Geo-informatics in Precision Agriculture

Juthasinee Thanyapraneeedkul, Ph D.
Thammasat University, Faculty of Science and Technology,
Department of Environmental Science.
Outline

- Introduction
- Basics of remote sensing (RS)
- Electromagnetic wave
- Thermal imaging
- RS in precision agriculture
- RS band composite
- Hyperspectral Remote Sensing
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GIS Data Model

Raster and vector data with attribute table
- Raster data: rows and columns of values representing spatial phenomenon;
- Vector data: representation by points, lines and areas;
Attributes: descriptive data stored in a database table
(Remote Sensed) image, photo....
Platform types and observation objects

<table>
<thead>
<tr>
<th>Platform types and observation objects</th>
<th>Table 5.1.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>platform</td>
<td>altitude</td>
</tr>
<tr>
<td>geostationary satellite</td>
<td>36,000m</td>
</tr>
<tr>
<td>(earth observation)</td>
<td></td>
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<tr>
<td>circular orbit satellite</td>
<td>500km -</td>
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<td>(earth observation)</td>
<td>1,000km</td>
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<tr>
<td>space shuttle</td>
<td>240km -</td>
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<tr>
<td></td>
<td>350km</td>
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<td>radio-sonde</td>
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<tr>
<td></td>
<td>100km</td>
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<td>high altitude jet-plane</td>
<td>10km -</td>
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<tr>
<td></td>
<td>12km</td>
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<tr>
<td></td>
<td></td>
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<tr>
<td>low or middle altitude plane</td>
<td>500m -</td>
</tr>
<tr>
<td></td>
<td>8,000m</td>
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<td></td>
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<tr>
<td>aerostat</td>
<td>500m -</td>
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<tr>
<td></td>
<td>3,000m</td>
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<td></td>
<td></td>
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<tr>
<td>helicopter</td>
<td>100m -</td>
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<tr>
<td></td>
<td>2,000m</td>
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<td></td>
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</tr>
<tr>
<td>radio-controlled plane</td>
<td>below 500m</td>
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<tr>
<td></td>
<td>500m</td>
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<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>hang-plane</td>
<td>50 - 500m</td>
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<tr>
<td>hang-balloon</td>
<td>800m</td>
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<tr>
<td>cable</td>
<td>10 - 40m</td>
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<td>crane car</td>
<td>5 - 50m</td>
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<tr>
<td>ground measurement car</td>
<td>0 - 30m</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Diagrams:
- MODIS satellite
- World View 2 satellite
- Octocopter UAS
- SenseFly eBee UAS
Types of sensor

- Non-Scanning
  - Non-Imaging
    - Microwave Radiometer
    - Magnetic sensor
    - Gravimeter
    - Fourier Spectrometer
    - Others
  - Imaging
    - Camera
      - Monochrome
      - Natural Color
      - Infrared
      - Color Infrared
      - Others
    - Image Plane Scanning
      - TV Camera
      - Solid Scanner
    - Object Plane Scanning
      - Optical Mechanical Scanner
      - Microwave Radiometer
- Scanning
  - Imaging
    - Non-Imaging
      - Microwave Radiometer
      - Microwave Altimeter
      - Laser Water Depth Meter
      - Laser Distance Meter
    - Object Plane Scanning
      - Real Aperture Radar
      - Synthetic Aperture Radar
    - Image Plane Scanning
      - Passive Phased Array Radar
Passive vs. Active Sensing

- Passive:
  - Measure energy that is naturally available.
  - The sun's energy is either reflected, as it is for visible wavelengths, or absorbed and then re-emitted, as it is for thermal infrared wavelengths.
  - Can only take place during the time when the sun is illuminating the Earth.

- Active:
  - Provide their own energy source for illumination.
  - The sensor emits radiation which is directed toward the target to be investigated.
  - The radiation reflected from that target is detected and measured by the sensor.
  - Ability to obtain measurements anytime, regardless of the time of day or season.
Incoming Solar radiation

- **SOLAR**
  - Short Wavelength
  - Visible: (Reflective Bands)
  - Infrared: (Emissive Bands)

- **THERMAL**
  - Long Wavelength
  - Infrared: (Emissive Bands)

**Data:**
- 29% reflected
- 23% absorbed in the atmosphere
- 48% absorbed at the surface

**Diagram Details:**
- Solar radiation incoming at $140 \text{ W/m}^2$
- Solar radiation scattering, cloud reflection, and earth reflection.
- Infrared radiation from the atmosphere and cloud emission.

**Source:**
CTCN Climate Technology Centre & Network
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Electromagnetic wave

Blue is 0.4 to 0.5 microns (or 400 to 500 nanometers)
Green is 0.5 to 0.6 microns (or 500 to 600 nanometers)
Red is 0.6 to 0.7 microns (or 600 to 700 nanometers)
Near Infrared is 0.7 to 0.9 microns (or 700 to 900 nanometers)

Wavelength = \( \frac{\text{Speed of Light}}{\text{Frequency}} \)
Multi-spectral Remote Sensing

- Sun
- Incident radiation
- Scatter/absorption
- Reflected radiation
- Diffusion
- Target
- Absorption
- Sensor
- Band 1
- Band 2
- Band 3
- Band 4
- Satellite
- Prism
DN is scaled from Radiance measured by sensors

\[ L_{\lambda} = \text{gain} \times \text{DN} + \text{offset} \]

or

\[ L_{\lambda} = \frac{L_{\text{MAX}_{\lambda}} - L_{\text{MIN}_{\lambda}}}{Q_{\text{CALMAX}} - Q_{\text{CALMIN}}} (Q_{\text{CAL}} - Q_{\text{CALMIN}}) + L_{\text{MIN}_{\lambda}} \]

\[ \text{gain} = \frac{L_{\text{MAX}_{\lambda}} - L_{\text{MIN}_{\lambda}}}{Q_{\text{CALMAX}} - Q_{\text{CALMIN}}} \]

\[ \text{offset} = -\frac{L_{\text{MAX}_{\lambda}} - L_{\text{MIN}_{\lambda}}}{Q_{\text{CALMAX}} - Q_{\text{CALMIN}}} + L_{\text{MIN}_{\lambda}} \]

\[ \text{DN} = Q_{\text{CAL}}, \text{offset} = \text{bias} \]

DN (Digital Number)

Radiance

ToA Reflectance

Atmospheric correction

Reflectance

\[ \rho_{\lambda} = \frac{\pi L_{\lambda}}{G_{\lambda}} = \frac{\pi L_{\lambda}}{\mu_i E_{\lambda}} \]

\[ E_{\lambda} = \frac{E_{\text{SUN}_{\lambda}}}{d_s^2} \]

\( E_{\text{SUN}_{\lambda}} \): Exo - atmospheric Solar Spectral Irradiance \( W / m^2 \cdot \mu m \)

\( E_{\text{SUN}_{\lambda}} \): Average Exo - atmospheric Solar Spectral Irradiance \( W / m^2 \cdot \mu m \)

\( d_s \): Earth - Sun distance in astronomical units

\( \mu_i = \cos(\theta_i), \theta_i \): Solar zenith angle

Please go to for each satellite calibration

**Reflectance**: Ratio of reflected flux from the surface to the incident flux.
Ranges from **0 to 1**.
Equipment: **Spectrometer**

**Spectral Reflectance**: Reflectance w.r.t. specific wavelength. Spectral Reflectance is unique and different from one object to an unlike object.
Ranges from **0 to 1**.
Equipment: **Spectrophotometer**
Spectral Signature

Soil

Vegetation

Snow

Ocean
http://www.seos-project.eu/modules/remotesensing/remotesensing-c06-p03.html
Terminology of radiant energy

Energy from the Earth Atmosphere over time is Flux, which strikes the detector area Irradiance at a given wavelength interval Monochromatic Irradiance over a solid angle on the Earth Radiance observed by satellite radiometer

Emitted is described by the Planck function, which can be inverted to Brightness temperature can be converted to Surface temperature

Brightness Temperature is the temperature, in Kelvin, of a blackbody that emits the observed radiance

Reflected can be converted to TOA Reflectance Atmospheric correction Reflectance

Radiance is the “flux of energy (primarily irradiant or incident energy) per solid angle leaving a unit surface area in a given direction”
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Thermal imaging

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The Planck function

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Brightness temperature

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Surface temperature

Brightness Temperature is the temperature, in Kelvin, of a blackbody that emits the observed radiance
THERMAL INFRARED RADIATION is a form of electromagnetic radiation with a wavelength between 3 to 14 micrometers (μm). Its flux is much lower than visible flux.

All objects have a temperature above absolute zero (0 K) emit EM energy (in 3.0-100 μm).
- Human being has normal 98.6 °F (37 °C)
Our eyes are only sensitive to visible energy (0.4-0.7 μm). Human sense thermal energy through touch. While detectors (sensors) are sensitive to all EM spectrum.
All objects (vegetation, soil, rock, water, concrete, etc) selectively absorb solar short-wavelength energy and radiate thermal infrared energy.

Source: J-L. Casanova
Comparison of spectral irradiance of solar light at sea level with black body radiation
Spectral Characteristics of Energy Sources and Sensing Systems

- Used to observe terrestrial energy emitted by the Earth system in the IR between 4 and 15 µm
- About 99% of the energy observed in this range is emitted by the Earth
The amount of thermal radiation emitted at a particular wavelength from a warm object depends on its temperature.

If the earth’s surface is regarded as a blackbody emitter, its apparent temperature (known as the brightness temperature) and the spectral radiance are related by the Planck’s blackbody equation, plotted in the above figure for several temperatures.

For a surface at a brightness temperature around 300 K, the spectral radiance peaks at a wavelength around 10 µm. The peak wavelength decreases as the brightness temperature increases.

For this reason, most satellite sensors for measurement of the earth surface temperature have a band detecting infrared radiation around 10 µm.
Emissivity ($\varepsilon$)

$\varepsilon$ of Blackbody = ……

Factors Influencing the Emissivity $\varepsilon$:

- The material (minerals, water etc.)
- The surface geometry (roughness of the surface)
- The wavelength of the radiation
- The view angle

Sobrino, 2005
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Precision Agriculture??

Agricultural Mechanization + Information Technology
Satellite Agriculture Applications

- Identify land cover/land use/objects
- Land leveling
- Nutrient
- Pest control
- Soil moisture
- Yield
- etc...
How to start ...
Satellite Remote Sensing Systems

1. Spectral resolution

<table>
<thead>
<tr>
<th>gamma rays</th>
<th>X-rays</th>
<th>ultraviolet rays</th>
<th>infrared rays</th>
<th>radar</th>
<th>FM</th>
<th>TV</th>
<th>shortwave</th>
<th>AM</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10^{-11}$</td>
<td>$10^{-10}$</td>
<td>$10^{-9}$</td>
<td>$10^{-8}$</td>
<td>$10^{-7}$</td>
<td>$10^{-6}$</td>
<td>$10^{-5}$</td>
<td>$10^{-4}$</td>
<td>$10^{-3}$</td>
</tr>
</tbody>
</table>

Visible Light

Wavelength (nanometers)

400 500 600 700

2. Spatial resolution

3. Temporal Resolution

4. Radiometric Resolution
1. Spectral Resolution

Specifies the number of spectral bands in which the sensor can collect reflected radiance. But the number of bands is not the only important aspect of spectral resolution. The position of bands in the electromagnetic spectrum is important, too.

- **High spectral resolution:** 15 - 220 bands
- **Medium spectral resolution:** 3 – 15 bands
- **Low spectral resolution:** < 3 bands
2. Spatial Resolution

The spatial resolution specifies the pixel size of satellite images covering the earth surface:

- High spatial resolution: 0.41 - 4 m
- Low spatial resolution: 30 - > 1000 m
## Map scale and raster resolution

<table>
<thead>
<tr>
<th>Map scale</th>
<th>Detectable size (in meters)</th>
<th>Raster resolution (in meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1:1,000</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>1:5,000</td>
<td>5</td>
<td>2.5</td>
</tr>
<tr>
<td>1:10,000</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>1:50,000</td>
<td>50</td>
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<td>1:100,000</td>
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<td>1:250,000</td>
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<td>125</td>
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<tr>
<td>1:500,000</td>
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<td>1:1,000,000</td>
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</tr>
<tr>
<td>1:1,000,000</td>
<td>1,000</td>
<td>500</td>
</tr>
</tbody>
</table>
3. Temporal Resolution (re-visiting time)

The temporal resolution specifies the revisiting frequency of a satellite sensor for a specific location.

- High temporal resolution: < 24 hours - 3 days
- Medium temporal resolution: 4 - 16 days
- Low temporal resolution: > 16 days
4. Radiometric resolution

- The bit depth is the number of bits used to represent each pixel.
RELATIONSHIP BETWEEN SENSOR SWATH WIDTH AND GLOBAL SEASONAL ARCHIVE CAPABILITY

**MODIS**
- Spatial resolution: 250m, 500m, 1000m
- Spectral coverage: VIS, NIR, SWIR, MIR, TIR
- Calibrated $\pm 5\%$ absolute
- Global coverage, 2 days
- Nadir only

**Landsat**
- Spatial resolution: 15m, 30m
- Spectral coverage: VIS, NIR, SWIR, TIR
- Calibrated $\pm 10\%$ absolute
- 16 day orbital repeat
- Seasonal global coverage capability
- Nadir only

**IRS**
- Spatial resolution: 6m, 24m, 72m
- Spectral coverage: VIS, NIR, SWIR
- Relative calibration
- 22 day orbital repeat
- Color nadir only, pan pointable, stereo

**SPOT**
- Spatial resolution: 10m, 20m
- Spectral coverage: VIS, NIR
- Relative calibration
- 26 day orbital repeat
- Pointable, stereo capability

**Proposed Commercial Systems**
- Spatial resolution: 1m, 5m
- Spectral coverage: VIS, NIR
- Uncalibrated
- Global coverage, years to $\infty$
- Pointable, stereo capability

**Figure 6**
Let's start!

Digital Image Processing

- Download image (Free satellite, Camera, Google earth, etc.)
- Pre-process (Geometric, Radiometric correction)
- Calculate (map algebra, statistics, Veg. Index, etc.)
- Post-process (accuracy assessment, produce printable maps)
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Now – how do we make color images of all that grayscale data so we can work with it more easily?
Remember, satellite uses some bands of *infrared light*. And the human eye is *not sensitive* to infrared. So to build an image we can see that includes data about infrared light gathered by satellite, we must represent that data with colors we can see: red, green, and blue.
Color Composite

- True color (Natural color)
- False color
- Pseudo color
True-Color Composite \((3,2,1)\)

True-color composite images approximate the range of vision for the human eye, and hence these images appear to be close to what we would expect to see in a normal photograph. True-color images tend to be low in contrast and somewhat hazy in appearance. This is because blue light is more susceptible than other bandwidths to scattering by the atmosphere. Broad-based analysis of underwater features and landcover are representative applications for true-color composites.

Near Infrared Composite \((4,3,2)\)

Adding a near infrared (NIR) band and dropping the visible blue band creates a near infrared composite image. Vegetation in the NIR band is highly reflective due to chlorophyll, and an NIR composite vividly shows vegetation in various shades of red. Water appears dark, almost black, due to the absorption of energy in the visible red and NIR bands.

Shortwave Infrared Composite \((7,4,3\) or \(7,4,2)\)

A shortwave infrared composite image is one that contains at least one shortwave infrared (SWIR) band. Reflectance in the SWIR region is due primarily to moisture content. SWIR bands are especially suited for camouflage detection, change detection, disturbed soils, soil type, and vegetation stress.
Map Calculation

- intersecting vector data using `v.overlay` with OR and AND operators
- a map merge using `r.patch` (left) and `r.mapcalc` (right). The module `r.patch` patches on basis of overlays, while `r.mapcalc` combines the raster maps based on a user defined expression
Spectral indices

Indices be grouped by feature type:
- Vegetation Indices
- Geology Indices
- Burn Indices
- Miscellaneous Indices
The Vegetation Spectrum in Detail

Visible

Near Infrared

Shortwave Infrared

Water Content
Leaf Biochemicals
Protein Lignin, Cellulose

Leaf Pigments
Cell Structure

High Reflectance of Vegetation in the Near-IR

Atmospheric Water Absorption Bands

Chlorophyll Absorption

Red Edge

Apparent Reflectance

Wavelength (microns)
Why do plants reflect lots of **infrared** light?

They’re really absorbing **red**, **green**, and **blue**, to convert into food. **Infrared** is all that’s left over.
The difference of red and NIR measurements divided by their sum is **normalized difference VI ("NDVI")**

$$\text{NDVI} = \frac{(\text{NIR} - \text{Red})}{(\text{NIR} + \text{Red})}$$
Leaf Area Index (LAI)

- LAI can be estimated by remote sensed image!!
- LAI relates to Biomass
### Many kinds of Index

<table>
<thead>
<tr>
<th>Structural Vegetation Indexes</th>
<th>Equation</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normalized Difference Vegetation Index (NDVI)</td>
<td>( \text{NDVI} = \frac{(R_{NIR} - R_{red})}{(R_{NIR} + R_{red})} )</td>
<td>Rouse et al. (1974)(^9)</td>
</tr>
<tr>
<td>Modified Triangular Vegetation Index (MTVI1)</td>
<td>( \text{MTVI1} = 1.2 * \left[ 1.2 * (R_{800} - R_{550}) - 2.5 * (R_{670} - R_{550}) \right] )</td>
<td>Haboudane et al. (2004)(^8)</td>
</tr>
<tr>
<td>Modified Triangular Vegetation Index (MTVI2)</td>
<td>( \text{MTVI2} = \frac{1.5 \left[ 1.2 * (R_{800} - R_{700}) - 2.5 * (R_{670} - R_{700}) \right]}{\sqrt{(2 * R_{800} + 1)^2 - (6 * R_{670} - 5 * R_{700}) - 0.5}} )</td>
<td>Haboudane et al. (2004)(^8)</td>
</tr>
<tr>
<td>Renormalized Difference Vegetation Index (RDVI)</td>
<td>( \text{RDVI} = \frac{(R_{800} - R_{670})}{(R_{800} + R_{670})} )</td>
<td>Rougean and Breon, (1995)(^34)</td>
</tr>
<tr>
<td>Simple Ratio Index (SR)</td>
<td>( \text{SR} = \frac{R_{NIR}}{R_{red}} )</td>
<td>Rouse et al. (1974)(^9)</td>
</tr>
<tr>
<td>Modified Simple Ratio (MSR)</td>
<td>( \text{MSR} = \frac{R_{NIR}}{R_{red}} - 1 )</td>
<td>Chen (1996)(^35)</td>
</tr>
<tr>
<td>Modified Chlorophyll Absorption in Reflectance Index (MCARI(_1))</td>
<td>( \text{MCARI(<em>1)} = 1.2 * \left[ 2.5 * (R</em>{865} - R_{700}) - 1.3 * (R_{670} - R_{550}) \right] )</td>
<td>Daughtry et al. (2000)(^36)</td>
</tr>
<tr>
<td>Modified Chlorophyll Absorption in Reflectance Index (MCARI(_2))</td>
<td>( \text{MCARI(<em>2)} = \frac{1.5 \left[ 2.5 * (R</em>{800} - R_{700}) - 1.3 * (R_{670} - R_{700}) \right]}{\sqrt{(2 * R_{800} + 1)^2 - (6 * R_{670} - 5 * R_{700}) - 0.5}} )</td>
<td>Daughtry et al. (2000)(^36)</td>
</tr>
<tr>
<td>Soil Adjusted Vegetation Index (SAVI)</td>
<td>( \text{SAVI} = (1 + L) * \frac{(R_{800} - R_{700})}{(R_{800} + R_{700} + L)} )</td>
<td>Huete (1988)(^10)</td>
</tr>
<tr>
<td>Transformed Soil-Adjusted Vegetation Index (TSAVI)</td>
<td>( \text{TSAVI} = \frac{a(NIR - a \text{RED} - b)}{(NIR + a \text{RED} - b)} )</td>
<td>Baret et al. (1989)(^37)</td>
</tr>
<tr>
<td>Modified SAVI with self-adjustment factor L (MSAVI)</td>
<td>( \text{MSAVI} = \frac{1}{2} \left[ 2 * R_{800} + 1 - \sqrt{(2 * R_{800} + 1)^2 - 8 * (R_{670} - R_{700})} \right] )</td>
<td>Qi et al. (1994)(^38)</td>
</tr>
<tr>
<td>Optimized Soil-Adjusted Vegetation Index (OSAVI)</td>
<td>( \text{OSAVI} = \frac{(1 + 0.16) * (R_{800} - R_{670})}{(R_{800} + R_{670} + 0.16)} )</td>
<td>Rondeaux et al. (1996)(^39)</td>
</tr>
</tbody>
</table>

Soil and Vegetation indexes for mineral and biochemical estimation calculated from multispectral and hyperspectral data.

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### Chlorophyll Indexes

<table>
<thead>
<tr>
<th>Equation</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transformed CARI (TCARI) ( TCARI = 3.0 \cdot [ (R_{700} - R_{750}) - 0.2 \cdot (R_{700} - R_{550}) \cdot (R_{520} / R_{670})] )</td>
<td>Haboudane et al. (2002)(^{40})</td>
</tr>
<tr>
<td>Triangular Vegetation Index (TVI) ( TVI = 0.5 \cdot [120 \cdot (R_{550} - R_{580}) - 200 \cdot (R_{700} - R_{550})] )</td>
<td>Broge and Leblanc (2000)(^{41})</td>
</tr>
<tr>
<td>Photochemical Reflectance Index (PRI) ( \text{PRI}<em>1 = (R</em>{528} - R_{567})/(R_{528} + R_{567}) ) ( \text{PRI}<em>2 = (R</em>{531} - R_{570})/(R_{531} + R_{570}) )</td>
<td>Gamon et al. (1992)(^{42})</td>
</tr>
<tr>
<td>Cellulose Adsorption Index (CAI) ( CAI = 0.5 \cdot (R_{2020} + R_{2200}) - R_{2100} )</td>
<td>Daughtry et al.(1995)(^{43})</td>
</tr>
</tbody>
</table>

### Vegetation Water Indexes

<table>
<thead>
<tr>
<th>Equation</th>
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</thead>
<tbody>
<tr>
<td>Normalized Difference Water Index (NDWI) ( \text{NDWI} = (R_{860} - R_{1240}) / (R_{860} + R_{1240}) )</td>
<td>Gao, (1996)(^{44})</td>
</tr>
<tr>
<td>Simple Ratio Water Index (SRWI) ( \text{SRWI} = R_{670} / R_{1240} )</td>
<td>Zarfco-Tejada et al., (2003)(^{45})</td>
</tr>
<tr>
<td>Shortwave Infrared Water Stress Index (SIWSI) ( SIWSI = \frac{\rho_6 - \rho_2}{\rho_6 + \rho_2} ) ( \rho_2 = 0.841 - 0.876; \rho_6 = 1.628 - 1.652 )</td>
<td>Fensholt and Sandholt (2003)(^{46})</td>
</tr>
<tr>
<td>Plant Water Index (PWI) ( \text{PWI} = R_{970} / R_{660} )</td>
<td>Peñuelas et al. (1997)(^{47})</td>
</tr>
</tbody>
</table>

### Spectral Absorption Metrics

\( \sigma = \) shape parameter as defined by the inverted-Gaussian curve-fit model

\[
g(\lambda) = R_{\lambda_1} + \frac{(R_{\text{min} 500-600} - R_{\text{max} 700-730}) \cdot \exp \left( -\frac{(\lambda - \lambda_{\text{min} 500-600})^2}{2\sigma^2} \right)}{8 \cdot \exp \left( -\frac{(\lambda - \lambda_{2800})^2}{2\sigma^2} \right)}
\]

\[D_B = \frac{R_C - R_B}{R_C}\]

\[D_n = \frac{D_B}{D_C}\]

\[D_n = \frac{D_B}{A}\]

\( \lambda_1 \) and \( \lambda_2 \) are the inflection points of the spectrum

\( R_{\text{min} 500-600} \) and \( R_{\text{max} 700-730} \) are the minimum and maximum reflectance in the 500-600 and 700-730 nm bands

\( R_{2800} \) and \( R_{\text{max} 1200-1800} \) are the reflectance at the 2800 nm and maximum reflectance in the 1200-1800 nm bands

Miller et al. (1990)\(^{20}\); Bonham-Carter (1988)\(^{19}\) | Whiting et al. (2004)\(^{33}\) |

Clark and Roush (1984)\(^{15}\) | Kokaly and Clark (1999)\(^{17}\) |

Curran et al. (2001)\(^{18}\) | |
PA applications (narrow-band data)

- soil management zoning,
- weed sensing and control,
- crop nitrogen stress detection,
- crop yield estimation,
- pest and disease detection
- soil properties (e.g., organic matter, moisture, salinity) and/or mineral contents (e.g., Ca, Mg, P, and Zn), and/or other properties (e.g., texture, color).
The best wavebands for specific applications

- **Nitrogen status evaluation**: 430, 550, 670 (or 680), and 780 (or 801) nm
- **LAI and percent green cover**: 674 and 755 nm
- **Biomass and yield**: 680 and 900 nm
- **Crop chlorophyll content prediction**: 550, 670, 700, and 800 nm
- **Vegetation water content**: 1300–2500 nm
- **Pest and disease infestation**: 745 nm or a combination of 531 and 570 nm

To select waveband, a generic approach such as stepwise discriminant analysis, artificial neural networks (ANN), or other multivariate statistical procedures can be used.
Introduction
Basics of remote sensing (RS)
Electromagnetic wave
Thermal imaging
RS in precision agriculture
RS band composite
Hyperspectral Remote Sensing
Hyperspectral Remote Sensing

“Hyperspectral data allows us to provide more specific actionable information to our clients who manage high-value crops,”

- Airborne: AVIRIS, HYDICE, AISA, HyMAP, ARES, CASI 1500, MIVIS, AisaEAGLET
- Satellite: Hyperion onboard EO-1, CHRIS onboard PROBA, ARTEMIS onboard TacSat-3
Hyperspectral data & Vegetation
Crop yield estimation in cotton

Plant and water indexes provided good predictors of cotton condition as harvest approached. With hyperspectral data, absorption modeling and strength measurements are viable means of estimating plant moisture and nutrient status. Measuring soil mineral abundance can be improved by accounting for the effect of soil moisture on the spectra. Further research in use of imaging spectroscopy will lead to higher precision as producers refine their prescription models and application techniques. Our field data, and collaborators airborne imagery and field data on plant mapping and canopy density, make a tremendous dataset that will take additional time to process. Continued investigations into irrigation scheduling using crop reflectance over a broad range of water contents, readiness for harvest aid chemical applications, and related field measurements will lead to improved accuracy in providing this key management.
Detection of Nutrient Deficiencies

Hyperspectral image of "sugar end" potato strips shows invisible defects
Optimal Hyperspectral Narrow bands in 400–2500 nm to Study Vegetation *

<table>
<thead>
<tr>
<th>Wavelength (nm)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>405</td>
<td>Nitrogen, senescing: sensitivity to changes in leaf nitrogen. Significant absorption due to chlorophyll and carotenoids; reflectance changes due to pigments is moderate to low. Sensitive to senescing (yellow and yellow green leaves)</td>
</tr>
<tr>
<td>450</td>
<td>Chlorophyll, carotenoids, senescing: sensitive to chlorophyll a and b. Significant absorption due to chlorophyll and carotenoids; reflectance changes due to pigments is moderate to low. Sensitive to senescing (yellow and yellow green leaves)</td>
</tr>
<tr>
<td>490</td>
<td>Carotenoid, LUE, stress in vegetation: Sensitive to senescing and loss of chlorophyll browning, ripening, crop yield, and soil background effects</td>
</tr>
</tbody>
</table>

* A nominal 5 nm waveband width can be considered optimal for obtaining best results with a aforementioned wavebands as band centers. So, for 970 nm waveband center, we can have a band of range of 968–972 nm. Ideal bandwidth is about 3 nm. But, noise levels in lower bandwidths can be a significant problem.

515 Pigments (carotenoid, chlorophyll, anthocyanins), nitrogen, vigor: positive change in reflectance per unit change in wavelength of this visible spectrum is maximum around this green waveband

531 LUE, xanophyll cycle, stress in vegetation, pest and disease: Senescing and loss of chlorophyll browning, ripening, crop yield, and soil background effects

550 Anthocyanins, chlorophyll, LAI, nitrogen, LUE: sensitive to numerous vegetation variables

570 Pigments (anthocyanins, chlorophyll), nitrogen: negative change in reflectance per unit change in wavelength is maximum as a result of sensitivity to vegetation vigor, pigment, and N
Optimal Hyperspectral Narrow bands in 400–2500 nm to Study Vegetation * (II)

<table>
<thead>
<tr>
<th>650</th>
<th><em>Pigment, nitrogen</em>: moderate to high sensitivity to changes in pigments (chlorophyll, anthocyanins) and nitrogen</th>
</tr>
</thead>
<tbody>
<tr>
<td>687</td>
<td><em>Biophysical quantities, chlorophyll, solar induced chlorophyll fluorescence</em>: LAI, biomass, yield, crop type/discrimination. Greatest soil-crop contrast. Actively induced emission peaks in red/far-red 687 and 740 nm</td>
</tr>
<tr>
<td>700–740</td>
<td><em>Chlorophyll, senescing, stress, drought</em>: first-order derivative index over 700–740 nm has applications in vegetation studies (e.g., blueshift during stress and redshift during healthy growth)</td>
</tr>
</tbody>
</table>

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Optimal Hyperspectral Narrow bands in 400–2500 nm to Study Vegetation *(III)*

<table>
<thead>
<tr>
<th>Wavelength (nm)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>760</td>
<td>Biomass, LAI, Solar-induced passive emissions: NIR reference band for many indices. Solar-induced passive emissions with retrievals made in O$_2$ atmospheric features at 687 and 760 nm</td>
</tr>
<tr>
<td>855</td>
<td>Biophysical/biochemical quantities, heavy metal stress: LAI, biomass, yield, crop discrimination, chlorophyll, anthocyanin, carotenoids. Sensitive to heavy metal stress due to reduction in chlorophyll. High stability in NIR band for developing indices</td>
</tr>
<tr>
<td>970</td>
<td>Water absorption band: most prominent water absorption trough. Also useful in quantifying most biophysical and biochemical properties</td>
</tr>
<tr>
<td>1045</td>
<td>Biophysical and biochemical quantities: leaf area index, wet and dry biomass, plant height, grain yield, crop type, crop discrimination, total chlorophyll, anthocyanin, carotenoids</td>
</tr>
<tr>
<td>1100</td>
<td>Biophysical quantities: sensitive to biomass and leaf area index. A point of most rapid rise in spectra with unit change in wavelength in far near infrared (FNIR)</td>
</tr>
<tr>
<td>1180</td>
<td>Water absorption band</td>
</tr>
<tr>
<td>1245</td>
<td>Water sensitivity: water band index, leaf water, biomass. Reflectance peak in 1050–1300 nm</td>
</tr>
</tbody>
</table>

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Optimal Hyperspectral Narrow bands in 400–2500 nm to Study Vegetation * (IV)

<table>
<thead>
<tr>
<th>Waveband</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1450</td>
<td>Water absorption band: very high moisture absorption trough in early short wave infrared (ESWIR). Use as an index with 1548 or 1620 or 1690 nm</td>
</tr>
<tr>
<td>1548</td>
<td>Lignin, cellulose: plant biochemical properties</td>
</tr>
<tr>
<td>1620</td>
<td>Lignin, cellulose: plant biochemical properties. Peak reflectance in SWIR 1 for vegetation</td>
</tr>
<tr>
<td>1650</td>
<td>Heavy metal stress, Moisture sensitivity: Heavy metal stress due to reduction in chlorophyll. Sensitivity to plant moisture fluctuations in ESWIR. Use as an index with 1548 or 1620 or 1690 nm</td>
</tr>
<tr>
<td>1690</td>
<td>Lignin, cellulose, sugar, starch, protein: plant biochemical properties</td>
</tr>
<tr>
<td>1760</td>
<td>Water absorption band, senescence, lignin, cellulose: high to moderate moisture absorption in ESWIR for moisture in plant leaves. Use as an index with 1548 or 1620 or 1690 nm</td>
</tr>
<tr>
<td>1950</td>
<td>Water absorption band: highest moisture absorption trough in FSWIR. Use as an index with any one of 2025, 2133, and 2213 nm. Affected by noise at times</td>
</tr>
<tr>
<td>2025</td>
<td>Litter (plant litter), lignin, cellulose: litter-soil differentiation</td>
</tr>
<tr>
<td>2050</td>
<td>Water absorption band: high moisture absorption trough in FSWIR. Use as an index with any one of 2025, 2133, and 2213 nm. Not affected by noise</td>
</tr>
<tr>
<td>2133</td>
<td>Litter (plant litter), lignin, cellulose: typically highest reflectivity in FSWIR for vegetation. Litter-soil differentiation</td>
</tr>
<tr>
<td>2145</td>
<td>Water absorption band: moderate moisture absorption trough in FSWIR. Use as an index with any one of 2025, 2133, and 2213 nm. Not affected by noise</td>
</tr>
<tr>
<td>2173</td>
<td>Water absorption band: moderate to low moisture absorption trough in FSWIR. Use as an index with any one of 2025, 2133, and 2213 nm. Not affected by noise</td>
</tr>
</tbody>
</table>

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Optimal Hyperspectral Narrow bands in 400–2500 nm to Study Vegetation *

<table>
<thead>
<tr>
<th>Waveband</th>
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</tr>
</thead>
<tbody>
<tr>
<td>2205</td>
<td>Litter, lignin, cellulose, sugar, starch, protein; Heavy metal stress: typically, second highest reflectivity in FSWIR for vegetation. Heavy metal stress due to reduction in chlorophyll</td>
</tr>
<tr>
<td>2295</td>
<td>Stress and soil iron content: sensitive to soil background and plant stress</td>
</tr>
</tbody>
</table>

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Infestation

Aerial infra-red image of kiwi fruit areas affected by kiwifruit bacterial canker (Psa)

Geo-referenced map of the study compared the degree of disease previously developed
The spatial distribution N, P and K

Data Space –
relative numerical position of measurements

Potassium (K)
Mean 167.0
StdDev 41.8
Level Min 99.8
Level Max 412.0

Phosphorous (P)
Mean 12.42
StdDev 4.41
Level Min 8.17
Level Max 20.70

Geographic Space –
relative spatial position of measurements

High P

High K

High PhK

Phosphorous (P)
Min 4.2
Max 57.2

Potassium (K)
Min 15.2
Max 412.0

Nitrogen (N)
Min 4.9
Max 52.8
The Precision Ag Process (Fertility)

As a combine moves through a field it...
1) uses GPS to check its location, then
2) checks the yield at that location to
3) create a continuous map of the yield variation every few feet. This map is then...
4) combined with soil, terrain and other maps to
5) derive a “Prescription Map” that is used to
6) adjust fertilization levels every few feet in the field (variable rate application).
Regression analysis was used to relate a map of NDVI (derived from remote sensing imagery) to a map of corn yield for a farmer’s field. Then the equation was used to derive a map of predicted yield based on the NDVI values and the results evaluated for how well the prediction equation performed.
A “Difference” surface is calculated by subtracting two yield surfaces...

For example, a grid location with 185.1 bushels in 1997 and 147.0 in 1998 shows a -38.1 bushel loss.
Q&A

LAB Session

Please install software before start session!
- QGIS
  with openlayers, Semi-Automatic Classification Plugin
- Google Earth pro
Register and login to USGS to download Landsat, sentinel-2