Combined Use of Landsat-8 and Sentinel-2 Data for Agricultural Monitoring

S. Skakun\textsuperscript{1,2}, J.-C. Roger\textsuperscript{1,2}, E. Vermote\textsuperscript{2}, B. Franch\textsuperscript{1,2}, C. Justice\textsuperscript{1}, J. Masek\textsuperscript{3}

\textsuperscript{1} Department of Geographical Sciences, University of Maryland, College Park MD 20742, USA
\textsuperscript{2} NASA Goddard Space Flight Center Code 619, Greenbelt, MD 20771, USA
\textsuperscript{3} NASA Goddard Space Flight Center Code 618, Greenbelt, MD 20771, USA
Introduction

- **Major tasks of agricultural monitoring**
  - Crop mapping
  - Crop area estimation
  - Crop state assessment
  - Crop yield assessment/forecasting

- **Remote sensing**
  - Valuable source of data for agricultural monitoring
  - Large body of works using coarse spatial, but high temporal (daily) resolution, e.g. AVHRR, MODIS
  - **Combined use of Landsat-8 and Sentinel-2**
    - An image every 3–5 days globally
    - Next generation agricultural products at ≤ 30 m
Objective of the study

- **Overarching goal**
  - To explore *high frequency* Landsat-8 & Sentinel-2A images for *winter wheat mapping* and *yield assessment*

- **Objectives**
  - (i) to assess performance of **downscaling the peak–NDVI–based empirical model** for winter wheat yield forecasting
  - (ii) to explore the combined use of images acquired by **Landsat-8 and Sentinel-2A satellites (HLS)** for *winter crop mapping* and *winter wheat yield* assessment at regional level
Study area

- **Agriculture in Ukraine**
  - **Wheat:** 7th world largest producer and 6th world largest exporter (in 2017)
  - **Sunflower:** 1st world largest producer and 8th world largest exporter (in 2017)

**Study area**

- Kirovohradska oblast with 21 districts (counties)
  - Geographical area: 65–165 thousand ha
  - Cropland area: 27–112 thousand ha

- **Winter wheat**
  - Accounts for 20% of production of all crops in the region
  - Mainly rainfed
  - Yield range: 3.4–4.7 t/ha
Data

- Remote sensing
  - HLS: Landsat-8 & Sentinel-2A
  - 8 Sentinel-2 tiles
  - Overall 138 scenes
    - March-June 2016

- Statistical data
  - Department of Agro-Industry Development of Kirovohrad State Administration (http://apk.kr-admin.gov.ua)

- Meteorological
  - MERRA2 from NASA
Methodology

Winter crop mapping

Calculate maximum NDVI from March 1 to April 6

Run Gaussian mixture model (GMM) over cropland mask (Eq. 1)

Winter crop map

Landsat-8 Sentinel-2A

Winter crop yield mapping

Calculate maximum NDVI from March 1 to June 30

Run yield model

Winter wheat yield map

Cropland mask

Downscaled crop yield model
Methodology

- An automatic method for **early season large-area** winter crop mapping
- The method is based on **NDVI** and **Gaussian Mixture Model (GMM)**
- The method can map winter crops **1.5–2 months before harvest** with accuracies > 90%

Gaussian mixture model (GMM) to discriminate between winter and other crops

\[ p(x) = \sum_{k=1}^{K} \pi_k N(x | \mu_k, \Sigma_k), \]

where \( N(x | \mu_k, \Sigma_k) \) is the Gaussian distribution with mean \( \mu_k \) and covariance \( \Sigma_k \), and weights \( \pi_k \)

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Methodology

- **Downscaling** a winter wheat yield model at coarse scale, that is based on MODIS NDVI and GDD, to higher spatial resolution (30m) with Landsat-8
- **Generalized** empirical model calibrated for US
- **Interpolate** the coarse model with mixed pixels of winter wheat to the high spatial resolution (HR) model with pure winter wheat pixels
- **Use GDD** to predict the NDVI peak


Results: winter crop mapping

- Overall accuracy, when comparing to ground truth, is 94.1%
### Results: winter crop mapping

- Winter crop area, when comparing to official statistics, harvested area (in ha)

<table>
<thead>
<tr>
<th>Metric</th>
<th>LC8</th>
<th>S2A</th>
<th>LC8-S2A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy (bias)</td>
<td>1081</td>
<td>839</td>
<td>612</td>
</tr>
<tr>
<td>Precision (repeatability)</td>
<td>5061</td>
<td>1962</td>
<td>1719</td>
</tr>
<tr>
<td>Uncertainty</td>
<td>5056</td>
<td>2090</td>
<td>1785</td>
</tr>
<tr>
<td>rU, %</td>
<td>32.7</td>
<td>13.5</td>
<td>11.6</td>
</tr>
<tr>
<td>R²</td>
<td>0.64</td>
<td>0.88</td>
<td>0.90</td>
</tr>
</tbody>
</table>

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Results: winter crop yield assessment

- Winter crop yield (no GDD), when comparing to official statistics (in t/ha)

<table>
<thead>
<tr>
<th>Metric</th>
<th>LC8</th>
<th>S2A</th>
<th>LC8-S2A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy (bias)</td>
<td>-0.48</td>
<td>-0.34</td>
<td>-0.17</td>
</tr>
<tr>
<td>Precision (repeatability)</td>
<td>0.31</td>
<td>0.32</td>
<td>0.26</td>
</tr>
<tr>
<td>Uncertainty</td>
<td>0.57</td>
<td>0.46</td>
<td>0.31</td>
</tr>
<tr>
<td>rU, %</td>
<td>14.3</td>
<td>11.5</td>
<td>7.7</td>
</tr>
<tr>
<td>R²</td>
<td>0.29</td>
<td>0.28</td>
<td>0.45</td>
</tr>
</tbody>
</table>


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## Results: winter crop yield assessment

- Winter crop yield (with GDD), when comparing to official statistics (in t/ha)

<table>
<thead>
<tr>
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<th>LC8</th>
<th>S2A</th>
<th>LC8-S2A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy (bias)</td>
<td>-0.40</td>
<td>-0.22</td>
<td>-0.06</td>
</tr>
<tr>
<td>Precision (repeatability)</td>
<td>0.31</td>
<td>0.32</td>
<td>0.26</td>
</tr>
<tr>
<td>Uncertainty</td>
<td>0.50</td>
<td>0.38</td>
<td>0.26</td>
</tr>
<tr>
<td>rU, %</td>
<td>12.5</td>
<td>9.6</td>
<td>6.5</td>
</tr>
<tr>
<td>R²</td>
<td>0.31</td>
<td>0.24</td>
<td>0.50</td>
</tr>
</tbody>
</table>

**Equations:**
- **Landsat-8 only:**
  \[ y = 0.658x + 1.623 \]
  \[ R^2 = 0.309 \]
- **Sentinel-2A only:**
  \[ y = 1.435x - 1.646 \]
  \[ R^2 = 0.501 \]
- **Landsat-8 & Sentinel-2A:**
  \[ y = 1.435x - 1.646 \]
  \[ R^2 = 0.501 \]


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Conclusion

- Winter crop mapping with HLS:
  - Adopted from MODIS approach works well, yielding ~94% accuracy and 11.6% error for planted areas

- Winter wheat yield assessment with HLS:
  - Downscaled from MODIS peak-NDVI approach (no GDD) at regional scale showed performance $RMSE=0.31 \text{ t/ha (7.7\%)}$ and $R^2=0.45$
  - The model was efficient in explaining moderate yield values (<4 t/ha) with $R^2=0.8$; however, it failed to capture the variance of high yield values (>4 t/ha) due to NDVI saturation

- Combined use of Landsat-8 and Sentinel-2A was essential for both tasks
  - HLS outperformed both single dataset

- Application Readiness Level (for crop yield)
  - ARL3 (Proof of Application Concept (Viability Established))
Acknowledgment

- NASA’s Harmonized Landsat Sentinel-2 (HLS) product
- NASA-funded project “Crop Yield Assessment and Mapping by a Combined Use of Landsat-8, Sentinel-2 and Sentinel-1 Images”
- Presentation contains modified Copernicus Sentinel data (2016) processed by ESA
Thank You!