Gliders in the Gulf Stream: A model for sustained observing of western boundary currents

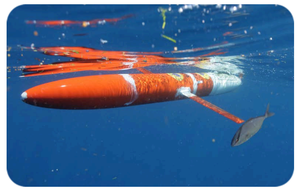
Robert E. Todd (rtodd@whoi.edu), Woods Hole Oceanographic Institution

Overview:

The Gulf Stream is a key part of the climate system, carrying warm waters poleward as part of the Atlantic Meridional Overturning Circulation. As it flows along the US East Coast from the Florida Strait to the open North Atlantic, the Gulf Stream triples its volume transport and separates from the continental margin; meandering and eddy shedding increase downstream. To fill a 1500-km-long gap in sustained, high-resolution monitoring of the Gulf Stream's subsurface structure and variability along the US East Coast, autonomous underwater gliders are routinely surveying the Gulf Stream.

Spray Glider Observations in the Gulf Stream:

- Spray gliders steer across observed currents while being advected downstream in the Gulf Stream from Miami, FL to New England.
- New missions lasting about 110 days start about every 2 months.
- Instrumentation sampling during all ascents (box 1):
  - Pumped Sea-Bird 41CP CTD
  - 1-MHz Nortek AD2CP Doppler current profiler
  - Seapoint chlorophyll fluorometer
  - Sea-Bird 63 dissolved oxygen sensor
- Near-real time temperature and salinity observations are distributed via NOAA ERDDAP, the IOOS Glider DAC, GTS, and email for operational usage.
- Post-processed data are publicly available for research purposes.



A Spray glider beginning a mission in the Gulf Stream.

Summary of Findings:

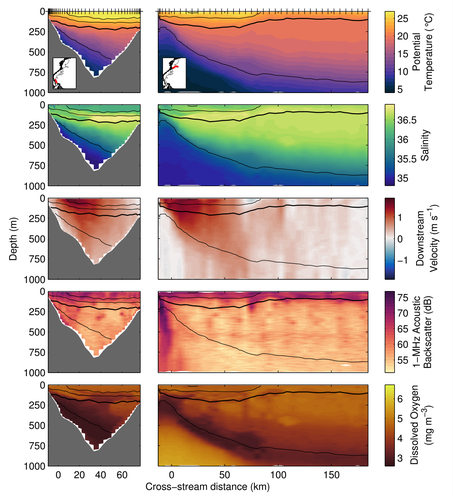
Spray glider observations in the Gulf Stream have been used to:

- Investigate the time-mean, three-dimensional structure the western boundary current including eddy kinetic energy (box 2).
- Characterize the along-stream evolution of Gulf Stream transport (box 2).
- Identify multiple phenomena associated with strong flow over relatively shallow bathymetry (box 3).
- Constrain numerical simulations (box 4).
- Examine impacts of hurricanes on the Gulf Stream (Todd et al., 2018).

Future Outlook:

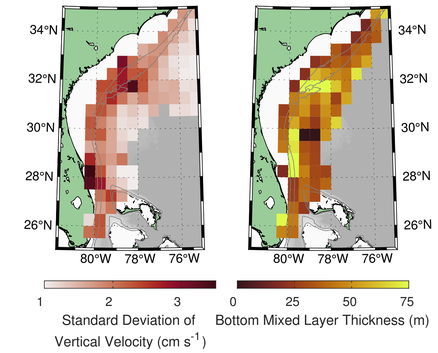
- The goal is to sustain glider observations in the Gulf Stream for years to come, building a dataset that captures seasonal to interannual variability along the US East Coast.
- This work serves as a model for sustained, glider-based surveillance of other western boundary currents (e.g., Kuroshio, Agulhas, East Australian Current, Brazil Current).
- The OceanGliders Boundary Ocean Observing Network (BOON) is working to build a global network of glider-based observatories along ocean boundaries.

1. Cross-Gulf Stream Transects



Spray gliders have returned more than 285 high resolution transects across the Gulf Stream and over 33,000 profiles as of April 2022. Examples of observed parameters are shown here from a glider mission in spring 2019. Transects in the left (right) column are from the Florida Strait (downstream of Cape Hatteras).

3. Topographic Effects



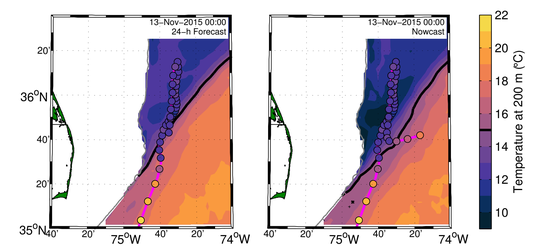
Glider observations have been used to document three processes by which energy is extracted from the Gulf Stream as it flows over the relatively shallow Blake Plateau.

1. *Large-amplitude internal lee waves with strong vertical velocities (left; Todd, 2017).*
2. *Bottom mixed layers with O(100)-m thickness (right; Todd, 2017)*
3. *Submesoscale coherent vortices formed due to bottom friction and mixing that transport water from the boundary into the basin (Gula et al., 2019).*

2. Time-Mean Gulf Stream Properties and Transport

Persistent glider sampling across multiple years is beginning to illuminate the time-mean, three-dimensional structure of the Gulf Stream, including its mean and eddy kinetic energy (left; Todd, 2021). Concurrent velocity and hydrographic measurements from many transects reveal how entrainment of various water classes contributes to the growth of Gulf Stream transport along the US East Coast (right). Water classes are: surface waters (SW), thermocline waters (TW), Eighteen Degree Water and related waters (EDW), Antarctic Intermediate Water (AAIW), upper Labrador Sea Water (uLSW), and waters influenced by Middle Atlantic Bight shelf waters (MABW) (Heiderich & Todd, 2020).

4. Impacts on Numerical Simulations



Subsurface observations provide important constraints for both operational numerical simulations (above) and for numerical state estimates that are used for scientific analyses. Glider observations with high spatial resolution are particularly important for constraining the large property gradients associated with western boundary currents such as the Gulf Stream (Todd & Locke-Wynn, 2017).

References:

- Todd, Owens, Rudnick (2016), Potential vorticity structure in the North Atlantic western boundary current from glider observations. *J. Phys. Oceanogr.*, 46, 327-348.
- Todd, Owens (2016). *Gliders in the Gulf Stream* [Data set]. Scripps Institution of Oceanography, Instrument Development Group. doi: 10.21238/s8SPRAY2675.
- Todd (2017), High-frequency internal waves and thick bottom mixed layers observed by gliders in the Gulf Stream, *Geophys. Res. Lett.*, 44(12), 6316-6325.
- Todd, Locke-Wynn (2017), Underwater glider observations and the representation of western boundary currents in numerical models, *Oceanography*, 30(2), 88-89.
- Todd, Asher, Heiderich, Bane, Luettich (2018), Transient response of the Gulf Stream to multiple hurricanes in 2017. *Geophys. Res. Lett.*, 45, 10,509–10,519.
- Gula, Blacic, Todd (2019), Submesoscale coherent vortices in the Gulf Stream, *Geophys. Res. Lett.*, 46, 2704-2714
- Heiderich, Todd (2020), Along-stream evolution of Gulf Stream volume transport, *J. Phys. Oceanog.*, 50(8), 2251-2270.
- Todd (2021), Gulf Stream mean and eddy kinetic energy: Three-dimensional estimates from underwater glider observations, *Geophys. Res. Lett.*, 48(6), e2020GL090281

Acknowledgements:

P. Deane, R. Graham, J. Heiderich, L. George, K. Kausch, J. Sherman, B.Reineman, and the Instrument Development Group at Scripps have been key to the success of glider operations. Spray glider observations in the Gulf Stream are available from https://doi.org/10.21238/S8SPRAY2675 (Todd and Owens, 2016). We gratefully acknowledge funding from the National Science Foundation, NOAA's Global Ocean Monitoring and Observing program, the Office of Naval Research, Eastman Chemical Co., and WHOI.