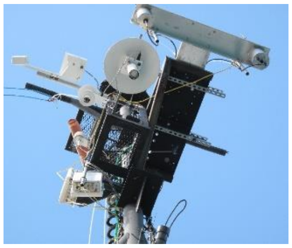
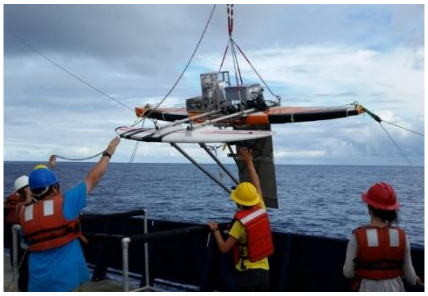
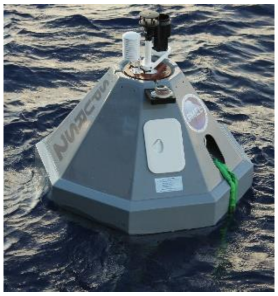
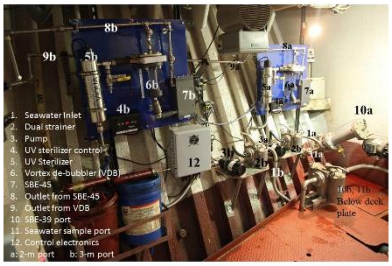
SPURS - 2
Salinity Processes in the Upper Ocean Regional Study

SPURS-2 Cruise Report: R/V *Roger Revelle RR1610*









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SPURS-2 2016 Cruise Report

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W. Asher, F. Bingham, L. Centurioni, C. A. Clayson, K. Drushka, J. Edson, T. Farrar, P. Gaube, D. Ho, B. Hodges, W. Kessler, G. Li, L. Rainville, G. Reverdin, M. Reynolds, J. Schanze, R. Schmidt, A. Shcherbina, J. Sprintall, D. Volkov

A. Overview

The first SPURS-2 research cruise (RR1610) aboard the R/V *Roger Revelle* departed from Honolulu, HI at 1600 HST on 13 Aug 2016 (0200 UTC 14 Aug) and returned to Honolulu on 23 Sep 2016. On 21 Aug, after approximately 7 days transit, the ship entered the study area, a 3° x 3° box centered at 125° W, 10° N. Figure A1 shows the entire ship track and dates of departure/arrival, entering/leaving the study area, and the extent of measurement periods after leaving the study area.

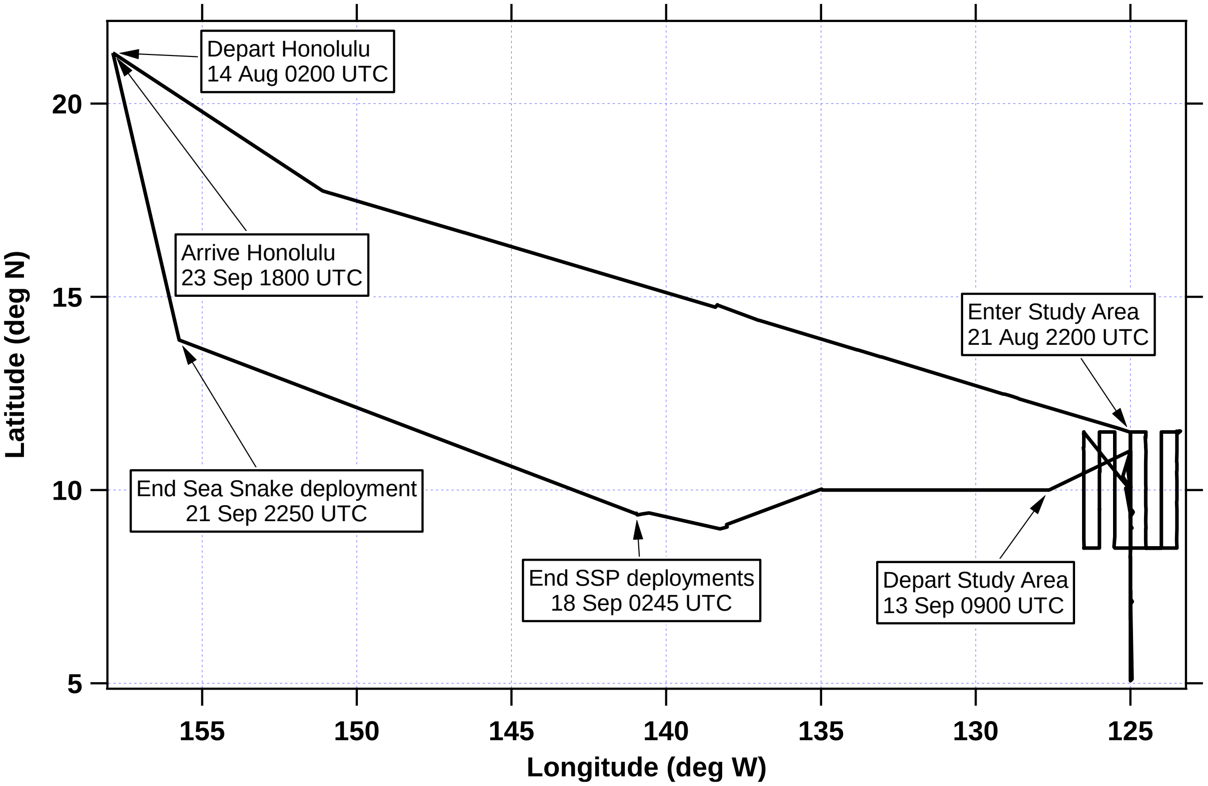


Figure A1. Ship track of the R/V *Roger Revelle* during the 2016 SPURS-2 cruise.

In this section, we briefly outline the orginal cruise plan and address modifications to that plan that were made during the cruise. Following sections contain contributions from participants. Table 1 lists the major proposals and investigators that contributed to the 2016 SPURS-2 cruise.

Table 1. Proposal title, investigators, and lead institutions for the 2016 SPURS-2 cruise

Project Name	**Investigators**	**Lead**
Studies of Near-surface Salinity with Surface Lagrangian Drifters in Support of SPURS-2	Luca Centurioni, Yi Chao and Nikolai Maximenko	SIO
An Annual Cycle of Upper Ocean Salinity in a Rainfall–Dominated Region Captured by High-Resolution Glider Surveys	Luc Rainville, Craig M. Lee, Charles Eriksen, Kyla Druska	APL-UW
The SPURS-2 Information System (SPURS-IS)	Frederick Bingham, Peggy Li and Zhijin Li	UNC Wilmington
Multi-Scale Data Assimilation, Forecasting and Modeling in Support of SPURS-2	Zhijin Li, Peggy Li, and Frederick Bingham	NASA / JPL
Ship-based Quantification of Evaporation, Precipitation, and Surface Fluxes in SPURS-2	Carol Anne Clayson and Jim Edson	WHOI
Moored measurements for SPURS-2: salinity, precipitation, evaporation and other quantities	Tom Farrar, Al Plueddemann, Jim Edson, Chidong Zhang, Jie Yang, and William Kessler	WHOI
Autonomous Surveys in the SPURS Freshwater Regime	Ben Hodges and Ray Schmitt	WHOI
High-resolution Lagrangian observation of ocean boundary layer shear and stratification during SPURS-2	Andrey Shcherbina, Eric D'Asaro, Ramsey Harcourt, and Nikolai Maximenko	APL-UW
Understanding the Formation and Evolution of Near Surface Salinity Gradients Produced by Rain	Bill Asher, Andrew Jessup and Kyla Druska	APL-UW
Understanding regional scale upper ocean variability in the eastern tropical Pacific	Janet Sprintall	SIO
Very-near Surface Salinity Measurements during the SPURS-2 Field Campaign	Julian Schanze	ESR
Observing the Fresh Water Cycle Near the Sea Surface in SPURS-2 Using Profiling Float	Steve Riser, Jie Yang	UW
Rain-formed fresh lenses in SPURS-2	Kyla Druska, Bill Asher, Andy Jessup, Luc Rainville	APL-UW
Continuous surface pCO2 and DIC measurements during SPURS-2	David Ho	U. Hawaii
Measurements and Modeling of Precipitation Effects on Turbulence, Mixing, and Salinity Dilution in the Near-Surface Ocean	Chris Zappa and Arnold Gordon	LDEO

The four main activities for the SPURS-2 2016 cruise on the R/V *Roger Revelle* were:

1. Deployment of three moorings
    a. WHOI – Central
    b. PMEL – North
    c. PMEL – South

2. Deployment of autonomous Lagrangian and Maneuverable Assets
    a. Argo/APEX floats
    b. Mixed-Layer Lagrangian Float
    c. SVPS Drifters
    d. Seagliders
    e. Wavegliders

3. Hydrographic Survey
    a. Underway CTD
    b. CTD stations to 1000 m

4. Ship-based measurements of meteorology and near surface signatures of rain events
    a. Flux measurement package mounted on the jackstaff
    b. Salinity Snake
    c. SSP – Surface Salinity Profiler (surface towed body)
    d. LTAIRS – Lighter-than-Air IR System (balloon)
    e. CFT-Controlled Flux Technique: CO_2 laser heating surface patch viewed with IR camera

The requirements for the hydrographic survey and the other ship-based measurement, which focused on measuring active rain events, required a design to accommodate both needs. The ship-based measurements and important constraints were:

- Hydrographic Survey
    - Multiple meridional transects focused around 125 W, 10 N
    - One transect from 2 N to 15 N along 125 W
    - Underway CTD
    - CTD/LADCP stations every 0.5 deg
- Air-sea fluxes
    - Main constraint is pointing into the wind; optimal wind speed range 4-7 kts
- Towed Salinity Snake
    - Can operate underway at all speeds
- Towed Surface Salinity Profiler (SSP) and Lighter-than-Air IR System (LTAIRS)
    - Main constraint is towing at 4 knots

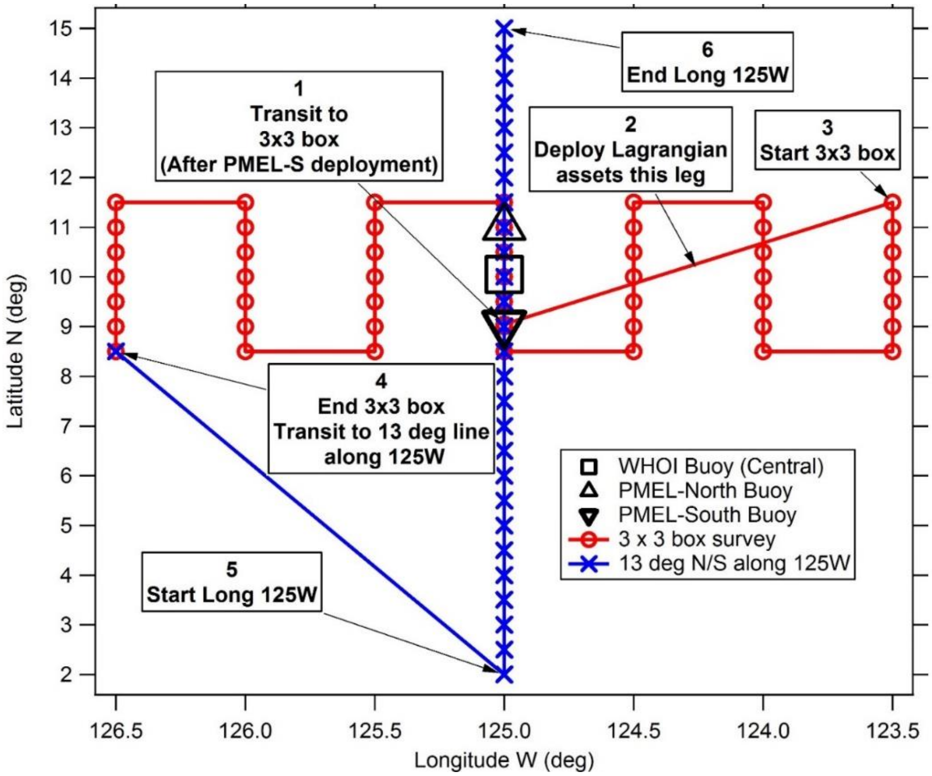


Figure A2: Planned hydrographic survey tracks consisting of 3°x3° Survey Box (red) and transect along 125°W (blue). Also shown are the mooring locations and potential location of deployment of Lagrangian assets.

The proposed combined hydrographic survey (Figure A2) and towed measurements were motivated by the statistical analysis of rain events. The conclusion was that we might expect 6-12 rain events in a 3-week period and only one event might have a rain rate greater than 10 mm/hr. This implied that when rain is encountered, the towed sampling and flux measurements should take priority over other activity.

Therefore, the following approach was developed:

- Conduct hydro survey as usual except when rain is present
    - When rain occurs
        - Stop ship to deploy SSP and balloon
        - Tow SSP into the wind for duration of rain event
        - Suspend CTD stations
        - uCTD deployment continues
    - When rain event ends
        - Stop ship to recover SSP and balloon
        - Resume CTD survey
            - May entail backtracking to missed CTD station(s)
            - May entail delay of up several hours (battery lifetime of SSP is 8 hours)

- If rain is not encountered after several days or weeks, may want to tow SSP between stations to sample "fossil" rain patches
- Time budget for hydro survey for planning purposes
  - 75% of distance at 10 kts
  - 25% of distance at 4 kts

The hydrographic survey carried out during the cruise included the planned 3x3 box centered on the mooring but the planned long transect along 125° W from 2° N to 15° N was modified to cover multiple transits along that meridian but from 5° N to 11° N. This reduction in the extent of the hydrographic survey provided additional time for underway sampling of rain events. The original plan was to transit directly back to Honolulu after completion of the hydrographic survey. This plan was modified to use the additional rain survey time by routing the return in a roughly westerly direction to transit within the ITCZ as much a possible.

The plan to sample rain by towing the SSP at 4 knots for 25% of the survey distance was implemented by deploying the SSP on every 4th leg between the CTD stations at 0.5 deg spacing. In addition, rain was sometimes sampled opportunistically when rain occurred outside of the designated SSP leg of the survey. One of the unanticipated issues with opportunistic sampling is that measurements generally did not begin until it was already raining at the ship locations. As a consequence, we usually missed sampling the onset of the fresh lens formation. After the hydrographic survey was concluded, we switched to sampling for 12 hours at a time on a daily basis. This provided the opportunity to measure the onset of the fresh lens formation when rain events were encountered. An additional unanticipated factor regarding sampling strategies was that the salinity snake measurements were compromised at a speed of 4 knots.

As noted above, our anticipation of the number of rain events we would encounter based on historical buoy data was a maximum of 12 encounters over a 3 week period, with only one strong event with a rain rate of greater than 10 mm hr^{-1}. This anticipated scarcity of events motivated us to do as much opportunistic sampling as possible at the beginning of the measurement period. In fact, we encountered 81 total rain events (greater than 1 mm/hr), 39 moderate events (greater than 10 mm/hr), and 12 strong events (greater than 50 mm/hr). Also, rain was detectable (greater than 0.1 mm/hr) 12% of the time and the total rain accumulation was 384 mm.

B. Ship-based Quantification of Evaporation, Precipitation, and Surface Fluxes

Carol Anne Clayson and Jim Edson

Fluxes and Mean Meteorological Measurements

The Clayson-Edson group deployed two direct covariance flux systems (DCFS) with Licor 7500 open-path infrared hygrometers on the MET mast of the R/V Revelle as shown in Figure B1 (left). These sensors occupied the space normally supporting the R/V Revelle's meteorological sensors, which were moved to a position higher on the mast. The MET mast also supported an optical rain gauge and aspirated temperature and humidity sensors as shown in Figure B1(right). Additional instruments were deployed on the forward and aft O2 and O3 decks. These instruments included self-siphoning and manually read rain-gauges, pressure sensors, solar and IR radiometers, a sky cam, and data loggers.

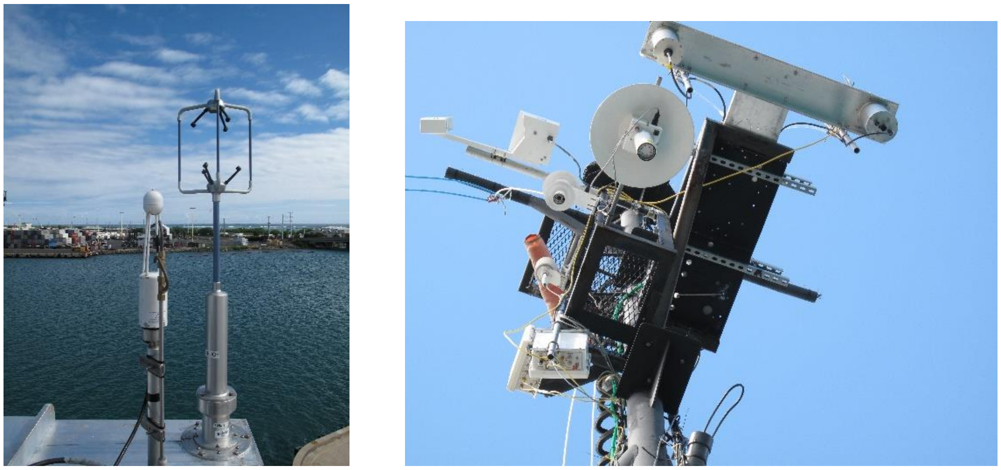


Figure B1. (left) The sonic and Licor from one of the DCFS systems on the MET mast. (right) The instrumented mount on the mast aboard the Revelle as seen from below. The two aspirated temperature/humidity sensors are visible, as is the optical rain gauge

A sea-snake was deployed off the port side of the ship to measure near subsurface sea temperature. This was comprised of a thermistor in heavy-duty tubing that is boomed-out and dragged along the sea-surface. Lastly, a 2-axis sonic anemometer and a RH/T sensor were deployed on the A-frame over the stern to provide improved measurements while traveling downwind. All sensors were operated 24/7 during the experiment with little human intervention. With the exception of the manually-read rain gauges and self-logging ASIMET sensors, all of the instruments were monitored from computers in the main lab.

The preliminary meteorological and upper ocean data set is available through the SPURS dropbox maintained by Fred Bingham. The data files includes:

Yday	Decimal yearday (UTC)
Lat	Latitude (deg)
Lon	Longitude (deg)
SOG	Speed over ground (m/s)
COG	Course over ground (deg)
Heading	Ship's heading (deg)
CurrentE	Eastward component of current (m/s) relative to earth
CurrentN	Northward component of current (m/s) relative to earth
WspdT	Wind speed (m/s) relative to earth at ~18 m
WdirT	Wind direction (deg) from relative to earth
U10	Wind speed (m/s) relative to earth adjusted to 10 m
U10N	Neutral wind speed (m/s) relative to earth adjusted to 10 m and neutral stratification
WspdR	Wind speed (m/s) relative to water at ~18 m
WdirR	Wind direction (deg) from relative to water
Ur10	Wind speed (m/s) relative to water adjusted to 10 m
Ur10N	Neutral wind speed (m/s) relative to water adjusted to 10 m and neutral stratification
Tair	Air Temperature (C) at ~16.5 m
T10	Air Temperature (C) adjusted to 10 m
Tsea	Near surface sea temperature (C) at ~5 cm from the sea snake
SST	Sea surface temperature (C)from Tsea minus cool skin
Tsea2	Near surface sea temperature (C) at 2 m from from the Osspre
Tsea3	Near surface sea temperature (C) at 3 m from from the Osspre
RH	Relative humidity (%) at ~16.5 m
RH10	Relative humidity (%) adjusted to 10 m
Pair	Pressure (mb) at O3 deck

Qair	Specific humidity (g/kg) at ~16.5 m
Q10	Specific humidity (g/kg) adjusted to 10 m
SSQ	Specific humidity (g/kg) at sea surface
Salt	Salinity (psu) from TSG. This will be replaced by Salinity Snake
Salt2	Salinity (psu) at 2 m from the Osspre
Salt3	Salinity (psu)at 3 m from the Osspre
SolarDown	Measured downwelling solar (W/m2)
SolarUp	Reflected solar (W/m2) estimated from Payne (1972)
IRdown	Measured downwelling IR (W/m2)
IRup	Upwelling IR (W/m2) computed from SST with sky correction
Precip	Accumulated precipitation (mm)
Prate	Precipitation rate (mm/hr)
Evap	Accumulated evaporation (mm)
Erate	Evaporation rate (mm/hr)
Ust	Friction velocity (m/s) from COARE 3.5
Tau	Surface stress (N/m2) measured relative to earth
Shf	Sensible heat flux (W/m2)
Lhf	Latent heat flux (W/m2)
Bhf	Buoyancy flux (W/m2)
Rhf	Sensible heat flux from rain (W/m2)

A time series of the radiative fluxes is shown in Figure B2.

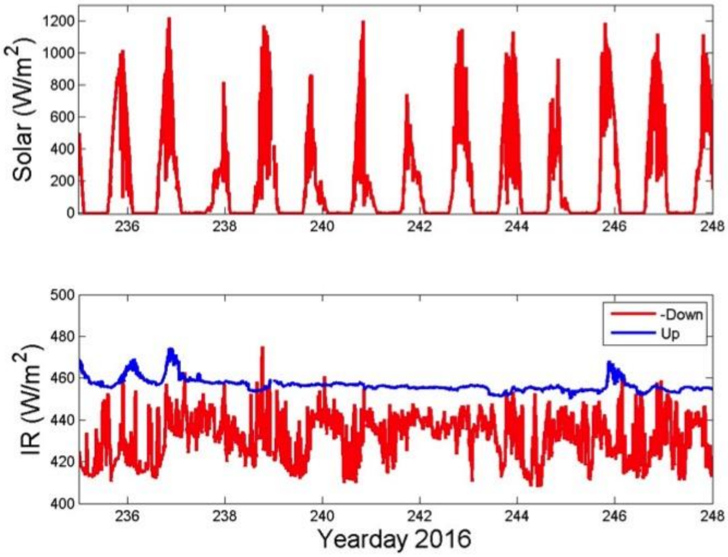


Figure B2. Time series of (top) downwelling solar radiation and (bottom) up and downwelling infrared radiation measured during the cruise.

The wind and current directions are provided in meteorological convention (i.e., direction from). Pair is measured by UConn barometers on the O3 deck. Tair is taken from the calibrated WHOI and UConn aspirated air temperature sensors on the bow mast. These were least affected by solar heating. Qair is computed from the calibrated UConn and WHOI RH/T sensors on the on the bowmast. Qair is less sensitive to solar heating as long as the temperature and RH are measured simultaneously. RH is reconstructed from the Q, aspirated Tair and P measurements to remove the effects of solar heating. The sonic anemometers on the bow mast are used to measure the wind speed and direction. Relative wind speed is taken into consideration to minimize flow distortion.

Tsea is primarily measured by the sea snake after calibration with the Osspre sensors during the night using data processed by Mike Reynolds (RMR). SST is estimated from Tsea after correction for cool skin. This accounts for the difference between Tsea and SST. SSQ, the sea surface specific humidity, is computed from SST. Values of Tsea and Salinity are also provide from the Osspre. SolarDown and IRdown shown in Figure B2 are measured by the pyranometer and purgeometer on the O3 deck, respectively. Solarup is taken from a commonly used parameterization for surface albedo of the ocean (Payne, 1972). IRup was derived from the SST measurements and a correction for reflected IR using the COARE 3.5 algorithm. The bulk fluxes of stress (momentum), sensible heat, latent heat, buoyancy and the sensible heat due to rain were provided by the COARE 3.5 algorithm. The COARE 3.5 algorithm was also used to compute the 10-m values of wind speed, temperature and humidity.

Lat, Lon, SOG, COG and Heading are taken from the ships *.COR files. These are used to compute the wind speed relative to earth. Surface currents are measured by the ship's ADCP provide by Audrey Hasson (LOCEAN) help from Janet Sprintall (SIO). These were used to compute the wind speed relative to water. The wind speed relative to water is used to compute the fluxes.

Rawinsonde Launch Station

The Clayson-Edson group launched rawinsondes every 6-hours to provide profiles of temperature, humidity, wind speed and direction through the marine atmospheric boundary layer and beyond. A new Vaisala sounding system was used during the experiment. It performed extremely well and provided approximately 85 profiles of the marine boundary layer. The average profile of all launches is shown in Figure B3 and height-time series of water vapor is shown in Figure B4. These profiles are being used to provide estimates of precipitable water and its storage and convergence over the SPURS-2 array.

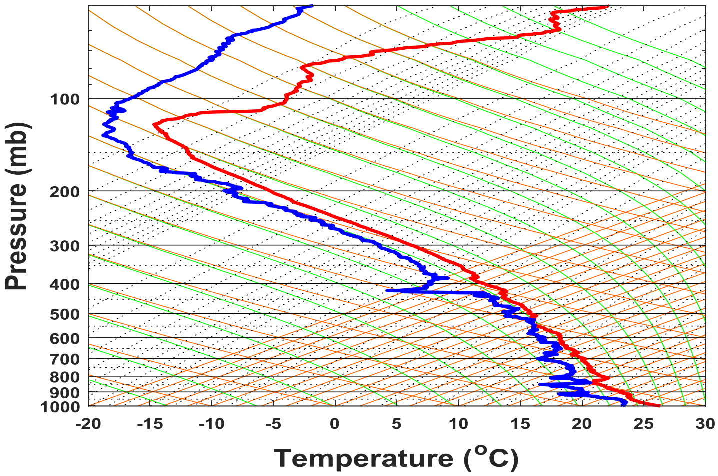


Figure B3. Mean profiles of air and dewpoint temperatures during the cruise.

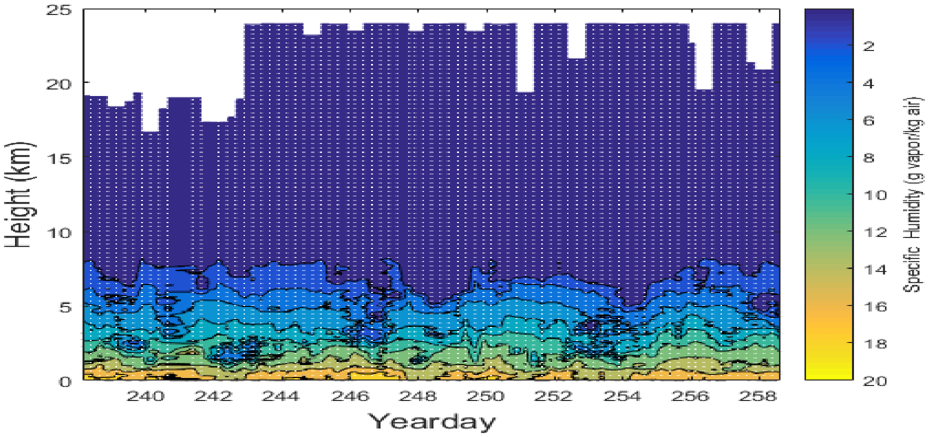


Figure B4. Height-time series plot of specific humidity during the cruise.

C. Moored measurements for SPURS-2: salinity, precipitation, evaporation

Tom Farrar, Al Plueddemann, Jim Edson, Chidong Zhang, Jie Yang, and William Kessler

WHOI mooring

The WHOI surface buoy used in this project is equipped with meteorological instrumentation for estimation of air-sea fluxes, including two Improved Meteorological (IMET) systems. The mooring line also carries current meters, and conductivity and temperature recorders. This mooring is of an inverse-catenary design utilizing wire rope, chain, and synthetic rope and has a scope of 1.45 (scope is defined as slack length/water depth). The buoy is a 2.8-meter diameter foam buoy with an aluminum tower and rigid bridle. The watch circle is 3.8 nm in diameter.

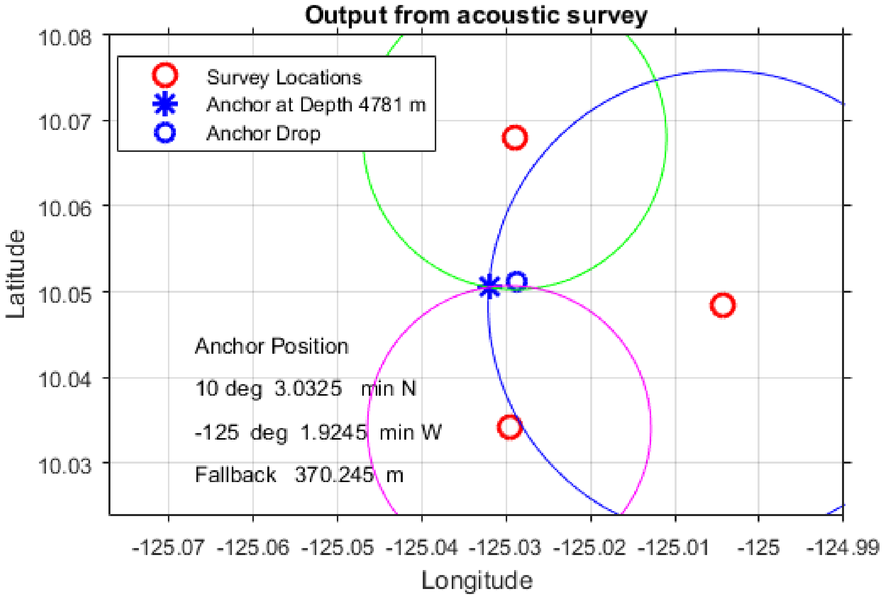


Figure C1: Summary of anchor survey, showing locations where the release was queried (red circles), the anchor drop position (asterisk) and the estimated anchor location (blue circle).

The mooring, WHOI PO mooring #1282, was deployed 24 August 2016, at 10°03.0481'N, 125° 01.939'W. The water depth was 4769 m. The anchor was released from the ship at 18:38:58 UTC and was settled on the seafloor before 20:00 UTC. The anchor position was estimated by performing an 'acoustic anchor survey', pinging the acoustic releases from several positions to triangulate the anchor position. The results of this survey are summarized in Figure C1.

Table C-1: Types of measurements collected on the WHOI-SPURS2 air-sea interaction surface mooring.

Surface Measurements	**Subsurface Measurements**
Wind speed	Temperature
Wind direction	Conductivity
Air temperature	Current speed
Sea surface temperature	Current direction
Barometric pressure	
Relative humidity	
Incoming shortwave radiation	
Incoming longwave radiation	
Precipitation	
Surface wave height and direction (buoy pitch, roll, heave, and yaw)	
Turbulent fluctuations of humidity, temperature, and wind	

Surface Instruments

There are two independent IMET systems (Hosom et al., 1995; Payne and Anderson, 1999) on the buoy (Figure C2). These systems measure the following parameters once per minute, and transmit hourly averages via satellite:

relative humidity with air temperature
barometric pressure
precipitation
wind speed and direction
shortwave radiation
longwave radiation
near-surface ocean temperature and conductivity

All IMET modules are modified for lower power consumption so that a non-rechargeable alkaline battery pack can be used. Near-surface temperature and conductivity are measured with two SeaBird MicroCat (SBE37) instruments with RS-485 interfaces attached to the bottom of the buoy.

One-hour averages of data from the IMET modules are transmitted via Iridium. Data are also logged redundantly on flash cards within the logger/controller for each system and within each meteorological module. The 1-minute data stored on the buoy are more suitable for scientific analysis; when the buoy and mooring are recovered, we will use the data from the two redundant IMET systems, as well as data from the freshly calibrated systems on the research vessels used for deployment and recovery and post-deployment calibrations, to identify any instrument performance problems and develop a "best" time series of the surface meteorology for estimation of air-sea fluxes. However, any SPURS investigators wishing to view the near-real-time data and derived air-sea fluxes may do so by visiting:

http://uop.whoi.edu/currentprojects/SPURS/flux/preliminary_flux.html.

In addition to the IMET measurements, the buoy also carries an instrument to measure the height and direction of surface waves. This instrument was purchased from the U.S. National Data Buoy Center (NDBC) under the terms of a WHOI-NDBC Memorandum of Agreement. The processed, real-time wave data are available from the NDBC web site under Station Number 43010.

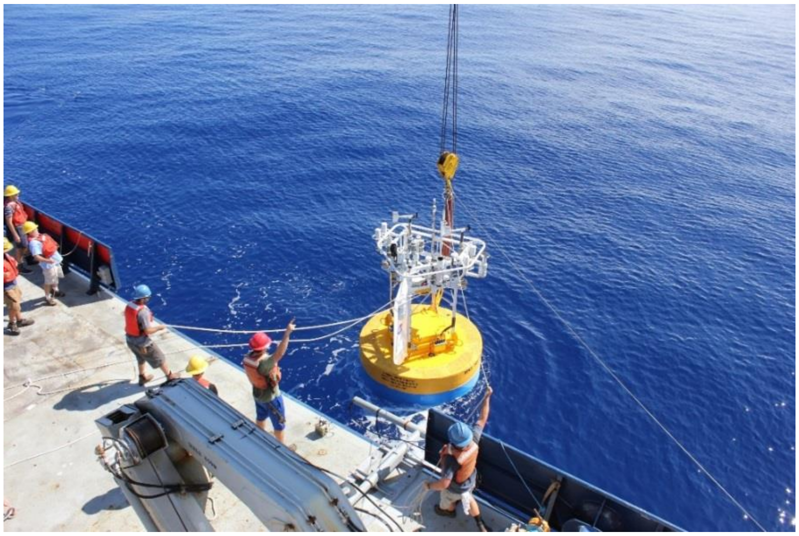


Figure C2: WHOI-SPURS2 surface mooring during deployment.

The buoy also carries an atmospheric turbulence packages for measuring turbulent sensible and latent heat fluxes and wind stress. This instrument package, known as a Direct Covariance Flux Systems (DCFS), includes a fast-response infrared hygrometer (LiCor 7200 model), Gill 3-axis sonic anemometer, and a motion package. The DCFS high frequency wind and platform motion information is used to compute air-sea fluxes. The raw sensors can generate as much as 47 MB of raw data per day. To reduce telemetry requirements, the DCFS calculates means, fluxes and diagnostic information. This information is transmitted back to WHOI in near real-time via a stand-alone Iridum system and disseminated via email to the PIs. The buoyancy fluxes shown in Figure C3 show good agreement with the estimates computed using the COARE 3.5 bulk algorithm with the IMET data. This result indicates that the correction for heave is satisfactory. However, there appears to be a problem with the real-time motion correction algorithm for stress. This is not unexpected as we are using a new motion package and “bugs” are expected due to, e.g., improper axis alignment, incorrect units (e.g., degrees rather than radians) and sign errors. These errors will be identified and corrected in post-processing.

For the IMET meteorological packages and other buoy instruments, instrument types and measurement heights are given in Table III-1, along with the instrument IDs and their associated loggers.

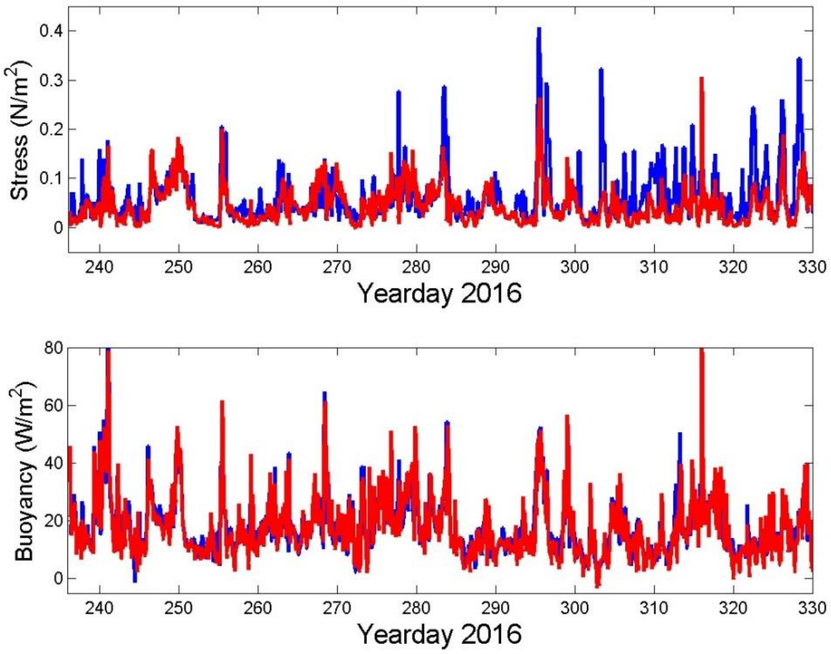


Figure C3. Time-series comparisons of surface stress and buoyancy fluxes computed from the Direct Covariance and Bulk methods using telemetered data.

Remote Sensing

The group has begun to combine remotely sensed variables in the SPURS-2 region with our in situ observations to investigate the larger scale variability in the region. An example of our initial efforts in shown in Figure C4 where time series of salinity from Aquarius overpasses from 2012-2014 are combined with those taken from SMOS and plotting against the in situ salinity telemetered from the SPURS buoy. This figure shows consistent behavior between these observations with slowing increasing salinity during this time period.

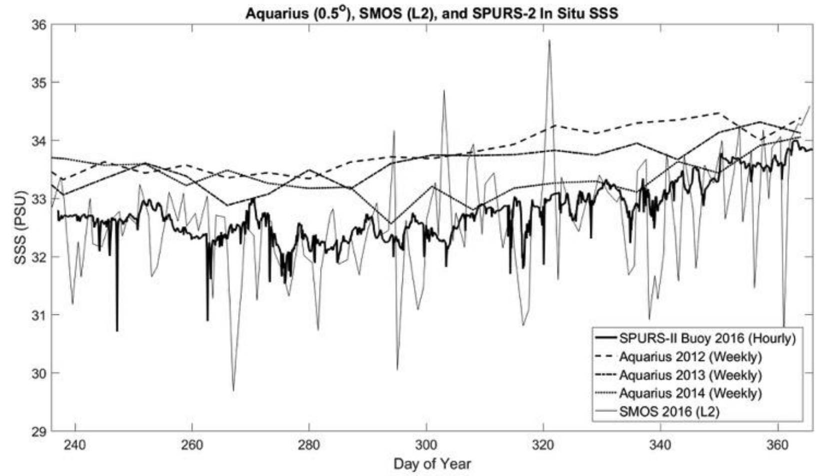


Figure C4. Time series of salinity from Aquarius and SMOS satellites and in situ salinity data from the SPURS mooring

Buoy- Mixed Layer Model Comparisons

One of our main research objectives was to combine our air-sea fluxes of heat, moisture, and momentum with other upper ocean measurements to investigate the effect of air-sea fluxes in particular in driving the upper ocean salinity budget. We have started this analysis by combining observations and one-dimensional mixed layer modeling. This activity will continue in year 3, but here we provide a few highlights from the work we have performed so far.

Several instances of barrier layers are observable in the CTD casts as taken by Janet Sprintall's group (Figure C5). The CTD measurements at the SPURS-2 buoy site were used as initialization fields for the model in the remaining simulations; almost 10 days separated the two casts and these are the days shown in the model simulations. The buoy surface conditions and the surface evolution of the model results are shown in Figure C6 and C7. The 1-m salinity measurements from the buoy are shown in Figure 11 as well. Note that only 1-hourly averages were available for forcing the model; it will be shown later on in this report that this substantially reduces the sharpness of the ocean response to the rainfall. The sharpness of the upper 1 m response to significant rainfall particularly under light wind conditions is evident in the buoy responses, particularly on September 1st. Also evident are days of diurnal warming, and accompanying stratification.

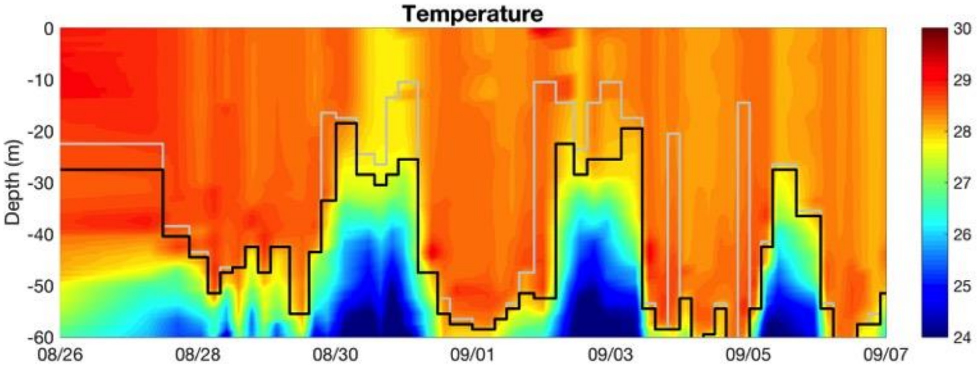


Figure C5. Temperatures from the CTD casts, with the temperature-defined daily mixed layer depth (black line) and the salinity-defined daily mixed layer depth (grey line).

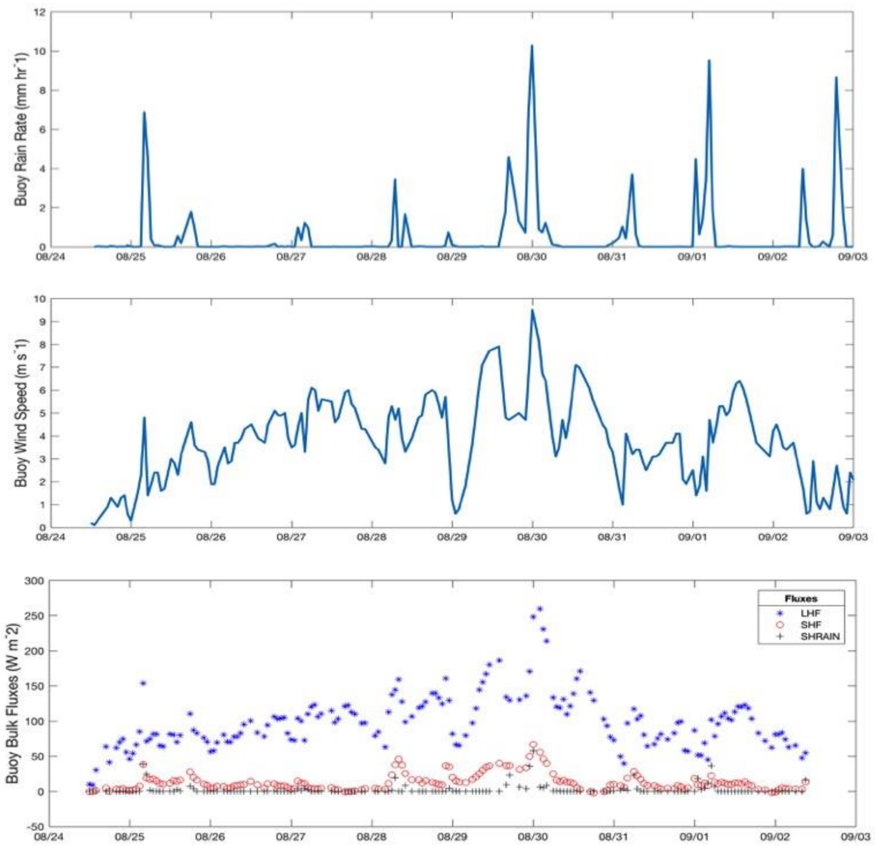


Figure C6. Telemetered buoy observations during cruse showing precipitation, wind speed, and heat fluxes.

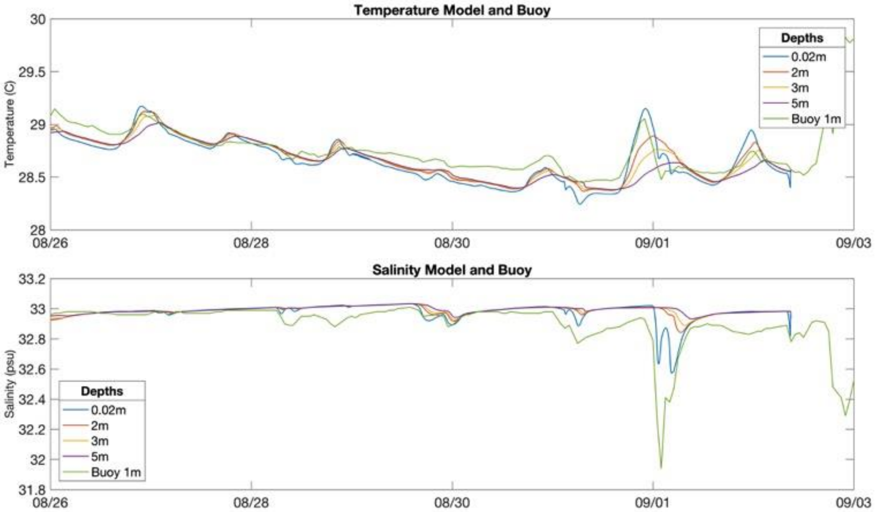


Figure C7. Upper panels: observed rainfall, wind speed, and fluxes from the meteorological instruments on the SPURS-2 buoy. Bottom panels: Temperature and salinity from the ocean mixed layer model and the buoy measurements.

Subsurface Instruments

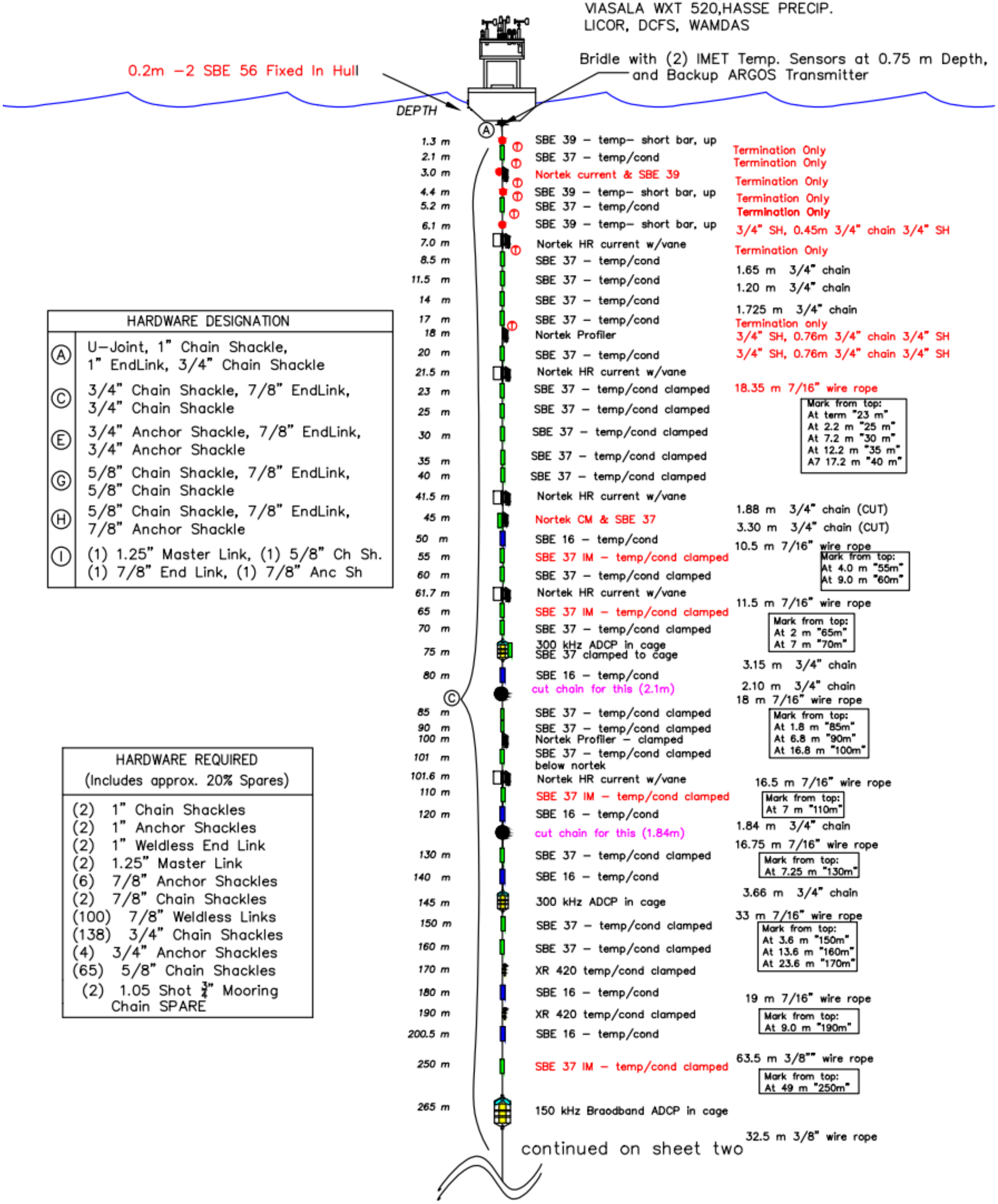
The mooring line is heavily instrumented for measuring temperature, conductivity, and velocity. Figure C8 shows how the instruments are configured on the mooring. The instruments will be described in more detail elsewhere.

Table C1: Measurement heights and sensor types for buoy measurements. The buoy deck is estimated to be 75 cm above the mean water line, so add 75 cm to height above deck to obtain height above sea level.

Parameter(s) measured	Sensor	Height above buoy deck (deck is ~75 cm above sea level)	Serial number and logger number
HRH/ATMP	Rotronic MP-101A	230 cm	506/L-38
BPR	Heise DXD (Dresser Instruments)	238 cm	225/L-38
WND	RM Young	267 cm	362/L-38
PRC	RM Young 50202 Self-siphoning rain gauge	252 cm	229/L-38
LWR	Eppley Precision Infrared Radiometer (PIR)	282 cm	236/L-38
SWR	Eppley Precision Spectral Pyranometer (PSP)	283 cm	504/L-38
SST/SSS	SeaBird Electronics SBE37-SI	-152 cm	3603/L-38
HRH/ATMP	Rotronic MP-101A	220 cm	247/L-43
BPR	Heise DXD (Dresser Instruments)	238 cm	233/L-43
WND	RM Young	266 cm	701/L-43
PRC	RM Young 50202 Self-siphoning rain gauge	253 cm	216/L-43
LWR	Eppley Precision Infrared Radiometer (PIR)	283 cm	209/L-43
SWR	Eppley Precision Spectral Pyranometer (PSP)	283 cm	211/L-43
SST/SSS	SeaBird Electronics SBE37-SI	-152 cm	7048/L-43
HRH/ATMP	LASCAR	162 cm	336/stand-alone
PRC	Hasse	228 cm	HAS001/stand-alone
ATMP	SBE 39, with external thermixtor and radiation shield	217 cm	5276/stand-alone
HRH/ATMP/PRC/WND	Vaisala WXT-520	239 cm	VWX002/stand-alone
HRH/ATMP	Rotronic MP-101A	228 cm	501/stand-alone
HRH/ATMP	Lascar	200 cm	10022364
PRC	Hasse Rain Guage	236 cm	001
DCFS WND			
DCFS H20	LiCor 7200		

PO Mooring # 1282

BUOY WATCH CIRCLE 3.8 N.Miles



continued on sheet two

HARDWARE DESIGNATION	
Ⓐ	U–Joint, 1" Chain Shackle, 1" EndLink, 3/4" Chain Shackle
Ⓒ	3/4" Chain Shackle, 7/8" EndLink, 3/4" Chain Shackle
Ⓔ	3/4" Anchor Shackle, 7/8" EndLink, 3/4" Anchor Shackle
Ⓖ	5/8" Chain Shackle, 7/8" EndLink, 5/8" Chain Shackle
Ⓗ	5/8" Chain Shackle, 7/8" EndLink, 7/8" Anchor Shackle
Ⓘ	(1) 1.25" Master Link, (1) 5/8" Ch Sh. (1) 7/8" End Link, (1) 7/8" Anc Sh

HARDWARE REQUIRED
(Includes approx. 20% Spares)

(2) 1" Chain Shackles
(2) 1" Anchor Shackles
(2) 1" Weldless End Link
(2) 1.25" Master Link
(6) 7/8" Anchor Shackles
(2) 7/8" Chain Shackles
(100) 7/8" Weldless Links
(138) 3/4" Chain Shackles
(4) 3/4" Anchor Shackles
(65) 5/8" Chain Shackles
(2) 1.05 Shot 3/4" Mooring Chain SPARE

SPURS 2 MOORING

V10- Sheet 1 of 2

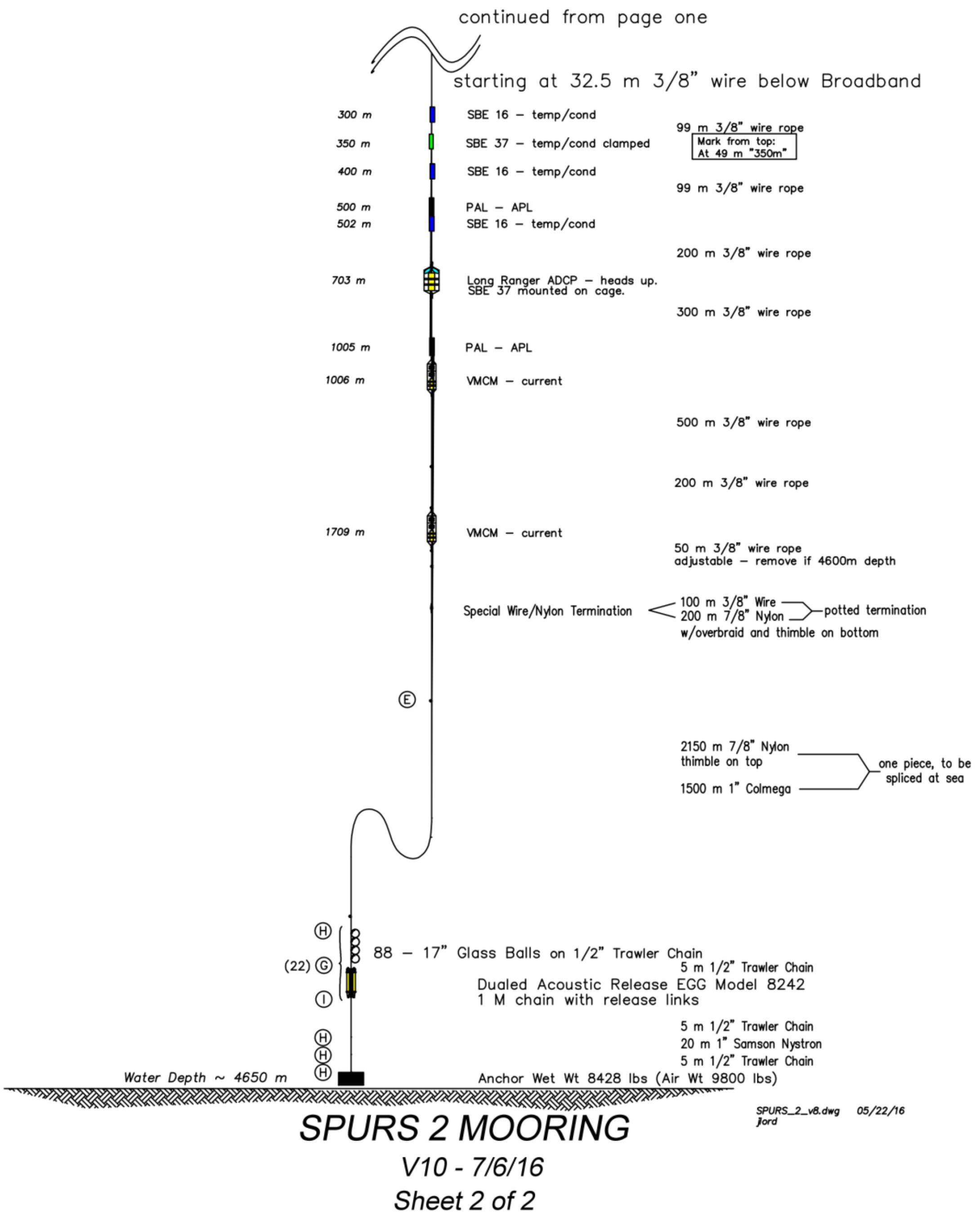


Figure C8 (continued from previous page): Diagram of WHOI-SPURS mooring, showing mooring design and subsurface instrumentation.

NOAA MOORINGS

NOAA-PMEL (Andrew Meyer) deployed two PRAWLER surface moorings at locations of 9° 2.830N, 124° 59.833W and 10° 59.0498N 124° 57.531W, based on a survey of the acoustic releases to determine position (see Figs C9a and b for position maps).

The surface buoy measurements include a Gill Windsonic anemometer, Rotronic Hygroclip2 ATRH, a PMEL-modified RM Young Capacitance raingauge, Druck barometer and Seabird Microcat SBE-37 along with a buoy light, backup positioning system and loadcell.

The PRAWLER is a mooring line crawler that make CTD and DO profiles between 4-450m, nominally set for 8 profiles per day. All data is returned via Iridium in realtime and the PRAWLER can be commanded to change sampling depth and frequency. See attached with mooring diagram (Figure C10) for details.

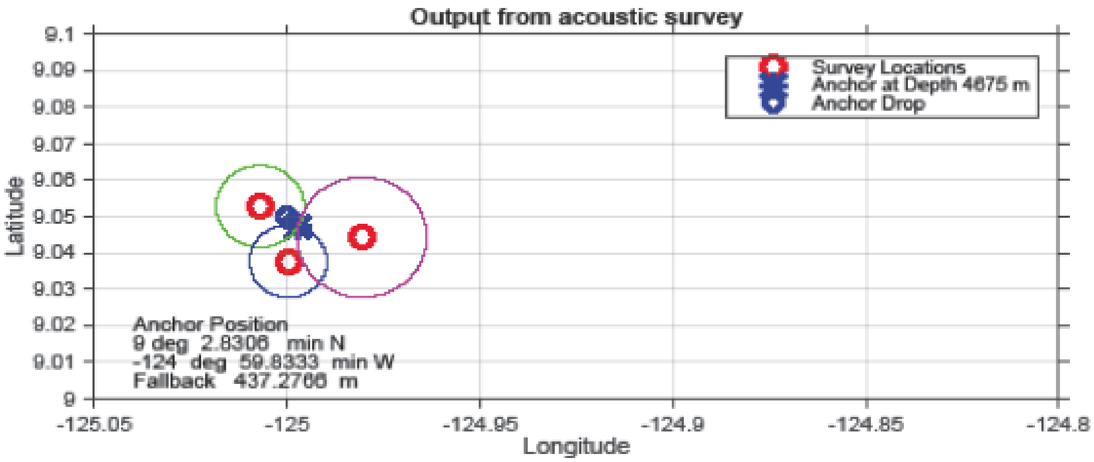


Figure C9a. Anchor position of PMEL nominal 9°N mooring.

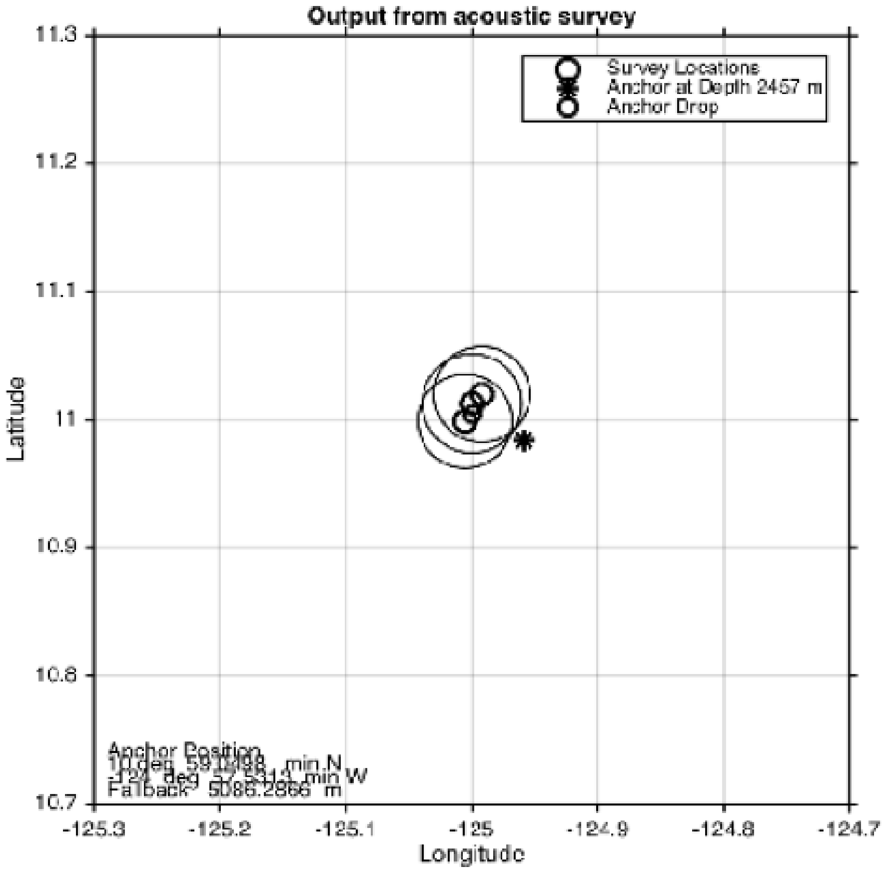


Figure C9b. Anchor position of PMEL nominal 11°N mooring.

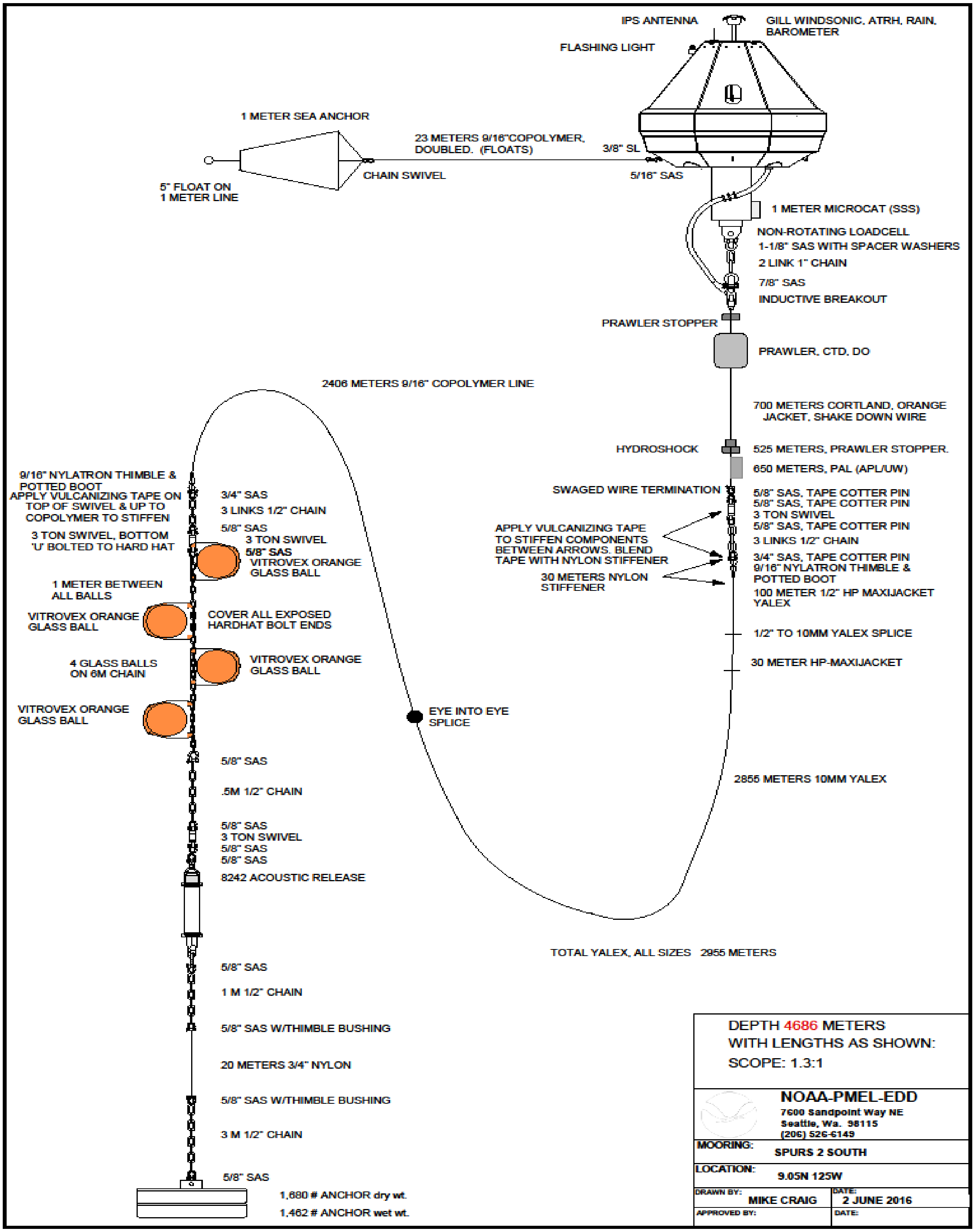


Figure C10. SPURS2 PMEL mooring diagram

D. High-resolution Lagrangian observation of ocean boundary layer shear and stratification during SPURS-2

Andrey Shcherbina, Eric D'Asaro, Ramsey Harcourt, and Nikolai Maximenko

On 26 August 2016, R/V Revelle deployed a cluster of 7 instruments for a coordinated quasi-Lagrangian drift.

Objectives

- Conduct a focused multiplatform coordinated study of the ocean surface boundary layer structure and dynamics in response to rain events, in a frame of reference minimizing horizontal advection.
- Observe formation, evolution, and dissipation of storm-induced “rain puddles” in quasi-Lagrangian water-following frame of reference
- Quantify the balance of diffusive, advective, and storage terms in the upper-ocean heat and salt budgets

Participating instruments

1 WHOI Wave Glider "Green" (WHOI-ASL42)	2xCTD, Wind, Tair
1 APL Seaglider (sg190)	CTD, Microstructure, PAL
1 APL Lagrangian float (LF84)	2xCTD, ADCP, PAL
1 UW Profiling APEX float (#12448)	CTD, PAL
3 AOML Salinity drifters	TS, GPS
18 SIO SVP(-S) drifters (deployed by R/V Lady Amber later on)	TS (some), waves (some), GPS

Deployment site selection

21-22 Aug R/V Revelle conducted a large-scale reconnaissance survey of the area surrounding the central mooring site in order to identify the optimal spot for deployment of the drifting instruments. In-situ information was compiled with the analysis of surface currents (SCUD, http://apdrc.soest.hawaii.edu/projects/SCUD/).

Initial survey (Figure D1) showed a flow pattern dominated by a mesoscale cyclonic eddy centered around 9.5°N, and an intense front with 30cm/s westward flow north of 12°N. To clarify the circulation pattern, 6 SVP drifters were deployed along the 125°W transect.

By 25 August mesoscale flow intensified. After another R/V Revelle survey and analysis of drifter trajectories (Figure D2), the central mooring site (10.05°N, 125°W) was selected as the deployment location.

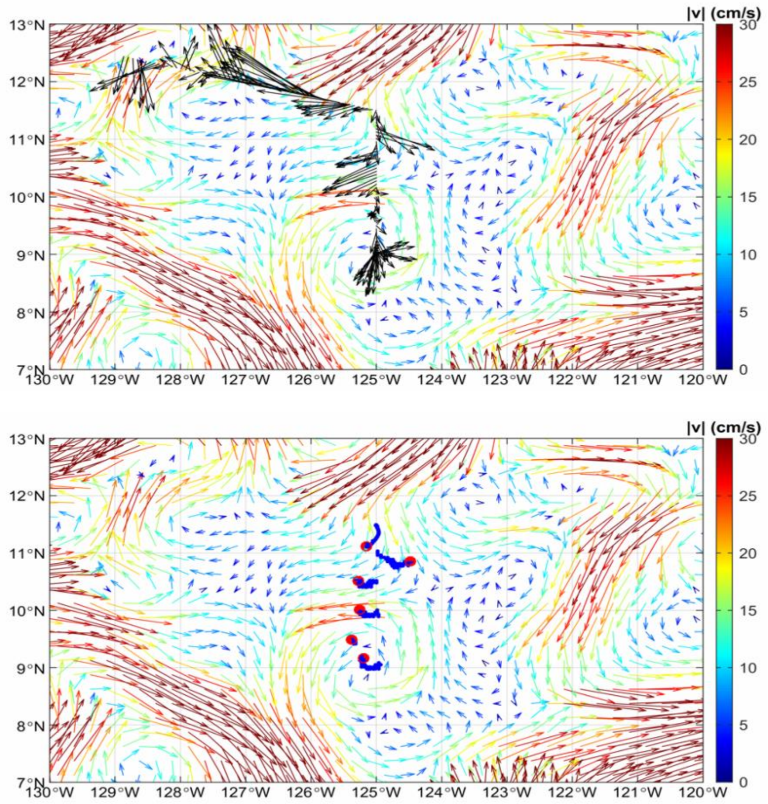


Figure D1 (top) R/V Revelle shipboard ADCP currents @15m during the 21-22 August survey (black arrows), overlaid on SCUD-diagnosed surface advection fields. (bottom) Trajectories of 6 SVP drifters as of 24 August.

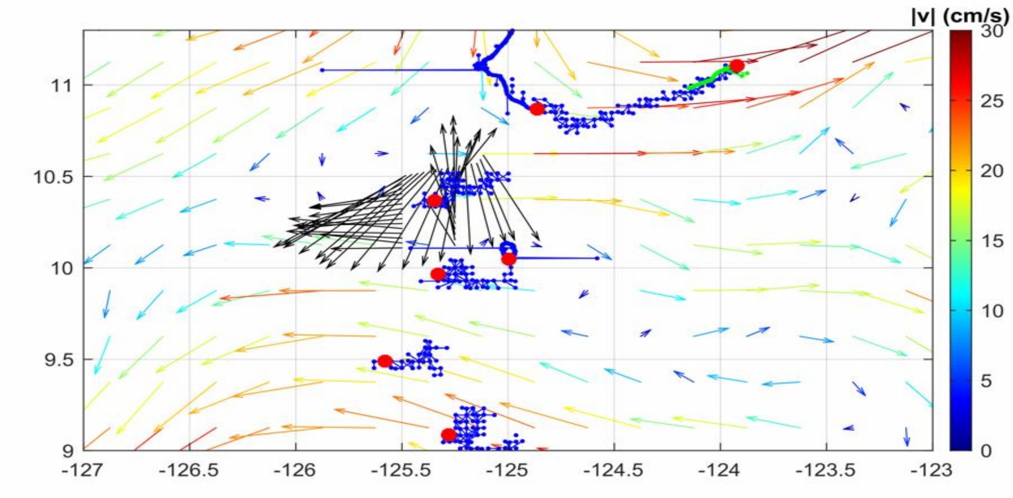


Figure D2 R/V Revelle shipboard ADCP currents @15m during the 25-26 August survey (black arrows), overlaid on SCUD-diagnosed surface advection fields. Trajectories of 6 SVP drifters are shown in blue. A “quiet spot” at (10.05°N, 125°W) was chosen for the Lagrangian array deployment.

Array deployment and initial drift

All the instruments were deployed in rapid succession 26 Aug 2016 in the vicinity of the target location (10.05°N, 125°W). Immediately after the deployment, the array started to drift eastward (Figure D3), subsequently turning towards NE. AOML salinity drifters quickly got ahead, moving at 0.13 m/s (12 km/day). APEX float lagged behind despite operating in rapid profiling mode (0–200m, 3.5-hour cycle). The Wave Glider was initially navigating a 20 km × 20 km square pattern centered on the Lagrangian float (LF). This, however, was not best suited for looking at the fine-scale lateral variability in the vicinity of the LF, so it was switched to a "butterfly" pattern of the same size. Seaglider was navigating a 20-km cross-track section relative to the LF. The drifting array was supplemented with 3 deployments of SVP drifters on 26 Sep, 3 Oct, and 7 Oct, each consisting of 5 SVP(-S) drifters and one wave-measuring drifter.

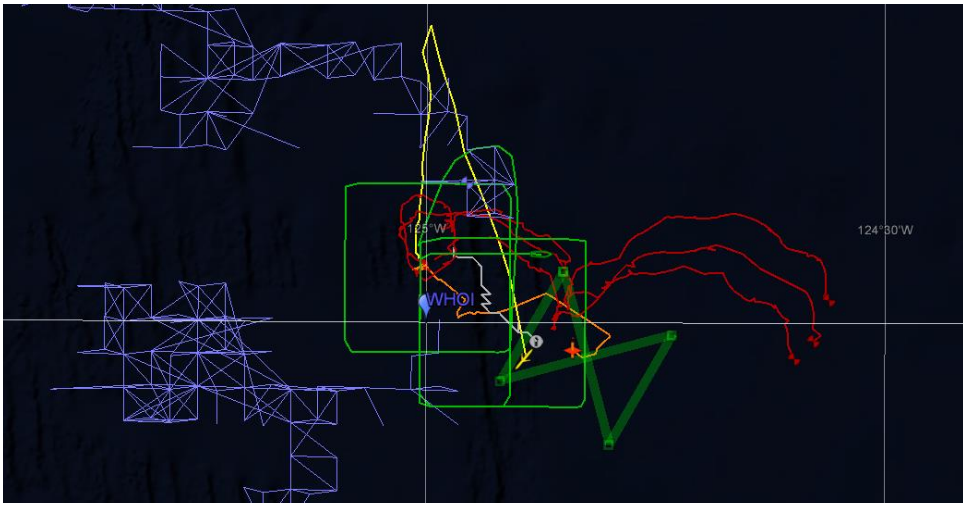


Figure D3 Initial drift of the Lagrangian array (26–30 Aug 2016). Shown are the trajectories of the Wave Glider (green), the Seaglider (yellow), AOML Salinity drifters (red), Lagrangian float (orange), APEX float (grey), SVP drifters (blue). Thick green lines show the Wave Glider route to be navigated.

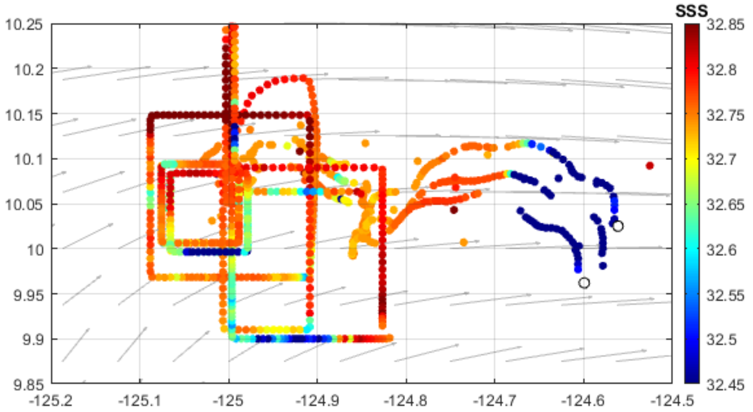


Figure D4 Surface salinity observations from the Wave Glider and AOML salinity drifters, showing fresh rain puddles in the vicinity.

Long-term evolution of the drift

The quasi-Lagrangian drift continued for over 100 days until 12 Dec 2016. During this time, APEX float stayed in the vicinity of the mooring. Seaglider followed the Lagrangian float until 17 Oct 2016 (>300 km) before returning to the mooring site. The Wave Glider followed LF for the duration of the drift, until both were recovered by R/V Lady Amber 1,800 km East of the deployment site (Figure D5). The instruments returned a set of complementary observations of upper-ocean hydrographic structure and surface forcing (Figure D6).

Lagrangian float surfaced and transmitted its position every 5 h for the duration of the drift. After each surfacing, an updated projection of the drift for the next 48 h was produced. Predictability of the drift was hampered by strong inertial oscillations of the flow. These oscillations were rarely in steady-state due to the long inertial period (3 days) and strong wind variability on comparable time scales. Oscillations were also not well resolved by the discrete LF fixes.

During the drift, the main objective for the Wave Glider and the Seaglider was to navigate pre-defined patterns in LF-centric coordinates. Survey tracks for both instruments were transformed into geographic coordinates based on each updated drift forecast. Navigation waypoints were then generated, reviewed manually, and sent to the instruments.

The drift initially progressed at 0.1−0.2 m/s, speeding up to 0.4 m/s by mid-October (east of 122°W). Surface current speed inferred from the Wave Glider drift was initially 0.2 m/s, but increased occasionally to over 0.8 m/s. Through-the-water speed of the Wave Glider was initially 0.6-0.8 m/s, dropping to 0.4 m/s as the drift progressed, presumably due to biofouling or umbilical twisting. Despite that, the Wave Glider managed to remain within a 15-km radius of the LF most of the time (Figure D7). Seaglider over-the-ground speed was 0.1−0.2 m/s, which was sufficient for it to keep up with the drift until mid-October.

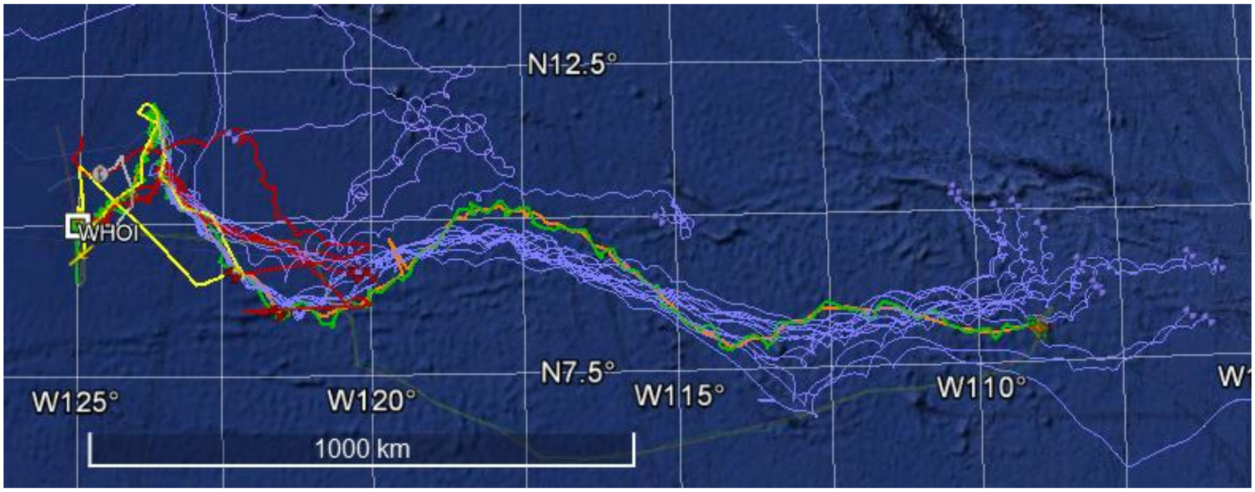


Figure D5 Lagrangian drift progress 26 Aug – 12 Dec 2016. Shown are the trajectories of the Wave Glider (green), the Seaglider (yellow), AOML Salinity drifters (red), Lagrangian float (orange), APEX float (grey), SVP drifters (blue).

For the duration of the drift, a Google Earth KML file containing the tracks of all drifting instruments was regularly produced and posted on-line (Figure D5 shows a typical view).

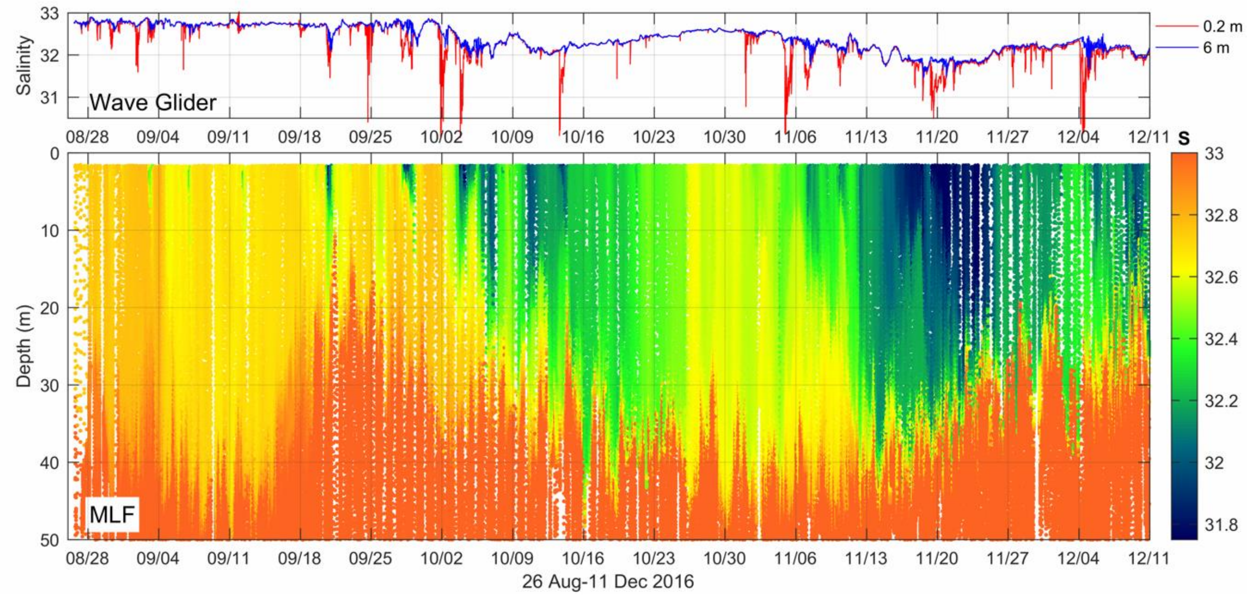


Figure D6 Concurrent Wave Glider (top) and Lagrangian Float (bottom) observations of upper-ocean salinity structure during the coordinated drift.

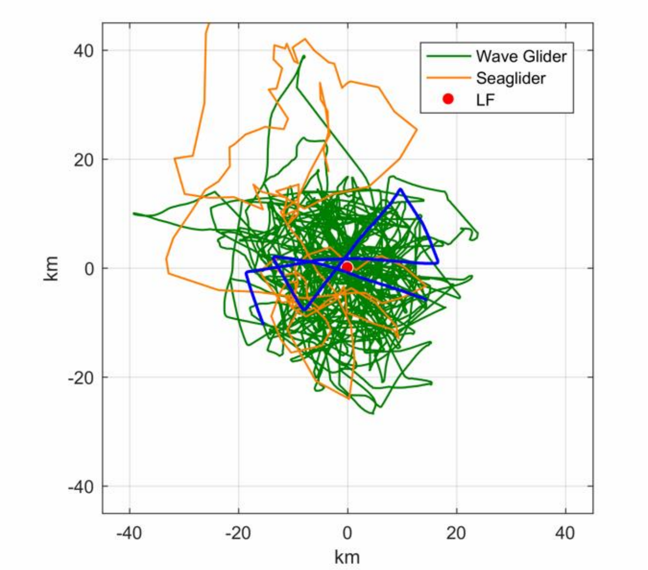


Figure D7 Trajectories of the Wave Glider (green) and Seaglider (orange) relative to the Lagrangian float (center). A 48-hour segment of the Wave Glider track showing the typical navigation pattern is highlighted in blue.

E. Studies of Near-surface Salinity with Surface Lagrangian Drifters

Luca Centurioni, Yi Chao and Nikolai Maximenko

5 SVP drifters were deployed.

300234063342420/ 11°N,125°W - deployed at UTC 8/22 00:46
300234063342690/ 10°30'N, 125W - deployed at UTC 8/22/04:20
300234063342450/ 10°N, 125W - deployed at UTC 8/22/07:18
300234063342750/ 9°30.31'N, 125W - deployed at UTC 8/22/10:29
300234063343400/ 9°07.39'N, 125W - deployed at UTC 8/22/12:55

The tracks are shown in figure E1. It was noted during the Revelle's transit from Hawaii to the deployment site, 5 SVP drifters were stored on-deck of the ship on the aft deck under direct sunlight. Such an arrangement probably caused the drifters to exceed their manufacturers storage temperature of +85C. Further, prior to deployment, the system magnets were removed, activating the electronics while they above their recommended operating temperature. These actions resulted in anomalous behavior at start up. Corrective actions were able to be performed remotely, and the drifters worked well afterward.

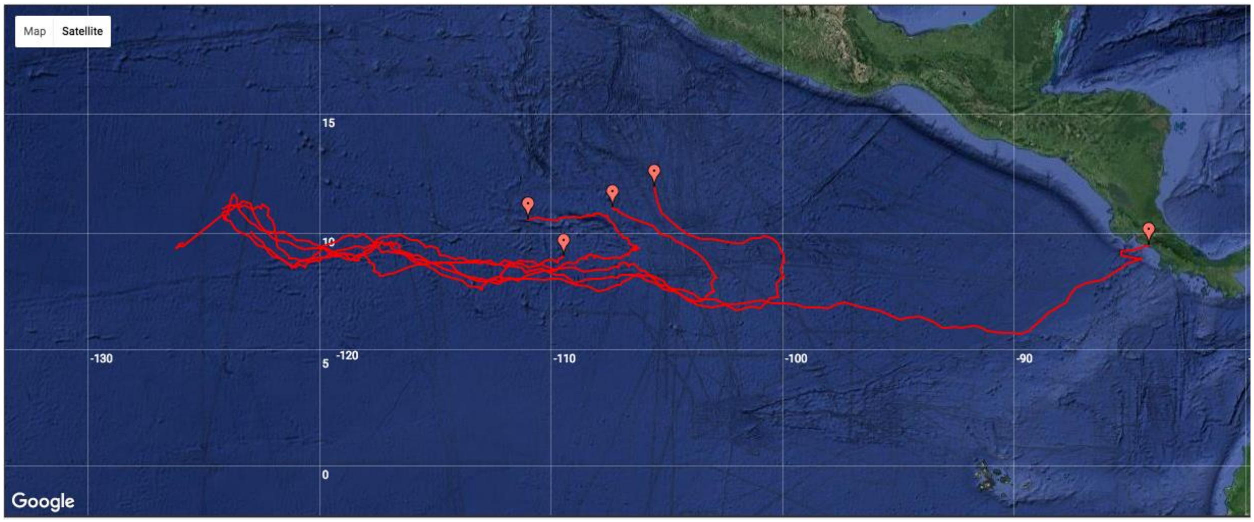


Figure E1. SVP drifter tracks.

Five CODE drifters outfitted with conductivity and temperature sensors were considered for use during a Rain Puddle study. However, due to low visibility when deployed, recovery operation time requirements became an obstacle. Further, there was an issue found with construction and reserve buoyancy available. Modifications were attempted while underway but deployment plans were scrapped and the CODE drifters returned to SIO for retrofit for use on future cruise legs.

F. Deployment of dual-sensor SVP-S (Surface Velocity Program - Salinity) drifters

D. Volkov

As part of the SPURS-2 field campaign, we deployed 6 dual-sensor Lagrangian drifters, provided by NOAA-AOML and NASA, and specifically designed to measure temperature and salinity near the surface (~20 cm depth) and at 5 m depth. The main objectives of this deployment were (i) to validate the satellite SSS retrievals and to investigate the reasons for the satellite-Argo SSS bias in the precipitation-dominated SPURS-2 region, and (ii) to explore salinity stratification in the upper 5 m and processes that determine it, in particular in relation to rain events.

The drifters were manufactured by Pacific Gyre (www.pacificgyre.com). Each drifter is equipped with a battery pack, a satellite transmitter, and two sets of conductivity/temperature sensors: one (SBE 37SI) is mounted to the bottom of an upgraded (41 cm in diameter) surface float to avoid direct radiative heating and the other is tether mounted at 5 m depth (SBE 37SM). The accuracy of conductivity and temperature sensors is $\pm 3\times10^{-4}$ S/m and $\pm 2\times10^{-3}$ °C, respectively. The sampling interval is about 30 min. The drifters have a drogue centered at 15 m to follow currents at this depth. Each drifter was packed and deployed in a biodegradable box that allowed proper deployment of the drogue, tether, and surface float. The drifter identification numbers, times, and locations of the deployment are shown in Table F1. Because it takes several hours for the deployment box to dissolve, the first data records lag the deployment times. The drifter records are publicly available through the Global Drifter Program (http://www.aoml.noaa.gov/phod/dac/index.php).

Table F1. The identification numbers of dual-sensor drifters, and dates, times, and locations of their deployments in SPURS-2 region.

Drifter ID	**Deployment**			
	Date	**Time (GMT)**	**Latitude (N)**	**Longitude (W)**
145738	21-Aug-2016	21:45	11° 29.68’	125° 00.01’
145718	23-Aug-2016	00:53	10° 03.23’	125° 00.60’
145722	26-Aug-2016	15:07	10° 04.45’	125° 00.77’
145733	26-Aug-2016	17:49	10° 03.46’	124° 59.98’
145778	31-Aug-2016	06:40	10° 20.35’	124° 05.20’
145787	07-Sep-2016	09:50	08° 36.00’	125° 00.00’

The first (145738) and the last (145787) drifters were deployed near the northern and southern margins of the SPURS-2 domain, respectively. Three drifters (145718, 145722, 145733) were deployed in a cluster near the central (WHOI) mooring, and one drifter (145778) was deployed about 0.5 degree west of the WHOI mooring. The deployment of all six drifters was successful, and all drifters are recording and transmitting data. The drifter trajectories during the first 30 days after deployment are shown in Fig. F1. The near-surface salinity records (color in Fig. F1) display low-salinity patches that are due to rain events.

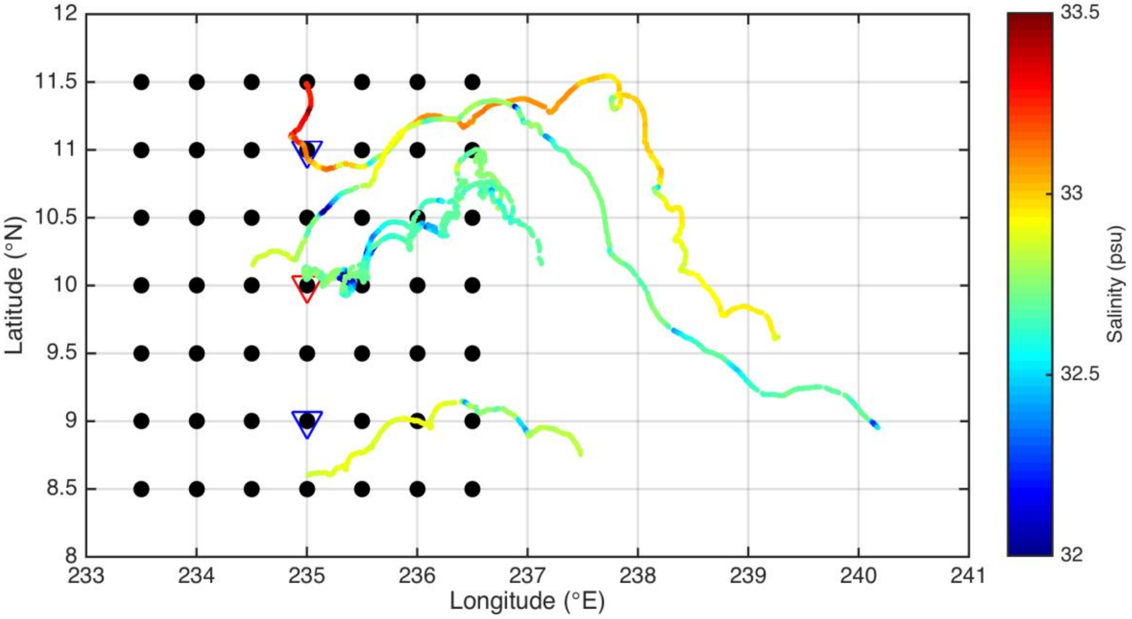


Figure F1. SVP-S drifter trajectories during the first 30 days after deployment. Color shows salinity at the surface (~20 cm depth). The black circles indicate the locations of CTD stations in the SPURS-2 domain; the red and blue triangles show the locations of WHOI and PMEL moorings, respectively.

For the preliminary analysis, the drifter records were collocated with the Advanced Scatterometer (ASCAT) contemporary measurements of wind speed, with a precipitation product derived from Global Precipitation Mission (GPM) records, and with wind speed simulated by the Global Forecast System (GFS) model. First records, illustrated in Fig. F2 and F3, suggest that there is a systematic difference of 0.01-0.02 psu between the surface and 5-m salinity. On sunny and usually low wind days, the surface temperature experiences diurnal variability with an amplitude of up to about 1C. Evaporation on these days can cause the surface to be saltier than the 5-m layer by 0.1-0.4 psu. When the wind is strong, usually greater than 6 m/s, the upper 5 meters are rather well mixed, and the salinity change caused by strong precipitation is suppressed. Rain and low wind events can cause salinity differences between the surface and 5 m depth of up to 2 psu (see an event on day 243 recorded by drifter 145733 in Fig. 3). Our observations show that strong rain events also affect salinity at 5-m depth. The mixing time scale between the surface and 5-m depth, i.e. the time required for both salinities to align, is usually less than a day. The drifter data exhibits a reasonable agreement with SMOS Level 3 salinities with respect to mesoscale features, however, sporadic and patchy rain events are not captured by SMOS. The comparison with SMAP Level 3 salinity data is still poor.

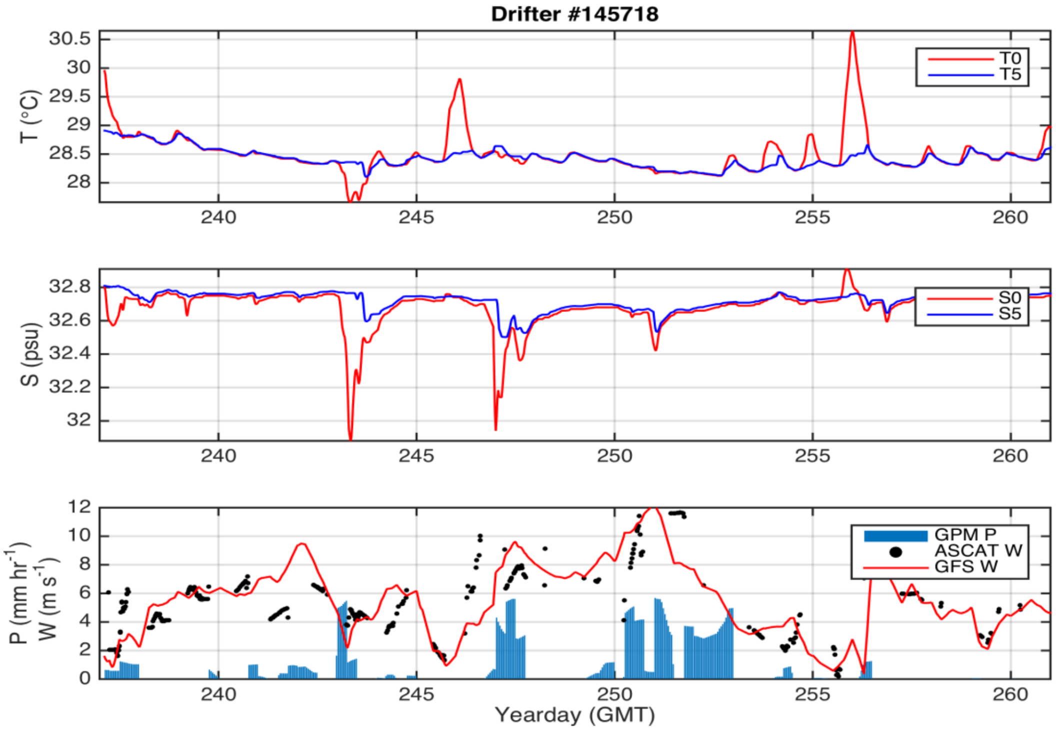


Figure F2. (top) Temperature and (middle) salinity at ~20 cm (red curves) and at 5 m (blue curves) depth, and (bottom) precipitation (mm/hr; blue bars), wind speed (m/s) from ASCAT (black dots) and from GFS model (red curve).

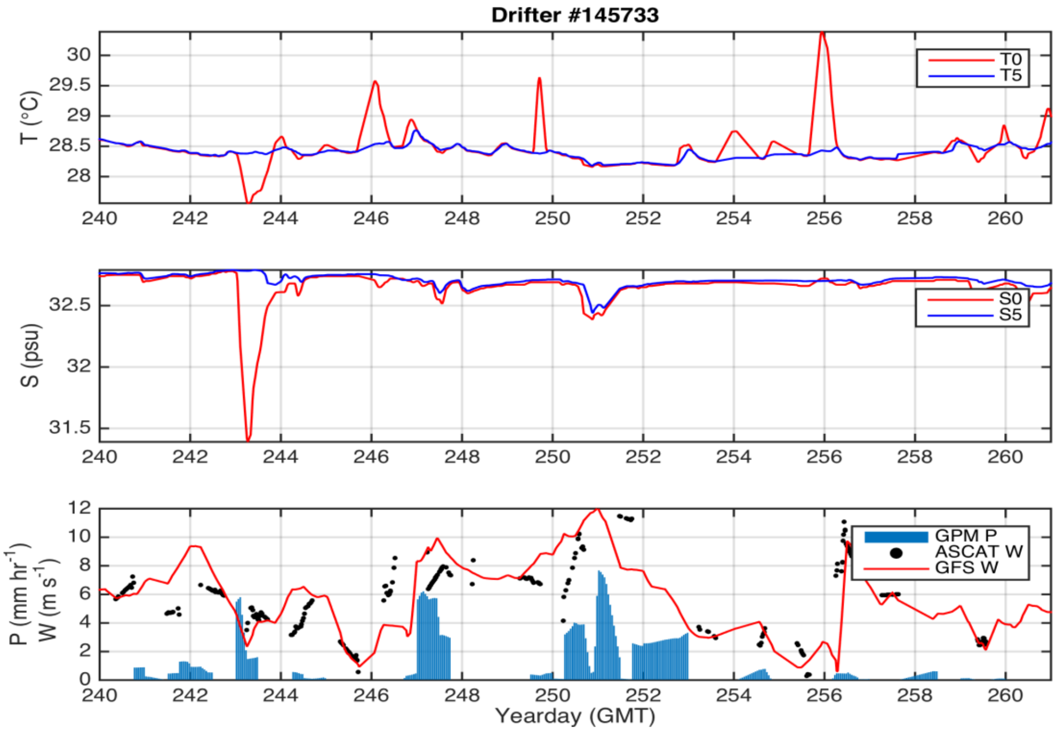


Figure F3. Same as Fig. F2, but for drifter 145733

G. Autonomous Surveys in the SPURS Freshwater Regime

Ben Hodges and Sam Levang

Configuration and Deployment

Three Liquid Robotics, Inc. SV-2 Wave Gliders were deployed from R/V *Revelle* (see Table). Each Wave Glider (WG) was equipped with two Sea-Bird GPCTD's: one at nominally 25 cm depth beneath the surface float and a second at approximately 6.6 m depth on the sub. Each of the six CTD's was configured to sample at 2-minute intervals. Additionally, each WG carried an Airmar WX200 Weather Station on a one-meter mast measuring wind speed and direction and air temperature and pressure, and an Airmar CS4500 ultrasonic water speed sensor, which, in conjunction with GPS, allows computation of surface current velocity. These auxiliary sensors were initially configured to sample at 10-minute intervals.

Two of the WG (Yellow and Green) carried SBE-56 temperature loggers sampling at 5-second intervals installed on the float (just below the chine, approximately 10-cm depth) and on the sub. The third WG (Red) was initially deployed with a custom "salinity rake," conceived by Ray Schmitt, affixed to the stern of the float. The rake carried 10 NBOSI conductivity/temperature sensors positioned every 10-cm, nominally from 10-cm to 1-m depth. Each sensor sampled continuously at 1-Hz, and the data was logged on board.

Vehicle	Flag	Deploy Time	Deploy Position
WHOI-ASL22	Red	24-Aug-2016 0050Z	10° 03.15'N 125° 00.86'W
WHOI-ASL32	Yellow	24-Aug-2016 0040Z	10° 03.05'N 125° 01.05'W
WHOI-ASL42	Green	26-Aug-2016 1520Z	10° 04.21'N 125° 00.86'W

Sampling Plan

Red, with the rake, was programmed to follow an 8-km square sampling pattern around the WHOI mooring (10° 03'N, 125° 00'W), just outside its calculated watch circle. Yellow was assigned to a meridional transect along 125°W from the WHOI mooring to the northern PMEL mooring (11° N). Green was initially designated as part of the "Lagrangian experiment," which also included a MLF, a Seaglider, APEX floats, and drifters. As such, its mission was to repeatedly sample, along transect lines with varying headings, a moving patch of water defined by the drifting assets. The planning for this operation and much of the WG piloting was done by Andrey Shcherbina. Green's permanently assigned meridional transect, to be occupied following the completion of the Lagrangian experiment, ran along 125°W from the WHOI mooring to the southern PMEL mooring (9° N).

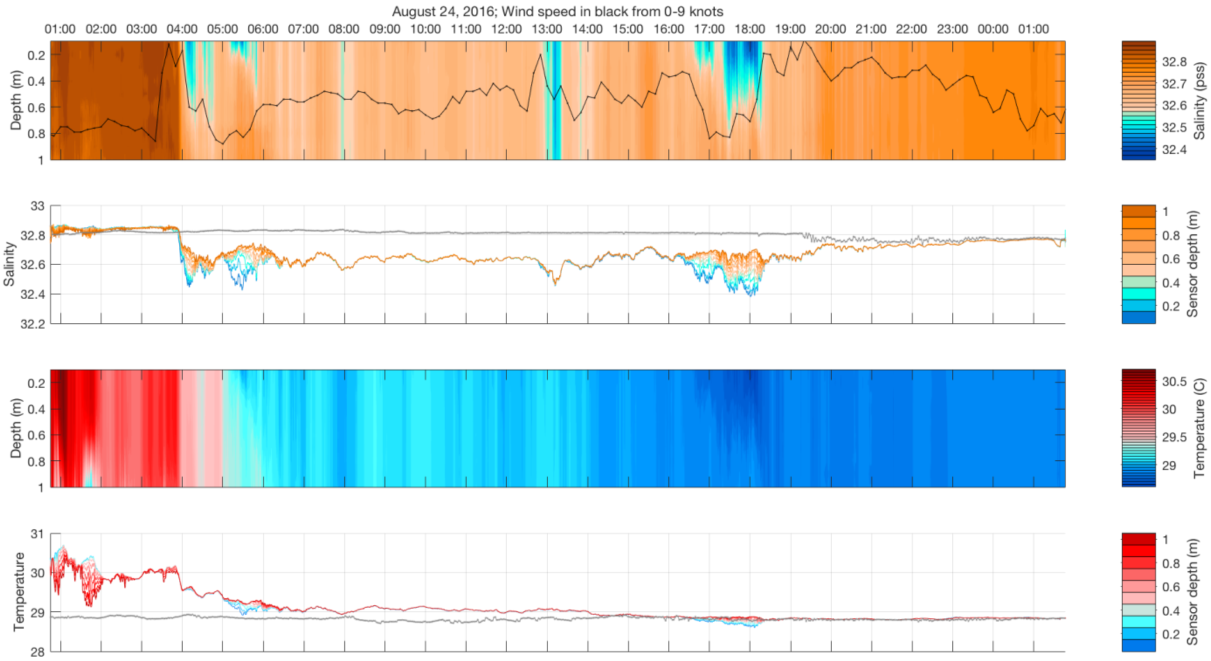


Figure G1: Rake salinity (upper panels) and temperature (lower panels) observations during the 25-hour period when all 10 sensors were sampling. Data are plotted first as sections of the upper meter, and then as time series of each sensor; time series plots also include data (gray line) from the GPCTD at 6.6-m depth. Wind speed is shown in the uppermost panel (black line) on an axis from 0-9 knots. Note the extreme temperature stratification early in the record and the multiple rain freshening events.

Performance

On 8 September 2016, at 2145Z, Red was recovered to inspect the rake and evaluate the record. It was discovered that half the sensors had stopped recording after functioning normally for 25 hours, leaving 5 sensors at 20-cm depth intervals. These remaining sensors had stopped recording after 4 days of sampling. Red was redeployed without the rake after approximately 5 hours on board, at 0258Z on 9 September. Post-cruise examination revealed that the cause of the failure was a leaky splice in the underwater Y-cable connecting the rake sensor boards to the logger, which was housed in the aft WG drybox. Fortunately, the short period during which all the sensors were sampling had low winds and multiple rain events, leading to lots of vertical structure in the upper meter (Figure G1).

On 6 November 2016, approximately 2.5 months after deployment, Red suffered a communication failure between the sub and the float: it was no longer possible to retrieve data from the sub CTD or steer the vehicle. After drifting for nearly 2 months, Red was recovered on 30 December, 2016 by the R/V *Lady Amber* near 13° 31'N, 126° 23'W, at which point it was discovered that the float had been lost, the umbilical tether having parted near its midpoint. The umbilical is engineered to withstand the stresses it is likely to experience; as of this writing the *Lady Amber* has yet to reach port, so an inspection of the broken umbilical has not been possible, but one possible cause of the failure is severe sharkbite.

In the weeks following the deployment of the Lagrangian array, the assets dispersed, with the drifters moving faster than the MLF and the APEX floats more slowly. Green remained with the MLF, attempting to intercept it on each ~20km transect. On 13 December 2016, after following the MLF for over 3.5 months, Green was recovered by the R/V *Lady Amber* approximately 1800 km east of the SPURS-2 site, near 8° 05’N, 108° 52’W. Following transit to the SPURS-2 site, Green was redeployed on 27 December 2016 near the WHOI mooring and commenced its meridional transect.

Yellow continues to sample along its prescribed transect, hampered at times by strong surface currents. Yellow and Green will be recovered, serviced, and redeployed during the March 2017 *Lady Amber* turnaround cruise.

Data Access

All WG data is transmitted via Iridium SBD messages, archived at LRI, and retransmitted to WHOI/ASL for initial processing and QC. Hourly-averaged scientific data and relevant supporting measurements are generated several times per hour and forwarded to JPL for assimilation and general access by SPURS participants. Raw data is available on request (bhodges@whoi.edu).

H. Understanding regional scale upper ocean variability in the eastern tropical Pacific

Janet Sprintall

Scientific Objectives:-

The principal aim of the proposed project is to characterize, measure and understand what drives surface layer variations in the low salinity/high precipitation regime of the eastern tropical Pacific Ocean. Our goal is to better understand the characteristics and variability of the upper ocean salinity stratification in the vicinity of the ITCZ and identify the main mechanisms that are responsible for this variability. The specific objectives are:

1. Determining the role that barrier layers may play in salinity stratification and in producing the warm SSTs found under the ITCZ in the eastern Pacific
2. Assessing the processes responsible for the spatial mismatches in salinity, temperature, winds and precipitation in the eastern Pacific

This project will make use of a full-suite of remotely sensed observational data sets, along with other *in situ* data from existing archives and importantly from direct measurements as part of fieldwork associated with the SPURS-2 campaign.

Cruise Objectives:-

Our contribution to the SPURS-2 field campaign will focus on the “mesoscale” box (10-300 km) spatial scale and long-line transects along 125°W. Specific objectives of this SPURS-2 cruise are to undertake upper ocean stratification and velocity measurements that will help provide some regional context for the nested small-scale and single-point moored measurements.

Cruise Measurements and Outcome:
We successfully completed 50 CTD/LADCP stations and 262 uCTD stations (see Figure G1 and Appendix Table G1). The LADCP profiles have been processed. The uCTD data have been quality controlled.

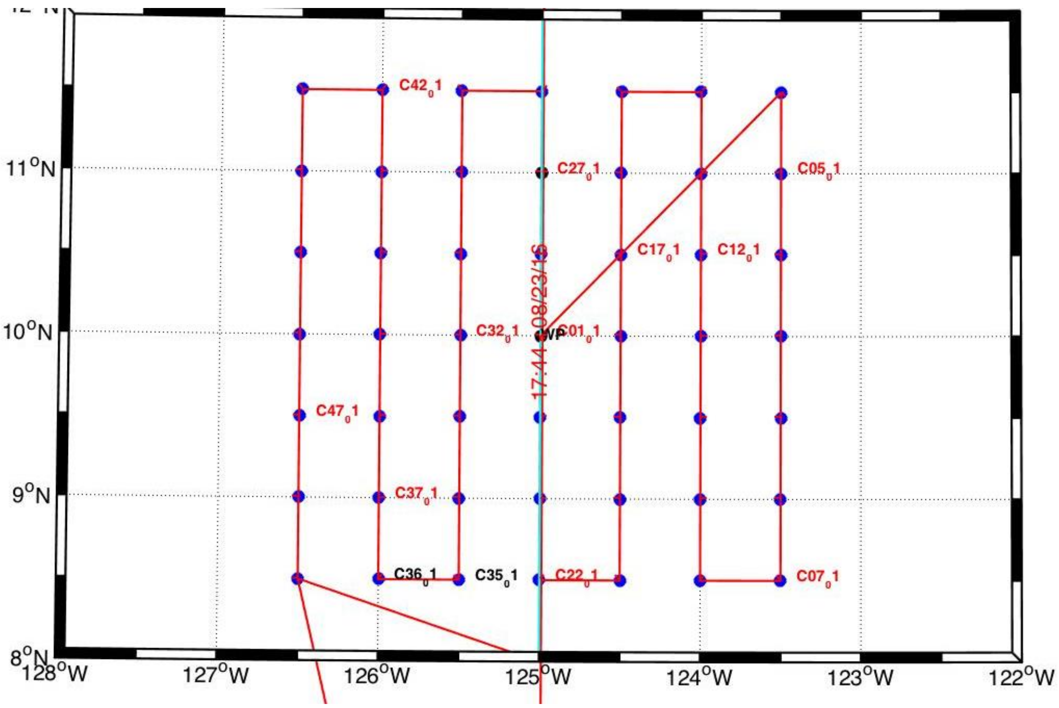


Figure H1: Location of Hydrographic CTD/LADCP Stations (blue); uCTD transects (along 125°W from 5°N to 11°N) (cyan), and moorings (black) deployed during the SPURS-2 Cruise.

I. Understanding the Formation and Evolution of Near Surface Salinity Gradients by Rain and Rain-formed fresh lenses in SPURS-2

Kyla Drushka, William Asher, Andrew Jessup

<u>Research approach and objectives:</u>

The research directed by the team of Drushka, Asher, and Jessup was focused on examining the effect of rainfall on the salinity, temperature, and turbulent kinetic energy (TKE) dissipation of the upper ocean. In the tropics, rainfall produces layers of cooler, fresher water at the sea surface that affect calibration/validation of remote measurements of salinity and temperature, and also modulate air-sea interaction and mixing in the upper ocean, in turn affecting the salt budget, heat content, surface currents, and TKE dissipation. It is necessary to understand how these fresh lenses form and decay in order to assess their role in air-sea interaction and their impacts on satellite validation. The primary objective of the measurements made during SPURS2 was to quantify the horizontal, vertical, and temporal evolution of rain-formed fresh lenses at the ocean surface.

There were four main systems deployed on the *R/V Roger Revelle* during the SPURS 2 cruise. These are:

> (1) a towed surface salinity profiler (SSP) that measured temperature, salinity, and turbulent dissipation in the upper meter using probes;
>
> (2) an infrared (IR) imager/laser-based "controlled flux technique" (CFT) system for measuring the net heat transfer velocity and TKE dissipation at the ocean surface;
>
> (3) an underway salinity profiling system (USPS) that made continuous measurements of salinity and temperature at depths of 2 m and 3 m using through-hull ports in the bow of the ship; and
>
> (4) a lighter-than-air IR imaging system (LTAIRS) for tracking the horizontal evolution and spatial scales of fresh lenses over length scales of hundreds of meters to a kilometer.

In addition, a suite of meteorological instruments (measuring air temperature, relative humidity, wind speed/direction, rain accumulation, and raindrop size distribution) was deployed on top of the lab van on the forward 02 deck. Two SWIFT floats for measuring near-surface ocean turbulence were also deployed several times. Finally, output from the ship's WAMOS radar was captured via time-lapse images every 10 seconds for the second half of the cruise so that spatial distributions of rainfall could be measured.

The observations from these systems will be used to quantify the vertical and horizontal structure of the salinity, temperature, and TKE dissipation fields at the ocean surface as a function of rain and wind. This information will be used to quantify the role of different processes in driving the build-up and decay of fresh lenses; to investigate the relationship between rain rate and the structure of ocean skin temperature; to understand how rainfall affects TKE dissipation at the air-sea interface and within the top meter of the ocean; in modeling studies to assess the impacts of rainfall on the upper ocean throughout the tropics; and to assess the impact of fresh lenses on satellite salinity measurements.

The SSP, CFT system, and USPS all functioned as designed during the cruise and provided data that will be used to achieve the research goals. In contrast, LTAIRS suffered from a number of technological challenges that were not easily addressed by ship-board modifications. Of the four main systems deployed in this work, the SSP, CFT, and USPS will all be used for the SPURS2 cruise in 2017. However, because LTAIRS would require significant and costly modifications in order to make it function reliably in rain, it will not be used for the upcoming SPURS2 work.

Cruise activities:

The SSP was deployed 19 times throughout the SPURS2 cruise, totaling over 200 hours of measurements. Several strategies were used to determine when to deploy the SSP: (1) conditional sampling, in which deployment occurred just as a rain event started; (2) sampling over fixed distances, in which the SSP was deployed for 0.5° transects between CTD casts; and (3) sampling over fixed time intervals, in which the SSP was deployed for 12 hours every 24 hours (nominally from 6am to 6pm). Conditional sampling resulted in data collection during a range rain/wind conditions. However, determine the optimum conditions for deploying the SSP under the conditional sampling protocol was complicated by difficulties in assessing the strength, duration, and propagation direction of rain events. Aside from there being no definitive way to determine if a particular rain event was large enough to warrant sampling, it was also challenging to deploy instruments quickly enough to capture the full rain event. Conditional sampling was at times disruptive to other activities on the ship (e.g. the salinity snake performance was degraded when the ship was towing the SSP at 2 m/s). It was found that the fixed-distance and fixed-time sampling strategies also captured numerous rain events, in addition to other interesting features, and avoided some of the issues associated with conditional sampling.

The two SWIFT floats were deployed in tandem three times, with each deployment into the actively forming rain layers. These autonomous floats make estimates of TKE dissipation and meteorological parameters. After deployment, the ship steamed away from the floats and then circled back to recover them after a period of 2-4 hours. In order to avoid small-boat operations, the SWIFTs were recovered from the ship, which was time consuming and resulted in the wind sensors getting damaged. They did, however, collect rain and dissipation measurements.

The CFT measurements were implemented on the *Revelle* using a carbon-dioxide (CO_2) laser and an IR imager, both of which were mounted on the forward 02 deck. The CO_2 laser was mounted on an APL-supplied frame secured to the 2-foot centers on the deck. The imager was mounted on an electrically operated deployable boom that was also mounted to the 2-foot deck centers. During transit and periods when the CFT system was inactive, this boom was swung inboards to rest on a support on the 02 deck. For the CFT measurements, the boom was rotated so that the imager was outboard of the ship and viewing the undisturbed ocean surface. When deployed with the imager outboard, the imager boom was secured to a support mounted to the railing on the 01 deck. The CFT control and data collection electronics were housed in a 20' UNOLS laboratory van mounted on the forward 02 deck just aft of the laser. The water chiller required for laser cooling was mounted in a 20' container mounted to the starboard side of the lab van. The CFT system operated when the SSP was deployed: after the SSP was under tow, the imager boom was rotated outboard, the area around the CO_2 was secured, and the system activated to make continuous measurements. This system performed reliably and had little, if any, impact on ship operations or science data collection.

LTAIRS was deployed several times during the cruise. LTAIRS consisted of a 24 m^3 helium balloon with an IR imager mounted in a gimbal suspended below the balloon. LTAIRS was stored and launched from the fantail, and its integrated mechanical tether/signal cable was spooled in and out from an APL-supplied winch. In the absence of rain from stationary platforms, LTAIRS has been shown to provide IR imagery of water surfaces. However, technical problems were encountered during SPURS-2 when operating the balloon system in rain. Rain is associated with downdrafts, and this air motion forced the balloon downward. Additionally, the fabric sheath supporting the gas chamber of the balloon became waterlogged in rain, adding weight so that buoyancy of the system was compromised. Attempts to overcome this problem were partially successful, and on its final deployment a tandem balloon was used. Although this worked, deployment and recovery in the presence of wind was problematic.

The meteorological instruments mounted on the roof of the laboratory van on the forward 02 deck collected data reliably throughout the cruise.

The USPS functioned throughout the cruise, although a problem was identified in the data collection program that was fixed midway through the cruise. Although this problem complicates data analysis, it did not render the data unusable. The USPS has a separate dedicated meteorological package, including a RM Young 50202 capacitance rain gauge. This rain gauge was found to be malfunctioning and was repaired by science personnel midway through the cruise.

To date, preliminary analysis has begun on data from the SSP, the CFT, and the USPS. Representative preliminary results from each of these three systems are presented below.

Preliminary Results: SSP

Figure I1 shows the Surface Salinity Profiler (SSP) built for, and deployed during, the 2016 SPURS2 field experiment. The SSP used in SPURS2 used a 4 m-long stand-up paddleboard as the main platform. Lateral stability was provided by a 2.4 m-long surfboard outrigger that was cross-braced to the 1.2-m keel. This design proved to be rugged and stable while it was towed by the *Revelle*. While under tow, the SSP sampled undisturbed water outside the wake of the ship. The SSP mounted four SBE-49 FastCAT CTDs at nominal depths of 0.1 m, 0.2 m, 0.5 m, and 1.0 m. In addition to the four CTDs, salinity in the top few centimeters was measured using a salinity snake similar to that deployed during SPURS2 by J. Schanze (ESR, Seattle, Washington). This new surface sensor worked by drawing seawater through an intake hose that was towed to the side of the SSP, passing that seawater through a vortex debubbler, and then through a Seabird SBE-45 micro thermosalinograph (TSG). Seawater temperature at the surface was measured by a Seabird SBE-56 self-recording thermistor.

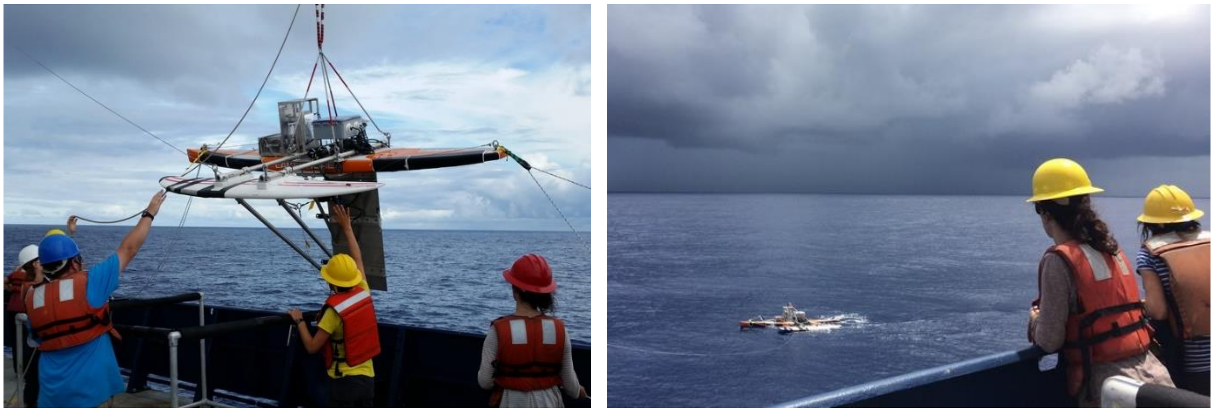


Figure I1: Left image: The Surface Salinity Profiler (SSP) used during the 2016 SPURS2 field experiment being deployed from the R/V *Revelle*. Right image: The SSP under tow.

A total of 31 rain events were sampled during the cruise, covering a range of wind speeds and rain rates. Although data analysis is continuing, a preliminary analysis of sixteen of these rain events was presented at the AGU Fall Meeting in December, 2016.

Figure I2 shows near surface salinity differences measured between a depth of 1.0 m and the surface plotted as a function of rain rate for sixteen of the rain events sampled by the SSP during the 2016 SPURS-2 field experiment. The salinity difference between the surface and 1-m, ΔS_{0-1}, is calculated as the difference between the salinity measured at 1.0 m by the keel-mounted CTD and the surface salinity measured by the salinity snake on the SSP. Rain rates in Figure I2 were measured by an optical rain gauge mounted on the ship's jackstaff. Wind speed is shown in Figure I2 as the color of the data point, with wind speeds provided by the meteorological measurements made aboard the R/V *Roger Revelle* by C.-A. Clayson (WHOI) and J. Edson (Univ. of Connecticut) and provided as one-minute averages.

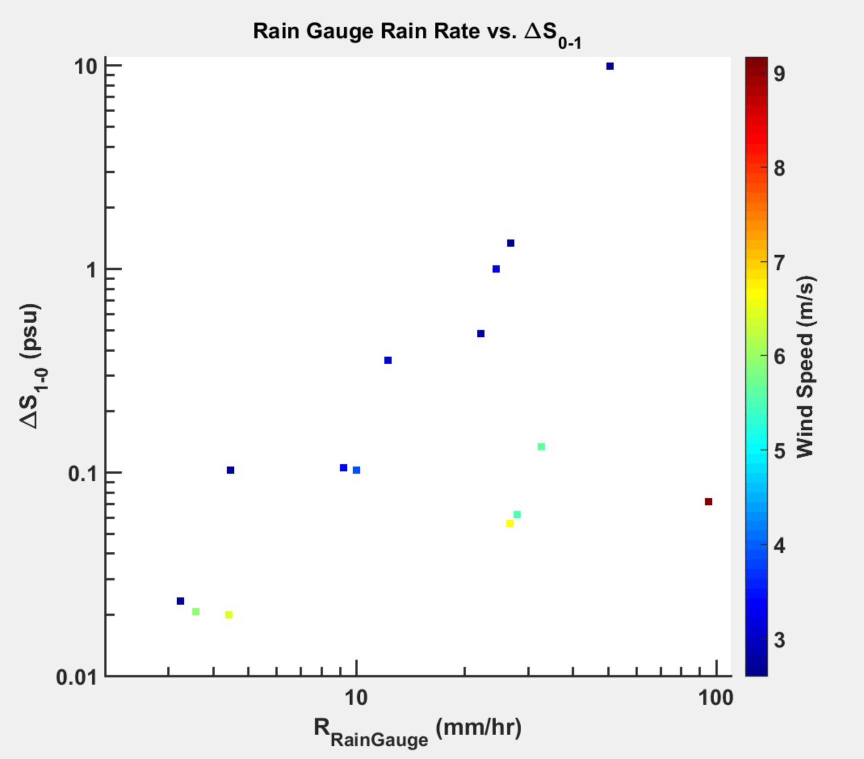


Figure I2: Data from the Surface Salinity Profiler (SSP) from the SPURS2 2016 field experiment showing the difference in salinity measured by the SSP between the surface and a depth of 1 m, plotted as a function of rain rate measured by a capacitance rain gauge on the jackstaff, $R_{RainGauge}$, where the color of the data point denotes wind speed. The wind speed color bar is shown on the right of the figure. Wind speeds were measured by C.-A. Clayson (WHOI) and J. Edson (Univ. of Connecticut) and provided as one-minute averages.

As expected based on previous measurements and modeling studies, ΔS_{0-1} increases with increasing rain rate with increasing wind speed resulting in a lower value of ΔS_{0-1} for an equivalent rain rate. Both of these observations agree with the results of modeling studies on the formation of fresh lenses. Furthermore, the linear correlation between ΔS_{0-1} and rain rate for lower wind speeds shown in Figure I2 agrees with the linear relationship found in these same numerical experiments.

Preliminary Results: CFT

The CFT system used during SPURS2 is shown in Figure I3. The photograph was taken on the forward 02 deck of the *Revelle*, looking out over the port side of the ship so that the bow is to the right in the image. The main components of the CFT system are the IR imager, which is in the white housing on the end of the boom, the electrically operated boom mounted on the pedestal, the CO_2 laser contained in the gray cylindrical housing in the aluminum frame, and the laboratory van to the left of the laser that contained the data acquisition system.

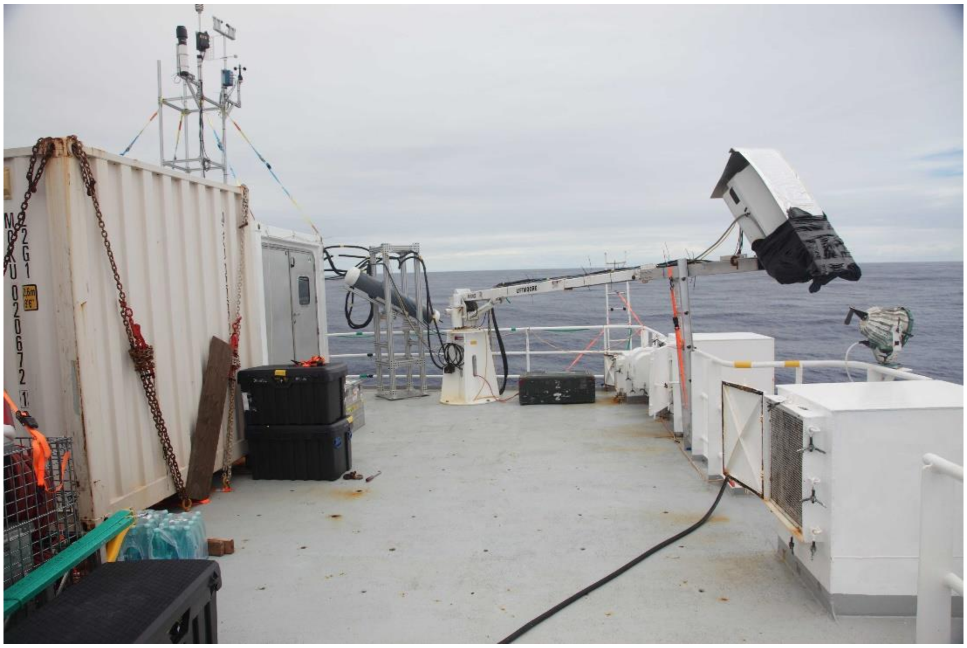


Figure I3: The Controlled Flux Technique instrumentation mounted on the forward 02 deck of rhe *R/V Roger Revelle*. The deployable boom is shown in the center-right with the imager in the housing on the end of the boom. The carbon dioxide laser is contained in the grey housing to the center. The laboratory van is to the left. The APL meteorological instruments are mounted on the rack on the roof of the van. From L-to-R in the picture, these instruments are: capacitance rain gauge, wind speed/direction-air temperature-relative humidity-acoustic rain gauge, disdrometer, and anemometer.

During CFT, the laser heated a small patch of water on the ocean surface, and the imager then tracked the thermal decay of this patch of water. The time rate of decay in temperature has been shown to be proportional to the dissipation of TKE at the water surface, which in turn can be used to scale the transfer velocity for the net heat flux. As TKE dissipation increases, the rate of cooling of the heated patch also increases. This means CFT is a useful tool for studying the turbulence generated at the ocean surface by the impact of raindrops.

The two time series in Figure I4 are preliminary data from the CFT system deployed during 2016 SPURS-2 and represent the normalized temperature of the heated patch at two different rain rates. Normalized temperature is defined as the temperature of the patch at time *t* divided by the maximum temperature of the patch. Each time series represents the average of several individual decay curves with rain rates contained in the ranges shown in the legend. Wind speeds were approximately constant for each curve. The data show that as rain rate increases, the heated patch cools faster. This is consistent with the hypothesis that higher levels of TKE at the ocean surface are generated by higher rain rates. This data is in the very preliminary stages of analysis.

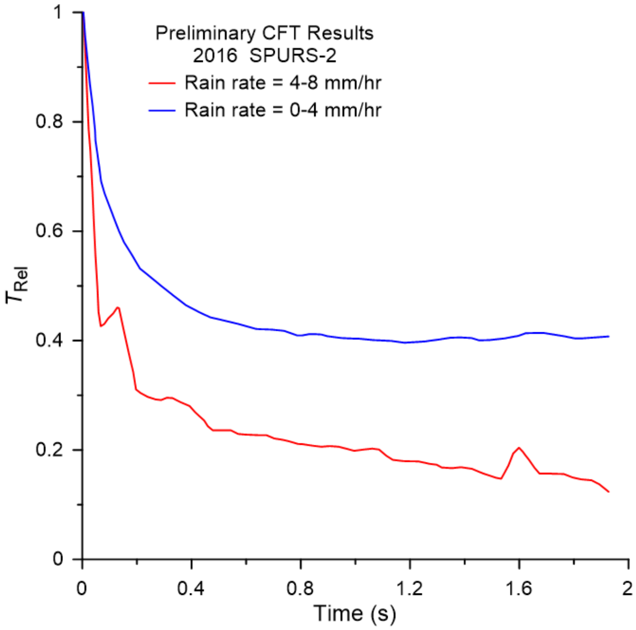


Figure I4: Preliminary data from the controlled-flux technique measurements made during the 2016 SPURS-2 cruise.

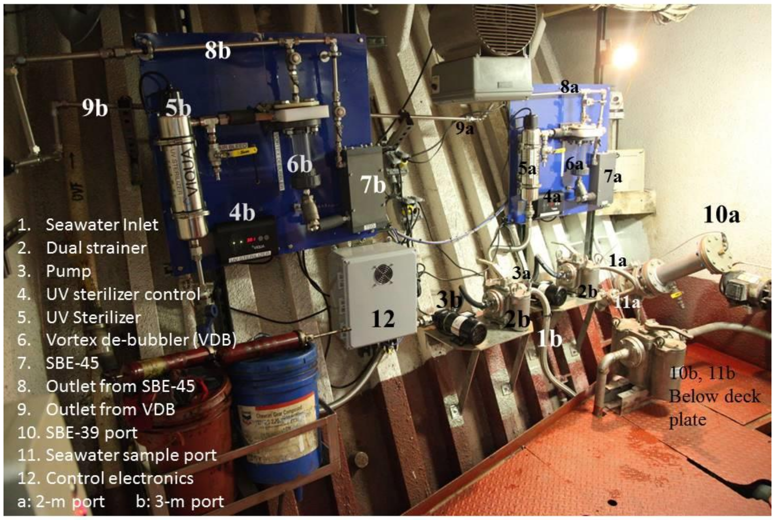


Figure I5: The Underway Salinity Profiling System (USPS) installed on the R/V Roger Revelle and used during the 2016 SPURS2 field experiment. The system measures temperature and salinity at nominal depths of 1-m and 2-m using two sets of two through-hull ports at 1-m and 2-m. The 2-m ports are shown in the figures as 10a and 11a, where 10a contains a temperature/pressure sensor and 11a is a 3-cm diameter port for sampling seawater.

Preliminary Results: USPS

Figure I5 shows the USPS installed on the R/V *Roger Revelle* in December of 2015 while the ship was undergoing a refit in Taiwan. Four thru-hull ports (two at a depth of 2 m, and two at a depth of 3 m) were installed in the bow thruster room of the ship. One pair of ports at 2 m and 3 m are used for sampling water, with water from a port being fed to one of a pair of SBE-45 thermosalinographs (TSG) to measure salinity. The second pair of thru-hull ports is instrumented with SBE-39 in-situ temperature and depth sensors. These instruments allow depth-dependent measurement of temperature and salinity as the ship transits through the water.

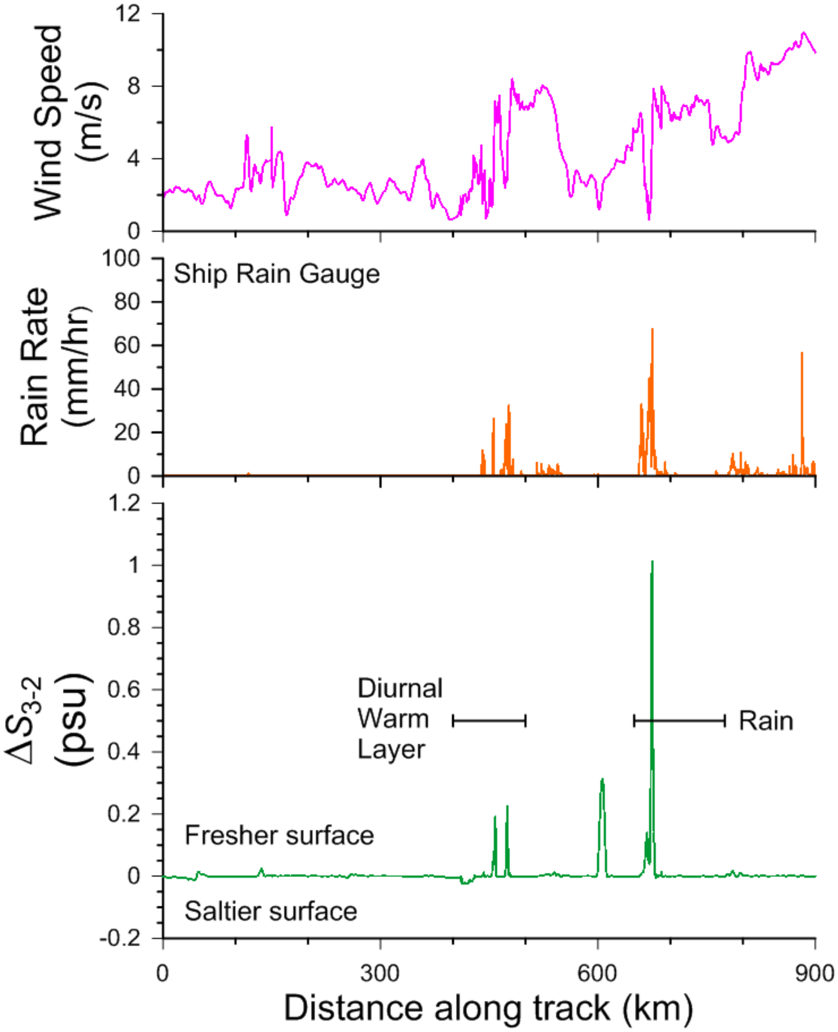


Figure I6: The salinity difference between 2 m and 3 m as measured by the Underway Salinity Profiling System (USPS) for the first 900 km of the data shown in Figure 1. In the figure, a positive value of ΔS corresponds to surface freshening. The data show that in general, rainy periods correlate with times when there is surface freshening. Periods of negative salinity gradients (surface saltier than the deeper water) caused by evaporation from a diurnal warm layer are seen at 50 km and 420 km.

Figure I6 shows USPS data from the R/V *Revelle* recorded during the SPURS2 2016 experiment in the eastern equatorial Pacific Ocean. The data are plotted as a function of track distance as the ship moved westward from 125 ºW at approximately 8 ºN. The top plot shows wind speed measured at the ship. The middle trace is rain rate measured by a capacitance rain gauge located on the ship's jackstaff. The bottom plot shows the difference in salinity measured at the 2-m and 3-m ports, ΔS_{3-2}, where ΔS_{3-2} is defined as the salinity at 2-m subtracted from the salinity at 3-m. In this case, a positive value denotes surface freshening.

Figure I6 shows that surface freshening is observed during rainy periods, and that the strength of the freshening (as denoted by the magnitude of ΔS_{3-2}) is a function of the rain rate and the wind speed. In particular, large surface freshening events are seen in the earlier parts of the data record when wind speed is low. However, when wind speed rises towards the end of the data record, ΔS_{3-2} values are smaller. Interestingly, at a distance of approximately 415 km, negative values of ΔS_{3-2} are observed. This is a positive salt anomaly caused by evaporation from diurnal warm layers. A smaller positive salt anomaly is also seen at a distance of 40 km.

One of the main uses of the USPS data is to understand how the horizontal variability of salinity is affected by rainfall and diurnal warm layers. The salinity data from the USPS was binned into 10 km segments and the standard deviation in salinity over that distance calculated. Figure I7 shows a plot of the horizontal variability of salinity, σ_S, as a function of rain rate and wind speed calculated at a depth of 2 m using salinity measured by the USPS installed on the R/V *Revelle*.

The data in Figure I7 provide further evidence that both wind speed and rain rate determine the effect of rain on the ocean surface. In general, σ_S increases with increasing rain rate. However, it is also seen that σ_S is larger for a given rain rate when wind speed is smaller.

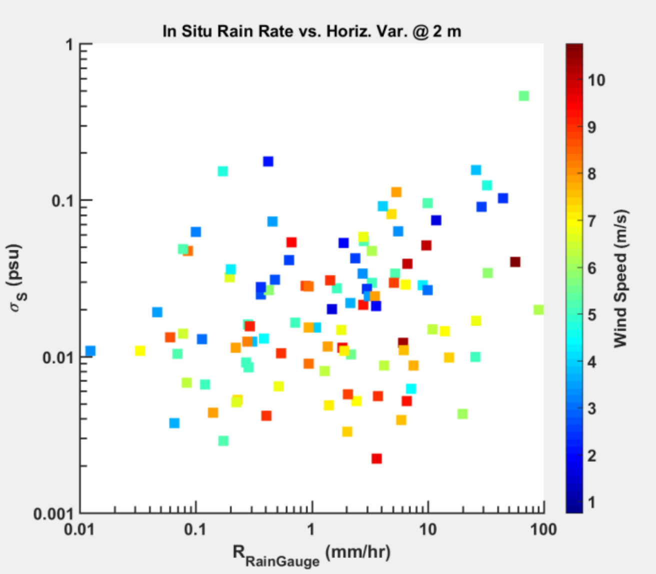


Figure I7**:** Salinity variability data from the Underway Salinity Profiling System (USPS) installed on the R/V Roger Revelle. Data were collected during the SPURS2 field measurements in September, 2016 in the eastern equatorial Pacific Ocean. The plot shows the horizontal variability in salinity, Δ_S, calculated as the standard deviation of salinity over 10-km distances plotted as a function of rain rate measured by a capacitance rain gauge mounted on the jackstaff of the R/V Revelle, $R_{RainGauge}$. The color of each data point denotes wind speed with the color bar for wind speed shown to the right.

Preliminary Results: LTAIRS

Figure I8 shows an IR image of the ocean surface taken from LTAIRS when it was deployed during a rain event. The ship is seen in the lower-left part of the frame. Dark streaks perpendicular to the ship's direction are visible in the central/upper part of the image: these were seen during rain and are hypothesized to be related to wind-driven ocean dynamics.

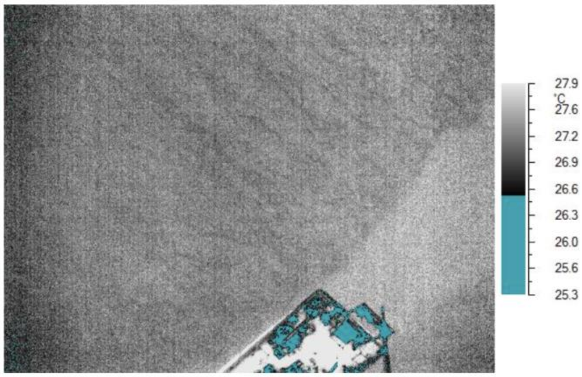


Figure I8. An example of the thermal signatures of the ocean surface that were recorded by LTAIRS. Image size is approximately 50 m in width. The ship's wake is visible as lighter (warmer) colors in the right side of the frame; cool (dark) streaks a few meters wide are visible in the upper part of the frame: these appear to be wind-driven features that are visible during rainfall.

J. Skin Temperature Measurements

Michael Reynolds

This is a brief description of the Remote Ocean Surface Radiometer (ROSR) instrument, SN#3, deployment in the SPURS2 cruise from Aug 12 to Sep 23, 2016 in the equatorial east Pacific. ROSR provided sea surface skin temperature (SSST) to support the salinity and other measurements taking place. The ROSR system was installed and running by 8/12 and continued reliably for the next days of the experiment. Normally, ROSR employs a sensitive rain sensor and closes a weather shutter door at the first onset of rain. For SPURS2 a fitted rain shield was tested so SSST measurements were possible during rain events. The rain shield was a success and after 8/24 measurements were made continuously without rain interrupts.

Figure J1: ROSR with rain baffle.

The final clean time series has 10260 points from 2016-08-14 (227) 03:01:58.0 to 2016-09-20 (264) 23:41:46.0. The sample rate was 283 sec (4.72 min). The only sources of data loss were times of power interruption from GFI failure. On 8/26 the GFI was replaced and ROSR was plugged into the same UPS used by the hi-power Laser system.

Clean, hand-edited data files are rosr_spurs_clean.txt and ROSR_SPURS2_clean.mat.

These are available on line at Remote Measurements & Research Co. LLC. Please contact the company for password details.

1 ROSR and data collection

The Remote Ocean Surface Radiometer (ROSR, pronounced ross'er) provides NIST-traceable sea-surface skin temperature (SSST) measurements in support of air-sea interaction studies or satellite calibration and validation activities. Its operational goals are to make observations autonomously from a ship at sea for six months and with a NIST traceable accuracy of +/-0.1 C.

A tiny hole in the inner scan drum looks into a 45° mirror that reflects incoming infrared radiation into the Heitronics IR radiometer inside a waterproof housing, through a transparent window. The scan drum can be pointed to the sea surface at a variety of angles, at the sky, and back into two high precision black-body cavities. This cycle allows correction for reflected sky radiance in the downward looking view. The system is self calibrating. A small amount of contamination can be tolerated by this open air design.

ROSR incorporates a pitch-roll sensor. A measurement cycle is completed once each 285 sec. A sensitive optical rain detector triggers closure of a flap shutter in the presence of precipitation. SPURS research is interested in the effects of rain on the upper ocean. Accordingly, a special rain baffle was designed and fitted to the ROSR main plates (Fig. 1).

An Infrared Seasurface Temperature Autonomous Radiometer (ISAR) from WHOI was also deployed on a shelf just below ROSR. However, that unit did not work properly, failed on Aug 25 and was removed.

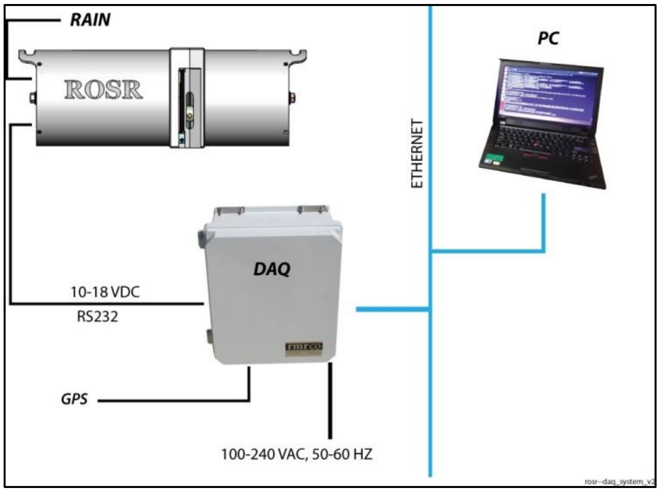


Figure J2: ROSR DAQ system.

The schematic shows the local area ethernet network used for ROSR installations. The Data Acquisition system (DAQ) electronic box was mounted on the ROSR frame. Power and ethernet cables were run from the scientific van to the frame (~ 25 m). The Lenovo T430 PC with data collection software was mounted in the scientific van.

2 Ancillary Data

1. OSSPRE 2m probe — osspre2m_flat.txt, osspre2m_flat.mat
   SBE39 thru-hull probe at 2 m depth. A software bug detected and all records prior to 2016,9,12,5,32,0 were adjusted by -9 min.

2. OSSPRE 3m probe — osspre3m_flat.txt, osspre3m_flat.mat
   SBE39 thru-hull probe at 3 m depth. A software bug detected and all records prior to 2016,9,12,5,28,0 were adjusted by -9 min.

3. TSG Temperature 5m bow — met_flat.txt, met_flat.mat
   The ship provided a file called “met” with about 80 variables. The met file was sorted for pertinent variables including the Thermosalinograph (TSG) temperature measurement in the bow. The intake hole is at 5 m depth in the bow. Note, the temperature sensor is after an intake tube and the water pump so is expected to be at high. After considerable comparison with the 2 and 3 m osspre probes a correction of +0.05 might be appropriate. However, that correction was not made for these files.

4. Seasnake (Edson) — ed1min.mat
   C. Clayson and J. Edson mounted a complete suite of meteorological instruments. The seasnake provided by J.Edson was a precision thermistor in a brass slug. It was suspended from a 3m staff off of the port side of the ship amidships. It was usually in the bow wake. Note that the ROSR ssst measurements were taken to starboard. At the time of this writing

the 1-min mat file has 37440 points from 2016-08-22 (235) 00:00:31.0 to 2016-09-17 (261) 00:00:31.0. See figure J4.

5. XBT cast:

   The expendable thermograph (XBT) was dropped from the stern at approximately 21Z. Data were recorded as it fell to around 1000 m. The first 5–10 m are questionable.

6. CTD cast:

   The conductivity-temperature-depth (CTD) cast was taken routinely. The cast began with a soaking at 10 m after which the unit was brought to the surface, probe depth 2 m, then lowered. The maximum depth was typically 1000m. For this cast the ship was fully stopped.

7. uCTD cast:

   The Underway CTD cast was made from the fantail while the ship was underway. As with the CTD it provided a profile of conductivity, temperature and pressure from near the surface down to 500m. The top 10m of these data are considered to be in error.

8. Seasnake (Schnaze):

   The seasnake provided by J.Schnaze was a large rubber hose hanging from a 10 m boom. A SBE probe was fitted into the very end of the hose. Water was pumped on board through holes just behind the probe. This snake suffered in that it was heavier than sea water and thus when the ship slowed or stopped it hung vertically so the probe was deep, ∼ 3 m below the surface.

3 Data

Shown below is the ship trackline, 18174 points from 2016-08-14 (227) 03:01:58.0 to 2016-09-20 (264) 23:40:58.0

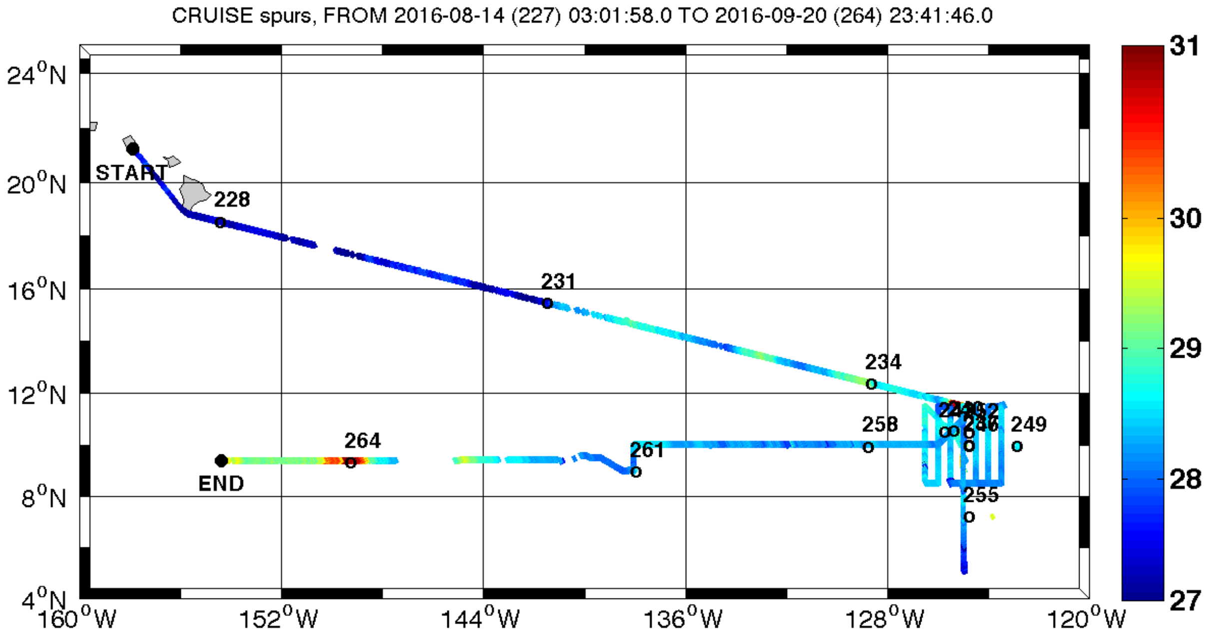


Figure J3: Trackline showing skin temperature and with year days noted.

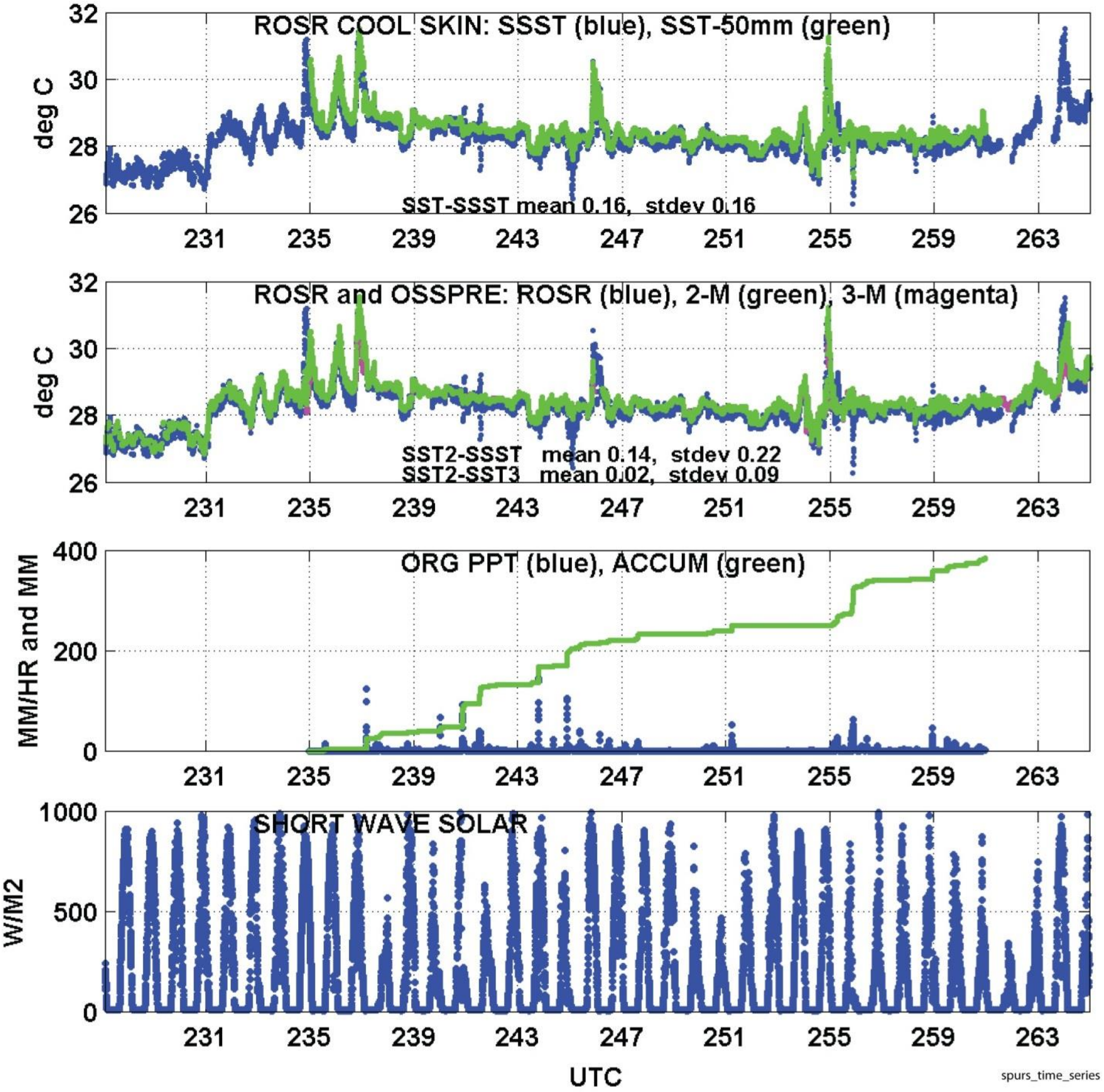


Figure J4: Timeseries for the entire cruise: 2016-08-14,030158 (JD 227) to 2016-09-20,234058 (JD 264). Top panel—Compares the ROSR ssst with the Edsen sea snake at approximately 50 mm depth. Second panel: Compares ROSR ssst with the OSSPRE bow probes at 2 and 3 m depth.

Third panel: Shows rain rate and accumulated rain fall from the ORG. Bottom panel: Shows the solar irradiance.

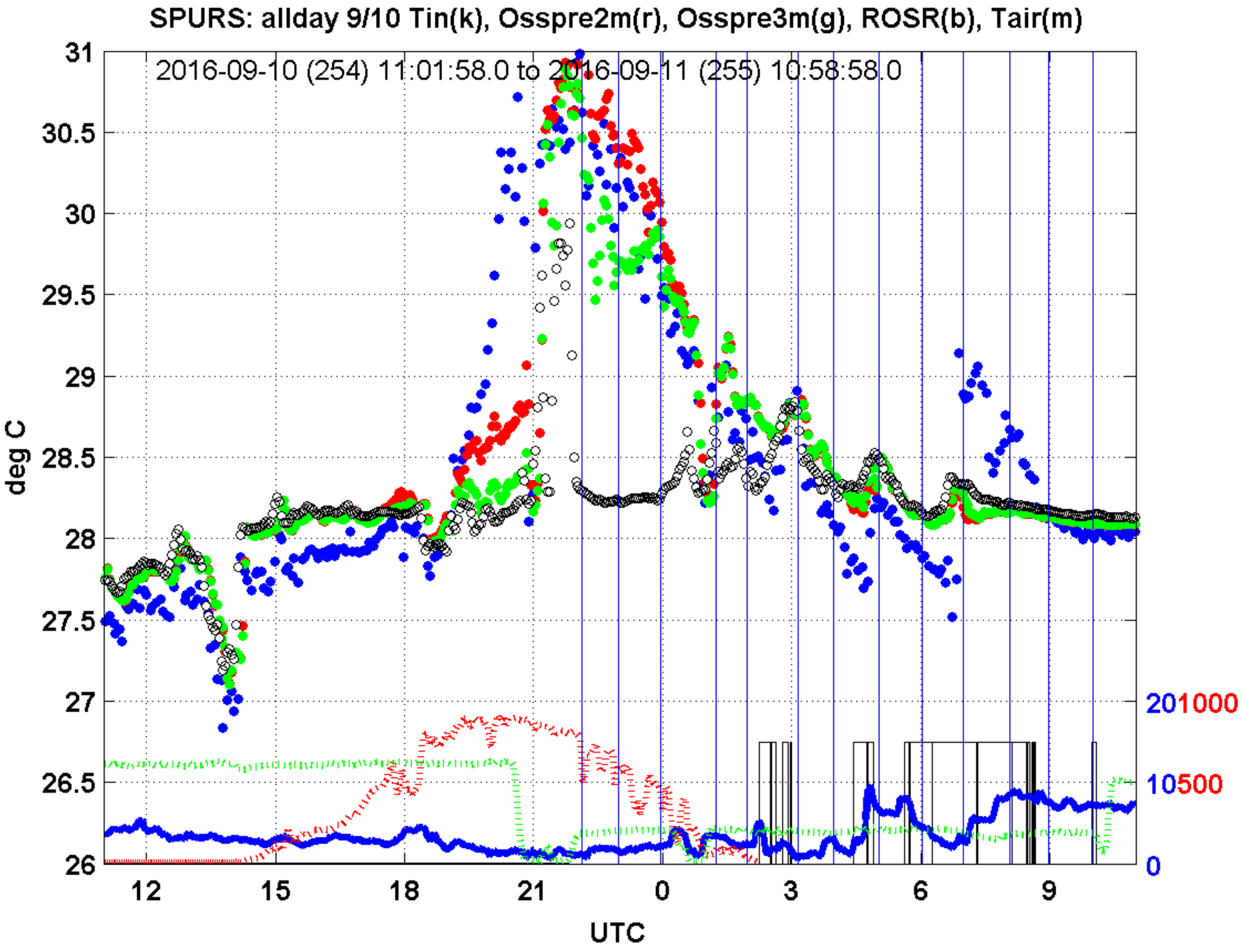


Figure J5: Time series 2016-09-10 (254) 110158— a heated surface layer interrupted by rain. Upper: Shows the ROSR ssst (blue), snake sst-50mm (open circles), Osspre sst-2m (red), Osspre sst-3m (green). Lower: Ship speed over ground, kts (green dashed), solar irradiance (red dashed), True wind speed, m/s (blue), and rain presence (black binary). Before sunrise the surface layer was well developed with a cool skin and well mixed below. During mid day the diurnal surface layer developed with a depth dependent time lag. At about 20.5 h the ship speed was reduced which resulted in a mixing of the surface layer. After 02h rain and variable winds complicated the profiles.

K. **Very-Near Surface Salinity Measurements During the SPURS-2 Field Campaign, or ‘The Salinity Snake’**

Julian Schanze, Ray Schmidt, Gary Lagerloef with further collaboration with David Ho

1.) Background and Description

The Salinity Snake Mk. 2 (SS2) was used during the R/V Revelle Cruise RR1610 to measure sea surface salinity in the top 1-2 cm, which is the radiometric depth of L-Band radiometers such as SMAP and SMOS and previously Aquarius/SAC-D. One of the challenges of these missions is that when precipitation occurs, the freshwater in input at the surface, which is conducive to the formation of layers or lenses in the upper ocean, creating a substantial gradient between 1-2 cm and the most common upper measurement depth of 3-5 m (Argo, TSGs). The SS2 consists of four basic components: a 32ft (~10m) boom/mast, which attaches to almost any diameter of round or square stanchions or rails, a hose, which is deployed from this boom using a halyard system (Figure K1), a powerful self-priming peristaltic pump which transports a constant stream of an emulsion of seawater and air from the intake at the hose, and a shipboard apparatus, which filters, de-bubbles, sterilizes and analyses the salinity of the water (Figure K2). The system is optimized to provide seawater at typical steaming speeds of 8-13 knots.

This system was also used to provide seawater for sampling in an auto-salinometer for calibration and validation purposes and a constant stream of surface seawater was supplied for further analysis for partial carbon dioxide (pCO_2) content, pH, oxygen (O_2), alkalinity, and dissolved inorganic carbon (DIC). These measurements were performed in collaboration with Dr. David Ho at the University of Hawai’i, Manoa.

Figure K1: Salinity Snake Mk. 2 Intake system, showing mast and vacuum rated EPDM/nylon/steel hose with intakes and recording thermistor acting as hose stopper.

During the deployment of this system during RR1610, a significant amount (~50%) of ship-time at the study site was dedicated to the deployment of other in-situ instruments, particularly the salinity surface profiler (SSP), a platform consisting of two surfboards with keel-mounted instruments. Due to the design of this instrument, the maximum vessel speed during these deployments was limited to approximately 4 knots. Since the SS2 was originally designed for higher vessel speeds, the sampling hose sank significantly to depths between 5-100cm owing to the heavy-duty rubber and steel construction of the vacuum-rated hose. This behavior was expected, and data sharing between the PIs for the SS2 and the SSP were agreed upon, as they both measure surface salinity. The use of SSP data only, however, had some minor drawbacks: 1) It is not verifiable through bottle samples and a salinometer, 2) The de-bubbling is less effective, as the pump on the SSP is unable to drive a cascade of vortex de-bubblers, resulting is slightly lower data quality, 3) No measurements of pCO_2, pH, O_2, DIC or alkalinity are made by the SSP, which are important quantities to understand air-sea fluxes and carbon fluxes in particular. Point 3) became relevant through a grant augmentation and the collaboration with David Ho to measure these parameters, and was unforeseen during the original design of the SS2. An augmentation is currently underway to address these issues in the second iteration through the implementation of a second salinity snake which is optimized for slow speeds.

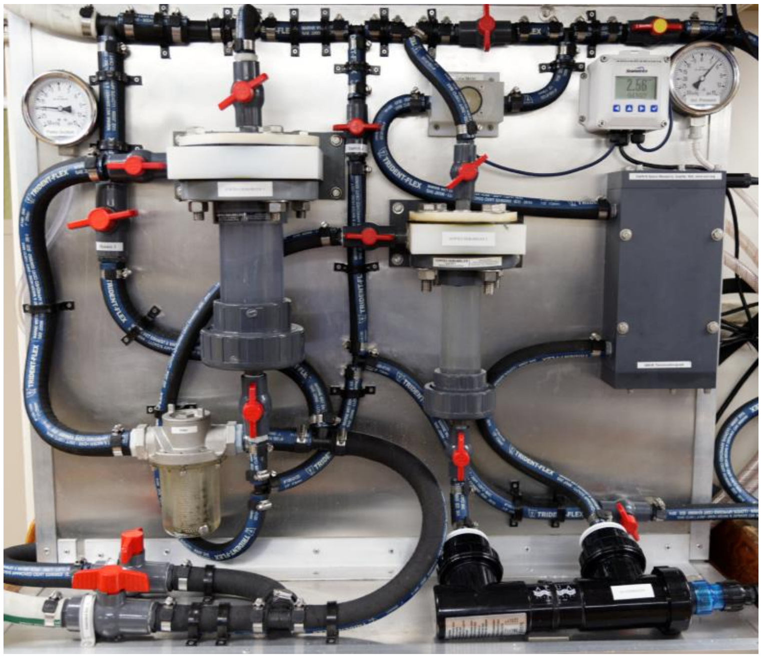


Figure K2: Shipboard system of the salinity snake, showing intake strainer, cascading vortex de-bubbler system, ultraviolet sterilizer, Seabird 45 thermosalinograph, flow meter and intake and discharge gauges.

2.) Time of deployment

The salinity snake was deployed after 2 days at sea, on the 15th of August 2016 and remained operational throughout the cruise until 2 days before returning to port. The hose assembly was occasionally retrieved using the halyard system during the deployment and recovery of assets such as moorings or drifters. These interruptions were logged.

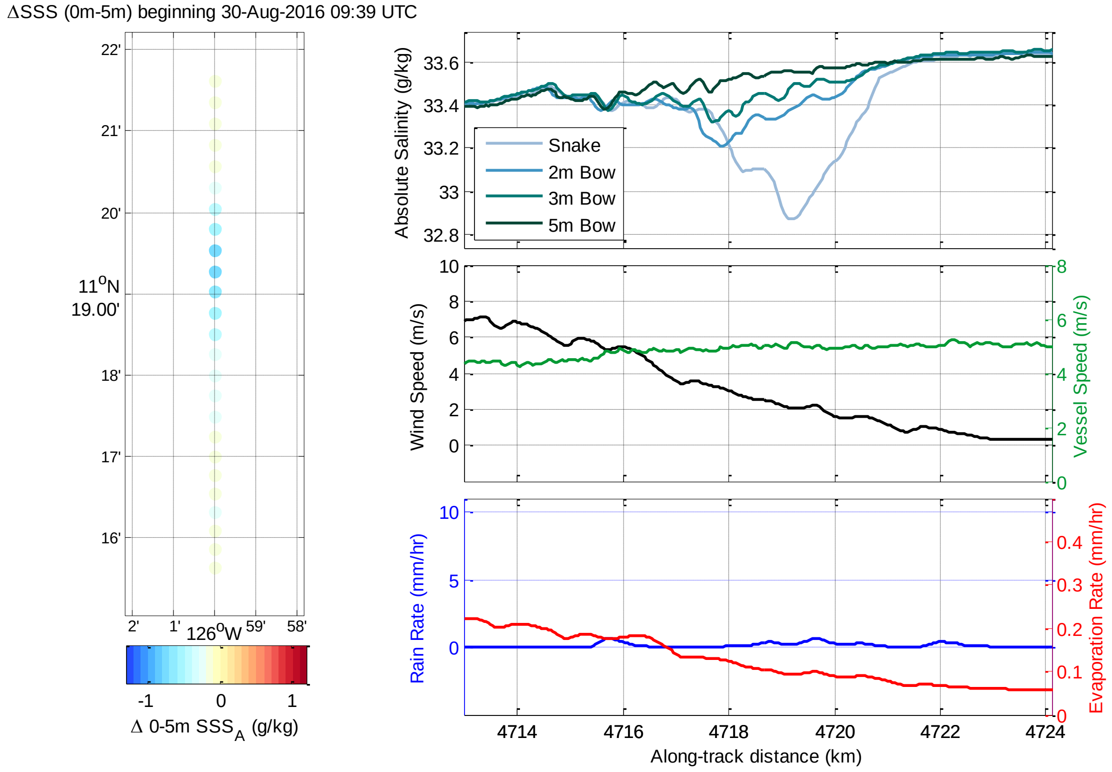


Figure K3: Data from a typical freshwater lens, extending approximately 3-4 km across. The left hand panel shows color-coded data points of the difference between the salinity snake intake and the ship's TSG at 5m depth. The top right hand panel shows salinities from the salinity snake (light blue), the 2m OSSPRE TSG intake (blue), the 3m OSSPRE intake (dark blue) and the 5m bow TSG intake (black), while the right central figure shows vessel speed (green) and wind speed (black) and the bottom figure shows rain rate (blue) and evaporation rate (red). Units are provided on the axes labels.

3.) Sample data

Sample data are provided in Figure K3. This is an example of a typical small freshwater lens which corresponded to little or no recorded precipitation at the vessel. The salinity stratification is negatively correlated with wind-speed, that is, the stratification is greater at lower wind speeds, which is an expected result.

L. Information System Field Support Team

Frederick Bingham, Audrey Hasson, Peggy Li and Zhijin Li

As part of our field support activity, the SPURS-2 IS team provided on a daily basis a set of satellite and in situ observations as well as forecasts. This set of data was available to all onboard on the R/V Revelle via its intranet. A summary of the datasets uploaded daily is described in the table below.

An analysis of the datasets listed in Table L1 as well as SPURS-2 in situ observations gathered during the ongoing cruise was presented daily in oceanic and atmospheric briefings by scientists onboard. Data visualization was also available real-time on the SPURS-2 website (Fig. L1).

Table L1. Summary of datasets uploaded daily onboard during the 2016 cruise.

Parameter	Product Type	Dataset	Platform Type
Sea Surface Height	L4	Aviso	Satellite Altimeters
Rain	L4	GPM	Satellite (Microwaves and Radar)
		SMOS	SMOS Satellite
Sea Surface Salinity	L2 and L3	SMOS-CEC LOCEAN	SMOS Satellite
		SMAP (JPL)	SMAP Satellite
Ocean Currents	L4	Aviso	Satellite (topography/altimeters)
		Oscar (ESR)	Satellite (topography and wind)
		SCUD (APDRC)	Satellite (topography and wind)
Salinity and Temperature Profiles	Raw	Coriolis	Argo
Winds	L2	ASCAT	Satellite
Top of Cloud Temperature		GOES-IR	Geostationary Satellite (Infrared)
Salinity, Temperature, Currents	Raw	TAO (PMEL NOAA)	Moorings
Significant height of combined wind waves and swell	72-hour Forecast	NCEP (WWW3)	Model
Wind and Precipitation	72-hour Forecast	GFS	Model
Salinity, Temperature, Currents	48-hour Forecast	ROMS (JPL)	Model

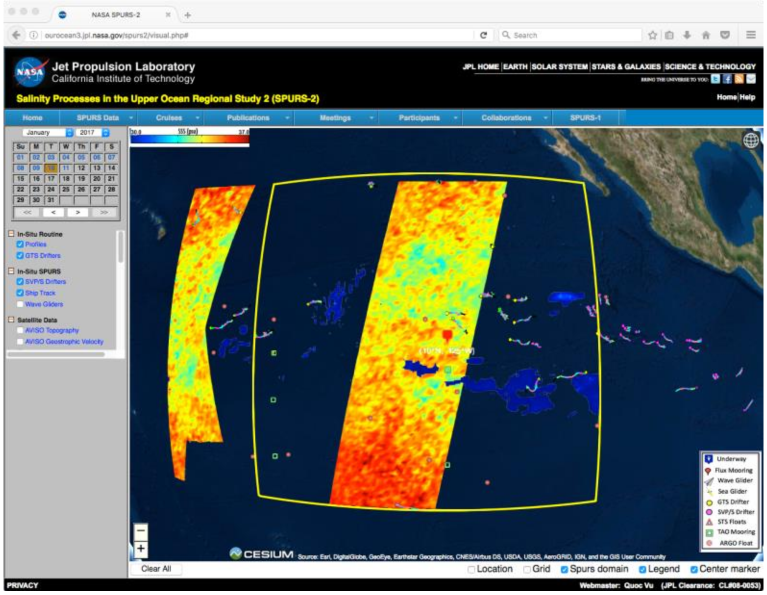


Figure L1. Screen capture of the data visualization SPURS-2 webpage on January 11, 2017.

During the first part of the cruise, daily briefings and the webpage were aimed at advising PIs onboard and onshore in the planning of the various assets deployments such as moorings, drifter floats, sea gliders, SPP, etc. Figure L2 is an example of maps presented during the daily ocean briefings showing the previous days of data.

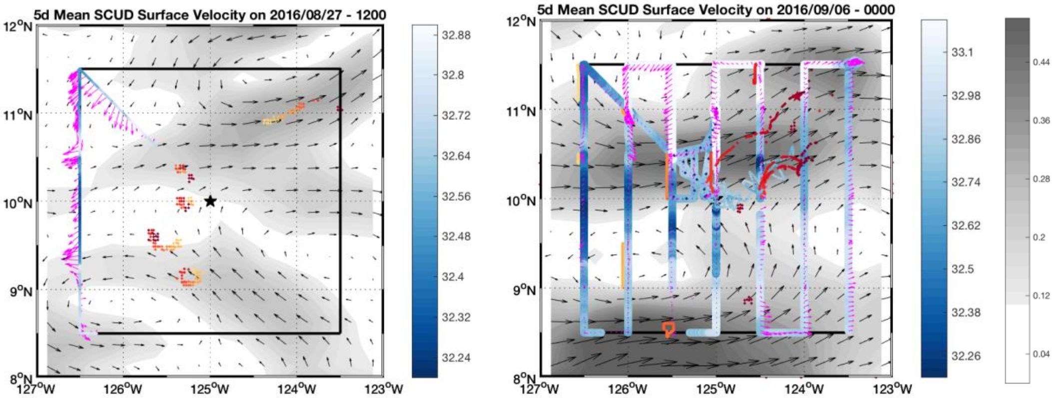


Figure L2. Maps of surface currents (SCUD, $m.s^{-1}$) for 2016/08/27 and 2016/09/06. Overlaid is the underway 3m TSG and .3 m Wavegliders salinity (blue); underway ADCP current (10 m bin, pink), as well as drifters, Argo and SSP locations (orange, darker with time). The star indicates the central mooring, the box is the survey area and the line the hydrographic transect.

Specific analyses for the planning of the hydrographic survey on the 125ºW transect were produced daily in order to identify the features PIs were interested in sampling. Two persistent fronts were identified around 10.5ºN and 7ºN due to tropical instability waves constraining the fresh pool to the south and a largescale intrusion present to the north (Fig. L3). With the help of satellite and in situ data analyses the original transect of 2ºN to 15ºN was reduced to 5ºN to 11ºN.

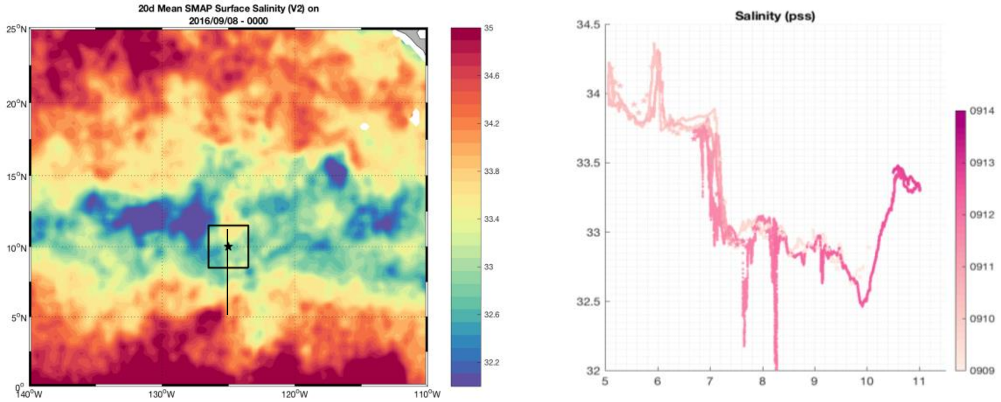


Figure L3. (left) SSS (L3, SMAP) averaged between 2016/08/30 and 2016/09/18. The star indicates the central mooring, the box is the survey area and the line the hydrographic transect. (right) 3m TSG salinity during the transect back and forth. Color scale represents time. Stars are the uCTD top level salinity measurement.

During the last part of the cruise, PIs were interested in steaming back to Hawaii following the lowest winds. Our team was able to provide them with observations and forecasts such as shown on Figure L4. In addition to the cruise support efforts, during the cruise we posted materials on the SPURS-2 facebook page as public outreach. http://www.facebook.com/nasaspurs2

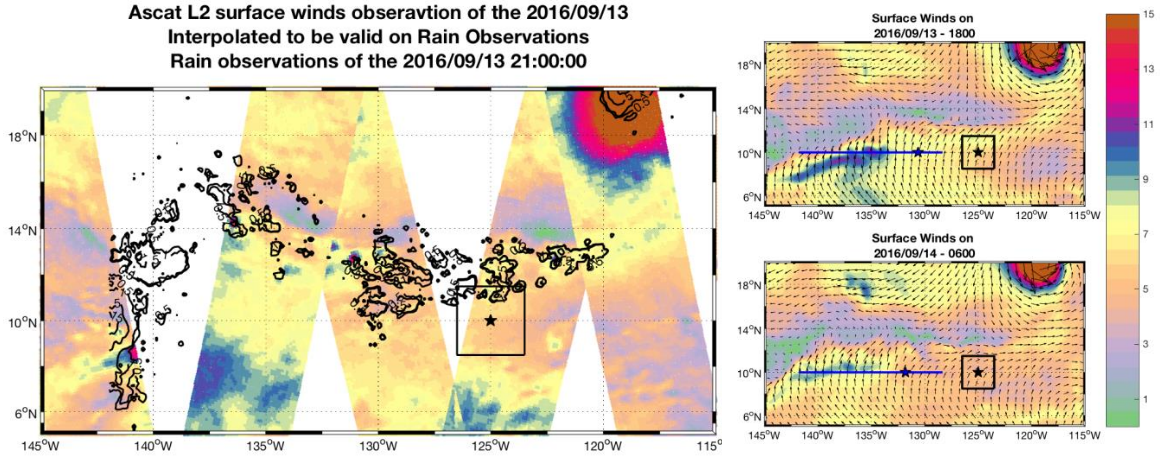


Figure L4. 2016/09/13 surface wind observations (ASCAT, left) and forecast (GFS, right). Observed precipitation (GPM) is shown on the left. Forecasted ship position along 10ºN is shown on the right. The SPURS-2 central mooring and survey box are shown on all panels.

M. Modeling Support

Zhijin Li, Frederick Bingham, Peggy Li, and Audrey Hasson

Before the R/V Roger Revelle sailed to the SPURS-2 region on August 12, 2016, the JPL data assimilation and forecasting system was created. Relying on the Regional Ocean Modeling System (ROMS), we produced ocean state analyses and forecasts out to three days on a daily basis. The system assimilated observations from operational observing networks such as Argo floats, satellite surface temperatures, salinities and altimetry data. SPURS-2 measurements that were available realtime were also assimilated. The analysis and forecast results were delivered to the SPURS-2 chief scientist and other SPURS-2 PIs through email and the SPURS-2 Information System (SPURS-IS).

Preliminary evaluations show that the modeling system successfully predicted large-scale oceanic conditions. The modeling system predicted that SST was about 2^{o}C above normal in the SPURS-2 region while the SST near the equator was 1-2^{o}C below normal. SSS was fresher than normal in the SPURS-2 region and saltier near the equator. Stronger than normal meridional SST and SSS gradients established abnormally strong density gradients and thus led to development of active tropical instability waves (TIWs), and a stronger than normal South Equatorial Current (SEC). Figure M1 is the model forecast of oceanic conditions on 8 August 2016.

For the mesoscale and submesoscale flows, however, the modeling system did not provide predictions as accurate as required for guiding the SPURS2 field operations. The system overpredicted the amplitudes of mesoscale eddies and often misplaced them by up to 100 km. We investigated the unsatisfactory performance of the modeling system and found that the satellite altimetry data was not assimilated due to an error when the system was set up for real-time operations. At the late stage of the cruise, the error was fixed, and the prediction of the mesoscale and submesoscale flows became skillful as expected. Figure M2 shows an example where the model velocity field matched up with drifter trajectories. Some preliminary evaluations give a root-mean-square error of the model velocity of around 0.15 m/s in comparison with the hourly drifter velocities.

During the 2017 cruise, we expect to provide model mesoscale analysis and forecast fields that are of accuracy for guiding SPURSS-2 site operations. In particular, we will provide evaluations of the model analysis and forecast fields against measurements, and thus the uncertainty can be taken into account for decision making by the chief scientist and other PIs.

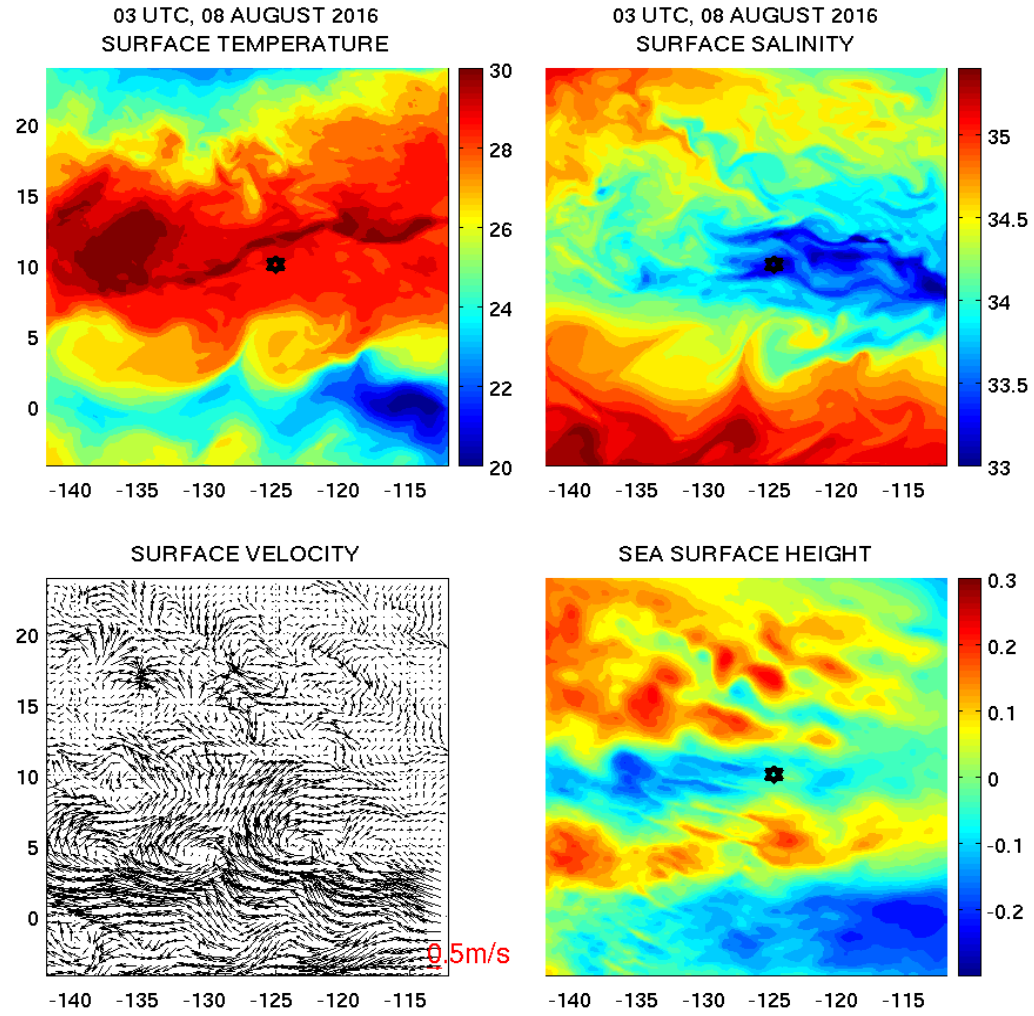


Figure M1 Analysis of SST, SSS, surface velocity vectors and SSH on August 8, 2016. The nowcast is produced using the ROMS data assimilation and forecasting system for SPURS2.

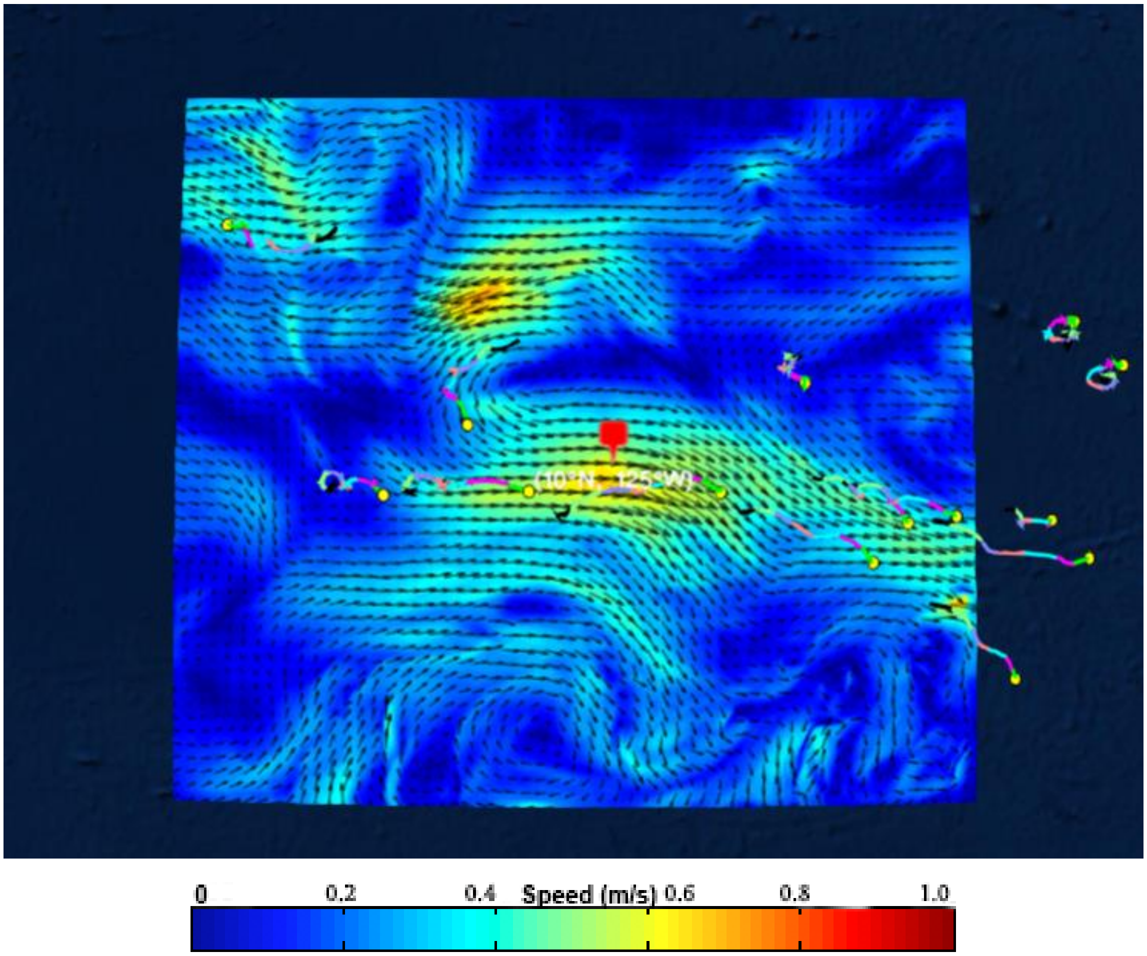


Figure M2 Analysis of surface velocity vectors on October 7, 2016. Colored curves show trajectories of GTS drifters over a period of 7 days. The yellow dot indicates the location of the end of the trajectory. One color on the curve is the trajectory portion for one day. The colors in the plot show the speed.

N. SURPACT

Gilles Reverdin[1] and Audrey Hasson

Deployment (UTC)	Recovery (UTC)	CTD calibration interval	Trans-mission	Debug Flag	Data	Configuration	Additional Comments
2016/08/24 15:15	2016/09/01 23:12	1s	1	0	24 MB	Attached to the Central Mooring	Via SPIP-2
2016/09/14 02:55	2016/09/15 22:54	3s	0	1	915 kB	With 2 Swift floats	Deployed after rainfall was observed
2016/09/17 21:59	2016/11/05 02:45 (End of transmission)	99 (off)	1	0	-	Attached to a CODE drifter	"Marseillaise" farewell

Surpact 13260 deployments info during the 2016 SPURS-2 cruise

Surpact is a small wave-rider based on modified 'seal tags' (www.meop.net) . In Argos mode (last deployment), it measures T, S near 7 cm below the surface and vertical acceleration that can be transformed in wave spectra (messages every 15 minutes, Reverdin et al., 2013). The tag is held by a rod connected to brakets in an outer floating ring, with the possibility or rotation. In addition, the 'prototype version' used here also measures the sound power in two frequency bands from a microphone placed under a little hemispheric cap on top of the tag. This was designed and tested to record in particular the noise of rain drops. To fit all information in the Argos message, unfortunately, the number of frequency band of the wave spectra was reduced, as well as the resolution. Investigating the data recorded during the last deployment suggest that we should revert to two more frequency bands and increase resolution.

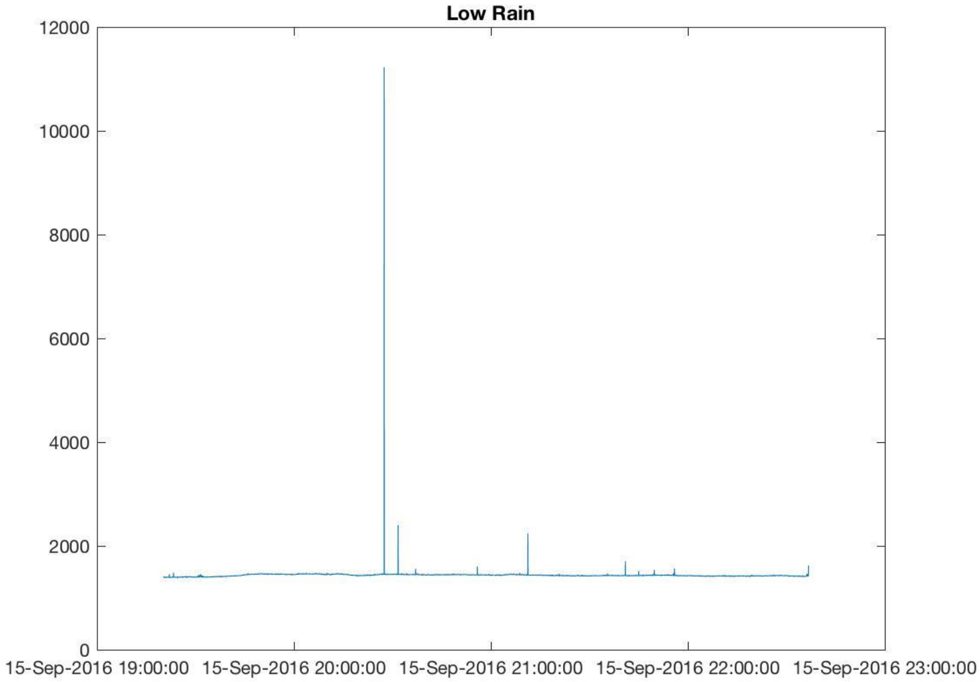
Data can also be acquired in continuous fashion for short deployments with data downloaded upon recovery (first deployment with all parameters, second parameter without the accelerometer data). This is however limited due to storage space, and during the first deployment data were only stored until 28/08 at 11:04:18.

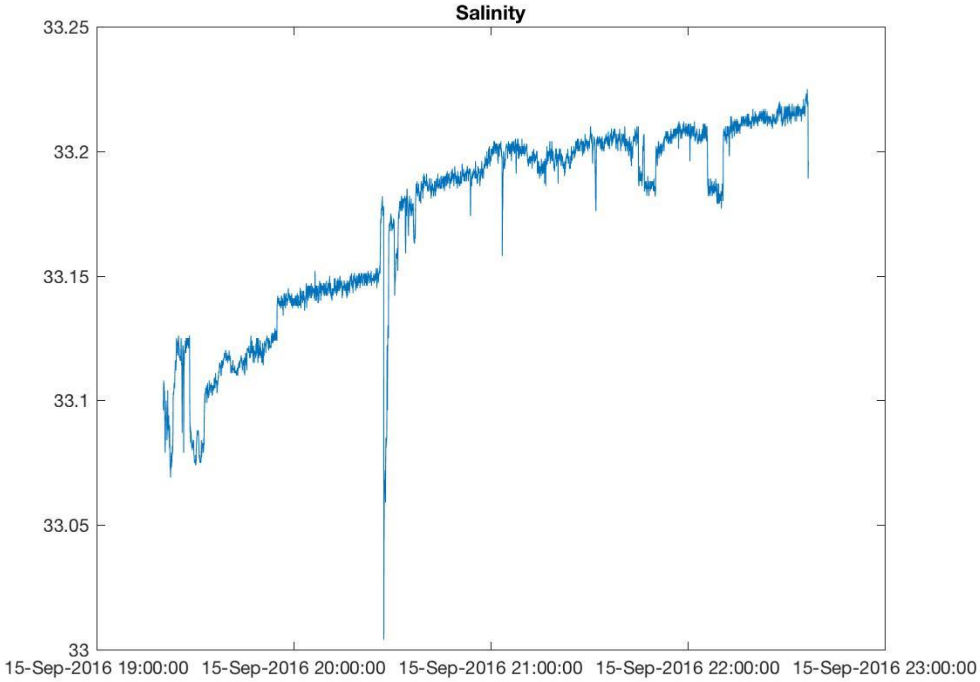
Another change was that the antenna on this prototype was longer and more rigid and that the tag had the unfortunate habit to turn over during waves with the antenna probably stuck so that it could not turn back to its normal position. This was found during deployment 1 from 26/08 at 02:05:39 until the 28/08 at 10:09:35, and from 28/08 at 12:55:21 until the end of the record.

This also happened more than a third of the time during the last Argos-mode deployment.

There is not much to report at this point from deployment 1, as it did not rain during the data recorded.

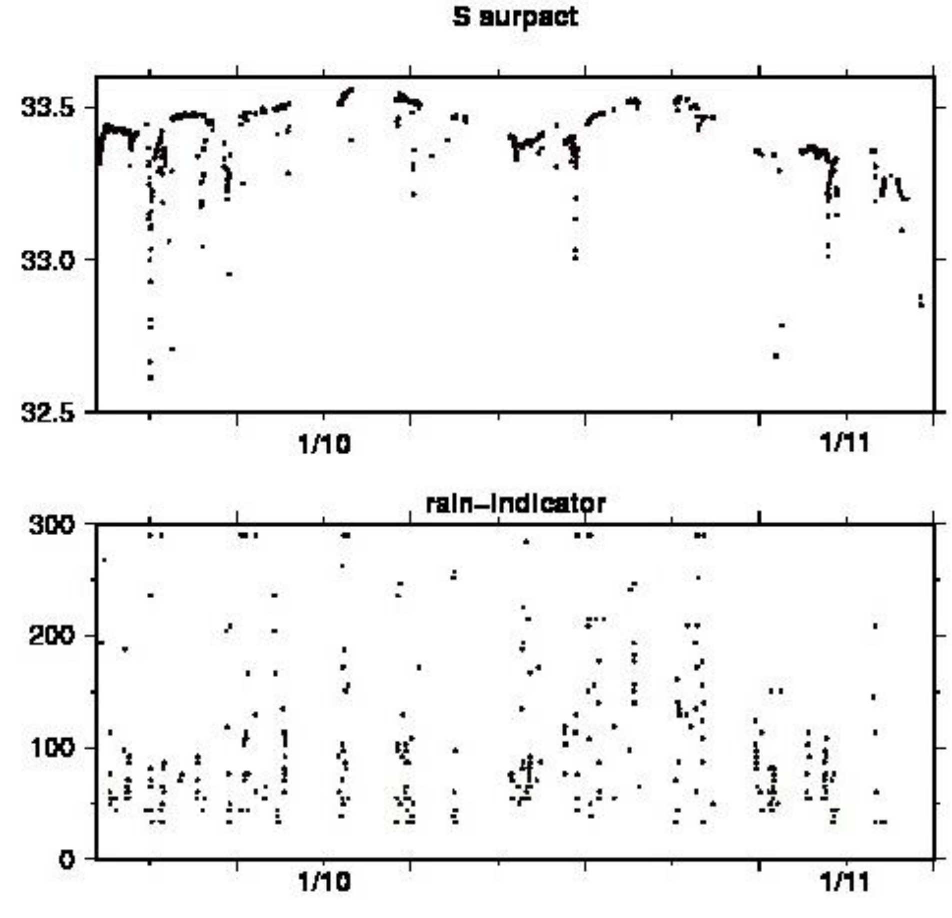
Deployment 2 is more interesting, as it investigates salinity recovery just after a large rain event. The data also suggest a very-short duration rain event.





It shows in particular, a very brief noise event (rainfall) (second panel) near 20:25 associated with a 1-minute long decrease of SSS (larger than 0.15 pss). Probably a very brief and isolated local shower. The recovery is also interrupted by short periods with lower S(7 cm) before and after 10 pm that are not associated with rainfall, and suggest sharp spatial inhomogeneities.

During the last deployment at the end of the cruise in Argos mode, the surpact wave rider attached to the code drifter mostly drifted eastward in the NECC, in rather low-SSS water. Its last position is actually rather close to the SPURS2 mooring. It experienced at time rain events, but never associated with very strong freshening, maybe as the wind never abated fully (as seen in the wave spectra slope). The data also indicate that the two sound frequency power indicators are responsive to rainfall, but also responsive to other noise sources, probably in presence of wave braking. They seem to be also sensitive to direct sun exposure, near mid-day, probably an electronic effect. We will need to find whether we can separate the different effects with the help of the wave spectra, but this requires a larger set of events that the ones recorded during this deployment.



Deployment of the surpact in the NECC (18/09 to 4/11).

The rain indicator has been cut at a maximum of 290.

Reverdin, G., S. Morisset, D. Bourras, N. Martin, A. Lourenço, J. Boutin, C. Caudoux, J. Font, J. Salvador. A SMOS surface drifter for air-sea interaction (SURPACT). Oceanography, 26, 48-57.

O. Underway measurements of surface pCO_2, DIC, pH and DO

David Ho, University of Hawaii

During the cruise, continuous measurements of partial pressure of CO_2 (pCO_2), dissolved inorganic carbon (DIC), pH, and dissolved oxygen (DO) were made on water pumped continuously from the Salinity Sea Snake (Salinity Snake) operated by Julian Schanze of Earth and Space Research. The pCO_2 system uses a membrane contactor coupled to a nondispersive infrared (NDIR) analyzer, and has a temporal resolution of ca. 1 min. The DIC system takes a small volume of water, acidifies it with phosphoric acid to drive all the DIC to pCO_2, and sends the resulting gas to an NDIR analyzer for quantification. The system has a temporal resolution of 3 min. pH was measured with a ion sensitive field effect transistor (ISFET)-based pH sensor, and dissolved oxygen was measured with an optical dissolved oxygen sensor, both with time resolutions of better than 1 min. Calibration for pCO_2 was done with two compressed gas standards; calibration for DIC and pH were made with certified reference material (CRM) from Andrew Dickson's lab at Scripps; calibration for DO was made with water saturated air.

Measurements were made from the Salinity Snake whenever it was deployed. At other times, water from the Revelle's uncontaminated seawater intake was measured in order to compare results with those measured by the underway pCO_2 system from Rik Wanninkhof's group at NOAA/AOML.

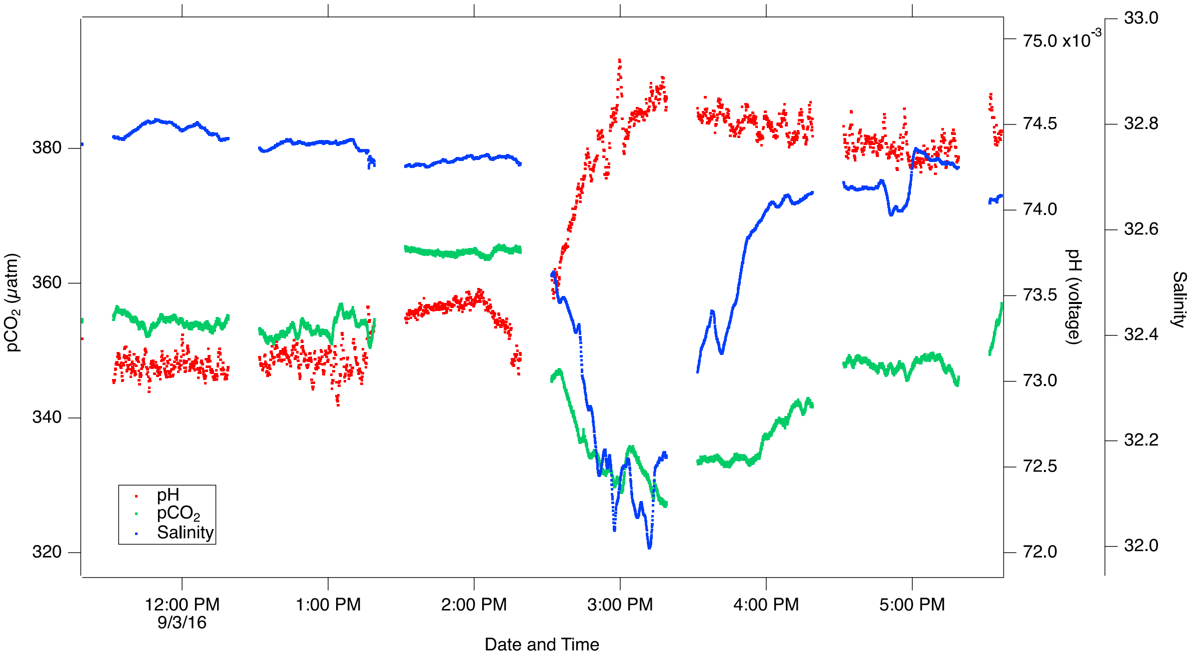


Figure.O1 An example of continuous measurements of pCO_2 and pH across a "puddle", showing a decrease in pCO_2 and increase in pH when salinity decreased.

P. An Annual Cycle of Upper Ocean Salinity in a Rainfall–Dominated Region Captured by High-Resolution Glider Surveys

Luc Rainville, Craig M. Lee, Charles Eriksen, Kyla Drushka, Caitlin Whalen

Objectives of the SPURS-2 Seaglider Program

The SPURS-2 field program aims to understand the structure and variability of upper-ocean salinity in the Eastern Tropical Pacific Ocean over more than one complete annual cycle. The SPURS-2 glider surveys will characterize the upper ocean in a consistent, repeated manner at temporal and spatial scales that are well matched to those of remote sensing. Over a pair of deployments covering an **entire year**, the main objectives of the SPURS Seaglider program are to:

- Resolve salinity, temperature, density, and their lateral gradients, in the top 1000 m of the water column on horizontal scales of ~20 km and time scales on the order of the inertial period (~3 days) near mooring sites(s).
- Provide direct estimates of turbulent dissipation in the mixed layer and in the sharp thermocline and halocline, via microstructure measurements.
- Provide gradients and turbulence estimates around freshwater patches as they are advected by the mean and mesoscale circulations, in combination with surface drifters or Lagrangian floats.

With these measurements, we will be able to resolve the salt storage and the horizontal and vertical advection of salt, and quantify diapycnal mixing of salt by small-scale turbulence around the mooring(s). This will provide a direct view of the processes by which the ocean spreads and integrates freshwater from precipitation.

Deployments and Missions

3 Seagliders were deployed in August 2016 from the R/V *Roger Revelle* and have been sampling around the moorings and Lagrangian Array. The gliders are equipped with temperature, salinity, dissolved oxygen sensors, as well as passive acoustics and temperature and shear microstructure systems.

Because of the schedule of the recovery cruise (Oct. 2017), the complete SPURS-2 field experiment is expected to last 14 months. Gliders will be recovered and 3 new gliders will de deployed during the turnaround cruise on the Lady Amber in March 2017, requiring each Seaglider to do a 7-month mission.

One of the SPURS-2 Seagliders (sg190) spent about 2 months following the Lagrangian Array (Figure 1), a drifting cluster of instruments consisting of a Mixed Layer Lagrangian Float (MLF; Shcherbina et al.), a Wave Glider (Hodges et al.), and surface drifters (Centurioni et al.), and the Seaglider. During the first 2 months of SPURS-2, the Lagrangian Array traveled about 700 km, first to 12°N and then to 9°N, while generally drifting eastward. On October 19th, about 330 km from the central mooring, it was decided that sg190 would not be able to keep up with the MLF and surface drifters, so the Seaglider abandoned the Lagrangian Array and came back to the

Eulerian Array, around the SPURS-2 central mooring. The Lagrangian Array (MLF and Wave Glider) has been recovered by the Lady Amber in late December 2016 about 1800 km east of the central mooring.

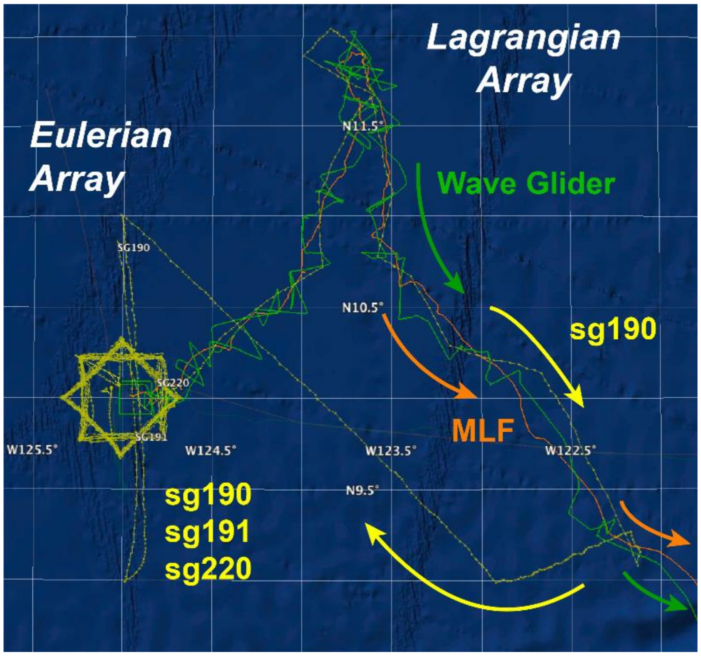


Figure P1: Map of the SPURS-2 region, with the track of the Seagliders (yellow) and selected other instruments (Mixed Layer Lagrangian Float or MLF, orange; Wave Glider, green). Seagliders are part of the Eulerian Array around the moorings (left, with sg190 doing a meridional section between 9 and 11°N; sg191 occupying a 50-km box; and sg220 occupying a 50-km diamond), and sg190 followed the MLF for the first 2 months as part of the Lagrangian Array.

Seagliders 191 and 220 have been sampling around the central mooring (Farrar et al.), occupying an overlapping box and diamond with 50km sides (Figure P1). A gilder takes 10 to 14 days to go around the box, and the complete pattern has been occupied about 10 times so far. Since returning, sg191 is occupying a 220-km long section between PMEL-N (11°N) and PMEL-S (9°N).

Q. SPURS-2 progress summary related to ARGO float operations

Jie Yang, Dana Swift, and Stephen Riser

I. Research objective and approach

Rain over the ocean is a central process in the global freshwater cycle, and the density gradients generated by the freshwater input play a role in vertical mixing and horizontal advection of the ocean surface over a range of spatial and temporal scales. Understanding the details of this freshwater flux to the ocean surface and the freshwater is redistributed in time and space in the ocean is a key goal of the second experiment in the NASA-funded Salinity Processes in the Upper Ocean Regional Study (SPURS-2).

In conjunction with other measurements including ship-board profiling systems, moorings, sea gliders, and satellite products, we have deployed 15 profiling floats, 10 of which are regular US Argo floats, with the remaining 5 being US Argo floats equipped with Surface Temperature and Salinity (STS) and Passive Aquatic Listener (PAL) sensors. Each of the 15 floats sample over spatial scales of 50 – 1000 km and measure vertical profiles of temperature and salinity at

10-day intervals. The 5 floats equipped with PAL sensors also provide a time series of rainfall and wind speed during times when the float is not profiling.

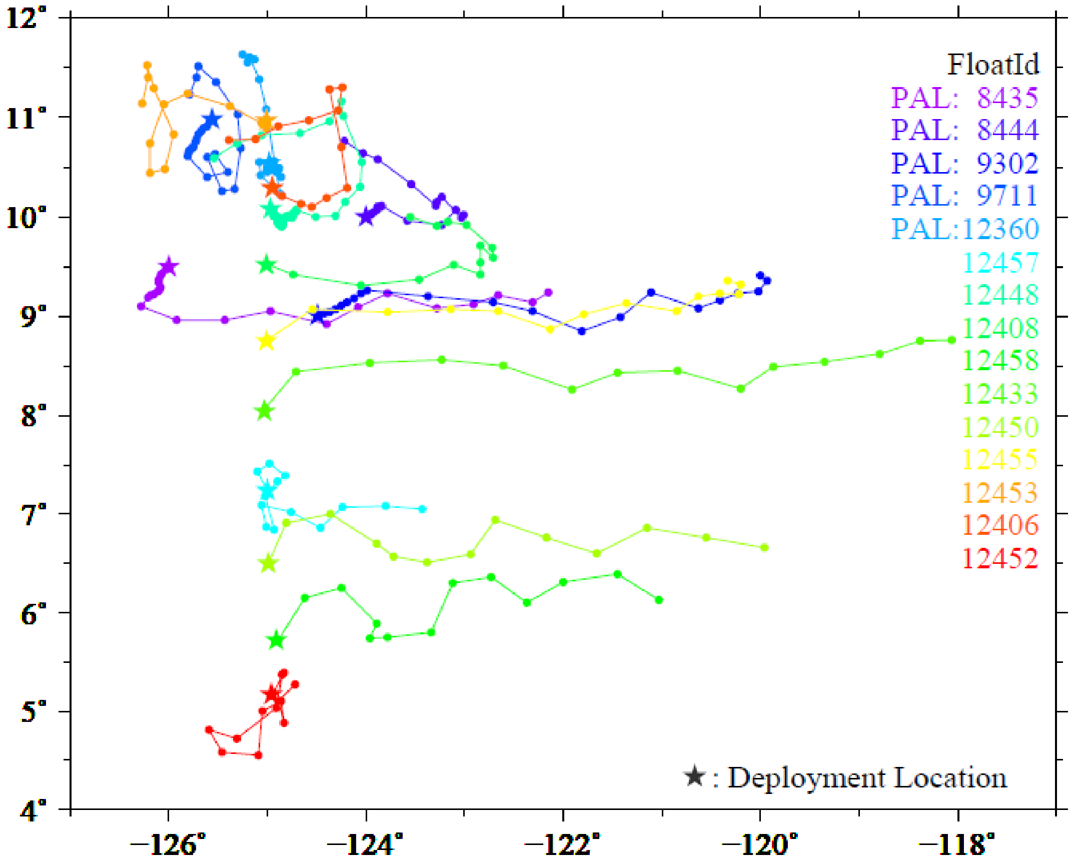


Figure Q1 Trajectories for the 15 floats deployed for SPURS2 from September 2016–16 January, 2017.

II. Preliminary data

1. Float drifting pattern

The 15 floats were deployed in the time period of Aug. 31 – Sep. 14, 2016 with park depth of about 1000 m. Ten were deployed on a meridional transect along 125 °W from 5 °N to 11 °N. The remaining 5 were deployed in a box bounded by 9 °N, 11 °N and 124 °W,126 °W. The deployment locations and trajectories of the floats (till Jan. 16, 2017) are shown in Fig. Q1. The floats that were deployed between 5.5°–9.5° N, drift eastward with a maximum speed of 5 cm/s. For floats deployed either north of 9.5° N or South of 5.5° N, the trajectories tend to be circular and limited to in general 1° x 1° area. The trajectories are consistent with floats that were deployed previously in the same area (more float trajectories, see runt.ocean.washington.edu/.)

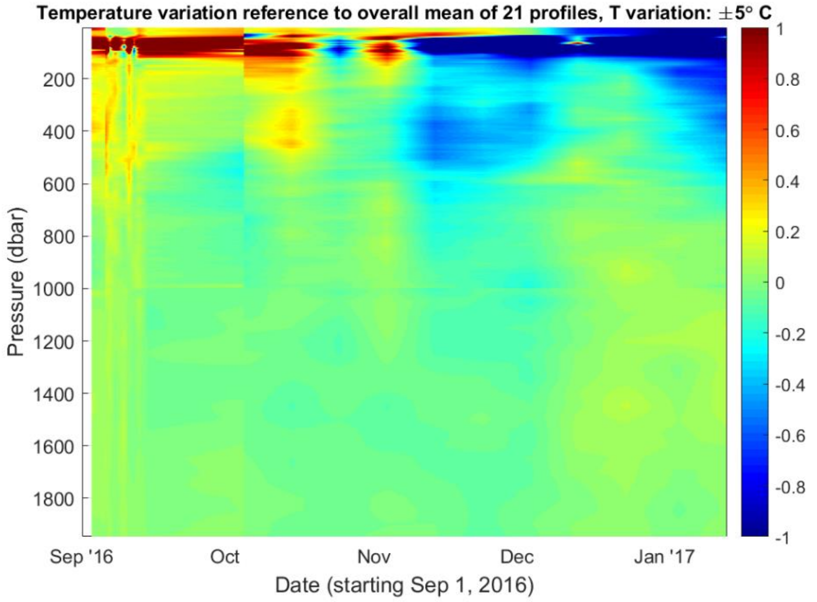


Figure Q2Temperature variation of float 12360, closest to the central mooring. A total of 21 profiles were collected from Sep. 2, 2016 – Jan. 13, 2017. Temperature variation is defined as the difference between individual profile and the overall mean of the 21 profiles. Color is saturated to ± 1° for display purpose.

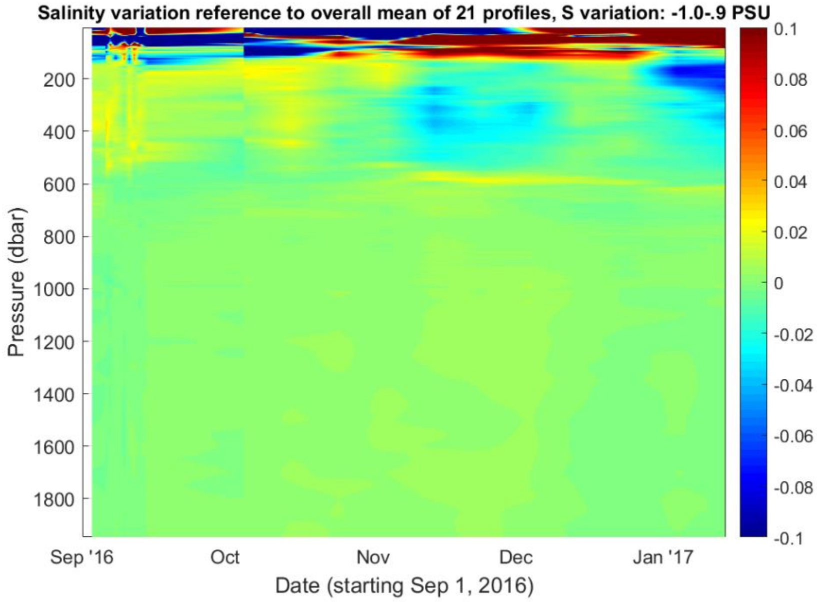


Figure Q3 Concurrent salinity variation of float 12360, closest to the central mooring. A total of 21 profiles were collected from Sep. 2, 2016 – Jan. 13, 2017. Salinity variation is defined as the difference between individual profile and the overall mean of the 21 profiles. Color is saturated to ± 0.1 PSU for display purpose.

2. S/T data

The temperature and salinity data from the float (float 12360) that is closest to the central mooring are presented here. Float 12360 was deployed on Sep. 2. From Sep. 2 – 14, float was set on a daily profiling cycle and after that on a regular 10-day profiling cycle. A total of 21 profiles were collected from Sep. 2, 2016 – Jan. 13. These profiles, starting from 2000 m up to the sea surface, are taken at the end of the drifting phase as the float ascents to surface. For both temperature and salinity, an overall mean of the 21 profiles was first obtained and the difference between each individual profile and the mean is shown in Figs. Q2 and Q3. The maximum temperature variation relative to the mean is ± 5 ºC; while the salinity ranges from –1.0 psu below, to 0.9 psu above the mean value. For both Figs. Q2 and Q3, color is saturated at a minimum and maximum value in order to better display the vertical structure. Beginning in November 2016, Figure Q2 shows the upper 600 m of the ocean cooled. During this same time, a layer of water from 200 m to 400 m became fresher, although the upper 200 m shows a stratified salinity profile, with layers of high and low salinity. In the middle of December 2016 salinity increases in the 200 m to 400 m depth range, followed by a decrease in salinity a few weeks later. This increase in salinity in December 2016 coincides with a period of decreased rainfall, as shown below in Fig. Q6.

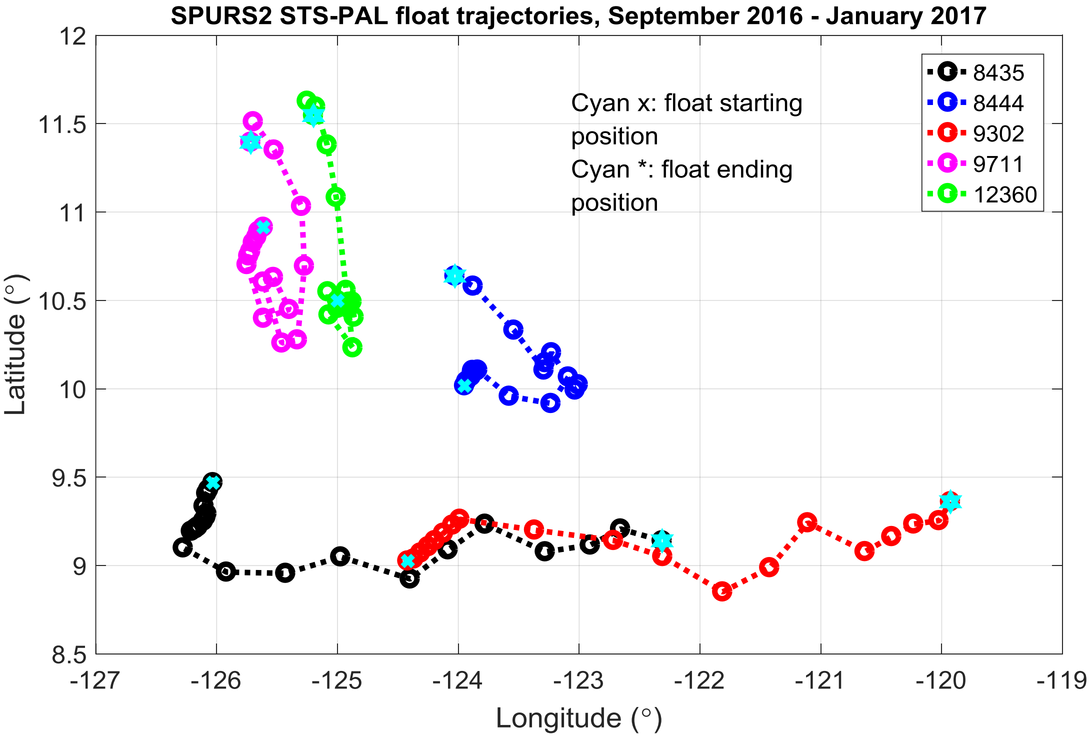


Figure Q4 Trajectories for the 5 STS floats with Passive Aquatic Listeners, September 2016–16 January, 2017.

3. Acoustically measured wind speed and rain rate

As mentioned earlier, there are five STS floats with Passive Aquatic Listener (PAL) sensors, which measure wind speed and rain rate. Figure 4 shows the detailed trajectories for the five STS-PAL floats. Again, since float 12360 is the closest to the central mooring, its wind speed and rain rate will be shown here.

Figure Q5 shows the comparison of wind speed between the central mooring and PAL. In general, the PAL wind speed is consistent with wind speed measured by surface anemometers on the central mooring. Rain rates measured by PAL are shown in Fig. Q6. They will be compared to rain rates derived from satellite data products.

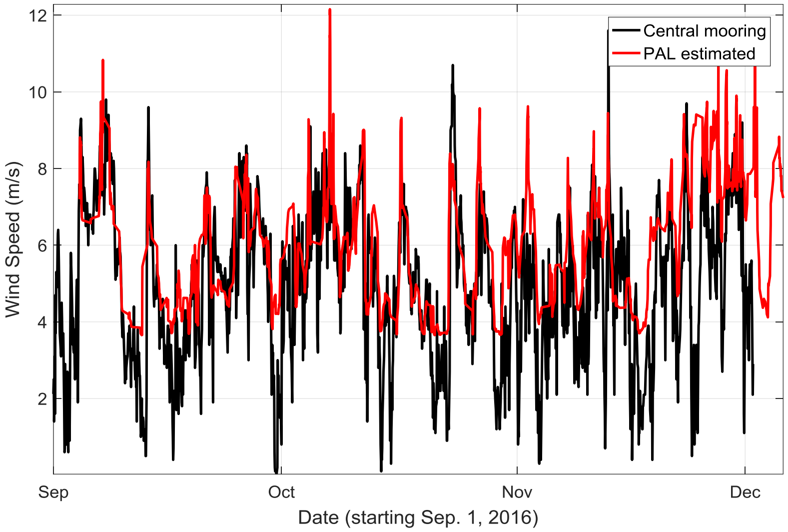


Figure Q5 Wind speed comparison between the central mooring and PAL estimates.

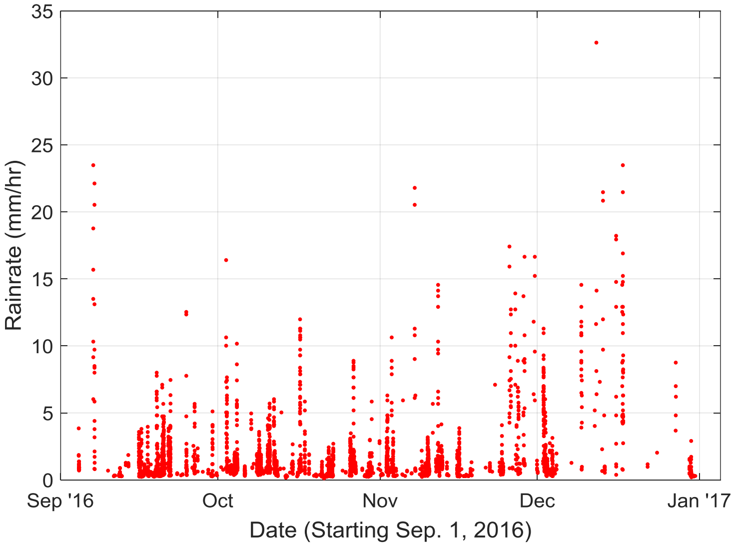


Figure Q6 PAL estimated rainrate.

R. SPURS-2 Ship-Board Acoustic Observations

Peter Gaube

1 Motivation

The SPURS-2 expedition presented a unique opportunity to collect acoustic observations of stratifi- cation and deep scattering layers (DSLs) in the tropical Pacific Ocean. My acoustic system is easy to deploy and would allow the collection of a complementary dataset that will be made available to the SPURS science team.

2 Description of cruise activity

The Rotating Universal Mounting Pole (RUMP) was affixed to the aft deck on the port side forward of the fantail. The location was chosen as it would prevent bubbles from the aft thrusters from being pushed under the transducer and thus introducing noise in the data. In addition, the location was easy to access for deployment.

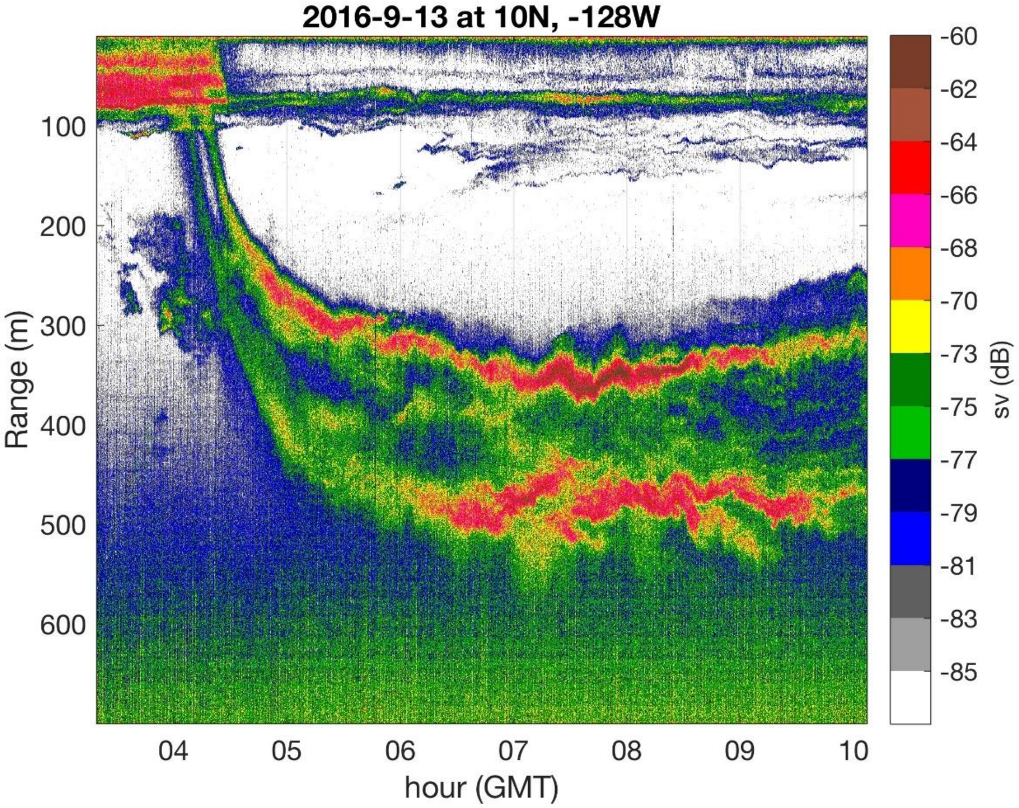


Figure R1: Echogram computed from 38 kHz acoustic backscatter over the 7 hour occupation of the station at 19N, 128W. Downward migration of organisms at sunrise is clearly visible, as are persistent stratification at depths of 75m and 100m.

3 Summary of when measurements were made

The RUMP system col- lects measurements of acoustic backscatter at a frequency of 38 kHz to a depth of 1,000m at a vertical resolution of 1m. At 38 kHz, the primary scatters are organisms with body sizes > 1cm and density inter- faces. When the ship was slowed to a speed of $\leq$ 4 knots, the RUMP was rotated into the down- ward position and the DT-X Echosounder was turned on to collect data. In total, $\approx$ 289 hours of acoustic data, at an inter- val of 1 second, was collected, resulting in nearly 300 Gb of files. An example echogram showing the downward migration of fish and zooplankton, as well as many fish schools and density interfaces, is shown in Figure R1.

4 What worked and what did not work

On the next SPURS expedition I will install an additional transducer that operates at 120 kHz. This will allow me to collect high-resolution observations of stratification in the upper 100 m. In addition, I plan to send along my postdoc, Alice Dellapenna, to operate the acoustics system and perform on-board analysis using the concurrent CTD and surface structure observations to develop a real-time estimate of stratification from the acoustics.

Appendix

Table H1: Event Log: Chronology of CTD/LADCP stations and uCTD transects

Station	Cast	Lat (Start)	Long (Start)	Type	(u)CTD Depth (m)	Water depth (m)	Start cast (GMT)
000	01	16° 40.167N	146° 32.86W	CTD test	1500	5475	16 August 2016 18:51
000	02	16° 40.178N	146° 32.85W	CTD test	1053	5477	16 August 2016 20:32
T1	01	11° 25.8N	125W	uCTD T1 start	500	?	21 August 2016 21:50
T1	22	9° 3N	125W	uCTD T1 end	500	?	22 August 2016 11:51
001	01	10° 3.1N	125° 4W	CTD	4620	4634	24 August 2016 02:28
002	01	11° 30N	126° 30W	CTD	1030	4558	27 August 2016 06:46
TB	u001	11° 30N	126° 30’W	uCTD SSP-1 start	500	?	27 August 2016 08:55
TB	u009	11° N	126° 30’W	uCTD SSP-1 end	500	?	27 August 2016 14:53
003*	01	11° N	126° 30’W	CTD	1020	4782	27 August 2016 16:57
TB	None	10° 30N	126° 30’W	SSP-2 start	-	?	27 August 2016 20:58
TB	none	10° 30N	126° 30’W	SSP-2 end	-	?	28 August 2016 00:35
004	01	10° 30N	126° 30’ W	CTD	1050	4660	28 August 2016 01:12

005	01	10° N	126° 30’W	CTD	1020	4646	28 August 2016 05:44
006	01	9° 30’N	126° 30W	CTD	1020	4653	28 August 2016 09:57
007	01	9° N	126° 30’W	CTD	1020	4634	28 August 2016 14:10
008	01	8° 30’N	126° 30’W	CTD	1020	4709	28 August 2016 18:51
009	01	8° 30’N	126°W	CTD	1020	4641	28 August 2016 23:07
010	01	9° N	126°W	CTD	1020	4663	29 August 2016 03:28
TB	u014	9°N	126°W	uCTD SSP-3 start	500	?	29 August 2016 04:35
TB	u019	9° 30’N	126° 30’W	uCTD SSP-3 end	500	?	29 August 2016 12:14
011	01	9° 30’N	126°W	CTD	1020	4618	29 August 2016 12:34
012	01	10° N	126°W	CTD	1020	4654	29 August 2016 16:56
013	01	10° 30’N	126°W	CTD	1020	4644	29 August 2016 21.10
014	01	11°N	126°W	CTD	1020	4726	30 August 2016 03:10
TB	None	11°N	126°W	SSP-4 start	-	?	30 August 2016 05:47
TB	None	11° 30’N	126°W	SSP-4 end	-	?	30 August 2016 07:48
015	01	11° 30’N	126°W	CTD	1020	4639	30 August 2016 11:33

016	01	11° 30’N	125° 30W	CTD	1020	4969	30 August 2016 15:49
017*	01	11° 00N	125° 30W	CTD	1020	4665	30 August 2016 19:47
018	01	10° 30’N	125° 30W	CTD	1020	4659	30 August 2016 23:55
TB	u027	10° 30N	125°30W	uCTD SSP-5 start	500	?	31 August 2016 00:58
TB	u033	10° 00’N	125° 30W	uCTD SSP-5 end	500	?	31 August 2016 09:18
019	01	10° 00N	125° 30W	CTD	1020	4717	31 August 2016 09:34
020	01	9° 30’N	125° 30W	CTD	1020	4627	31 August 2016 13:49
021	01	9°N	125° 30W	CTD	1020	4710	31 August 2016 17:59
TB	U036B	8°30N	125°30W	uCTD SSP-6 start	500	?	31 August 2016 22:05
TB	U037	8° 30’N	125° 30W	uCTD SSP-6 end	500	?	1 Sept 2016 04:56
022	01	8° 30’N	125° 30W	CTD	1020	4543	1 Sept 2016 05:37
023	02	8° 30’N	125° 00W	CTD	1020	4565	1 Sep 2016 09:46
024	01	9° 00N	125° 00W	CTD	1020	4692	1 Sep 2016 13:58
025	01	9° 30’N	125° 00W	CTD	1020	4561	1 Sep 2016 18:13

026	01	10° 00’N	125° 00W	CTD	1020	4696	2 Sep 2016 02:26
TB	U044	10°04N	125°00W	uCTD SSP-7 start	500	?	2 Sept 2016 04:05
TB	U047	10°30’N	125° 00W	uCTD SSP-7 end	500	?	2 Sept 2016 07:01
027	01	10° 30’N	125° 00W	CTD	1020	4651	2 Sep 2016 09:12
028	01	11° 00’N	125° 00W	CTD	1020	4702	2 Sep 2016 13:12
029	01	11° 30’N	125° 00W	CTD	1020	4589	2 Sep 2016 18:15
030	01	11° 30’N	124° 30W	CTD	1020	4677	2 Sep 2016 22:39
TB	U052	11°30N	124°30W	uCTD SSP-8 start	500	?	2 Sept 2016 23:38
TB	U053	11°20’N	124° 30W	uCTD SSP-8 end	500	?	3 Sept 2016 04:34
031	01	11° 00’N	124° 30W	CTD	1020	4577	3 Sep 2016 08:41
032	01	10° 30’N	124° 30W	CTD	1020	4562	3 Sep 2016 13:21
033	01	10° 00’N	124° 30W	CTD	1020	4699	3 Sep 2016 17:50
034	01	9° 30’N	124° 30W	CTD	1020	4605	3 Sep 2016 09:58
035	01	9° 00’N	124° 30W	CTD	1020	4622	4 Sep 2016 02:05

036	01	8° 30’N	124° 30W	CTD	1020	4655	4 Sep 2016 06:17
037*	01	8° 30’N	124° 00W	CTD	1020	4609	4 Sep 2016 10:19
038	01	9° 00’N	124° 00W	CTD	1020	4439	4 Sep 2016 14:18
039	01	9° 30’N	124° 00W	CTD	1020	4677	4 Sep 2016 18:17
040	01	10° 00’N	124° 00W	CTD	1020	4562	4 Sep 2016 22:21
041	01	10° 30’N	124° 00W	CTD	1020	4621	5 Sep 2016 02:29
042	01	11° 00’N	124° 00W	CTD	1020	4613	5 Sep 2016 06:33
043	01	11° 30’N	124° 00W	CTD	1020	4595	5 Sep 2016 10:28
TB	None	11°30’N	123°31W	SSP-9 start	500		5 Sep 2016 14:13
TB	None	11°20’N	123° 30W	SSP-9 end	500		5 Sep 2016 18:54
044	01	11° 30’N	123° 30W	CTD	1020	4453	5 Sep 2016 23:01
045	01	11° 00’N	123° 30W	CTD	1020	4793	6 Sep 2016 03:25
046	01	10° 30’N	123° 30W	CTD	1020	4497	6 Sep 2016 07:46
047	01	10° 00’N	123° 30W	CTD	1020	4513	6 Sep 2016 11:58

048	01	9° 30’N	123° 30W	CTD	1020	4517	6 Sep 2016 16:00
049	01	9° 00’N	123° 30W	CTD	1020	4442	6 Sep 2016 20:00
050	01	8° 30’N	123° 30W	CTD	1020	4471	7 Sep 2016 00:08
T2	001	8° 30’N	125°W	uCTD	500		7 Sep 2016 09:18
T2	167	11° 00N	125°W	uCTD	500		12 Sep 2016 16:10

* No LADCP data