Saildrone

Adaptively Sampling
the Marine Environment

Adapted from "Saildrone: Adaptively Sampling the Marine Environment," by C. L. Gentemann (Farallon Institute, and Earth and Space Research), Joel P. Scott, Piero L. F. Mazzini, Cassia Pianca, Santha Akella, Peter J. Minnett, Peter Cornillon, Baylor Fox-Kemper, Ivona Cetinić, T. Mike Chin, Jose Gomez-Valdes, Jorge Vazquez-Cuervo, Vardis Tsonetos, Lisan Yu, Richard Jenkins, Sebastien de Halleux, Dave Peacock, and Nora Cohen. Published online in *BAMS*, June 2020. For the full, citable article, see [DOI:10.1175/BAMS-D-19-0015.1](https://doi.org/10.1175/BAMS-D-19-0015.1).

A saildrone is a wind- and solar-powered, unmanned ocean-observing platform that carries a sophisticated suite of scientific sensors to observe air–sea fluxes and other key variables on long-duration missions of up to 12 months. With a narrow 7-m-long hull, a 5-m-tall hard wing, and a keel with a 2.5-m draft, each saildrone weighs 750 kg and travels at an average speed of 1.25 m s^{-1} . It autonomously navigates between programmed waypoints under the supervision of a remote human pilot.

Saildrones collect data to inform research into upwelling dynamics, river plumes, submesoscale variability, and carbon cycling. With speeds up to 4 m s^{-1} , the vehicle provides rapid spatial sampling of the air–sea interface, and it complements moored buoys, drifters, subsurface gliders, and profilers with dynamic tasking and sampling.

It is important, however, to assess the accuracy of saildrone observations for science. Unlike many ocean research instrument-makers, Saildrone, Inc., owns and operates its vehicles and sensors; it is the data that are purchased. Initial results from other studies are promising, but in a limited range of environmental conditions. Further validations are necessary to establish saildrone measurement accuracies.

From 11 April to 11 June 2018, the saildrone collected valuable measurements on a 60-day cruise from San Francisco Bay down the coast to Guadalupe Island, and back. The cruise track aimed to establish the accuracy of these new measurements with collocated satellite, buoy, and glider data while

sampling oceanographic features such as upwelling fronts, river plumes, and upper-ocean diurnal warming events.

In the California Current region, the air–land–sea interface is complex, with coastal promontories, upwelling jets and shadows, river plumes, and a narrow continental shelf that affects coastal dynamics, producing highly variable patterns in sea surface temperatures (SSTs) and photosynthetic pigment chlorophyll *a* (Chl) concentrations. Upwelling induces a flux of cold, nutrient-rich, dense, low-in-oxygen, and acidic waters to the surface layers, leading to important air–sea and coastal–open ocean interactions. Even in this heavily sampled region, satellites with discrete glimpses and buoys at fixed locations leave substantial observing gaps.

Data quality

The cruise featured 16 sensors measuring atmospheric pressure, temperature, humidity, wind speed and direction, skin SST, subsurface temperature, salinity, Chl fluorescence, colored dissolved organic matter fluorescence, red backscatter, dissolved oxygen, and upper-ocean 3D velocities. Four temperature loggers were installed along the keel to measure subsurface water temperature at 0.295 to 1.785 m depths; the other sensors were connected to onboard computers and transmitted data in real time via satellite.

Most sensors should not be affected by being mounted on a saildrone versus another air–sea platform, except the sonic anemometer, acoustic Doppler current profiler (ADCP), and flow-through measurements (e.g., dissolved oxygen). Platform heating could affect the flow-through observations during diurnal temperature fluctuations. The results from the cruise indicate that for the days that would most likely exhibit some platform heating effects on the flow-through temperature measurements, any effect appears to be within the expected geophysical and instrumental noise.

In short, all instruments except two worked well and demonstrated encouraging accuracy,

▲ The saildrone returning to San Francisco 11 Jun 2018. The wind anemometer is visible at the top of the wing and solar panels are on both the wing and vehicle hull. Credit: Saildrone/Gentemann.

as compared to external data sources. A constant air pressure bias compared to the buoys indicated a problem with this saildrone sensor. It is suspected that moisture infiltrated the instrument during a previous deployment. Also, the saildrone ocean skin temperatures for this cruise had large errors due to the lack of a correction for reflected sky radiation. saildrone is currently testing a correction method.

A longer cruise involving multiple buoys and saildrones would help develop a more robust understanding of the saildrone’s accuracy for measuring wind speed and direction. Differences between individual satellite and model products with these variables require further investigation and underscore the value of saildrone measurements in remote and data-scarce regions for satellite retrieval algorithms and model development. Satellite retrievals of SST show general agreement with the saildrone subsurface measurements.

Scientific contributions

During this 2-month cruise, the saildrone collected a new dataset with substantial scientific value. For example, the experiment showed the magnitude of the horizontal currents and their components in the upper 80 m of the water column in diurnal warming on 20 April 2018. The saildrone data, along with satellite-derived SST and high-frequency (HF) radar currents, revealed the complex

Cruise track for the 2018 Baja saildrone over VIIRS SSTs for 10 Jun 2018. The prevalent north wind is reflected in the relatively straight lines on the southward portion of the cruise, and the zig-zag (tacking) of the return.

interactions of the circulation in this region. The cruise data raised intriguing questions about the role of diurnal warming and horizontal gradients in these coastal dynamics. Additional saildrone deployments and HF radar current data may advance understanding of such coastal and diurnal events.

Saildrones are well instrumented to study frontal-scale air–sea interactions because of their coherent sampling of meteorological and oceanographic variables. They also have the flexibility to sail along and across frontal features. On 18–19 April 2018, the saildrone measured winds both perpendicular and parallel to a strong oceanic front, defined by a sharp change in SST. The data show the effects of wind direction, relative to the SST front, on air–sea energy fluxes. Submesoscale theory has sought to describe such relationships, but the directionality has not been accounted for in large-scale model parameterizations or for global observational products—an opportunity for saildrone measurements to reduce potential systematic biases in these systems.

The value of outfitting saildrones with subsurface temperature loggers was reinforced on 20 Apr 2018 during a diurnal warming event due to strong insolation and little near-surface mixing in weak winds. Almost 2 K of warming in the top 1.5 m of water was strongly concentrated at the surface and deepened through the day, thermally stratifying the upper ocean. The daytime SSTs measured by the saildrone (black track with white dots marking 10-km intervals) differ from the ensuing night's SSTs (measured in a satellite pass when the saildrone was located at the cyan dot) by 0.5–1 K. The temperatures observed by along-keel loggers diverge from each other, reflecting the change in temperature with small differences in depth. Observations of diurnal stratification with coincident atmospheric observations are scarce.

Light blue vectors along the track show the uppermost acoustic Doppler current profiler (ADCP) measurements of currents (4.2 m). Red vectors: wind measured by the saildrone. Gray vectors: HF radar currents at 21:00:00 UTC on 20 Apr 2018. White: clouds or land. The saildrone circum-navigated NOAA buoy 46086 five times along the square west of the cyan dot.

Saildrones are deployed around the world—circumnavigating Antarctica, in the Arctic, surveying fish stock off the U.S. West Coast and off Norway, surveying the tropical Pacific, and conducting bathymetric surveying in the Gulf of Mexico. This year Saildrone, Inc., expects to expand deployments further and openly distribute

data from a University of Rhode Island survey of the wintertime Gulf Stream. Future cruises with open data policies are planned in the Arctic Ocean and North Brazil Current. The data collected could substantially impact our understanding of upper-ocean dynamics and the complex interactions between the ocean and atmosphere. ●●

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BAMS: What would you like readers to learn from this article?

Jorge Vazquez–Cuervo (Jet Propulsion Laboratory, CalTech): *Saildrone can measure the smallest scales of ocean dynamics and will be a great complement to satellite-derived measurements.*

Peter Minnett (University of Miami, Florida): *The saildrone measurements also complement those made from buoys and ships. These autonomous vehicles provide a paradigm shift in how measurements in the upper ocean and lower atmosphere can be made over long periods.*

Sebastien de Halleux (Saildrone, Inc.): *And saildrones use only renewable energy...no carbon footprint.*

BAMS: How did you become interested in doing this experiment?

Chelle Gentemann (Farallon Institute and Earth and Space Research): *I learned about saildrones in 2016 and wanted to see how an autonomous vehicle might be able to gather data at the air–sea interface and adapt sampling to changing conditions. There are some questions that are hard to get at from existing remote sensing and in situ datasets.*

PM: *I'm interested in better sampling of ocean surface and lower-atmosphere variables, and of air–sea fluxes: taking measurements*

that can be used to assess the accuracy of satellite measurements of the ocean surface, and which can guide improvements in algorithms used to derive those variables.

BAMS: What's an example of those difficult-to-study areas suited to saildrones?

JVC: *I have always been interested in the coast, as it affects so many people. Saildrone provides a capability to measure how things change in these critical areas of the world's oceans.*

SdH: *Satellites have an amazing power to produce large-scale remote sensing data sets, but they have challenges with fine features, land proximity, and, of course, the need to connect to subsurface phenomena. An in-situ platform such as the Saildrone USV can enhance the value of large (and expensive) remote sensing datasets. I was excited to see this possibility being adopted in the field by this talented team.*

BAMS: What surprised you during the project?

PM: *The ability to reprogram the vehicles in real time to focus on sampling and resampling interesting surface features. The quality of the measurements is impressive.*

JVC: *I was amazed to see how well the saildrone observations matched up with the satellite measurements.*

SdH: *As an engineer, I am fascinated*

by the amount of scientific insights derived from in situ observations collected by the saildrone. It illustrates the importance of rigorous quality control and strong community involvement to get the best out of new data being generated.

CG: *I was surprised by how much fun it was to design and run the field campaign from my computer. The ocean can be beautiful but dangerous, and gathering ship observations can require long absences from your family.*

BAMS: What was the biggest challenge you encountered while doing this work?

CG: *Clouds. It was challenging to access high-resolution satellite imagery at the right time and place to plan vehicle trajectories when clouds kept blocking the view of the ocean.*

SdH: *Remote communications. One of the challenges of using autonomous platform was how to keep a large team communicating efficiently over a long period of time. Many of the lessons from this mission have been used to create a "virtual mission control center," which has proved invaluable.*

BAMS: What's next?

SdH: *The key and exciting question is: what new science will these platforms enable? I hope this article will trigger new ideas for further exploration.*