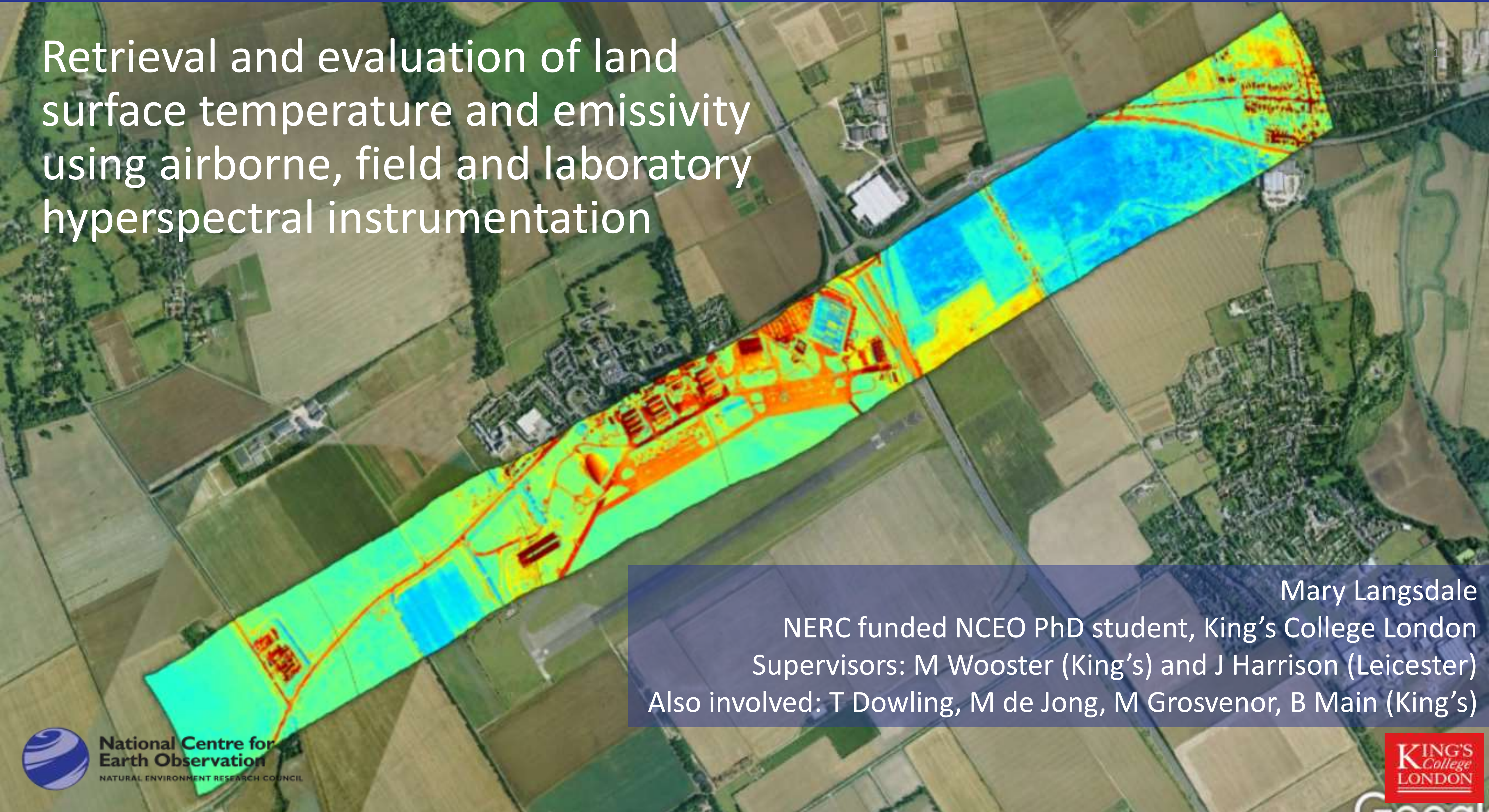
Retrieval and evaluation of land surface temperature and emissivity using airborne, field and laboratory hyperspectral instrumentation



Mary Langsdale
NERC funded NCEO PhD student, King's College London
Supervisors: M Wooster (King's) and J Harrison (Leicester)
Also involved: T Dowling, M de Jong, M Grosvenor, B Main (King's)

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Outline

- **What are land surface temperature (LST) and land surface (spectral) emissivity (LSE)?**
- **Hyperspectral LWIR airborne imaging instrumentation**
  - NERC NCEO's OWL
  - NASA-JPL's HyTES
- **LST + LSE retrieval from airborne hyperspectral imagers**
  - HyTES's retrieval algorithm
- **Validation of LST/LSE retrieval methods**
  - Development of robust validation methodology
  - Assessment of HyTES retrieval algorithm
- **Preliminary LST/LSE retrieval work - OWL**

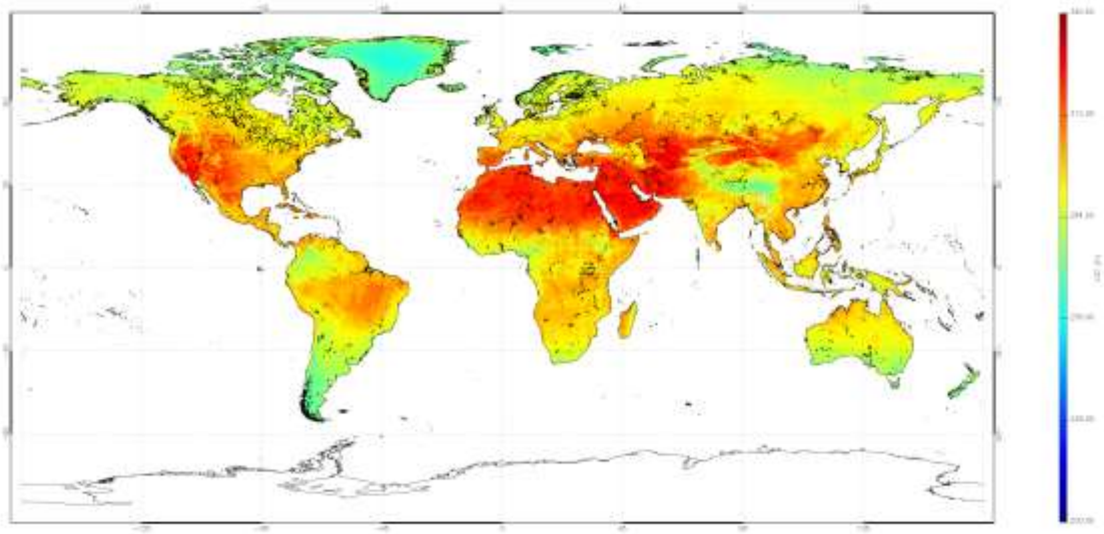
Land Surface Temperature Mission

Copernicus High Priority Candidate
(see Mike Perry's talk)

Land Surface Temperature (LST)

- Aggregated radiometric surface temperature of the ensemble of components within the sensor FOV
- Why important?
  - ✓ evaluating land surface & land-atmosphere interactions (e.g evapotranspiration)
  - ✓ constraining surface energy budgets (& model parameters)
  - ✓ providing observations of surface temperature change both globally and in key regions
- Estimated from TOA spectral radiance in Thermal Infrared atmospheric window (8 – 13 μm)… but requires knowledge of other parameters

Sentinel 3A SLSTR



07/2017 – 11/2017

$$L_{sen,\lambda} = \tau_\lambda(\theta)\left[\varepsilon_\lambda B_\lambda(\mathrm{LST}) + (1-\varepsilon_\lambda)L^{\downarrow}_{sky,\lambda}\right] + L^{\uparrow}_{sky,\lambda}(\theta)$$

What sensor measures (spectral radiance)

emissivity

What we want to estimate

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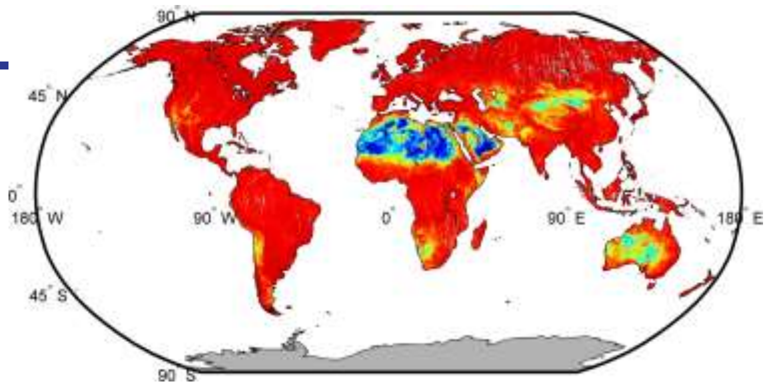
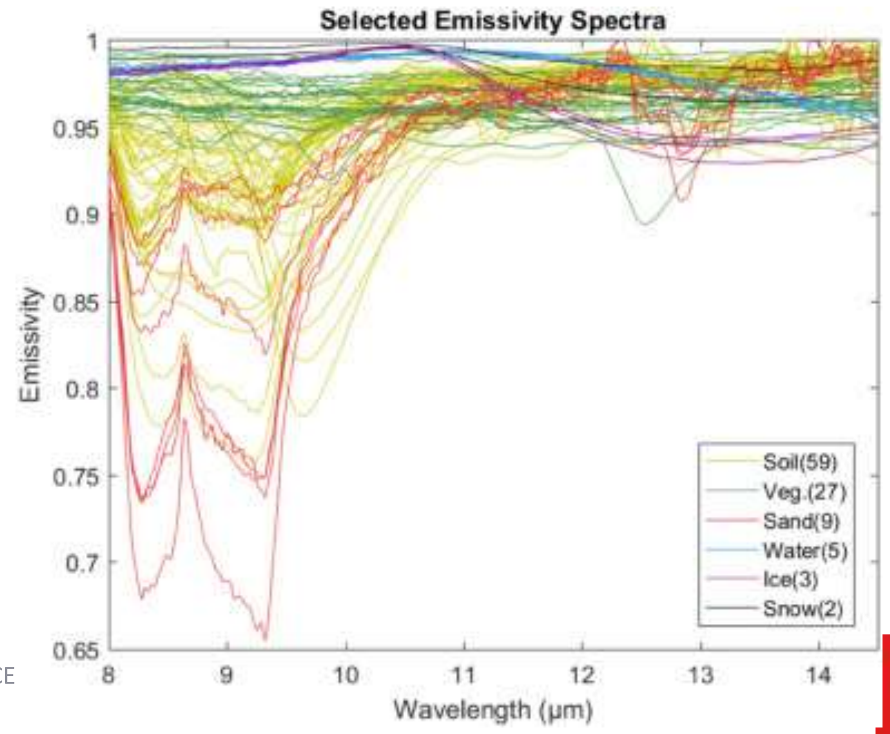
Land Surface [Spectral] Emissivity (LSE)



- Ratio of radiance emitted by objected to radiance that would be emitted by perfect emitter (‘blackbody’) at same temperature and wavelength

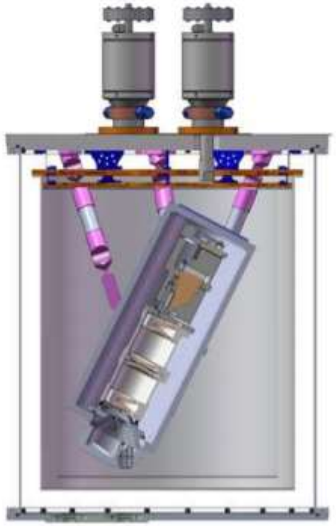
- Why important?
  - Calculating land surface temperature/ surface energy budgets
  - Land cover changes
  - Mineral mapping and resource exploitation

- Hyperspectral sensors offer new opportunity for simultaneous LST/emissivity retrieval + satellite mission development



Hyperspectral LWIR Airborne Instrumentation

- NCEO's Specim AisaOWL [OWL]
- NASA-JPL's Hyperspectral Thermal Emission Spectrometer [HyTES]



OWL	HyTES
Spectral range: 7.6 – 12.6 µm	Spectral range: 7.5 – 12.0 µm
96 spectral bands (50 nm bandwidth)	256 spectral bands (17.6 nm bandwidth)
TFOV = 24.2°	TFOV = 50.0°
At 1000m, pixel size 1.2m; swath ~410m (384 pixels)	At 1000m, pixel size 1.7m; (512 pixels)
Mass (scanhead): 13.1 kg	Mass (scanhead): 12 kg

Airborne data collected with HyTES in European sites (UK/Italy) June 2019 – data input for LSTM Design Studies

LST/LSE retrieval

- Multiple algorithms been developed to tackle this

Remote Sensing of Environment
Volume 102, Issues 1–2, 30 May 2006, Pages 99-115

ELSEVIER

Land surface temperature derived from airborne hyperspectral scanner thermal infrared data

José A. Sobrino, Juan C. Jiménez-Muñoz, Pablo J. Zarco-Tejada, Guadalupe Sep... de Miguel

Retrieving Atmospheric and Land Surface Parameters From At-Sensor Thermal Infrared Hyperspectral Data With Artificial Neural Network

Publisher: IEEE | Cite This | PDF

4 Author(s) Mengshuo Chen ; Li Ni ; Xiaoguang Jiang ; Hua Wu All Authors

remote sensing MDPI

Article

Physical Retrieval of Land Surface Emissivity Spectra from Hyper-Spectral Infrared Observations and Validation with In Situ Measurements

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Received: 17 May 2018; Accepted: 14 June 2018; Published: 20 June 2018

Abstract: A fully physical retrieval scheme for land surface emissivity spectra is presented,

4 May 2006

Land surface temperature an... emissivity retrieval from ther... hyperspectral imagery

Marvin Boonmee, John R. Schott, David W. Messinger

Author Affiliations +

Proceedings Volume 6233, Algorithms and Technologies for M...
Ultraspectral Imagery XII; 62331V (2006) https://doi.org/10.11...
Event: Defense and Security Symposium, 2006, Orlando (Kiss...

International Journal of Remote Sensing, 2013
Vol. 34, Nos. 9–10, 3051–3068, http://dx.doi.org/10.1080/01431161.2012.716925

Taylor & Francis

Land surface temperature from multiple geostationary satellites

Sandra C. Freitas[a], Isabel F. Trigo[a,b]*, João Macedo[a], Carla Barroso[a], Ricardo Silva[a], and Rui Perdigão[a,b]

[a]*Instituto de Meteorologia, 1749-077 Lisbon, Portugal;* [b]*Instituto Dom Luiz, 1749-016 Lisbon, Portugal*

(*Received 13 January 2011; accepted 25 October 2011*)

This article provides a description of a land surface temperature (LST) data set generated (and provided in near-real-time or offline) based on infrared data from sensors onboard different geostationary (GEO) satellites: Meteosat Second Generation (MSG), Geostationary Operational Environmental Satellite (GOES), and Multifunction Transport Satellite (MTSAT). Given the different characteristics of the imagers onboard

...ANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, VOL. 49, NO. 4, APRIL 2011 1291

Temperature and Emissivity Retrievals From Hyperspectral Thermal Infrared Data Using Linear Spectral Emissivity Constraint

Ning Wang, Hua Wu, Françoise Nerry, Chuanrong Li, and Zhao-Liang Li

...ract—Owing to the ill-posed problem of radiometric equa... the separation of land surface temperature (LST) and land ...e emissivity (LSE) from observed data has always been a ...esome problem. On the basis of the assumption that the ...pectrum can be described by a piecewise linear function, ...method has been proposed to retrieve LST and LSE from ...herically corrected hyperspectral thermal infrared data us-

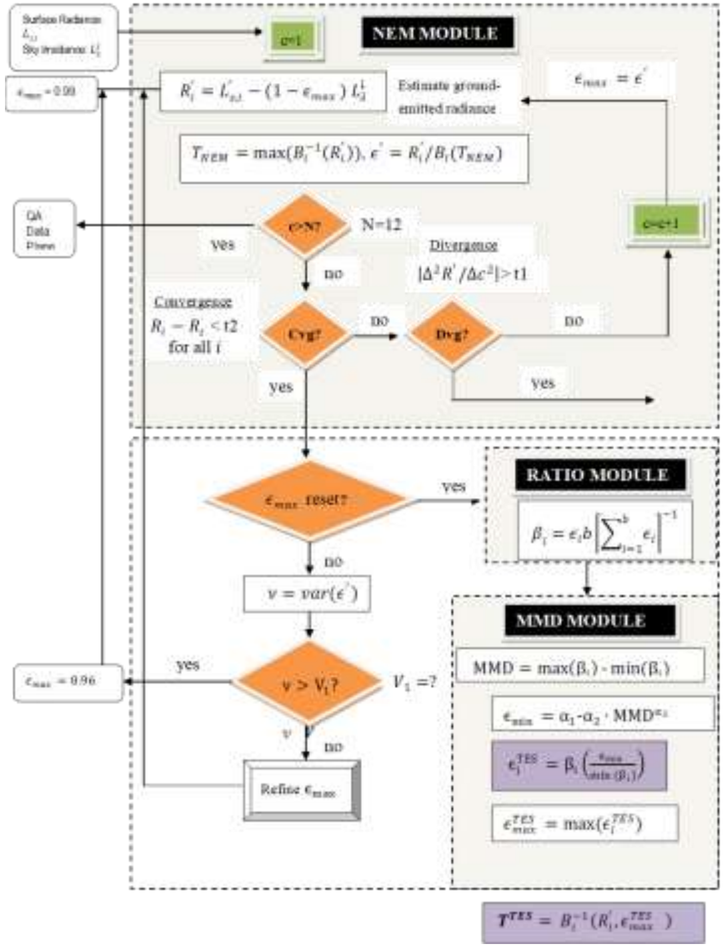
Temperature–emissivity separation (TES), as one of the key problems in thermal infrared (TIR) remote sensing, is attractive, although many studies have been undertaken on this aspect [1]. However, the retrieval of LST and LSE from space is a difficult task. First, the radiative transfer equation (RTE) shows that the radiance emitted from the surface is the function of LST and

Temperature and Emissivity Separation (TES) algorithm

- ➢ Combination of 3 different algorithms (NEM, Ratio, MMD)

Operational LST&E products using TES

- ASTER
- MODIS v6
- ASTER GED
- **HyTES**
- ECOSTRESS
- VIIRS (planned)



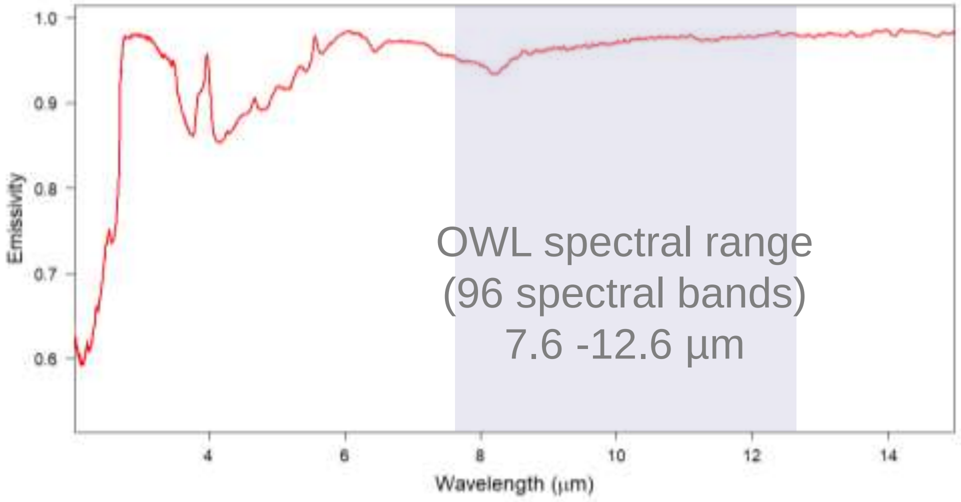
Gillespie et al, 1998
Doi: [10.1109/36.700995](https://doi.org/10.1109/36.700995)

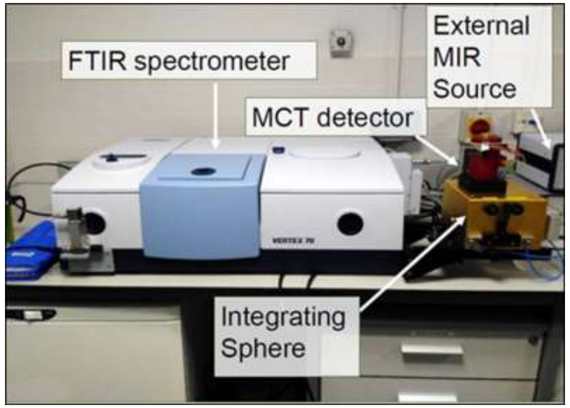
Validation of LST/ Emissivity Retrieval Algorithm

Temperature measurements from LWIR radiometers over thermally distinct surfaces

Spectral emissivity measurements from:

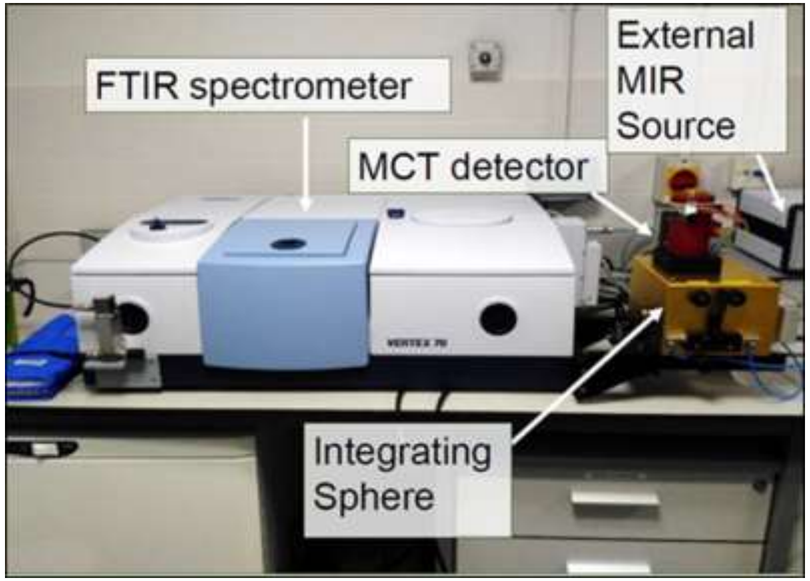
(i) Samples collected + measured in laboratory
(ii) Measurements in field using portable instruments

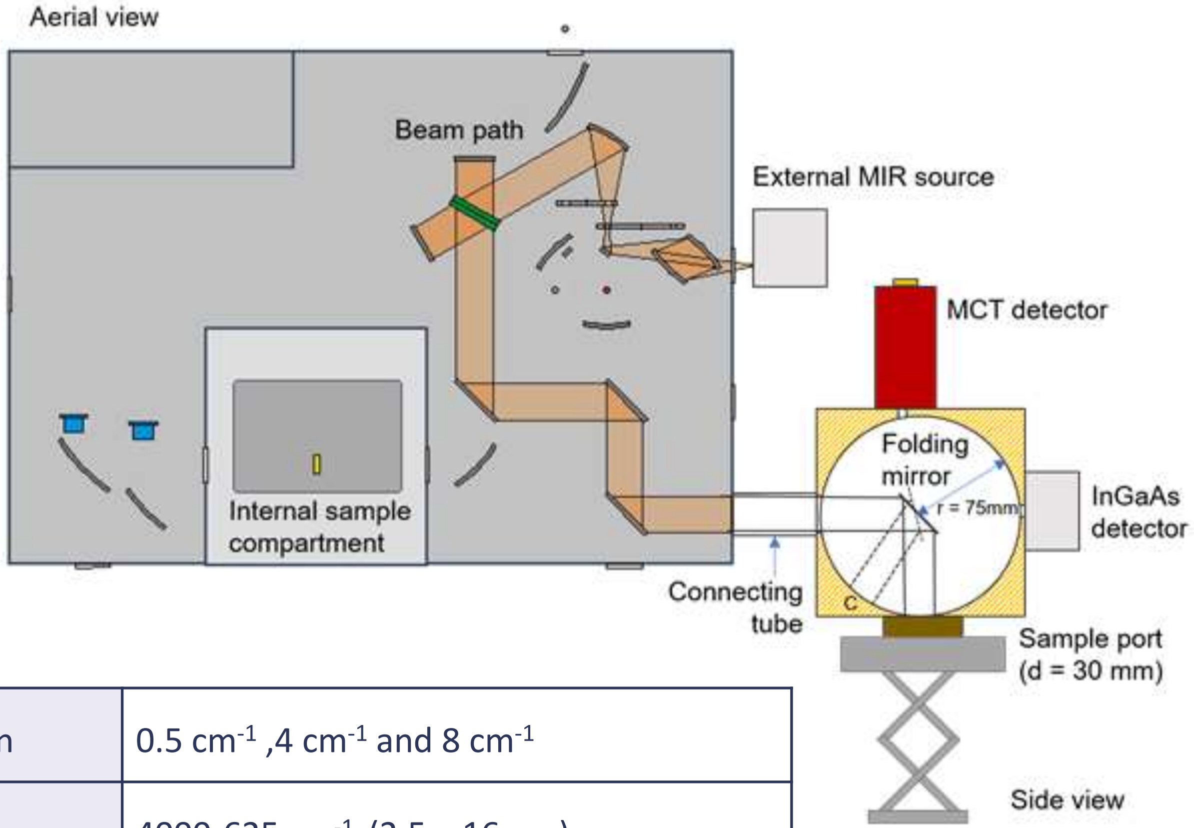




Laboratory Instrumentation: Emissivity

- NCEO's Bruker Vertex V70 FTIR spectrometer with external gold integrating sphere [Vertex]





Spectral resolution	0.5 cm^{-1} ,4 cm^{-1} and 8 cm^{-1}
Spectral recording range	4000-625 cm^{-1} (2.5 – 16 µm)
Meas. Type	Directional Hemispherical Reflectance
Sample port	30 mm

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Field Instrumentation: Emissivity

- NCEO's Bruker EM27 Open Path FTIR spectrometer [EM27]
- NASA-JPL's Designs & Prototypes microFTIR spectrometer [D&P]

	EM27	D&P
Spectral resolution	0.5 cm^{-1} ,4 cm^{-1}	6 cm^{-1}
Spectral recording range	5000 – 700 cm^{-1} (2 – 14 μm)	3333 - 2000 cm^{-1} (3 - 5 μm); 1250 – 833 cm^{-1} (8 - 12 μm)
Type	Passive Emission	Passive Emission
FOV at 1m	60 mm	80 – 160 mm (depending on foreoptics)
Mass/ Power	18 kg, 40 – 80 W	12.5 kg, 18 W

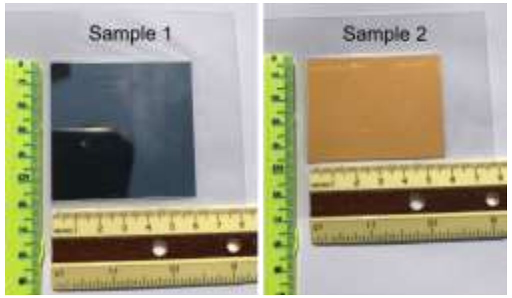
EM27 measuring LWIR surface emissivity

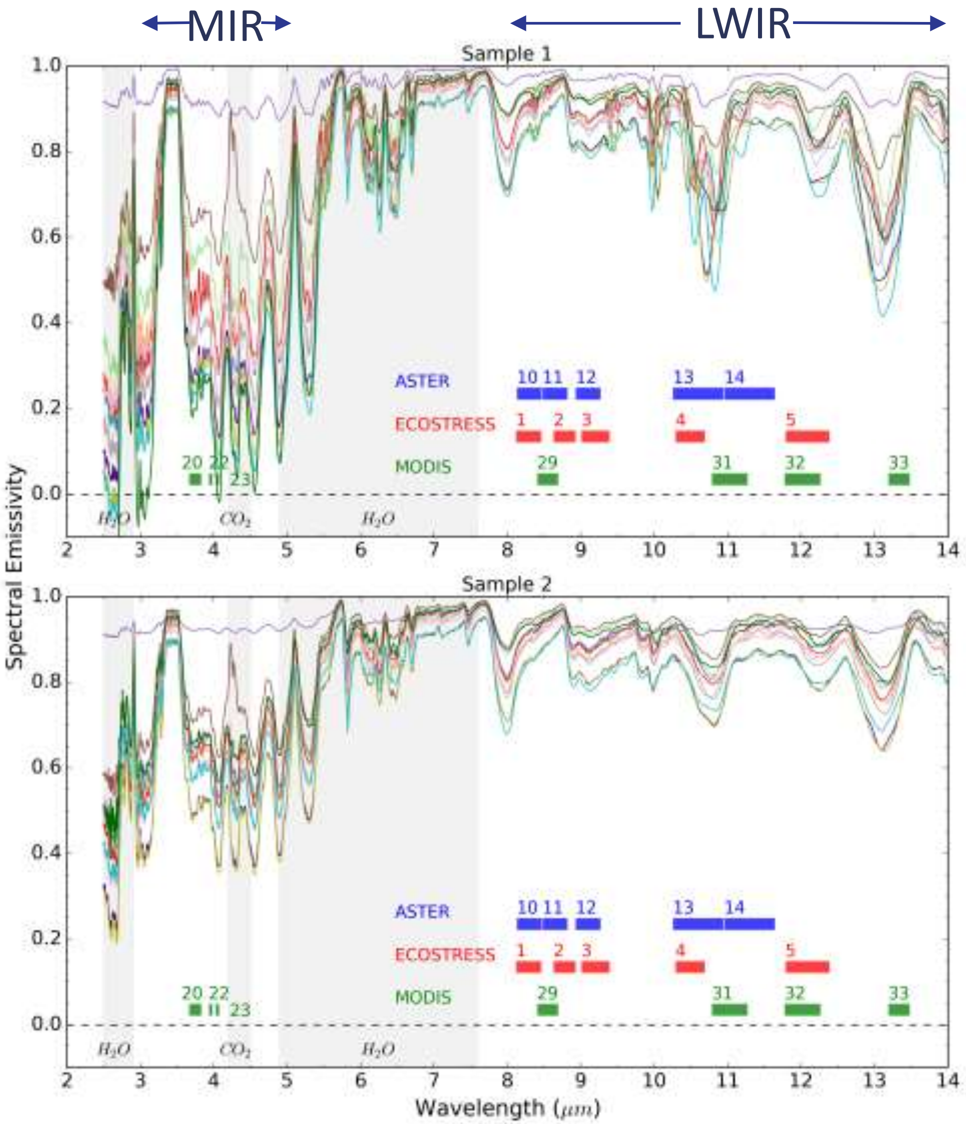
EM27 measuring LWIR downwelling irradiance

Can we trust these 'truths'? – Laboratory Round Robin

Intercomparison of measurements from **13** different setups at **8** laboratories (incl NCEO-King's, NASA JPL, DLR..)

Samples: aluminium/gold sheets laminated in polyethylene





Standard Deviation over LWIR (% mean)

Sample 1a: 0.142 (16.6%)
Sample 2a: 0.110 (12.5%)

Higher uncertainties from laboratory measurements of emissivity than previously assumed

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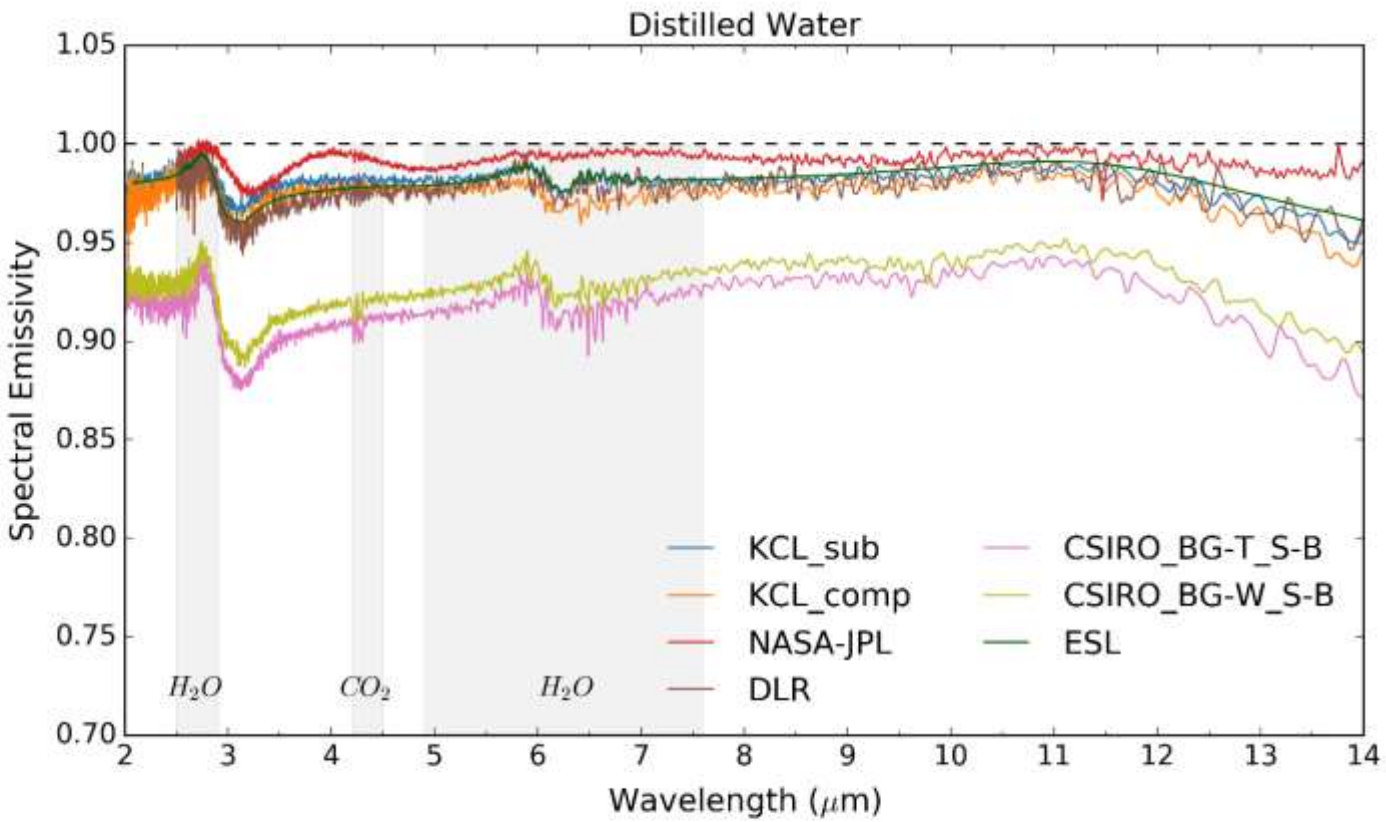
Can we trust these ‘truths’? – Laboratory (2)

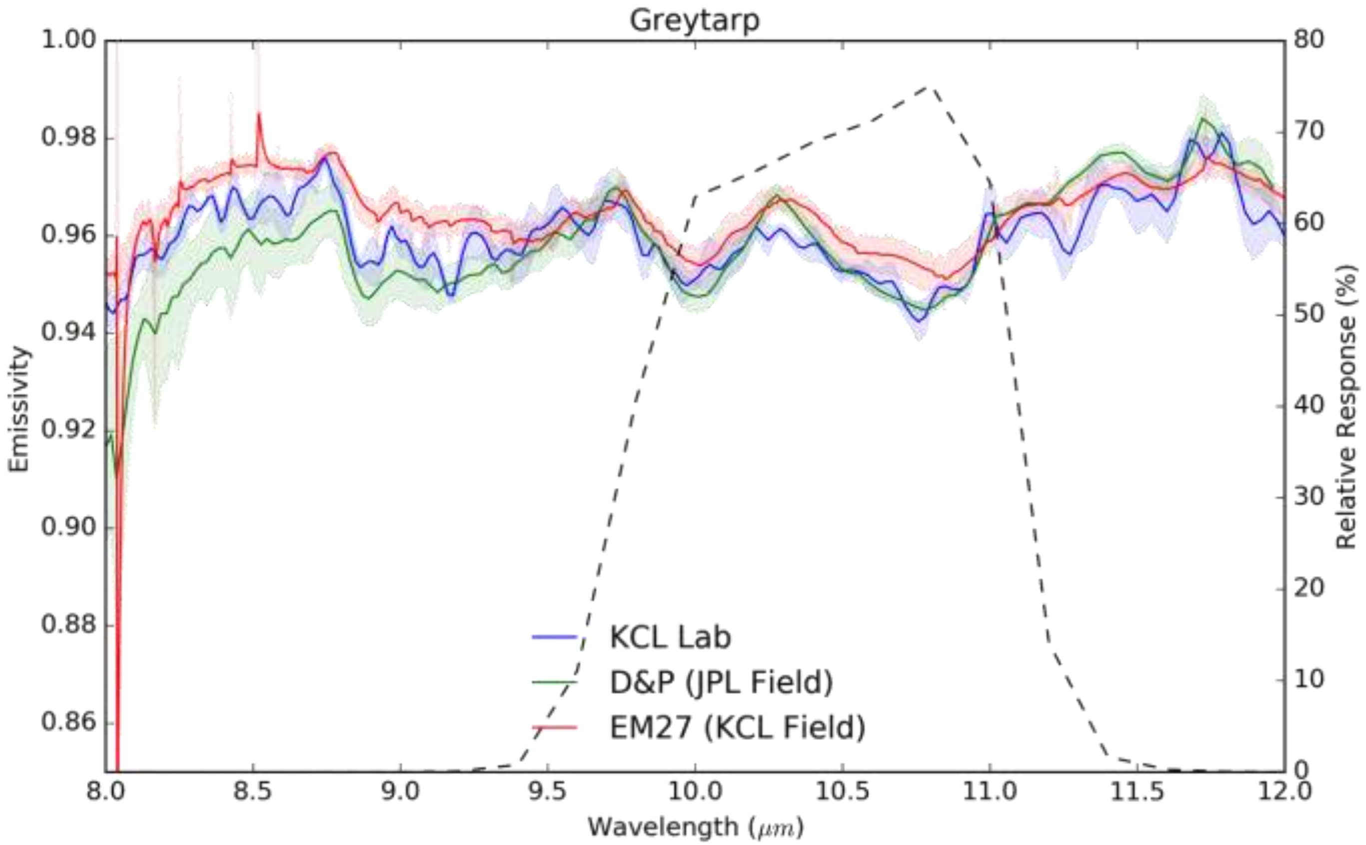


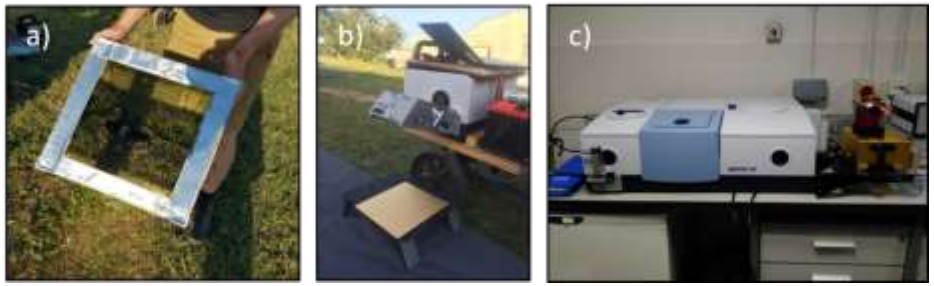
Differences observed amongst measurements of distilled water

Use of lowest measurement would result in LST 2.9 K less than if used highest emissivity

Amongst higher emissivity group, differences would lead to surface temperature retrieval differences of 0.7 K

Can we trust these 'truths'? – Field/Laboratory





Method	Heitronics KT15.85 band-specific emissivity
Laboratory (Vertex-V70)	0.956 ± 0.003
Field (EM27)	0.952 ± 0.009
Field (D&P)	0.956 ± 0.002

Data Collection [HyTES] during ESA/NASA NETSense Campaign 2019

Data collected as part of NETSense campaign (June 2019)

Grosseto, Italy

Duxford + surrounding areas, UK

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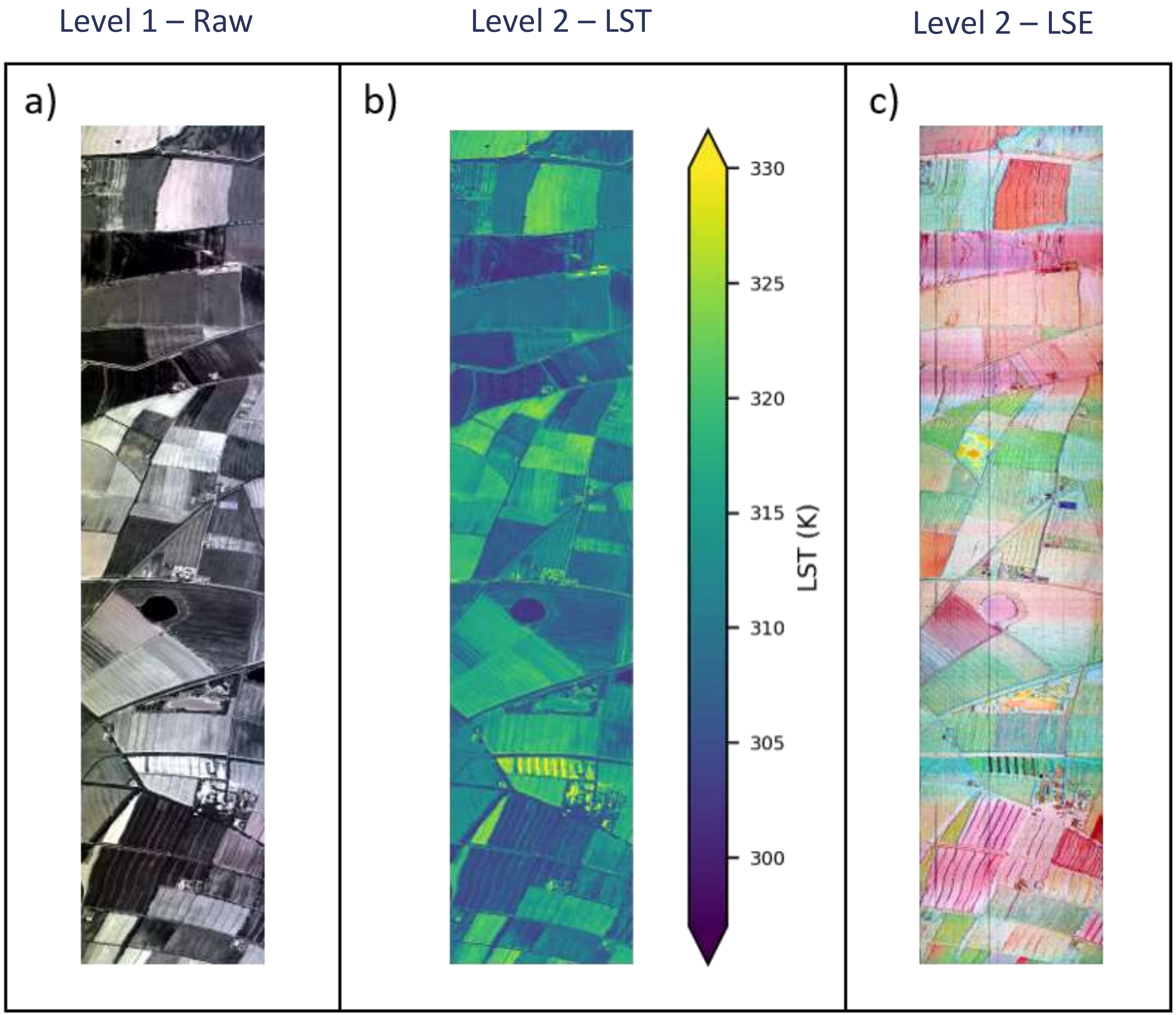
esa

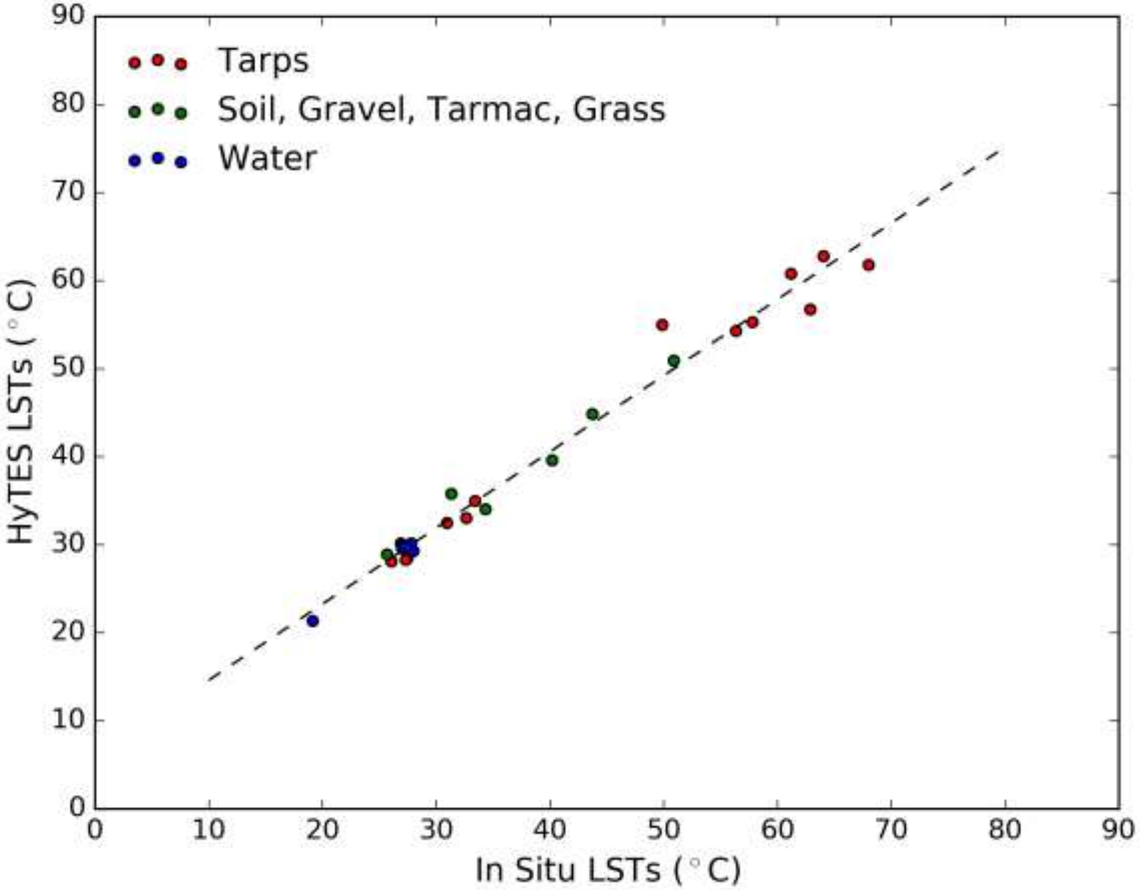
NASA
Jet Propulsion Laboratory
California Institute of Technology

HyTES data from NETSense Campaign

Grosseto AM 23 June 2019

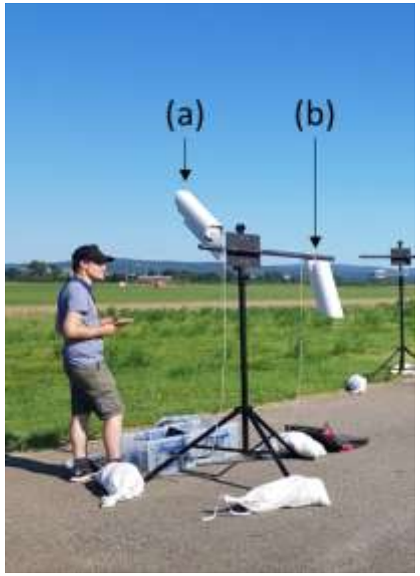


HyTES Airborne *vs.* In Situ LST Data Comparison

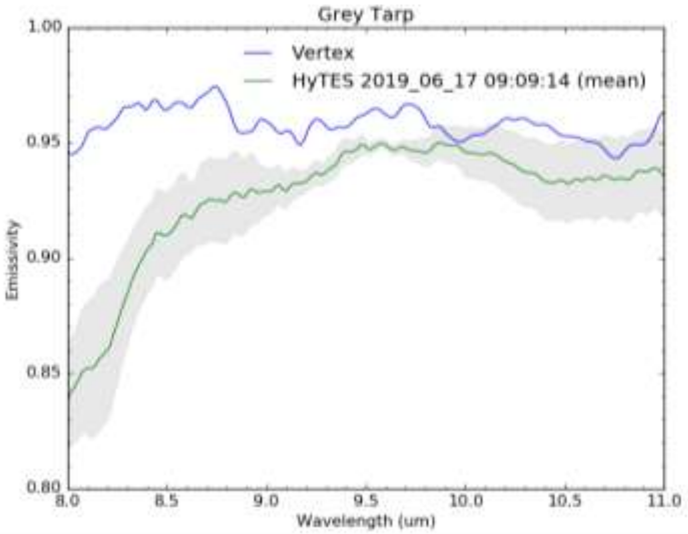


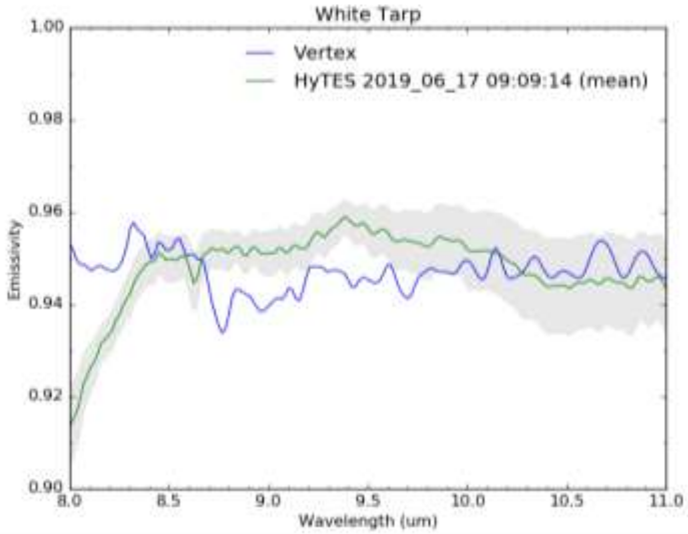
All surfaces:
Bias = + 1.35 °C
Scatter = 2.21 °C

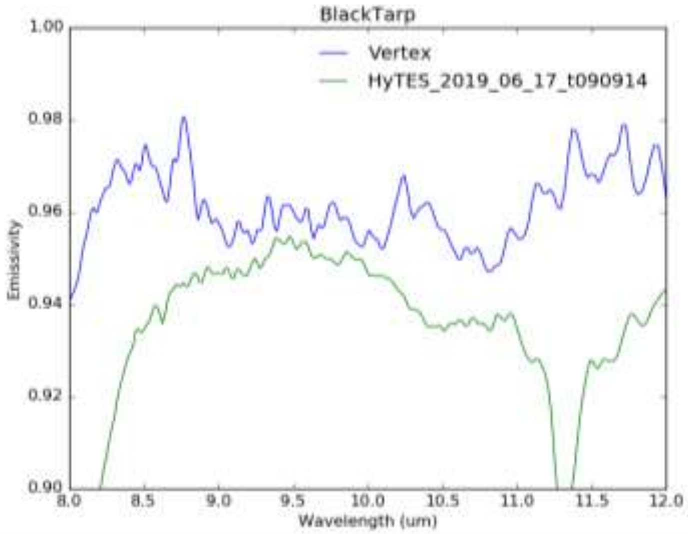
Just land:
Bias = + 0.8 °C
Scatter = 2.21 °C

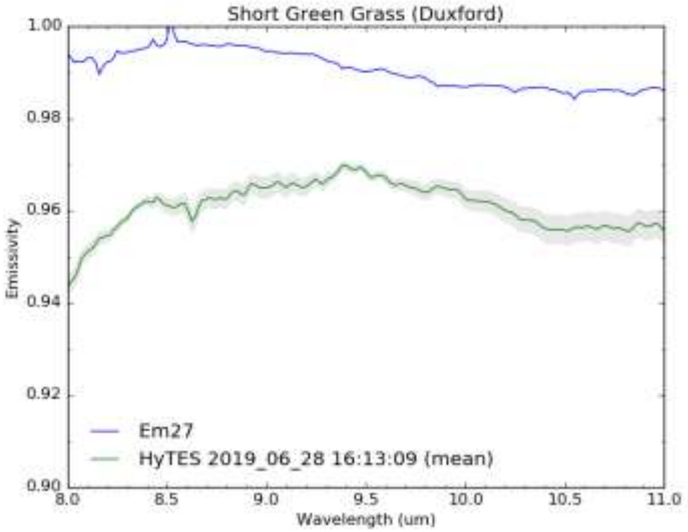


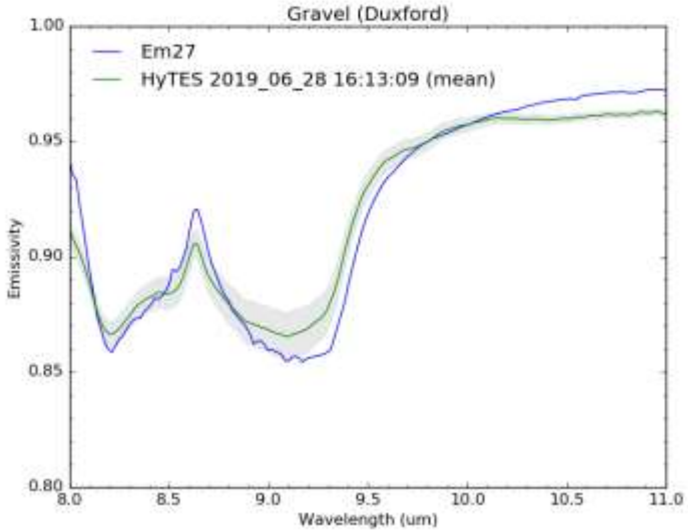
HyTES – In Situ Field/Lab LSE

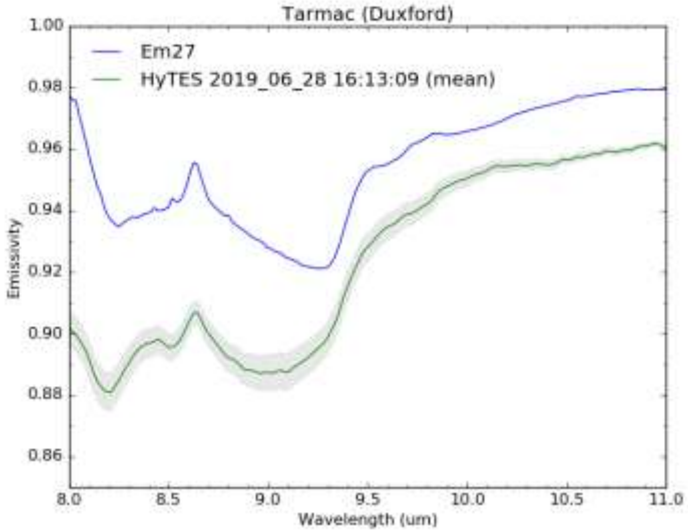




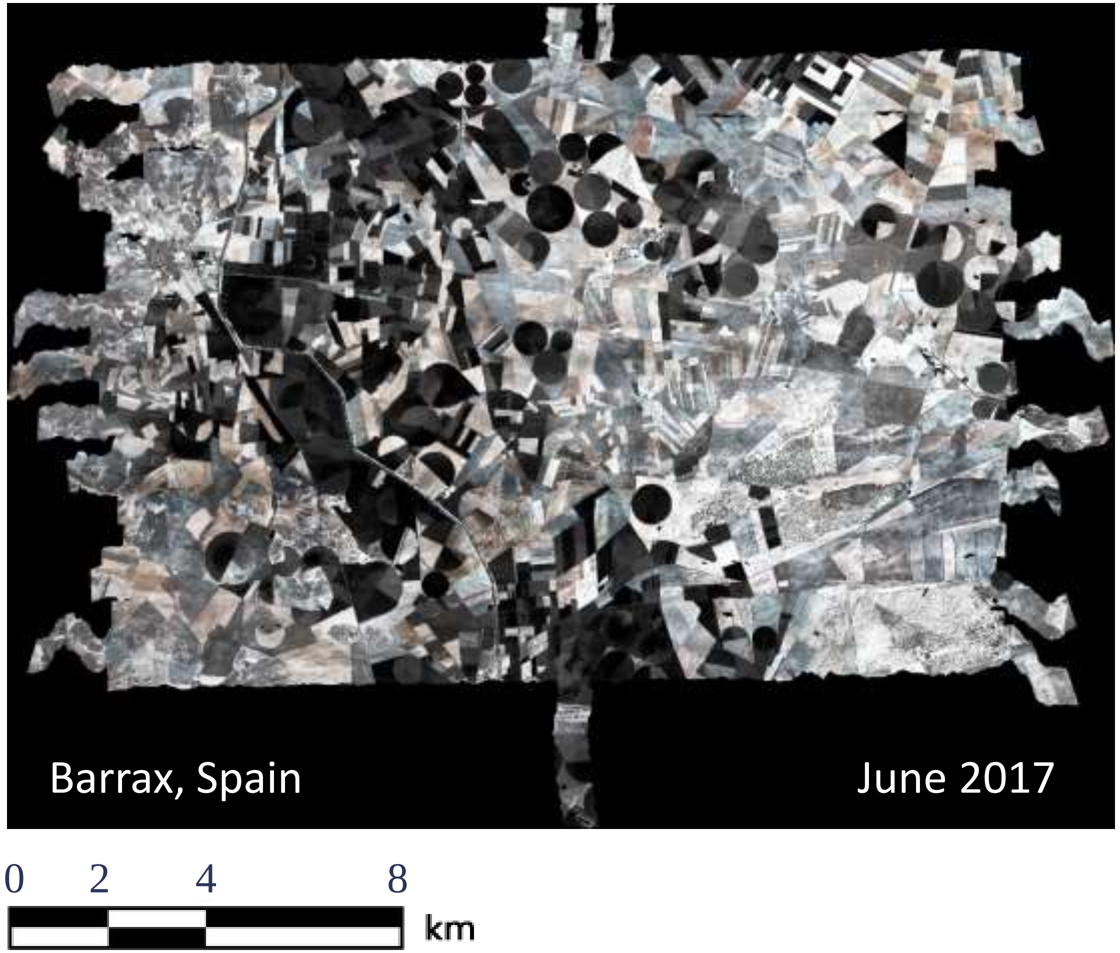




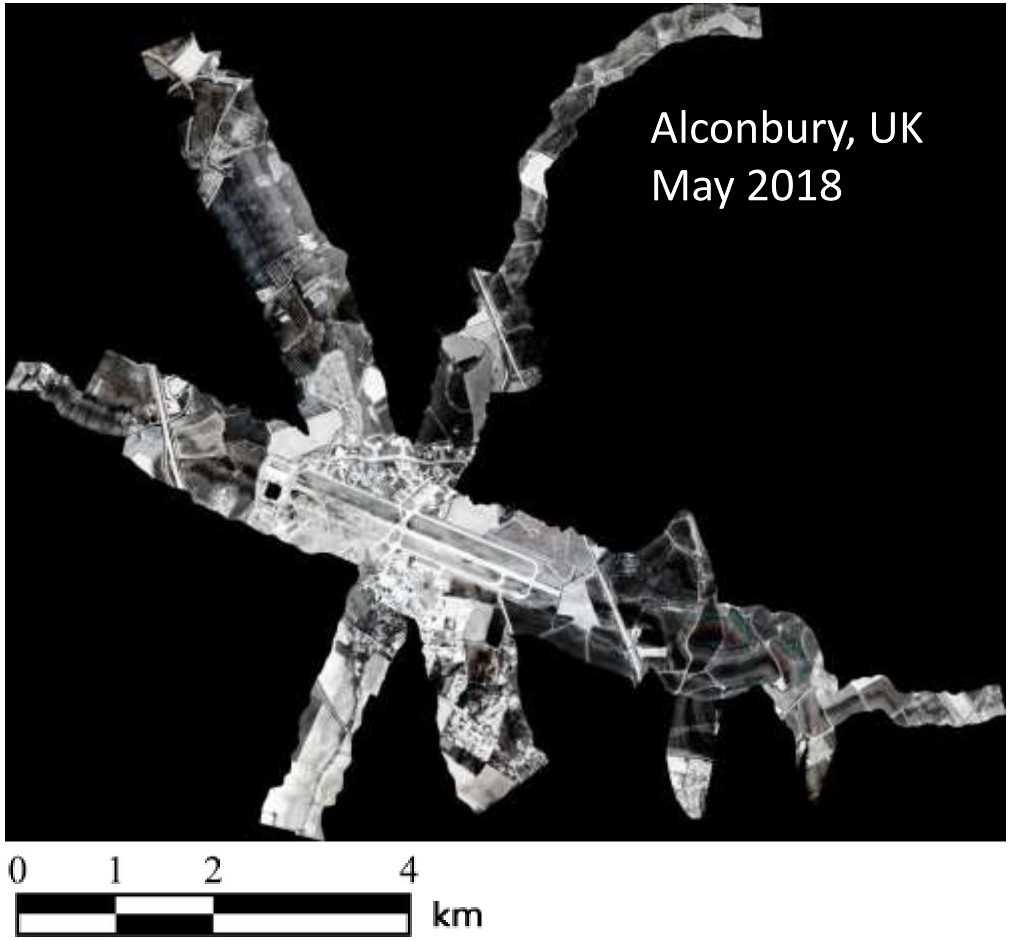




Data Collection (OWL)



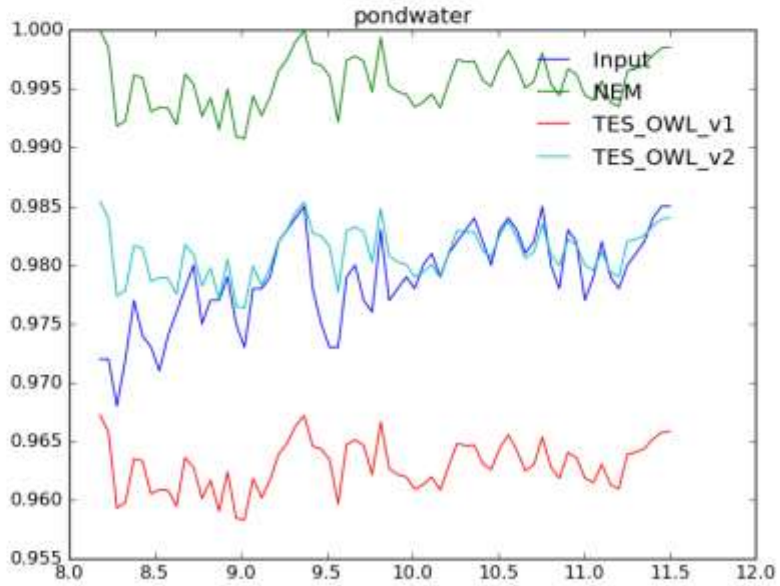
R: 8.03μm
G: 10.0μm
B: 12.0μm



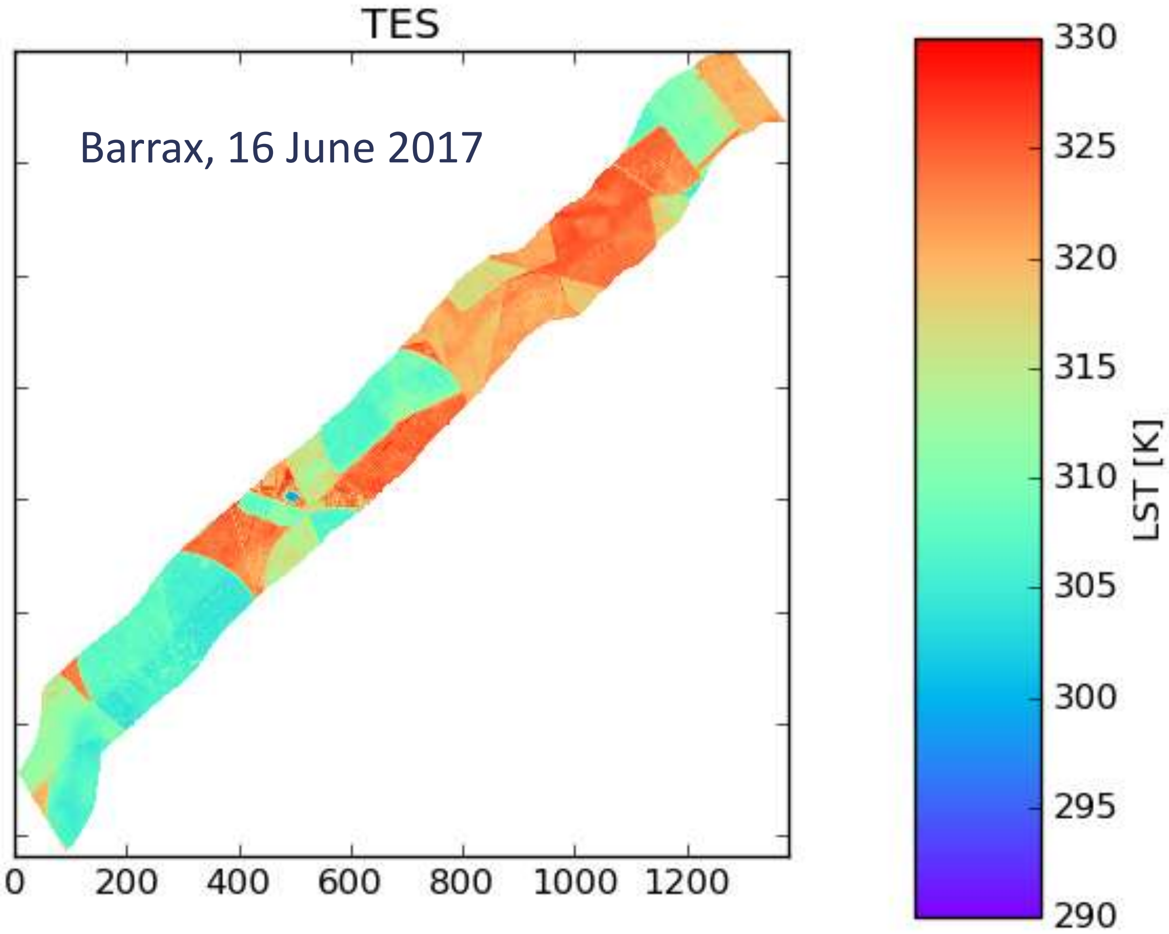
LST/Emissivity algorithm development: OWL Airborne Sensor

(1) Testing HyTES alg. adapted to OWL on simulated data

Sample	LST bias [OWL_v1] (K)	LST bias [OWL_v2] (K)
Water	1.096	0.161
Soil	1.966	1.125
Rock	0.338	0.734



(2) Testing OWL-derived LSTs and emissivity vs. in situ data



Summary and Concluding Remarks

- Hyperspectral airborne sensors offer new opportunities for mission and alg development for LST/LSE
- HyTES' LST and LSE retrieval alg. has been tested through deployment of field and lab instrumentation
  - HyTES LSTs found to be within 1.35 K for all surfaces considered and 0.8 K for natural surfaces
- Evaluation of algorithms must take into account accuracy of field/laboratory instrumentation and outputs
  - Intercomparison of different laboratory emissivity setups suggests NCEO laboratory setup within 2% of mean over LWIR
- Early application of HyTES LST/emissivity retrieval algorithm to OWL data promising
  - OWL algorithm within 1.2 K when tested on simulated data of natural surfaces
- Next steps: OWL validation with existing in situ data and HyTES 2021 campaign in Barrax flying OWL alongside in same platform