Ship-Based UAV Measurements of Air-Sea Interaction in Marine Atmospheric Boundary Layer Processes in the Equatorial Indian Ocean

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LONG-TERM GOALS

The long-term goal of this project is to develop the scientific use of ship-based unmanned aerial vehicles (UAVs) for air-sea interaction (ASI), marine atmospheric boundary layer (MABL) and surface mixed layer (i.e. marine boundary layer, MBL) research, including real-time transmission of data for assimilation into models.

OBJECTIVES

The objective has been to demonstrate that three scientific payloads for measuring (a) air-sea fluxes of heat momentum and energy; (b) radiometric fluxes of upwelling and downwelling radiation; and (c), visible and infrared (IR) imaging of the ocean surface, could be flown on Boeing-InSitu ScanEagle UAVs that are launched from and recovered on research vessels, could make scientific-grade measurements for basic research in ASI, MABL and MBL processes.

To demonstrate that data could be transmitted back to the vessel and land in real time for monitoring and assimilation into models.

APPROACH

Due to unforeseen administrative issues and subsequent tight scheduling , the deployment of the ScanEagle UAV's from the R/V Revelle was postponed from the multi-agency international DYNAMO program in Nov.-Dec., 2011, until October, 2012, as part of the EquatorMix cruise (Jerry Smith, Chief Scientist) on the equator at 140W.

Three instrument payloads were built for the UAVs: the "flux" payload for atmospheric turbulence measurements and momentum, heat and water vapor fluxes, included a laser altimeter for surface wave measurements; the "radiometric" payload for measuring upwelling and downwelling radiation; and the "imaging" payload for visible and IR video. The payloads and their component systems are displayed in Figure 1. A full description of the development of the payloads and their pre-cruise testing on the ScanEagle platform are described in Reineman et al. (2013).

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The high resolution scientific data were stored on board the UAV but low frequency (1 Hz) summary data was transmitted back to the vessel in real time and displayed on an array of video screens in a Google Earth reference frame with UAV position and altitude information (Figure 2).

UAVs and flight services (pilots, technical support) were provided by the UAV group at NSWC, Dahlgren, VA. Flights were conducted at altitudes of 30-1500 m (the ScanEagle has an upper altitude limit of approximately 5 km) at a typical cruise speed of 55 kts out to a range of 20 km from the vessel for an endurance up to 11 hrs. Over the course of 12 days on station between 8-19 October, 2012, 11 flights were conducted for a total flight time of 71 hrs. The radiometric payload was lost on the first science flight of the cruise when the airspeed measurements in the UAV navigation system malfunctioned leading to a loss of full control of the UAV, which had to be ditched in the ocean close to the Revelle.

During one 24-hr period, the same flux payload was flown on back-to-back 11hr flights with approximately 1.5 hrs for recovery, data download, refueling and systems check before relaunching. On another occasion two UAVs were in flown in "stacked flight" with the imaging UAV at approximately 300 m altitude, with the lower flux UAV in view at approximately 30 m altitude (Figure 3). In this configuration, the upper UAV can image processes at the surface while the lower UAV measures their influence on the MABL.

The approach and techniques developed in EquatorMix were subsequently employed from the R/V Knorr in Trident Warrior 2013 (TW13) during July 2013, with the additional benefit that 1 Hz MABL and ASI data were transmitted to NRL Monterey for assimilation into models. (Note that N00014-13-1-0193 is effectively an expansion of N00014-11-1-0368 to cover TW13 and related analysis of data.)

Videos showing the ScanEagle operations from the R/V Revelle in EquatorMix and the R/V Knorr in Trident Warrior 13 are available on the Field Experiments/EquatorMix and Field Experiments/Trivent Warrior tabs at http://airsea.ucsd.edu.

WORK COMPLETED

The successful design, construction testing and deployment of the three ScanEagle scientific payloads on two field experiments (EquatorMix and TW13) has been accomplished.

We have demonstrated that data acquired from the ScanEagle science payloads can be distributed in real time to the research vessel, naval vessels and land-based centers for monitoring and assimilation into MABL and EO/EM models of propagation and scattering.

RESULTS

The primary result of this research so far is the demonstration that scientific-quality data can be acquired from ship-launched and recovered UAVs, and distributed in real time for scientific and naval use. This is a new opportunity for environmental monitoring, modeling and prediction for naval operations.

We have shown that with these payloads, ScanEagles can be flown back-to-back on 11 hr flights, effectively giving 24 hr coverage down to low altitudes , where manned scientific flights could not operate at night.

We are in the preliminary stages of data analysis for both EquatorMix and TW13, but initial results appear promising.

IMPACT/APPLICATIONS

There are broad opportunities for the use of UAVs with scientific payloads in ASI, MABL and MBL research, and for naval operations. The technology clearly "projecting science" by extending the reach and capabilities of the research vessels.

RELATED PROJECTS

NONE

REFERENCES

Reineman, BD, Lenain, L, Statom, NM & Melville, WK (2013) Development and testing of instrumentation for UAV-based flux measurements within terrestrial and marine atmospheric boundary layers. J. Atmos. Ocean. Tech., **30**, 1295-1319.

PUBLICATIONS

Reineman, BD, Lenain, L, Statom, NM & Melville, WK (2013) Development and testing of instrumentation for UAV-based flux measurements within terrestrial and marine atmospheric boundary layers. J. Atmos. Ocean. Tech., **30**, 1295-1319.

HONORS/AWARDS/PRIZES

PI: W. Kendall Melville, SIO/UCSD, Sverdrup Gold Medal of the American Meteorological Society, 2013, "for pioneering contributions in advancing knowledge on the role of surface wave breaking and related processes in air-sea interaction."

(a) Flux Payload

9-port turbulence probe	Winds, momentum fluxes, other fluxes
Laser altimeter (Measurement Devices Ltd.)	Surface waves, a/c control
Humidity/temperature (Vaisala)	H/T profiles and bulk fluxes
SST sensor (Everest Sci.)	SST, frontal processes
Fast-response optical temperature sensor (Opsens)	T, sensible heat flux
Krypton hygrometer (Campbell)	Water vapor, latent heat flux
DAQ system (NI, Kontron)	Data acquisition
DGPS (NovAtel)	Georeferincing, winds
LN200 IMU (Northrop Grumman)	Georeferencing, winds

(b) Radiometric Payload

Humidity/temperature (Vaisala)	H/T profiles and bulk fluxes
Radiometers (Hukseflux)	radiation budget, SST
SST sensor (Everest Sci.)	SST, frontal processes
DAQ system (NI, Kontron)	Data acquisition
DGPS (NovAtel)	Georeferencing

(c) Imaging Payload

Laser altimeter (Measurement Devices Ltd.)	Surface waves
Digital video camera (Prosilica)	Ocean surface processes, wave kinematics and breaking
SST sensor (Everest Sci.)	SST, frontal processes
Humidity/temperature (Vaisala)	H/T profiles and bulk fluxes
FLIR A325 LWIR camera	SST, fronts, ocean surface processes
DAQ system (NI, Kontron)	Data acquisition
DGPS (NovAtel)	Georeferencing

Figure 1. Instrumentation descriptions and photographs of (a) the ScanEagle Flux payload, (b) the ScanEagle Radiometric payload (top cover removed), and (c) the ScanEagle Imaging payload (removed from the fuselage section). Inset shows a bottom view of the Imaging payload.
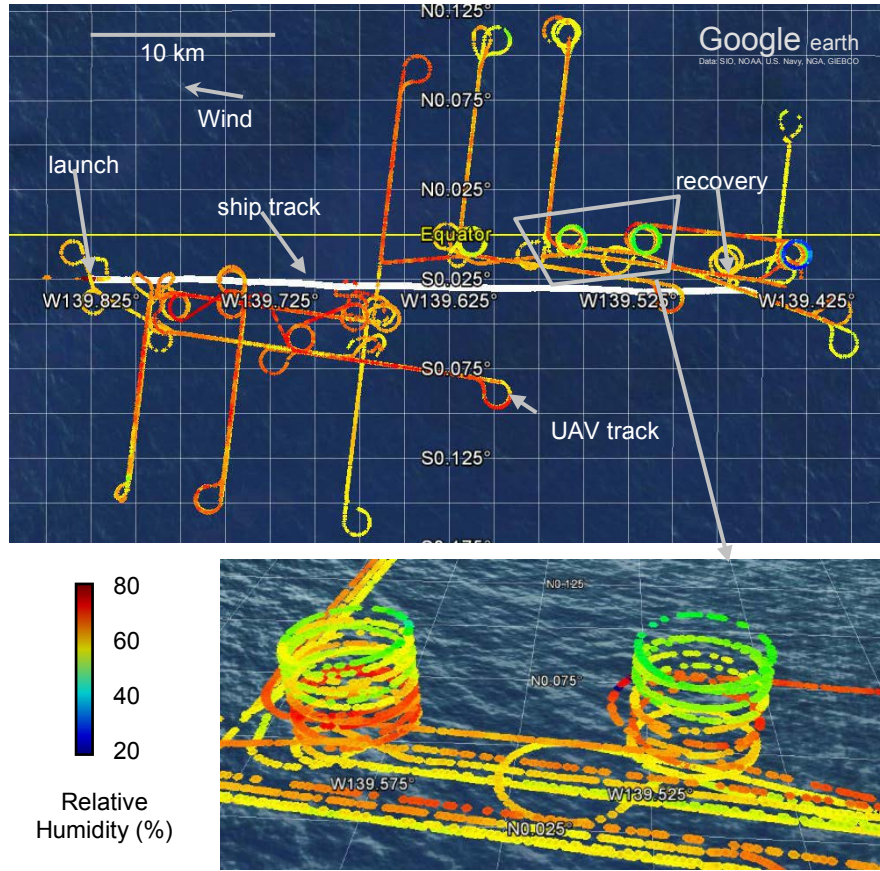
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Figure 2: Sample Google Earth real-time 1-Hz flight track during one 11-hr flight (19 October 2012). Color scale can be chosen to correspond to altitude or to any measured atmospheric variable, in this case relative humidity. The ship track is shown in white.
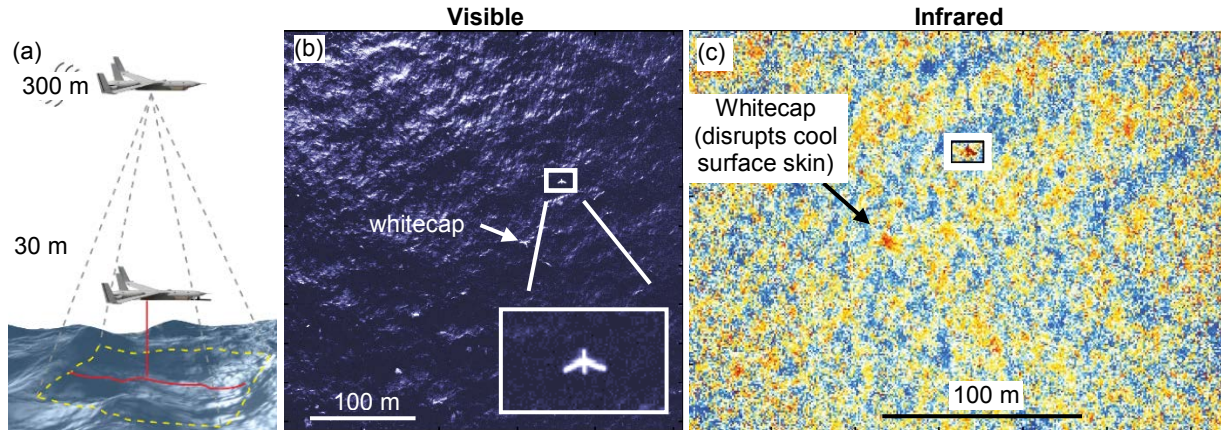

Figure 3: (a) Schematic of vertically-stacked flight of ScanEagles with Imaging (top) and Flux (bottom) payloads. (b) Visible imagery sample acquired by the Imaging payload during vertically-stacked formation flying on 18 October 2012. Scattered white-capping is evident (U_{10} = 9 m s^{-1}). The Flux payload ScanEagle can be seen in the imagery, 270 m below, and 30 m above the surface. (c) Infrared image sample (color scale is not calibrated). The ScanEagle is boxed.
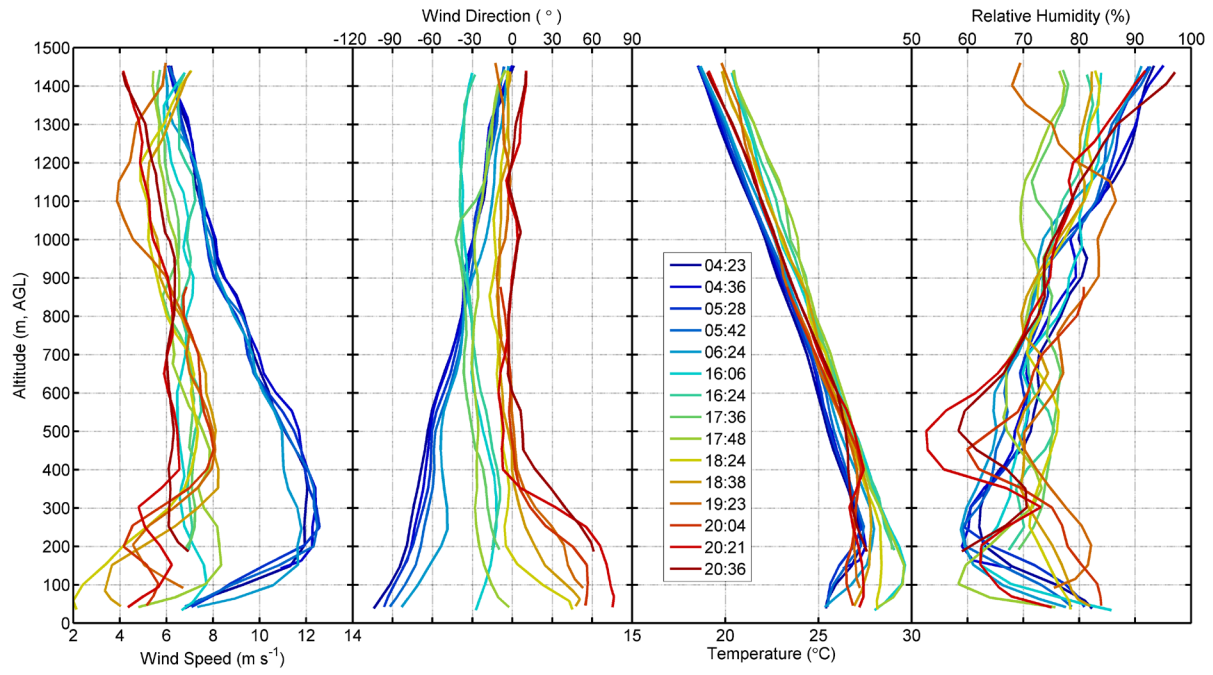
Figure 4. An example of wind speed, direction, temperature and humidity profiles in TW13 measured by the flux package on 2013/07/16 (color legend is local time), in helical sounding flights like those in Figure 2.