Separation of the North Equatorial Current at South Pt., Hawai'i: a case of downstream instability and vortex formation

Victoria Futch, University of Hawai'i at Manoa and United States Coast Guard Academy
Pierre Flament, University of Hawai'i at Manoa
Larry Armi, University of California San Diego, Scripps Institution of Oceanography
Rick Lumpkin, Atlantic Oceanic and Atmospheric Laboratory, NOAA

Abstract:

As the North Equatorial Current passes the South Point HI, it separates into a lateral shear layer which is unstable, forming vigorous anticyclonic mesoscale vortices observed west of the island. To fully examine the dynamics of vortex growth and merging, an historical analysis of the area downstream of the separation point was carried out using drifting buoy tracks, shipboard ADCP sections, satellite altimetry and SST. Drifting buoys show that instabilities appear predominantly in Fall and Winter, when the current intensifies and many buoys are trapped into eddies with a Rossby number frequently reaching Ro=-1. ADCP sections show that the eddies are surface intensified, with a typical e-decaying depth of ~100 m, and vorticity reaching *-f*. We propose that (i) the anticyclones are predominantly caused by shear layer instability, wind stress curl in the lee playing a secondary, possibly pre-conditioning, role through downward Ekman pumping, and (ii) that the zonal Hawai'i Lee Countercurrent which extends over 1500km westward, is forced mostly by the meridional convergence of the flux of zonal momentum carried by the instability vortices.

1.Background

1a) Determining Shear Instability in the NEC:

- As NEC passes South Point, Hawai'i it detaches into a shear layer
- Shear instability creates vigorous anticyclonic vortices.1,2

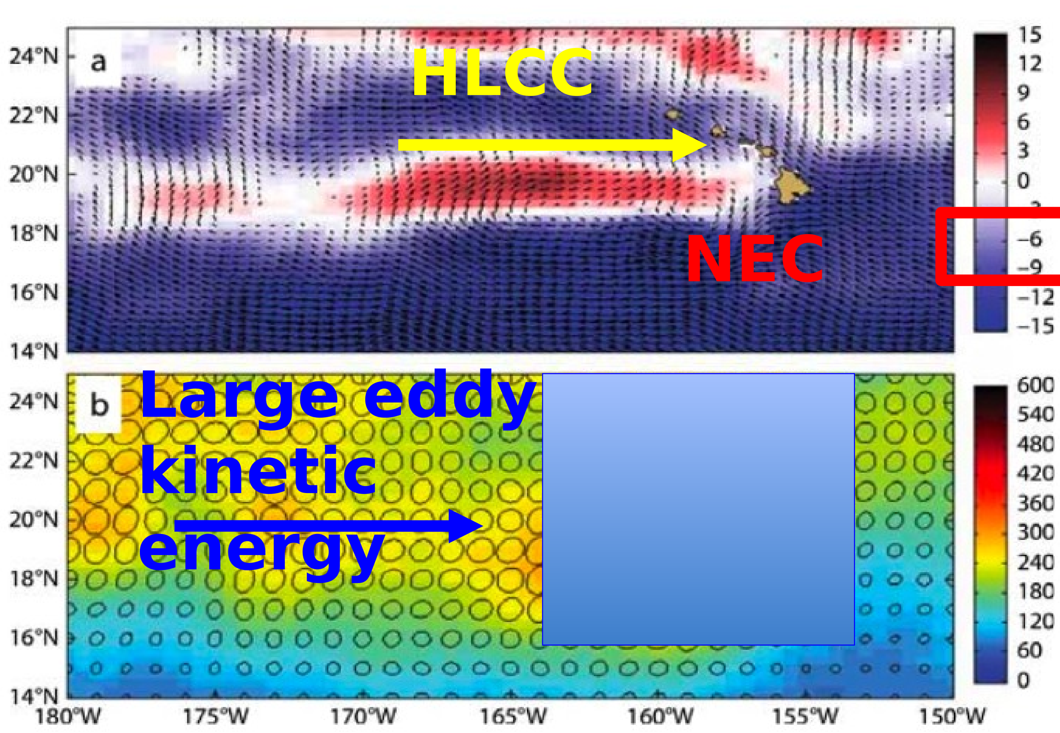

Fig. 1. (a) Time-averaged near-surface currents (arrows) superimposed on average zonal component (colors; cm/s) for all drifters launched until 2012; the blue-colored NEC appears south of 18 N and the red-colored HLCC is centered at 19.5 N. (b) Eddy kinetic energy in cm2/s and variance ellipses. After Lumpkin and Flament (2013)3

1b) Evidence of Vortex Merging:

- Anticyclones have initial orbital periods ~3 days (blue dot on Fig. 2)
- As they move downstream, vortices merge into larger anticyclones with orbital periods of 6 days (red dot) and 12 days (pink dot).

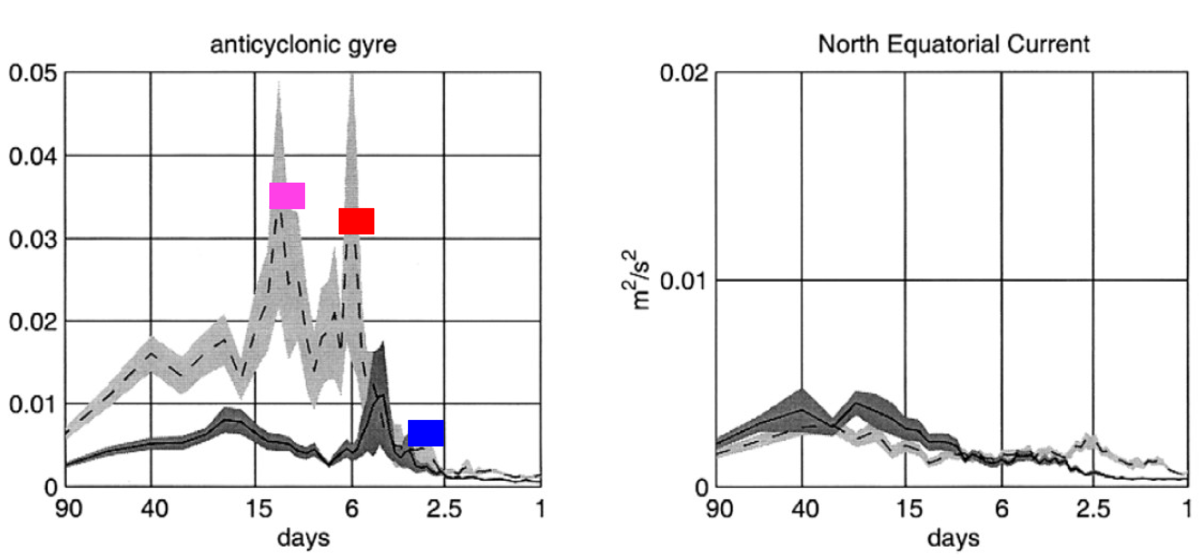

Fig. 2. Cyclonic (dark shading) and anticyclonic dashed (light shading) Lagrangian rotary spectra west of Hawai'i (left) and in the undisturbed NEC south of 15N (right). Peaks at 3, 6, and 12 days are highlighted with bullets. After Lumpkin and Flament (2001)5.

1c) Developing the Hawaii Lee Countercurrent (HLCC):

- Anticyclones appear to induce meridional transport of zonal momentum
- Helps maintain horizontal shear between HLCC and NEC3

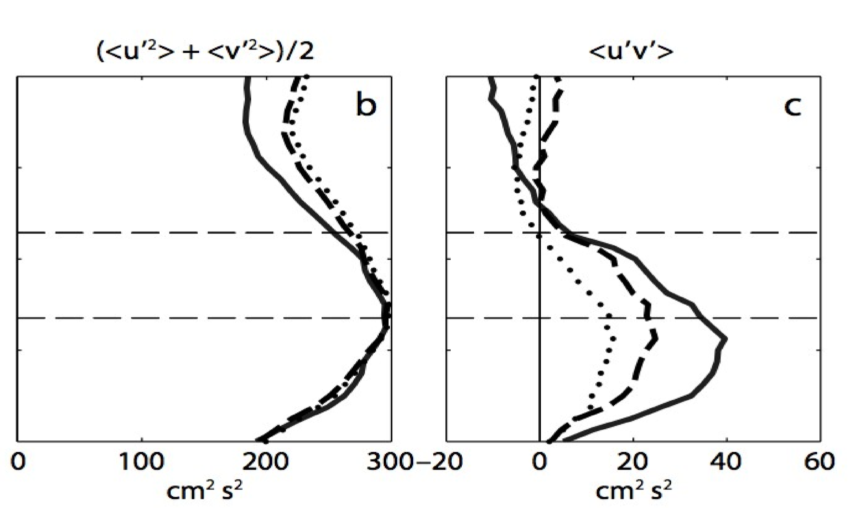

Fig. 3. Drifter currents zonally averaged over 160-168W as a function of latitude: annual mean (dashed); August to January, peak months of the HLCC (solid); annual mean Ekman removed currents (dotted). (b) eddy kinetic energy, (c) Reynolds shear stress. After Lumpkin and Flament (2013)3.

2. Data Collection & Analysis: Past and Future

2a) Past

- Used all surface drifter trajectories that passed in the vicinity of the Hawaiian islands since 1979.
- Isolated all drifters that passed through the region of predicted shear development.
- Collected ADCP tracks in vicinity of shear development and vortex merging.

2b) Future

2.b.1) HFDR

- Focused on both the near-shore region to the south and west of the island, and farther off shore to the west. (Figs. 5, 7)
- 2 long range radars on western Hawai'i and one short range near South Point Hawai'i .

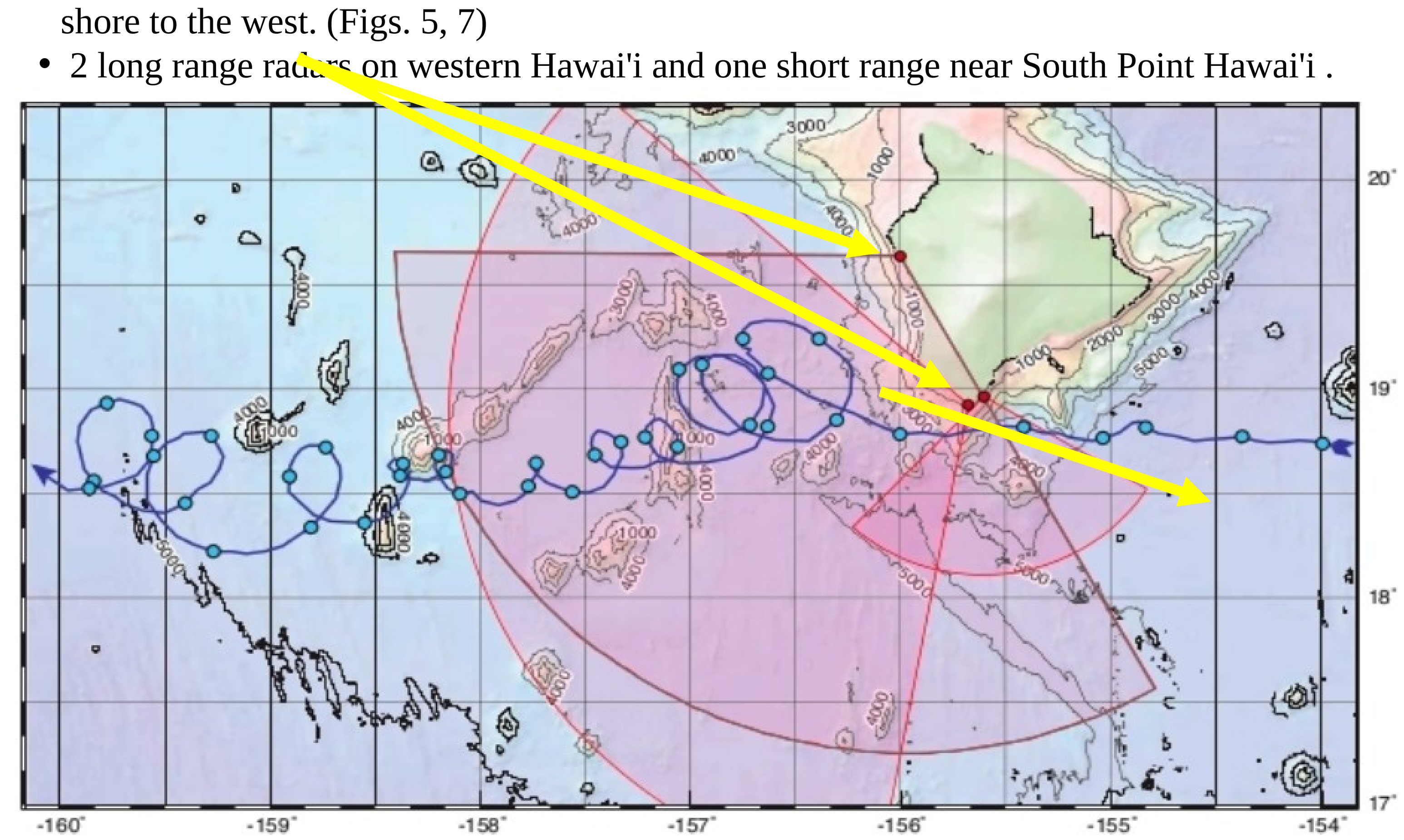

Figure 5. Overview of the experimental plan, showing the coverage of the long-range and short range HF Doppler Radios (red). The trajectory of a surface velocity drifter, which traversed the area in March 2001, is shown as an example of developing eddies (the bullets are spaced one inertial period or 1.5 days (blue).

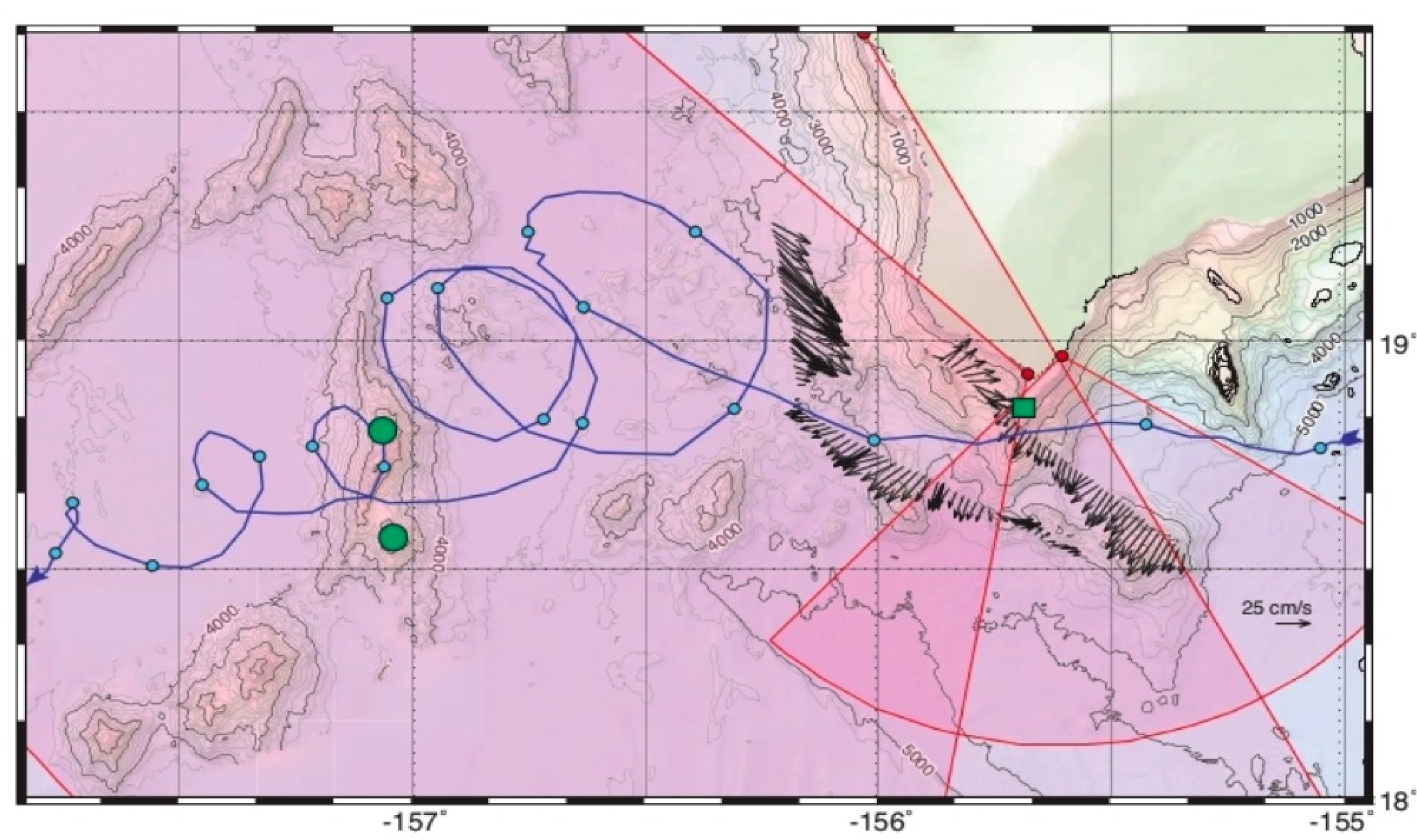

Figure 6. Same as Figure 5, enlarged to show the area in the immediate vicinity of the NEC separation point. The position of the moorings are shown (green). Surface velocity vectors from ADCP sections conducted in August 1990 (West) and December 1990 (East) are overlaid. After Lumpkin, 1998.

2.b.2) Moorings

- 3 Moorings are planned in the coverage of the HF radars.
  - A 300kHz upward looking ADCP in a TRBM will be located on a shallow shelf directly off the tip of South Point.
  - The second and third moorings will be identical in set up, a 49" subsurface sphere at 500m depth, with 75kHz upward looking ADCP. They will be moored on two seamounts in projected region of eddy formation (Fig. 6)

2.b.3) Surface Drifting Buoys

- 70 Self-Locating Datum Marker Buoys (SLDMBs) were acquired for this project.
- The SLDMBs will be deployed in two locations:
  - directly off South Point in lines spanning the region of shear development
  - in clusters to the west of the island, where fully formed vortices are anticipated.

3. Results

3a) Wind Stress Curl

- Positive wind stress curl can also excite anticyclonic vortices6
- Would generate a wide range of anticyclones
- This is not observed, vortices narrowly focused at *–f* period.

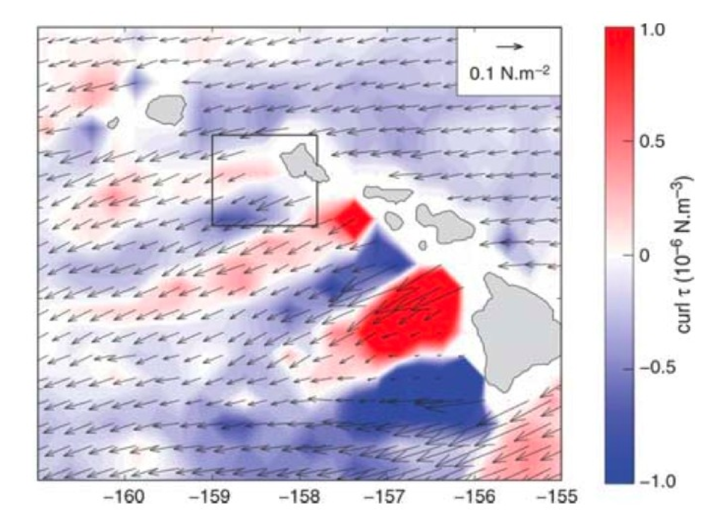

Fig. 7. Wind stress and wind stress curl from QuikSCAT at 25-km resolution, averaged over 23-30 Oct 2002 showing dipole of upward and downward Ekman pumping in the lee of Hawaii. Ekman transport convergence is shown in blue, while divergence is shown in red. After Chavanne et al., 20107.

3b) Surface Drifters

- Existing drifter data is sparse (Fig 8).
- Only 12 surface drifters passed through the region of shear development off of South Point since 1979.
- 4 revealed anticyclonic behavior in the lee of Hawaii.
- All 4 of the anticyclonic drifters passed through the region of shear development during the months of March or April.
- This indicates a seasonal pattern

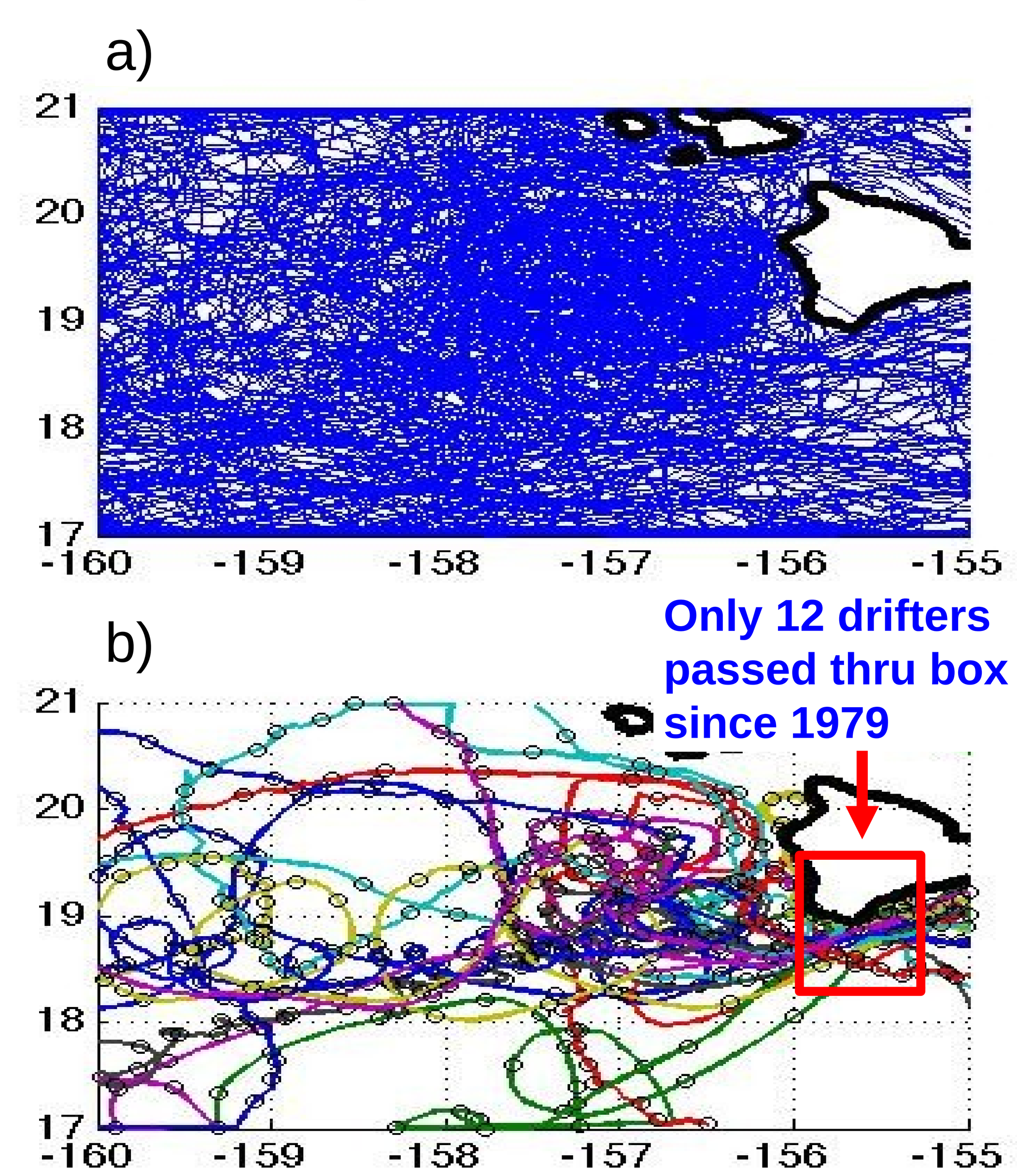

Fig 8. (a) Overlay of all drifters that passed in the vicinity of the island of Hawaii from 1979 to 2013. (b) Overlay of only those drifters that passed within 0.3 degrees of South Point, Hawaii.

4. Future Work

- Use seasonal occurrences of anticyclones to plan SLDMB deployments
- HFDR will be placed long term,
  - Verify that March/April is the peak of shear instability vortex formation
  - ID any other seasonal patterns
- In addition, the HFDR and SLMDB data will be assimilated into the Regional Ocean Modeling System (ROMS).

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