Precision Remote Sensing and Image Processing for Precision Agriculture (PA)

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Presented to
Colorado State University, Fort Collins, CO
October 20, 2005

- **Speaker's Current Activities: Consultant**
  - **EarthMap Solutions, Inc., Longmont, CO: www.earthmapsolutions.com**
  - **MicroImages SML Developer: www.microimages.com**
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- **Speaker's Experience & Education:**
  - **DigitalGlobe, Inc.: New Product Development Scientist (2002-October 2004): www.digitalglobe.com**
  - **California State University (1989-2002)**
    - **Monterey Bay (1996-2002): Retired**
    - **Fresno (1989-1996)**
  - **NASA (1980-1989)**
    - **JPL (1983-1989)**
    - **Lyndon B. Johnson Space Center (1980-1983)**
  - **University of Houston at Clear Lake (1975-1980)**
  - **Lockheed (1971-1975): Subcontractor to NASA in Houston**
  - **Ph.D. Texas A&M University 1971**

AGENDA

LECTURE

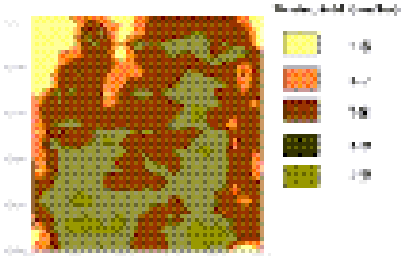
- Precision Agriculture
  - Need for Information When Making Ag Management Decisions
- Precision Remote Sensing (RS)
  - Multispectral RS
  - Precision Vegetation Index Maps
  - AgroWatch™ Products
  - Temporal Changes Using Precision Vegetation Index
  - EarthMap Solutions, Inc.

LAB

- Installing TNTlite
- About the MS Images & AgroWatch™ Products
- About Files & TNT Objects & Subobjects
- Displaying a MS Image
  - Contrast Enhancement
  - True & False Color
- Making a Zone Map
- Displaying an AgroWatch™ Product
- Making Cluster Maps

Arable Precision Farming Cycle

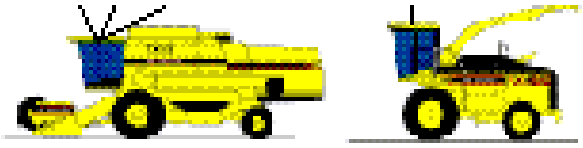
Mapping



External Information

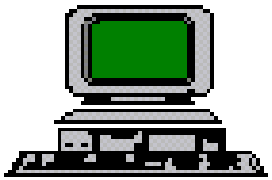
* Prices
* Weather

Data Collection at harvest



* Yield
* Moisture Content
* Quality

Decision Support



* Data Processing
* Data Analysis
* Advice

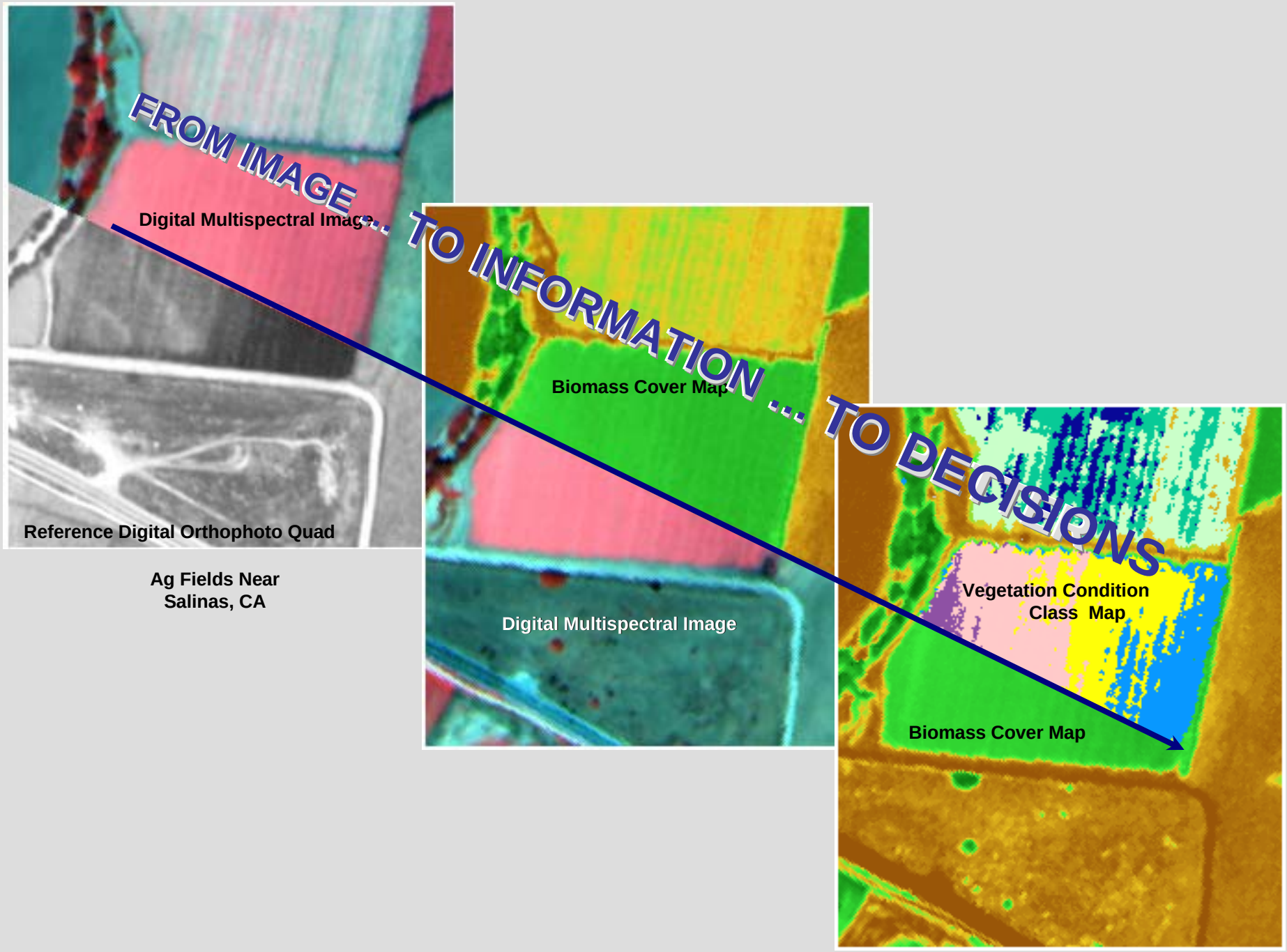
Variable treatment

Variable-Rate Spraying

Variable-Rate Fertilising

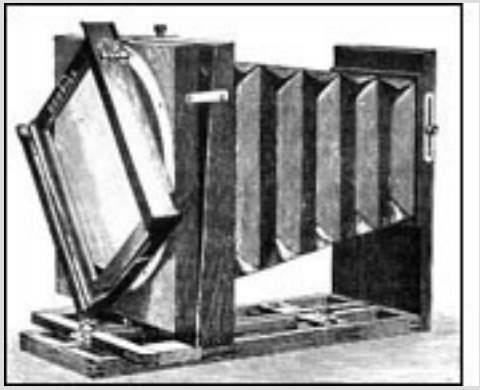
Data Collection in growing season

* Soil Analysis
* Weed Patches
* Diseases
* Crop Growth Stage
* Chlorophyll Content


FROM IMAGE ... TO INFORMATION ... TO DECISIONS
Digital Multispectral Image
Reference Digital Orthophoto Quad
Ag Fields Near
Salinas, CA
Biomass Cover Map
Digital Multispectral Image
Vegetation Condition
Class Map
Biomass Cover Map

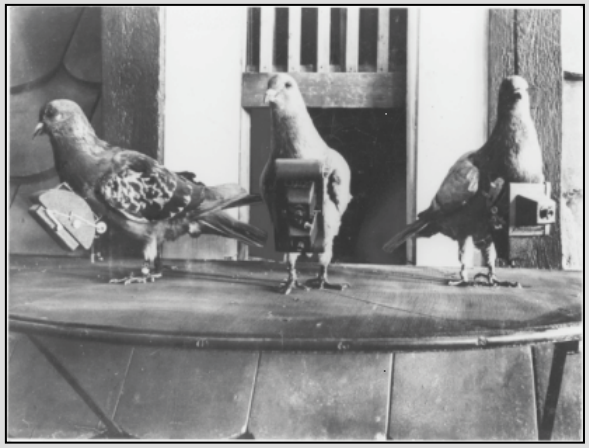
Precision Remote Sensing

Remote Sensing Applications to Ag: 80 Years of History … and Counting



First Aerial Photos For Ag … **1930s**
Soil Mapping

The Camera and Film



Human Eyes
Pigeons
Aircraft
Rockets
Satellites
Digital Cameras

Extending Human Vision

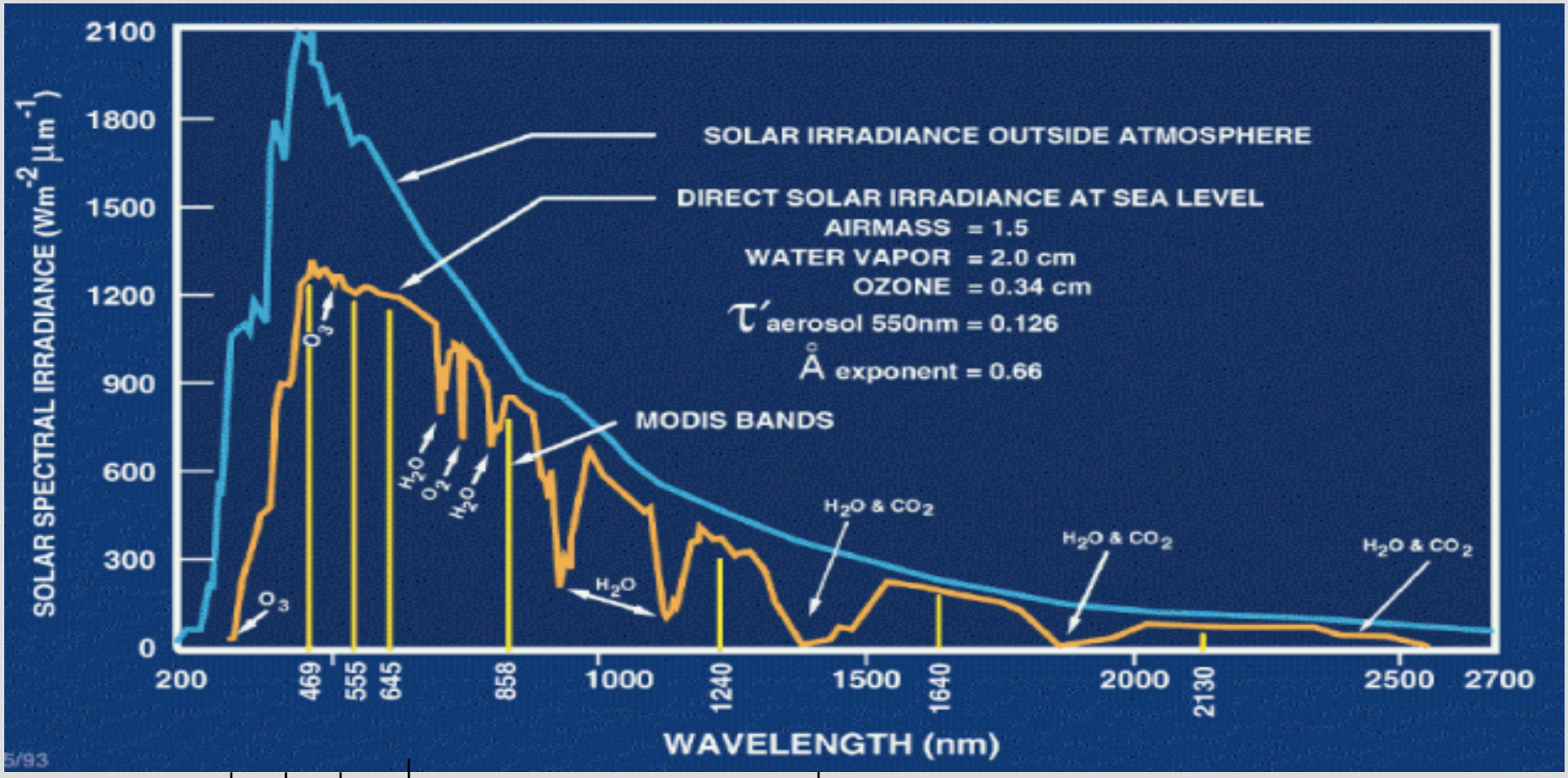
Visible Light

- Before Technology … There Was Only Human Vision: **Light** & **Color**
- Mid-1800s: Photography
  UVBlue (as B&W)
- 1930s: **Pan** Airphotos of Ag Land (Soil Maps)
- **1940s**: **True Color Film**
  BL GL RL
- **After 2005**: **Super Multispectral**
  – **CB BL GL YL RL RE**

Invisible "Light"

- **1940s: Color IR (CIR) Film**
  GL RL NIR
- **1950s: Multispectral Scanners (MS)**
- **1960s: NASA Remote Sensing (RS)**
- **1970-90s+: Satellite MS**
  - **Landsat: 3 to 7 Bands (Plus Pan for L # 7)**
- **After 2000:**
  - **Color RADAR**
  - **Hi-Res MS RS**
  - **Hyperspectral RS**


Natural (Scanners)
Artificial (RADAR & LIDAR)
Many Kinds of
Remote Sensors
24 New Imagers
Coming in the Next Decade


SOLAR SPECTRAL IRRADIANCE (Wm-2 µm-1)
2100
1800
1500
1200
900
600
300
0
SOLAR IRRADIANCE OUTSIDE ATMOSPHERE
DIRECT SOLAR IRRADIANCE AT SEA LEVEL
AIRMASS = 1.5
WATER VAPOR = 2.0 cm
OZONE = 0.34 cm
τ′aerosol 550nm = 0.126
Å exponent = 0.66
MODIS BANDS
O3
H2O
O2
H2O
H2O
H2O & CO2
H2O & CO2
H2O & CO2
O3
200
469
555
645
858
1000
1240
1500
1640
2000
2130
2500
2700
WAVELENGTH (nm)
5/93

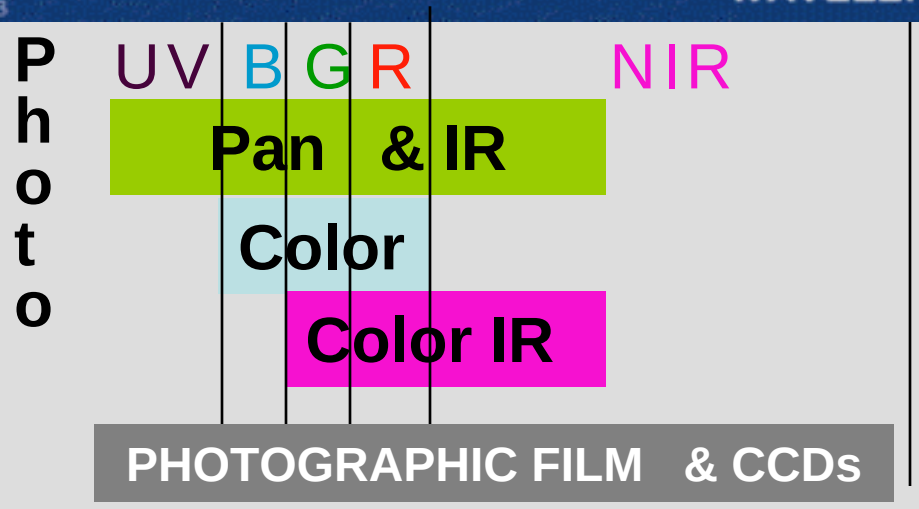
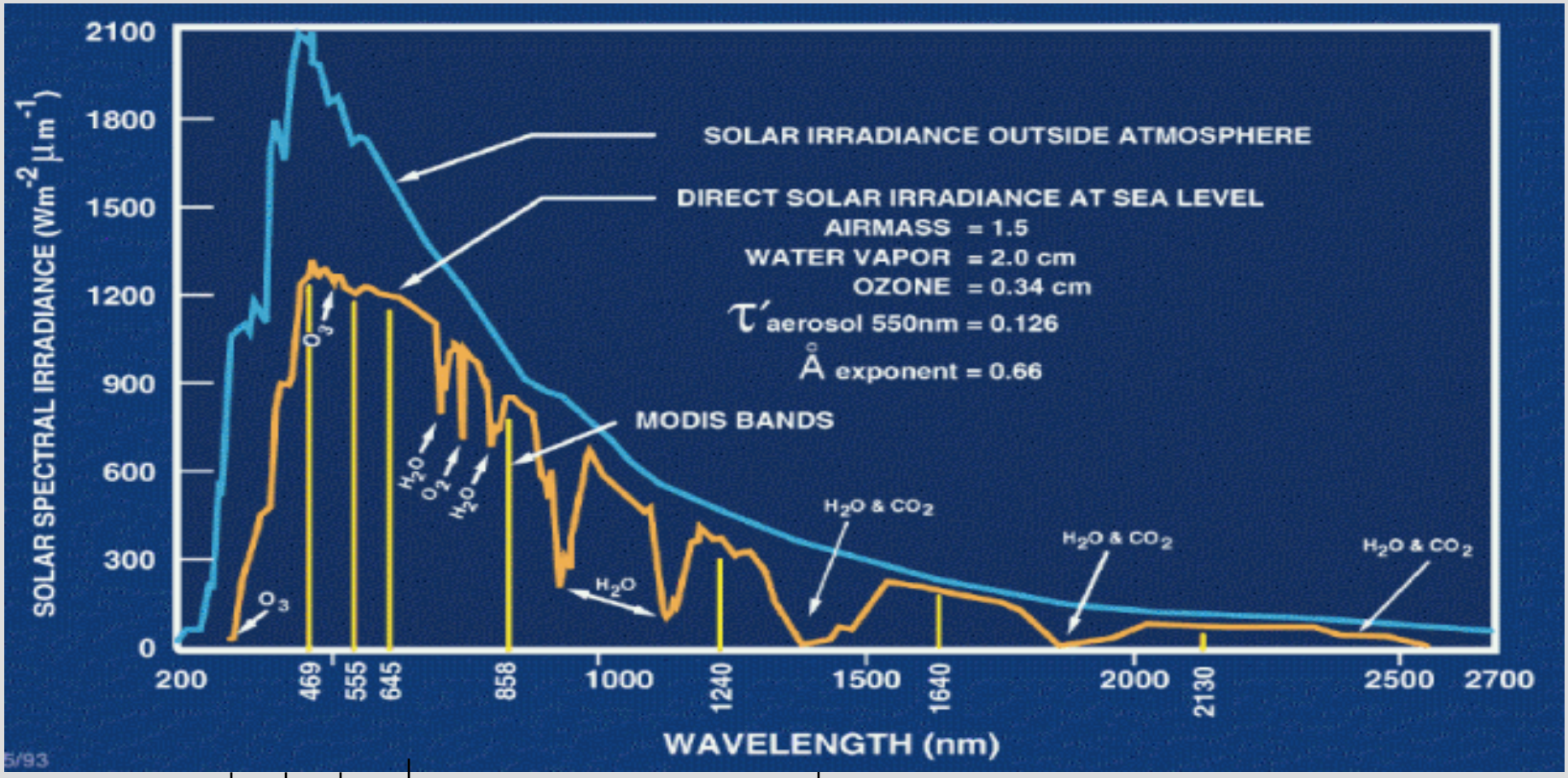


Photo
UV
B
G
R
NIR
Pan & IR
Color
Color IR
PHOTOGRAPHIC FILM & CCDs



Photo

UV B G R

NIR

Mid IR

Pan & IR

Thermal IR >

Color

Microwave / Radar >

Color IR

Scanners (Multispectral & Hyperspectral)

Abbreviations

- CB: “Coastal” Blue Light
- BL: Blue Light (a.k.a., “Cyan Light”)
- GL: Green Light
- YL: Yellow Light
- RL: Red Light
- RE: Red Edge
- NA: Near-Infrared Radiation – Band A
- MIR: Middle-Infrared Radiation (a.k.a., SWIR)
- TIR: Thermal-Infrared Radiation

Spacecraft-Based Imagers

Current or Archive Only (Not Current, But Can Get Data)

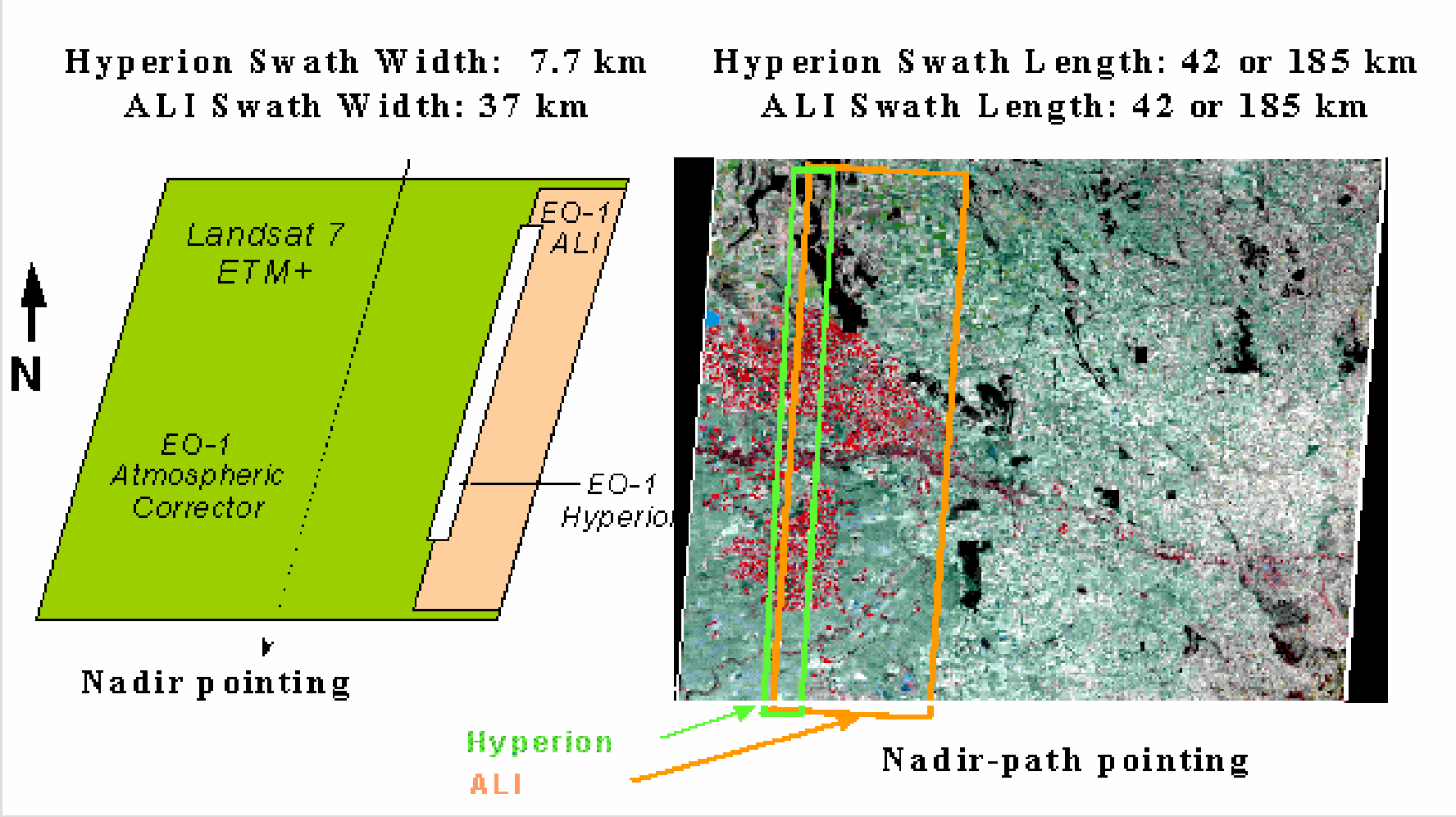
Ranked from High Spatial Resolution to Low Spatial Resolution

Current

1. **QuickBird** Multispectral (MS, 2.4-m) and Panchromatic (PAN, 0.6-m)
2. **IKONOS** MS (4-m) and PAN (1-m)
3. **OrbView 3** MS (4-m) and PAN (1-m)
4. **SPOT 5** MS (10-m) and PAN (5-m or 2.5-m possible from 2 images)
5. **SPOT 4** MS (20-m) and PAN (10-m)
6. **SPOT 2** MS (20-m) and PAN (10-m)
7. Indian Remote Sensing System (**IRS**) MS (23.5-m) and PAN (5-m)
8. **Landsat 7** Enhanced Thematic Mapper Plus (**ETM+**, 30-m) and PAN (15-m): Scan Line Correction (SLC) System Broke in May 2003
9. **Landsat 5** Thematic Mapper (**TM**, 30-m)
10. Terra **ASTER** MS (30-m)
11. **DMC** MS (31.5-m)
12. Terra & Aqua **MODIS** RL NIR (250-m), BL, GL, 3 Mid-IR (500-m)
13. **SPOT VEGETATION** & NOAA **AVHRR** MS (1000-m)

… MANY MORE ARRIVING EVERY MONTH

Swath Widths



EO-1's ALI and Hyperion can be pointed sideways a distance of one Landsat Width

Elements of Image Interpretation

High-Resolution Panchromatic Images	Low-Res MS Images
Shape	**Shape**
Size (Relative and Absolute)	**Size**
Pattern (Regular Variations)	**Not Used**
Texture (Irregular Variations)	**Not Used**
Shadows (Sun Angle, 3-D, Profiles)	**Not Used**
Tone (Black & Whiteness or Grayness)	**Color / MS / Radar**
Site & Association (Context)	**Context**
Temporal Pattern	**Temporal Pattern**

QuickBird Multispectral (MS) Images: Ft. Collins, CO

Natural Color: 4/23/2002

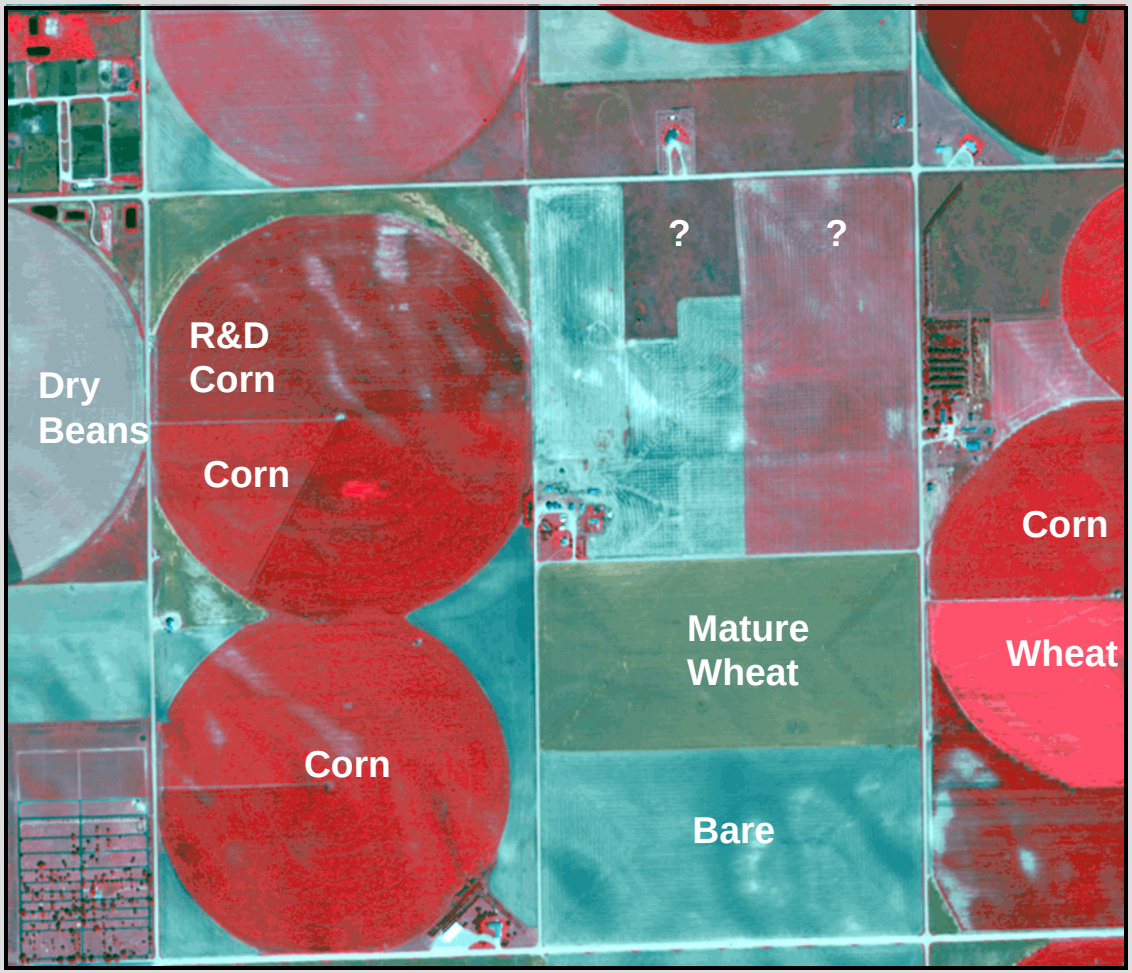
Color Infrared (CIR): 4/23/2002

QuickBird MS Images:
Ft. Collins, CO

Natural Color: 9/14/2002

CIR: 9/14/2002

Visual Interpretation of CIR Image is Interesting … But is not as Precise as Information Extraction Via Image Processing Software.



Yuma, CO
DigitalGlobe, Inc.
QuickBird MS

8-ft Resolution
CIR Image

July 2, 2003

Multispectral Images for Agricultural Mapping & Monitoring

with Special Attention to:

Red Light (RL)
and
Near Infrared – Band A (NA)
Combinations

Reflectance of Objects Varies with Wavelength / Spectral Region

Leaves are Dark; Soil is Bright.

Leaves are Bright; Soil is Dark.

Reflectance varies from one spectral band to the next. This leads to variations in image radiance (brightness)

Red-Light, RL, Image

Near Infrared – Band A (NA) Image

Pictures that involve NIR show what is "invisible" to your eyes.

NOTE: NIR involves reflected sunlight. Thermal Infrared (not shown here) involves emitted heat radiation. Don't confuse these two "IR" types!

2-Space Plot

Spectral Mixing Causes “Curving Triangle” Zone Called the TASSELED CAP

QuickBird MS, Yuma, CO, July 2, 2003

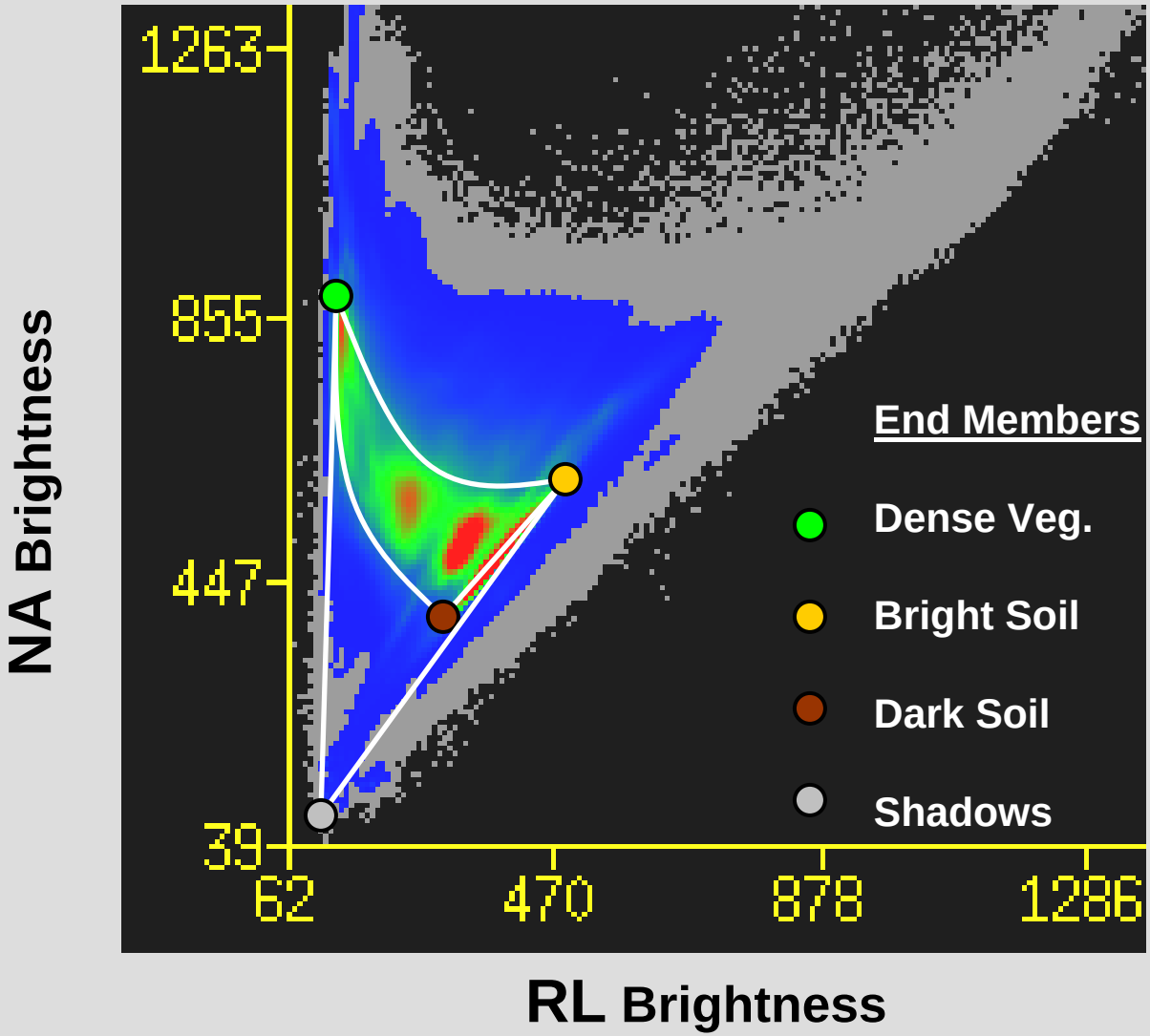


Image DNs Converted to Standardized Reflectance Factor Index (SRFI)

For Details about SRFI:

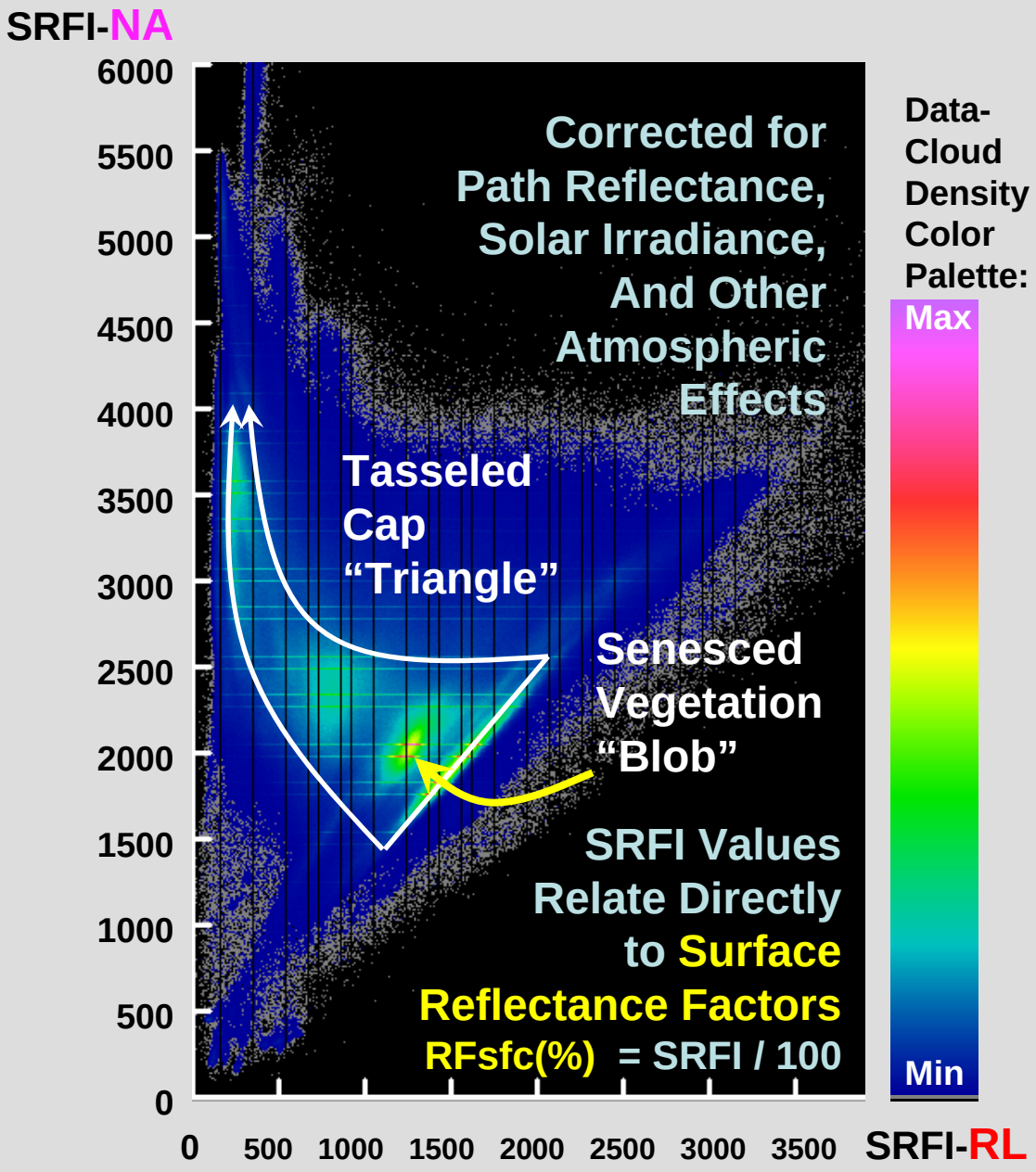
See:

Scripts by Jack™
www.microimages.com/freestuf/ScriptsByJack.htm

FAQs by Jack™
www.microimages.com/freestuf/FAQsByJack.htm

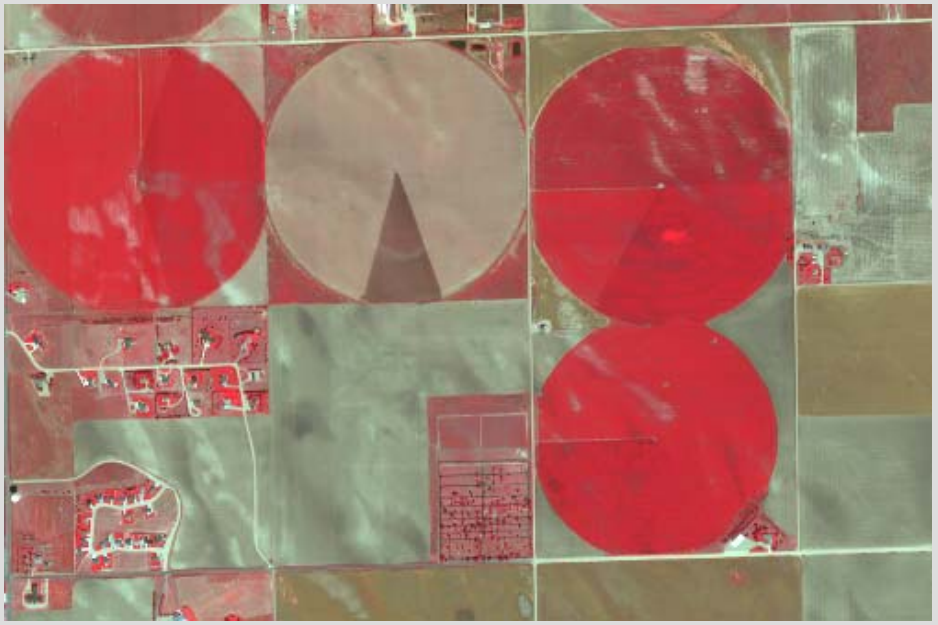
at the
MicroImages, Inc.,
Web Site:

www.microimages.com



Precision Vegetation-Index Maps

Precision Vegetation-Index Maps



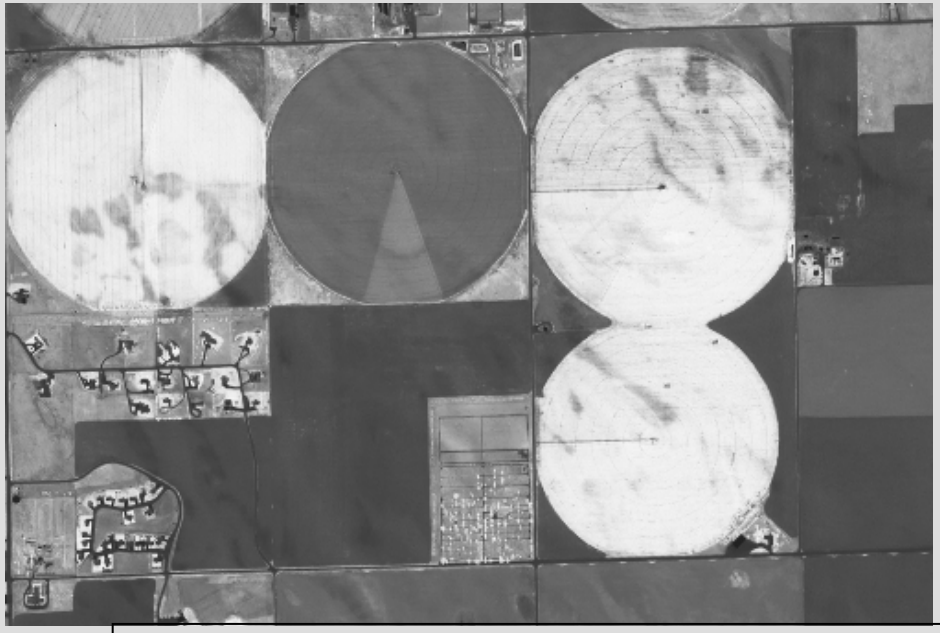
GRUVI:

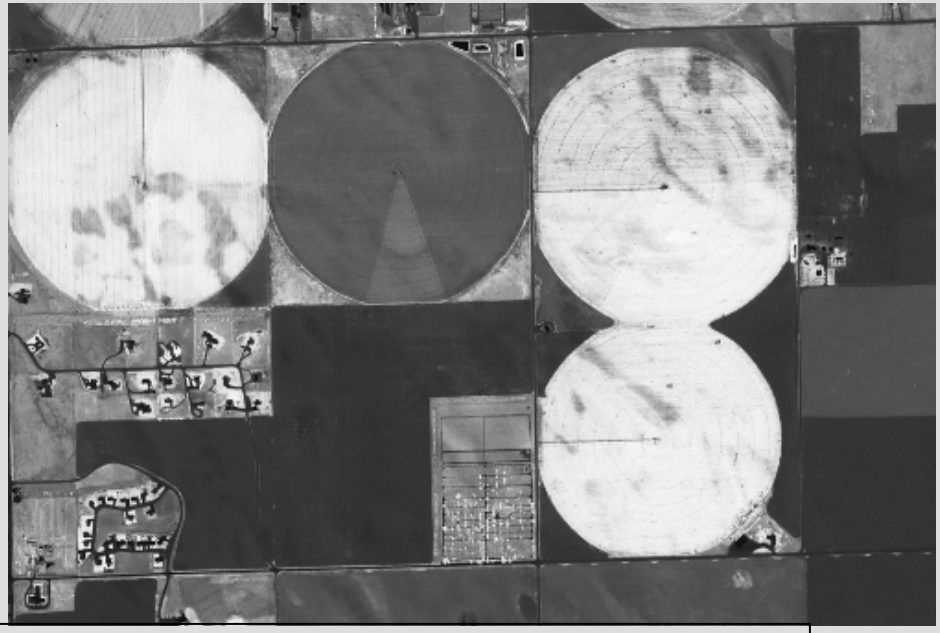
http://www.microimages.com/documentation/cplates/71GRUVI.pdf

GRand Unified Vegetation Index (GRUVI) is able to mimic any classic Vegetation Index and, more importantly, can produce the optimal VI that minimizes soil background noise & that has a good response to vegetation biomass distributions.

Classic **NDVI**

Transformed **NDVI**





Yuma, CO, July 2, 2003, Source: QuickBird MS Image

Classic NDVI and Transformed NDVI do not account for effects of soil wetness (south slide of dark pivot); it over-estimates the biomass density in that part of the field. Same error occurs in mature fields that are wet from pivot irrigation.

Classic **TSAVI**

Classic **SAVI**

Yuma, CO, July 2, 2003, Source: QuickBird MS Image

Classic TSAVI and Classic SAVI handle the soil-wetness effect better than NDVI. However, the absolute values of SAVI do not track the effects of the specific soils present in this scene.

Optimized **GRUVI**

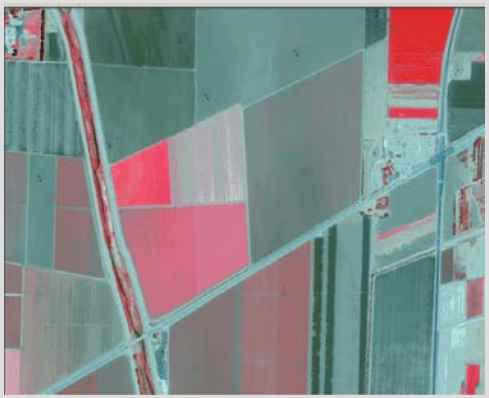
WDVI

Yuma, CO, July 2, 2003, Source: QuickBird MS Image

Optimized GRUVI minimizes the effects of soil background wetness and tracks the effects of the specific soils in this scene. Weighted-Difference VI overcorrects for the effects of soil wetness.

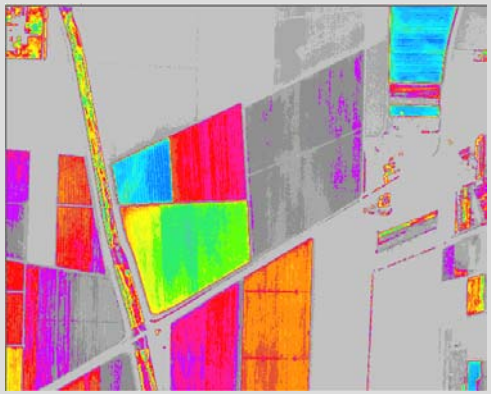
AgroWatch™ Products

AgroWatch™ Products: 4 Ways to Map Variability in an Ag Field



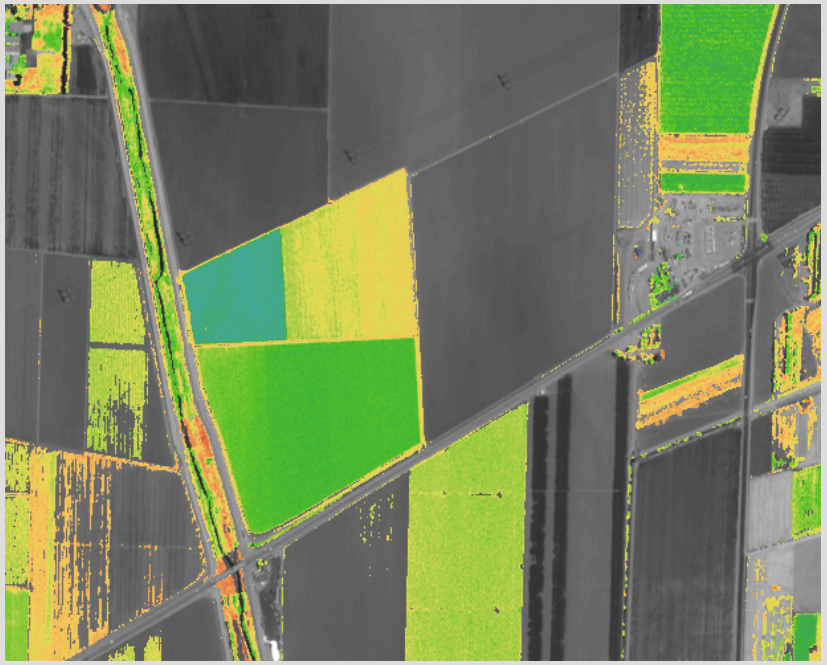
Color Infrared Reference Image

1



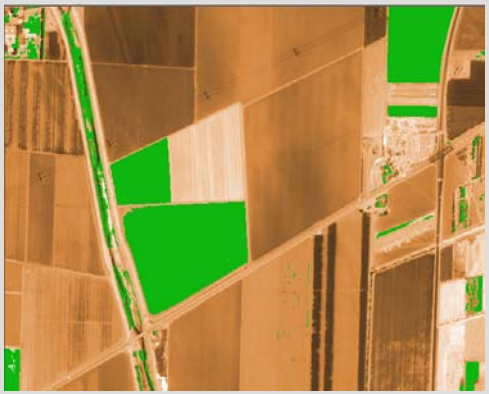
Green Vegetation Map

2



Vegetation Color (Hue) Map
QuickBird & Landsat Only

3



Soil Brightness Map

4

NOT SHOWN HERE:

QuickBird Green Veg Change Map

THIS IS SIMILAR TO SPOT-BASED Green Veg Change Map has a much higher spatial resolution

Comes from 2 or more QuickBird scenes

<u>Value of This New AgroWatch™ Product</u>
Identifies vegetated pixels (colored pixels).
Determines calibrated hue for these pixels.
Provides brightness for non-veg pixels.

Shows natural hue colors of vegetation.

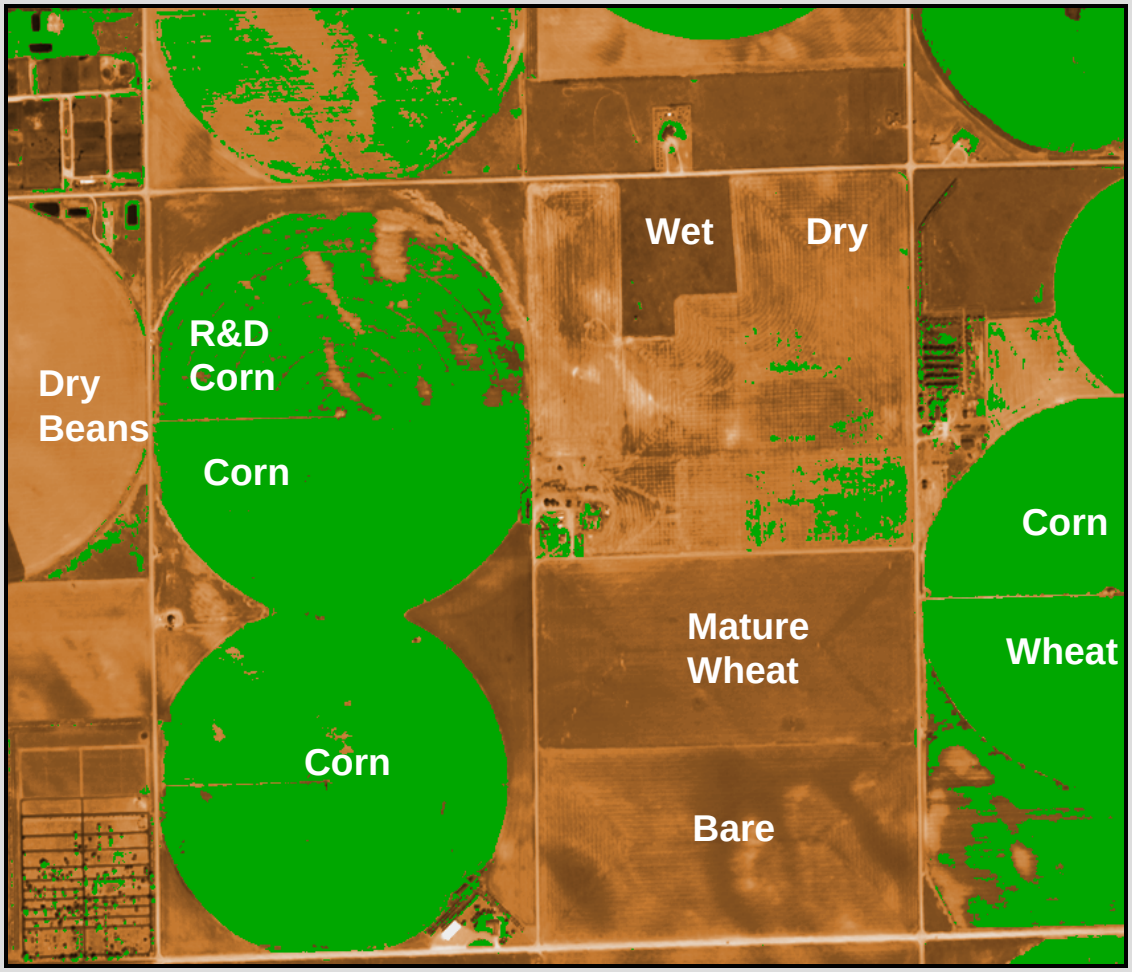
Consider: QuickBird Imagery, Yuma, CO

Yuma
DigitalGlobe, Inc.
QuickBird

8-ft Resolution
Multispectral
CIR Image

July 2, 2003

AgroWatch™ Soil Zone Index, Colorized (SZC)

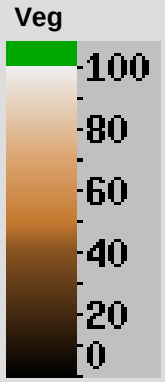


Yuma
DigitalGlobe, Inc.
QuickBird

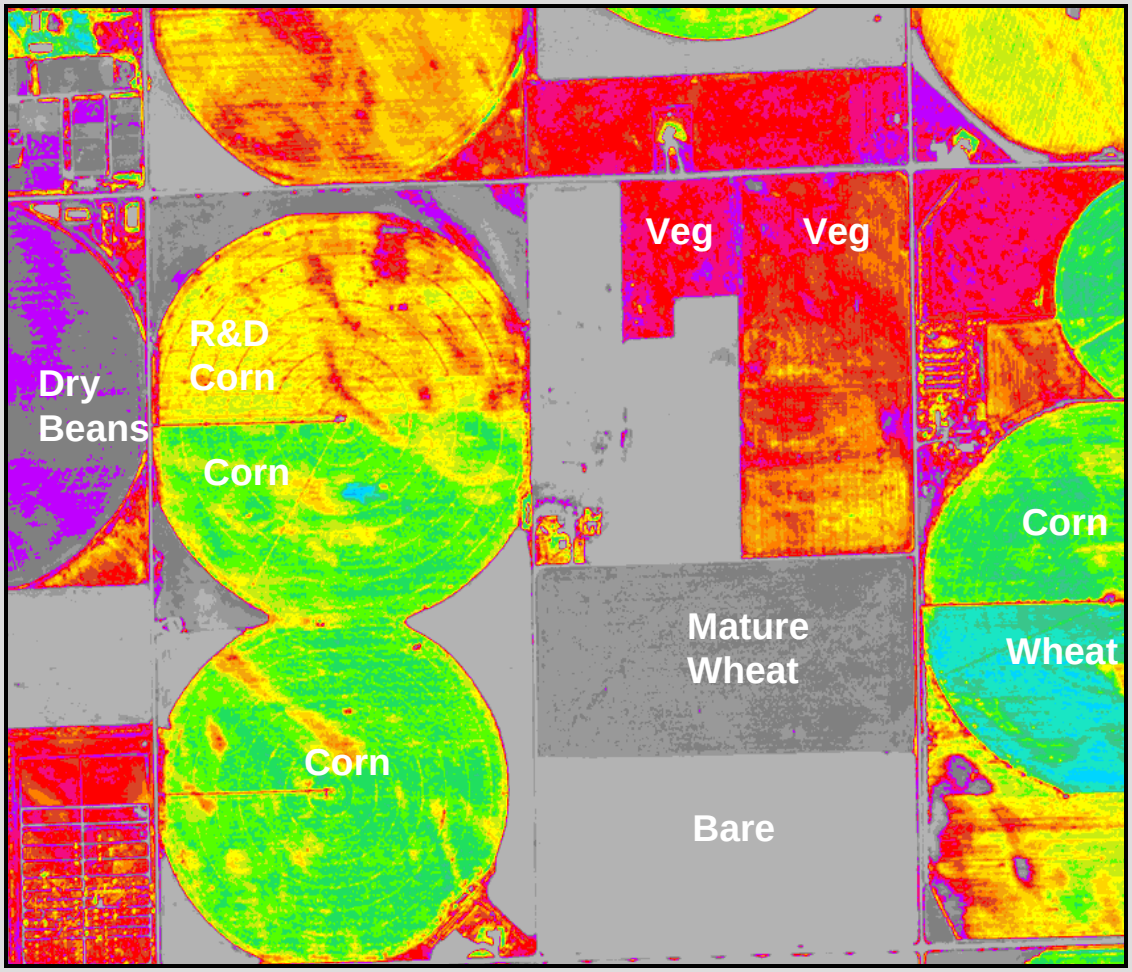
8-ft Resolution
Soil Zone
Index, Colorized
SZC

July 2, 2003

SZC Color Scale



AgroWatch™ Green Vegetation Index, Colorized (GVC)



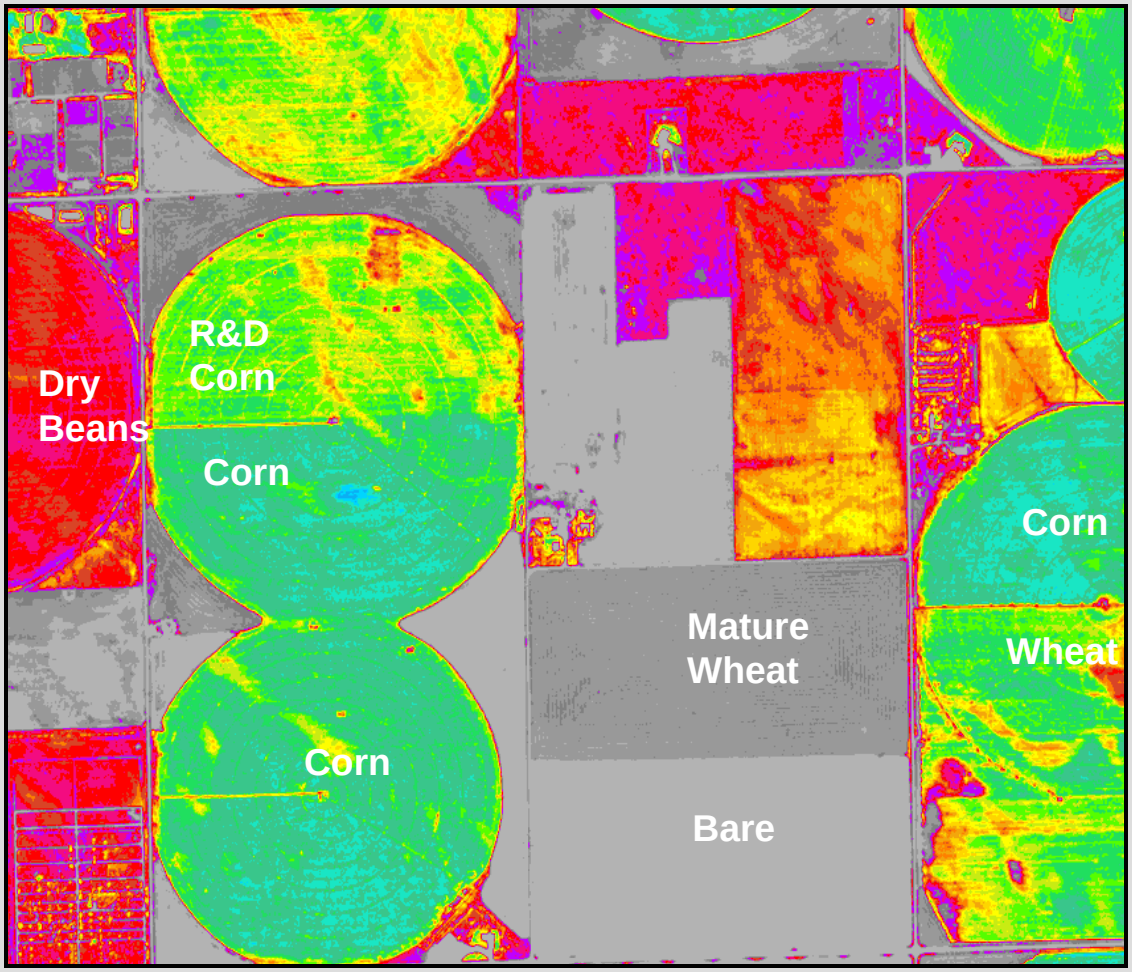
Yuma
DigitalGlobe, Inc.
QuickBird

8-ft Resolution
Green Vegetation
Index, Colorized
GVC

July 2, 2003

GVC Color Scale

AgroWatch™ Green Vegetation Index, Colorized (GVC)

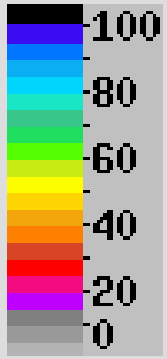


Yuma
DigitalGlobe, Inc.
QuickBird

8-ft Resolution Green Vegetation Index, Colorized GVC

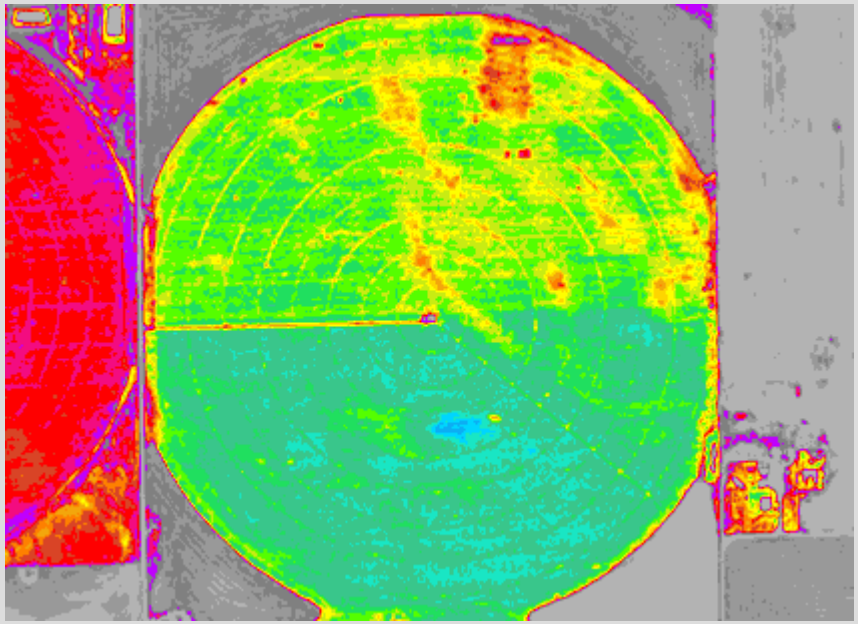
July 7, 2003

GVC Color Scale



Precise Change Mapping Can Be Done Based on GVC Values

QuickBird, Yuma, CO, Corn Fields Under Pivot Irrigation



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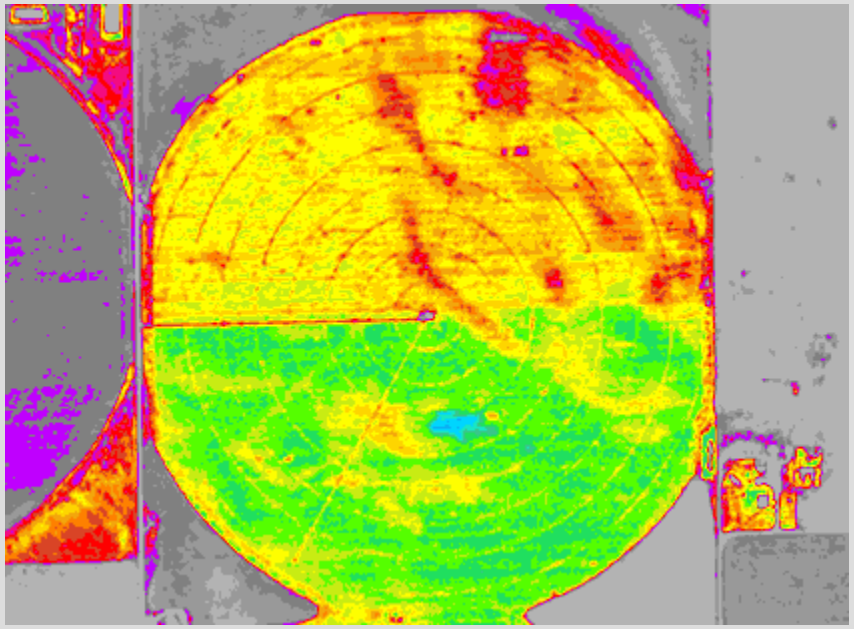


+

100

Shown at 1X Zoom.
Green Vegetation Index, Colorized (GVC).

July 7, 2003. Later Date.

Shown at 1X Zoom.
Green Vegetation Index, Colorized (GVC).

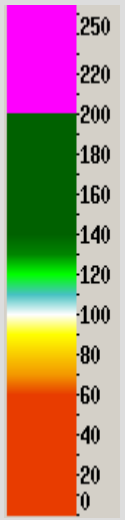
July 2, 2003. Earlier Date.

AgroWatch™ Change Product: Called ScoutAide™

QuickBird, Yuma, CO, Corn Fields Under Pivot Irrigation

- Re-georeference **Earlier** date to **Later** date.
- Resample **Earlier** date to match **Later** date.
- Perform raster subtraction on a pixel by pixel basis (and add 100 to result) to get **SAC** value.

SAC Color Scale



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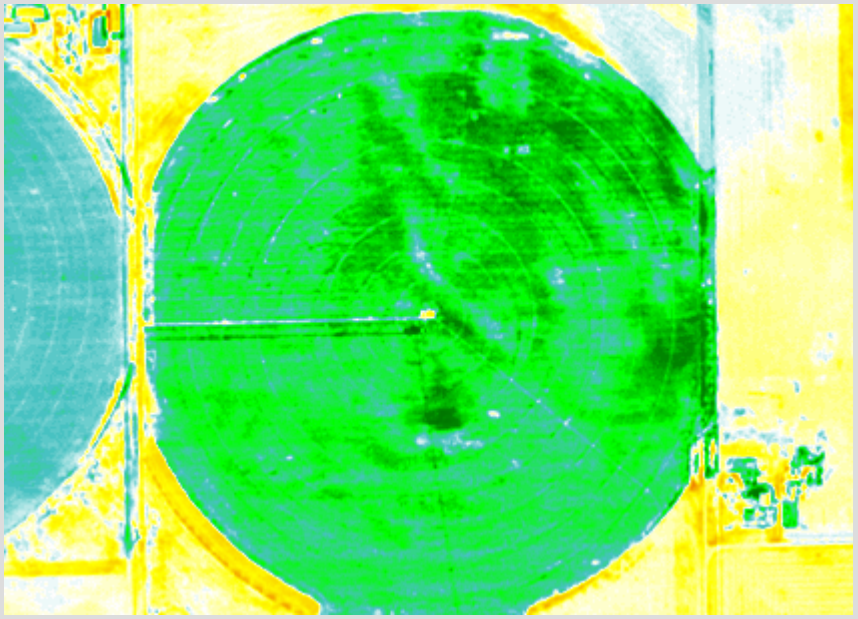
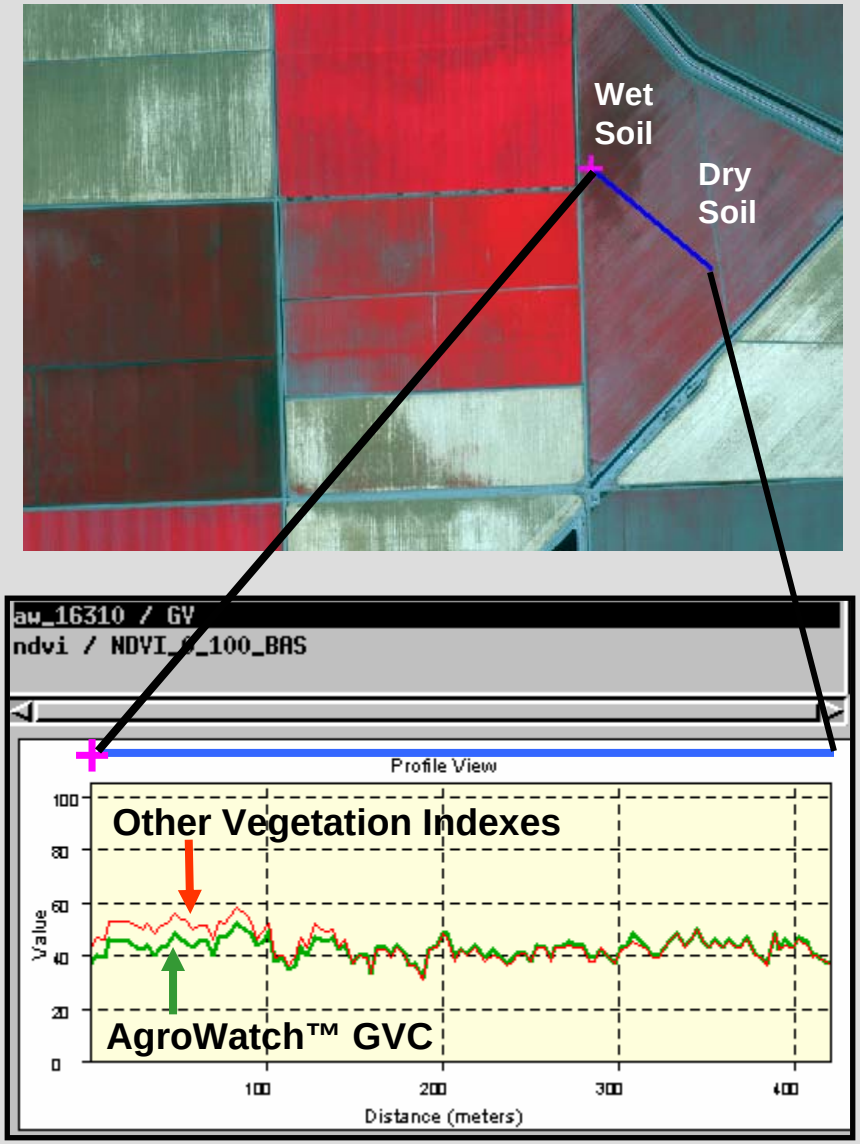


Shown at 1X Zoom.
GVC Change: Called ScoutAide, Colorized (SAC).

Change from July 2nd to July 7th, 2003 (plus 100 to make values > 0).

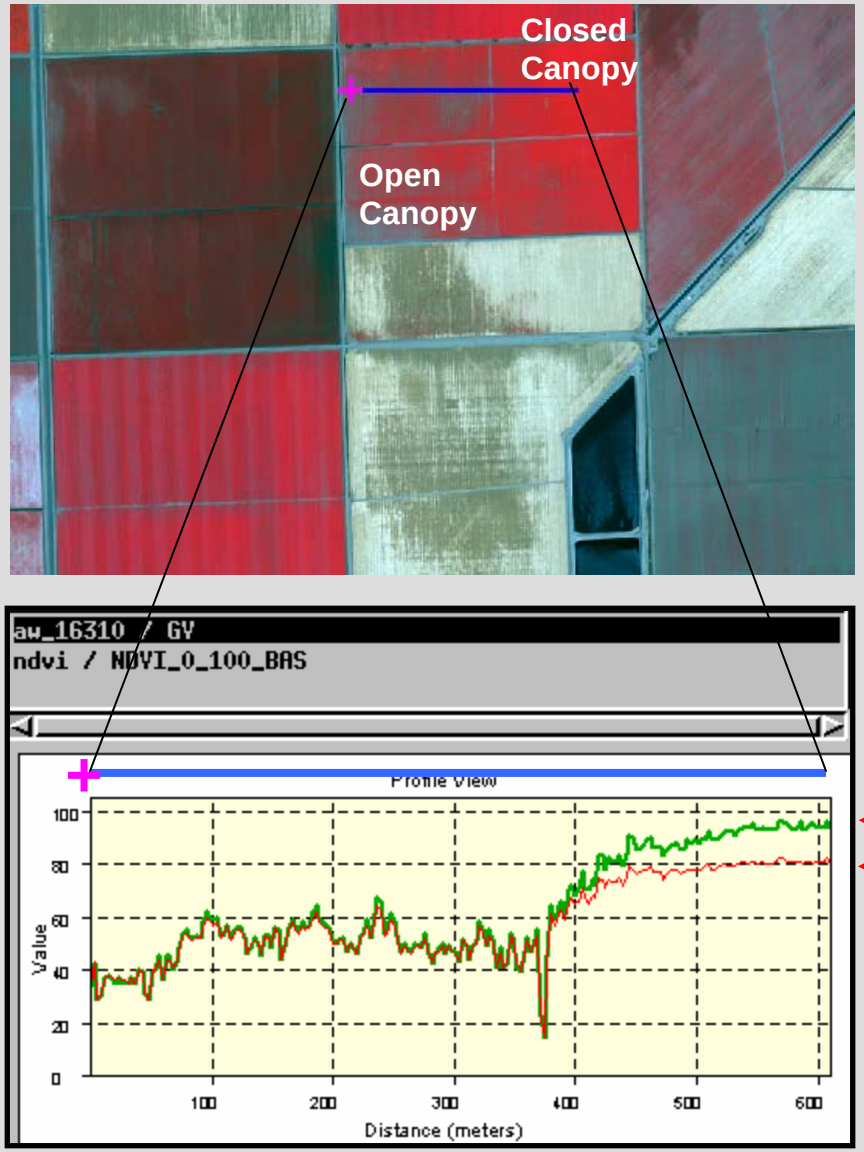
Irrigation does not Affect AgroWatch™'s GVI, Colorized (GVC) Values



AgroWatch™ GVC products are not affected by variations in background soil brightness, e.g. resulting from irrigation.

Other indexes erroneously indicate that 20-25% more vegetation is present when background soils are dark (e.g., when they are wet).

GVC Allows Measuring Changes in Canopy Density After Row Closure



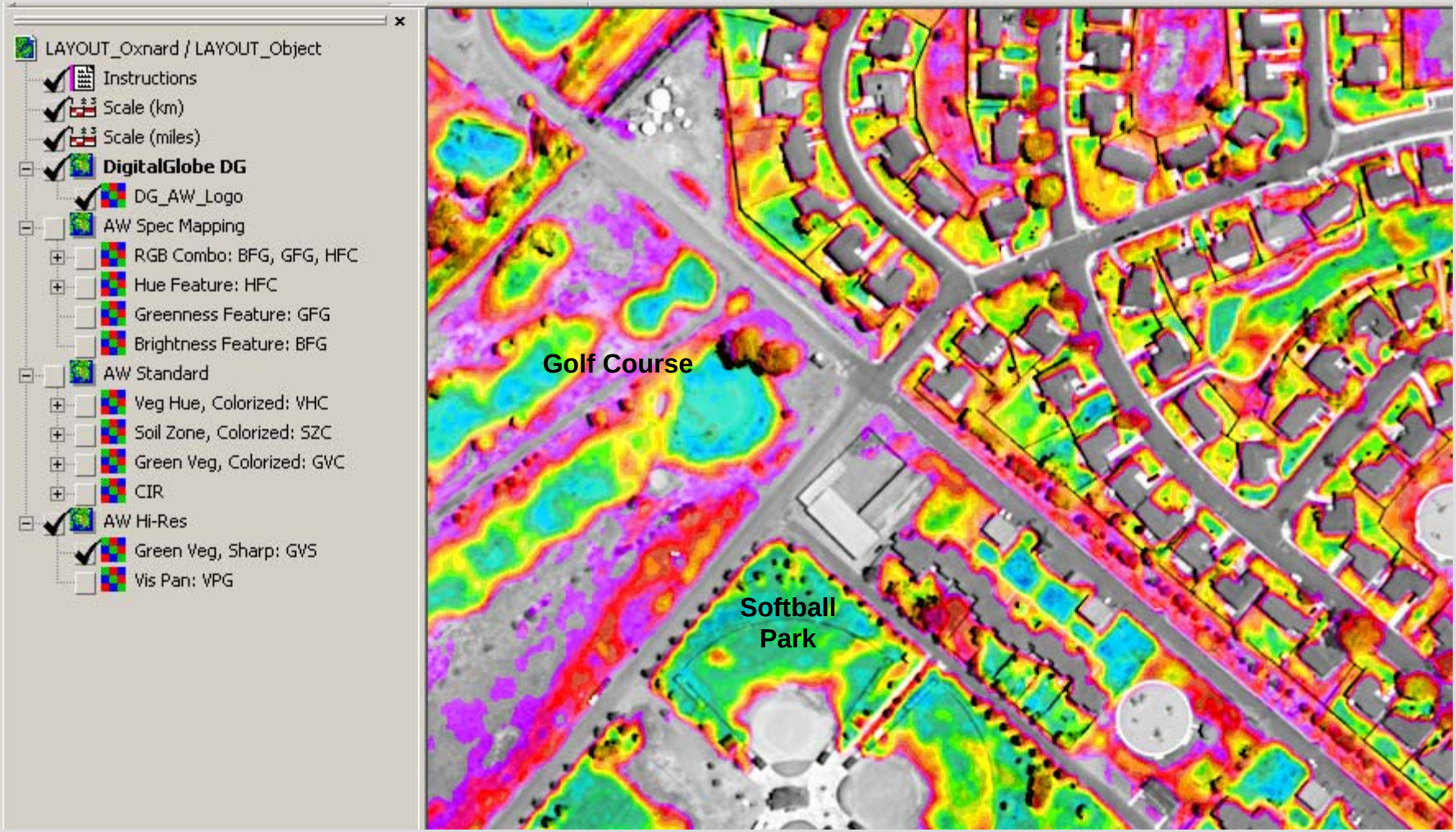
AgroWatch™ GVC products are uniquely sensitive to changes in canopy density after row closure.

AgroWatch™ GVC

Other Vegetation Indexes

Other indexes stop responding to changes in crop during growth / senescence when canopy closure occurs.

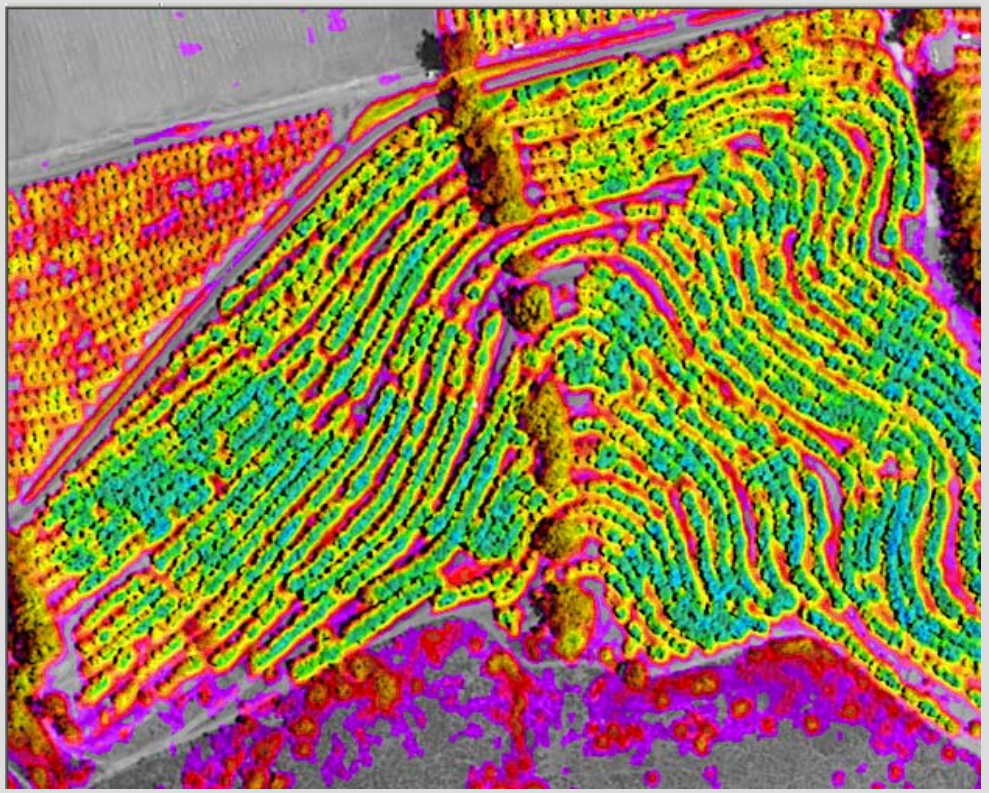
AgroWatch™
Green Veg Index (GVI), Sharpened: GVS
Urban Veg Mapping: 2-ft Res



AgroWatch™ GVS Products: Combining 2-ft Details with 8-ft GVC Colors

Visible Black & White Reference Image
QuickBird Only

<u>Value of This New Product</u>
Compatible with low-end GIS (or non-GIS).
8-Bit, Hi-Res image (smaller file size).
Looks like historic panchromatic (no NIR).
2-ft Resolution.

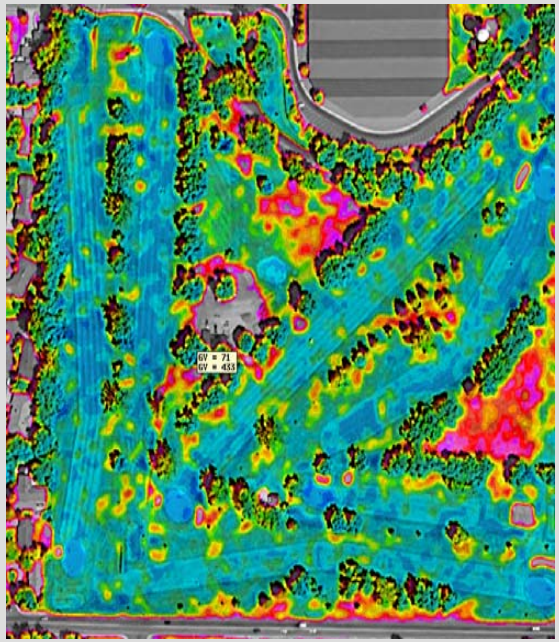


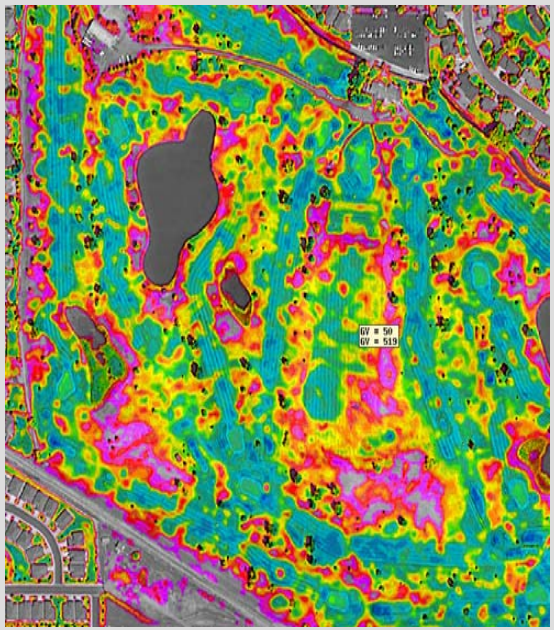
Green Vegetation Index, Sharpened: GVS
a.k.a., Canopy Greenness Map
QuickBird Only

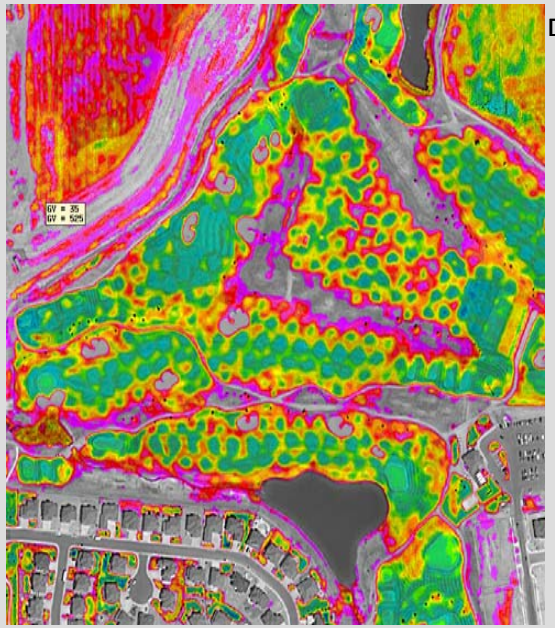
<u>Value of This New Product</u>
Compatible with low-end GIS (or non-GIS).
24-Bit, Hi-Res image (smaller file size).
Merges calibrated GVC colors with VPG.
2-ft Resolution.

AgroWatch™ HR Sharpened Product
Many other applications and opportunities

Three Longmont Golf Courses







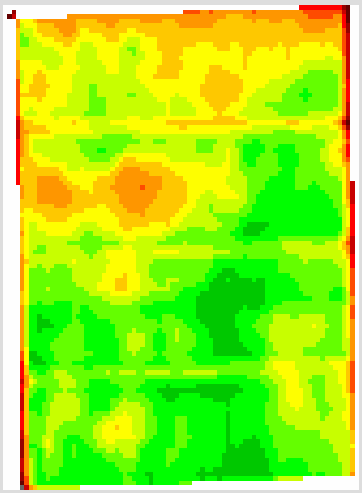
Green Vegetation Index, Sharpened

2 ft resolution

QuickBird Imagery
Collected August 14, 2002
Longmont, CO

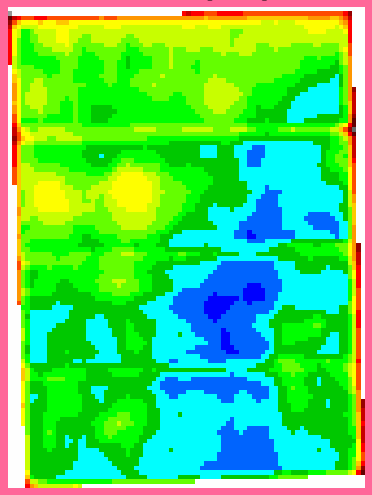
AgroWatch™ Green Vegetation Index for Different Imagers **Mix and Match HR and MR products**

SPOT (MR)



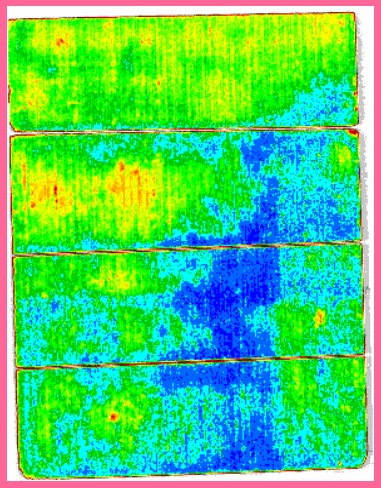
06/06/02

SPOT (MR)



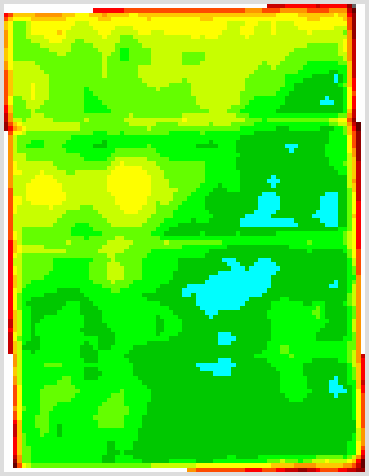
06/26/02

QuickBird (HR)



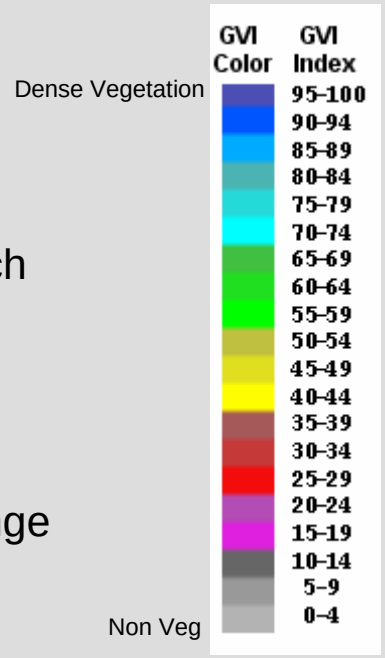
06/22/02

SPOT (MR)



07/21/02

Asparagus Ferns
Central California
40 Acre Blocks

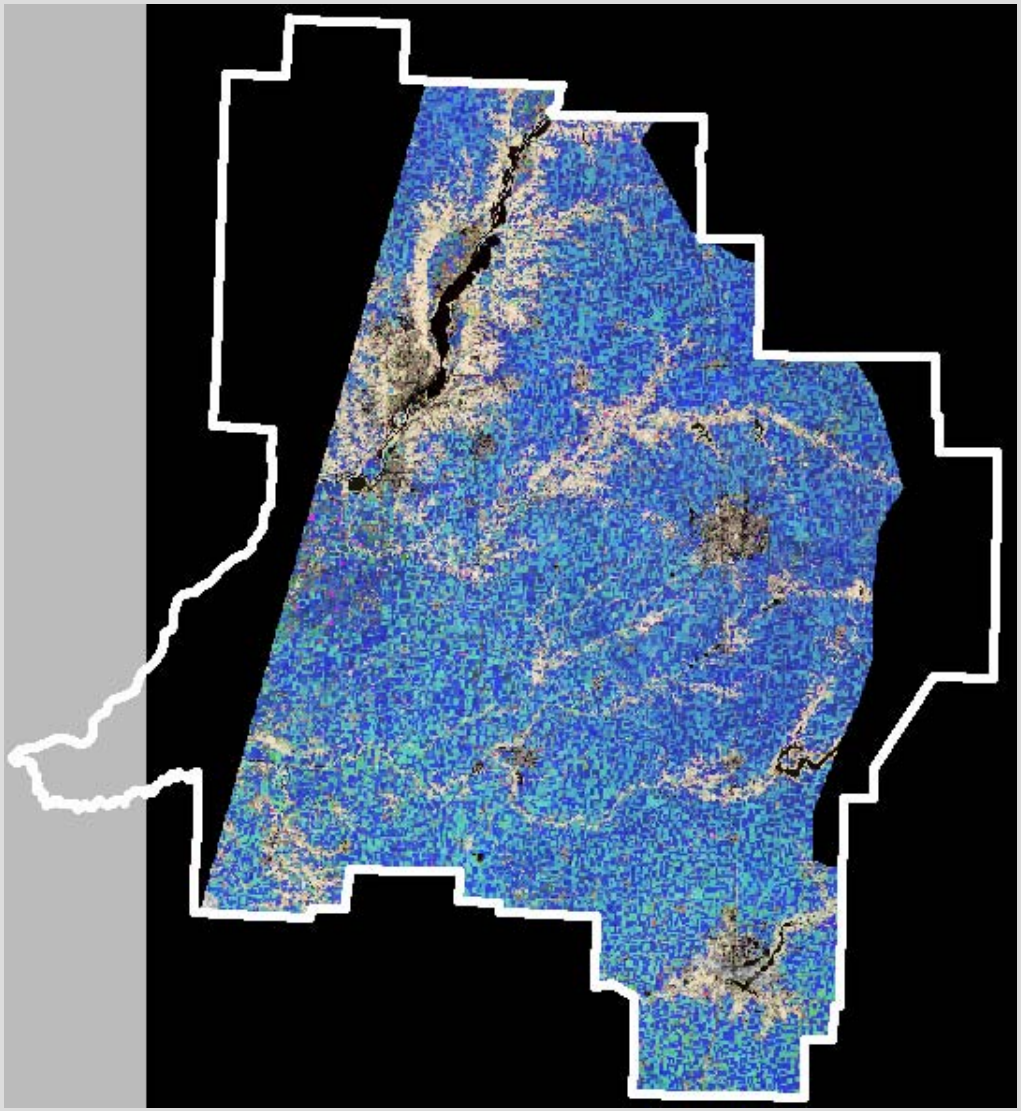


AgroWatch™ products are calibrated with a technique that is **imaging-system independent**.

- Users can mix and match **SPOT** and **QuickBird** imagery-based **Information Products** regardless of resolution.
- Users can quantify change and rate of change in a crop between dates

Usefulness of Being Able to Track Changes in Vegetation Density from Date to Date During a Growing Season

Land-Cover Mapping Possibilities

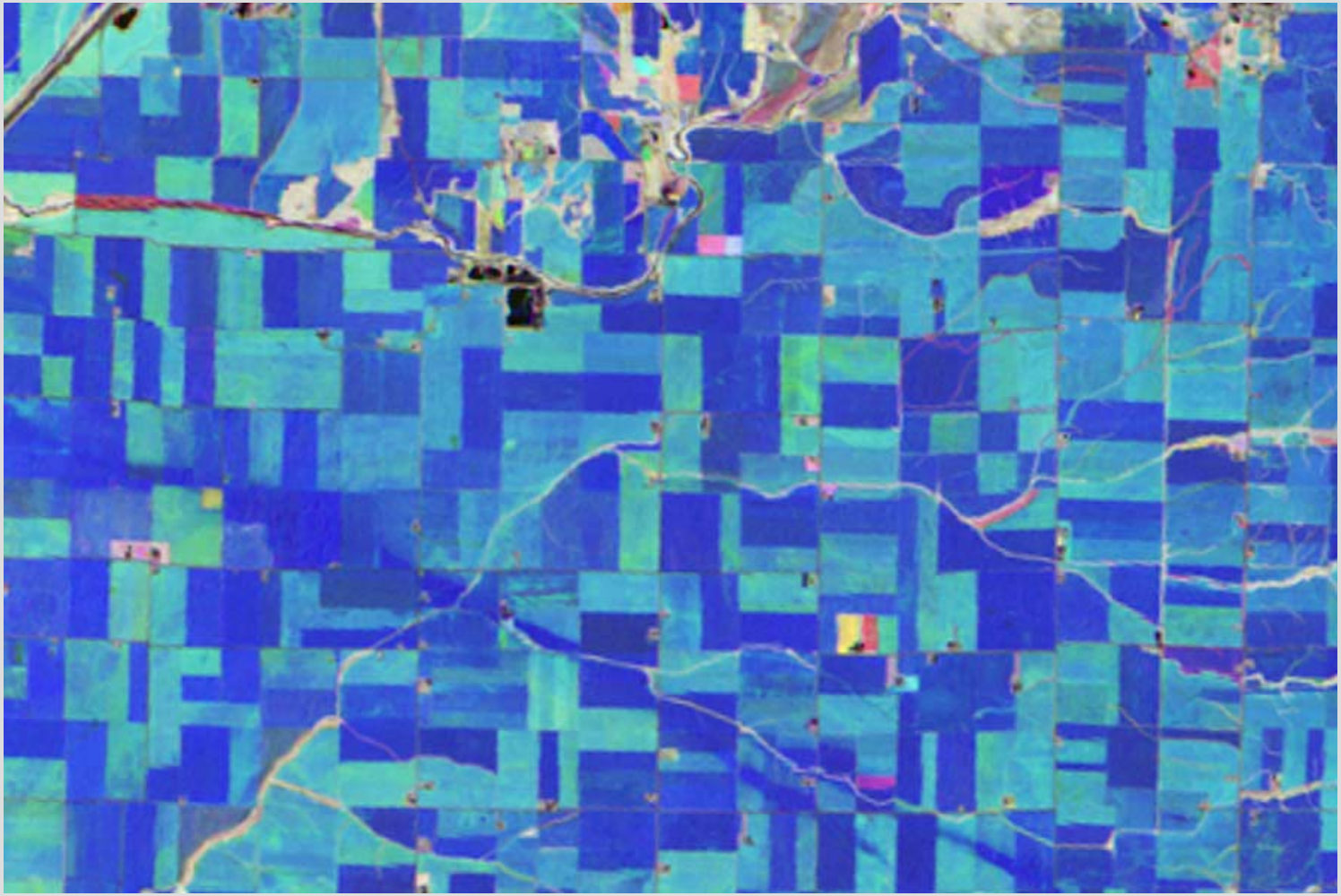


- This **RGB** color combo of AgroWatch™ **Green Feature** (**GF**) rasters shows general kinds of land cover in the selected AOI. White Line outlines **IL CRD 4**.
- **See next slide for full-resolution details.**
- **Dark blue** areas are **soybean** fields.
- **Light blue & greenish** areas are **corn** fields.
- **Gray** areas are **woodland** & **urban**.
- **Dark** areas are **open water**.

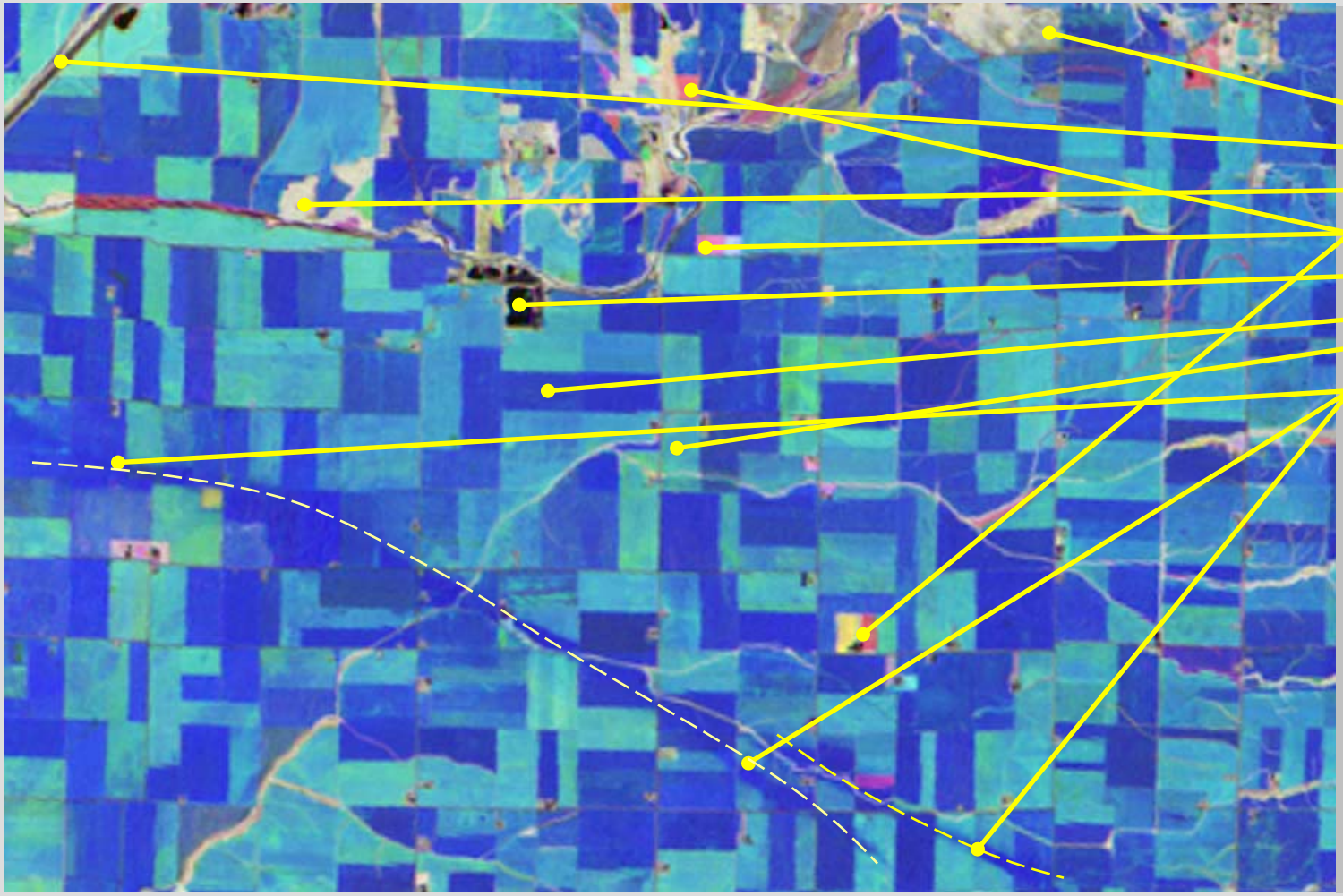
Multidate Color Combo of Landsat Data

R = GF_Jun05, G = GF_Jun21, B = GF_Aug24

All in 2003



Damage by a Tornado is Evident in this Multidate Image that Uses Calibrated Vegetation Index Crop Insurance Implications



GENERAL LAND COVER TYPES:

- **Urban**
- **Highway**
- **Woodland**
- **Spring Crop**
- **Open Water**
- **Soybeans (Blue)**
- **Corn (Greenish)**
- **Path of Damage**

(Hail or Tornado?): Long, Thin WNW to ESE Oriented Non-Vegetation Paths Appeared in the 06/21/03 Data and Then Became Dense Volunteer Vegetation in the 08/24/03 Data. The CIR Image was Checked for Possible Clouds; There were no Cirrus Clouds or Contrails.

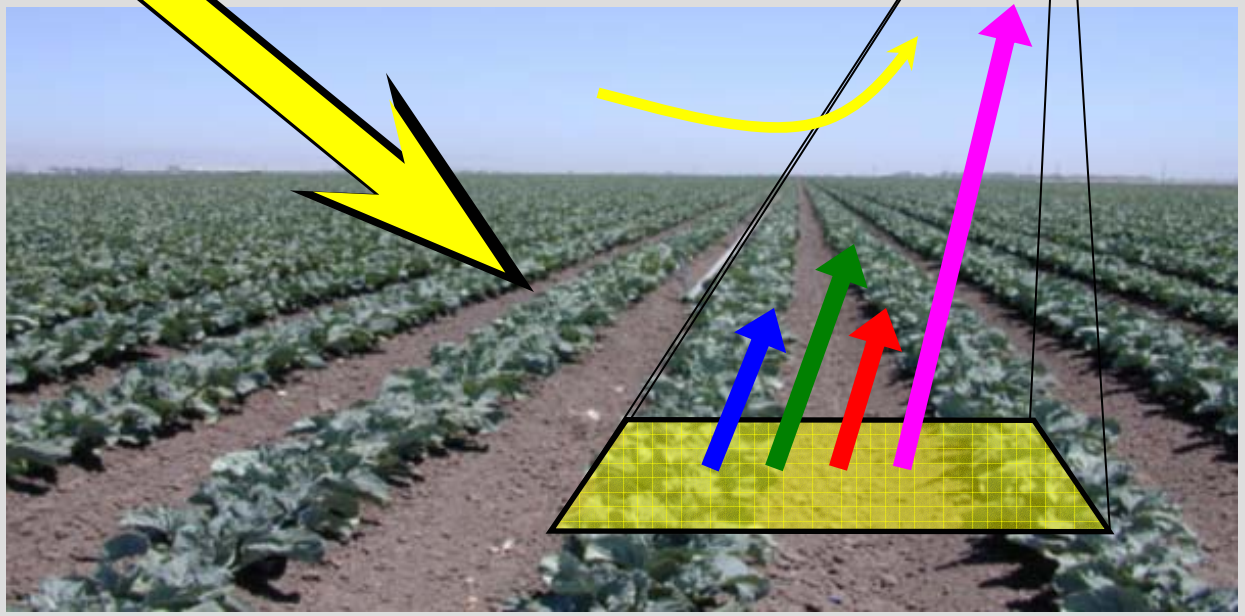
These 3 dates in 2003 appear to be sufficient for land-cover classification.

EarthMap Solutions, Inc.

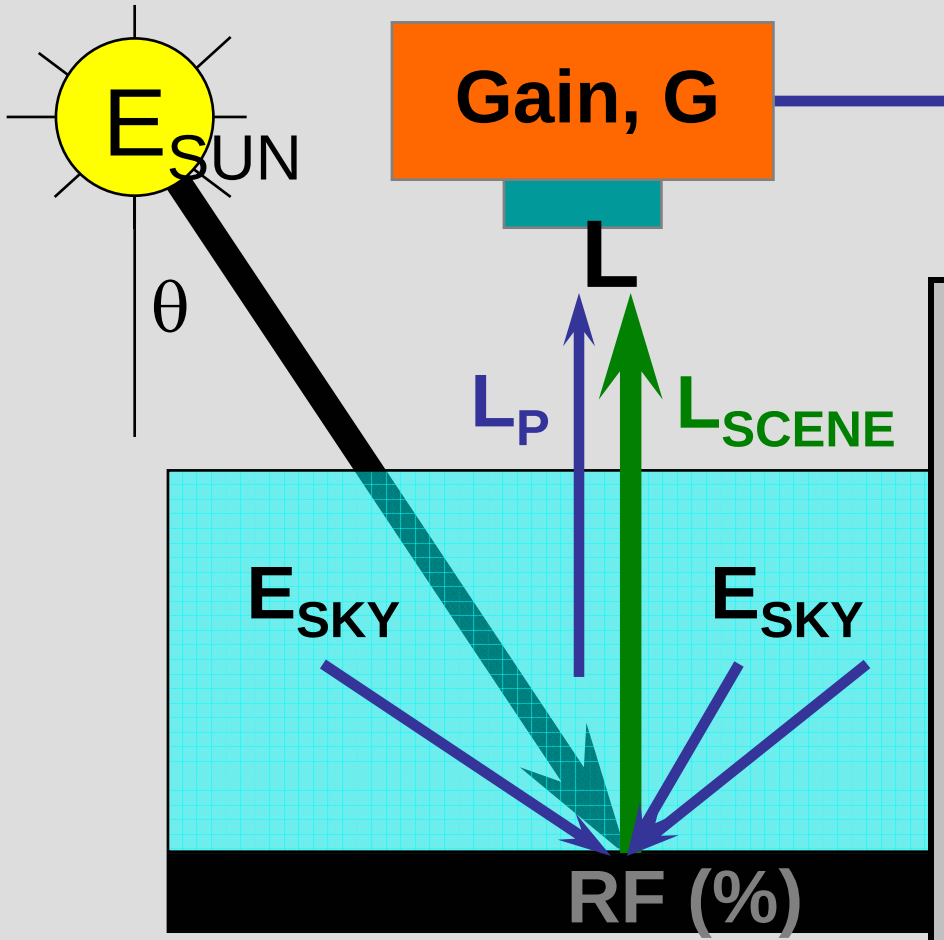
Irradiance / Reflectance / Radiance => Image DN

Spectral irradiance
of the sun

BL GL RL NA
Spectral radiance
of the scene



REFLECTANCE FACTOR, RF (%)



RV

Image Raster Value

Thus, $RF = (RV - RV_P)\ m$

where *m* and RV_P are the Empirical Line Method's calibration factors (each band)

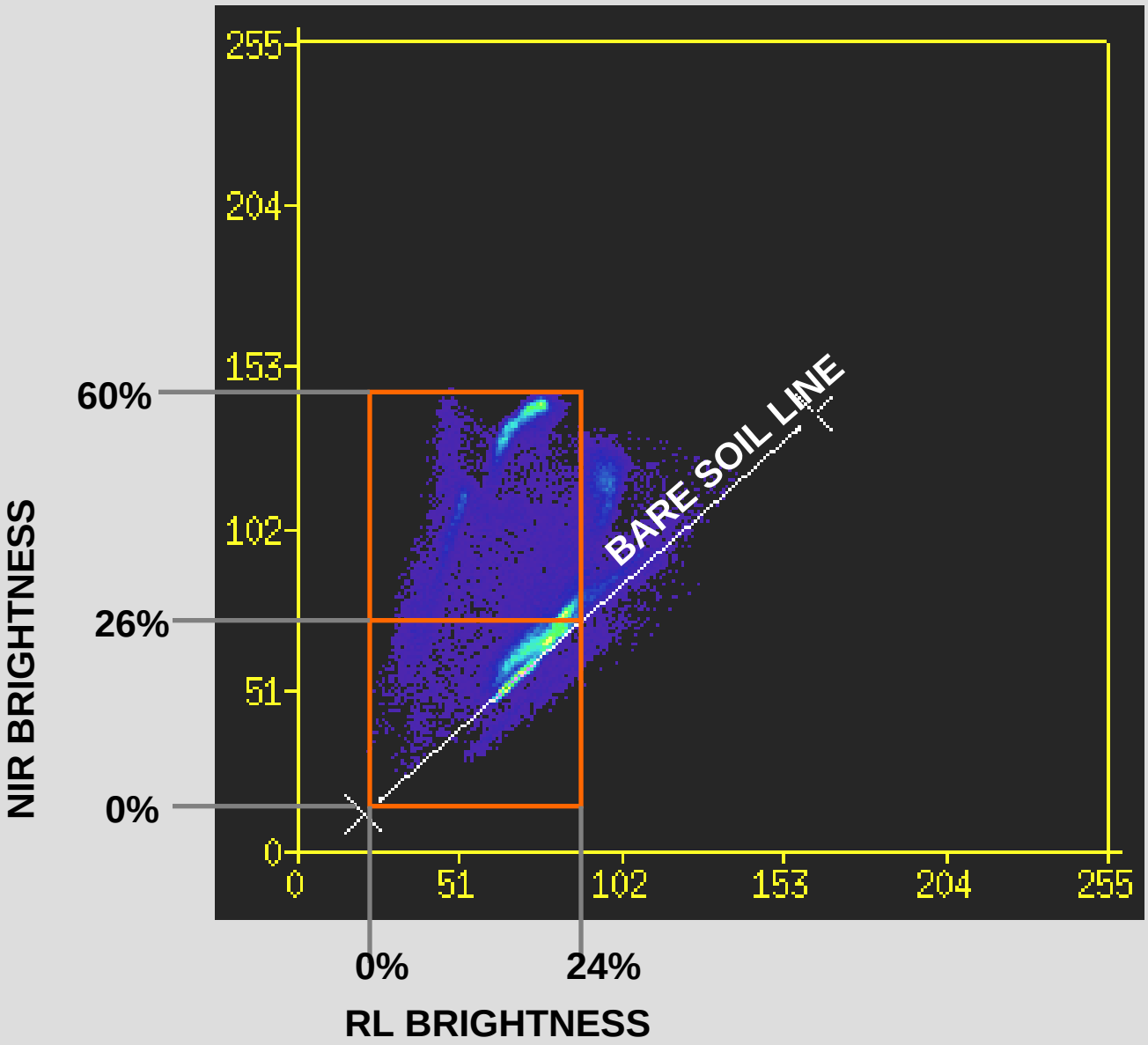
RV_P is a RV where:

$E_{SFC} = 0$ (shadow)

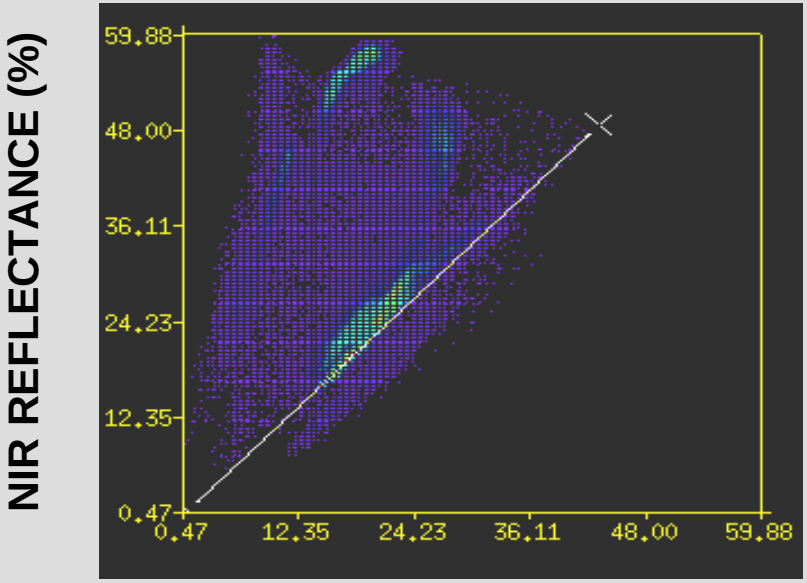
or $RF = 0$ (black object)

$$RV = \left\{ \frac{(E_{SUN}\ t_S\ \cos\theta\ RF\ +\ E_{SKY})\ t_O}{\pi} + L_P \right\} G$$

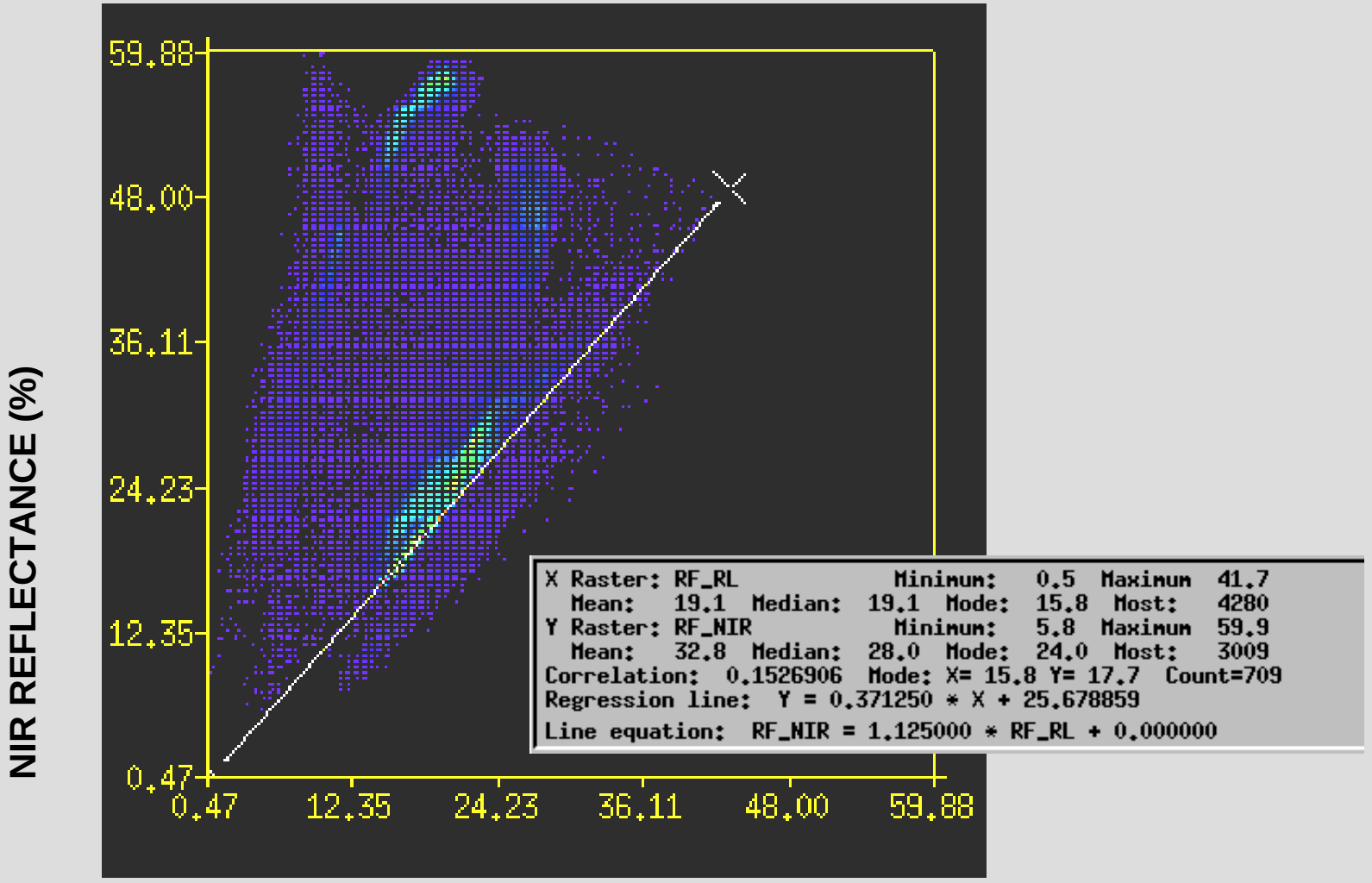
Calibrate


255
204
153
102
51
0
60%
26%
0%
BARE SOIL LINE
NIR BRIGHTNESS
0
51
102
153
204
255
0%
24%
RL BRIGHTNESS

Calibrate


NIR REFLECTANCE (%)
59.88
48.00
36.11
24.23
12.35
0.47
0.47
12.35
24.23
36.11
48.00
59.88
RL REFLECTANCE (%)

Calibrate


59.88
48.00
36.11
24.23
12.35
0.47
0.47
12.35
24.23
36.11
48.00
59.88
NIR REFLECTANCE (%)
RL REFLECTANCE (%)
X Raster: RF_RL Minimum: 0.5 Maximum 41.7
Mean: 19.1 Median: 19.1 Mode: 15.8 Most: 4280
Y Raster: RF_NIR Minimum: 5.8 Maximum 59.9
Mean: 32.8 Median: 28.0 Mode: 24.0 Most: 3009
Correlation: 0.1526906 Mode: X= 15.8 Y= 17.7 Count=709
Regression line: Y = 0.371250 * X + 25.678859
Line equation: RF_NIR = 1.125000 * RF_RL + 0.000000

EarthMap SOLUTIONS

www.earthmapsolutions.com

303-485-0868

Grow Smarter. Manage Better. See Where you cannot Walk.

1860 Industrial Circle, Suite D, Longmont, CO 80501

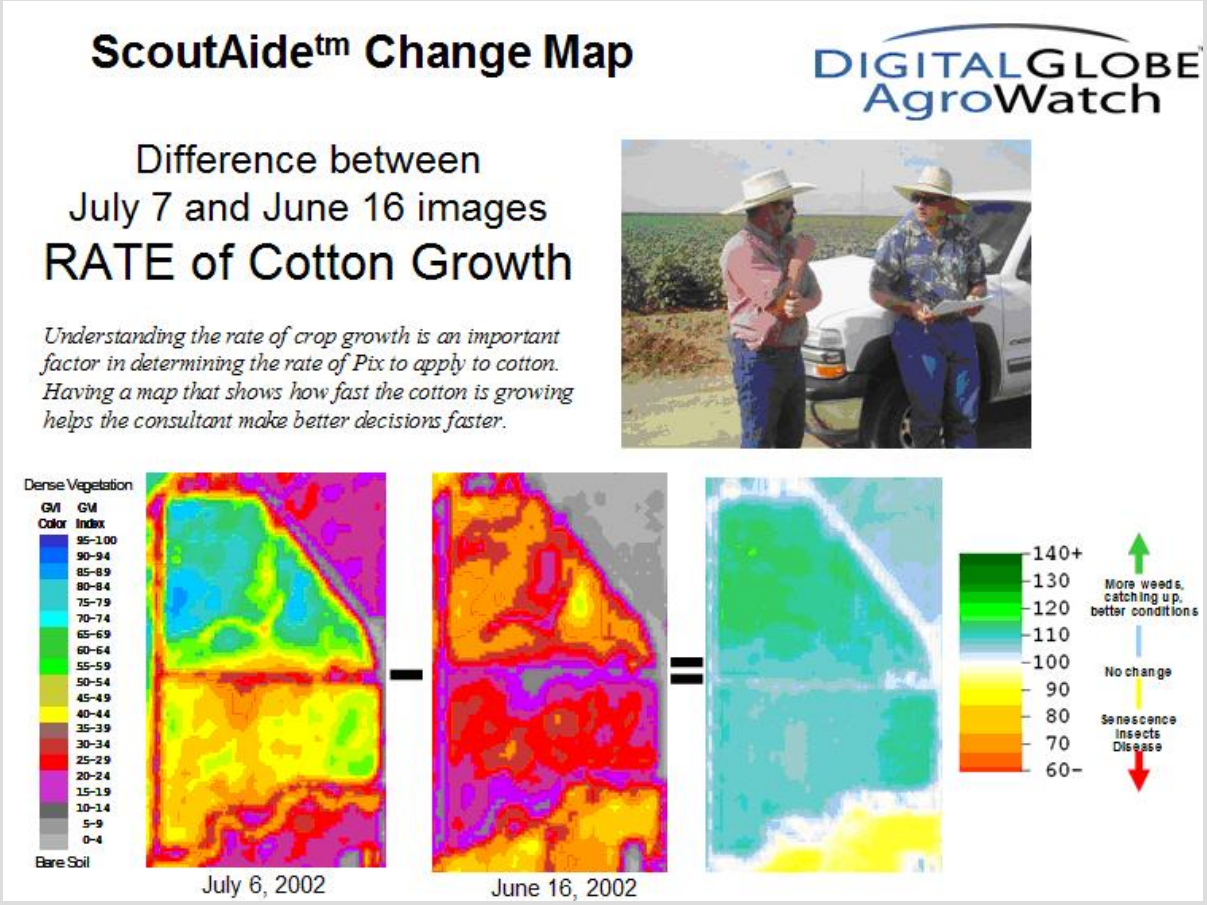
Precision Agriculture

AgroWatch™

- **Green Vegetation**
- Soil Zone Map
- **Scout Aide™**
- Canopy Density Maps

Variable Rate Pix

Yield Trax



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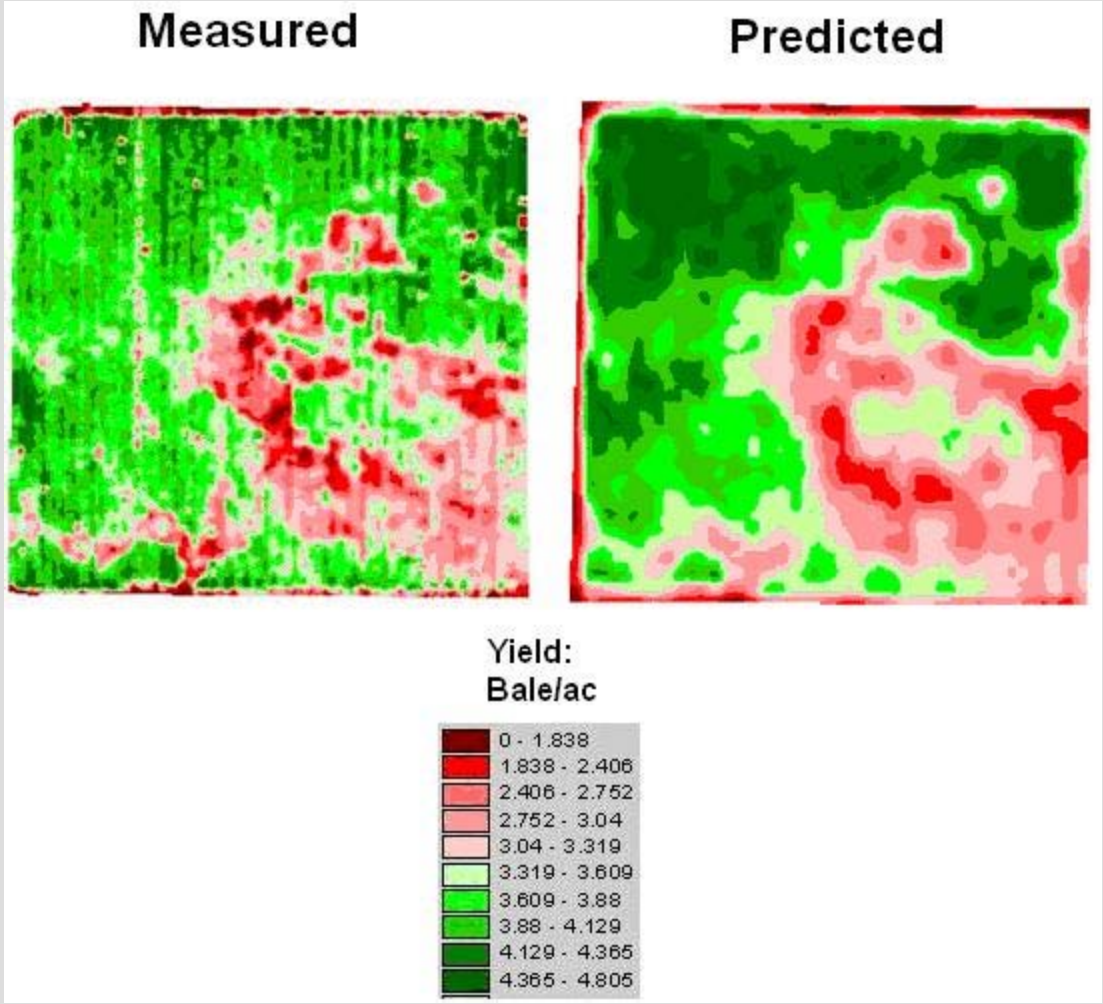
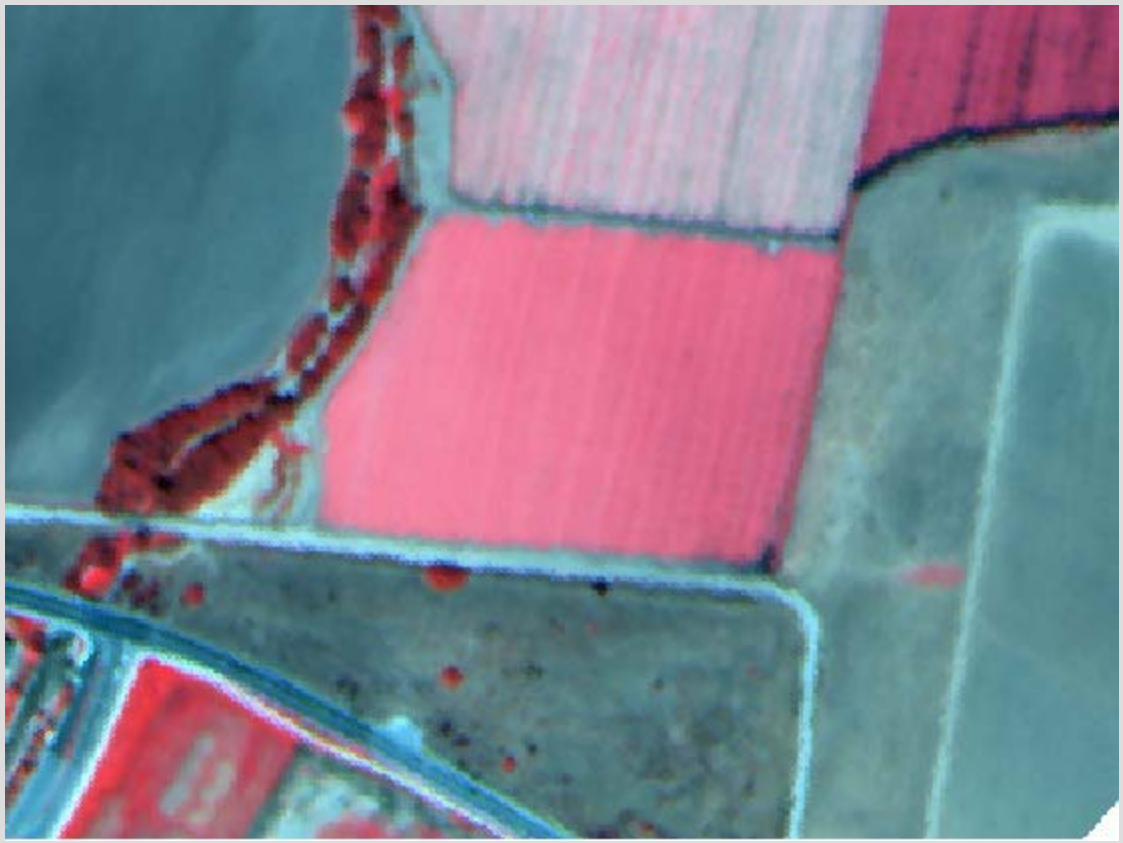


LAB

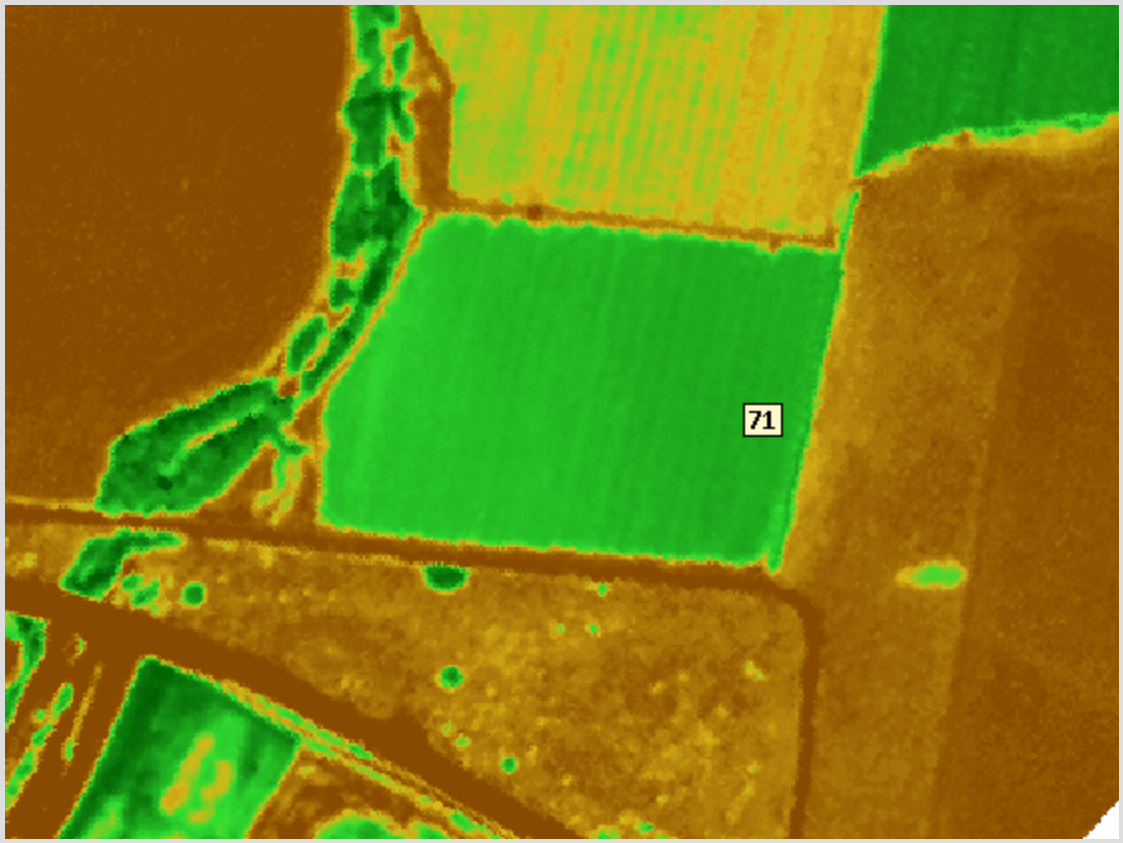
FOCUS:

How to Do Basic Tasks with a Free Software Package (TNTlite, from MicroImages, Inc.)

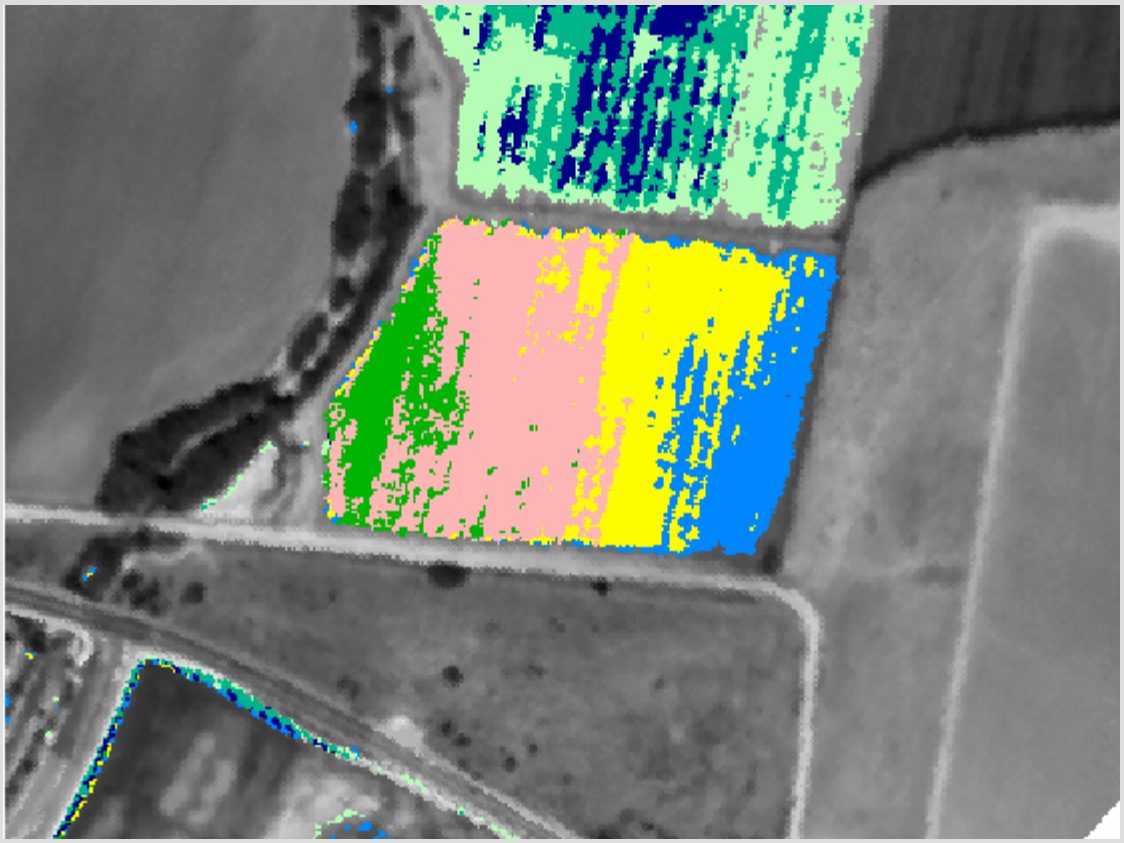
Input
Multispectral Raster Set



Input
AgroWatch™ Products



Output
Vegetation Classification Map



Output
Management Zones Map