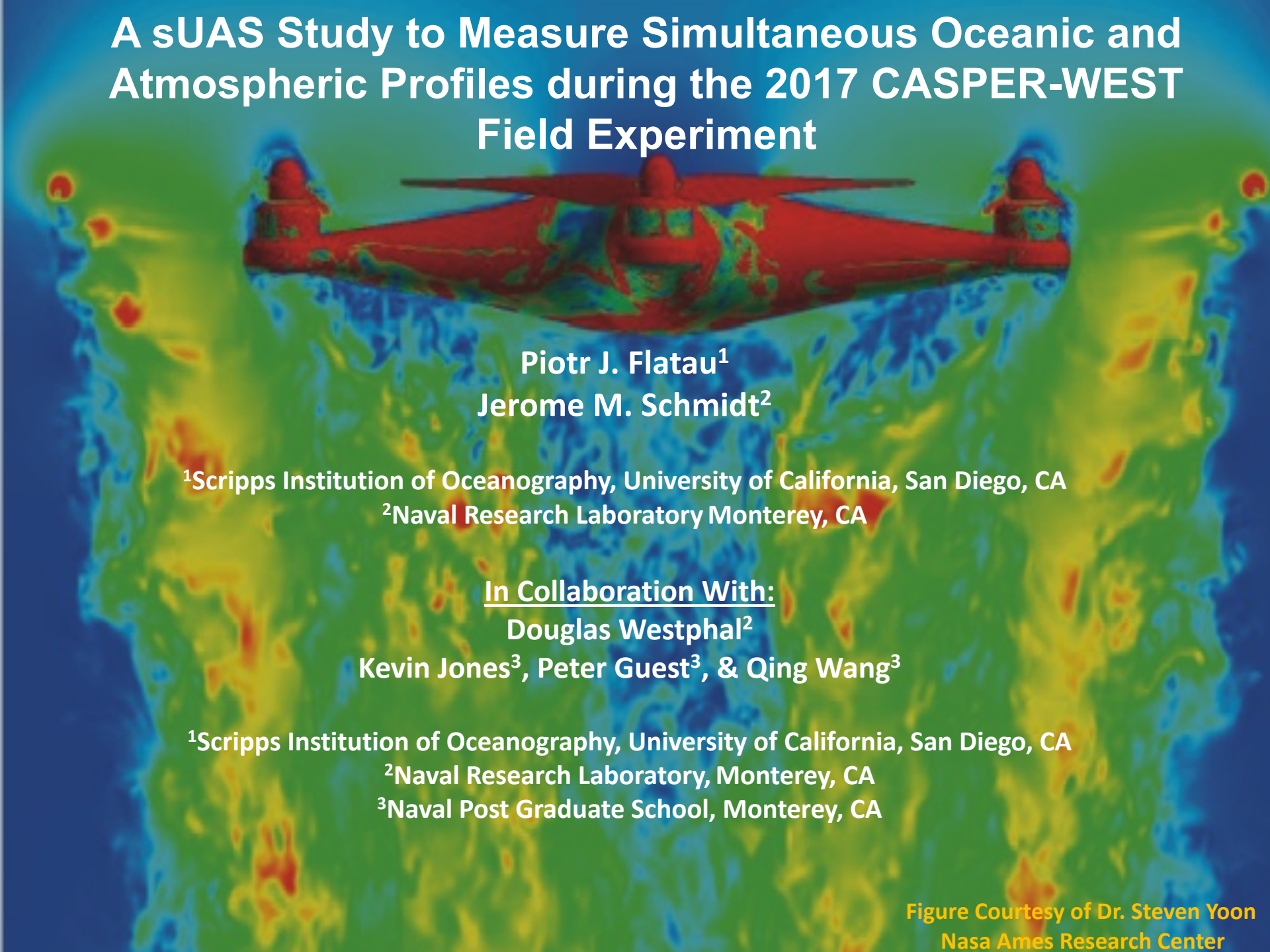
A sUAS Study to Measure Simultaneous Oceanic and Atmospheric Profiles during the 2017 CASPER-WEST Field Experiment



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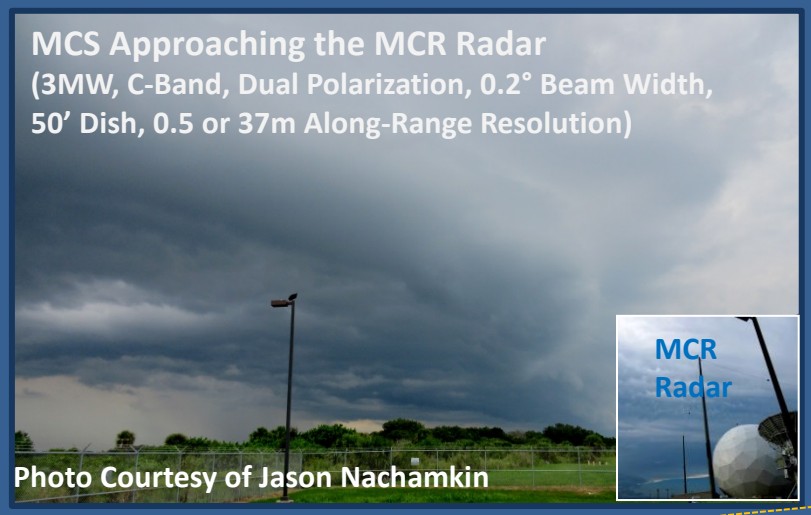
[2]Naval Research Laboratory, Monterey, CA
[3]Naval Post Graduate School, Monterey, CA

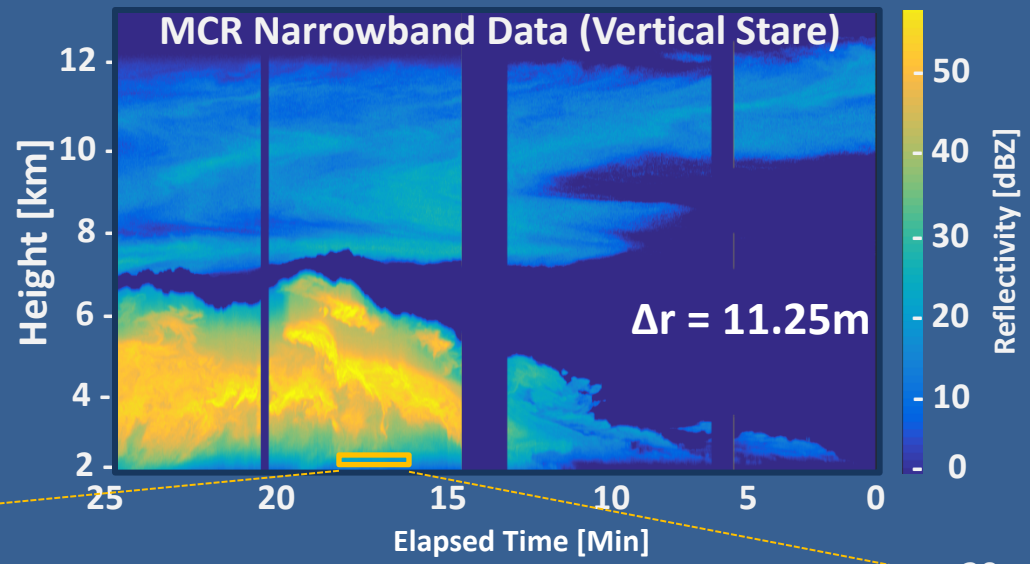
Figure Courtesy of Dr. Steven Yoon
Nasa Ames Research Center

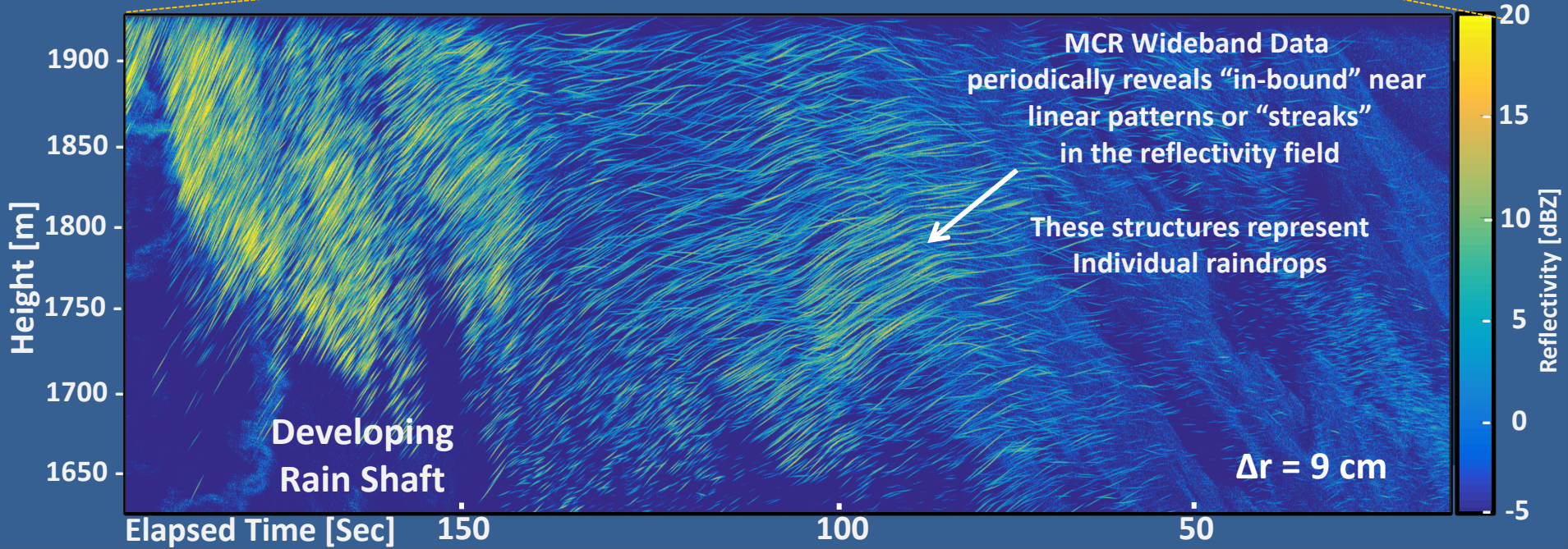
NRL Marine Meteorology Division Remote Sensing Applications : Historical Review

Detection of Individual Raindrops: The U.S. Navy's MCR 3MW C-band Doppler Radar

Multi-agency Collaboration (NRL, NSWC, Scripps Institution of Oceanography, NOTU,
The Johns Hopkins Applied Physics Laboratory ,NASA, UND, IEC Corp)







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)

E) Surface Flux Tower (T', U', V', W', Q'v, CO2, P, Soil T,Q, Net R)

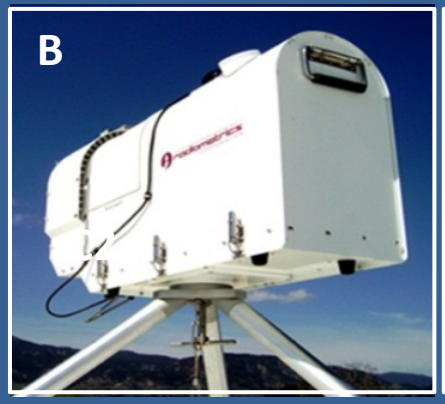
F) FM 120 Fog Monitor (D < 50um)

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

H) Vaisala Rawinsondes (MW41, RS41)

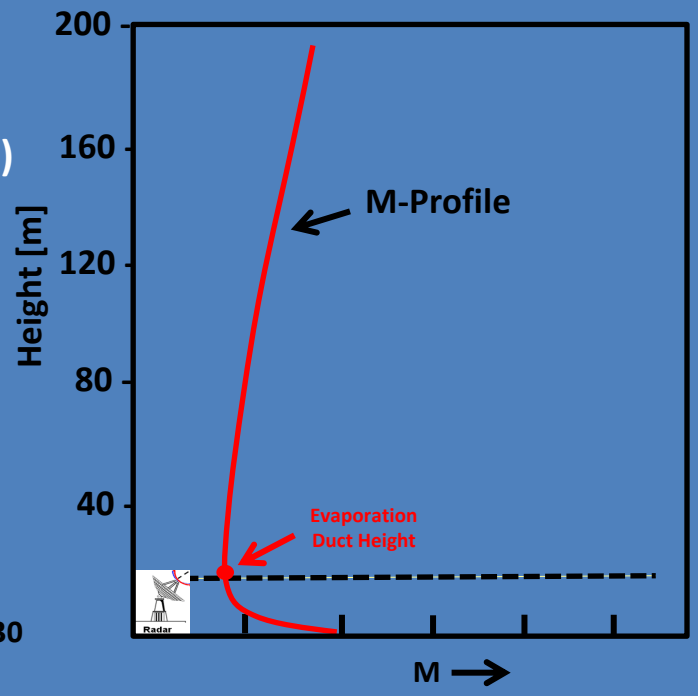
I) Novalynx Professional 12" Rain gauge

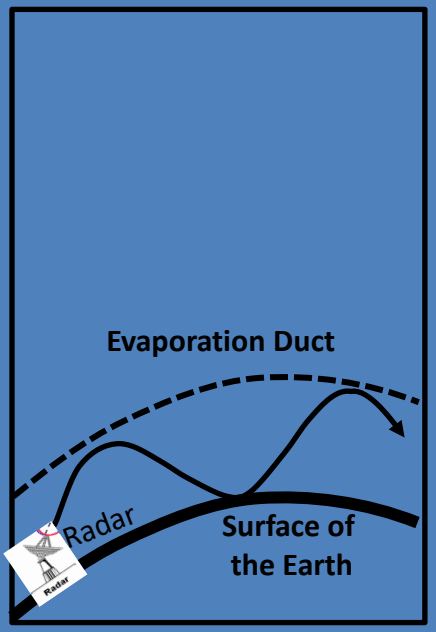
J) Cloud/Aerosol/Radiation Splash Drone

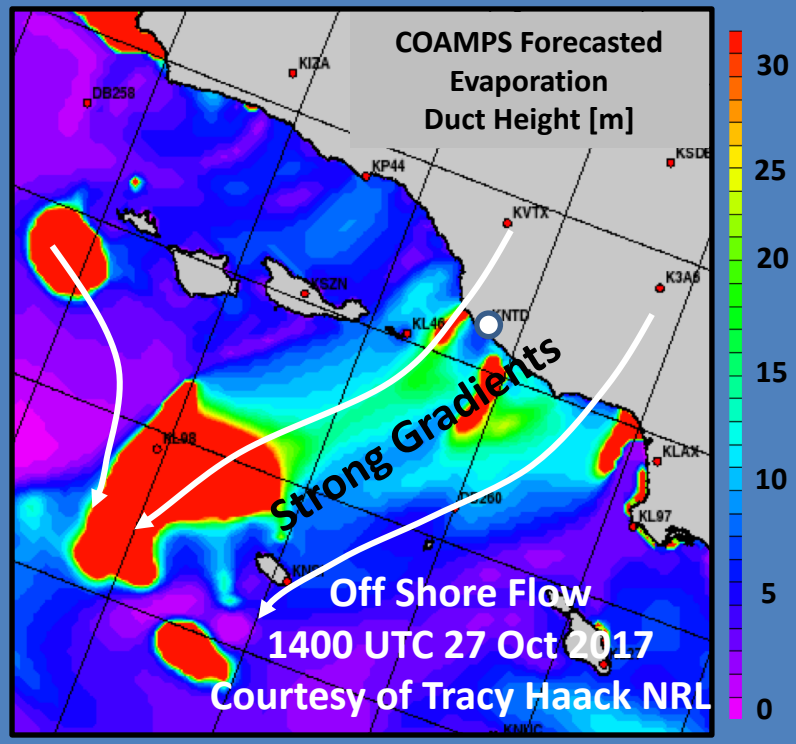


The characterization of the evaporation duct is important scientifically & operationally:

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







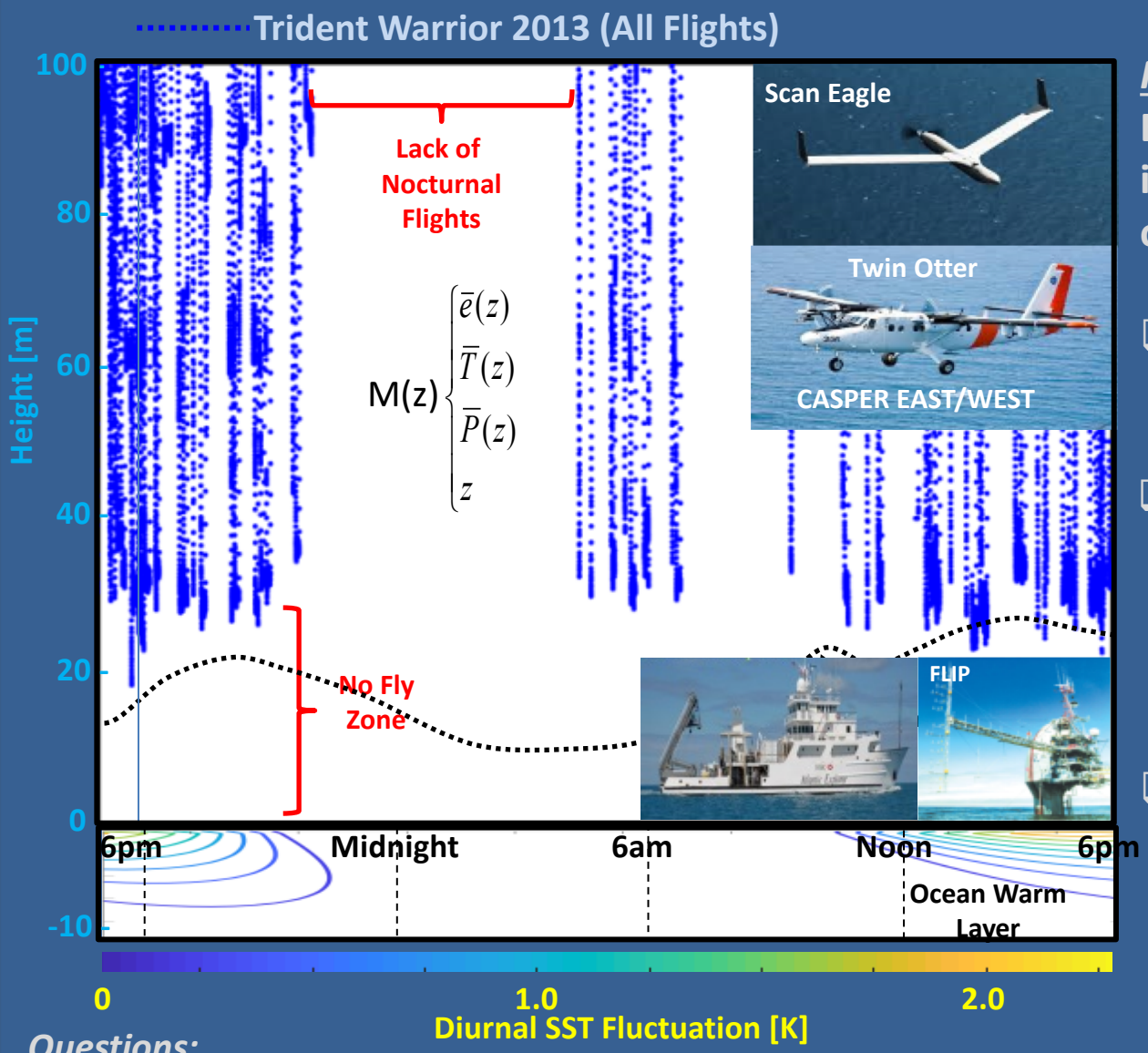
The ***evaporation duct*** is a shallow downward refracting surface-based layer resulting from the rapid decrease in the water vapor pressure with height [e(z)] above bodies of water:

$$M(z) = \frac{77.6}{T(z)}\left(p(z) + \frac{4810e(z)}{T(z)}\right) + .157z$$

Approaches:

- Use Model Forecasts & Surface Layer Theory
- Observations & Validation

On the Use of Small Unmanned Aerial Systems for Evaporation Duct Measurements



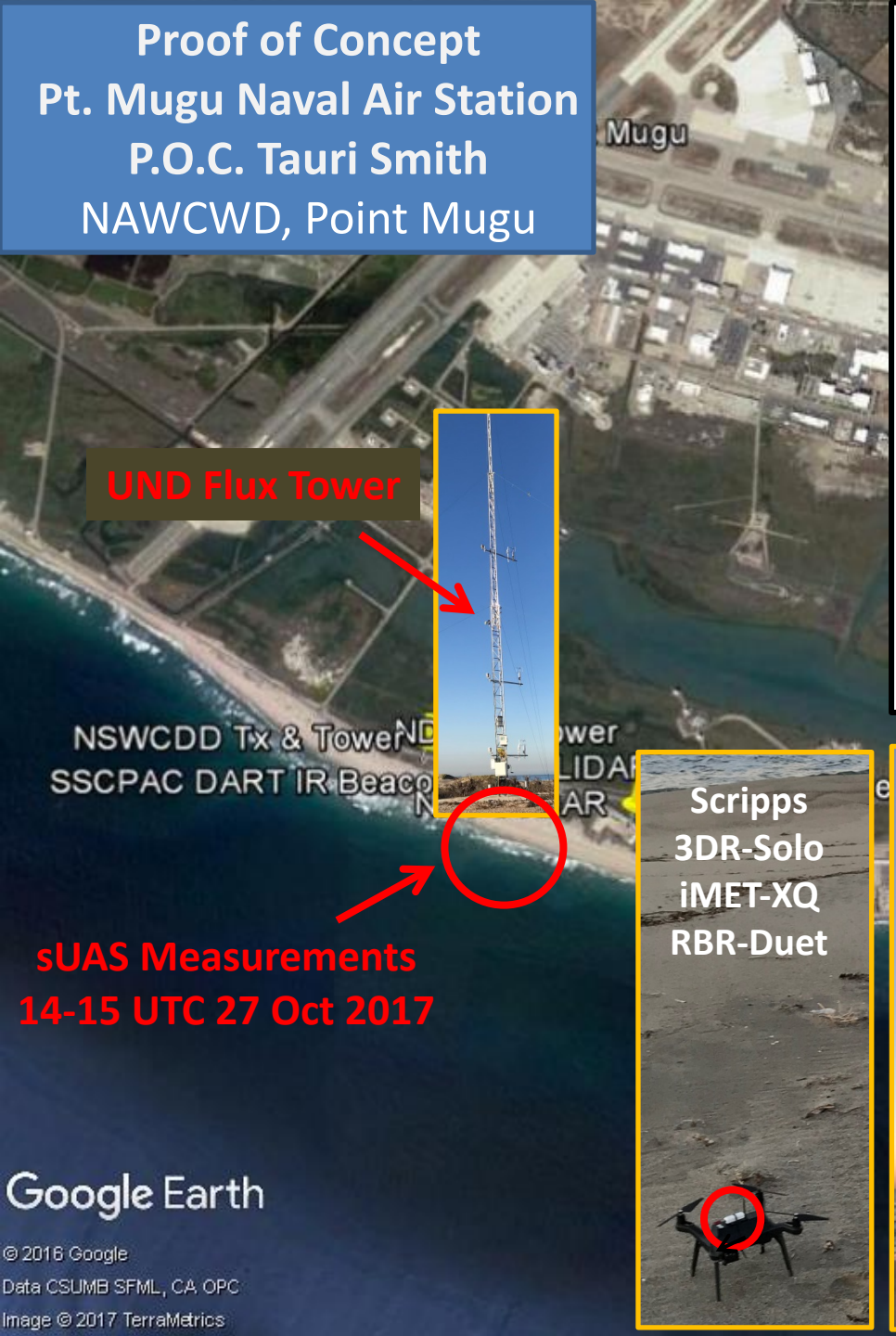
Problem: The near-surface Evaporation Duct Height (EDH) is difficult to both model and observe:

- ❑ 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?

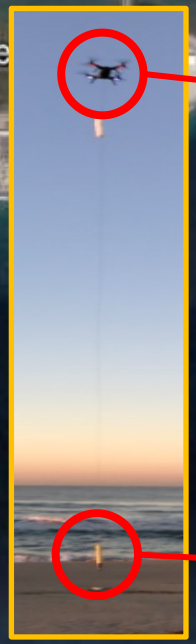
Proof of Concept
Pt. Mugu Naval Air Station
P.O.C. Tauri Smith
NAWCWD, Point Mugu

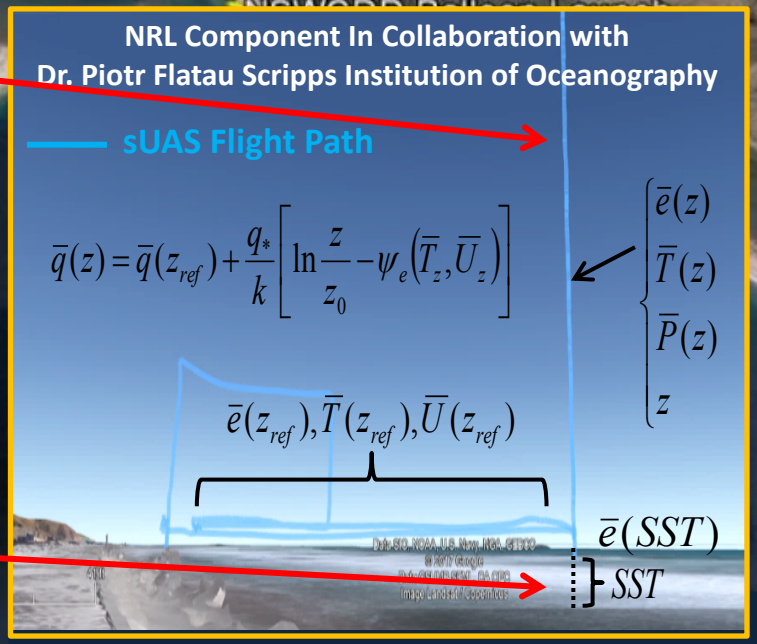


Coupled Air/Sea Processes & EM Ducting Research (CASPER-West) PI: Dr. Qing Wang NPS

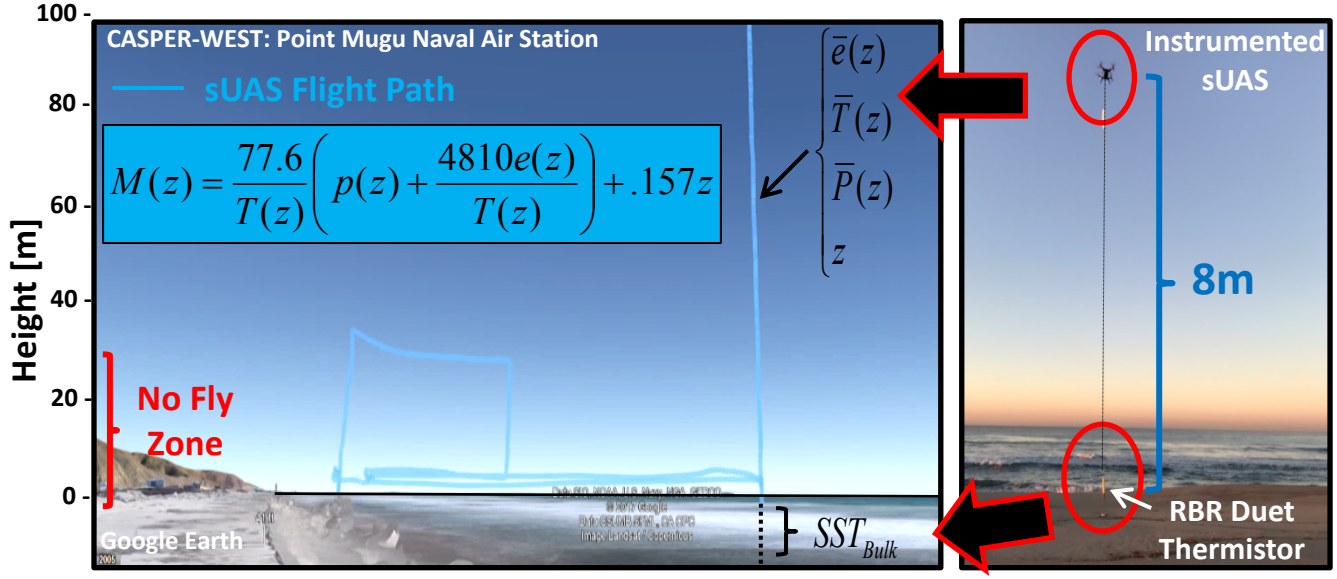
Modified Refractivity

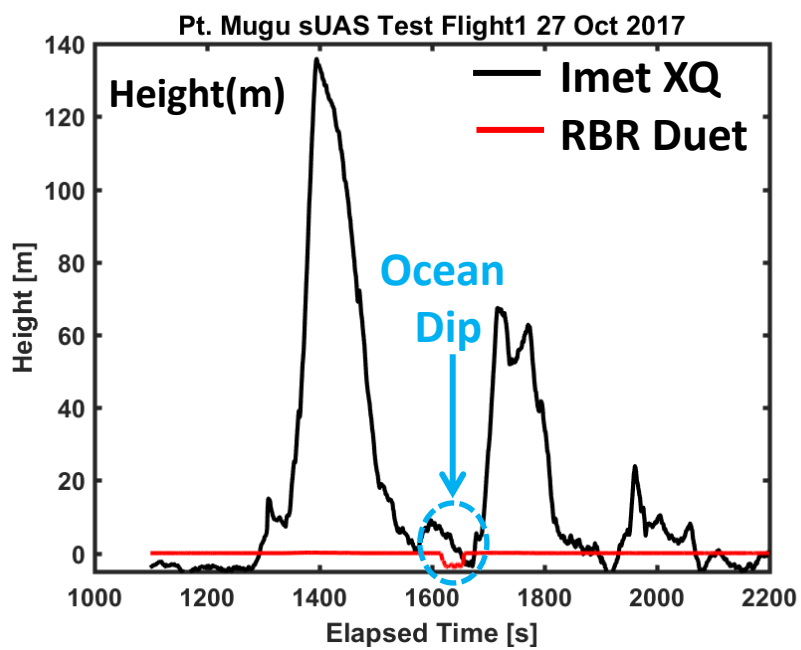
$$M(z) = \frac{77.6}{T(z)}\left(p(z) + \frac{4810e(z)}{T(z)}\right) + .157z$$

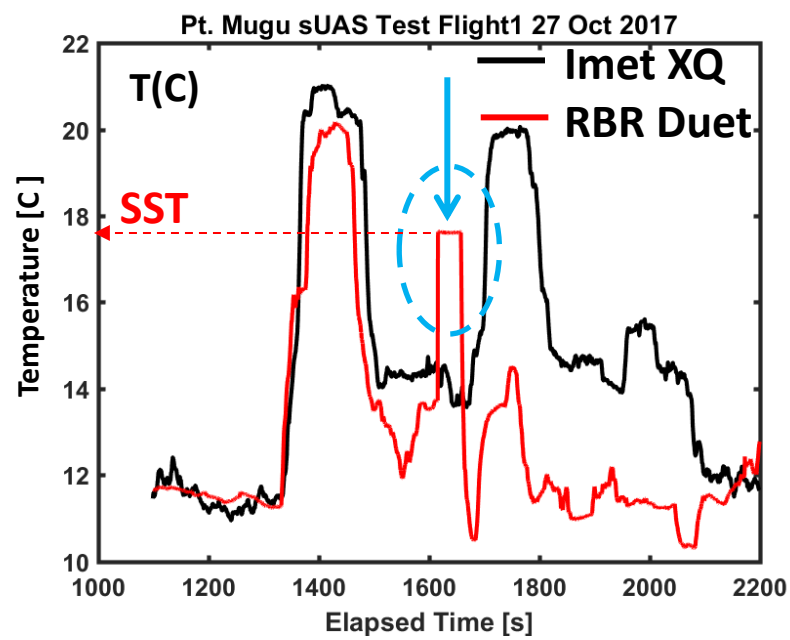




Initial Tests: Evaluating the Evaporation Duct Structure
CASPER-WEST (2017): Test Flight 1

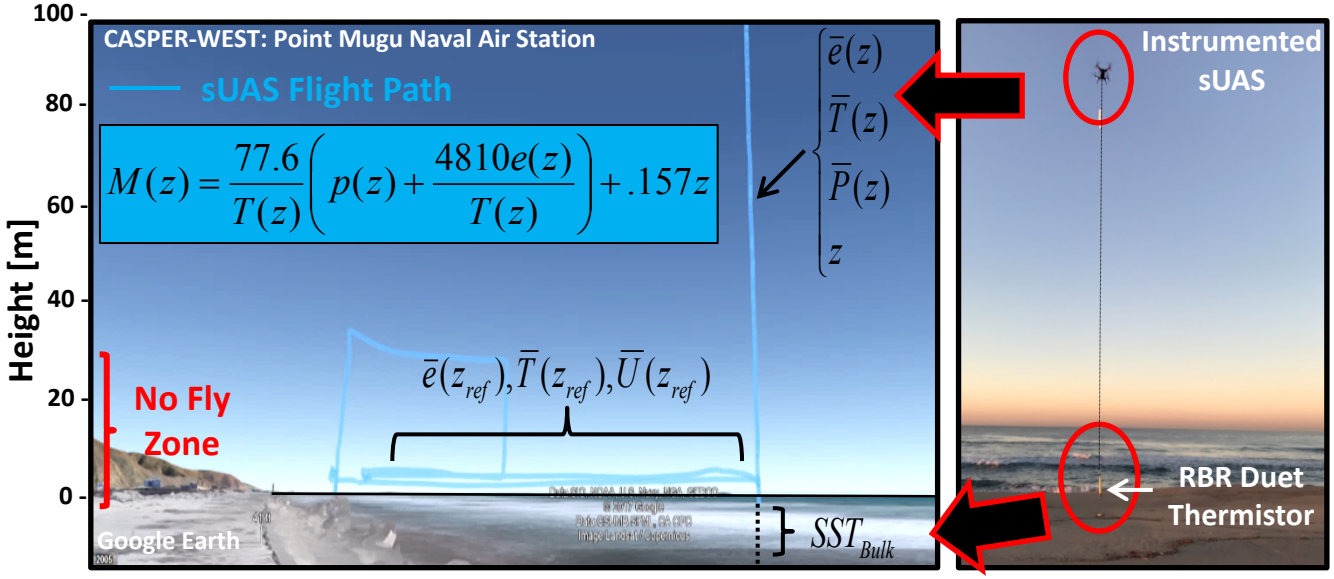


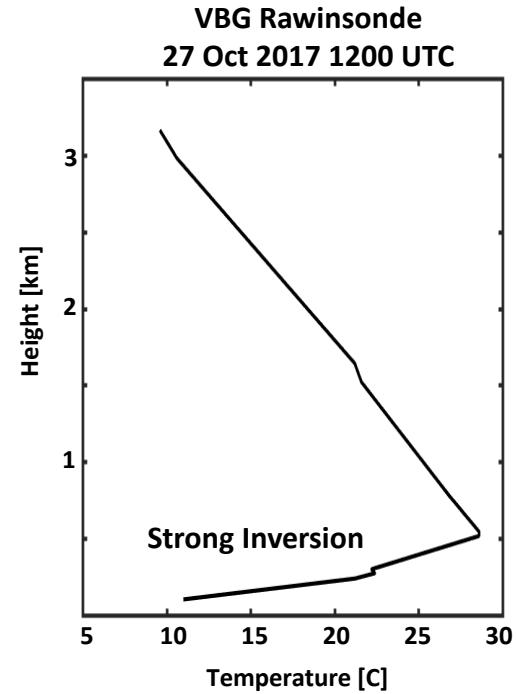




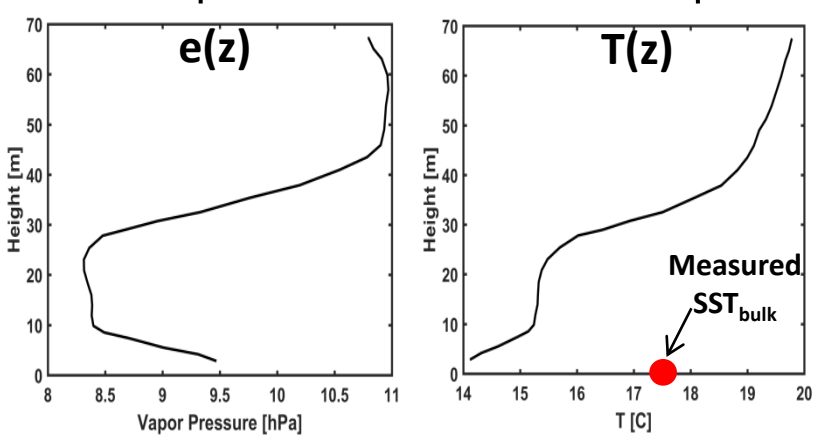
Initial Tests: Evaluating the Evaporation Duct Structure

CASPER-WEST (2017)

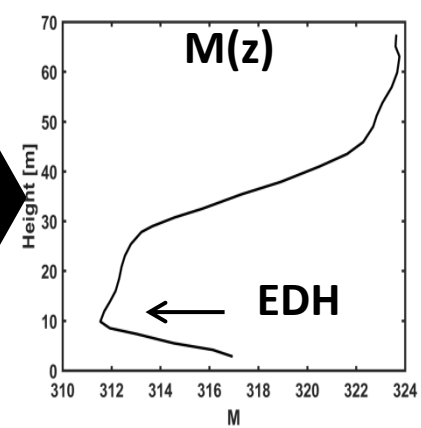


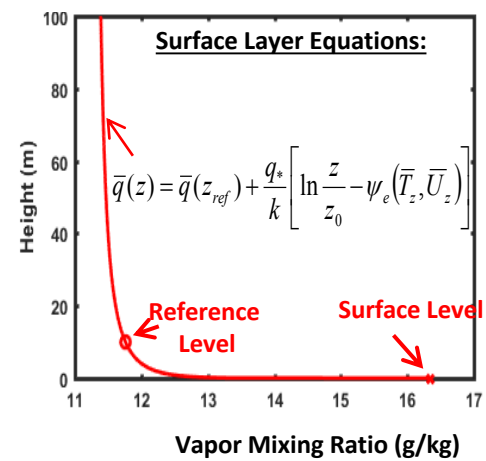


sUAS-Derived Observations



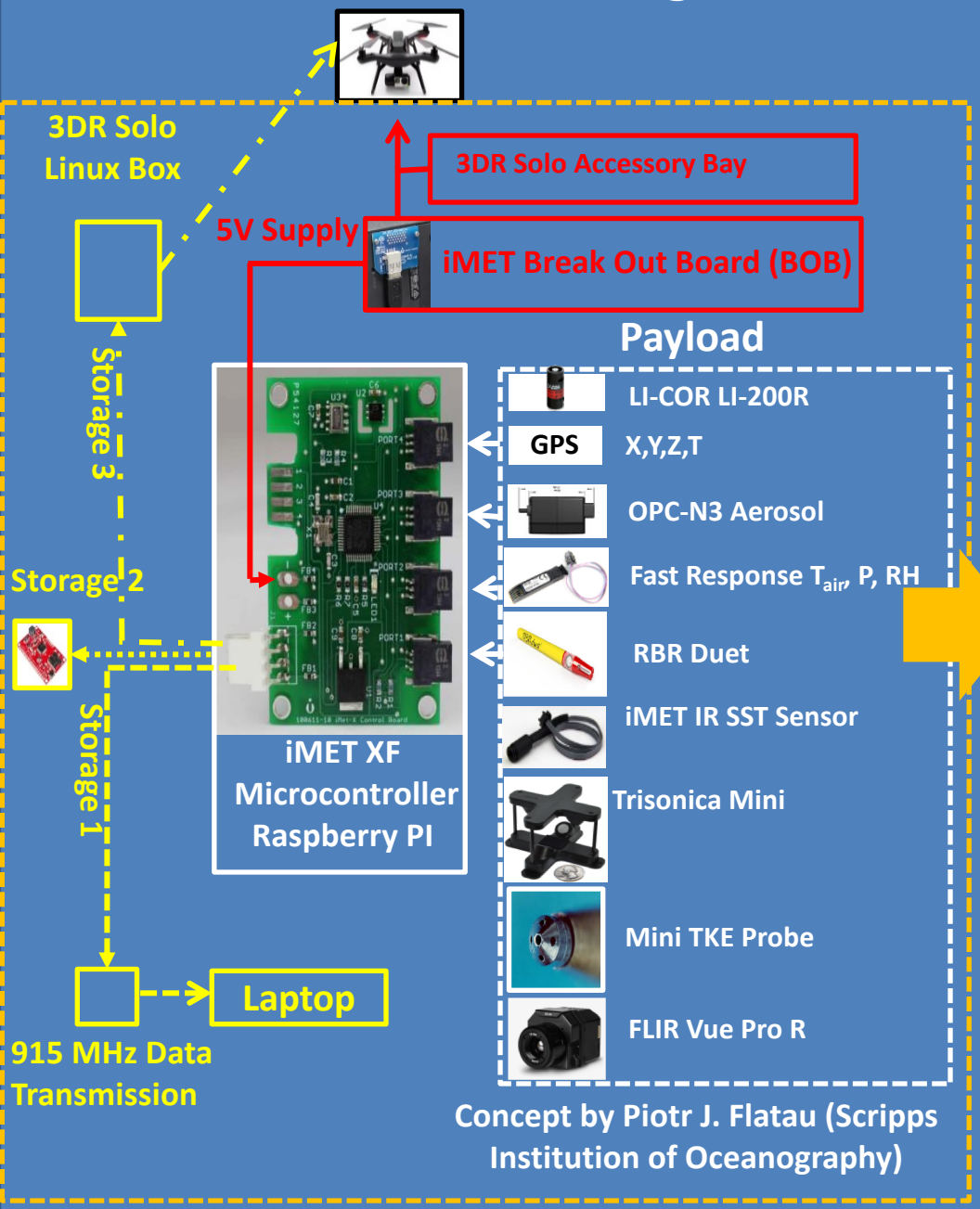
Derived M-Profile





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

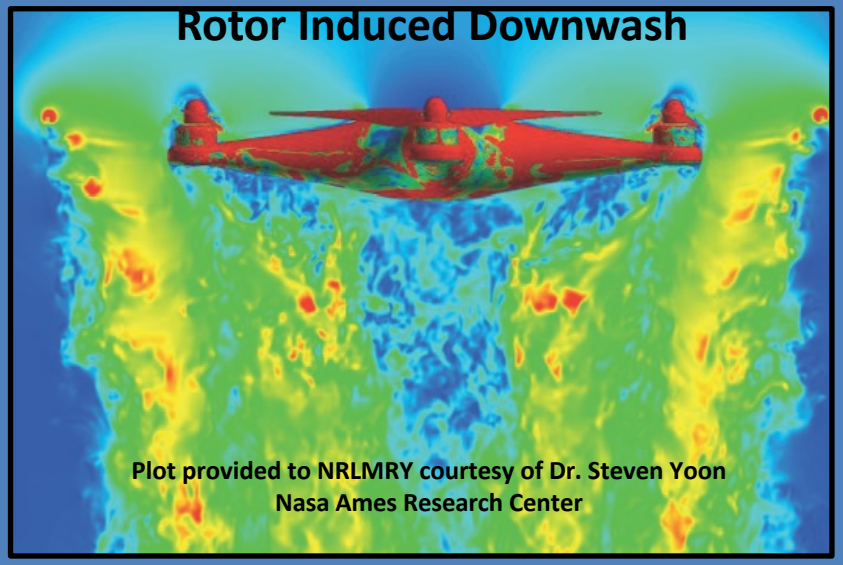


Concept by Piotr J. Flatau (Scripps Institution of Oceanography)

Commercial sUAS Candidates

Others?

Instrumental Payload Placement & Calibration Experiments
The NRL Laboratory for Autonomous Systems Research (LASR)



Science Questions Addressed at the NRL LASR Facility:

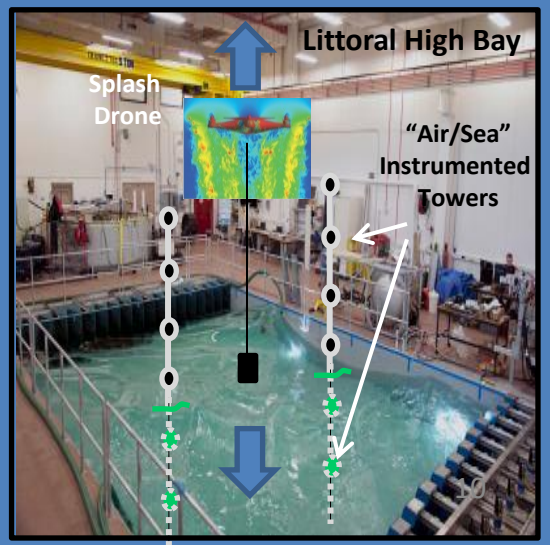
- What is the optimal placement of the payload on a quad-based sUAS?

- 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?

NRL Laboratory for Autonomous Systems Research (LASR)



Evaporation Duct Structure Measurement Strategy

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?

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

Required Inputs:

q_* & z_0	[Parameterized]
P, T, q, & U	[Reference Level]
P, SST, q_{sea}, U	[Ocean Surface]

SUMMARY

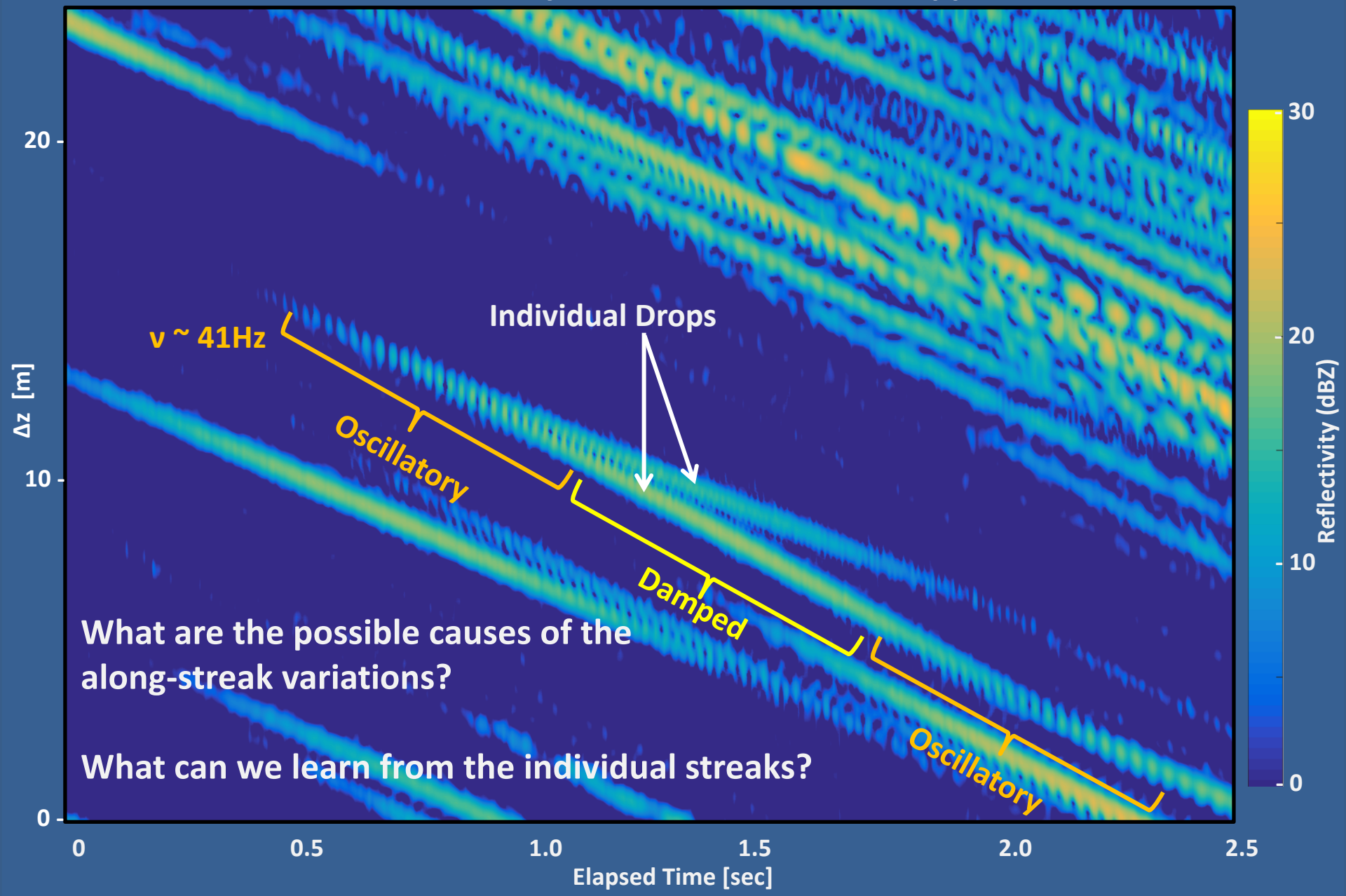
- NRL has developed a Mobile Cloud Observing Facility to promote cloud research studies:
  - Access to the high-resolution MCR C-band Doppler Radar (Raindrop Detection)
  - Ka-Band Scanning Doppler Radar
  - Microwave Radiometer
  - Ceilometer, All-Sky camera,Disdrometers, Rawinsondes
  - *Instrumented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

- 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

- 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

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?