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Advanced Multispectral Sensor Requirements for Remote Sensing of Agriculture and Land Cover

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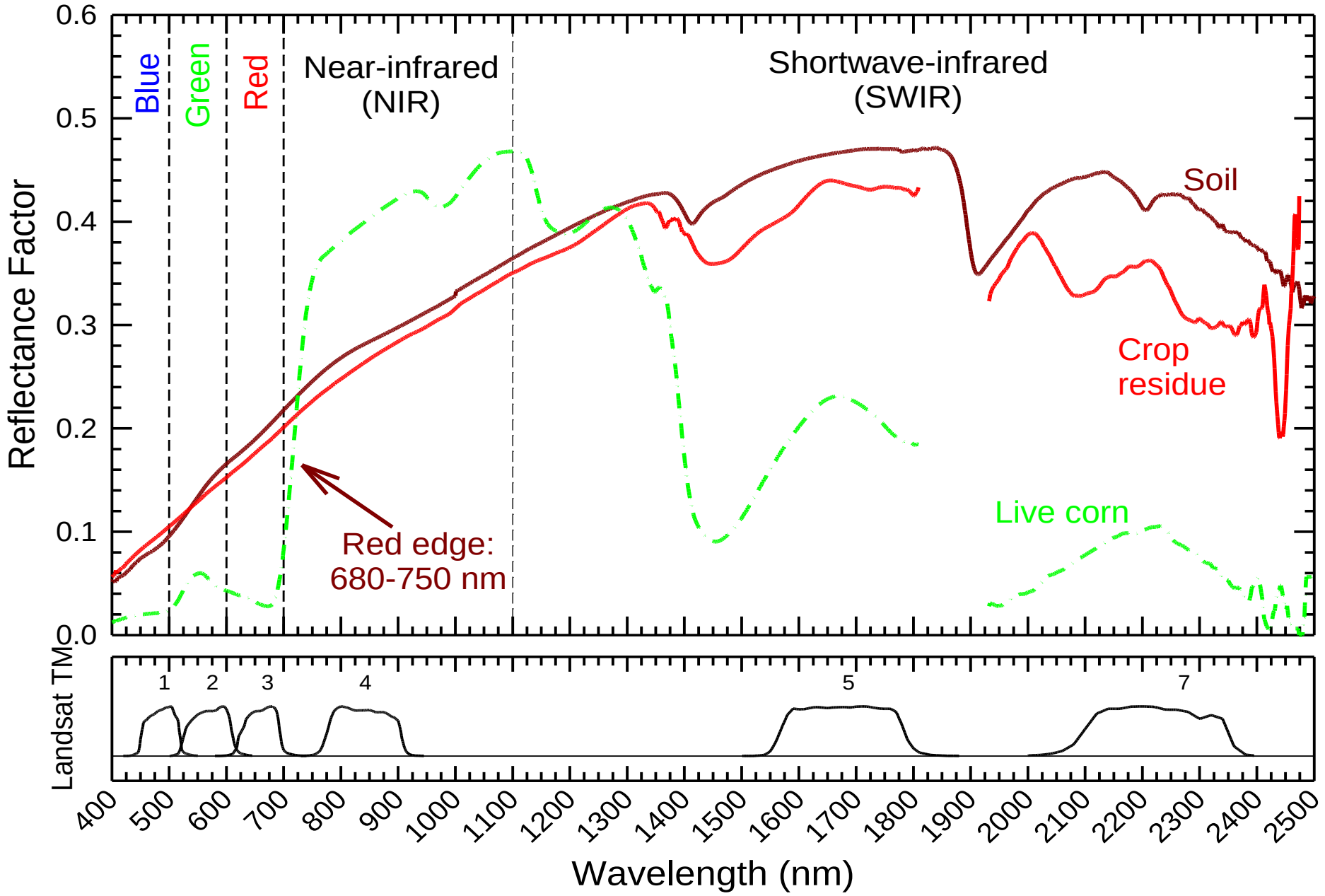
Introduction

- Agricultural remote sensing provides valuable crop intelligence to government and agribusiness.
- Remote sensing data are used for:
  - Global crop forecasting;
  - In-field crop stress mapping/ precision farming;
  - Verification of:
    - Crop insurance claims;
    - Conservation practices- cover crops/ tillage.

Advances in Remote Sensing

- Recent research utilizing advanced multi- and hyper-spectral sensing systems have developed measurement methods for a number of new parameters:
    - Chlorophyll (plant nitrogen stress);
    - Dry cellulose (crop residues/ plant litter/ non-photosynthetic vegetation);
    - Evapotranspiration.
- Time-series analyses of remote sensing have resulted in improved:
    - Land Cover – Land Use Classifications (LCLUC);
    - Agricultural production and yield forecasting.

Spectral bands: visible through SWIR



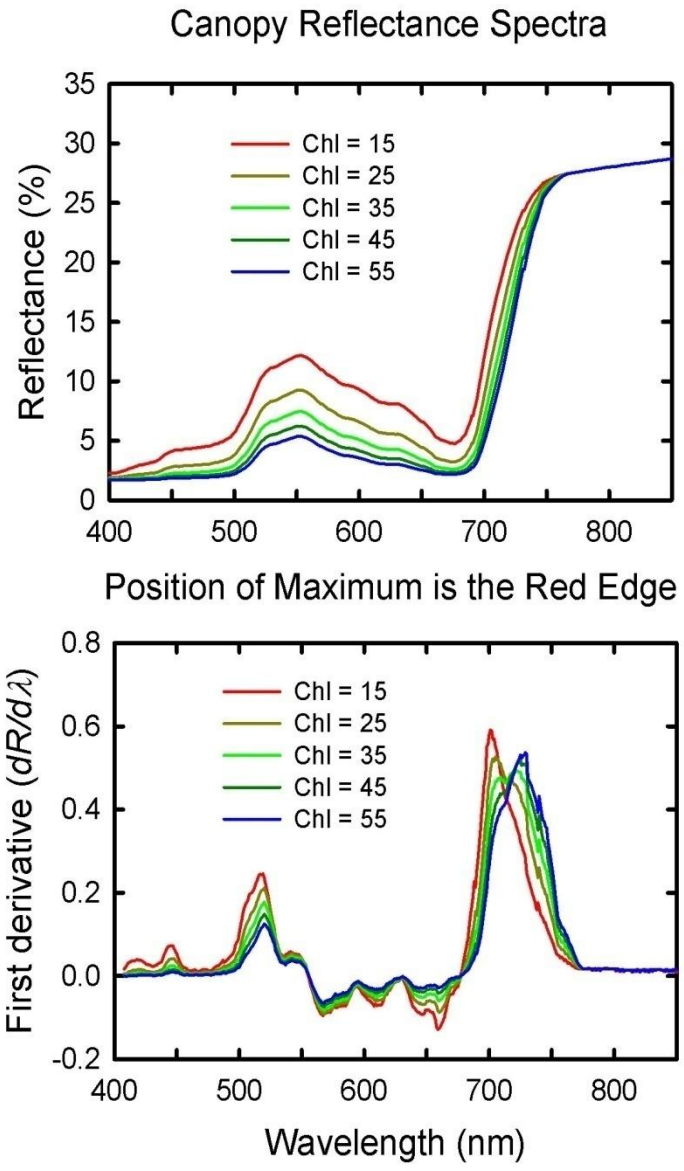
Medium-resolution sensors: Current and near future

- Current nadir-looking operational medium resolution sensors, e.g., Landsat 5 TM & 7 ETM+, Indian ResourceSat AWiFS, are optimized for detecting plant cover (red and NIR bands) or plant water (SWIR band at 1610 nm).
- The upcoming Landsat Data Continuity Mission (LDCM) includes additional bands for atmospheric correction and split thermal bands for evapotranspiration.
- ESA's upcoming Sentinel-2 mission includes additional bands for detecting the "Red Edge" for leaf chlorophyll concentrations and atmospheric correction.

Medium-resolution sensors: Current and near future

- LDCM has 16-day repeat cycle:
- Can limit monitoring capabilities due to cloud cover;
- Miss critical crop development stages or tillage operations.
- Sentinel-2 has a much better 5-day repeat cycle.
- AWiFS lacks SWIR bands beyond 2000 nm and atmospheric correction bands.
- None of these sensors are ideal for measuring crop residues/ non-photosynthetic vegetation.

Remote Sensing of Plant Cover and Chlorophyll



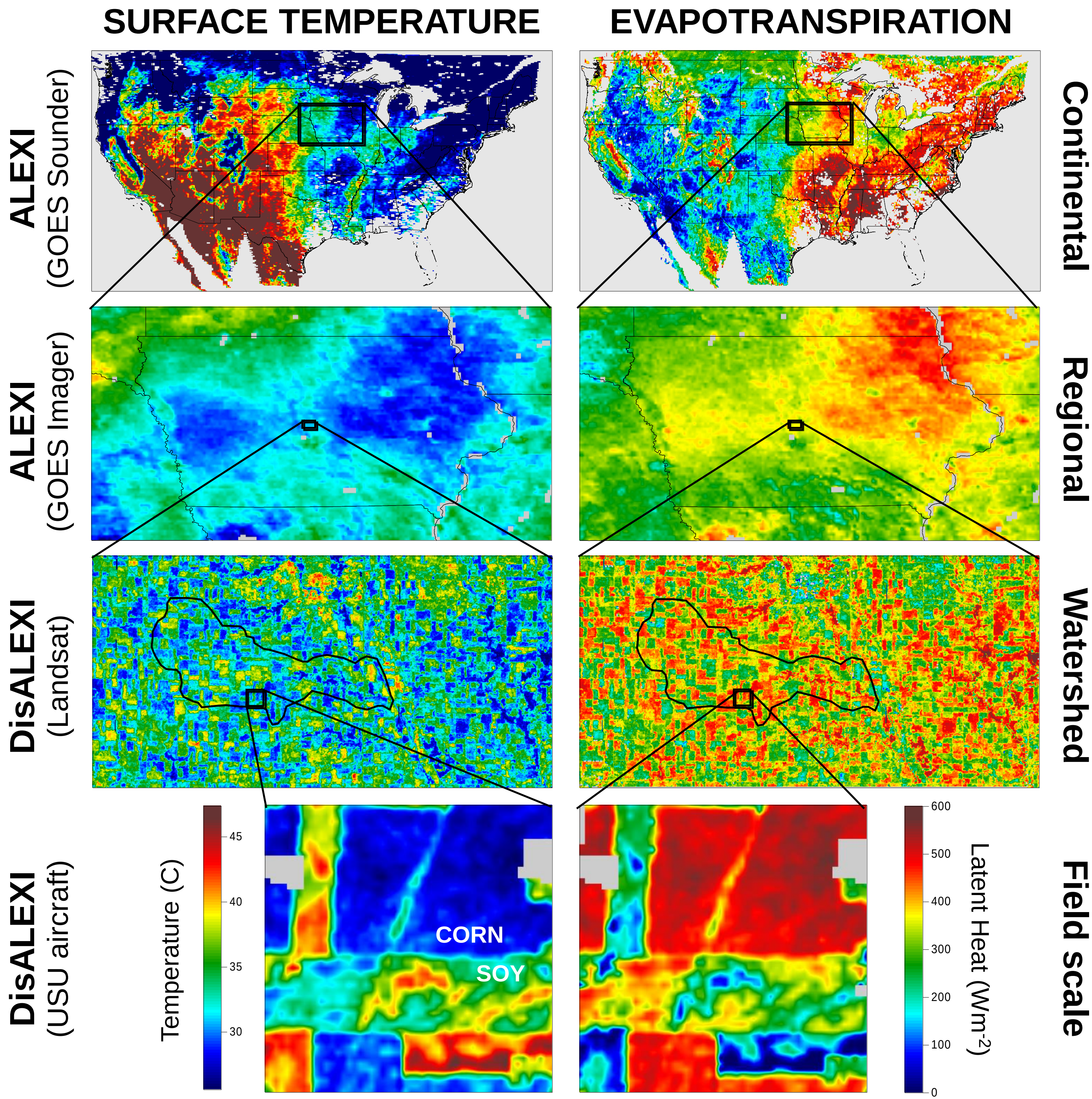
- Most plant cover/ condition remote sensing use Normalized Difference Vegetation Index (NDVI):

$$NDVI = \frac{NIR - R}{NIR + R}$$

- NDVI not overly sensitive to chlorophyll.
- Red edge indices are sensitive to chlorophyll/ leaf nitrogen.
- The position of the Red Edge can indicate nitrogen stress conditions.

Remote Sensing of Canopy Water and Evapotranspiration

- Soil moisture deficiencies cause leaf stomata to close up:
- Evapotranspiration and photosynthesis decrease;
- Vegetation heats up;
- Yields can be negatively impacted.
- NIR and SWIR band at 1610 – 1650 nm can be used to estimate canopy water content:
- SWIR band reflectance inversely related to leaf water content.
- LDCM's split thermal infrared (TIR) bands (10.8 and 12.0 μm) will allow for estimation of canopy evapotranspiration (ET).


SURFACE TEMPERATURE
EVAPOTRANSPIRATION
ALEXI
(GOES Sounder)
Continental
ALEXI
(GOES Imager)
Regional
DisALEXI
(Landsat)
Watershed
DisALEXI
(USU aircraft)
Field scale
Temperature (C)
45
40
35
30
CORN
SOY
Latent Heat (Wm-2)
600
500
400
300
200
100
0

What are crop residues?

- They are the plant parts left behind after a harvest.
- When left on the soil surface, they:
  - Protect the soil from wind and water erosion.
  - Reduce evaporation by acting as a mulch.

  - Their breakdown helps sequester carbon to the soil and recycle nutrients.
  - Improve soil structure and water retention.
- Can be removed for silage or cellulosic ethanol feedstock.

Tillage systems and residues

A. Intensively tilled field

B. Conservation tilled (No-tilled) field

- Intensive tillage removes residue, exposes soil to erosion.
- Conservation tillage (e.g., no-till) leaves residue on fields.
- Springtime tillage operations typically occur over a 2-3 week period.
- With conservation tillage, farmers save money on fuel, can sell carbon credits, and receive monetary benefits.

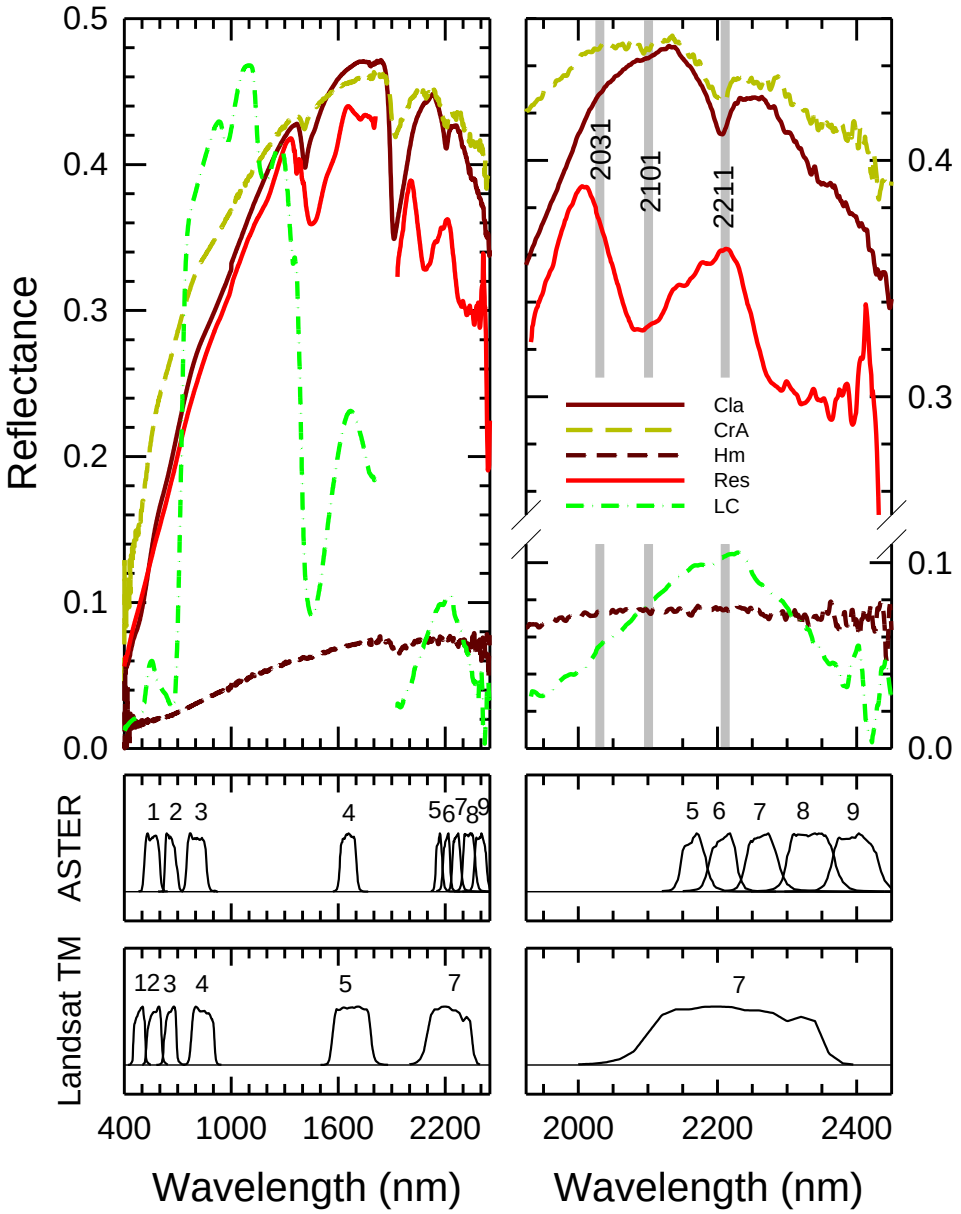
Where else is mapping non-photosynthetic vegetation important?

Prescribed rangeland burn, image courtesy Wyoming Wildlife and Natural Resource Trust

Simi Valley, CA, Oct. 14, 2008. (Associated Press)

- Dry vegetation is an important indicator of rangeland quality and soil health.
- Dry plant material easily catches fire:
  - Prescribed burning is an important management practice in Western US.
  - In Oct. 2007, California wildfires caused over $1 billion in damage.
  - Over 200 people killed in Australian wildfires in 2009.
  - Fires across Russia caused $15 billion in damage in 2010.

Remote sensing crop residue cover

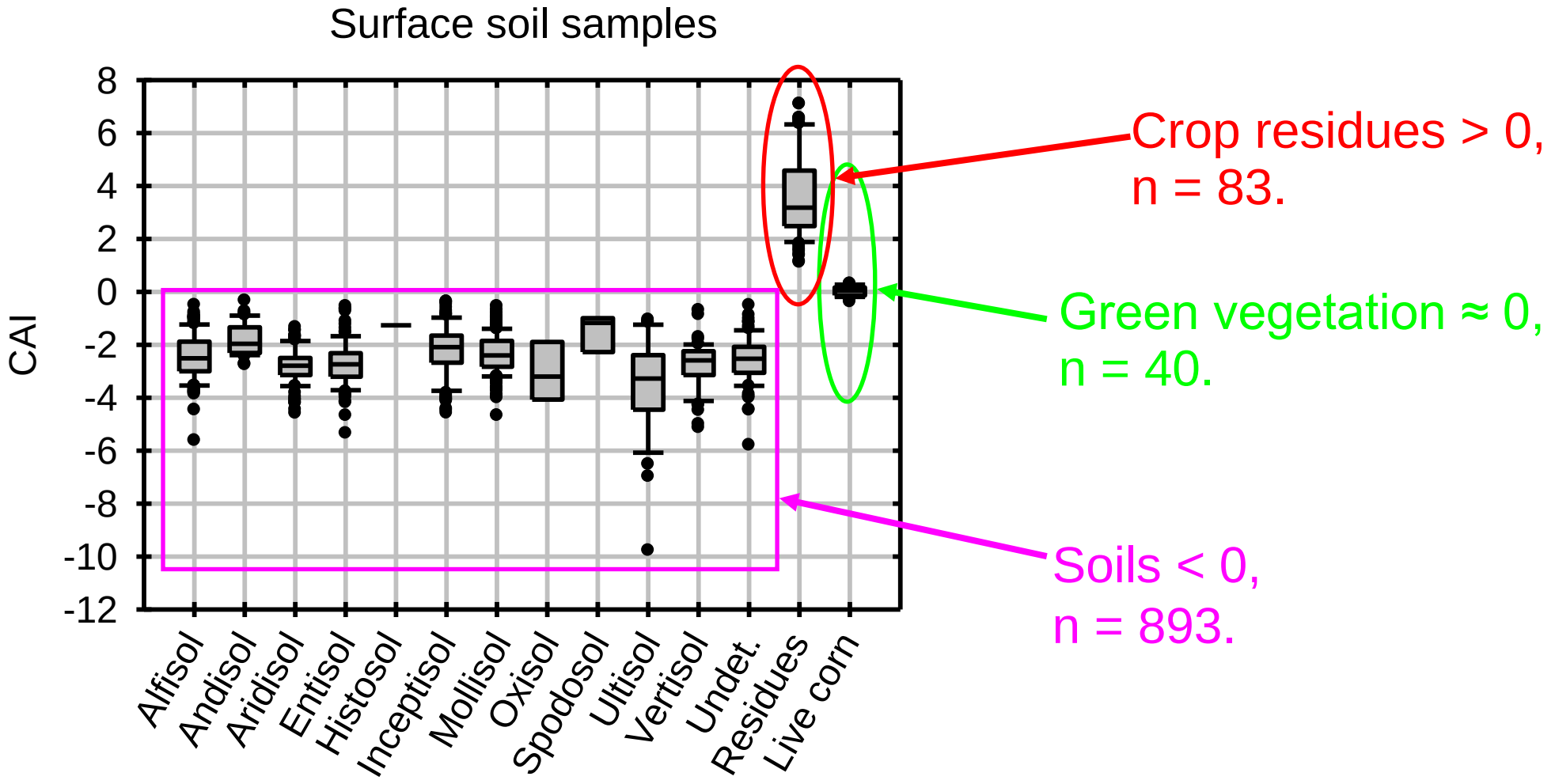


- Below 2000 nm, crop residues and soils can be spectrally similar.
- Broad Landsat TM bands cannot discriminate narrow spectral features of dry vegetation components.
- Cellulose Absorption Index (CAI) ideal for sensing dry vegetation:

$$CAI = 0.5(R_{2031} + R_{2211}) - R_{2101}$$

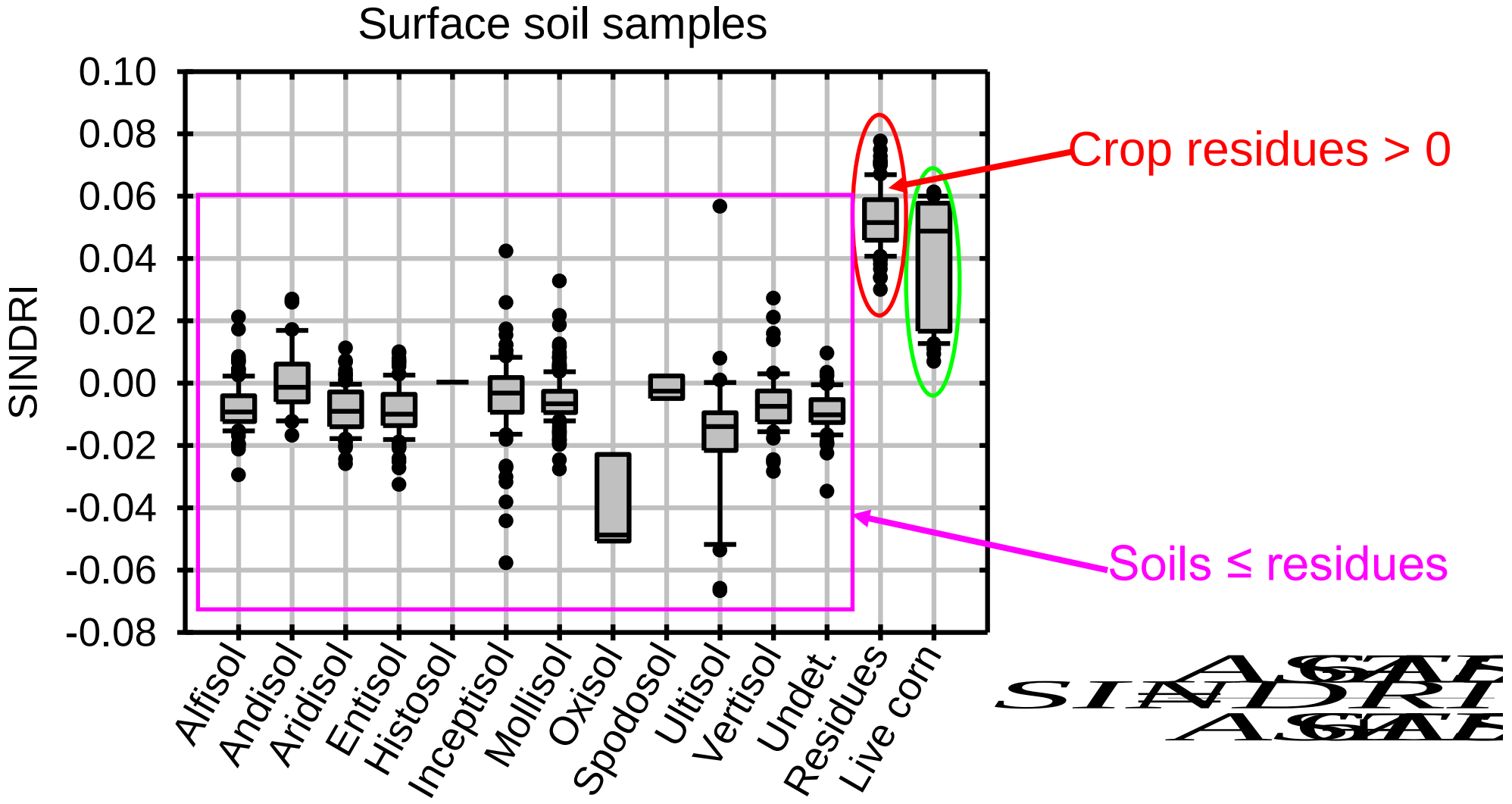
- CAI targets an absorption occurring at 2101 nm present for all sugars, including cellulose.
  - Most soil minerals do not have absorptions in this region.
- CAI has a linear relationship between bare soil, 100% residue cover.

Narrowband CAI best for sensing crop residues



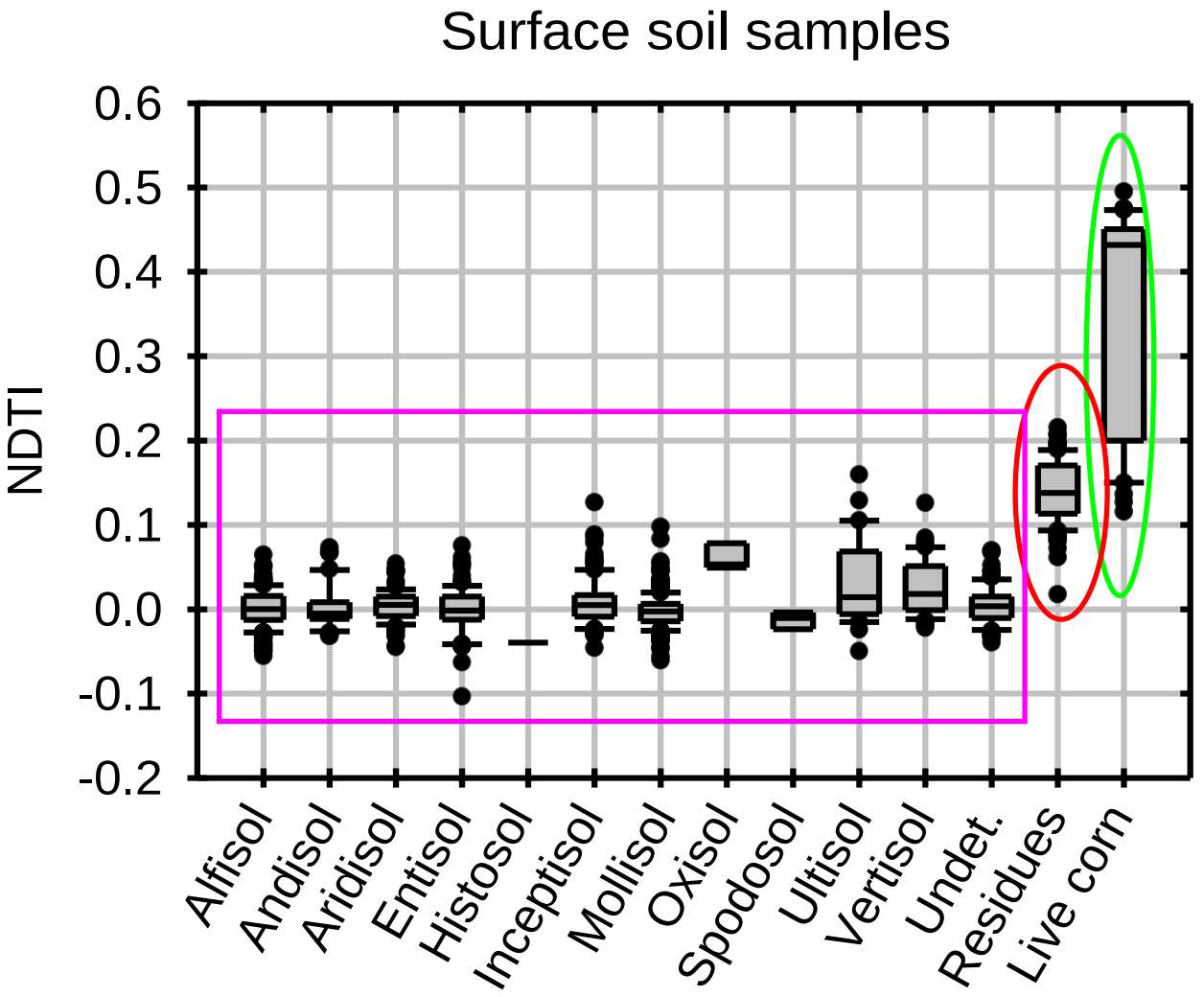
- Crop residues contrast well with all soils, green vegetation.

ASTER SWIR band indices also good



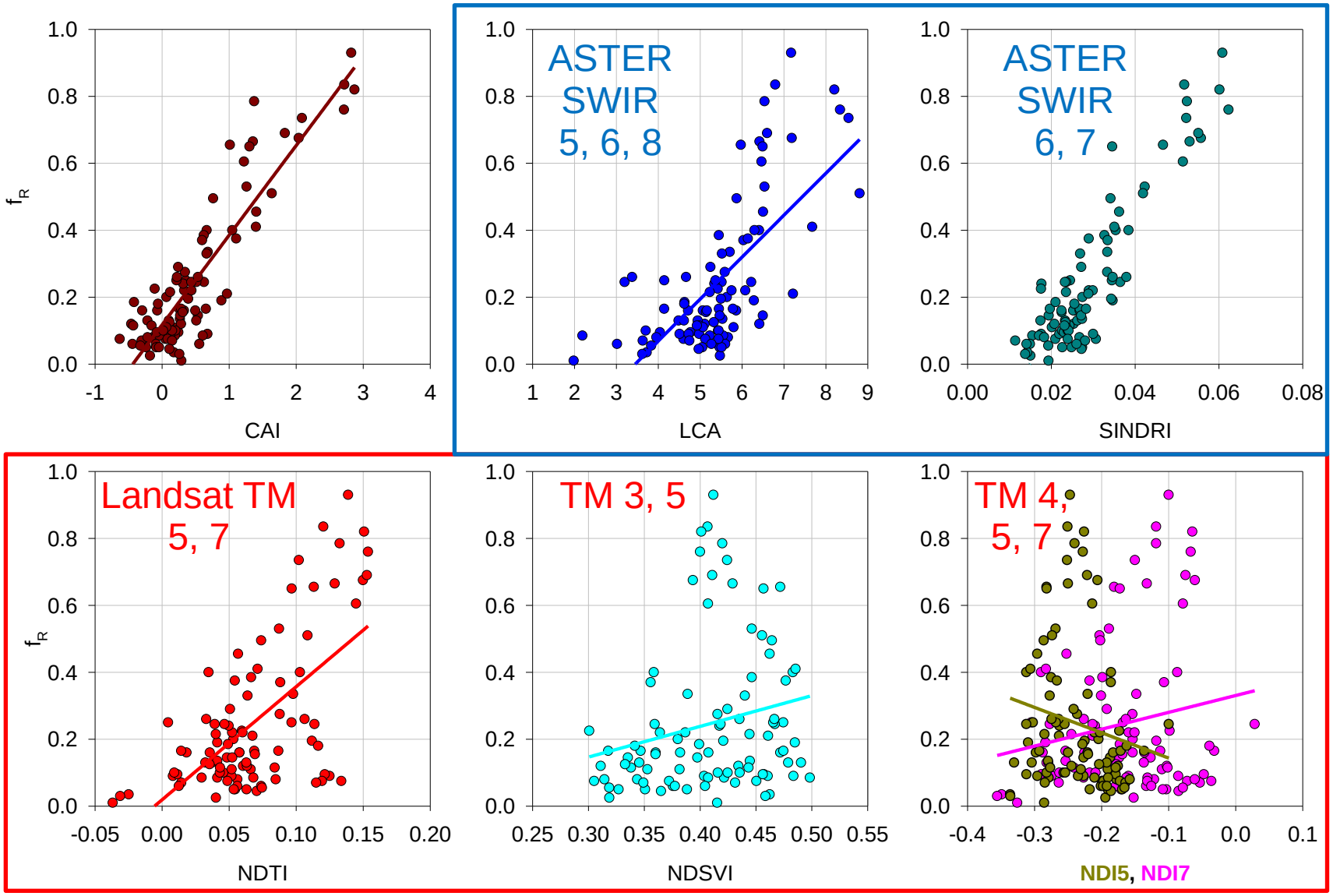
- 9 soils have SINDRI > 0.02, lacking contrast.
- Residues and green vegetation also lack contrast.

Landsat TM bands not so good



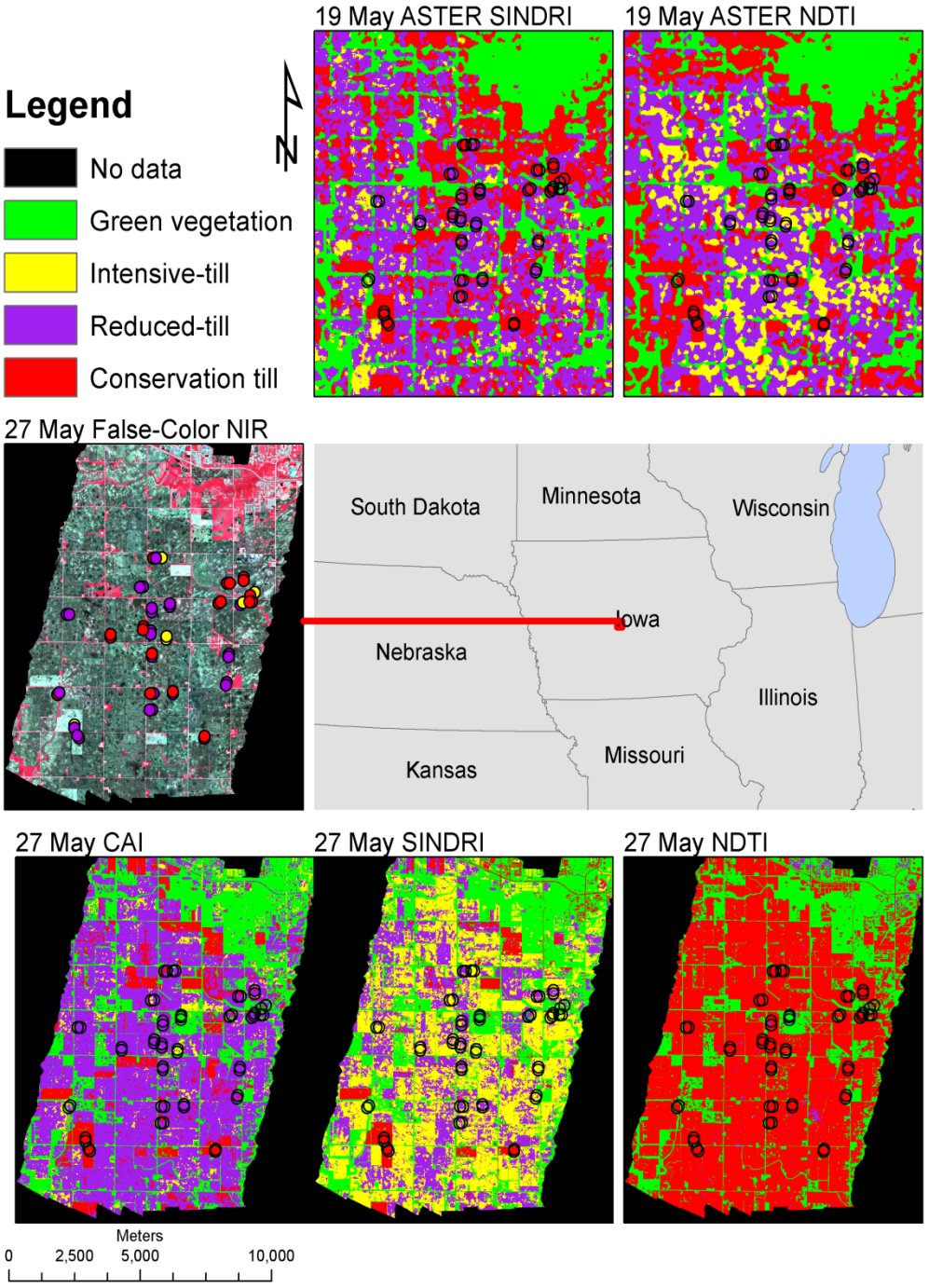
- Many soils, residues lack contrast.
- Green vegetation has a much stronger signal than residues or soils- will strongly bias mixed pixels.

Remote sensing crop residue: Indiana 2006



- ASTER SWIR-based indices work well, but are more affected by soils than CAI.
- Landsat TM- based indices do not separate well between residues, soils.

Remote sensing crop residue: Ames, IA, 2007



Tillage classes (% residue cover):

- Intensive: 0 – 15
- Reduced: 15 – 30
- Conservation: 30 – 100

Figure to left contains:

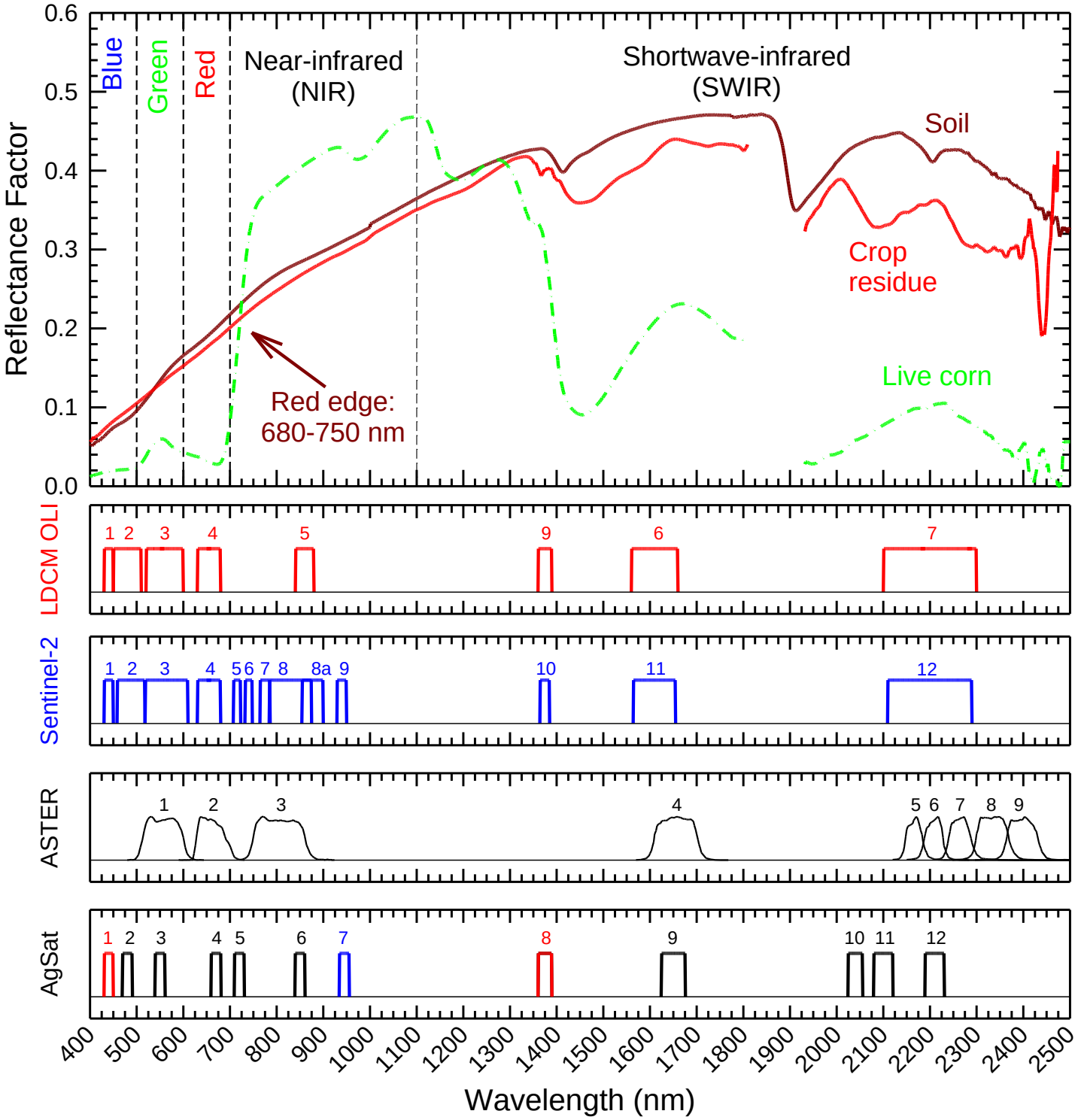
- Multispectral ASTER imagery, 27 May 2007.
- Hyperspectral imagery acquired by SpecTIR LLC (Sparks, NV):
  - Convolved to equivalent ASTER and Landsat TM bands.
- Circles denote ground-truth locations.

So what are the requirements for an agricultural satellite (AgSat)?

- Temporal resolution requirements: < 7 days, 5 day or better ideal to capture critical crop development stages, tillage operations.
- Pixel size: 60 m maximal in visible through SWIR (VSWIR), 100 m TIR;
  - Ideal: 20 m VSWIR, 60 m TIR.
- Nadir looking.
  - Swath width constrained to a maximum 20° off-nadir view angle:
    - Minimizes BRDF problems, obscurement of soil by canopy, residue;
    - Ensures radiometric accuracy in TIR.

So what are the requirements for an agricultural satellite (AgSat)?

- Quantization = 12 bits.
- Signal-to-Noise Ratio (SNR) requirements: >250.
- Narrower ASTER-type bands in SWIR to discriminate cellulose absorption:
- Tillage monitoring;
- Agricultural greenhouse gas and soil erosion/ water quality monitoring/ modeling;
- Rangeland health/ soil quality monitoring;
- Grassland fire hazard mapping and monitoring.
- 72-hour max turnaround time from acquisition to end user.


Reflectance Factor
0.0
0.1
0.2
0.3
0.4
0.5
0.6
Blue
Green
Red
Near-infrared
(NIR)
Shortwave-infrared
(SWIR)
Soil
Crop
residue
Live corn
Red edge:
680-750 nm
LDCM OLI
1 2 3 4 5 9 6 7
Sentinel-2
1 2 3 4 5 6 7 8 8a 9 10 11 12
ASTER
1 2 3 4 5 6 7 8 9
AgSat
1 2 3 4 5 6 7 8 9 10 11 12
400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000 2100 2200 2300 2400 2500
Wavelength (nm)

Band number	Band center and bandpass (nm)	Region	Parameter	Heritage
1	443 (433–453)	Blue	Coastal/Aerosols	LDCM
2	480 (470–490)	Blue	Aerosols	Landsat TM
3	550 (540–560)	Green	Chlorophyll	Landsat TM
4	670 (660–680)	Red	Vegetation cover	Landsat TM
5	720 (710–730)	Red edge	Chlorophyll	RapidEye, Worldview-2
6	850 (840–860)	NIR	Vegetation cover	Landsat TM
7	940 (950–960)	NIR	Water vapor	Sentinel-2
8	1375 (1360–1390)	SWIR	Cirrus clouds	LDCM
9	1650 (1625–1675)	SWIR	Vegetation water content	Landsat TM
10	2040 (2025–2055)	SWIR	Cellulose	New band
11	2100 (2080–2120)	SWIR	Cellulose	New band

Disclaimer

This concept is based on discussions about satellite data requirements for agricultural monitoring and does not represent official USDA or ARS policy.