Optical Turbulence and Mean Meteorological Measurement Capabilities for Small UAS Penguin

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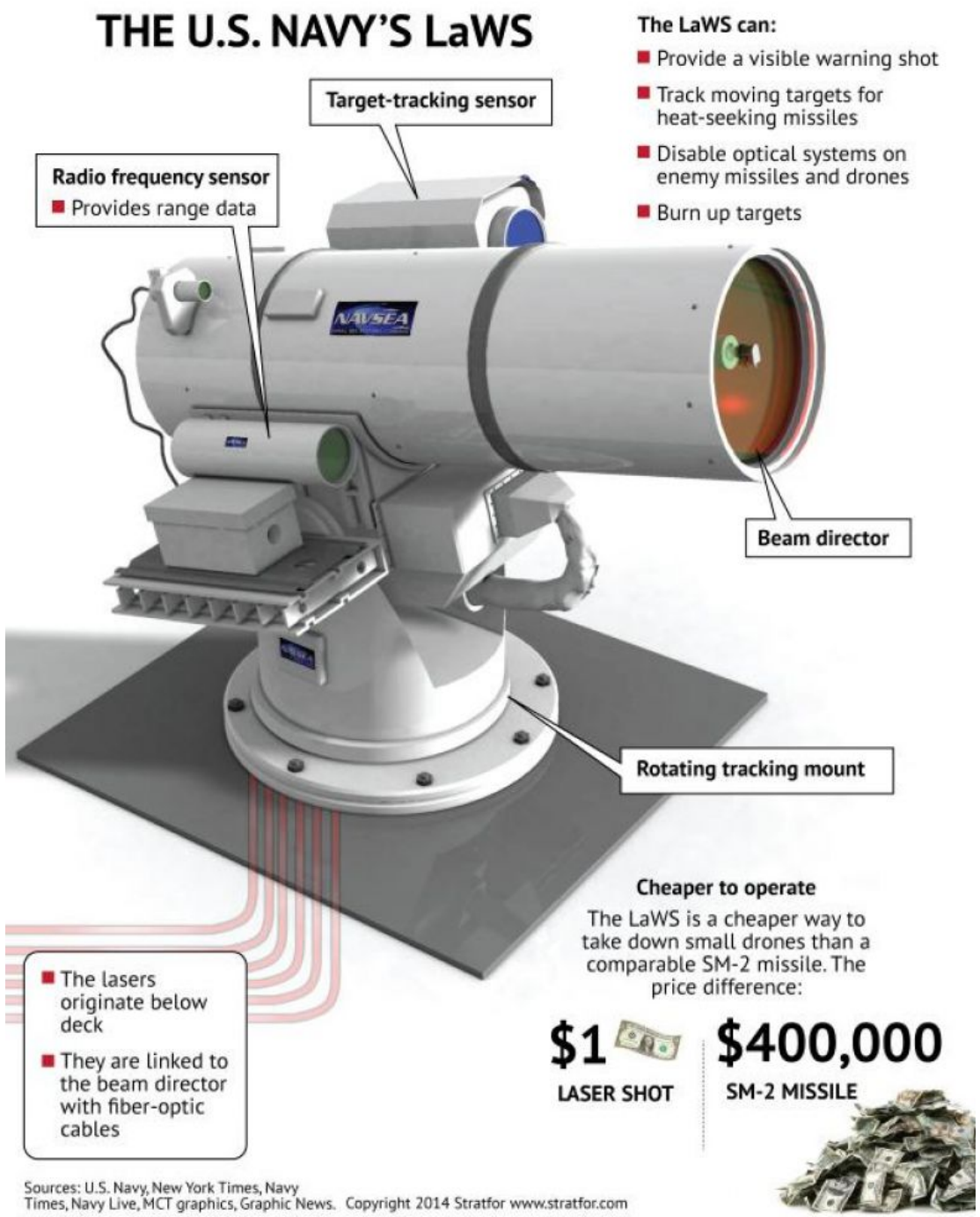
(Based on the thesis work of Lee Suring).

DoD Interest in Electro-Optical Systems

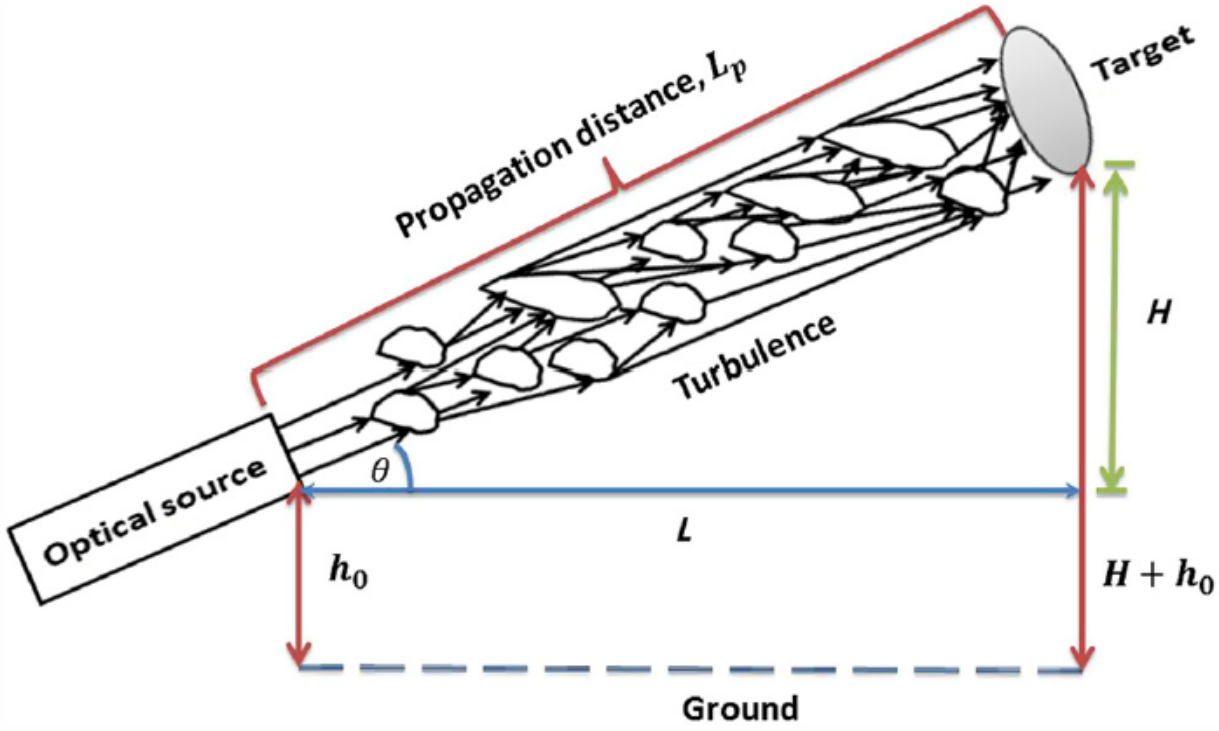
UAV, UAS, artillery and mortar defense capabilities

Navy’s XN-1 LAWS



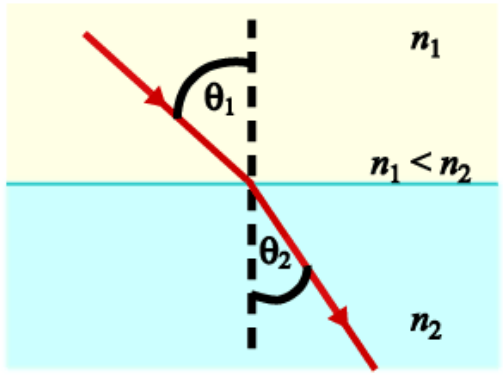
Electro-Optical Hurdles

- Electro-optical (EO) wavelengths are affected by small-scale variabilities in atmospheric refractivity
- Atmospheric boundary layers have significant turbulence and refractivity gradients which cause scintillation (defocus)
- Aerosols in the atmosphere also result in scattering and absorption, and hence attenuations of laser beams

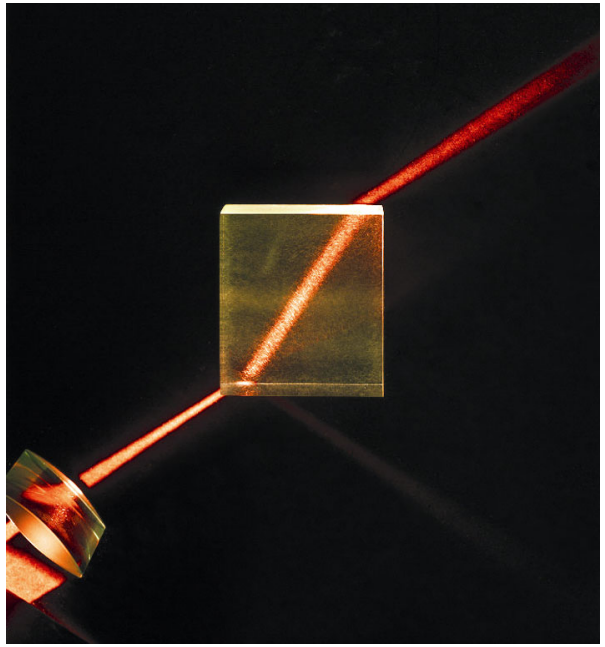


Background

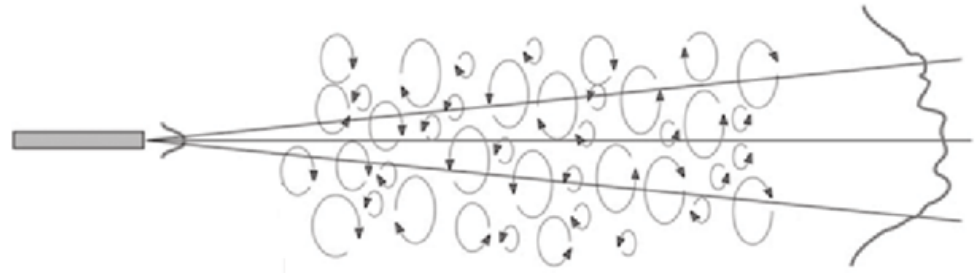
- Refraction of light
- Meteorological measurements can be used to characterize optical propagation conditions
- Data collection needs to be at a significantly high sampling rate in order to capture the small scale eddies affecting optical propagation



$$\frac{\sin\theta_2}{\sin\theta_1} = \frac{v_2}{v_1} = \frac{n_1}{n_2}$$

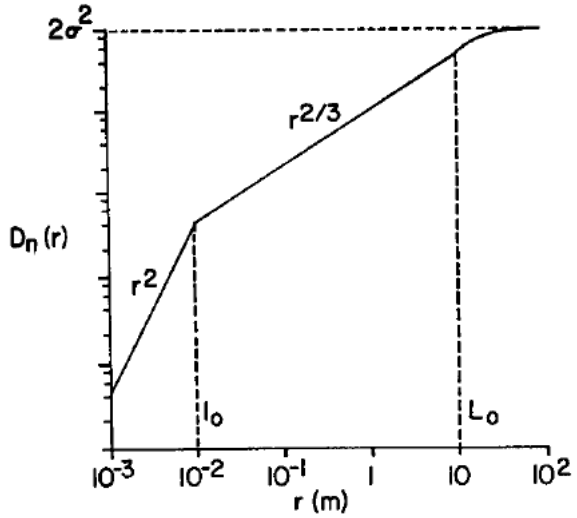


$$n = 1 + 10^{-6}\{m_1(\lambda)\frac{P}{T} + [m_2(\lambda) - m_1(\lambda)]\frac{qP}{T\varepsilon\gamma}\}$$



Background

- Optical propagation is most significantly affected by turbulence eddies in the inertial subrange
- To resolve the small scale eddies in the inertial subrange, high-rate sampling of relevant variables is needed
- Turbulence structure parameter, C_n^2, is used in optical propagation models to describe the magnitude of atmospheric scintillation
- Temperature perturbations affect scintillation the most



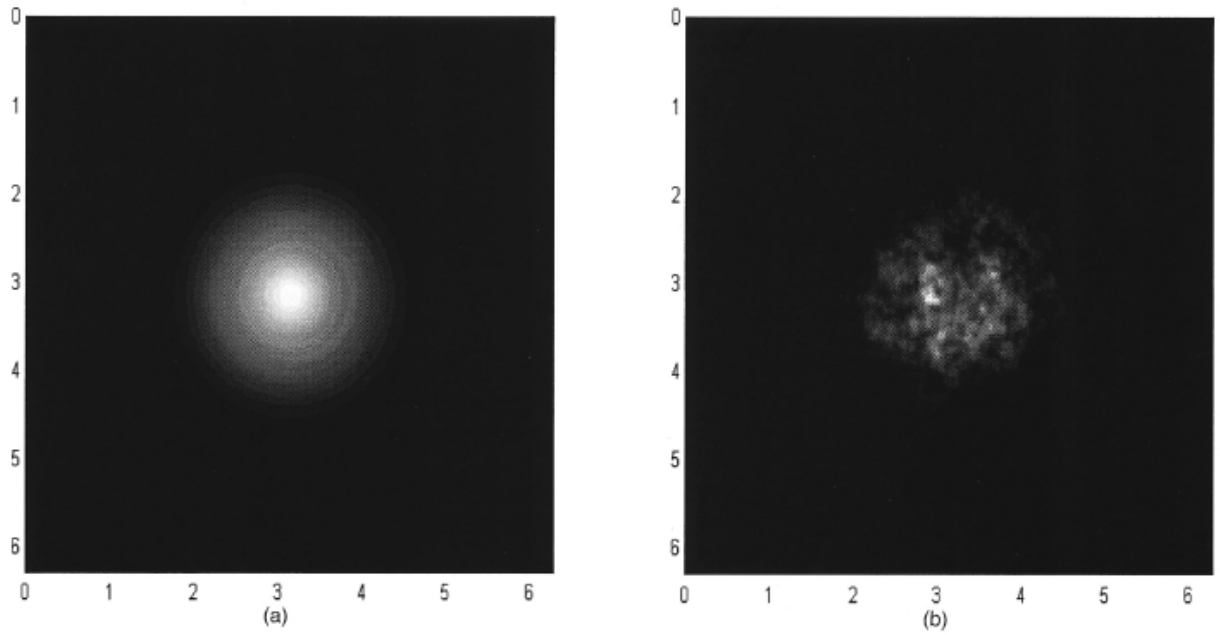
$$<[T'(x)-T'(x+r)]^2>=C_T^2 r^{-2/3}$$

$$C_n^2 = \boxed{B_1 C_T^2} + B_2 C_{Tq} + B_3 C_q^2$$

Background

- Scintillation can distort beam and degrade “power in bucket” at the target

10.6-μm laser beam @ 7300m 3m above the ground



(Don Walters 2000, NPS)

(a) Zero turbulence
(b) Uniform turbulence of $C_N^2 = 10^{-14}\ m^{-2/3}$

Research Objectives

- Increase data for model evaluation/improvement
- Collect data above the levels of surface towers
- Collect data to account for strong spatial and temporal variations in environmental propagation
- Test the feasibility of small and low-cost meteorological sUAS platforms for supporting operations of directed energy weapons

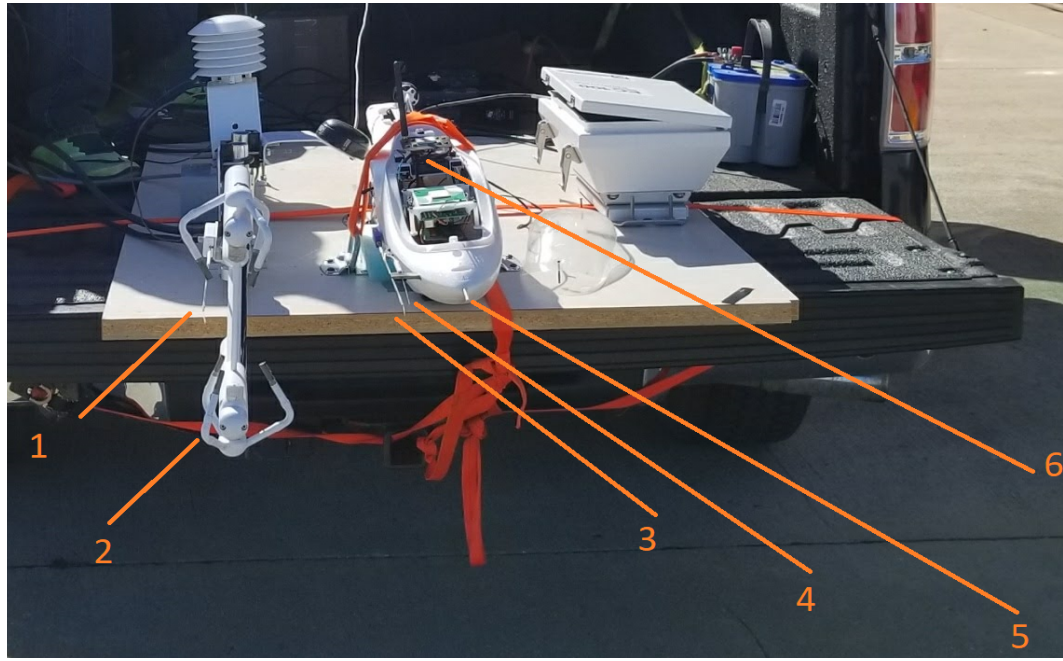
NPS Penguin sUAS

- Airframe: Finwing Penguin developed for FPV flying
  - Large payload bay
  - Push propeller
  - Modified engine and payload bay
- Instruments onboard
  - iMet radiosonde package modified to self-record basic meteorological parameters (GPS, temperature, pressure, and humidity)
  - iMet-XQ mean meteorological sensor package specifically designed for fixed wing UAVs
  - Pitot tube
  - Pixhawk (GPS & Autopilot)
  - Fine-wire thermocouple for temperature perturbations
  - Platinum temperature sensor for reference temperature

Sensor Package Ground Evaluation

Truck-bed testing, Marina Airport

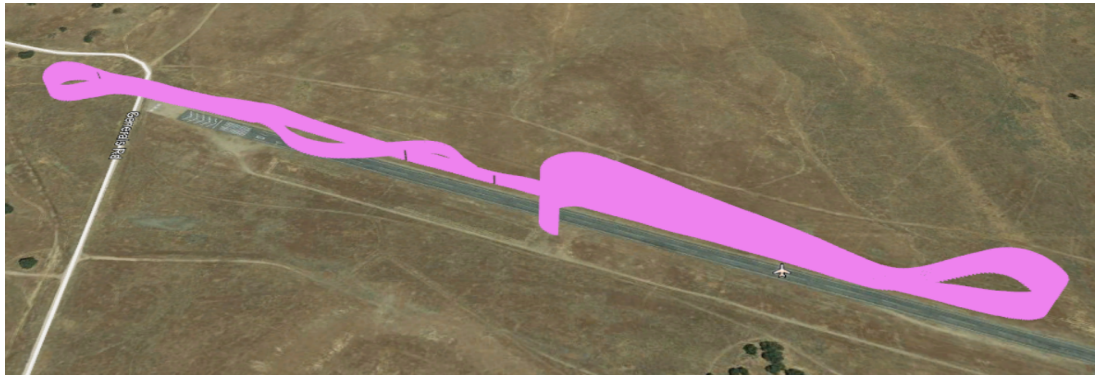
- Instrumented NPS Penguin vs sonic anemometer + gas analyzer + thermocouple and standard data acquisition system
- Data collection at variable backward driving speed



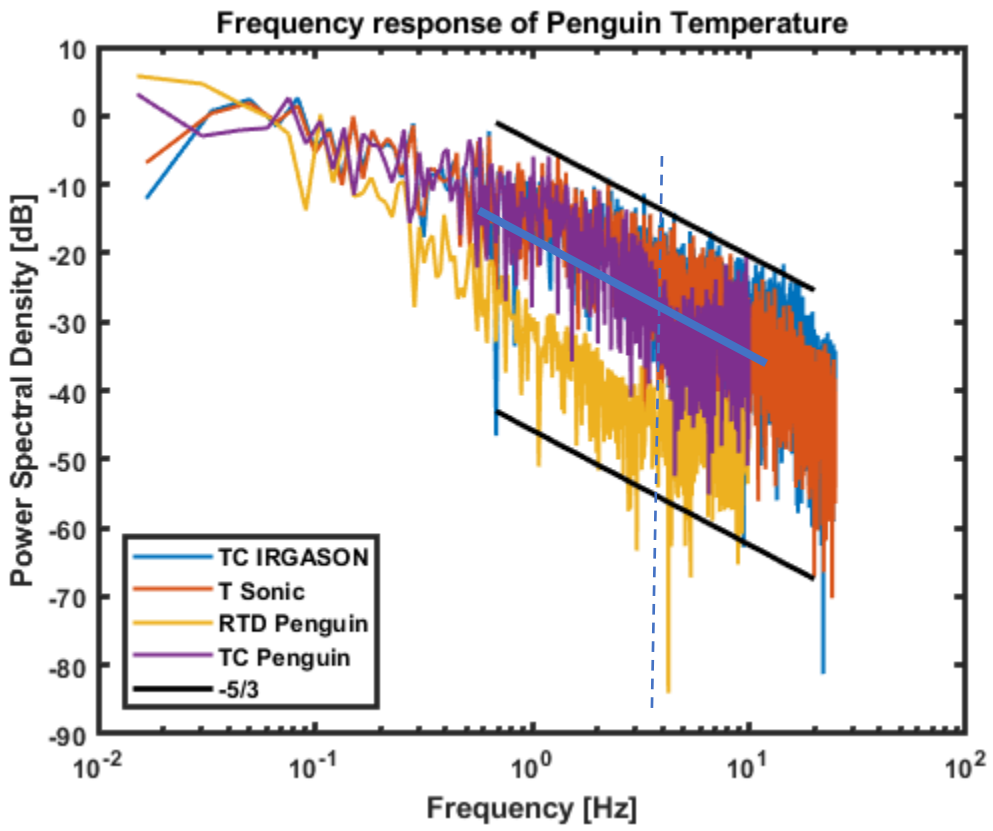
1. Clean air Thermocouple 10Hz sensor (.001”)
2. Sonic Anemometer
3. Airframe Thermocouple 10Hz sensor (.001”)
4. Airframe Pt100 RTD (.02”) Platinum temperature sensor (mean temperature)
5. Pitot Static Tube
6. Pixhawk
    - Mean wind speed (pitot static tube)
    - Wind direction
    - GPS coordinates

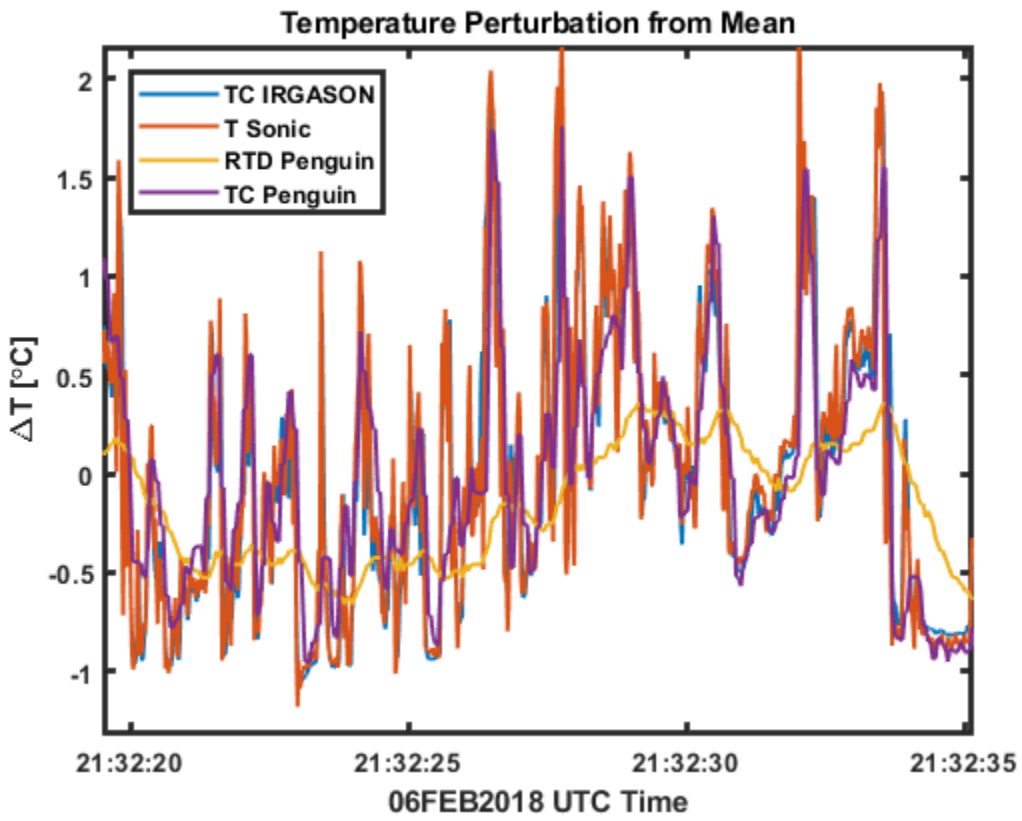
Camp Roberts (McMillan Air Field) Flight Testing

- Test 1: Nov 16, 2017
- **Test 2: March 26, 2018**
- Instrumented NPS Penguin
- Ground-based tower and tripod
- Side-by-side sampling

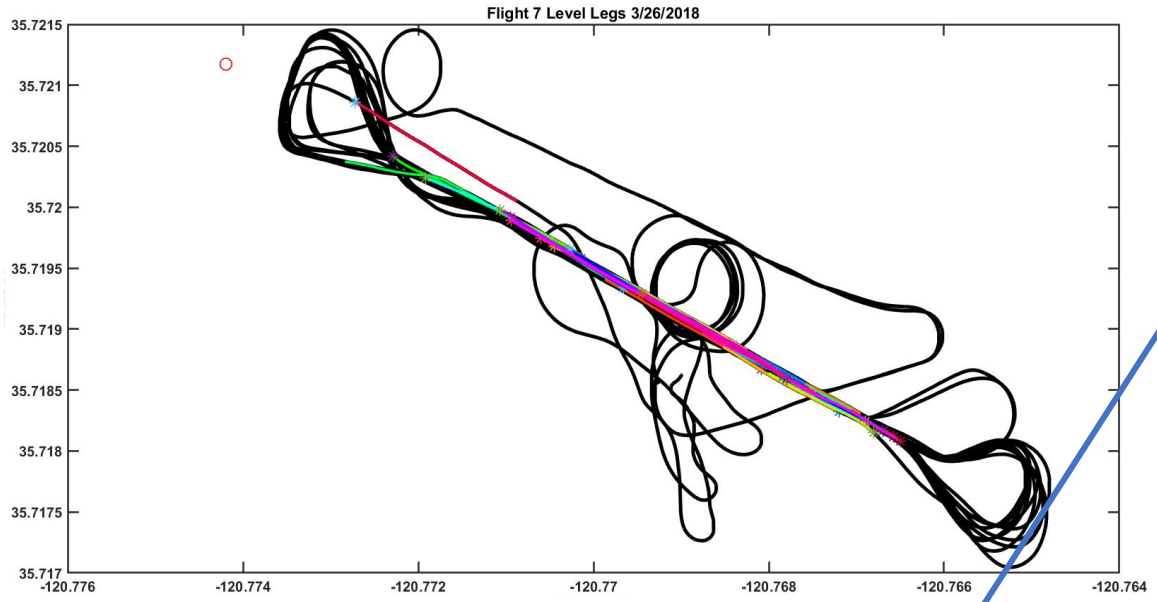


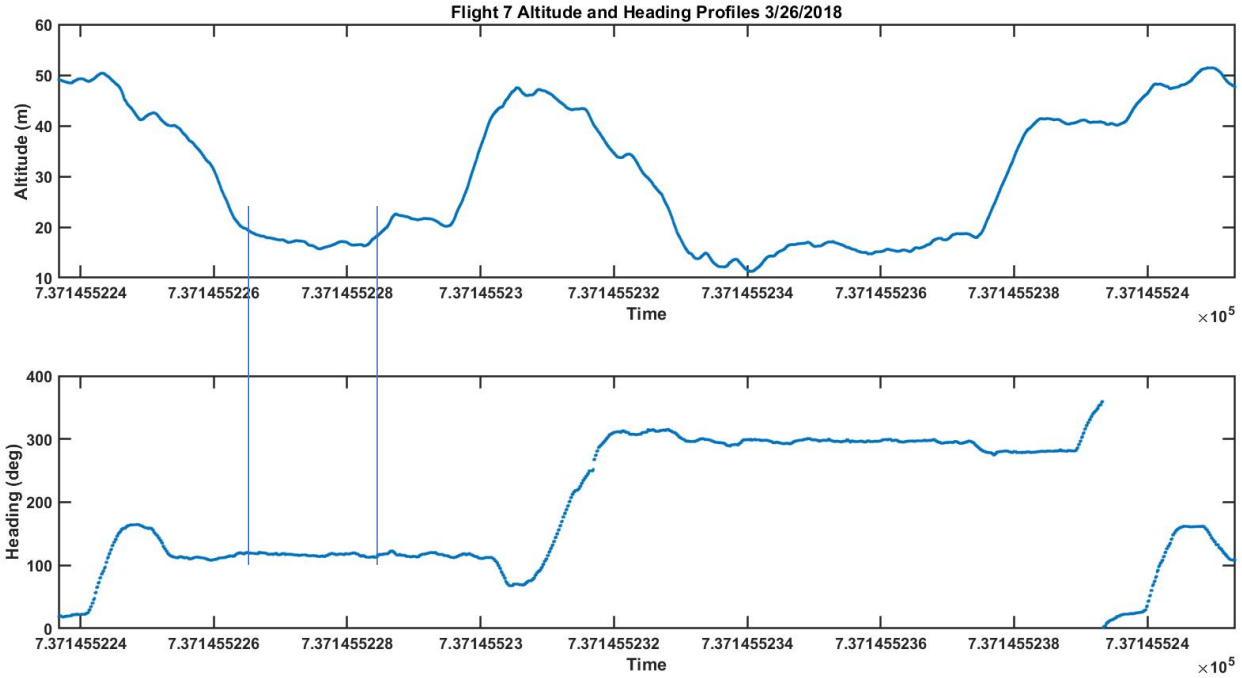
Example Results

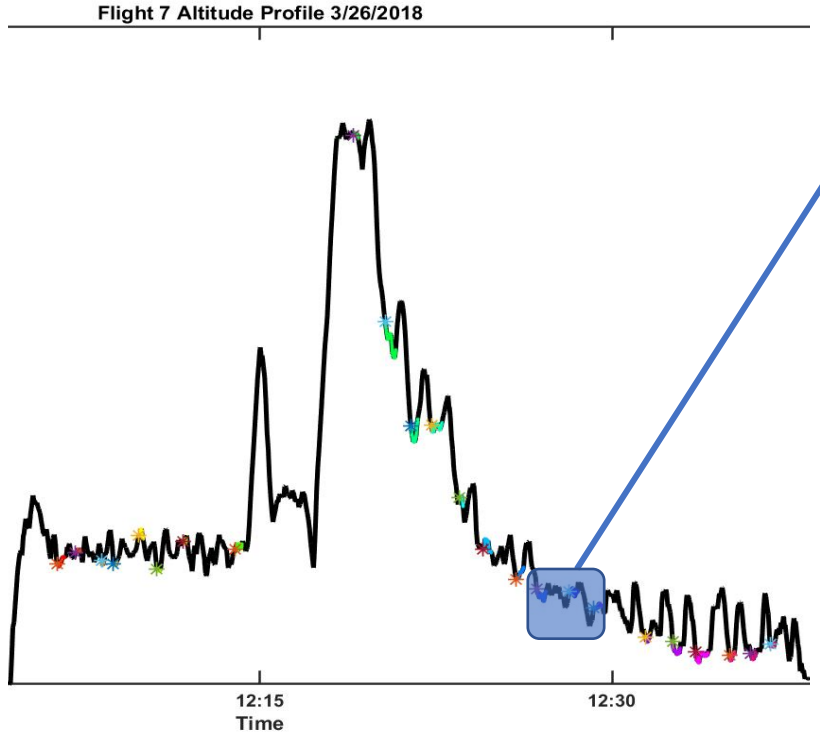




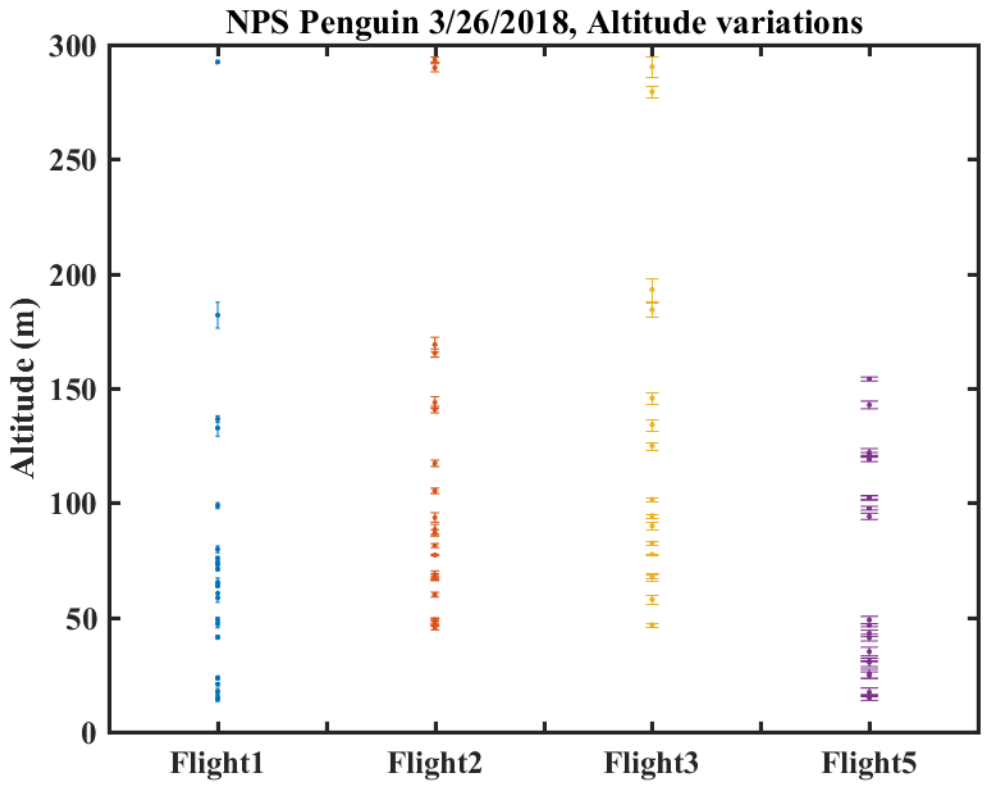
Marina CIRPAS Runway Testing

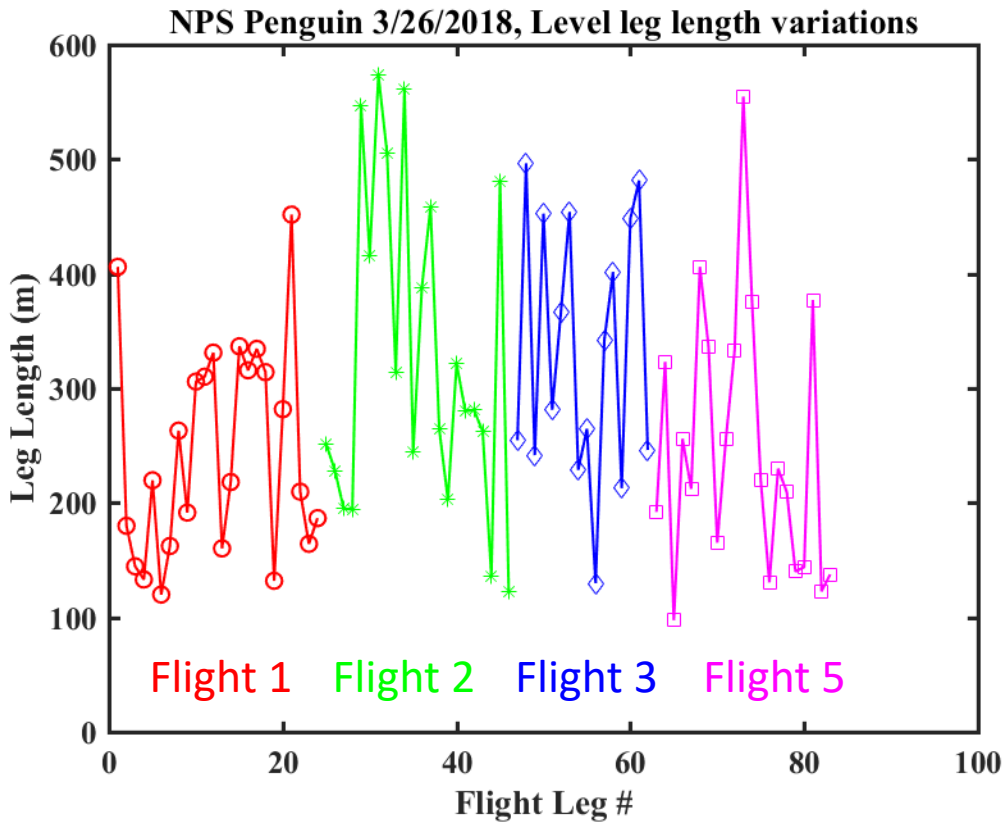




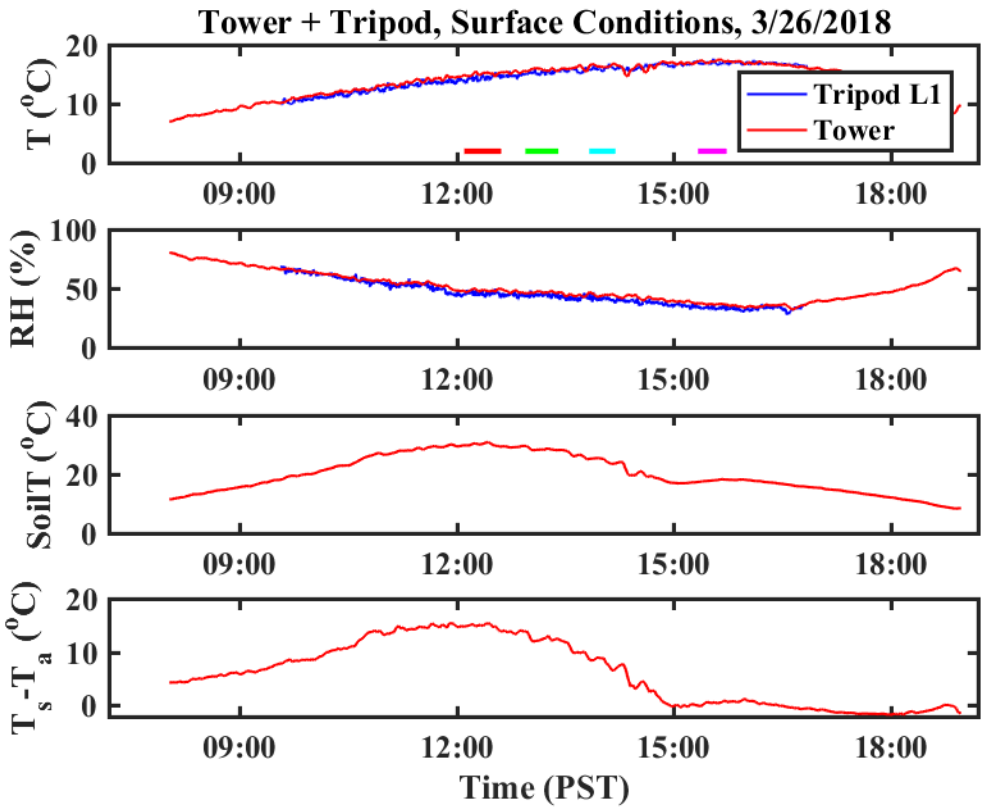


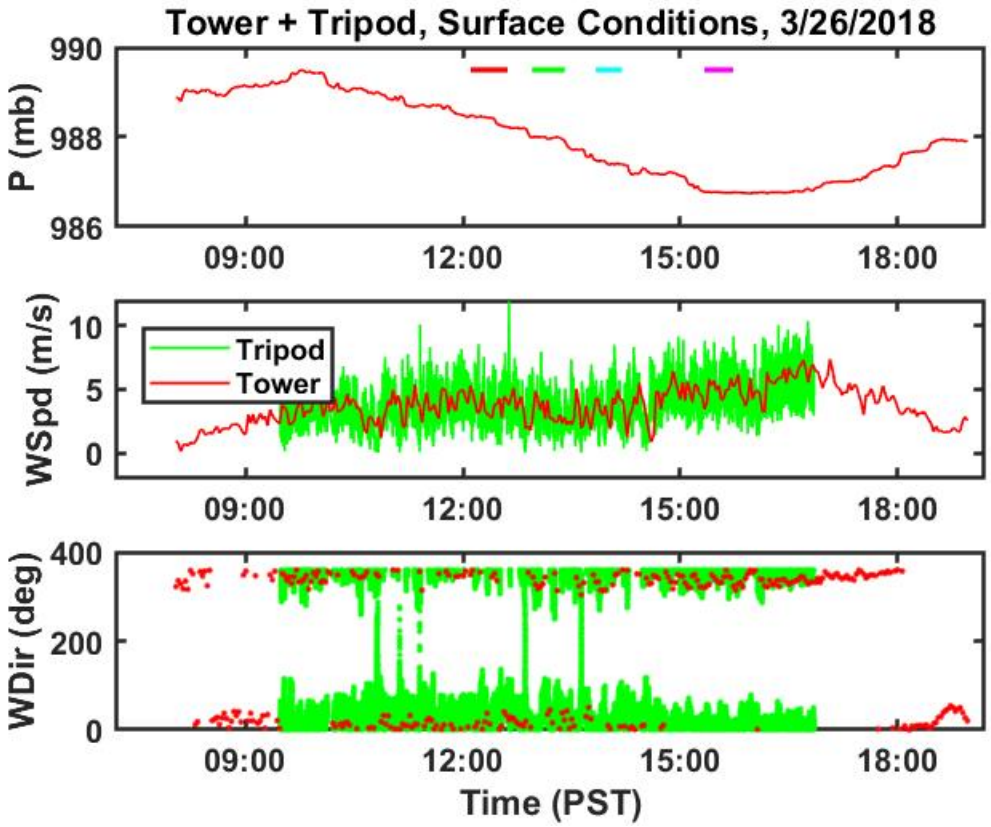
Sample Flight Run from 26 March, 2018 testing at McMillian Airfield





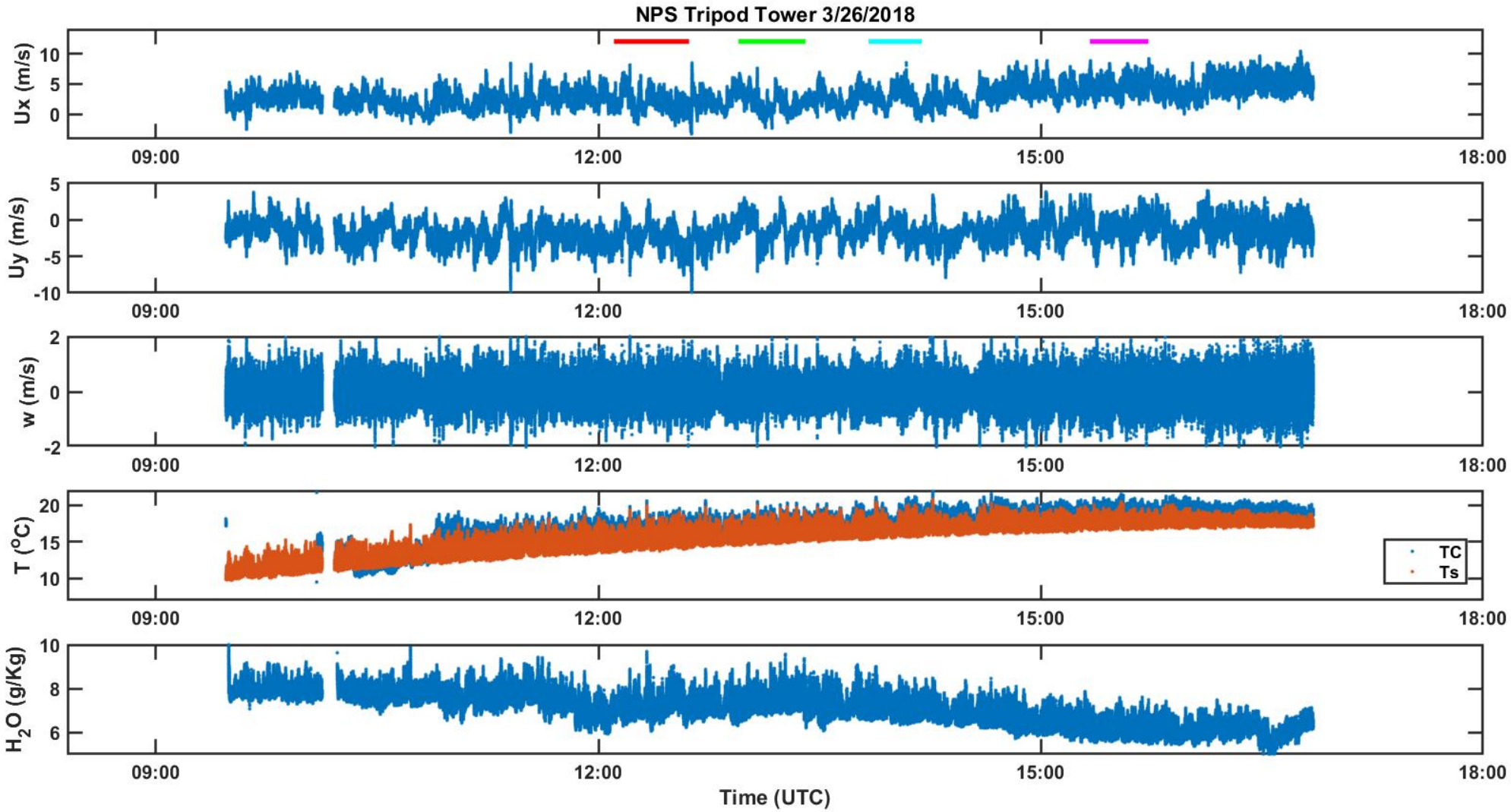
Flight leg variability

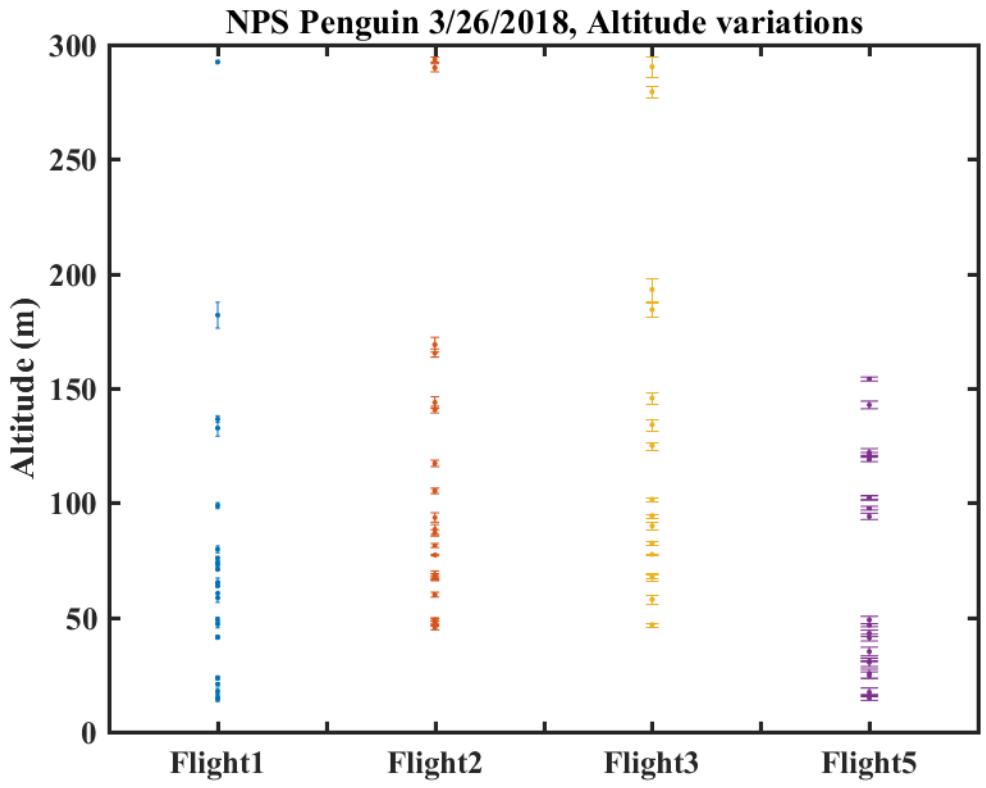


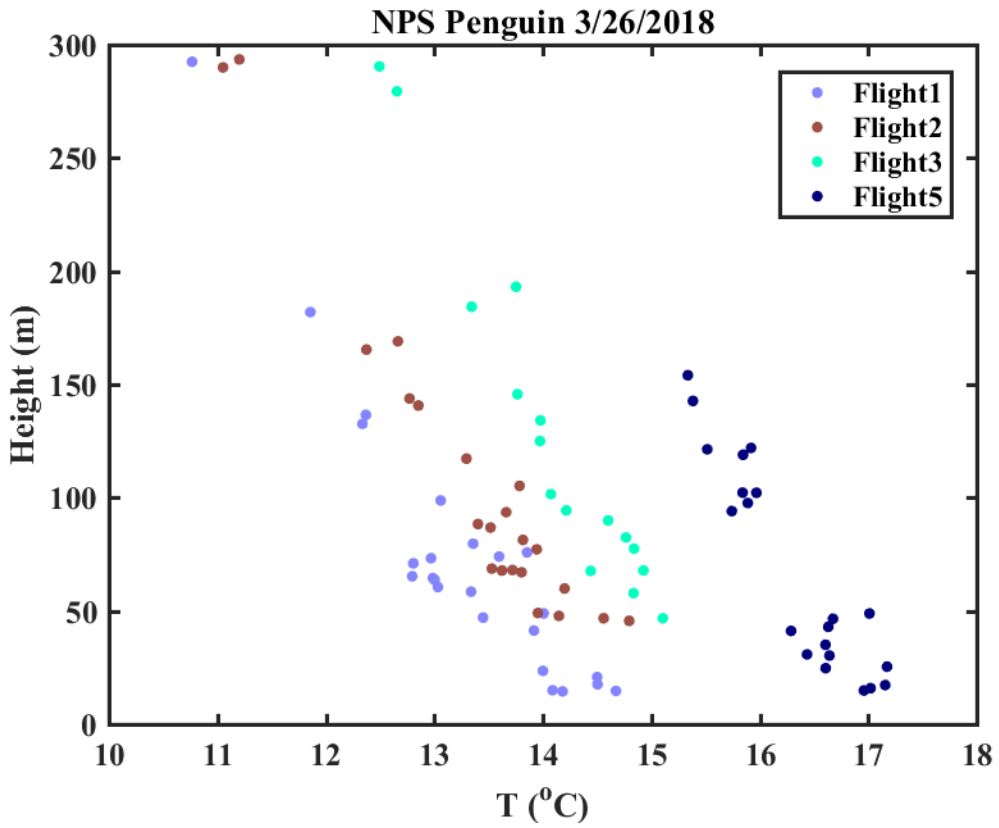


Variability of Mean Meteorological Conditions

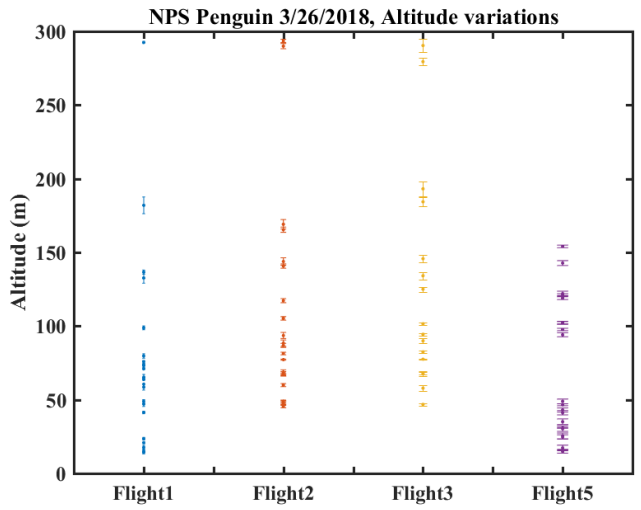
Variability of Turbulence Conditions

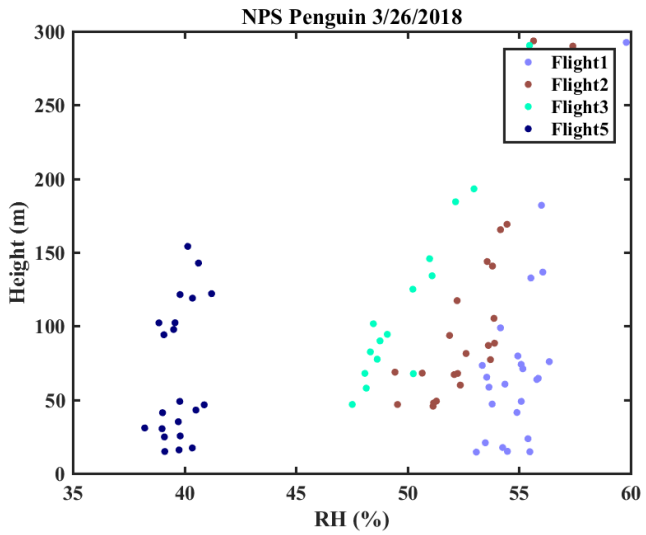


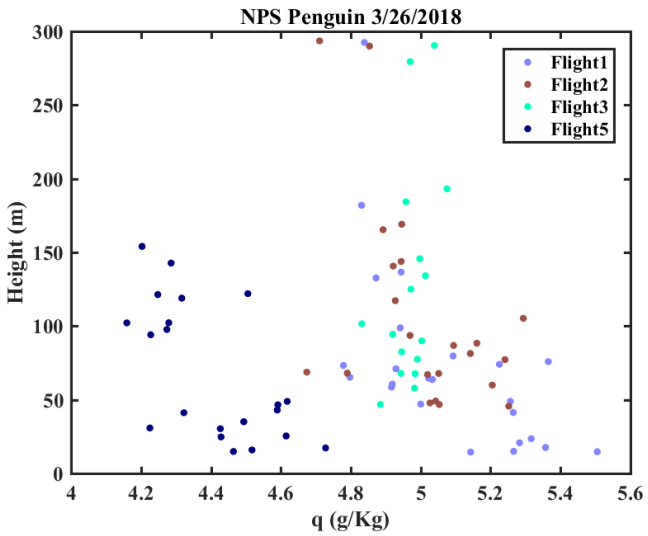




Mean Temperature Profile from sUAS

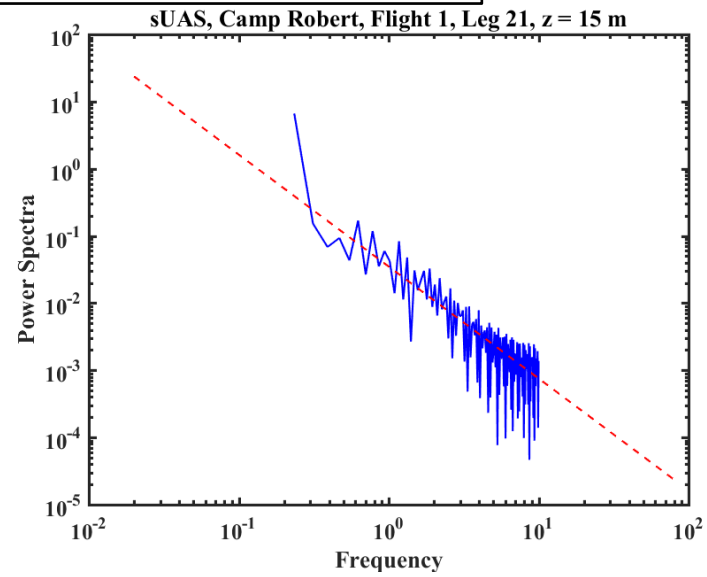


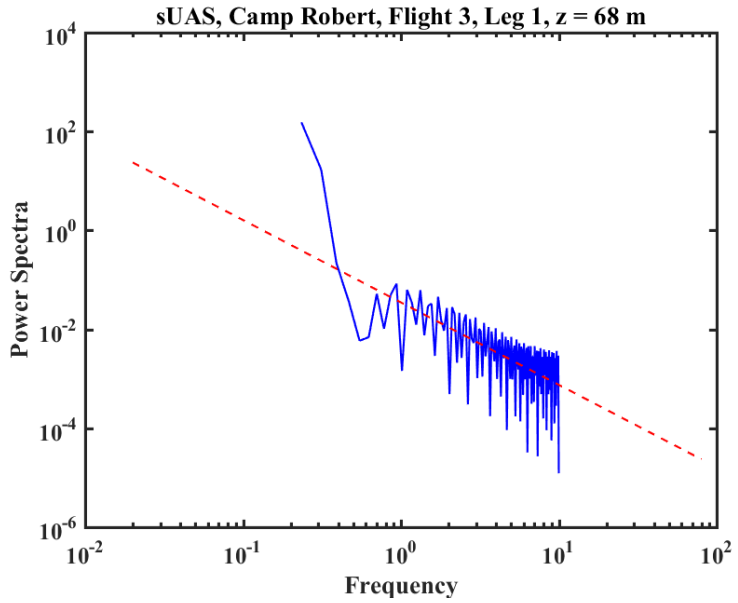


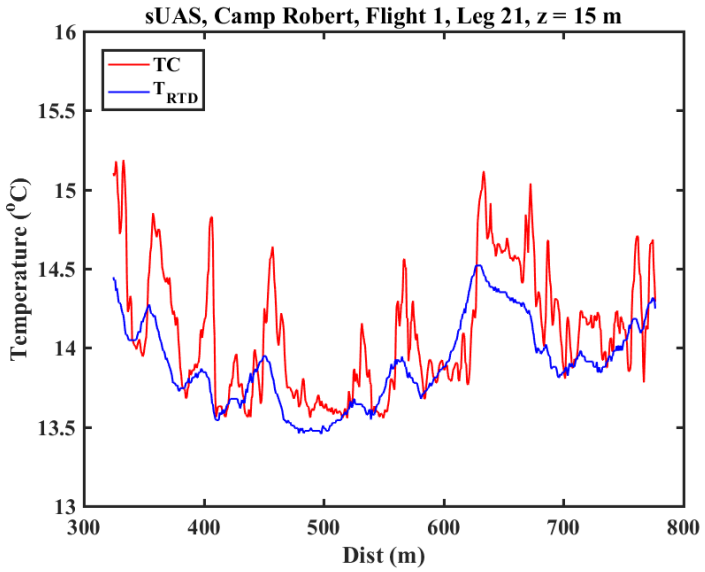


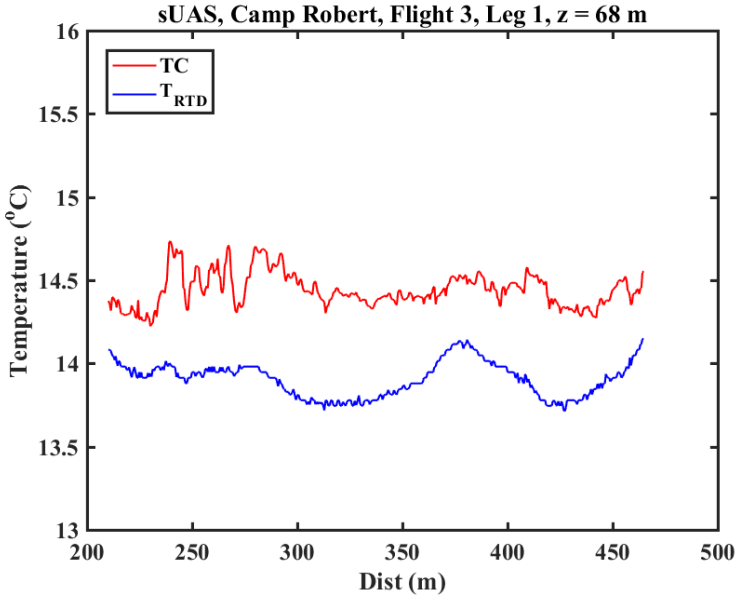
Mean Humidity Profile from sUAS

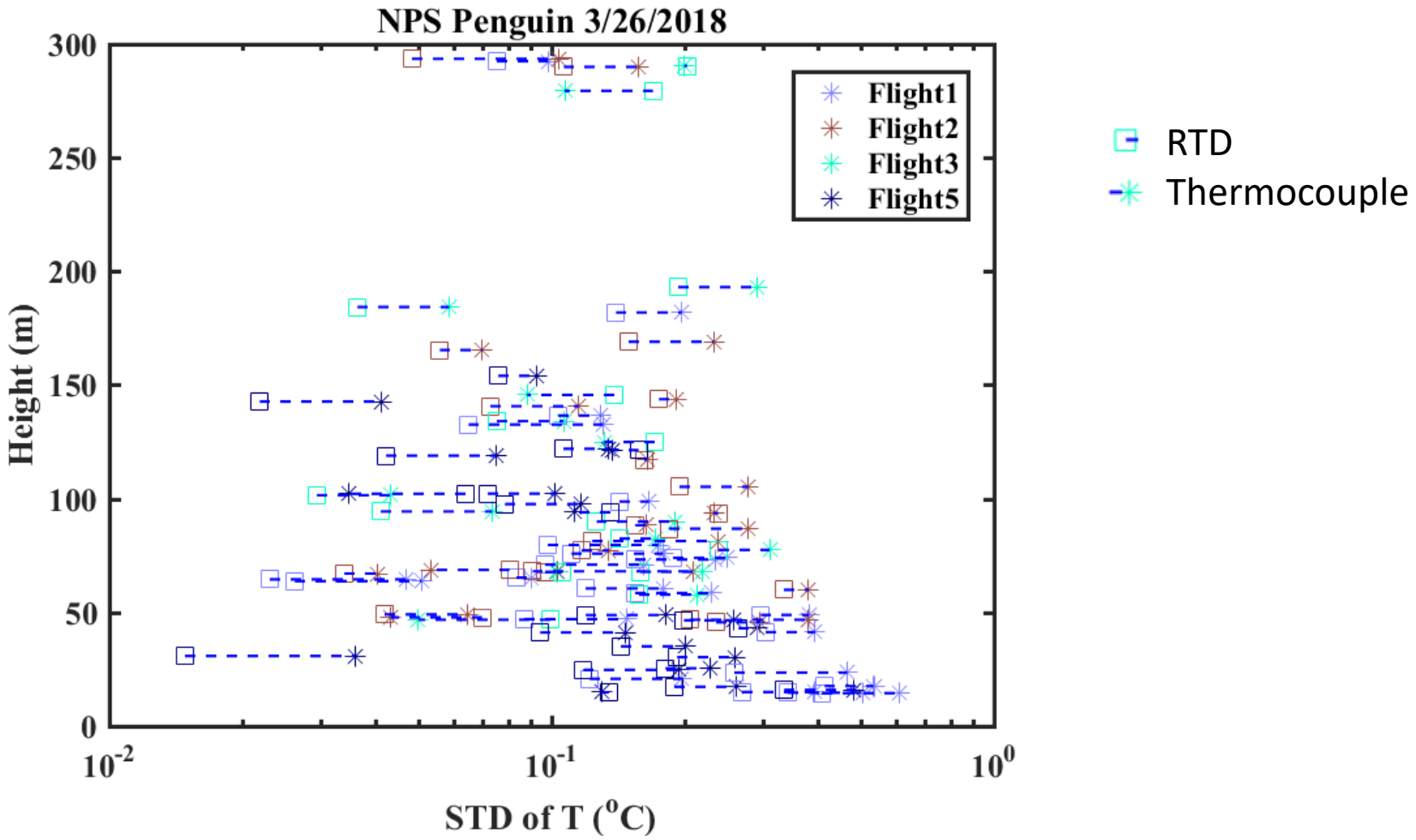
High-rate temperature measurement





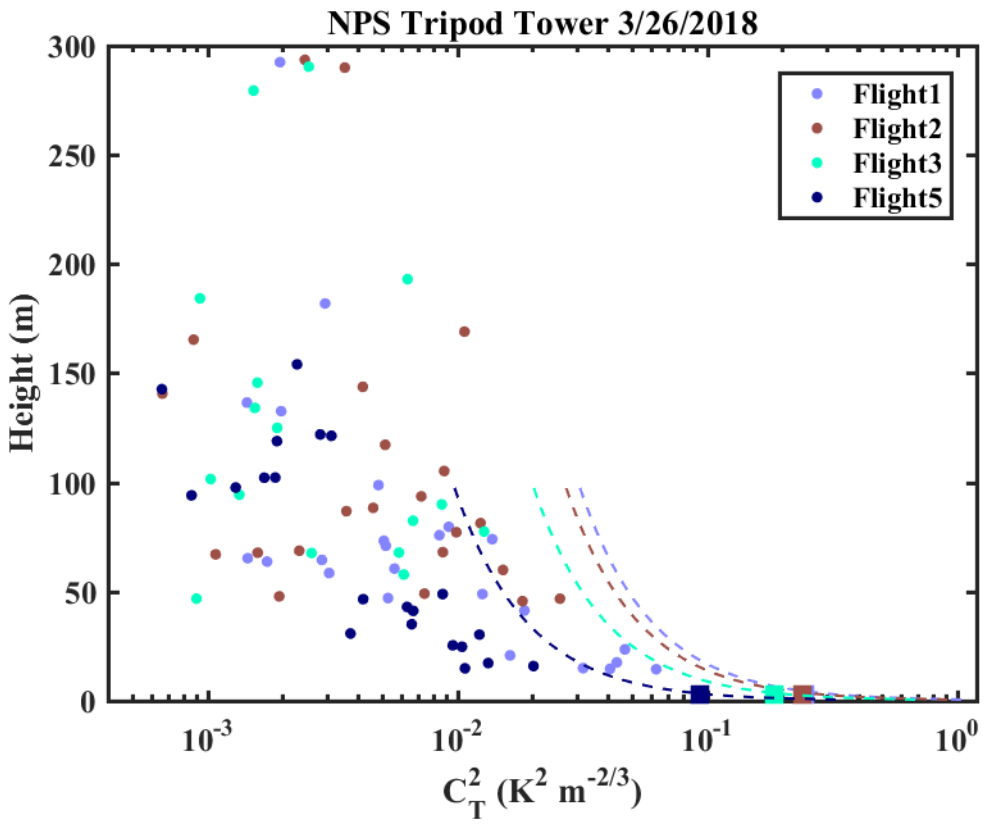


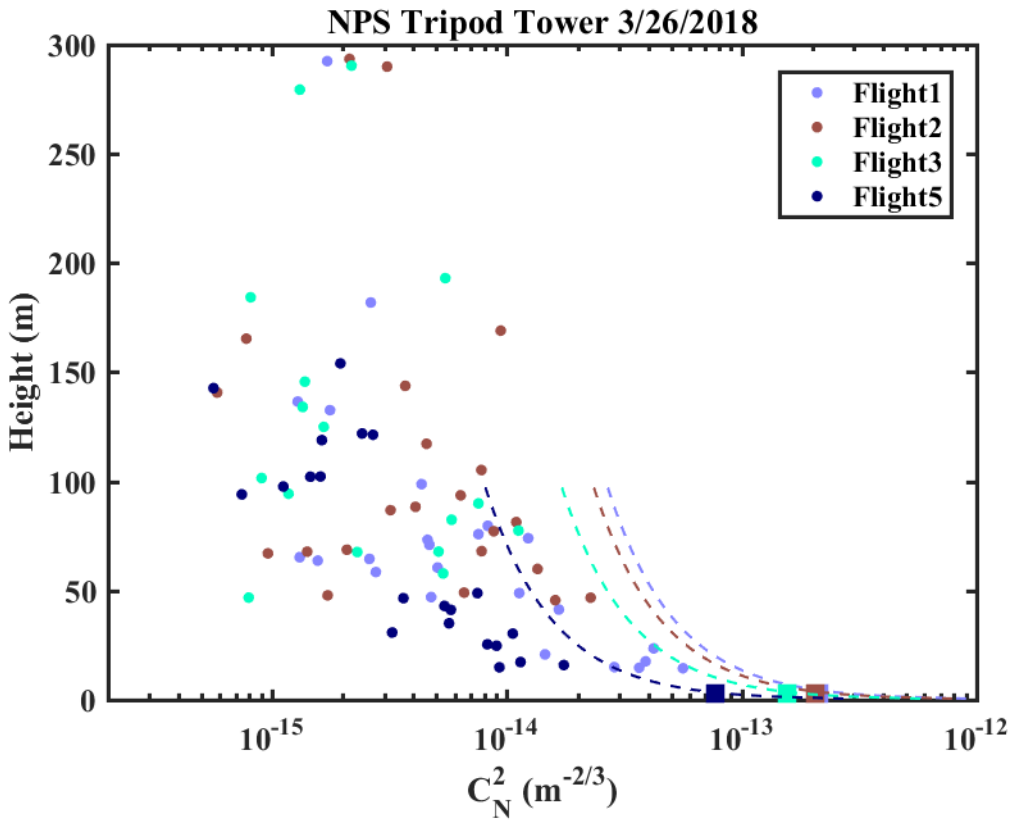


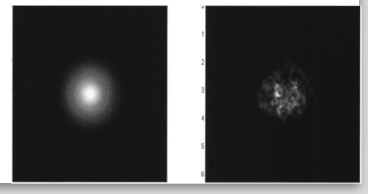


Spatial Variability of Temperature

Structure Function Parameter Profile

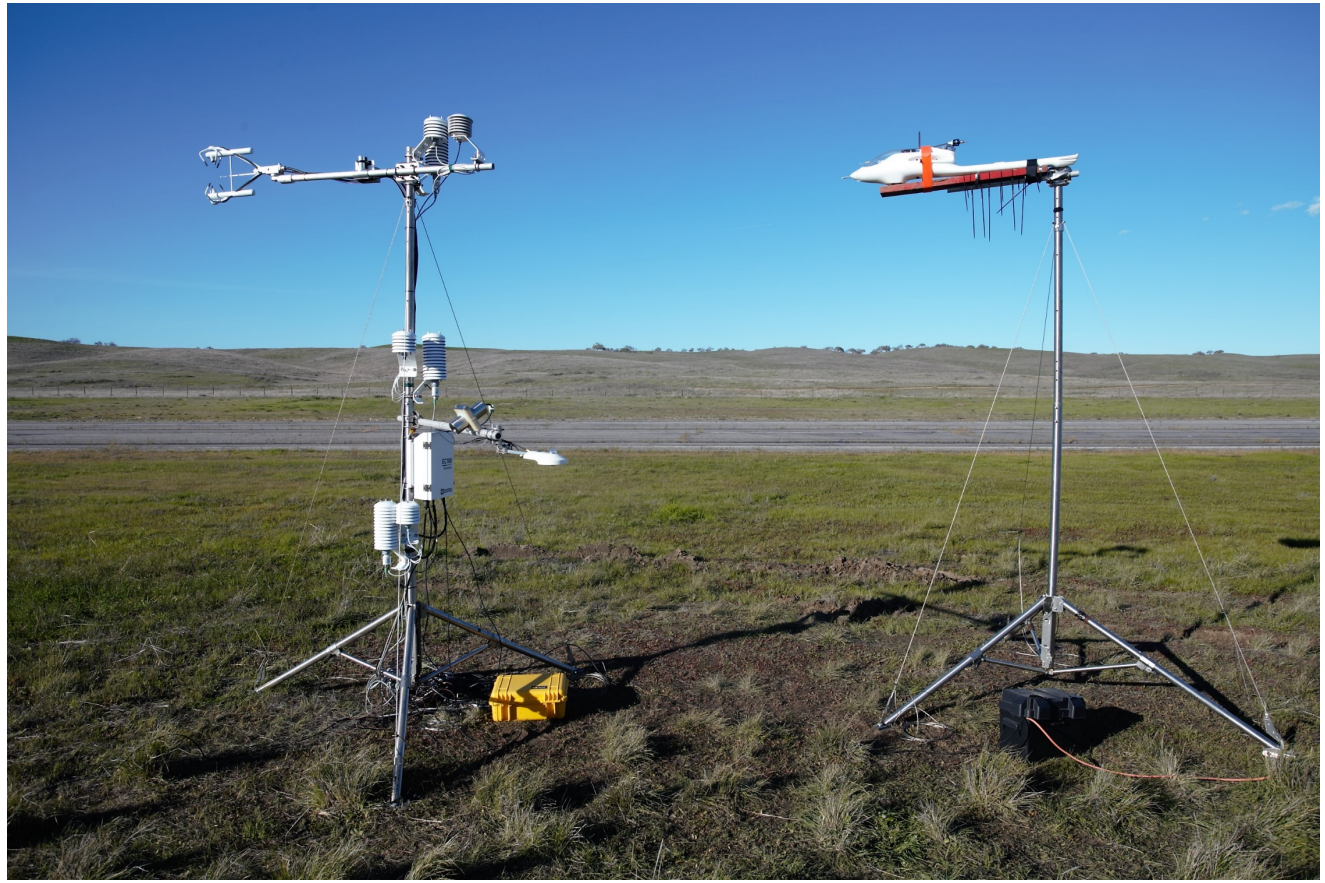






Summary and Conclusions

- Team conducted successful instrumentation and testing of NPS sUAS Penguin to support high energy laser weapon deployment.
- A low-cost, light weight, and low power consumption thermocouple was integrated onto the Penguin alongside mean meteorological sensors.
- Test flights at Camp Robert resulted in reasonable near surface mean and CN2 profiles.



Lessons Learned

- Longer level legs are needed to improve turbulence statistics
- Need to fine tune waypoint settings to ensure level flight legs at constant flight altitude
- Higher sampling rate temperature sensors are desired to reveal more details of optical turbulence

Future Research

- More test flights in different meteorological conditions
- Flight in coastal and marine environment
- Use of higher rate fine wire temperature probes to sample down to millimeter eddies
- Explore 3-D turbulence measurements from the Penguin
- Quadrotor flights
- Autonomous and ship launching and landing

Research Sponsors:

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NPS Naval Research Program (NRP)

Thank you!