Small Unmanned Aircraft Systems for High-Resolution Thermal Mapping: An Application for Freeze-Thaw Remote Sensing

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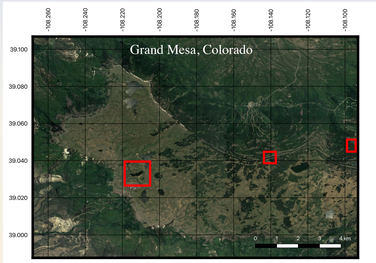
INTRODUCTION

- **Why measure the Earth's surface Freeze/Thaw (FT) state?**
  - Carbon cycling - FT seasonality regularly defines the growing season, plant productivity
  - Hydrology - frozen ground can reduce infiltration, increase flooding and store water
  - Global energy balances[1] – evaporation, energy fluxes are impacted by frozen ground
  - Climate – useful method to monitor impacts of changing climate, trends in growing season duration
- **How is Freeze/Thaw state measured?**
  - Traditionally FT has been measured/assumed using in-situ soil and air temperature observations
  - More recently, FT has been derived from observations from the microwave or thermal infrared bands of the electromagnetic spectrum using radar and radiometers (tower mounted, airborne, or satellite-based global products)
- **Why Small UAS?**
  - The utilization of drones and thermal cameras systems has been implemented in search and rescue, agriculture, industry, and other research applications providing affordable, easily deployable on demand, and high-resolution mapping capabilities
  - Small UAS systems have the potential to capture high-resolution estimates of surface temperature and associated FT dynamics
  - They also can help improve FT products (9-36km resolution) beyond the current binary estimates given over large regions by more accurately depicting FT variability
- **Key Terms**
  - **Unmanned Aircraft System (UAS)**
  - **Thermal Infrared (TIR)**
  - **Freeze/thaw (FT)**

UAV SYSTEM & STUDY SITES

DJI Inspire 2 – Dual Gimbal-Mounted Thermal and RGB Cameras



Study areas indicated in red. Grand Mesa, located in western Colorado sits at >3000m elevation and is site of NASA snow measurement and modeling campaign (SnowEx)

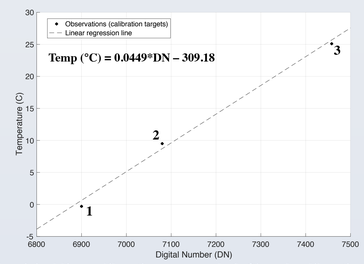
FLIR Vue Pro R (left), DJI Zenmuse X4S (middle), sUAS 2-axis gimbal w/ FLIR (right)

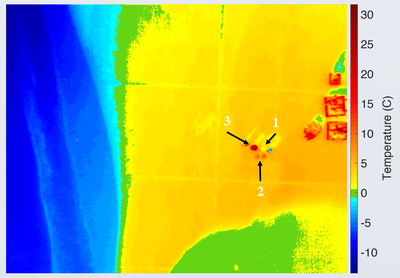
- **Study Area:** Grand Mesa, Colorado
- **Data Collection Periods:** April & November 2019 during FT transitional periods
- **System Specifications**
  - DJI Inpsire 2: Weighs 2.4kg w/ payload capacity ~1kg, up to 30 min flight time
  - Zenmuse X4S: 20-megapixel RGB camera, mounted on DJI built in gimbal
  - FLIR Vue Pro R: Radiometric thermal camera, 640 x 512 pixels, stated +/- 5 °C accuracy
  - sUAS Drone Thermal Vision 2-axis gimbal w/ GPS and data logging
- **Data Resolution:** Ground sampling distance (GSD) 2.7 – 15.7 cm (20 – 120m flight altitude)
- **Image Collection and Flight Planning:** Pix4D auto-pilot flight plan, FLIR automated image capture at 2 second intervals, Zenmuse RGB capture automated in Pix4D software
- **Ground Measurements:** Contact and IR measurements of different ground targets and cover (calibration targets, vegetation, rocks, soil, and snow). Meteorological station w/ continuous weather and soil temperature data

OBJECTIVES

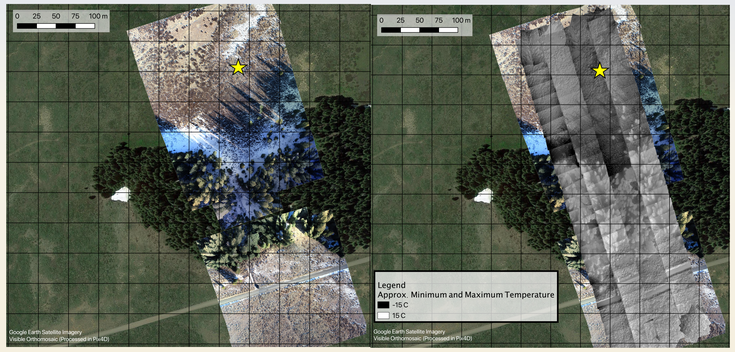
- **Develop** accurate (+/- 1 °C) and high-resolution (~1-15 cm) maps of land surface temperature
- **Identify** potential challenges and appropriate data collection and processing techniques
- **Assess** dynamics of freeze/thaw and its variability over small regions

RESULTS

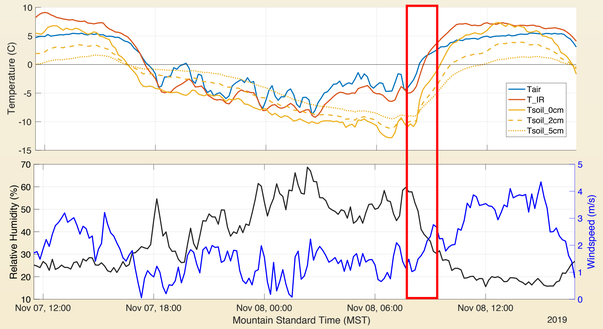




Empirical line calibration approach (left) and calibration image (right). Calibration targets identified as ice water (1), sun exposed black polyurethane (2), and warm water (3). These targets were used for the calibration line and regression fit to then convert image DNs to temperature values. Accuracy estimated +/- 5 °C. Taken April 8, 2019

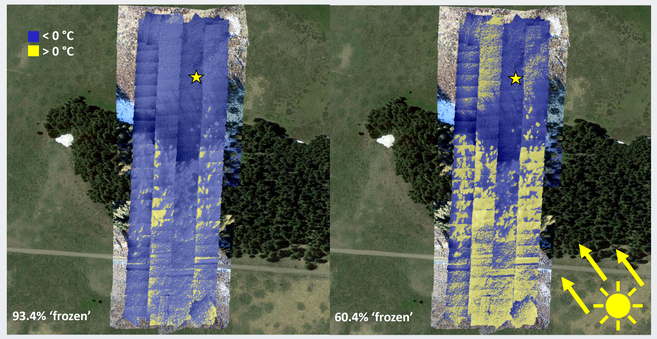


Orthophoto of study site from RGB (left), Raw flight thermal images (right) projected onto map. Yellow star indicates location of meteorological site. Images collected from 8:23 – 8:28 AM @ 50m AGL, November 8, 2019



Meteorological site data from during flight period (indicated by red box ~7:30 AM – 9AM). Soil, infrared, and air temperatures shown (top), relative humidity and windspeed shown (bottom)

CHALLENGES



FT Uncertainty: Thermal imagery calibrated using ground observations of object temperatures and regression approach. Left image calibrated using minimum of object measured temperature range; Right image calibrated using maximum of measured temperature range

- **UAS based thermal calibration challenges** [2-6]
  - Sensor temperature drift – impacts due to wind and air temperature
  - Varied target emissivity
  - Atmospheric, wind, and solar illumination effects
  - Camera lens effects – leads to higher DN values in center of image (vignette effect)
- **Other challenges**
  - Mosaicking – effected by number of images and angle of data collection
  - Use and placement of uniform, easily identifiable calibration targets
  - Trade off of resolution for spatial coverage

DISCUSSION & CONCLUSIONS

- **Small UAS systems** have the capability to **affordably** map land surface temperature at **high resolutions** (<3 cm GSD at 20m flight altitude) with **frequent revisit** times
- **High spatial variability** in temperature and thus FT is observed at fine scales, enabling FT dynamics to be studied spatially at enhanced scales
- Both **geolocation and observed temperature uncertainty** can considerably impact the accuracy of land surface FT state estimation
  - Non-trivial calibration is required to retrieve radiometric level temperature data by correcting for sensor and environmental effects and by using calibration targets during each flight
- **Next Steps**
  - Improved data processing and thermal calibration
  - Utilizing image processing software to create seamless thermal orthophotos
  - Comparing sUAS mapped TIR to satellite- based thermal and microwave observations

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