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)
• 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 (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

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

What sensor measures (spectral radiance)
emissivity
What we want to estimate
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]

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

Airborne data collected with HyTES in European sites (UK/Italy) June 2019 – data input for LSTM Design Studies
Multiple algorithms been developed to tackle this
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)
Validation of LST/ Emissivity Retrieval Algorithm

Spectral emissivity measurements from:
(i) Samples collected + measured in laboratory
(ii) Measurements in field using portable instruments

Temperature measurements from LWIR radiometers over thermally distinct surfaces

OWL spectral range (96 spectral bands)
7.6 - 12.6 µm
Laboratory Instrumentation: Emissivity

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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectral resolution</td>
<td>0.5 cm(^{-1}), 4 cm(^{-1}), and 8 cm(^{-1})</td>
</tr>
<tr>
<td>Spectral recording range</td>
<td>4000-625 cm(^{-1}) (2.5 – 16 μm)</td>
</tr>
<tr>
<td>Meas. Type</td>
<td>Directional Hemispherical Reflectance</td>
</tr>
<tr>
<td>Sample port</td>
<td>30 mm</td>
</tr>
</tbody>
</table>
Field Instrumentation: Emissivity

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

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

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
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

<table>
<thead>
<tr>
<th>Method</th>
<th>Heitronics KT15.85 band-specific emissivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laboratory (Vertex-V70)</td>
<td>0.956 ± 0.003</td>
</tr>
<tr>
<td>Field (EM27)</td>
<td>0.952 ± 0.009</td>
</tr>
<tr>
<td>Field (D&amp;P)</td>
<td>0.956 ± 0.002</td>
</tr>
</tbody>
</table>
Data Collection [HyTES] during ESA/NASA NETSense Campaign 2019

Data collected as part of NETSense campaign (June 2019)

Grosseto, Italy

Duxford + surrounding areas, UK
HyTES data from NETSense Campaign

Grosseto AM
23 June 2019

Level 1 – Raw

Level 2 – LST

Level 2 – LSE
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)

Barrax, Spain  
June 2017

R: 8.03µm  
G: 10.0µm  
B: 12.0µm

Alconbury, UK  
May 2018
LST/Emissivity algorithm development: OWL Airborne Sensor

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

<table>
<thead>
<tr>
<th>Sample</th>
<th>LST bias [OWL_v1] (K)</th>
<th>LST bias [OWL_v2] (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>1.096</td>
<td>0.161</td>
</tr>
<tr>
<td>Soil</td>
<td>1.966</td>
<td>1.125</td>
</tr>
<tr>
<td>Rock</td>
<td>0.338</td>
<td>0.734</td>
</tr>
</tbody>
</table>

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

Barrax, 16 June 2017
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
  o 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
  o 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
  o 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