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High Resolution Geospatial Mapping of Actual Evapotranspiration Using Small UAS Based Imagery for Site Specific Irrigation Management

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Outline

- Background
- Hypothesis and objectives
- Methods
- Results
- Conclusions
- Future plan and scope
Background

Water: the most critical resource

- Covers 71% of earth
- 96.5% in oceans/seas
- Only 0.77% of fresh water

Source: NASA

Agriculture
- Accounts over 80% of the US consumptive use
- Biggest consumer of fresh water about 70% (globally)

Background

Current challenges

- Population
- Food demand
- Climate change impacts
- Arid and semi arid areas
- Area under irrigation

Conventional irrigation practices
- Constant or over irrigation

“This calls for specific/precision irrigation management tools at local/grower level”
Irrigation management requires accurate estimates of actual crop water demands at field level.

Evapotranspiration (ET)
- Amount of water lost by plants and soil to the atmosphere
- Indicator of actual plant water requirements
Current methods of ET estimation

- Small/point scale:
  - Lysimeters, neutron probes, soil moisture measurements, point measurement tools etc.
  - Limited sampling accuracy and laborious
Weather based estimations of ET:

- Penman Monteith method and typical crop coefficients
- Irrigation scheduling tools examples
  - WSU irrigation scheduler and AgWeather network (Washington State University)
  - Irrigation management online (Oregon State University)
  - CropManage (University of California)
- Limitations: standard crop coefficients may not be the same within field and globally

Background

Courtesy: http://www.weather.wsu.edu/
Large scale: Remote sensing and energy balance

- Remote sensing: satellites
  - Low spatial resolution ex: Landsat 7/8 (~30 m) and MODIS (1 km)
  - Large recurrence period (~16 days) and cloud cover limitations
  - Unsuitable for high resolution spatiotemporal mapping

- Small unmanned aerial systems (UAS)
  - High spatial and temporal resolution
  - On-demand data

Source: earth magazine
Energy balance models

- Single source (crop transpiration and soil evaporation combined)
- Dual source (separate crop transpiration and soil evaporation)
  - Complex measurements
  - Limited adaptability
- METRIC (Allen et al., 2007)
  - Developed for satellite-based imagery data (multispectral and thermal)
  - Widely adopted, robust and independent of crop specifications
  - Internal calibration using stressed and unstressed conditions

Energy balance concept:

\[ LE = Rn - G - H \]
\[ LE = \lambda \times ET \]

\( \lambda = \text{latent heat of water vaporization} \)
Hypothesis and Objectives

Problem statement and hypothesis

- Site specific irrigation management at field level
- Integration of high-resolution imagery data to energy balance model

Objectives

- METRIC energy balance model for high spatiotemporal mapping of actual evapotranspiration using small UAS based multispectral and thermal infrared imagery
- Comparison and validation of the modified METRIC with the conventional approaches
Methods

- Data collection
  - Season: 2018
  - Selected crops
    - Potato
    - Grapevine
    - Alfalfa
    - Spearmint
Irrigation methods

**Potato:** center pivot

**Grapevines:** surface and sub-surface drip

**Alfalfa:** wheel line

**Spearmint:** center pivot
Methods

- **Data collection (cont.)**
  - Imagery data
    - Visible, near-infrared and thermal infrared
  - Imaging platforms (overlapped missions)
    - Small UAS
    - Landsat 7/8 satellites
  - Weather data: (WSU AgWeathernet network)

Source: WSU AgWeathernet
Methods

Table 1. Imaging sensor specifications

<table>
<thead>
<tr>
<th>Platform</th>
<th>Imaging sensor</th>
<th>Spectral Bands</th>
<th>Ground sampling distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small UAS</td>
<td>Five band multispectral</td>
<td>Red, Green, Blue, NIR and Red Edge</td>
<td>6.9 cm/pixel @ 100m</td>
</tr>
<tr>
<td></td>
<td>Thermal</td>
<td>Long wave infrared</td>
<td>13.20 cm/pixel @ 100m</td>
</tr>
<tr>
<td>Satellite (Landsat 7/8)</td>
<td>Multispectral</td>
<td>Red, Green, Blue, NIR, SWIR</td>
<td>30 m/pixel</td>
</tr>
<tr>
<td></td>
<td>Thermal</td>
<td>Long wave infrared</td>
<td>30 m/pixel</td>
</tr>
</tbody>
</table>

Table 2. Data collection dates

<table>
<thead>
<tr>
<th>Day of year (DOY)</th>
<th>Date</th>
<th>Crop</th>
<th>Nearest AgWeathernet station</th>
</tr>
</thead>
<tbody>
<tr>
<td>175</td>
<td>06/24/2018</td>
<td>Mint</td>
<td>Toppenish</td>
</tr>
<tr>
<td>184</td>
<td>07/03/2018</td>
<td>Potato</td>
<td>Wheelhouse</td>
</tr>
<tr>
<td>191</td>
<td>07/10/2018</td>
<td>Alfalfa</td>
<td>Roza</td>
</tr>
<tr>
<td>192</td>
<td>07/11/2018</td>
<td>Grapevine</td>
<td>Benton City</td>
</tr>
<tr>
<td>207</td>
<td>07/26/2018</td>
<td>Grapevine</td>
<td>Benton City</td>
</tr>
<tr>
<td>207*</td>
<td>07/26/2018</td>
<td>Potato</td>
<td>Wheelhouse</td>
</tr>
<tr>
<td>208</td>
<td>07/27/2018</td>
<td>Potato</td>
<td>Wheelhouse</td>
</tr>
<tr>
<td>208*</td>
<td>07/27/2018</td>
<td>Grapevine</td>
<td>Benton City</td>
</tr>
<tr>
<td>223</td>
<td>08/11/2018</td>
<td>Alfalfa</td>
<td>Roza</td>
</tr>
</tbody>
</table>

*Additional imagery data from Landsat 7/8 for same area of study
Methods

- Adapting METRIC energy balance
  - Surface albedo
  - Leaf area index: using fraction canopy cover
  - Digital land surface elevation model
  - Incoming short-wave radiation (~2 m AGL)
  - Surface temperature map

Data preprocessing

1. Collection of image snapshots
2. Image stitching
3. Image georectification
4. Image orthorectification
5. Image ortho mosaicking
6. Image radiometric calibration
7. Band maps and DEM generation
8. Thermal map georectification to multispectral map
9. Thermal map resampling to multispectral map
10. Corrected maps

Stop
Methods

Data processing

- Area of interest
- Weather data file
- Flight metadata file

METRIC

- VIS-NIR image maps
- Thermal image map
- Digital elevation model

Soil heat flux
Sensible heat flux
Net radiation

Latent heat flux
Latent heat of vaporization

Actual evapotranspiration
Crop coefficient
Daily evapotranspiration
Reference evapotranspiration

Comparison and validation

- Landsat 7/8 and METRIC (LM)
- Small UAS and METRIC (SUASM)
- Small UAS and Modified METRIC (SUASMM)
- Single crop coefficient approach (FAO-Kc)
Methods

High resolution imagery data preprocessing and processing illustration

- Thermal infrared image snapshot
- Stacks of multispectral snapshots

Preprocessing

Weather data
- Imagery band maps

Processing

- Temperature map
- NDVI map
- SAVI map
- Digital elevation model

- Actual evapotranspiration map
- Site-specific irrigation prescription map
Results: Potato

Satellite (Landsat) and METRIC based ET map (30m/pixel)

Small UAS and METRIC based ET map (7 cm/pixel)

Small UAS and modified METRIC based ET map (7 cm/pixel)
Results: Grapevine

Satellite (Landsat) based actual crop ET map (30 m/pixel)

Small UAS based actual crop ET map (6.9 cm/pixel)
Results: Alfalfa

Satellite (Landsat) and METRIC based ET map (30m/pixel)

Small UAS and METRIC based ET map (7 cm/pixel)

Small UAS and modified METRIC based ET map (7 cm/pixel)
Results

Approach
- SUASM: small UAS METRIC
- SUASMM: small UAS modified METRIC
- LM: Landsat METRIC
- FAO-Kc: Standard single crop coefficient
### Results (Mean of actual crop ET maps)

#### Table 3. Mean of actual crop ET maps

<table>
<thead>
<tr>
<th>Approach/Platform</th>
<th>Mean of actual crop ET maps (mm/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUASM</td>
<td>5.21 ± 1.59</td>
</tr>
<tr>
<td>SUASMM</td>
<td>5.25 ± 1.14</td>
</tr>
<tr>
<td>LM</td>
<td>5.20 ± 1.32</td>
</tr>
<tr>
<td>FAO-Kc</td>
<td>6.42 ± 1.29</td>
</tr>
</tbody>
</table>

#### Table 4. Comparison of mean actual crop ET mapped from different approaches

<table>
<thead>
<tr>
<th>Approach/Platform</th>
<th>RMSE (mm/day)</th>
<th>MBE (mm/day)</th>
<th>RMSE (%)</th>
<th>MBE (%)</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUASM-LM</td>
<td>0.56</td>
<td>0.02</td>
<td>10.72</td>
<td>0.29</td>
<td></td>
</tr>
<tr>
<td>SUASMM-LM</td>
<td>0.53</td>
<td>0.05</td>
<td>10.20</td>
<td>1.04</td>
<td>NS (P&gt;0.05)</td>
</tr>
<tr>
<td>SUASM-FAO-Kc</td>
<td>1.63</td>
<td>-1.37</td>
<td>24.79</td>
<td>-20.81</td>
<td></td>
</tr>
<tr>
<td>SUASMM-FAO-Kc</td>
<td>1.43</td>
<td>-1.33</td>
<td>21.72</td>
<td>-20.22</td>
<td></td>
</tr>
</tbody>
</table>
### Table 5. Standard deviation in actual crop ET maps

<table>
<thead>
<tr>
<th>Approach/Platform</th>
<th>Mean Std. Dev. in actual crop ET maps (mm/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUASM</td>
<td>1.55</td>
</tr>
<tr>
<td>SUASMM</td>
<td>1.24</td>
</tr>
<tr>
<td>LM</td>
<td>0.31</td>
</tr>
<tr>
<td>FAO-Kc</td>
<td>0</td>
</tr>
</tbody>
</table>

### Table 6. Comparison of standard deviation in actual crop ET maps from different approaches

<table>
<thead>
<tr>
<th>Approach/ Platform</th>
<th>RMSE (mm/day)</th>
<th>Difference</th>
<th>Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>LM-SUASM</td>
<td>1.47</td>
<td></td>
<td>b, a</td>
</tr>
<tr>
<td>LM-SUASMM</td>
<td>1.14</td>
<td>S (P&lt;0.05)</td>
<td>b, a</td>
</tr>
<tr>
<td>FAO-Kc-SUASM</td>
<td>1.73</td>
<td></td>
<td>b, a</td>
</tr>
<tr>
<td>FAO-Kc-SUASMM</td>
<td>1.40</td>
<td></td>
<td>b, a</td>
</tr>
</tbody>
</table>
Conclusions

- **High spatial resolution- METRIC**
  - Better handling of heterogeneous pixels (soil and crop)
  - High resolution mapping of spatial variations in crop water demand
  - Suitable for tree fruit crops

- **Future plan and scope**
  - Model local calibration using artificial reference materials (Hot and Cold)
  - Crop ET estimation with reliable soil water balance approach
  - Validation and improvement of SUASMM with soil water balance approach
  - Site specific irrigation prescription maps
Acknowledgments

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Questions/ suggestions ?