Appendix A. 2016 R/V Roger Revelle Cruise

Overview

The four main activities for the SPURS-2 2016 cruise on the R/V *Roger Revelle*, designated RR1610 are:

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 focus on measuring active rain events, require a design to accommodate both needs. The ship-based measurements and important constraints are:

- 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
- 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

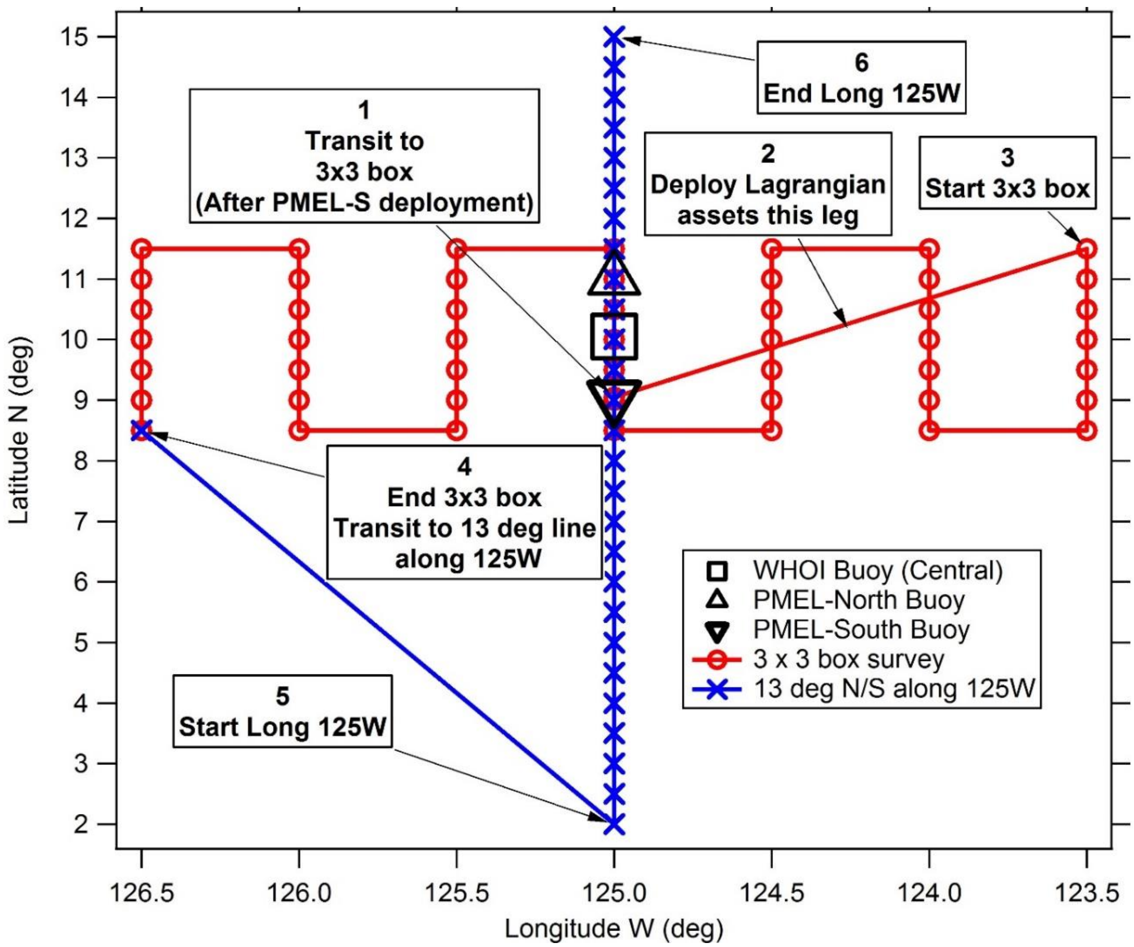

Figure A1: Planned hydrographic survey tracks consisting of 3°x3° Survey Box (red) and transect along 125°W (blue). Also shown are the mooring locations and potential location of deployment of Lagrangian assets.

The proposed combine hydrographic survey and towed measurements is 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 implies that when rain is encountered, the towed sampling and flux measurements should take priority over all other activity. With this in mind, the following approach has been 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 proposed locations of the moorings and the hydrographic survey tracks are shown in Figure A1. Deployment of the moorings will be the first priority in order to establish these critical *in situ* measurements as early as possible and to clear the deck for subsequent operations. To reduce unnecessary transit time, the preferred sequence of the mooring deployments is in order along the 125 W meridian, either North to South or vice versa. Following completion of the mooring deployments, the ship will transit to the starting point of the 3x3 box at 123.5 W, 11.5 N. This transit is a candidate for deployment of the Lagrangian assets. Deployment of the ship-based assets for measuring near-surface rain signatures will occur in conjunction with the hydrographic survey, as outlined above. Upon completion of the 3x3 box, the ship will transit to 125 W, 2 N to commence the transect along 125 W to 15 N. The ship will then begin the return voyage to Honolulu.

A total of 26 days have been allocated for the scientific operations at the study site. The nominal schedule below is based on the details of the deployments and ship-based measurements that follow.

- 8 Aug: Begin mobilization
- 12 Aug: Depart Honolulu
- 19 Aug: Arrive study site, begin scientific operations
    - Days 1-5: Mooring deployment
    - Days 6-18: 3x3 box survey, deploy Lagrangian/maneuverable assets
    - Days 19-26; 125 W survey
- 14 Sep: Conclude operations, depart study site
- 22 Sep: Arrive Honolulu
- 24 Sep: Conclude demobilization

Moorings

Summary of mooring deployment requirements

The estimated time required to deploy each mooring and conduct addition requirements are listed below and summarized in Table 2. The mooring deployments will be conducted during daylight hours while the additional requirements may occur at night and in conjunction with other activities.

- Mooring deployment time
    - WHOI: 9 hours
    - PMEL (2): 4 hours each
- Additional requirements
    - Full depth CTD to check depths and sensors
        - 4 hours
        - Can be done at night or days after deployment
    - Anchor survey
        - 2 hours
        - Square, 2 miles per side, 10 min each location, avg speed 6 kts
    - Met sensor check: 24 hours standby WHOI central mooring pointed into the wind

- Verify and calibrate meteorological sensors
- Consider combining with full depth CTD

Table 2: Summary of time require for mooring operations

Activity	No.	Hrs each	Hrs total	Days total
WHOI Mooring				
Deployment	1	9	9	0.4
Standby - compare buoy and ship	1	24	24	1.0
anchor survey	1	4	4	0.2
full depth CTD	1	4	4	0.2
WHOI Total		41	41	1.7
PMEL Moorings				
Deployment	2	4	8	0.3
anchor survey	2	4	8	0.3
full depth CTD	2	4	8	0.3
WHOI Total		12	24	1.0

The requirement for daylight operations to deploy the moorings plus additional requirements suggests one mooring plus the anchor survey and CTD could be done in a 24 hour period. The additional requirement for 24 hr standby for the WHOI mooring adds another day. For planning purposes, a minimum of 4 days should be assigned to accomplish the mooring deployment and associated additional requirements.

Bathymetry information and mooring sites

MultiBeam bathymetry data were collected during two previous cruises to the SPURS-2 region for the PACS experiment (PACS03MV and GENE04RR). The locations and depths of the moorings are summarized in Table 3. There was another PACS cruise aboard the RV *Thomas Thompson* that probably also conducted a bottom survey, but those data are not available in national data archives or from the PIs (R. Weller and S. Anderson). The available data were assessed by someone at WHOI with expertise in MultiBeam data (Tom Bolmer), and they were blended with the latest version of the Smith and Sandwell 15-second gridded bathymetry product (Figure A2). The data appear to be adequate to use to select the precise locations of the mooring sites now, without conducting extensive bottom surveys when we arrive to the site, which will ease some pressure on ship time during the initial cruise.

Table 3: Planned mooring sites and water depths.

Mooring	Latitude	Longitude	Depth
WHOI	10.05°N	125.0°W	4674
PMEL-South	9.05°N	125.0°W	4686
PMEL-North	11.0°N	125.0°W	4647

The WHOI surface mooring will be of an inverse-catenary design utilizing wire rope, chain, and synthetic rope and will have a scope of about 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 will be 4.4 nmi diameter.

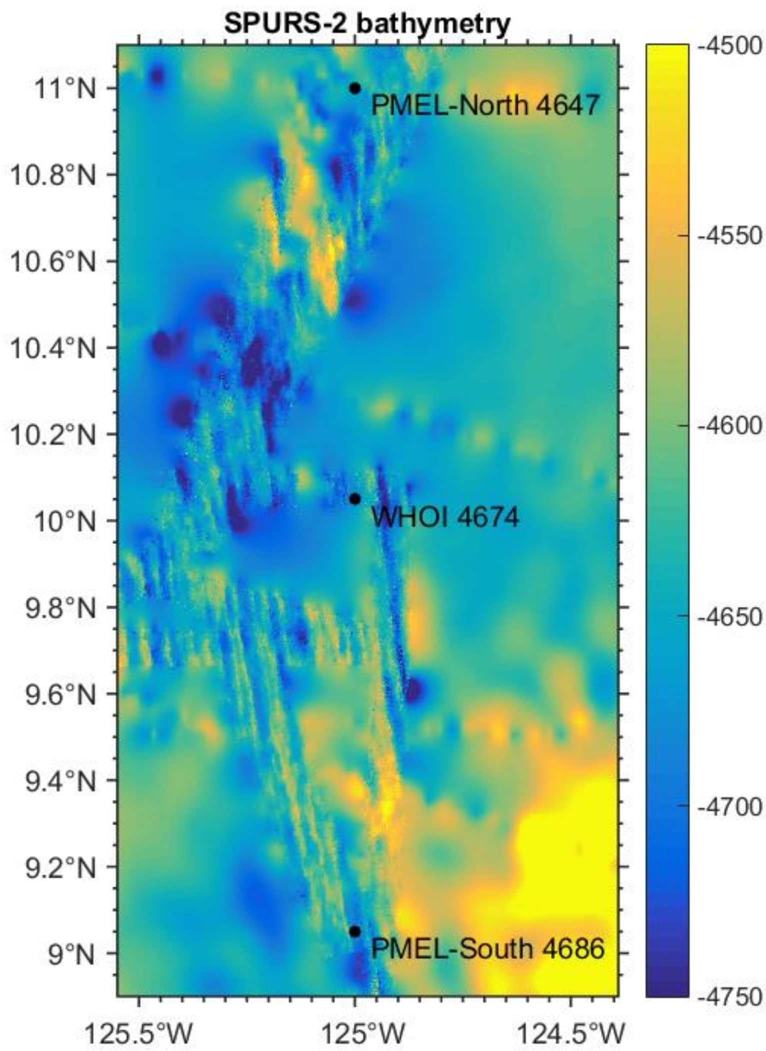

Figure A2: Bathymetry map around the SPURS-2 mooring sites (meters). The data are a blend of MultiBeam data and the Smith and Sandwell product. The bottom depths in meters are given for a 1-km radius around each planned site. Data were compiled and processed by Tom Bolmer, WHOI.

Shipboard mooring operations

A tentative deck plan for mooring gear is shown in Figure A3. Prior to deployment, we would like to collect a full-ocean-depth CTD profile and make sure that the bottom depths at the site inferred from historical data agree with the ship's echosounder. Deployment of the WHOI mooring would nominally take 9 hours, and it is best to start as early as possible (in case there are complications—it is not desirable to conduct mooring operations at night). Deployment of the PMEL moorings is faster, requiring about 4 hours.

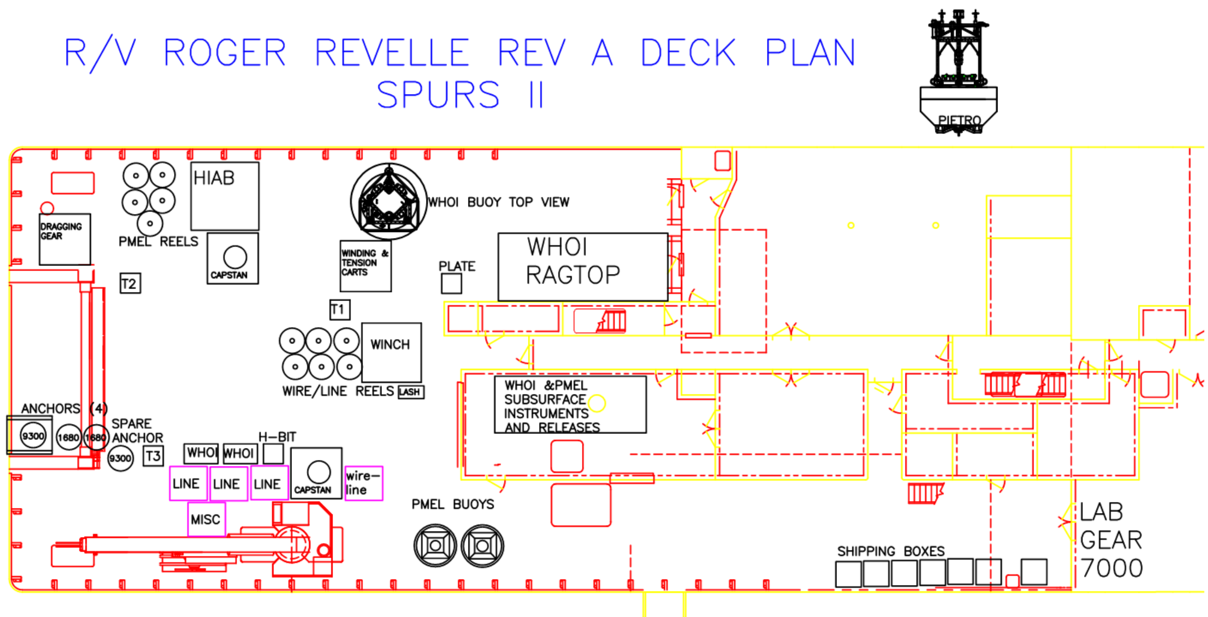

Figure A3: Draft deck plan for the RV *Roger Revelle* for the initial part of the 2016 SPURS-2 cruise (Ben Pietro, WHOI).

The general procedure is about the same for the WHOI and PMEL moorings; the WHOI procedure is described here. There will likely be variations in this procedure at the discretion of the lead mooring technician and bosun. The ship will take a position some distance away from the anchor target site, perhaps 8 nmi, depending on wind and currents. The buoy will be deployed first using the ship's crane. The ship will move forward so that the buoy swings aft of the ship and the load on the mooring line is transferred to the winch. The winch will be slowly unspooled, pausing every few seconds for instruments to be attached. After about 1700m of wire have been deployed, long sections of nylon and then polypropylene rope will be deployed; these sections will go faster. After all of the line is in the water, the load will be transferred to the anchor. Depending on how far we are from the anchor target at this point, we may have to tow for hours at ~1.5 knots.

Immediately after deployment, we would like to spend some time in the vicinity of the mooring. After deployment (but perhaps in following days after other activities), we need to conduct an acoustic survey of the anchor position (using the ship's 12 kHz transducer). For the WHOI mooring, we would also like the ship to spend at least 24 hours in the vicinity of the mooring with an orientation favorable to collection of good shipboard meteorological data (bow into the wind) to provide information to help identify any instruments that are damaged or lose calibration during deployment/shipping.

Deployment of autonomous Lagrangian and Maneuverable Assets

Figure A4 illustrates the Lagrangian and Eulerian sampling plan presented above. The estimated time required to deploy the Lagrangian and maneuverable assets are summarized in Table 4.

Table 4: Lagrangian and Maneuverable Assets to Deploy

Asset Type	**Num-ber**	**Hrs each**	**Total hrs**	**Days**
Argo*	15	1	15	0.6
APEX				
MLF – Mixed Layer Float	1	6	6	0.3
SVPS* – Salinity/velocity drifter	5	1.2	6	0.3
Seaglider	3	3	9	0.4
Waveglider	3	2	6	0.3
subtotal			42	1.8

*Some or all of the Argo and APEX floats may be deployed by the Lady Amber

The Lagrangian assets will be deployed in a location “upstream” of the central mooring with the intention that they drift through the study area, ideally passing close to the central mooring. Deployment will be coordinated to maximize the possibility that they will encounter the ship as it executes the 3x3 box survey.

We will target an area 200-300 km (or roughly 2 weeks drifting time at an estimated 10-20 km/day) up-stream of the mooring(s) site, as predicted by operational numerical models and in-situ reconnaissance of the flow field. In conjunction with other operational activities, the R/V *Revelle* will conduct a TSG/SSP survey of the area, identifying freshwater lenses (“rain puddles”) and quantifying their extent.

A subset of autonomous SPURS-2 assets will be deployed in a cluster (Figure A4) within an isolated rain puddle (if found). A Lagrangian float, profiling APEX float(s), and a set of surface drifters will establish the quasi-Lagrangian frame of reference generally following the advection of the freshwater lens, mixed layer, and the upper pycnocline. A Seaglider will conduct the surveys within this frame using the same patterns as in the Eulerian study. A Wave Glider will ensure rapid surveying of the local surface gradients and provide the Lagrangian component with the co-located observations of surface forcing. The large-scale hydrographic context of the drifting array will be established by the continued shipboard / SSP surveying.

The Lagrangian array will likely stay coherent for a period of a few days to a week or two, drifting towards the moorings (but likely missing them). When the separation becomes too large, “drivable” assets (Seaglider and Wave Glider) will return to the moored array to resume their Eulerian-frame observations.

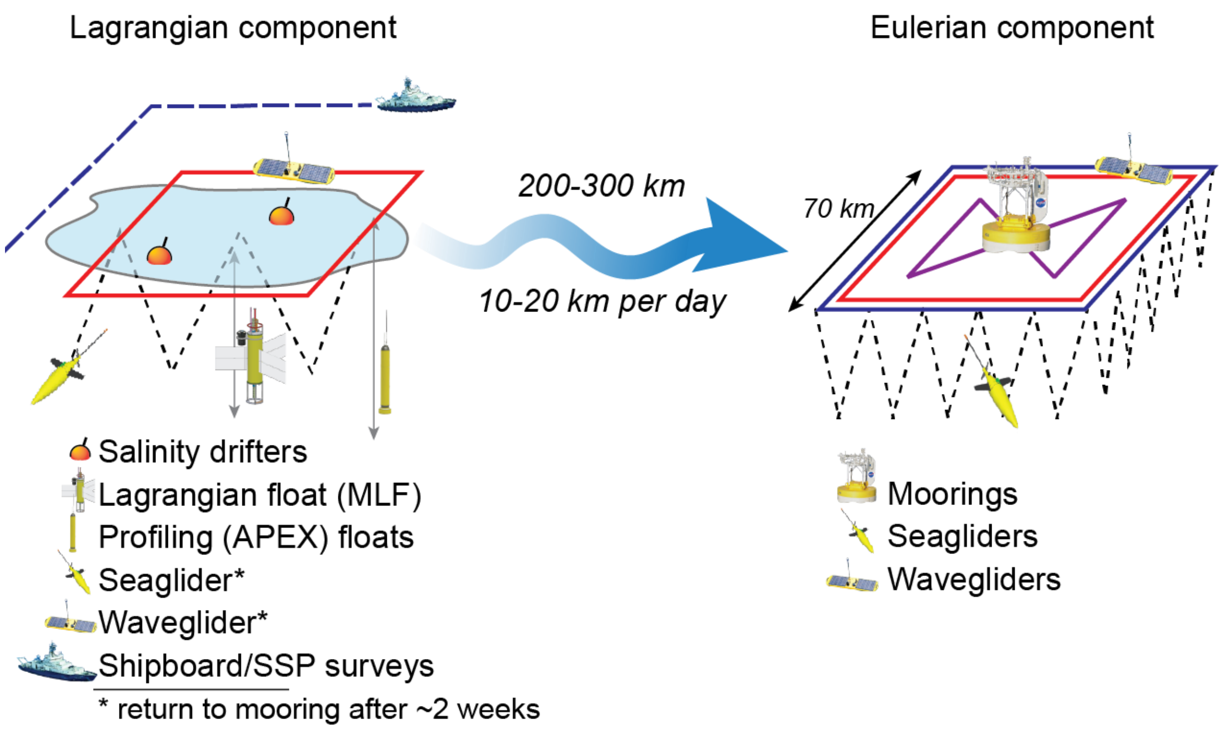

Figure A4: Illustration of Lagrangian and Eulerian components of sampling plan.

Hydrographic Survey

The main instruments for the hydrographic survey are:

- Underway CTD: continual sampling enables profiling to 500 m depth every 15 minutes at ship speed of 10 knots (2.5 nm / profile)
- Discrete CTD/LADCP profiles to 1000 m depth at specified locations
- Underway ADCP, TSG, Met data

Transit to site: We do not plan to survey during the transit to the 10°N, 125°W mooring deployment site, unless we end up coming due south along the 125°W meridian and then we may deploy the uCTD opportunistically. As noted above, we will take a CTD/LADCP profile at mooring sites to help with calibration as needed.

3 deg x 3 deg Box Survey (Figure A1):
We will conduct 56 discrete CTD/LADCP casts to 1000 m depth (~1.5 hours/cast) every 0.5° (84 hours total CTD time). We may deploy the uCTD in between each of the casts. When rain occurs during the survey period, we would suspend the CTD stations (to allow for SSP/balloon deploy) and resume once the rain event ends. We would like to be able to deploy the uCTD while the SSP it being towed, subject to approval by the Captain.

125°W Survey Transect (Figure A1):

Undertake uCTD survey during transit to 2°N, 125°W (or start location for survey transect dependent on ship time available/remaining). Conduct CTD/LADCP cast every 0.5° and uCTD underway. Ideally one complete transect along 125W from ~2N to 15N (3.25 day steam@10 kn == 312 uCTD profiles + CTD/LADCP cast every 0.5° (27 casts == 1.7 day) == 5 days)

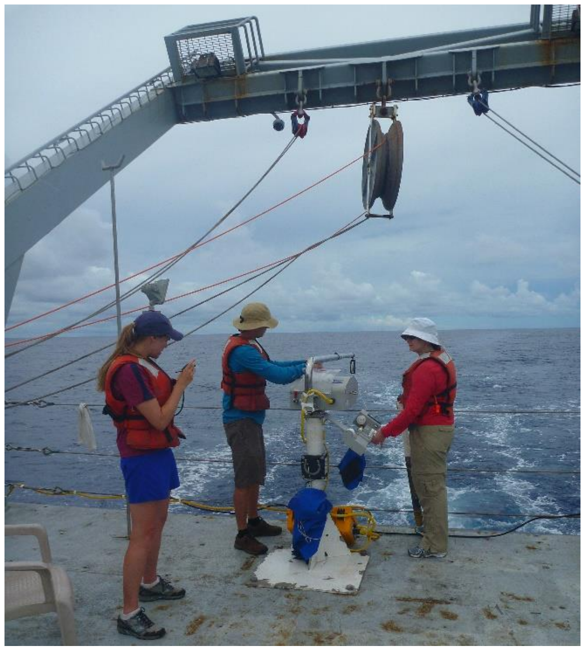

Figure A5: Underway CTD set-up

uCTD: The center of the A-Frame is the ideal place to put the uCTD (Figure A5), but in order to keep the A-frame clear for deployment and recovery it can be mounted to the side or possibly Port Corner. For maximum separation from the towed SSP, the aft port corner is preferred. The uCTD is fairly self-sufficient and has it's own winch, so we will not need to use any ship winches. The arm must be pointed aft when the probe is deployed. The main thing is to keep the probe from hitting the side of the boat. We will fabricate a pedestal/base to attach the uCTD to the Revelle on 2' x 2' square of the bolt pattern, centreline, as far aft as possible. The rewinder is ideally on the starboard side and that way the controls are inboard of the davit, when it is rotated inboard (i.e, davit parallel to the lifelines). This requires 4' space on the davit/starboard side and 2' on the port side. We attach the probe holder to the A frame base to soak the probe while rewinding. A chair is also nice for terminating, watching, etc. Power cables are secured to the lifelines. We will need a 110v/240v power hook up to supply power to the system.

Ship-based measurements of meteorology and near surface signatures of rain events

Fluxes and Mean Meteorological Measurements
Two direct covariance flux systems (DCFS) will be deployed on the MET mast of the R/V Revelle. During the DYNAMO experiment on the R/V Revelle, the DCFS were deployed on a boom as shown in Figure A6. We anticipate using a similar setup for SPURS-2 based on the schematic shown in Figure A7. The boom was attaching to an existing platform that is readily accessible from the crow's nest. This platform is

normally used to deploy some of the R/V Revelle's meteorological sensors. During DYNAMO, these sensors were moved to the platform at the top of the mast. We would request the same setup for SPURS-2.

Figure A6: Photos of the setup used on the R/V Revelle during the DYNAMO experiment. We plan to deploy two direct covariance flux systems to measure momentum, sensible heat and mass fluxes and instrumentation to measure their associated means.

Alternatively, the DCFS could be deployed from the platform at the top of the mast. However, we would require more information from the Revelle to design new mounts. The MET mast would also support an optical rain gauge and aspirated temperature and humidity sensors. These were deployed off the crow's nest supports during DYNAMO and we would expect to deploy them at similar locations during SPURS.

Additional instruments will be deployed on the O2 and O3 decks on the bow-side of the ship. These instruments will include self-siphoning and manually read rain-gauges, solar and IR radiometers, a sky cam, and data loggers. These are normally deployed on the available space along the railing surrounding these decks. Lastly, we plan to deploy a sea-snake to measure near subsurface sea temperature. This is comprised of a thermistor in heavy-duty tubing that is boomed-out and dragged along the sea-surface. The boom is normal deployed off the port side but could be deployed on either side to remain clear of, e.g., the salinity snake.

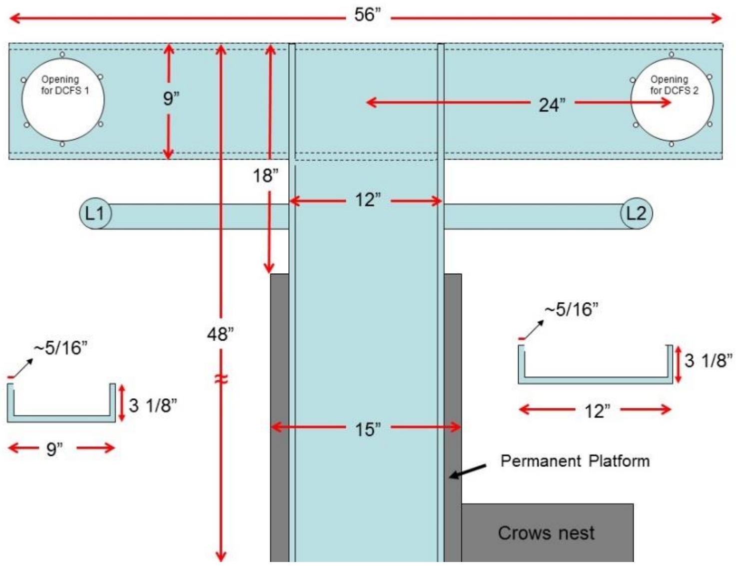

Figure A7: A schematic of the proposed mount for the two DCFS systems on the MET mast. The grey elements are the existing structures on the mast. The green structures would be added to support the sensors.

Once deployed, all sensors would be operated 24/7 during the experiment with little human intervention. With the exception of the manually-read rain gauges, all of the sensors typically monitored from computers in the main lab. For example, power and data cables for the MET mast sensors are typically passed though opening at the bow of the ship into the boatswain's locker. The Revelle's boatswain's locker is set up with Ethernet connections back to the dry lab. The DCFS will include a LI-7500 infrared hygrometer on the MET mast that will require occasional cleaning. However, we have a washing system that allows us to do this remotely using the ship hose and fresh water. The group will make daily rounds to check on the instrumentation and perform maintenance as required.

Rawinsonde Launch Station

Rawinsondes will launched twice-daily to provide profiles of temperature, humidity, wind speed and direction through the atmospheric boundary layer and beyond. The launches would be conducted to provide data for the 0Z and 12Z model runs. Data from these launches will be provided to NCEP for assimilation into their forecast models. We will require a small bench (at least 3' x 4') inside the ship for telemetry equipment and sonde preparation. The telemetry system requires access to a stuff tube for its GPS and radio antennas. The balloons will be filled with helium and we will require a large rack holding 8-12 helium tanks. Balloon launches are typically preformed on the fantail, but we have launched from the O2 deck on several cruises. It is best to have the indoor preparation station and launch area on the same deck.

Near surface salinity and turbulence measurements

Salinity Snake

The Salinity Snake Mk. 2 (SS2) shown in Figure A8 is used to measure sea surface salinity in the top 1-2 cm. The SS2 consists of four basic components: a 32ft (~10m) boom/mast with a selection of UHMW polypropylene mast foots that attach to almost any diameter of round or square stanchions or rails, ideally close to the bow to the vessel where the influence of the bow wake is at a minimum distance from the ship. The top of the boom is a solid aluminum mast head with a number of 5600 lbs. tested eye bolts and a block for a halyard. This boom is secured with three 7200 lbs. test Dyneema rigging lines, a fore-stay, a top-stay and an aft-stay.

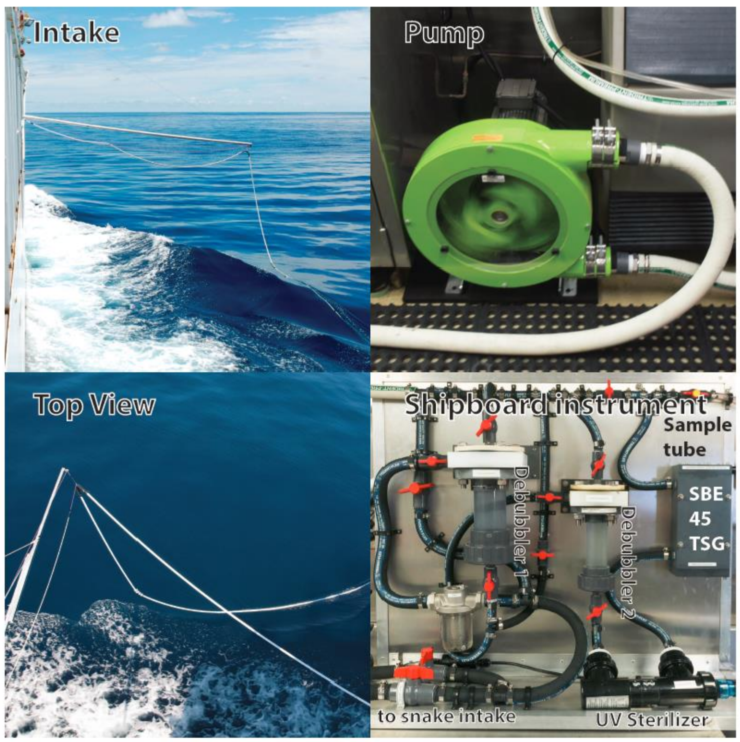

Figure A8: Intake, Pump, Top View and Shipboard Apparatus view of the Salinity Snake Mk. 2.

The boom is first lifted over the rail of the vessel (or lifted down, as appropriate) by 3-4 people. At this point, the mast foot is secured and the aft- and top-stays are installed at appropriate positions, such as close to the bridge for the top stay. It is then swung forward by pulling on the fore-stay, with continuous adjustments of the top-stay. As soon as the boom is in place, the fore-stay is secured, thus holding the boom in position in all directions.

As soon as the boom is in position, the 1” vacuum-rated hose is attached to the halyard and positioned as close to the masthead (as far away from the vessel) as possible using the block attached to the mast head. This also allows the easy recovery of the hose for maintenance, adjustments, securing during extreme bad weather, or small boat ops and the like.

The hose is run to the wet lab in the shortest, lowest (to avoid unnecessary suction head) and safest (foot traffic) path possible, up to 200 ft.

Assembly of the shipboard apparatus will begin as soon as possible before the departure. The boom will also be assembled and secured before departure. The boom is generally deployed as soon as the ship is underway and no longer under the control of pilots and away from the dock, as described below. At this point all components are connected and the system is operational. The total setup takes approximately one day (16-18 hours). The boom deployment takes approximately one hour with sufficient assistance from ABs/volunteers.

Surface Salinity Profiler (SSP)

The SSP is a towed surface-following catamaran where two stand-up paddle boards are used as the two pontoons. Figure A9 shows a previous version of the SSP stored in its deck cradle and a photo of it deployed from the *R/V Thompson* showing how it tows outboard of the ship's wake.

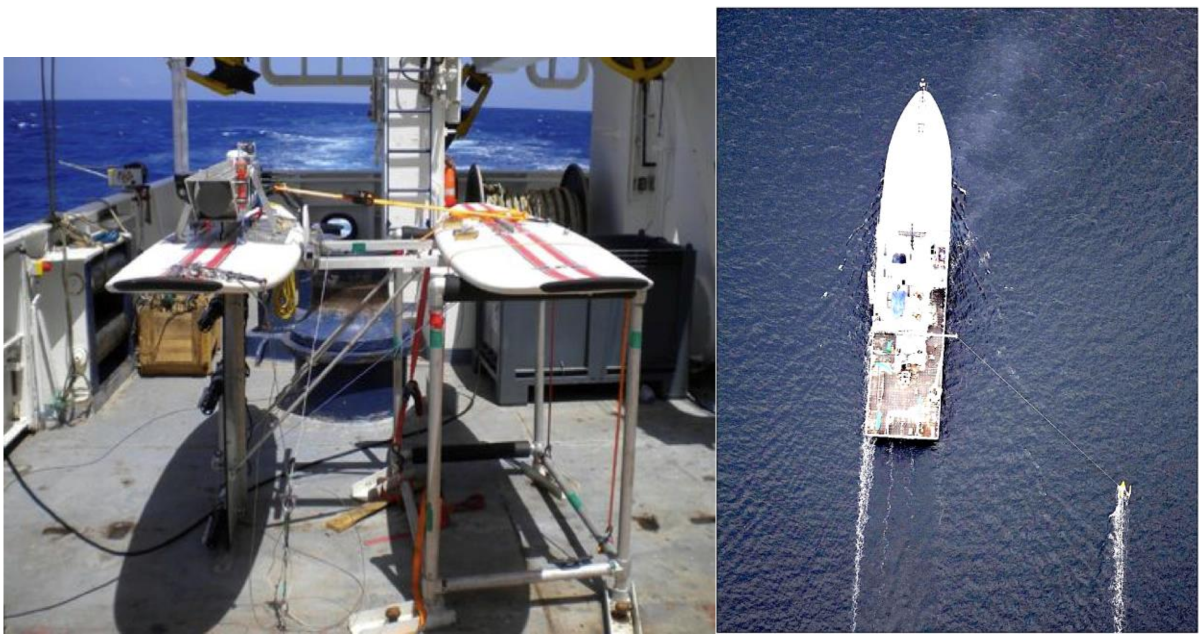

Figure A9: (left) Surface salinity profiler; (right) R/V Thompson towing the SST

The outboard pontoon (from the perspective of the tow cable to the ship) has a 1-m long keel that is instrumented with four CTDs and a turbulence microstructure profiler. There will also be a salinity snake water sampling system mounted to the top side of the outboard pontoon. The inboard pontoon will have a downward-looking ADCP. The SSP is approximately 2.5 m wide x 3.5 m long and weighs approximately 200 kg. Based on prior experience with the AGOR class ships towing the SSP, it functions best when towed from slightly aft of mid-ship on the starboard side (the auxiliary CTD boom has been used in the past). The SSP tows from a 3-point harness connected to the keel, bow, and stern of the outboard pontoon. This forces the SSP to maintain thrust away from the ship when under tow so that it rides outboard of the ship's wake, approximately 50 m to 100 m from the ship. The SSP has been towed successfully at up to a maximum speed of 3 m/s depending on sea state. Typical tow speed of the SSP is 2 m/s. The SSP will require a winch and block capable of towing it at speeds up to 3 m/s. The SSP will also require a crane for deployment. When not deployed, the SSP is stored in a docking cradle mounted to the 2' centers on the main deck. The SSP is equipped with a small on-board gasoline-powered generator. Storage for approximately 100 L of unleaded regular gasoline will be required.

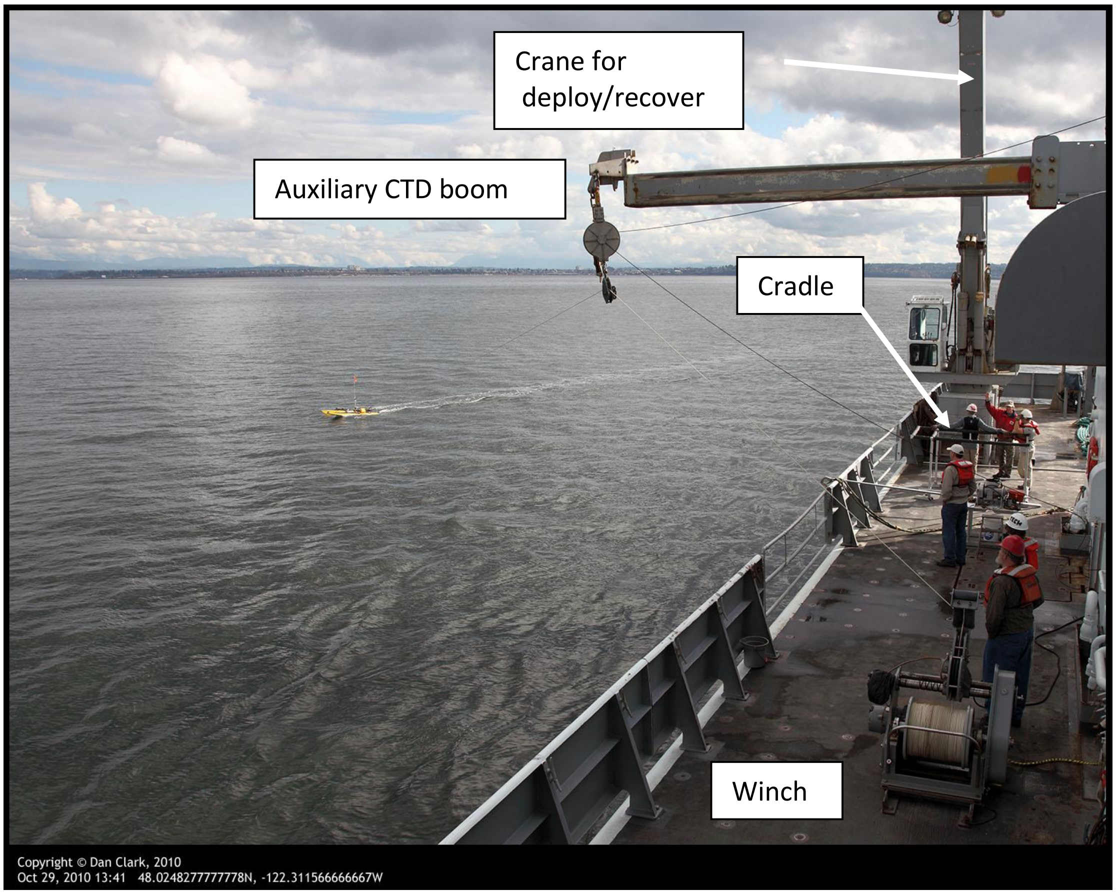

Figure A10: Deployment of SSP on R/V Thompson use of auxiliary CTD boom, aft crane for deployment and recovery, and location of cradle.

Based on prior experience with the AGOR class ships towing the SSP, it functions best when towed from slightly aft of mid-ship on the starboard side (the auxiliary CTD boom has been used in the past). Figure 10 shows the towing configuration on the R/V Thompson that we suggest could be duplicated on the R/V Revelle. The SSP tows from a 3-point harness connected to the keel, bow, and stern of the outboard pontoon. This forces the SSP to maintain thrust away from the ship when under tow so that it rides outboard of the ship's wake, approximately 50 m to 100 m from the ship. The SSP has been towed successfully at up to a maximum speed of 3 m/s depending on sea state. Typical tow speed of the SSP is 2 m/s. The SSP will require a winch and block capable of towing it at speeds up to 3 m/s. The SSP will also require a crane for deployment. When not deployed, the SSP is stored in a docking cradle mounted to the 2' centers on the main deck. The SSP is equipped with a small on-board gasoline-powered generator. Storage for approximately 100 L of unleaded regular gasoline will be required.

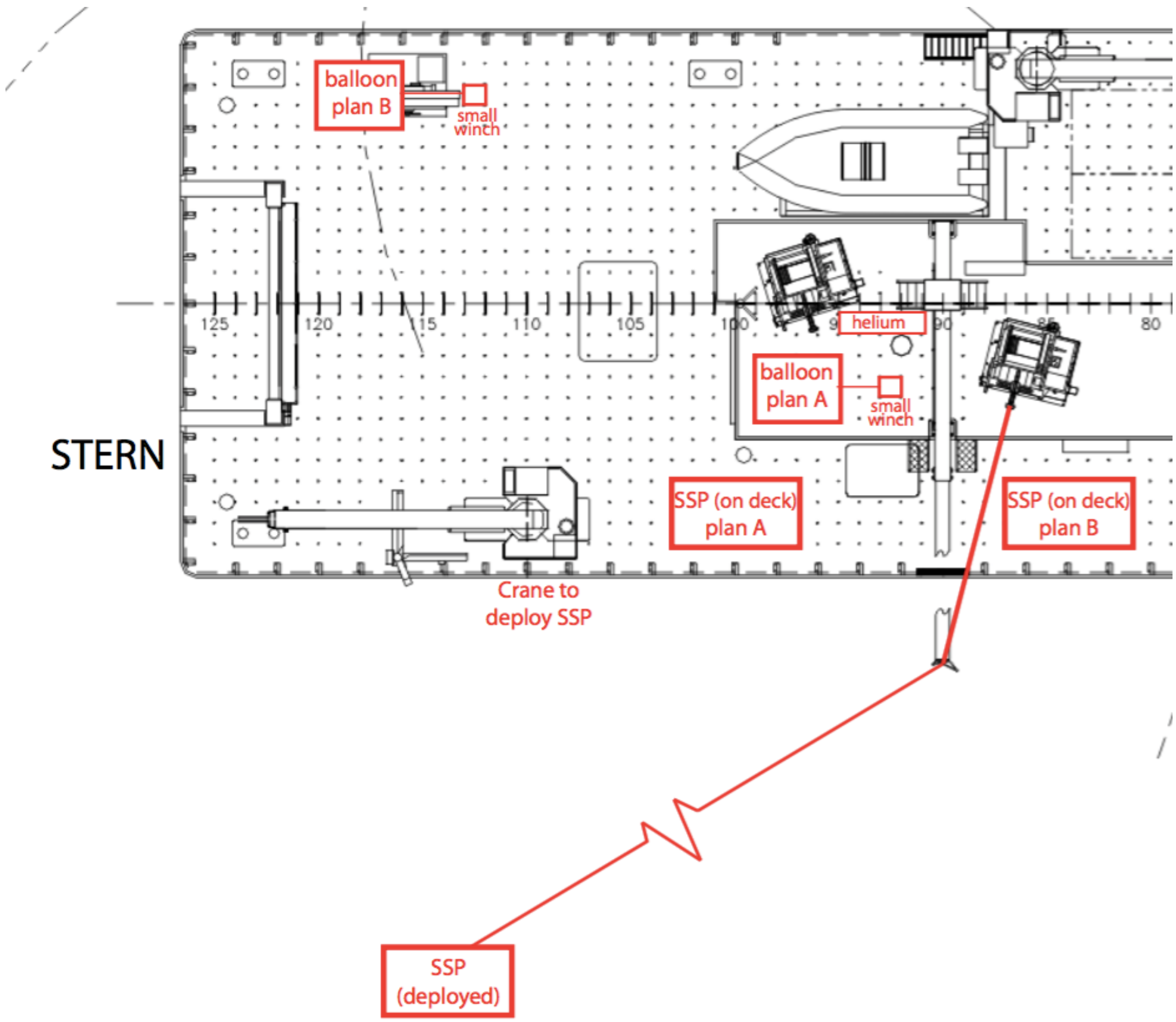

Figure A11: Schematics for possible locations for SSP and LTAIRS (balloon).

Possible locations for storing the SSP on the deck are shown in Figure A11, noted as plan A and plan B. The A location is where the SSP was stored during the deployment on the R/V *Thompson* shown in Figure A10. This location is approximately where the PMEL buoys are shown in storage in Figure A3. Since we would like to do a test deployment of the SSP during the transit to the study site, we anticipate that the PMEL buoys can be stored in an alternative location. If the A location is used, we will need to make sure that there is enough clearance for foot traffic. The plan B location is less desirable because of the potential blockage for access to the main lab and would likely require the use of the crane on the 02 deck. We will request a UNOLS winch to use for the SSP – note the winch location on the 02 deck in Figure A11 is a possible location that would be out of the way (compared to the winch location on the main deck shown in Figure A10).

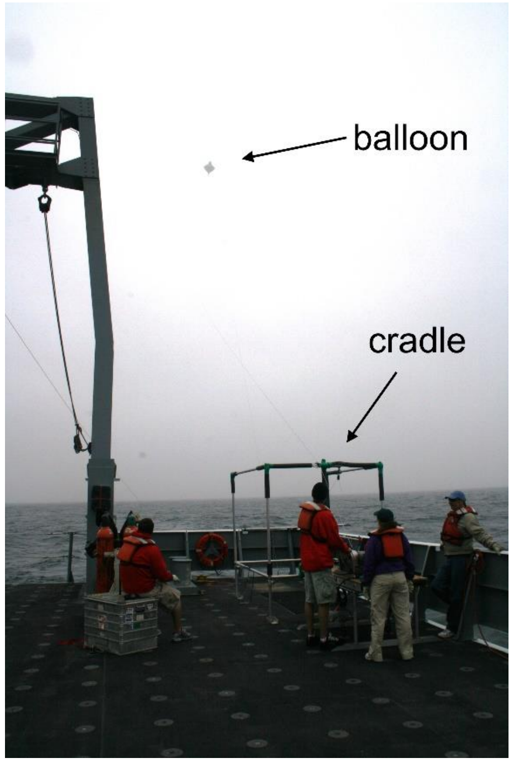

Figure A12: Location of LTAIRS cradle on the aft port deck during a deployment on the R/V *Thompson*.

LTAIRS: Lighter-than-Air Infrared System

The LTAIRS system consists of a tethered helium balloon instrumented with stabilized gimbal with both infrared (IR) and visible cameras. The balloon has a diameter of ~4 m and between deployments it is tied down to a frame that is ~5 m x 3 m mounted to 2' centers on the deck. It is deployed with a custom winch (user supplied) and will be flown at altitudes of 50 m to100 m. The balloon will be flown while the SSP is under tow. Based on our experience deploying LTAIRS on AGOR class vessels, the main considerations are to be away from vertical structures and off to the side to avoid deploying in the lee of the ship's superstructure, which can cause unpredictable gustiness. The photograph in Figure A12 shows the locations of the cradle on the aft port deck during a deployment on the R/V Thompson, which coincide with the plan B location shown in Figure A11. Location B is the first choice but would require relocating the portable HAIB crane and some of the mooring gear shown Figure A3 (the capstan shown in Figure A3 would also need to be moved if it is present). Location A on the 02 deck is shown as a possibility but the concerns there are the proximity of the GPS antenna mast, the current use of the space for ship's storage, and the possibility that the space may be too small for safe operation. Approximately 24 bottles of helium will be stored in existing metal racks which can be attached 2' centers.

CFT-Controlled Flux Technique: CO_2 laser heating surface patch viewed with IR camera

The Controlled Flux Technique (CFT) uses a CO_2 laser to heat a spot on the ocean surface that is simultaneously viewed by an IR camera to measure the decay time of the spot, which is related to the turbulence intensity. The system will be deployed from the forward 02 deck as shown in Figure A13.

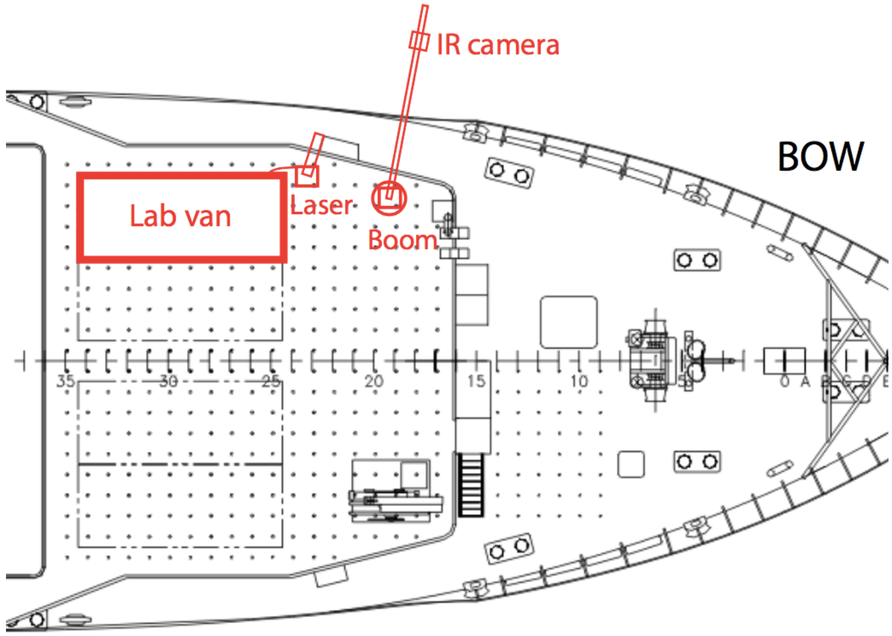

Figure A13: Schematic of forward 02 deck for CFT operations showing location of instrument van, laser, and boom for mounting and positioning the IR camera.

A 125 W CO_2 laser will be mounted on a ~2 m-high platform using 2' centers immediately forward of the lab van on the port side of the 02 deck. (A 20' lab van has been requested from the UNOLS pool.) The laser platform will be mounted as close as possible to the port-side railing on the 02 deck. The laser will be held in a rigid mount so that it is aimed toward the ocean surface at an angle that the beam strikes the water at least 20 m outboard of the ship's bow wake. Preliminary geometrical calculations indicate that this aim point will prevent the laser beam from contacting any point on the ship and be at least 4 m above walkways before it is outboard of the ship's hull. A detailed laser safety plan developed in coordination with the Laser Safety Officer at the University of Washington, Ms. Amy Lim, will be provided to the ship discussing the particular hazards associated with operation of the laser and how these hazards will be mitigated. The laser requires 30 A of 208 V three-phase power and will have a water-to-air heat exchanging system that will be mounted to the roof of the lab van on the port side of the 02 deck and requires a source of seawater with a flow rate of ~3 gal/minute on the port side forward 02 deck.

An IR imager will be mounted on a rotating and elevating boom installed on 2' centers just forward of the laser stand. Figure A14 shows the boom and stand mounted on the bow of the R/V *Kilo Moana*. This imager will be used to measure and track the patch of water heated by the CO_2 laser. The imager is mounted in a housing attached to the end of the boom. The camera boom is based on a Liftmoore 4000X-20 electrically operated 12 V truck crane with the winch and block removed so it cannot be used as a crane. The boom is 7 m long and has a rated capacity of 1800 kg and the camera and housing will weigh approximately 100 kg. The boom operates off battery power supplied by a series of lead-acid car batteries in a waterproof case located on the deck near the boom. The boom is guyed using wire rope to ensure that it is deployed in the correct orientation and to minimize vibration-induced motion. An overview of IR measurement from the bow and balloon is shown in Figure A15.

Figure A14: Boom for IR camera as deployed on the R/V Kilo Moana: (left) shows the pedestal, which attached to 2’ centers, and (right) shows fully extended boom.

Continuous meteorological measurements will be made using a RM Young 50202 capacitance rain gauge, a Vaisala 520XT weather sensor, an optical disdrometer, and an anemometer. The rain gauge and weather sensor will be mounted on the forward 02 deck on top of the van and the disdrometer will ideally be mounted as high up as possible to minimize the effects of spray and as forward as possible to flow distortion. Suitable locations for the disdrometer (in order of preference) include the jackstaff on the bow, above the pilothouse, or the roof of the van on the 02 deck.

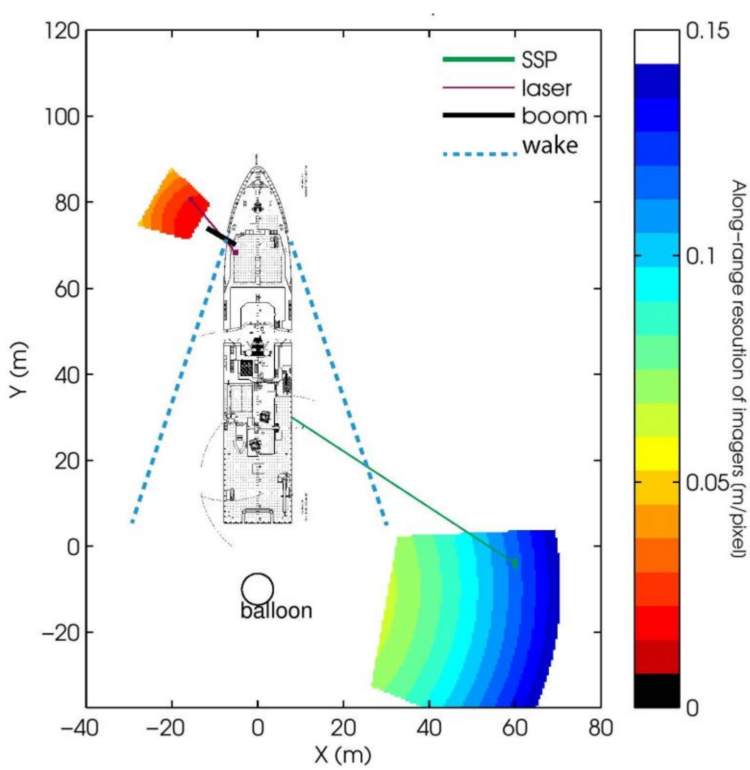

Figure A15: Overview of ship-based measurements to be deployed during rain, showing location and resolution of IR measurements from the bow and LTAIRS (balloon).