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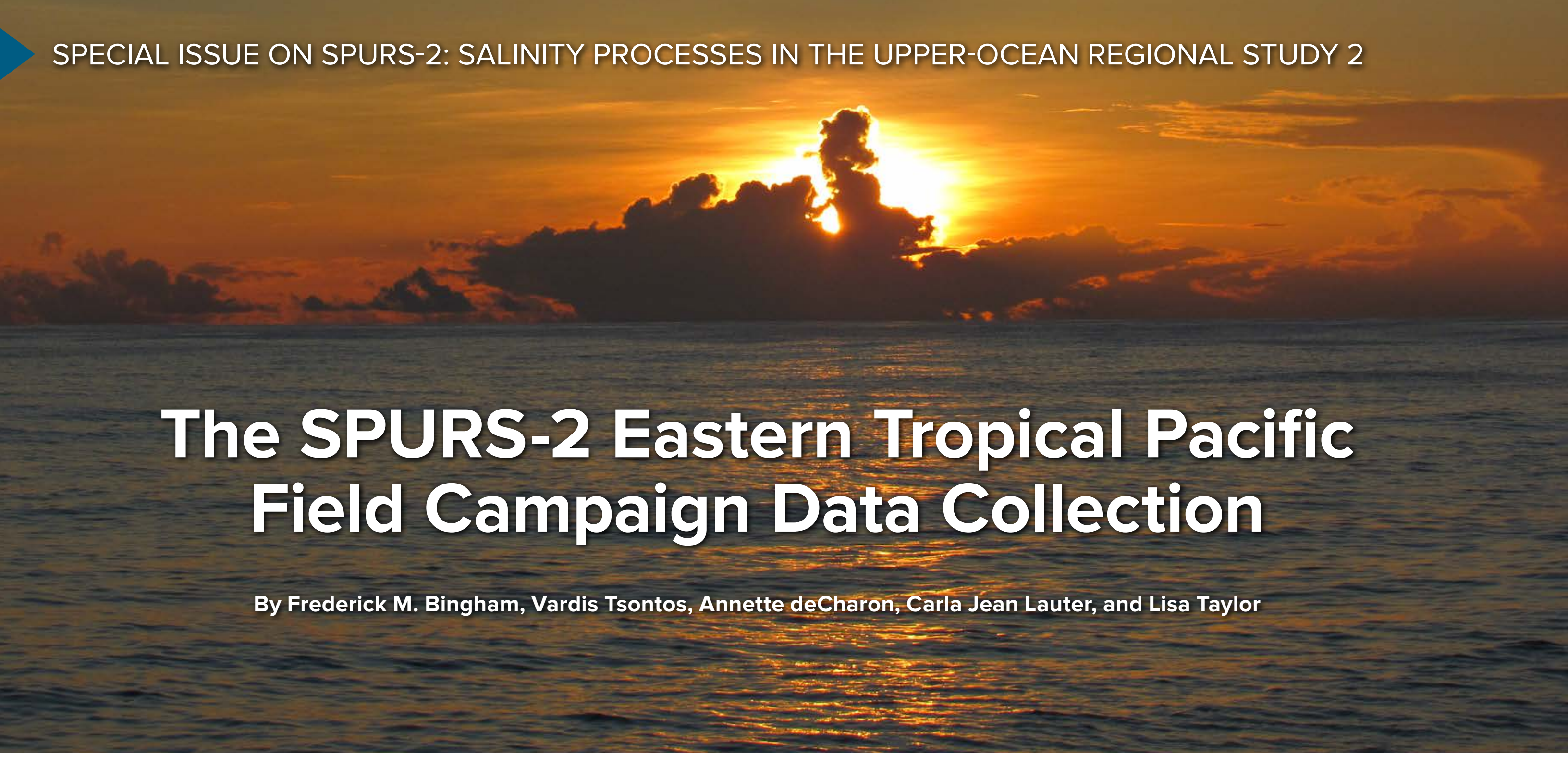
SPECIAL ISSUE ON SPURS-2: SALINITY PROCESSES IN THE UPPER-OCEAN REGIONAL STUDY 2



The SPURS-2 Eastern Tropical Pacific Field Campaign Data Collection

By Frederick M. Bingham, Vardis Tsontos, Annette deCharon, Carla Jean Lauter, and Lisa Taylor

ABSTRACT. This paper describes the large, diverse set of in situ data collected during the Salinity Processes in the Upper-ocean Regional Study 2 (SPURS-2) field campaign. The data set includes measurements of the ocean, atmosphere, and fluxes between atmosphere and ocean; measurements of the skin surface layer, bulk mixed layer, and deeper water; (mostly) physical, chemical, and biological measurements; and ship-based, mobile drifting/floating, and moored observations. We include references detailing the methods for collection of each data set, provide DOIs for accessing the data, and note some papers in this special issue that use them. To facilitate broader access to SPURS-2 data and information, we created an online tool that allows users to explore data sets organized by various categories (e.g., instrument type, mobility, depth). This tool will complement content available from the Physical Oceanography Distributed Active Archive Center (PO.DAAC) and will be highly engaging for visual learners.

INTRODUCTION

The Salinity Processes in the Upper-ocean Regional Study 2 (SPURS-2) field campaign was an international, multi-investigator project that took place in the eastern tropical Pacific Ocean during 2016–2017 (Figure 1a). It was designed as a complement and follow-on to SPURS-1, which was conducted in the subtropical North Atlantic in 2012–2013. Results from SPURS-1 can be found in the March 2015 issue of *Oceanography* (Lindstrom et al., 2015). The purpose of SPURS-2 was to study the dynamics of the rainfall-dominated surface ocean at the western edge of the Eastern Pacific Fresh Pool (Alory et al., 2012), a region characterized by high seasonal variability (Fiedler and Talley, 2006; Guimbard et al., 2017) and subject to strong zonal flows associated with the North Equatorial Current and Counter Current (Kessler, 2006). The campaign sought to address the questions: How does the ocean integrate the freshwater forcing and destroy variance created at the surface? What are the local and non-local effects of freshwater flux on the ocean? More detailed information about SPURS-2 can be found in SPURS-2 Planning Group (2015), Lindstrom et al. (2017), and in articles in this special issue of *Oceanography*.

The SPURS-2 field campaign consisted of a large variety of autonomous, drifting, ship-based, and moored in situ instrumentation. Some of the instruments were standard (e.g., CTDs) and others very unusual or innovative (e.g., SEA-POL radar and saildrones). The activity was centered at a main mooring located near 10°N, 125°W, and two other moorings were deployed to the north and south (Figure 1b).

Two ships visited the SPURS-2 site, R/V *Roger Revelle* (Table 1) operated by Scripps Institution of Oceanography, and the schooner *Lady Amber*. There were two cruises on *Revelle* in August–September 2016 and October–November 2017 (Table 1 and Figure 1a,b).

Lady Amber is a 20 m long twin-masted schooner, outfitted with a thermosalinograph and meteorological instrumentation (Rainville et al., 2019, in this issue). It represents a proof-of-concept for the NASA Physical Oceanography Program's exploration of new avenues for conducting oceanographic research in an environment constrained by cost and high demand for major research vessel time. Perhaps it could be considered a throwback to an earlier era of oceanographic research. *Lady Amber* visited the SPURS-2 site several times during the yearlong field campaign, (see Rainville et al., 2019, in this issue), whereas *Revelle* was only able to visit the site at the beginning and end. *Lady Amber* was used for light deployment and recovery of instrument platforms as well as coordinated scientific activities with the larger and more mobile and capable *Revelle*.

The SPURS-2 field campaign was extensive in its scope, innovative in its approach, diverse in its participation, and heterogeneous in its methods. The purpose of this paper is to give an overview of the various component data sets that were collected during the program. Many of these data sets are described more fully elsewhere, but it is useful to put all of this information into one place to emphasize the degree of unity and coordination that went into the field program. In addition, we gathered all of the data set DOIs into one table (Table 2) to allow readers access to the full suite of data. Lastly, we describe an interactive online tool that is designed to actively explore the relationships among SPURS-2 data sets. This tool also includes links to additional contextual information such as posts from the cruise blog.

DATA ELEMENTS

The full list of SPURS-2 data sets (Table 2) shows the collection's heterogeneity. SPURS-2 was unique in the use of innovative sensors and platforms coordinated with more traditional ones. The innovative sensors and platforms included saildrones (Zhang et al., 2019, in this issue), *Lady Amber* (Rainville et al., 2019, in this issue), the salinity snake, the surface salinity profiler (Drushka et al., 2019, in this issue), and the SEA-POL radar (Rutledge et al., 2019, in this issue), plus a dedicated regional modeling system (Li et al., 2019, in this issue). The tropical

FACING PAGE. All photos, except as noted, courtesy of Eric Lindstrom. Abbreviations are defined in Box 1. Middle set of photos, starting at the top left, proceeding clockwise and spiraling inward: (1) SEA-POL radome installed on R/V *Revelle* for cruise 2. Also visible are the laser for the CFT in front of radome and the radiometer for the ROSR to the right. (2) Janet Sprintall (pointing) and some members of her group watching a display during a CTD cast on *Revelle* cruise 1. (3) Two yellow Seagliders in the foreground and a neutrally buoyant float in the background before deployment on *Revelle* cruise 1. (4) Two gray and white PICO moorings on the aft deck of *Revelle*, one about to be deployed. (5) A radiosonde about to be launched. (6) A front view of the SSP secured on deck. (7) The LA. (8) A Wave Glider being deployed from *Revelle*. (8) Flotation for the central mooring being prepared for deployment on the aft deck of *Revelle*. (9) A nighttime view of some of the meteorological instrumentation on the bow of *Revelle* (photo courtesy of Julian Schanze). (10) The central mooring.

Pacific, particularly in this region, is a difficult place to sample. Currents are strong and highly variable, both on seasonal and shorter timescales (Guimbard et al., 2017; Melnichenko et al., 2019, in this issue). This fact renders traditional Lagrangian methods less effective, as drifters placed into the region have very short residence times. The Lagrangian frame experiment, making use of Seagliders and Wave Gliders to follow the motion of a neutrally buoyant float (Shcherbina et al., 2019, in this issue), was set up to finesse this issue. Heavy rainfall, the principal reason for conducting SPURS-2 in this region, is patchy and difficult to sample, necessitating the use of sophisticated rain radar (Rutledge et al., 2019, in this issue). Surface-intensified freshwater lenses are the principal mechanism by which this heavy rainfall gets incorporated into the bulk mixed layer and spread across the Pacific basin (SPURS-2 Planning Group, 2015). These layers, generally not more than a couple of meters thick and transient, last on the of order hours or less and are small in horizontal scale, no more than a few kilometers (Drushka et al., 2019, and Schanze et al., 2019, both in this issue). This motivated the use of rain radar, along with high vertical resolution sampling of surface layers in the wakes of rain events. These observations could then be related back to satellite measurements of sea surface salinity (SSS) made by Soil Moisture and Ocean Salinity (SMOS) and Soil Moisture Active Passive (SMAP) satellites (Supply et al., 2018). This gives us an improved understanding of the surface signature being resolved by these satellite missions and provides a better sense of what satellite data can tell us about this and other similar rainfall-dominated regions.

Scientists wishing to use the data collected during SPURS-2 are urged, if possible, to cite directly the individual data sets they use (e.g., Drushka, 2018). This issue is undergoing a spirited debate in the world of science publishing (http://www.copdess.org/enabling-fair-data-project/enabling-fair-project-overview/). We believe that in the future data sets will be acknowledged by such citations. If a particular journal does not allow this kind of data set citation, those using these data should endeavor to find and cite the most appropriate reference. Table 2 gives a place to start that search.

For the sake of organization, the elements of Table 2 are divided loosely into categories as to how deep they measure; whether they are drifting, fixed (moored), mobile, or ship-based; and whether they are physical, chemical, or biological. Several papers in this special issue of *Oceanography* have made extensive use of these data as can be seen in the References column.

DATA SET EXPLORATION TOOL

The information in Table 2 has also been organized into an ontology, which is a collection of encoded terms and relationships used in computer sciences (Antoniou and van Harmelen, 2004). Ontologies can be visualized to illustrate complex conceptual relationships, for example, between

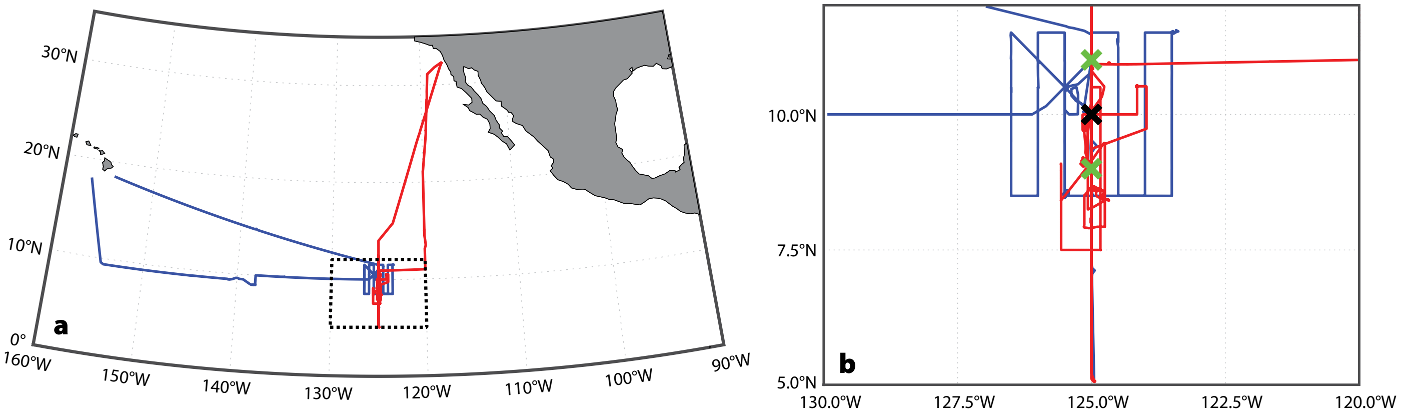


FIGURE 1. Tracks of R/V *Revelle* for cruise 1 (blue) and cruise 2 (red). See Table 1 for cruise dates. Boundaries for panel b are shown in panel a by a dotted line. The black "X" marker in panel b is the nominal location of the central mooring (Table 2, #s 27–30) and green "X"s are the locations of the north and south PICO (Platform Instrumentation for Continuous Observations) moorings (Table 2, #s 23–26).

TABLE 1. Information about R/V *Revelle* cruises.

Cruise Number	Departure Date/ Port	Completion Date/ Port	UNOLS Cruise Designation	Data URL*	Chief Scientist (Institution)
1	August 13, 2016/ Honolulu, HI	September 23, 2016/ Honolulu, HI	RR1610	http://www.rvdata.us/catalog/RR1610	A. Jessup (UW APL)
2	October 16, 2017/ San Diego, CA	November 17, 2017/ San Diego, CA	RR1720	http://www.rvdata.us/catalog/RR1720	K. Drushka (UW APL)

*This column shows where some of the processed shipboard data can be accessed.

TABLE 2. Information about individual SPURS-2 data sets. "Revelle-1"/"Revelle-2" refers to data sets associated with the first/second R/V *Revelle* cruise (Table 1).

O/A/F: O = Ocean; A = Atmosphere; F = Ocean-Atmosphere Flux

P/C/B: P = Physical; C = Chemical; B = Biological; Pc = Currents;
Pt = Temperature/Salinity; Pw = Waves

D/F/M/S: D = Drifting; F = Fixed; M = Mobile; S = Ship-Based

S/T/D: S = Skin (<2 cm); T = Top (2 cm–6 m); D = Deep

Table 2 forms the heart of this paper, listing the individual SPURS-2 data sets. Because many of the data sets were not finalized by the time of submission of this paper, the DOIs given in Table 2 may not be active immediately. We plan to maintain an updated version of this table at the SPURS archive website, https://podaac.jpl.nasa.gov/SPURS.

#	Data Set Name and DOI	Institution[1]	O/A/F	P/C/B	D/F/M/S	S/T/D	References[2]
1,2	Revelle-1 and -2 ADCP 150 kHz BB https://doi.org/10.5067/SPUR2-ADCP0	SIO	O	Pc	S	D	
3,4	Revelle-1 ADCP 150 kHz NB https://doi.org/10.5067/SPUR2-ADCP0	SIO	O	Pc	S	D	
5,6	Revelle-1 ADCP 75 kHz NB https://doi.org/10.5067/SPUR2-ADCP0	SIO	O	Pc	S	D	
7,8	Revelle-1 and -2 CTD https://doi.org/10.5067/SPUR2-CTD00	SIO	O	Pt	S	D	
9,10	Revelle-1 and -2 XBT https://doi.org/10.5067/SPUR2-XBT00	SIO	O	Pt	S	D	
11,12	Revelle-1 and -2 uCTD https://doi.org/10.5067/SPUR2-UCTD0	SIO	O	Pt	S	D	Ullman and Hebert, 2014; Sprintall, 2019
13,14	Revelle-1 and -2 underway/USPS https://doi.org/10.5067/SPUR2-USPS0	UW APL	O	Pt	S	T	Asher et al., 2014a; Drushka et al., 2019
15	Argo floats https://doi.org/10.5067/SPUR2-ARGO0	UW APL	O	Pct	D	D	Riser et al., 2019
16	PALS on floats and moorings https://doi.org/10.5067/SPUR2-PALS0	UW APL	F		D, F		Yang et al., 2015
17	Wave Gliders https://doi.org/10.5067/SPUR2-GLID3	WHOI	O, A, F	Pt	M	T	
18	Seagliders https://doi.org/10.5067/SPUR2-GLID1	UW APL	O	Pt	M	D	Eriksen et al., 2001
19	SVP-S drifters https://doi.org/10.5067/SPUR2-DRIFT	SIO	O	Pct	D	T	Hormann et al., 2015; Lindstrom et al., 2017; Centurioni, 2018; Volkov et al., 2019
20	Surpact drifters https://doi.org/10.5067/SPUR2-DRIFT	L'OCEAN	O, F	Pct	D	T	Reverdin et al., 2013
21	Revelle-2 CODE drifters https://doi.org/10.5067/SPUR2-DRIFT	SIO	O	Pct	D	T	Centurioni, 2018
22	Revelle-2 ADOS drifter https://doi.org/10.5067/SPUR2-DRIFT	SIO	O	Pct	D	T	Centurioni, 2010, 2018
23	North PICO mooring meteorological https://doi.org/10.5067/SPUR2-MOOR2	PMEL	A, F		F		Freitag et al., 2018
24	South PICO mooring meteorological https://doi.org/10.5067/SPUR2-MOOR2	PMEL	A, F		F		Freitag et al., 2018
25	North PICO mooring CTD https://doi.org/10.5067/SPUR2-MOOR2	PMEL	O	Pt	F	T, D	Osse et al., 2015
26	South PICO mooring CTD https://doi.org/10.5067/SPUR2-MOOR2	PMEL	O	Pt	F	T, D	Osse et al., 2015
27	Central mooring meteorological https://doi.org/10.5067/SPUR2-MOOR1	WHOI	A, F		F		Clayson et al., 2019
28	Central mooring CTD https://doi.org/10.5067/SPUR2-MOOR1	WHOI	O	Pt	F	T, D	Farrar and Plueddemann, 2019

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TABLE 2. *Continued from previous page...*

#	Data Set Name and DOI	Institution[1]	O/A/F	P/C/B	D/F/M/S	S/T/D	References[2]
29	Central mooring velocity https://doi.org/10.5067/SPUR2-MOOR1	WHOI	O	Pc	F	T, D	Farrar and Plueddemann, 2019
30	Central mooring direct covariance flux https://doi.org/10.5067/SPUR2-MOOR1	WHOI	F		F		Clayson et al., 2019
31	Revelle-2 WAMOS waves https://doi.org/10.5067/SPUR2-WAMOS	UW APL	O	Pw	S	T	
32,33	Revelle-1 and -2 X-band radar imagery and derived rain intensity https://doi.org/10.5067/SPUR2-XBAND	UW APL	F		S		Thompson et al., 2019
34	Neutrally buoyant float https://doi.org/10.5067/SPUR2-NBFLT	UW APL	O	Pct	D	T, D	D'Asaro, 2003; Lindstrom et al., 2017; Shcherbina et al., 2019
35	*Lady Amber* underway https://doi.org/10.5067/SPUR2-LAMBR	UW APL	O, A, F	Pt	S	T	Rainville et al., 2019
36	Revelle-2 Ecomappers https://doi.org/10.5067/SPUR2-ECOMP	WHOI	O	Pt	M	T, D	Hodges and Fratantoni, 2014
37	Revelle-2 underway biology and optics https://doi.org/10.5067/SPUR2-BIONT	ODU	O	B	S	S, T	Olson and Sosik, 2007
38	Revelle-2 profile biology and optics https://doi.org/10.5067/SPUR2-BIONT	ODU	O	B	S	T, D	Olson and Sosik, 2007
39	Saildrones https://doi.org/10.5067/SPUR2-SDRON	PMEL	O, A, F		M	T	Zhang et al., 2019
40	Revelle-1 rawinsondes https://doi.org/10.5067/SPUR2-SONDE	WHOI	A		S		Clayson et al., 2019
41	Revelle-2 rawinsondes https://doi.org/10.5067/SPUR2-SONDE	CSU	A		S		Ciesielski, 2018
42,43	Revelle-1 and -2 meteorological https://doi.org/10.5067/SPUR2-MET00	WHOI	A, F		S		Clayson et al., 2019
44,45	Revelle-1 and -2 salinity snake https://doi.org/10.5067/SPUR2-SNAKE	ESR	O	Pt	S	S	
46,47	Revelle-1 and -2 ROSR https://doi.org/10.5067/SPUR2-ROSR0	UW APL	O	Pt	S	S	Remote Measurements & Research, 2015
48,49	Revelle-1 and -2 CFT https://doi.org/10.5067/SPUR2-CFT00	UW APL	F		S	S	Asher et al., 2004
50,51	Revelle-1 and -2 underway $p\text{CO}_2$, DIC, and pH https://doi.org/10.5067/SPUR2-WQAL	UH	O	C	S	S	Ho et al., 1997; Pierrot et al., 2009; Friederich et al., 2002; Martz et al., 2010
52,53	Revelle-1 and -2 A-sphere https://doi.org/10.5067/SPUR2-ASPHER	WHOI	F		S		
54	Revelle-2 SEA-POL rain radar https://doi.org/10.5067/SPUR2-RNRDR	CSU	A, F		S		Rutledge et al., 2019; George et al., 2018
55,56	Revelle-1 and -2 SSP https://doi.org/10.5067/SPUR2-SSP00	UW APL	O	Pt	S	S, T	Asher et al., 2014a,b; Drushka et al., 2019
57	Synthesis rain product[3] https://doi.org/10.5067/SPUR2-SNTH0	UW APL	F		S		
58	Synthesis SSS product[3] https://doi.org/10.5067/SPUR2-SNTH0	UW APL	O	Pt	F		

[1] See Box 1 for a list of abbreviations.

[2] The list of references gives references to the methods associated with the measurement and papers in this special issue that make use of the data. More information may be available in the archived data file at the given DOI.

[3] The nature of these products is not certain as of the publication date of this paper.

oceanographic instruments, data types, and underlying scientific concepts (deCharon et al., 2015). Information about SPURS-2 data sets has been categorized into a set of terms. Relationships between these terms have been mapped using five mathematical symbols (>, <, =, ~, ≈). In turn, the meaning of each symbol has been translated to phrases. These terms and their relationships are visualized via a customized data exploration tool developed for SPURS-2 that can be accessed at https://salinity.oceansciences.org/science-spurs-datatool.htm.

Within this online tool, the ontology is viewed as interactive objects whose relationships are depicted as labeled arrows (Figure 2). As a result, the tool has flexible starting points and no "dead ends," enabling self-directed exploration of the SPURS-2 data collection. Figure 3 shows an expanded view of the term "surface salinity profiler," as presented by the data exploration tool. This visualization allows users to quickly grasp how this particular instrument fits into the bigger picture of the SPURS-2 campaign. In the live tool, clicking on any of the peripheral terms will re-center and update the display; for example, "Ship-Based" would be encircled by all the data sets marked as "S" in the sixth column of Table 2.

The data exploration tool also connects to additional SPURS-2 content, including data sources and detailed descriptions of instruments. This technical information is augmented by links to pertinent content on the SPURS-2 blog, hosted by the NASA Earth Observatory (Figure 4). Informative and entertaining, this extensive blog captures not only the stories behind SPURS-2 data acquisition but also provides insights

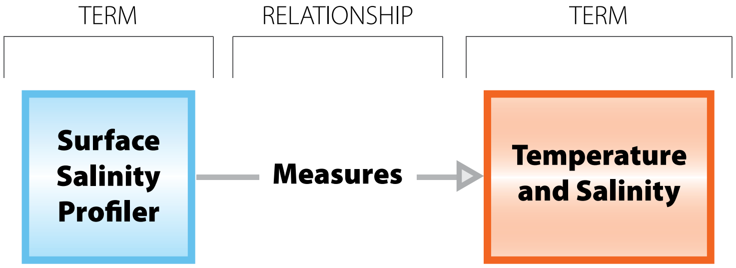
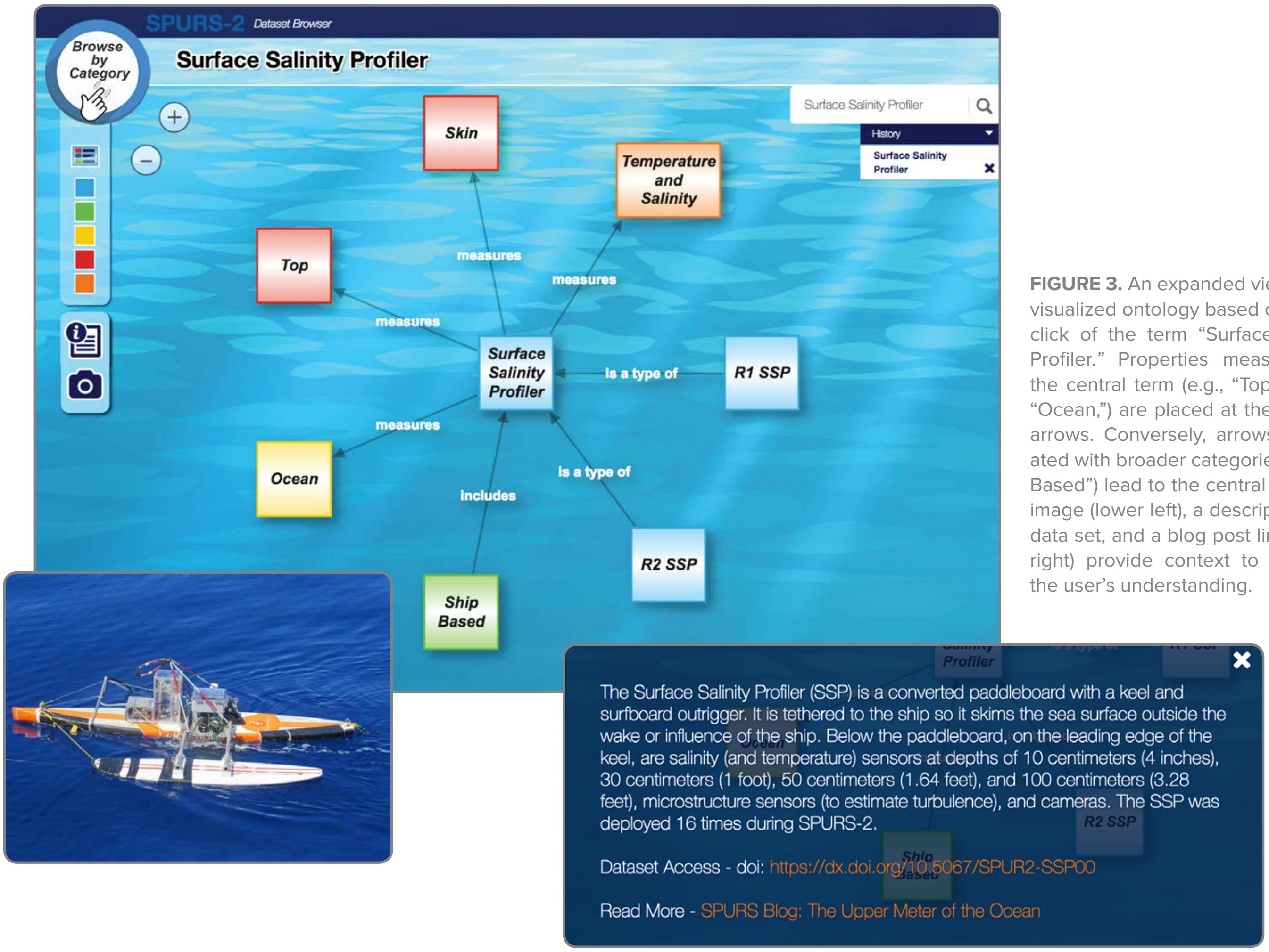


FIGURE 2. An example of a link between terms in the SPURS-2 ontology. When viewed in the data exploration tool, the relationship between terms is described by a linking phrase ("measures").



The Surface Salinity Profiler (SSP) is a converted paddleboard with a keel and surfboard outrigger. It is tethered to the ship so it skims the sea surface outside the wake or influence of the ship. Below the paddleboard, on the leading edge of the keel, are salinity (and temperature) sensors at depths of 10 centimeters (4 inches), 30 centimeters (1 foot), 50 centimeters (1.64 feet), and 100 centimeters (3.28 feet), microstructure sensors (to estimate turbulence), and cameras. The SSP was deployed 16 times during SPURS-2.

Dataset Access - doi: https://dx.doi.org/10.5067/SPUR2-SSP00

Read More - SPURS Blog: The Upper Meter of the Ocean

FIGURE 3. An expanded view of the visualized ontology based on a user click of the term "Surface Salinity Profiler." Properties measured by the central term (e.g., "Top," "Skin," "Ocean,") are placed at the ends of arrows. Conversely, arrows associated with broader categories ("Ship-Based") lead to the central term. An image (lower left), a description of a data set, and a blog post link (lower right) provide context to enhance the user's understanding.

into the individuals, teams, and skills needed to investigate salinity-related processes at the ocean surface.

FIGURE 4. The data exploration tool links to many posts in the SPURS-2 blog, maintained by the NASA Earth Observatory (http://earthobservatory.nasa.gov/blogs/fromthefield/category/spurs/). This example post focuses on the central mooring from the Woods Hole Oceanographic Institution.

Anchoring Ocean Science – Moored Measurements with Steady Humans!

November 12th, 2017 by Eric Lindstrom

WHOI Mooring Buoy (credit Ray Graham).

One of the reasons our work requires a large research vessel is that we are dealing with large arrays of sensors moored in the deep ocean. That requires big buoys, lots of rope and wire, lots of floatation, and big anchors with very strong and steady human guidance.

BOX 1. ABBREVIATIONS

INSTITUTIONS

CSU	Colorado State University
ESR	Earth and Space Research
L'OCEAN	Laboratoire d'Océanographie et du Climat: Expérimentation et Approches Numériques
ODU	Old Dominion University
PMEL	NOAA Pacific Marine Environmental Laboratory
SIO	Scripps Institution of Oceanography, University of California San Diego
UH	University of Hawaii
UW APL	University of Washington Applied Physics Laboratory
WHOI	Woods Hole Oceanographic Institution

OTHER

ADCP	Acoustic Doppler Current Profiler
ADOS	Autonomous Drifting Ocean Station
BB	Broadband
CFT	Controlled Flux Technique
CODE	Coastal Ocean Dynamics Experiment
DOI	Digital Object Identifier
LA	Schooner *Lady Amber*
NB	Narrowband
NCEI	NOAA National Centers for Environmental Information
PALS	Passive Acoustic Listening System
PICO	Platform Instrumentation for Continuous Observations
PO.DAAC	Physical Oceanography Distributed Active Archive Center
ROSR	Remote Ocean Surface Radiometer
SEA-POL	SEAgoing–POLarimetric
SMOS	Soil Moisture and Ocean Salinity Satellite
SMAP	Soil Moisture Active Passive Satellite
SPURS	Salinity Processes in the Upper-ocean Regional Study
SSP	Surface Salinity Profiler
SSS	Sea Surface Salinity
SVP-S	Surface Velocity Program–Salinity
uCTD	underway CTD
URL	Uniform Resource Locator
USPS	Underway Salinity Profiling System

ARCHIVING AND DISTRIBUTION

Efforts are ongoing among SPURS-2 PIs to complete the production of finalized data sets. Once these data sets are produced, they will be packaged with appropriate metadata and placed into a permanent archive at PO.DAAC at the Jet Propulsion Laboratory. The available files will be in netCDF format and CF-compliant consistent with the NOAA National Centers for Environmental Information in situ standard templates (https://www.nodc.noaa.gov/data/formats/netcdf/v2.0/). The URL for SPURS-1 and -2 at PO.DAAC is https://podaac.jpl.nasa.gov/SPURS. In addition to the data that are searchable and accessible via a range of tools and services, there is a list of available SPURS-related publications, reports, and artifacts for these field campaigns.

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