Results from Finite Time Lyapunov Exponent calculations using High Frequency Radar observed surface currents around Palmer Deep Canyon from January to March of 2020

Website: https://www.bco-dmo.org/dataset/917914
Data Type: Other Field Results
Version: 1
Version Date: 2024-01-08

Project
» Collaborative Research: Physical Mechanisms Driving Food Web Focusing in Antarctic Biological Hotspots (Project SWARM)

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Abstract
Several LCS techniques have been applied to ocean systems in the past decade for their ability to quantify areas in ocean currents (or any velocity field) that exert an impact on nearby drifting particles (Haller, 2015). Such areas are known as coherent structures. Coherent structures can identify local extrema of repulsion, attraction, and shearing of flow (Haller, 2015). Attracting coherent structure will quantify the attraction of passive drifters in a flow field, or plankton in ocean currents (Shadden et al., 2005; Haller, 2015). These data contains results from Finite Time Lyapunov Exponent calculations using High Frequency Radar observed surface currents around Palmer Deep Canyon from January - March 2020. Finite Time Lyapunov Exponents use the horizontal separation distance between two particles relative to a fixed point over a defined time interval to quantify the strength of coherent structure (either repelling or attracting) at each point on a gridded velocity field. To calculate repelling FTLEs, a forward trajectory is used, and to calculate attracting FTLEs, a backward trajectory is used. In this study, attracting FTLEs were calculated. FTLE's ability to integrate over trajectories sets this technique apart from instantaneous separation rate (Okubo, 1970; Weiss, 1991) by introducing particle position "memory". Coherent structures are defined by the FTLE metric as ridges in the flow field where neighbouring particles are converged toward, and then diverged along the ridge. The strengths of these ridges are quantified by the integrated separation rate between two particles (Veatch et al., 2024 Figure 2D). This relative motion between two neighbouring particles is the key way in which the FTLE metric differs from the RPD metric. Like RPD, FTLE will vary over space and time when applied to a discrete set of velocity data. FTLE calculations result in a material surface that then can be projected at a set resolution back onto the study region. FTLE results were projected at the resolution of the HFR (1km) so as to not stretch the observations further than the input data should be able to resolve. FTLE calculations were performed using a MATLAB software toolbox (Haller) that was modified for use on HFR data (Veatch et al., 2024 Figure 2D). To negate artifacts in results caused by the edges of the HFR domain where it may seem that particles suddenly stop or are lost, the domain of FTLE results used was smaller than the domain of the inputted velocity field. The domain was shrunk by three kilometers (Veatch et al., 2024 Figure 3). This about how far the average particle travels over the integration time of 6 hours.

Table of Contents

Coverage

Location: Palmer Deep Canyon in the coastal ocean west of the Antarctic Peninsula (~ 64.3 W, 64.9 S)
Spatial Extent: **N**:-64.7 **E**:-63.8 **S**:-65 **W**:-64.6
Temporal Extent: 2020-01-09 - 2020-03-31

Methods & Sampling

Methods for these LCS results can be found in Veatch, et al., (2024), In revision.

Finite Time Lyapunov Exponents assign scalar values to points on a gridded velocity field that characterizes the horizontal separation distance between two drifters about a point over a defined

time interval. From particle trajectories in a velocity field, FTLE will define stretching as the integrated separation rate between two particles. To calculate repelling FTLEs, a forward trajectory is used, and to calculate attracting FTLEs, a backward trajectory is used. In this study, attracting FTLEs were calculated. FTLE differs from the instantaneous separation rate (Weiss 1991; Okubo 1970) by integrating over trajectories, providing a more realistic interpretation (one with particle position “memory”) of transport in the velocity field. Coherent structures are defined by the FTLE metric as ridges in the flow field where neighboring particles are converged toward, and then diverged along the ridge. This relative motion between two

neighboring particles is the key way in which the FTLE metric differs from the RPD metric. FTLE will vary over space and time when applied to a discrete set of velocity data. FTLE calculations result in a material surface that then can be projected at a set resolution back onto the study region. FTLE results were projected at the resolution of the HFR so as to not stretch the observations further than the input data should be able to resolve. FTLE calculations were performed using a MATLAB software toolbox (Haller) that was modified for use on HFR data and available at https://github.com/JackieVeatch/SWARM_LCS.
* Curatorial note: See supplemental file SWARM_LCS-related_to_bcodmo_917926_917914_v1.zip which contains a release corresponding to commit (10931d9).

Data Processing Description

All data were processed using MATLAB 2019b. Scripts used for data analysis can be found at https://github.com/JackieVeatch/SWARM_LCS.
* Curatorial note: See supplemental file SWARM_LCS-related_to_bcodmo_917926_917914_v1.zip which contains a release corresponding to commit (10931d9).

BCO-DMO Processing Description

* netcdf file imported into BCO-DMO. No changes made.
* A copy of code repository supplied by submitter https://github.com/JackieVeatch/SWARM_LCS (commit 10931d9) forked to BCO-DMO for curatorial purposes and a release was made on 2024-01-08 https://github.com/BCODMO/SWARM_LCS/releases/tag/related_to_bcodmo_91792.... No changes to the code were made. Zip file of this release attache as a supplemental file.

[table of contents | back to top]

Data Files

File
FTLE results (netCDF format)

filename: ftle.nc

(NetCDF, 85.50 MB)
MD5:4db9e625c1cfcf702d56aea25f878c86

Finite Time Lyapunov Exponent Results (FTLE) results in netCDF format.

Netcdf header:

```
ncdump -h ftle.nc
netcdf ftle\ \(1\) {
dimensions:
	Time = 1273 ;
	Lat = 44 ;
	Lon = 100 ;
	Char = 20 ;
variables:
	double FTLE_values(Time, Lon, Lat) ;
		FTLE_values:long_name = "Finite Time Lyapunov Exponent" ;
		FTLE_values:standard_name = "finite_time_lyapunov_exponent" ;
		FTLE_values:units = "1/hr" ;
		FTLE_values:FillValue = "0" ;
		FTLE_values:resolution = 100., 44. ;
		FTLE_values:domain = -65.5019, -65.4322, -63.4104, -64.5329 ;
	double time(Time) ;
		time:long_name = "Time" ;
		time:standard_name = "time" ;
		time:units = "days since 0000 01-01-T00:00:00; datenum serial date number" ;
		time:FillValue = "NaN" ;
		time:calendar = "georgian" ;
		time:TimeZone = "GMT" ;
	char time_readable(Char, Time) ;
		time_readable:long_name = "Time" ;
		time_readable:standard_name = "time" ;
		time_readable:units = "date_string" ;
		time_readable:FillValue = "NaN" ;
		time_readable:calendar = "georgian" ;
		time_readable:TimeZone = "GMT" ;
	double FTLE_binary(Time, Lon, Lat) ;
		FTLE_binary:long_name = "Finite Time Lyapunov Exponent Binary (greater than 0.2)" ;
		FTLE_binary:standard_name = "finite_time_lyapunov_exponent" ;
		FTLE_binary:units = "none" ;
		FTLE_binary:FillValue = "0" ;
	double lat(Lat) ;
		lat:long_name = "Latitude" ;
		lat:standard_name = "latitude" ;
		lat:units = "degrees_north" ;
		lat:FillValue = "NaN" ;
	double lon(Lon) ;
		lon:long_name = "Longitude" ;
		lon:standard_name = "longitude" ;
		lon:units = "degrees_east" ;
		lon:FillValue = "NaN" ;
}
```

[table of contents | back to top]

Supplemental Files

File
Gridded ftle results (data in alternate format, Matlab) filename: ftle_LR_binary.mat (MATLAB Data (.mat), 38.94 MB) MD5:27d45fd8a3fe20c16db208c104b5cb70 Data in alternate format (matlab .mat). These files contain the same dataset as the primary file for this dataset ftle.nc (netCDF). Note that the .nc file contains datetime in string format while the .mat files contain only matlab datenum type. Finite Time Lyapunov Exponents (ftle_LR.mat) matlab file contains FTLE results gridded by longitude and latitude hourly. ftle_LR = struct with fields: ftle: [44x100x1273 double] time: [737804 7.3780e+05 7.3780e+05 7.3780e+05 7.3780e+05 7.3780e+05 7.3780e+05 7.3780e+05 7.3780e+05 7.3780e+05 7.3780e+05 7.3780e+05 7.3780e+05 7.3780e+05 ...] (1x1273 double) resolution: [100 44] domain: [2x2 double] dnum: [737804 7.3780e+05 7.3780e+05 7.3780e+05 7.3780e+05 7.3780e+05 7.3780e+05 7.3780e+05 7.3780e+05 7.3780e+05 7.3780e+05 7.3780e+05 7.3780e+05 ...] (1x1273 double) binary: [44x100x1273 double] x: [-65.5019 -65.4808 -65.4597 -65.4385 -65.4174 -65.3963 -65.3752 -65.3540 -65.3329 -65.3118 -65.2906 -65.2695 -65.2484 -65.2273 -65.2061 -65.1850 ...] (1x100 double) y: [-65.4322 -65.4113 -65.3904 -65.3695 -65.3486 -65.3276 -65.3067 -65.2858 -65.2649 -65.2440 -65.2231 -65.2022 -65.1812 -65.1603 -65.1394 -65.1185 ...] (1x44 double) VariableName Description Units Missing data identifier ftle gridded FTLE results 1/hour lon x lat x time time timestamp of FTLE results serial date number. a serial date number representsthe whole and fractional number of days from January 0,0000 in the proleptic ISO calendar resolution dimensions of grid n/a used in FTLE projection domain extent of results decimal degree used in FTLE calculation binary gridded FTLE results with n/a 1 indicating strong FTLE and 0 indicating no or weak FTLE x coordinates of result longitude (decimal degree) y coordinates of result latitude (decimal degree)
SWARM_LCS (github code release) filename: SWARM_LCS-related_to_bcodmo_917926_917914_v1.zip (ZIP Archive (ZIP), 33.15 KB) MD5:0a80fa71bfa25eee2b5f1a607d194f99 Code release made from https://github.com/JackieVeatch/SWARM_LCS forked to BCO-DMO https://github.com/BCODMO/SWARM_LCS/releases/tag/related_to_bcodmo_917926_917914_v1 for curatorial purposes. The repository was forked from https://github.com/JackieVeatch/SWARM_LCS on 2024-01-08. No changes to the code were made. Release corresponds to commit https://github.com/JackieVeatch/SWARM_LCS/commit/10931d9a1508316fa65e2f82fd6052882d4e0aea Repository README: code for the calculation of Lagrangian coherent structures from HFR observed surface currents in Palmer Deep Canyon RPD calculations can be computed following instructions in "READ_ME.docx" in this repo. FTLE calculations can be computed using "backward_ftle_loop_short.m" within George Haller's LCS toolbox. Place "backward_ftle_loop_short.m" in the LCS-Tool-master/demo/ocean_dataset directory within toolbox. Access toolbox here: Haller, K. O. F. H. G. LCS Tool: A Computational Platform for Lagrangian Coherent Structures. https://github.com/jeixav/LCS-Tool-Article/. Haller, K. O. F. H. G. LCS Tool: A Computational Platform for Lagrangian Coherent Structures (https://doi.org/10.48550/arXiv.1406.3527)

[table of contents | back to top]

Related Publications

Okubo, A. (1970). Horizontal dispersion of floatable particles in the vicinity of velocity singularities such as convergences. Deep Sea Research and Oceanographic Abstracts, 17(3), 445–454. https://doi.org/10.1016/0011-7471(70)90059-8
Methods

Oliver, M. J., Kohut, J. T., Bernard, K., Fraser, W., Winsor, P., Statscewich, H., Fredj, E., Cimino, M., Patterson-Fraser, D., & Carvalho, F. (2019). Central place foragers select ocean surface convergent features despite differing foraging strategies. Scientific Reports, 9(1). https://doi.org/10.1038/s41598-018-35901-7
Methods

Onu, K., Huhn, F., & Haller, G. (2014). LCS Tool : A Computational Platform for Lagrangian Coherent Structures. https://github.com/jeixav/LCS-Tool-Article/ *ArXiv*. https://doi.org/10.48550/ARXIV.1406.3527
https://doi.org/10.48550/arXiv.1406.3527

Software

Veatch, J., Kohut, J., Oliver, M., Statscewich, H., Fredj, E. (2024) Quantifying the role of sub-mesoscale lagrangian transport features in the concentration of plankton in a coastal system ICES JMS, In Revision.
Results

Weiss, J. (1991). The dynamics of enstrophy transfer in two-dimensional hydrodynamics. Physica D: Nonlinear Phenomena, 48(2–3), 273–294. https://doi.org/10.1016/0167-2789(91)90088-q https://doi.org/10.1016/0167-2789(91)90088-Q
Methods

[table of contents | back to top]

Related Datasets

IsRelatedTo

Veatch, J., Klinck, J. M., Oliver, M., Statscewich, H., Kohut, J. (2024) **High Frequency Radar (HFR) observed surface currents at Palmer Deep Canyon in the coastal ocean west of the Antarctic Peninsula in 2020.** Biological and Chemical Oceanography Data Management Office (BCO-DMO). (Version 1) Version Date 2024-01-08 doi:10.26008/1912/bco-dmo.917884.1 [view at BCO-DMO]
Relationship Description: The "High Frequency Radar, Palmer Deep" dataset provided the observed surface currents (velocity field) from which these Finite Time Lyapunov Exponent Results were calculated from.

[table of contents | back to top]

Parameters

Parameters for this dataset have not yet been identified

[table of contents | back to top]

Instruments

Dataset-specific Instrument Name	High Frequency Radar
Generic Instrument Name	High Frequency Radar
Generic Instrument Description	High (5-50 MHz) frequency radar transmits electromagnetic waves and records the backscattered signal. Oceanographic usage includes sea surface radar in which the backscattered signals are analyzed to obtain surface current and wave parameters.

[table of contents | back to top]

Project Information

Collaborative Research: Physical Mechanisms Driving Food Web Focusing in Antarctic Biological Hotspots (Project SWARM)

Coverage: West Antarctic Peninsula

NSF Award Abstract:

NSF Award Abstract:
Undersea canyons play disproportionately important roles as oceanic biological hotspots and are critical for our understanding of many coastal ecosystems. Canyon-associated biological hotspots have persisted for thousands of years Along the Western Antarctic Peninsula, despite significant climate variability. Observations of currents over Palmer Deep canyon, a representative hotspot along the Western Antarctic Peninsula, indicate that surface phytoplankton blooms enter and exit the local hotspot on scales of ~1-2 days. This time of residence is in conflict with the prevailing idea that canyon associated hotspots are primarily maintained by phytoplankton that are locally grown in association with these features by the upwelling of deep waters rich with nutrients that fuel the phytoplankton growth. Instead, the implication is that horizontal ocean circulation is likely more important to maintaining these biological hotspots than local upwelling through its physical concentrating effects. This project seeks to better resolve the factors that create and maintain focused areas of biological activity at canyons along the Western Antarctic Peninsula and create local foraging areas for marine mammals and birds. The project focus is in the analysis of the ocean transport and concentration mechanisms that sustain these biological hotspots, connecting oceanography to phytoplankton and krill, up through the food web to one of the resident predators, penguins. In addition, the research will engage with teachers from school districts serving underrepresented and underserved students by integrating the instructors and their students completely with the science team. Students will conduct their own research with the same data over the same time as researchers on the project. Revealing the fundamental mechanisms that sustain these known hotspots will significantly advance our understanding of the observed connection between submarine canyons and persistent penguin population hotspots over ecological time, and provide a new model for how Antarctic hotspots function.

To understand the physical mechanisms that support persistent hotspots along the Western Antarctic Peninsula (WAP), this project will integrate a modeling and field program that will target the processes responsible for transporting and concentrating phytoplankton and krill biomass to known penguin foraging locations. Within the Palmer Deep canyon, a representative hotspot, the team will deploy a High Frequency Radar (HFR) coastal surface current mapping network, uniquely equipped to identify the eddies and frontal regions that concentrate phytoplankton and krill. The field program, centered on surface features identified by the HFR, will include (i) a coordinated fleet of gliders to survey hydrography, chlorophyll fluorescence, optical backscatter, and active acoustics at the scale of the targeted convergent features; (ii) precise penguin tracking with GPS-linked satellite telemetry and time-depth recorders (TDRs); (iii) and weekly small boat surveys that adaptively target and track convergent features to measure phytoplankton, krill, and hydrography. A high resolution physical model will generalize our field measurements to other known hotspots along the WAP through simulation and determine which physical mechanisms lead to the maintenance of these hotspots. The project will also engage educators, students, and members of the general public in Antarctic research and data analysis with an education program that will advance teaching and learning as well as broadening participation of under-represented groups. This engagement includes professional development workshops, live connections to the public and classrooms, student research symposia, and program evaluation. Together the integrated research and engagement will advance our understanding of the role regional transport pathways and local depth dependent concentrating physical mechanisms play in sustaining these biological hotspots.

This award reflects NSF's statutory mission and has been deemed worthy of support through evaluation using the Foundation's intellectual merit and broader impacts review criteria.

[table of contents | back to top]

Funding

Funding Source	Award
NSF Office of Polar Programs (formerly NSF PLR) (NSF OPP)	OPP-1745009
NSF Office of Polar Programs (formerly NSF PLR) (NSF OPP)	OPP-1744884
NSF Office of Polar Programs (formerly NSF PLR) (NSF OPP)	OPP-1745011

[table of contents | back to top]