Airborne Mapping and *In Situ* Validation of European Land Surface Temperature (LST) using the NASA-JPL HyTES Sensor.

First Results from the 2019 European NET-Sense Campaign in Support of the Copernicus High Priority Candidate LSTM Satellite Mission Development

Martin Wooster, James Johnson, Thomas Dowling, Mary Langsdale, Mark De Jong, Mark Grosvenor, Weidong Xu
Department of Geography and NERC National Centre for Earth Observation King’s College London, UK.

Simon Hook, Bjorn Eng, William Johnson, Gerardo Rivera, Glynn Hulley
NASA JPL, Pasadena, California, USA.

Dirk Schuttemeyer and Benjamin Koetz
ESA-ESTEC and ESA-ESRIN, European Space Agency.

A Copernicus High Priority Candidate Mission

**LSTM Observation Requirements:**

- **Pixel size 30 - 50 m → European field scale variability**
- **LST observations should optimally be acquired daily (goal), with a minimum threshold of 3 days**
- **Minimum 3 bands in LWIR for evapotranspiration [ET] rate estimation based on LST measures – recommended additional narrow LWIR bands for improved separation of LST/emissivity**
- **Simultaneous VIS/NIR/SWIR required for atmospheric correction, cloud detection and emissivity estimation**
- **Collocation of S-2 & S-3 observations within +/-3 days for ancillary parameters**
- **Optimal LST obs in early afternoon (goal ~ 13:00 hrs)**
- **LST goal:** Accuracy 1.0 K @ 300 K
- **LST & LSE threshold:** Accuracy 1.5 K at 300 K, LSE 2%

<table>
<thead>
<tr>
<th>Key requirement</th>
<th>Design Concept</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometrical revisit</td>
<td>1 day/4 sats (2d/2s)</td>
</tr>
<tr>
<td>Local time</td>
<td>13:00 (Europe) &amp; night observations</td>
</tr>
<tr>
<td>SSD</td>
<td>50 m (37m at nadir)</td>
</tr>
<tr>
<td>Spectral Bands</td>
<td>5 TIR, 4 VNIR, 2 SWIR</td>
</tr>
<tr>
<td>Swath</td>
<td>700 km, at 640 km altitude</td>
</tr>
<tr>
<td>Acquisition system</td>
<td>Whiskbroom scanner</td>
</tr>
<tr>
<td>Geo-location L1c</td>
<td>1 SSD</td>
</tr>
<tr>
<td>MTF</td>
<td>0.2-0.3</td>
</tr>
<tr>
<td>Data latency (L2)</td>
<td>6-12 hours</td>
</tr>
<tr>
<td>NeDT</td>
<td>&lt; 0.1 K</td>
</tr>
<tr>
<td>ARA</td>
<td>&lt; 0.5 K</td>
</tr>
<tr>
<td>Satellite mass</td>
<td>about 1.1 ton</td>
</tr>
</tbody>
</table>
HyTES is a compact LWIR imaging spectrometer for airborne use.
- Acquiring data in 256 spectral bands between 7.5 and 12 μm.
- Incorporates several new technologies to maximise performance.

**Mass (Scanhead) & Power** | 12 kg & 400 W
---|---
**Number of pixels Across track** | 512
**Number of bands** | 256 across 7.5 - 12 μm @ 17nm resolution
**Total Field of View** | 50 °
**Pixel Size/Swath at 2,000 m alt** | 3.4 m
**Spectrometer Temperature** | 100 Kelvin
**Detector Temperature** | 40 Kelvin

First time HyTES was operated outside of North America
**Objectives**

- Provide Pathfinder data for future ESA Copernicus expansion TIR mission (LSTM)
- Support Calibration and Validation of the ESA Sentinel 3B
- Participate in ESA FLEX In Situ Campaign
  - Observe instrumented agricultural targets in Italy and the UK
  - Observe geo-thermal targets near Grosetto, Italy
  - Underfly ECOSTRESS, ASTER, Landsat and Sentinel 3 satellite
- Observe controlled-burn fire target and smoke plume in Italy.
  - Multiple passes, from ignition till completion.
  - Coordinate with HyPLANT fluorescence sensor.
- Produce quicklook L1A radiance images daily in the field
- Process to L1B and L2 surface temperature and emissivity at JPL
- Produce L3 products for select scenes
- Prepare for follow-on campaign in 2020 (now 2021)

**Approach**

- Establish a Space Act Agreement between King’s College, London (KCL) and NASA
- Work with KCL and British Antarctic Survey (BAS) to design mounting for BAS Twin Otter
- Ship HyTES to UK and install in BAS aircraft, together with UK-provided FENIX instrument.
- Fly to Italy and participate in Campaign over targets near Grosetto, Italy
- Coordinate with NASA and ESA satellite overpasses, multiple aircraft and ground teams.
- Process all ground data and HyTES data and share with partners

**Key Milestones**

- Space Act Agreement in place
- Ship to UK & Install in BAS Aircraft
- Transit to Italy, along with field team for in situ measurements
- NET-Sense Campaign in Grosetto/Siena
- Return to UK and perform UK flights and UK in situ measurements
- All data processed to L2 and available for public ordering on HyTES site
As well as the HyTES and Specim Fenix Airborne Imaging Spectrometers, a large amount of *in situ* ground equipment was deployed, including FTIRs, White, Grey and Black spectral targets, Microtops measuring AOD ~5 min intervals, DGPS, Onset TC Loggers in lakes, Heitronics LWIR radiometers and JPL Nulling LWIR radiometers, along with drone flights over crop stress experiments and eddy covariance sites measuring ET.
NET-Sense Field Sites. Italy 17\textsuperscript{th} – 24\textsuperscript{th} June 2019

\textit{In Situ} Validation Sites @ Grosseto

Land

Water
In Situ Data Examples - Surface Temperatures @ Grosseto

**Heitronics LWIR Radiometer Viewing Black Calibration Tarp.**

- **Blue:** Raw brightness temperature.
- **Orange:** logger temperature.
- **Green:** sky temperature.
- **Red:** emissivity and downwelling adjusted LST.
- **Purple:** QA flag.
- **Brown:** cumulative uncertainty.

**Lake Surface Temperature Measurements (Lake 2, Ring 2)**

- **Blue:** Thermocouple (TC) 1 temperature.
- **Orange:** TC 2 temperature.
- **Green:** TC 3 temperature.
- **Red:** TC 4 temperature.
- **Purple:** Mean water surface temperature.
Detail of HyTES Land Surface Temperatures

Calibration Tarps & “Radiometer Forest”

Land Surface Temperature (°C)

Onset TC Logger

LST (Kelvin)

400 410 420
0 250 500
Meters
NET-Sense Campaign Targets, UK. 28-30th June 2019

In Situ Validation Sites @ Duxford, UK
Test of field spectral emissivity measurement

“Vertex” is King’s lab FTIR with an intense LWIR source and gold integrating sphere. Considered most accurate measurement.

“D&P” is a specially designed field FTIR for measuring a sample’s upwelling LWIR signal and using this to determine emissivity via the spectral smoothness approach of Salvaggio & Miller (2001).

“EM27” is a field portable Bruker FTIR adapted by KCL to measure a sample’s upwelling LWIR signal and determine its emissivity via the same approach as deployed by the D&P instrument.
HyTES/In Situ Field/Lab Spectral Emissivity Intercomparison
Final LST Validation Results & Next Steps

- Finalise the final Level 2 processing of the remaining few flight lines. A total of 98 flight lines (1442 km) of airborne data were collected.

- Put uncertainties on all in situ measurements.

- Start to derive ET from HyTES LST data, compare to in situ.

- Spatially degrade HyTES LST and $\varepsilon$ data and compare to spaceborne estimates (ECOSTRESS, Sentinel-3, Meteosat).

- Provide full in situ and airborne data record to ESA/NASA and LSTM Project Teams.