Combined VSWIR-TIR analysis of vegetation in natural, urban and agricultural settings from the HyspIRI airborne campaign

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NASA HyspIRI Preparatory Program
NASA ESSF Program
NSF GRF Program
Jet Propulsion Laboratory
Broad Research Questions

• What are the synergies between the VSWIR and TIR for vegetation analysis?
  – What is the potential of VSWIR fractions combined with LST?

• Can we map plant species over large areas over multiple years and seasons using imaging spectrometry?
  – What is the potential of developing a global spectral library?
Outline

• Developing a VSWIR-TIR model
  – Roberts et al., 2015 (RSE/ESA)

• Applying a VSWIR-TIR model
  – Agricultural Settings: Shivers et al. (in prep)

• Mapping plant species over large areas and multiple seasons and years
  – Santa Barbara Flight Box: Meerdink et al. (in prep)

• Thoughts and conclusions
Developing the Model

- An inverse relationship exists between GV fraction and LST
- Plant species cluster uniquely in the GV-LST space

Roberts et al., 2015 (RSE)
Subpixel Temperature Modeling

\[ \text{Modeled mixed pixel} \ (309 \text{ K}) \]

\[ \text{Residual} = \text{LST}_{\text{measured}} - \text{LST}_{\text{modeled}} > 1 \]

Roberts et al., 2015 (ESA)

- Oak suffering heat stress?
- Lower albedo/hotter road?
- Non-linearity?
Subpixel Temperature Modelling

- VSWIR Fractions from AVIRIS
- LST from MASTER
  - Isolated for each thermal class
  - Limited to 100% cover

\[ LST_m = f_{gv} \times LST_{gv} + f_{npv} \times LST_{npv} + f_{soil} \times LST_{soil} + f_{rock} \times LST_{rock} + f_{paved} \times LST_{paved} + f_{roof} \times LST_{roof} \]

LST (thermal class)
Senesced Mustard is cool (<-6 C)
East-west large roads are cool (<-5 C)
Concrete is cool (<-3 C)

Citrus and Avocado are warm (> 5 C)
North-south large roads are warm (> 2 C)

\[ \text{LST}_{\text{resid}} = \text{LST}_{\text{mea}} - \text{LST}_{\text{mod}} \]
Agricultural Applications: Sarah Shivers

- Developed a VSWIR-LST model for the Soda Straw analyzed changes in crops 2013-2015
- Used MESMA to map fractions of GV, NPV and Soil

\[ \text{Red: NPV} \]
\[ \text{Green: GV} \]
\[ \text{Blue: Soil} \]

- Used MESMA results and crop species information to divide GV, NPV, and soil into subclasses expected to have similar thermal properties
- Modeled expected temperature using fractional cover and thermal endmembers

\[ \text{LST}_{\text{expected}} = f_{\text{GV}} T_{\text{GV}} + f_{\text{SOIL}} T_{\text{SOIL}} + f_{\text{NPV}} T_{\text{NPV}} \]

- Calculated a temperature residual

\[ \text{Residual} = \text{LST}_{\text{MASTER}} - \text{LST}_{\text{expected}} \]

Shivers et al., in prep
Crop groups and MESMA thermal classes are unique

Crop groups show distinct LST distributions

MESMA endmember groups are suitable as thermal classes and show sensitivity to soil moisture

Shivers et al., in prep
Residuals vary by Crop

Of 11 crops, 7 showed unique LST residual distributions

Residuals increased as the drought progressed

Shivers et al., in prep
LST Residuals reflect crop yield

Crops with the highest positive temperature residuals, also had the largest reductions in yield during the study period.

Shivers et al., in prep
Wetherley, Erin B., Joseph P. McFadden, and Dar A. Roberts. 2018. “Megacity-Scale Analysis of Urban Vegetation Temperatures.”, RSE, 2018

Study Area = 4,466 km$^2$
Modeling LST by Plant Type & Material

- 1,756,302 Mixed Pixels
- 4 Mixture Types

Vegetation mixed with...

NPV

Impervious

LST (°C)

Vegetation Fraction

0% 100% 0% 100%

Tree

Turfgrass

X%
Turfgrass or Tree

1 - X%
NPV or Impervious

LST

0% 100%
Subtracting modeled from measured vegetation LST reveals ~15°C of variability independent of fraction & plant type.
Examining other sources of temperature variability across LA, including...

Building Fraction (LA County GIS)

Building Fraction has a 3x greater effect on measured tree LST compared to turfgrass LST.

Turf: $y = 0.55x + 0.09, \ R^2 = 0.54$

Tree: $y = 1.25x + 0.40, \ R^2 = 0.60$
Examining other sources of temperature variability across LA, including...

**Vegetation Management**

Wealthier areas in L.A. have more vegetation.

For each $10,000 increase in median income, vegetation LST decreased by 0.23°C.

Areas with more outdoor water use are cooler!
Classifying California plant species across seasons
Susan Meerdink, Dar Roberts, Paul Gader, Keely Roth, Jennifer King, Zachary Tane, and Alexander Koltunov

- **Imagery**
  - 2013 Spring 04/11/13
  - 2013 Summer 06/06/13
  - 2013 Fall 11/25/13
  - 2014 Spring 04/16/14
  - 2014 Summer 06/06/14
  - 2014 Fall 08/29/14
  - 2015 Spring 04/16/15
  - 2015 Summer 06/02/15
  - 2015 Fall 08/24/15

Total of 88 Images

- **Approach:**
  - Spectral libraries from reference polygons
  - Mapping using CDA/LDA
Single Date Libraries Outperform all Other Libraries

Example of classifying Fall 2015 imagery:

- Single Date Library: Fall 2015
- Seasonal Library: Fall ‘13/‘14/‘15
- Yearly Library: Spr./Sum./Fall ‘15
- All Dates Library: All 9 Image Dates

<table>
<thead>
<tr>
<th>Single Date Library</th>
<th>Seasonal Library</th>
<th>Yearly Library</th>
<th>All Dates Library</th>
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</thead>
<tbody>
<tr>
<td>0.78 – 0.84 mean kappa</td>
<td>0.76 – 0.82 mean kappa</td>
<td>0.74 – 0.82 mean kappa</td>
<td>0.71 – 0.79 mean kappa</td>
</tr>
<tr>
<td>Spring 2013 &amp; 2014 highest accuracy</td>
<td>Kappa loss ranging 0.02 - 0.07</td>
<td>Kappa loss ranging 0.01 – 0.08</td>
<td>Kappa loss ranging 0.03 – 0.10</td>
</tr>
</tbody>
</table>
**Juniperus californica** (Juniper)

**Pinus monophylla** (Single-leaf Pinyon)

**Artemisia californica & Salvia leucophylla** (CA Sagebrush & Purple Sage)

**Quercus douglasii** (Blue Oak)
Libraries perform poorest when applied to data sets excluded from training.

### Overall Kappa Classification Accuracy

<table>
<thead>
<tr>
<th>Image Date</th>
<th>All Dates</th>
<th>Leave One Date Out</th>
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<tbody>
<tr>
<td>2013 Spring</td>
<td>0.75</td>
<td>0.44</td>
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<tr>
<td>2013 Summer</td>
<td>0.75</td>
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<tr>
<td>2013 Fall</td>
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<tr>
<td>2014 Spring</td>
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<tr>
<td>2014 Fall</td>
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<td>0.58</td>
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<tr>
<td>2015 Spring</td>
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<td>0.56</td>
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<tr>
<td>2015 Summer</td>
<td>0.77</td>
<td>0.70</td>
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<tr>
<td>2015 Fall</td>
<td>0.73</td>
<td>0.57</td>
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Conclusions and Thoughts

• The hyperspectral VSWIR-LST residual model has considerable promise
  – Does not require simultaneous observations
  – Broad applications in multiple ecosystems

• Plant species can be mapped over large areas and multiple dates
  – Highest accuracies were achieved when image dates and libraries were the same
  – Seasonal libraries outperformed yearly, multi-year libraries
  – Existing spectral libraries may not be transferable across dates
    • Develop geodatabase of reference species locations
  – A spaceborne system will likely outperform airborne data
    • Improved sun-sensor geometry
    • Fewer cross track/cross flight line artifacts
Identify within-field stress