Final Report on Wave Glider data collection over the West Antarctic Peninsula shelf and within Drake Passage
24 October, 2019 – 20 February, 2020
R/V *Laurence M. Gould* cruises LMG 19-09 and LMG 20-02

An experiment sponsored by the National Science Foundation's Office of Polar Programs under the Antarctic Atmospheric and Oceanic Sciences Program (Peter Milne, OPP-1853291) :

"Wave Glider observations of surface fluxes and mixed-layer processes in the Southern Ocean"

James B. Girton and Jim Thomson
Applied Physics Laboratory
University of Washington
1013 NE 40th Street
Seattle, WA 98105
Tel: 206-543-8467
girton@uw.edu,
jmt3rd@uw.edu

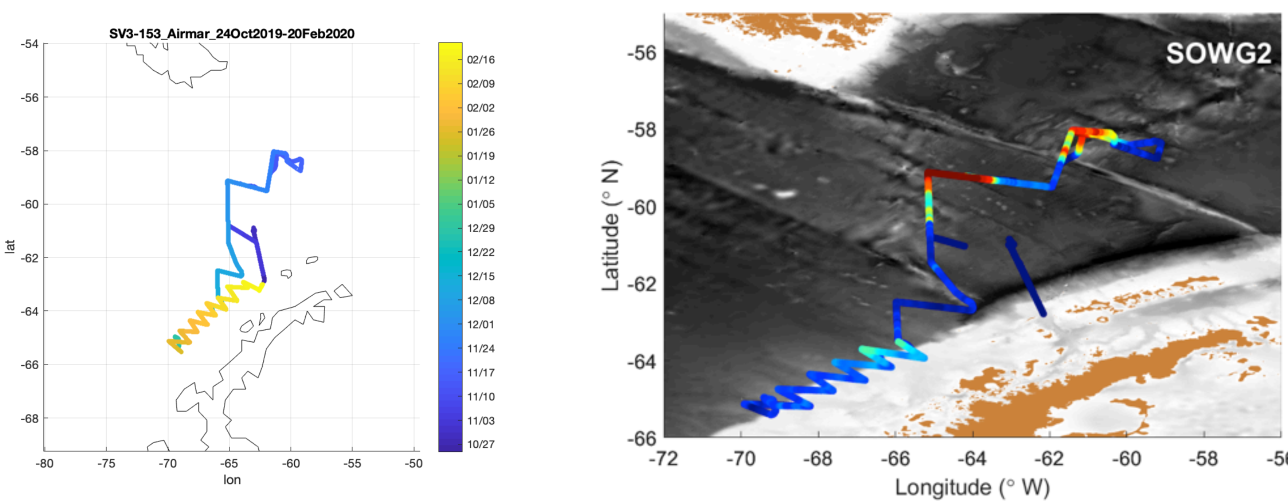

Figure 1: Two views of the 2019–2020 survey track of Wave Glider SV3-153. The left panel is colored by time, and the right by temperature (0–4°C blue-to-red range).

1 Intro/Background

Air–sea fluxes of heat, freshwater, and momentum in the Southern Ocean play important roles in the global climate system and yet are sparsely sampled. The Antarctic Circumpolar Current (ACC) is driven by prevailing westerly winds. Surface waves, driven by the winds but also propagating long distances and refracted by the currents, determine the surface roughness and wind drag. Heat and freshwater fluxes modify the properties of global ocean watermasses and, together with wind-induced upwelling and downwelling, drive the ocean's meridional overturning circulation. Coincident observation of the multiple factors forcing the surface ocean (particularly winds, waves, and currents) has long required ship presence and so has been extremely limited in the Southern Ocean. New long-endurance autonomous vehicles stand to improve observational coverage if they can (a) provide measurements of comparable quality to existing ships and buoys, and (b) survive the harsh conditions of the high-latitude open ocean for sufficient periods of time.

This report describes the second of two deployments of an autonomous Wave Glider surface vehicle (SV3-153) in the Drake Passage region by APL-UW in partnership with the US Antarctic Program and funded by NSF [*Girton et al.*, 2022].

The Wave Glider deployment went from Oct 24, 2019 through Feb 20, 2020, and ran a track in the ACC and near the Antarctic Peninsula (Fig. 1). The region covered is similar to the track occupied in a previous deployment [Dec 2016 – Mar 2017, see *Thomson and Girton*, 2017; *Thomson et al.*, 2018] and remained outside of the Exclusive Economic Zones (EEZ) of Argentina and Chile.

2 Field Deployment

Due to heavy ice conditions and a late spring thaw, initial plans to coordinate sampling with Slocum gliders near Palmer Station had to be scrapped. Instead, a combined open-ocean and coastal survey plan was developed–starting from and ending at the South Shetland Islands so as to be (a) near both the inbound and outbound tracks of the deployment vessel, the R/V *Laurence M. Gould* (LMG), en route to Palmer Station, and (b) ensure adequate topographic sheltering in the case of strong winds during launch or recovery.

In the end, both launch and recovery of the Wave Glider were accomplished smoothly and in relatively calm conditions (Figs. 2 and 3).

The Wave Glider occupied timeseries stations and spatial surveys, sampled the open ocean and continental margins, transited broad frontal zones and sharp ACC jets, and collected measurements in periods with both weak winds and strong storms. Taken together, the observations span the typical range of Southern Ocean conditions, allowing for analysis of processes driving co-variability in these quantities in addition to data quality evaluation at different headings, sea states, and current speeds.

On December 27, just over mid-way through the mission, the Wave Glider's subsurface propulsion and steering unit stopped reporting compass headings, making navigation more difficult. As a backup, an alternative navigation mode was used which determined vehicle heading solely from the course-over-ground (from GPS positions collected on the surface float). This mode ("GPSAsRudderCompass") has the potential to fail when the vehicle is being pushed around too much by winds, waves, and currents, but instead it was able to permit the Wave Glider to successfully navigate the remainder of the planned waypoints quite successfully.

3 Data Summary

In preparation for this 2019/20 field deployment, the APL-UW team integrated two new instruments onto the LRI Wave Glider: a Nortek Signature 1000 ADCP, and a new LRI profiling winch with 150 m wire. For the previous deployment (2016/17), integration of several other instruments had already been completed: a Gill 3-axis anemometer (for turbulent wind stress), the GPSWaves wave-measurement system, an Aanderaa conductivity and temperature (CT) sensor, and a Paroscientific MET4 (air pressure, temperature, humidity). All but the MET4 were used in the deployment described here.

Figures 4–8 show the under-way measurements collected by the Wave Glider during its mission. Most sensors performed well, although there were several failures.

The Aanderaa CT was unfortunately damaged during launch (likely snagged by one of the lines used to control the vehicle while lifting it over the side of the ship) and returned no data for this mission. Instead,

Figure 2: Wave Glider launch via crane (left) and release (right) from the R/V *Laurence M. Gould* in a calm region protected by the South Shetland Islands.

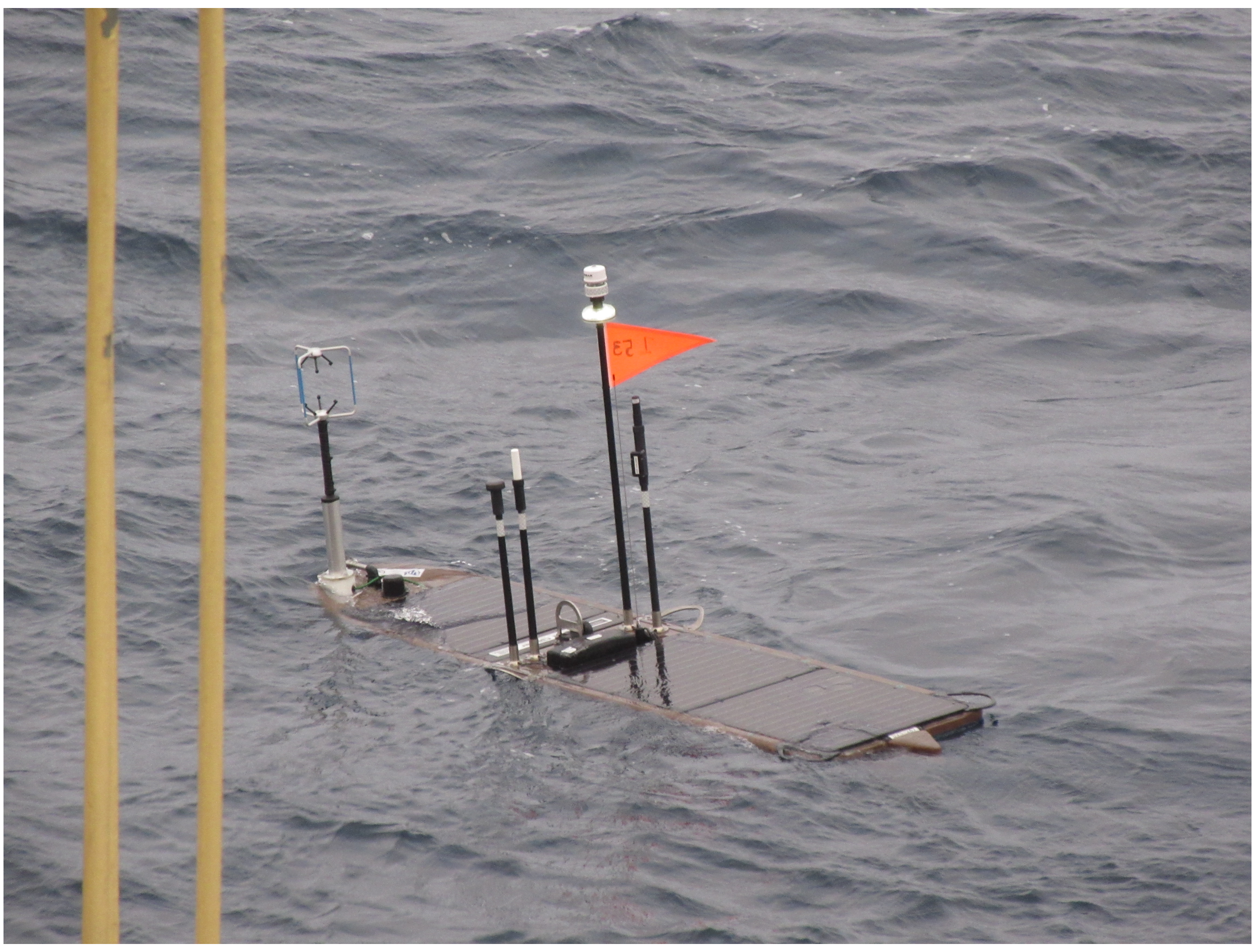

Figure 3: Illustration of the Wave Glider's minimal surface float freeboard and frequent overwash while under way (weighted down by a new profiling winch). Forward propulsion is provided by a set of fins hanging 8 meters below the surface float and oriented to pull the vehicle forward in response to vertical heaving by surface waves.

surface temperatures measured by the ADCPs (both RDI and Nortek) and 8 m temperature and salinity measurements from the GP-CTD were used for surface ocean properties.

The air temperature measurement on the Airmar weather station failed mid-way through the deployment, but other Airmar measurements (air pressure, wind speed and direction) continued to return data up to the time of the vehicle's recovery (Fig. 4). As a substitute for the missing air temperatures, sonic air temperatures from the Gill 3-axis anemometer are available.

The profiling winch was able to successfully lower the GP-CTD package to 150 m depth multiple times (Fig. 8), and after initial tests an automated script was developed to allow CTD profiling to proceed continuously at specified intervals (which, due to solar power limitations, was expected to be no more than a handful of times per day). Unfortunately, shortly after the first fully automated profile, the CTD and sinker electronics stopped communicating, indicating a significant problem. Other systems on the Wave Glider continued to function, but the CTD never came back on line. When the vehicle was recovered, it was found that the cable had parted, resulting in the loss of the CTD package. As a major goal of this Wave Glider deployment, the ability to successfully test the profiling CTD winch and shore-side control was a significant accomplishment. However, the short lifetime of the CTD and sinker at the end of the winch cable was disappointing—and points to the need for an improved mechanical design for these components.

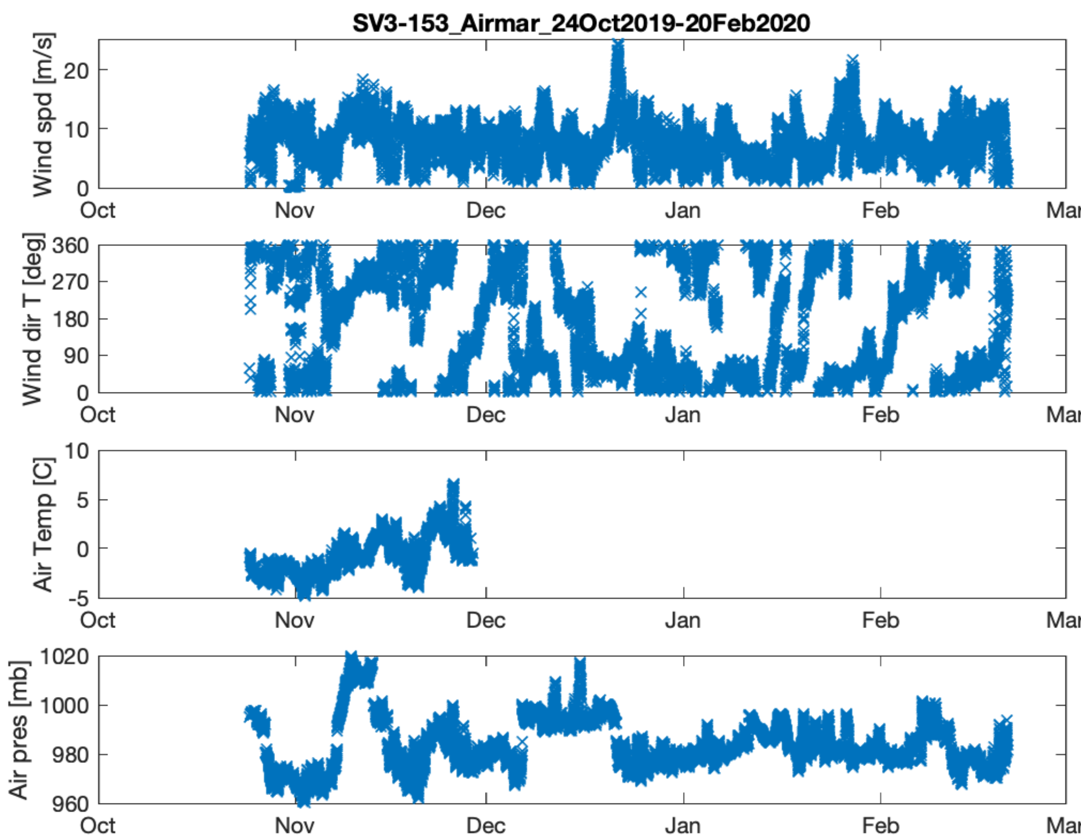

Figure 4: Near-surface atmospheric data collected by the Airmar weather station (∼1.5 m height) at 10 minute intervals.

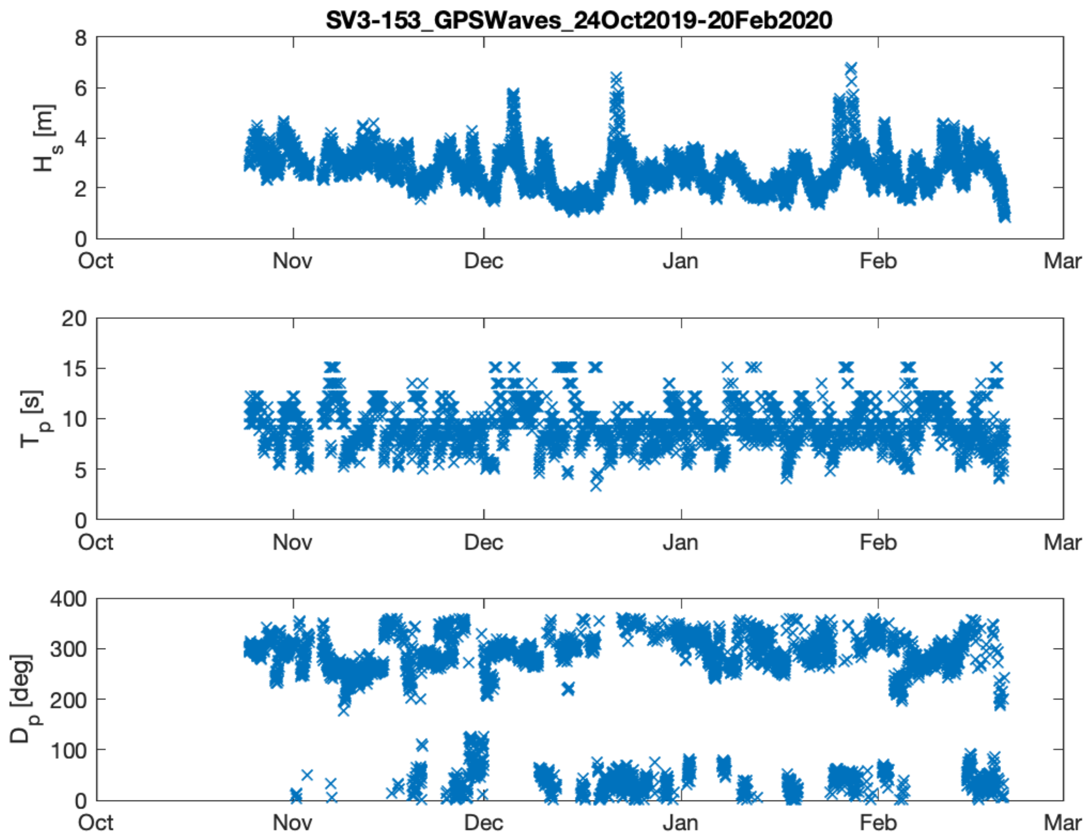

Figure 5: Surface wave data collected by the GPS Waves sensor. Quantities shown include significant wave height (H_s), peak period (T_p), and peak direction (D_p).

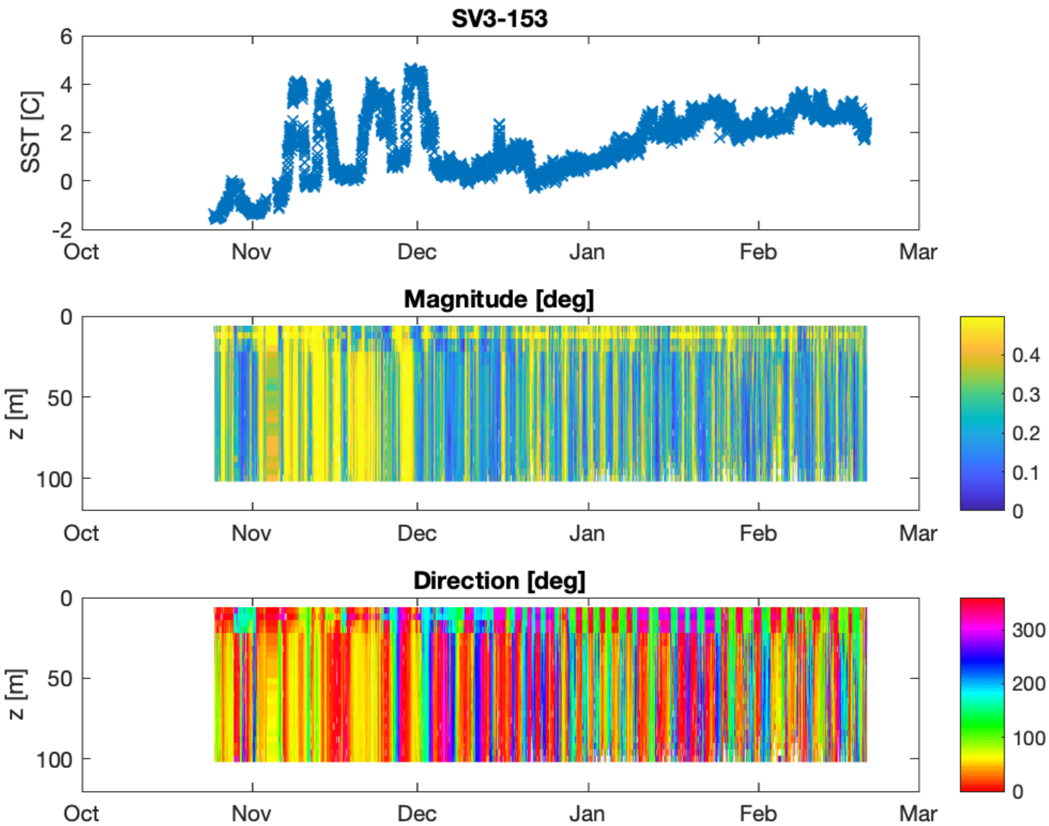

Figure 6: Surface temperature and upper-ocean currents measured by the 300 kHz RDI Workhorse acoustic Doppler current profiler (ADCP) mounted on the surface float.

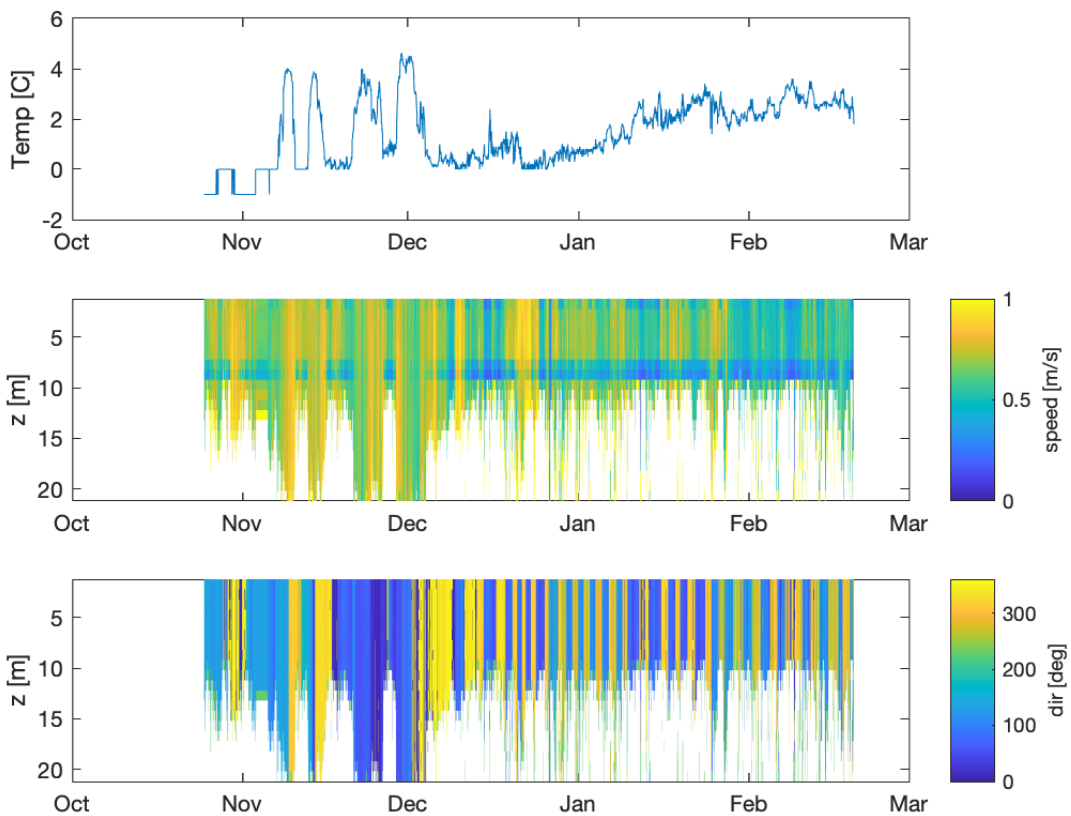

Figure 7: Additional temperature and current measurements at high resolution and short range by the 1 MHz Nortek Signature ADCP. Data plotted here were collected in broadband mode at 2 minute intervals.

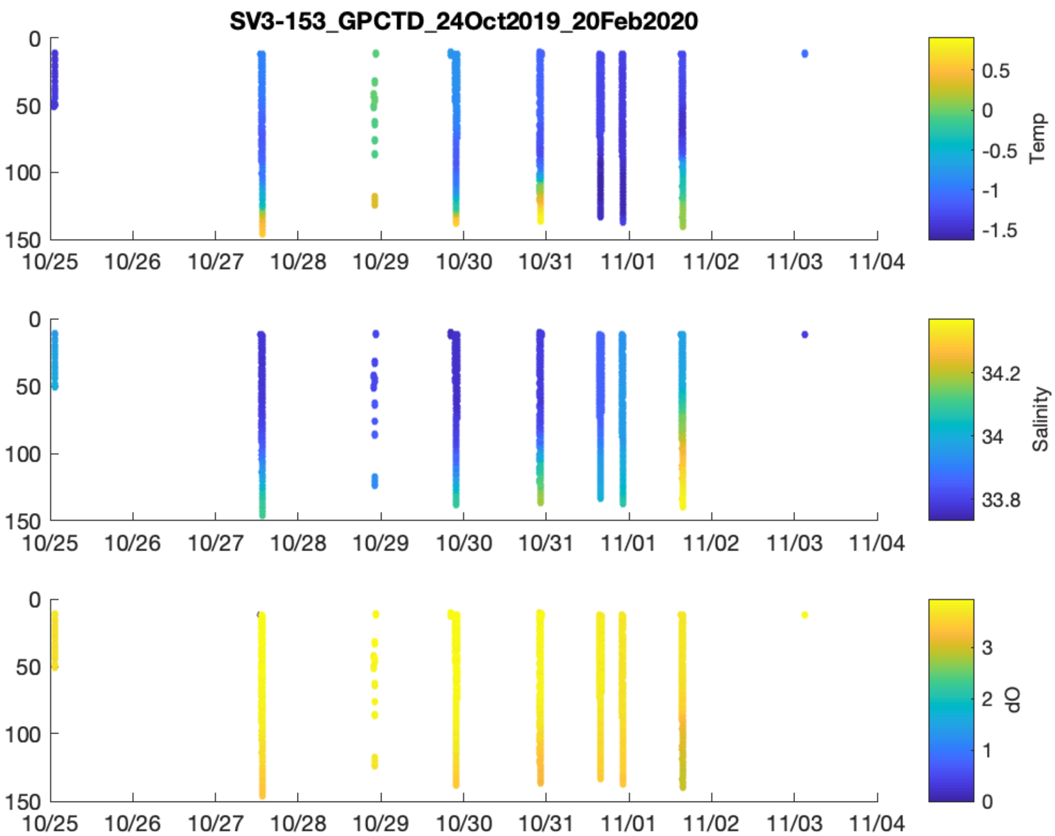

Figure 8: Conductivity–temperature–depth profiles to 150 m depth collected from a winched CTD system attached to the Wave Glider's propulsion unit.

4 Results and Discussion

Analysis of data from the two Wave Glider missions is ongoing, focusing on wind–wave–current co-variability and hypothesized causes, including air–sea temperature contrasts (Fig. 9). Wind–SST correlation has been seen in the 2016/17 dataset [*Thomson et al.*, 2018]. Simultaneous sampling of wind, waves, and currents allows evaluation of the contributions of secondary influences on air–sea fluxes (Fig. 11), as well as known responses such as mixed-layer inertial oscillations and Ekman transport. Wave spectra allow estimation of the effects of currents on long-range propagating waves (swell) vs. wind waves.

4.1 Surface Fluxes

Surface fluxes were computed using the COARE algorithms and shown in Figure 10. The multiple simultaneous measurements on the Wave Glider allow exploration of deviations from the dominant forcing parameters and functional relationships. For example, the range of surface wave conditions encountered at a given wind speed illustrates the impact of waves on drag coefficient (Fig. 11).

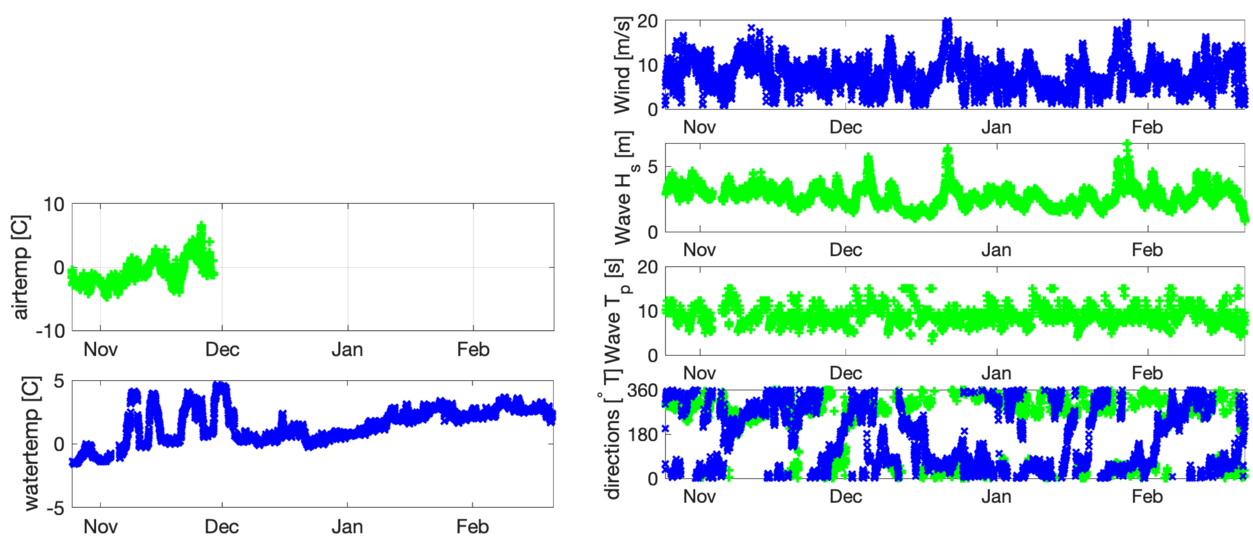

Figure 9: Left: Co-variability of air temperature (from Airmar weather station) and water temperature (from ADCP). Right: Co-variability of wind (from Airmar weather station) and wave (from GPSWaves sensor) parameters.

4.2 Upper-ocean structure

Several timeseries stations (generally implemented as octagonal loops) were occupied in both Wave Glider surveys in order to allow estimates of the synchronization between wind and wave quantities while also capturing spatial variability over small scales. Spatial surveys allow estimation of current gradients and ocean dynamics via repeated transects across coherent jets, but may alias tides or high-frequency wind-forced ocean variability. Comparison of wavenumber spectra with vessel crossings (*e.g.*, the route of the LMG across Drake Passage) will allow separation by frequency due to different measurement platform speeds.

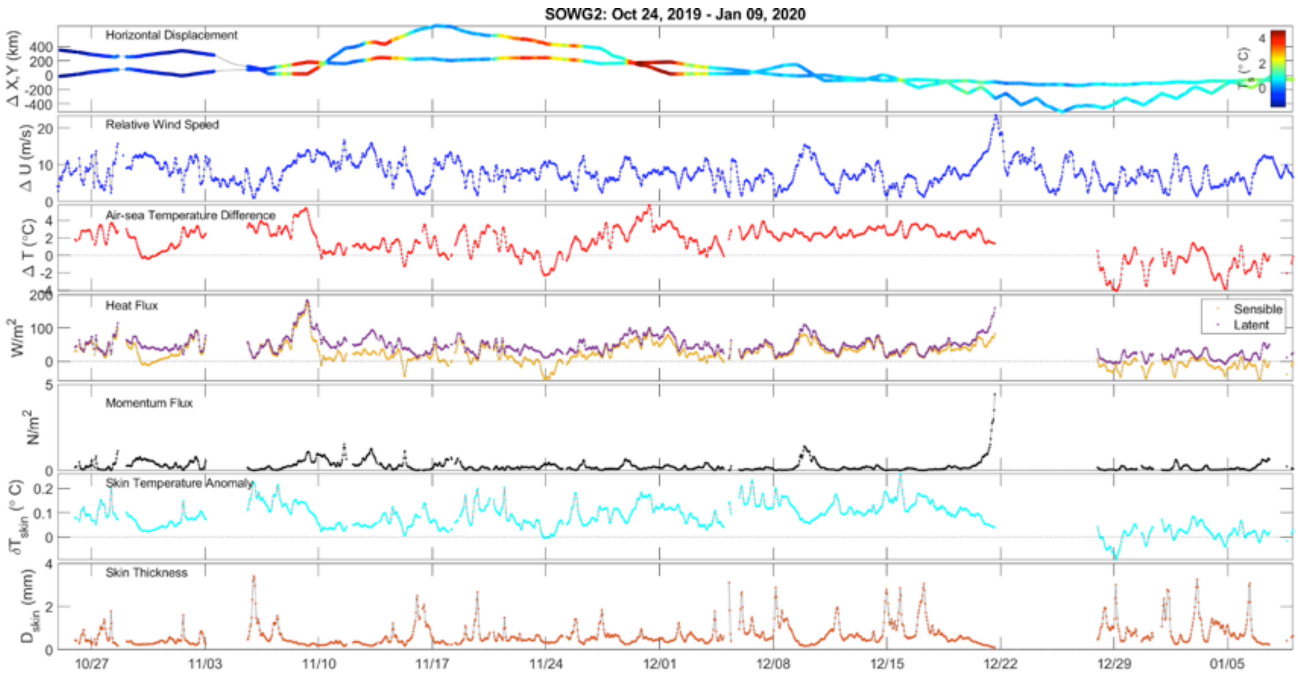

Figure 10: Timeseries of bulk properties (direct measurements of wind speed, wind direction, and air-sea temperature difference) and computed air–sea fluxes (output of bulk formulae for sensible and latent heat flux, momentum flux, or skin temperature and thickness).

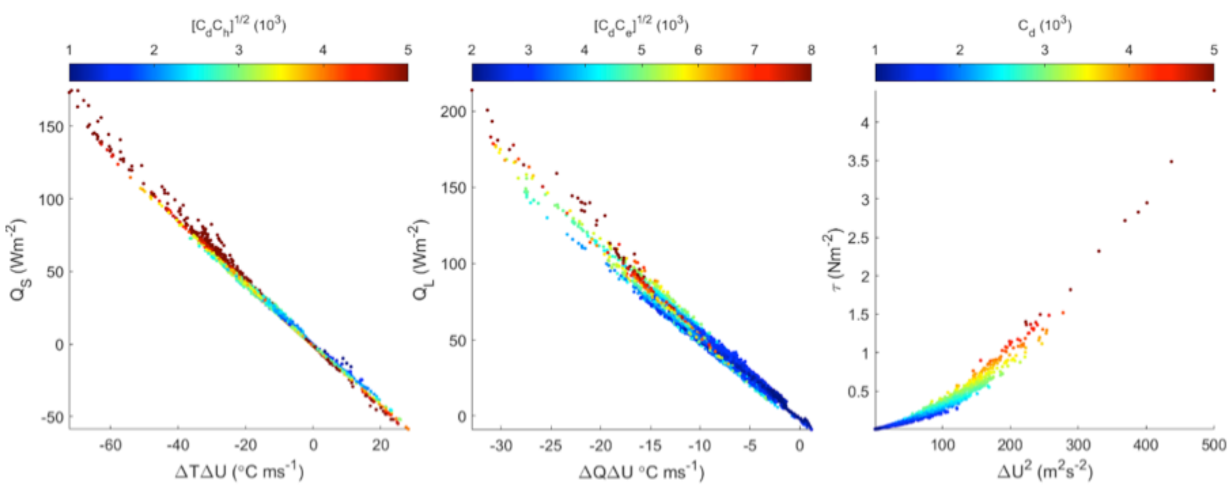

Figure 11: First and second-order flux dependencies. Sensible heat flux depends on air–sea temperature difference and shear (drag and heat exchange coefficient product colored in left panel). Latent heat flux depends on humidity and shear (drag and enthalpy exchange coefficient product colored in center panel). Stress (momentum flux) depends on shear (drag coefficient colored in right panel).

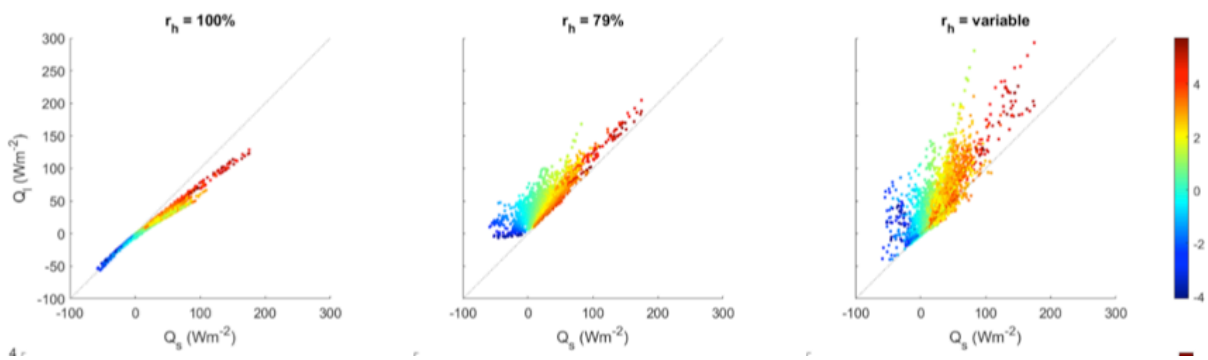

Figure 12: Sensitivity of the sensible and latent heat flux calculation to the missing relative humidity measurement.

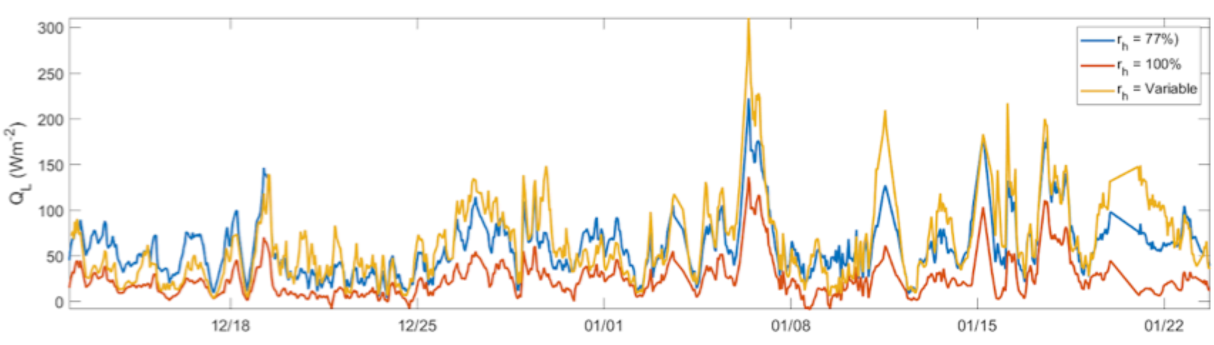

Figure 13: Latent heat flux timeseries computed using different relative humidity values.

5 Preliminary Conclusions

Over the course of the two Southern Ocean deployments, we learned several valuable lessons about the technical challenges, including that:

- The Wave Glider's dependence on solar power limits high-latitude work to the 5 summer season months (Oct–Feb).
- Sensor longevity is limited—particularly for newly-integrated systems during initial trials. Season 1 failures before the end of the mission included the Gill 3-axis sonic anemometer, Aanderaa CT, and MET4. Season 2 failures included the CTD winch sinker (early), the Aanderaa CT (on launch), the Gill (intermittent), and the Airmar air temperature.
- In particular, the profiling CTD winch needs sinker improvements (for both hydrodynamics and durability). This could be a vital addition to the scientific capabilities of the Wave Glider, so we are optimistic that future versions will make big steps forward.
- Humidity is also a very difficult measurement to make in such a low-profile vehicle, but an improved humidity sensor or method would add a great deal of value to the flux estimates.
- A GPS heading sensor would add a vital improvement to ADCP accuracy over the current magnetic compass.

In the end, sustained presence by autonomous surface vehicles is the most promising way forward for sparsely-sampled regions like the Southern Ocean. A Wave Glider allows simultaneous measurements of wind speed, wind stress (from high-frequency 3-D wind sampling), air–sea heat flux, directional wave spectra, and surface currents. So far, it is apparent that the vehicle speed, piloting capability, and longevity can produce innovative scientific results. Further improvements in durability and year-round operations will make this an even more valuable tool.

6 Acknowledgements

The assistance of the captain and crew of the R/V *Laurence M. Gould*, as well as the many excellent people who support the US Antarctic Program, was invaluable throughout this work. Critical assistance was also given by Liquid Robotics, Inc. (LRI) and the APL-UW wave glider team (including Alex DeKlerk, Ryan Newell, Avery Snyder, and Joe Talbert).

7 References

References

Girton, J. B., J. Thomson, and K. Zeiden, Wind/wave/current co-variability in two Southern Ocean autonomous surface vehicle surveys, 2022, poster PSP02-5198, presented at Ocean Sciences Meeting 2022, Honolulu, HI.

Thomson, J., and J. Girton, Sustained measurements of Southern Ocean air-sea coupling from a Wave Glider autonomous surface vehicle, *Oceanography*, *30*, 104–109, 2017.

Thomson, J., J. B. Girton, R. Jha, and A. Trapani, Measurements of directional wave spectra and wind stress from a Wave Glider autonomous surface vehicle, *J. Atmos. Ocean. Technol.*, *35*, 347–363, 2018.