Sensors And Image Processing

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Platforms And Sensors

Platforms

- Handheld
- Manned/Unmanned Ground Vehicles
- Phenotyping Robots
- Blimps
- Multi-rotor UAVs
- Small Fixed-Wing UAVs
- Manned Aircraft
- Satellites

Platform and sensor choices are driven by multiple factors

- The physical traits to be measured
- The frequency of measurements
- Required spatial resolution and spectral bands
- Required accuracy and confidence level

Platforms And Sensors

Handheld Sensors

- Sensors: SPAD, CropScan, CropCircle, GreenSeeker, Apogee MC-100, Handheld Spectrometers, LAI-2200, ACCUPAR LP-80, etc.
- Data Products: Single-point / Local-canopy VI measurements

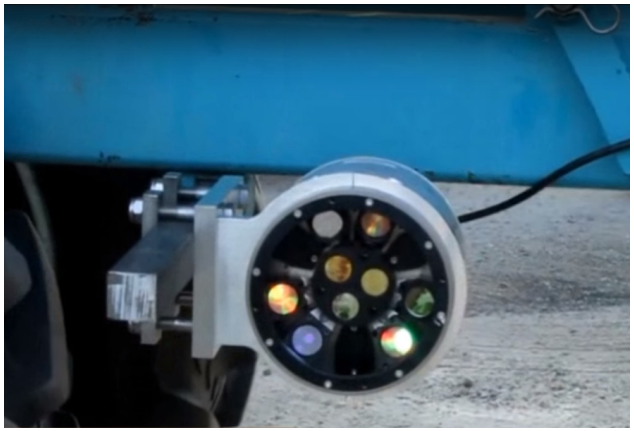


- A person takes every measurement - very labor intensive
- Small sample sizes and prone to human error

Platforms And Sensors

Ground-Vehicle-Mounted Sensors

- CropCircle, GreenSeeker, Yara N-Sensor, Force-A Multiplex, etc.
- Local canopy measurements (average over many plants)
- Data Products: Low-resolution Vegetation Index maps (shapefiles)

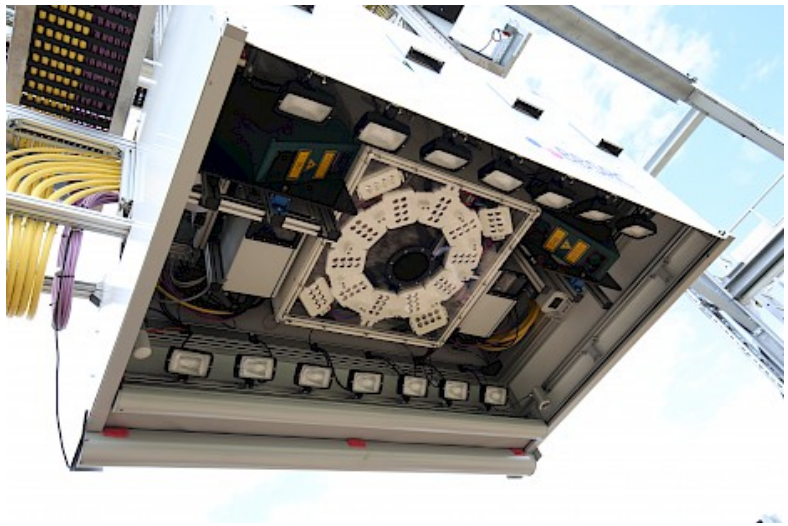


- Measurements taken continuously - Requires driving over or alongside sensing area. Not ideal for frequent measurements. Low spatial resolution mapping.

Platforms And Sensors

Phenotyping Robots

- LemnaTec Field Scanalyzer, Others?
- Plant-level sensing with multiple active and passive sensors
- Data products: VNIR/SWIR/LWIR Imaging, LIDAR, fluorescence



- Near-continuous, automated sensing in field conditions.
- Cost limits scale of application.

Platforms And Sensors

Blimps

- Few or no off-the-shelf products for agriculture
- Sensors: Similar to larger fixed-wing or multi-rotor platforms

- Pros: High payload capacity (many sensors at once), long endurance
- Cons: Some sensors and data products need motion or multiple viewpoints; not possible if tethered. Difficult to manage and poor in wind.

Platforms And Sensors

Multi-Rotor UAVs

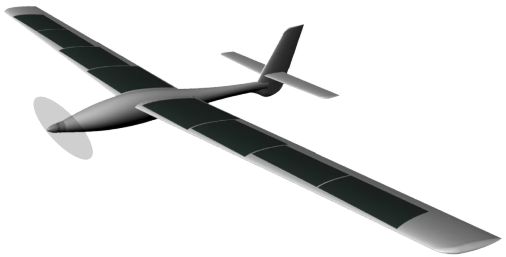
- Vehicles: 3DR, DJI, Parrot, etc.
- Multi-Spec Sensors: Sentek GEMS, RedEdge, Sequoia, Tetracam, Sentera, SlantRange, standard and modified RGB cameras, FLIR, etc.
- Hyper-Spec Sensors: Headwall Micro-Hyperspec, Resonon Pika, Specim, Imec, Neo Hyspex, Rikola, Bodkin, Bayspec, Pixelteq, Cubert, etc.
- Data products: Orthomosaics, DEMs, NDVI/VI maps, Thermal pics, etc.

- High-resolution mapping, but less detailed than phenotyping robots.
- Low-cost. Good for frequent monitoring of medium-sized areas.
- Plot-scale or plant-scale analysis depending on sensor and configuration.

Platforms And Sensors

Small Fixed-Wing UAVs

- Vehicles: Hawkeye Systems, AgEagle, SenseFly, PrecisionHawk, HoneyComb, Sentera, Trimble, etc.
- Sensors + Data Products: Same as for small multi-rotor UAVs



- Longer endurance than multi-rotors, but often lower-resolution results.
- Often more expensive than multi-rotors. Good for monitoring larger areas.
- More difficult to use than multi-rotors - Manual takeoff and landing, flight planning must be aware of wind.

Platforms And Sensors

Manned Aircraft

- Small planes equipped with high-res RGB/NIR or modified RGB cameras for NDVI. Usually provided as a service.
- NASA AVIRIS (By Request): 1-20 m GSD 224-band VNIR-SWIR imagery

- Can cover large areas at lower resolution.
- Somewhat expensive - not well-suited for frequent monitoring.
- Wide range in quality, from poor to calibrated and excellent (AVIRIS).

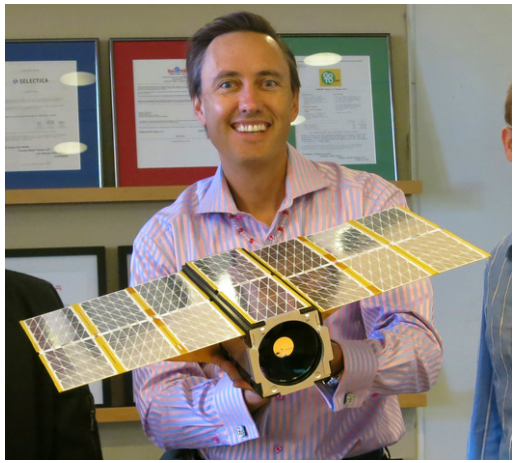
Platforms And Sensors

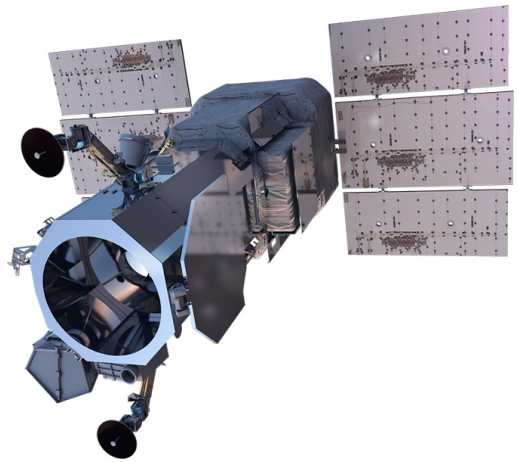
Satellites - Continuous Coverage Constellations

- Many small satellites - every point on Earth is imaged every $\approx$ 24 hours.
- Low-resolution, often poor-quality imagery, RGB or RGB+NIR only.

Satellites - Tasking Constellations

- Few satellites in a constellation - Can revisit frequently, but limited coverage. Must be commanded to image a given area ($).
- Better sensors - up to 28-band multi-spec, high-res VNIR (30 cm GSD)



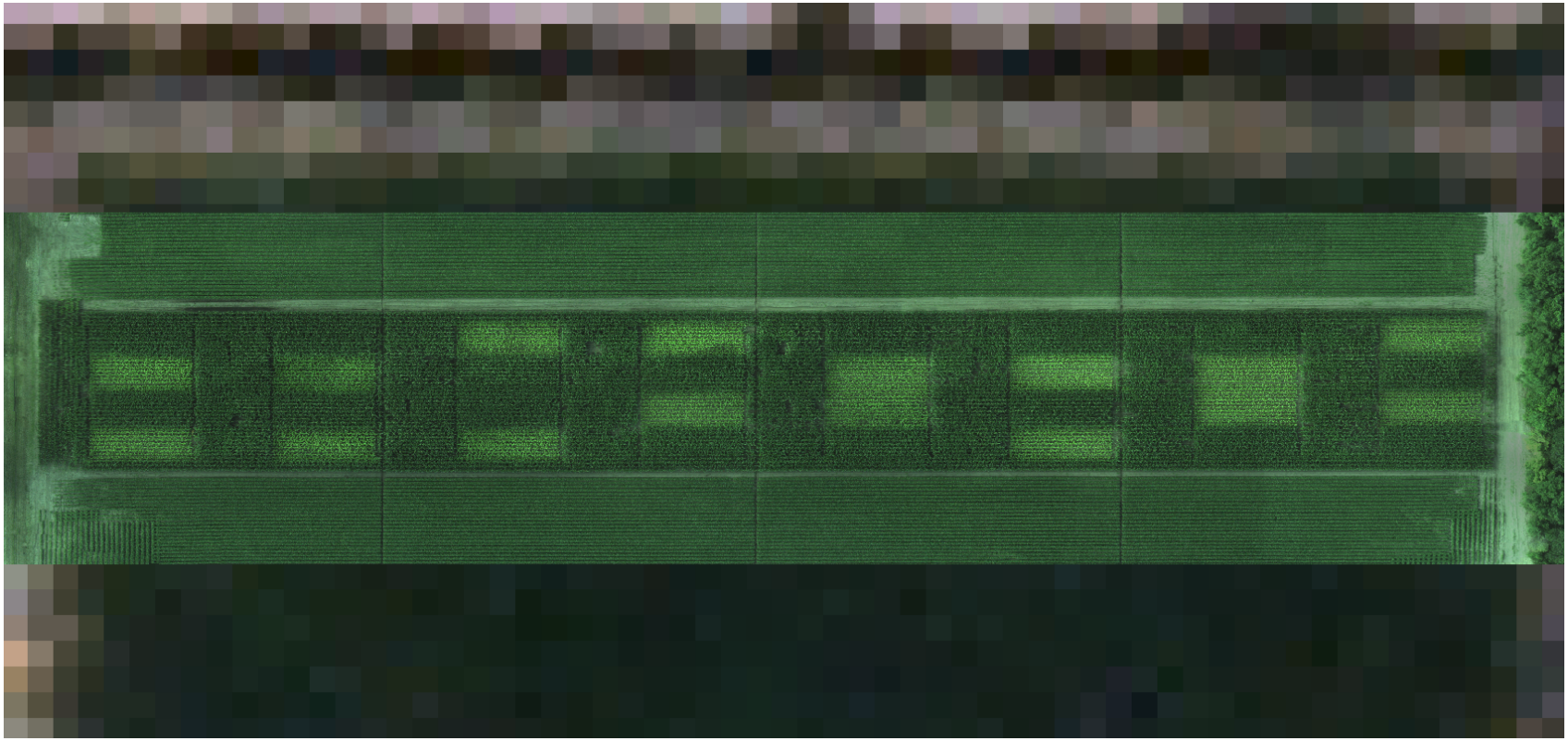


Current and Future Satellites

Satellite/Constellation	Active	Revisit Rate	Bands + GSD
ESA Sentinal-2	Now	5-10 days	VNIR: 10m, RE+SWIR: 20m Others: 60m
Planet - Dove	Now	1 day	RGB+NIR: 2.7-4.9 m
Planet - SkySat	Now	1 day	RGB+NIR: 2m, Pan: 0.86m
DigitalGlobe - WorldView	Now	1 day	RGB+NIR: 1.24m, Pan: 0.31m SWIR: 3.7m
ASI PRISMA (Italy)	2018		$\approx$ 250-band VNIR+SWIR: 30m
IAI/ImageSat EROS C	2019		Competitive with Worldview
Urthecast Urthedaily	2019	1 day	13-band VNIR: 5m
DLR EnMAP (Germany)	2019	4 days	244-band VNIR+SWIR: 30m
Airbus/CNES Pleiades Neo	2020	1 day	RGB+NIR: 0.3m Pan: 0.2-0.3m
DigitalGlobe WorldView Legion + Scout	2020	0.025-1 days	Maintain leadership position

PlanetScope Dove Satellite (3.7 m GSD)

Sentek GEMS RGB Imagery (from 216 feet, 0.032 m GSD)



Sentek GEMS Elevation Map (from 216 feet, 0.032 m GSD)

PlanetScope Dove Satellite (3.7 m GSD)

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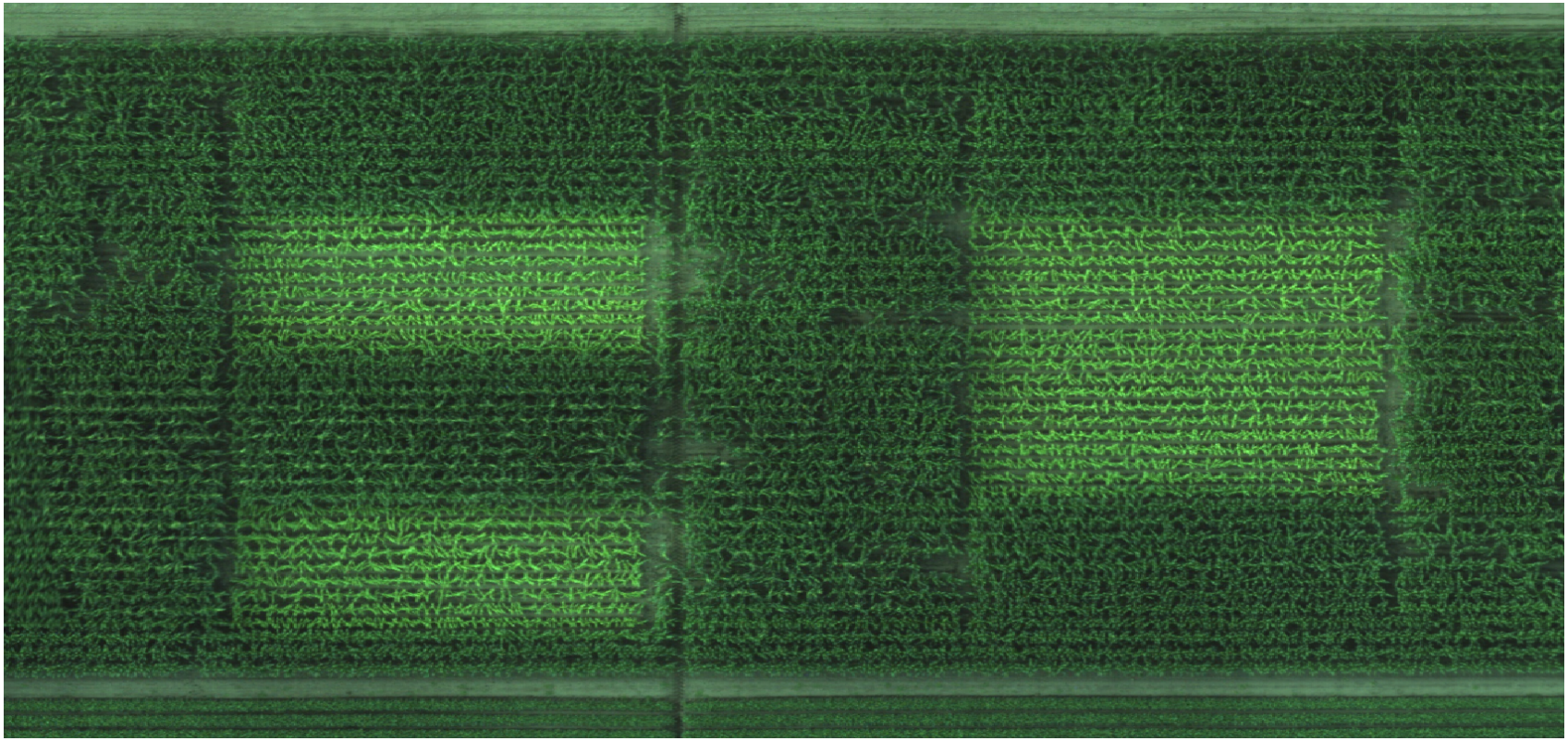

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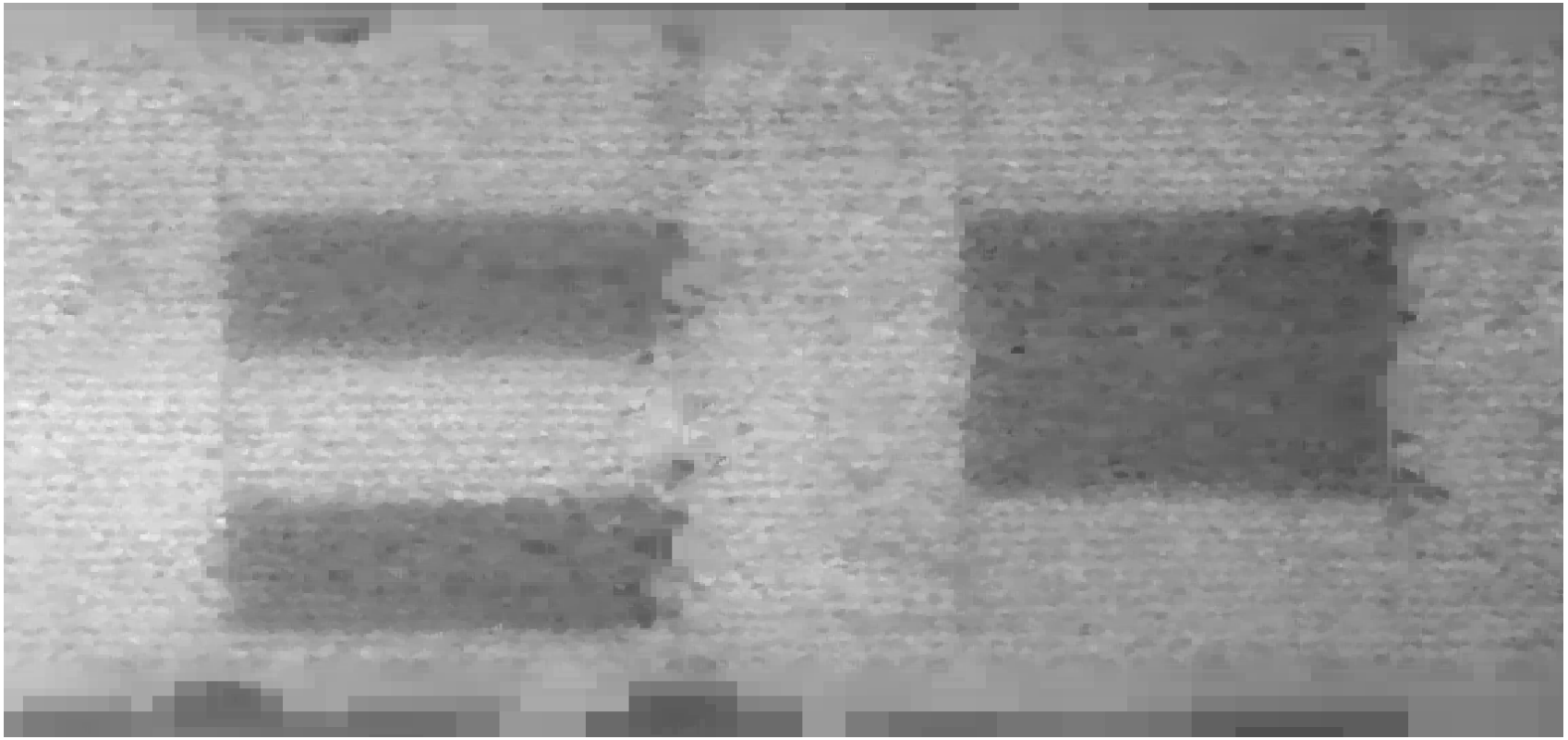
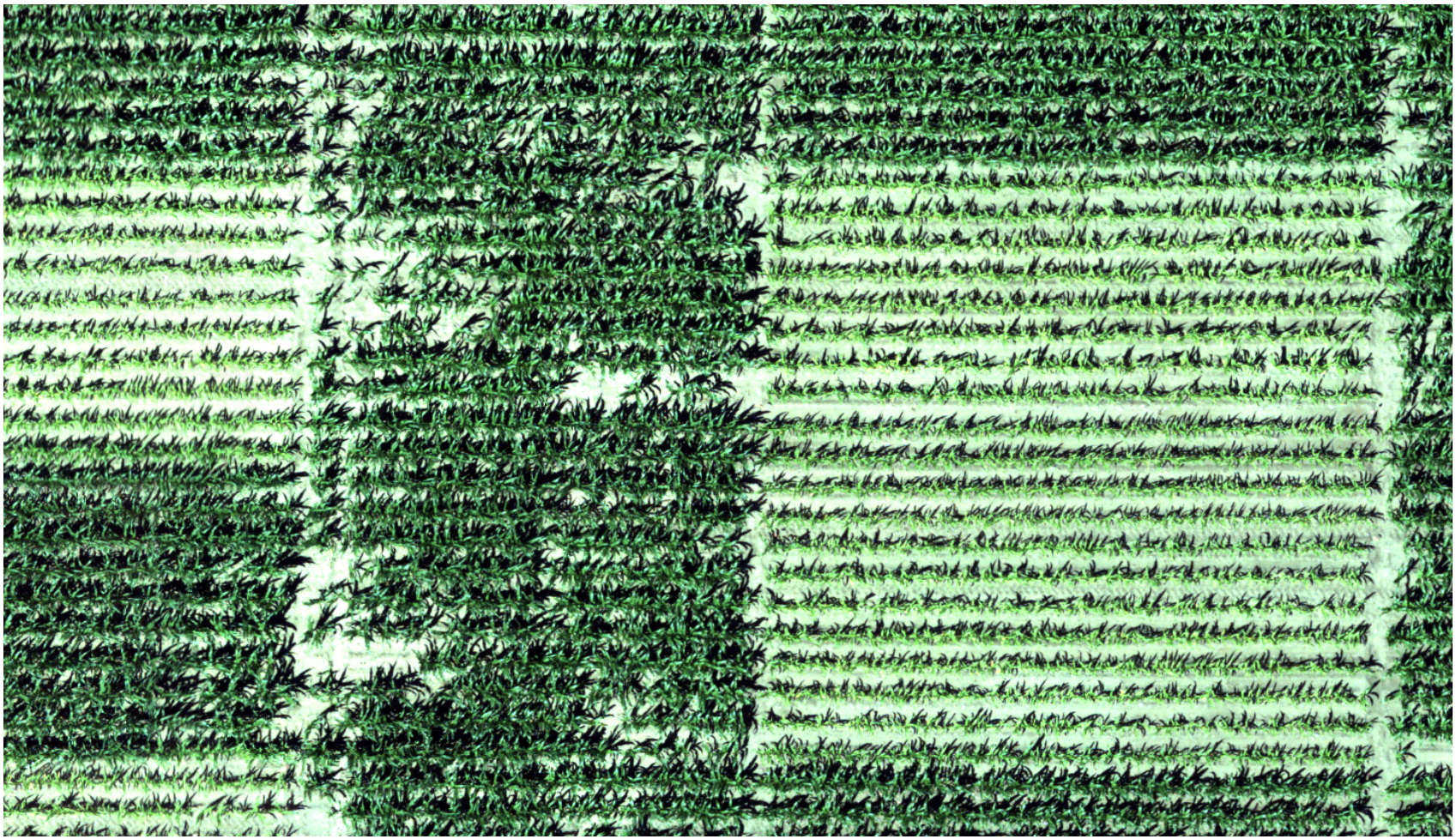
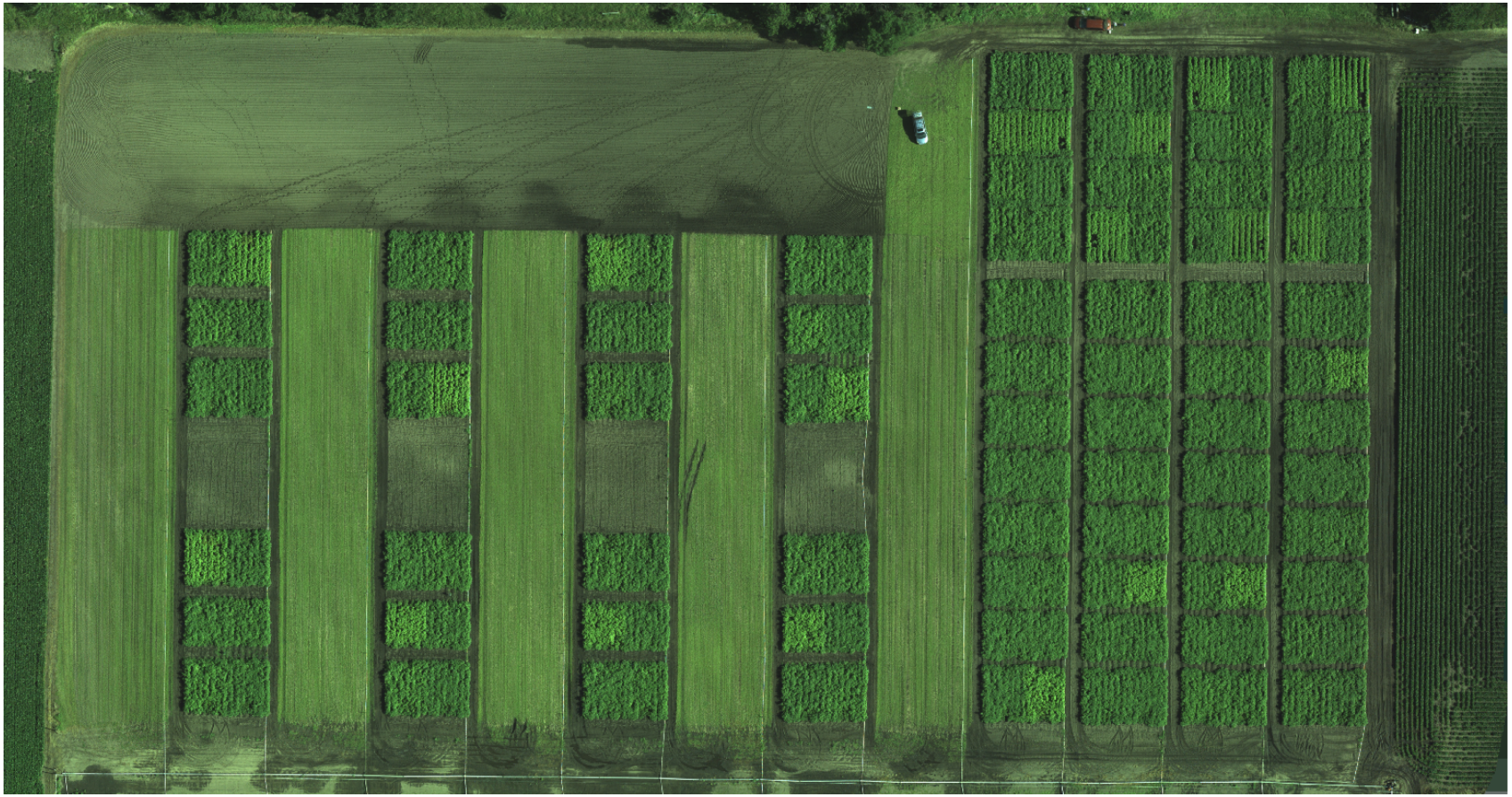


Sentek GEMS RGB Imagery (from 105 feet, 0.016 m GSD)



PlanetScope RapidEye-5 Satellite (6.5 m GSD)

Sentek GEMS RGB Imagery (from 305 feet, 0.045 m GSD)

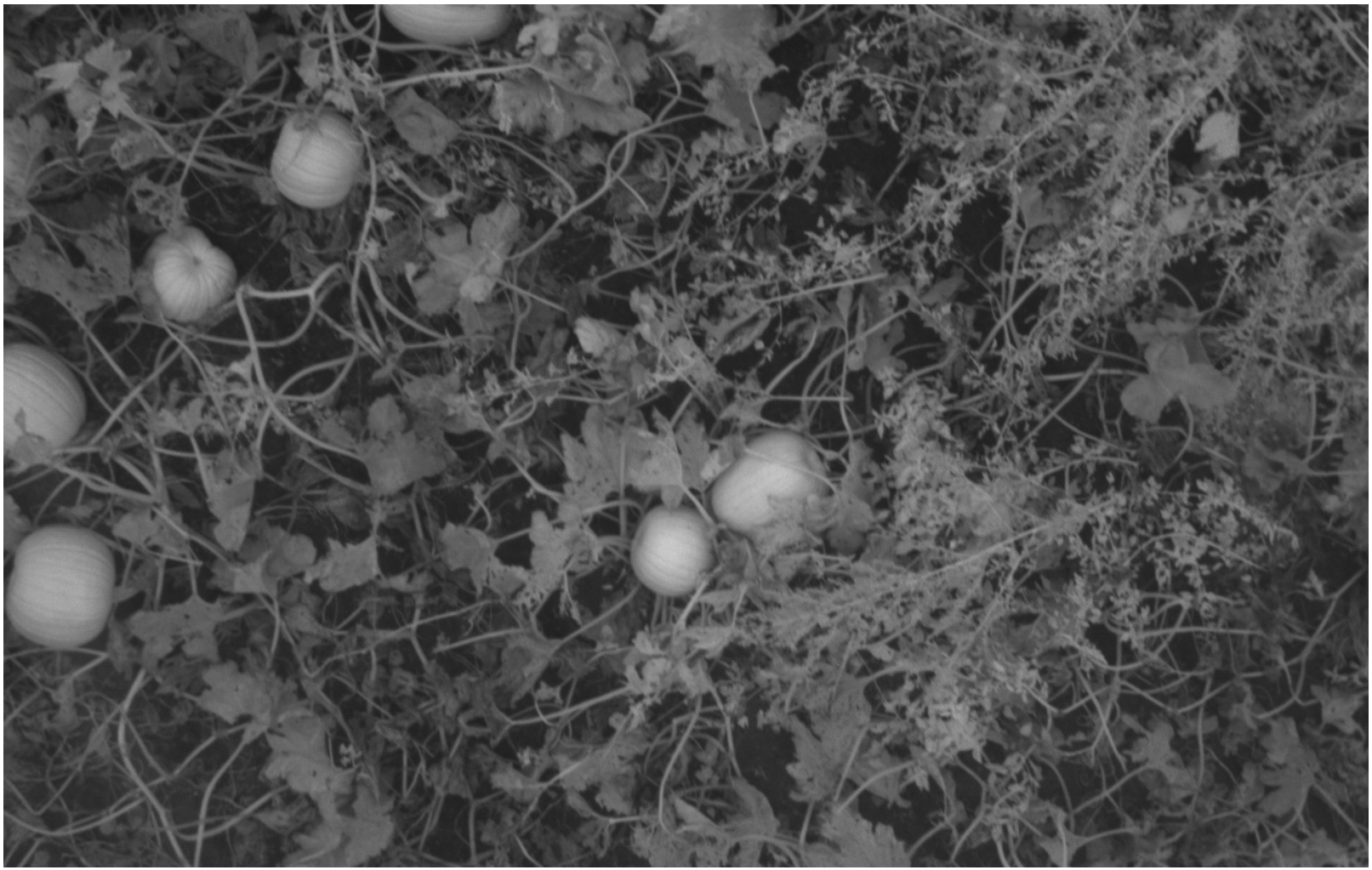


Data Product Comparison - Highest Res From a Drone

Sentek GEMS RGB Imagery (from 15 feet 0.002 m GSD)

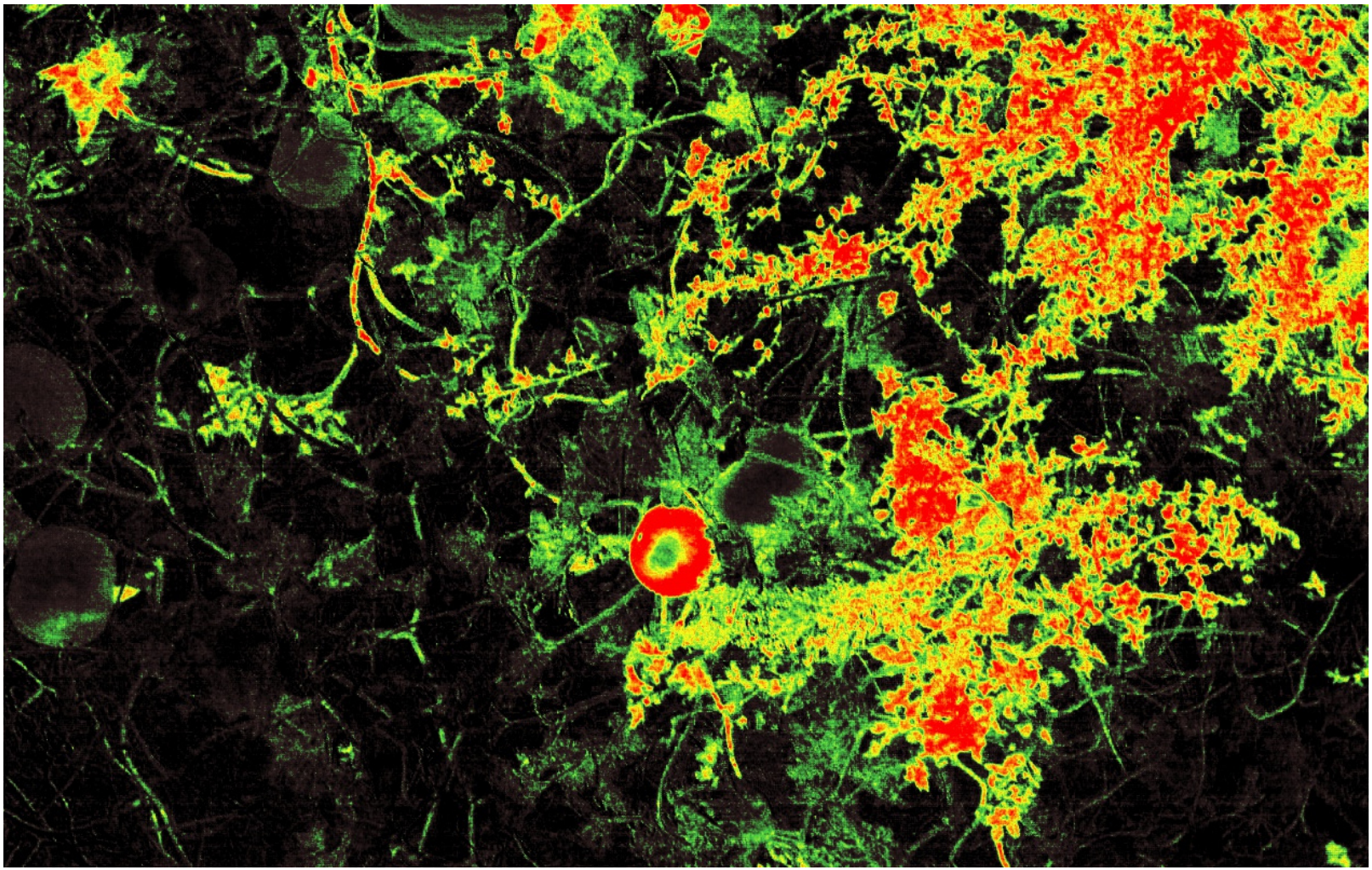
Data Product Comparison - Highest Res From a Drone

Sentek GEMS NIR Imagery (from 15 feet 0.002 m GSD)



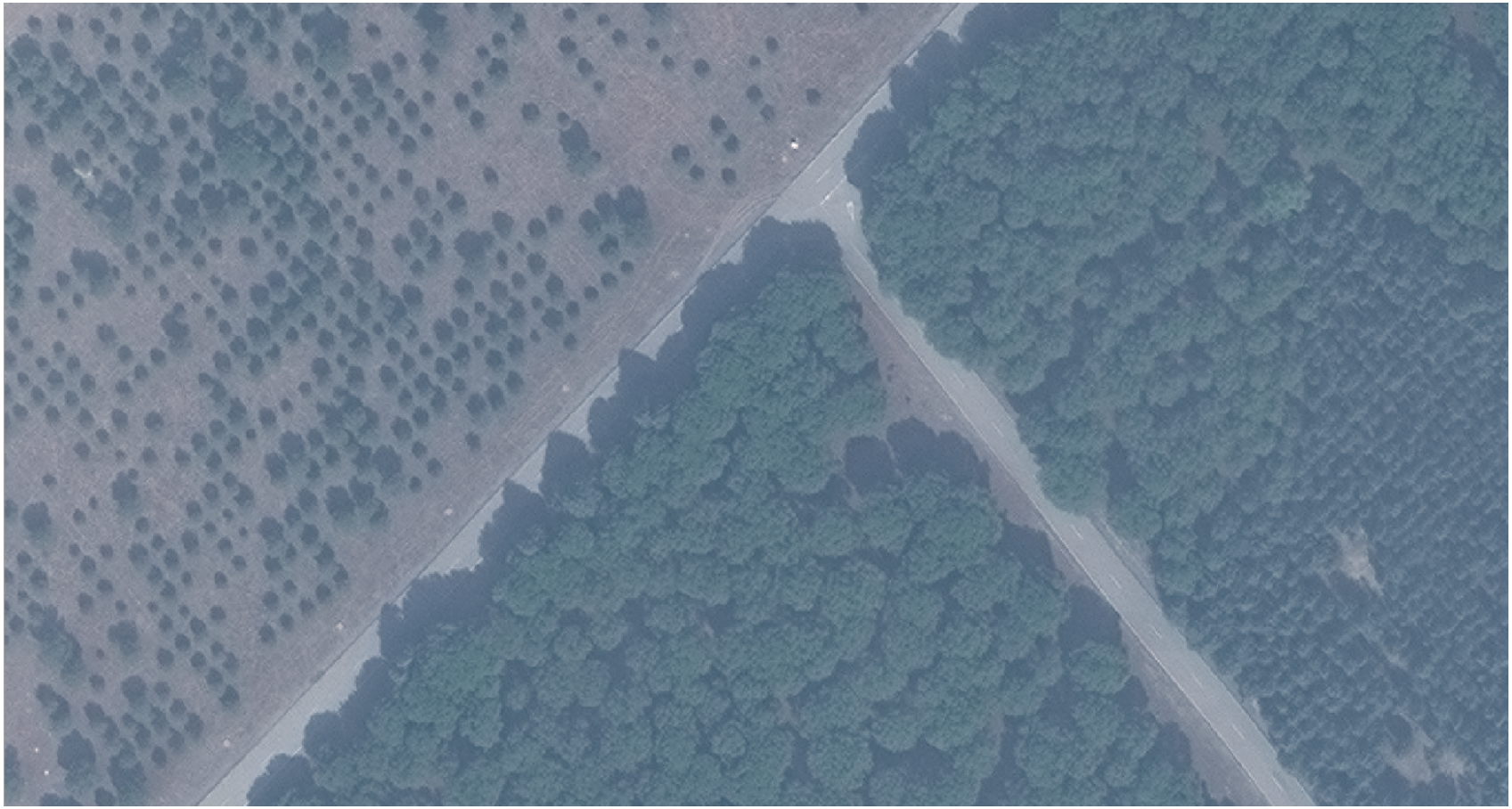
Data Product Comparison - Highest Res From a Drone

Sentek GEMS NDVI Imagery (from 15 feet 0.002 m GSD)



Data Product Comparison - Highest Res From a Satellite

Digital Globe WorldView-3 Pan-Sharpened RGB (0.3 m GSD)



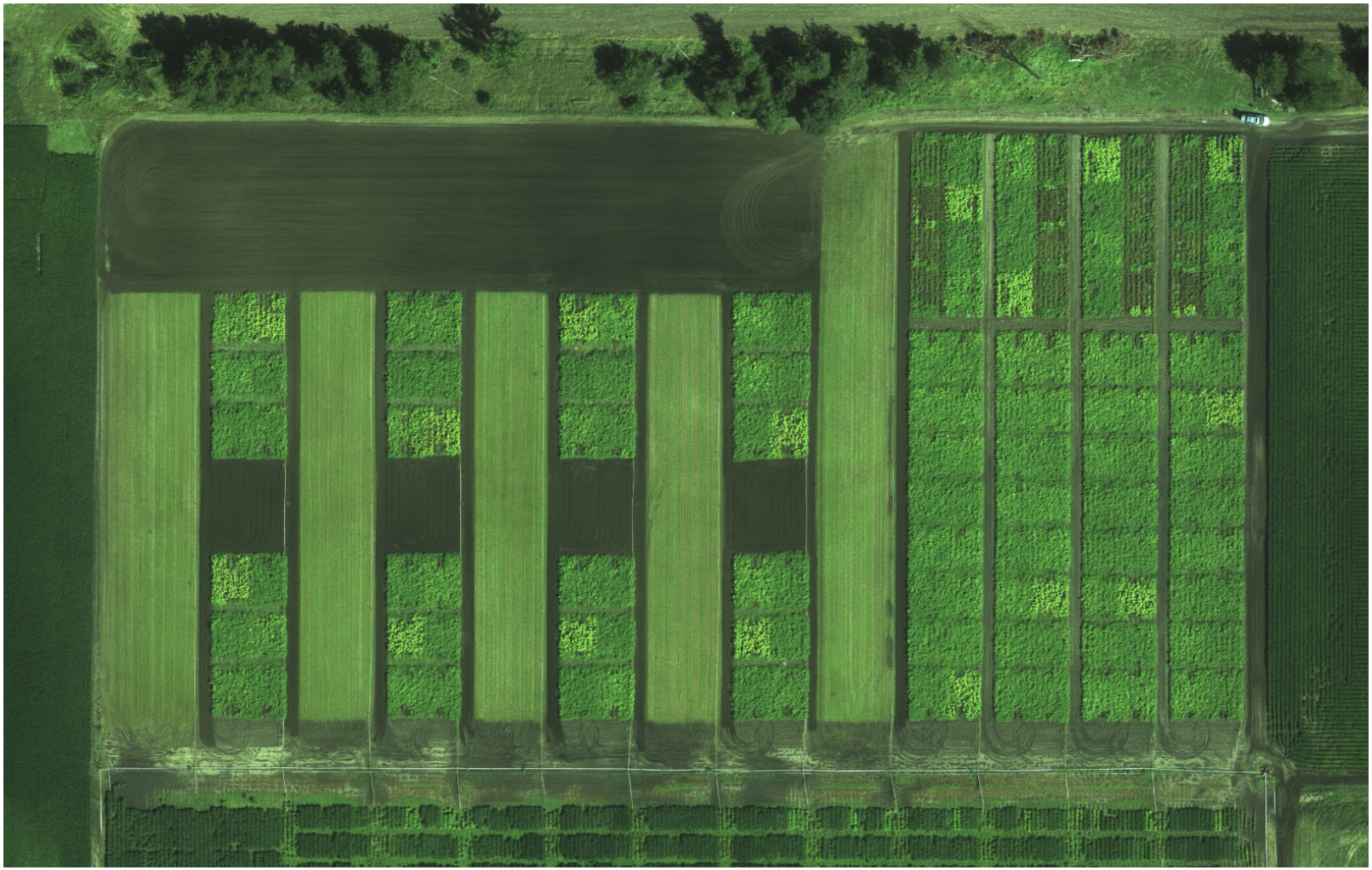
Min order is 100 km^2. 1 image at $\approx$ 30 cm GSD with $<$ 5% clouds is \$4,325. (That's only 17.5 cents/acre!)

Image and Signal Processing

Typical Image Processing And Analysis

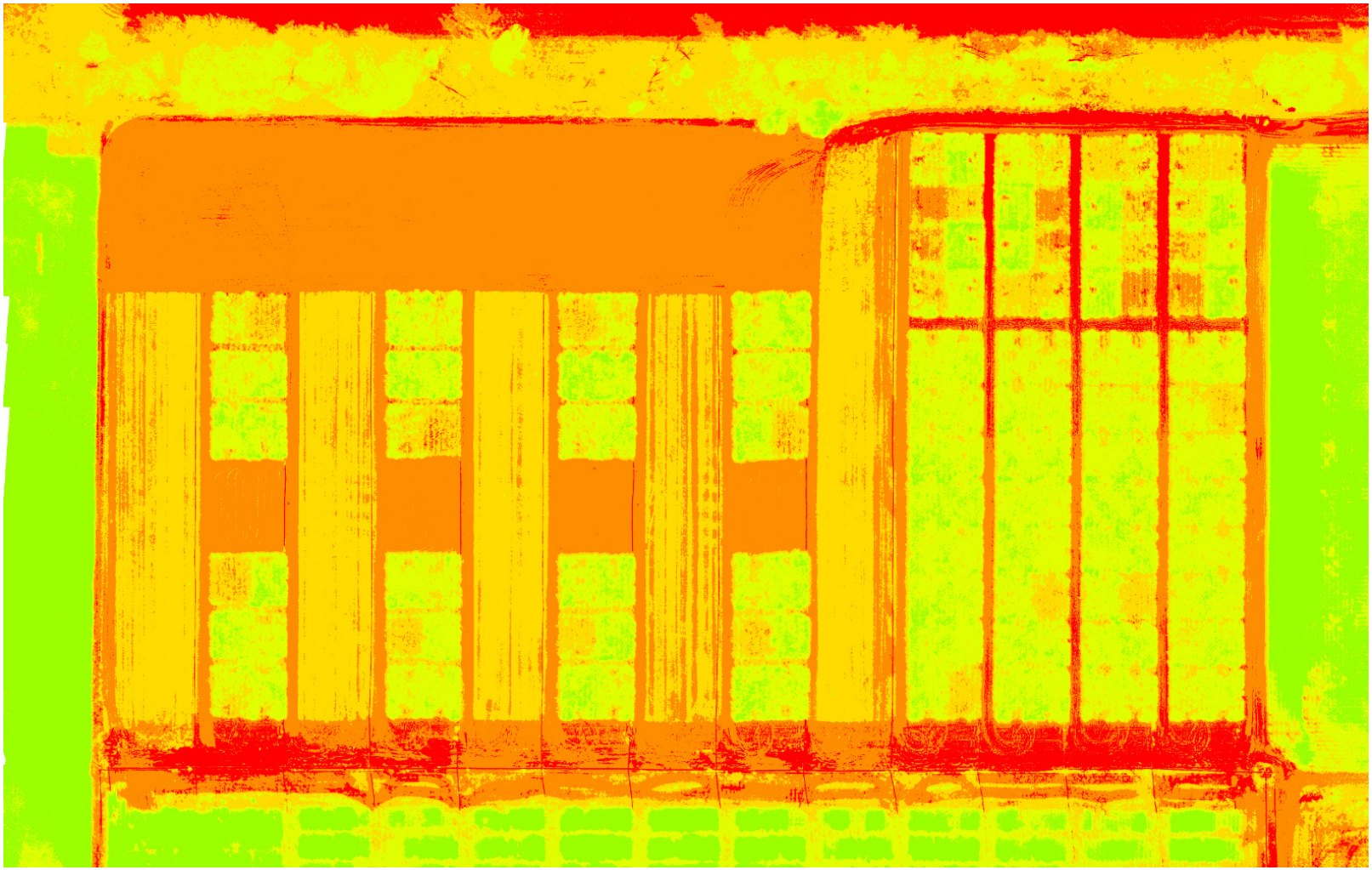
- Build 3D scene reconstruction from collected images
- Build calibrated multi-spectral orthomosaics from images and DEM
- Extract sub-images for each plot in trial
- Reduce to plot level averages of irradiance or reflectance
- Compute VI (e.g. Red NDVI) for each plot
- Fit regression model connecting VI to relevant agronomic parameter

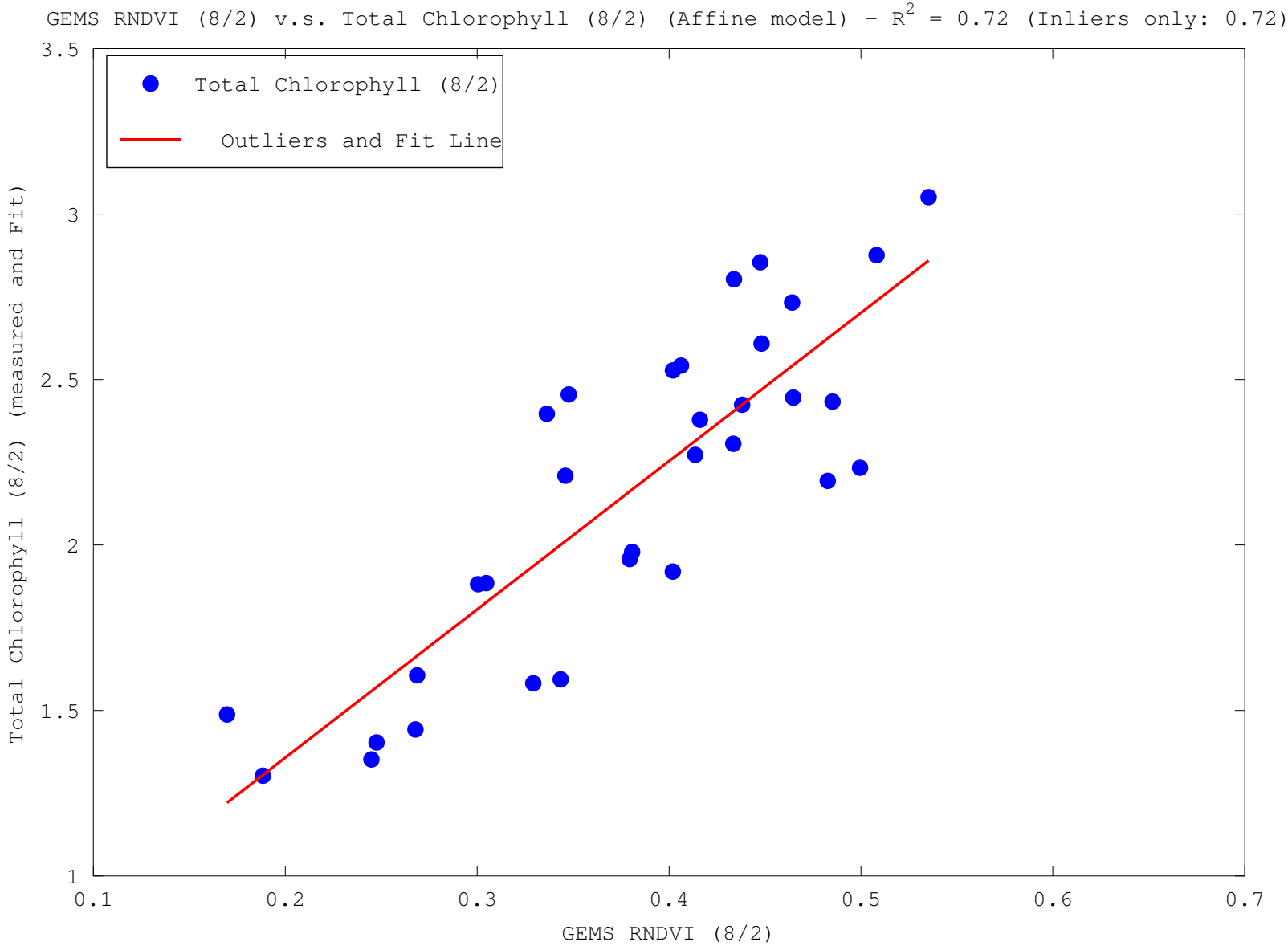
Sentek GEMS RGB Imagery



Sentek GEMS NIR Imagery

Sentek GEMS NDVI Imagery




GEMS RNDVI (8/2) v.s. Total Chlorophyll (8/2) (Affine model) - R^2 = 0.72 (Inliers only: 0.72)
Total Chlorophyll (8/2)
Outliers and Fit Line
Total Chlorophyll (8/2) (measured and Fit)
GEMS RNDVI (8/2)
3.5
3
2.5
2
1.5
1
0.1
0.2
0.3
0.4
0.5
0.6
0.7

Sensors and Image Processing

Different sensors and platforms are good for different traits

Rule of thumb: The smaller the features, the closer you must be to the plant.

- Phenotyping bots: image each leaf and build 3D models of each plant.
- Drones: plant/plot-scale sensing.
- Manned aircraft and high-res satellites: plot/field-scale sensing.
- Low-res satellites: field-scale sensing.

Questions

- What traits are most important to potato breeders?
- How are these traits measured today?
- What are the deficiencies of current measurement methods?
- Which traits are good candidates for remote sensing?
- What is the status of automated post-processing software for physical trait extraction from remote sensing imagery?
- What measurements can be meaningfully compared across phenotypes?

Discussion

Barriers to wide adoption of remote sensing for potato production + breeding

- Automated and validated algorithms and equations for extracting physical traits and agronomic quantities of interest from remote sensing measurements
- Quantitative proof of growers return on investment
- Ease of use
- Post-processing speed and reliability
- System reliability
- Scalability to large areas and large datasets
- System cost

Discussion

How can public sector extension contribute to overcoming these obstacles?

- Support field-scale remote sensing trials with growers
- Transition remote sensing methods and sensors for potato production and breeding from the lab to the field
- Inform growers of the latest research results from independent public sector research trials

Discussion

How can public sector research contribute to overcoming these obstacles?

- Develop and scientifically validate remote sensing technologies
- Develop algorithms and equations which extract agronomic quantities of interest from remote sensing measurements
- Quantify the accuracy and reliability with which agronomic quantities of interest can be measured with different remote sensing technologies
- Conduct controlled research trials with measured ground truth to validate remote sensing methods, sensors, and algorithms
- Publish and disseminate the results on how well different sensor technologies performed in independent public sector research trials