A sUAS Study to Measure Simultaneous Oceanic and Atmospheric Profiles during the 2017 CASPER-WEST Field Experiment

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Figure Courtesy of Dr. Steven Yoon
Nasa Ames Research Center
Detection of Individual Raindrops: The U.S. Navy’s MCR 3MW C-band Doppler Radar

MCS Approaching the MCR Radar
(3MW, C-Band, Dual Polarization, 0.2° Beam Width, 50’ Dish, 0.5 or 37m Along-Range Resolution)

Reflectivity [dBZ]

Δr = 11.25m

Developing Rain Shaft

Δr = 9 cm

MCR Wideband Data periodically reveals “in-bound” near linear patterns or “streaks” in the reflectivity field

These structures represent Individual raindrops

MCR Narrowband Data (Vertical Stare)

Δr = 11.25m

Photo Courtesy of Jason Nachamkin

Reflectivity [dBZ]

Δr = 9 cm

The NRL Mobile Cloud Observing Facility

A) ProSensing Scanning Ka-Band Dual Polarization Doppler Radar

B) Radiometrics Microwave Profiler: Profiles of T, H, LWC

C) Vaisala CL51 Ceilometer: Cloud & Aerosol backscatter

D) OTT2 Parsivel Laser Disdrometer: (N, D, VT)


F) FM 120 Fog Monitor (D < 50um)

G) Prede All-Sky Camera: Cloud type and fractional coverage

H) Vaisala Rawinsondes (MW41, RS41)

I) Novalynx Professional 12” Rain gauge

J) Cloud/Aerosol/Radiation Splash Drone
The characterization of the evaporation duct is important scientifically & operationally:

- Evaporation Duct: \( f(T, P, e) \)
- Alters the radar propagation (\( v > 1 \text{GHz} \))
- Small changes in depth can drastically modify ship-based threat detection
- Global ocean phenomenon (\( z < 50 \text{m} \))
- Highly variable spatially & temporally

The evaporation duct is a shallow downward refracting surface-based layer resulting from the rapid decrease in the water vapor pressure with height \( [e(z)] \) above bodies of water:

\[
M(z) = \frac{77.6}{T(z)} \left( p(z) + \frac{4810e(z)}{T(z)} \right) + 0.157z
\]

Approaches:
- Use Model Forecasts & Surface Layer Theory
- Observations & Validation
On the Use of Small Unmanned Aerial Systems for Evaporation Duct Measurements

**Problem:** The near-surface Evaporation Duct Height (EDH) is difficult to both model and observe:

- Validation data is difficult & dangerous to obtain
- Diurnal Sea Surface Temperatures (SST) required but not currently accounted for operationally
- Spatial variability requires mobile observational platforms that can routinely measure at altitudes less than 50m

**Questions:**
- Can instrumented sUAS, such as quadcopters or hybrid quad/fixed wing variants, obtain the Evaporation Duct height & structure?
- What design considerations are needed for sensor performance, placement, and validation?
Coupled Air/Sea Processes & EM Ducting Research (CASPER-West) PI: Dr. Qing Wang NPS

$M(z) = \frac{77.6}{T(z)} \left( p(z) + \frac{4810 e(z)}{T(z)} \right) + 0.157z$

Modified Refractivity

$\bar{q}(z) = \bar{q}(z_{ref}) + \frac{q_z}{k} \left[ \ln \frac{z}{z_0} - \psi_e(\bar{T}_z, \bar{U}_z) \right]$

$\varepsilon(z_{ref}), \bar{P}(z_{ref}), \bar{T}(z_{ref}), \bar{U}(z_{ref})$

$\varepsilon(SST)$
Initial Tests: Evaluating the Evaporation Duct Structure

CASPER-WEST (2017): Test Flight 1

\[ M(z) = \frac{77.6}{T(z)} \left( p(z) + \frac{4810e(z)}{T(z)} \right) + 0.157z \]

儀器化的sUAS

Google Earth

CASPER-WEST: Point Mugu Naval Air Station

- sUAS Flight Path

- No Fly Zone

- RBR Duet Thermistor

- SST_{bulk}

- Instrumented sUAS

- 8m

- Ocean Dip

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Initial Tests: Evaluating the Evaporation Duct Structure
CASPER-WEST (2017)

\[ M(z) = \frac{77.6}{T(z)} \left( p(z) + \frac{4810e(z)}{T(z)} \right) + 0.157z \]

\[ \bar{e}(z), \bar{T}(z), \bar{P}(z) \]

\[ \bar{e}(z_{\text{ref}}), \bar{T}(z_{\text{ref}}), \bar{U}(z_{\text{ref}}) \]

sUAS-Derived Observations

\[ e(z) \]

\[ T(z) \]

\[ M(z) \]

Derived M-Profile

Use of Instrumented sUAS to measure all required parameters needed to generate & validate similarity-based M-profiles and to validate model predictions
Integrated sUAS & Payload Development

- **3DR Solo Linux Box**
- **3DR Solo Accessory Bay**
- **iMET Break Out Board (BOB)**
- **5V Supply**
- **iMET XF Microcontroller Raspberry PI**
- **Storage 1**
- **Storage 2**
- **Storage 3**
- **Laptop**
- **915 MHz Data Transmission**

**Payload**
- LI-COR LI-200R
- GPS
- OPC-N3 Aerosol
- Fast Response $T_{air}$, $P$, RH
- RBR Duet
- iMET IR SST Sensor
- Trisonica Mini
- Mini TKE Probe
- FLIR Vue Pro R

**Commercial sUAS Candidates**
- **Splash Drone**
- **FlightWave Edge**
- **Flightwave Jupiter H2**
- **Others?**

Concept by Piotr J. Flatau (Scripps Institution of Oceanography)
**Science Questions Addressed at the NRL LASR Facility:**

- What is the optimal placement of the payload on a quad-based sUAS?

- At what level does the sUAS downwash impact the near air-sea interface measurements and what steps can be taken to mitigate this issue?

- How accurate are sUAS-based aerosol sensors?

- What instrumental response time is optimal?
Specific Scientific Questions to be Addressed:
What are the fundamental differences in the day/night or on-off shore flow evaporation ducts structures & what governs these differences?

Can sUAS provide both the mean environmental vertical gradients & SST_{skin} to close all terms needed in surface layer theory?

How can we best account for the sUAS measured variability resulting from turbulent conditions & instrumental error?

How best to validate the sUAS measurements?

\[
\bar{q}(z) = \bar{q}(z_0) + \frac{q_v}{k} \ln \frac{z}{z_0} - \psi \left( \frac{z}{z_0}, \frac{U}{U_0} \right)
\]

Required Inputs:
- \(q_v, z_0\) [Parameterized]
- \(P, T, q, U\) [Reference Level]
- \(P, SST, q_{sea}, U\) [Ocean Surface]

**Evaporation Duct Structure Measurement Strategy**

**Navy Coastal Field Sites**

Co-located Measurements at Specific Model Grid Columns

NRL CICADA mk5

User-defined sUAS Waypoints

Real-time Guidance (CPP Instrumentation)

Use real-time remote sensing output to guide sUAS flights

NRL CICADA Profiles

Adjusted Model Column

Example of Vertical Gradients

Time-Height Back Scatter

Ceilometer

Model Column
NRL has developed a Mobile Cloud Observing Facility to promote cloud research studies:
- Access to the high-resolution MCR C-band Doppler Radar (Raindrop Detection)
- Ka-Band Scanning Doppler Radar
- Microwave Radiometer
- Ceilometer, All-Sky camera, Disdrometers, Rawinsondes
- Instrumented sUAS

Future Work:
- Expand collaboration with interested partners
- Develop/Test an integrated instrumental payload to obtain lower atmospheric state variables, upper ocean structure, and cloud/aerosol structure
- Develop a validation effort at the NRL LASR facility & evaluate commercially available sUAS platforms
- Conduct integrated field programs using sUAS and the Mobile Cloud Observing Facility

SUMMARY
NRL has a pending sUAS-based research project:
- Basic research and operational applications such as the Evaporation Duct Structure
- Initial tests demonstrate simultaneous & co-located air/sea measurements are feasible
Extra Slides
Detection of Individual Raindrops
The U.S. Navy’s MCR 3MW C-band Doppler Radar

What are the possible causes of the along-streak variations?

What can we learn from the individual streaks?