Satellite remote sensing applications to support cropland conservation management

W. Dean Hively, U.S. Geological Survey

with Alison Thieme, Jyoti Jennewein, Feng Gao, Greg McCarty, Steven Mirsky, USDA-ARS

in collaboration with MDA, DACD, Stroud Water Research Center, USDA CEAP and LTAR programs

- U.S. Department of the Interior
- U.S. Geological Survey

Contact: whively@usgs.gov

Chesapeake Bay Program Agricultural Working Group
2/15/2024

Remote sensing of cropland conservation practices

- Winter cover crop location
- Winter cover crop performance
- Crop residue cover / tillage intensity / conservation tillage
- Not discussing structural conservation practices (barnyards, fencing, etc…)

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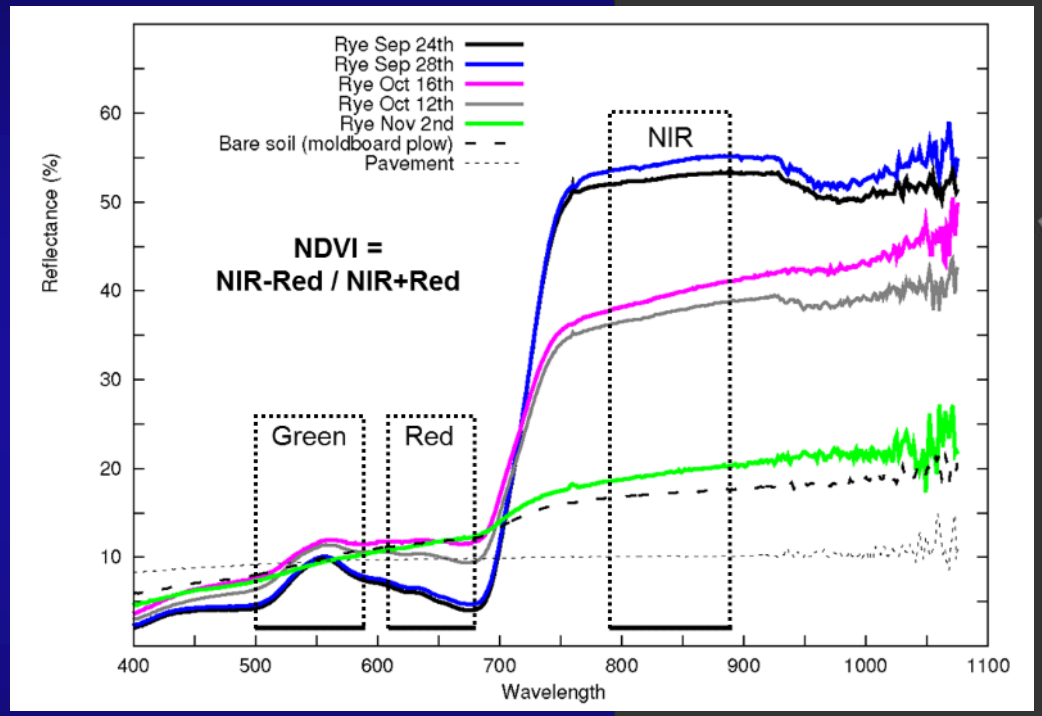
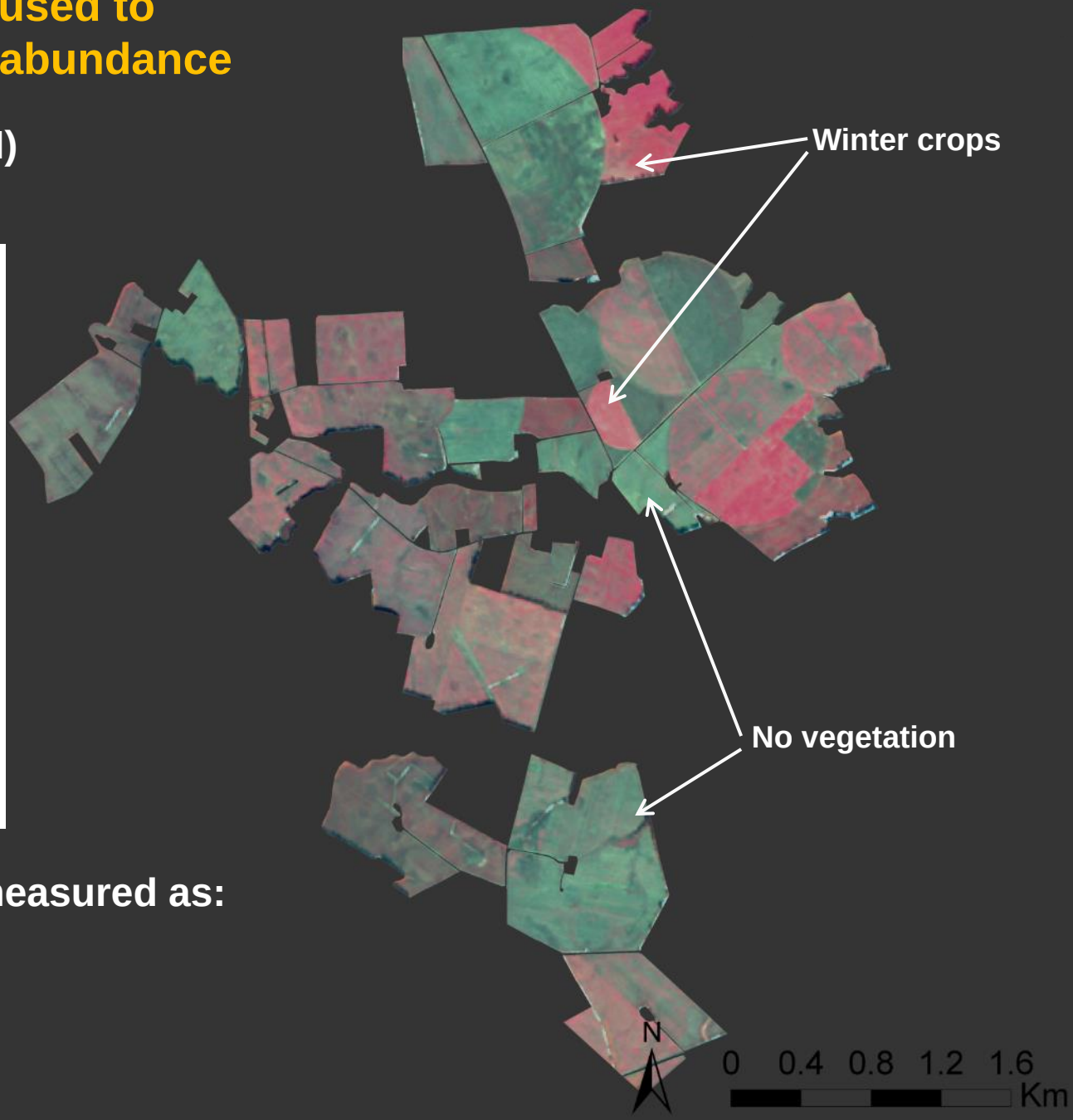
Satellite NDVI is used to measure vegetation abundance

Normalized difference vegetation index (NDVI)
measures biomass from 0-2000 kg/ha





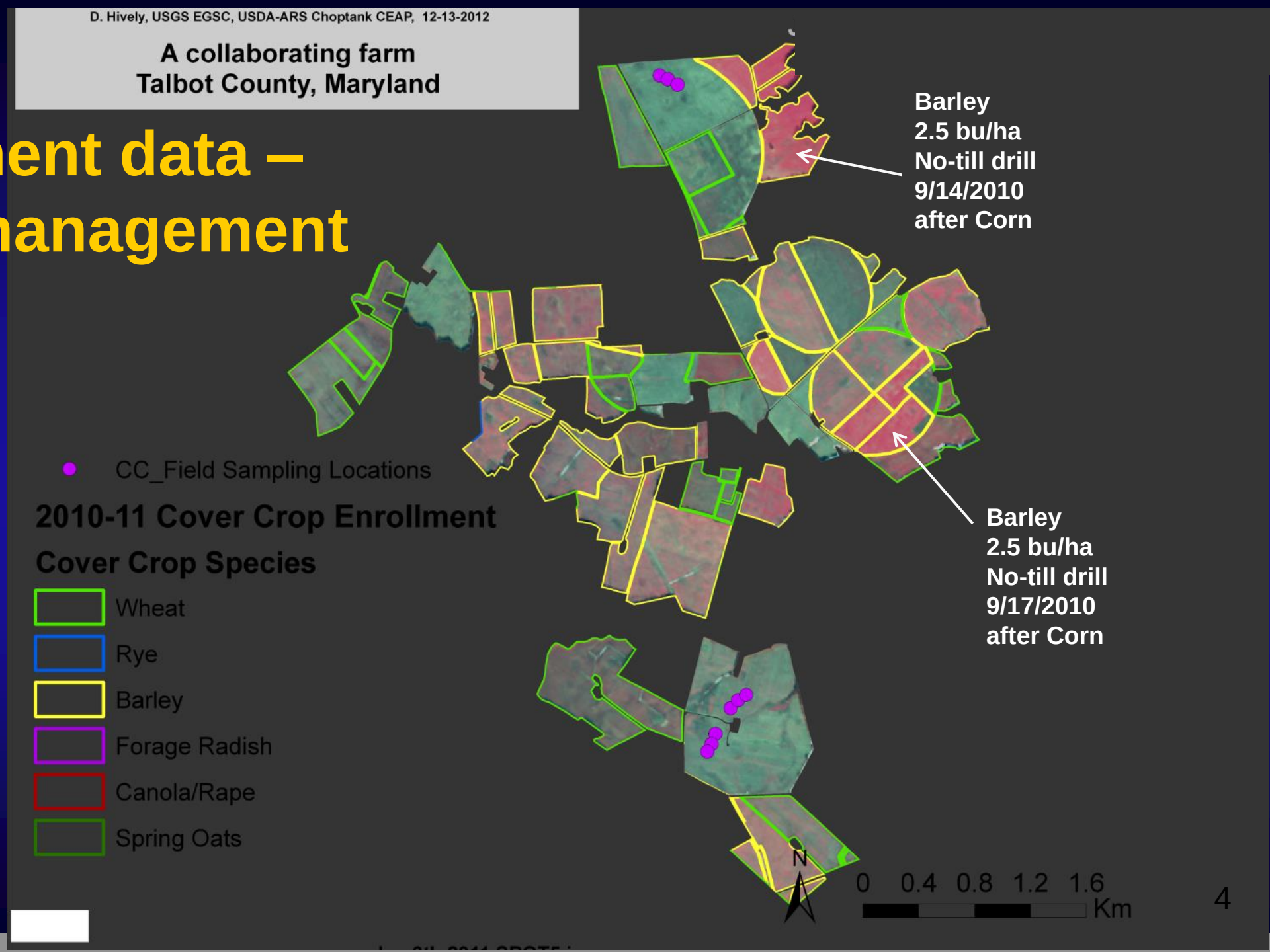
Cover crop performance is measured as:

- **Aboveground biomass**
- **Fractional green cover**
- **Nitrogen content**

USGS

MDA enrollment data – agronomic management

- Cover crop species
- Planting date
- Planting method
- Planting rate
- Previous crop
- Termination date
- Termination method
- Watershed HUC 12 ID
- County
- Field boundary

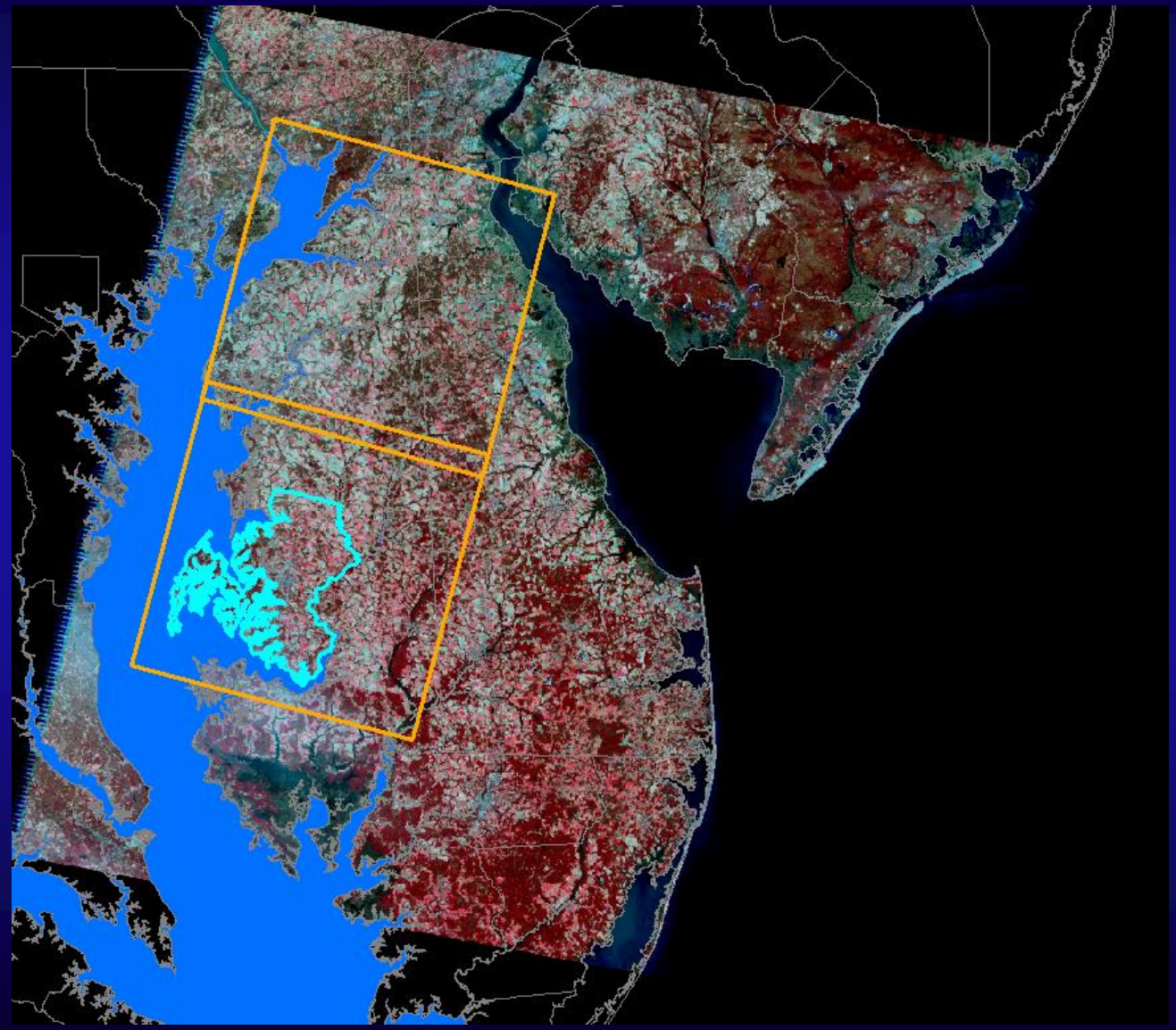


USGS

Harmonized Landsat Sentinel (HLS) satellite imagery

- Landsat (NASA) and Sentinel 2 (ESA) have been harmonized for combined analysis
- Available at no cost, 30-m pixels
- 5-day revisit, global coverage
- Each image is a snapshot in time
- Interference from clouds and snow
- Time series provides growth curve

Much of our fundamental work has been focused on the Delmarva Peninsula

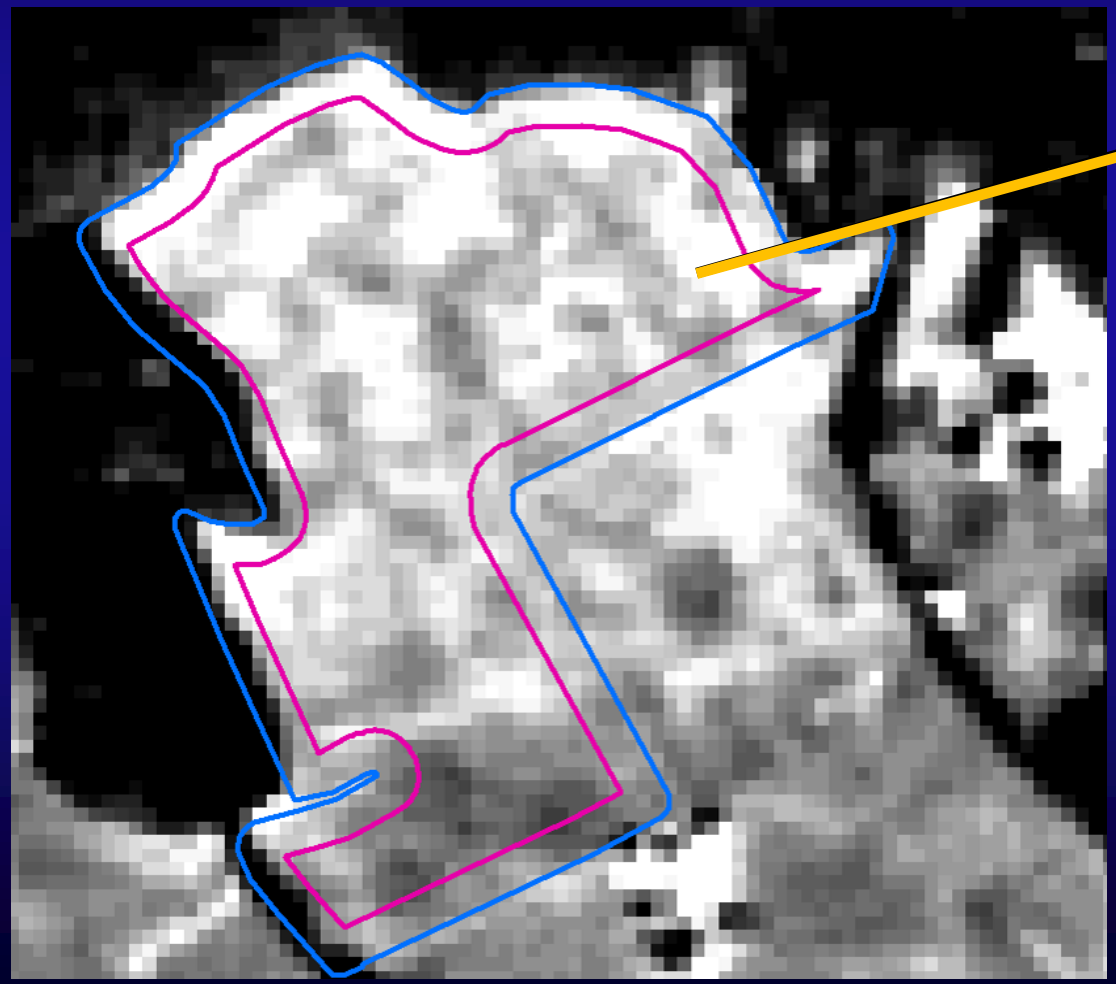


USGS

Calculate satellite vegetation index time series for each field

- Harmonized Landsat and Sentinel (HLS) satellite imagery
- Up to 5-day repeat frequency depending on clouds

Normalized difference vegetation index (NDVI)



Average NDVI per field, per image date

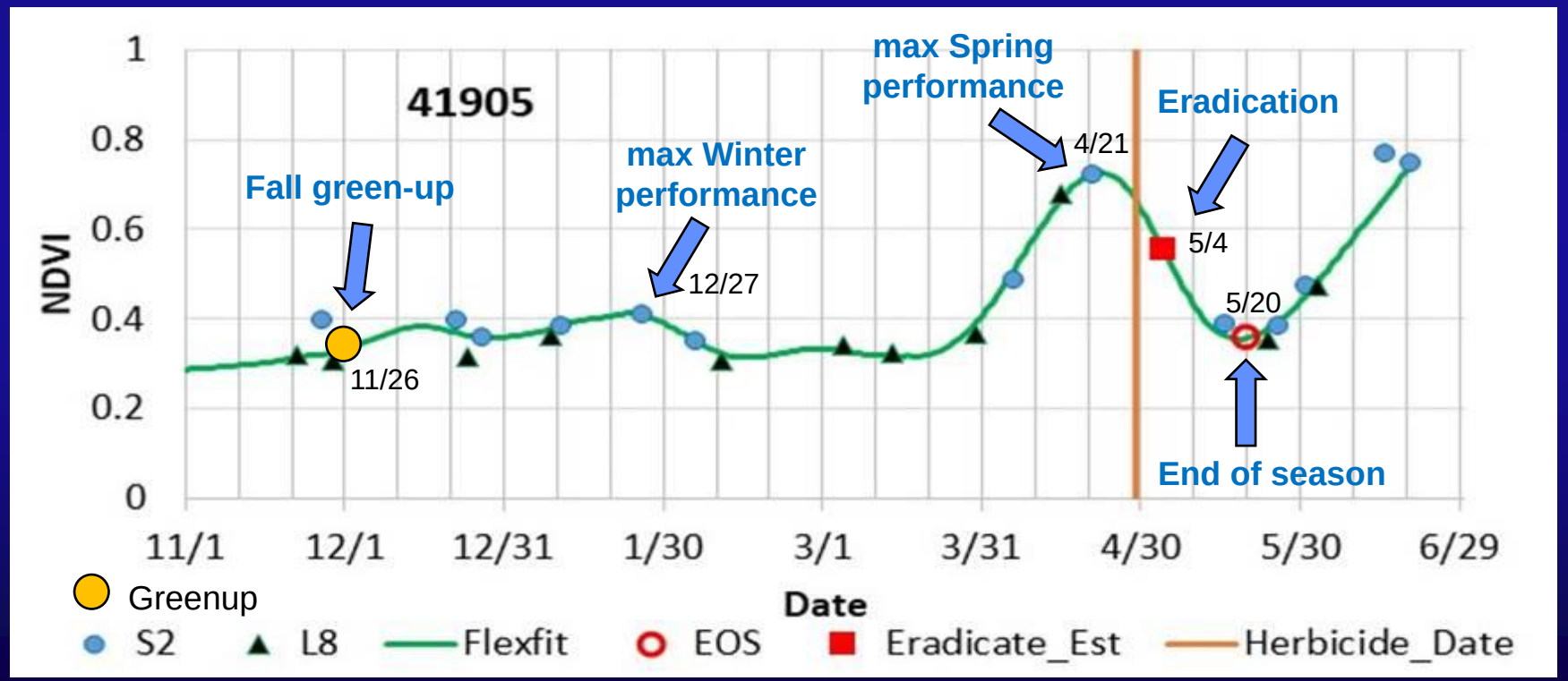
Normalized difference vegetation index

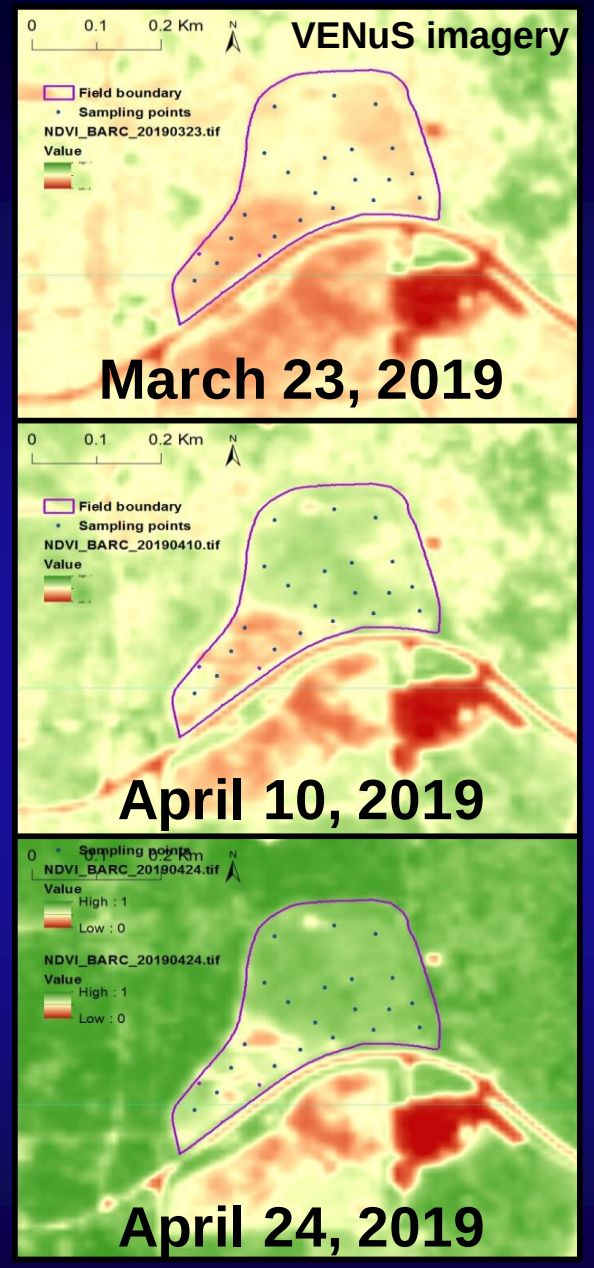
Curve fitting approach to phenology identifies:

- Green-up date
- Green-up momentum
- Maximum wintertime and springtime NDVI and associated performance
- Termination date

Field-specific growth curves

- Greenup and termination dates are identified from vegetation index inflection points using Harmonized Landsat Sentinel data
- Winter and spring maximum NDVI values are used to quantify environmental performance (biomass, fractional ground cover)





These data are preliminary and are subject to revision.

Cover crop identification – where are the fields?

Actual cover crop locations are known by:

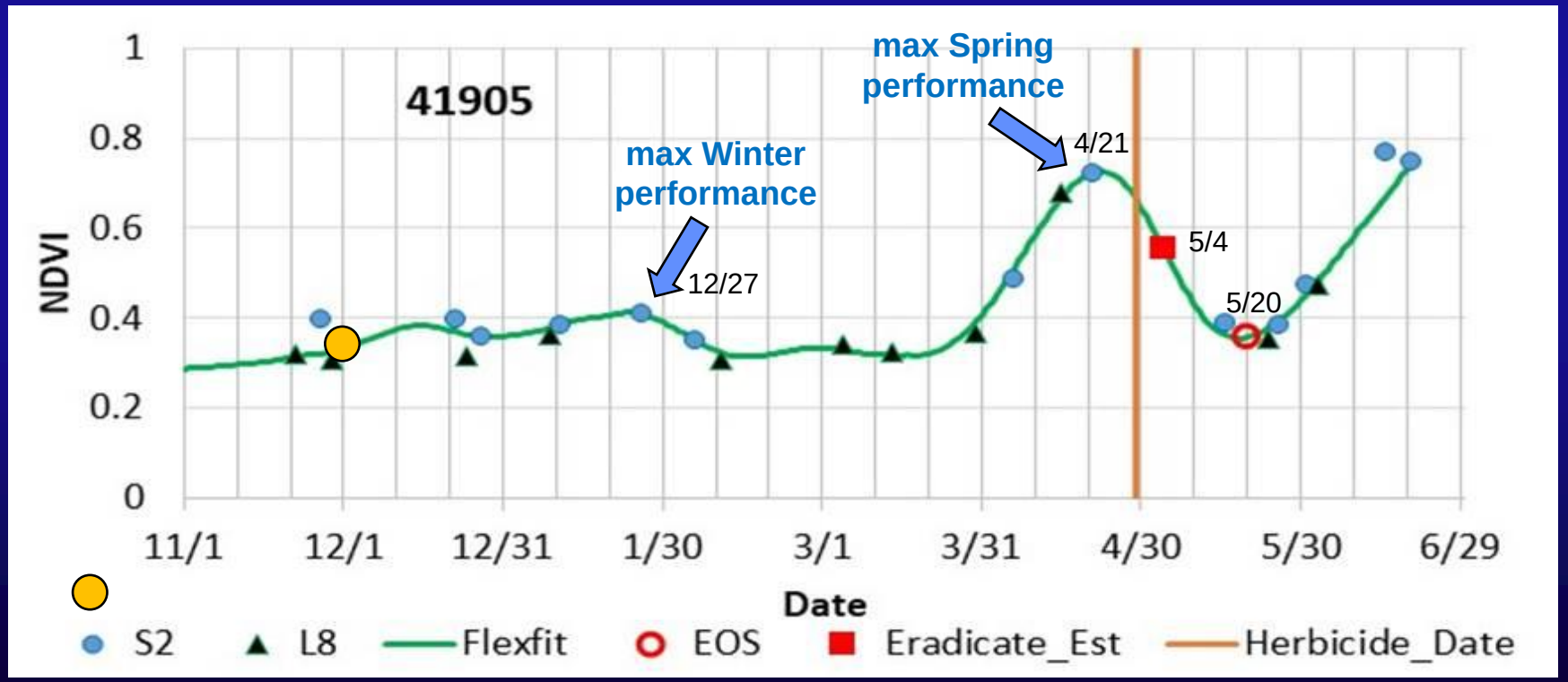
- Cost-share program managers
- Transect surveys
- Census of agriculture (2012, 2017, 2022)
- Individual farmers

- Satellite identification methods tend to compare observed vegetation indices on agricultural fields (or pixels) and identify cover crops as having more green vegetation and exhibiting the proper phenological patterns

USGS

Cover crop identification – where are they?

- OpTIS – NDVI, seasonal thresholds to identify winter, spring, full season cover crop
- Indigo - NDVI, similar to OpTIS with NDVI thresholds varying with climate zones
- Illinois - Kayu Guan - EVI, soil baseline reflectance subtraction, CC > weeds
- USDA-ARS is developing CONUS public cover crop map by 2027



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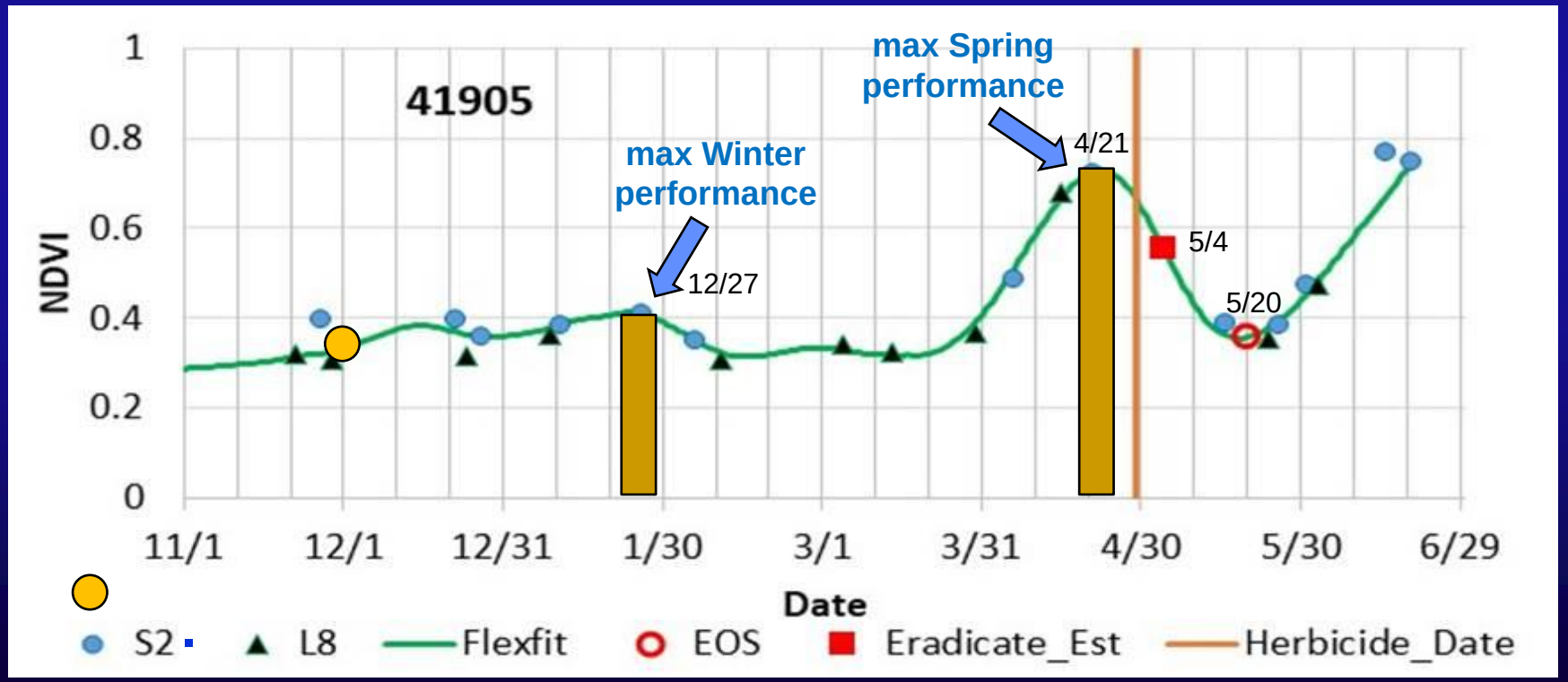

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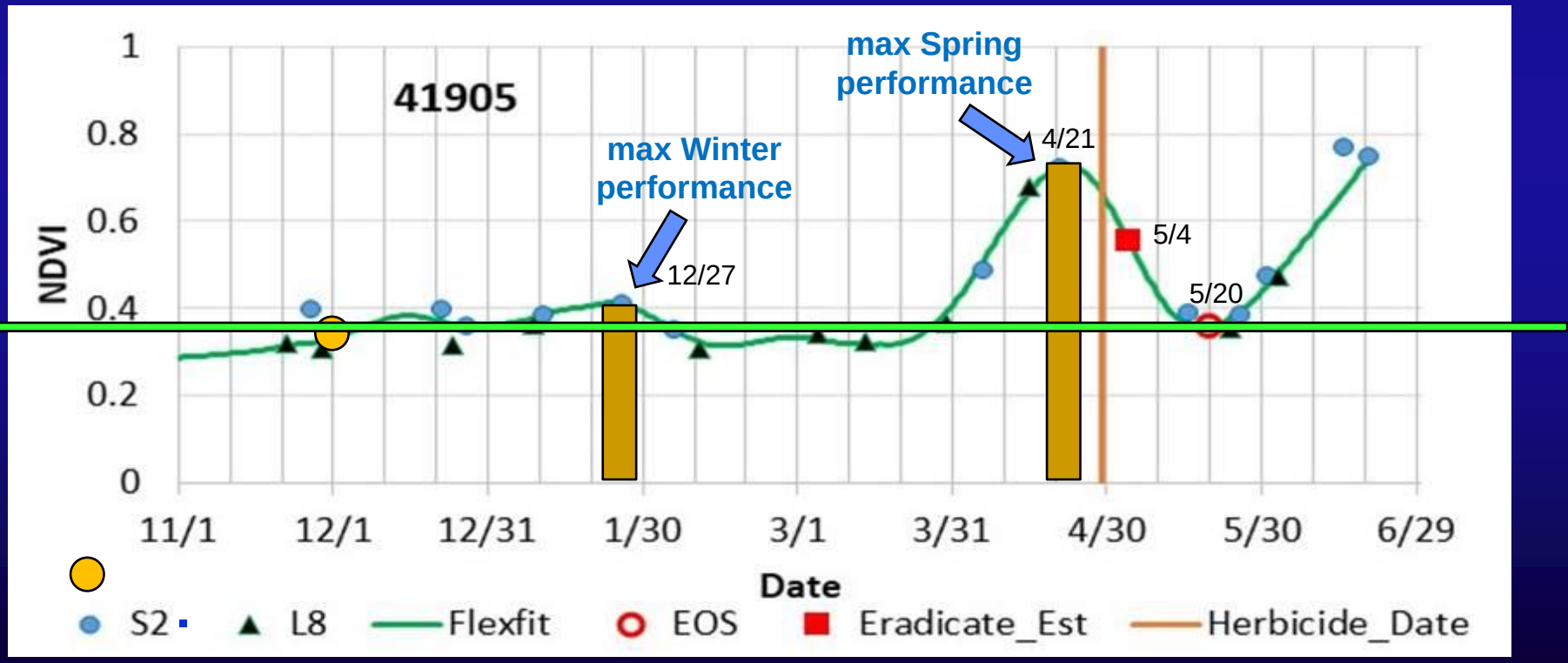

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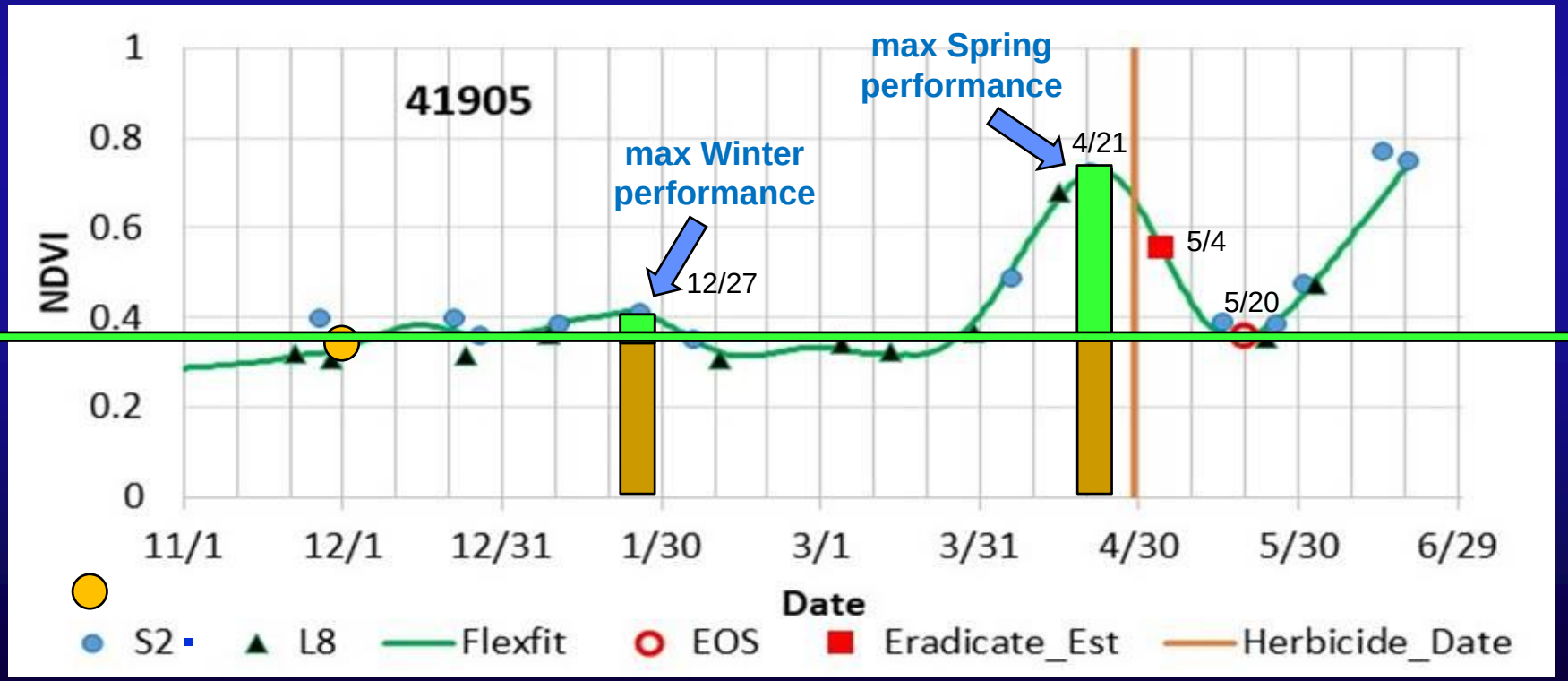

NDVI above threshold identifies cover crop

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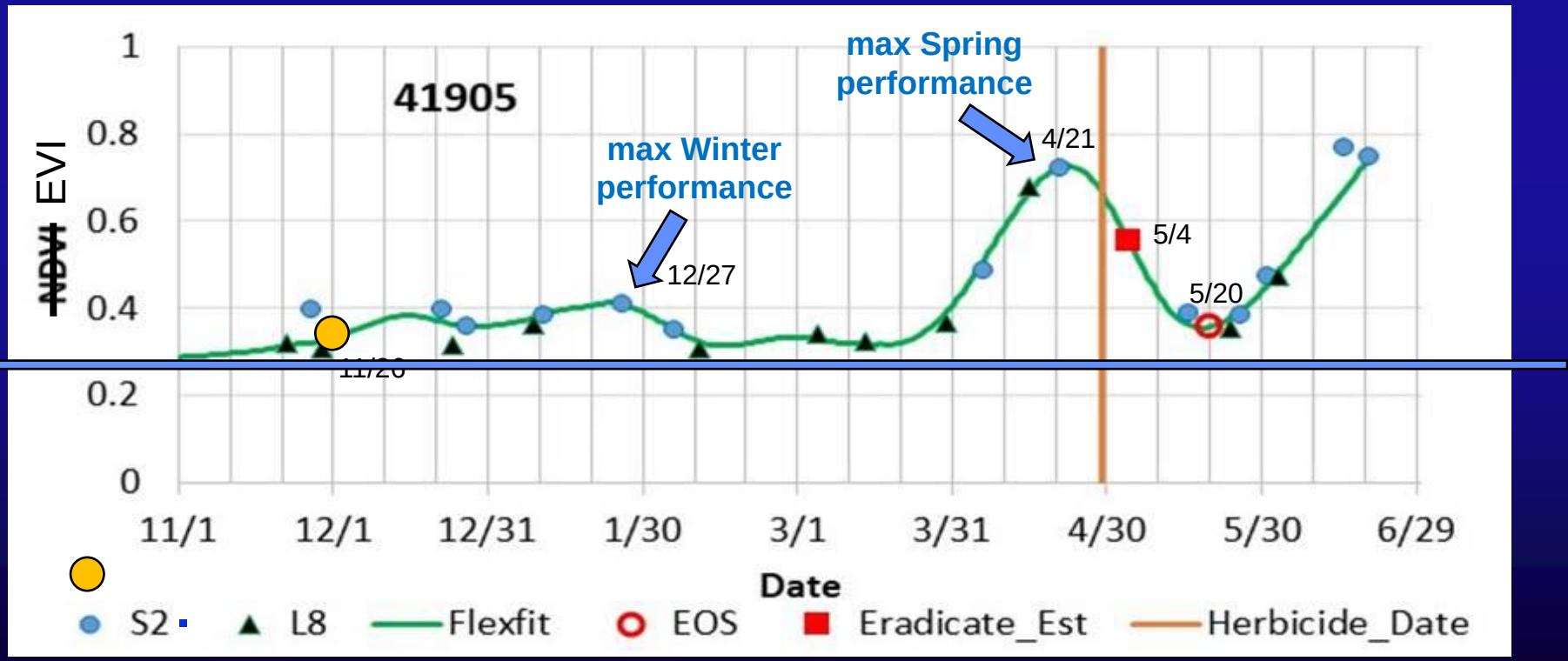

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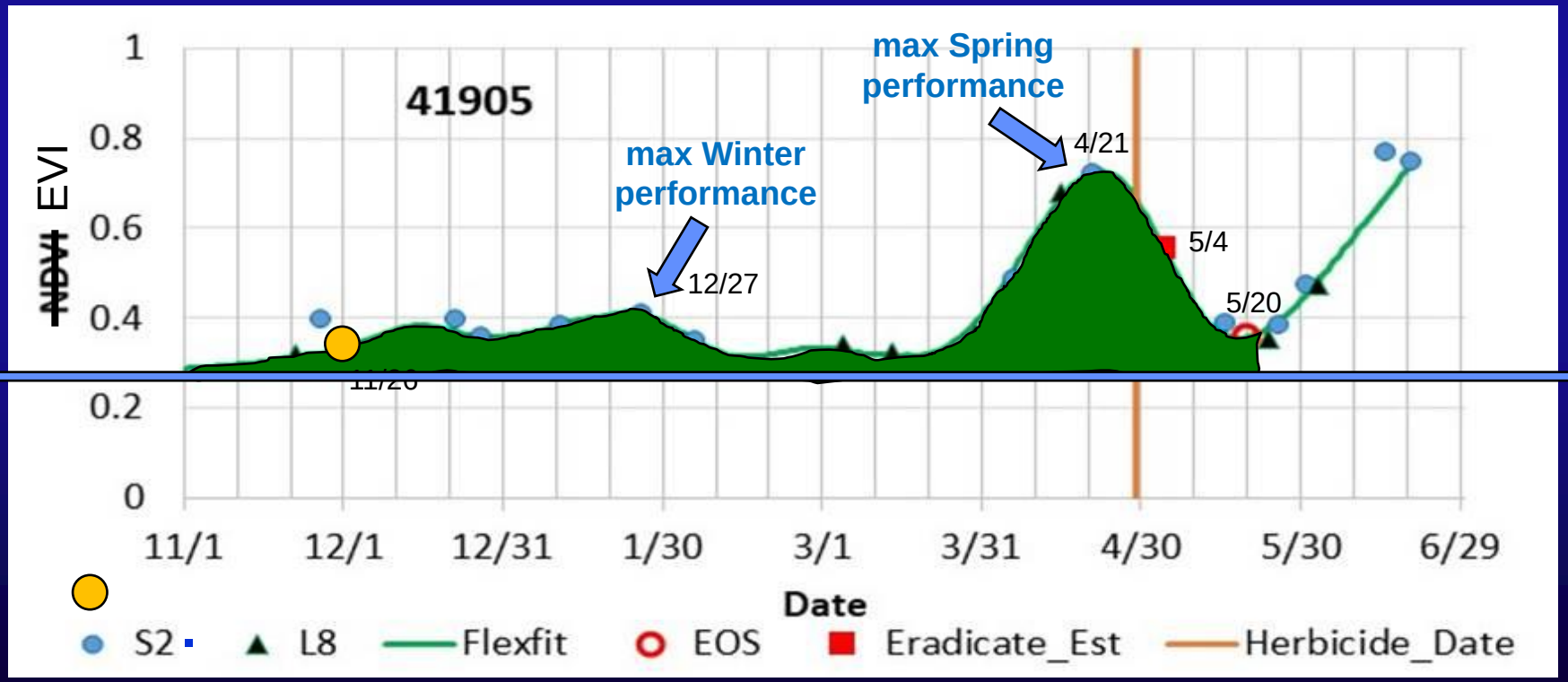

Threshold of the sum of EVI above soil baseline identifies cover crop

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These data are preliminary and are subject to revision.

Cover crop identification methods

Challenges:

- Determining field boundaries
- Pixel placement for small fields
- Impact of surface moisture conditions
- Separation of cover crops from weeds
- Low-performing cover crops
- Year to year climate variation
- Adequate validation and accuracy assessment
- Transparency of methods

USGS

Cover crop identification methods

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- **Transparency of methods**

Our group is conducting accuracy assessment of OpTIS and Indigo cover crop products in MD using MDA enrollment data as verification

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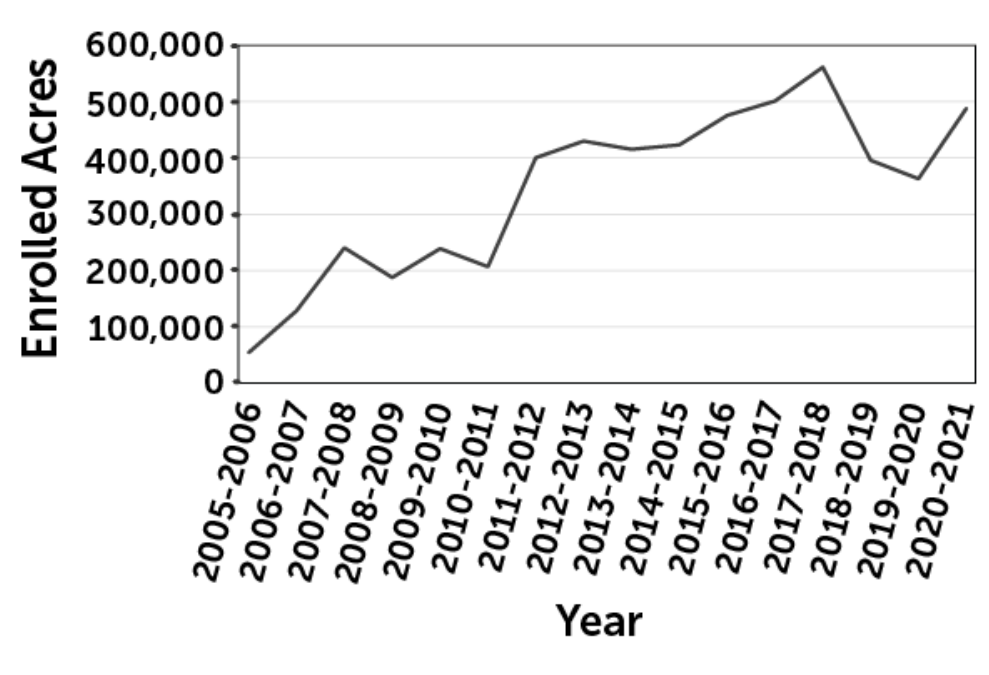
Cover crop performance:
measuring environmental benefit

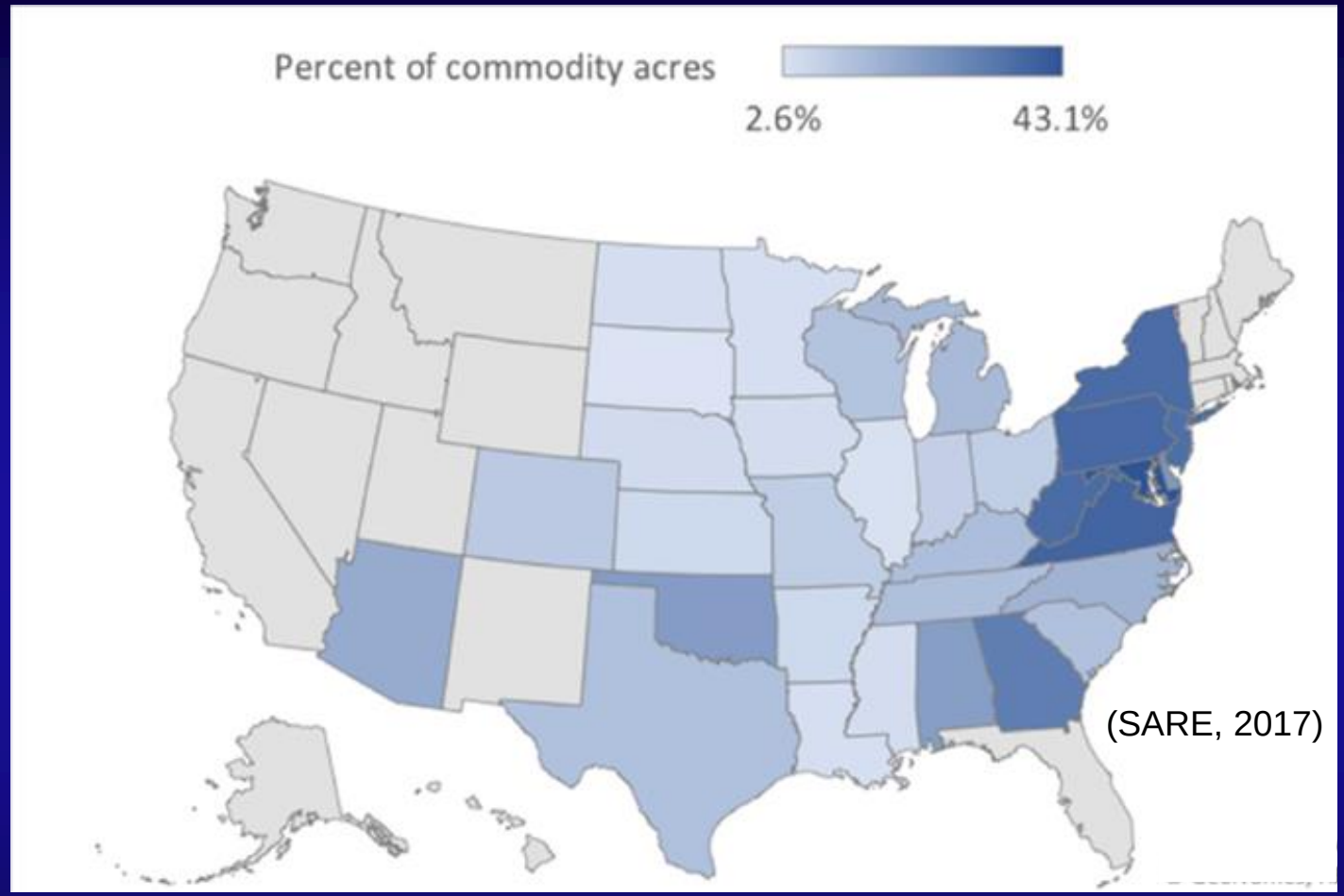
USGS

Mid-Atlantic cover crop use is highest in the nation

Maryland has the highest percent cover crop use of any state (29% of cropland, 43% of commodity acres)

(PA = 37%)





Maryland cover crop enrollment doubled from 2009 to 2013

USGS

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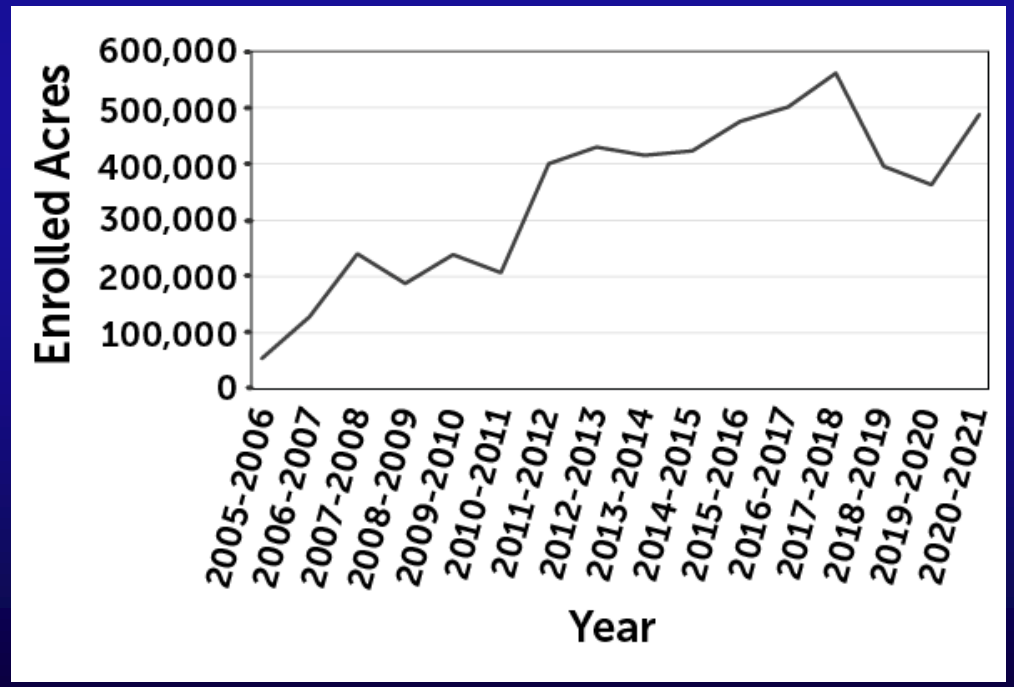

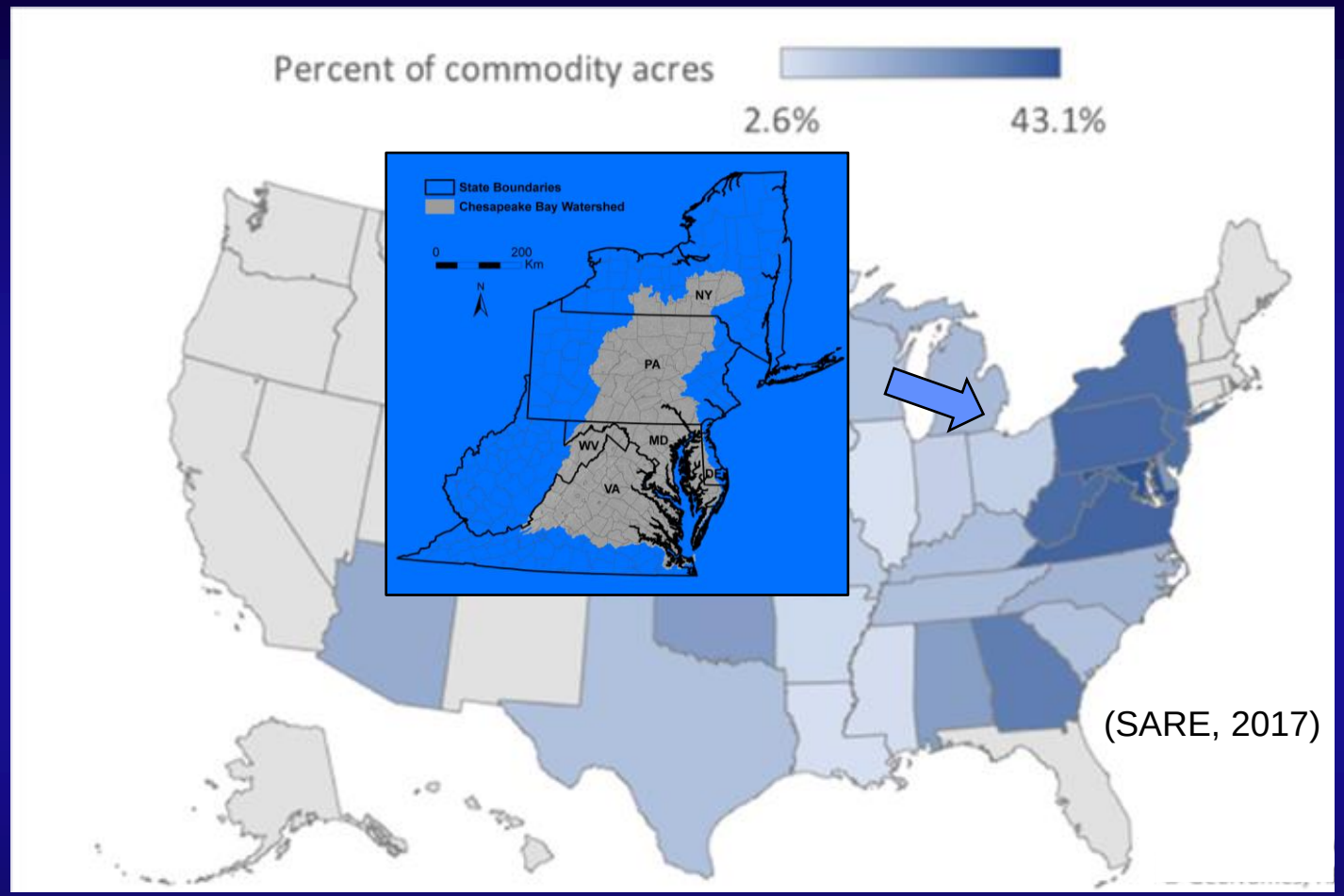

Maryland cover crop enrollment doubled from 2009 to 2013

On-farm conservation performance is variable

Green vegetation
crop residue
and bare soil
reflect light differently

We can measure and map performance using satellite imagery

Mapping the outcomes of agricultural conservation practices

- Remote sensing of winter cover crop performance (biomass, fractional cover, N content)


Minimal


Low


Medium


High

Cover crops

- Remote sensing of crop residue and tillage intensity (non-photosynthetic vegetation)


Plow tillage
0-30% cover


Conservation tillage
30-60% cover


High residue / no-till
60-100% cover

Crop residue

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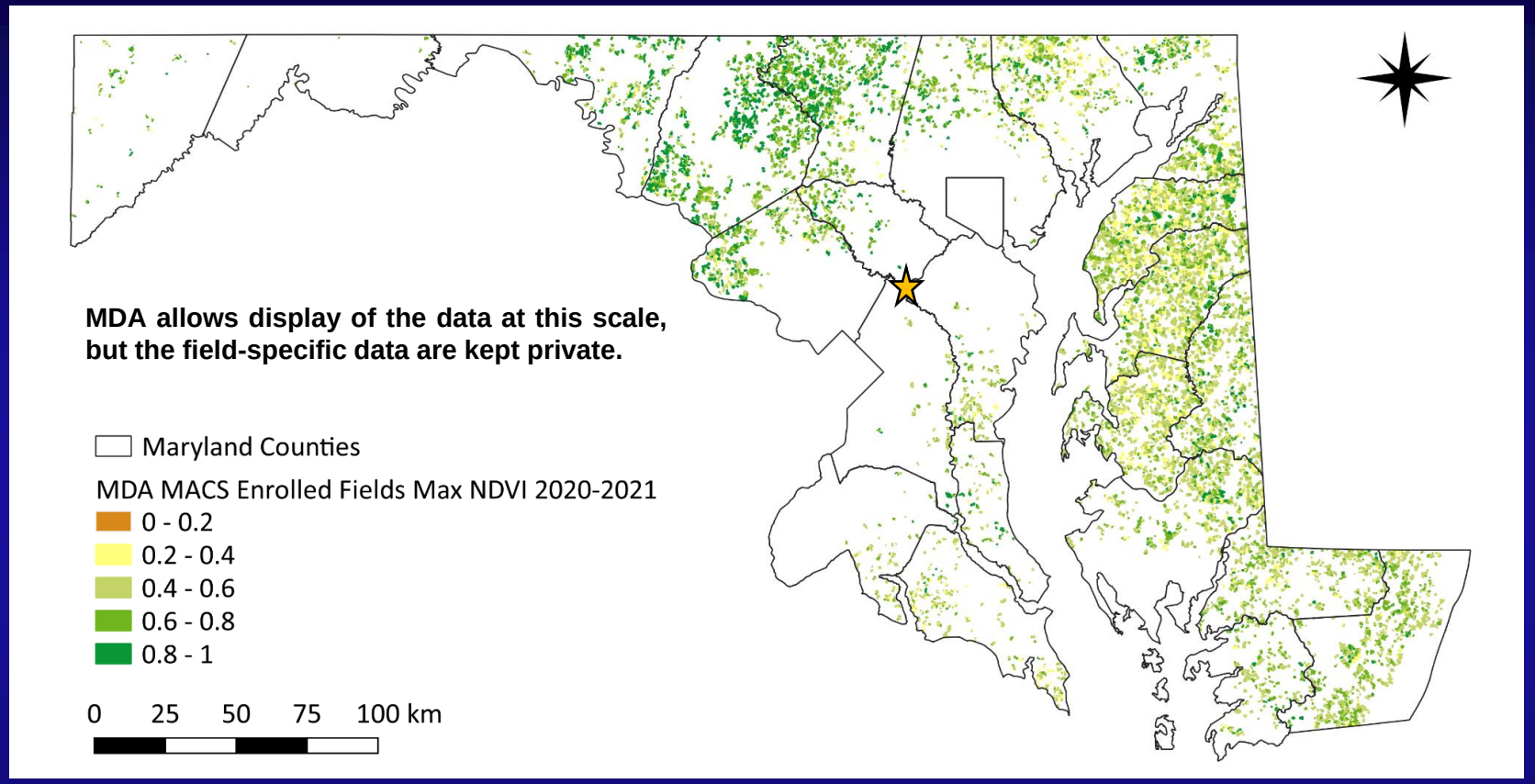
Projects in MD, PA, IA, MS, MO

Maryland cover crop cost-share program data



Maryland cover crop enrollment		
Year	# Fields	Acres
2019-20	26,393	156,900
2020-21	21,538	129,300

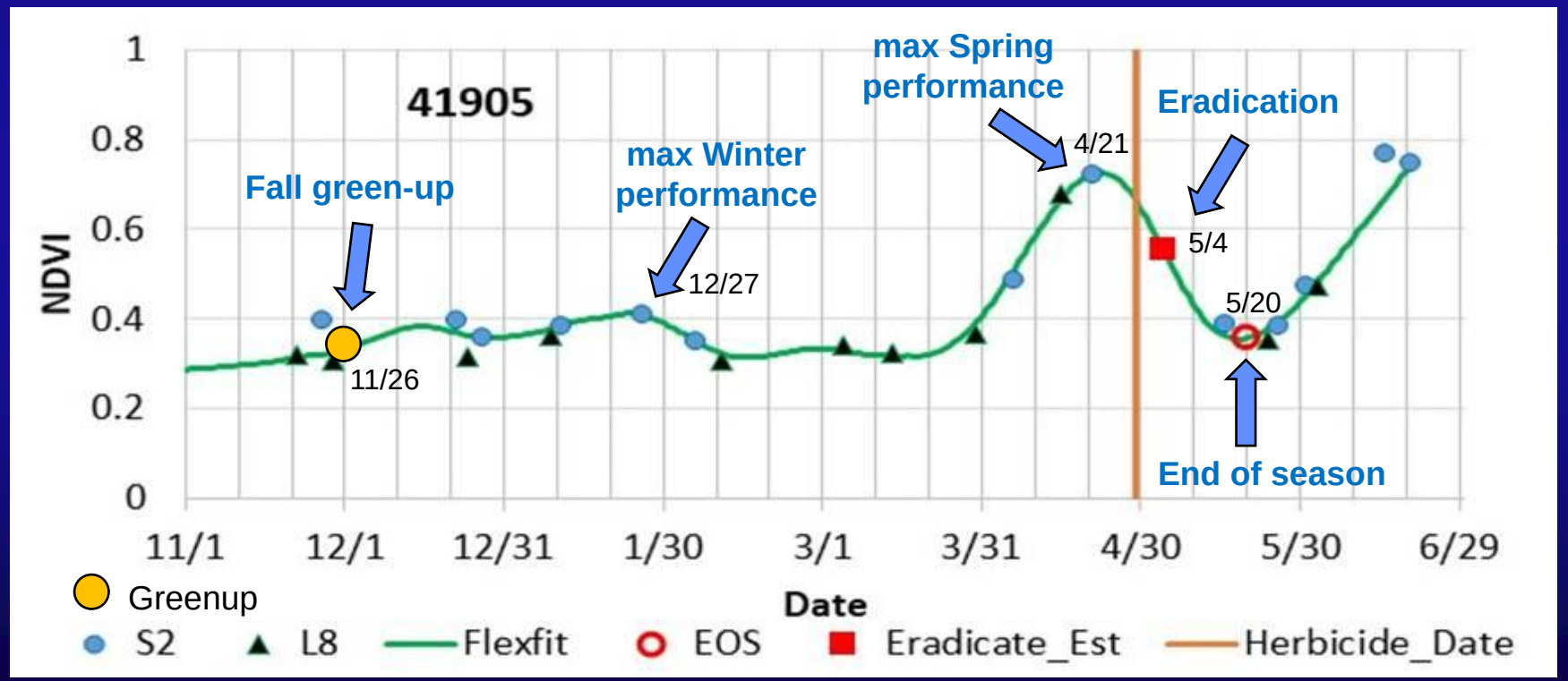
9-years of field-specific data

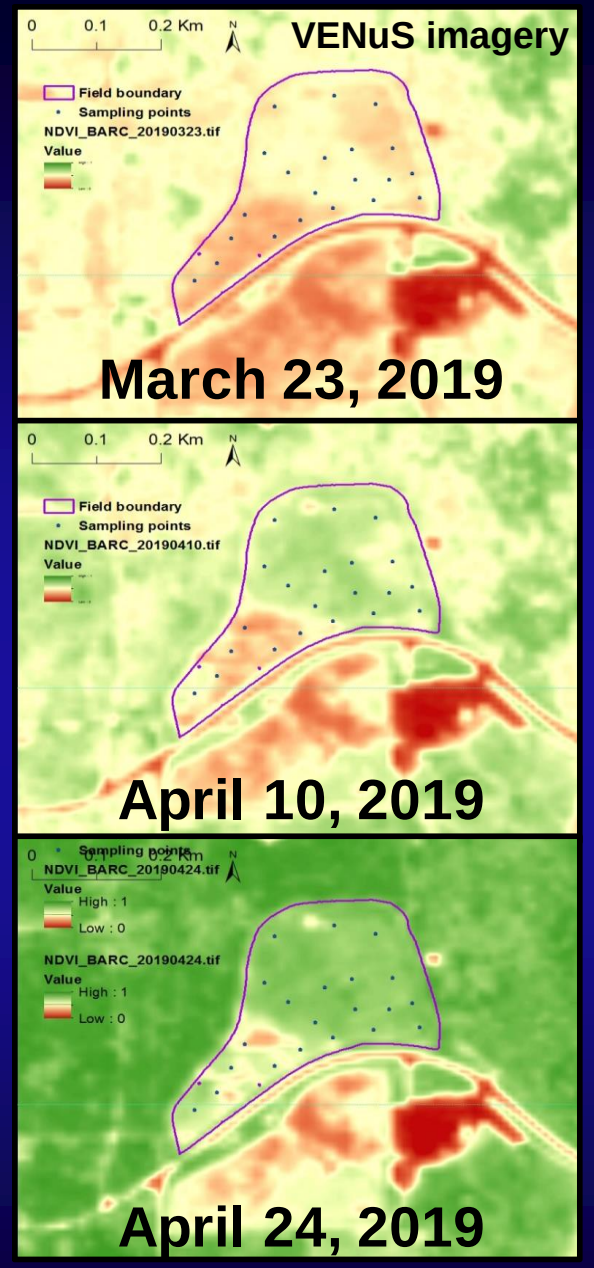
USGS can also access NRCS EQIP data

Research collaboration with Maryland Dept. of Agriculture allows access to site-specific cover crop management data for MD farms

Field-specific growth curves

- Greenup and termination dates are identified from vegetation index inflection points using Harmonized Landsat Sentinel data
- Winter and spring maximum NDVI values are used to quantify environmental performance (biomass, fractional ground cover)





These data are preliminary and are subject to revision.

In-field data collection provides cal/val

Physical sampling of plants and residue

- Biomass (weight per 0.5 m^2 quadrat)
- Ground cover (by photo analysis)
- Plant nitrogen content, C:N ratio
- Plant growth stage, height, tillering, etc…

- 3 quadrats per field, > 10 photos
- 60 m apart to fall in different pixels
- Avoiding edges and irregular areas
- > 2000 on-farm samples over 10 yr

Thank you conservation district staff and farmers for supporting field access!

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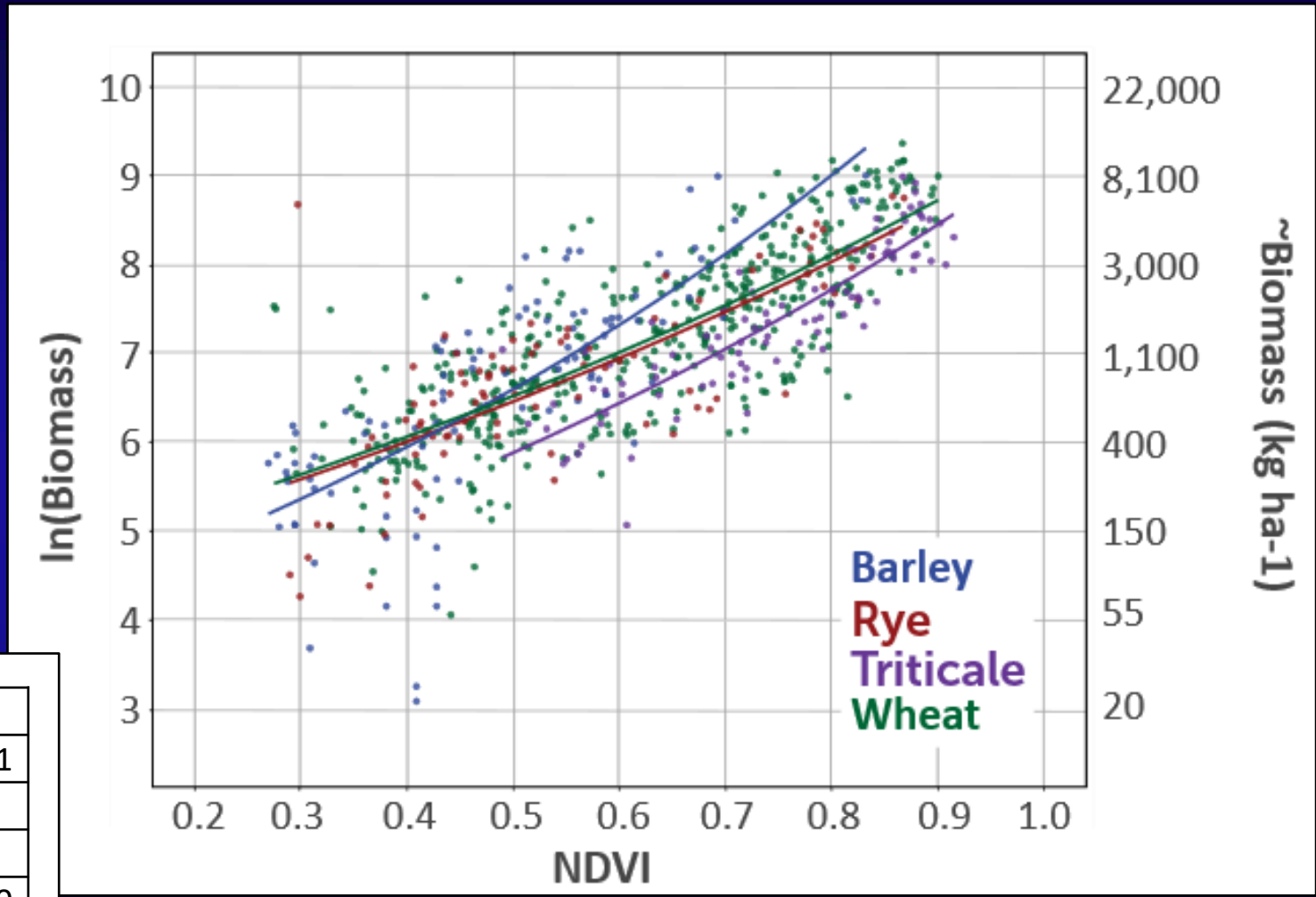
Estimating biomass and groundcover from NDVI

- Species-specific correlation with field sampling data
- Accurate up to ~1500 kg/ha and 80% cover



Species	Formula	Adjusted R^2	n
Barley	ln(biomass) ~ 7.29 * NDVI + 3.00	0.57	101
Rye	ln(biomass) ~ 5.01 * NDVI + 3.99	0.60	96
Triticale	ln(biomass) ~ 6.46 * NDVI + 2.58	0.77	95
Wheat	ln(biomass) ~ 5.10 * NDVI + 4.00	0.62	430

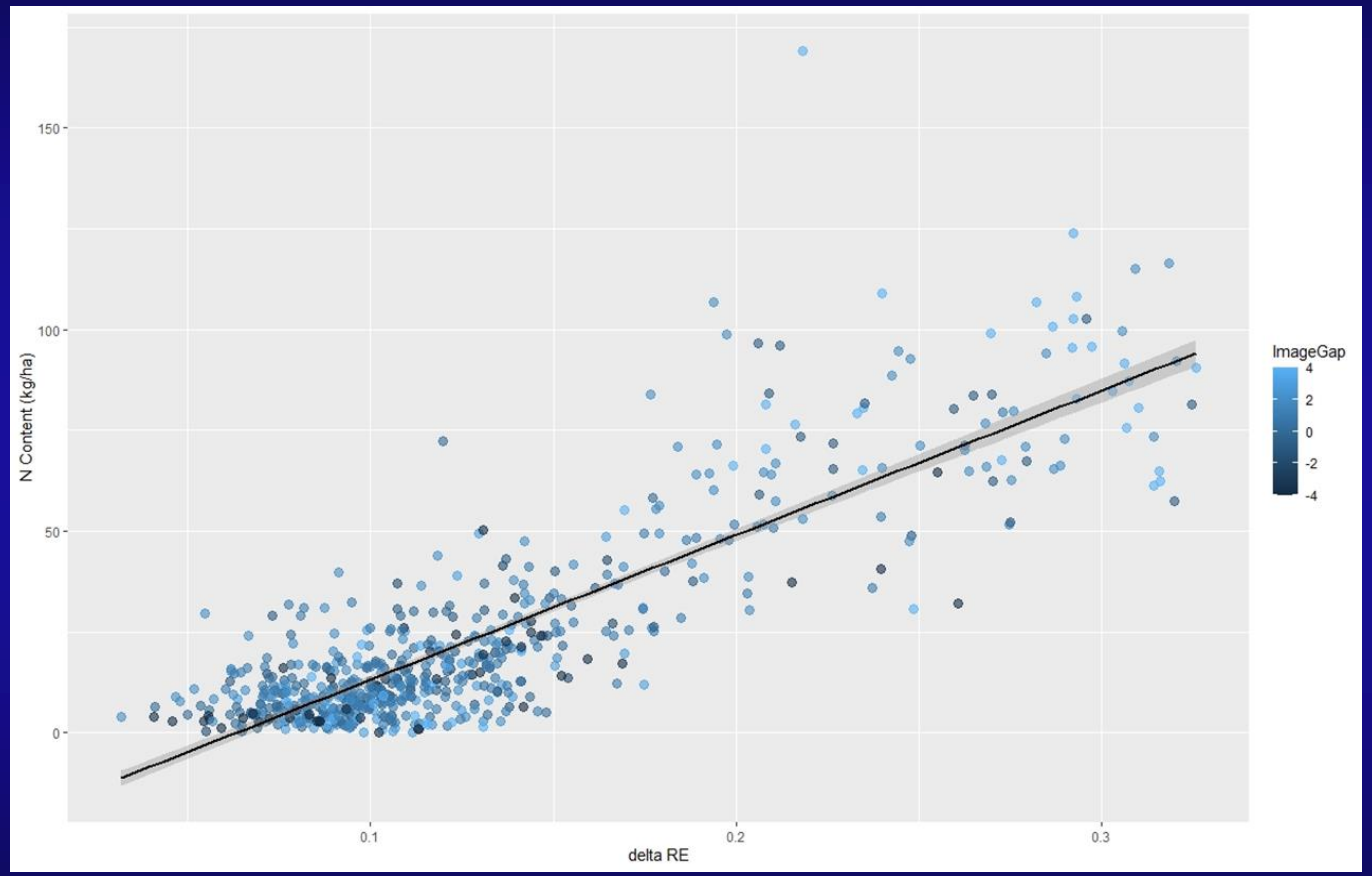
USGS

Thieme et al., 2022

Direct measurement of Nitrogen content

Using red edge indices from Sentinel 2 satellite imagery

- ΔRE = ln(R783) - ln(R740)
- N Content = %N * biomass
- 645 samples, subset to sampling within +/- 4 days of image
- N Content = 358.6 * ΔRE – 22.7 R^2=0.74



Connecting performance to agronomy

Seasonal performance measures:
(> 25,000 fields/year in MD)

- **Aboveground biomass**
- **Nitrogen content**
- **Fractional vegetative cover**

  - **Modelling of N leaching (SWAT)**
  - **Modelling of erosion (RUSLE2)**
  - **Modelling of C dynamics (SWAT-C)**

Agronomy data from enrollment:

- **Cover crop species**
- **Planting date, method, rate**
- **Previous crop**
- **Termination date and method**
- **Watershed HUC 12 ID**
- **County ID**
- **Field boundary**

What factors affect cover crop success?

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Species choice

USGS


Planting date

Planting method

Aerial Seeding

Broadcast +/- tillage
or stalk chop

No-till drill or
light tillage + drill

USGS

Termination date

$10 MDA incentive to terminate after May 1

USGS

Termination method

Herbicide

Plow

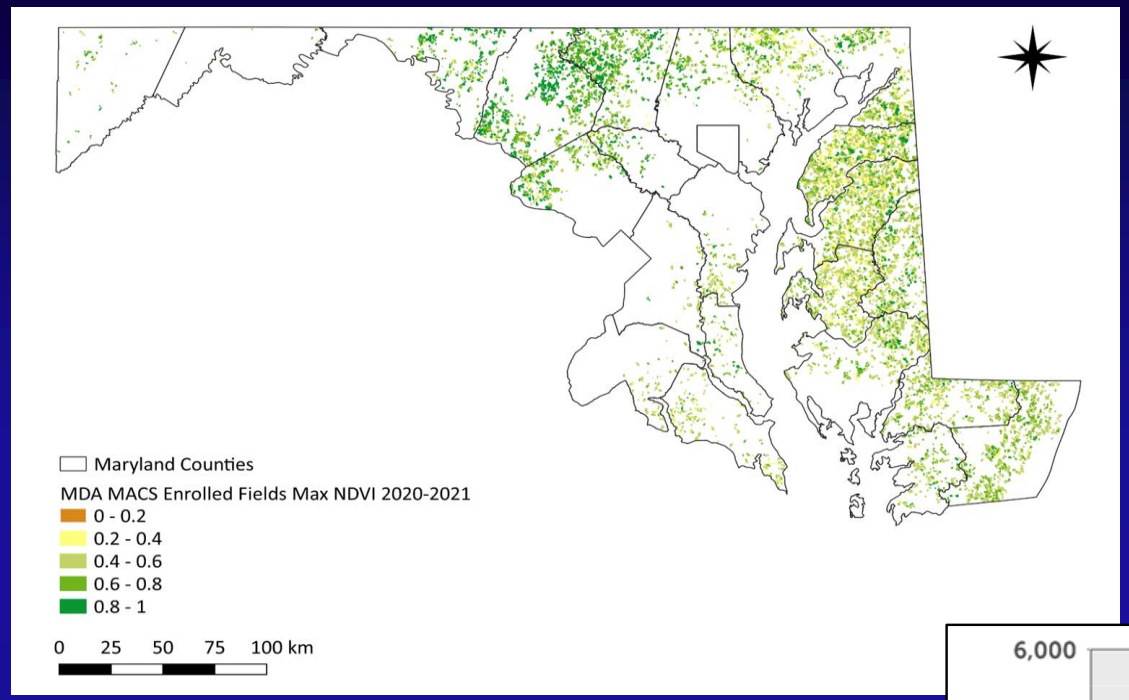
Green chop

Roller-crimp

Harvest

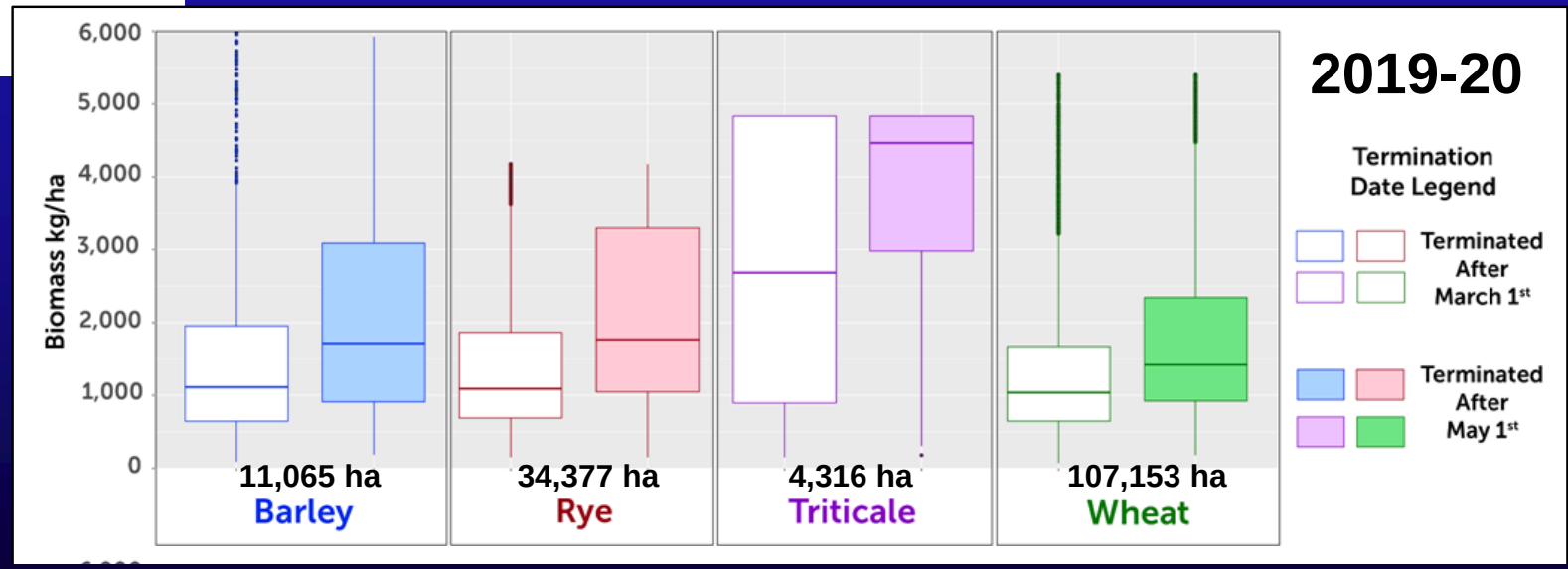
USGS

Results from Maryland: species and termination date



- Triticale was the top performer (often planted early after corn silage harvest)
- Late termination incentive (after May 1) increased biomass by 69% and N uptake by 48%
- SWAT modeling estimated a 29% reduction in N leaching in Tuckahoe due to winter cover crops

- Wheat underperformed but comprised 68% of acreage
- 32% of MDA cover crops were late-planted wheat, with minimal N uptake in Fall



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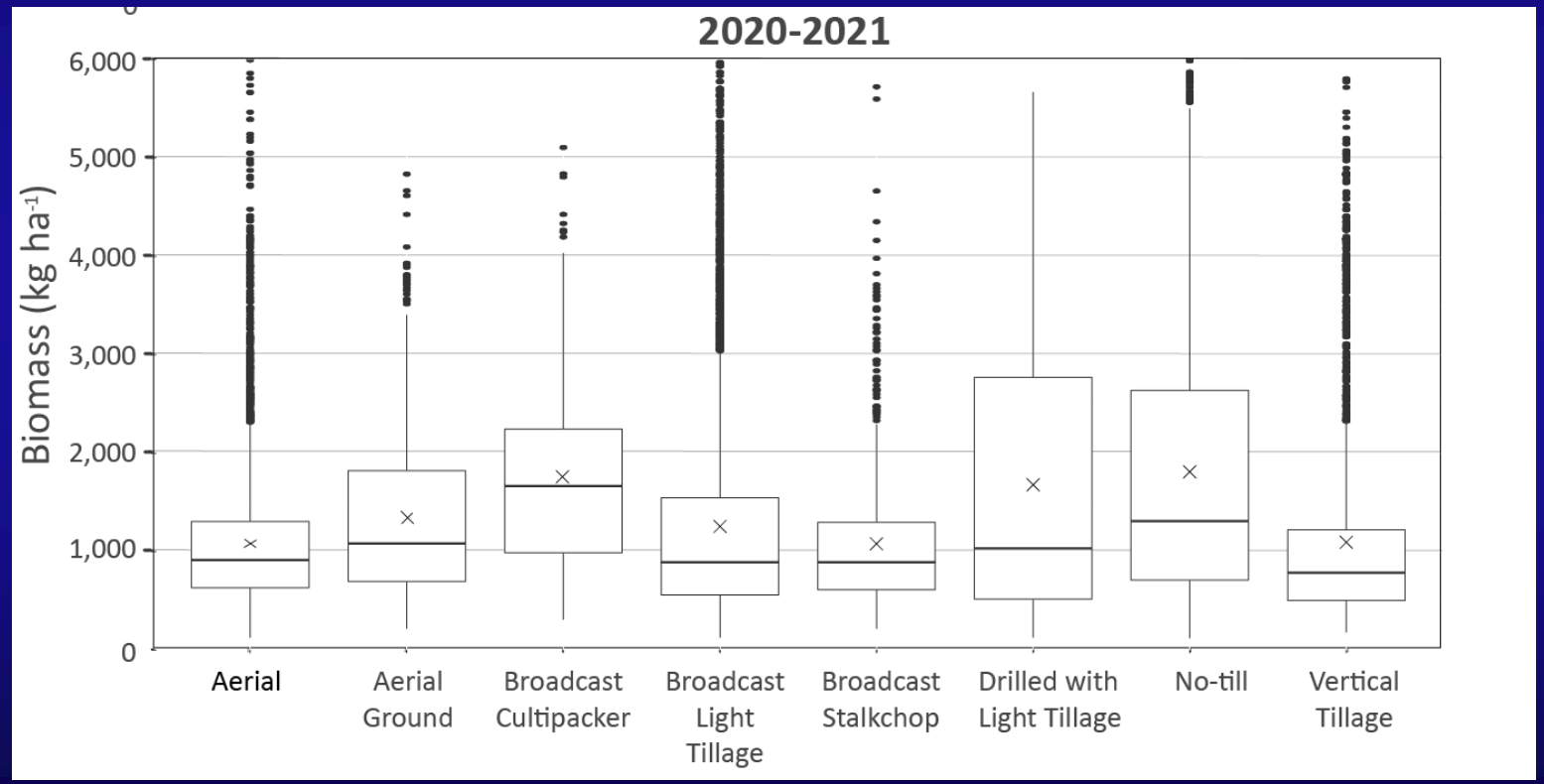
Thieme et al., 2022, Agronomy Journal. https://doi.org/10.1002/agj2.21207

Results from Maryland: planting methods

- **Planting methods promoting higher seed-soil contact (drilled) outperformed broadcast and aerial seeding**



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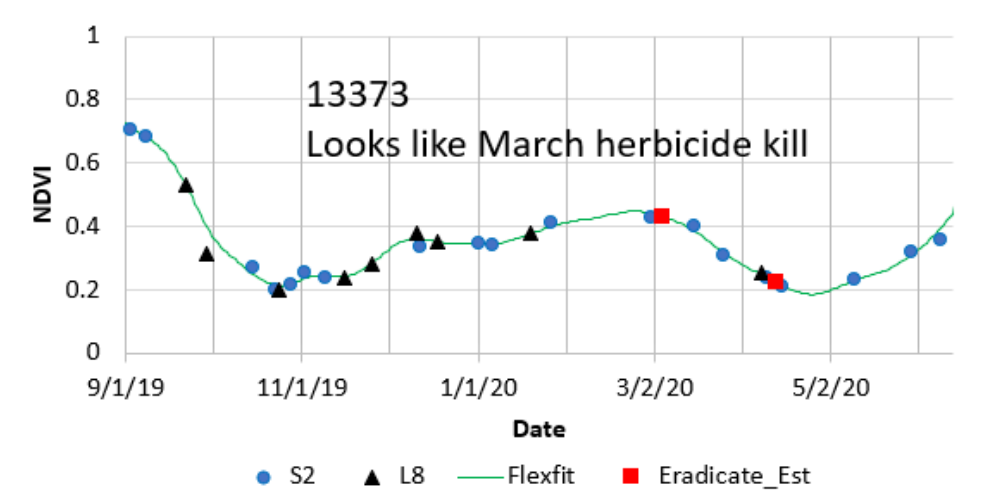
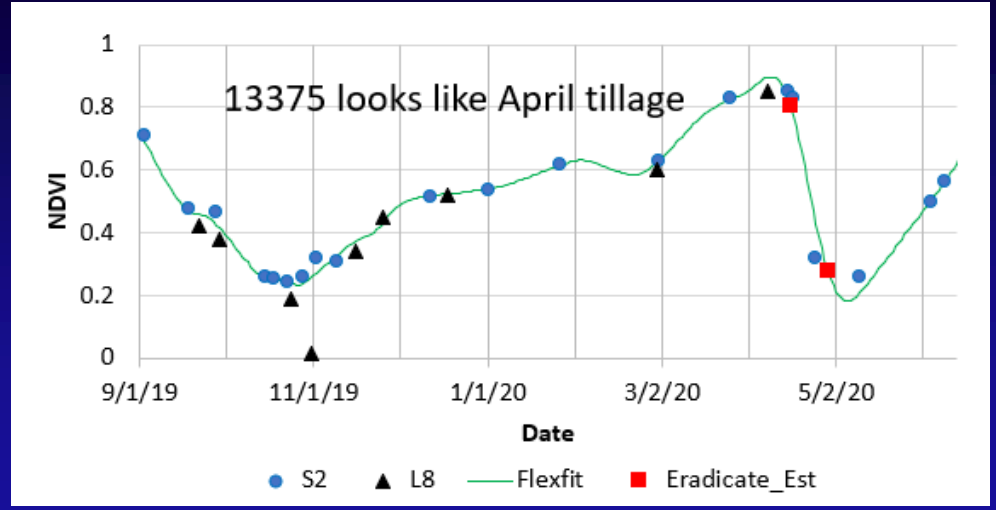
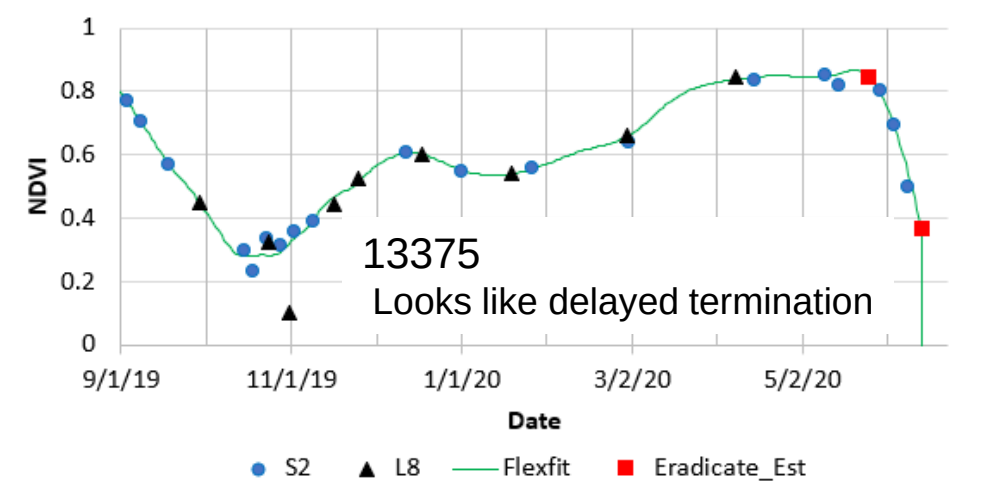
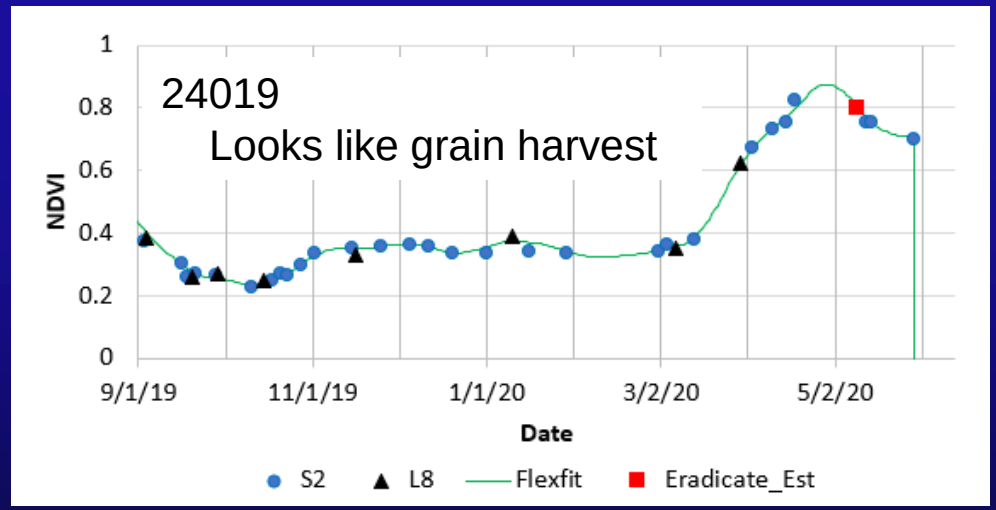
Program management - detecting termination









- **Satellite detection of termination dates can assist conservation program managers, potentially reducing need for field-visits by conservation staff**

USGS

These data are preliminary and are subject to revision.

Possibilities for verification - cover crop management

- **Planting**
  - December imagery significant vegetation = likely cover crop, no field check
  - December imagery little vegetation = field check (poor performance)
  - Early April threshold could identify >25% groundcover
  - Planting date categories are difficult to distinguish (e.g., > < Oct 15) therefore most feasible areas that do not offer an early planting bonus

- **Termination**
  - Clear drop in NDVI = termination
  - No drop, high NDVI through June = harvest (or error from planting green) = field check
  - No drop, low NDVI = poor performance, remote sensing can't tell = field check

These contrasts have tested well in MD, and would save much time by reducing field visits

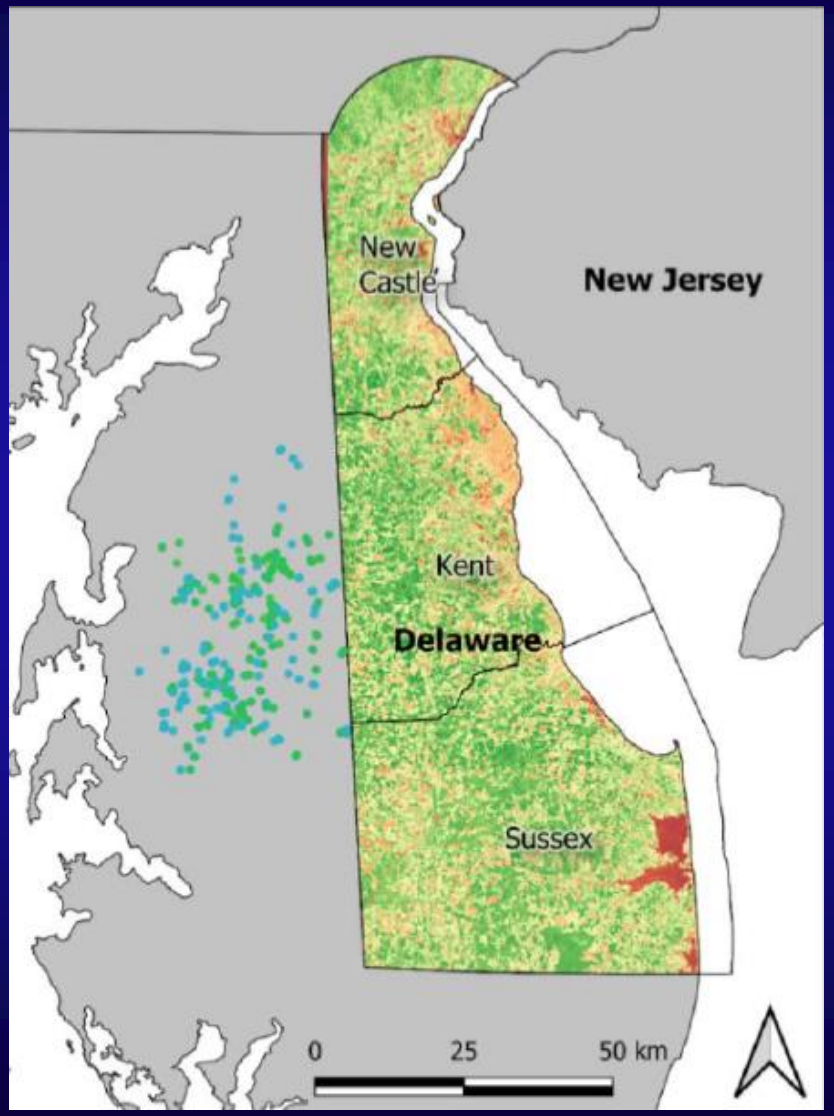
Insights and adaptive management in Maryland

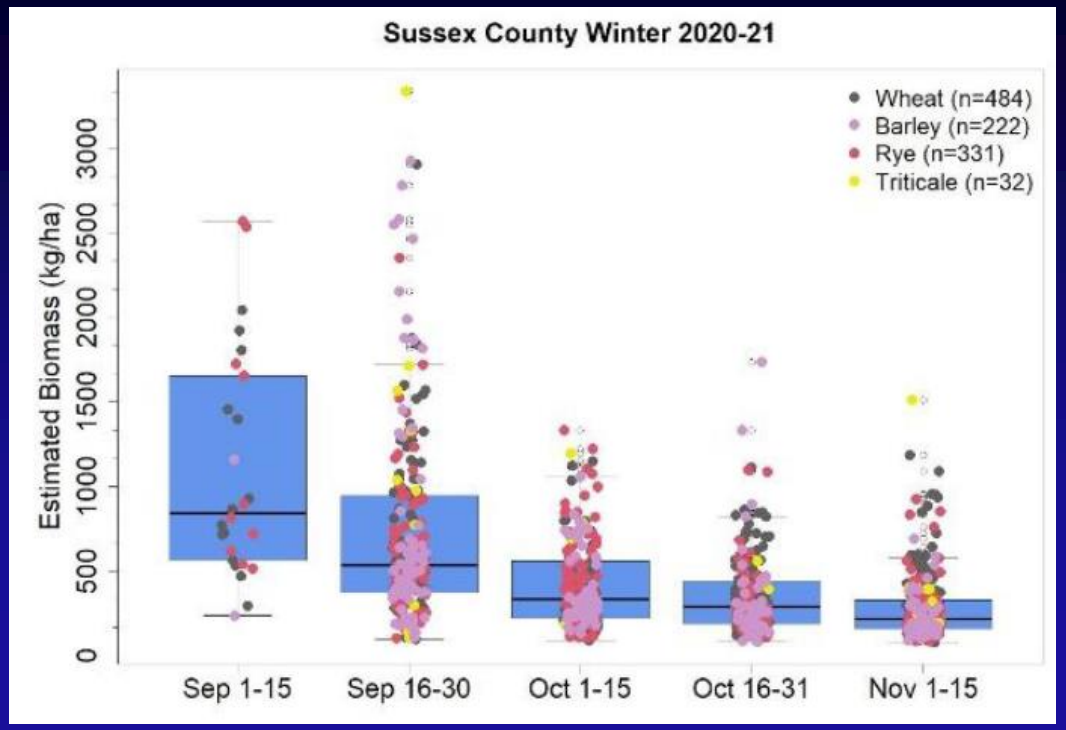
- Insights from multiple years of satellite performance analysis on MDA enrolled fields have supported adaptation of incentive rates to require late termination for late planted fields, to promote triticale and rye, and to continue early planting and late termination bonus payments

- Remote sensing termination analysis has been run in parallel with MDA's 20% springtime spot checks for three years, with good success in identifying priority fields for spot checks. The MDA intends to explore approval of remote sensing in their quality assurance plan with CBP. This could significantly reduce time required for field visits by conservation district staff while maintaining accuracy

- Analysis of fields not enrolled in the cover crop cost-share program helps to identify areas for outreach and extension

Delaware cover crops





- Districts that incentivize early planting (Kent, Sussex) have higher rates of early planted fields which have higher wintertime biomass - important in reducing nitrate leaching

- Districts that allow both traditional (terminated) and commodity (harvested) cover crops (New Castle) have higher rates of conventional and no-till drill planting, with higher springtime biomass

USGS

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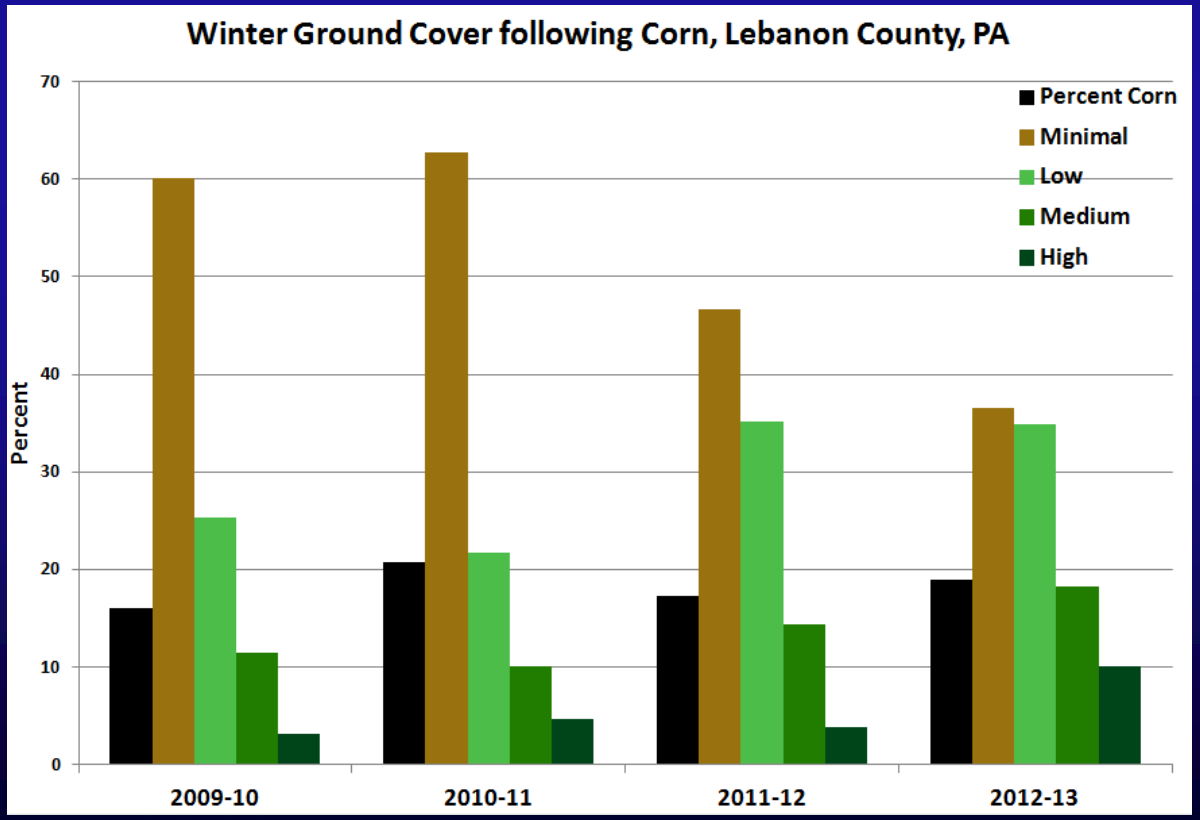
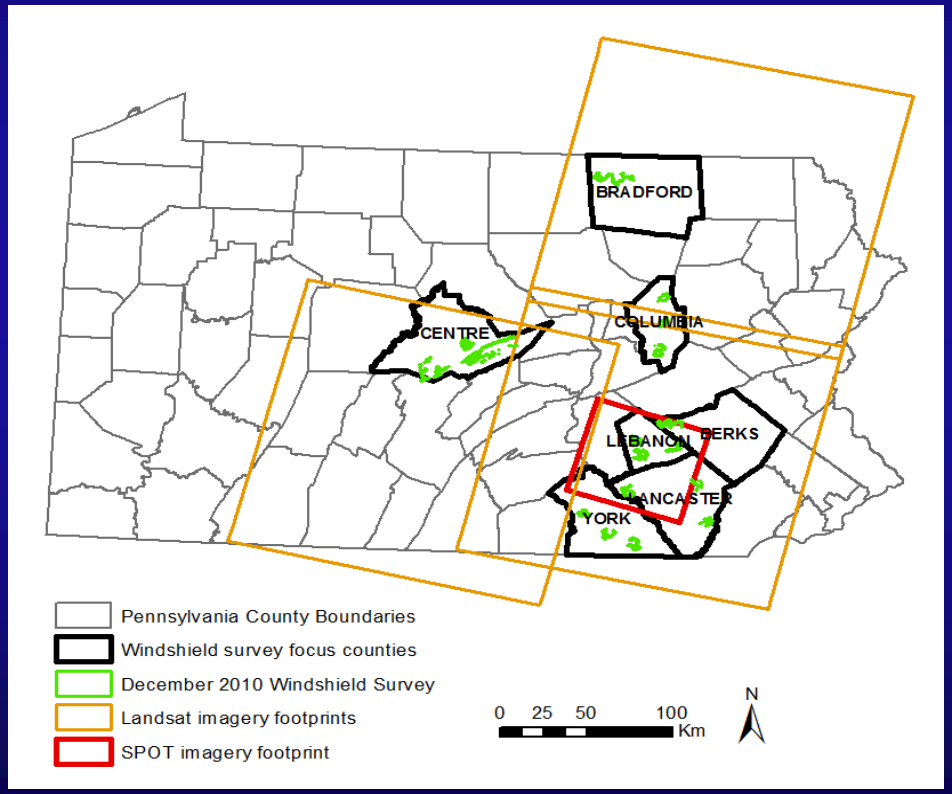
Pennsylvania cover crops: 2013-2014 Without Carrot or Stick

- Identified multi-year vegetation trends associated with increasing use of cover crops
- Separated trends from effects of weather

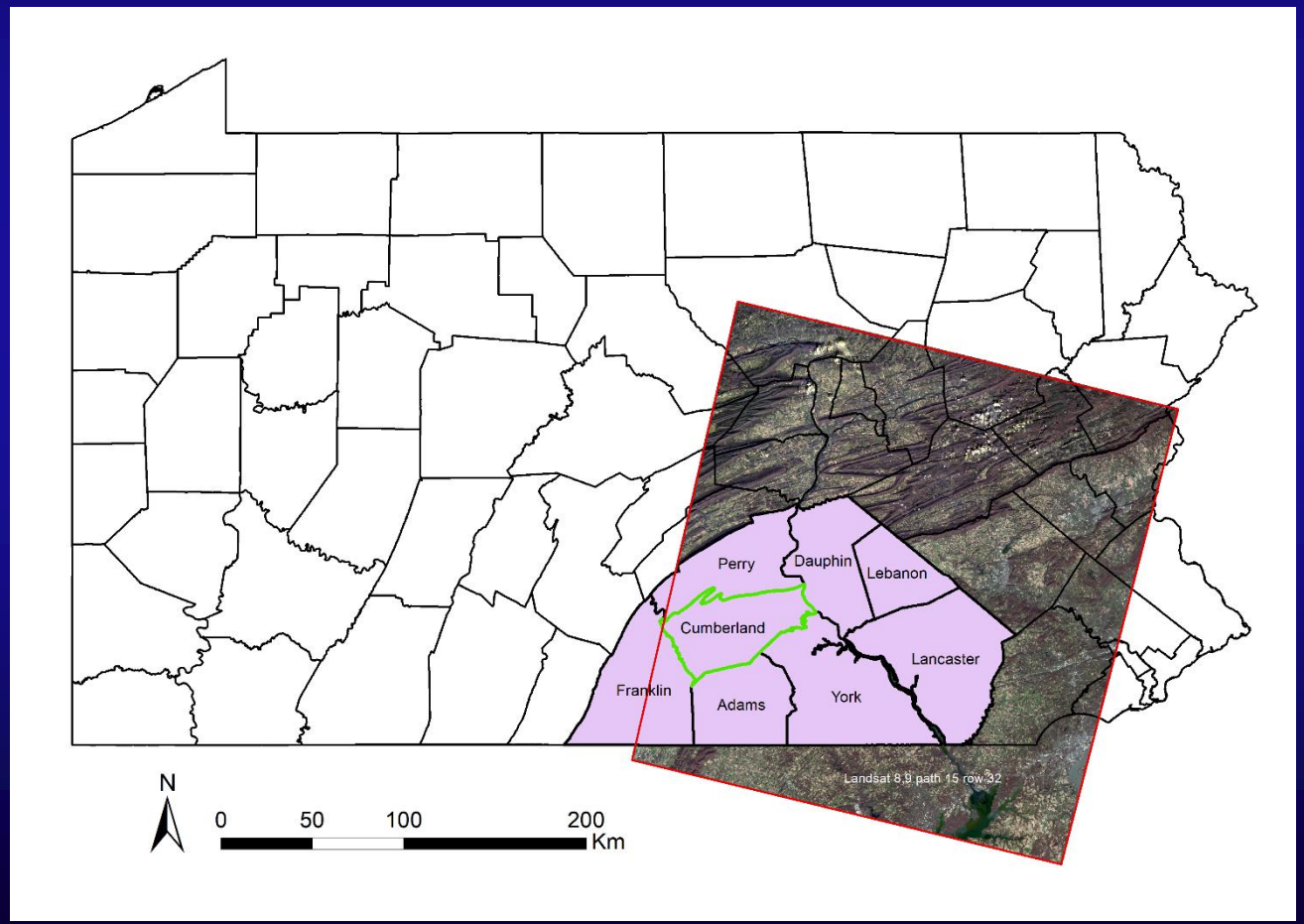




Hively et al., 2015. JSWC, httpps://doi.org/10.2489/jswc70.6.340

Project goals in Pennsylvania, 2024-2027

- Satellite remote sensing to monitor cover crop implementation and performance
- 2024 focus in Cumberland (Lancaster, York), develop operational tools by 2027
- Questions of interest include:
  - cover crop identification/mapping
  - cover crop species identification
  - produce daily growth curves for fields identified as cover crop
  - cover crop performance analysis (biomass, fractional ground cover)
  - Integrate with enrollment datasets for calibration/validation



USGS *Funded by CSS, NFWF*

STROUD WATER RESEARCH CENTER

These data are preliminary and are subject to revision.

Caveats of satellite imagery analysis for cover crops

Requires cloud-free, snow-free conditions (difficult in NY winter)

Small fields and strip cropping require small pixels

Saturates above 1500 kg/ha

Cannot distinguish mixes

Interference from weeds

USGS

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Measuring Crop Residue Cover

Agricultural crop residues

- Indicate tillage intensity
- prevent soil erosion
- preserve moisture
- improve soil health
- promote C cycling

Plow tillage
0-30% cover

Conservation tillage
30-60% cover

High residue / no-till
60-100% cover

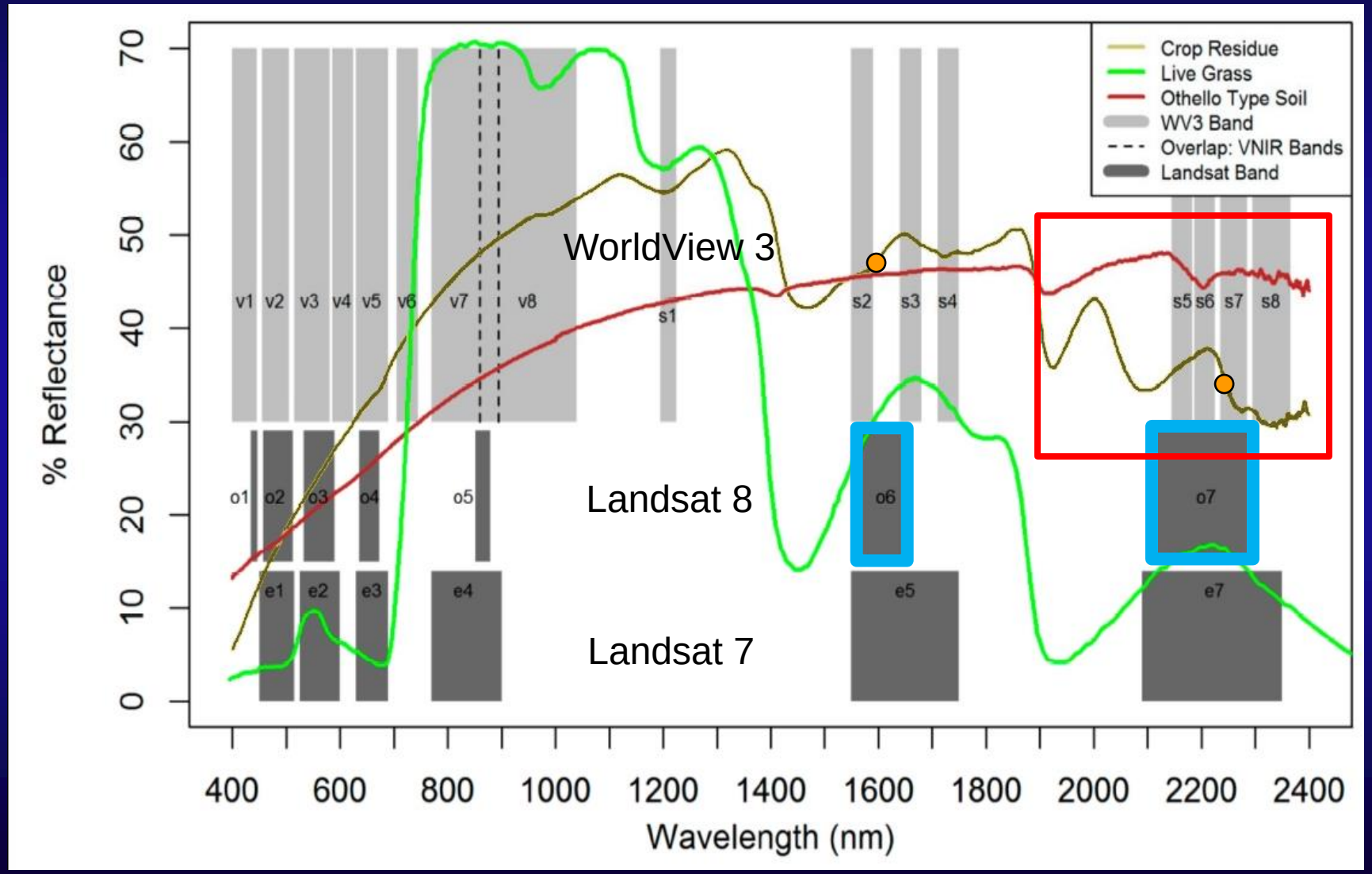
Measuring Crop Residue Cover

CONUS methods such as OpTIS typically use the normalized difference tillage index

NDTI = (1600–2200)/(1600+2200)

using Landsat satellites

This index can achieve good results (R^2 0.6-0.8) but is prone to interference from green vegetation and surface moisture



USGS

Hively et al., Remote Sensing, 2018.

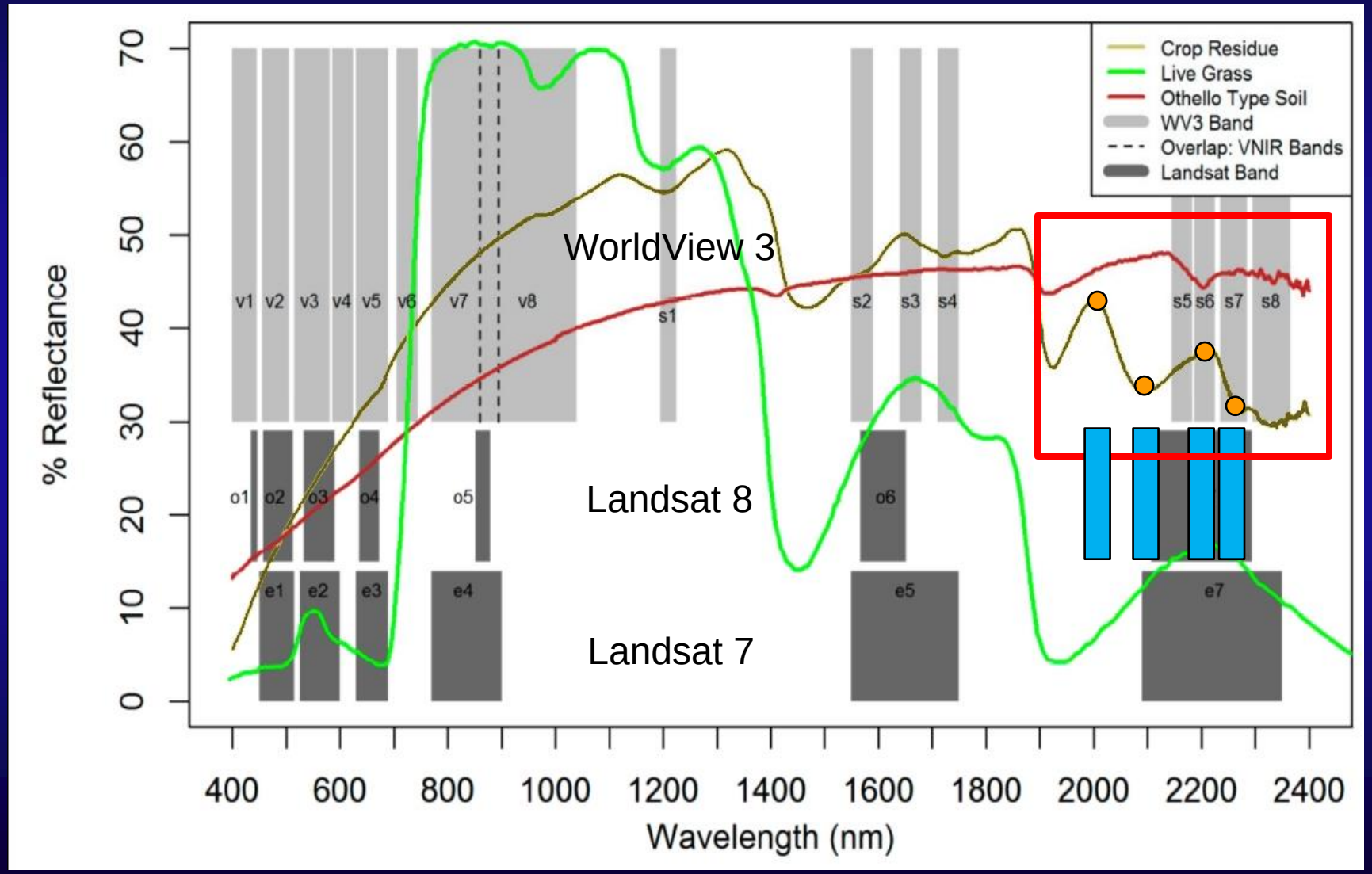
Measuring Crop Residue Cover

Increased accuracy can be achieved by measuring lignin and cellulose absorption features from 2100-2300 nm

Cellulose absorption index

CAI is ratio of 2040, 2160, 2240 nm reflectance

This index achieves superior results (R^2 0.8-0.9) but requires high resolution satellites that do not currently have wall-to-wall coverage



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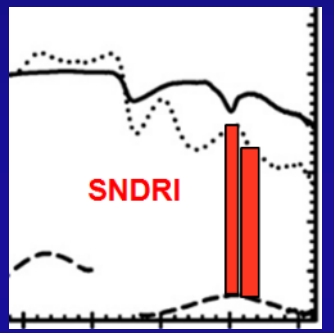
Hively et al., Remote Sensing, 2018.

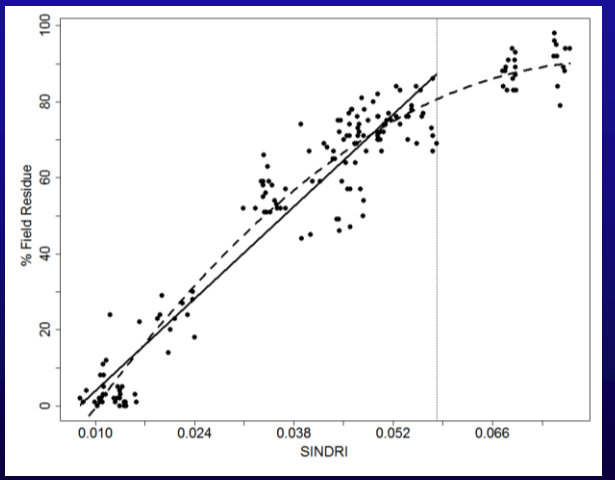
Mapping crop residue using Worldview 3 SWIR imagery

Achieved high accuracy in mapping crop residue on fields with minimal vegetation (NDVI <0.3)

SINDRI R^2 = 0.94

NDTI R^2 = 0.83





Worldview 3 SWIR imagery acquired May 14, 2015

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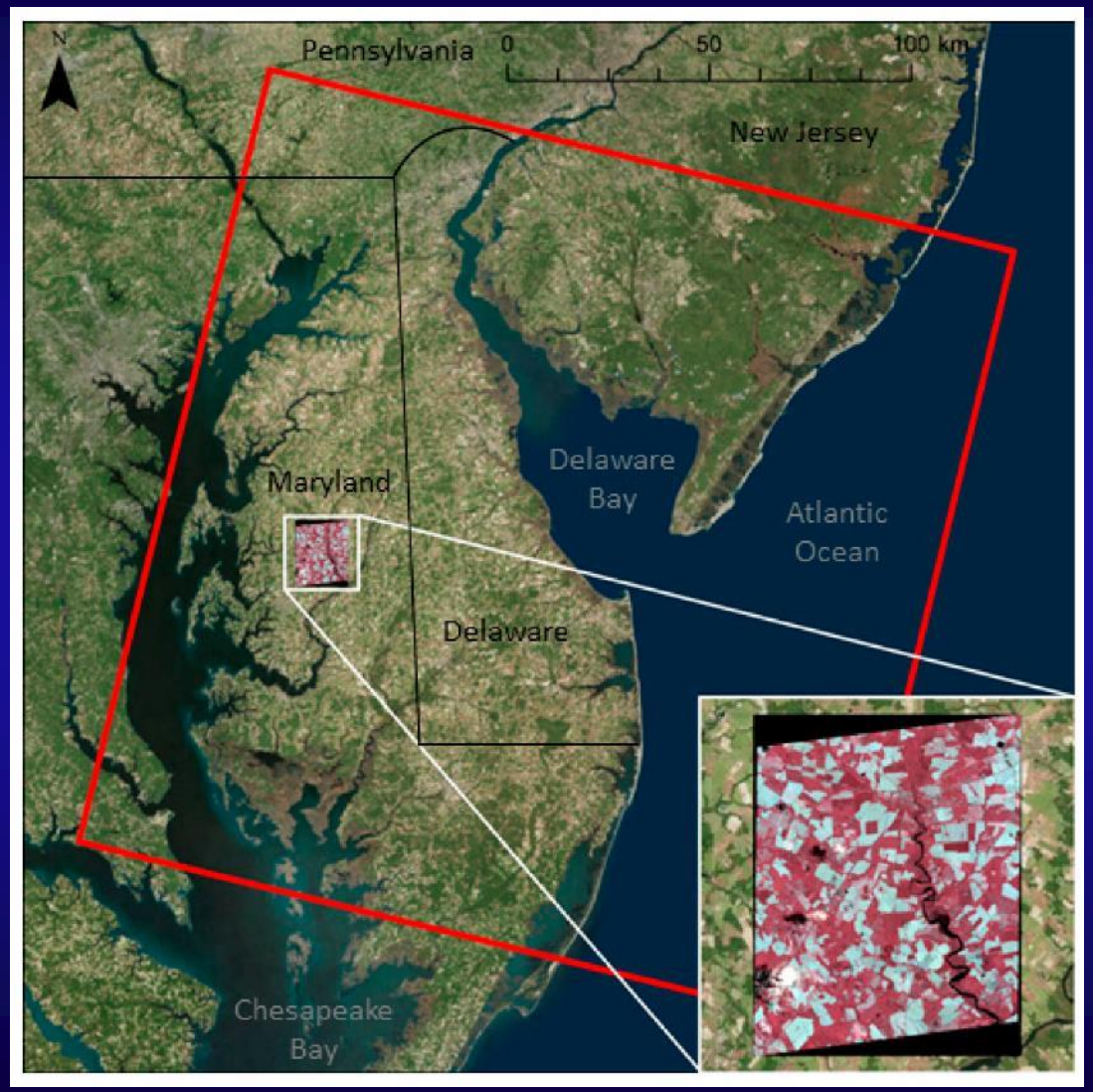
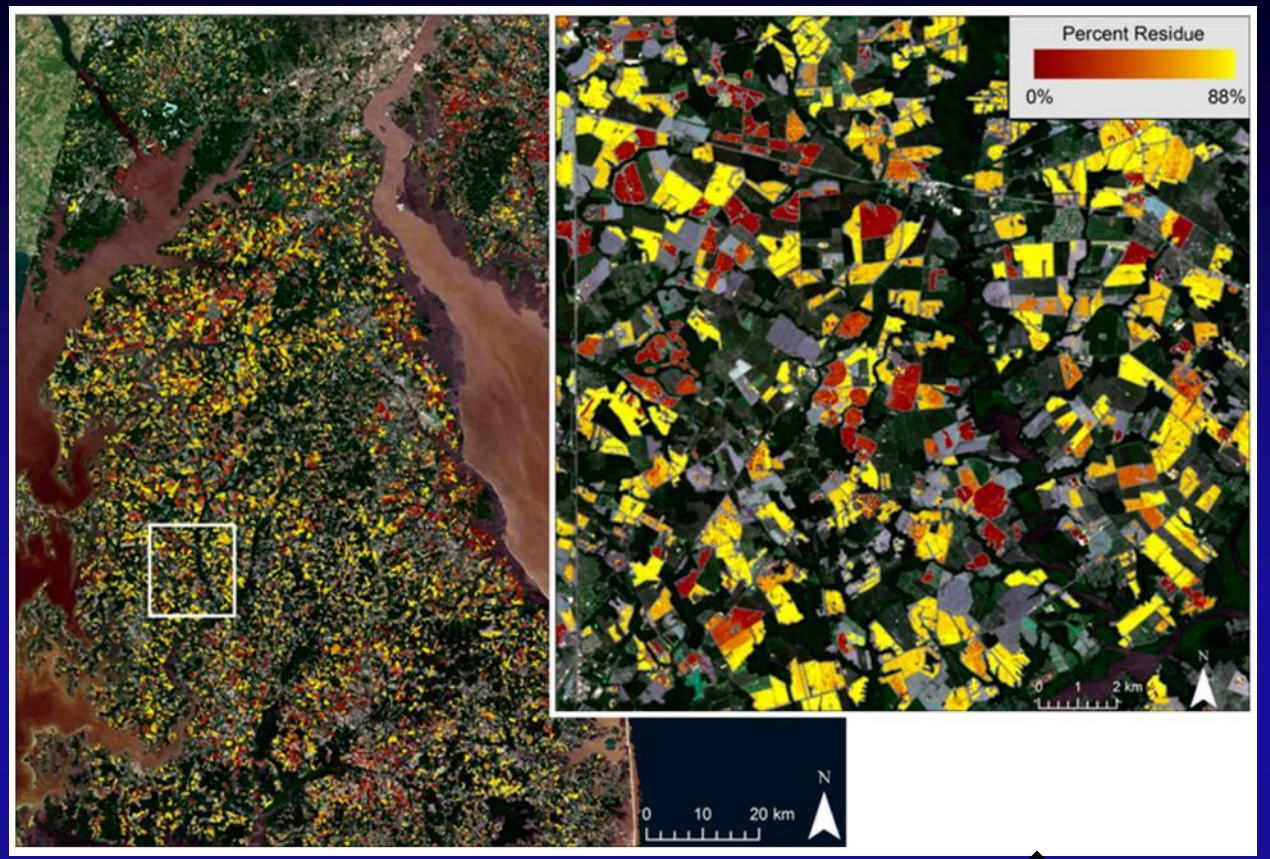
Hively et al., Remote Sensing, 2018.

Scaling up from SWIR to Landsat

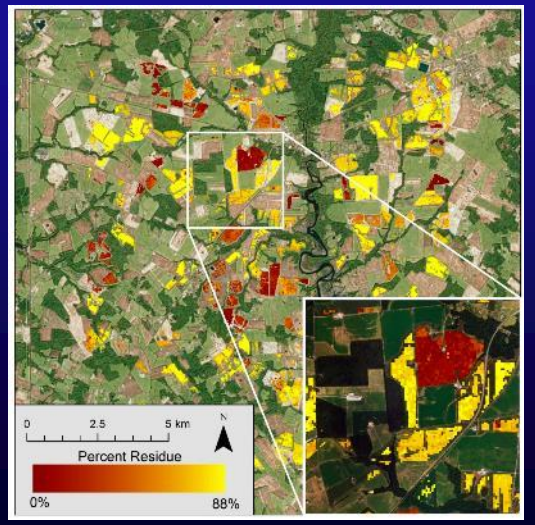


USGS

Hively et al. (2018, 2019)



SWIR-classified residue cover as calibration & validation



Machine learning prediction of crop residue cover from Landsat 8 imagery

R^2 = 0.92 wet , 0.93

Crop residue and tillage intensity

- Now completing a 7-year study mapping tillage intensity on the Delmarva using SWIR lignocellulose indices
- Results will be compared to MD and DE reported data to NEIEN

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    - Green vegetation (NDVI >0.4)
    - Moisture
    - Residue type
    - Residue age
    - Springtime window is small and variable field to field
    - Roadside surveys can have trouble distinguishing 30-60 vs. 60-100%

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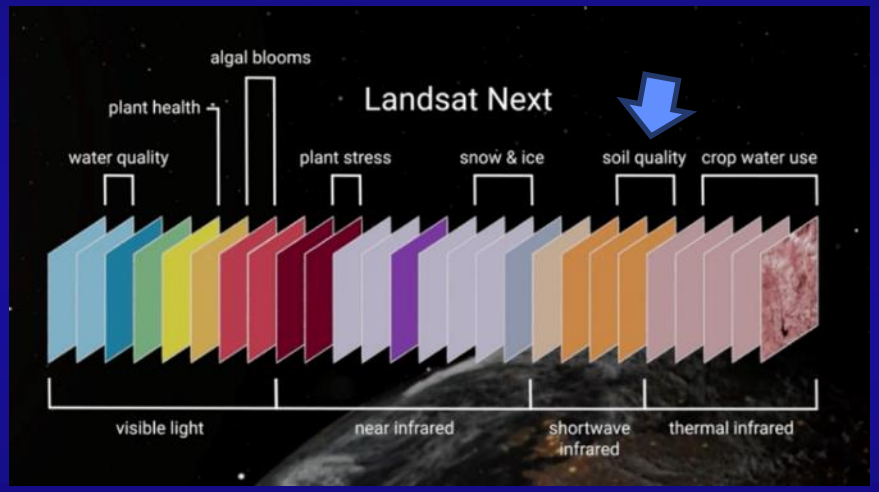

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The launch of Landsat Next in 2028 will greatly increase accuracy of crop residue mapping with global coverage, 6 day return, 20m pixels

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Satellite imagery sources

- **MODIS**
  daily revisit, free, 250 m pixel – too large for Chesapeake agriculture
- **Harmonized Landsat and Sentinel**
  ~6 day revisit, 30m pixel, free - our main tool for landscape scale analysis
- **Planet**
  daily revisit, 4 m pixel, costly, calibration issues – the best solution for small strip cropped fields
- **WorldView3**
  – 4 m pixel, SWIR bands measure lignocellulose absorption, small footprint
- **PRISMA, EMIT**
  hyperspectral satellites best for high biomass fields, N content, crop residue – more difficult acquisition and processing
- **Landsat Next, SBG**
  future missions will provide high spectral resolution, 20m pixel, 6 day revisit – launch by 2028, plan for future use

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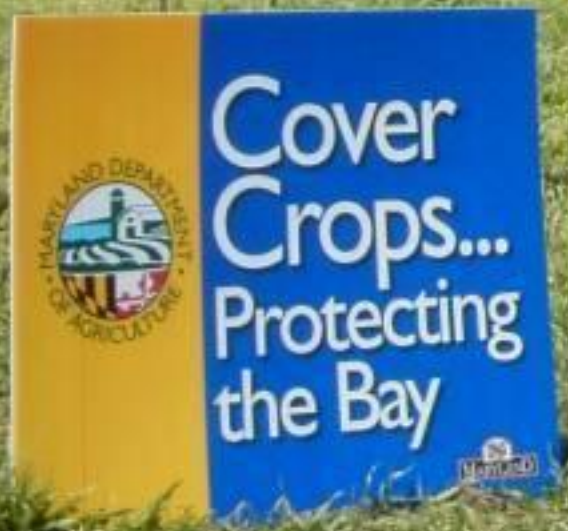
Selected references

- Thieme et al., 2022. Remote Sensing Evaluation of Winter Cover Crop Springtime Performance and the Impact of Delayed Termination. Agronomy Journal 115(1) Jan 2023, 442-458. https://doi.org/10.1002/agj2.21207
- Gao et al., 2023. Near real-time detection of winter cover crop termination using harmonized Landsat and Sentinel-2 (HLS) to support ecosystem assessment. Science of Remote Sensing 7 (2023) 100073. https://doi.org/10.1016/j.srs.2022.100073
- Hively et al., 2020. Estimating the effect of winter cover crops on nitrogen leaching using cost-share enrollment data, satellite remote sensing, and Soil and Water Assessment Tool (SWAT) modeling. Journal of Soil and Water Conservation 75 (3) 362-375. https://doi.org/10.2489/jswc.75.3.362
- Dennison et al., 2023. Modeling global indices for estimating non-photosynthetic vegetation cover. Remote Sensing of Environment 295 (2023) 113715. https://doi.org/10.1016/j.rse.2023.113715

Thank you!



W. Dean Hively, Research Physical Scientist
Lower Mississippi-Gulf Water Science Center
phone: 607-351-3196 email: whively@usgs.gov
posted to USDA-ARS Hydrology and Remote Sensing Laboratory
Bldg 007 BARC-W, 10300 Baltimore Ave, Beltsville, MD 20705

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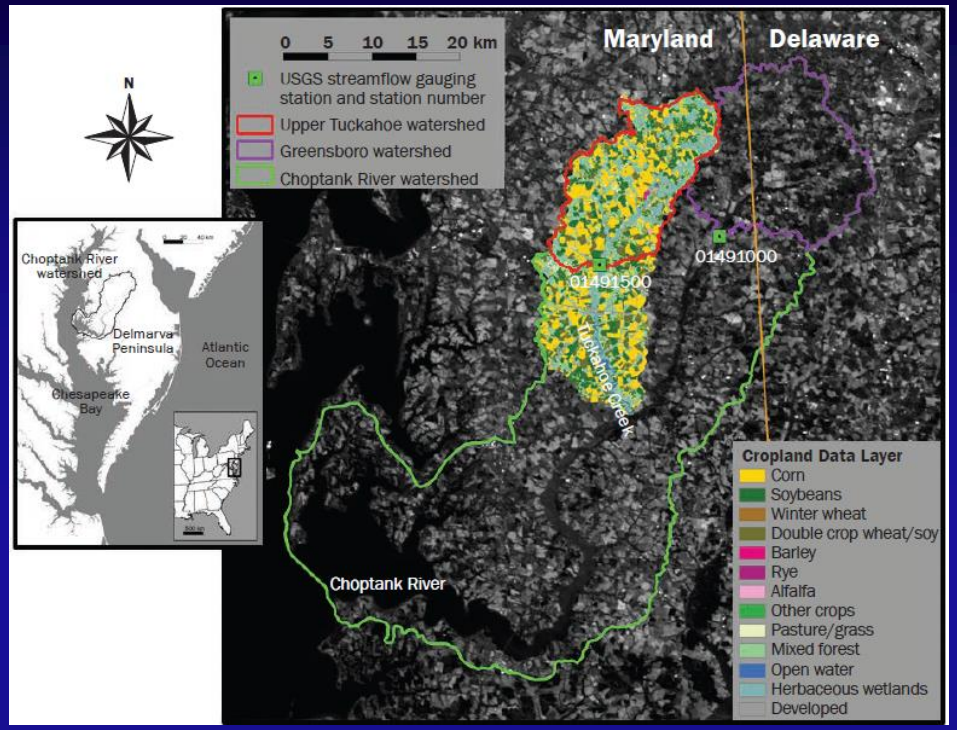
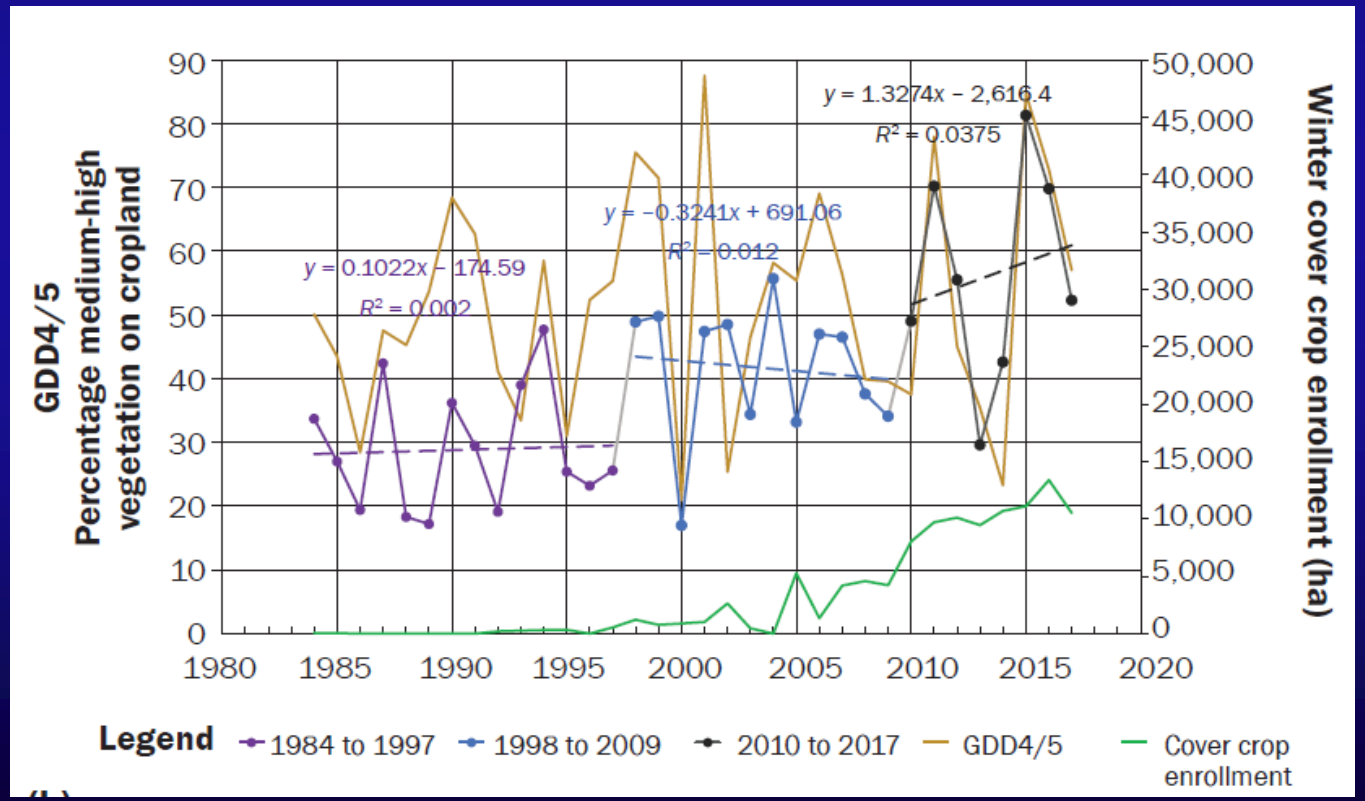
SWAT modeling in the Tuckahoe Creek watershed, MD



- **SWAT modeling predicted a 25% decrease in nitrogen leaching due to increased cover crop implementation from 2007 (14% of cropland) to 2017 (64% of cropland)**



- **Wintertime vegetation responded to:**
  1) warm conditions
  2) cover crop implementation

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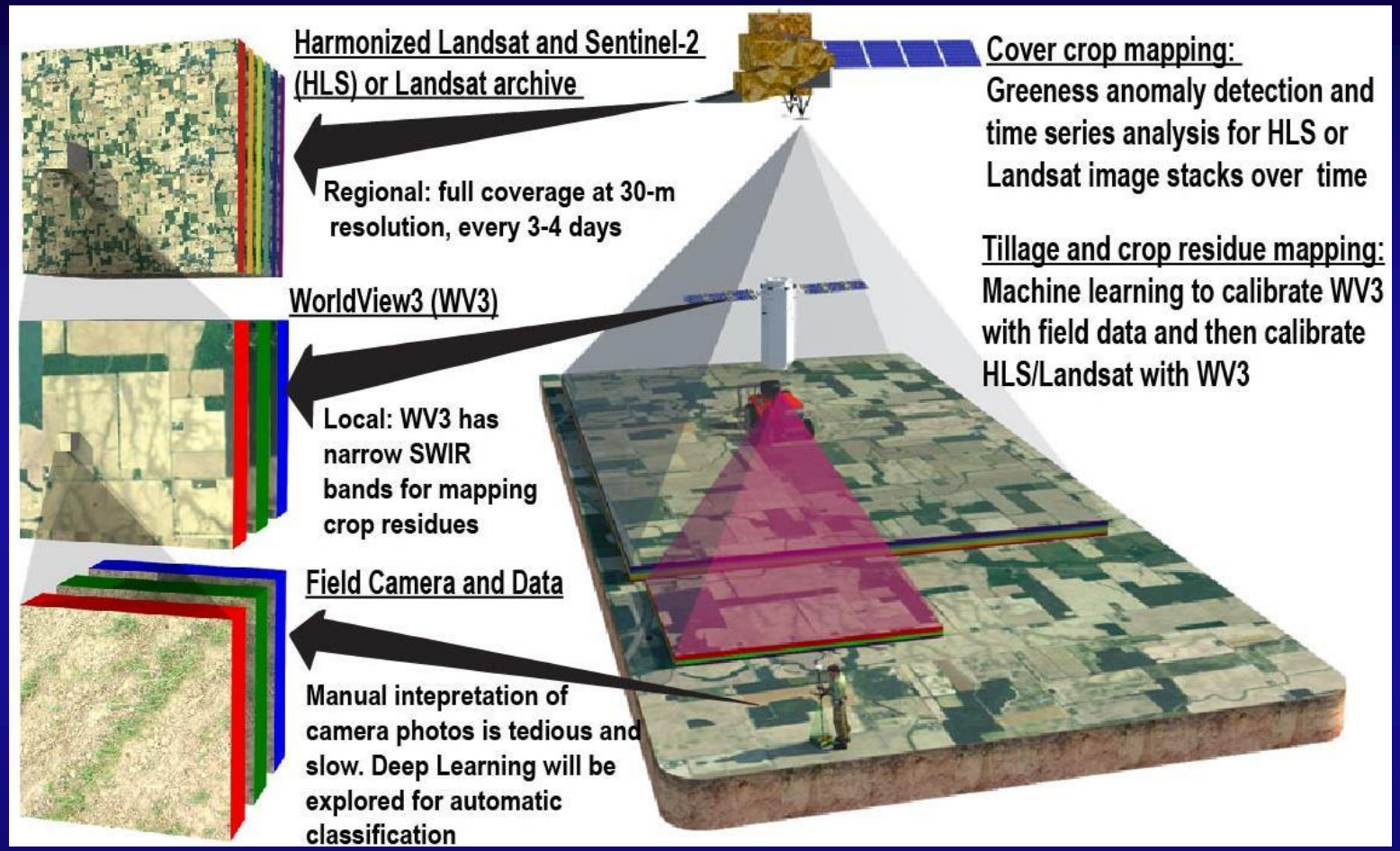
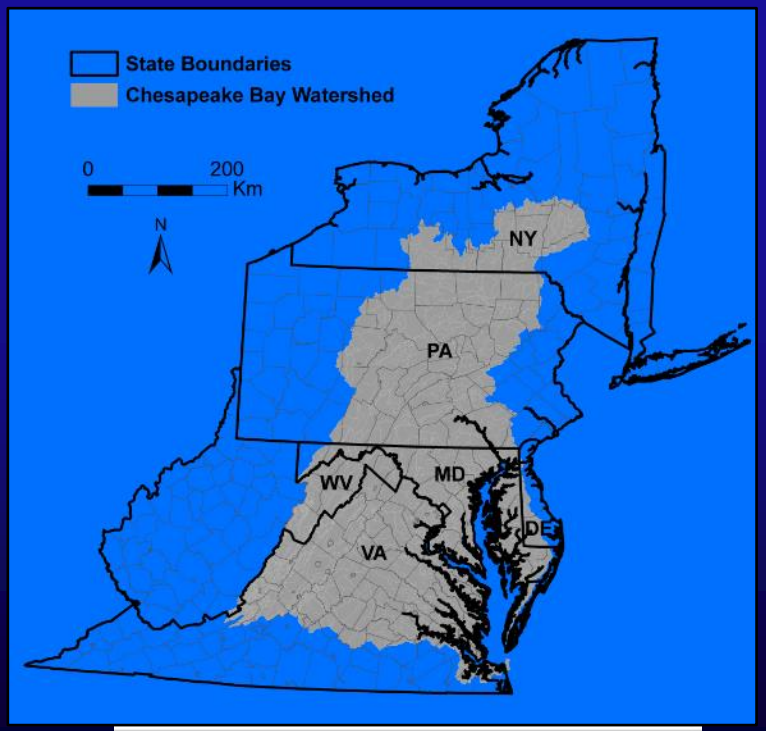
Hively et al., 2020

Chesapeake Bay input maps for SWAT-C CMS



- **Impact of *cover crops* (biomass, ground cover)**
- **Impact of *crop residue* (conservation tillage)**



Goal: To produce annual maps of wintertime green biomass and spring residue cover for input to SWAT-C and Chesapeake CMS

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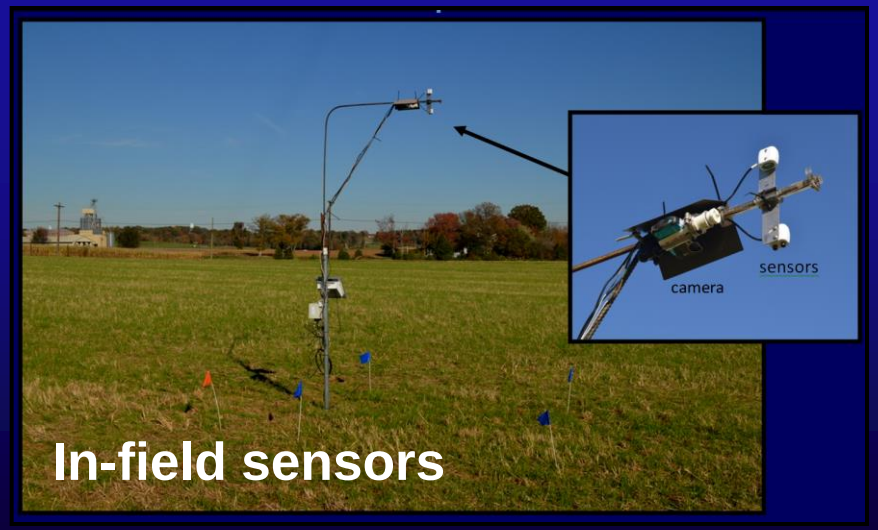
Proximal technology can expand understanding



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