The Lagrangian Properties of the flow West of Oahu

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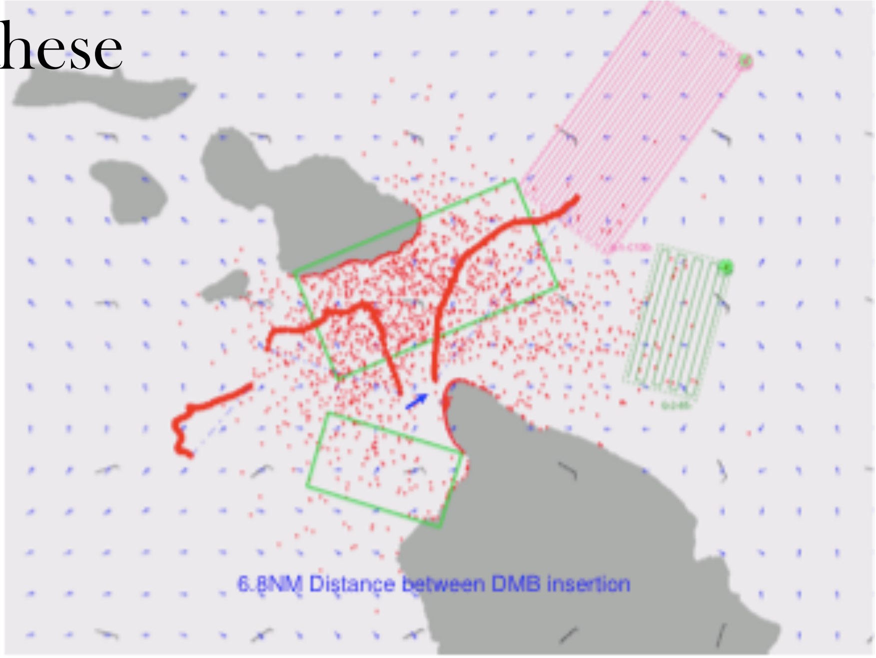
Presentation Outline

- Motivation: Why study Lagrangian properties?
- Data: High Frequency (HF) Radar Deployment
- Methods:
  - How do you measure Lagrangian properties?
  - Finite Time Lyapunov Exponents
  - Defining a separation coefficient from velocity gradient tensors
- Results:
  - General dispersion statistics
  - Eddy Impacts
  - Frontogenesis
  - Tidal Impacts
- Conclusions

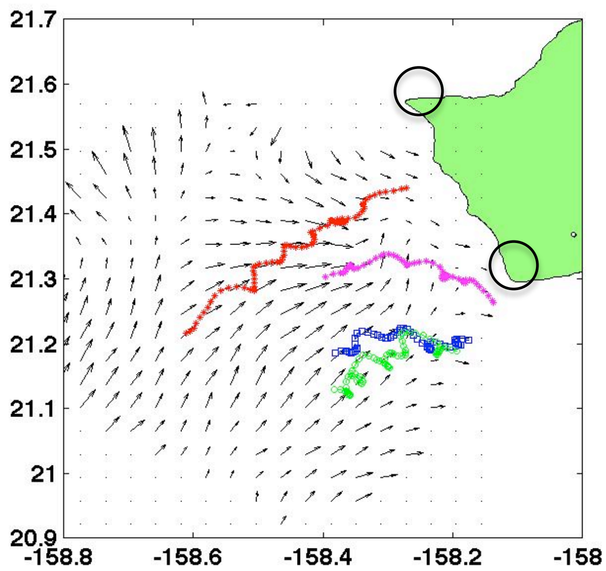
Why study Lagrangian behavior?

- To know where something will "go" in the water
  - Search and rescue
  - Pollution mitigation
  - Larval distribution
- Is HF Radar a benefit for these applications?



Data

- Two HF Radars deployed at Kaena Pt and Ko'olina from September 2002 until May 2003.
- Every hour, 5041 particles were seeded into the flow and integrated for 100 hours.



Methods

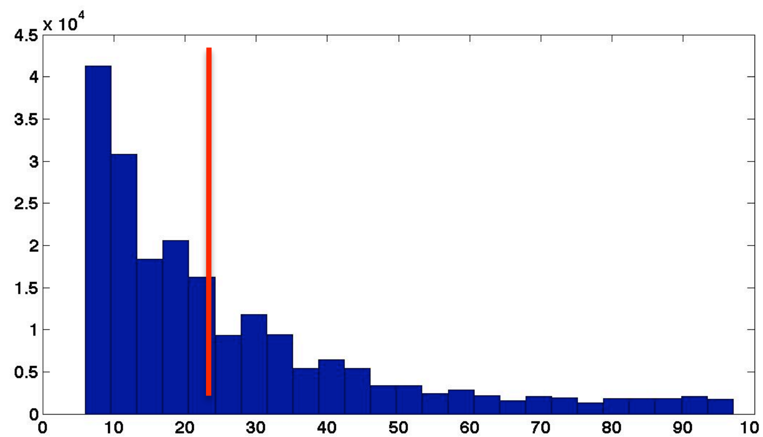
- Particle dispersion:
  - Absolute dispersion:
    - Distance one particle travels from its original location over a fixed time interval
  - Relative Dispersion:
    - Distance two particles separate after a fixed time.

Lagrangian Rate of Separation (RoS)

- Measures how far particles separate after a fixed time, τ .
  - $\delta(t+\tau) = \delta(t)*e^{\lambda\tau}$
  - $[\lambda] = 1/s$
  - Time, τ , dependent on how long particles remain inside the coverage of the HF Radars.

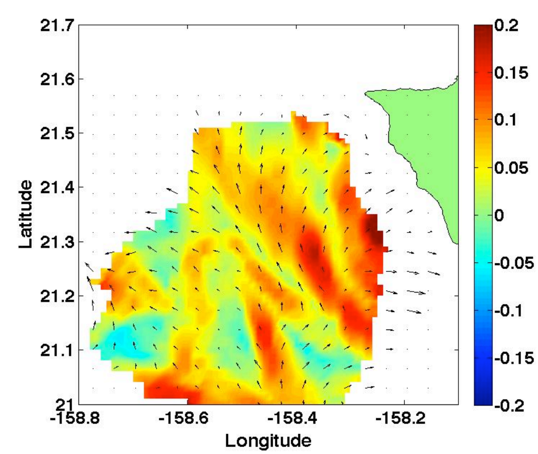
When 50% of particles have exited radar coverage area

Number of particles in coverage area



Time, in hours

12 hour Lagrangian RoS for 10/18/2002

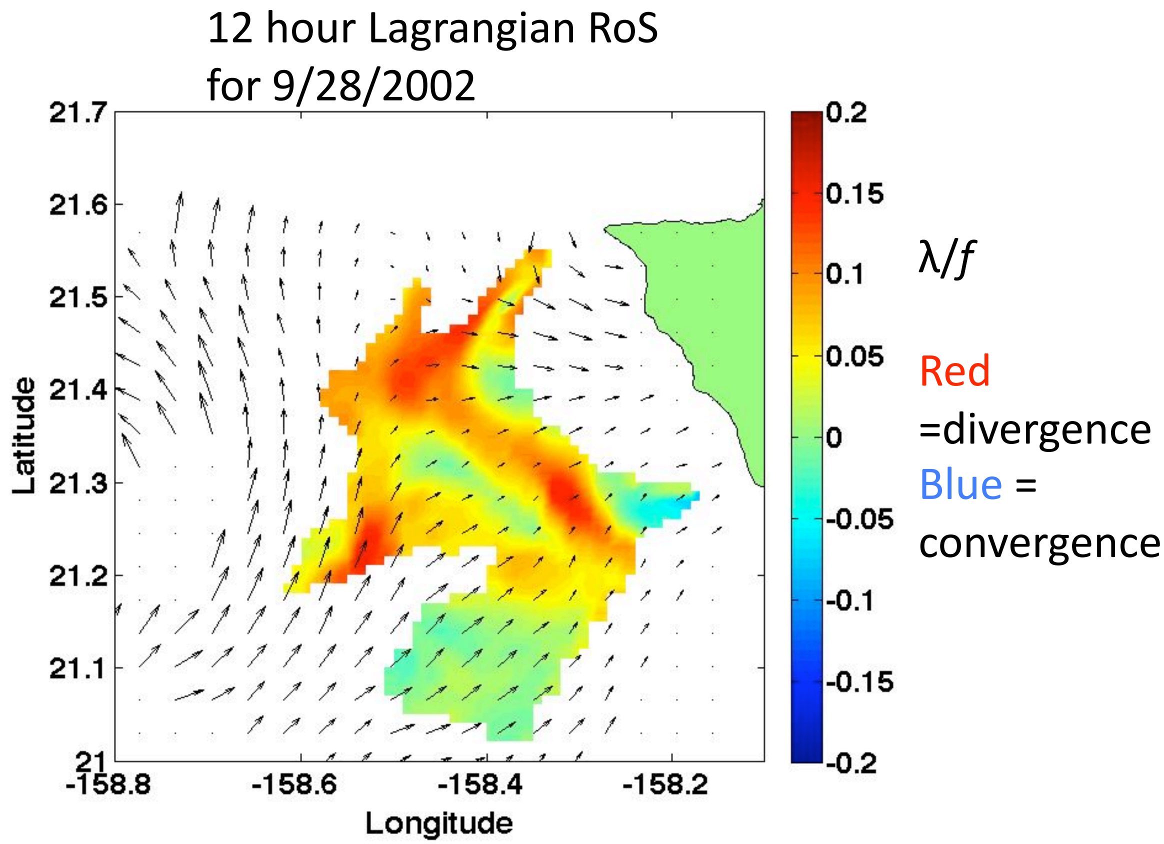


λ/f

Red =divergence

Blue = convergence

Lagrangian RoS drawbacks with HF Radar



✓Coverage varies with time: dependent on variations in HF radar coverage and particle retention time

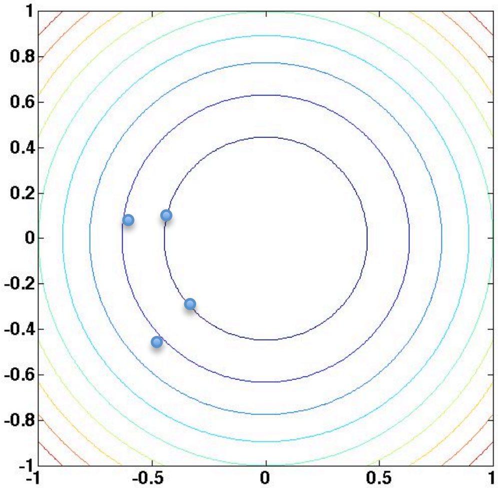
✓ Can only used limited fixed times, up to 24 hours. After that, only a few particles remain inside integration field

Instantaneous Rate of Separation (RoS)

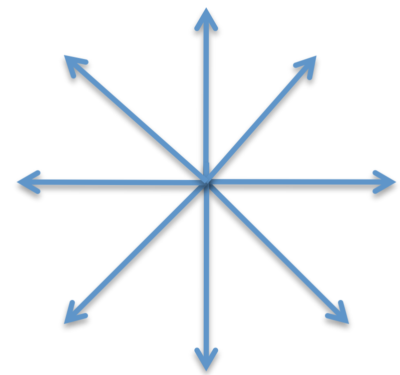
It's the rate of change of two particle's separation over one timestep

– $d/dt(\sqrt{((x-x_o)^2 + (y-y_o)^2)}) = \lambda \ (\sqrt{((x-x_o)^2 + (y-y_o)^2)})$

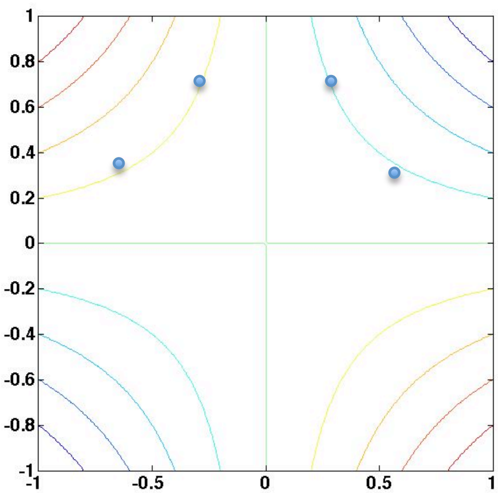
- Use components of velocity gradient tensor to define kinematics in a velocity field
  - Assuming a two-dimensional velocity field:
  - $\mathbf{U}(x, t) = \mathbf{U}_o + \mathbf{A}^* (x-x_o)$
  - Where $\mathbf{U}_o$ is the mean current and **A** is the velocity gradient tensor
  - **A** can be broken down into a symmetric part, S, and an anti-symmetric part, T.
    - A= T + S



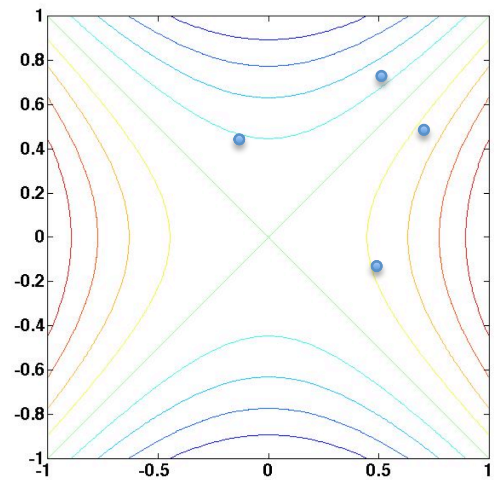
Anti-symmetric part of **A**, representing pure rotation/vorticity, ζ (∂v/∂x - ∂u/∂y)



Symmetric part of **A**, representing isotropic divergence, d, (∂u/∂x + ∂v/∂y)



Symmetric part of **A**, representing first component of pure strain, σ_1, (∂u/∂x - ∂v/∂y)

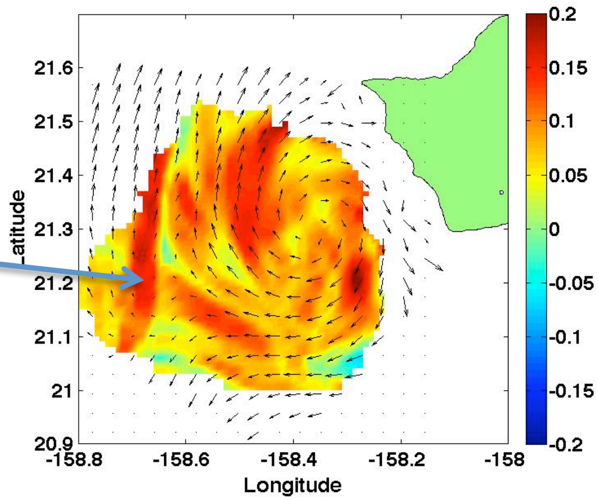


Symmetric part of **A**, representing second component of pure strain, σ_2, (∂u/∂y + ∂v/∂x)

- Anti-symmetric portion of the velocity gradient tensor can be left out
- Any strain can be built by combination of two strain components
  - $\sigma_o = \sqrt{(\sigma_n^2 + \sigma_s^2)}$
  - Measure of absolute value of strain to absolute value of vorticity:
    - $\sigma_n^2 + \sigma_s^2 - \zeta^2$
- **Instantaneous RoS :**
  - $\lambda = \sigma_o + d$
  - So the coefficient can be described by the sum of the strain and the divergence.
  - Same result as mathematical derivation

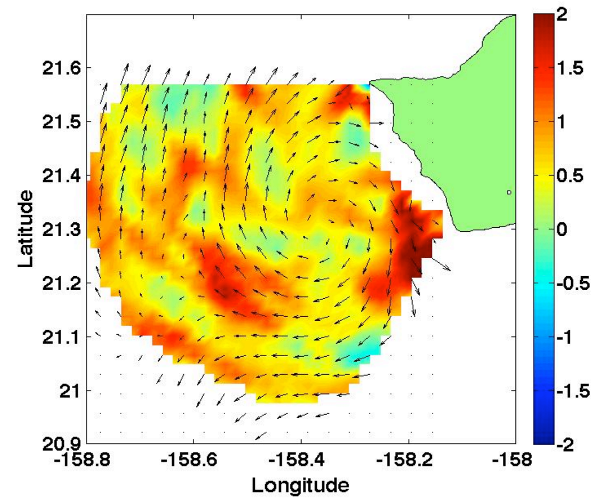
Lagrangian versus Instantaneous RoS

Lagrangian RoS for 10/27/02 at 2100

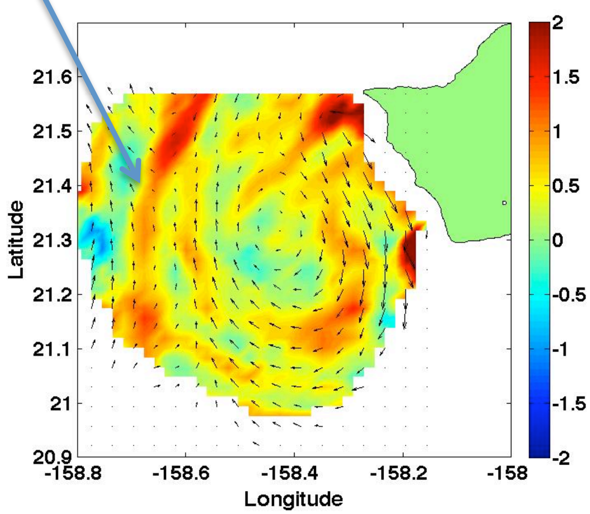


Front visible

Instantaneous RoS for 10/27/02 at 2100

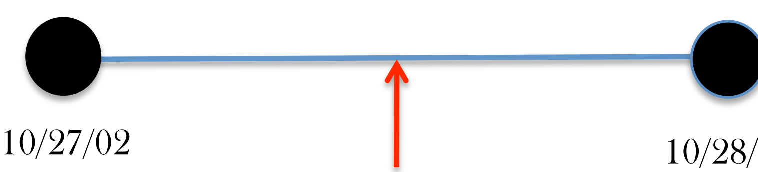


Instantaneous RoS for 10/28/02 at 0300



Lagrangian RoS integration began

Lagrangian RoS integration stopped



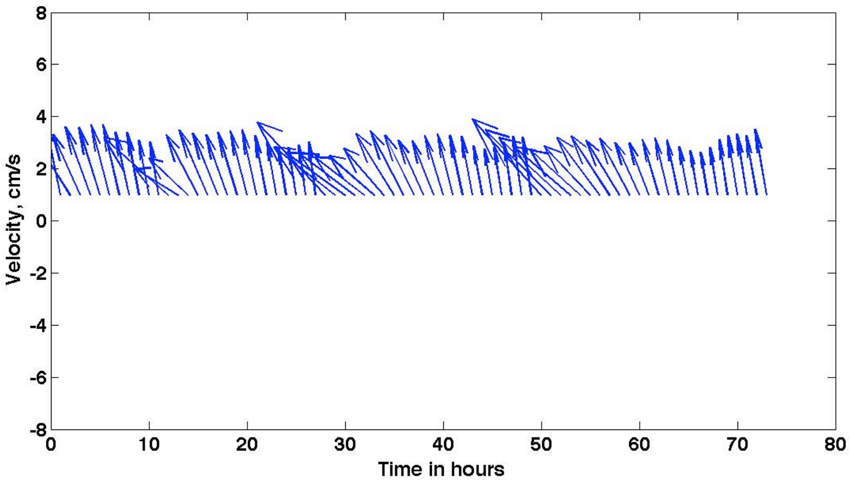
10/27/02 at 2100

Front first observed 10/28/02 0300

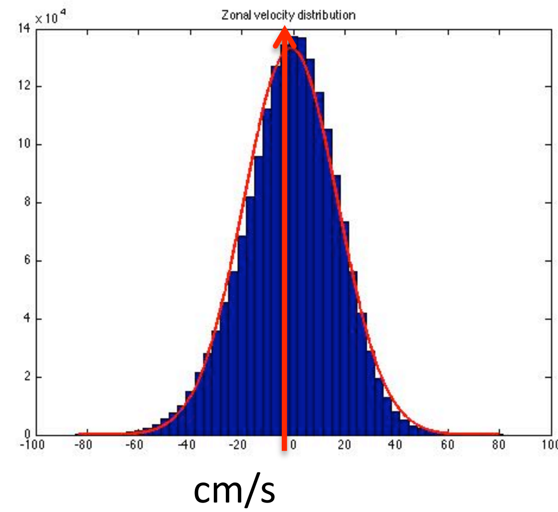
10/28/02 at 0900

General flow statistics

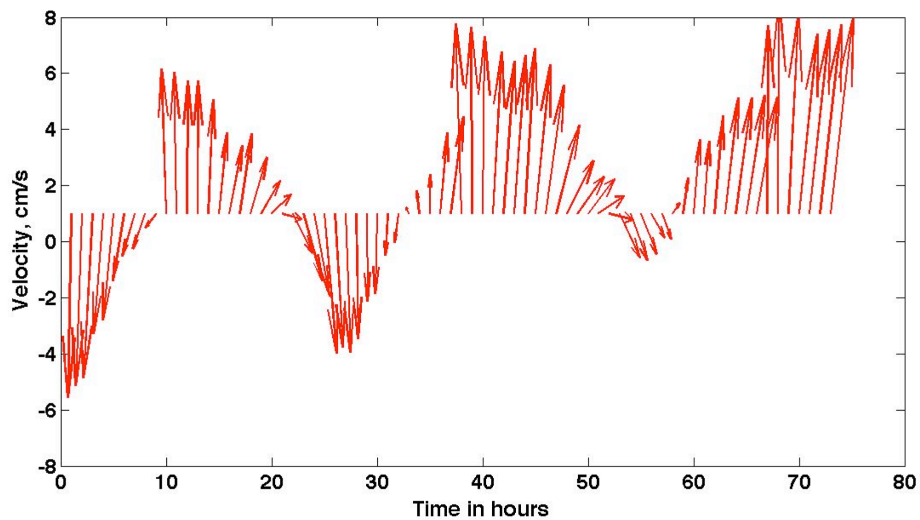
Spring spatially averaged hourly current direction for 3 days



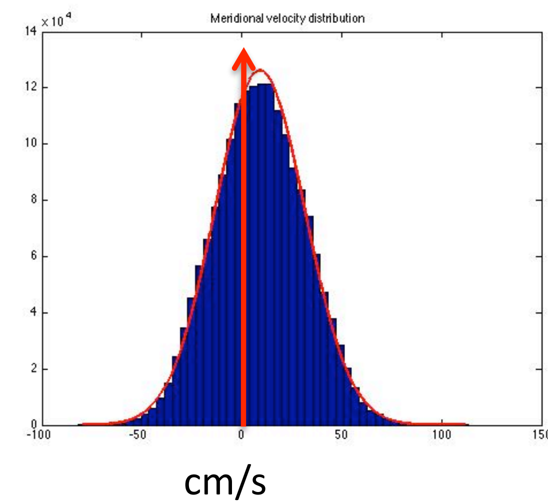
Zonal velocity distribution



Fall spatially averaged, hourly current direction for 3 days

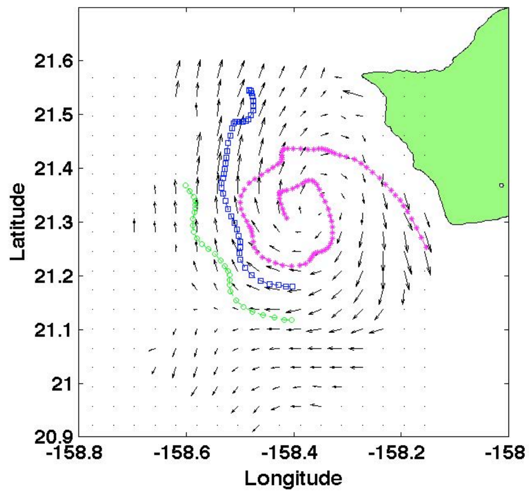


Meridional velocity distribution

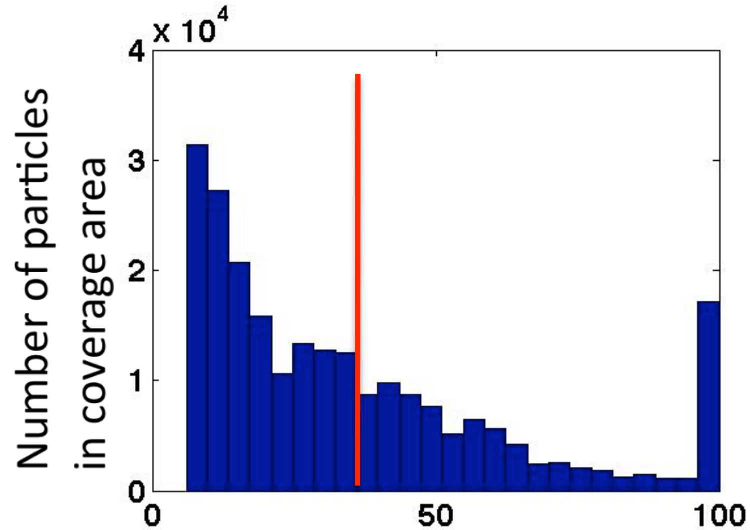


How did anticyclone impact particle behavior?

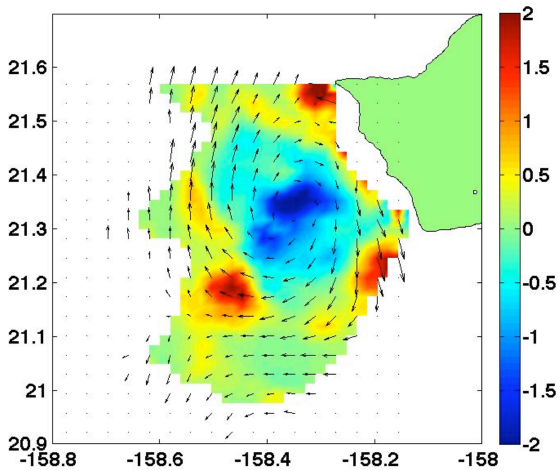
Current field during anti-cyclonic eddy with simulated particle tracks



When 50% of particles have exited radar coverage area



Magnitude of absolute value of strain to absolute value of vorticity, W



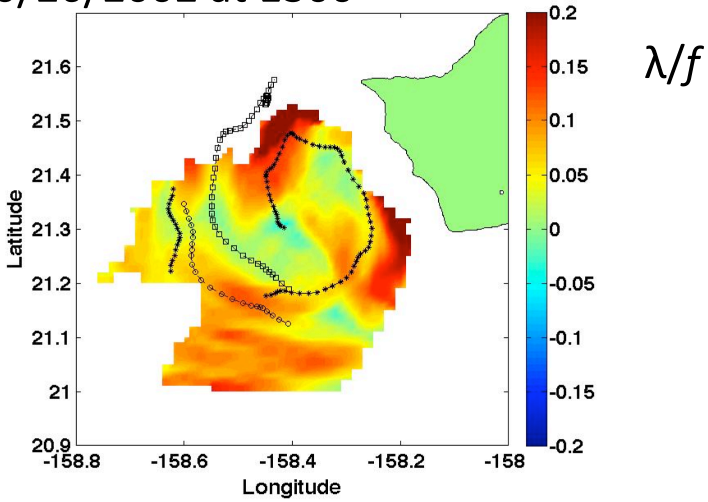
W/f^2

Red = strain dominated

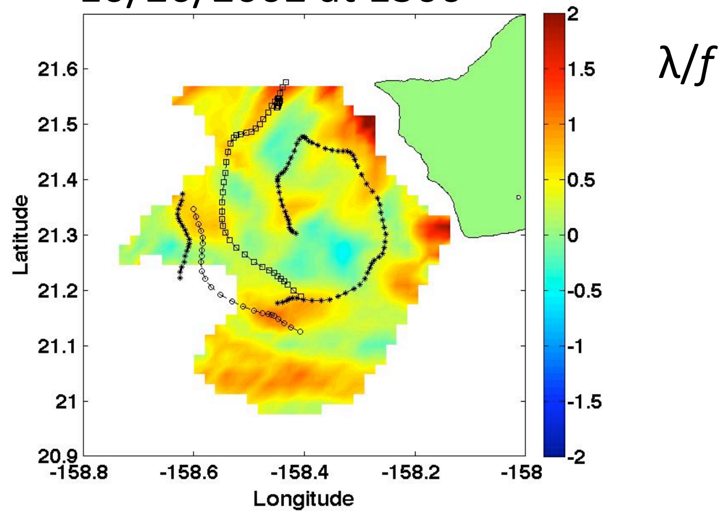
Blue = vorticity dominated

Instantaneous R.S. Versus Lagrangian R.S. during Anticyclonic Eddy

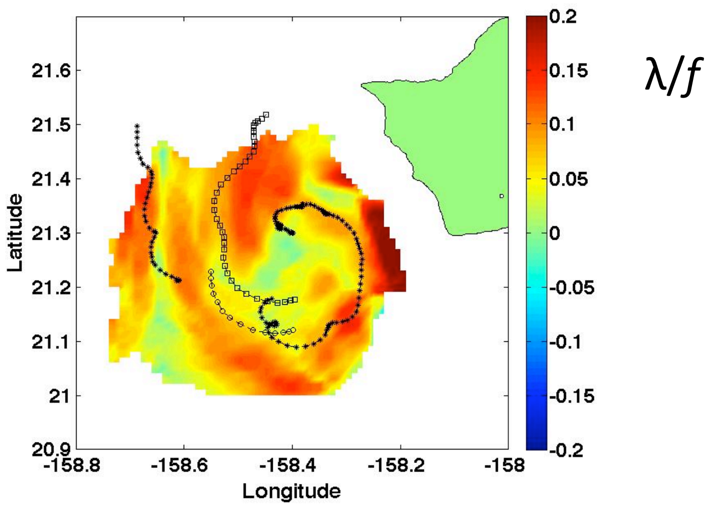
12 hour Lagrangian R.S. for
10/26/2002 at 1300



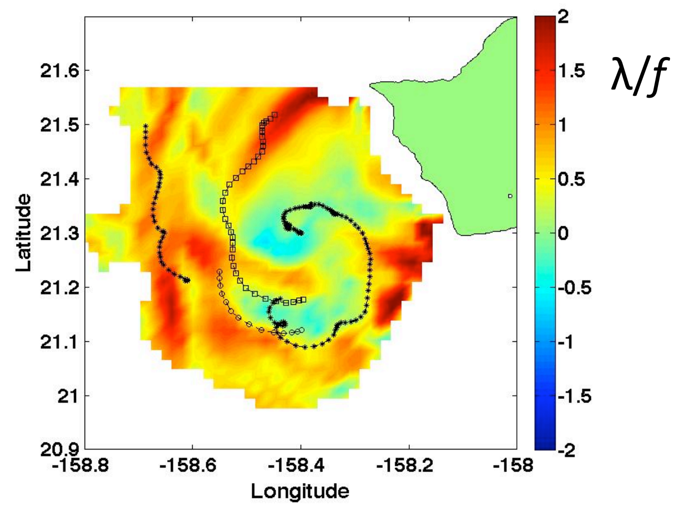
Instantaneous R.S. for
10/26/2002 at 1300



12 hour Lagrangian R.S. for
10/28/2002 at 1900



Instantaneous R.S. for
10/28/2002 at 1900



Can Instantaneous R. S. pick up frontogenesis?

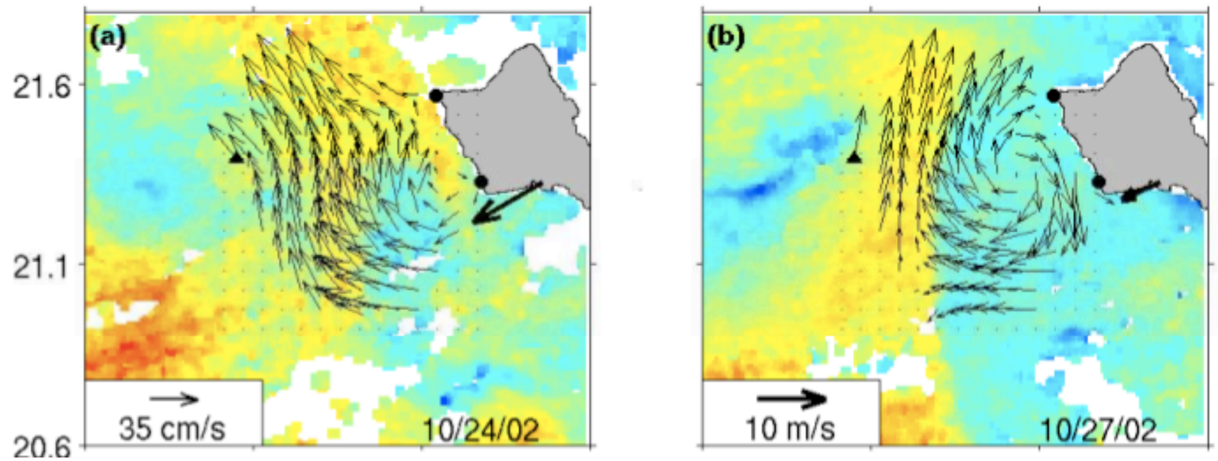
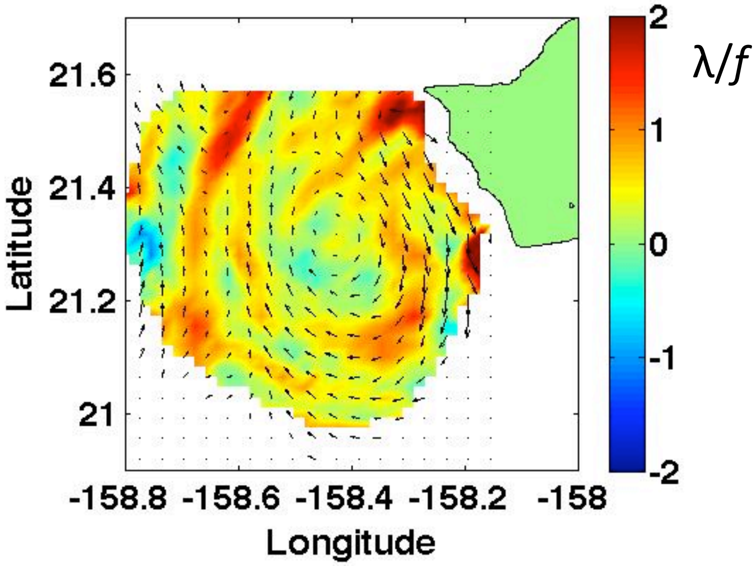
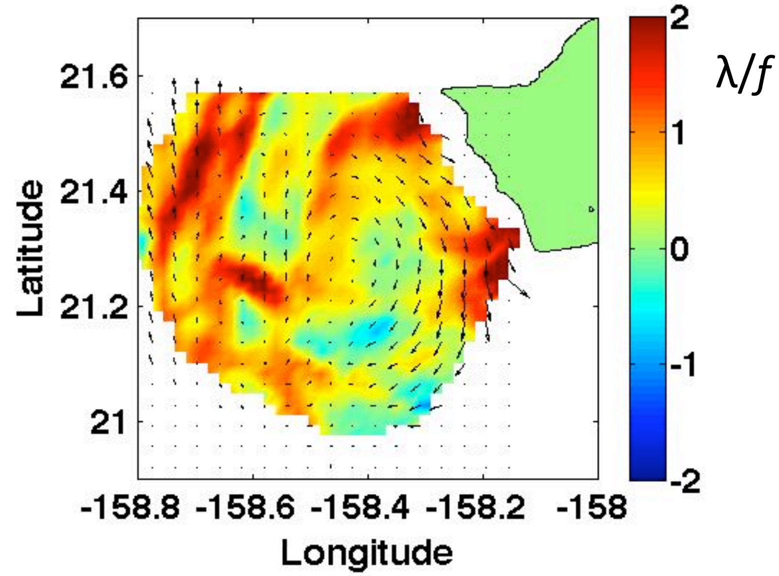


Fig. 4 from Chavanne et al., 2008 submitted

Front visible on Oct 27, 2002

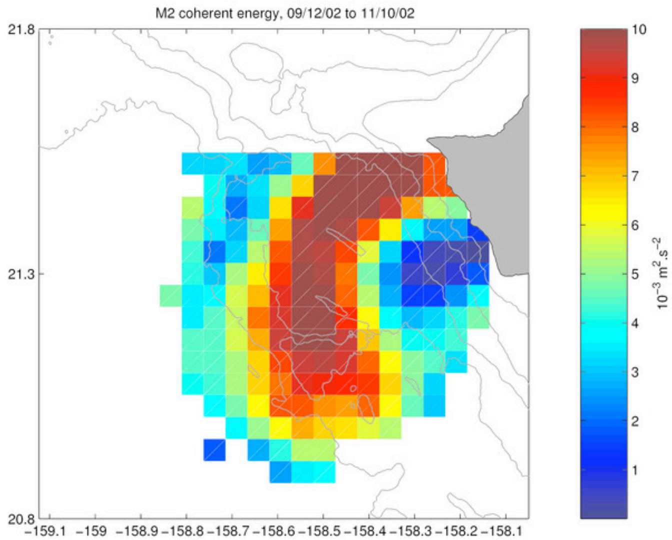


Front visible on Oct 28, 2002

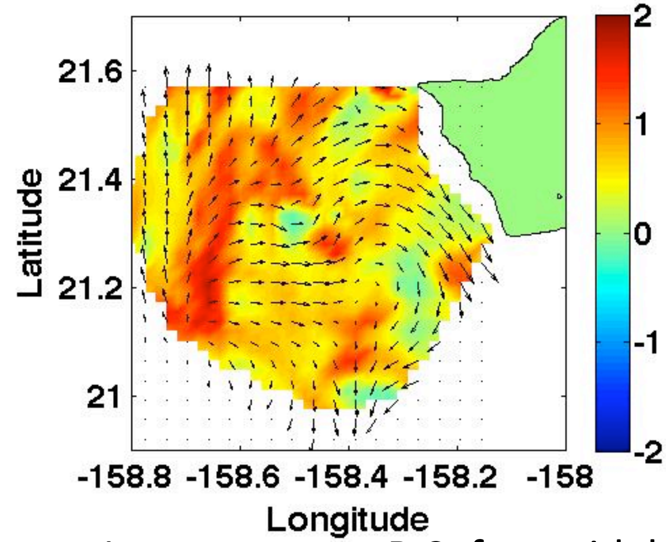


Tidal Impacts

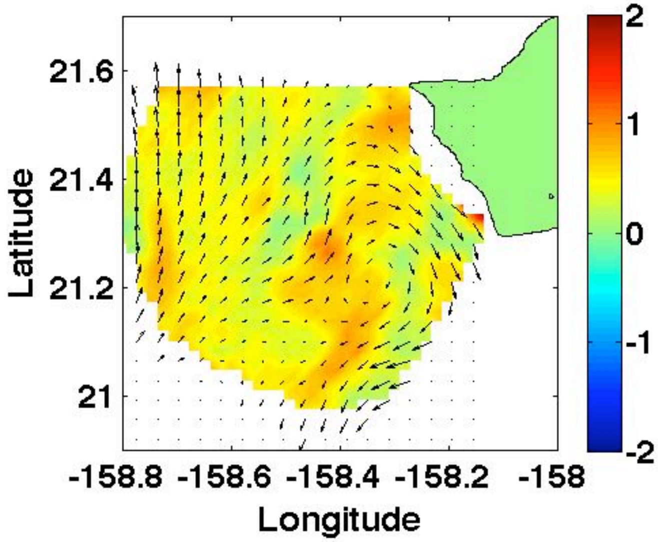
M2 Coherent energy, (Chavanne)



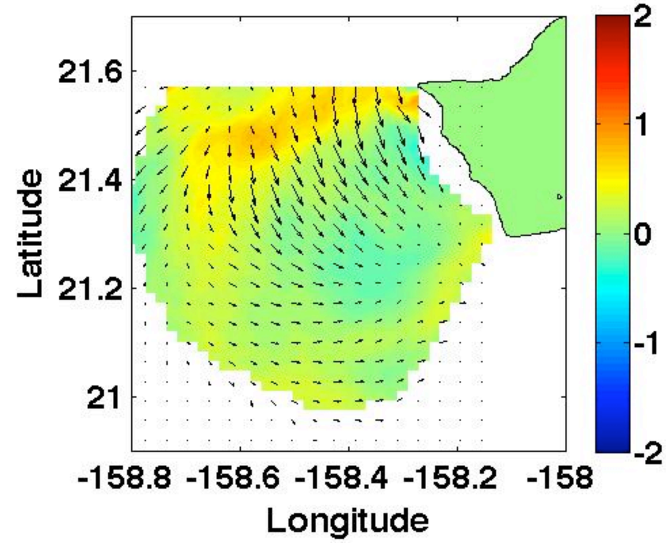
Instantaneous R.S. from total currents for 10/31/02 2200



Instantaneous R.S. from detided currents for 10/31/02 2200



Instantaneous R.S. from tidal currents for 10/31/02 2200



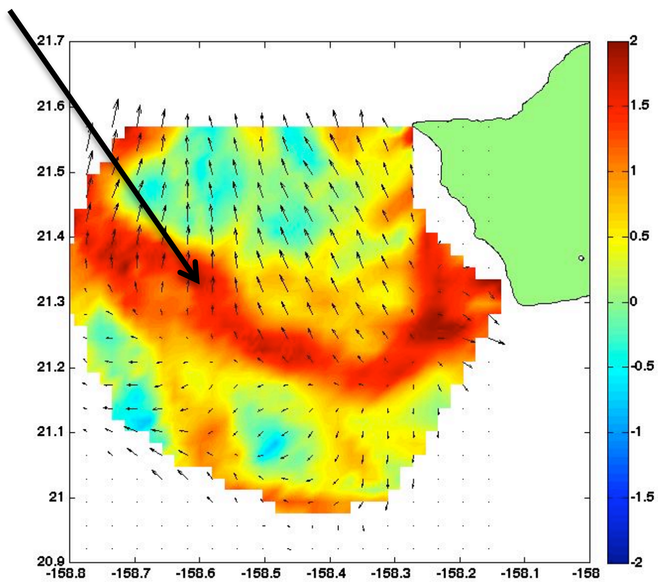
Internal tides

Energetic internal tides are generated on Kaena Ridge, in Kauai Channel (Aucan et al., 2005)

One energy beam propagates to the South and to the surface.

This beam is visible in HF Radar current field

Ridge of High
Separation Coefficient
visible on Oct 5, 2002.



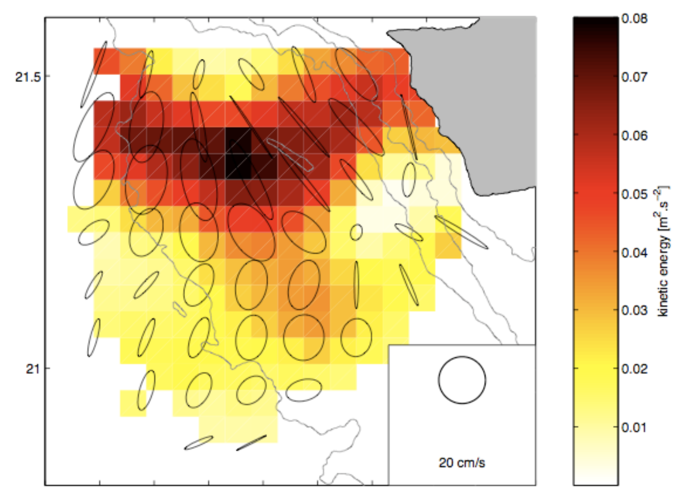
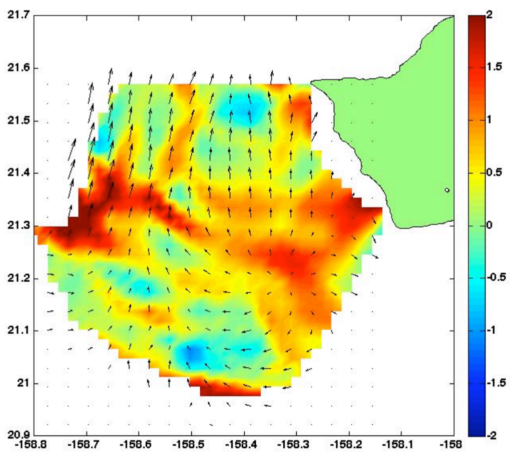


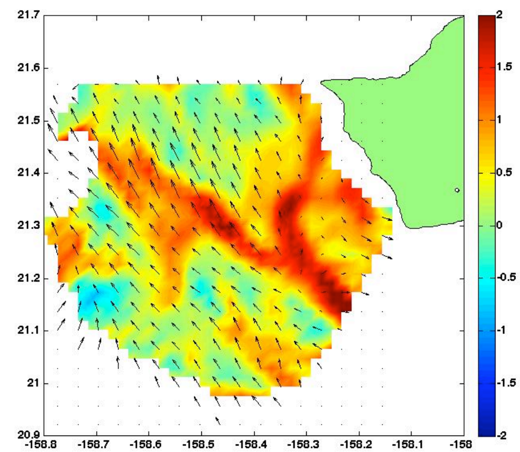
FIG. 17. Complex demodulated semi-diurnal kinetic energy and ellipses on 11/05/2002.

Internal tides

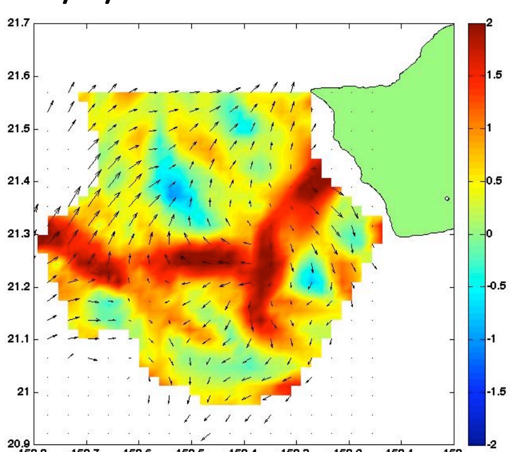
10/7/02



10/18/02



11/7/02



Unique ridge of High separation coefficient visible many times throughout entire study

Conclusions

- Flow to the West of Oahu is a very dynamic region
- 50% of particles in flow escape from HF radar coverage with in 25 hours.
- Regions where particles converge or divergence over a fixed time varies greatly, both daily and seasonally
- The Lagrangian Rate of Separation can be used to identify these regions of high particle dispersion, but lacks consistency in spatial coverage
- The Instantaneous Rate of Separation can be used in its place
  - The Instantaneous R. S. can help identify eddy features, active frontogenesis, and surface internal tidal signals.

- Future Work:
  - Deploy surface drifting buoys and compare dispersion statistics with separation coefficient results. Validation or rework the equation.
  - Dig deeper into individual dynamics identified by separation coefficient
  - Compare results with larger scale velocity field and with other locations:
    - Tehauntepec, Adriatic, and Philippines data available