Using Ship-Deployed High-Endurance Uncrewed Aerial Vehicles for the Study of Ocean Surface and Atmospheric Boundary Layer Processes

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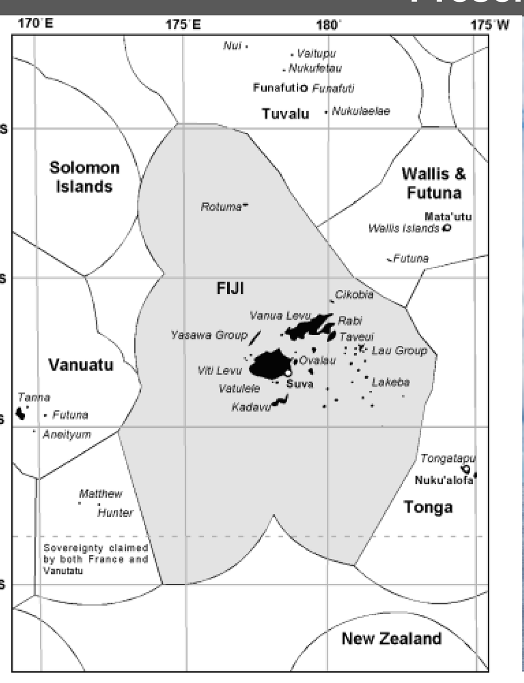
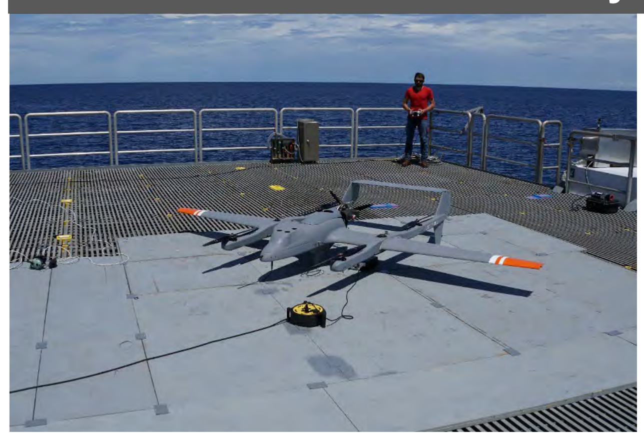
Abstract

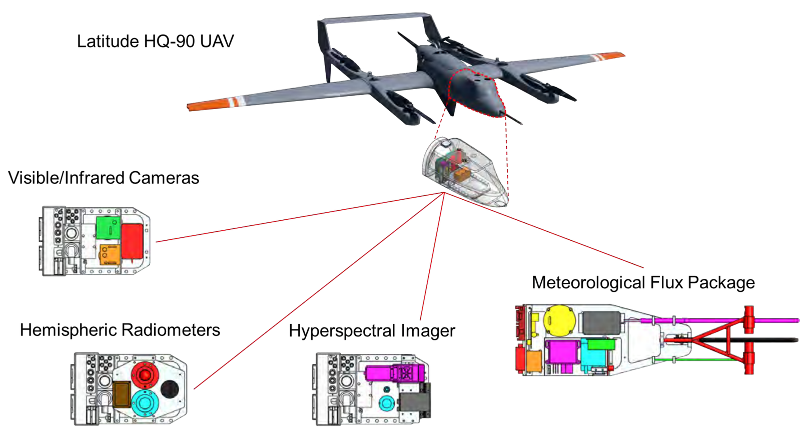
Uncrewed aerial vehicles (UAVs) are proving to be an important modern sensing platform that supplement the sensing capabilities from platforms such as satellites, aircraft, research vessels, moorings, and gliders. UAVs, like satellites and aircraft can provide a synoptic view of a relatively large area. However, the coarse resolution provided by satellites and the operational limitations of land-based aircraft and ships has motivated the development of uncrewed systems. UAVs offer unparalleled flexibility of tasking; for example, low altitude flight and slow airspeed allow for the characterization of a wide variety of geophysical phenomena at the ocean surface and in the marine atmospheric boundary layer. Here, we present the development of cutting-edge payload instrumentation for UAVs that provides a new capability for ship-deployed operations to capture a unique, high-resolution spatial and temporal variability of the changing air-sea interaction processes than was previously possible. The instrument payloads are built with a modular design for ease of interchangeability. Additionally, we implement a novel capability for vertical take-off and landing (VTOL) from research vessels. We succeeded in the first fully-autonomous deployment of a hybrid-VTOL fixed winged UAV from a moving ship on the open ocean, with an endurance of over 12 hours carrying 15-lb payloads and the ability for multiple aircraft tandem orchestrated simultaneous flight. Real-time high-bandwidth data telemetry (100+ Megabits at up to 50 nm) allowed for the ability to adapt to observations in real-time for more efficient and targeted measurements towards our science goals. The payloads developed include thermal infrared, visible broadband and hyperspectral, and near-infrared hyperspectral high-resolution imaging. Additional capabilities include quantification of the longwave and shortwave hemispheric radiation budget (up- and down-welling) as well as direct air-sea turbulent fluxes. These technological advancements provide the next generation of instrumentation capability for UAVs. We will demonstrate these capabilities by showing the results aboard the R/V Falkor near Fiji in Nov-Dec 2019. For example, we highlight the use of UAVs for reconnaissance to find features of interest that included large-scale temperature fronts, the 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. When deployed from research vessels, UAVs will provide a transformational science prism unequaled using 1-D data snapshots from ships or moorings alone, and improve asset mobilization for targeted efficient data collection.

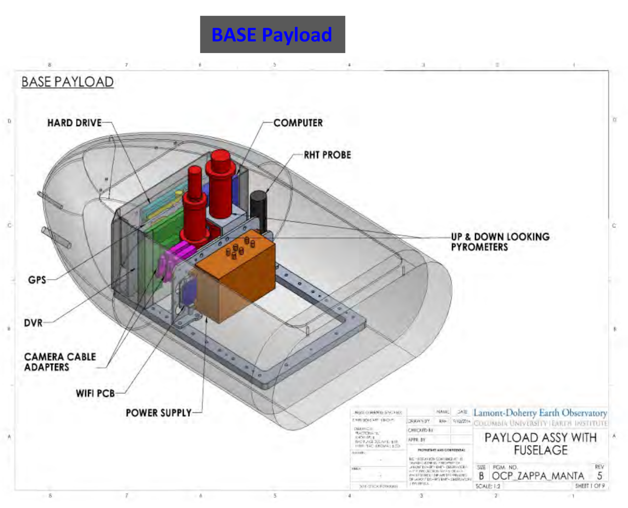
Investigating Near-Surface Ocean Heating and Mixing Processes in the Presence of Surface Material

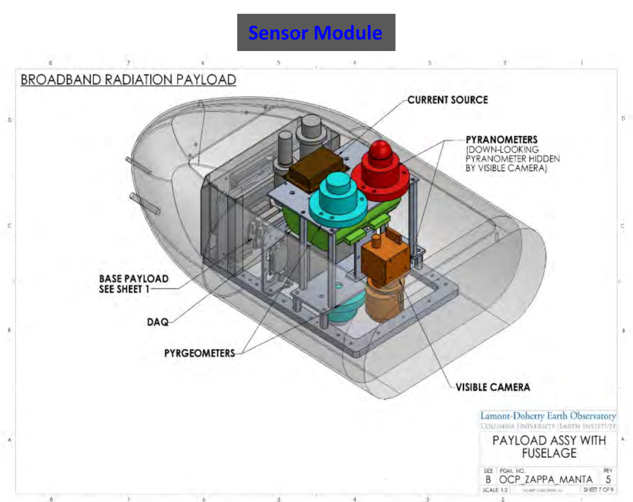


UAS Payload Development









BASE payload allows for quick change between sensor payloads

Table 1: Implemented science payloads and applications

Payload	Sensing technologies
VIS-TIR*	High-resolution broadband visible (400-700 nm) imager, uncooled microbolometer (8-14 µm) imager sensitive to 0.05°C for skin sea surface temperature (SST) mapping, whitecapping, and other upper ocean processes.
Hi-TIR*	Cooled infrared (7.7 – 9.5 µm) imager sensitive to 0.02°C for skin SST mapping, whitecapping, and other upper ocean processes.
HYP-VNIR*	Hyperspectral visible (300-1000 nm) imaging spectrometer with better than 3 nm spectral resolution for spectral radiance measurements of the upper-ocean to determine ocean color and biogeochemical mapping. Upward-looking narrow FOV spectrometer provides measurements for estimates of spectral albedo of varying surfaces including ocean.
HYP-NIR*	Hyperspectral near-infrared (900-1700 nm) imaging spectrometer with better than 3 nm spectral resolution for spectral radiance measurements of the near-surface ocean to determine ocean color and biogeochemical mapping.
Li-MET	LiDAR for wave height and surface roughness; fast response 3D wind speed and direction (100 Hz), fast response temperature (50 Hz), fast response relative humidity (100 Hz) for estimating momentum, latent heat and sensible heat turbulent fluxes.
RAD*	Upward- and downward-looking pyranometer (broadband solar 285-3000 nm) and pyrgeometer (broadband longwave; 4.5-40 µm) to measure full hemispheric irradiance to understand the surface energy budget and map albedo of varying surfaces including the ocean. High-resolution broadband visible (400-700 nm) imaging is used to map whitecapping and other upper ocean processes.
DDµD*	Drone-Deployed Micro-Drifters with launcher for in-flight ejection of up to four micro-dropsonde packages. The DDµD measures temperature, pressure, and relative humidity as it descends through the atmosphere. Once it lands on the ocean's surface, it deploys a string of sensors that measures temperature and salinity of the ocean in the upper 2-3 meters of the ocean at fifteen minute intervals for up to two weeks as a buoy. The ocean sensors on the DDµD collect and store data and then transmit the data back to the UAS on subsequent flights from up to 10 miles away.

*also included upward- and downward-looking pyrometers (8-14 µm) to measure narrow field-of-view (FOV) skin SST and ice-surface temperature.

UAS from Ships – Accomplishments

- 1st Complete autonomous takeoff, flight and landing from moving ships
  - Aircraft Dual-GPS with Ground Station dGPS ALIGN system
- Dual-UAV aircraft continuous flight operations.
  - 3 aircraft utilized
  - Multiple payloads at varying altitude
- 42 Flights with Payloads (242 hours)
  - MET, RAD, ATOM, VNIR payloads
- High endurance flights for > 8-hours.
- Long-range capability (50+ nm) with high bandwidth data link for real-time mission control and tasking.
- Demonstrated 24-hour operations.


frontiers in Marine Science

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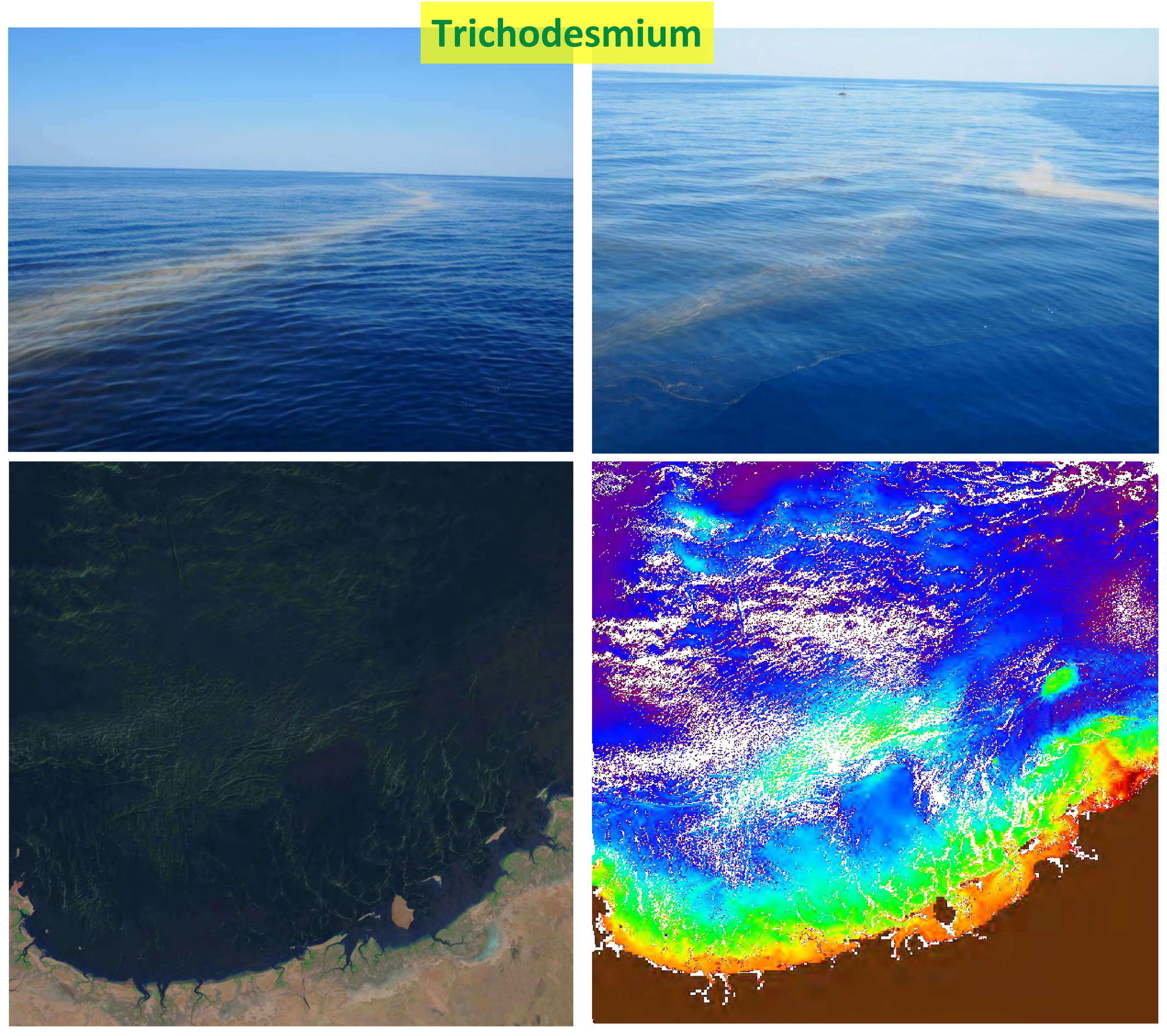
R/V Falkor Air-2-Sea Project Website: https://schmidtocean.org/cruise/studying-the-sea-surface-microlayer-2/

Satellite Imagery of Ocean Surface Slicks

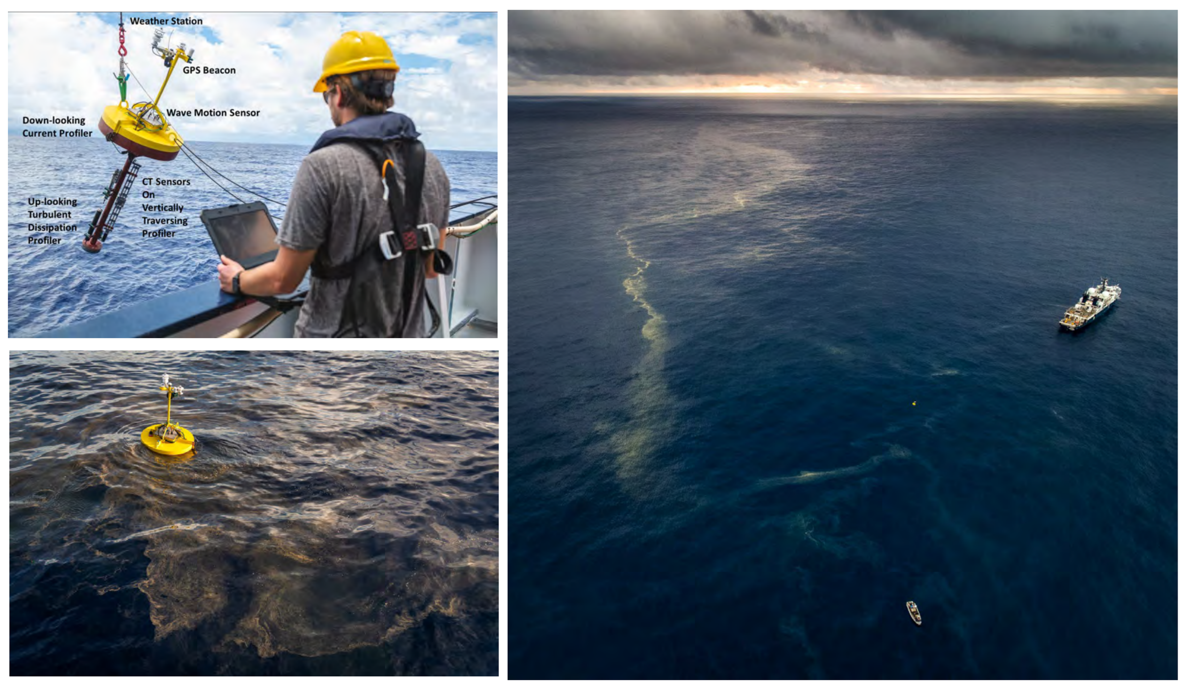


(Top Left) True color image captured by the Landsat satellite on November 17, 2014, of the coast of Northwestern Australia, east of Point Samson. (Top Right) 30 m resolution chlorophyll map obtained from the Landsat data. The high albedo from the dense surface slicks trigger the cloud mask (white).

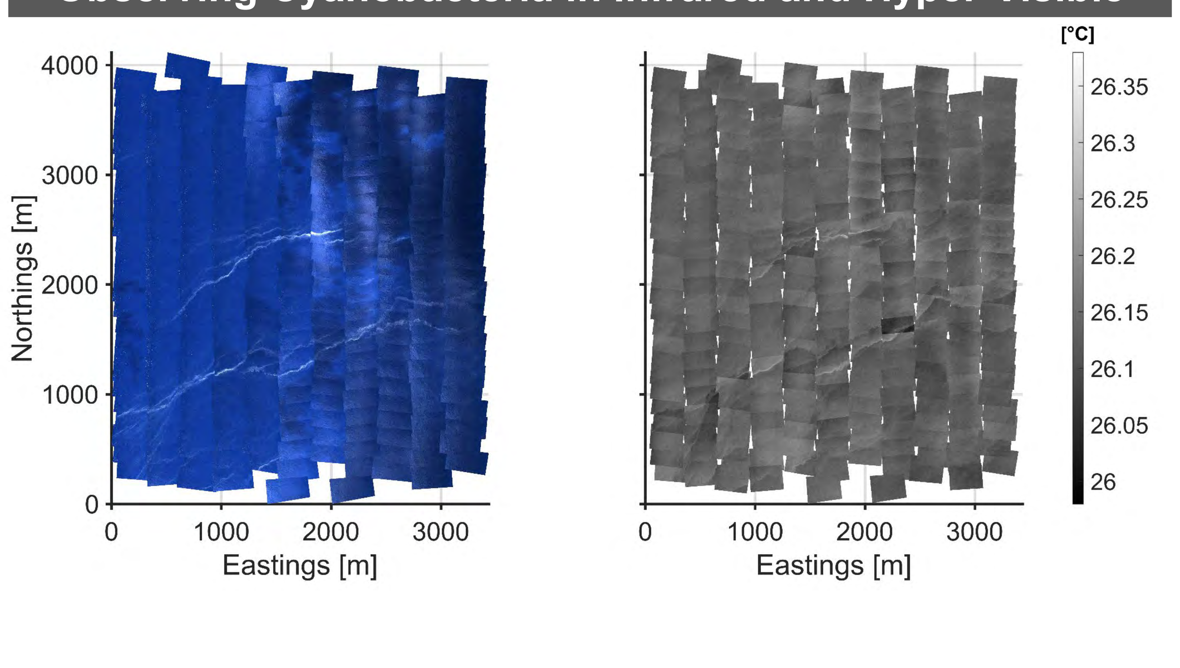
Eyes Over the Horizon

UAS Mission Control on R/V Falkor

UAS Reconnaissance of Cyanobacteria from R/V Falkor



Observing Cyanobacteria in Infrared and Hyper-Visible



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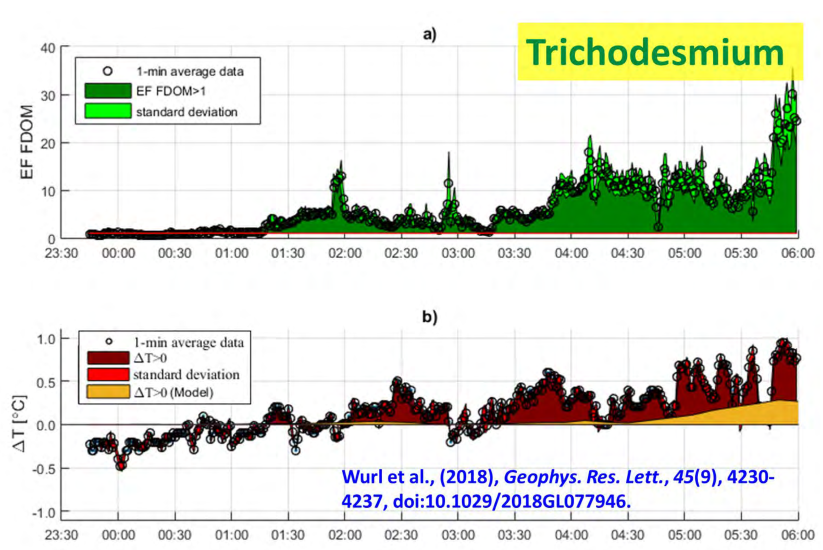
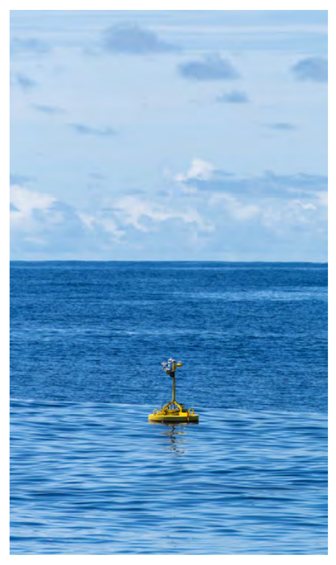
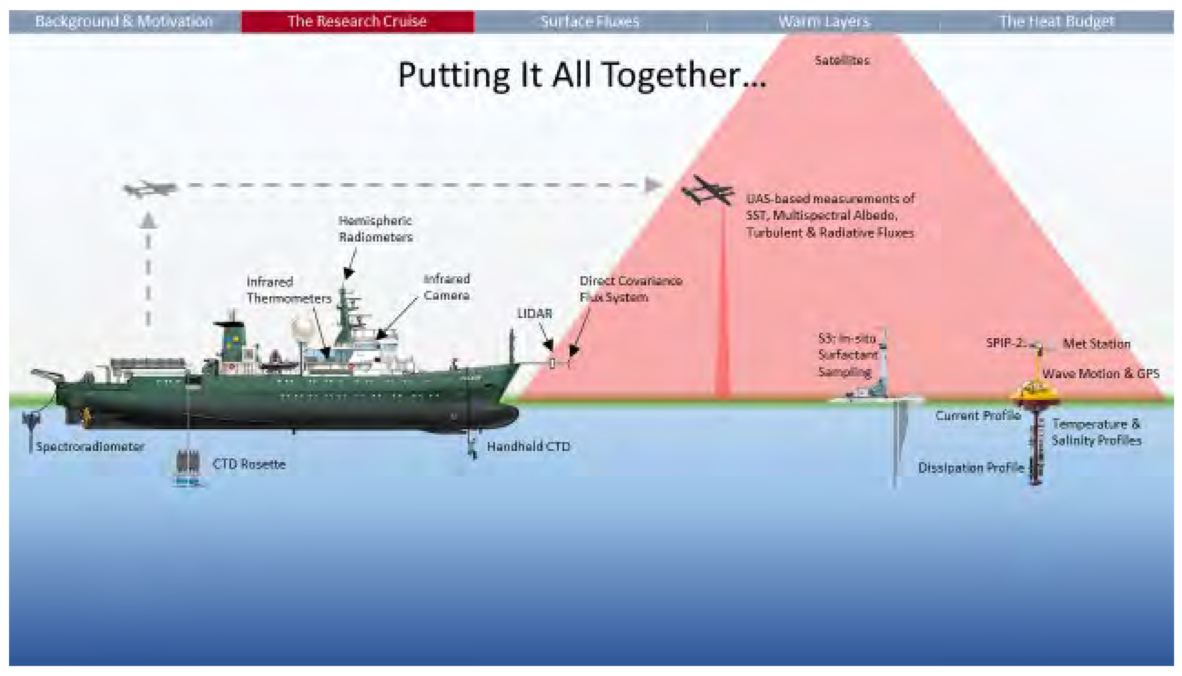
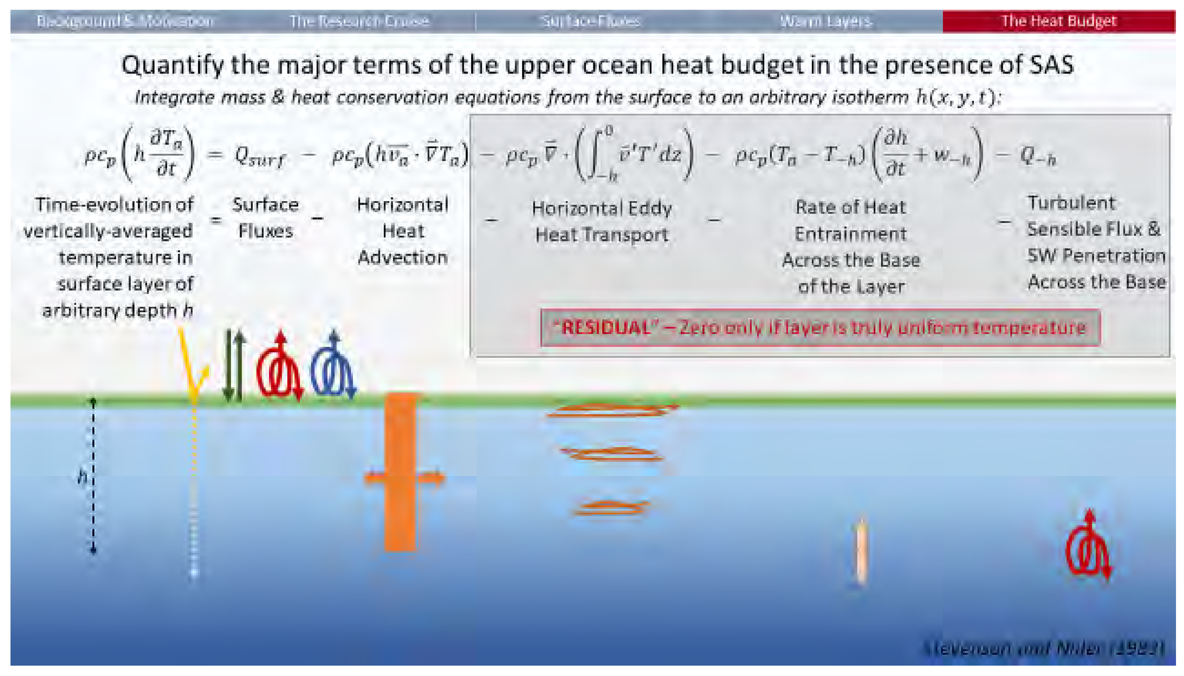


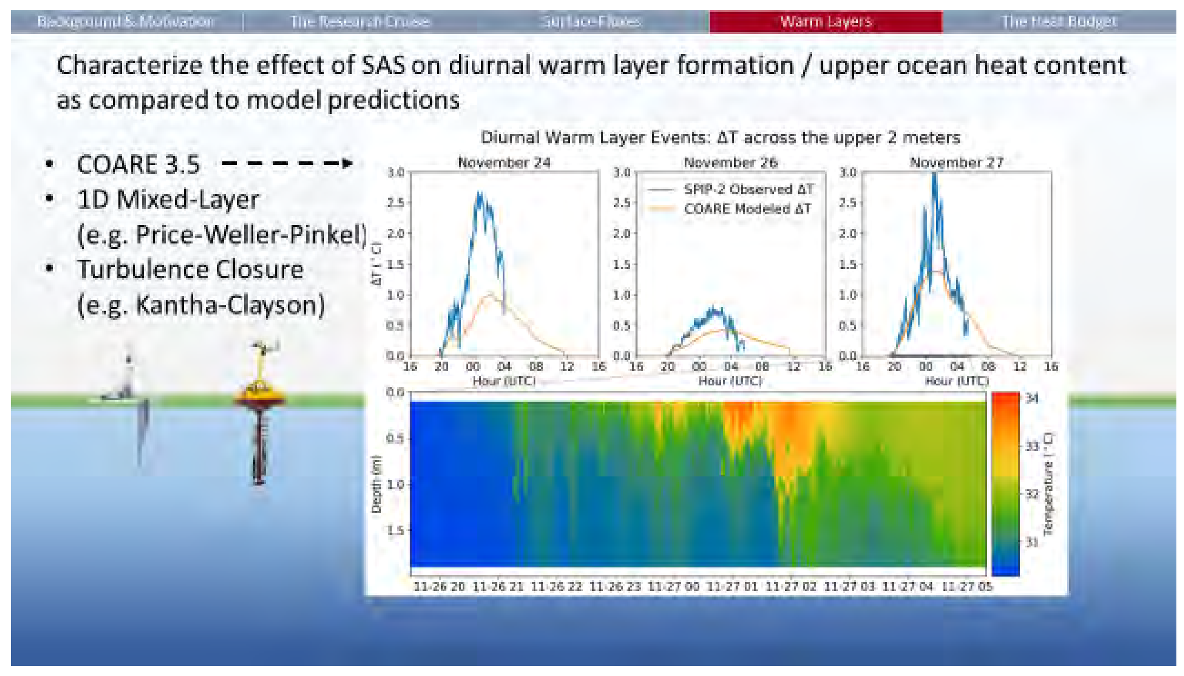


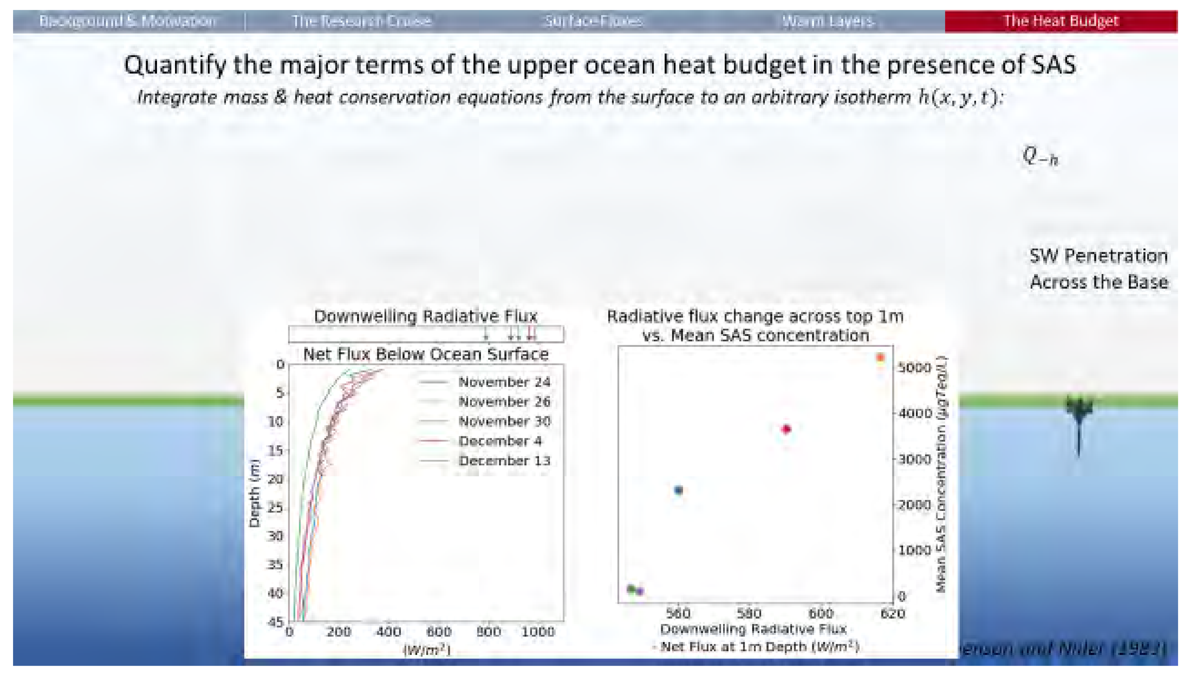
Upper Ocean Heat Budget

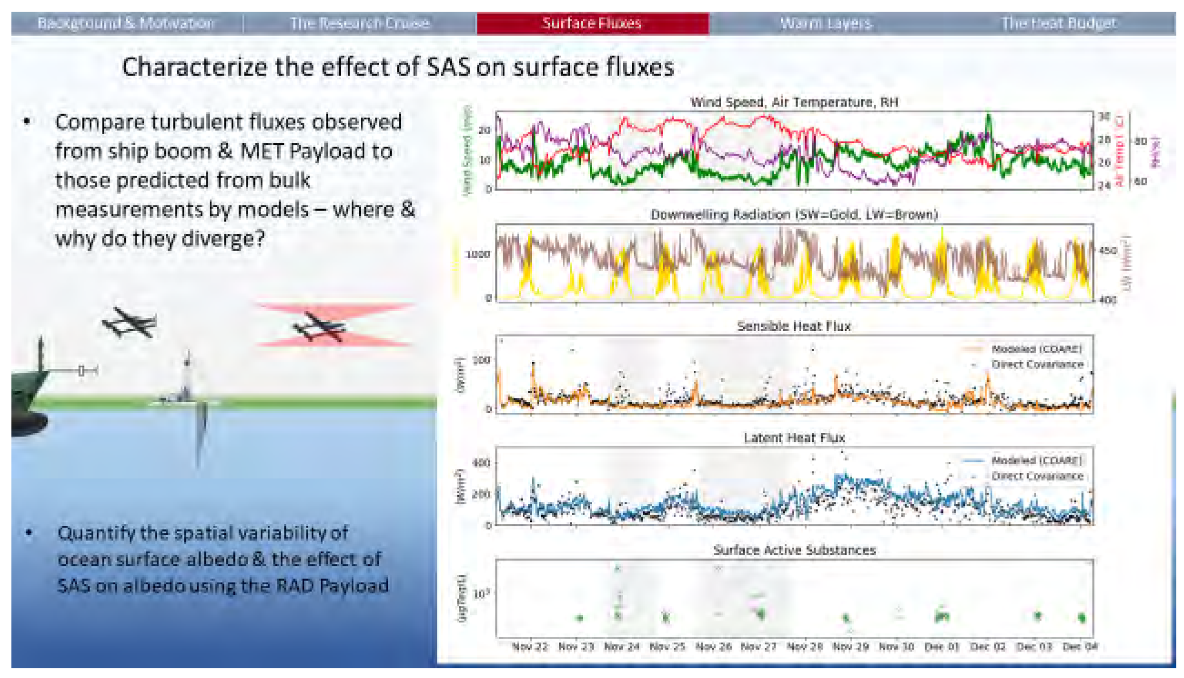
Effects of biogenic slicks on albedo, near-surface heat flux, diurnal warm-layer processes and mixing.











Concluding Summary

- **Demonstrated that UAVs provide for "New Transformational Measurement Perspectives"**
  - Real-Time Adaptive Tasking for Enhanced Science from Ships
- **Complex impacts of Cyanobacteria (Tricho) blooms on the upper ocean heat budget:**
  - Blooms cause increased absorption of solar radiation
  - Leads to enhanced near-surface warming that is not predicted by diurnal warm-layer models
  - Air-sea fluxes respond with higher sensible fluxes than predicted by COARE 3.5.
- **Total heat budget will provide insights and lead to improvements for models of air-sea heat fluxes (COARE ?.0) and diurnal near-surface warm-layer models.**