NOAA UAS Research and Technology Program moving research UAS platforms into Operations

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Boulder, CO

The Cast of Characters

Co-Investigators

Ed Dumas, ORAU

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Collaborators

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George Matthews, NOAA/NWS MIC Morristown WFO

Joe Cione, NOAA/AOML

Mark Rogers, OMAO/AOC

Test Facility Objectives

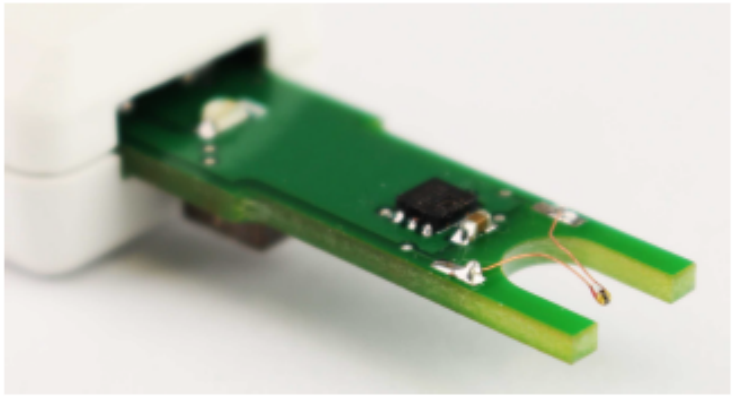
- Evaluate, test, calibrate, and validate UAS payloads: The Test Facility Approach.
- Project Goal: to develop a UAS test facility to validate, integrate, calibrate, and evaluate new technology and sensors for routine boundary layer research, validation of operational weather models, improvement of model parameterizations, and recording observations within high-impact storms.

How do we do this??

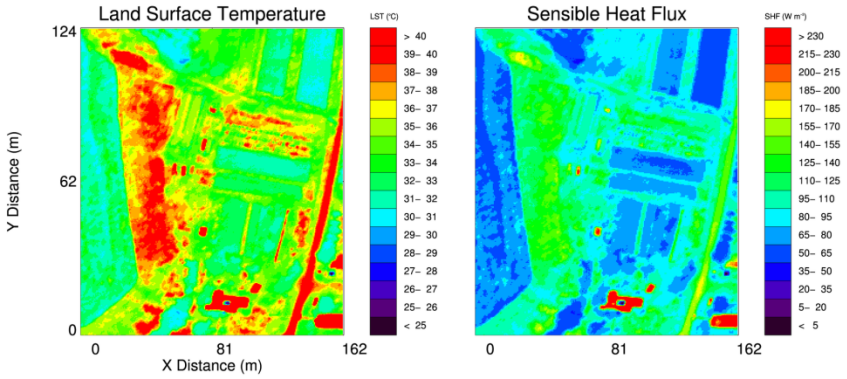
1. Evaluate meteorological sensor sUAS payloads to measure thermodynamic parameters and define surface characteristics with visible, IR, and multi-spectral cameras.
2. Calibrate all sensors to NIST-traceable standards to determine both their accuracy and precision.
3. Validate the sensors performance against other measurement systems, to include remote sensing, radiosondes, fixed towers, and other sUAS.
4. Gain valuable experience in assessing the value of airborne observing systems for monitoring weather conditions on a routine basis.

Outline

ATDD sUAS Platforms and Instrumentation



Sensor Evaluation

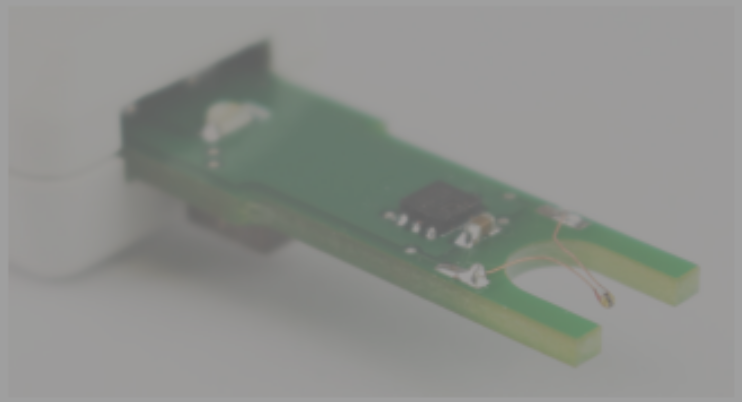


Recent Research Results Using sUAS

New Sensors for sUAS

Outline

ATDD sUAS Platforms and Instrumentation



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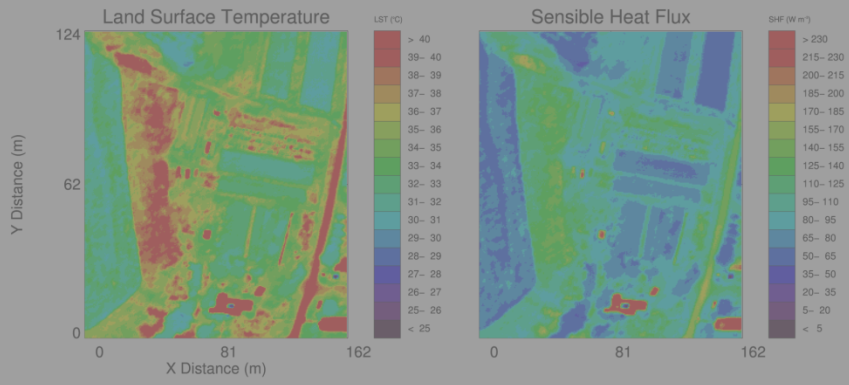

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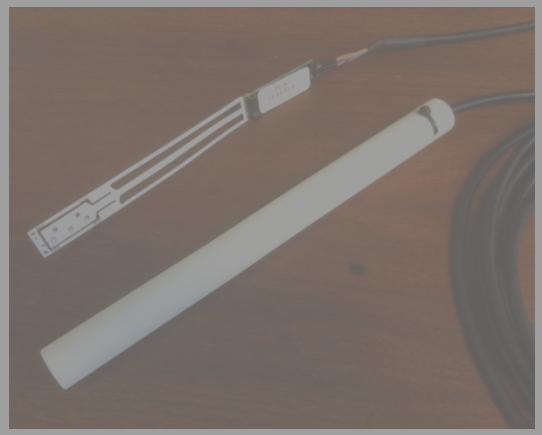


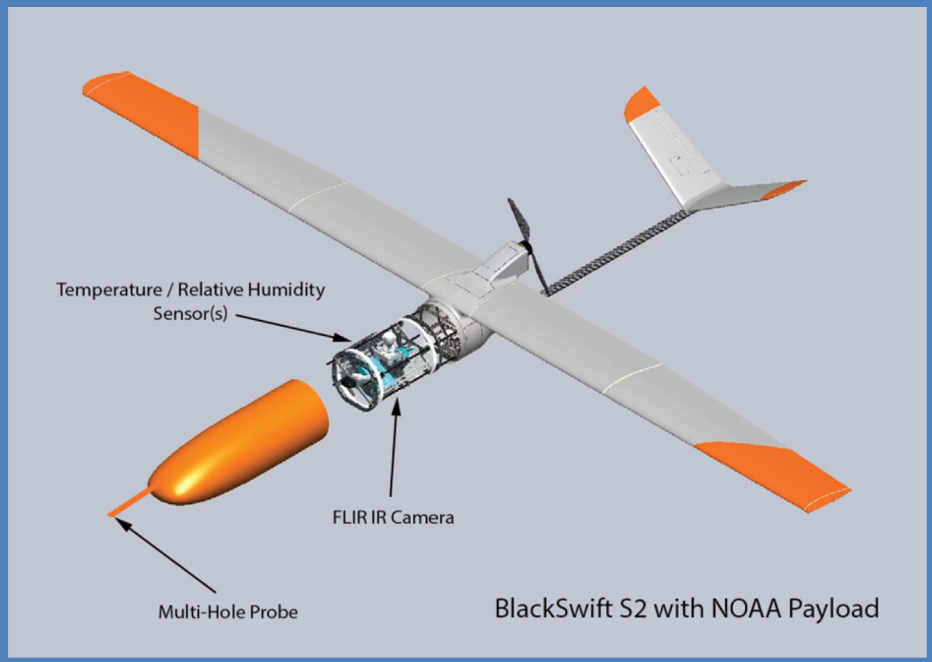
New Sensors for sUAS

ATDD sUAS Platforms

Model	DJI S-1000	Microdrone MD4-1000	BlackSwift S2
Registration	N542FC	N536JN	Pending
Manufacturer	DJI	Microdrone	BlackSwift Technologies
Owner/Operator	NOAA/ARL/ATDD	NOAA/NMFC/CCUT	NOAA/ARL/ATDD
Mission	Atmospheric profiling	Atmospheric profiling	Atmospheric profiling
Units in Fleet	1	1	1
Vehicle Type	Multi-rotor	Multi-rotor	Fixed-wing
Gross Weight	11 kg	3.85 kg	6.6 kg
Wing Span	1.0 m	1.0 m	3.0 m
Length	1.0 m	1.0 m	2.0 m
Payload Capacity	4.5 kg	1.2 kg	2.3 kg
Engine Type	8 electric motors	4 electric motors	1 electric motor
Autopilot	DJI A2 with iOSD Mk II	Microdrone	BlackSwift Technologies SwiftPilot
Max Speed	10 m s^{-1}	10 m s^{-1}	24.7 m/s
Loiter Speed	0 m s^{-1}	0 m s^{-1}	15 m/s
Endurance	15 min	25 min	120 min
Ceiling	365 m	1000 m	6096 m

NOAA/ATDD BlackSwift S2 sUAS

Model	BlackSwift Technologies S2
Registration	Pending
Manufacturer	BlackSwift Technologies
Owner/Operator	NOAA/ARL/ATDD
Mission	Atmospheric profiling
Units in Fleet	1
Vehicle Type	Fixed-Wing
Gross Weight	6.6 kg
Wing Span	3.0 m
Length	2.0 m
Payload Capacity	2.3 kg
Engine Type	1 electric motor
Autopilot	BlackSwift Technologies SwiftPilot
Max Speed	24.7 m/s
Loiter Speed	15 m/s
Endurance	120 minutes
Ceiling	6096 m



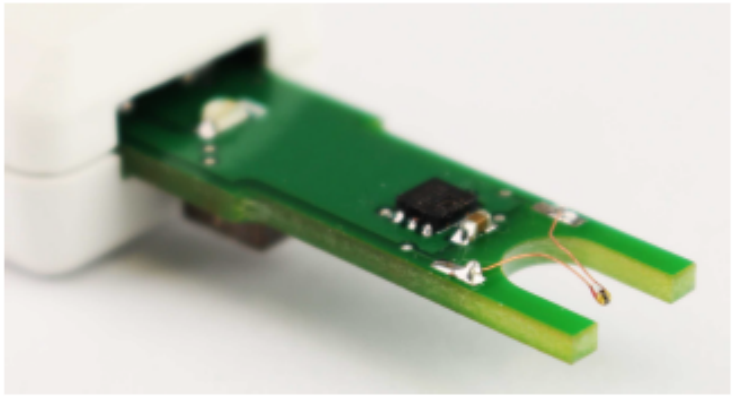
BlackSwift S2 with NOAA Payload

Scientific Instruments
- TeAx Thermal Fusion NIR camera (FLIR Tau 2) + Visible camera
- iMet-XQ T/RH/P
- UPSI F-TUTNA.44 fast-response T/RH sensor
- BlackSwift MHP (Multi-hole probe) 3-dimensional winds

Typical mission profile
- Manual takeoff
- Spiral climb to maximum altitude (1000 m AGL)
- Spiral descent over takeoff site
- Manual landing

Outline

ATDD sUAS Platforms and Instrumentation



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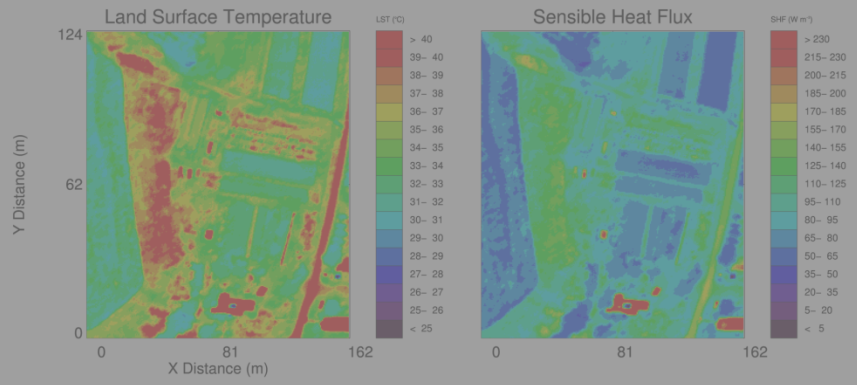

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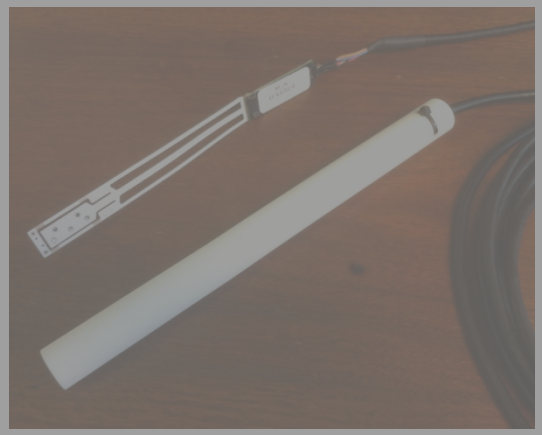
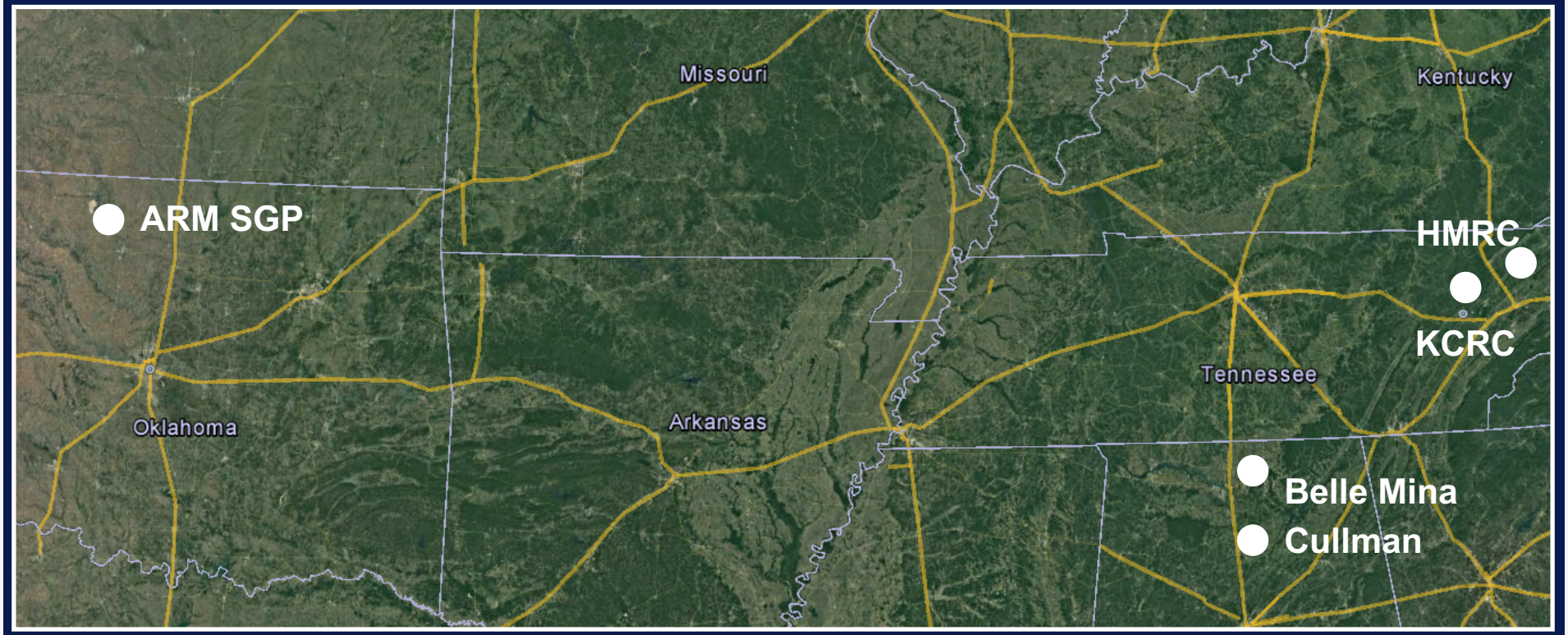


New Sensors for sUAS

ATDD sUAS Test Facilities and field campaign Sites

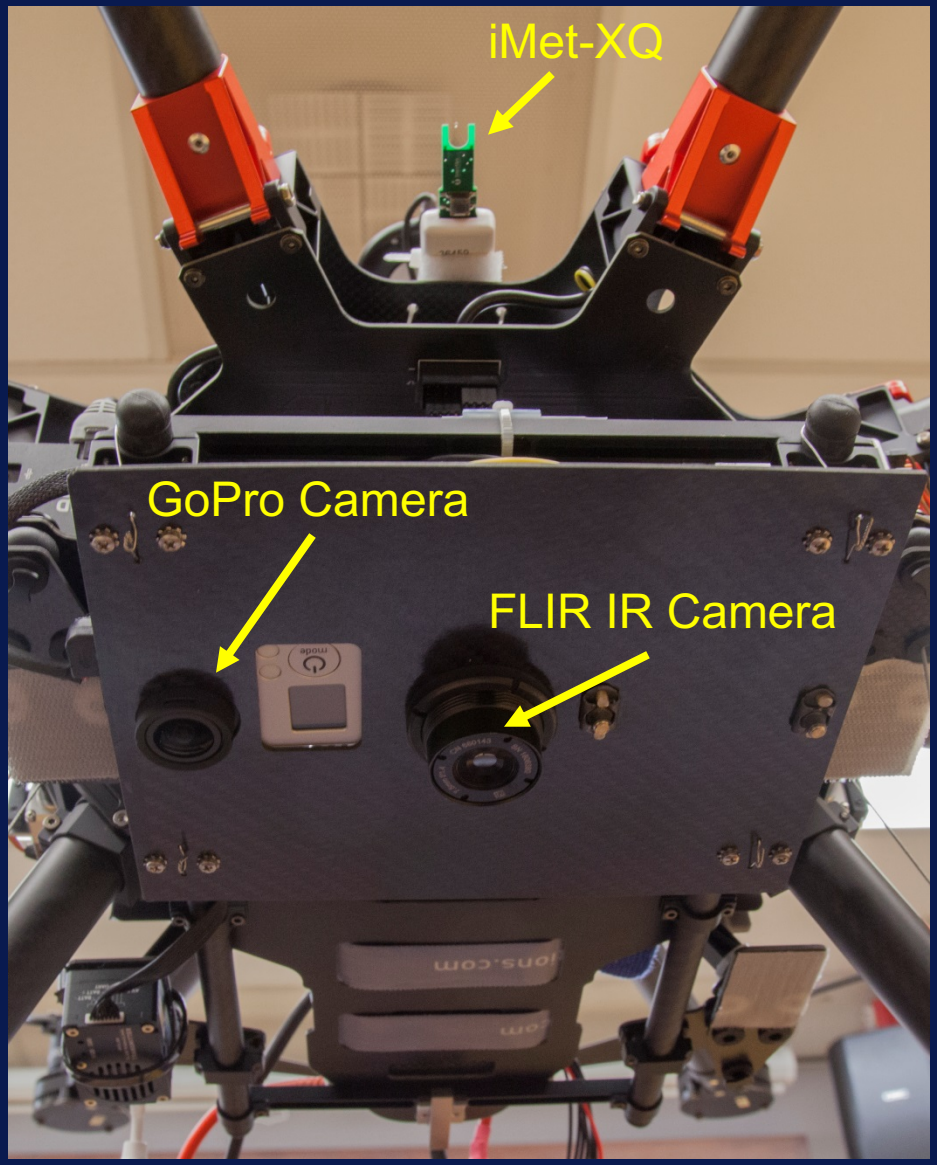


ARM SGP, OK: Aug 2017
Belle Mina, AL: Oct 2015 – present
Cullman, AL: March 2016 – present
House Mountain Radio Control (HMRC), TN: Dec 2016 – present
Knox County Radio Control (KCRC), TN: Nov 2015 – present

sUAS Flights with DJI S-1000 and MD4-1000 2015 – Present

Year	2015	2016	2017
ARM SGP, OK	0	0	52
Belle Mina, AL	8	3	0
Cullman, AL	0	4	20
House Mountain, TN	0	7	0
KCRC, TN	15	3	7
TOTAL FLIGHTS	**23**	**17**	**79**

Sensors on sUAS



Underside of DJI S-1000 sUAS

iMet-XQ

- 1 Hz sampling of temperature, pressure, humidity
- Two sensors on each sUAS

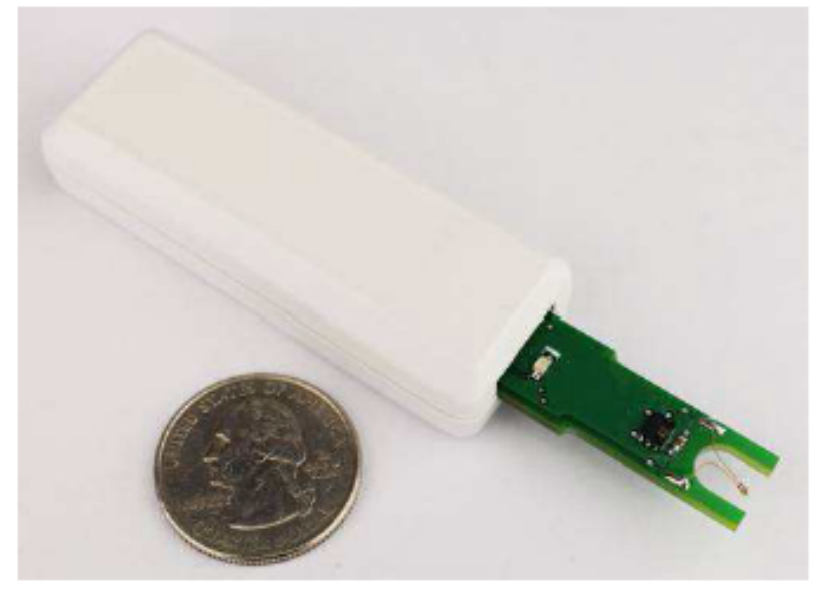
GoPro Hero 3 Visible Camera
(DJI S-1000 only)

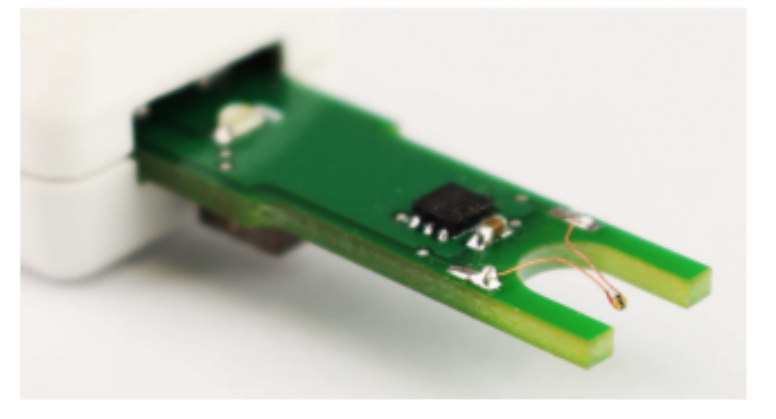
- 1024 x 768 resolution
- Real-time and recorded video
- 30 Hz

FLIR Tau 2 Near-infrared Camera
(DJI S-1000 only)

- 336 x 256 resolution
- Recorded images only
- 7.5 Hz
- TeAx data recording system

iMet-XQ Sensor





Operating Parameters

Power: rechargeable battery
Size/Weight: 100 x 30 mm, 15 g
Sampling rate: 1 Hz

Humidity Sensor

Type: capacitive
Accuracy: ±5% RH
Response time: 5 sec 1 m s^{-1} velocity
Resolution: 0.7% RH

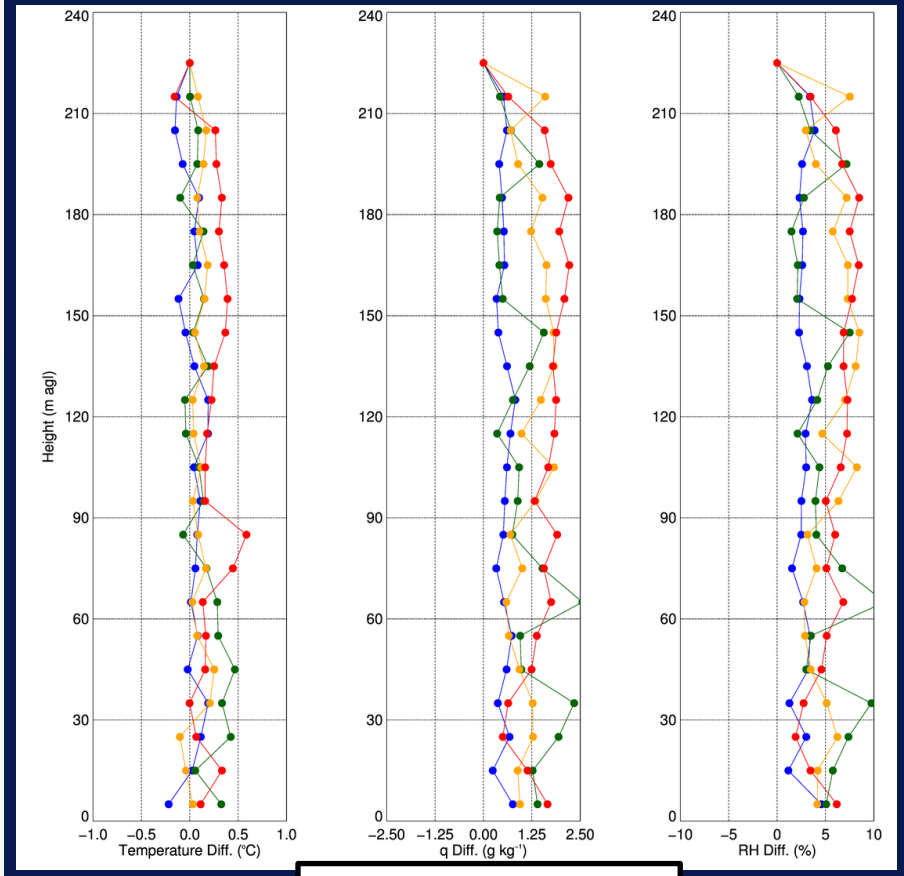
Temperature Sensor

Type: Bead thermistor
Response time: 2 sec
Accuracy: ±0.3 °C
Resolution: 0.01°C

Pressure Sensor

Type: Piezoresistive
Accuracy: ±1.5 mb
Resolution: 0.02 mb

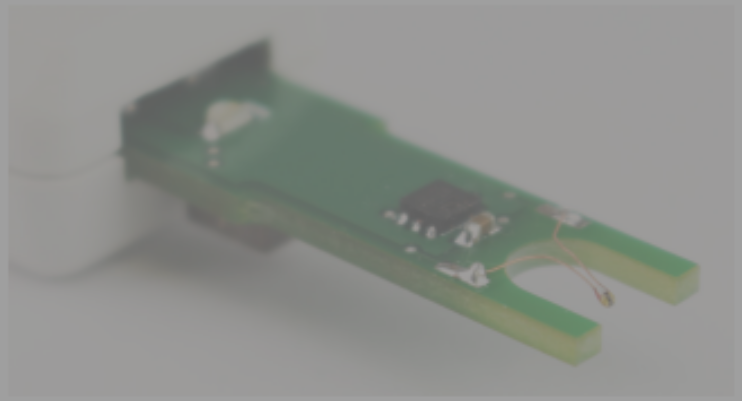
Comparison between iMet Measurements from DJI S-1000 and MD4-1000 flown simultaneously ~100 m apart on 28 April 2017



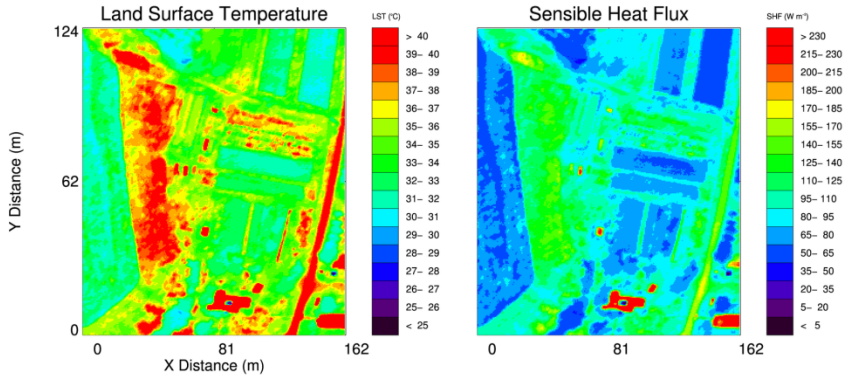
Difference between measurements from DJI S-1000 and MD4-1000			
	Mean T Diff. (°C)	Mean q Diff. (g kg^{-1})	Mean RH Diff. (%)
Flight 1	0.02	0.54	2.78
Flight 2	0.13	1.07	4.81
Flight 3	0.08	1.19	5.45
Flight 4	0.22	1.57	5.96

Outline

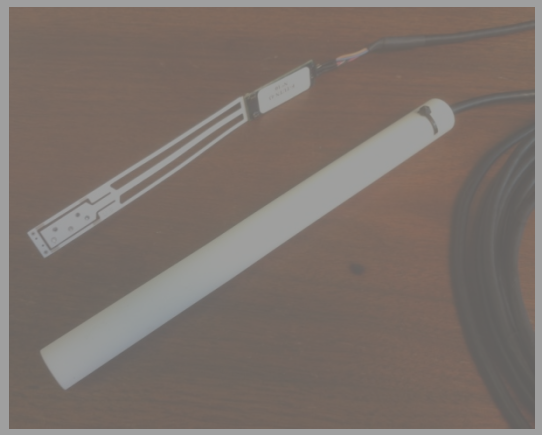
ATDD sUAS Platforms and Instrumentation



Sensor Evaluation

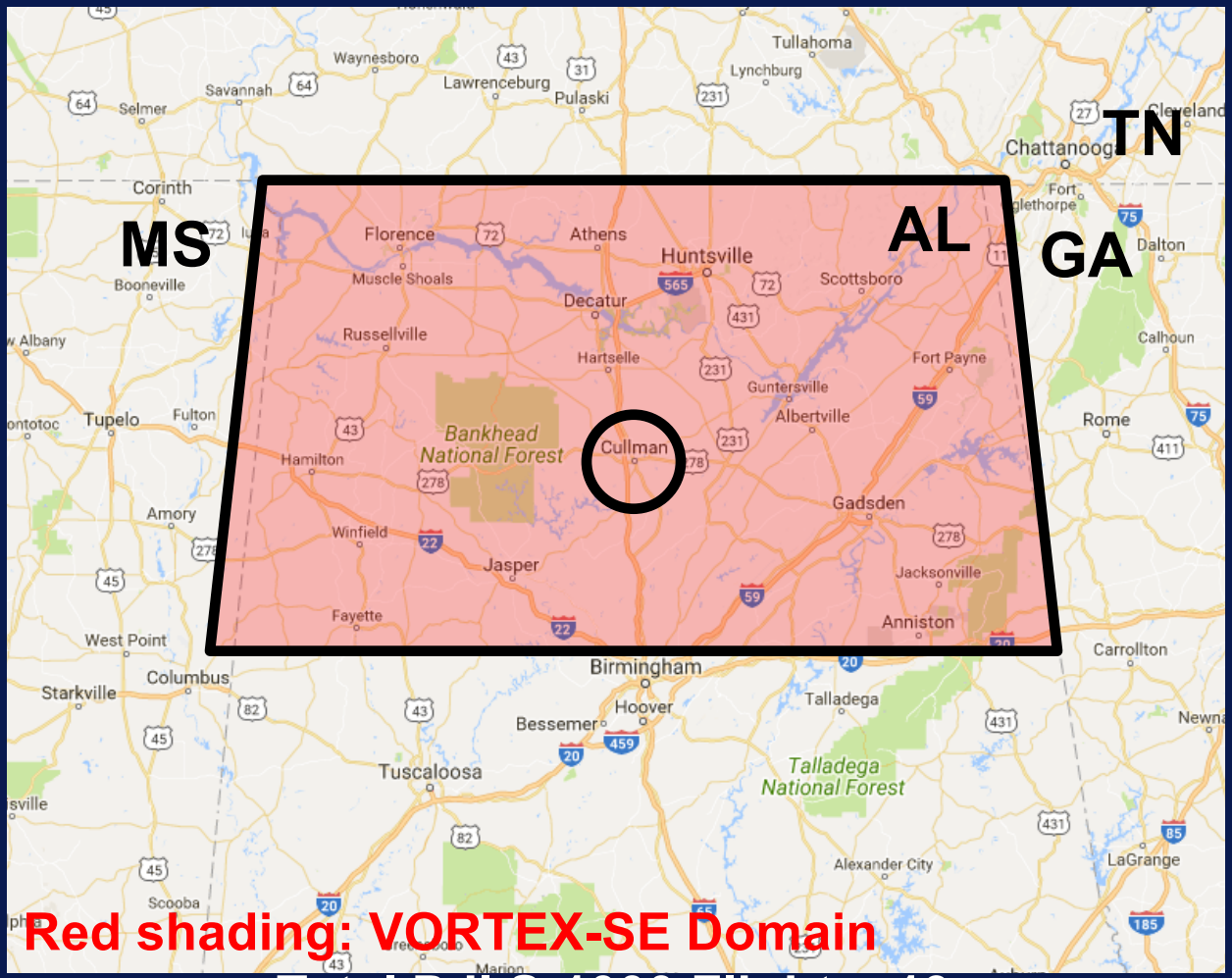


Recent Research Results Using sUAS



New Sensors for sUAS

2017 VORTEX-SE sUAS Operations: Cullman, AL

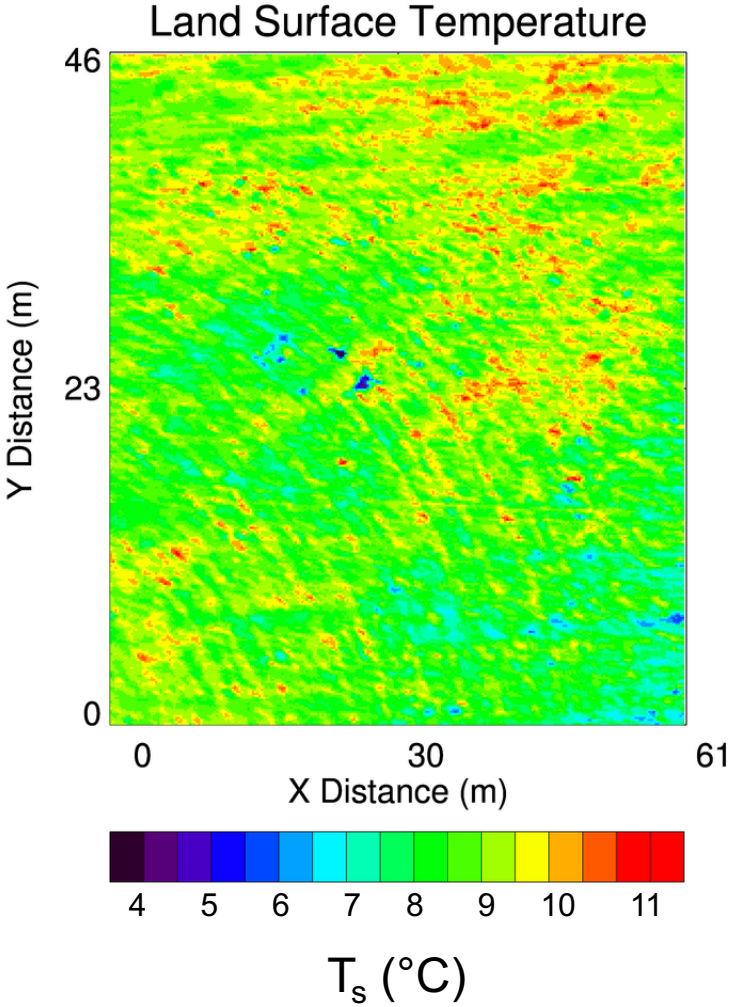


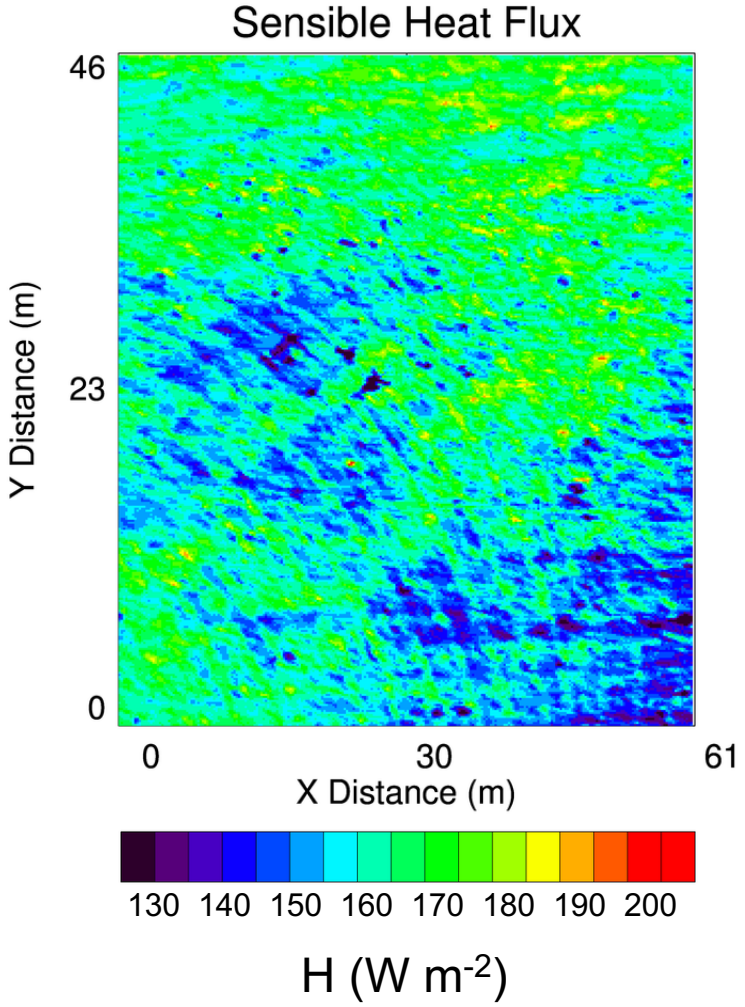
Red shading: VORTEX-SE Domain

Total DJI S-1000 Flights: 19

Total MD4-1000 Flights: 6

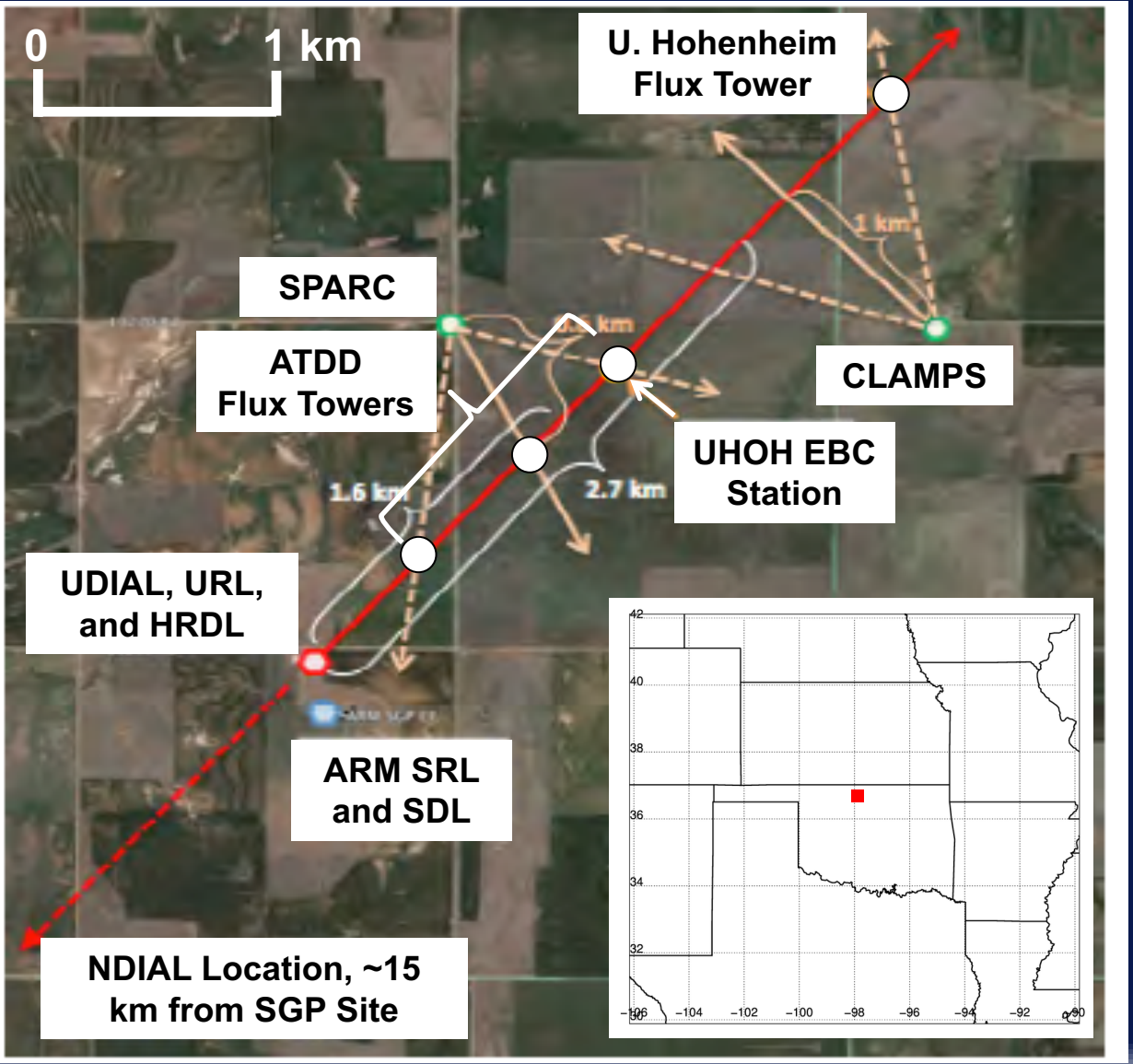
Sample application of technique during sUAS flight on 15 Dec 2016 near Knoxville





Lee et al. 2017

August 2017 Deployment near DOE ARM Site

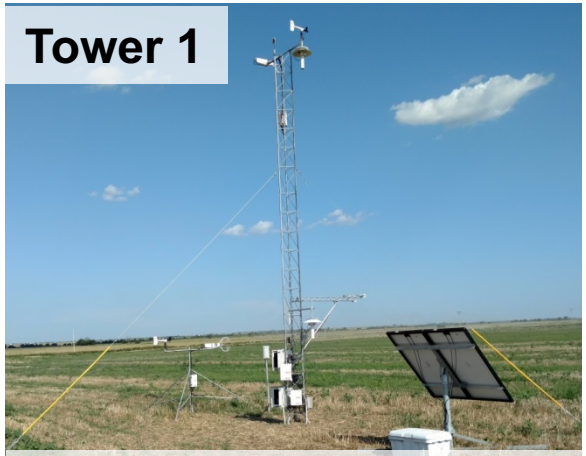


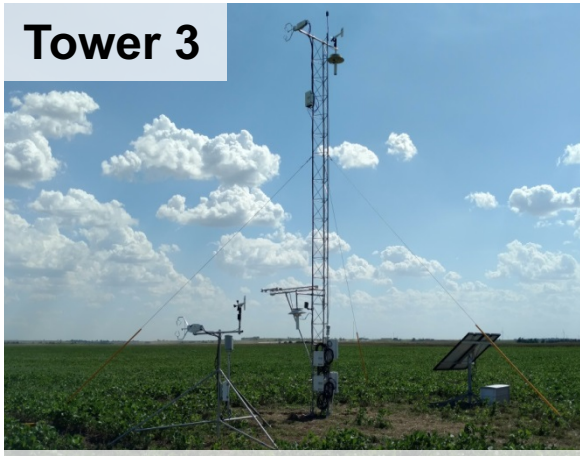
Instrument Platforms

(Dept. of Energy, NOAA ESRL, U. Hohenheim, ATDD)

- Doppler wind lidars
- Water vapor and temperature lidars
- Atmospheric Emitted Radiance Interferometer
- Microwave radiometers
- Flux towers
- sUAS
- Rawinsondes

ATDD Operations During LAFE





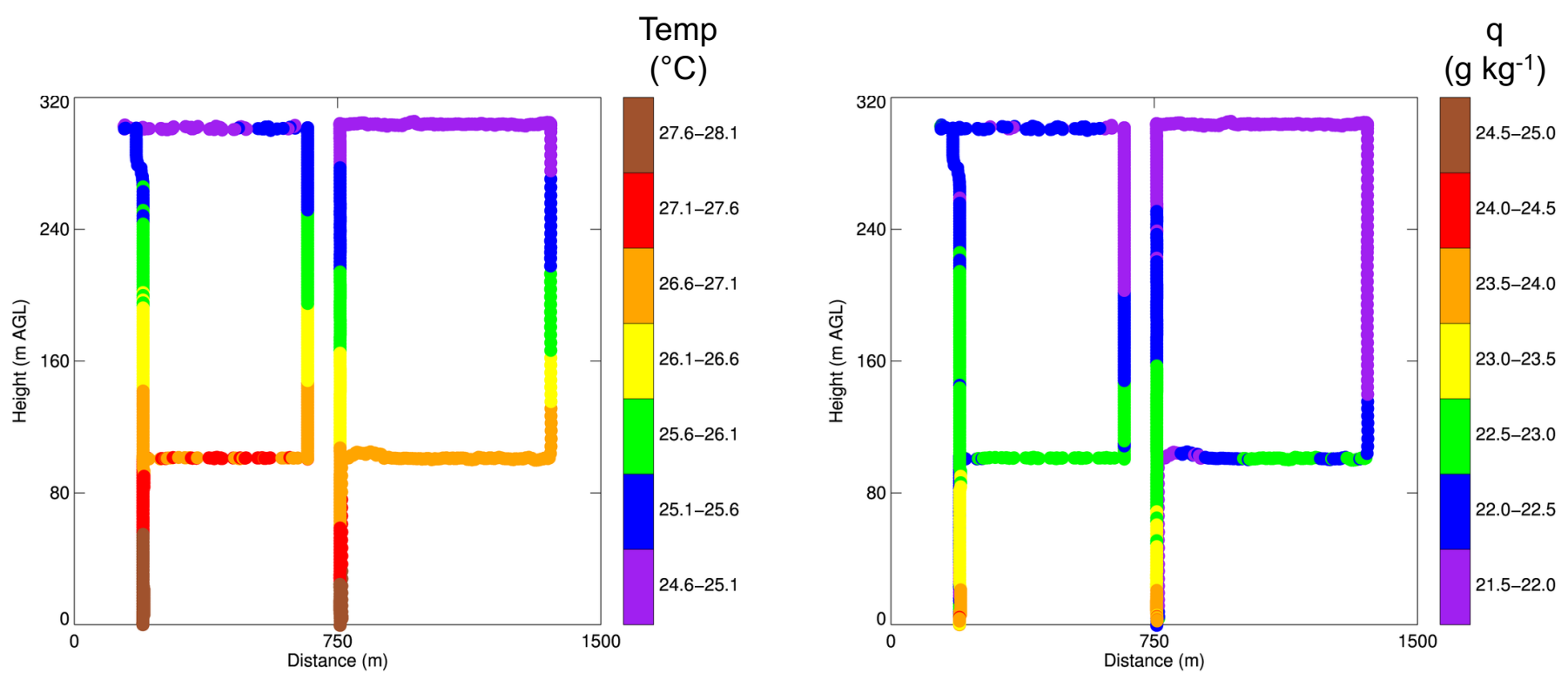
Instrument	Sampling Height(s) (m AGL)
HMP110 T, RH probe	1.5
Aspirated PRT	1.5, 10
Pressure sensor	1
Hukseflux net radiometer	2.5
TP01 soil temperature probe	-0.05, -0.10, -0.20
Decagon soil moisture probe	-0.05, -0.10, -0.20
Propeller anemometer	3, 10
PAR sensor	2.4
Closed path gas analyzer	3, 10
Sonic anemometer	3, 10
Rain gauge	2.5

Sonde Launches

sUAS Operations Total: 52 Flights

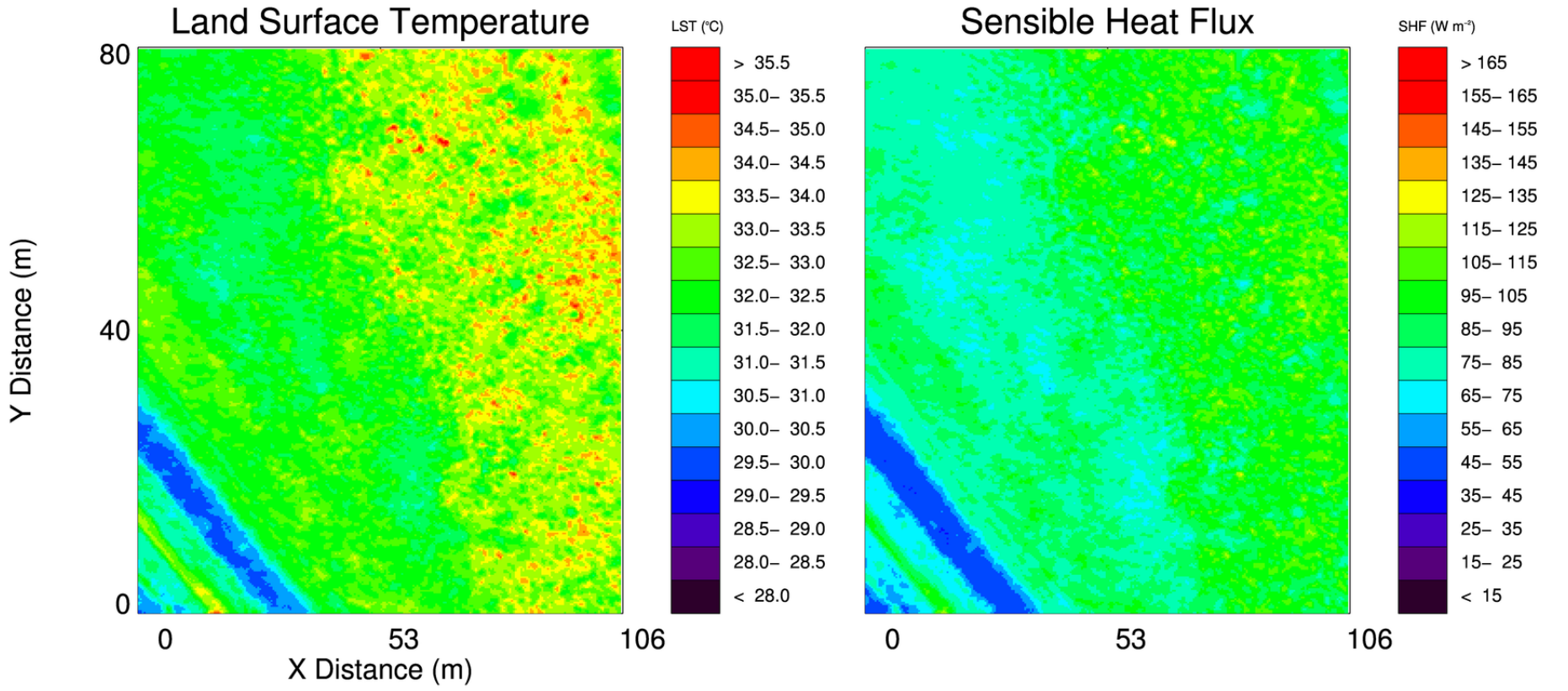
UAS's flown in box-like pattern between along SW-NE transect to characterize temperature and moisture variability between towers and along lidar RHI scans

1710 UTC 15 Aug 2017



DJI S-1000 FLIR used to characterize finescale LST changes and to derive heat flux

15 Aug 2017, 1713 UTC
DOE ARM SGP



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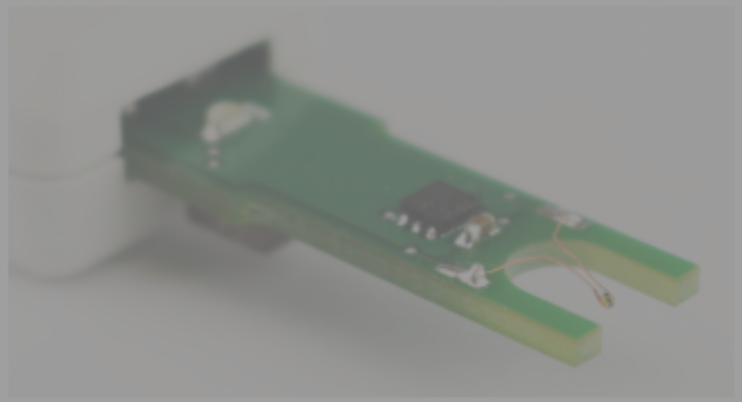
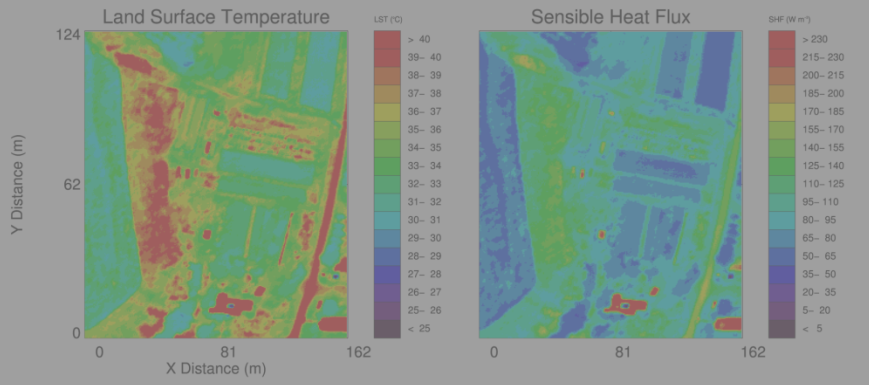
ATDD sUAS Platforms and Instrumentation



Sensor Evaluation

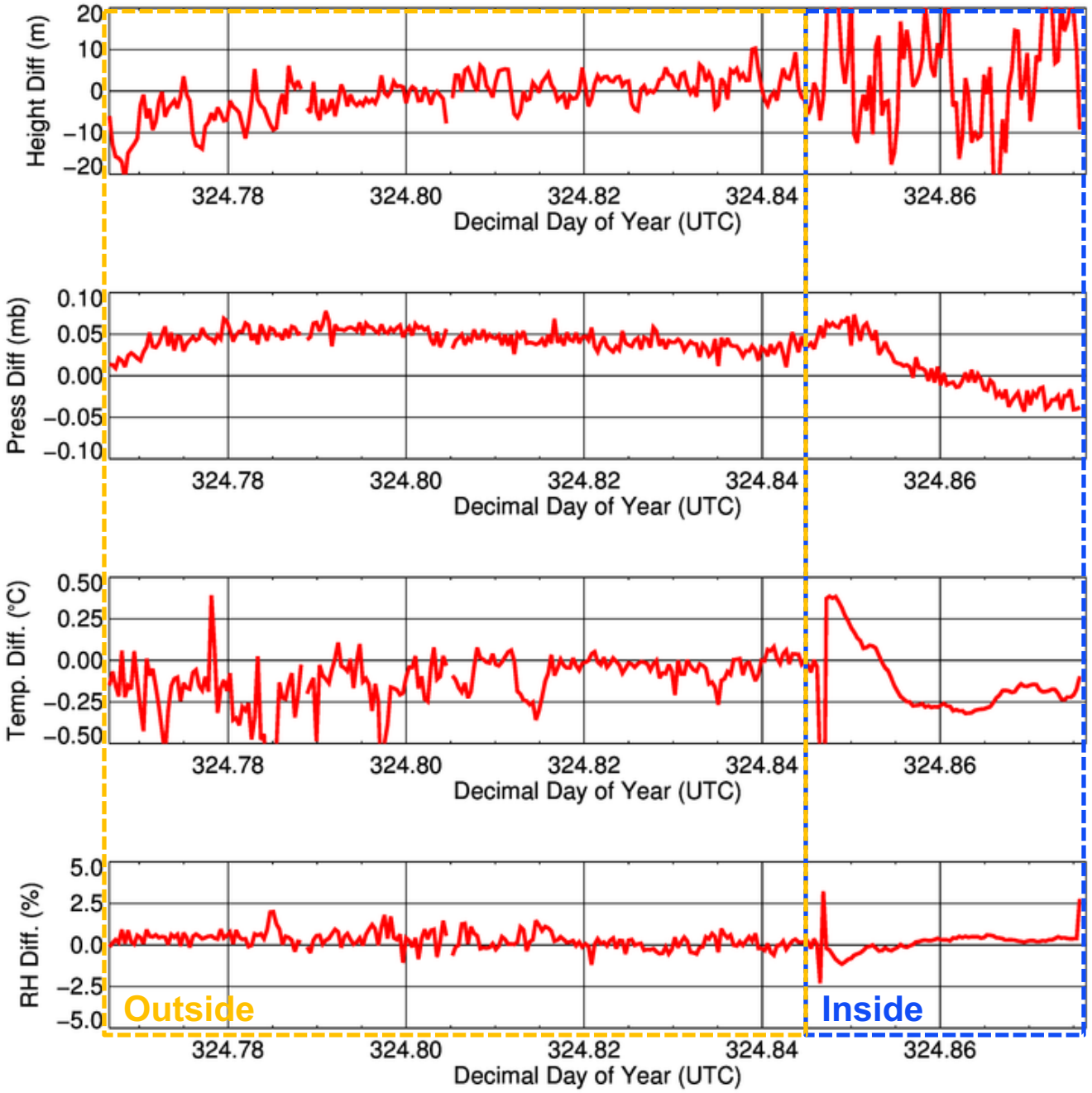


Recent Research Results Using sUAS

New Sensors for sUAS

Newest Version of iMet-XQ: iMet-XQ2 (Nov 2017)

ATDD Test, 20 Nov 2017



iMet-XQ2 Chamber Test Temperature Evaluation

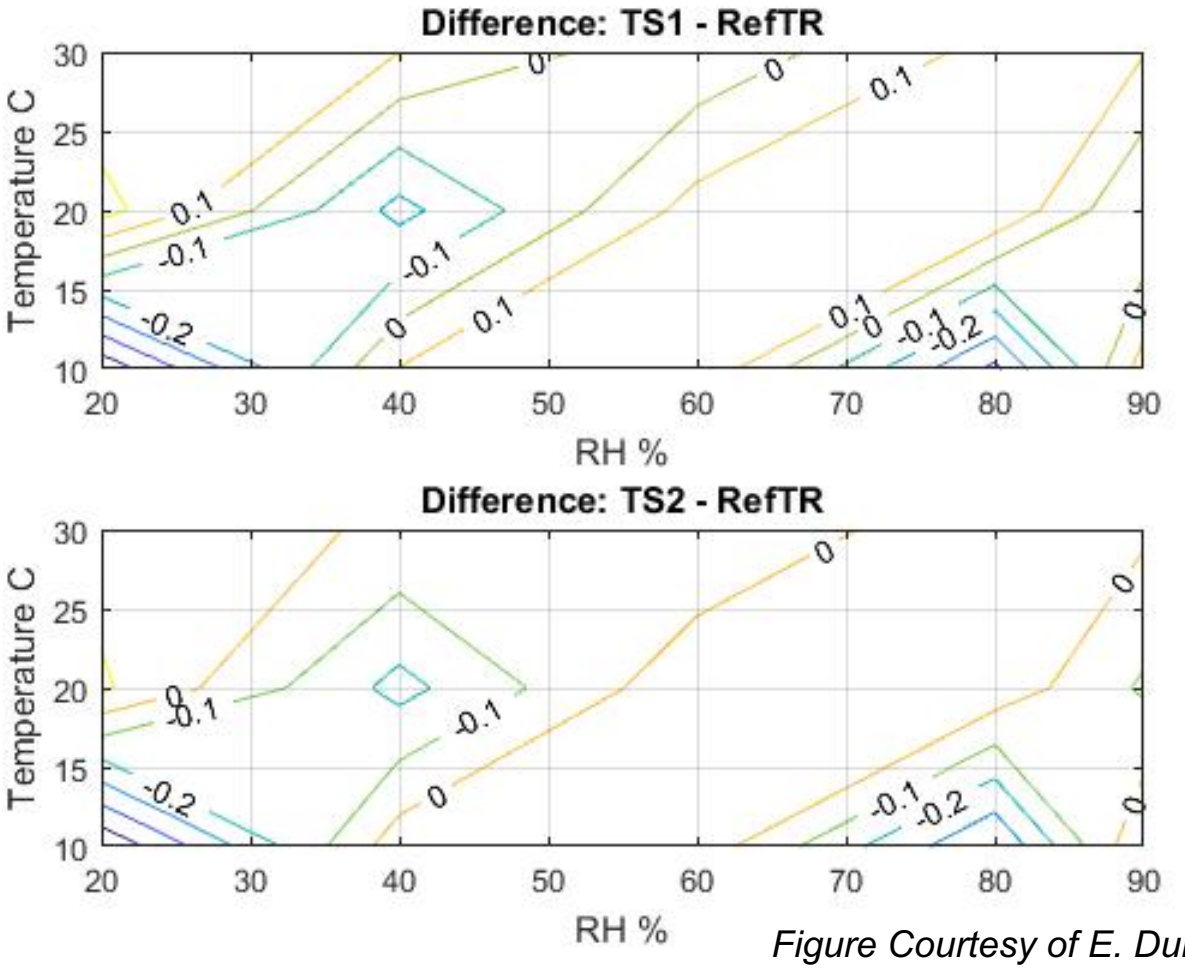


Figure Courtesy of E. Dumas

iMet-XQ2 Chamber Test Humidity Evaluation

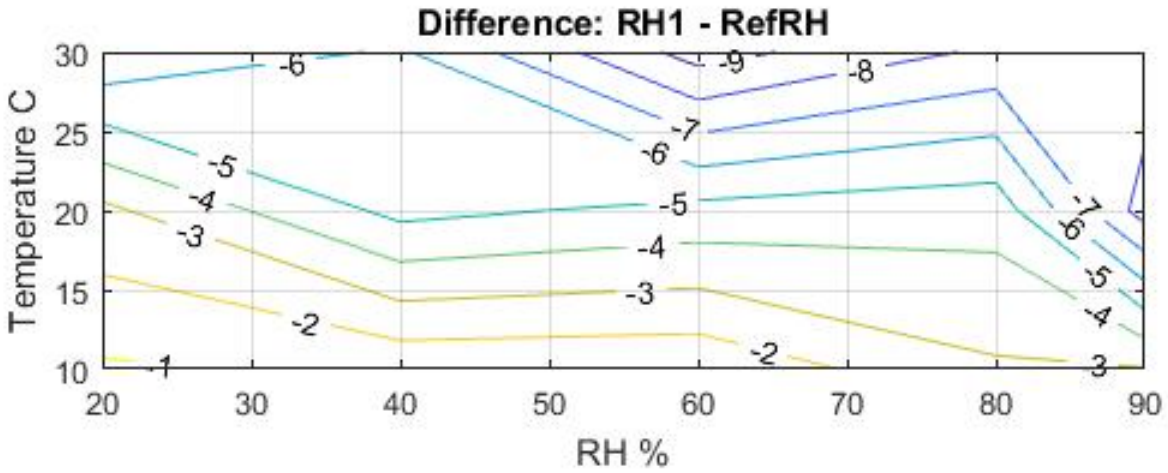


Figure Courtesy of E. Dumas

New Fast-Response Sensor

UPSI F-TUTN fast-response temperature and humidity sensor

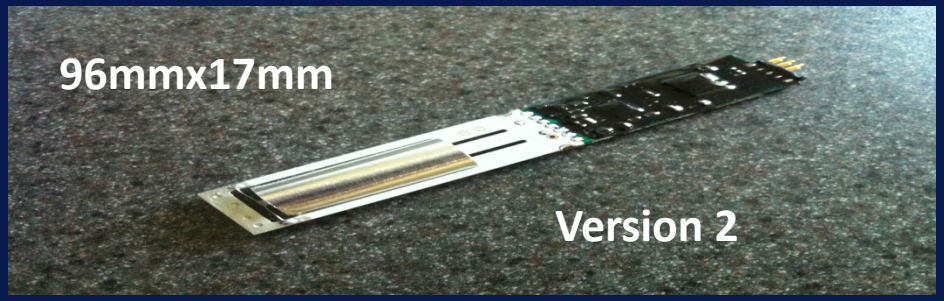
185 mm long, 17 mm wide flexible probe

Measurement ranges:
1% RH to 99% RH
–50°C to +50°C

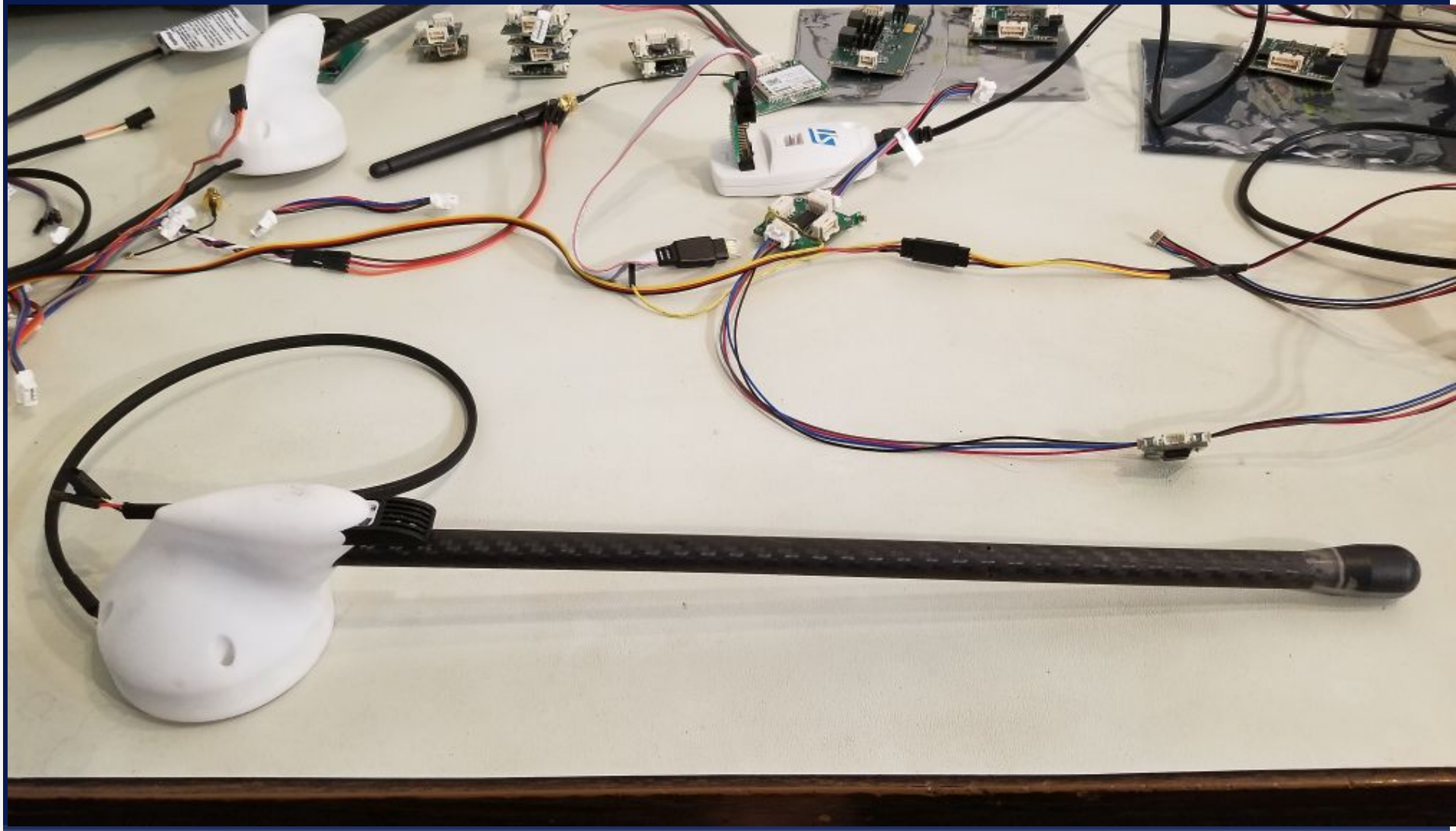
Humidity time constant: <0.2 s at 25°C

Operating temperature:
– 50°C to +50°C

Cost: ~ $200



Blackswift Multi-port UVW probe

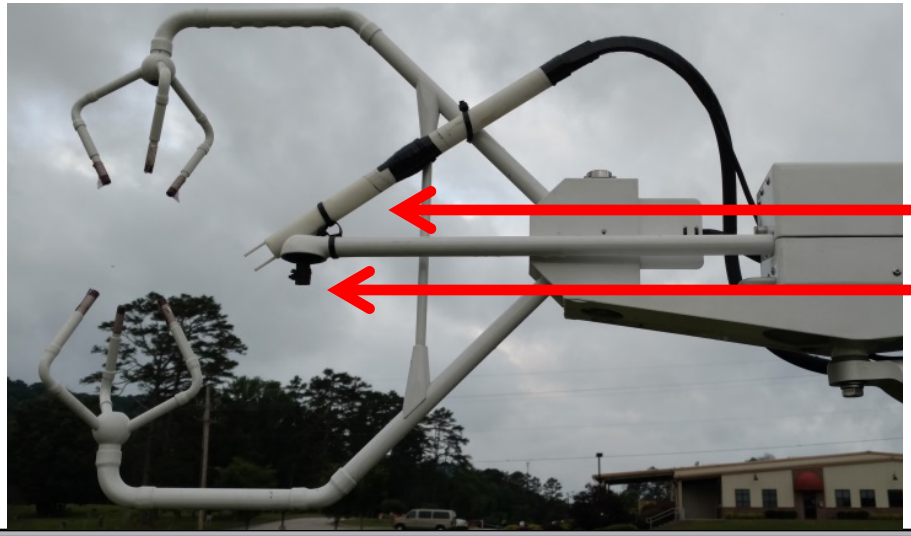


Intercomparison in Field

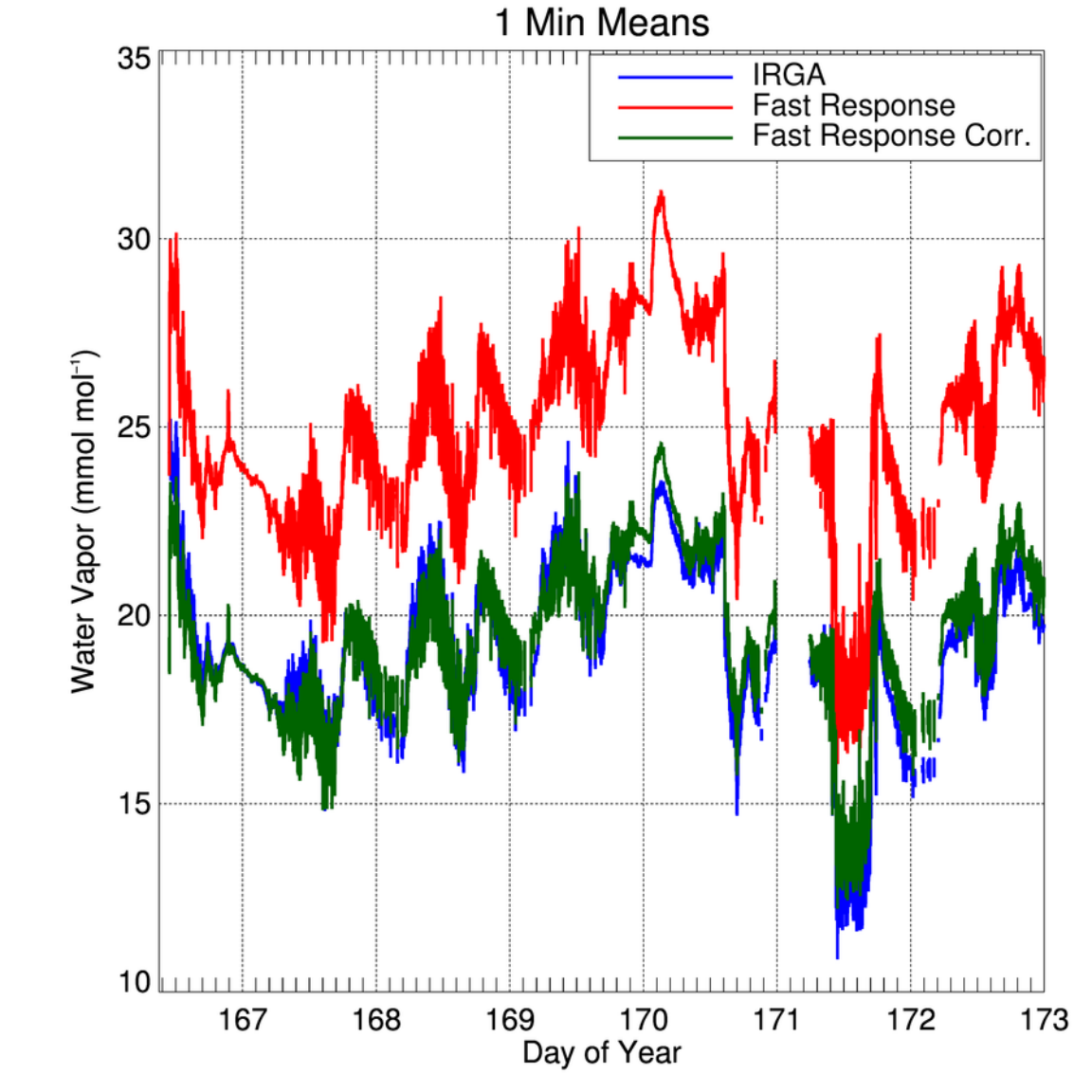
2 m Tripod installed for ~9 days near Oak Ridge, TN

Instrument
Fast-response RH Sensor
Vaisala T, RH Probe
EC155 Closed Path Infrared Gas Analyzer (IRGA)
CSAT3 Sonic Anemometer

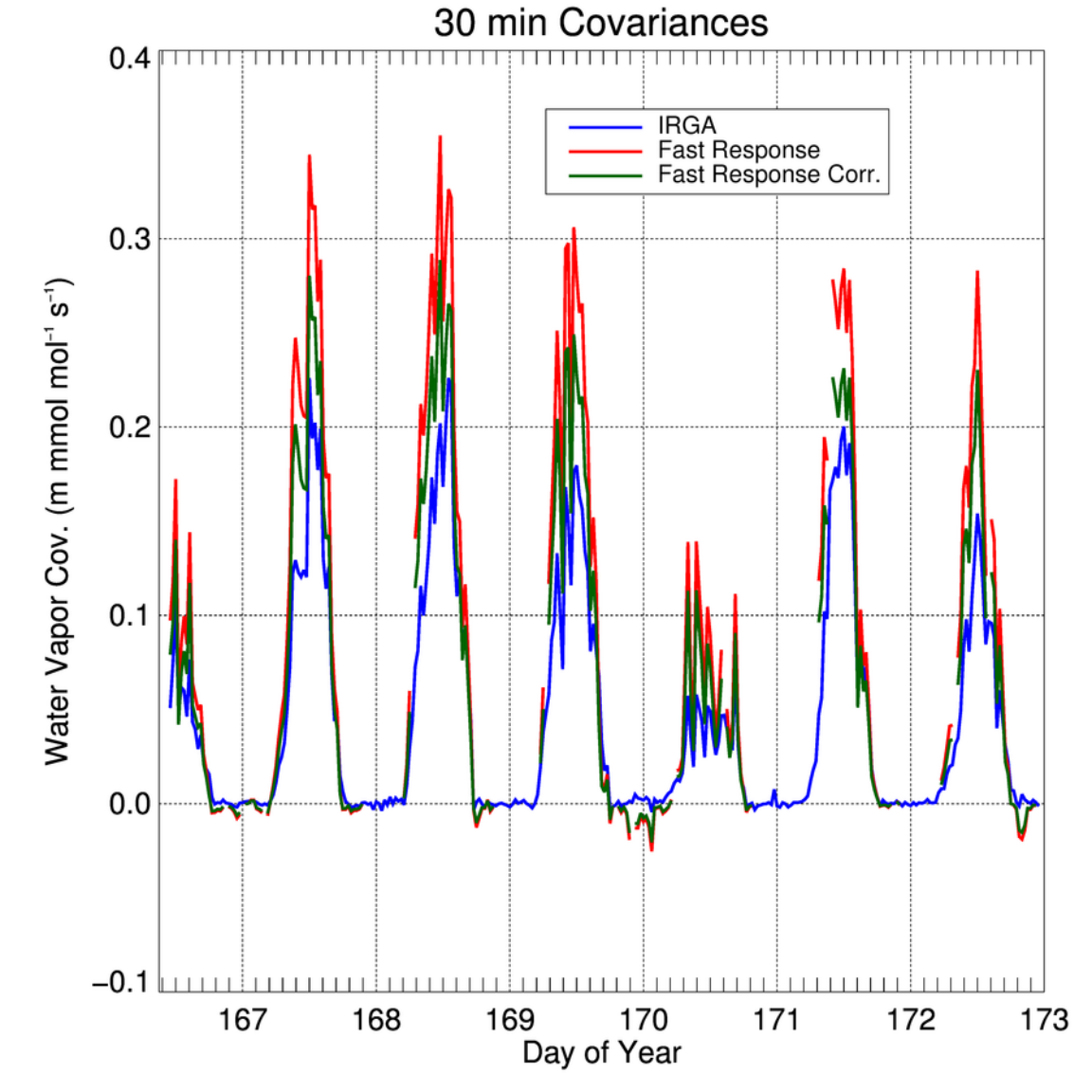
1 min means and 30 min covariances computed using 10 Hz data



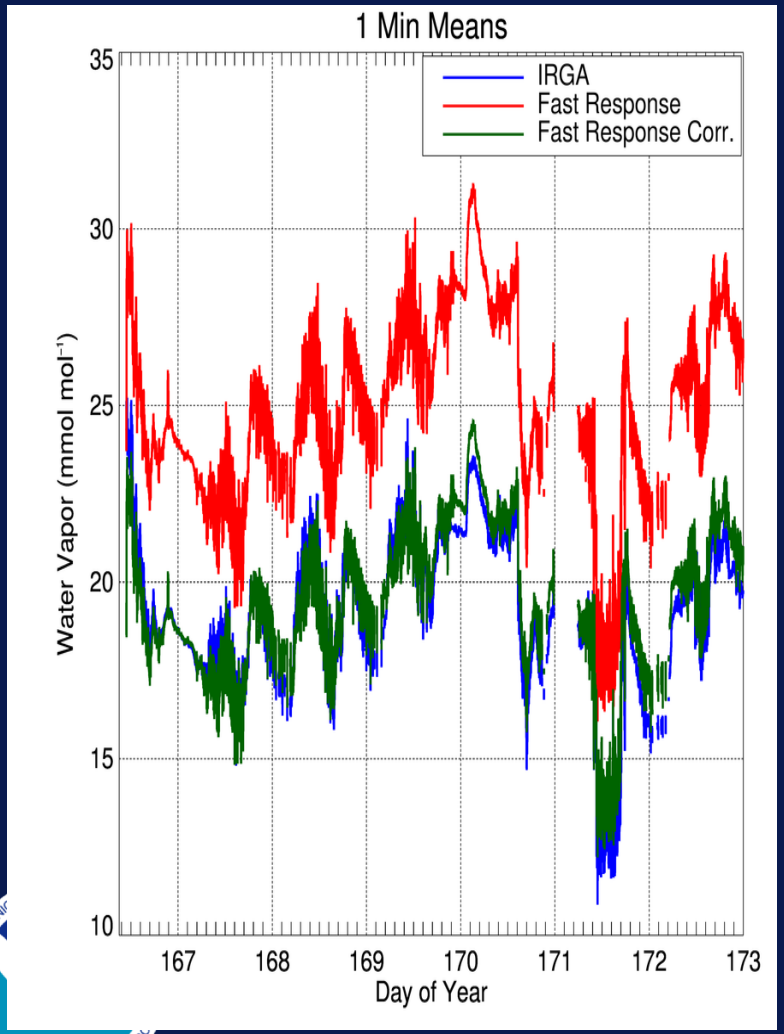
1 min means of 10 Hz Water Vapor Measurements Corrected Using Linear Transfer Function

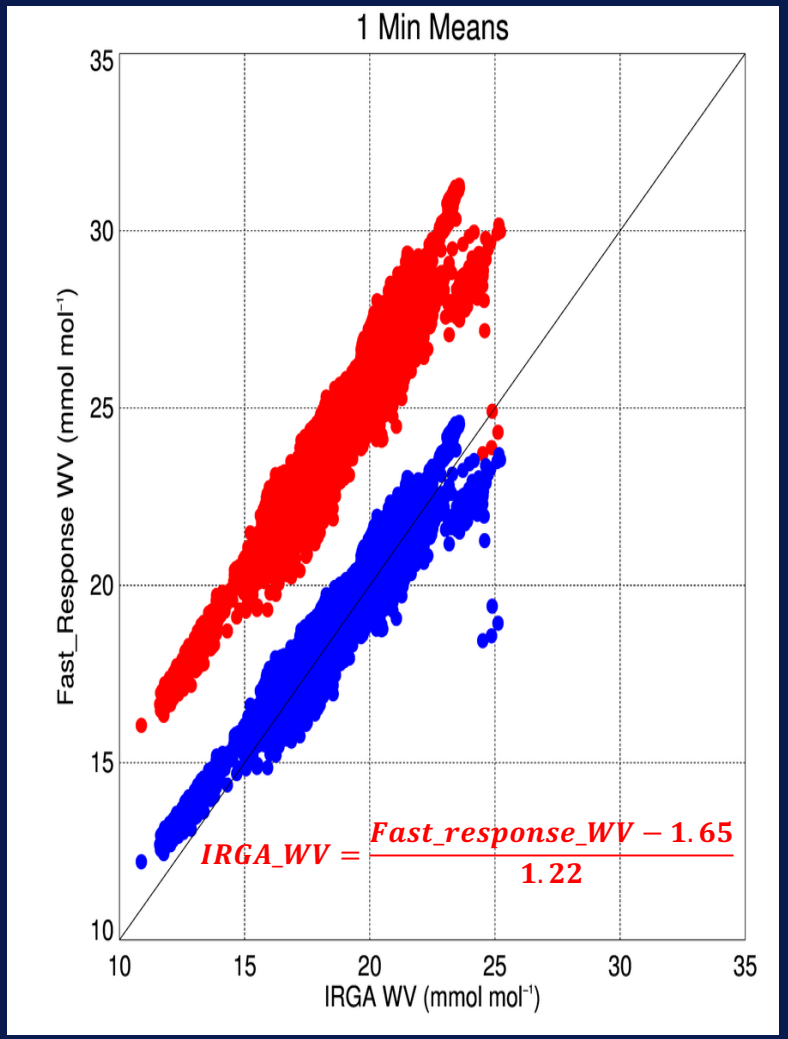


30 min Covariances
Corrected Using a Linear Transfer Function

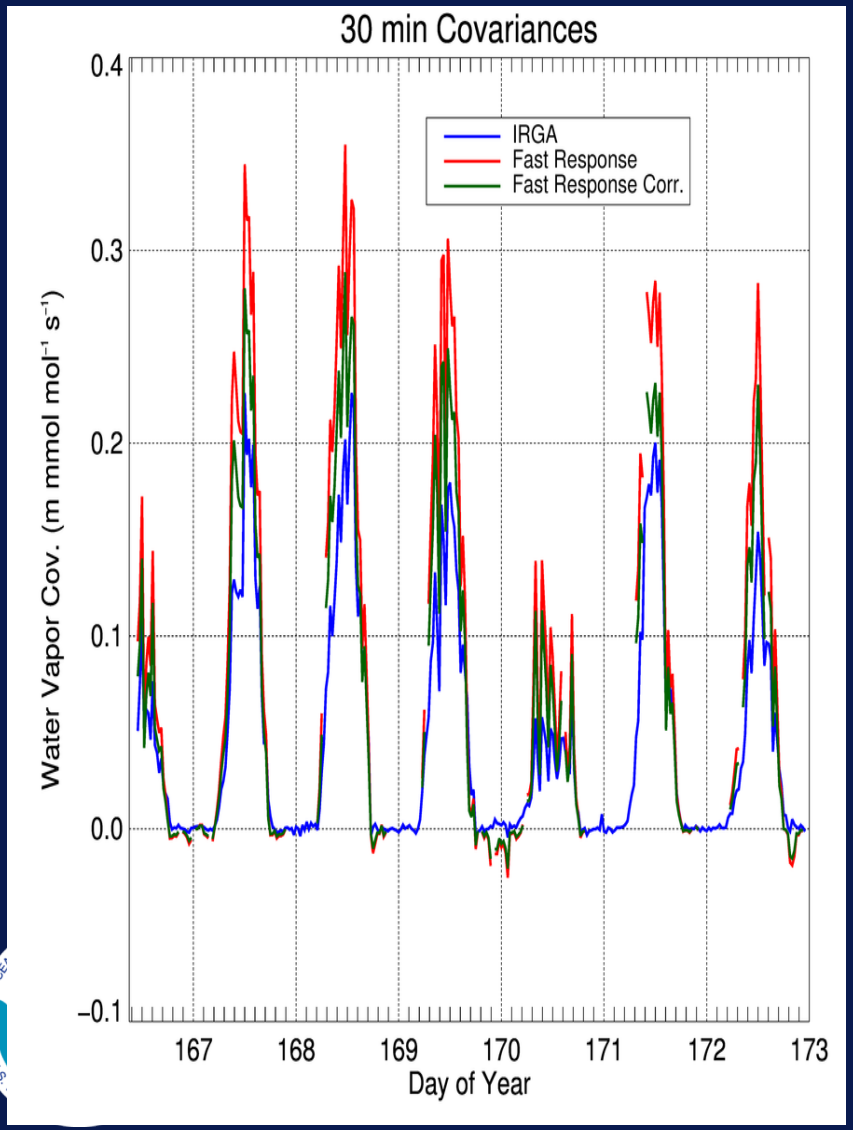


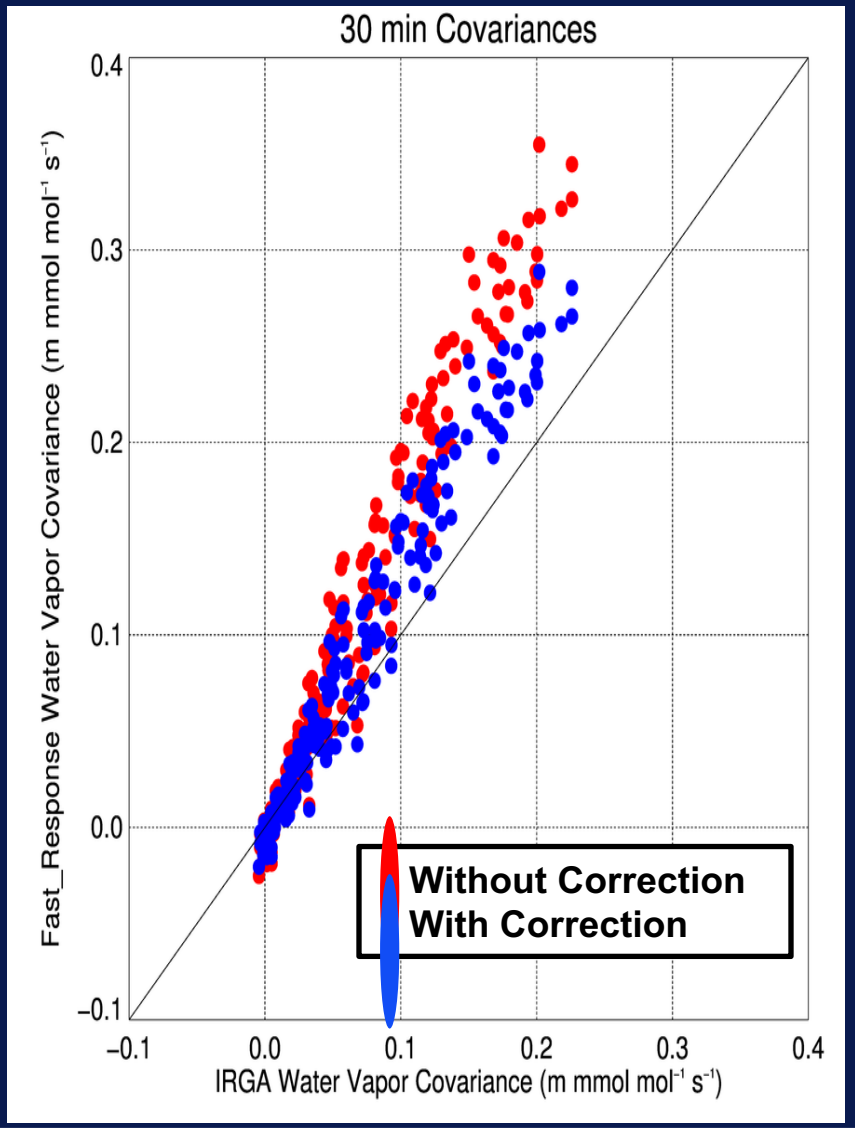
Water vapor concentrations





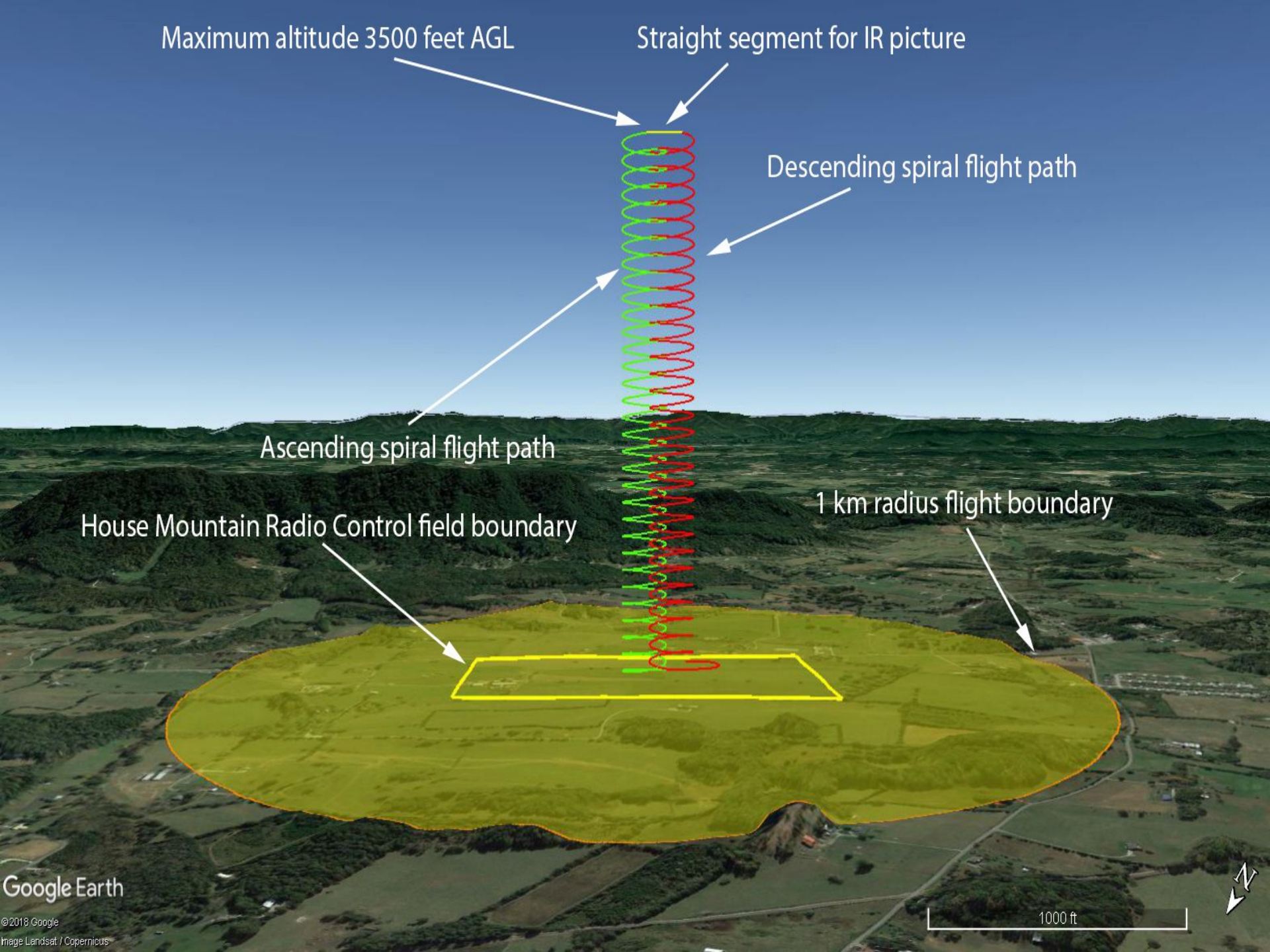
Eddy covariance fluxes





NEXT STEPS

NOAA
U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION


Maximum altitude 3500 feet AGL
Straight segment for IR picture
Descending spiral flight path
Ascending spiral flight path
House Mountain Radio Control field boundary
1 km radius flight boundary
Google Earth
© 2018 Google
Image Landsat / Copernicus
1000 ft
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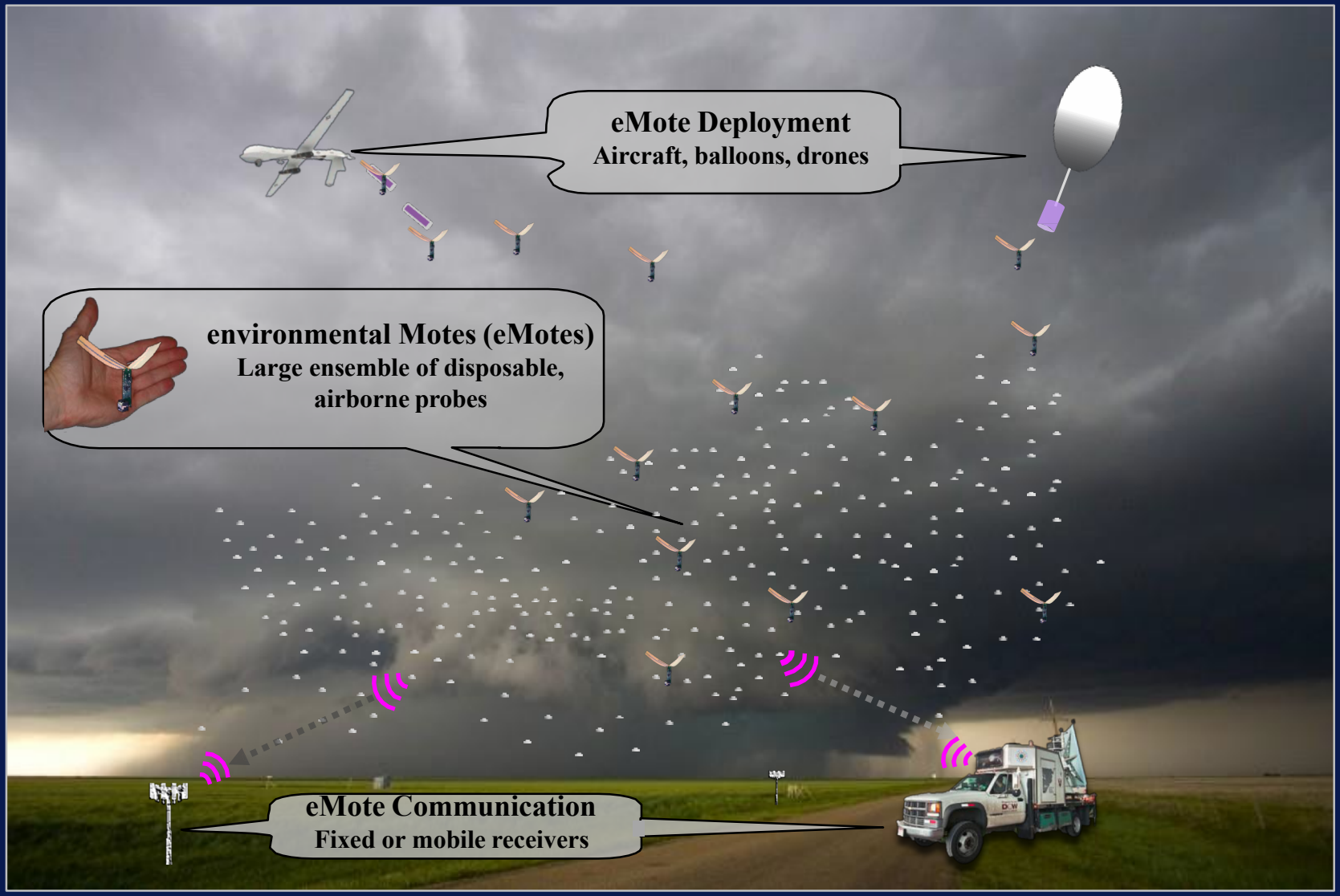
Semi-Lagrangian Sensors



GAPS and Objectives

More frequent flight Campaigns to:

1) Capture boundary layer evolution (needs to be done in different ecosystems)
2) Routine Vertical profiles T,RH,P, winds
3) Land surface interactions seasonal

Use of sUAS's as a routine observing platform and scale up to a national level

1) Contiuous profiles up to 3Km
2) Autonomous or semi autonomous operation
3) Create a network sUAS for input into forecast models

Need to develop the infrastructure within NOAA and work with FAA for BVLOS

SUMMARY

- UAS

Evaluate surface fluxes and upscale these fluxes to larger (i.e. ≥4 km) spatial scales (Fixed Wing)

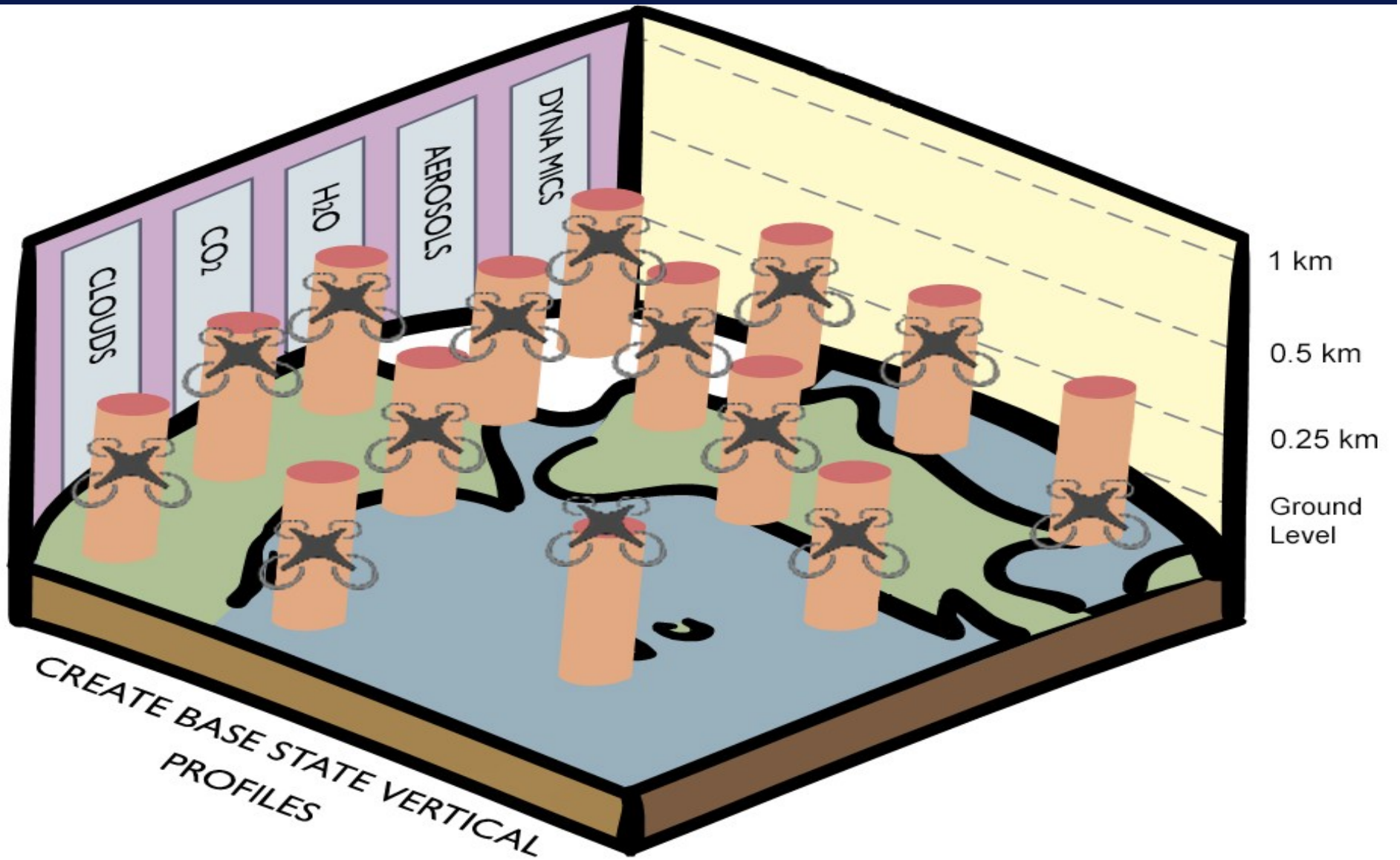
Expand profiling capabilities

Wind speed, wind direction

CO_2, CH_4, O_3

- Continue Severe weather research

Low-level temperature/moisture information for improved short-term winter storm forecasts, severe thunderstorms and tornado potential

- Contributions to other NOAA missions across Line Offices

FUTURE DIRECTIONS