Vortex formation downstream of a cape: an analysis of anticyclone formation off Hawaii

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Background

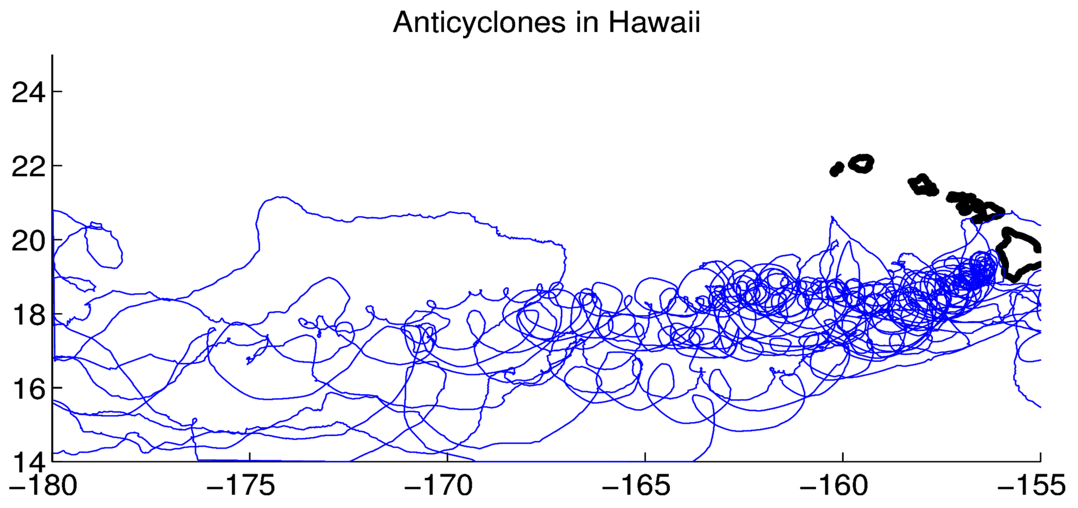

Fig 1 - Drifter tracks showing the path of anticyclonic vortices in the lee of Hawaii over the last 30 years. Over this time period, 27 distinct anticyclones were identified, some contained multiple drifter tracks.

Goal: Identify spatial and temporal patterns in the oceanic and atmospheric flow around the Hawaiian Islands that could help determine the specific cause of anticyclone formation.

Data: Global Drifter Program Surface Drifters from 1979-2014; Aviso Sea Surface Height, 0.25 degree resolution, 1992-2012; QuikScat Winds 1999-2009; ASCAT winds 2009 on.

Possible Causes of Anticyclones:

1. Shear Instability in the NEC:
As NEC passes South Point, Hawaii, it detaches into a shear layer. Shear instability creates vigorous anticyclonic vortices.

2. Wind Stress Curl:
Negative wind stress curl can also excite anticyclonic vortices through convergence of surface waters and Ekman pumping.

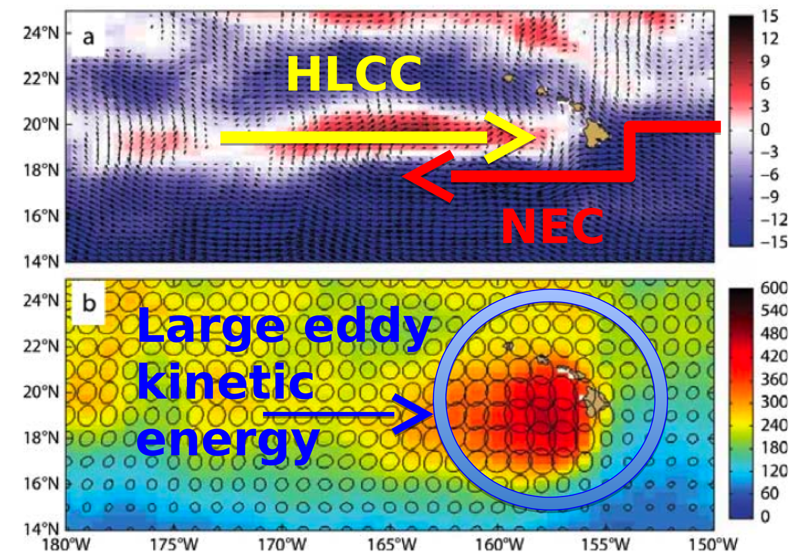

Fig. 2 - (a) Time-averaged near-surface currents (arrows) superimposed on average zonal component (colors; cm/s); (b) Eddy kinetic energy in cm²/s and variance ellipses. After Lumpkin and Flament (2013)

RESULTS - EOF Analysis of satellite winds

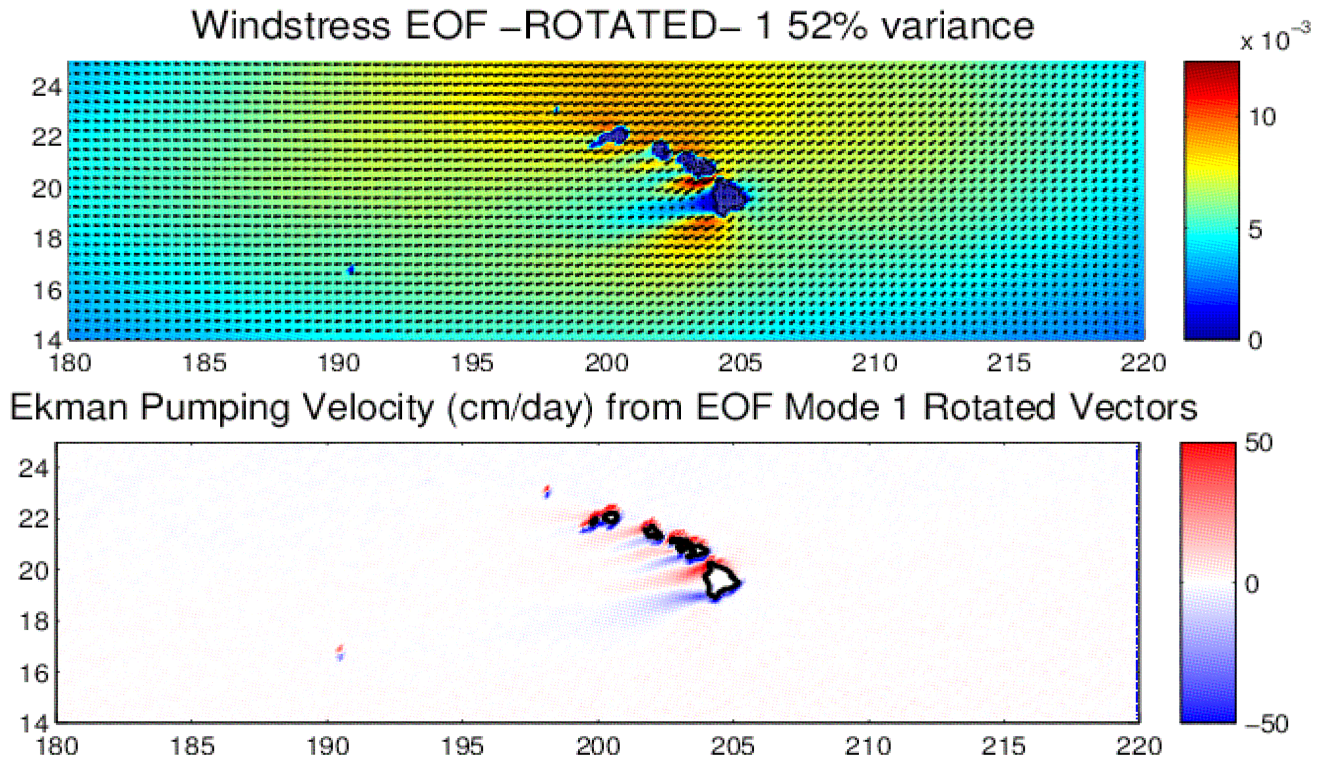

Fig 3 - Top: EOF 1, rotated, for windstress, showing wind variability in lee of Hawaiian Islands. Bottom: Ekman Pumping Velocity (cm/day) calculated from EOF mode 1 windstress (blue= down, red=up).

- First four modes dominated by annual cycle of wind stress patterns around Hawaiian islands (Fig. 4, right)
- The islands block the flow causing a wind stress curl dipole in the lee of the larger islands
- The EOF amplitudes show that this is most important in winter months (Jan-Mar), however this does not correlate with the occurrences of anticyclones seen in drifter trajectories, which are most common in fall, during which, this mode is weaker. (Fig. 4, left)

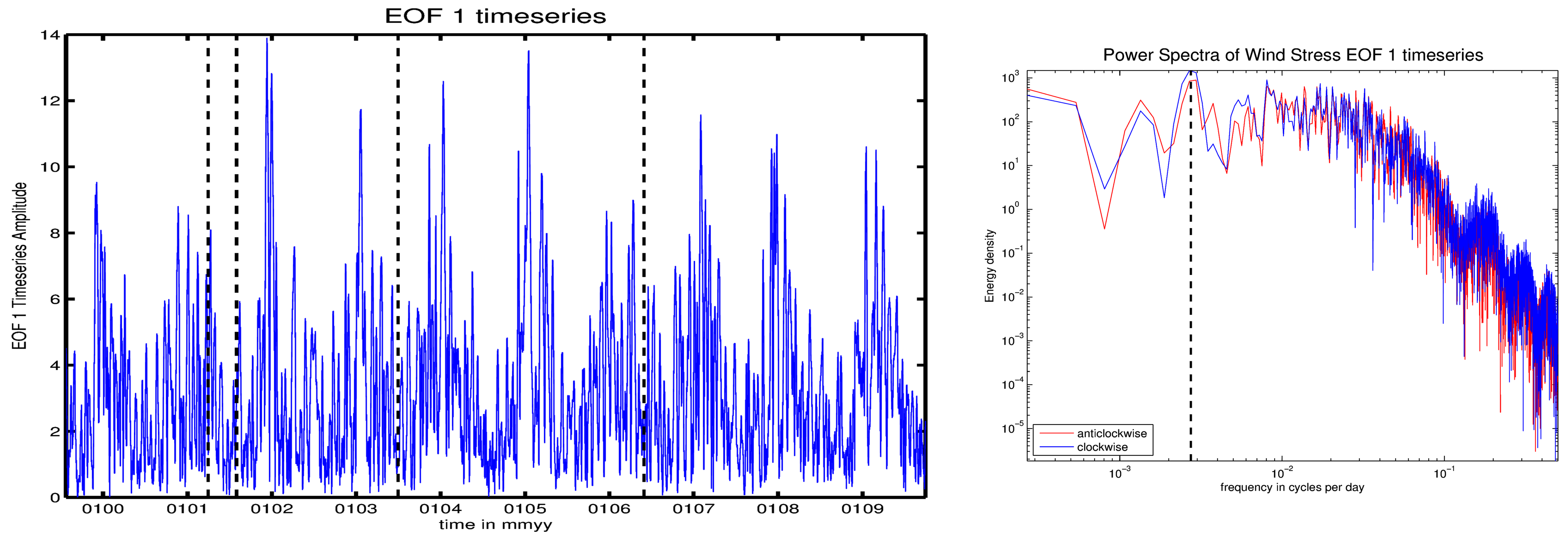

Fig 4 - Left: EOF 1 time series showing changes in the importance of this mode over time. The dashed black lines are origin dates of anticyclones seen in drifting buoy tracks. Right: Power Spectra of wind EOF 1 time series. The dashed black line is the annual cycle (period of 365 days). This mode as well as higher modes did not display the same distinct 100 day peak seen in the ssh EOF.

RESULTS - EOF Analysis of sea surface height

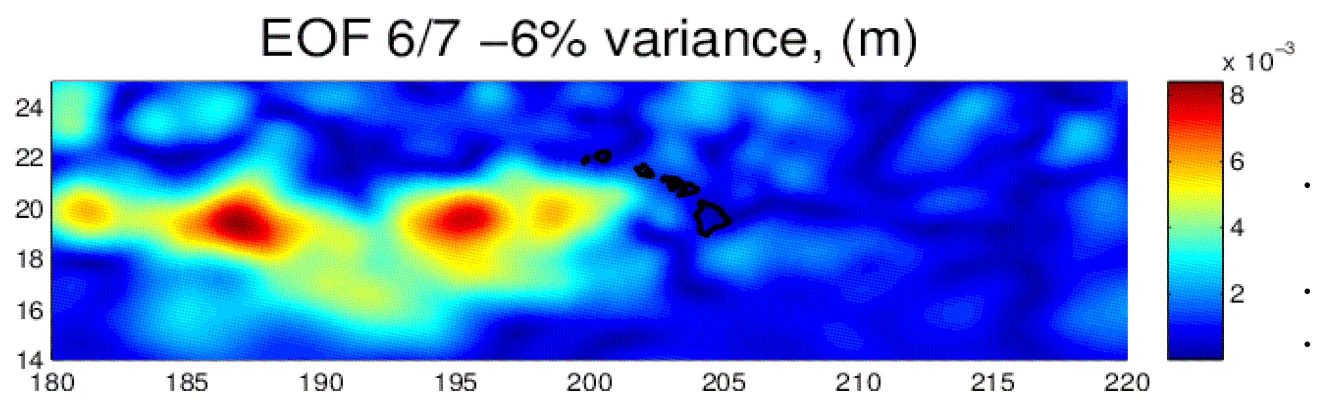

Fig 5 - Top: Weighted average (from percent variance) of EOFs 6 and 7 for ssh, showing pattern of ssh variability in lee of Hawaiian Islands.

- First three modes dominated by annual cycle as ssh changes due seasonal shifts in wind adjusting gyre location.
- The higher modes (6,7) exhibit dominant periods of 100 days (Fig. 6, right).
- Anticyclones seem to occur during stronger phases of these EOF modes (Fig. 6, left).
- The spatial pattern of these modes is confined to the island lee (Fig. 5).

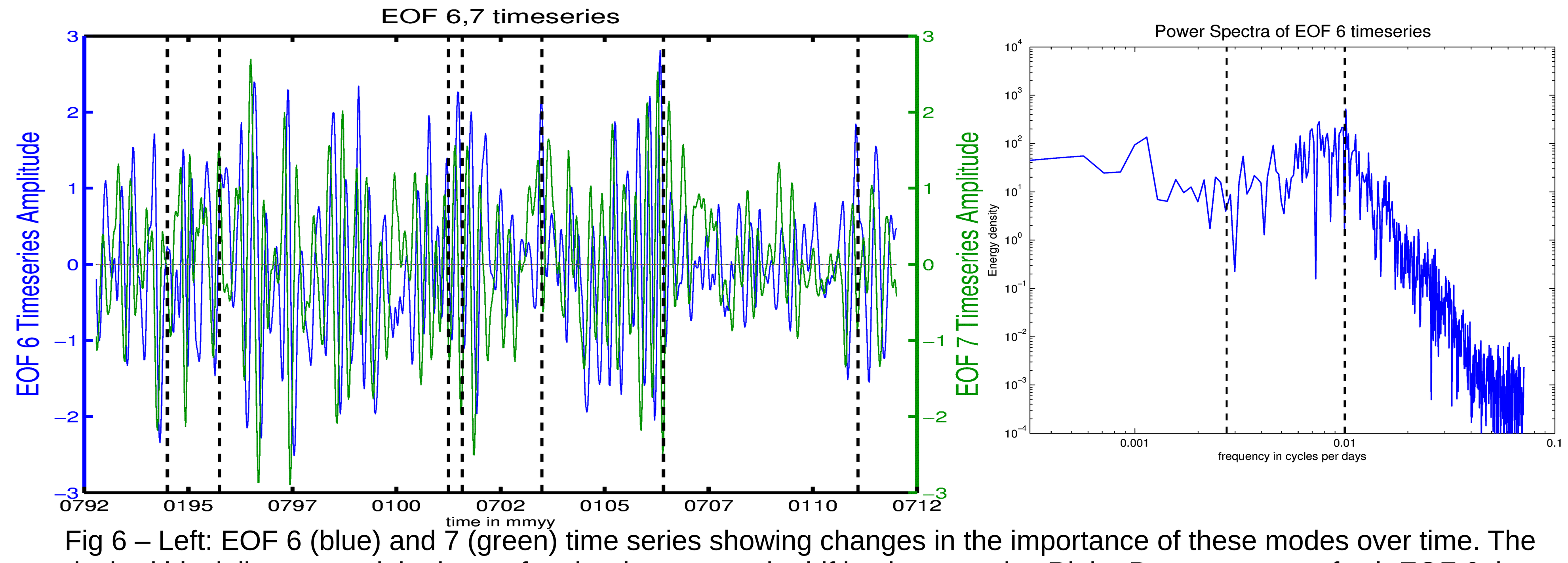

Fig 6 – Left: EOF 6 (blue) and 7 (green) time series showing changes in the importance of these modes over time. The dashed black lines are origin dates of anticyclones seen in drifting buoy tracks. Right: Power spectra of ssh EOF 6 time series. The two dashed black lines are periods of 365 (left) and 100 (right) days. There is no apparent annual cycle (see in the first 3 EOF modes), but instead, a peak at 100 days.

Historical Anticyclone Characteristics

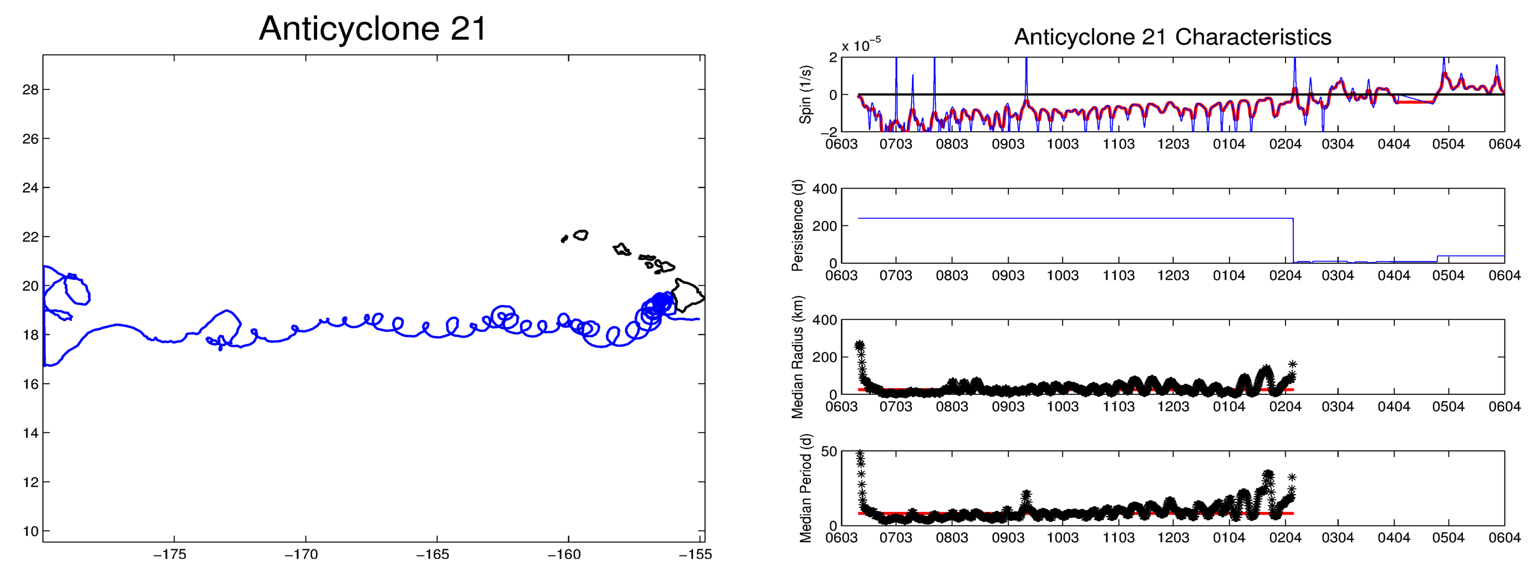

Fig 7- Left: drifter id# 22936, from 2003, showing Anticyclone #21. Right: estimated anticyclone characteristics calculated from the spin of drifter 22936. The median period was 8 days, and the median radius was 25km over the duration of the drifter's presence in the anticyclone. The anticyclone was visible in the drifter track for 1456km.

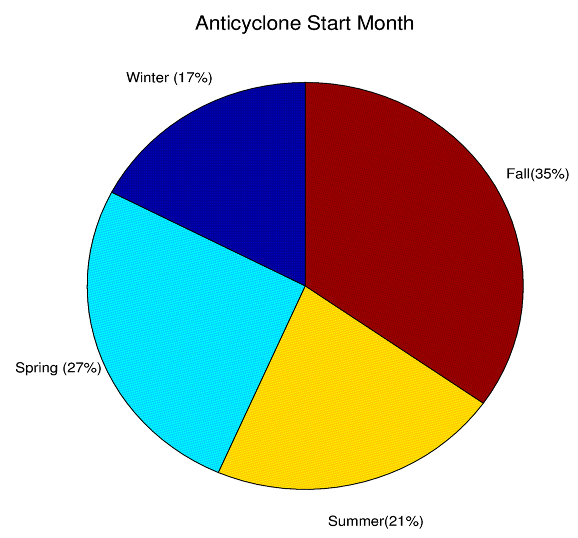

Fig 8 – Pie chart showing the occurrence of anticyclones in the drifter data by season. Spring and fall show more anticyclones, particularly October/November.

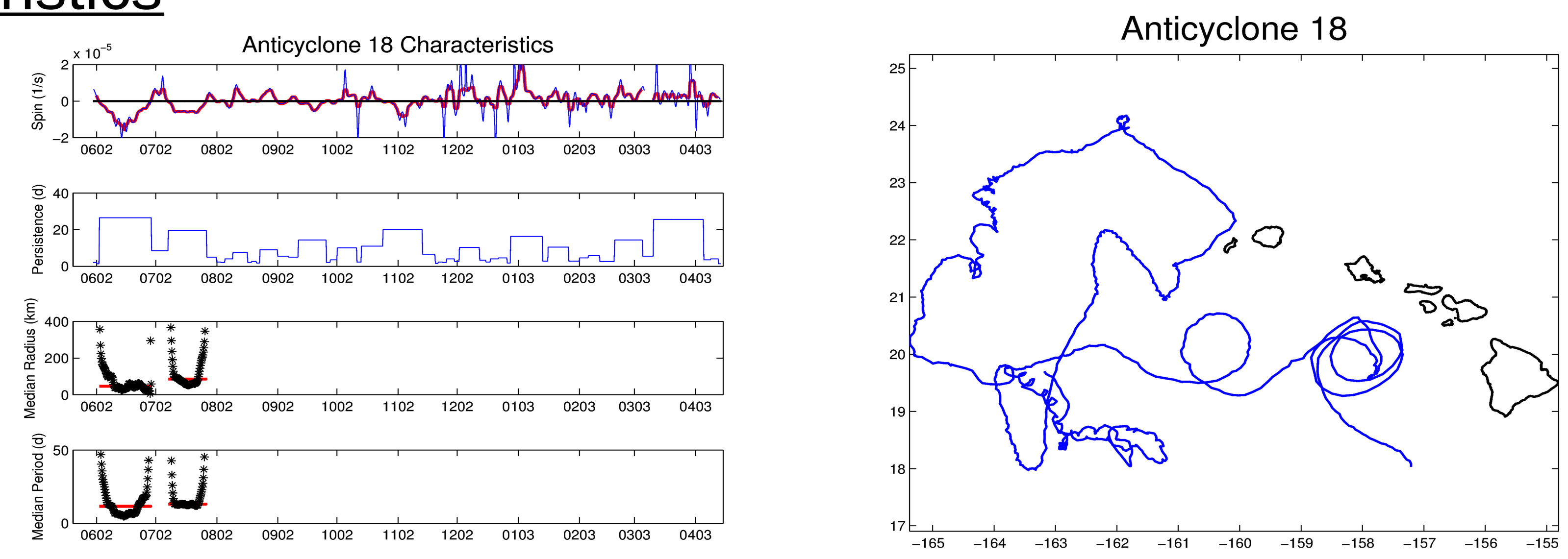

Fig 9 - Left: estimated anticyclone characteristics calculated from the spin on drifter 34332. The median period was 12 days, and the median radius was 46km over the duration of the drifter's presence in the anticyclone. The anticyclone was visible in the drifter track for 156km. Right: drifter id# 34332, from 2002, showing Anticyclone #18.

Conclusions & Grouping of Anticyclones:

- Based on their characteristics, anticyclones classified into two groups.
  - Group 1: long duration, steadier period/radius, similar tracks (example Anticyclone 21), occur ~100days
  - Group 2: shorter duration, variable period/radius, close to lee of Hawaii Island (example Anticyclone 18).
- Group 1 theorized to be predominantly NEC shear driven
- Group 2 theorized to be predominantly wind driven

Questions to be answered:

- What drives the 100 day cycle?
- How much preconditioning is done by wind stress?
- Do models show these Group 1 anticyclones occurring at ~100 day intervals? If not, what do the models show?
- What are bio/geo-chemical implications of these long duration anticyclones?

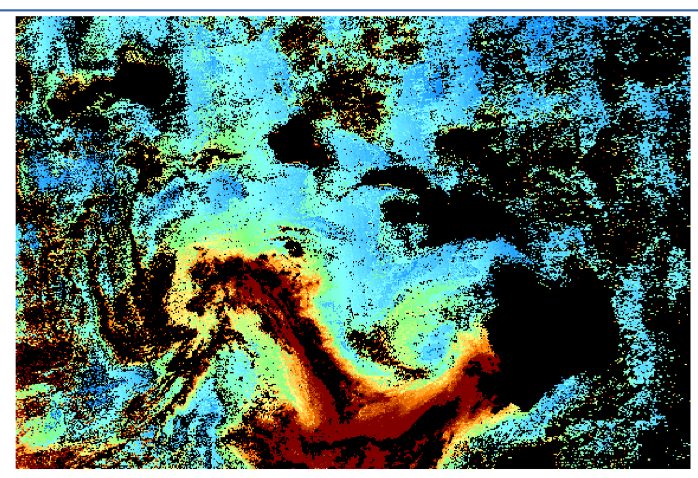

Fig 10 –Aerosols/vog spread by NE winds

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