I 2 R Innovative Imaging & Research

Landsat Data Continuity Mission and Sentinel-2 Multi-Spectral Instrument Image Product Simulations for Sensor Comparisons and Data Fusion Research

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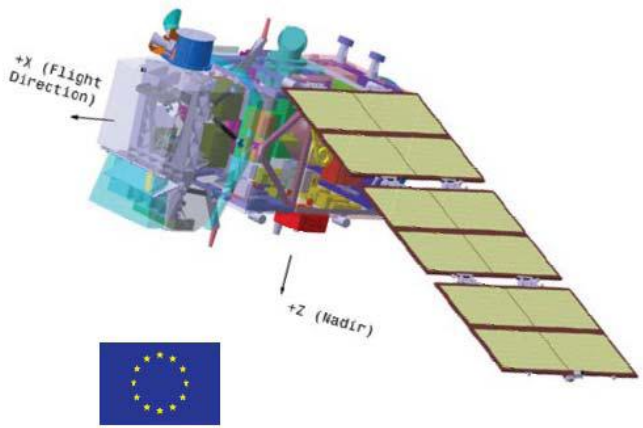
It's a Growing World Out There…

- There are now more than 50 Earth observing satellites acquiring imagery with spatial resolutions comparable or better than Landsat
- Access to data is greatly improving
  - Free digital downloads are becoming more common
- As the quality of these data sets improve, the greater the likelihood that they will be incorporated into the scientific community
  - Provide increased temporal frequency
  - Fill Landsat gaps
- However to use these data sets effectively it is necessary to understand their differences

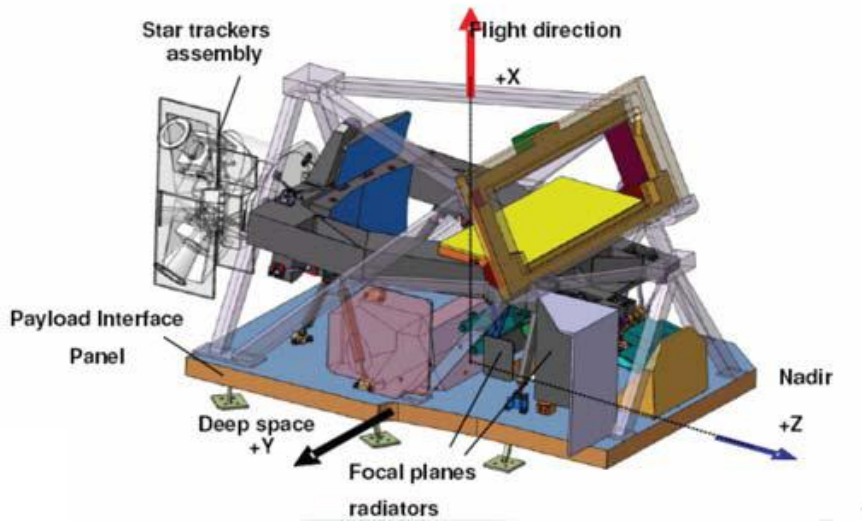
Sentinel-2

- Optical High Resolution Imagery Mission for GMES (Global Monitoring for Environment and Security) – the European Earth Observation Program
  - Global Monitoring of land/coastal between −56° and +83° latitude
- Co-developed by the European Space Agency (ESA) and the European Commission (EC)
- Two spacecraft operating 180° apart in same sun synchronous orbit to yield a 5 day revisit at equator
- Emergency lateral pointing mode: access any point on Earth within 1 to 2 days
- Data availability similar to Landsat being considered
- Proposed launch November 2013



Sentinel-2 MSI

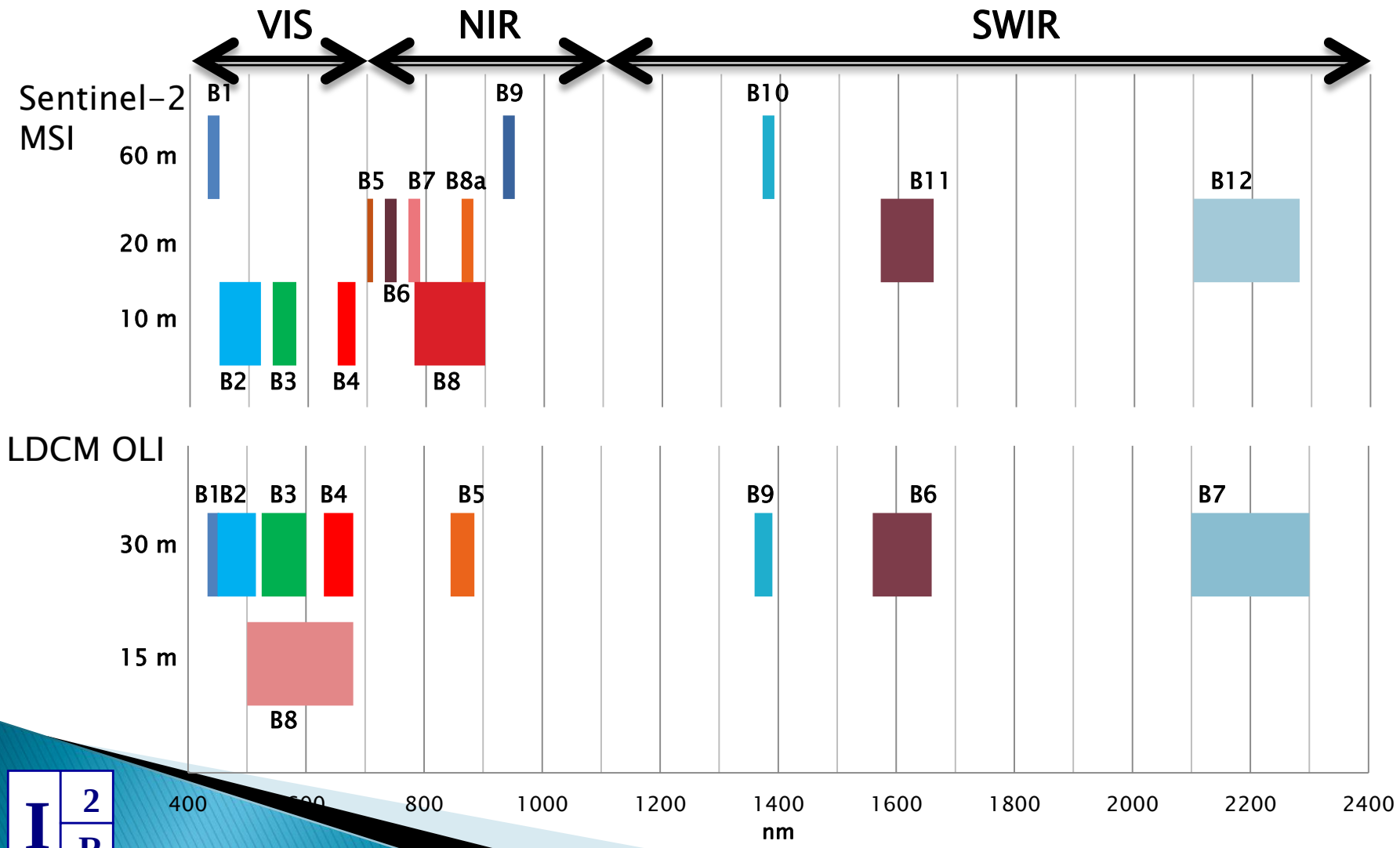
- MultiSpectral Instrument (MSI)
  - Pushbroom architecture
  - 13 spectral bands (VNIR-SWIR)
  - 10m-20m-60m GSDs to identify spatial details consistent with 1 ha Minimum Mapping Unit
  - 290 km swath
- Geo-location accuracy within 20 m without use of GCP's
- Radiometric accuracy within 5%
  - Utilizing onboard absolute and on ground vicarious calibration



Sensor Specification Comparison

Parameter	Landsat ETM+		LDCM OLI		Sentinel-2 MSI	
	Band	µm	Band	µm	Band	µm
Spectral Bands			1 (Blue)	0.43-0.45	B1 (Blue)	0.43-0.45
	1 (Blue)	0.45–0.52	2 (Blue)	0.45–0.52	B2 (Blue)	0.46-0.52
	2 (Green)	0.52–0.60	3 (Green)	0.52–0.60	B3 (Green)	0.54-0.58
	3 (Red)	0.63–0.69	4 (Red)	0.63–0.68	B4 (Red)	0.65-0.68
					B5 (Red Edge)	0.70-0.71
					B6 (Red Edge)	0.73-0.75
					B7 (Red Edge)	0.77-0.79
	4 (NIR)	0.76–0.90			B8 (NIR)	0.78-0.90
			5 (NIR)	0.84-0.88	B8a (NIR)	0.86-0.88
					B9 (Water Vapor)	0.93-0.95
			9 (Cirrus)	1.36-1.39	B10 (Cirrus)	1.37-1.39
	5 (SWIR1)	1.55–1.75	6 (SWIR1)	1.56-1.66	B11 (SWIR1)	1.57-1.66
	7 (SWIR2)	2.08–2.35	7 (SWIR2)	2.10-2.30	B12 (SWIR2)	2.10-2.28
	6 (TIR)	10.4–12.5	10 (TIR1)	10.3-11.3		
			11 (TIR2)	11.5-12.5		
GSD at Nadir	30 m VNIR, 15 m Pan, 60 m TIR		30 m VNIR, 15 m Pan, 100 m TIR		10 m (B2, B3, B4, B8) 20 m (B5, B6, B7, B8a, B11, B12) 60 m (B1,B9,B10)	
Quantization	8 bits		12 bits		12 bits	
Onboard Cal	Yes		Yes		Yes	
Revisit Time	16 days		16 days		5 days (two satellites)	
Off-Axis Viewing	Up to 7.5 deg off Nadir		Up to 7.5 deg off Nadir		Up to 10.3 deg off Nadir (w/o pointing)	
Altitude	705 km		705 km		786 km	
Swath	185 km		185 km		290 km	
Architecture	Cross-track scanner		Pushbroom		Pushbroom	

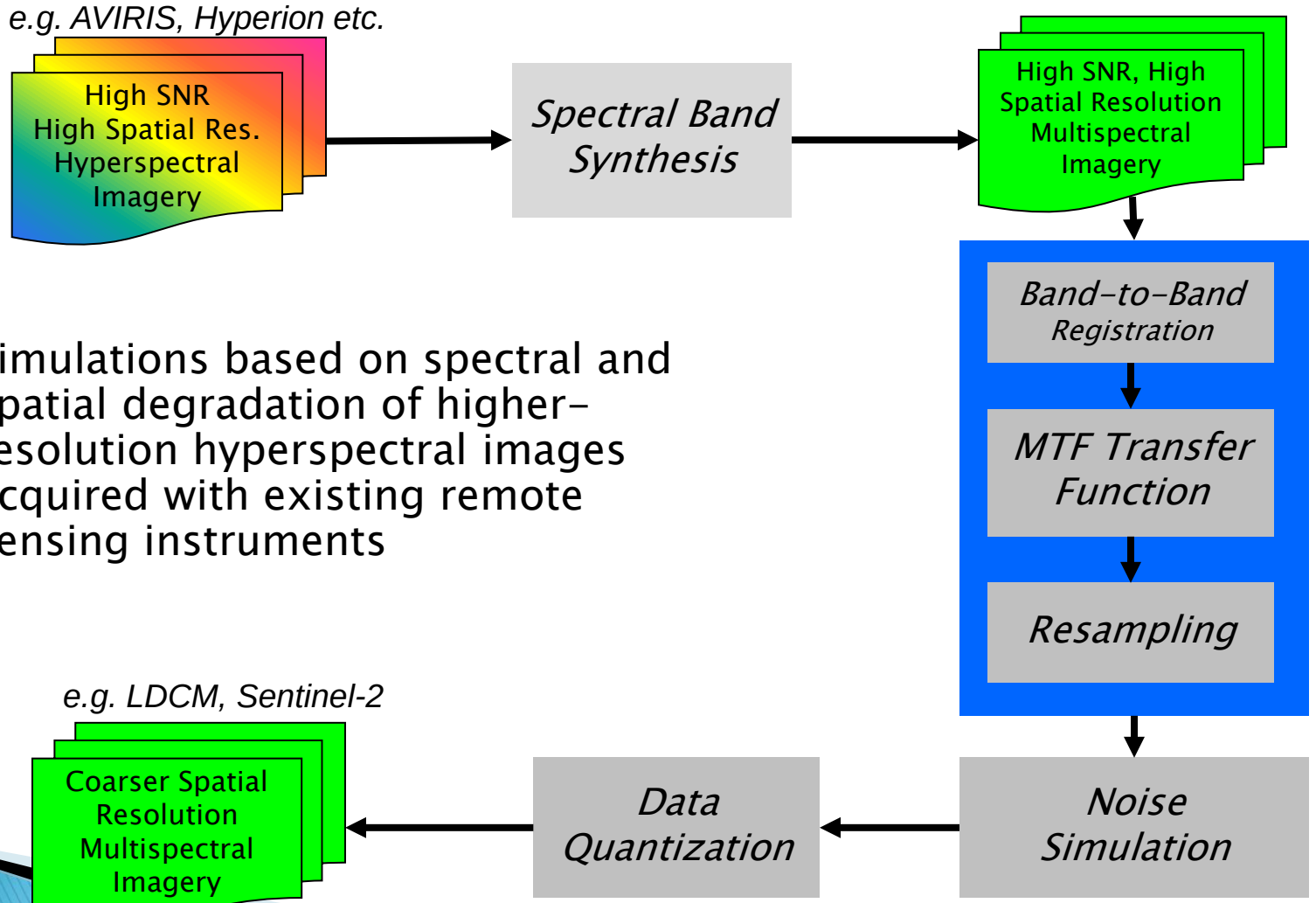
Sensor Spectral Band Comparison



Sensor Footprint Comparison

Footprints of
Sentinel-2 MSI (green)
and LDCM OLI (red)

Image Simulation using the Applications Research Toolbox (ART)



- Simulations based on spectral and spatial degradation of higher-resolution hyperspectral images acquired with existing remote sensing instruments

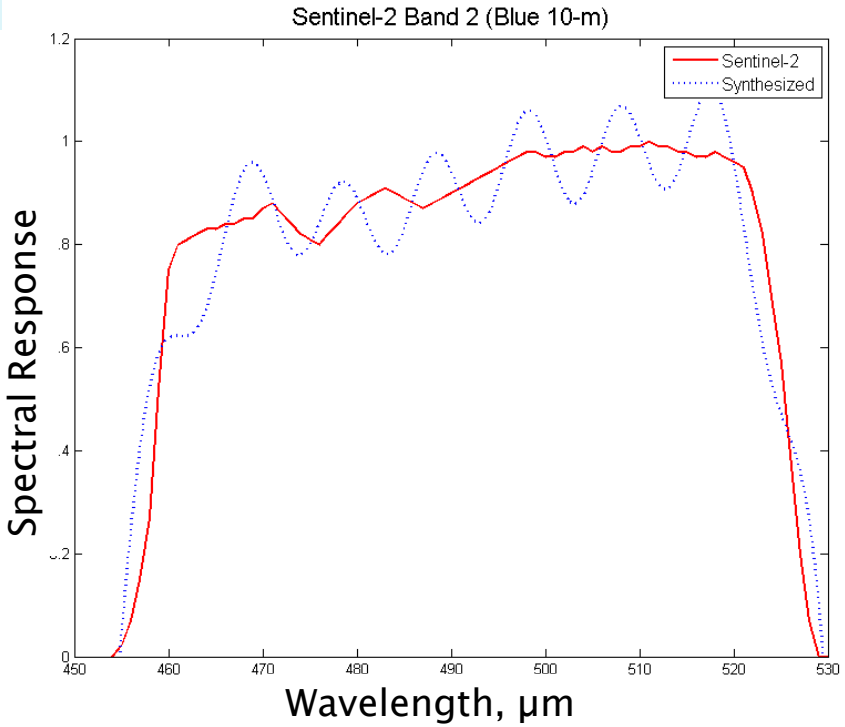
Spectral Band Synthesis Algorithm

- Spectral response of a multispectral band of the target sensor is approximated with a linear combination of spectral responses of the AVIRIS hyperspectral channels:

$$R_i^{Simulated}(\lambda_k) = \sum_{j=1}^{224} c_{ij} R_j^{AVIRIS}(\lambda_k) \quad \text{for} \quad k = 1, ..., n$$

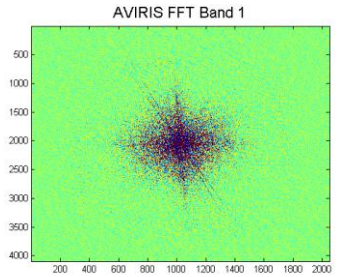
- The above set of equations is solved in the least-squares sense to derive the coefficients c_{ij} which are further used to calculate the synthesized multispectral pixels from the hyperspectral ones (under assumption that all the AVIRIS channels have Gaussian shape and equal width):

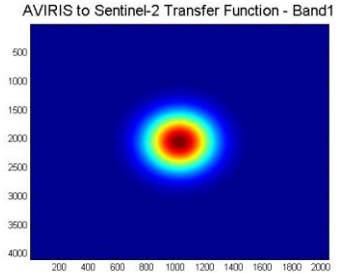
$$I_i^{Simulated} = \frac{\sum_{j=1}^{224} c_{ij} I_j^{AVIRIS}}{\sum_{j=1}^{224} c_{ij}}$$

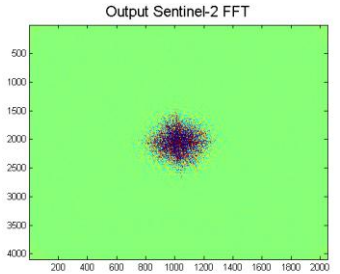


Frequency Domain Spatial Synthesis

$I(x,y)$	Input Image
$\tilde{I}(f_x, f_y) = F[I(x,y)]$	Fourier Transform Input Image
$H(f_x, f_y) = \frac{MTF(f_x, f_y)_{Out}}{MTF(f_x, f_y)_{In}}$	Transfer Function
$O(x,y) = F^{-1}[\tilde{I}(f_x, f_y)H(f_x, f_y)]$	Simulated Output Image (Inverse Fourier Transform –Resampled)







Noise Simulation

- SNR of AVIRIS data sets exceeds 500 in most cases.
- Assume that the detector non-uniformity can be corrected to better than the temporal noise level.
- A two-point noise model is used to approximate the noise:

$$NER(L) = \sqrt{\frac{(NER)_L^2 L_H - (NER)_H^2 L_L - ((NER)_L^2 - (NER)_H^2)L}{L_H - L_L}}$$

Where:

$NER(L)$: Noise equivalent radiance as a function of radiance.

NER_H : High scene radiance noise equivalent radiance.

NER_L : Low scene radiance noise equivalent radiance.

L : Radiance

L_H : High scene radiance.

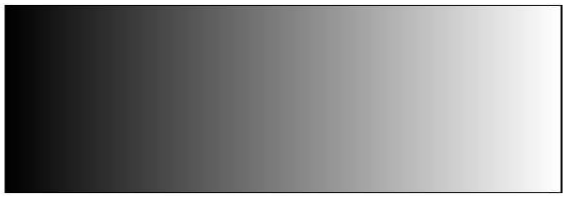
L_L : Low scene radiance.

Image Quantization

- Data quantization is to the process by which data with one precision is converted to data with another precision, usually lower than the initial precision

$$DN = INT\left[DN_{\min} + (L - L_{\min}) \frac{DN_{\max} - DN_{\min}}{L_{\max} - L_{\min}} \right]$$

$$L' = L_{\min} + (DN - DN_{\min}) \frac{L_{\max} - L_{\min}}{DN_{\max} - DN_{\min}}$$



16 bit test image
Range 0-100

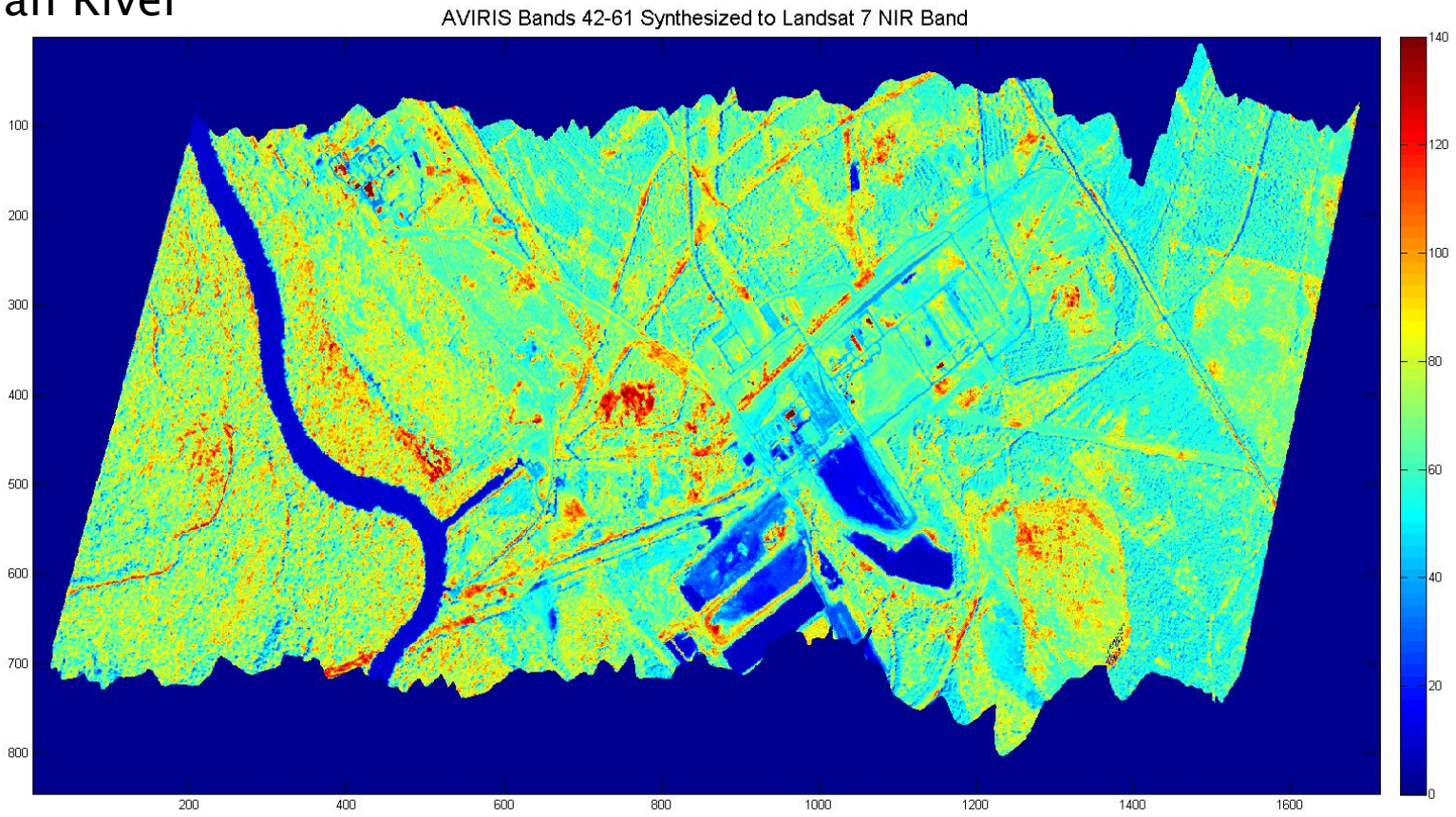
Quantized to 4 bits
image Range 0-100

Validation

- Located 3.3m AVIRIS flight data that had near coincident Landsat-7 imagery
  - Utilized two scenes for this validation
    - Savannah River on 7/26/1999 (Path 37 Row 37)
      AVIRIS acquired at 15:30 GMT
      Landsat-7 acquired at 15:53 GMT
    - Stennis Space Center on 7/29/1999 (Path 22 Row 39)
      AVIRIS acquired at 14:20 GMT
      Landsat-7 acquired at 16:25 GMT
- Registered AVIRIS to the nearest Landsat pixel
- Masked L7 data to generate same geographical coverage as AVIRIS flight lines
- Performed first order/reasonable atmospheric correction to partially remove the atmospheric component from the comparison
- Compared single bands, CIR imagery and NDVI maps

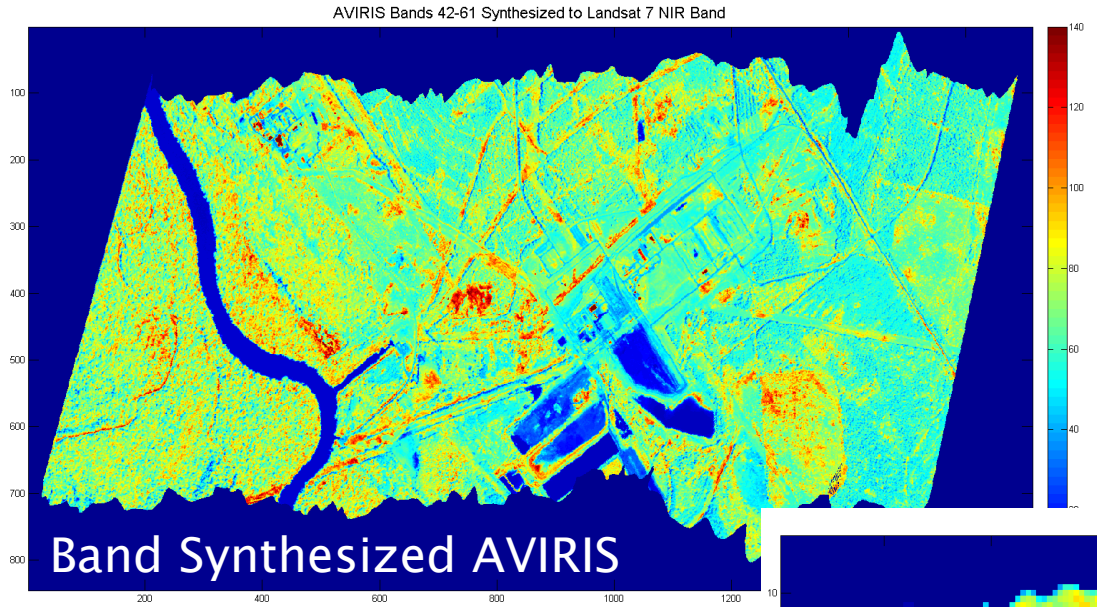
NIR Band Synthesized AVIRIS

Savannah River



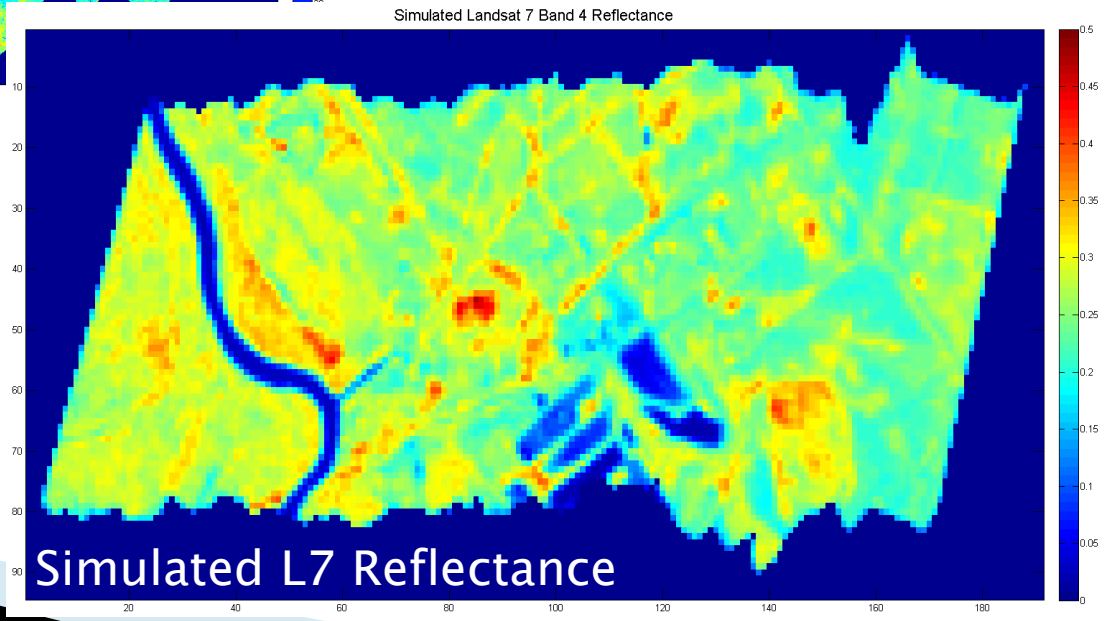
AVIRIS Bands 42-61 Synthesized to Landsat 7 NIR Band
Average Spectral Radiance

Simulated L7 NIR Reflectance Product

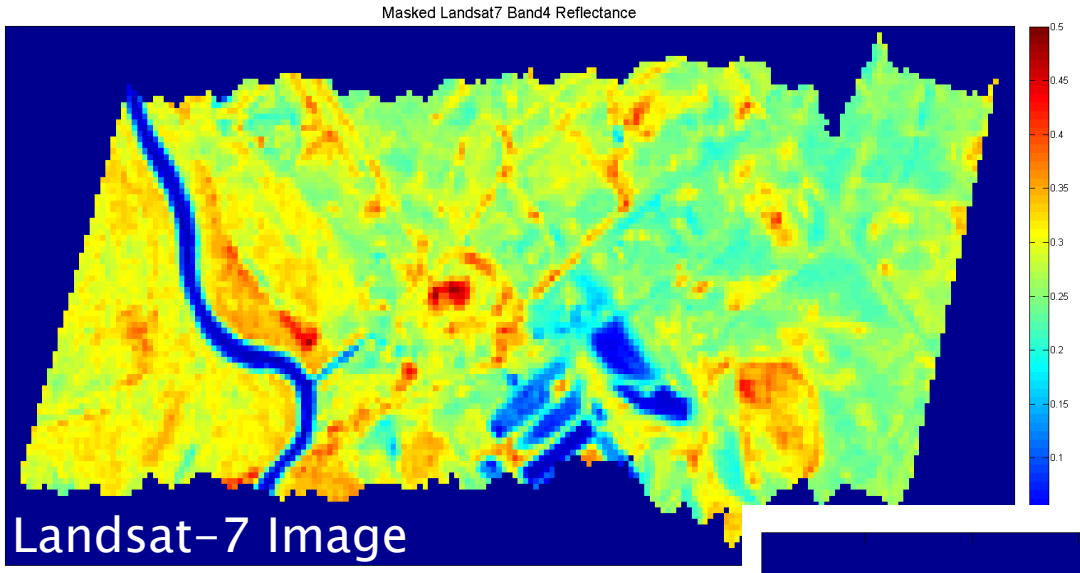


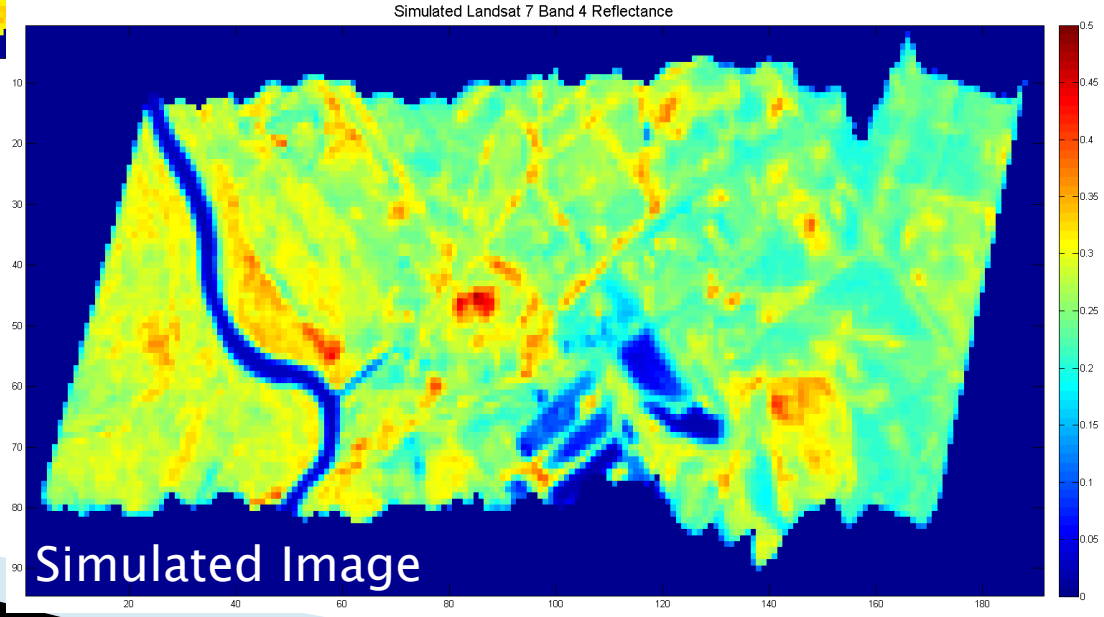
Savannah River

AVIRIS Bands 42-61 Synthesized to Landsat 7 NIR Band
Average Spectral Radiance



Comparison of Landsat-7 with Simulation – Savannah River

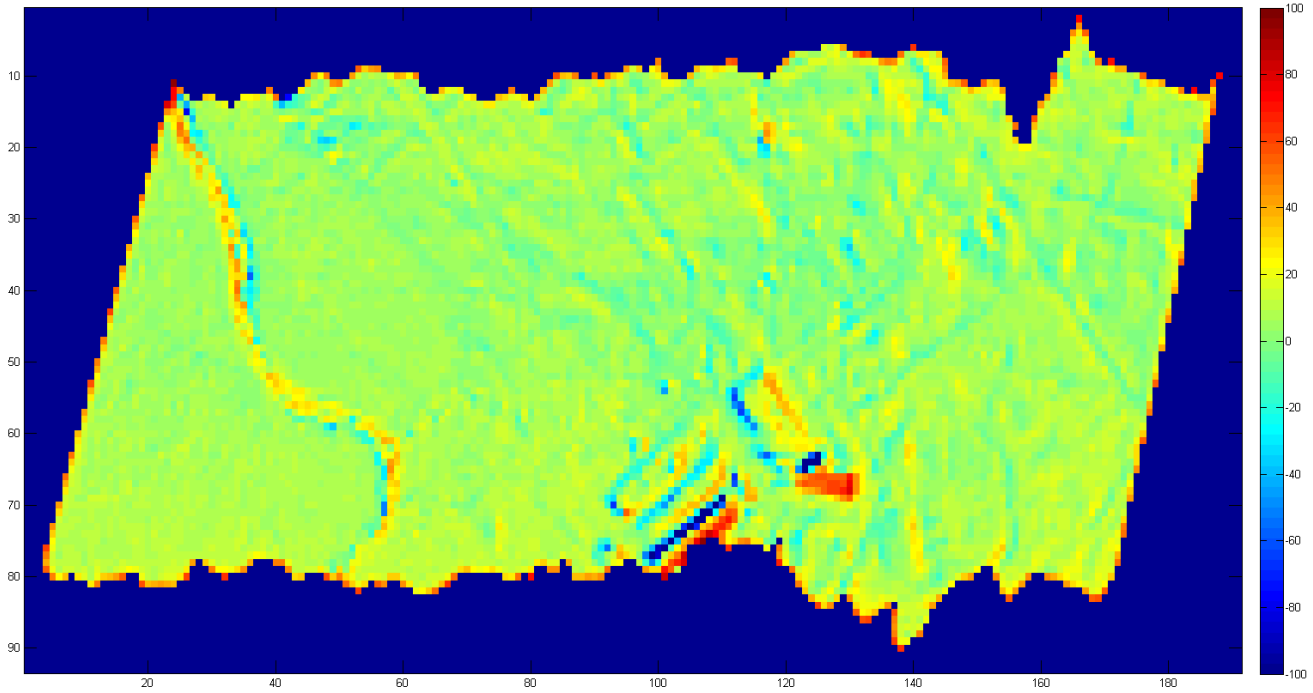




NIR Band 4 Reflectance Example
L7 values slightly higher

Comparison of Landsat-7 with Simulation – Savannah River

Percent Difference = (Actual-Simulation)/Actual



Differences likely due to simplified atmospheric correction (actual L7 is slightly higher than simulation)
Water shows greater difference due to slight mis-registration

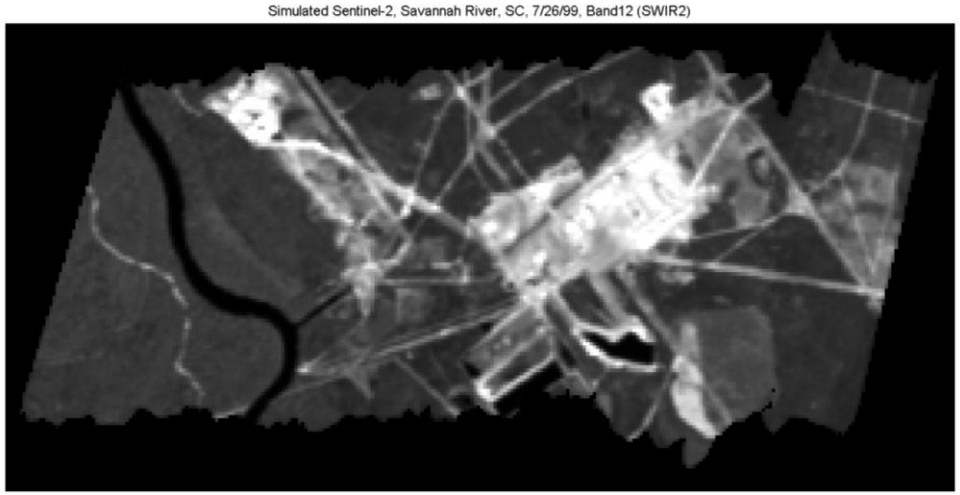
Simulations

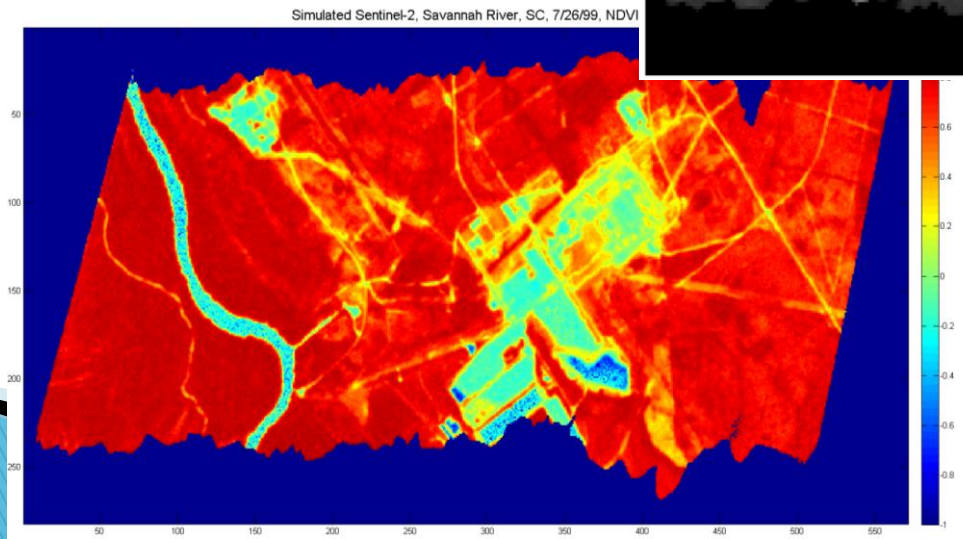
- Simulated Sentinel-2 and LDCM imagery over the two validation sites
  - Savannah River
  - Stennis Space Center
- Sentinel-2 noise model was developed using engineering estimates
- Band-to-band registration assumed to be perfect

Sentinel-2 Simulated Scene-Savannah River

10 m CIR radiance (RGB=843)

20 m SWIR-2 radiance

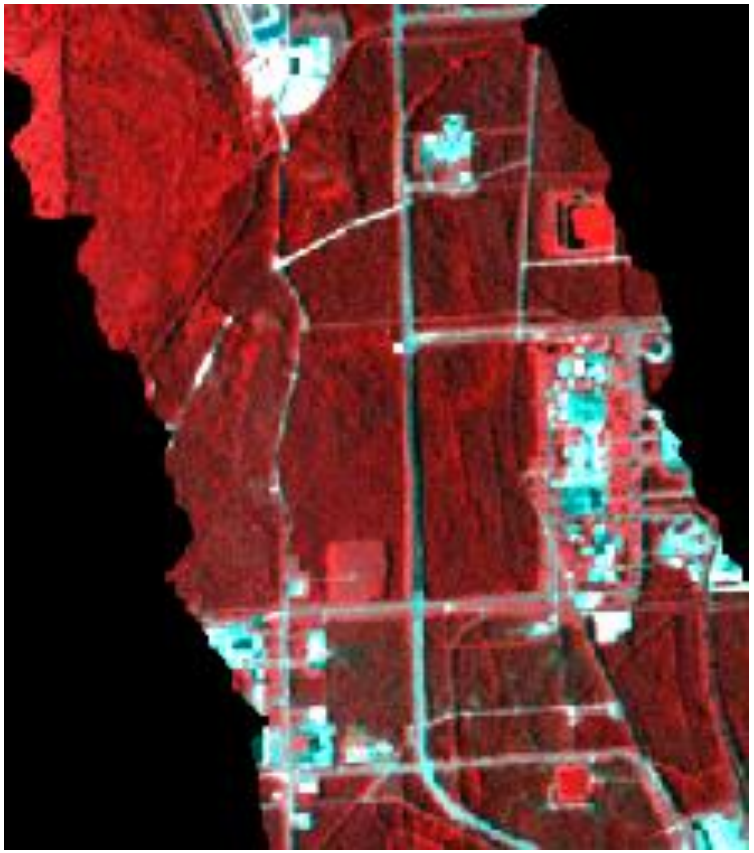




10 m
NDVI= $\frac{(B8-B4)}{(B8+B4)}$

Sentinel-2 Simulated Scene-Stennis Space Center

10 m CIR radiance (RGB=843)



20 m SWIR-2 radiance (B12)

Simulations Allow "What if" Scenarios

- Higher order products based on different red edge bands can be simulated to see how these products improve scientific research
  - MSI has a single broad red band plus 3 new narrow bands to detect the red edge, one broad NIR band and one new narrow NIR band
  - L7 has a single broad red band and a single broad NIR band
- Leaf Area Index (LAI)
- Chlorophyll concentration

Leaf Area Index Vegetation Products

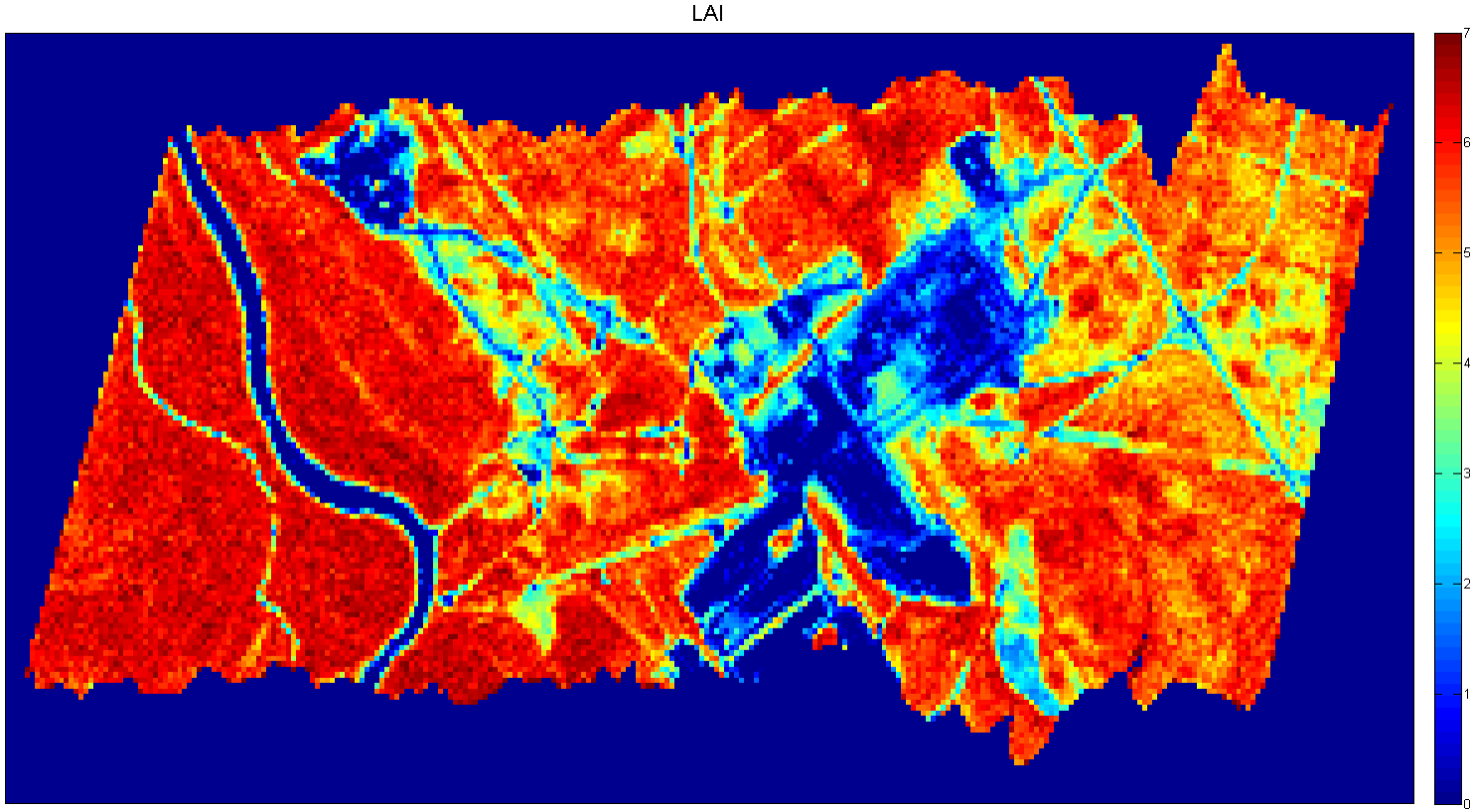
- Sentinel-2 with its narrow red edge and NIR bands opens up the development of alternative algorithms for vegetation products
- LAI (yields high dynamic range 0-7)

$$LAI = 6.753 \frac{R_{712} - R_{674}}{R_{712} + R_{674}}$$

Jesús Delegido, Jochem Verrelst, Luis Alonso and José Moreno, Evaluation of Sentinel-2 Red-Edge Bands for Empirical Estimation of Green LAI and Chlorophyll Content, *Sensors* 2011, *11*, 7063-7081

Sentinel-2 LAI Product

20 m



$$LAI = 6.753 \frac{R_{B5} - R_{B4}}{R_{B5} + R_{B4}}$$

Band	Center	FWHM
B4	665 nm	30 nm
B5	705 nm	15 nm

Chlorophyll Content Algorithm

- Hyperspectral algorithms such as the Normalized Area Over reflectance Curve (NAOC) is used to estimate Ch

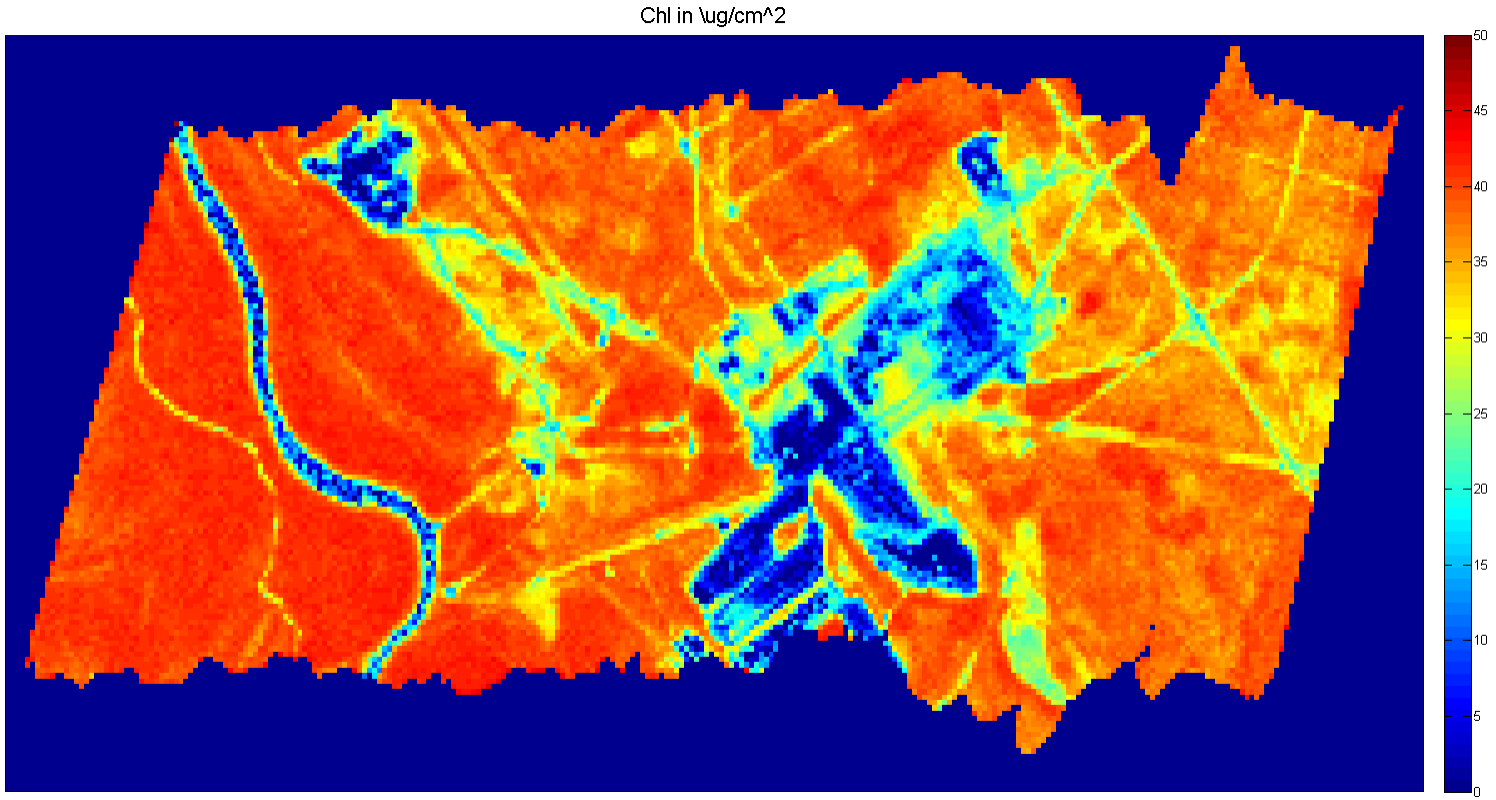
$$NAOC = \frac{\int_a^b R d\lambda}{R_b (b-a)}$$

  - Where: a~643 nm and b~795 nm
- Ch = -3.886+101.94 NAOC

Jesús Delegido, Jochem Verrelst, Luis Alonso and José Moreno, Evaluation of Sentinel-2 Red-Edge Bands for Empirical Estimation of Green LAI and Chlorophyll Content, *Sensors* 2011, *11*, 7063-7081

Sentintel-2 Chlorophyll Product

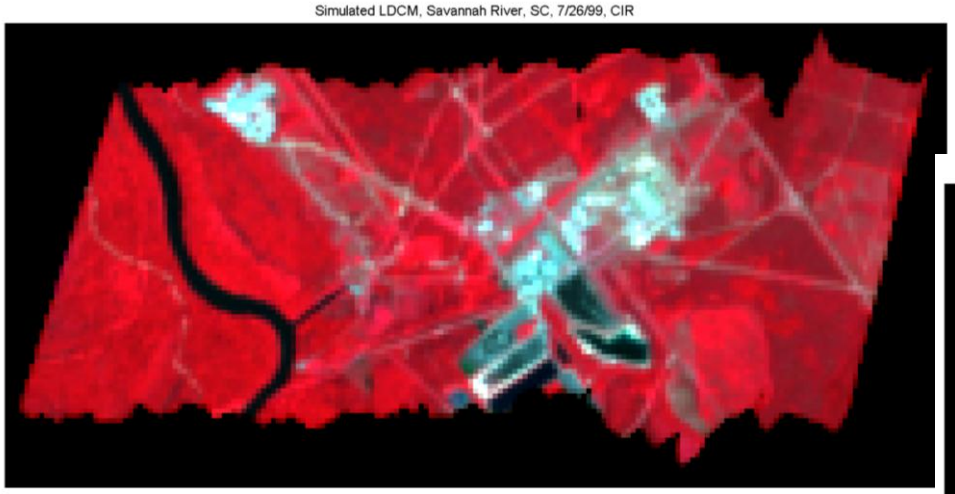
20 m



Numerically integrate Sentinel-2 bands B4, B5, B6 and B7 to determine NAOC

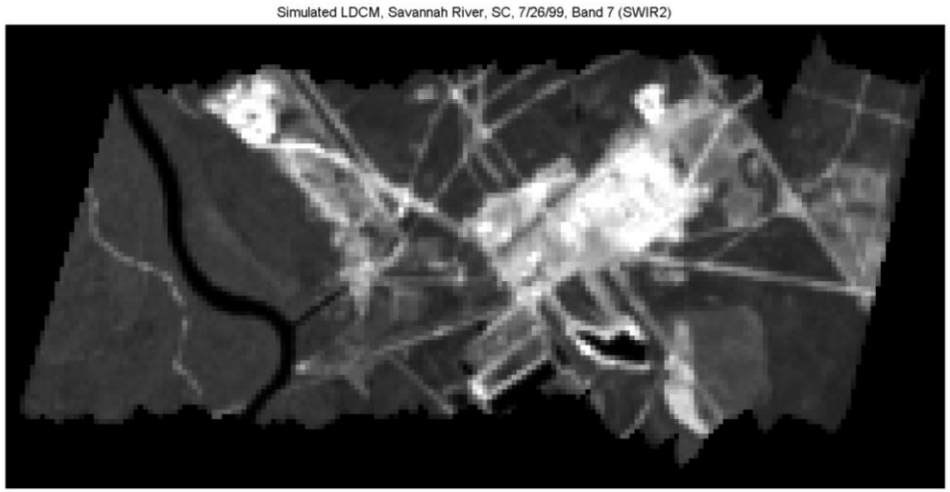
Band	Center	FWHM
B4	665 nm	30 nm
B5	705 nm	15 nm
B6	740 nm	15 nm
B7	783 nm	20 nm

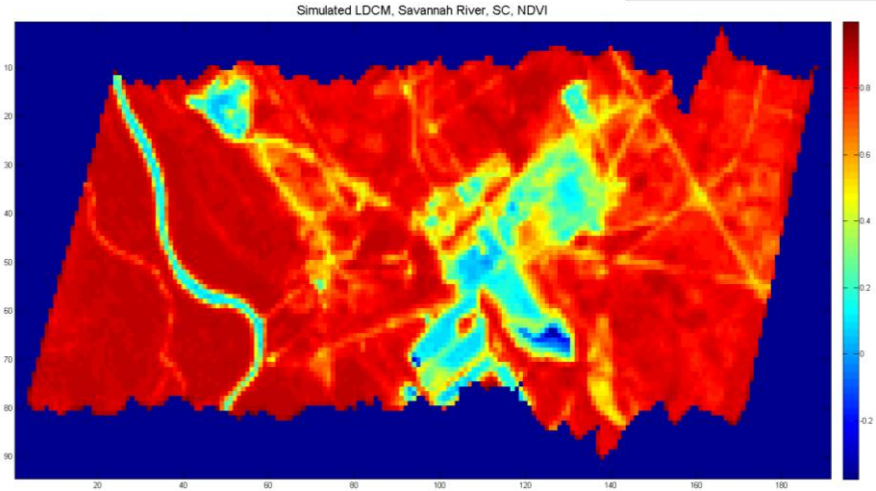
LDCM Simulated Scene–Savannah River



30 m CIR radiance (RGB=543)

30 m SWIR-2 radiance (B7)





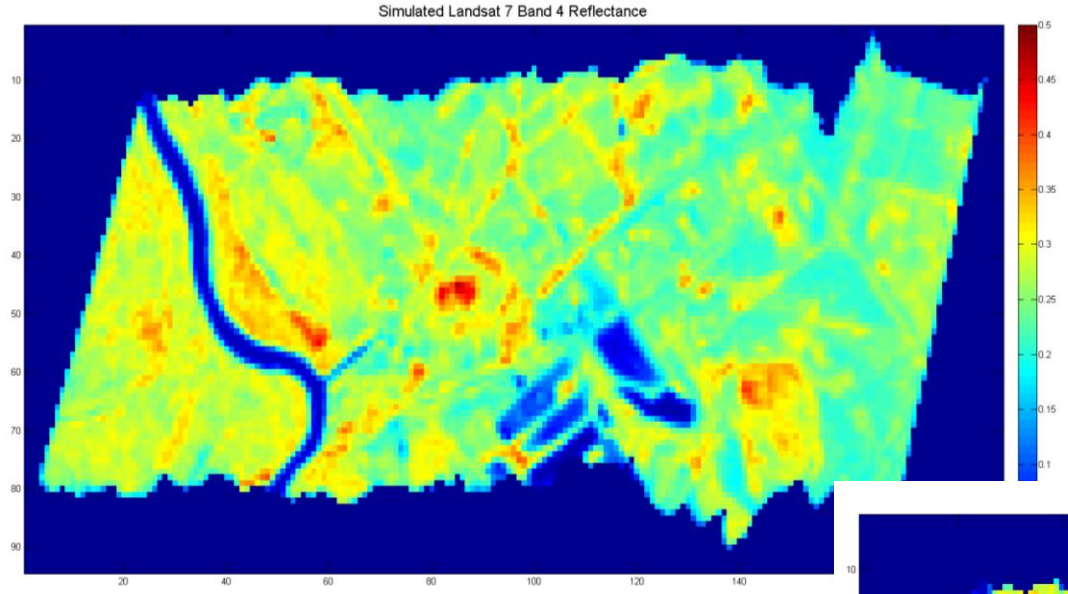
30 m

$$NDVI = \frac{(B5 - B4)}{(B5 + B4)}$$

Simulations Allow "What if" Scenarios

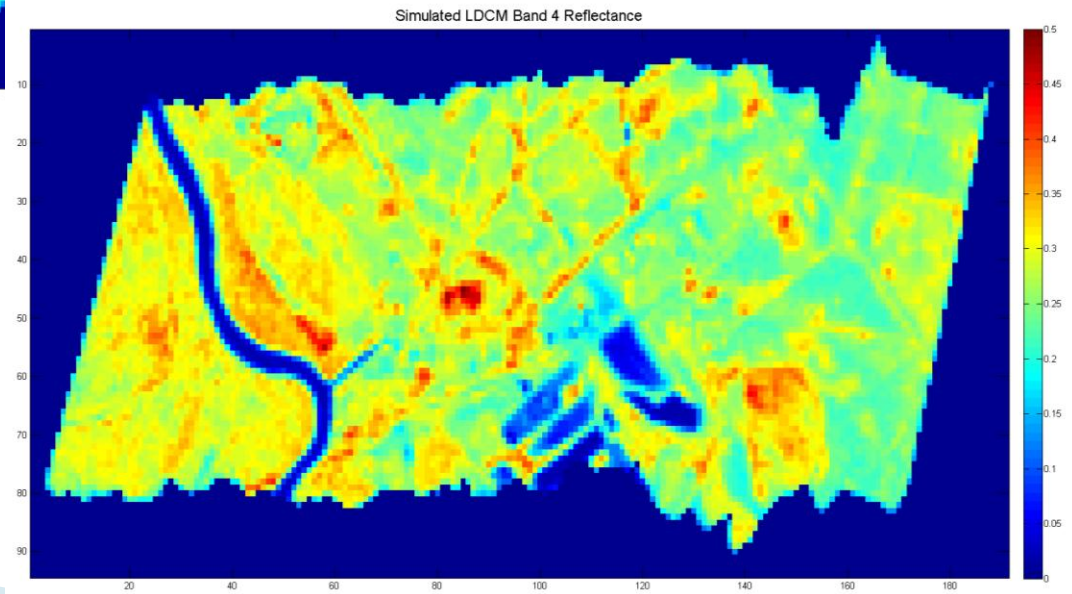
- Comparing simulated L7 with simulated LDCM enables one to examine how the differences in spectral response affect science results
  - LDCM NIR (.84–.88 μm) and L7 NIR (.76–.90 μm)
- Simulations based on the same hyperspectral high spatial resolution imagery so there are no atmospheric, viewing angle or mis-registration differences

L7-LDCM NIR Band Comparison



Savannah River

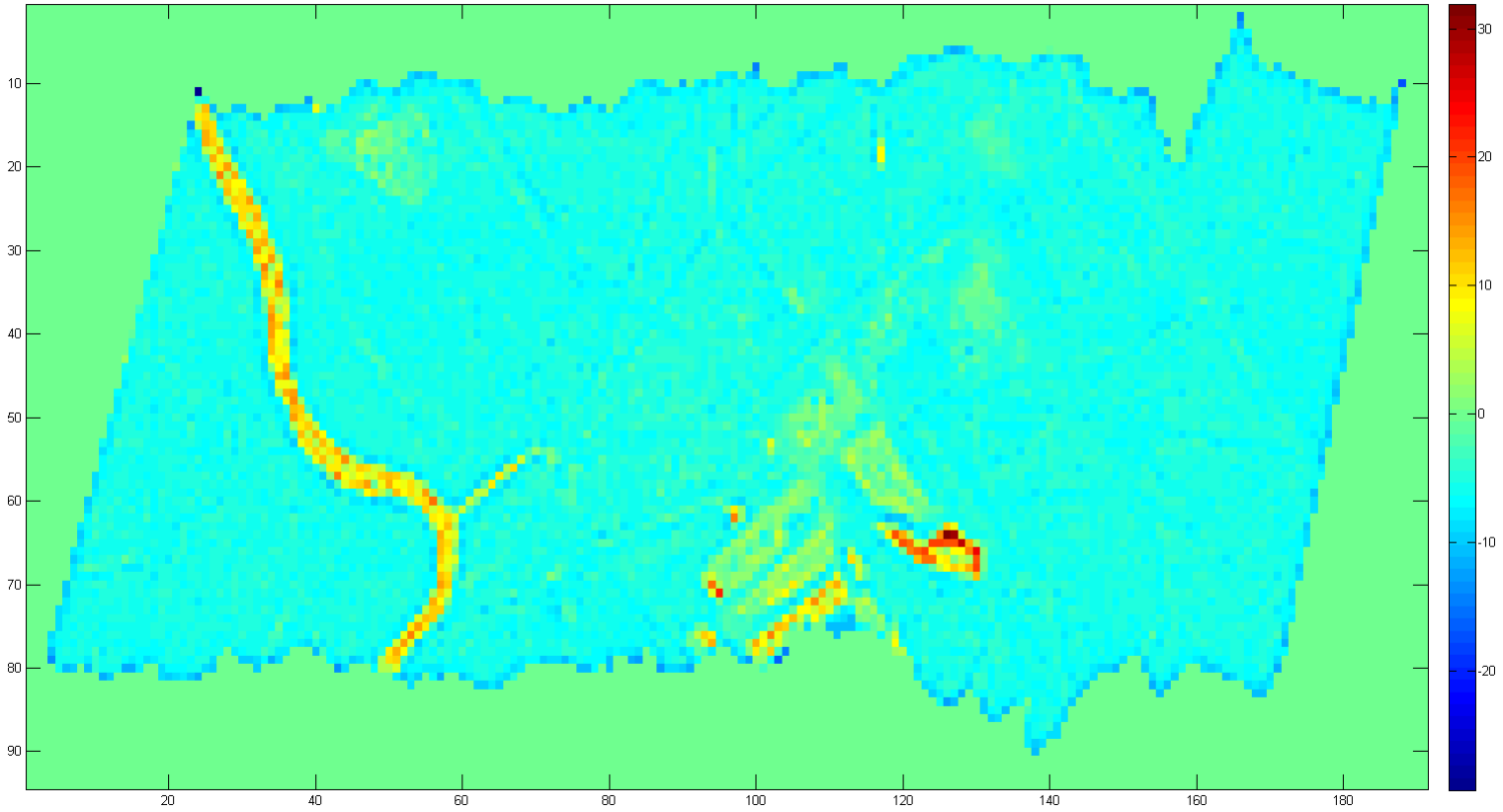
Simulated L7
NIR Band4 0.76–0.90 µm



Simulated LDCM
NIR Band5 0.84-0.88 µm

L7-LDCM NIR Band Comparison Percent Difference Plot

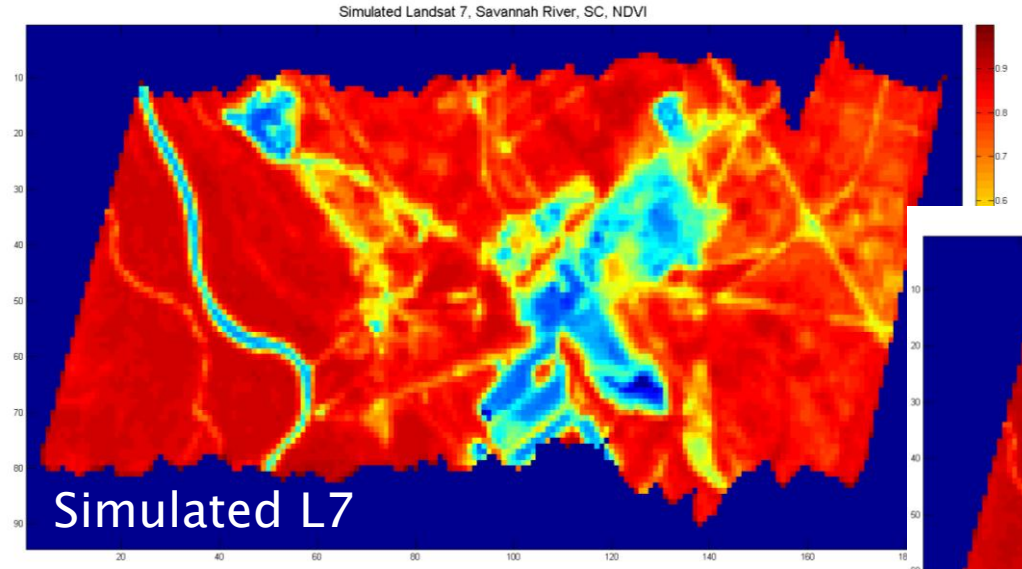
Percent Difference = (L7-LDCM)/L7)

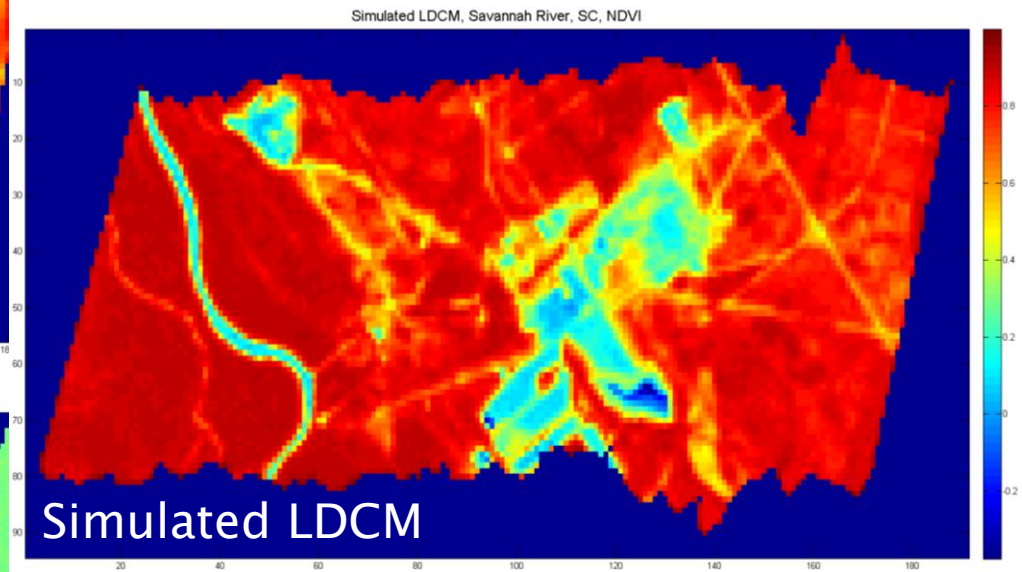


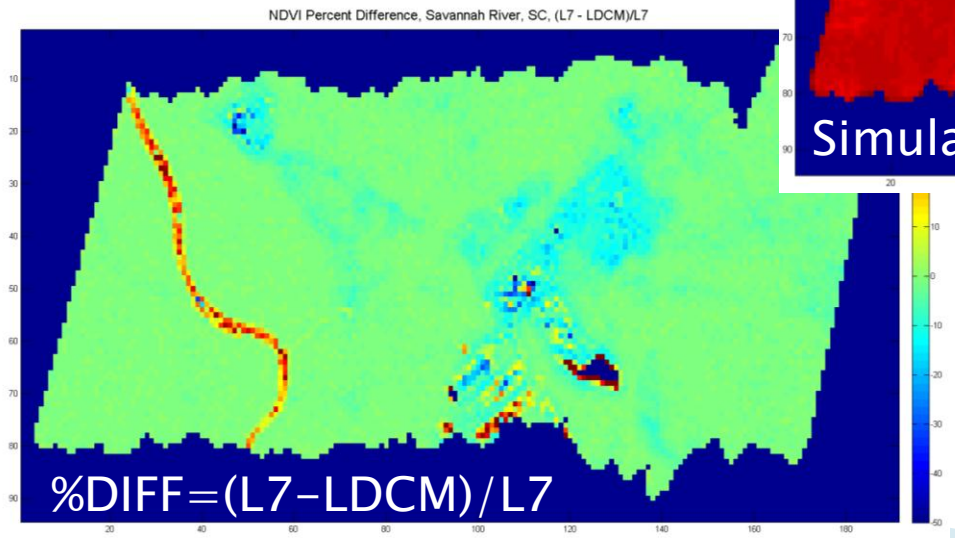
In general LDCM is ~5% higher than L7 in the NIR
Greater percent difference seen in water bodies
L7 may be observing sediment

L7-LDCM NDVI Comparison

Savannah River



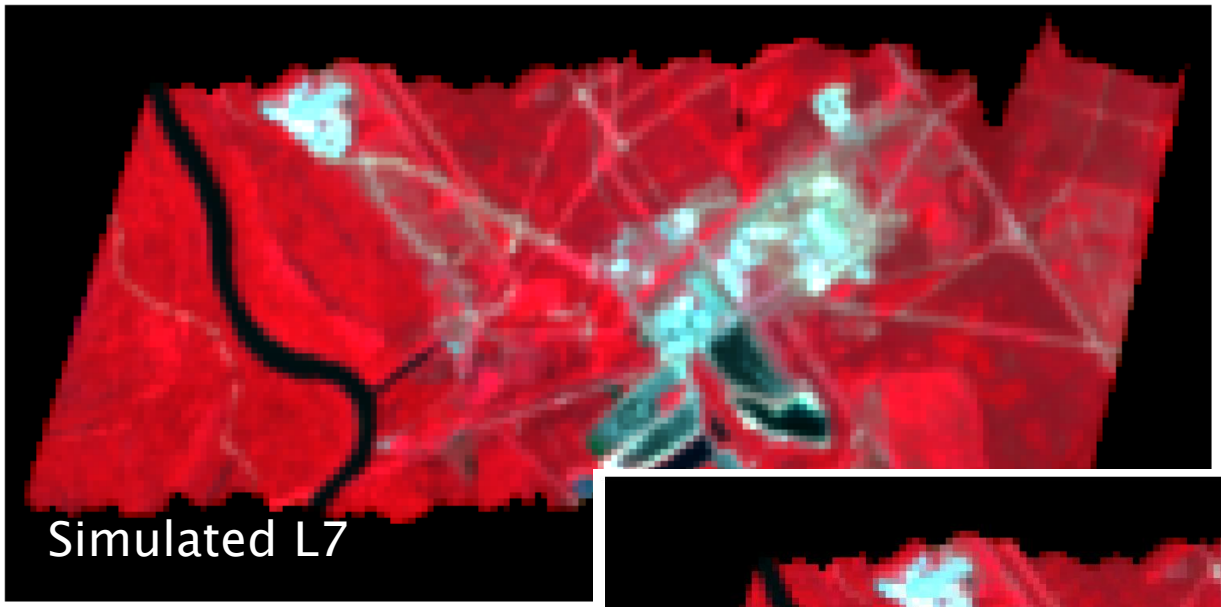


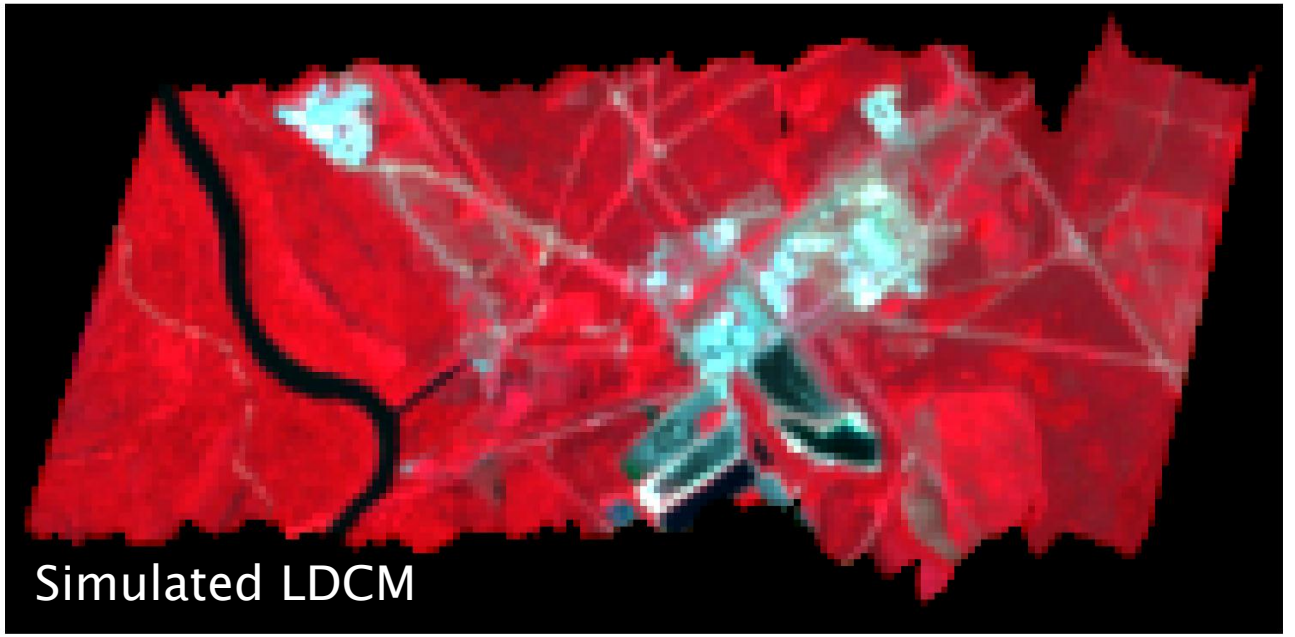


L7-LDCM CIR Comparison

Savannah River

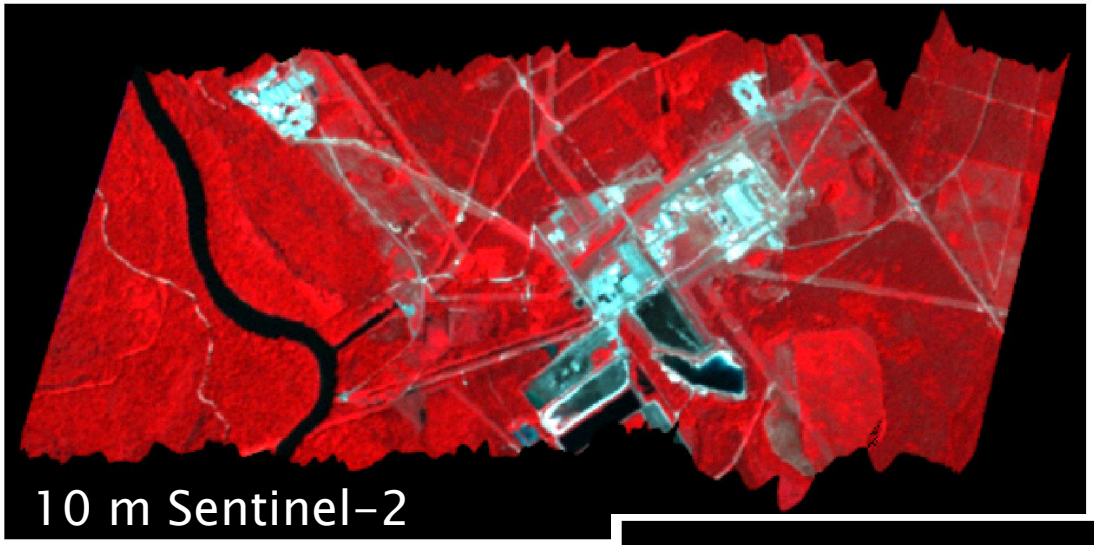
30 m CIR radiance
(RGB=543)

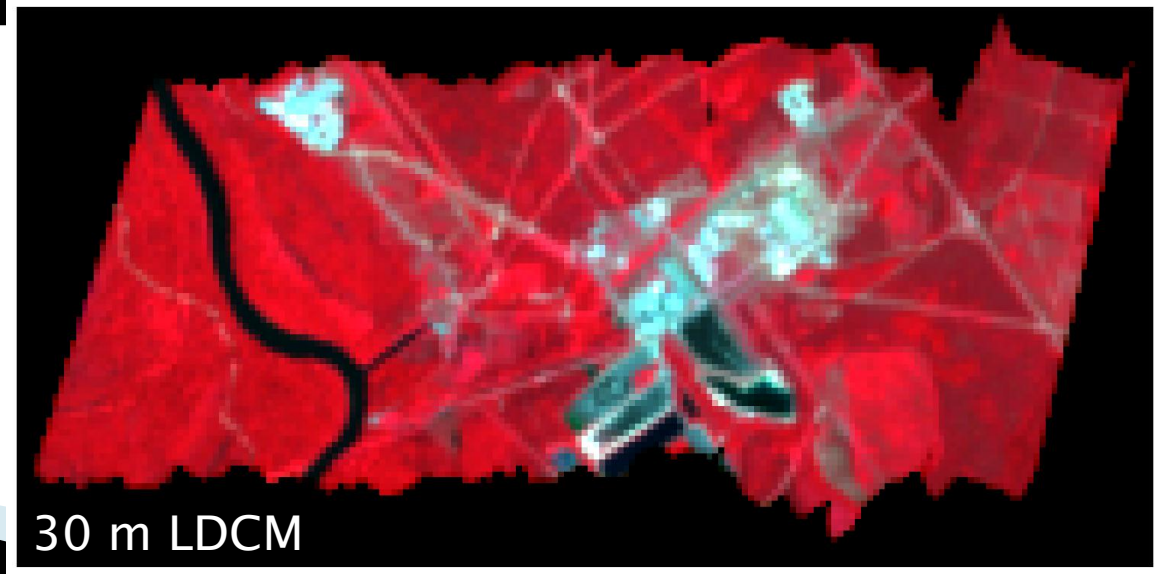




LDCM / Sentinel-2 CIR Comparison

Simulated Sentinel-2, Savannah River, SC, 7/26/99, CIR





Summary

- A tool has been developed to simulate multispectral imagery based on higher spatial resolution hyperspectral imagery
  - Areas of interest are limited to where we have high spatial resolution hyperspectral data sets (AVIRIS)
- This tool can help users understand how to work with new data streams before they become available
  - All source solutions
- This tool can assist data providers select band centers and other parameters to best meet customer requirements

Acknowledgements

- Sentinel-2 and LDCM simulations were funded under the NASA Land Cover Land Use Change Program
- Simulations leverage algorithms initially developed under the NASA Commercial Remote Sensing Program at Stennis Space Center
- AVIRIS data used in these simulations obtained through: http://aviris.jpl.nasa.gov/data