Wildland Fire Metrics Measurement Using Small UAS

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Project Contributors

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- Dr. Xiaolin Hu (Georgia State Univ.)
- Dr. Ming Xin (Univ. Missouri)
- Dr. Tiebiao Zhao

Outline

I. **Introduction**

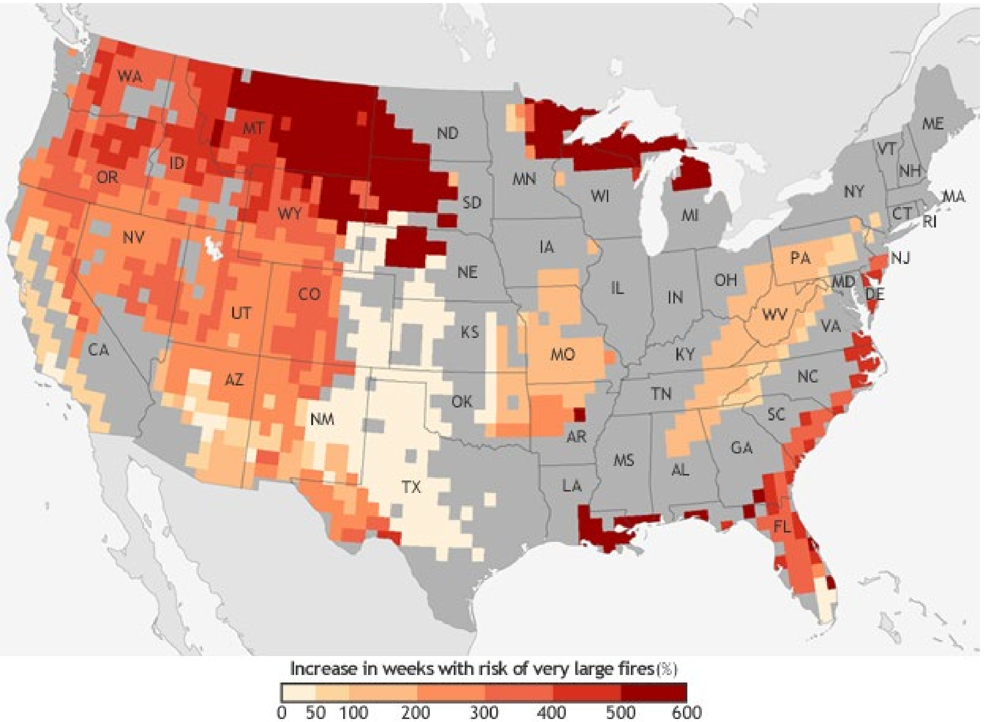
II. UAS Platform

III. Fire Metrics Measurement Using sUAS

IV. Conclusions and Future Work

Wildfire in the US

- It is predicted that global warming will cause an increase in very large fires (50,000+ aces) across the western United States by the middle of the century (2041-2070) compared to the past (1971-2000).
- It is especially important to understand the fires in Wildland Urban Interface (WUI) areas.
- The Starbuck fire in 2007 burned over 800,000 acres in Oklahoma and Kansas.



https://www.climate.gov/news-features/event-tracker/hot-dry-summer-and-slow-start-wet-season-primed-california-november-2018

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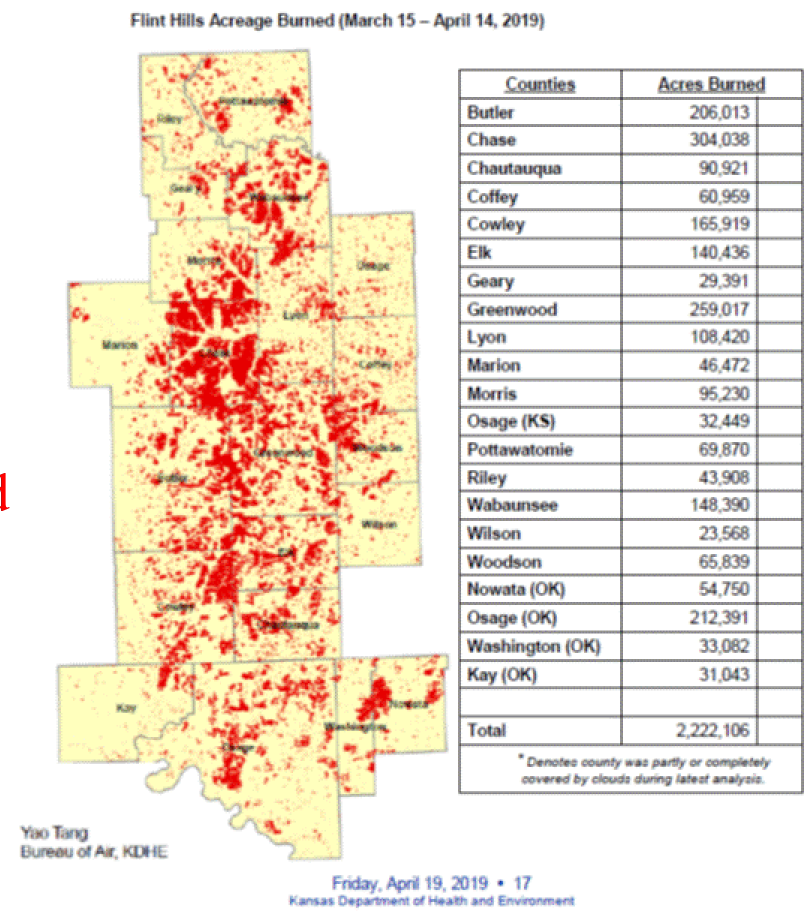
UAS Fire Measurement over Kansas Controlled Burns

- Millions of acres of Kansas grasslands are burned each year presenting opportunities for development and testing of NextGen fire sensing and fighting instruments that can help answer critical fire science questions.
- UAS can provide high accuracy measurements of fire metrics such as fire front location, fire rate of spread (ROS), flame height, fire intensity, mid-flame wind speed, fire generated updraft and turbulence level, pre-burn biomass, post-burn severity, etc.
- A combination of ground measurements, UAS, and satellite can form a multiple scale sensing network for improved fire situational awareness.



Flint Hill fire statistics in 2019 from KDHE.

Advantages & Challenges for UAS based Fire Sensing

- UAS Advantages
  - Pilot and firefighter safety
  - Images with high spatial resolution
  - Quick recovery time and deployment
  - Rapid revisit times (minutes)
  - Easy handling
  - Low-cost
- Fire Sensing Challenges
  - Varying spatial and temporal scales for different prescribed fires and wildfires
  - Fast evolving fire fronts
  - Fire environment
    - High temperature
    - Strong wind and turbulence
    - Smokes and fire plumes

Fire Aerial Video from Dr. Ming Xin, University of Missouri

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CUSL UAS Platform

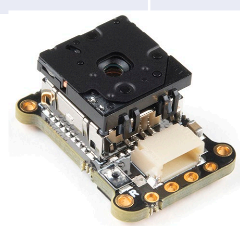
- Fixed-Wing & Multirotor UAS

	Weight & Size	Payload	Endurance	Autopilot	Wind	Other
KHawk 55 Thermal	5.8 lbs. 55 in. wingspan	FLIR Vue Pro R + GoPro NIR + Aeroprobe 5-hole Probe	20 min.	Pixhawk Cube	<15 mph	Cruise speed: 25 m/s
KHawk Hexcopter	2.88 lbs. 22 in. diagonal length	GoPro RGB + GoPro NIR	10 min.	Pixhawk 2	<10 mph	Cruise speed: 10 m/s
KHawk Quadcopter	6.09 lbs. 26 in. diagonal length	FLIR Lepton + RGB	35 min.	Pixhawk Cube	<10 mph	Wireless WIFI + Raspberry PI


CUSL UAS Measurements

- UAS Motion Sensing and Wind Sensing
  - Pixhawk autopilot ($[Lat, Lon, Alt]$, $[V_N, V_E, V_D]$, $[\phi, \theta, \psi]$, $[p, q, r]$, $[a_x, a_y, a_z]$)
  - Aeroprobe 5-hole probe ($[V_a, \alpha, \beta]$)
- Fire Sensing Payload

	Spectral Band	Resolution	FOV	Temperature Range	Temperature Accuracy	Data Format
FLIR Vue Pro R	7.5 – 13.5 um	640×512 pix	69×56 deg	High gain: -25° to+135°C Low gain: -40° to+550°C	High gain: 5 % Low gain: 10 %	14-bit TIFF Frame
FLIR Lepton 3.5	8 – 14 um	160×120 pix	71×57 deg	High gain: -10° to+140°C Low gain: 10° to+450°C	High gain: 5 % Low gain: 10 %	8-bit PNG
PeauPro NIR	825.4-880 nm	1920×1080 pix.	74×45 deg	-	-	Video Mode
PeauPro RGB	RGB	1920×1080 pix.	74×45 deg	-	-	Video Mode



Outline

I. Introduction

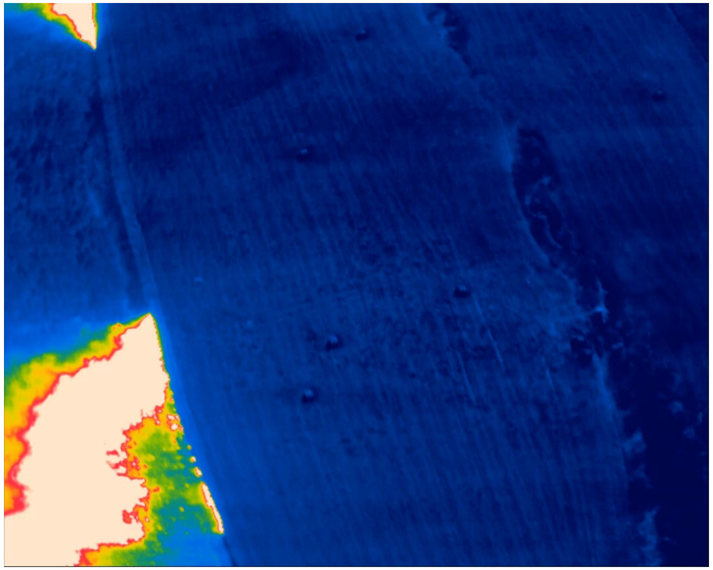
II. UAS Platform & Fire Data Collection

III. Fire Metrics Measurement Using sUAS
a) Fire Front Location and Rate of Spread Measurement
b) UAS based Wind Measurement during Fire Burning

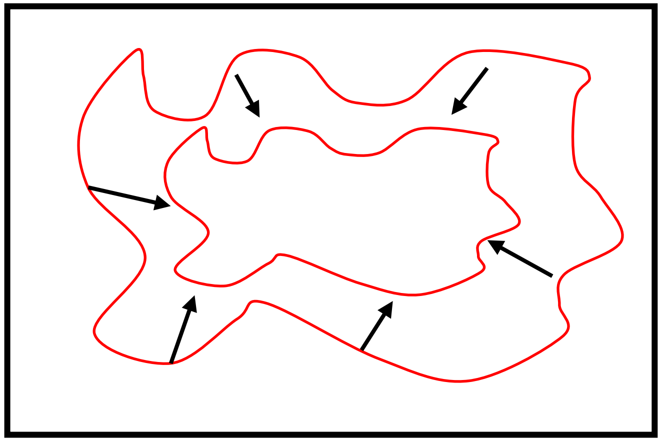
IV. Conclusions and Future Work

Fire Front Location & Rate of Spread Measurement

- Fire metrics, including fire front location and rate of spread (ROS), are critical to understanding the fire behavior and to fire spread modeling and prediction.
- A new method is developed for recapture of a prescribed fire and for fire evolution mapping using orthorectified repeat-path thermal images from a small fixed-wing UAS.



Raw UAS Thermal Imagery and GPS

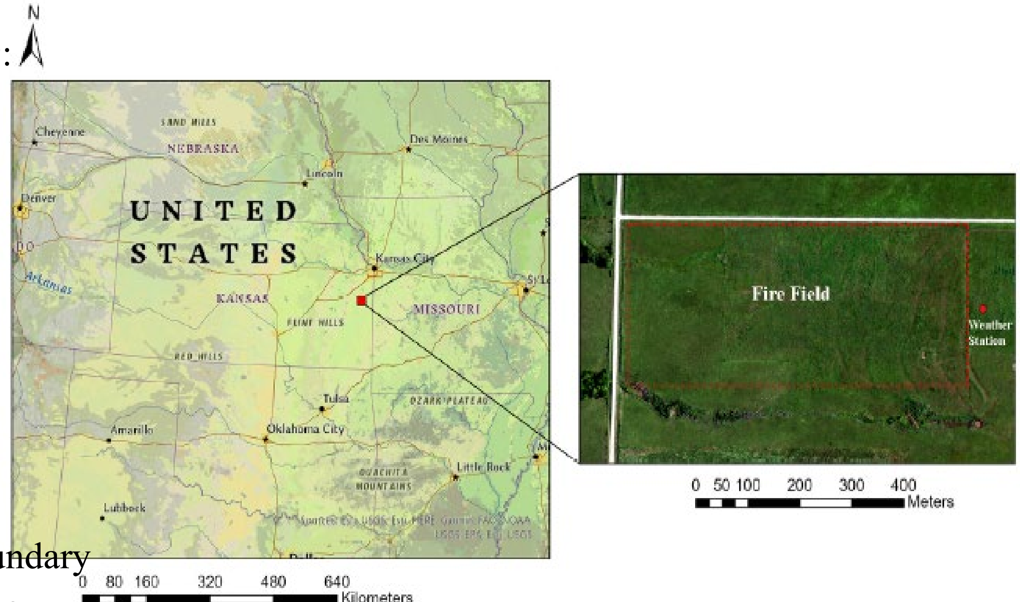


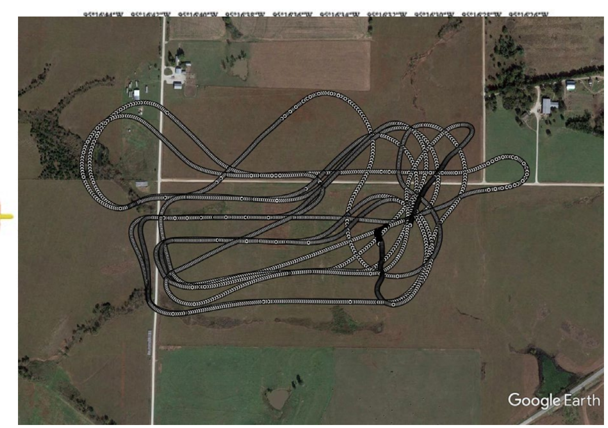
Fire Evolution Map and Fire Metrics Measurement

S. Gowravaram, H. Chao, et. al., "Prescribed Fire Evolution Mapping and Rate of Spread Measurement Using Orthorectified Thermal Imagery from a Fixed-Wing UAS", submitted to Int. J. Remote Sensing, under revision.

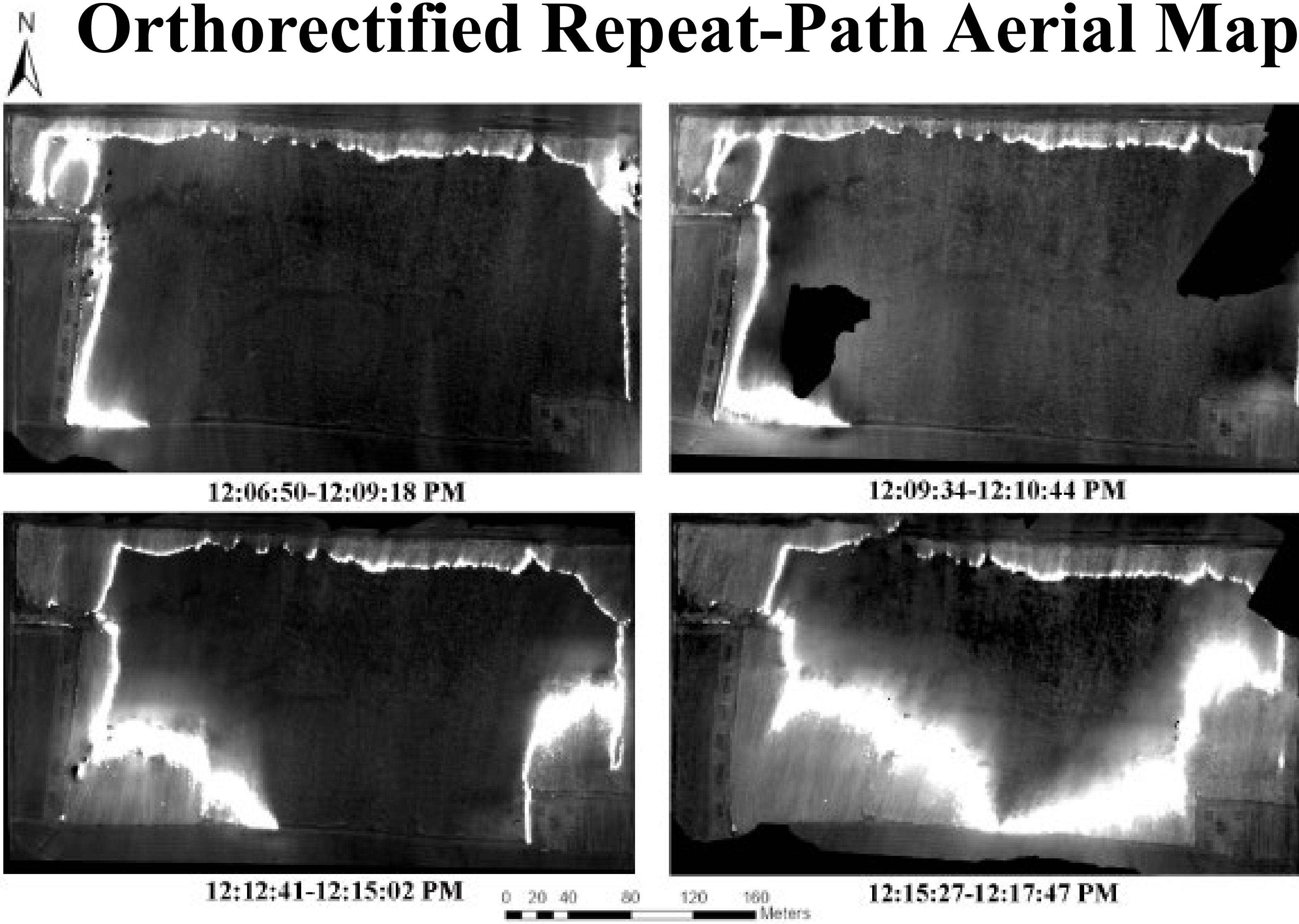
Prescribed Fire Experiment: 2019 Anderson County

- **Prescribed Fire**
  - Anderson County Prairie Preserve: Oct. 8, 2019:
  - Area: 650 m×350 m
  - KHawk 55 flight (Thermal + NIR): 2
- **Weather Conditions**
  - Temperature: 73 °F
  - Ground wind (2 m): ~13 mph from South
  - Humidity: 44 %
- **Fire Setting**
  - Two KBS teams start the fire (ring fire)
  - Team 1: clockwise from mid-point of North boundary
  - Team 2: counterclockwise from the same starting location
- **KHawk Flight**
  - Altitude: 120 m above the ground level
  - Part 107 flight in class G airspace
  - Trajectory: Autonomous, multiple loops around the area (2 min each loop)



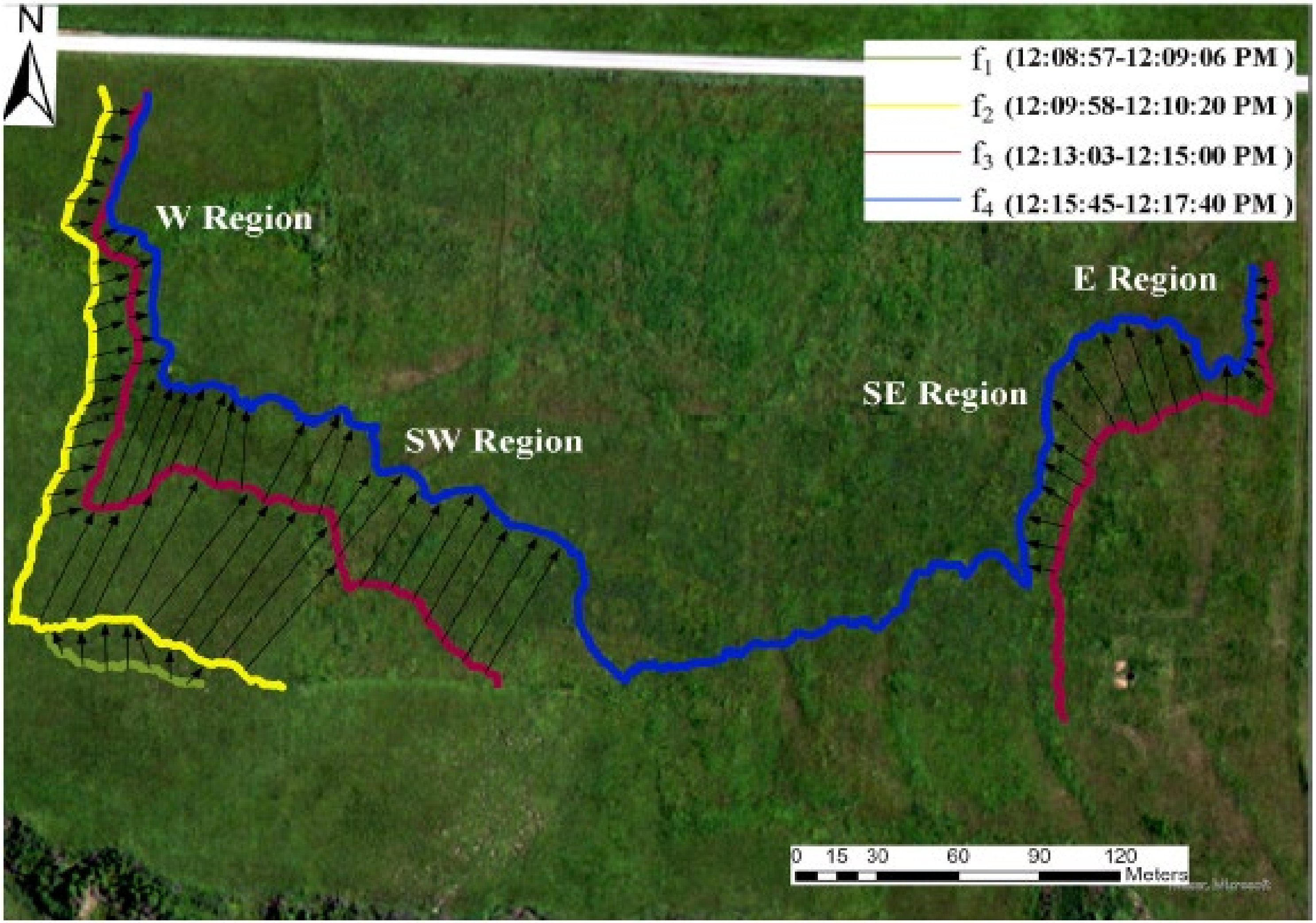


Orthorectified Repeat-Path Aerial Maps



Four maps are generated using Agisoft from synced thermal aerial images and GPS data. Horizontal RMSE: ~ 2 m (after registration with a NAIP image).

Fire Front Extraction & Fire Evolution Map



Maximum and mean fire ROS of 0.4 m/s and 0.27 m/s were observed along the direction of the prevailing wind.

Real-time Fire Metrics Measurement Using UAS Thermal Imagery

- Ongoing efforts on real-time measurement of fire front location and rate of spread. Preliminary result for direct georeferecing method.

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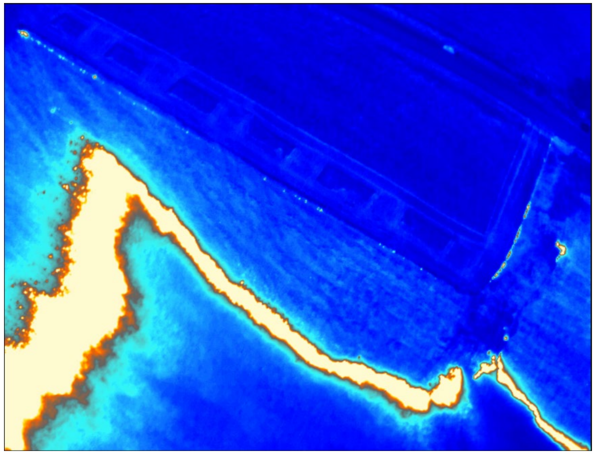

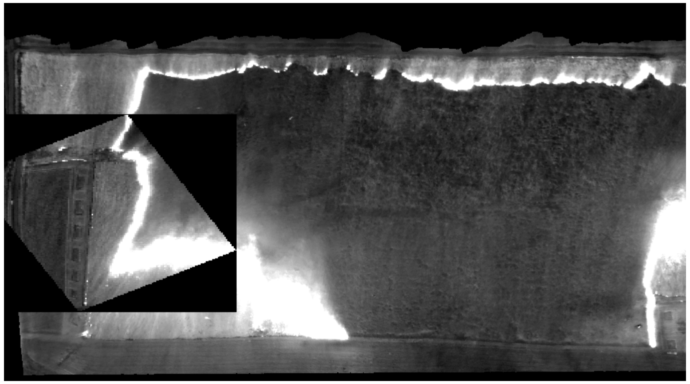

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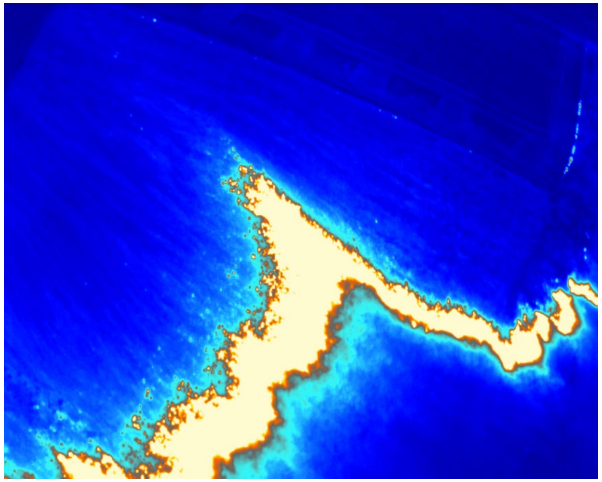
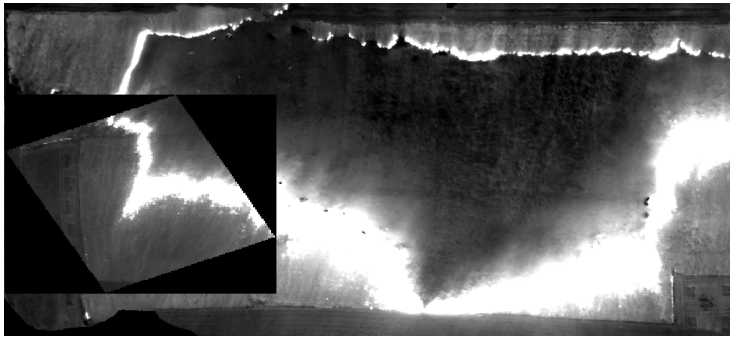
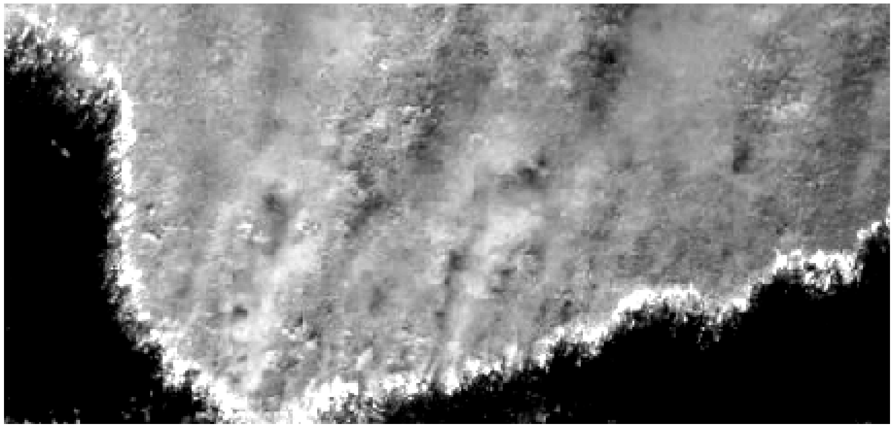




Fire Front Location & Rate of Spread Measurement from UAS NIR Data

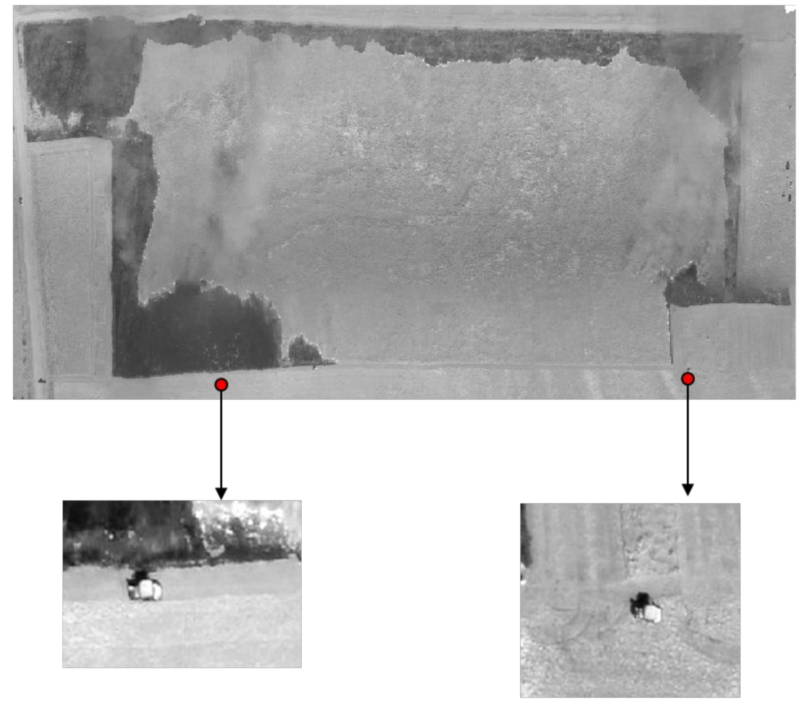
- Currently working on developing a new method for low-cost NIR based solution for accurate fire detection and ROS measurement.

Fire Front Location & Rate of Spread Measurement from UAS NIR Data



Zoomed in view of NIR map

Zoomed in view of thermal map



38°10′52.43″N, 95°16′37.38 W
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38°10′52.36″N, 95°16′26.17 W
12:13:41 PM

NIR imagery has higher spatial resolutions than thermal imagery while thermal data is richer in spectral information.

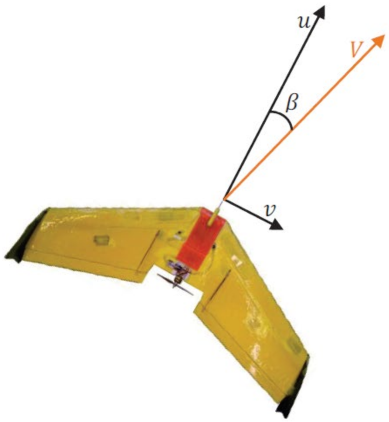
UAS based Wind Estimation during Fire Burning

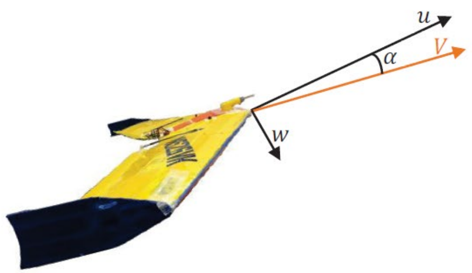
- Wind estimation equation from airspeed and ground speed measurements.

$$\begin{bmatrix} W_N \\ W_E \\ W_D \end{bmatrix} = \begin{bmatrix} V_N \\ V_E \\ V_D \end{bmatrix} - R_b^n(\phi,\theta,\psi) R_a^b(\phi_a,\theta_a,\psi_a) \begin{bmatrix} u \\ v \\ w \end{bmatrix} = \begin{bmatrix} V_N \\ V_E \\ V_D \end{bmatrix} - R_b^n R_p^b V_a \begin{bmatrix} cos\alpha\ cos\beta \\ sin\beta \\ sin\alpha\ cos\beta \end{bmatrix}$$

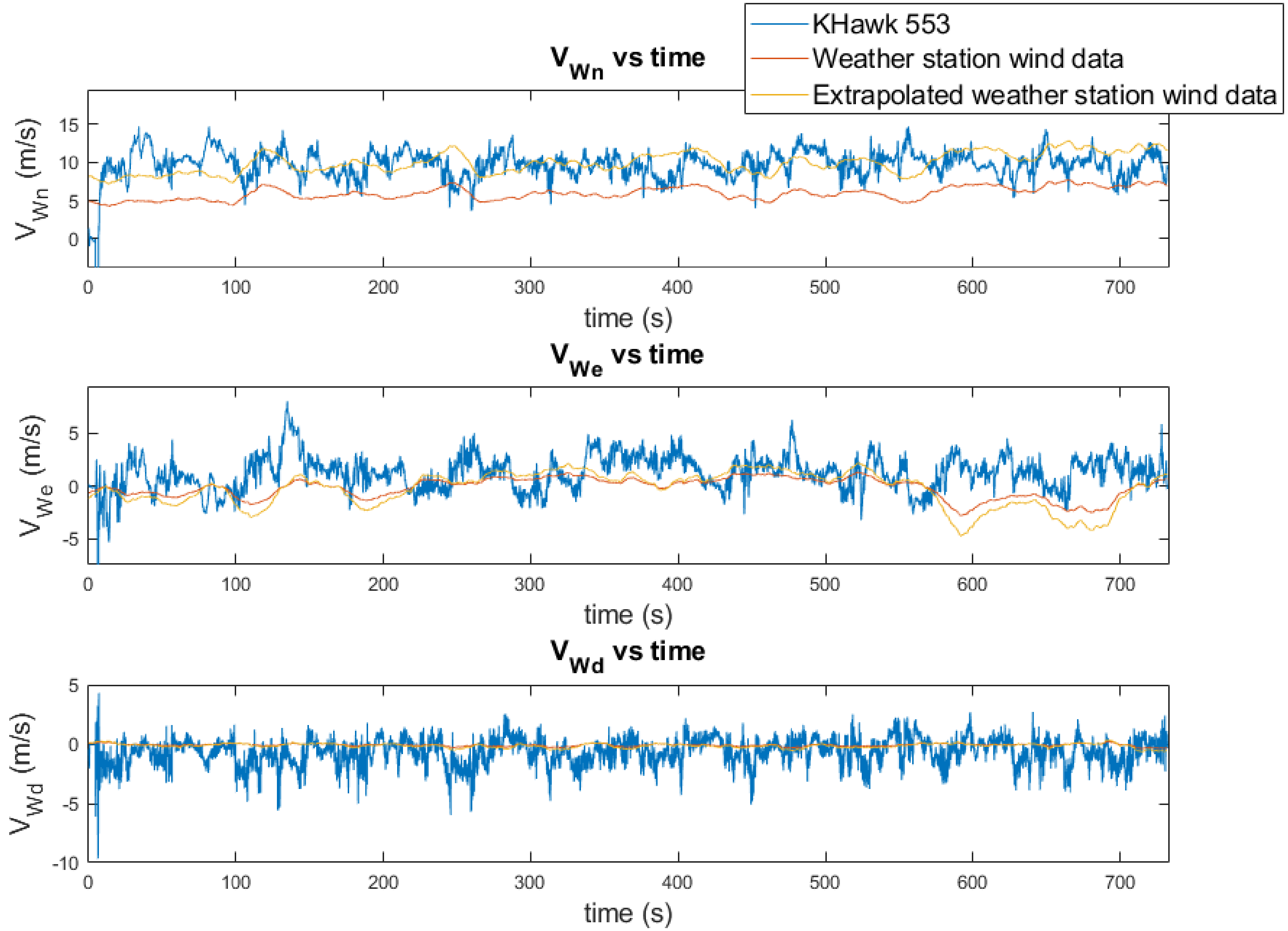
- $[V_N, V_E, V_D]$ is the GPS ground speed, $[\alpha, \beta]$ are angles of attack and sideslip.
- R_b^n is the rotation matrix from the aircraft body frame to the local NED frame.
- R_p^b is the rotation matrix from the 5 hole probe frame to the aircraft body frame.
- Wind shear extrapolation model: power law. $\gamma = 1/7$.

$$V_{W_h} = V_{W_{hr}} \left(\frac{h}{h_r}\right)^{\gamma}$$





UAS based Wind Estimates vs Ground Weather Station Measurements



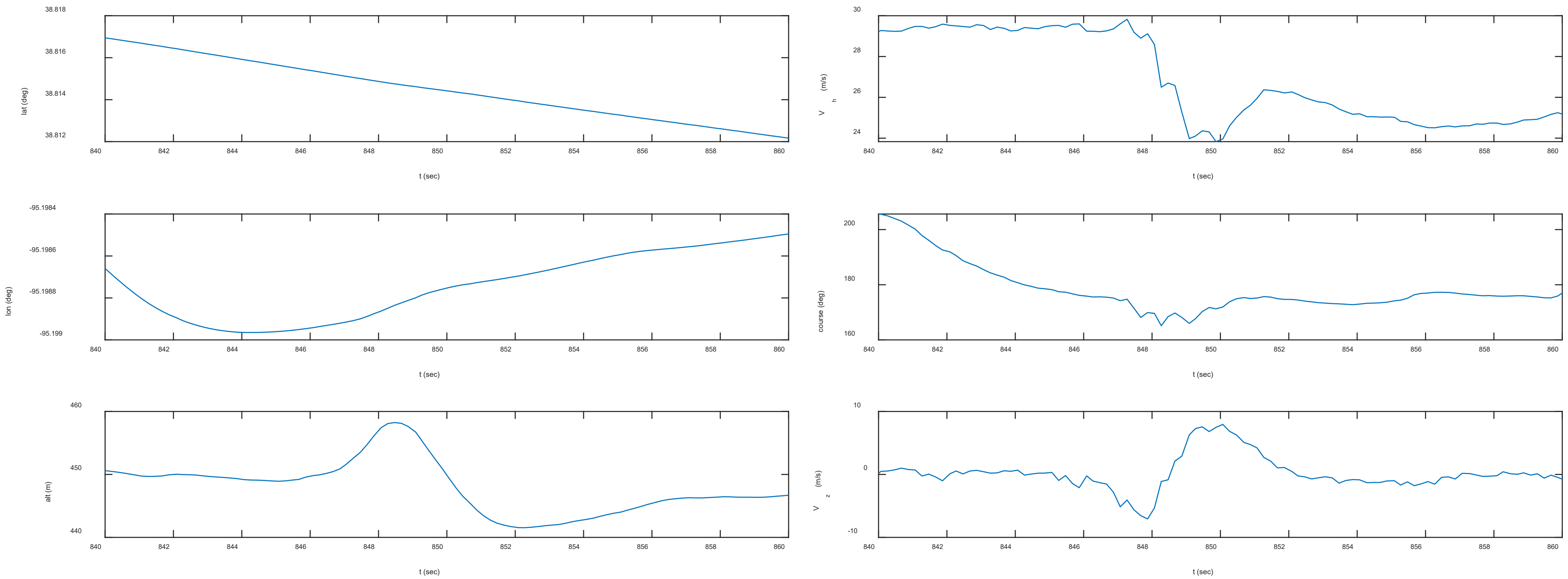
Ground wind measurement from Campbell Scientific CSAT3b (stationed by the fire burning site and ~ 2m above the ground).

UAS based Wind Estimation during Fire Plume Encounters

- Ongoing efforts on wind velocity estimation during UAS turbulence counters of fire generated plumes

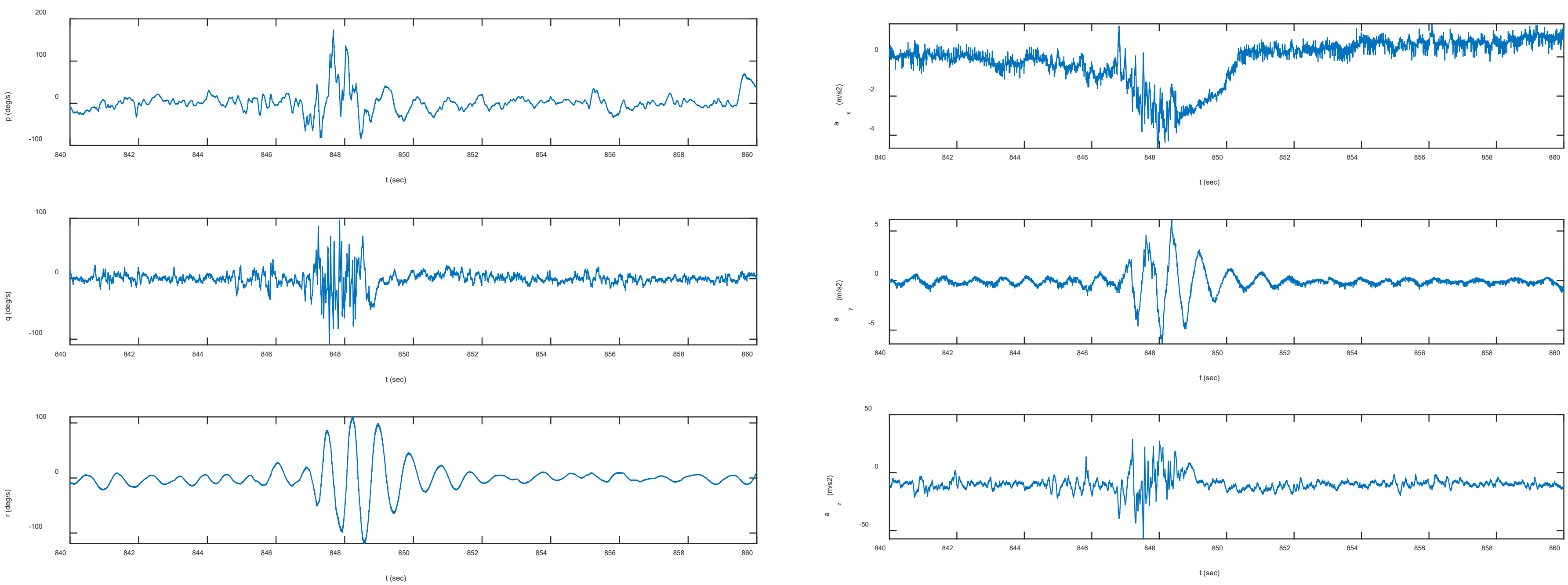
UAS based Wind Estimation during Fire Plume Encounters: Initial Data

- The measured UAS turbulence response data can be used for estimation of updraft velocity and fire plume turbulence level (TKE).
- GPS measurements during UAS turbulence encounters in fire plumes
  - Altitude change +- 10 m; V_z change [-6, 7] m/s; ground speed change: 30 – 24 m/s



UAS based Wind Estimation during Fire Plume Encounters: Initial Data

- Inertial measurements of UAS turbulence encounters in fire plumes
  - p, q, r change +- 100 deg/s; a_z change [-4, 4] G



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Conclusions & Future Works

Conclusions

- Initial results showed the effectiveness of small UAS in fire metrics measurements including fire front location, fire rate of spread, and mid-flame mean wind velocity during fire burning.
- There are still a lot of challenges in UAS based fire data collection, calibration, and validations due to the dangerous, complex, and dynamic nature of fire and local fire weather.

Future Works

- Fire perception and UAS flight simulation.
- Fire wind sensing, estimation, and modeling.
- Autonomous fire boundary following for UAS.
- Gust suppression flight controller design.
- UAS fire path planning in consideration of smokes and fireline evolution.

Acknowledgements

CUSL Team

- Dr. Pengzhi Tian
- Dr. Harold Flanagan
- Jacksen Goyer
- Justin Matt
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- Zhenghao Lin
- Mosarruf Hosain Shawon
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Kansas Biological Survey

- Sheena Parsons
- Dr. Bryan Foster
- Dr. Dean Kettle
- Bruce Johanning
- Vaughn Salisbury

Research Collaborators

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