DOI

https://doi.org/10.5670/oceanog.2017.210

Observing the Ocean with Gliders

TECHNIQUES FOR DATA VISUALIZATION AND ANALYSIS

By Christine E. Hanson, L. Mun Woo, Paul G. Thomson, and Charitha B. Pattiaratchi

PURPOSE OF ACTIVITY

Ocean glider missions can provide a catalyst for student participation and education in oceanography, as recently demonstrated by the trans-Atlantic Slocum glider expeditions operated from Rutgers University (Glenn et al., 2011). For the present activity, we developed a series of hands-on, computer-based exercises that allow students (and other interested users) to become familiar with the types of data collected by ocean gliders, and to learn how to analyze them using visualization software developed specifically for glider data (*GLIDERSCOPE*; Figure 1). In addition to demonstrating general techniques for oceanographic data analysis and interpretation, this activity explores key principles of physical and biological oceanography that include water column structure, upwelling and mesoscale eddy dynamics, and the distribution of particulate matter within the water column.

AUDIENCE

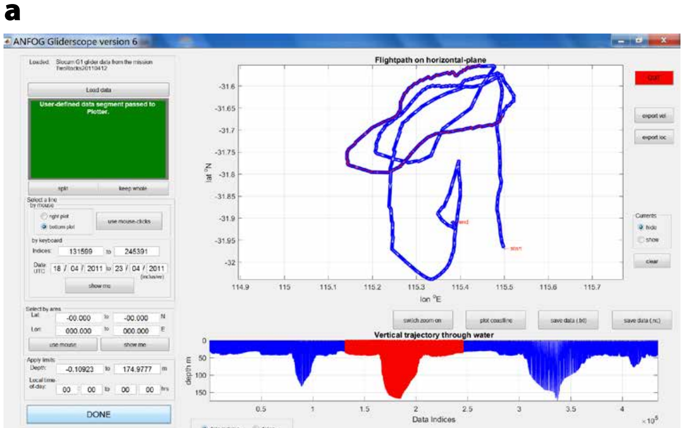
This activity has been designed for undergraduate and graduate oceanography students but will also be useful for anyone wishing to become familiar with ocean glider data and visualization software.

BACKGROUND

The use of long-range, autonomous ocean gliders to conduct oceanographic surveys is contributing substantially to our understanding of ocean dynamics. These underwater vehicles use battery-driven buoyancy engines to alter vehicle volume, reducing their volume at the surface to increase their density and sink, and increasing their volume at depth to decrease their density and float (Rudnick et al., 2004). Wings convert this vertical momentum into forward motion, with the gliders propelling themselves in saw-toothed patterns through the water column (Figure 2). Vehicle pitch—the vertical angle at which they travel through the water—is adjusted by moving an internal mass (typically the battery pack) toward the front or back of the vehicle, thereby changing its center of mass. Steering is accomplished by either rotating this same internal mass from side to side, which induces the vehicle to roll, or by using a rudder (Rudnick et al., 2004).

A number of ocean glider "types" are commercially available, for example, the Seaglider developed at the University of Washington (Eriksen et al., 2001), the Spray Glider developed by Scripps Institution of Oceanography (Sherman et al., 2001), and the Slocum Electric Glider and Slocum Thermal Glider. Maximum operating depth for gliders typically ranges between 200 m and 1,000 m, depending on the model used. All gliders carry a suite of scientific sensors that allow sampling of various water properties as the vehicles travel through the ocean. These sensors are miniaturized versions of standard oceanographic instruments that have been optimized for low power consumption and minimal weight (Rudnick et al., 2004). Typically measured parameters include temperature, conductivity (used to calculate salinity), dissolved oxygen, irradiance (light), optical backscatter of particulates at various wavelengths, fluorescence

a



b

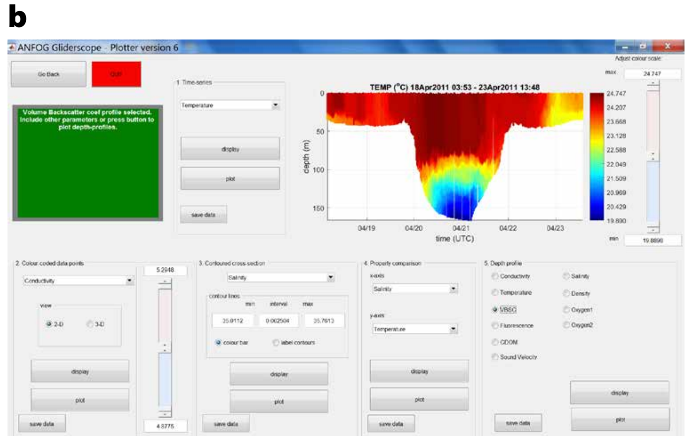


FIGURE 1. The *GLIDERSCOPE* program includes (a) the main dashboard with controls for loading selecting data, and (b) a plotter dashboard for producing various types of data plots.

of phytoplankton pigments (e.g., chlorophyll *a*, phycocyanin), and colored dissolved organic matter (CDOM). The incorporation of additional instruments into gliders is an active area of research, with recent progress including sensors for measuring acoustic backscatter, small-scale turbulence, and dissolved nutrients, as well as acoustic Doppler current profilers (ADCPs).

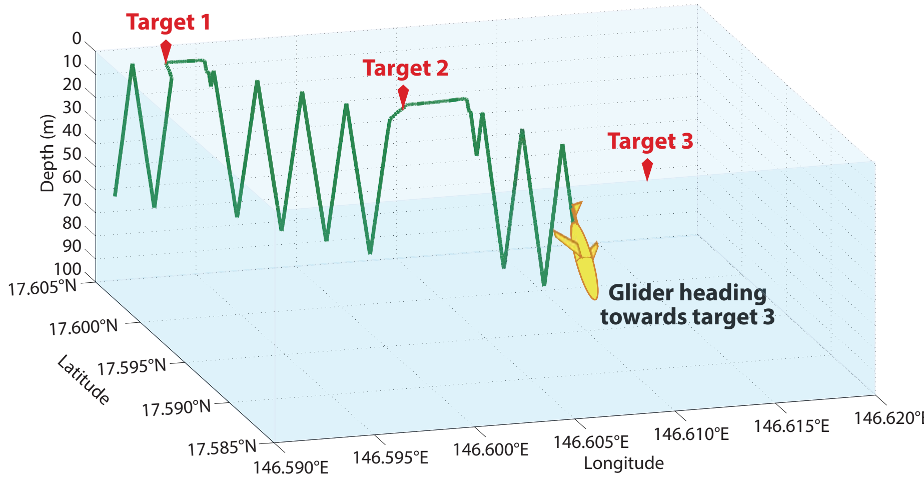


FIGURE 2. Example of the track of a Slocum glider performing three segments of sawtooth sampling lines between surfacings at target way points. This contrasts somewhat with a Seaglider, which typically surfaces after every descent-ascent cycle.

Ocean gliders are typically deployed for periods of weeks to months and can operate under a wide range of weather conditions, providing higher resolution measurements at a much lower cost than traditional ship-based oceanographic surveys. Depending on the specific research program being conducted, gliders may be operated singly or in fleets. Glider-based research projects and observatories now exist in various locations around the world (Testor, 2010), including the North Atlantic, North and South Pacific, Indian, and Southern Oceans (see the Everyone's Gliding Observatories [EGO] website for an updated catalogue of glider programs and deployment locations, http://www.ego-network.org). The Australian National Facility for Ocean Gliders (ANFOG) operates a fleet composed of both Slocum Electric Gliders and Seagliders under the auspices of Australia's Integrated Marine Observing System (IMOS; Hill et al., 2010). Since its inception in 2007, ANFOG has collected a substantial volume of oceanographic data that is available for both students and researchers to mine.

MATERIALS

ANFOG *GLIDERSCOPE* (Figure 1) is a software package designed specifically to visualize netCDF-based ocean glider data. To complete this exercise, please download the ANFOG *GLIDERSCOPE* software (to suit your computer operating system), User's Manual, and ANFOG data sets indicated below from http://imos.org.au/gliderscope.html. As the software files are fairly large, we recommend downloading and installing the following list of them prior to tutorial sessions.

- ANFOG *GLIDERSCOPE* v6.0 is currently available in three versions:
  - > Windows stand-alone installation (562 MB)
  - > Mac stand-alone installation (513 MB)
  - > MATLAB APP version for computers with MATLAB software installed (for both Windows and Mac; 2.1 MB)
- *GLIDERSCOPE* v6.0 User's Manual (2.1 MB)
- SAMPLE DATA file (32 MB)
- *GLIDERSCOPE* tutorial files (6 MB zip folder) that include:
  - > Data Set 1: Perth Two Rocks Transect (Slocum glider deployment, March 2011)
  - > Data Set 2: Capes Current Transect (Slocum glider deployment, December 2009)
  - > Data Set 3: Leeuwin Current Eddy (Seaglider deployment, June 2011)

In accordance with IMOS data file convention, ANFOG data formats are based on NetCDF (Network Common Data Form), which allows the scientific data to be stored with appropriate quality control flags indicating the usability/validity of each data entry and an inherent metadata (data about data) construct. Other glider deployment data sets are freely available from the IMOS Ocean Portal (http://imos.aodn.org.au).

A series of online tutorials are also available to help students and researchers familiarize themselves with the software and how it works. There are three tutorials, each of approximately two to four minutes duration. These are available for viewing on The Oceanography Society's YouTube channel: https://www.youtube.com/playlist?list=PLW7NnkFyzEHMQhMy7SSvenKjg7QvaCFYz.

ACTIVITY: PART 1

The first part of this activity familiarizes the user with the operation of *GLIDERSCOPE* based on a sample data file. Approximately 45 minutes should be allocated for this session. Prior to the tutorial, instructors should follow the *GLIDERSCOPE* User's Manual instructions for installing the software, and ensure that Google Earth is also available for use.

First, view the three online tutorials to provide a general overview of the software. Then, following the detailed instructions in the Using *GLIDERSCOPE* section (3.0) of the *GLIDERSCOPE* User's Manual or working in tandem with the video tutorials, go through the following steps:

1. Load data by selecting and loading the file S*ampleData.nc*.
2. Plot the glider's path in relation to the Australian coastline. Use the "clear" button to return the plot to the original

view whenever required.

3. Examine the glider's path both horizontally (aerial view, top plot) and vertically (side view, bottom plot). Practice using the zoom button to magnify the flight paths.
4. Show and hide arrows that indicate the depth-averaged currents along the glider path.
5. In the vertical plot, change the values of the x-axis from data indices to date.
6. Extract data to be visualized. Select a subsection of data by clicking "split" and (a) by using mouse clicks on the horizontal and vertical flight paths, (b) by keyboard using data indices or dates or area coordinates, or (c) by selecting an area by mouse. Your selections can be further limited by depth or time of day. Alternatively, you can use all the data by selecting "keep whole." If necessary, use the "clear" button to return the plots to the original view.
7. Once you have finalized your selection of data, press the "done" button to pass the data to *GLIDERSCOPE's* plotter window.
8. Visualize the glider data by following the instructions in the Data Visualization section (3.3) and create the following plots from the available variables:
   > Time series
   > Color-coded data points
   > Contoured cross section
   > Property comparison
   > Depth profile
9. Plots can either be displayed (press "display") within *GLIDERSCOPE's* plotter window or you can export each plot in a variety of formats (e.g., .jpg, .tif, .pdf) by pressing "plot" and using the "save" button.
10. If at any point you would like to select another subsection of data or load a different data file, press the "go back" button.

ACTIVITY: PART 2

The second part of this activity involves visualization and analysis of a series of ocean glider data sets collected off the west coast of Australia that can be used to examine particular oceanographic regimes and analytical techniques. Approximately one hour in the computer laboratory should be allocated for this session (with additional time required to evaluate and write up a report on the results).

To place these data sets in context, we first provide a brief background on the general oceanographic dynamics found off Western Australia.

Background: Oceanography of Western Australia

Eastern boundary currents, found off the west coasts of continents, are typically equatorward-flowing currents known for their large-scale upwelling of cold, nutrient-rich waters and productive fisheries—examples are the California Current located off the western United States and the Benguela Current off the west coast of South Africa (Wooster and Reid, 1963). In contrast, waters off the west coast of Australia are dominated by the Leeuwin Current (LC), a poleward-flowing eastern boundary current that transports warm, low-salinity tropical water southward along the continental shelf break (Woo and Pattiaratchi, 2008). The influence of Ekman forces on the LC, which act toward the left in the Southern Hemisphere, also result in large-scale downwelling along the coast of Western Australia. As a result of these physical dynamics, surface waters off Western Australia are generally oligotrophic, low in both nutrients and associated pelagic production (Hanson et al., 2005b).

The LC is present year-round, but flows most strongly and deeply during the autumn and winter months (April to August) when the opposing equatorward winds are weakest. The LC is typified by a broad (400 km) and shallow (50 m) flow off the North West Shelf (Figure 3a) that narrows to 100 km and deepens to 300 m as it progresses southward, attaining speeds of up to 0.5 m s^{-1} along Western Australia's west coast (Smith et al., 1991). Below the LC, the Leeuwin Undercurrent flows northward toward the equator with core flow at approximately 400 m depth (Woo and Pattiaratchi, 2008). During much of the year, there is generally very little phytoplankton biomass in Leeuwin Current surface waters, although a deep chlorophyll

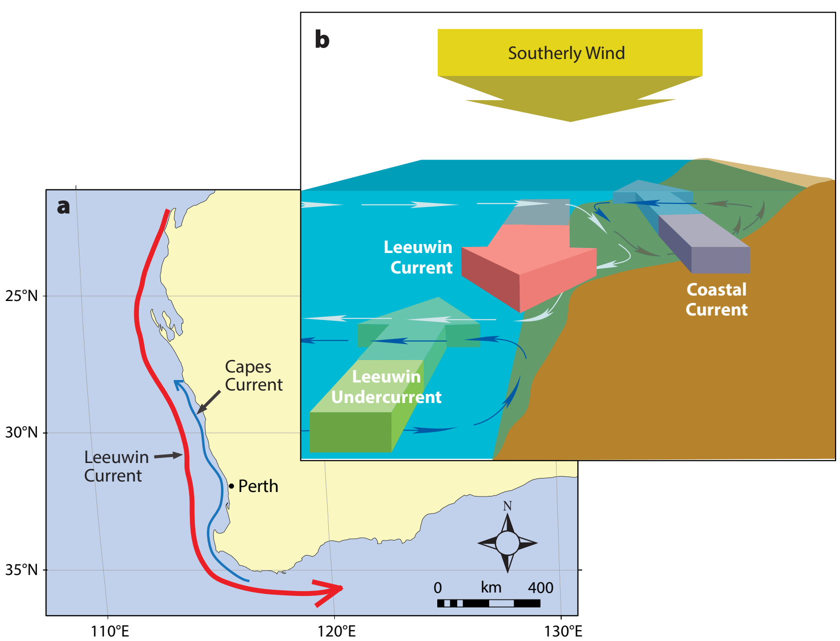


FIGURE 3. (a) The position and direction of flow of the Leeuwin Current and the Capes Current off the coastline of Western Australia, and (b) positions of the Leeuwin Undercurrent and coastal currents such as the Capes Current (modified from Woo and Pattiaratchi, 2008). Ekman forces result in downwelling of Leeuwin Current waters while seasonal wind patterns drive the coastal currents.

maximum is often found near the pycnocline at the base of the LC's mixed layer (Hanson et al., 2007), where phytoplankton can take advantage of the clear LC waters (and resulting strong light penetration) to access nutrients sequestered at depth. The scenario during the autumn and winter months is somewhat different, with a large-scale increase in surface phytoplankton concentrations likely associated with winter mixing processes (Lourey et al., 2006).

During the summer months (December to March), the northward-flowing Capes Current (CC) is present on the inner-shelf (Pearce and Pattiaratchi, 1999). This coastal countercurrent is largely generated by strong southerly winds and localized Ekman-driven upwelling, and is associated with an offshore movement of the LC (Figure 3b; Gersbach et al., 1999). The upwelling sources water from within the Leeuwin Current itself, resulting in a relatively modest nutrient enrichment to inshore surface waters that nevertheless can support episodic summer phytoplankton blooms on the continental shelf (Hanson et al., 2005a). Dense shelf water formation, and subsequent offshore transport as a near bed gravity current, is also a regular occurrence off southwest Western Australia from late summer through to winter (with dense water formed through either increased salinity via evaporation or decreased temperature via surface cooling; Pattiaratchi et al., 2011).

Data Set 1: Perth Two Rocks Transect, Summer 2011

ANFOG regularly conducts ocean glider transects at Two Rocks off Perth, Western Australia, to monitor oceanographic dynamics within the Leeuwin Current and inshore coastal currents (Figure 3). This data set demonstrates typical summer conditions within the region.

INSTRUCTIONS

1. View the file *Dataset1_TwoRocks.kml* in Google Earth to examine the physical location of the glider's path and the full mission track.
2. Open *GLIDERSCOPE* and load the file *Dataset1_TwoRocks.nc*, which contains a subsection of the glider mission (single onshore/offshore transect).
3. Plot the coastline, and zoom in to examine the glider transect both horizontally (aerial view) and vertically (side view). Using the satellite image in Figure 4a, examine sea surface temperature (SST), altimetric sea levels, and surface current velocities in the area of the deployment.
4. Pass the data to *GLIDERSCOPE's* plotter window.
5. Create and save a temperature/salinity (T/S) plot of the transect data, and also color-coded data point plots for the following variables:
   a. Temperature
   b. Salinity
   c. Density
   d. Fluorescence
   e. Oxygen
   f. Downwelling irradiance (OCR470.3)
6. Locate regions of the transect where the glider measured downwelling irradiance (during daylight hours), and export single vertical profiles of this data.

QUESTIONS TO GUIDE DATA ANALYSES

1. What key features are evident in the SST/altimetry image in Figure 4a, particularly in the region of the glider transect? Evaluate the plot of in situ glider temperature data in relation to this SST figure. Which features match in both images?

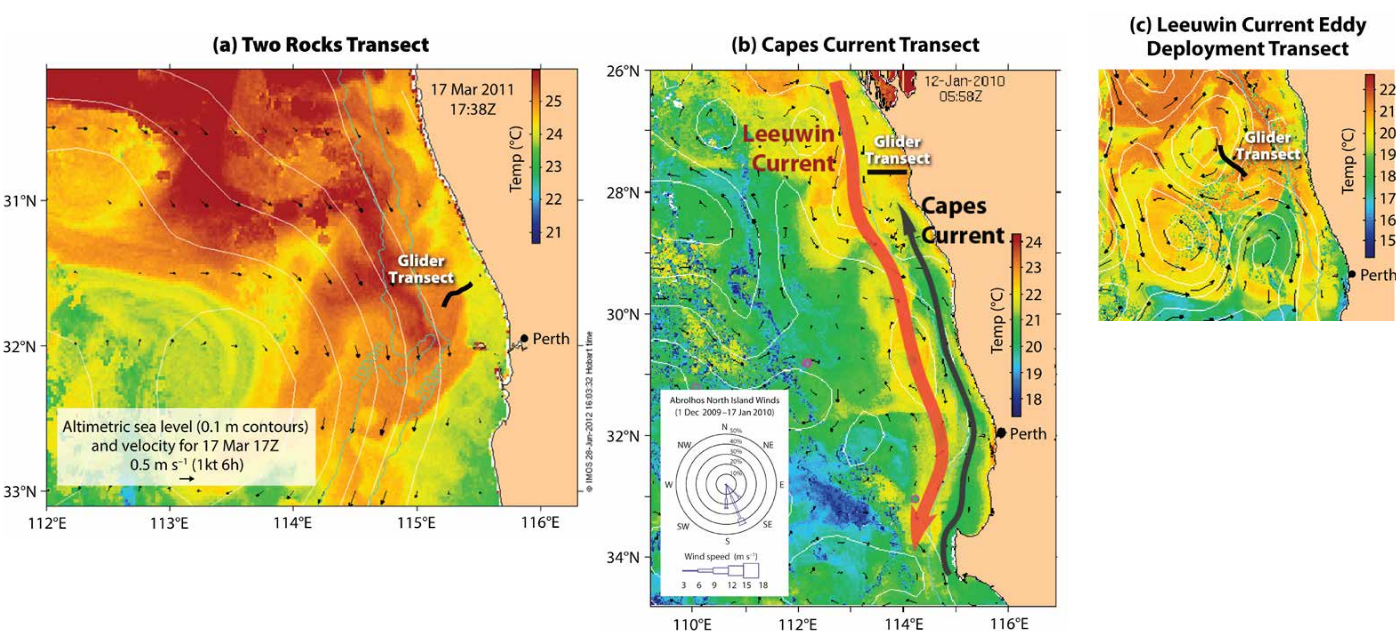


FIGURE 4. Sea surface temperature (SST), altimetric sea level (0.1 m contours), and arrows indicting surface current velocities during the (a) Two Rocks transect, (b) Capes Current transect (modified from Woo and Pattiaratchi, 2010), and (c) Leeuwin Current eddy deployment. Satellite imagery obtained from IMOS OceanCurrent (http://oceancurrent.imos.org.au).

Which features are evident only with the glider data? Also examine the cross-shelf plot of salinity—what features are evident from inshore to offshore? Based on these figures and the T/S plot that was created, identify the main water masses that are present across the transect.

2. Chlorophyll fluorescence is used as a general indicator of phytoplankton biomass. Examine the plot of fluorescence in relation to the temperature and salinity plots you have created. What is the relationship between the distribution of phytoplankton cells and the physical structure of the water column? What other important factors could be influencing this distribution?
3. Note that the downwelling light attenuation coefficient (K_d) and the depth of the euphotic zone can be calculated from the irradiance data collected by the glider. Irradiance decreases exponentially within the water column according to the relation

   $\ln E_d(z) = -K_d z + \ln E_d(0)$,

   where $E_d(z)$ and $E_d(0)$ are the values of downward irradiance at z m and the surface, respectively (Kirk, 2011). Using the extracted irradiance data, calculate the linear regression coefficient (K_d) of ln $E(z)$ with respect to depth over the depth interval of interest. How does K_d change with distance offshore? The depth of the euphotic zone (z_{eu}), defined as the depth where light intensity is reduced to 1% of surface values, can be calculated as $z_{eu} = \ln 100/K_d = 4.6052/K_d$. Evaluate the distribution of phytoplankton biomass (as chlorophyll fluorescence) in relation to the euphotic zone depth of the different water mass types.

Data Set 2: Capes Current Transect

The northward-flowing Capes Current is present along the Western Australia inner shelf during the summer months. This water mass is typically cooler and saltier than the adjacent surface waters of the Leeuwin Current, and often has higher phytoplankton biomass (Hanson et al., 2005a). This Slocum glider data set, from austral summer 2009/10, was collected to examine dynamics at the northern extent of the Capes Current.

INSTRUCTIONS

1. View the file *Dataset2_Capes_Current.kml* in Google Earth to examine the physical location of the glider's path. Also see Figure 4b, which is an SST image from the period of glider operation, overlaid with contours of altimetric sea level and arrows indicating surface current velocities.
2. Open *GLIDERSCOPE*, then select and load the file *Dataset2_Capes_Current.nc*.
3. Examine the glider's path both horizontally (aerial view) and vertically (side view).
4. Pass the data to *GLIDERSCOPE's* plotter window.
5. Create and save color-coded data point plots for the following variables:
   a. Temperature
   b. Salinity
   c. Density
   e. Fluorescence
   f. Oxygen
6. Extract temperature and salinity data from individual casts at multiple locations along the transect and create T/S plots of these data.

QUESTIONS TO GUIDE DATA ANALYSES

1. What key features are evident in the SST/altimetry image (Figure 4b)? Examining the ocean glider temperature and salinity plots, where is the location of the Capes Current? How does this compare with what you can see in the SST image, and based on your observation, what can you infer happens to the Capes Current at the northern extent of its flow? (*Hint*: see Woo and Pattiaratchi, 2010). Compare the T/S diagrams generated from various locations along the transect and use these to evaluate how the signature of the water column varies spatially.
2. What is the relationship between the distribution of phytoplankton cells and the physical structure of the water column? Try selecting individual vertical profiles (*Hint*: use the "go back" button to return to your data selection and select one or two vertical profiles) and then plot them on the same plot to examine vertical (physical) structure of the water column and its relation to fluorescence. How does the vertical density gradient and phytoplankton distribution change with increasing distance from shore? Also note the oxygen distribution along the transect—what could be influencing the observed patterns?

Data Set 3: Leeuwin Current Eddy

The Leeuwin Current is a meandering flow that often generates mesoscale eddies (Pearce and Griffiths, 1991), which are large (10–100 km) vortex-type features where water flows in a circular motion. Due to Coriolis forces associated with Earth's rotation, in the Southern Hemisphere cyclonic (clockwise-rotating) eddies have cold cores due to upwelling of water from depth to the surface, while anticyclonic (anticlockwise-rotating) eddies have warm cores due to downwelling of water from the surface to depth. This data set from a cyclonic Leeuwin Current eddy (Figure 4c) was collected by a Seaglider during austral winter (June–August 2011).

INSTRUCTIONS

1. View the file *Dataset3_LC_eddy.kml* in Google Earth to examine the physical location of the glider's path for this mission.
2. Open *GLIDERSCOPE* and load the file *Dataset3_LC_eddy.nc.*

3. Examine the subsection of the glider's path both horizontally (aerial view) and vertically (side view) and plot by coastline. In Figure 4c, examine SST, altimetric sea levels, and surface current velocities in the area of the deployment. How many eddies can you identify? Note that some eddies, including the one the glider transects, are smaller than the altimetry's resolution and will be visible only in the SST field.
4. Pass the data to *GLIDERSCOPE's* plotter window.
5. Using the temperature variable, create a color-coded data point plot and a contoured cross-section plot.
6. Click on the "go back" button, choose "split," select a "max depth" of 300 m, and resend the data to the plotter. Create and save a T/S plot and both two- and three-dimensional color-coded data point plots of the following variables:
    a. Temperature
    b. Salinity
    c. Fluorescence

QUESTIONS TO GUIDE DATA ANALYSES

1. What features are evident in the temperature and salinity contour plots? To what depth does the eddy appear to affect the water column? Based on the T/S plot, what water masses can be identified in the upper water column? (*Hint*: see Woo and Pattiaratchi, 2008, for background information). Compare the two- and three-dimensional plots, and evaluate which seems most useful for examining the properties of the eddy. Is there a relationship between temperature, salinity, and the distribution of chlorophyll biomass?

POSSIBLE MODIFICATIONS TO ACTIVITY

Any ocean glider data sets that are in NetCDF form can be visualized using *GLIDERSCOPE*. Additional ANFOG data sets from around Australia, including data from the East Australian Current, Coral Sea, and Southern Ocean, are available via the IMOS Ocean Portal at http://imos.aodn.org.au/webportal.

SUPPLEMENTAL MATERIALS

GLIDERSCOPE Tutorial 1: https://youtu.be/BiAvs-geunc?list=PLW7NnkFyzEHMQhMy7SSvenKjg7QvaCFYz
GLIDERSCOPE Tutorial 2: https://youtu.be/eLtea43m6uQ?list=PLW7NnkFyzEHMQhMy7SSvenKjg7QvaCFYz
GLIDERSCOPE Tutorial 3: https://youtu.be/C3wf1TRf8nQ?list=PLW7NnkFyzEHMQhMy7SSvenKjg7QvaCFYz

REFERENCES

Eriksen, C.C., T.J. Osse, R.D. Light, T. Wen, T.W. Lehman, P.L. Sabin, J.W. Ballard, and A.M. Chiodi. 2001. Seaglider: A long-range autonomous underwater vehicle for oceanographic research. *IEEE Journal of Oceanic Engineering* 26:424–436, https://doi.org/10.1109/48.972073.

Gersbach, G.H., C.B. Pattiaratchi, G.N. Ivey, and G.R. Cresswell. 1999. Upwelling on the south-west coast of Australia—Source of the Capes Current? *Continental Shelf Research* 19:363–400, https://doi.org/10.1016/S0278-4343(98)00088-0.

Glenn, S., O. Schofield, J. Kohut, J. McDonnell, R. Ludescher, D. Seidel, D. Aragon, T. Haskins, E. Handel, C. Haldeman, and others. 2011. The trans-Atlantic Slocum glider expeditions: A catalyst for undergraduate participation in ocean science and technology. *Marine Technology Society Journal* 45:52–67, https://doi.org/10.4031/MTSJ.45.1.12.

Hanson, C.E., C.B. Pattiaratchi, and A.M. Waite. 2005a. Seasonal production regimes off south-western Australia: Influence of the Capes and Leeuwin Currents on phytoplankton dynamics. *Marine and Freshwater Research* 56:1,011–1,026, https://doi.org/10.1071/MF04288.

Hanson, C.E., C.B. Pattiaratchi, and A.M. Waite. 2005b. Sporadic upwelling on a downwelling coast: Phytoplankton responses to spatially variable nutrient dynamics off the Gascoyne region of Western Australia. *Continental Shelf Research* 25:1,561–1,582, https://doi.org/10.1016/j.csr.2005.04.003.

Hanson, C.E., S. Pesant, A.M. Waite, and C.B. Pattiaratchi. 2007. Assessing the magnitude and significance of deep chlorophyll maxima of the coastal eastern Indian Ocean. *Deep Sea Research Part II* 54:884–901, https://doi.org/10.1016/j.dsr2.2006.08.021.

Hill, K., T. Moltmann, R. Proctor, and S. Allen. 2010. The Australian Integrated Marine Observing System: Delivering data streams to address national and international research priorities. *Marine Technology Society Journal* 44:65–72, https://doi.org/10.4031/MTSJ.44.6.13.

Kirk, J.T.O. 2011. *Light and Photosynthesis in Aquatic Ecosystems*, 3rd ed. Cambridge University Press, Cambridge, 662 pp.

Lourey, M.J., J.R. Dunn, and J. Waring. 2006. A mixed-layer nutrient climatology of Leeuwin Current and Western Australian shelf waters: Seasonal nutrient dynamics and biomass. *Journal of Marine Systems* 59:25–51, https://doi.org/10.1016/j.jmarsys.2005.10.001.

Pattiaratchi, C.B., B. Hollings, M. Woo, and T. Welhena. 2011. Dense shelf water formation along the south-west Australian inner shelf. *Geophysical Research Letters* 38, L10609, https://doi.org/10.1029/2011GL046816.

Pearce, A.F., and R.W. Griffiths. 1991. The mesoscale structure of the Leeuwin Current: A comparison of laboratory models and satellite imagery. *Journal of Geophysical Research* 96:16,739–16,757, https://doi.org/10.1029/91JC01712.

Pearce, A.F., and C. Pattiaratchi. 1999. The Capes Current: A summer countercurrent flowing past Cape Leeuwin and Cape Naturaliste, Western Australia. *Continental Shelf Research* 19:401–420, https://doi.org/10.1016/S0278-4343(98)00089-2.

Rudnick, D.L., R.E. Davis, C.C. Eriksen, D.M. Fratantoni, and M.J. Perry. 2004. Underwater gliders for ocean research. *Marine Technology Society Journal* 38:73–84, https://doi.org/10.4031/002533204787522703.

Sherman, J., R.E. Davis, W.B. Owens, and J. Valdes. 2001. The autonomous underwater glider "Spray." *IEEE Journal of Oceanic Engineering* 26:437–446, https://doi.org/10.1109/48.972076.

Smith, R.L., A. Huyer, J.S. Godfrey, and J.A. Church. 1991. The Leeuwin Current off Western Australia. *Journal of Physical Oceanography* 21:323–345, https://doi.org/10.1175/1520-0485(1991)021<0323:TLCOWA>2.0.CO;2.

Testor, P., G. Meyers, C. Pattiaratchi, R. Bachmayer, D. Hayes, S. Pouliquen, L. Petit de la Villeon, T. Carval, A. Ganachaud, L. Gourdeau, and others. 2010. Gliders as a component of future observing systems. In *Proceedings of OceanObs'09: Sustained Ocean Observations and Information for Society* (*Vol. 2*), Venice, Italy, September 21–25, 2009, J. Hall, D.E. Harrison, and D. Stammer, eds, ESA Publication WPP-306, https://doi.org/10.5270/OceanObs09.cwp.89.

Woo, M., and C.B. Pattiaratchi. 2008. Hydrography and water masses off the western Australian coast. *Deep Sea Research Part I* 55:1,090–1,104, https://doi.org/10.1016/j.dsr.2008.05.005.

Woo, M., and C.B. Pattiaratchi. 2010. How the Capes Current ends: An investigation of a west Australian coastal current using an autonomous ocean glider. *Proceedings of the 15th Physics of Estuaries and Coastal Seas (PECS) Conference,* Colombo, Sri Lanka, September 14–17, 2010*,* https://doi.org/10.13140/2.1.4854.6244.

Wooster, W.S., and J.L. Reid. 1963. Eastern boundary currents. Pp. 253–279 in *The Sea*. M.N. Hill, ed, Pergamon Press.

ACKNOWLEDGMENTS

The authors are affiliated with the Australian National Facility for Ocean Gliders (ANFOG). Data was sourced from the Integrated Marine Observing System (IMOS; http://imos.org.au), which is supported by the Australian Government through the National Collaborative Research Infrastructure Strategy and the Super Science Initiative. We thank Claire Gourcuff for assistance with data manipulation, the UWA ENVE 4615 physical oceanography undergraduate class for reviewing these exercises, and three anonymous reviewers for their helpful suggestions.

AUTHORS

Christine E. Hanson (christine.hanson@bmtoceanica.com.au) is Associate Principal Consultant at BMT Oceanica Pty Ltd, Australia. **L. Mun Woo** and **Paul G. Thomson** are Research Assistant Professors, and **Charitha B. Pattiaratchi** is Winthrop Professor, School of Civil, Environmental and Mining Engineering and The UWA Oceans Institute, The University of Western Australia, Crawley, WA, Australia.

ARTICLE CITATION

Hanson, C.E., L.M. Woo, P.G. Thomson, and C.B. Pattiaratchi. 2017. Observing the ocean with gliders: Techniques for data visualization and analysis. *Oceanography* 30(2):222–227, https://doi.org/10.5670/oceanog.2017.210.