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

Guy Serbin[1], E. Raymond Hunt Jr.[2], Craig S.T. Daughtry[2], and Martha C. Anderson[2]

[1] ASRC Research and Technology Solutions, Greenbelt, MD; [2] USDA/ARS Hydrology and Remote Sensing Lab, Beltsville, MD

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/ precision farming;
  - Verification of:
    - Crop insurance claims;
    - Conservation practices- cover crops/ tillage.
- 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 data have resulted in improved:
  - Land Cover – Land Use Classifications (LCLUC);
  - Agricultural production and yield forecasting.

Spectral bands: visible through SWIR

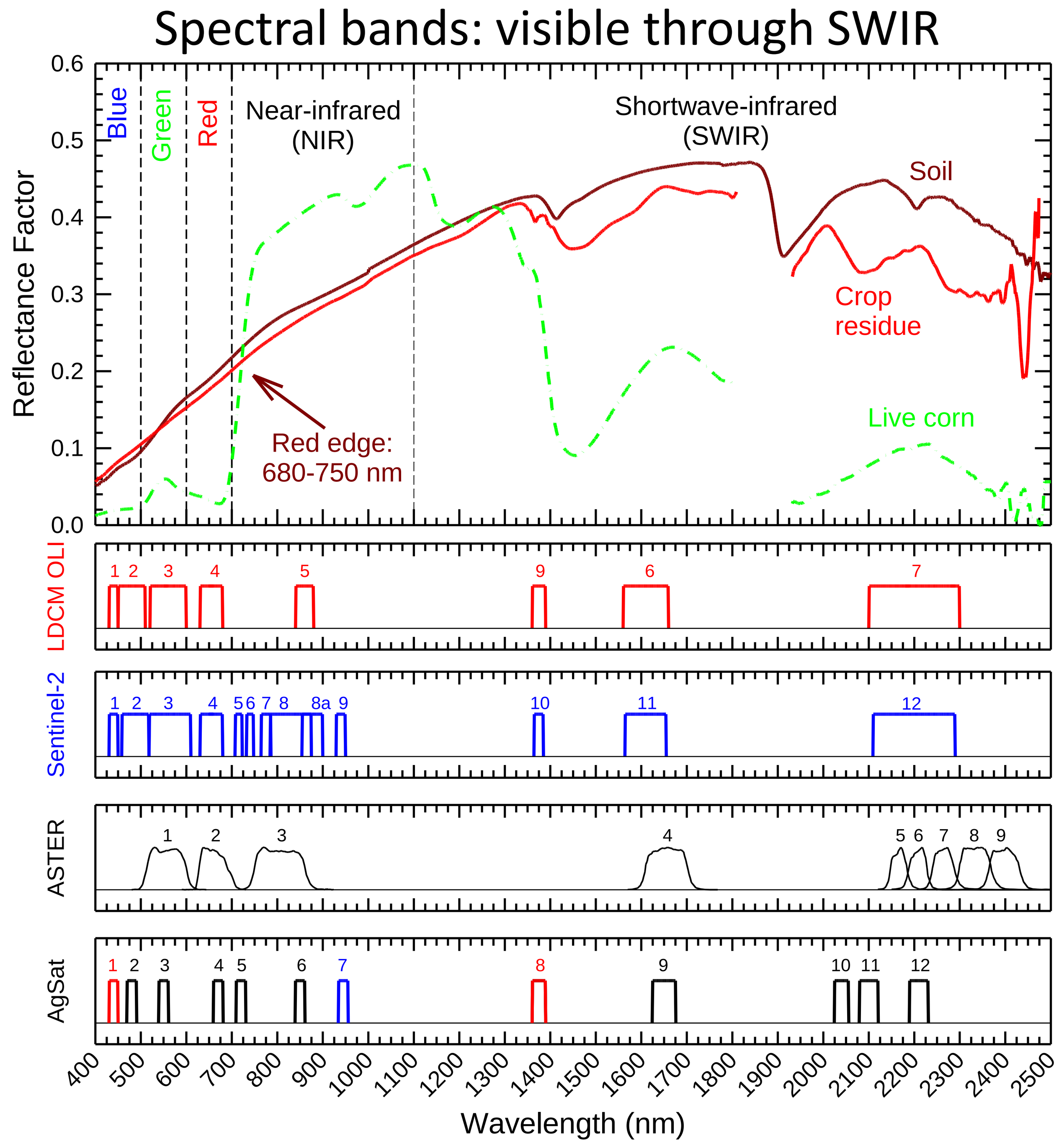

Figure 1. Spectra of soil, crop residue and green vegetation, proposed bandwidths for the Landsat Data Continuity Mission (LDCM)'s Operational Land Imager (OLI, Sentinel-2, and an ideal agricultural satellite mission (AgSat), and the spectral response functions for the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) sensor.

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.
- LDCM has 16-day repeat cycle, which can limit monitoring capabilities due to cloud cover and miss critical crop development stages.
- Sentinel-2 has a much better 5-day repeat cycle.
- AWiFS lacks SWIR bands beyond 2000 nm and atmospheric correction bands.

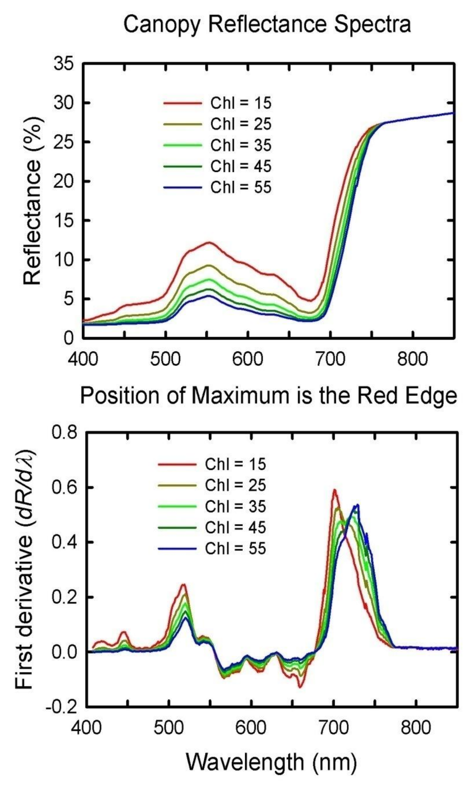

Figure 2. Chlorophyll content and the Red Edge.

Remote sensing live vegetation cover and health

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

[illegible]

- NDVI not overly sensitive to chlorophyll.
- Red Edge indices are sensitive and can better indicate nitrogen stress conditions.
- NIR and SWIR band at 1610 – 1650 nm can be used to estimate canopy water content.

- LDCM's split thermal infrared (TIR) bands (10.8 and 12.0 μm) will allow for estimation of canopy evapotranspiration (ET).

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

Remote sensing crop residues/ non-photosynthetic vegetation: Why is this important?

- Like live vegetation, non-photosynthetic vegetation/ crop residues on the soil surface:
  - 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.
- Crop residues can be removed for silage or cellulosic ethanol feedstock.

Figure 3A. Intensively tilled field.

B. No-tilled field.

- Intensive tillage removes residue, exposes soil to erosion.
- Conservation tillage (e.g., no-till) leaves residue on fields.
- With conservation tillage, farmers save money on fuel, can sell carbon credits, and receive monetary benefits.
- Tillage information is an essential input for water quality and agricultural greenhouse gas models.

Figure 4. Prescribed rangeland burn, image courtesy Wyoming Wildlife and Natural Resource Trust .

- Dry vegetation should be monitored as an important indicator of rangeland quality and soil health.
- Fire hazard mapping and management:
  - 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.

Figure 5. Simi Valley, CA, Oct. 14, 2008. (Associated Press).

Remote sensing crop residues: Why we need narrow SWIR bands

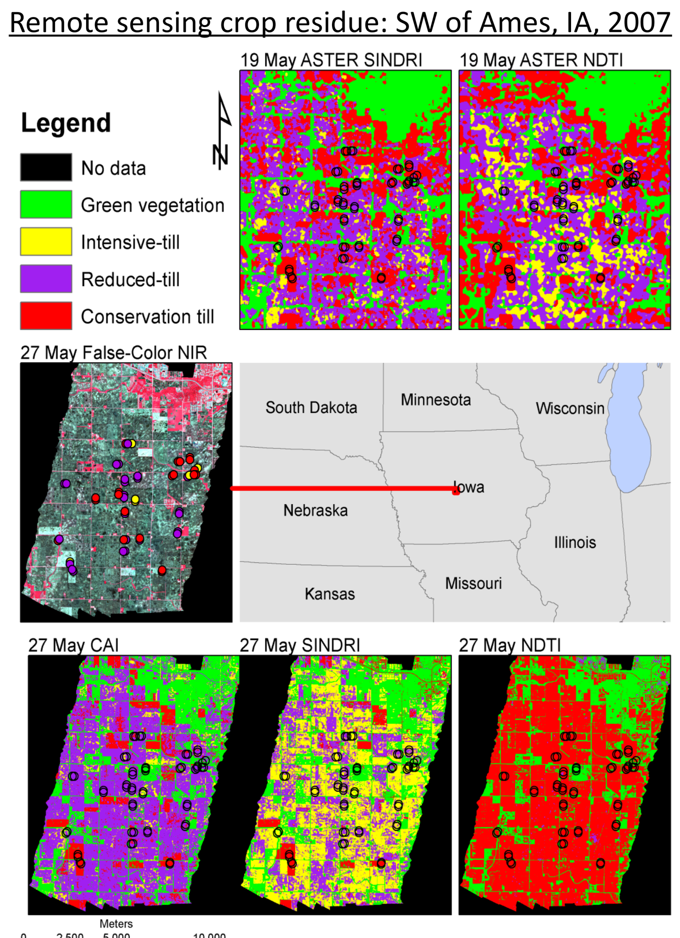

Figure 6. 19 May: Multispectral ASTER imagery; 27 May: Hyperspectral imagery acquired by SpecTIR LLC (Sparks, NV), convolved to equivalent ASTER and Landsat TM bands. Circles denote ground-truth locations. Color-coded circles in the 27 May 2007 false-color NIR image denote ground truth tillage classes. Analysis from Serbin et al. (2009a).

- Broad Landsat TM bands cannot discriminate narrow spectral features of dry vegetation components.
- Landsat TM band 7 is also very sensitive to live vegetation.
- Thus, Landsat TM- based indices do not contrast well among crop residues, soils, and live vegetation.
- Landsat Data Continuity Mission (LDCM) and Sentinel-2 band 12 will have similar issues to Landsat TM band 7.
- Cellulose Absorption Index (CAI) ideal for sensing dry vegetation:

[illegible]

- CAI targets an absorption occurring at 2101 nm present for all sugars, including cellulose.
  - Most soil minerals do not share absorptions in this region.
- CAI has a linear relationship between bare soil, 100% residue cover.
- CAI contrasts crop residues well among soils, live vegetation.
- ASTER SWIR-based indices, e.g., the Shortwave Infrared Normalized Difference Residue Index (SINDRI) work well, but are more affected by live vegetation, soils than CAI.
- The Normalized Difference Tillage Index (NDTI) outperforms other Landsat TM-based indices, but is very sensitive to live vegetation and lacks contrast with many soils.

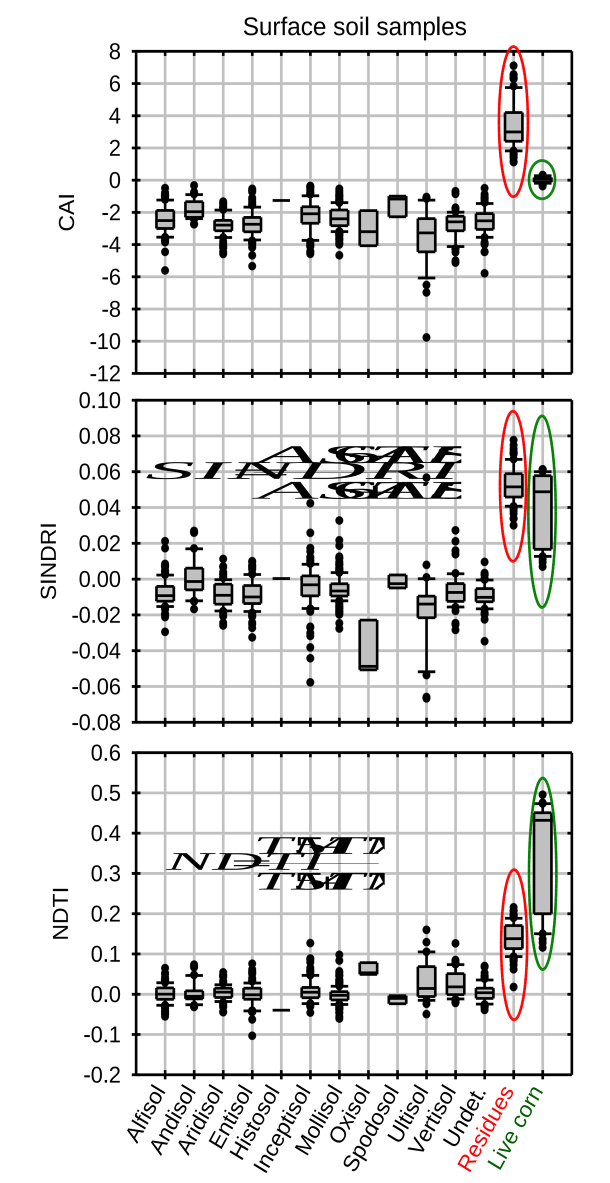

Figure 7. Figures from Serbin et al. (2009b, 2010). Data consist of 893 lab-acquired spectra of soil surface horizon samples from Brown et al. (2006), 40 field-acquired spectra of live corn canopy, and 83 lab-acquired crop residue spectra (corn, soybean, and wheat) from Serbin et al. (2009b).

Why not use a pointable sensor?

- Pointable sensors, e.g., SPOT XS, Quickbird, etc. allow for frequent images of a specific location.
- However, they must be tasked to look at a specific location.
  - "Higher priority" sites imaged more often;
  - However, this is very useful in emergency situations requiring frequent collects.
- But, they cannot provide "wall-to-wall" coverage for monitoring purposes, unlike "always on" nadir-looking sensors like Landsat TM, AWiFS.
- Also, large off-nadir view angles can cause problems due to BDRF, obscurement of soil by vegetation and residues.

What would an ideal agricultural satellite look like?

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
12	2210 (2190–2230)	SWIR	Cellulose	New band
13	10.8 (10.3-11.3) μm	TIR	ET, Vegetation stress	LDCM
14	12.0 (11.5-12.5) μm	TIR	ET, Vegetation stress	LDCM

- Temporal resolution requirements: < 7 days, 5 day or better ideal.
- Pixel size: 60 m maximal in visible through SWIR (VSWIR), 100 m TIR;
  - 20 m ideal VSWIR, 60 m TIR.
- Nadir looking.
  - Swath width constrained to a maximum 20° off-nadir view angle:
    - Minimizes BRDF problems;
    - Minimizes obscurement of soil by canopy, residue;
    - Ensures radiometric accuracy in TIR.
- Quantization = 12 bits.
- Signal-to-Noise Ratio (SNR) requirements: >250.
- Narrower ASTER-type bands in SWIR to discriminate cellulose absorption.

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