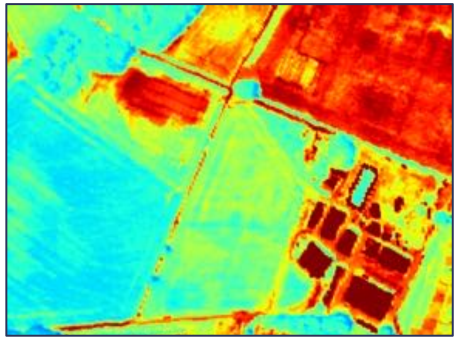
International TIR Airborne Campaign - Europe 2023

Presented by Martin Wooster

King's College London & NERC National Centre for Earth Observation [NCEO]

2023 Airborne Campaign Overview



- ESA / NASA co-funded airborne/ground campaign in Italy & France May – July 23

- Supporting development of multiple future satellite missions

1. LSTM
2. SBG
3. TRISHNA
4. NITROSAT

High-resolution future TIR satellite missions (1–3)

EE11 candidate for nitrogen cycle (NH_3 and NO_2) (4)

- Two intensive operation periods (IOPs) focused mainly on TIR Directionality

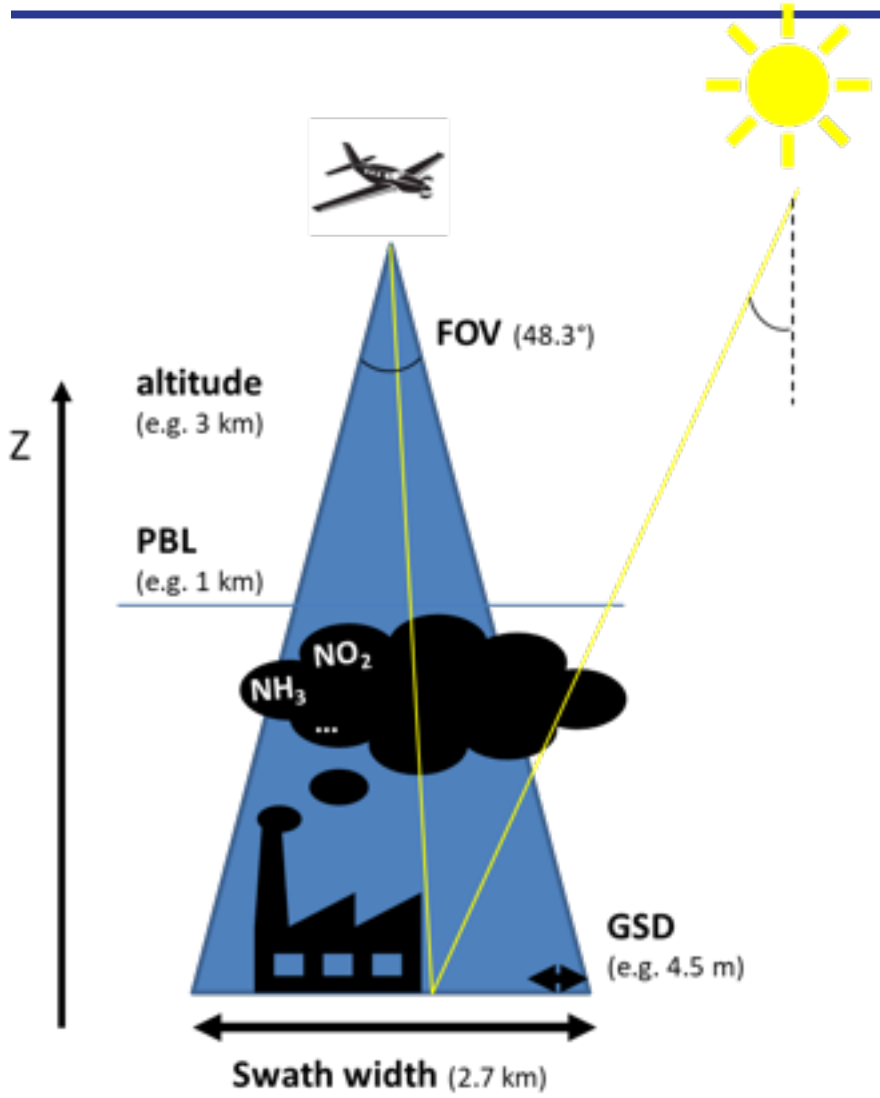
IOP1 = 21 May – 2 June **IOP2 = 25 June – 2 July**

- IOPs each involve two aircraft equipped with LWIR Hyperspectral Imagers

Kenn Borek Air [KBA] + British Antarctic Survey [BAS]

- Single aircraft period (KBA only) between IOPs focusing on other mission objs

NITROSat EE11 Candidate Mission



ESA Airborne campaign in support of the NITROSAT EE11 candidate (phase 0)

Main objectives:

1. Simultaneous retrieval of NO_2 and NH_3 from various sources based on **airborne demonstrator**: agricultural, industrial, domestic, transportation
2. Downsampling airborne to satellite resolution, study sensitivity + detection limit, emission rate retrieval, etc.

Instruments:

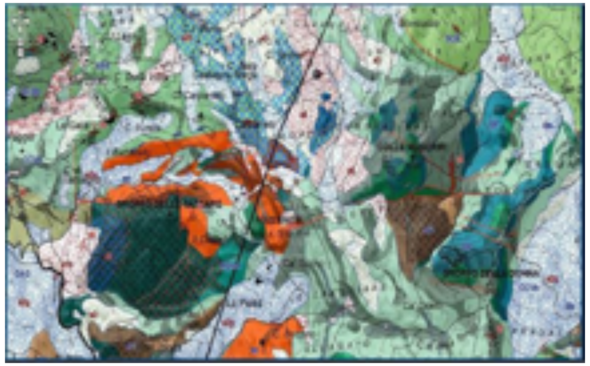
- HyTES (primary) (KBA)
- SWING (BAS)
- Miro (BAS)

- **“Controlled release” experiment for NH3**
- **Flights over urban polluted areas for NO2**

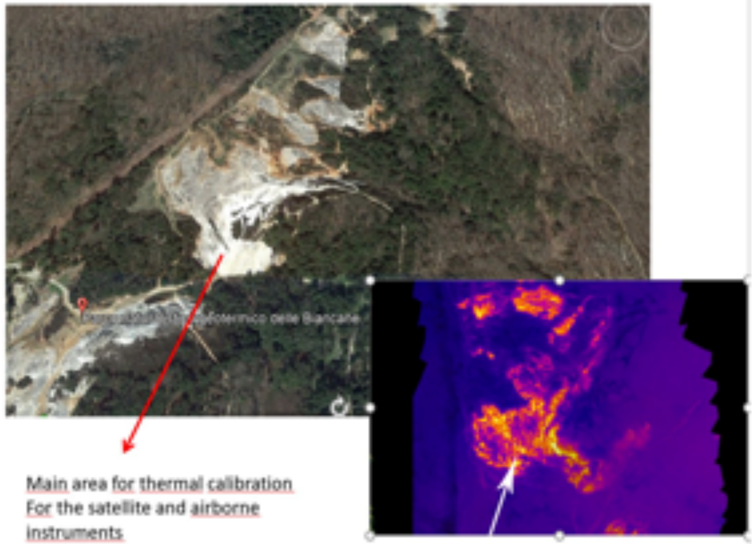
HyTES-derived NH_3
Grosseto (2019)

SBG-Selected Site Characterisation

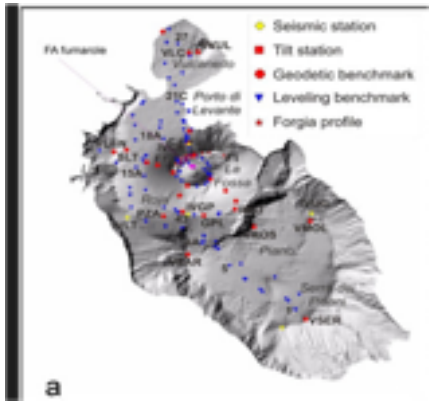
Six sites have been identified across Italy as target sites



Soil / mineral/ raw materials composition



Geothermal activity/ High temperature events



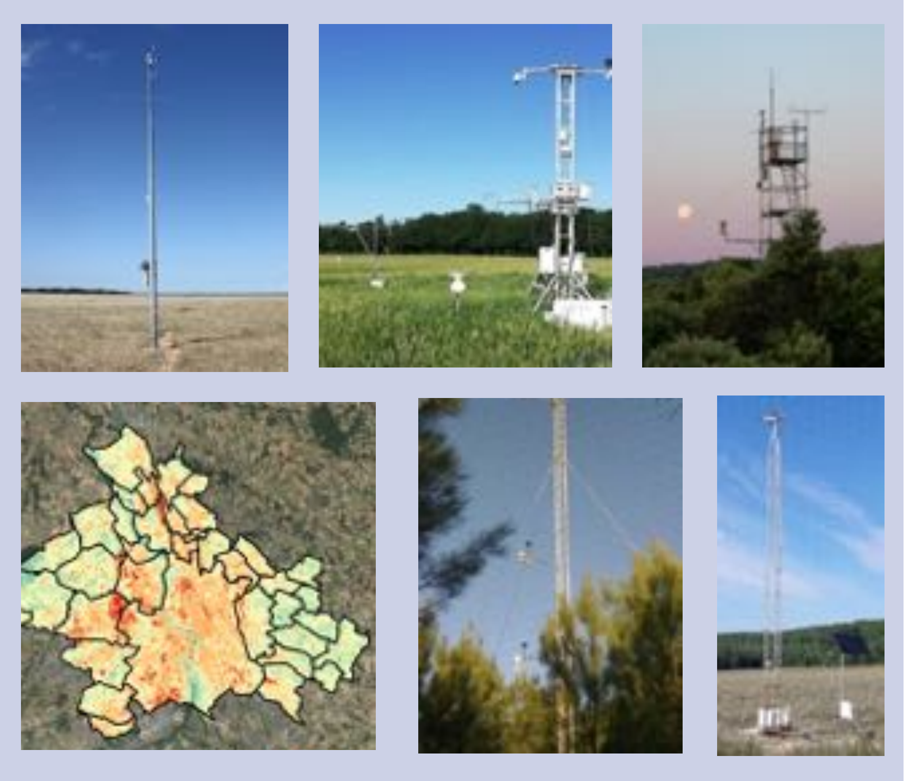
Coastal waters, coastal zone

TRISHNA-Selected Site Characterisation

Selection of sites identified across France as targets

Land covers include:

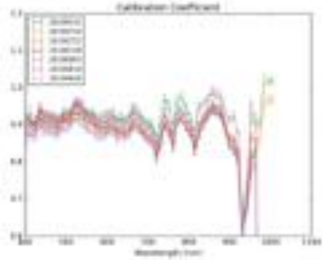
- Pebbles/ grass
- Forest
- Urban
- Coastal
- Agricultural



ICOS Ecosystem Thematic Centre

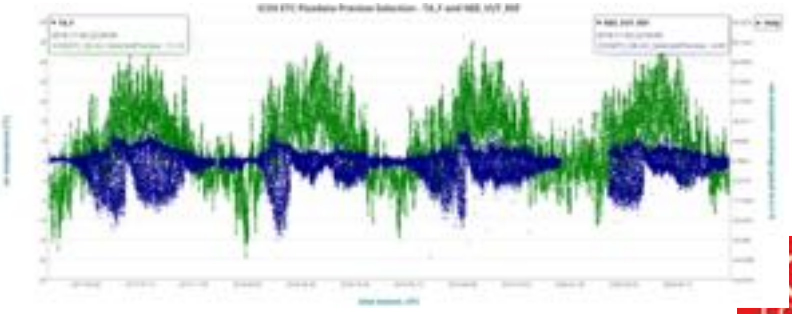
Accompanying in-situ instrumentation with many of the sites part of the ICOS network

VIS-SWIR spectrometers



TIR radiometers

Surface energy balance



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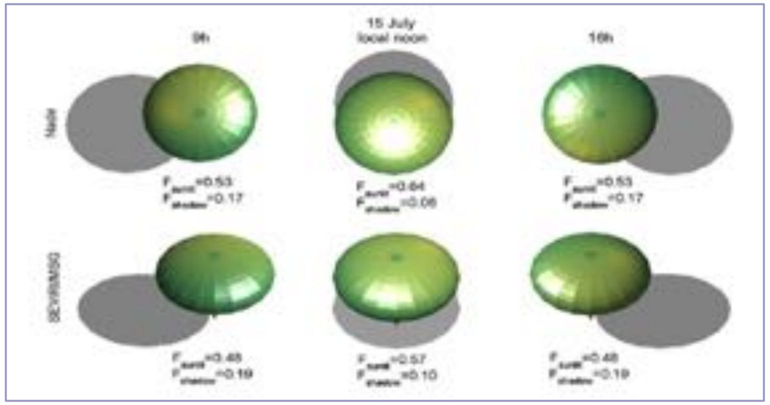
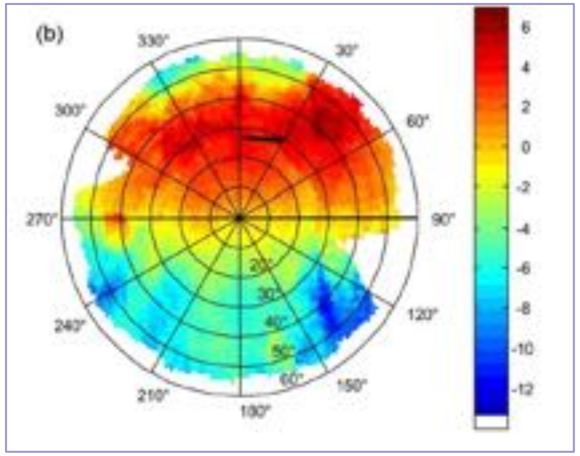
Motivation for TIR Directionality Focus – Grossetto, Italy

- Thermal infrared (TIR) remote sensing of LST involves potentially large **directional effects related to viewing and illumination geometries**.
- These are not as studied as VIS-NIR-SWIR BRDF effects, but are **important for wide swath (and geostationary) TIR missions**.
- Impacts come from **(i) varying proportions** of thermal components and shadows, **(ii) emissivity anisotropy**, and **(iii) hotspot** effects.
- **Effect magnitude varies** with sun-sensor geometry, temperature of the individual thermal components (so time of day), surface type etc.
- **Models** are available to assess + potentially adjust for the directional effects but have **limited validation against observations.**
- New wide-swath LST-focused missions like **LSTM, SBG & TRISHNA** will benefit from better understanding of **directionality effects.**
- A **2023 Airborne Campaign** will start soon after this workshop to help deliver this information, building on **recent past campaigns**.



Mixed Thermal Components/ Shadowing

[Ermida et al., 2014]



Hotspot Effect

[Lagouarde et al. 2015]

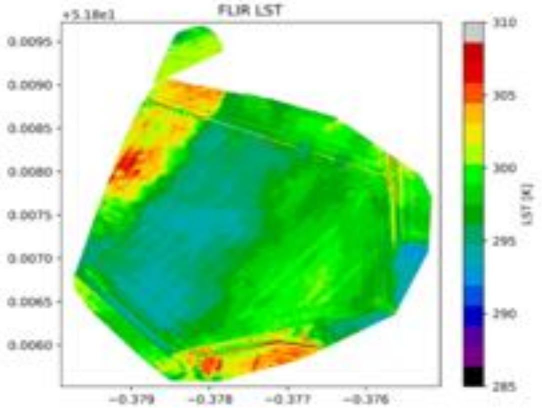
Martin Wooster | martin.wooster@kcl.ac.uk | NCEO King's

Grosseto Ground Instrumentation


Multi-angular LST, SIF + SR


Eddy Covariance System (Evapotranspiration)

UAV-derived LST/ ET maps



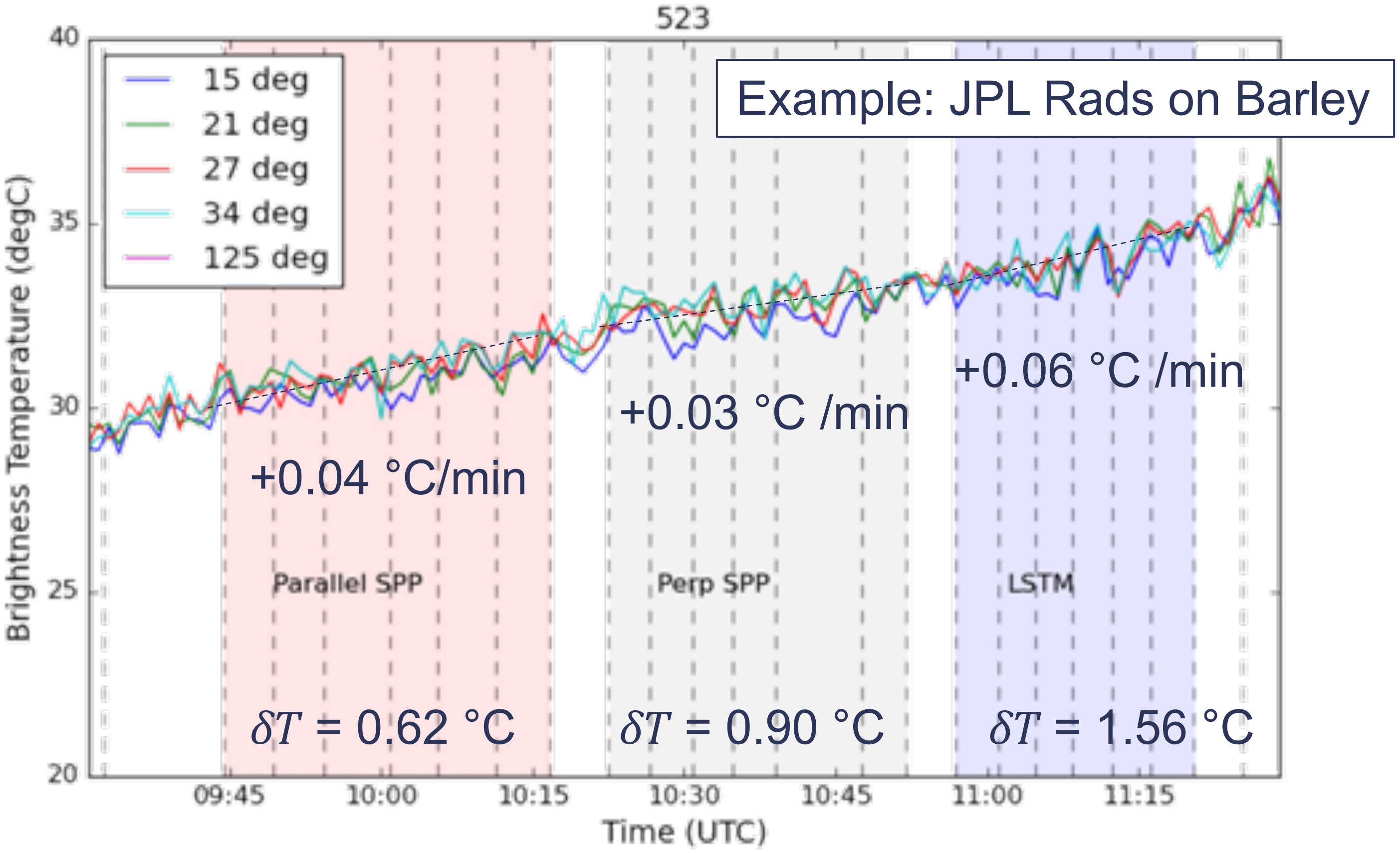
Spectral Emissivity

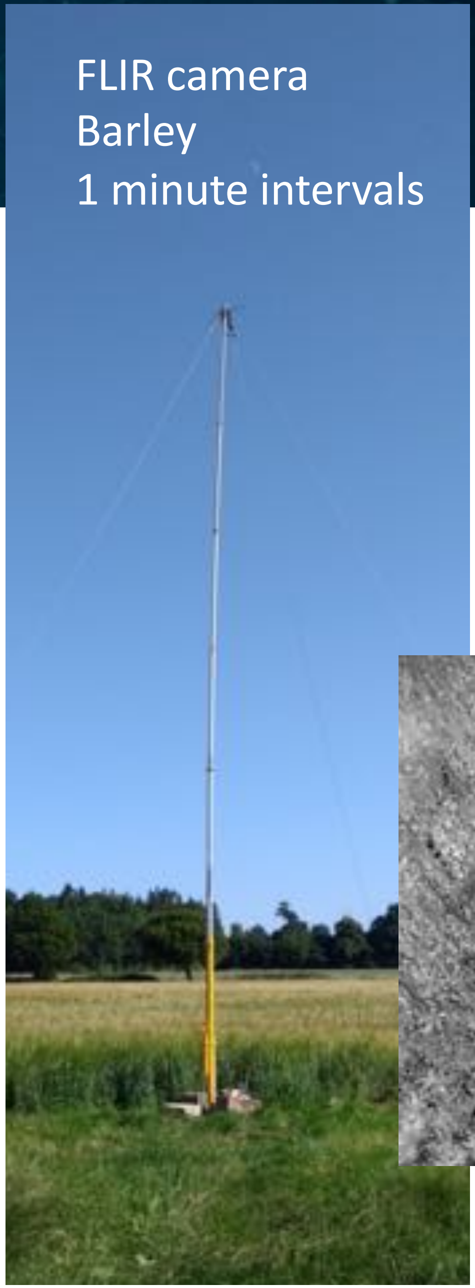

Aerosol Optical Depth

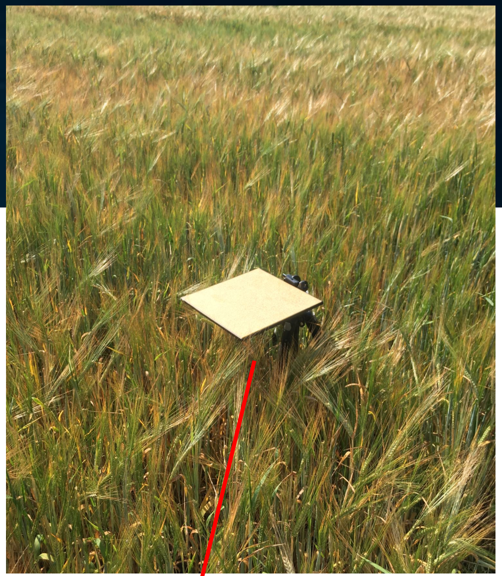

Spectral Reflectance (SR)/ Downwelling

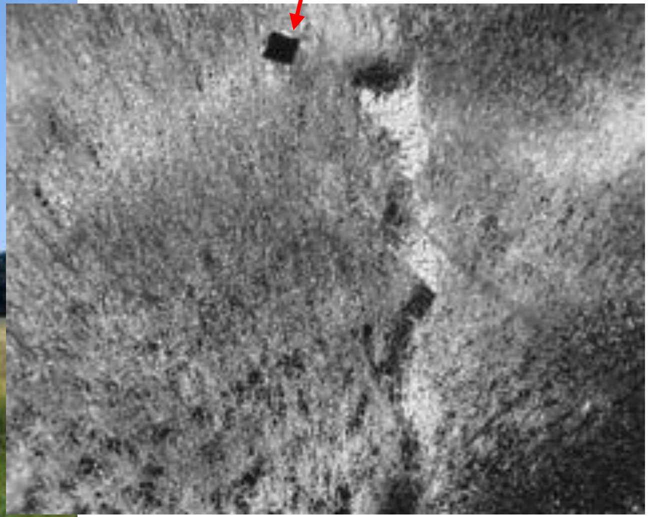

Radiometric LSTs & Water Surface Skin Temperature

Example Setup from Recent Campaigns









10:00 – 10:10 UTC
20th July 2021

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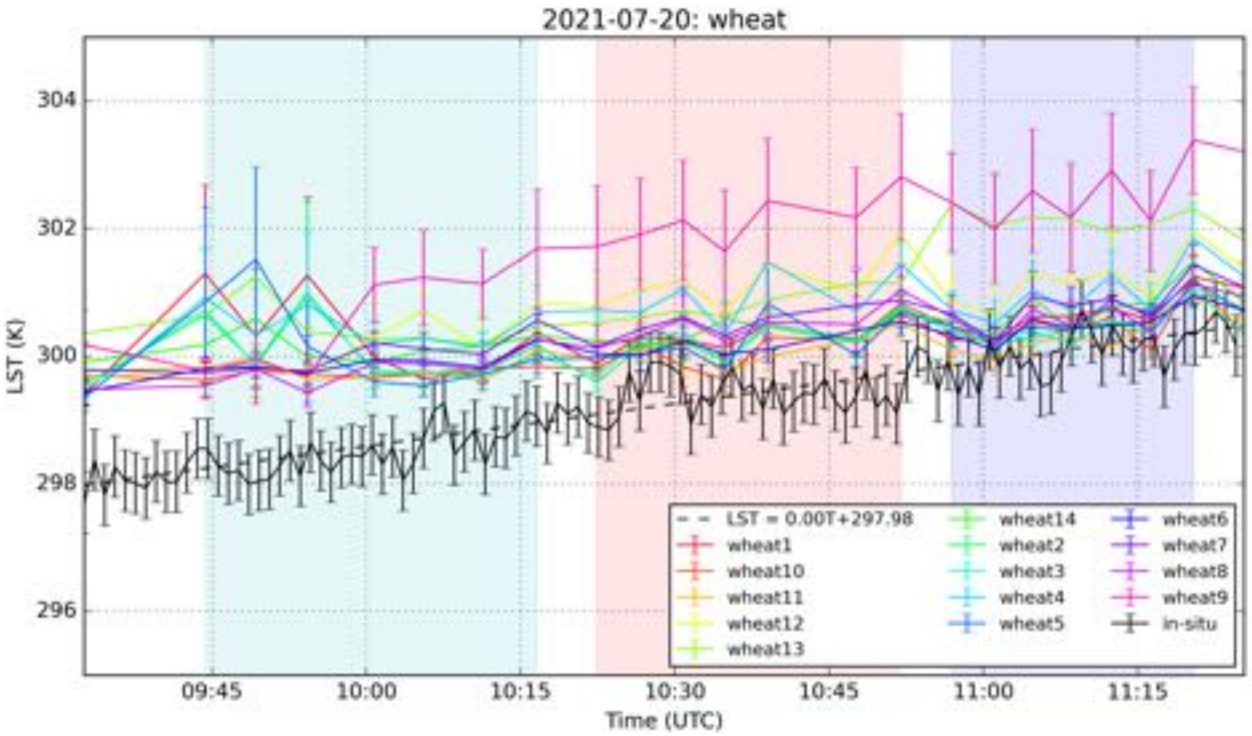
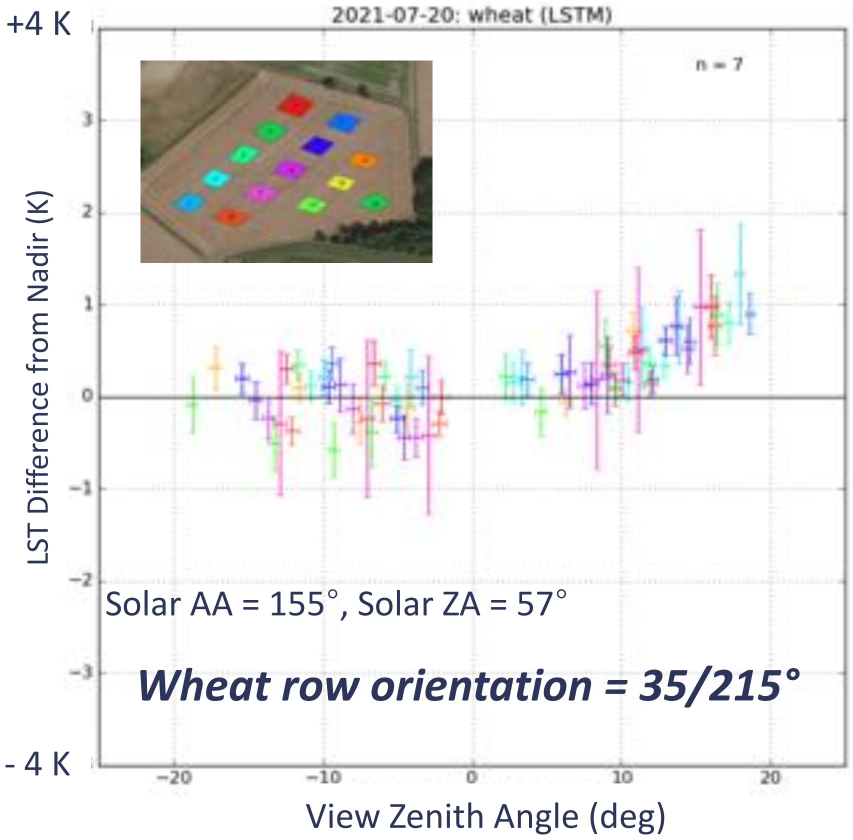
Multi-Angular Tests on Recent Campaigns

In-situ Radiometer Data (Heitronics KT15.85)



- Temporal trend in temperature over time
- Turbulence-induced short-term fluctuations
- 1.5 hrs here, minimum time to collect flightline data

LSTM Orbit Orientation (25° view azimuth angle)

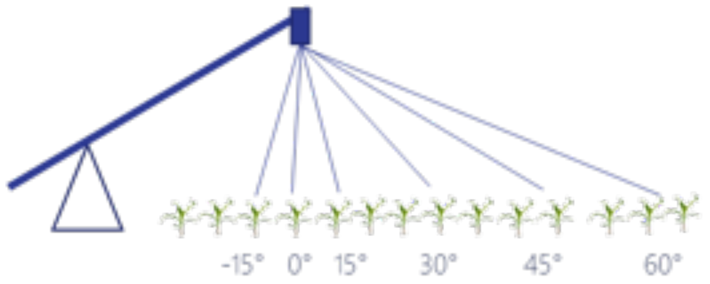


- Some evidence of LST directionality over wheat

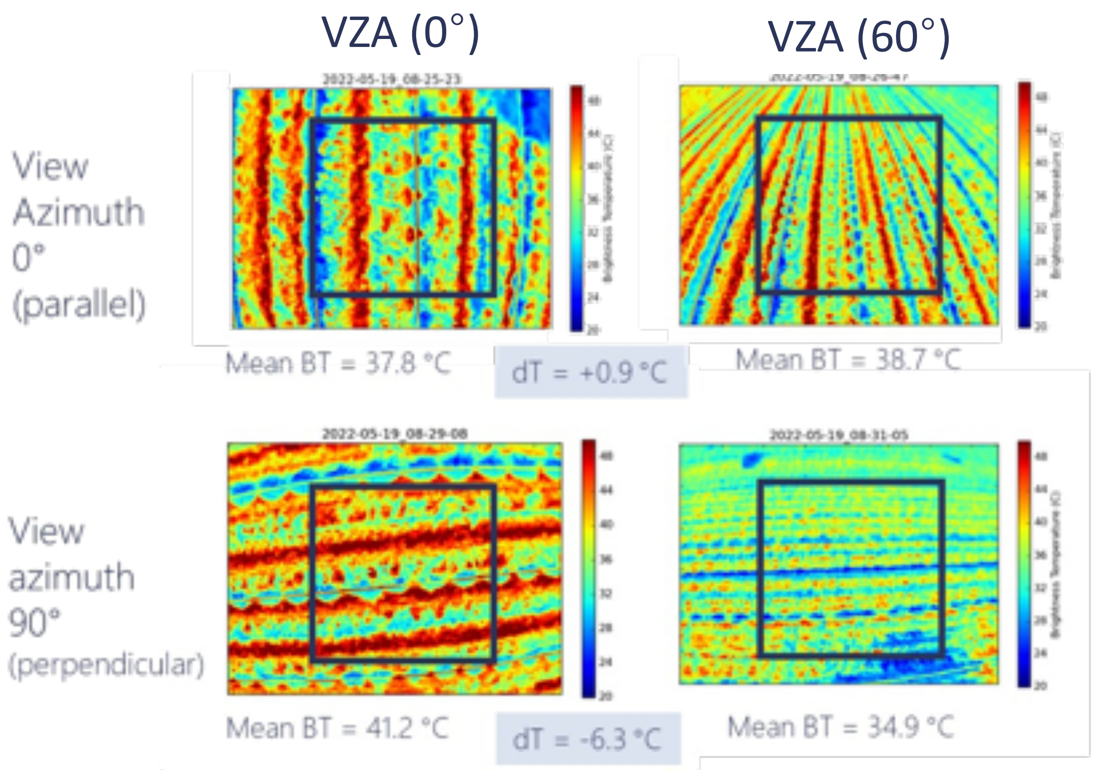
Multi-Angular Tests on Recent Campaigns

Multi-Angular Ground-Based Measurements

- 2022 multi-angular thermal imager and radiometer used to evaluate TIR directionality over corn, tomato, alfalfa
- Indication of directionality driven by **row orientation** & **crop growing stage** (LAI) - agrees with model results in literature
- Soil moisture/ irrigation shown to contribute at ground scale



VZA varied between -15° & + 60°
VAA of 0°, 90°, 180°, 270°



Early in growing cycle, larger ‘image-averaged’ BT differences when VAA is perpendicular to crop row orientation – as more (warmer) soil is viewed at low VZA than at high VZA.

Enhancements in 2023: Angular SiF

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Multi-Angular Tests on Recent Campaigns

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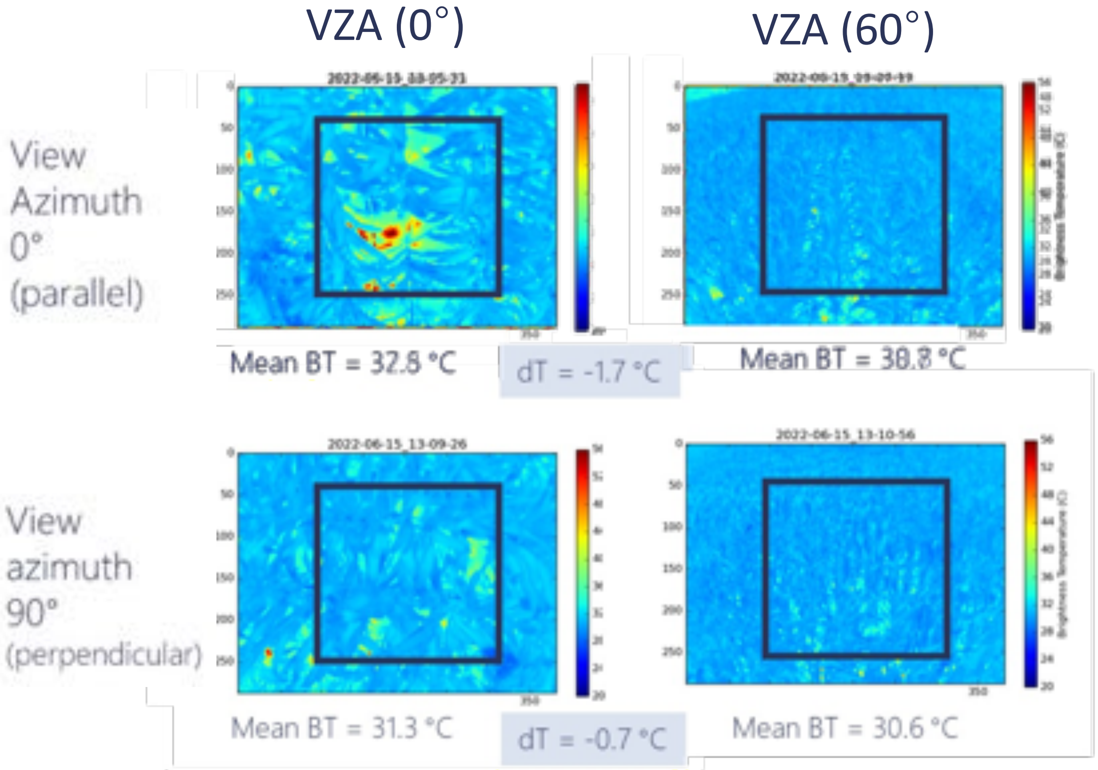

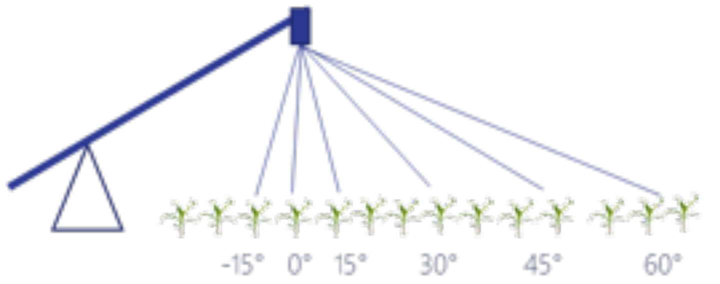

VZA varied between -15° & + 60°
VAA of 0°, 90°, 180°, 270°

Later in growing cycle, reduced BT difference when view azimuth perpendicular to row orientation as denser canopy means less warm soil viewed.

Two Aircraft Strategy - Sensors & Instrumentation

	Sensor	Details
KCL Instrumentation on BAS Aircraft	**Specim FENIX 1K**	**VNIR/SWIR Hyperspectral (333 bands, FOV = 40°)**
	Specim OWL (adapted)	**LWIR Hyperspectral (102 bands, FOV = 24.2°)**
	Infratec PIR UC-605 Camera	**LWIR Broadband (single-band 2D imager, FOV = 95° x 78°)**
	Miro MGA10	Gas Analyser (NH3, NO2 + Temp/Pressure/RH)
	SWING	UV VIS Spectrometer – to retrieve NH3 and NO2 atmospheric abundances
	IBIS	SIF (Solar Induced Fluorescence, FOV = 32.3°)
	PhaseOne IXM-RS100F	RGB imager (64° x 50°)
NASA-JPL Instruments on KBA Aircraft	**HyTES**	**LWIR Hyperspectral (256 bands, FOV= 50°)**

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Obtain wider VZA range whilst minimising time delay between nadir and off nadir data

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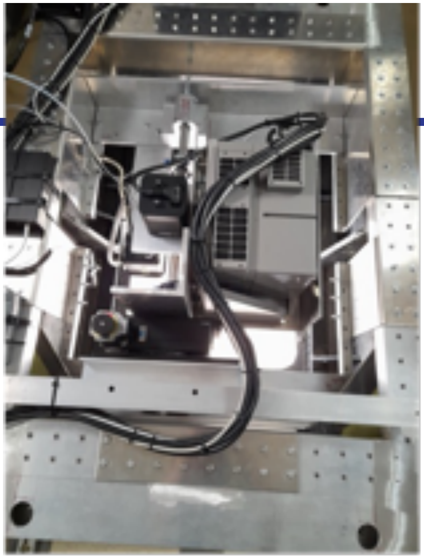
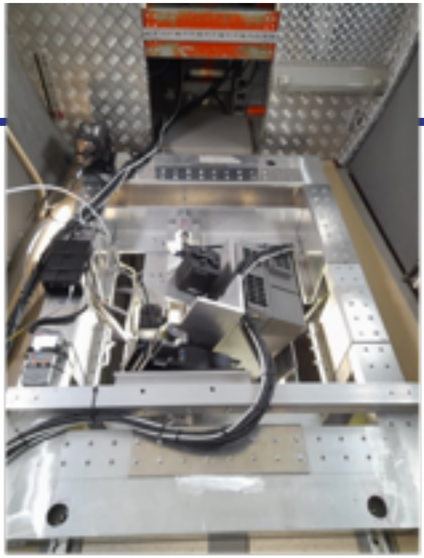
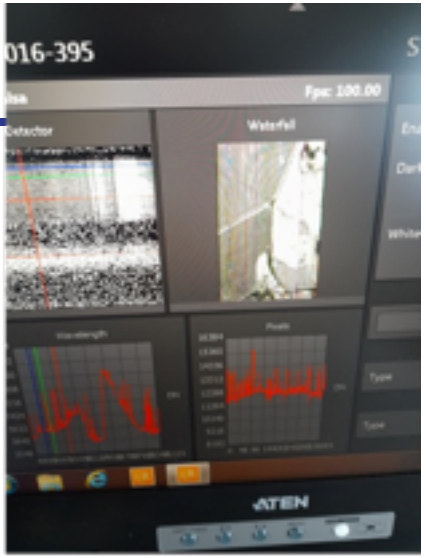
M-OWL (Multi-Angular OWL)

- Specim **OWL LWIR Hyperspectral** Imager
  [100 wavebands in LWIR]
- KCL designed/built a **multi-angular mount** - allowing OWL to view to 45 deg off-nadir at swath edge (mOWL System)
- **Successful test flights** confirm multi-angular strategies can be accurately planned and flown with this system
- **Dynamic frame IMU** allows nadir- and off-nadir mOWL data to be geo-located.

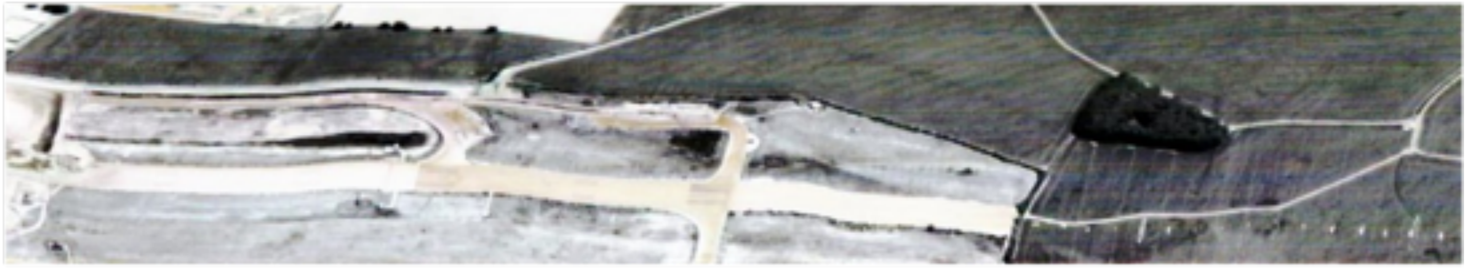

OWL in nadir-looking mode.


OWL in off-nadir looking mode.



OWL live data collection view.

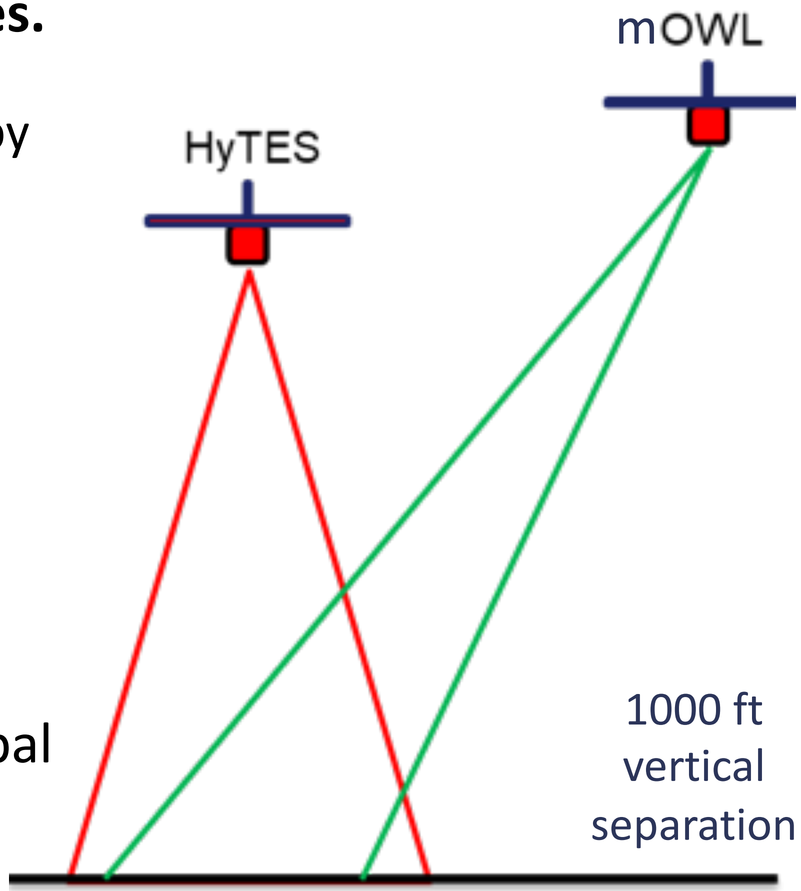

OWL quick-look data, nadir view.


OWL quick-look data, 36 degree offset view.

Overview of Multi-Angular Airborne Data Collection Strategy

Diurnal temperature cycle and/or near surface turbulence can introduce temperature changes between differently timed flightlines.

- Attempt to isolate directional component of TIR measurement sensitivity by reducing the temporal component of surface temperature change Basic concept = simultaneous acquisition using **two sensors** on **two aircraft**
- **mOWL and HyTES fly the same lines in same orientation near simultaneously** for cross-comparison / radiometric cross-validation.
- HyTES views at nadir and we use data up to ± **20° edge of swath**.
- mOWL focuses mainly on **VZA range 20° – 36°** (to 48° at far edge)
- Many flightlines oriented to collect along LSTM orbit & in the Principal Plane (but also additional orientations). All strategies include cross-calibration in air and on ground

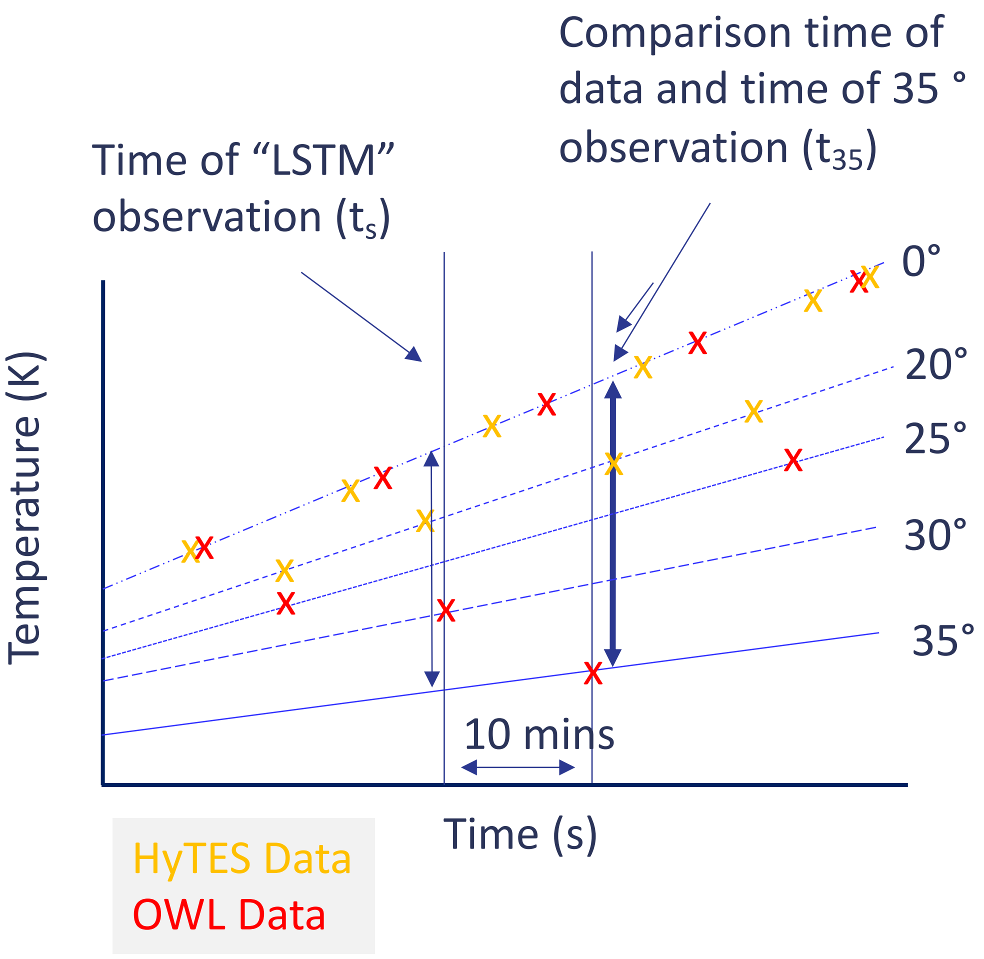


Considerations When Planning Dual Aircraft Flight Lines

- mOWL design enables offsetting the system to view to **right** of the aircraft only.
- Some striping evident on the **left-hand side** of the HyTES swath (up to 5° from edge depending on waveband)
- Each aircraft can fly for 4 hours (including transit time) - leaves ~3 hours for science data acquisition
- Strategies must account for the fact that rates of temperature change over time maybe different when viewing at different orientations

  - Soil likely changes temperature more rapidly than veg
  - More soil viewed at nadir than off nadir

  → A pixel may change its temperature with time more rapidly when viewed at nadir than off nadir (seen right).



Strategy of Measurement and Modelling

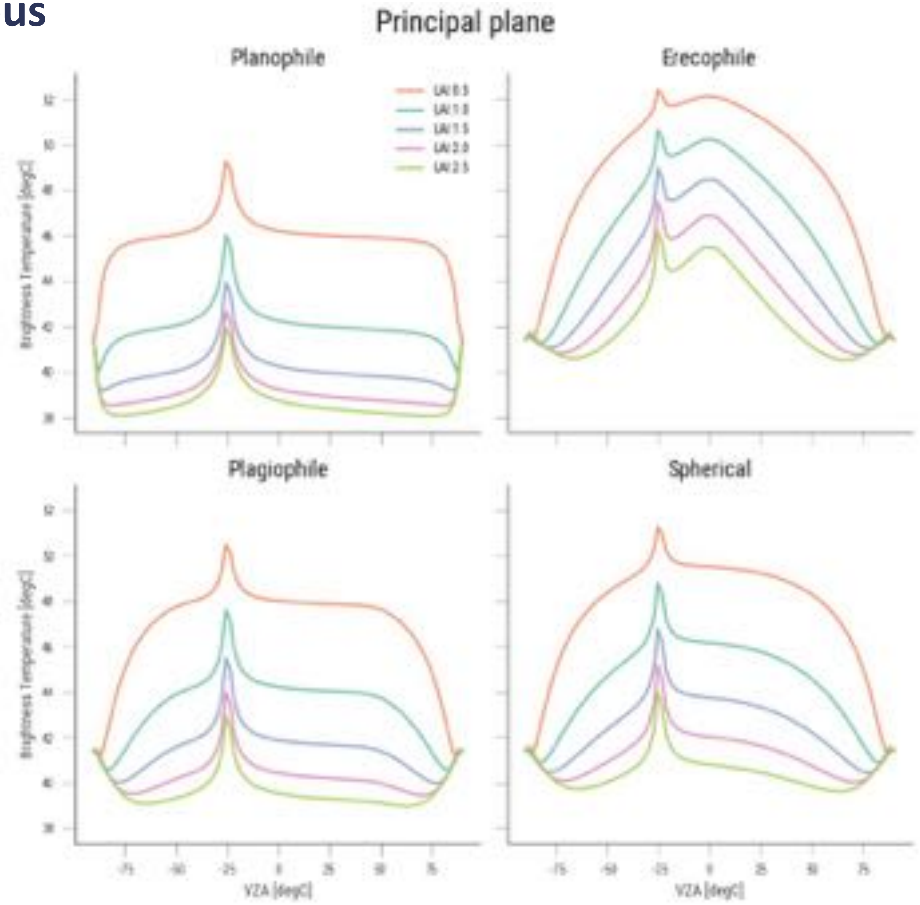
- Fast dynamics of land surface temperature over scales of minutes and below and difficulty to observe same location simultaneously with different angles
- Use Two Aircraft strategy to minimize time difference between different observation geometries
- Obtain data to validate & characterise RT model(s)
- Use RT models as *surrogate reality* for experiments, "what if" and testing inversion strategies
- Have a hierarchy of models:
    - DART (most detailed/accurate, hard(er) to parameterise)
    - SCOPE (simplified canopy, photosynthesis/evapotranspiration linkage)
    - 4SAIL (simplified canopy assumptions)
    - Semi-empirical models

LWIR Observation Modelling

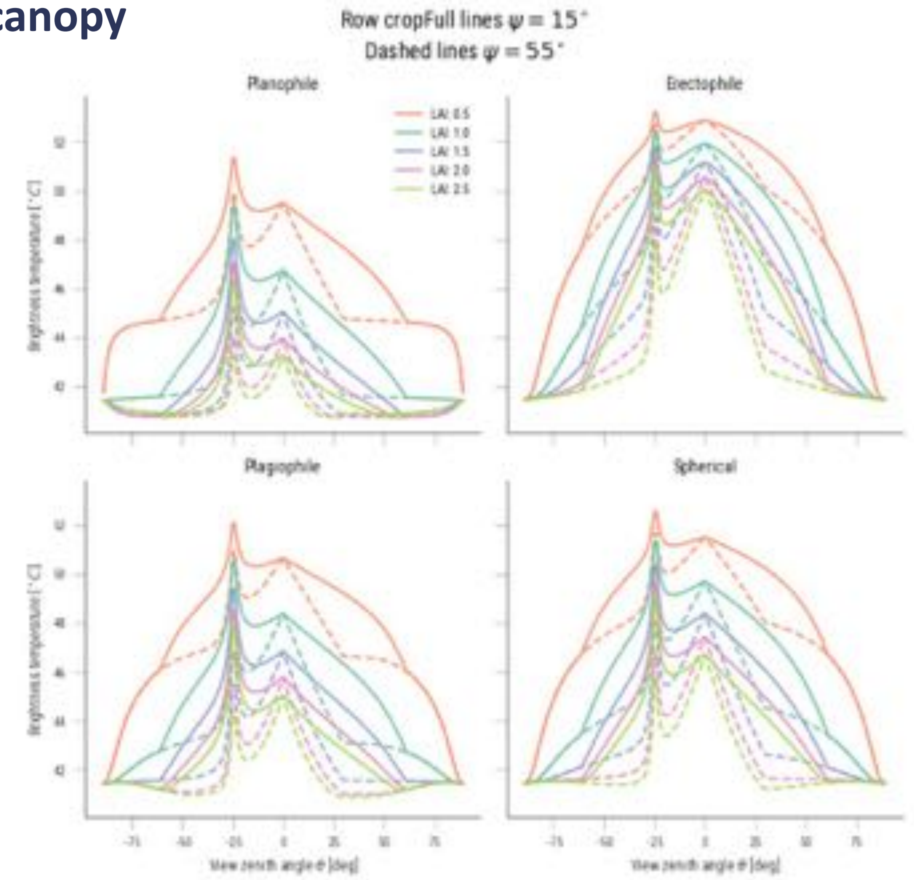
Examples generated using 4SAIL
12:15 UTC, Grosseto region

- SCOPE, 4SAIL, and DART can be used to simulate thermal observations, understand drivers, and plan observations.
- We can use the aircraft observations in part to undertake the study, but also to evaluate the model which we can then use for further investigations as required.

Homogeneous canopy



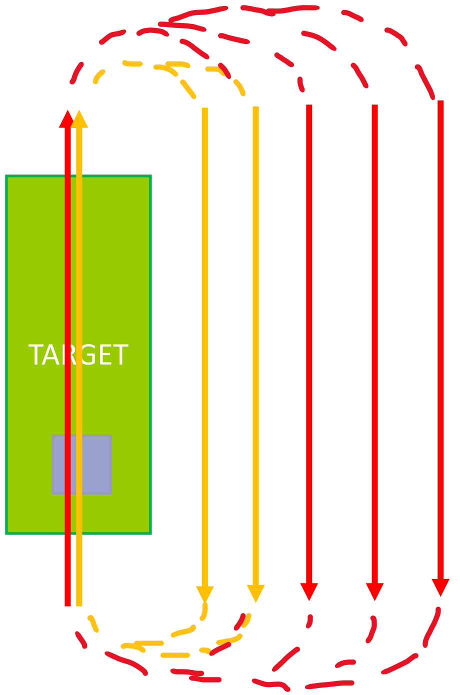
Row canopy

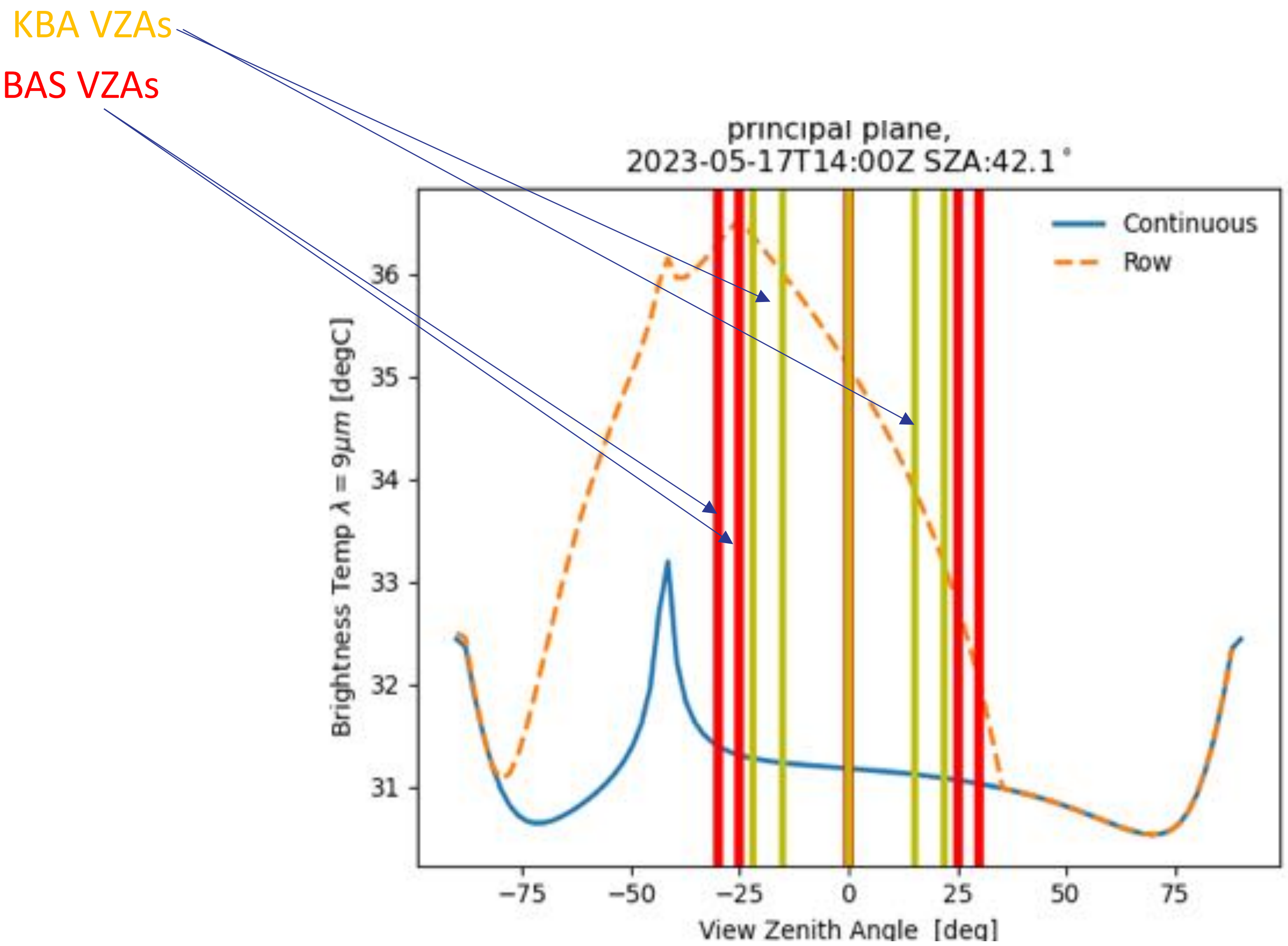


Example Flightline Collection – Strategy 3a. Multi-Angle Single Side

KBA Aircraft

BAS Aircraft





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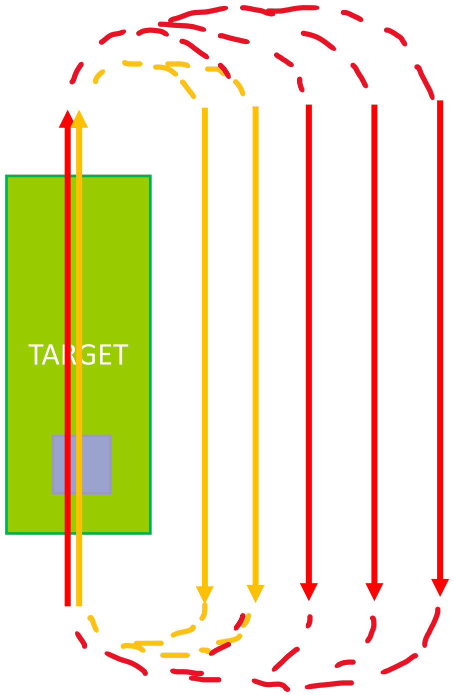
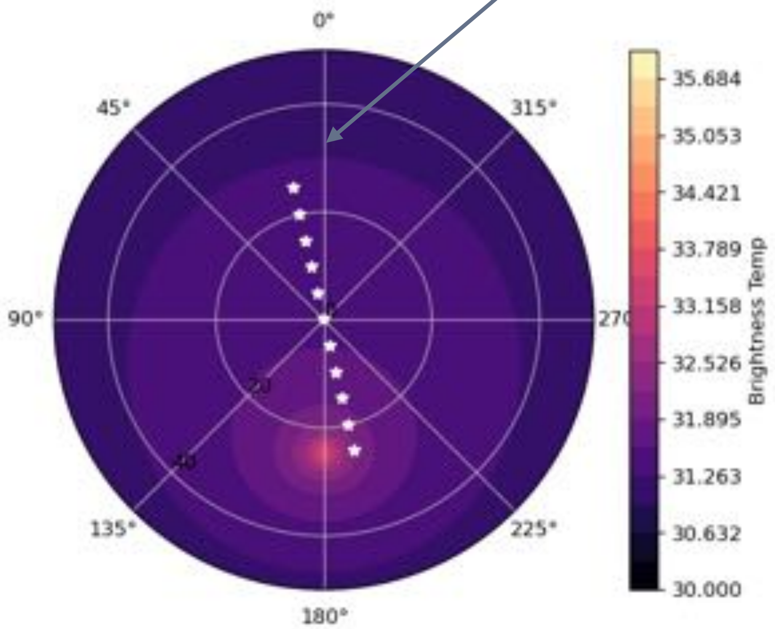
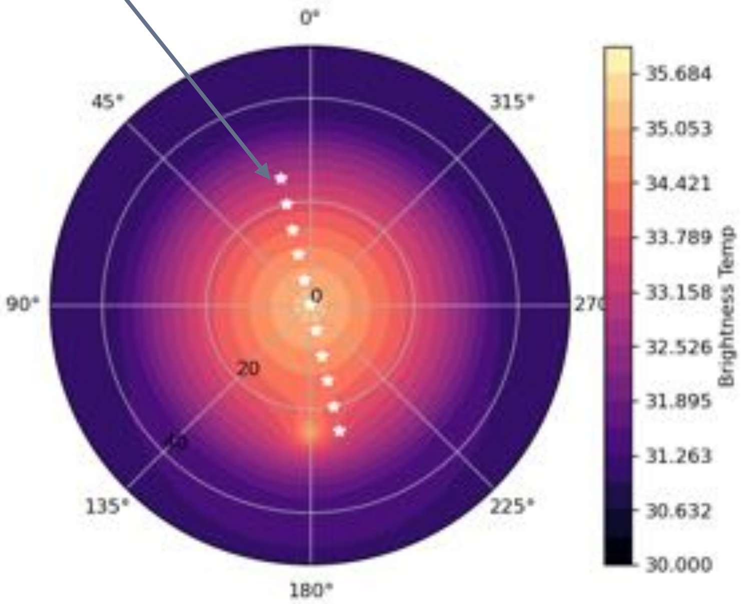


Sampled via flights



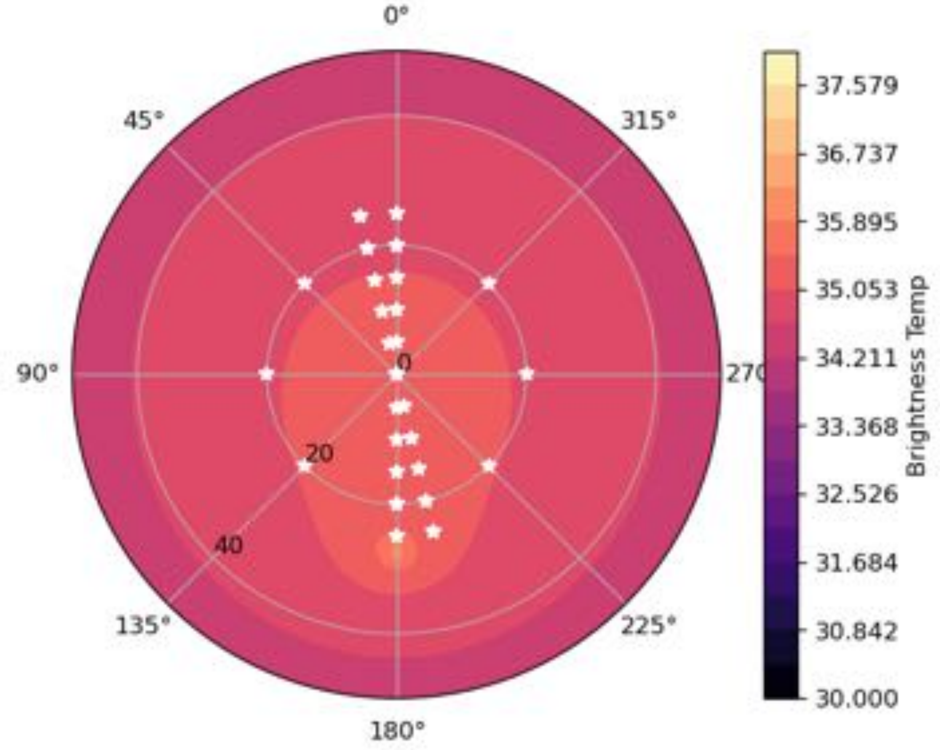
Continuous Canopy



Row Crop

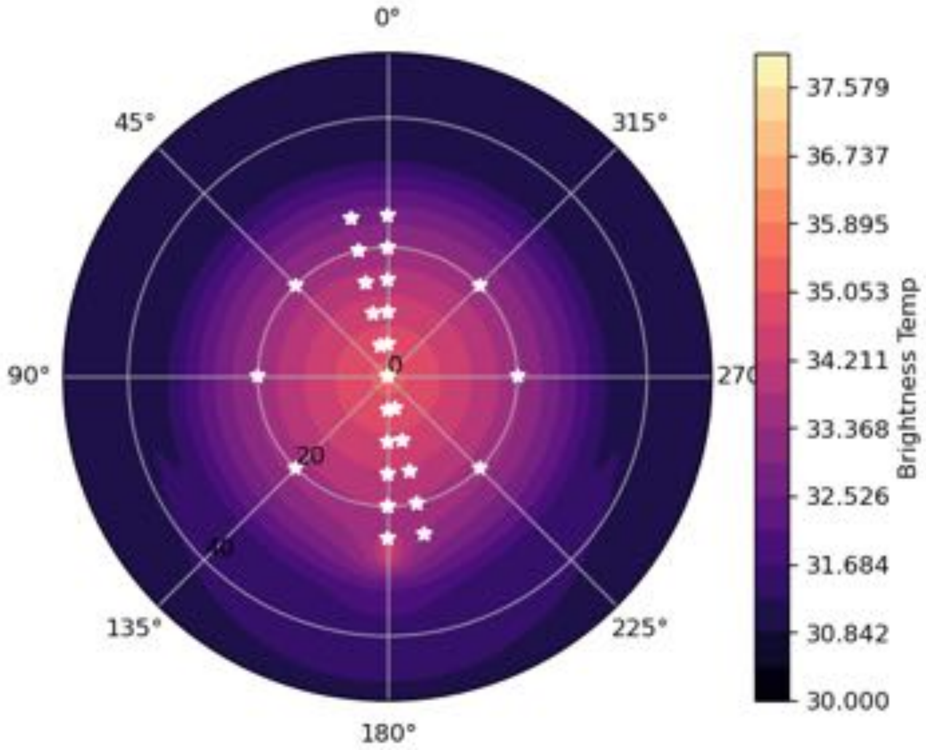
Example of Row Orientation Effects

Angle between Row and VZA: 5⁰



Viewing ~ along rows

Angle between Row and VZA: 50⁰



Viewing ~ at large angle to row

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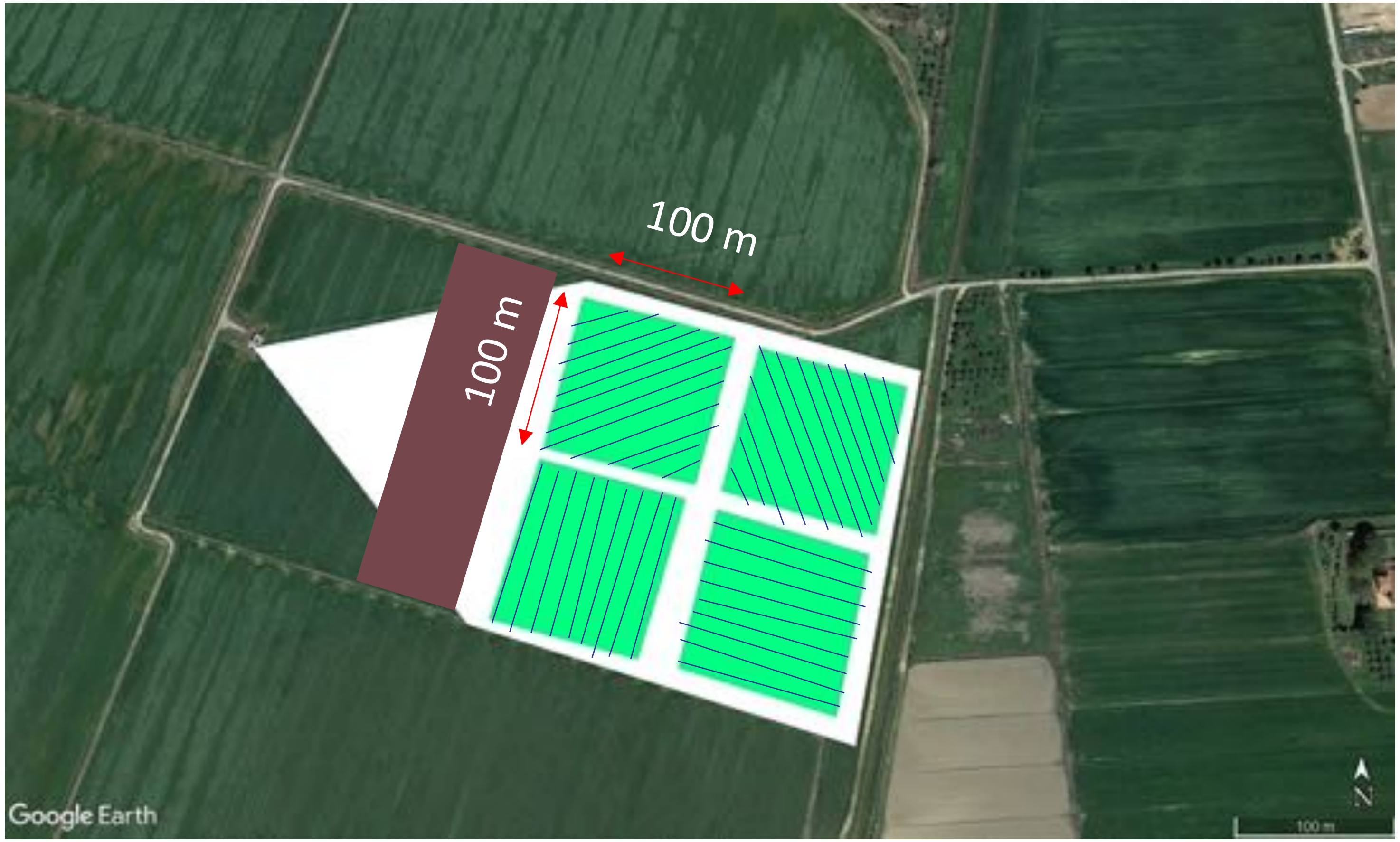
Addition of Dedicated Experiment: Row Orientation

- **Row orientation** is a **key driver** of TIR directionality of crops.
- Opportunity for a dedicated experiment to explore this.
- **Corn planted in different orientations** and **irrigated** using pivot irrigation once every 4 days (24 hr period to fully irrigate area)
- Different orientations **viewed** by airborne systems **on a single flightline** – minimising other sources of temperature variability.



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We Start Flying on 21st May

To all the Team

Thank you!