

# Schmidt Ocean Institute Expedition Report

## Studying the Sea Surface Microlayer 2

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# 1 Overview check date in table

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SOI Expedition ID	FK191120
Vessel	<i>R/V Falkor</i>
Expedition Name	Studying the Sea Surface Microlayer 2
Expedition Dates	2019/11/20 - 2019/12/22
Departure Port	Suva, Fiji
Termination Port	Suva, Fiji
Ocean	Pacific Ocean

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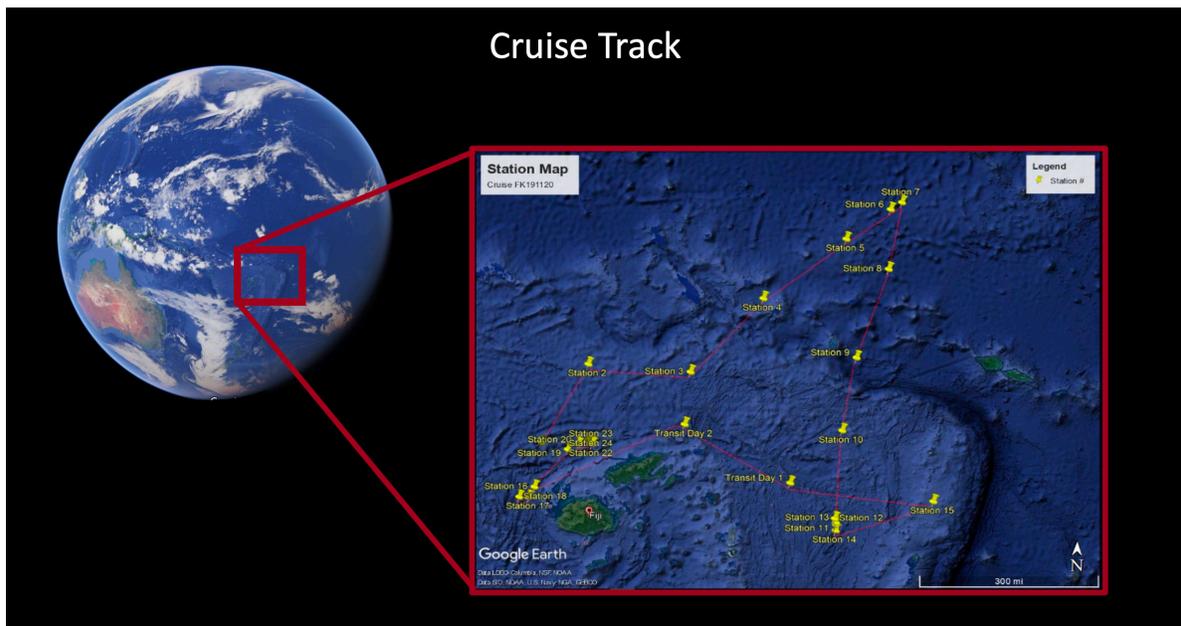


Figure 1: Map of Expedition Location

## 1.1 Expedition Overview

The sea surface microlayer is but a tiny slice of the ocean – only the top millimeter at most; however, this thin boundary serves as a mediator of air-sea gas exchange, controlling all transfers between the atmosphere and the ocean. It is the link between all processes that meet at the sea surface, and a huge part of marine biogeochemical cycles and air-sea interactions. Therefore, this tiny microlayer plays an influential role in regulating the entire planet’s climate. For something so small and easily overlooked, the surface microlayer is a key element in many important environmental actions.

The engineering and science team that first conducted this work on *R/V Falkor* in 2016 is back to continue their study with new and improved technology. This time around, they won't be just testing the Unmanned Aerial Vehicles (UAVs), but expanding their capabilities, utilizing a greater science payload. This will allow the team to launch the vehicles from *R/V Falkor* while in transit to better investigate surface sea slicks in real time. The work will continue to examine slicks in the Southwest Pacific near Fiji, creating a study of fine scale, transient oceanographic features that are hard to see only using satellites. The team aims to make unprecedented sea surface maps both in spatial and spectral resolution to address important questions about the ability of the ocean surface to absorb heat. Multiple cutting-edge technological tools and vehicles will be implemented simultaneously to answer these questions.

### **1.1.1 Project Description**

An impressive coordination of Uncrewed Aerial Vehicles (UAV) with fully automated vertical takeoff and landing (VTOL) from *R/V Falkor* were used to study the sea- surface microlayer during this expedition. The top layer of ocean is less than 1mm thick, but mediates all interactions between the ocean and atmosphere. Understanding this gateway is essential for improving models of sea surface temperature and biogeochemical cycling. Building upon initial work aboard *R/V Falkor* in 2016, the team used highly accurate sensors on the aircraft to map the temperature and color of the ocean surface in high spatial and temporal resolution imagery in real time at scales of 10 cm or less. Furthermore, these VTOL UAV systems have 15-hour endurance and high- bandwidth data telemetry (100 Mbits/s over 50+ nm range) for real-time mission control that provides our "eyes over the horizon." The expanded observation abilities led to the discovery of large rafts of pumice floating on the ocean surface and enormous blooms of *Trichodesmium* (harmful algae) that extended kilometers into the horizon. Both of these pumice and *Trichodesmium* patches showed clear evidence of near-surface heating patterns of the ocean. Over a period of five weeks, three aircraft were flown with four different payloads, studying the surface skin layer of the ocean for over 240 hours, collecting 43 TB of data, and covering a distance of more than 19,000 km. The technology used will help future scientists to understand a multitude of urgent questions about ocean heat and carbon-uptake and its impact on global temperatures, storms, and fisheries.

### **1.1.2 Opportunities & Challenges**

Our daily operation was to use satellite data to guide us to possible features of interest on the open ocean. The daily schedule highlighted the use of UAVs for reconnaissance to find features of interest that included a large temperature front, a discovery of floating pumice on the ocean surface likely the remnants of an undersea volcanic eruption near Tonga, and the discovery of a number of gigantic *Trichodesmium* blooms. Once we were able to target the feature of interest, we mobilized all the assets available and had the ship get to the targeted location to re-deploy the drifters and catamaran.

The Wurl group reported that weather prevented 2 days of their deployments and one day due to broken science party equipment. The Sea Surface Scanner Catamaran had a broken vertical arm for one day, which was fixed and replaced for the following day. The Van Dorn Sampler was leaking for two days and the Sniffle did not capture CO<sub>2</sub> measurements the last two days, which was probably an issue of power due to charger issues. On 23 November, the VNIR was brought down after 30 minutes due to rain; on 17 December the RAD flight was aborted due to rain. Three science UAV days were lost due to lost/broken/delayed science party-provided equipment – on 24 November troubleshooting was required to identify that the fuel was too hot and on 6 December the UAV had a late launch due to weather and on 17 December the PCC software had conflicting GPS-vs-commanded altitude and would not launch the UAV, which required a change in launch SOPs.

Zappa Shipboard (Infrared imaging, turbulent fluxes, radiative fluxes, SST, waves) & SPIP-2 drifting buoy systems lost no days due to weather or broken science equipment.

### 1.1.3 Expedition Timeline

The expedition commenced on November 20, 2019 departing from Suva, Fiji and returned to Suva, Fiji on December 22 2019.

### 1.1.4 Authorizations and Permitting

Permit Authority	Permit #
Fiji	097/2019
Solomon Islands	009/2019
Tonga	409/19
Tuvalu	ORM/MSR-1908
Vanuatu	057/MOFAICET/2019

## 1.2 Proposed Objectives

the project’s objectives were to understanding physical, chemical, and microbiological processes related to atmosphere- ocean interaction in the presence of cyanobacteria (*Trichodesmium*) at a multitude of spatial and temporal scales using uncrewed aerial vehicles (UAVs), drifters, remotely-operated surface vehicles (ROSVs), profiling spectrometers, surface spectrometers, and ship-based imaging systems.

## 2 Expedition Accomplishments

### 2.1 At-Sea Accomplishments

#### 2.1.1 Science

The science team encountered pumice that likely was produced by a recent undersea volcano eruption near Tonga and that drifted Westward. Also, a 200-micron mesh hand net was deployed most days and the contents of the net were examined under the microscope to help determine if Trichodesmium was present in the water. In the presence of Trichodesmium slicks, samples were taken to measure the optical properties of the surface slick.

Water samples were also collected using the CTD-rosette system and up to 3 liters were filtered onto GF/F filters for later analysis of diagnostic phytoplankton pigments.

- 173 samples of surfactants
- 167 samples of total alkalinity and dissolved inorganic carbon
- 27 samples of salinity
- 35 CTD casts were performed
- 44 Flights with over 250 science hours using 3 UAVs

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Types of samples and measurements	Methods	Instruments
Sea surface temperature imagery with 8 um - 14 um longwave IR high-resolution imagery (1024 by 768) up to 30 Hz, with noise-equivalent temperature difference of 0.05°C.	Flying of Unmanned Aerial Vehicles (Latitude model HQ-90B) above the ocean surface equipped with infrared imaging instrument payload.	Sofradir-EC Atom1024 LWIR Microbolometer.
Surface visible imagery mapping in the 400 nm - 800 nm visible high-resolution swath up to 15 Hz.	Flying of Unmanned Aerial Vehicles (Latitude model HQ-90B) above the ocean surface equipped with infrared imaging instrument payload.	Imperx Bobcat 6MP Visible Camera

Types of samples and measurements	Methods	Instruments
<p>Surface-emitted radiance (400 nm - 1000 nm) with horizontal 32° field-of-view (12mm), 10.5 mm slit length, 1.86 nm spectral resolution (601 bands), 1004 spatial pixels.</p> <p>Sky-emitted irradiance (350 nm - 1000 nm) Sky-emitted radiance (350 nm - 1000 nm) Total Surface Radiance (350 nm - 1000 nm)</p>	<p>Flying of Unmanned Aerial Vehicles (Latitude model HQ-90B) above the ocean surface equipped with hyperspectral imaging instrument payload.</p>	<p>Headwall Micro-HyperSpec VNIR A-Series Imaging Spectrometer. OceanOptics USB2000 Irradiance Spectrometer (Up-Looking). OceanOptics OceanFX Radiance Spectrometer (Up-Looking). OceanOptics OceanFX Radiance Spectrometer (Down-Looking).</p>
<p>Net solar irradiance and albedo with 285 nm - 3000 nm shortwave hemispheric solar irradiance in <math>W m^{-2}</math> at fast 1 s response time. Net longwave/IR irradiance with 4.5 <math>\mu m</math> - 40 <math>\mu m</math> hemispheric longwave irradiance in <math>W m^{-2}</math> at fast 1 s response time. Surface visible imagery mapping with 400 nm - 800 nm visible high-resolution swath up to 15 Hz.</p>	<p>Flying of Unmanned Aerial Vehicles (Latitude model HQ-90B) above the ocean surface equipped with the broadband radiation instrument payload.</p>	<p>Hukseflux SR03 Pyranometer (Up- and Down- Looking) Hukseflux IR02 Pyrgeometer (Up- and Down-Looking) Imperx Bobcat 5MP Visible Camera</p>

Types of samples and measurements	Methods	Instruments
<p>Turbulent momentum flux using 3D Air Velocity at 100 Hz.</p> <p>Turbulent latent heat flux using Water vapor at 100 Hz. Turbulent sensible heat flux using Air temperature at 50 Hz. Surface topography using distance ranging up to 500 m (<math>\pm 0.02</math> m) and up to 2 kHz Mapping capabilities, orthorectification of all imagery and MET datastreams using GPS Timing, Position, Angular Rotations &amp; Rates, fiber-optic gyro IMU angle accuracy of <math>0.001^\circ</math>, 100 Hz post- processed position with 5 cm accuracy.</p>	<p>Flying of Unmanned Aerial Vehicles (Latitude model HQ-90B) above the ocean surface equipped with the meteorological flux instrument payload.</p>	<p>Aeroprobe 5-port Gust Probe and Logger. Krypton KH20 Fast Response Hygrometer. Opsens OTG-F Temperature Probe. ULS LiDAR. Novatel OEM719 + KVH1700 IMU.</p>
<p>Turbulent momentum flux</p> <p>Turbulent sensible flux</p> <p>Turbulent latent flux</p> <p>Mean wind speed, air temperature, air pressure, humidity.</p>	<p>Direct covariance technique deployed from a boomed mast at the bow of the ship. Bulk mean properties at same location. Continuous measurements</p>	<p>CSAT-3 sonic anemometer and Licor 7500 hygrometer</p>
<p>Ocean skin temperature (calibrated and sky- corrected)</p>	<p>Infrared Radiation Pyrometers mounted to the ship both up-looking and down- looking at 20-degree incidence angle for continuous measurement.</p>	<p>Calibrated Wintronics model KT-15 pyrometers</p>
<p>Sea surface temperature imagery with 7.7-9.53 <math>\mu\text{m}</math> longwave IR high-resolution (640x512) imagery up to 100 Hz with noise-equivalent temperature difference of <math>0.02^\circ\text{C}</math></p>	<p>Ship-mounted from the sky bridge deck.</p>	<p>Infra-Red (IR) camera was a long wave SOFRADIR-EC, INC; MiTie-640L High Performance Miniature Thermal I</p>

Types of samples and measurements	Methods	Instruments
Downwelling solar irradiance and albedo with 285 nm - 3000 nm shortwave hemispheric solar irradiance in W m <sup>-2</sup> at fast 1 s response time. Downwelling longwave/IR irradiance with 4.5 um - 40 um hemispheric longwave irradiance in W m <sup>-2</sup> at fast 1 s response time.	Mounted to the main mast for continuous measurement.	Kipp and Zonen model CMP22 pyranometer and model CGR4 pyrgeometer.
Surface topography using distance ranging up to 50 m ( $\pm 0.02$ m) and up to 2 kHz	LIDAR mounted to the boomed mast at the bow of the ship for continuous measurement.	Riegl model LD90-3100VHS LIDAR
Near-surface Temperature, Salinity, & Current Profile Bulk Atmospheric Measurements	Drifting Spar Buoy	NBOSI CT Sensor Seabird SBE37SMP CTD Sensor Nortek Aquadopp HR Current Profiler MaxiMet GMX541 Met Station
Sea surface microlayer sampling of temperature, salinity, CDOM, UV-absorbing substances, fluorescence spectra, chlorophyll-a, and photosynthetic parameters, and photosynthetically active radiation.	Remote-controlled surface catamaran- style vessel with rotating glass disk samplers of the sea surface microlayer using capillary action. Catamaran is equipped with flow-through sensors Catamaran takes discrete water samples from the SML and 1 m depth can be collected remotely in bottles placed in a rotating carousel (total 24 bottles) for detailed analysis.	CTD

Types of samples and measurements	Methods	Instruments
Measuring CO <sub>2</sub> gas exchange rates and turbulence kinetic energy	Floating chamber buoy with sensors (SNIFFLE: 100cm x 100cm x 200cm)	
Hyperspectral surface reflectance and inwater multispectral light field	Spectroradiometers	Spectroradiometers

### 3 Appendix 1

All information below is up to date as of April 25 2022

#### 3.1 Data

Table 4: Datasets acquired during expedition FK191120 and data derived from the analysis of survey data and samples, and their location (*Shared at time of Report Publication*).

Data Type	Curator	Completed
ADCP	<a href="#">University of Hawaii</a>	Y
Environmental sensor data collected by <i>R/V Falkor</i>	<a href="#">Rolling Deck to Repository</a>	Y
Processed Multibeam	<a href="#">Marine Geoscience Data System</a>	Y
Measurements of pCO <sub>2</sub> and turbulence from an autonomous drifting buoy	<a href="#">PANGEA</a>	Y
Multiparameter Measurements of Biogeochemical properties of the sea surface microlayer, analyzed from seawater samples collected by the Sea Surface Scanner Catamaran	<a href="#">PANGEA</a>	

#### 3.2 Cruise Blogs

- A series of [Cruise Log Videos](#) are available

### 3.3 Science party information

#### 3.3.1 Scientists aboard *R/V Falkor*:

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Scientist	Institution
Dr. Christopher J. Zappa (Principal Investigator)	Lamont-Doherty Earth Observatory of Columbia University
Ajit Subramaniam (Co-PI)	Lamont-Doherty Earth Observatory of Columbia University
Oliver Wurl (Co-PI)	University of Oldenburg
Carson Witte	Columbia University
Nathan Laxauge	Columbia University
Una Miller	Columbia University
Kelly Luis	University of Mass
Aaron Farber	L3 Latitude
Thomas Lewis	L3 Latitude
Adam Newell	L3 Latitude
Scott Brown	
Joshua O'Brien	
Adrien Segal	Artist-at-sea

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#### 3.4 Funding Sources:

- National Science Foundation Grant # OCE 20-49546
- Schmidt Ocean Institute (Development & Logistics)
- Gordon and Betty Moore Foundation
- Lamont-Doherty Earth Observatory of Columbia University
- Deutsche Forschungsgemeinschaft (DFG); RI3176/1-1; Carbon microcycle.

#### 3.5 Media

There was a range of media engagements during research cruise FK191120 and these impressions and impacts are summarised in Table 6 (below) that was prepared by the SOI media team shortly following the cruise:

Table 6: Summary of media engagements, impressions and impacts during research cruise FK191120, from the SOI FK191120 Social Media and Press Report.

Section	Highlight
Website	<ul style="list-style-type: none"> <li>• 20 blogs posted on the site</li> <li>• 18,408 users from 160 Countries</li> <li>• 22,620 sessions and 46,238 page views during the cruise -Five weekly update video blogs (including One wrap-up video blog) were created, and they garnered 1,320 views on YouTube. These video blogs were published on Facebook also, along with several other shorter video clips (such as UAV autonomous landings), leading to more than 6,773 video views about the expedition on Facebook</li> </ul>
Programs	<ul style="list-style-type: none"> <li>• Adrien Segal was the Artist-At-Sea during this cruise. Her work included creating 3D printed sculptures on the ship by integrating scientific research and data visualization.</li> </ul>
Press	<ul style="list-style-type: none"> <li>• As of the submission of this report, there had been no press release or news articles.</li> </ul>
Community Events	<ul style="list-style-type: none"> <li>• 3 Ship-to-Shore calls totalling 370 participants. We connected twice with the Smithsonian Natural History Museum in Washington DC, and connected with the University of Oldenburg, Germany, for a climate change lecture. with a Ship-to-Shore video call reaching over 100 viewers</li> </ul>
Facebook	<ul style="list-style-type: none"> <li>• 1,174 page views</li> <li>• 81,417 people reached</li> <li>• 102,670 impressions from posts, - including 2,964 Likes on Posts; 349 Shares, 155 Comment</li> <li>• 104 new page likes (Followers)</li> <li>• Total of 6,832 video views; 3,722 Minutes of video watched overall</li> <li>• 5,560 engaged users</li> </ul>
Twitter	<ul style="list-style-type: none"> <li>• 59 Tweets 163,635 impressions over 48 days</li> <li>• 808 Likes, 438 url clicks, 281 retweets</li> </ul>
Instagram	<ul style="list-style-type: none"> <li>• 12 Videos posted, with 4,189 views and 13,259 minutes watched</li> <li>• 22 posts - 13 photo-based posts (some with multiple photos in post), 9 videos</li> <li>• 2,327 likes and 27 comments - overall 27,707 reach</li> <li>• 3,130 video views</li> </ul>
YouTube	<ul style="list-style-type: none"> <li>• 48.3K views and 208.0K Impressions</li> <li>• Watch time (hours) 1,340 - approximately 55 days, 20 hours</li> <li>• Five weekly update video blogs (including One wrap-up video blog)</li> </ul>

## **4 Appendix 2: Innovative Technologies advanced prior to expedition on *R/V Falkor***

### **4.1 Autonomous HQ-90 Takeoff/Landing from a Slow-Moving Platform**

Although the ability to fly autonomously from land had been demonstrated, there were obvious changes needed to upgrade the HQ-90 with the autonomous capability from a moving platform. This new capability would require additional GPS hardware in both the HQ-90 and its ground station, and would require tightly integrated software development to integrate the additional GPS data into existing navigational systems.

### **4.2 Dual-HQ-90/Dual-Payload Flight Operations**

Although the ability to fly simultaneous aircraft for other projects had been demonstrated previously, this was the first project to fly simultaneous payloads owned by LDEO. The choice to fly one payload vs another is determined by the science goals that a particular payload can address, and so that choice directly determines the flight patterns, flight lengths, and general flight mission ops. There are 5 primary steps of a science flight mission: 1) pre-flight, 2) launch, 3) science flight, 4) recovery, and 5) post-flight. The payloads and the UAVs each have unique procedures to accomplish these 5 steps, and they must happen in tandem to be successful.

### **4.3 Very High-Bandwidth Data Telemetry, Very Long-Baseline Flight Capability**

The ability for long flights at long distances had multiple obstacles working in tandem. The HQ-90 flight durations in previous projects could not exceed 4-6 hours since the original vertical-takeoff propellers were not powerful enough to lift the HQ-90 with max fuel (the lower power props would only allow for a partial tank). The original radio also only provided a limited bandwidth of 350kbps and a radio radius of up to only 10 miles, limiting the distances and scales of measurements for physical processes.

The payloads posed their own obstacles to this initiative. They were originally designed for a much smaller UAV that could only fly for 2-3 hours. Also, because payload instruments include high resolution imagers, the amount of data a payload acquired in a given flight was a constant limiting factor in two ways: 1) the amount of storage hardware in the payload and 2) the necessary post-flight downloading, archiving, and processing of the data, which take significant time for volumes of several terabytes, even for a 4-hour flight. There was also no way to know various in-situ conditions (ie, sea surface temperature, incoming and outgoing light intensity, etc) that have significant effects on instrument exposure and integration times, and on the ability to identify areas of interest in real-time.

Accordingly, four primary objectives were identified to enable real-time data telemetry and long flight durations: 1) upgrade the HQ-90 with a radio having higher bandwidth and ranges

more comparable to larger-scale physical ocean and atmospheric dynamics (10s of km), 2) upgrade the payloads with custom software that transmits the live in-flight payload data to the ground control (RTT described below), 3) upgrade the payloads and post-flight data archiving processes to support data volumes that support the increased flying time, and 4) upgrade the HQ-90 max takeoff weight allow max amount of fuel.

#### **4.4 Real-Time Tasking (RTT): Payload Control, Data Visualization, Flight Plan Plugin**

The RTT encompasses both the hardware and software necessary to enable real-time monitoring between the UAV and the ground and, hence, real-time assessment of payload data as it pertains to the science goals. The real-time data provides the ability to direct, or re-task, the UAV to regions of interest or to search for new regions of interest. Also, both imagery and calibrated non-imagery (ie, radiation) previously had to be downloaded post-flight and undergo nominal processing to check for data quality and sensor performance (other than successful recording). The RTT would allow for calibrated data to be QC'd in real-time instead of post-flight processing. This initiative saw 4 general objectives to enable real-time data telemetry for the ATOM, RAD, and VNIR payloads: 1) pack/unpack varying datastreams and transmit over the wireless link, 2) calibrate the datastreams, 3) plot the datastreams, and 4) quickly generate and load new UAV flight plans based on the data assessment.

The Silvus radio provided the hardware and bandwidth necessary for the wireless transmission. Estimates of bandwidth requirements-by-payload were discussed in the initial planning and determined that ~2Mbps would be a comfortable throughput to be able to transmit payload data at 1hz. The throughput estimates provided by Silvus were ~3Mbps, and so as a proof-of-concept, the Silvus was determined to be a good fit for the initiative. Discussion of the Silvus integration and performance evaluation can be found in the Very High-Bandwidth Data Telemetry section above.

The custom software development is the complementary effort to the hardware selection and integration. An in-house LDEO programmer, a 3rd party vendor, and a payload engineer worked to identify the requirements and implement the custom development. A prototype of the software was tested in Flight Test 2 and was shown to successfully pack, unpack, and plot ATOM and RAD payload datastreams on a remote PC through the Silvus radio. The datastream packing had to be run on the payload computer. The packing portion of the RTT software accepts/acquires many different formats (binary, ascii, numeric) and many different rates (1hz to 25hz) of datastreams that are already recorded locally onto the payload computer and transmits through the Silvus radio at a specified rate. The primary portion of the RTT software is a client that runs on a laptop plugged into the Silvus ground antenna. The ground client can be configured to use TCP or UDP protocol and is designed to handle regular dropouts in case of an unreliable connection. It has many display features such as the ability to scale and/or normalize data so that it is displayed in meaningful ways, set mix/max axis values, and save screenshots of the client display panel. It can also record all received data and perform

real-time calibration of raw data. Multiple clients can be run on a single laptop to acquire from multiple payloads. This software can be used over any network, wired or wireless.

#### **4.5 Very-High Longevity Science Payload Missions (24hrs)**

The initiative to fly science missions on a continuous, 24hr basis required many of the upgraded capabilities already discussed. The longer missions would produce more data for recording and downloading, but would also require the use of more than one UAV. The individual UAV endurance, based on max fuel and weight limits, is 12hrs. So, the only way to accomplish continuous missions is to fly at least one UAV and then land it to re-fuel or swap the payload from one UAV to another. The payloads would also be flying through various changing environmental conditions. These considerations identified the two primary objectives for this initiative as: 1) demonstrate the ability to quickly and efficiently swap payloads and UAVs after landing (quick “turn-arounds”), and 2) be able to monitor payload data and have the ability to adapt sensor settings in-flight to adapt to changing ambient environment.

The first objective to be efficient with payload and UAV swaps has been honed over all of Flight Tests 1, 2, & 3. The ability to turn-around a UAV or payload quickly was always a priority when considering the various upgrades and changes. The payloads have been fitted with faster onboard memory to download non-imagery data streams (a few GB per flight) and a suite of SSDs will provide the ability to simply swap SSDs out instead of waiting for several TB of imagery to download. Single-flight SOPs (which changed to take advantage of new Silvus radio) must be coordinated between the UAV and payload operators were discussed in the Dual Payload initiative and were primarily demonstrated in the final Flight Test 3. That final test showed the ability to fly all 4 LDEO payloads across a total of 8 flights in 4 days, 1 flight lasting approximately 5 hrs to assess payload and UAV longevity and help determine a final fuel burn rate.

The second objective to monitor payload data and change settings is discussed partially in the RTT initiative above. The discussion here will be to confirm that in Flight Test 2 & 3, it was confirmed that a remote desktop connection to the payload could be sustained at the 50 mile range and requires minimal bandwidth. That means that payload sensors settings can be altered in real-time. This is especially important on missions where cloud/lighting conditions have the potential to push sensor response and exposure times to be invalid (ie, camera images and spectral signatures would saturate or go dark). 24hr missions would see a complete diurnal shift in lighting from nighttime to daytime, and so the ability to not only re-configure but also turn off certain sensors in low lighting conditions will save on recording space and downloading efforts. Again, this ability to re-configure during a flight is only achieved by the Silvus high-bandwidth throughput.