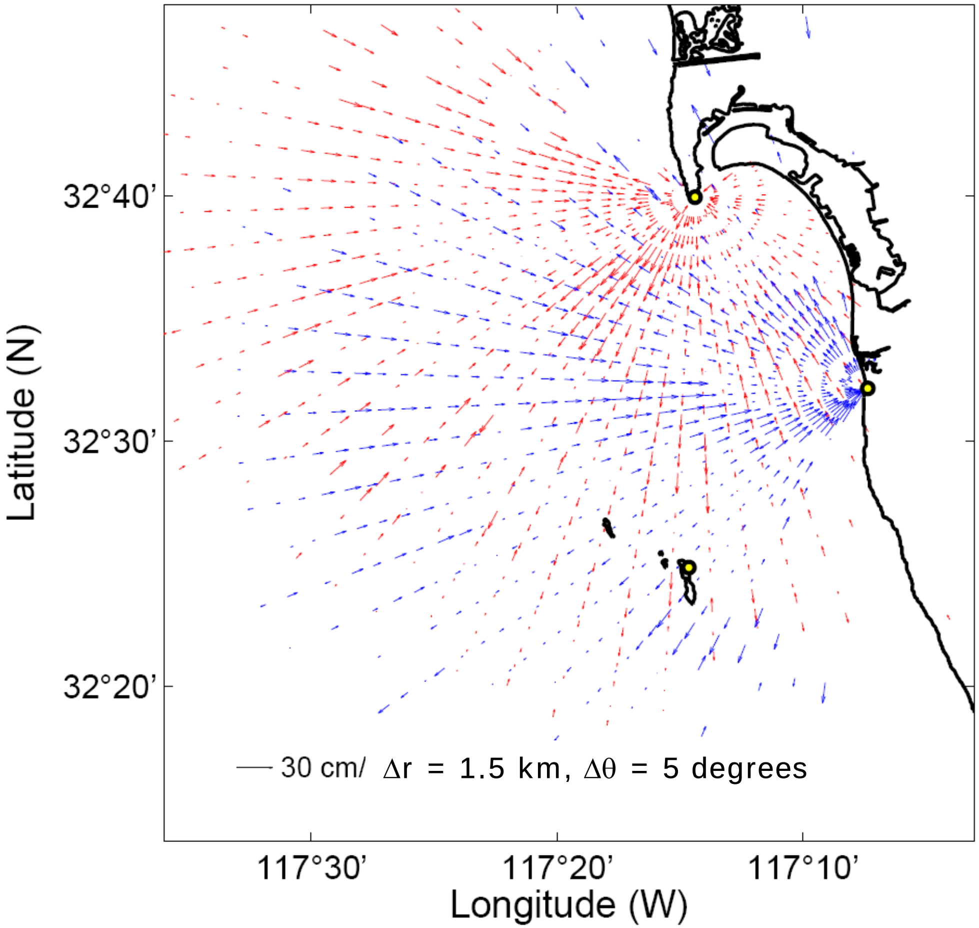
  - Surface radial velocity maps on a polar coordinate



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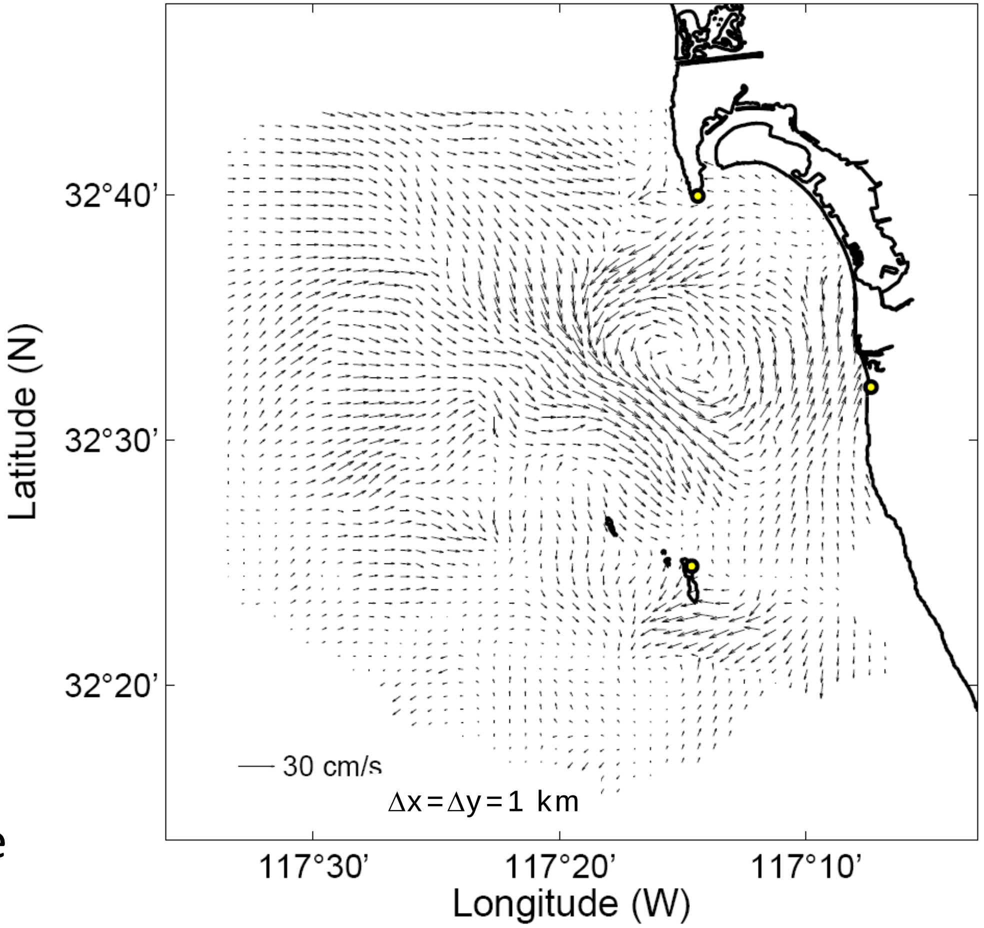
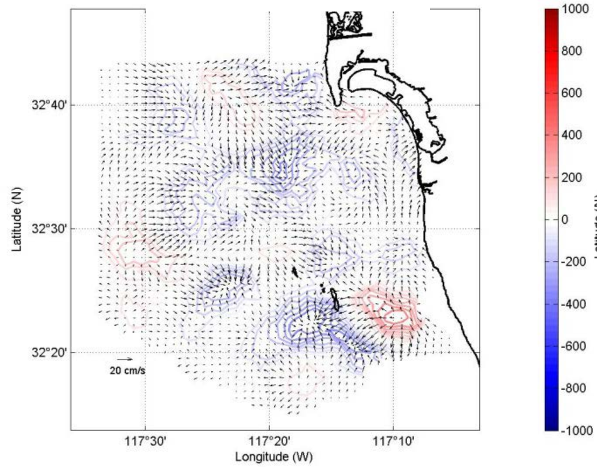
  - Hourly and O(1) km scale surface current maps



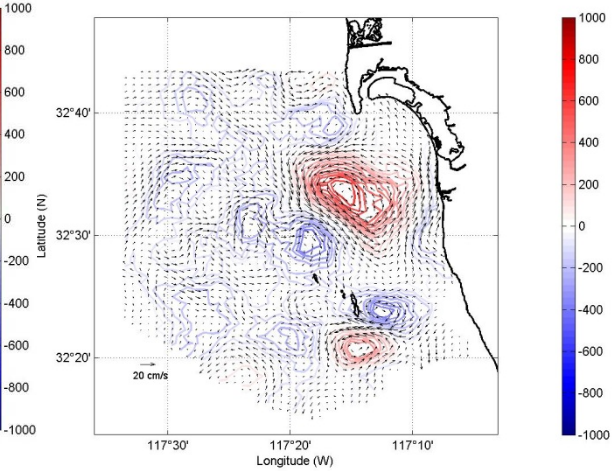
Observations of submesoscale eddies using high-frequency radar-derived kinematic and dynamic quantities

- Velocity potential and stream function

Velocity potential

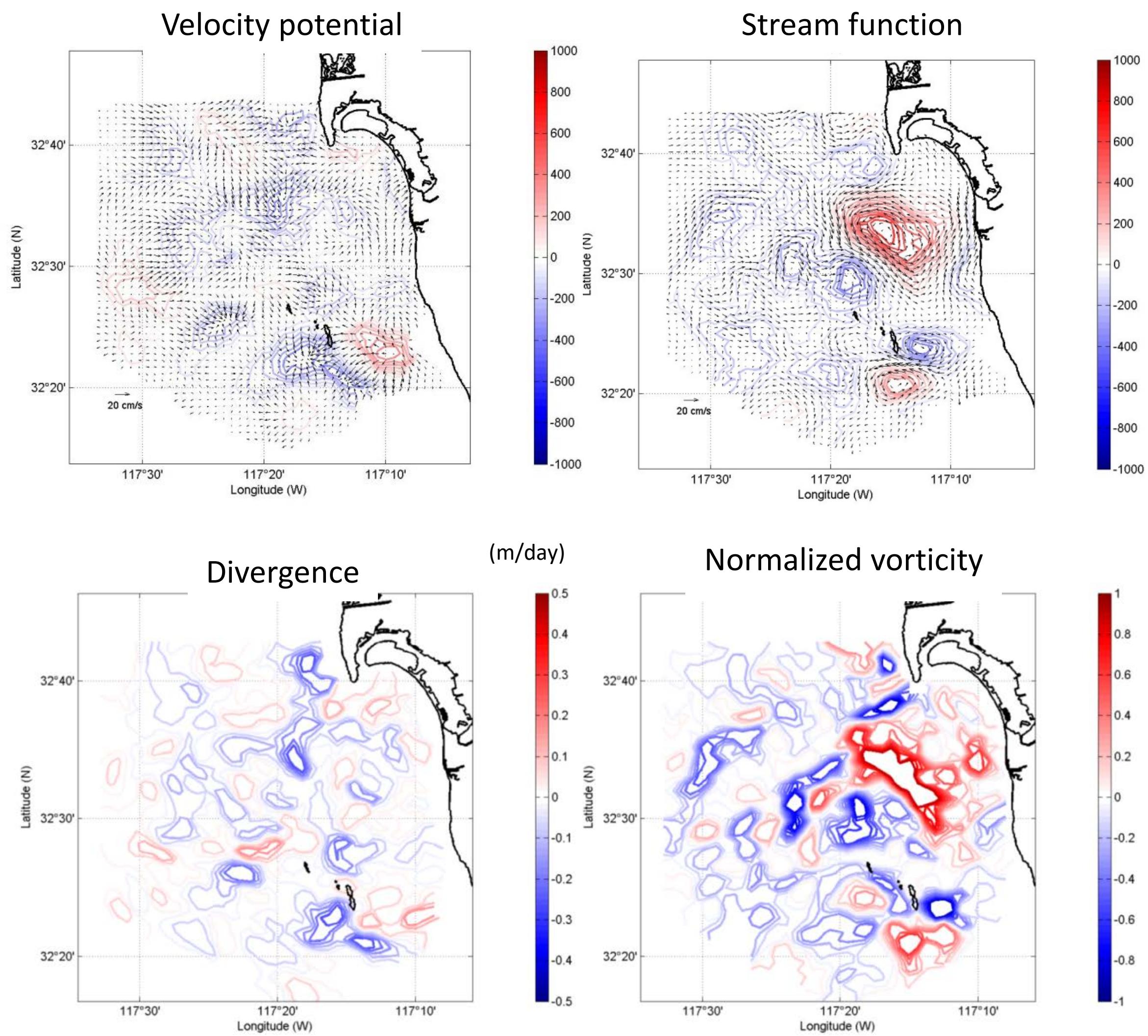


Stream function



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

- Velocity potential and stream function
- Divergence and normalized vorticity



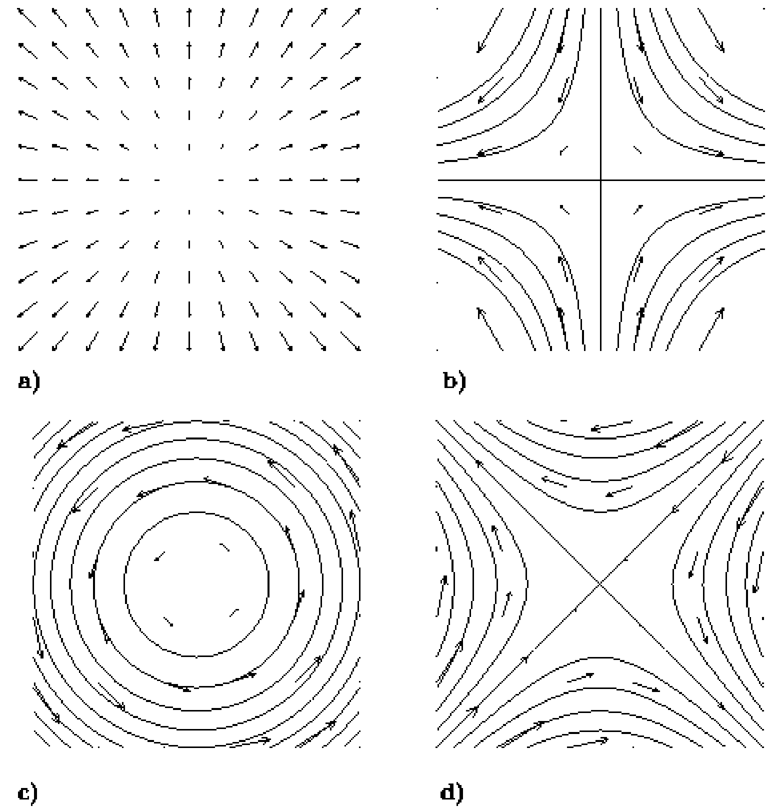
Observations of submesoscale eddies using high-frequency radar-derived kinematic and dynamic quantities

- Velocity potential and stream function
- Divergence and normalized vorticity
- Stretching and shearing deformation rates, and strain rate

$$\varrho = \frac{\partial v}{\partial x} + \frac{\partial u}{\partial y},$$

$$\varsigma = \frac{\partial u}{\partial x} - \frac{\partial v}{\partial y},$$

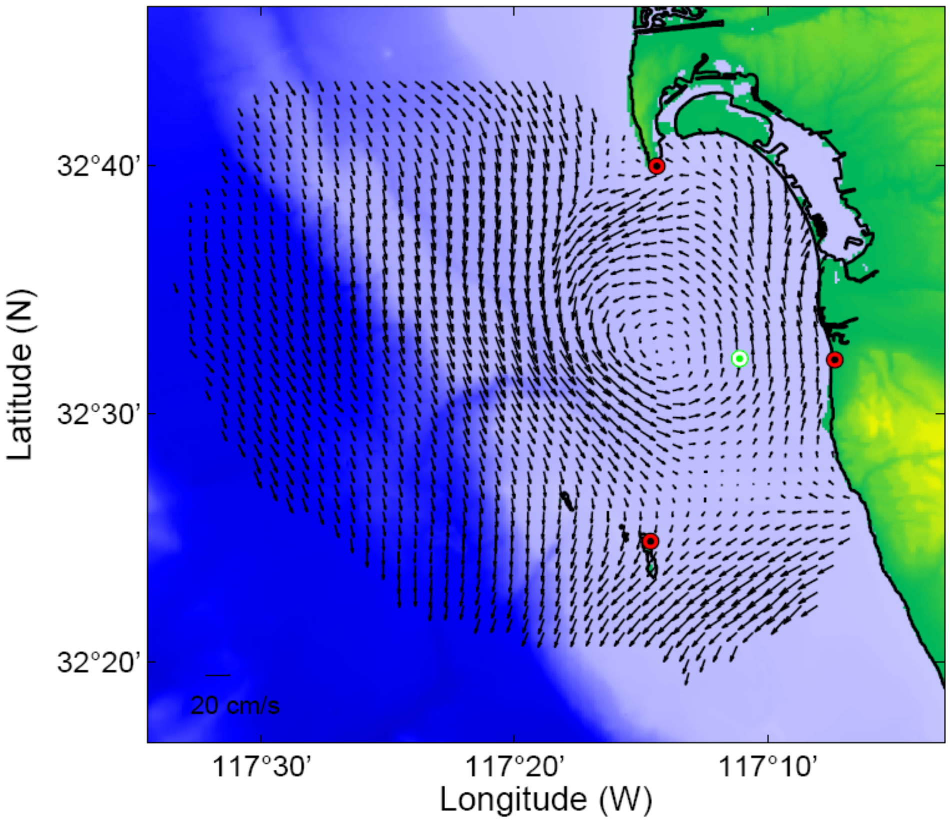
$$\kappa = \sqrt{\varrho^2 + \varsigma^2}.$$



(a) divergence; (*b*) stretching deformation; (*c*) vorticity; (*d*) shearing deformation.

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

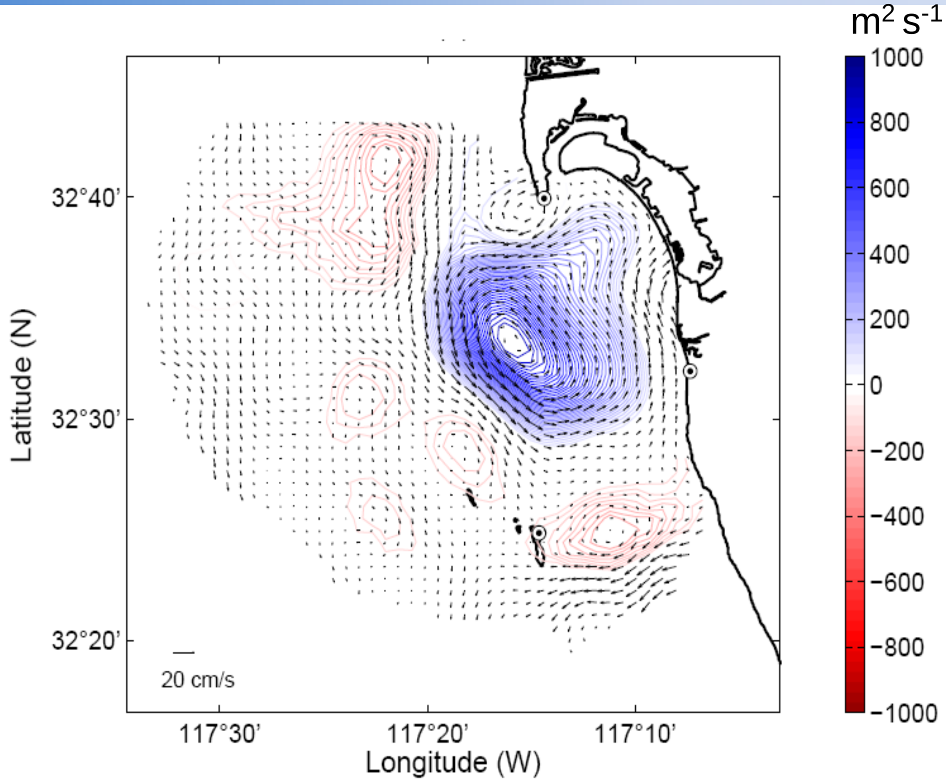
- Surface
  - Hourly and O(1) km resolution surface current maps
  - Their kinematic and dynamic quantities
- Subsurface
  - ADCP – current profiles
  - Temperature profiles – vertical movement of thermoclines

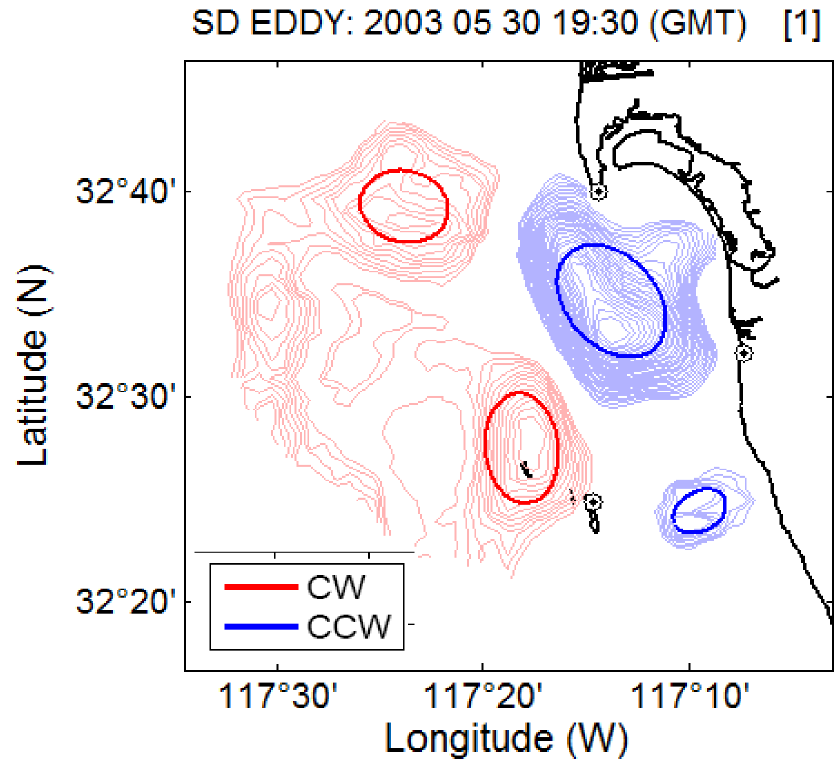


Outline for rest of the talk…

- Eddy detection using surface current maps
  - Geometry-based technique
- Interpretation of submeososcale 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

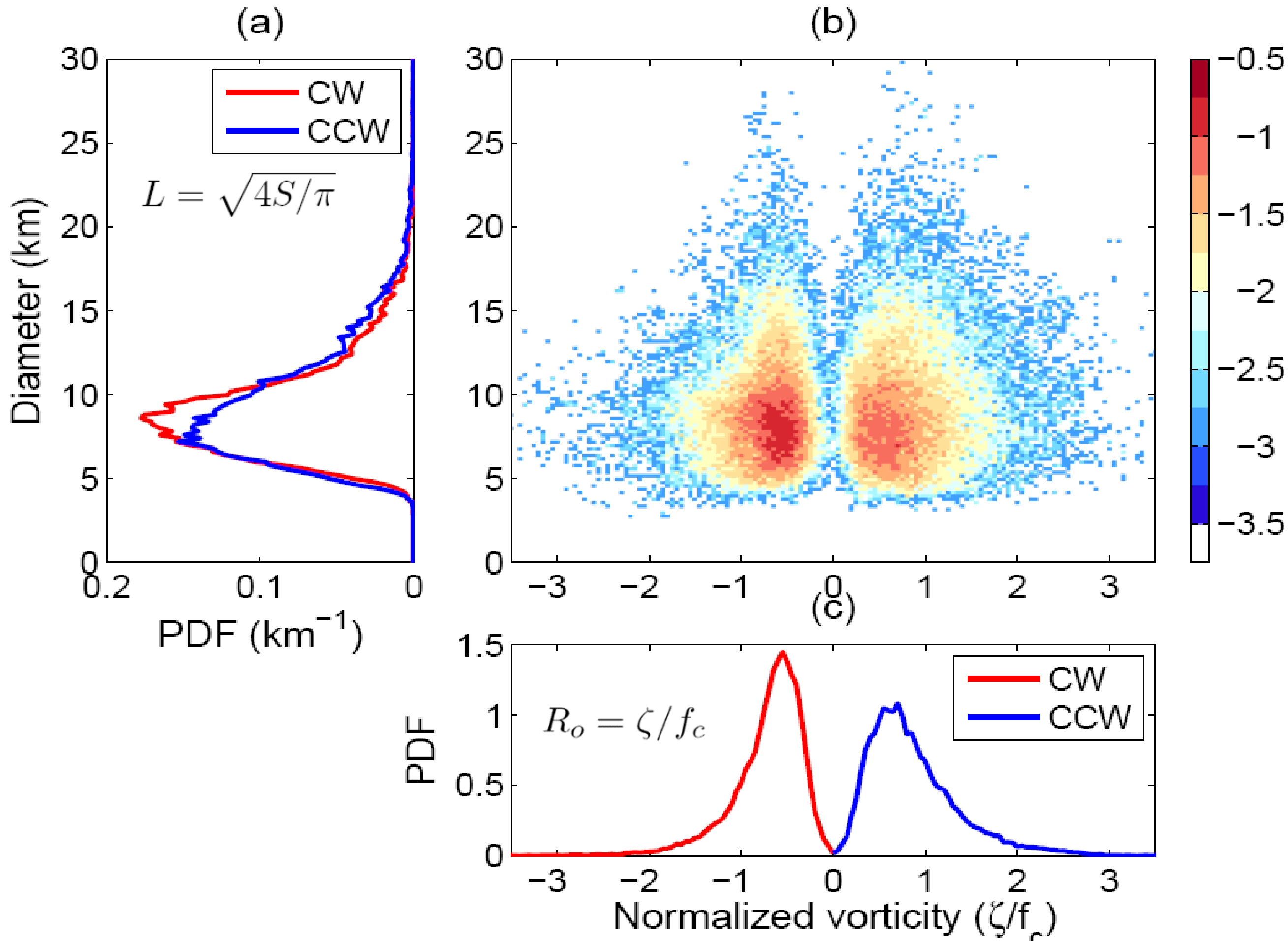




- Streamlines (nearly closed polygons) are identified with winding angle method.
- Co-centered streamlines are fitted into an ellipse.
- If the centers of ellipses in consecutive time steps are within a drifting range (e.g., 1.5 km) with the same rotation, ellipses are considered as a part of an eddy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

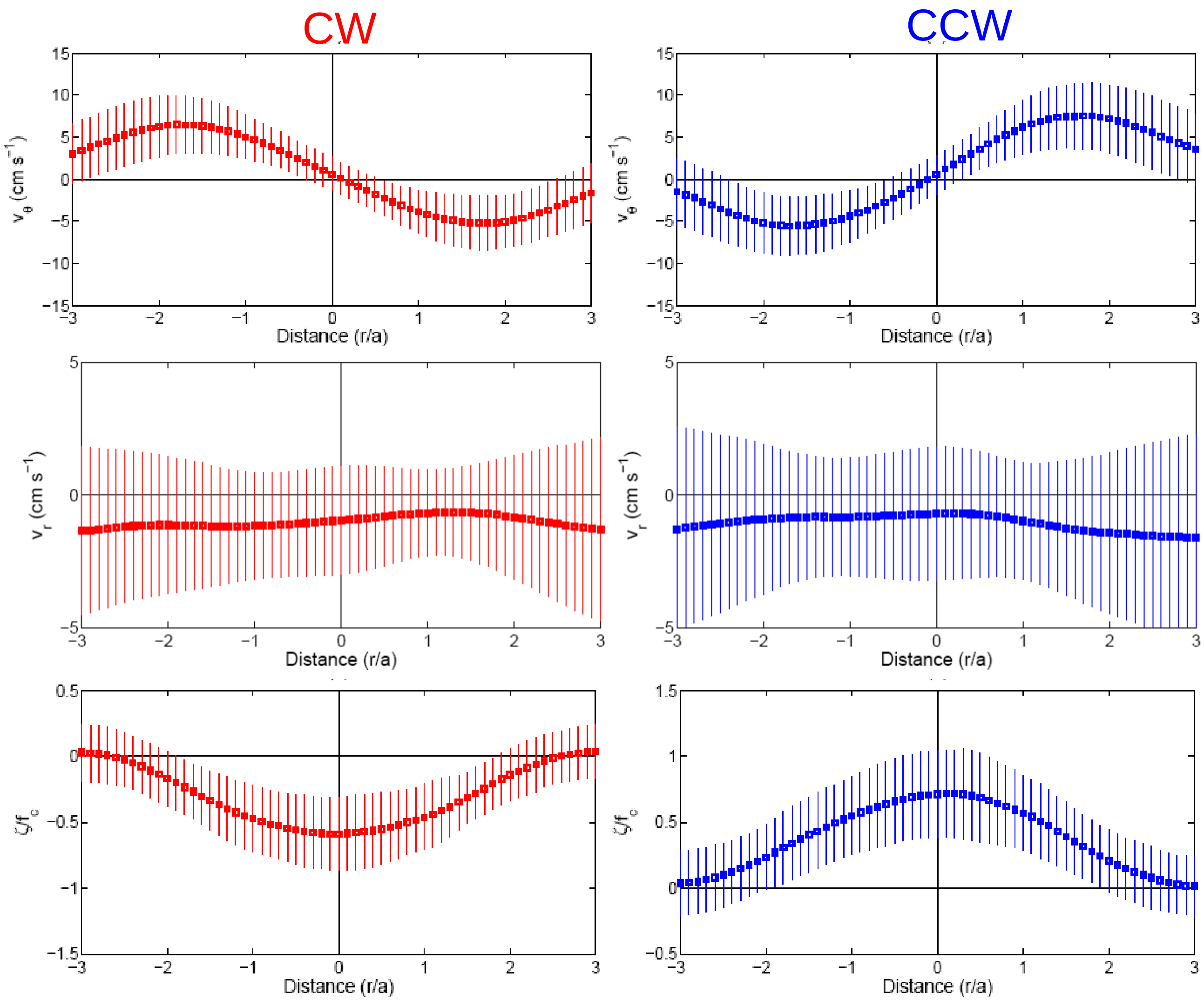
(Kim, CSR 2010)

Horizontal structure

V_Θ Tangential velocity

V_r Radial velocity

ζ/f_c Rossby number

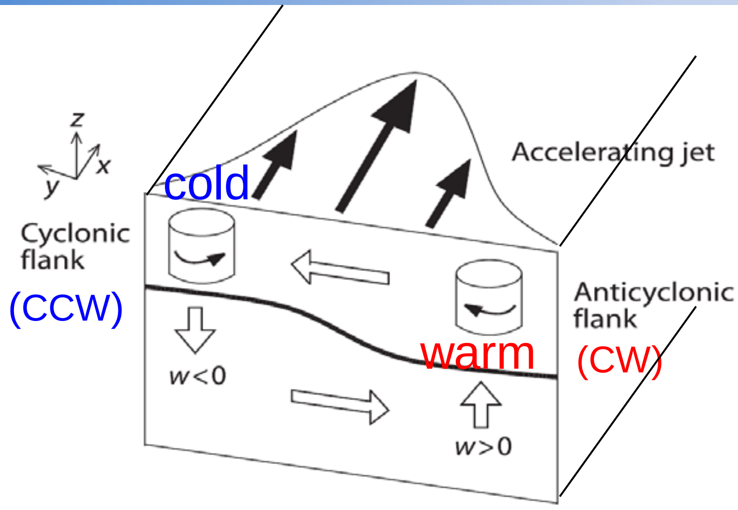


r/a: Relative distance on the major axis

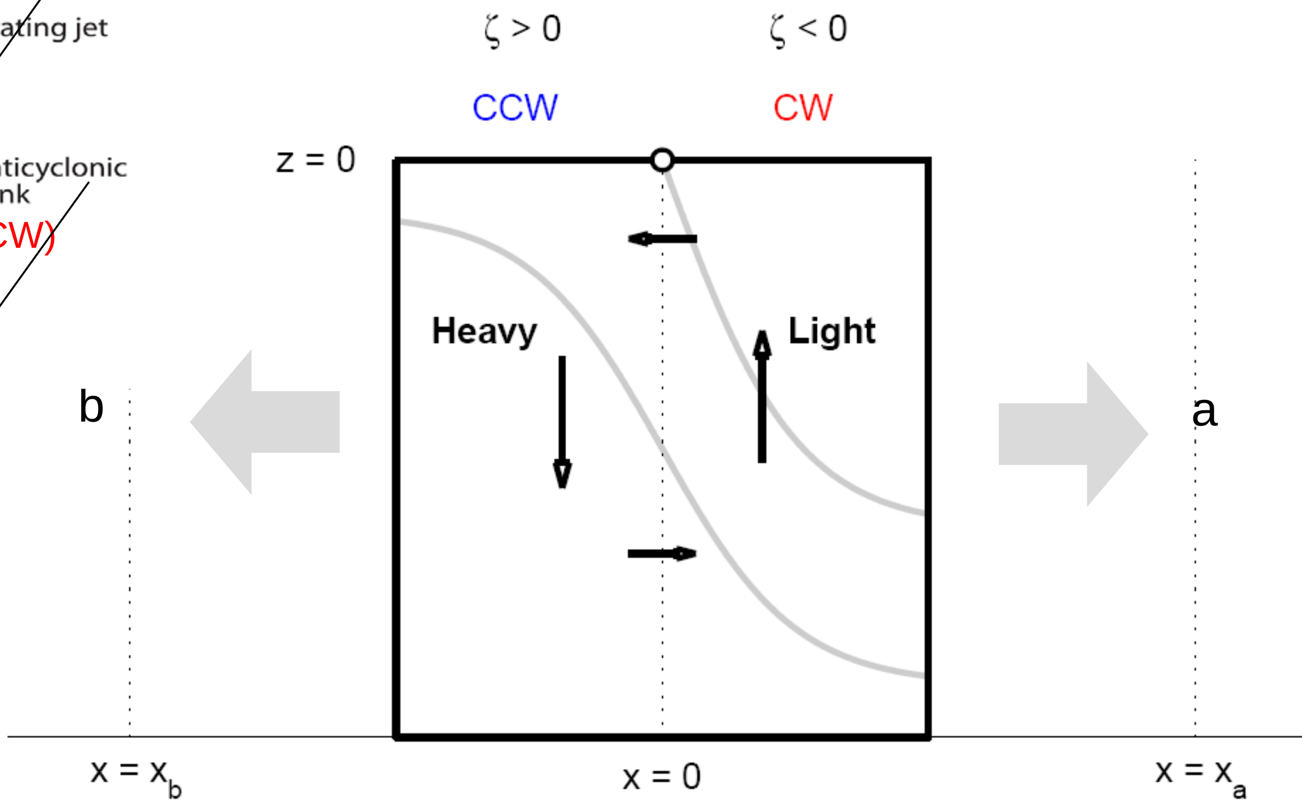
- V_Θ and ζ/f_c have similar shapes to the Taylor eddy.

(Kim, CSR 2010)

Frontal-scale secondary circulation: Expectation



(Williams and Follows, 2003)



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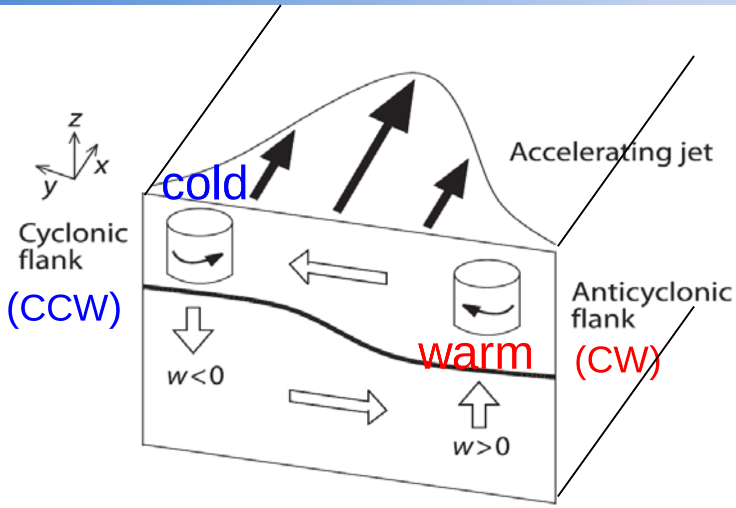

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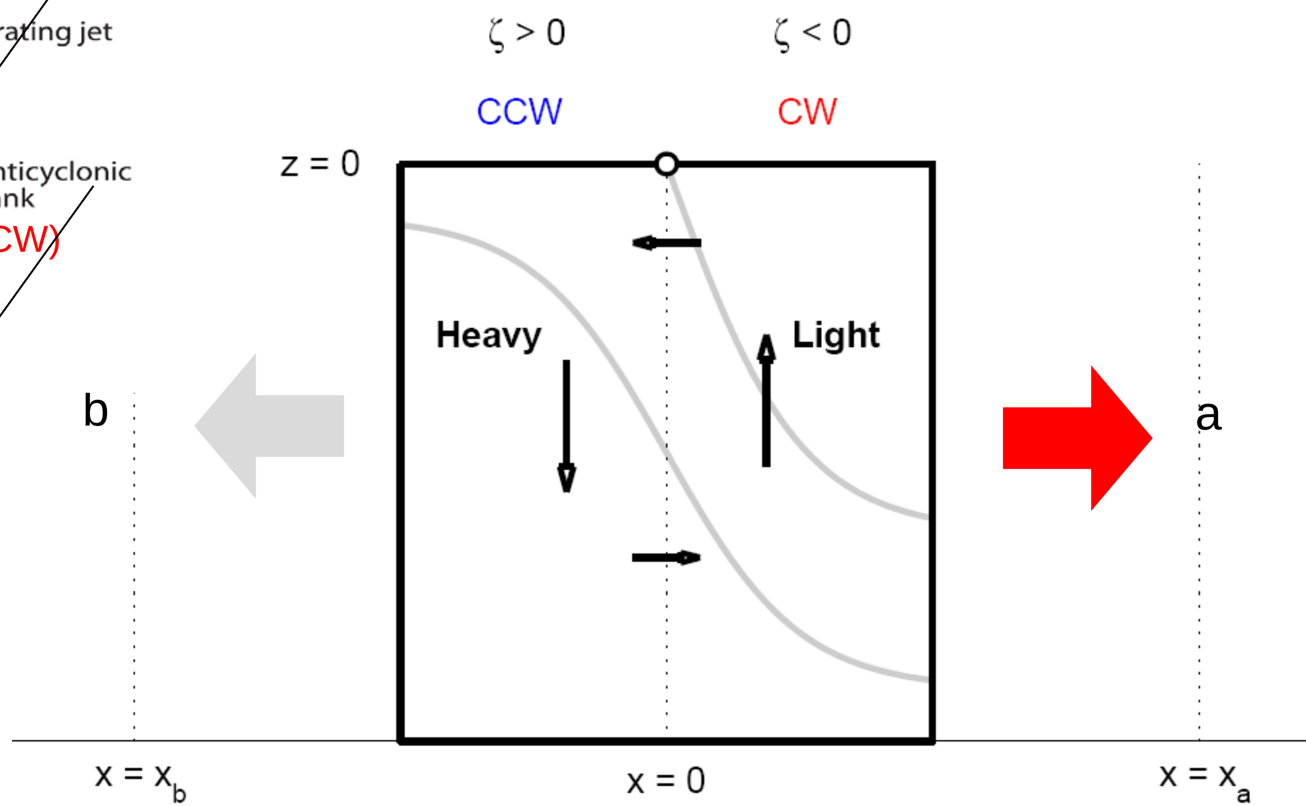
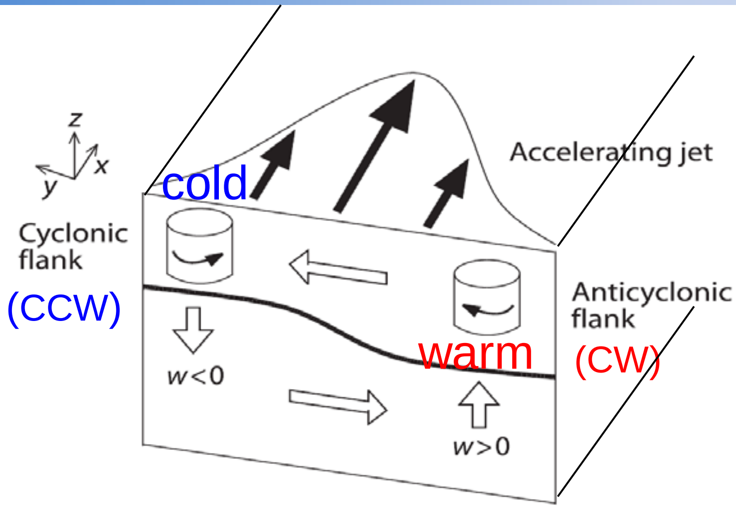


- Paired eddies (a front) move to ‘a’, thermoclines fluctuate up- and down-ward.

Frontal-scale secondary circulation: Expectation



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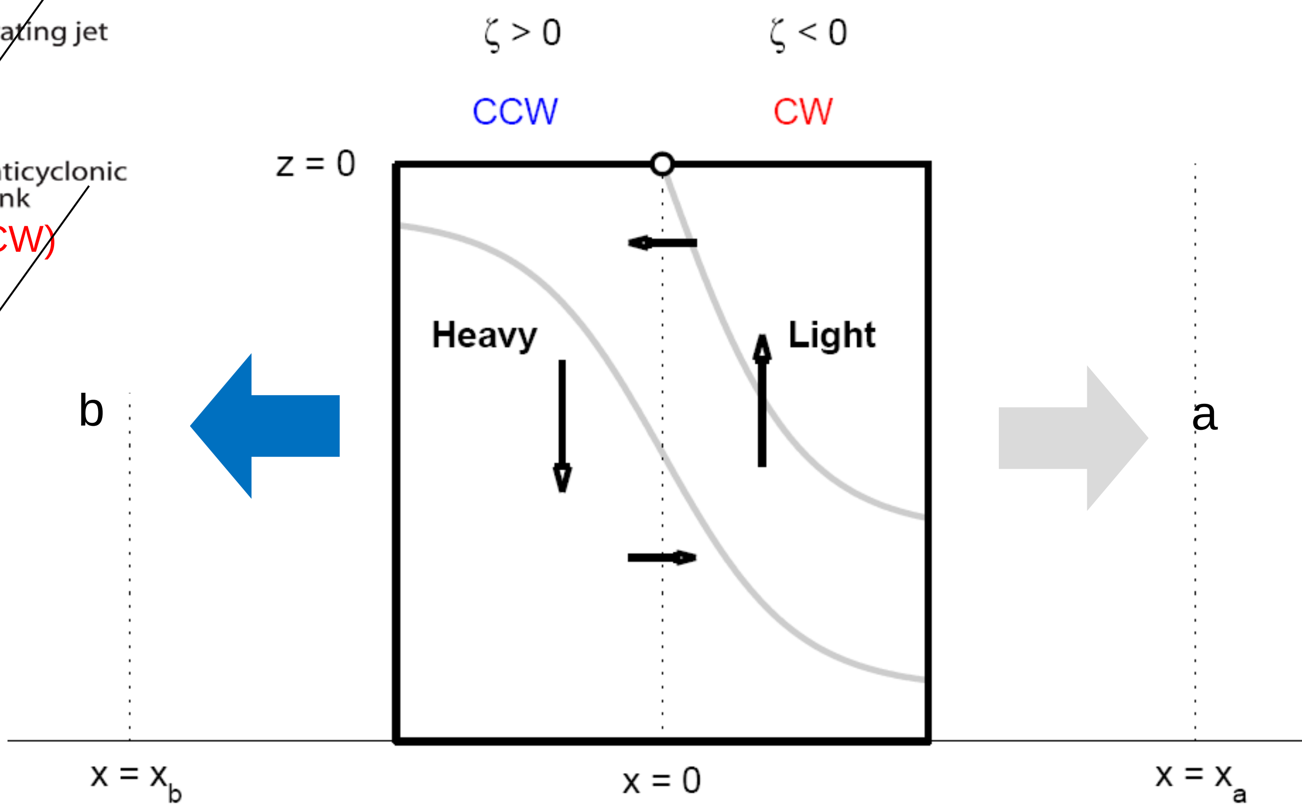


- Paired eddies (a front) move to ‘a’, thermoclines fluctuate up- and down-ward.
- On the other hand, due to moving paired eddies (front) to ‘b’, the thermoclines fluctuate down- and up-ward.

Frontal-scale secondary circulation: Data-derived indicator

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

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

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

$$\varrho = \frac{\partial v}{\partial x} + \frac{\partial u}{\partial y},$$

$$\varsigma = \frac{\partial u}{\partial x} - \frac{\partial v}{\partial y},$$

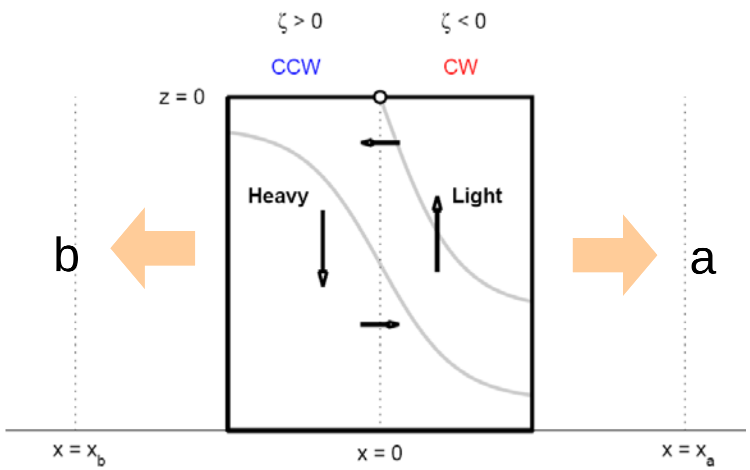
$$\kappa = \sqrt{\varrho^2 + \varsigma^2}.$$

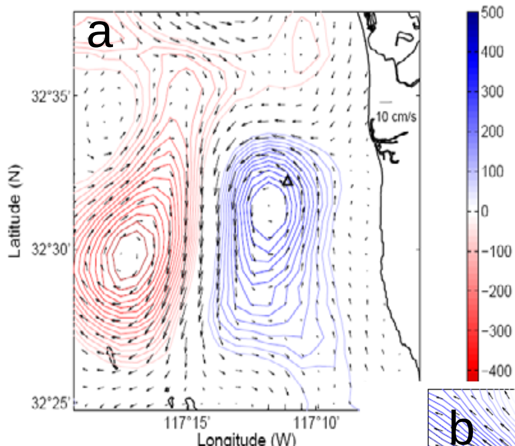
- Subsurface
  - ADCP Current profiles [**u** = **u**(z, t)]
  - Rotational tendency of the whole water column: Vertical rotary coefficients

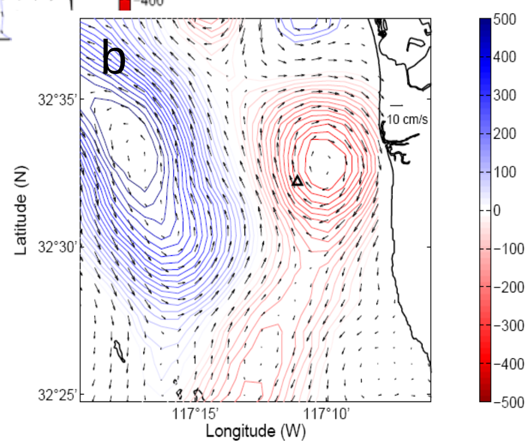
$$\alpha(t) = \frac{-\sum_{m<0} S(m,t) + \sum_{m>0} S(m,t)}{\sum_{m<0} S(m,t) + \sum_{m>0} S(m,t)},$$

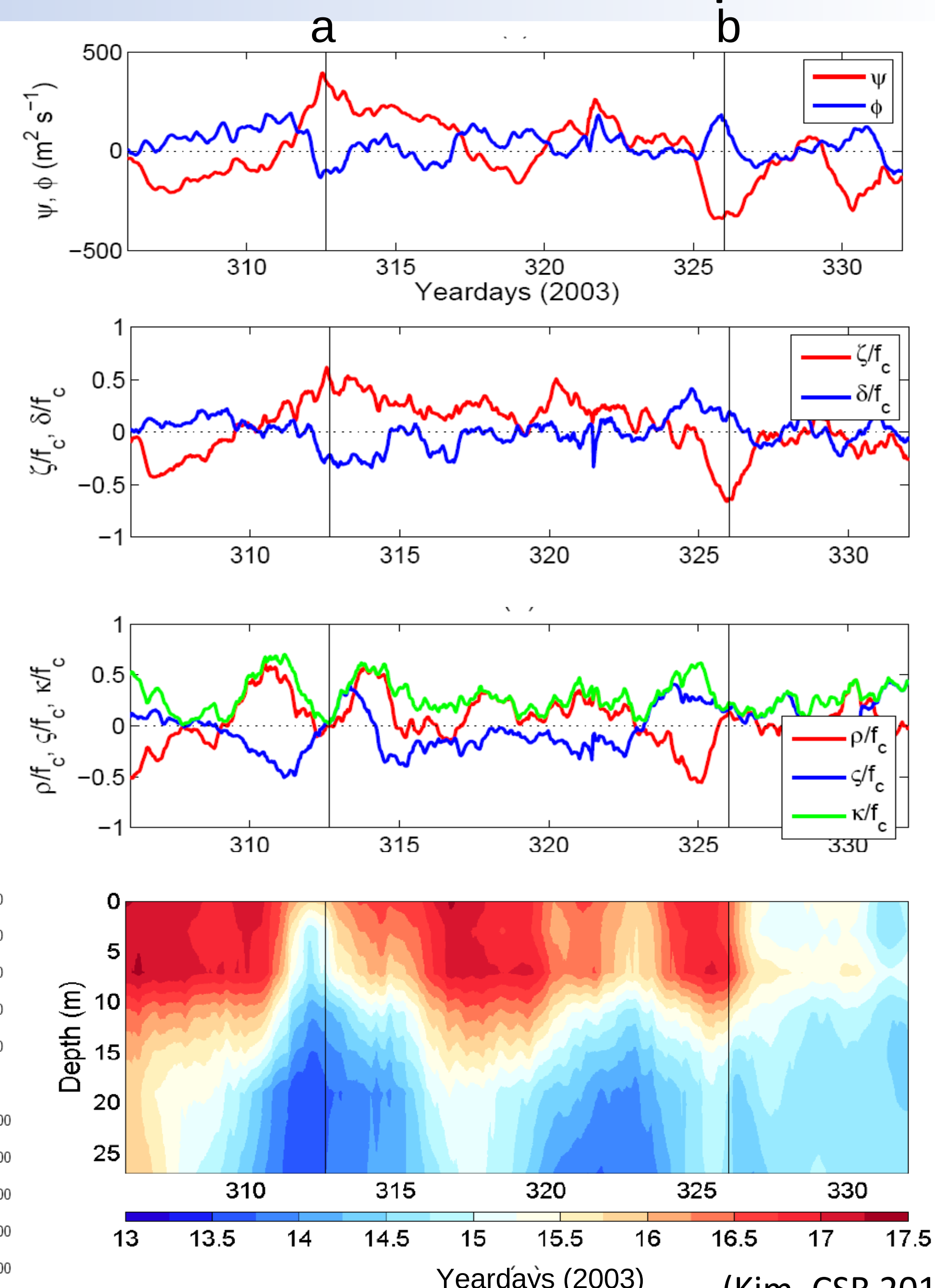
  - Vertical movements of thermoclines [T-string data]

Frontal-scale secondary circulation: Surface & Temp.









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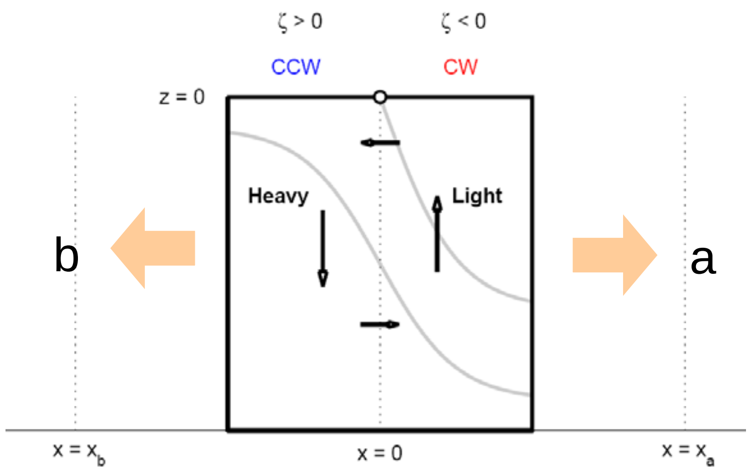
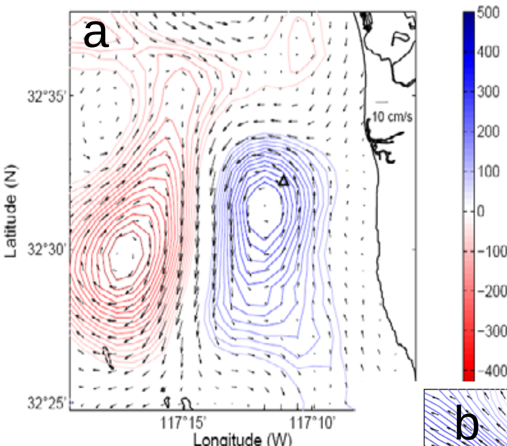
Frontal-scale secondary circulation: Subsurface & Temp





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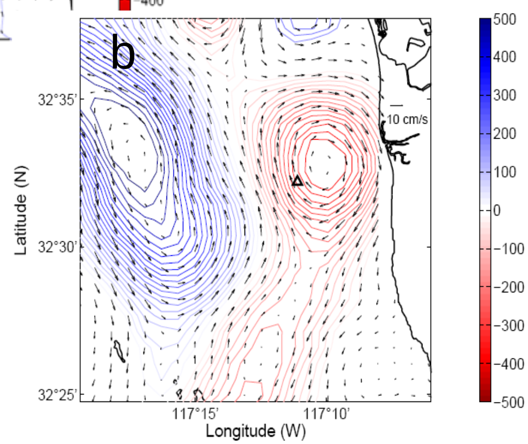
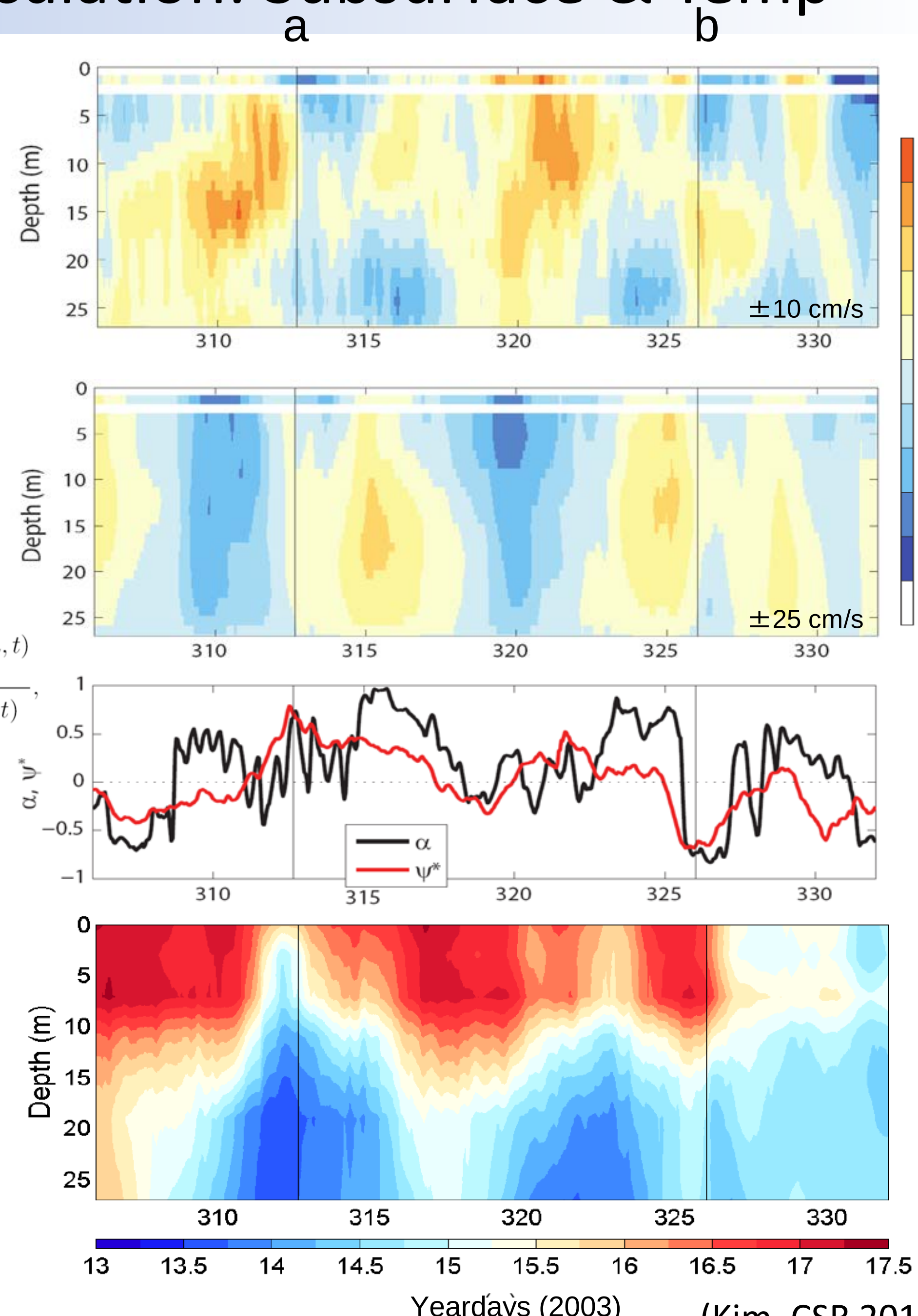
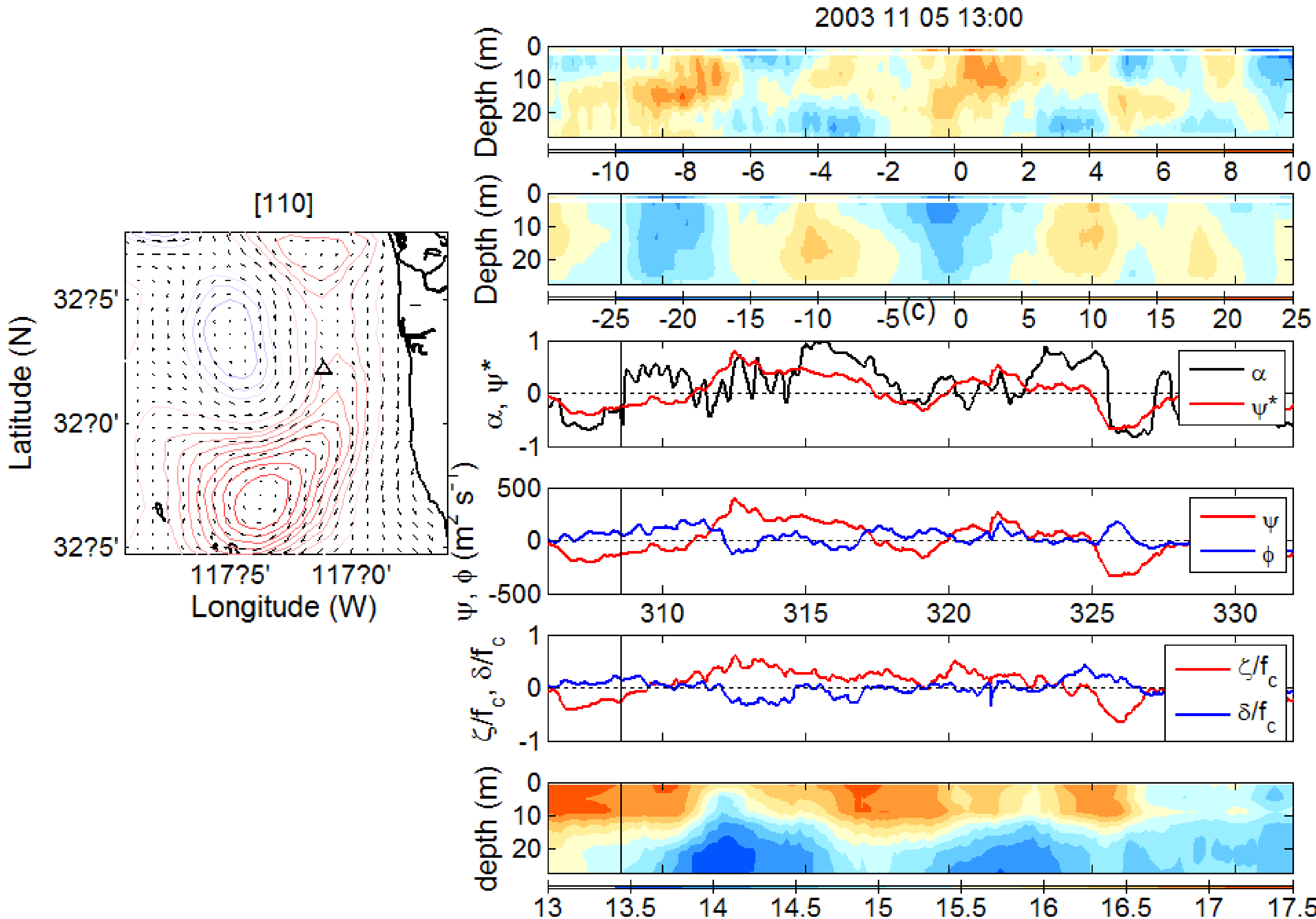




(Kim, CSR 2010)

Two events of submesoscale eddies approaching ADCP/T-string



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.