Ground-based experimental study into directionality of surface temperatures over different crops

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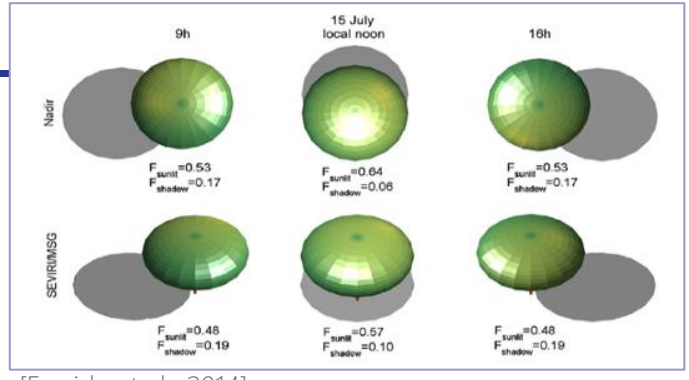
Scientific Background & Motivation

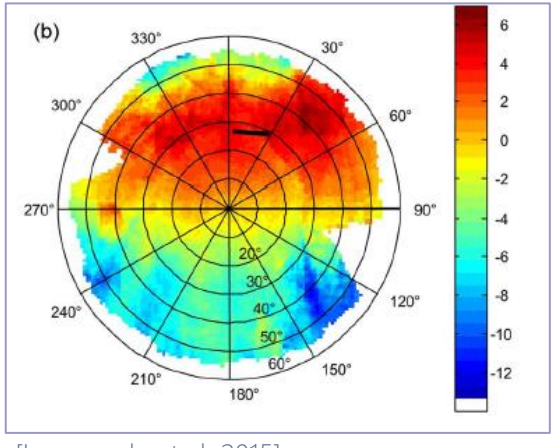
- Viewing & illumination geometry long been known to have significant impacts in thermal (although not as studied as BRDF in optical)
- Main causes: (i) **emissivity anisotropy**, (ii) **mixed components/shadowing** & **(iii) hotspot** effects
- Magnitude of impacts vary depending on different parameters
- Models have been developed to assess + potentially adjust for these directional effects but **limited validation against real observations & in-situ data**
- New TIR satellite missions (LSTM, SBG, TRISHNA) being developed - need to understand **what directionality effects there would be**, when/where these would be maximal/minimal & whether can correct for them

Mixed Components/ Shadowing



[Ermida et al., 2014]

Hotspot



[Lagouarde et al. 2015]

SwathSense Campaign Overview & Objectives

1 Practical showcase of directional effects

2 Identification of situations where effects are maximal

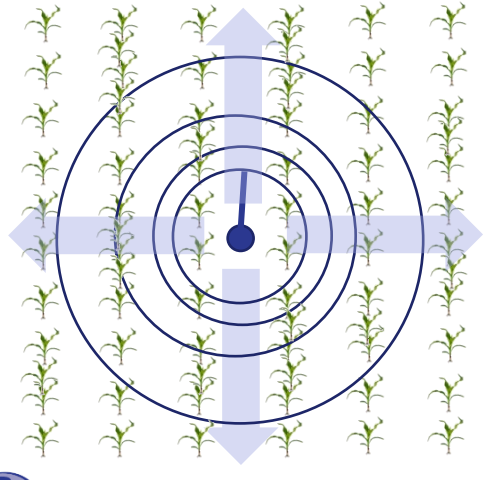
3 Demonstration case for future satellite missions

4 Demonstration of the viability of an airborne simulator

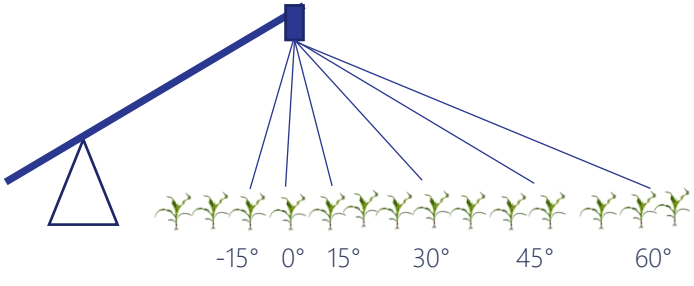
- First campaign organised for July/August 2021 in UK/ Spain
- Second campaign recently finished in Italy/ UK (May – July 2022)
- Third campaign planned for April/ May 2023

Multi-angular ground-based setup

- "Brontosaurus" = crane jib equipped with Optris PI450i thermal camera (7.5 – 13.5 um; 35° x 45° FOV), Heitronics KT15.85 IIP radiometer (9.6 – 11.5 um, narrow FOV), GoPro, & gyro sensor
- Measurements made in Grosseto (Italy) in May/June 2022 at 1Hz frequency
- Operated in 'mapping' & 'targeting' modes



View azimuth angles (VAA) = 0°, 90°, 180°, 270° (±3° depending on wind)



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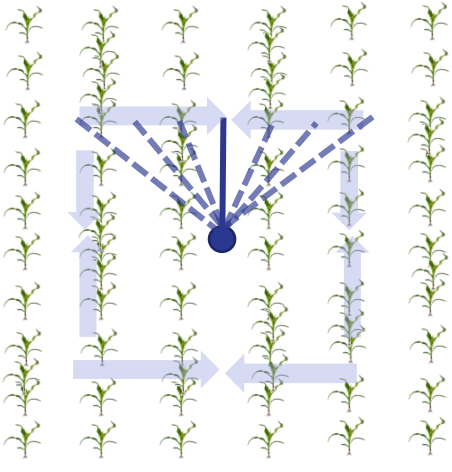

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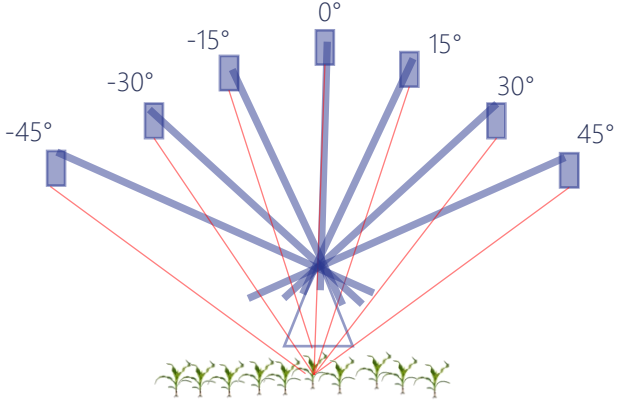

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Targets

ALFALFA: irrigated homogeneous crop

14/5

18/6

CORN: Irrigated row crop

16/5

15/6

TOMATO: irrigated row crop

18/5

19/6

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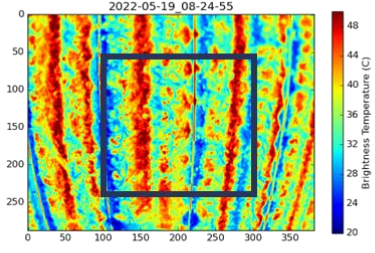
Mapping mode: Post-Processing

VZA: View zenith angle
VAA: View azimuth angle

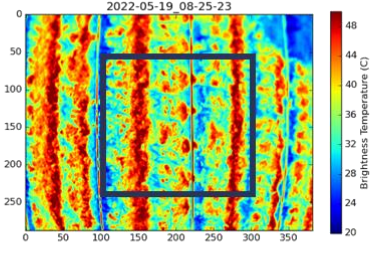
Collate angular information per image → Calculate mean BT at each non-nadir azimuth + view angle ($\overline{T_\theta}$) → Calculate mean BT at nadir for that azimuth angle ($\overline{T_0}$) → Calculate dBT = difference from mean nadir BT ($\overline{T_\theta} - \overline{T_0}$) → Plot dBT against VZA for each VAA

Example:
Corn 19/5

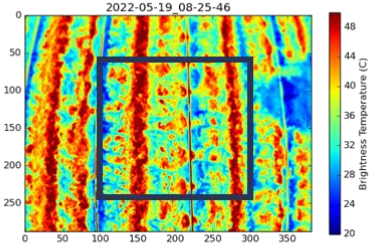
VZA = -15°



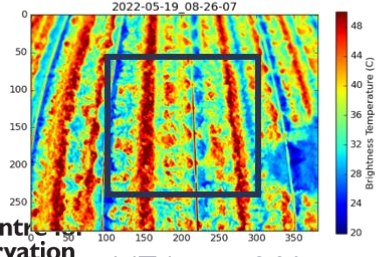
VZA = 0°



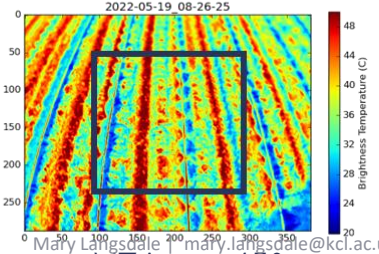
VZA = +15°



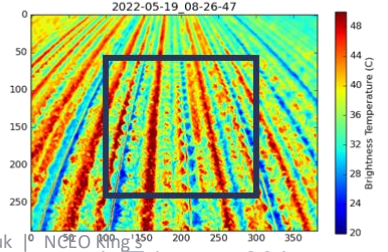
VZA = +30°



VZA = +45°



VZA = +60°



VZA	Mean BT (°C)	dBT (°C)
-15	37.26	-0.35
0	37.61	n/a
15	38.14	0.53
30	37.83	0.22
45	38.09	0.48
60	38.35	0.74

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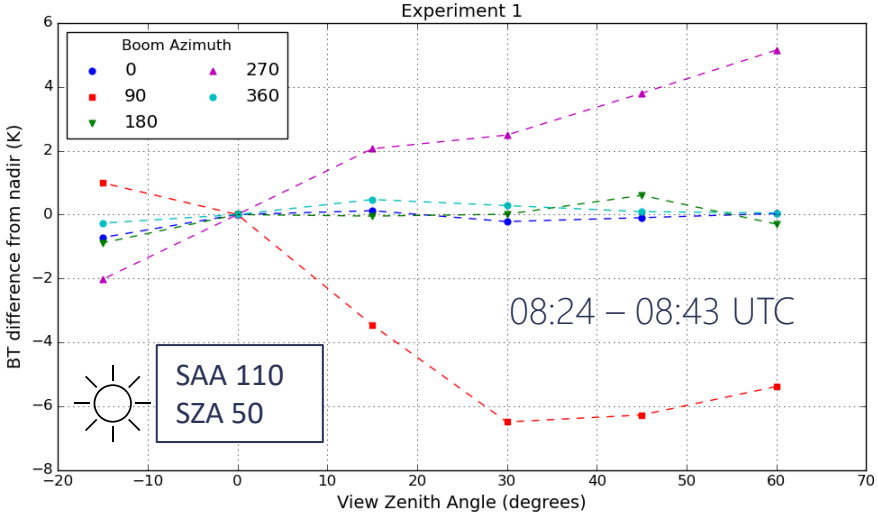
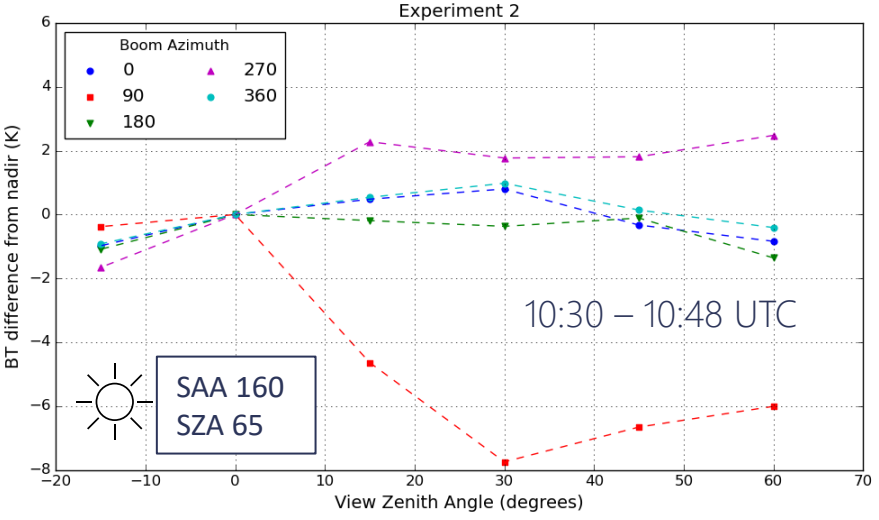
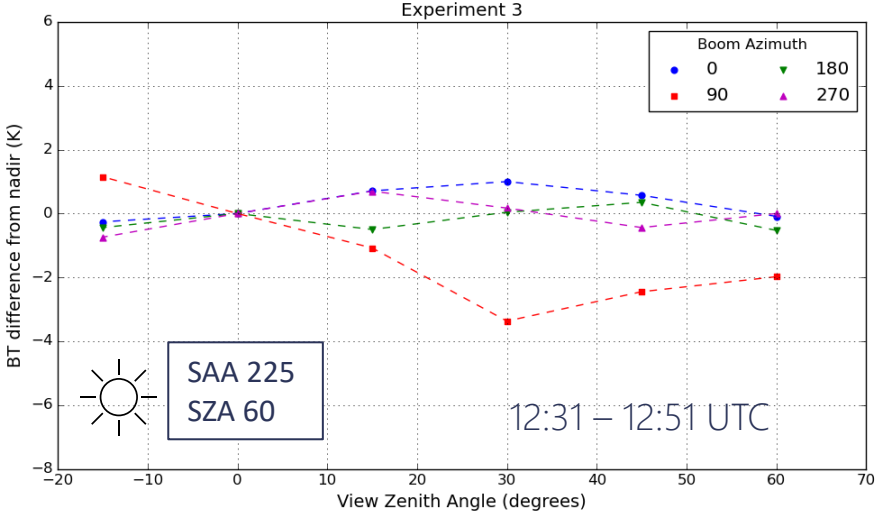
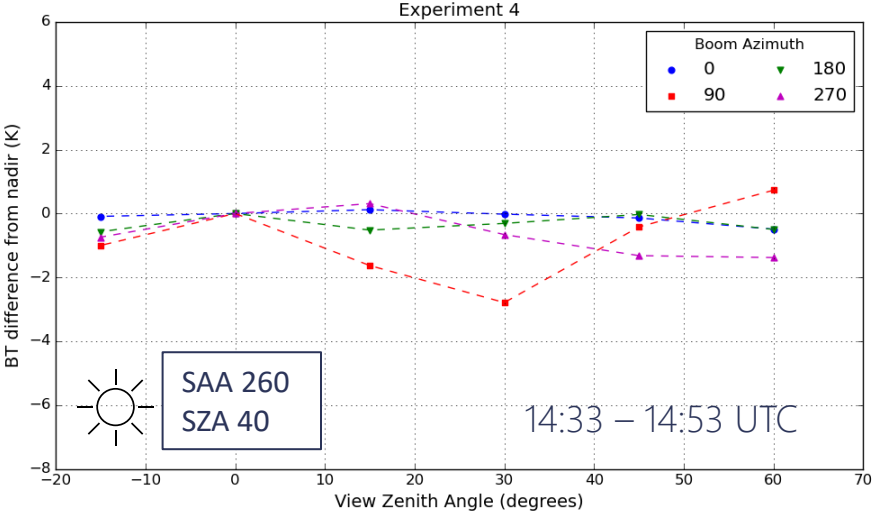
Corn: Early in Growing Cycle (19/5)









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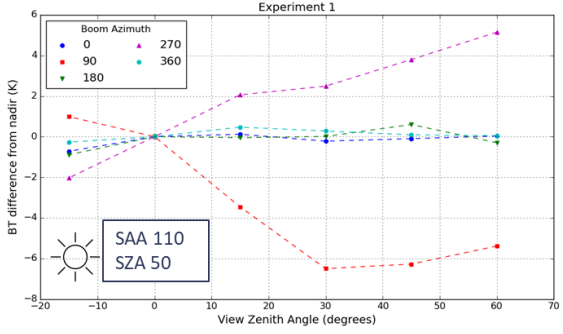
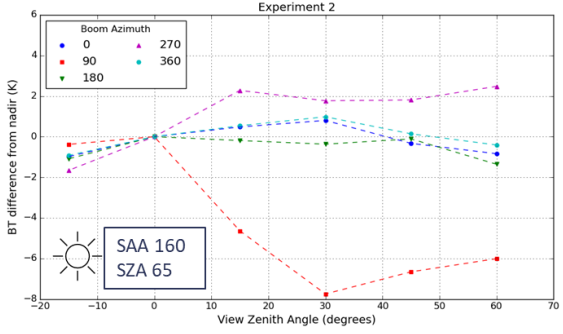
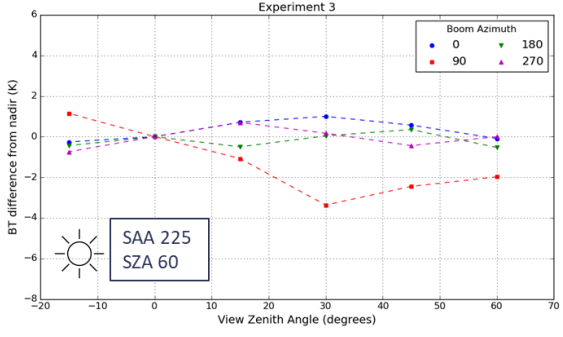
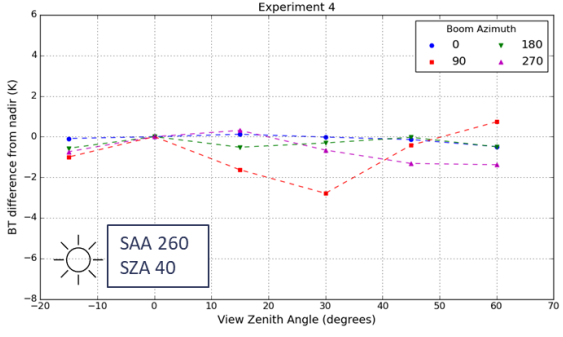








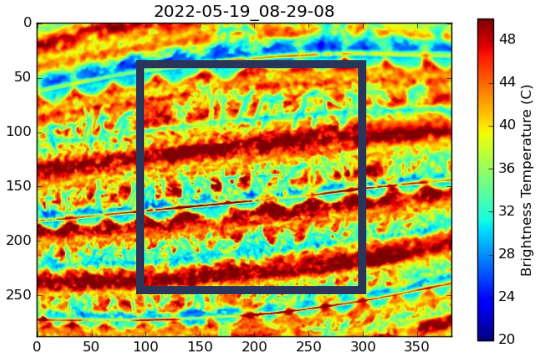
(1) View azimuth angle appears to have strong impact
   a. Consistently see reduced change in BT for VAA = 0 °, 180 °, 360 ° compared to VAA = 90 °, 270 °
   b. Large negative dBT when VAA = 90° and VZA = 30 °

(2) Magnitude of directionality varies depending on the time of day

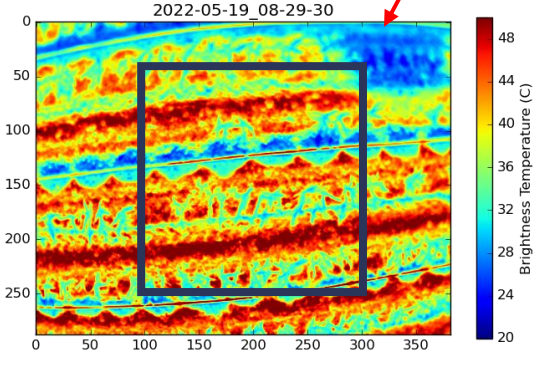
What causes large differences when VAA = 90°, VZA = 30°?

Experiment 1

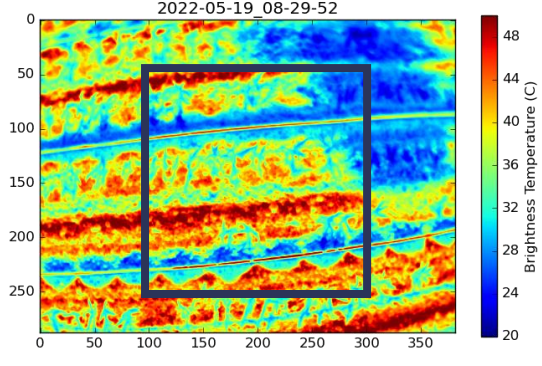
Irrigation puddle



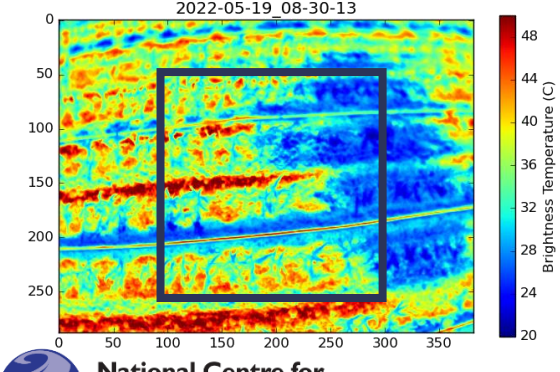
VZA = -15 °



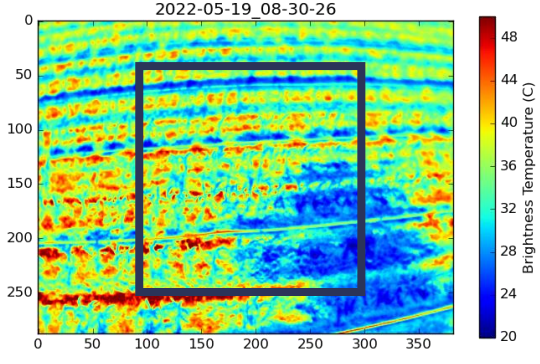
VZA = 0 °



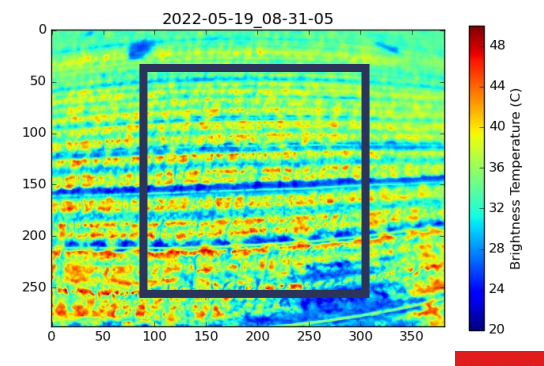
VZA = 15 °



VZA = 30 °



VZA = 45 °



VZA = 60 °

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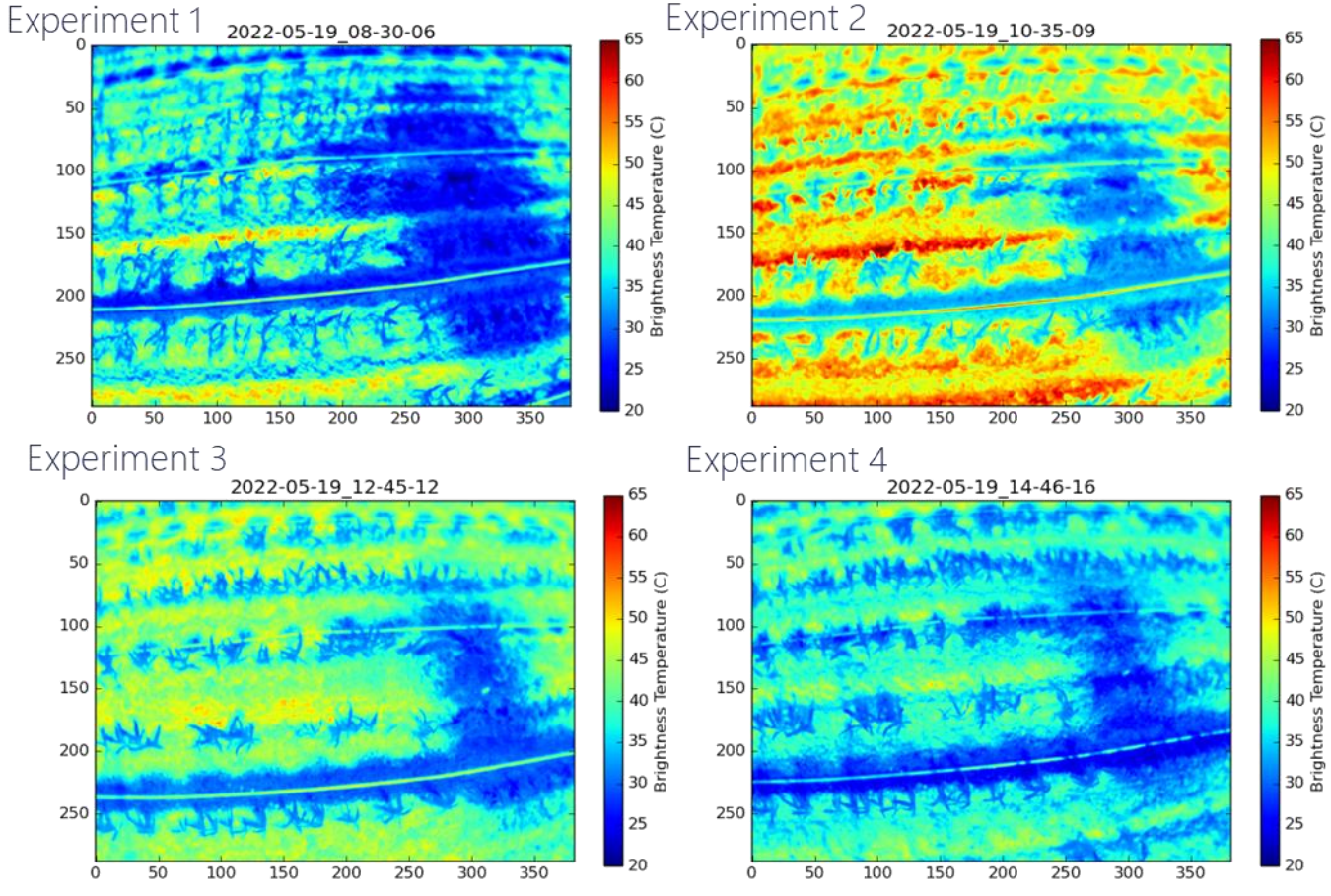
The impact of irrigation

VAA 90°, 30° VZA

- Irrigation also driving diurnal changes in directionality trends

Example: Corn 19/5

- ➢In morning corn was irrigated
- ➢Irrigation stopped prior to Experiment 1
- ➢Water gradually dried up through the day
- ➢This corresponds with reduction in bias (+ apparent directionality) at 30° over course of day



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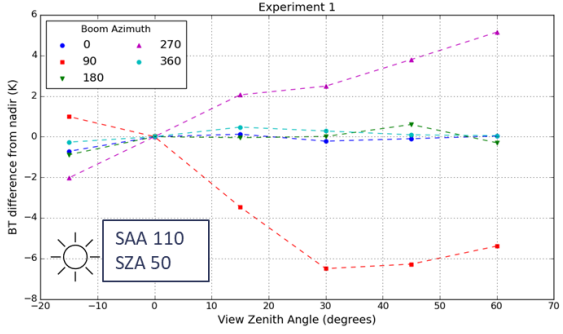

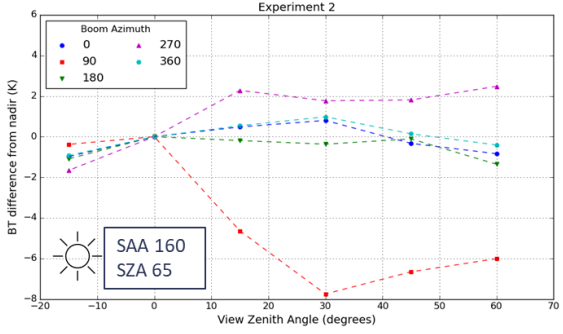

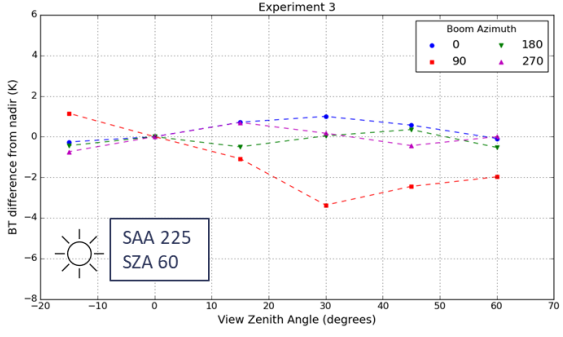

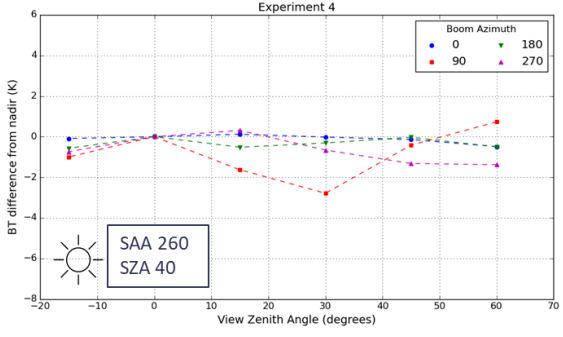

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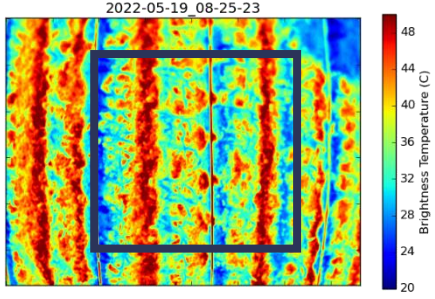
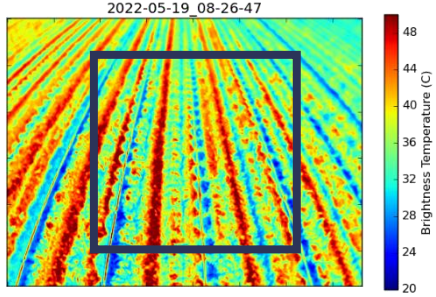
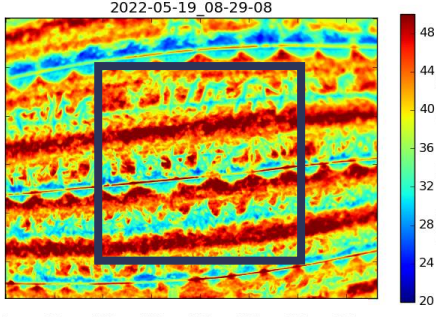
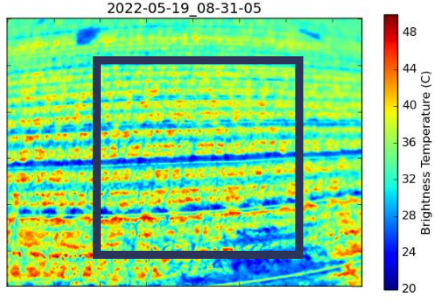
The impact of row orientation

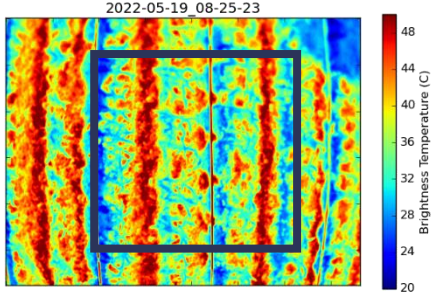
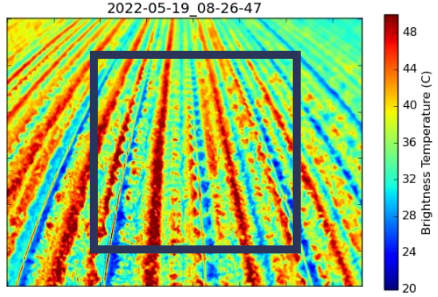
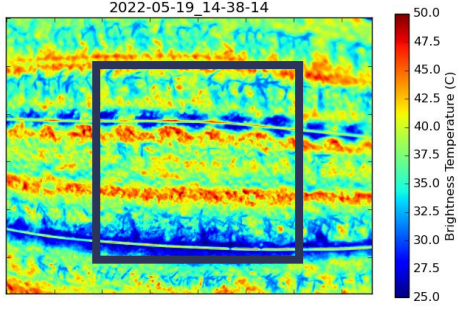
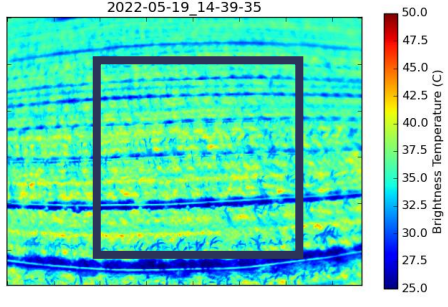
19/5 Mapping Mode

	Nadir	60 °
View Azimuth 0° (parallel)	 Mean BT = 37.8 °C	 Mean BT = 38.7 °C
	dT = +0.9 °C	
View azimuth 90° (perpendicular)	 Mean BT = 41.2 °C	 Mean BT = 34.9 °C
	dT = -6.3 °C	

The impact of row orientation

19/5 Mapping Mode

Larger BT difference when view azimuth perpendicular to row orientation as can't see as much soil between rows at high VZA

	Nadir	60 °
View Azimuth 0° (parallel)	 Mean BT = 37.8 °C	 Mean BT = 38.7 °C
View azimuth 270° (perpendicular)	 Mean BT = 37.3 °C	 Mean BT = 35.79 °C

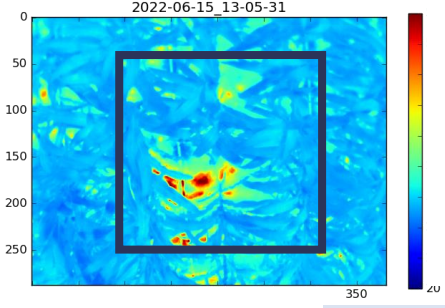
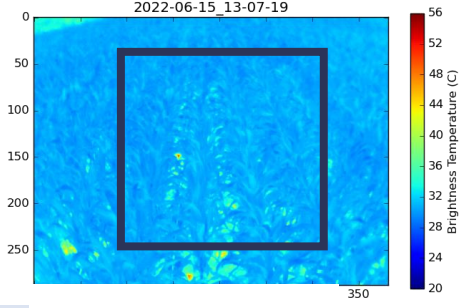
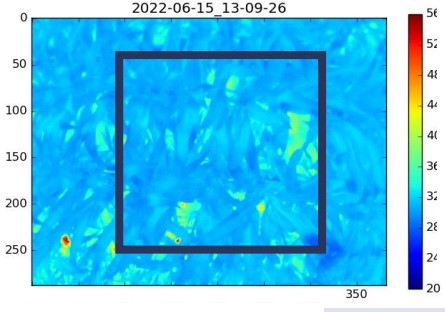
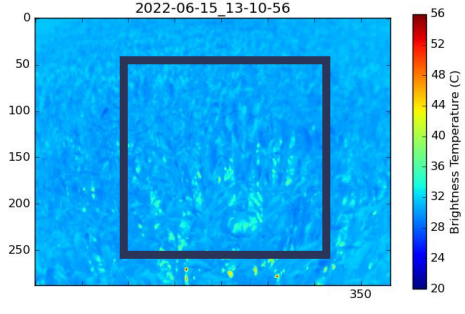
dT = +0.9 °C

dT = -1.5 °C

The impact of row orientation

15/6 Mapping Mode

Reduced BT difference when denser canopy cover compared to earlier in growing cycle due to reduced amount of soil visible through crops

	Nadir	60 °
View Azimuth 180° (parallel)	 Mean BT = 32.5 °C	 Mean BT = 30.8 °C
	dT = -1.7 °C	
View azimuth 270° (perpendicular)	 Mean BT = 31.3 °C	 Mean BT = 30.6 °C
	dT = -0.7 °C	

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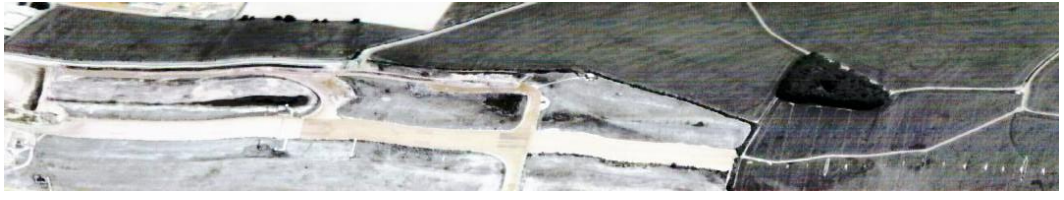
Future work: Upscaling to airborne/satellite scale

NCEO's LWIR airborne sensor with 100 bands (Specim AisaOWL) has been adapted for multi-angular observation

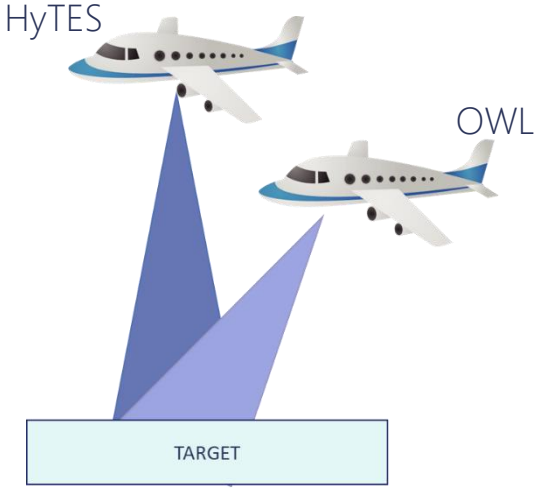
> Maximum 36° offset → can acquire angles up to 48° off nadir



OWL quick-look data, 36° offset view.

OWL quick-look data, nadir view.

Plan for 2023: Two aircraft simultaneously flying



One repeating nadir line, other acquiring simultaneous high angle observations of same area

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esa
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Summary & Conclusions

- Preliminary analysis from multi-angular ground experiments conducted in 2022 suggest that crop growing stage and row structure (especially row orientation) are key drivers of directionality at ground-scale
- Surface heterogeneity (e.g. from irrigation or gaps in planting) can be unpredictable driver of apparent directionality
- New multi-angular adaptation of OWL hyperspectral imager should enable assessment at airborne-scale (& satellite-scale) up to ~45 ° in future campaign
- Data collected in previous & future campaigns will be used to simulate directional effects for multiple proposed satellite missions including LSTM, SBG, TRISHNA

Any questions?
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