Remote Sensing for Agricultural Applications: Principles and Techniques (2023-2024)

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Lecture 3: characteristics of remotely sensed data

October 25, 2023

Outline

- Why do we need to know data characteristics?
- Resolutions
  I. Spectral resolution
  II. Spatial resolution
  III. Temporal resolution
  IV. Radiometric resolution
- Categories of remotely sensed data

What types of data are commonly used?

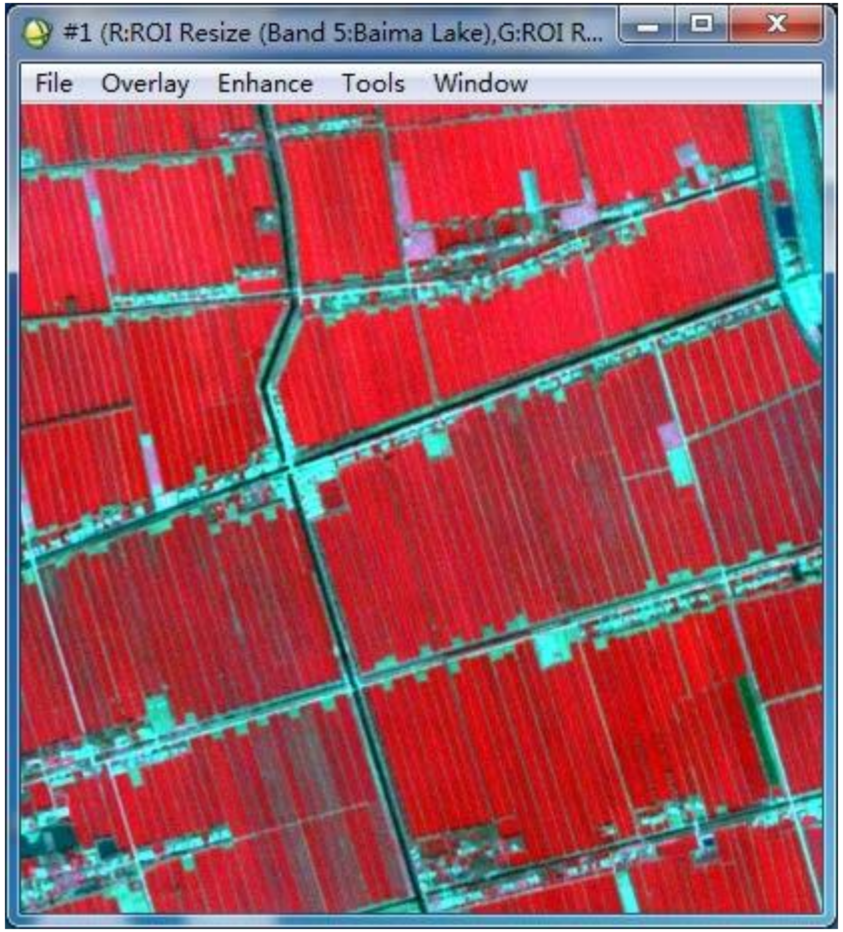
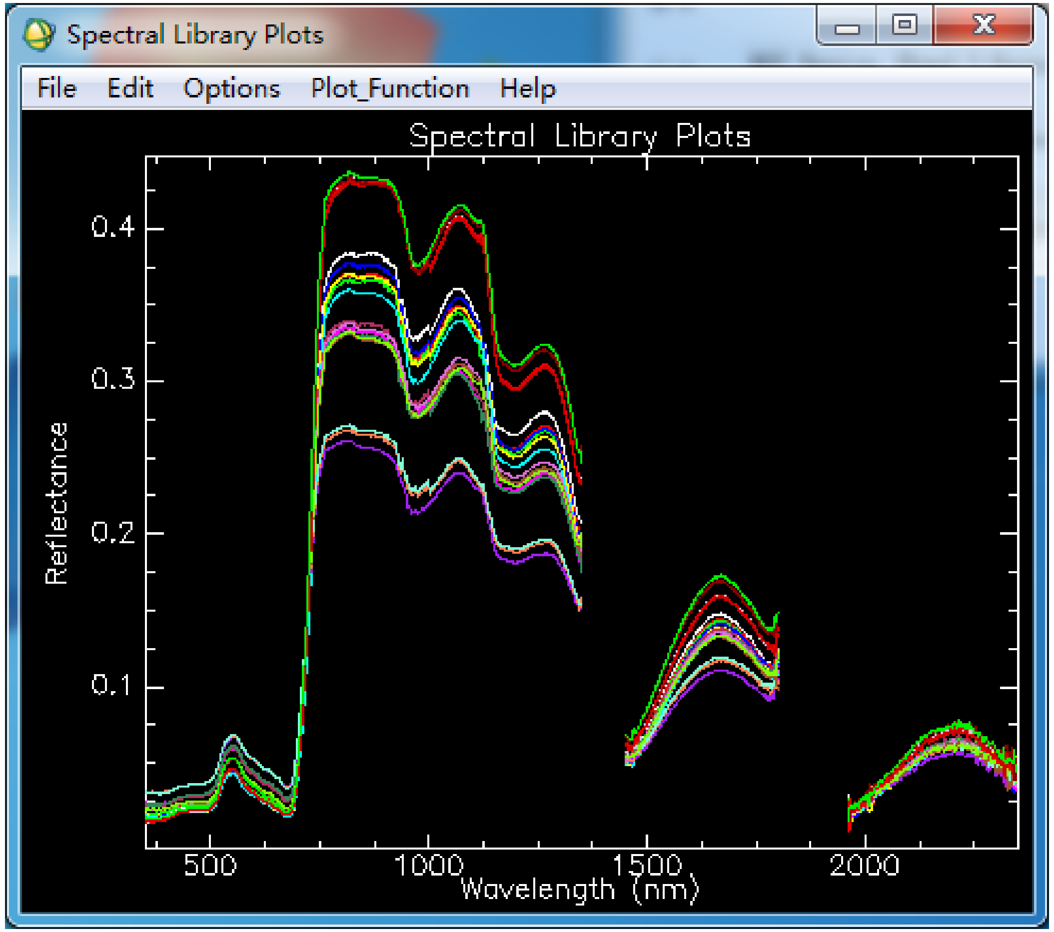
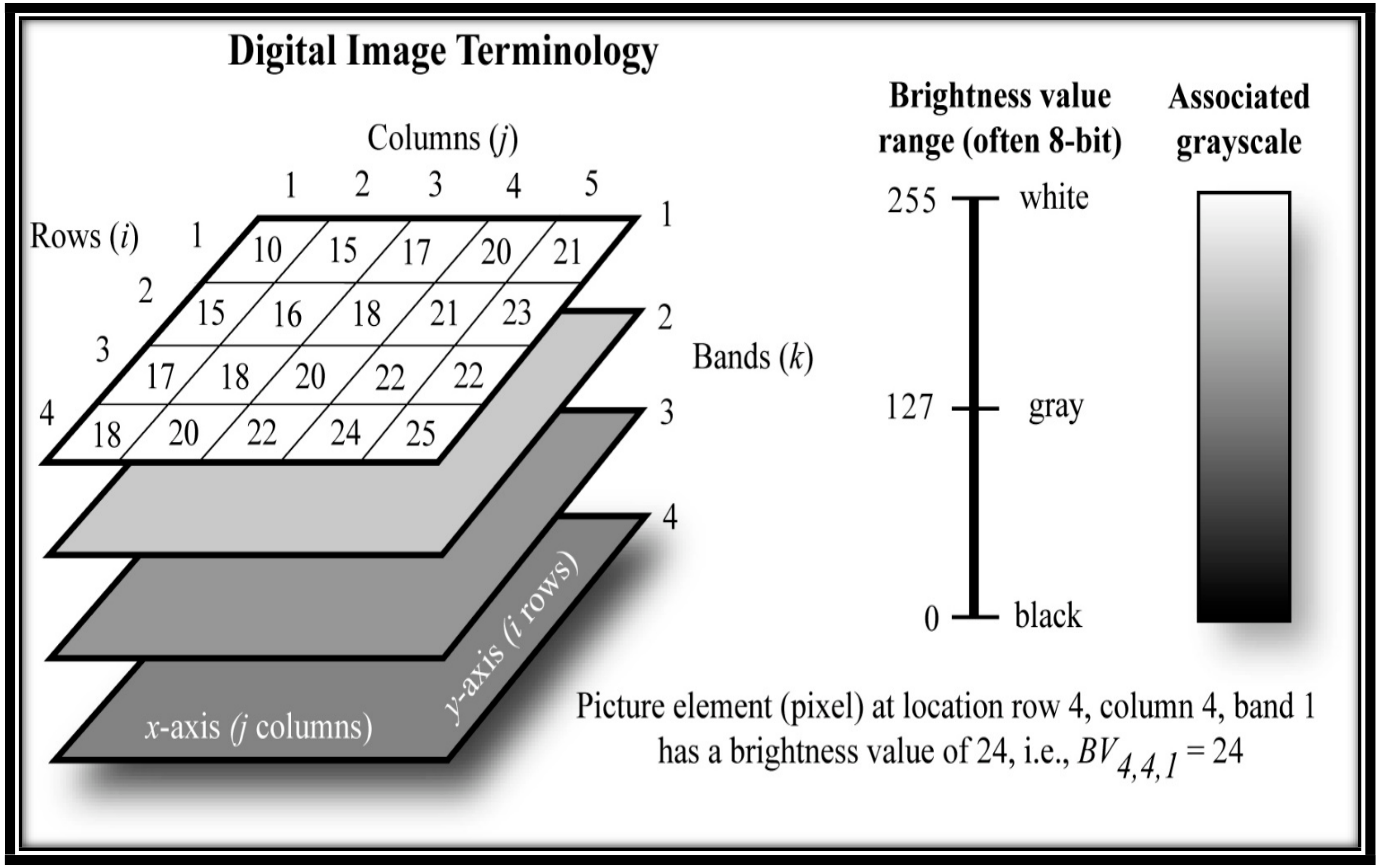


Image data



Spectral data

A first look of digital images



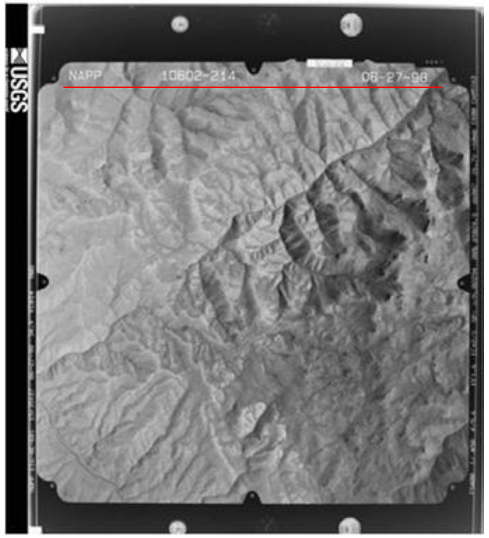
Jensen (2006)

- Pixel, brightness value, digital number (DN)

Remotely sensed data: images

- Output of a remote sensing system
- Types of images
  - Analog: e.g., aerial photos
    - obtained through a photographic process
    - acquired by cameras using light-sensitive films
    - 0.3-0.9 um
  - **Digital: e.g., satellite images**
    - **the same imaging principles**
    - **acquired by electronic scanners and linear/area arrays**
    - **detects a wider range of EM radiation**
    - **recorded in digital format**
    - **individual picture elements: pixels**

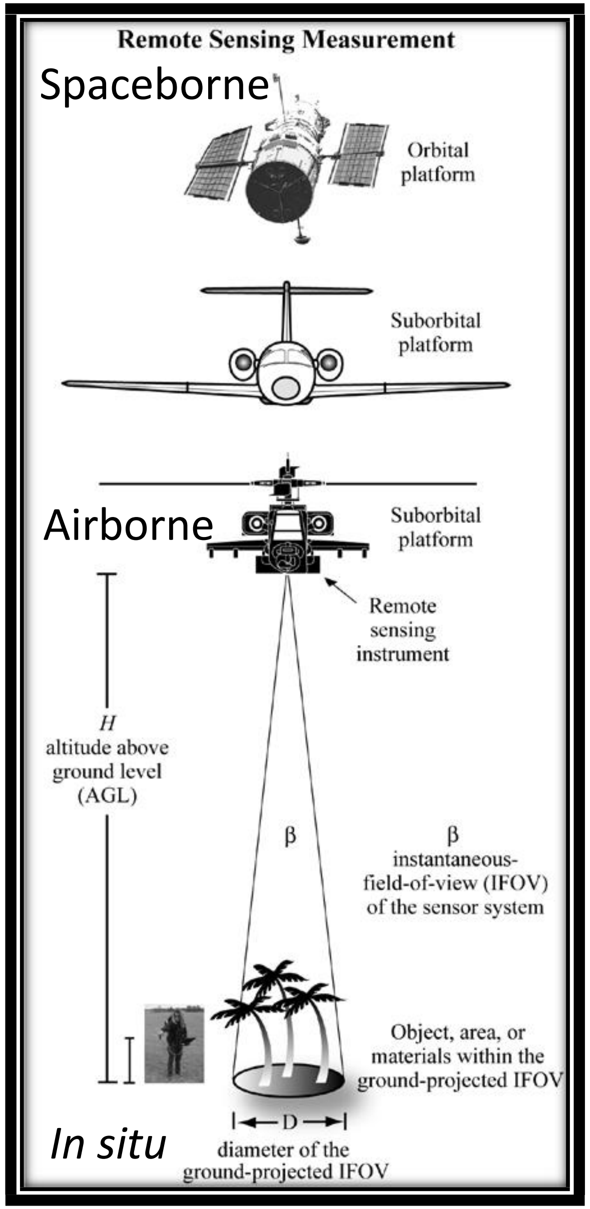
You were born in the digital era.



NAPP image taken on B & W film, Idaho, 1998/6/27.

A WorldView-2 satellite image of the Rakaia River, in New Zealand.

Remote sensing data collection



- Measured radiance by optical sensors:

$$\boldsymbol{L = f(\lambda, s_{x,y,z}, t, \theta, \Omega)}$$

$\boldsymbol{\lambda}$: spectral (wavelength)

$\boldsymbol{s_{x,y,z}}$: spatial (location and size)

t: temporal (time & frequency)

$\boldsymbol{\theta}$: angular (sun-target-sensor geometry)

$\boldsymbol{\Omega}$: radiometric (at sensor)

Jensen (2006)

Resolution characteristics

I. Spatial

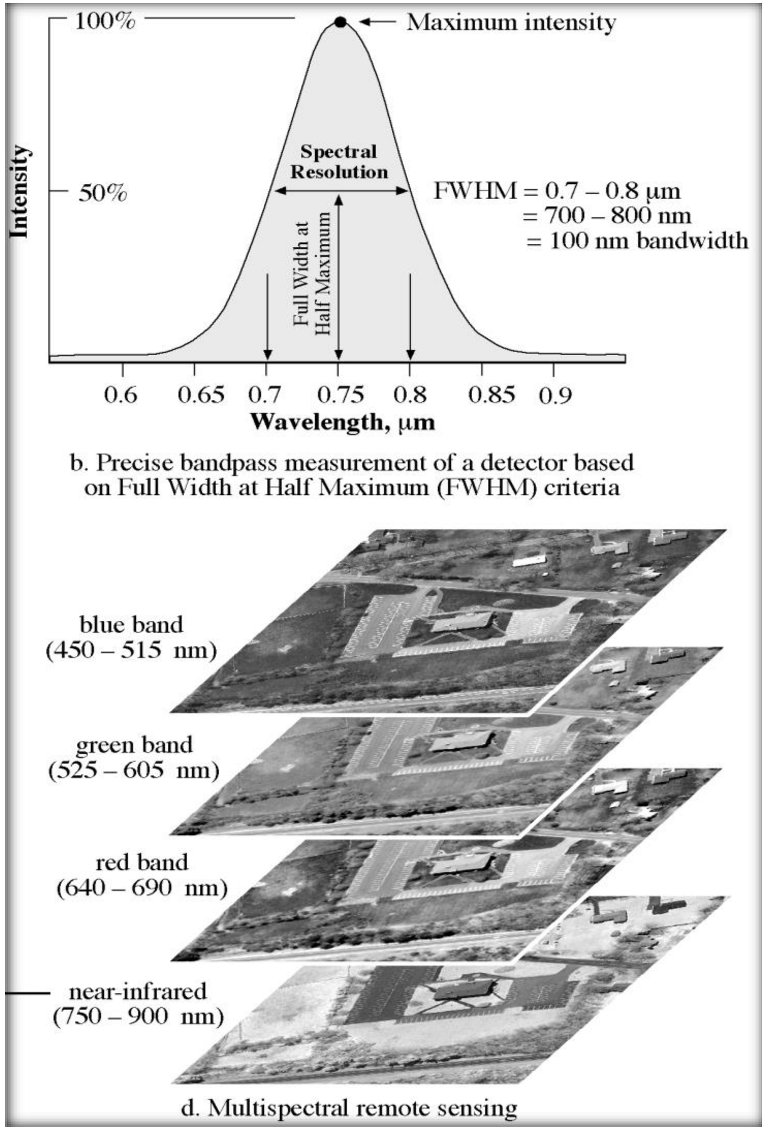
II. Spectral

III. Temporal

IV. Radiometric

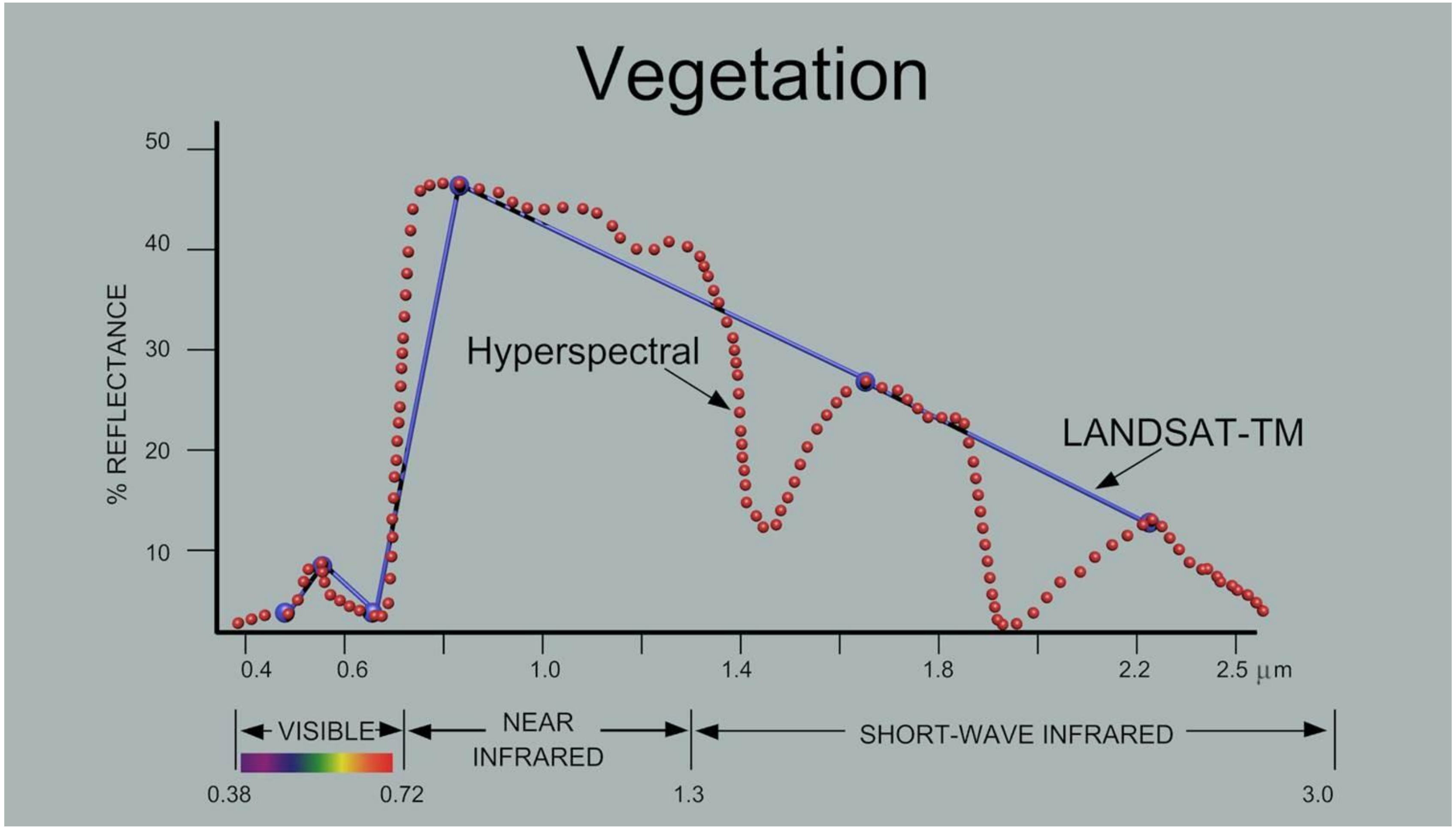
Spectral resolution

- **"The number and the size of the bands a remote sensor is able to record**." (Jensen, 2006)
- The position, width and number of spectral channels.
- The higher spectral resolution over a given spectral region,
  - the greater number of spectral channels
  - the narrower the range of wavelength for a particular channel
  - the higher cost in a remote sensing system



Jensen (2006)

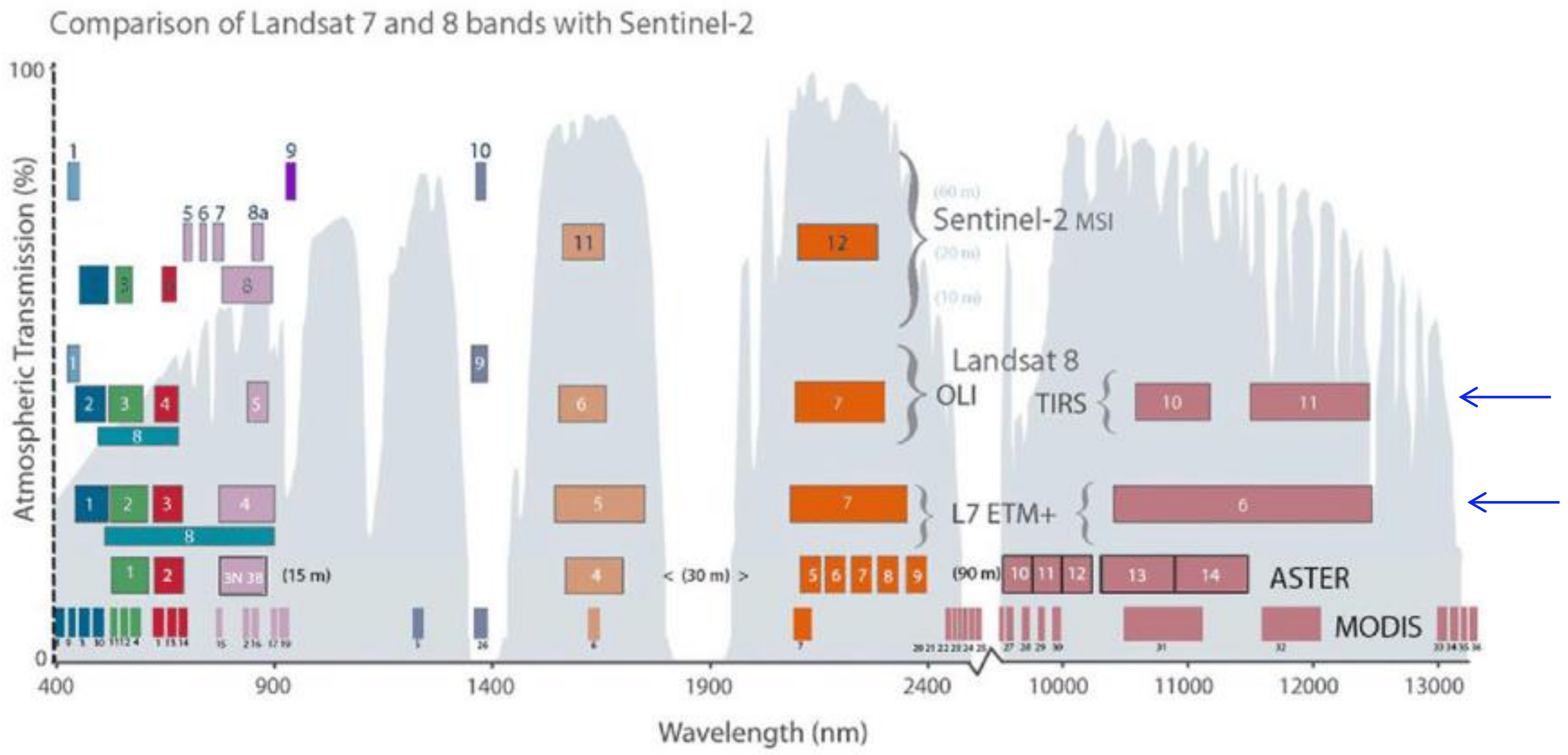
Multispectral vs hyperspectral



Q1: what is the fundamental difference between multispectral and hyperspectral data?

Figure from http://blog.neosgeo.com/2011/05/08/hyperspectral-101/

Comparison of Landsat bands with relevant instruments



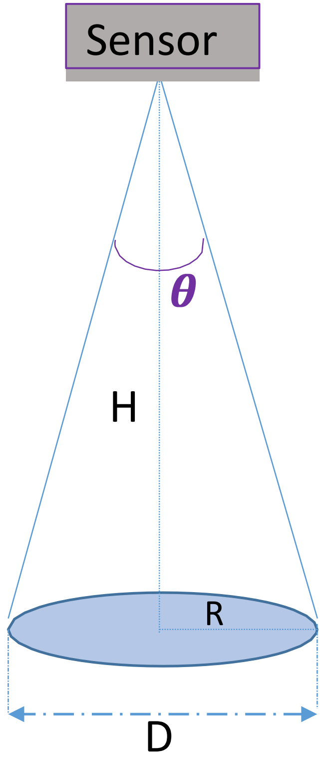
Visible NIR SWIR 1 SWIR 2 Thermal

- Multiple instruments have similar bands
- Most bands are located in the atmospheric windows

Q2: what has changed from Landsat 7 to Landsat 8 bands?

Spatial resolution

- Determines the level of spatial detail occurring in an image
- *"The size of the smallest possible feature that can be detected from an image" (Weng, 2012)*
- Relates to both detectability and separability
  - ✓ A small feature may be detectable if its signal dominates within a pixel.
  - ✓ A big feature may not be separable from its neighbors, in case of low spectral contrast.



Weng, Q. (2012). *An introduction to contemporary remote sensing.* New York: Mcgraw-Hill Professional, pp. 320.

Spatial resolution

- Spatial resolution is determined by sensor altitude, detector size, focal size, and system configuration.

- Considering spatial resolution relative to the geographical scale of a study area.
  - Local: fine spatial resolutions, WorldView-2/3, RapidEye,…
  - Regional: medium spatial resolutions, Landsat, ASTER,…
  - Global: coarse spatial resolutions, MODIS, AVHRR,…

Spatial resolution

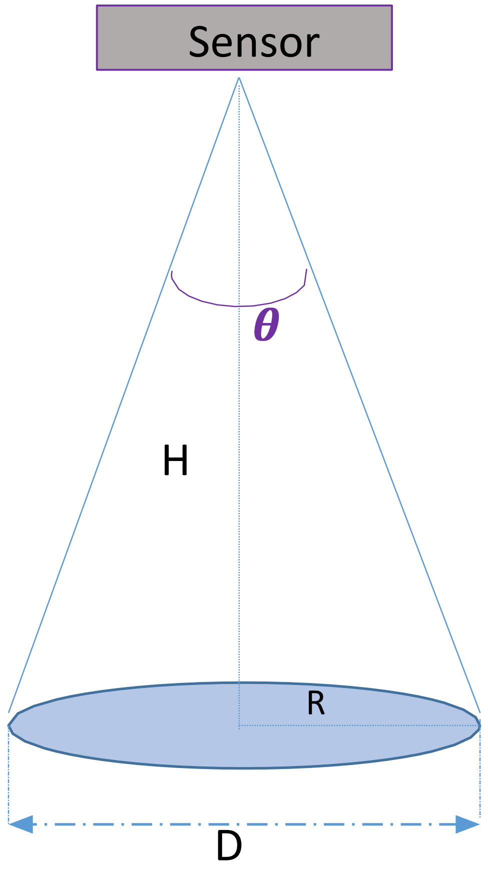
- The calculation of spatial resolution:

$D = 2 \times R = 2 \times \tan\frac{\theta}{2} \times H$

θ is usually very small, $tan\frac{\theta}{2} = \frac{\theta}{2}$.

Therefore, $D = 2 \times \frac{\theta}{2} \times H = \theta \times H$.

Unit: θ in *radian, and* H in *m*.



- Spatial resolution is determined by the IFOV and distance (flight altitude).
- Spaceborne sensors are at fixed distances from the Earth (Landsat-8 at 705 km, multispectral bands: 30 m spatial resolution).
- Airborne sensors could be flown at variable altitudes (AVIRIS: IFOV=1 *mrad*, spatial resolution = 8 *m* while flying at 8 km).

Q3: how to calculate the pixel size for the given flight altitude and sensor IFOV?

IFOV vs FOV

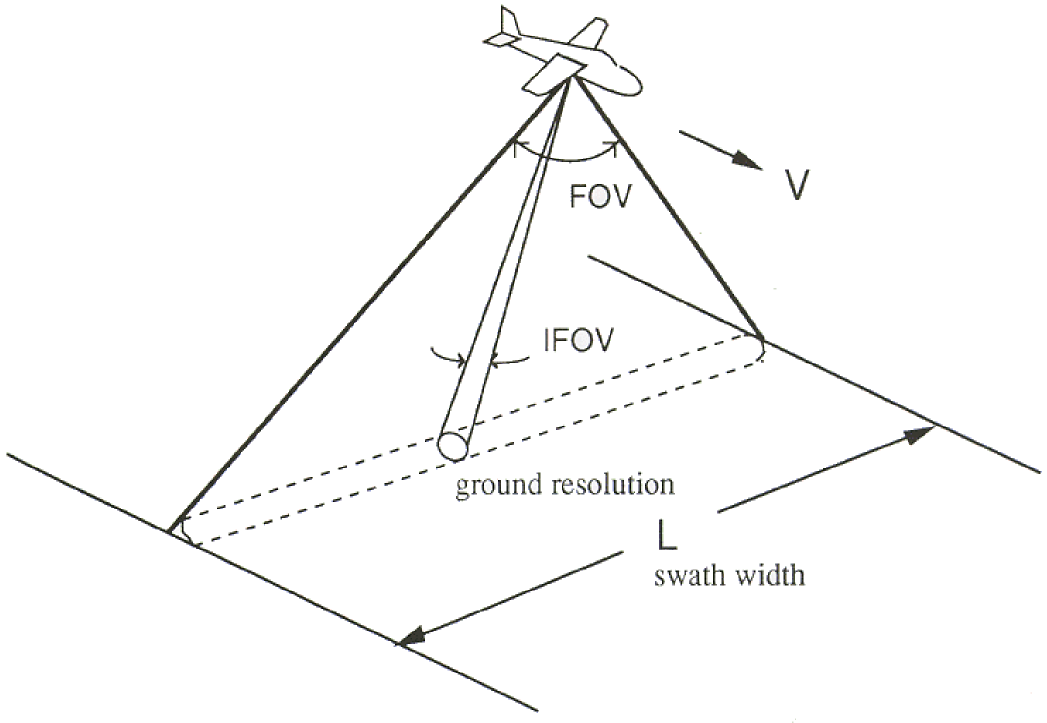
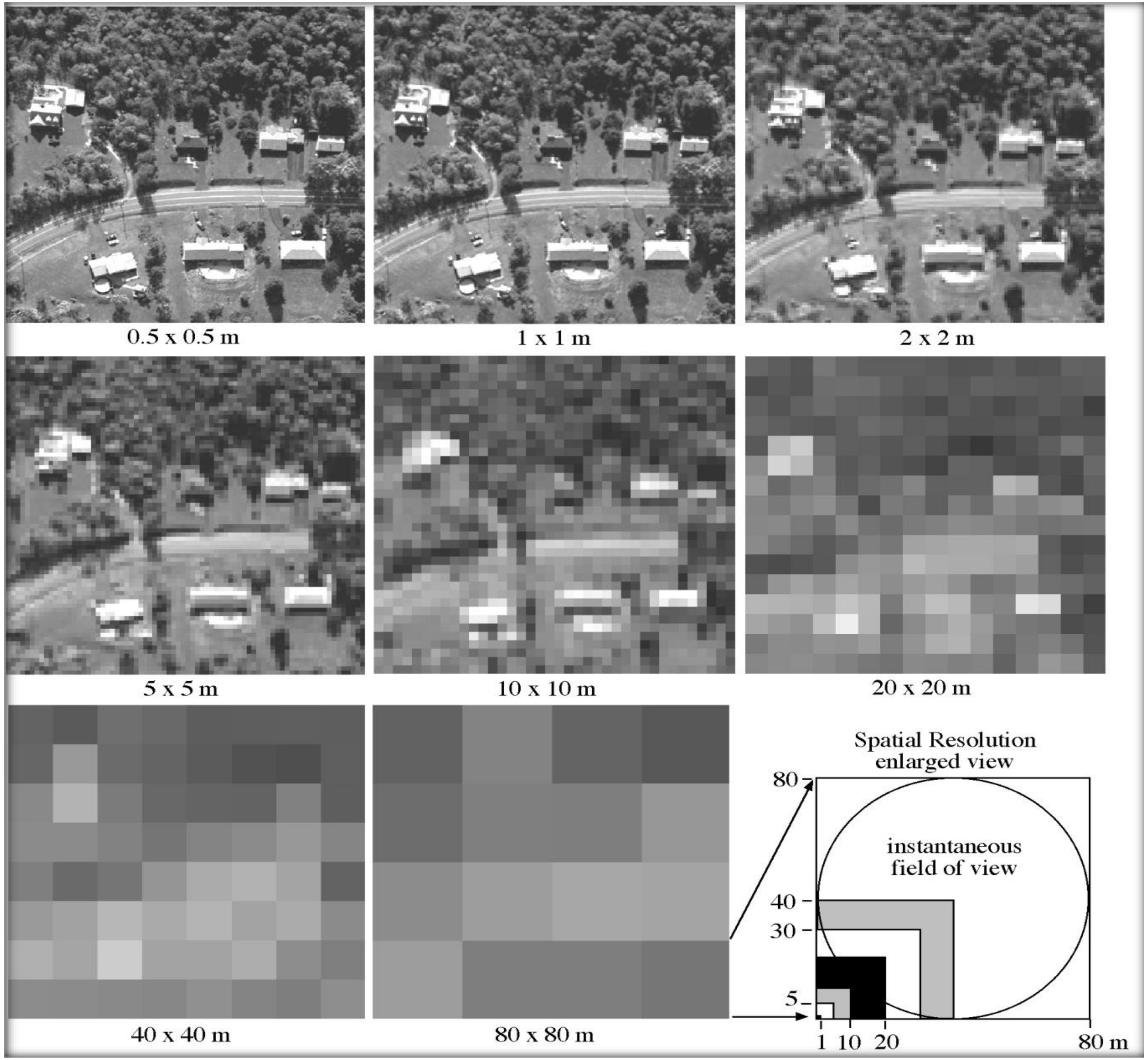


Figure 6.2.1 FOV and IFOV

- The **FOV** relates to the swath width, while the **IFOV** relates to the spatial resolution.

Figure courtesy of Japan Association of Remote Sensing.


0.5 x 0.5 m
1 x 1 m
2 x 2 m
5 x 5 m
10 x 10 m
20 x 20 m
40 x 40 m
80 x 80 m
Spatial Resolution
enlarged view
instantaneous
field of view
80
40
30
5
1
10
20
80 m

Jensen (2006)

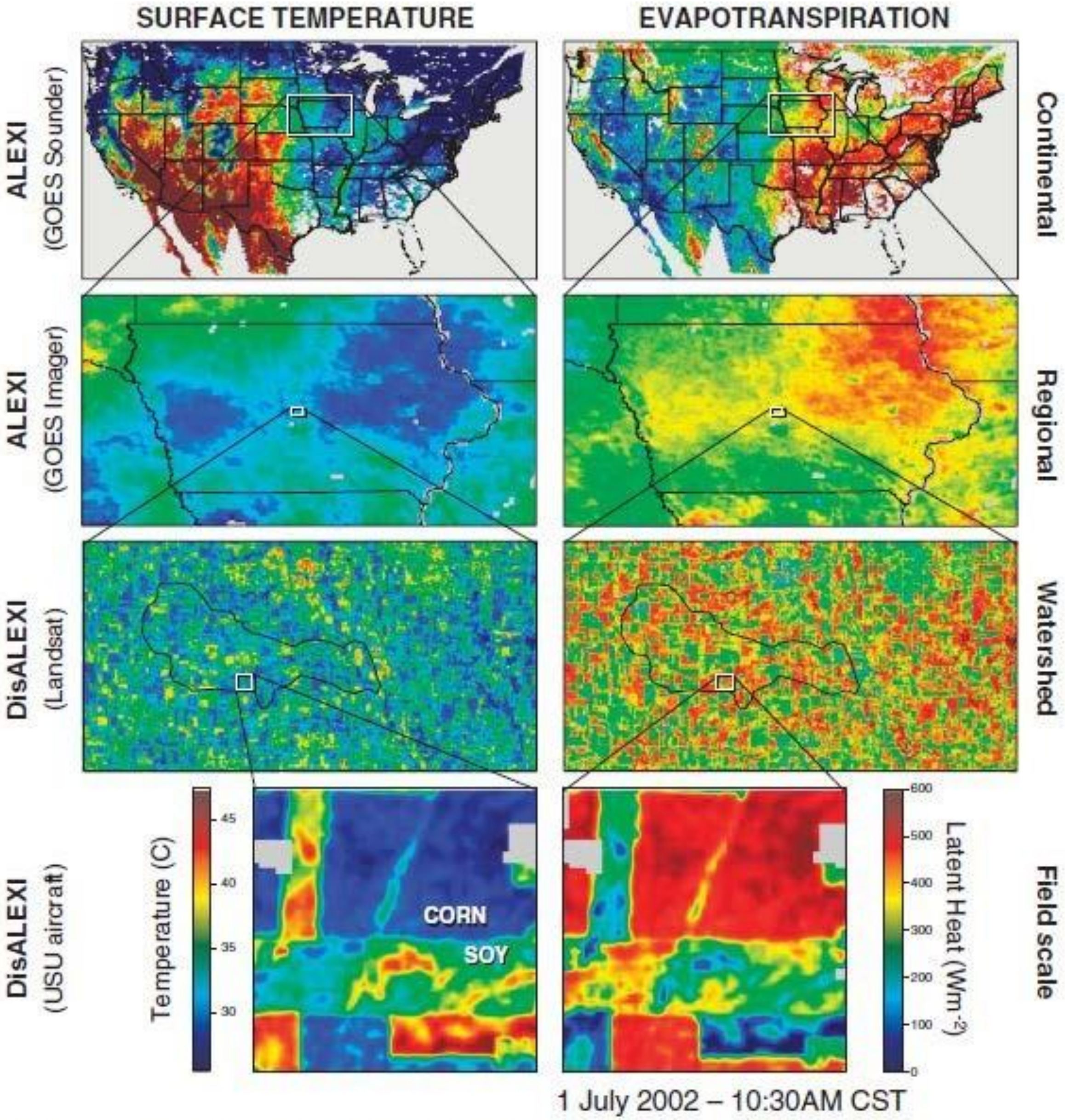
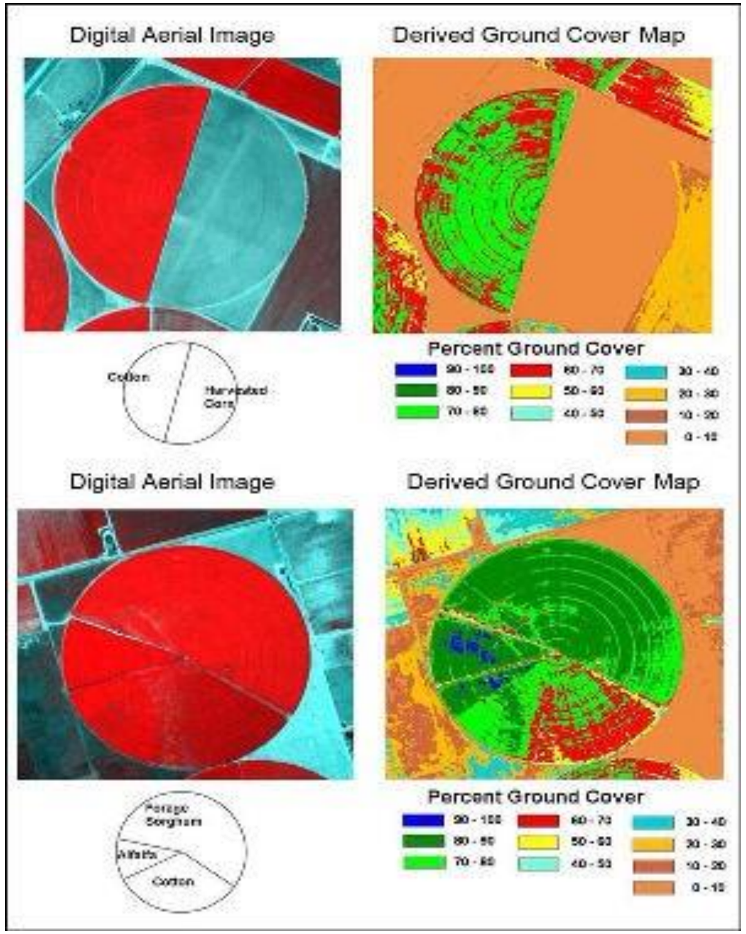


Fig. 9. Multiscale evapotranspiration (ET) maps for 1 July 2002 produced with ALEXI and DisALEXI using surface temperature data from aircraft (30-m resolution), Landsat (60 m), GOES Imager (5 km), and GOES Sounder (10 km). The continental-scale ET map is a 14-d composite of clear-sky model estimates.

Anderson, M.C., Kustas, W.P. , & Norman, J.M. (2007). Upscaling flux observations from local to continental scales using thermal remote sensing, *Agronomy Journal*, 99, 240-254.

Mapping crop fields at various resolutions

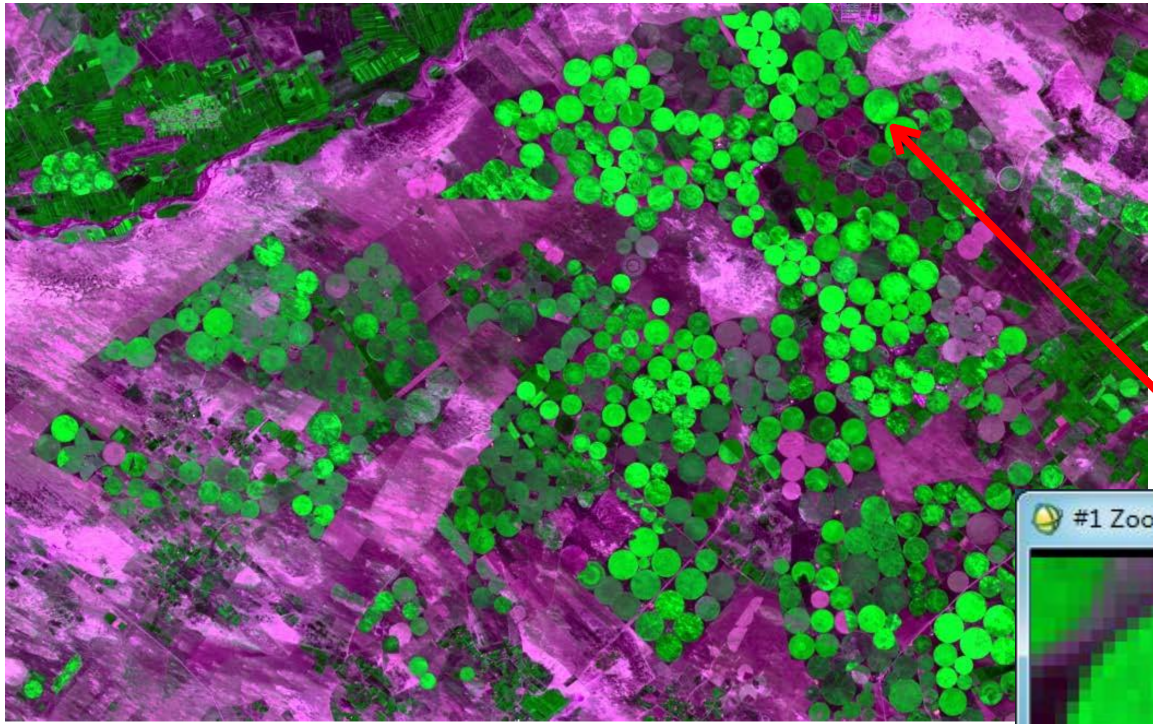


A circular field seen from the 2.5-m QuickBird multispectral imagery

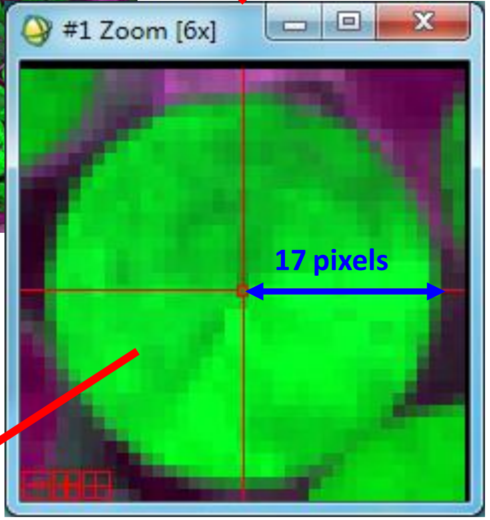
Source: Stephan J. Maas, Texas Technical University

A Landsat image of a farm in Kansas, USA.

These images can be used to examine the spatial variation within a single field and across many circular fields.



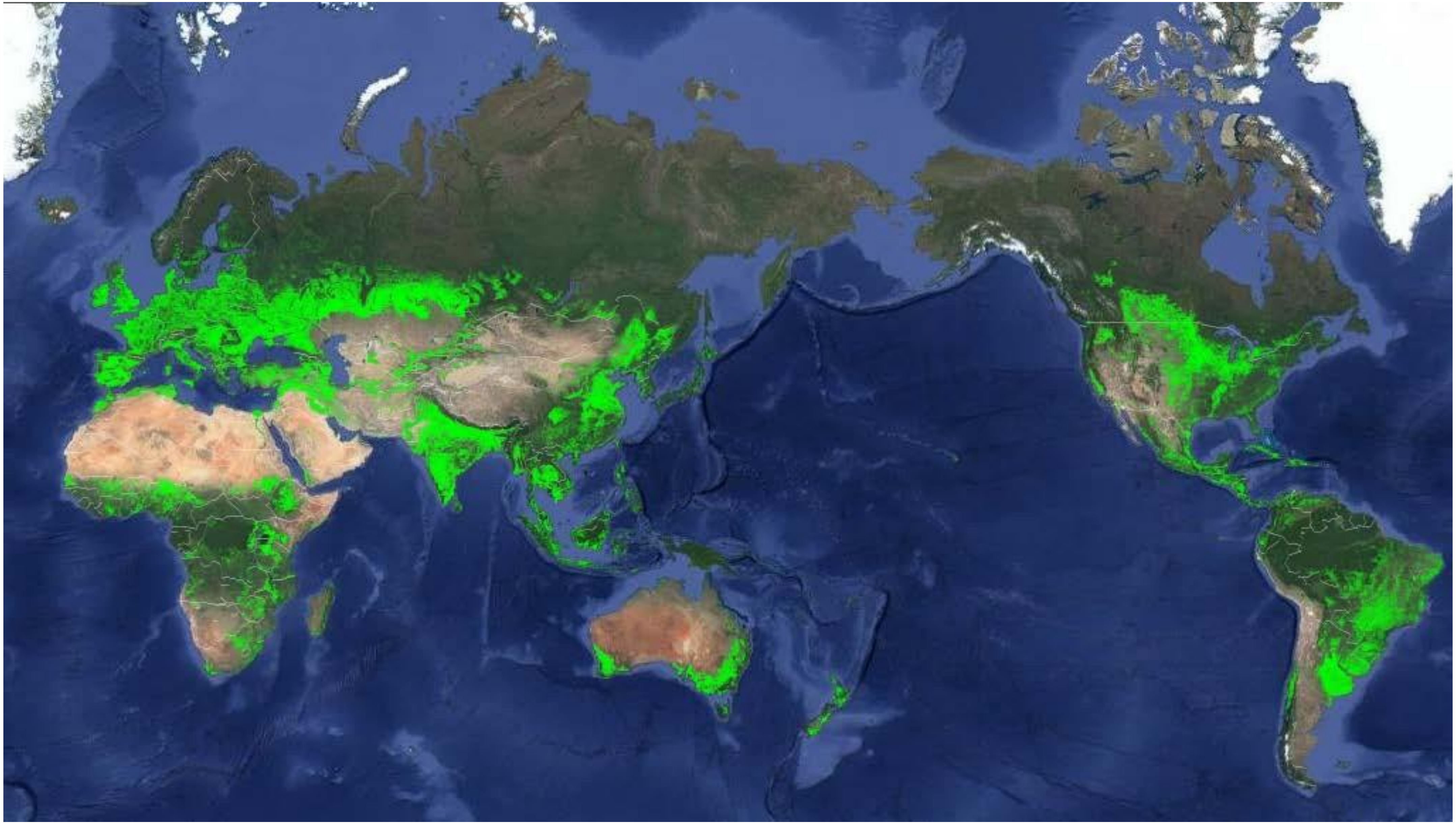
Chifeng, Inner Mongolia, China



Intensified farming

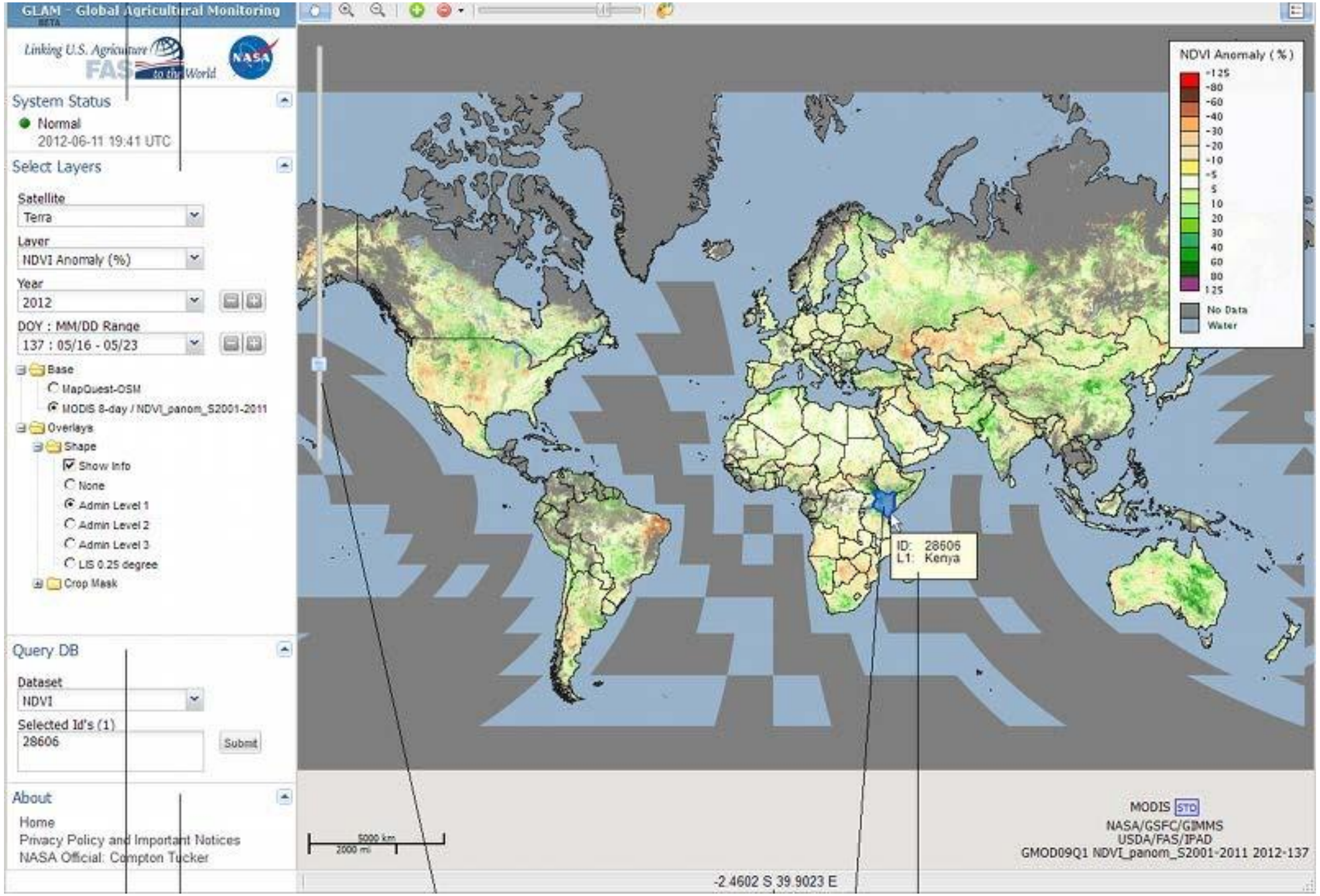
Q4: how big is this circular field in mu?

Global 30 m Cropland Extent of 2015



https://www.croplands.org

The GIMMS MODIS Global Agricultural Monitoring system



Maps are produced using 250 m MODIS NDVI data.

http://glam1.gsfc.nasa.gov/

Radiometric resolution

- Represented by the level of quantization or bit level that is used to digitize the continuous intensity value of the EM radiation detected

- The ability of a sensor to discriminate subtle differences in the detected radiation

- An image of higher radiometric resolution has more brightness levels or bit levels

4-bit

8-bit

8-bit Sentinel 2 – Tokyo Coast
Each band has 256 (=2^8) colors.

4-bit Sentinel 2 – Tokyo Coast
Each band has 16 (=2^4) colors.

2-bit Sentinel 2 – Tokyo Coast
Each band has 4 (=2^2) colors.

Q5: what is the benefit of an image with a higher bit level?

Radiometric resolution & number of bits

- The range of digital numbers (DNs) in an image corresponds to the number of bits (binary digits) for storing numbers

  - Landsat-1 MSS images: initially
    - 6-bit, level of quantization = 64 = 2^6, DN range: 0-63.

  - Landsat-1 MSS images: later
    - 7-bit, level of quantization = 128 = 2^7, DN range: 0-127.

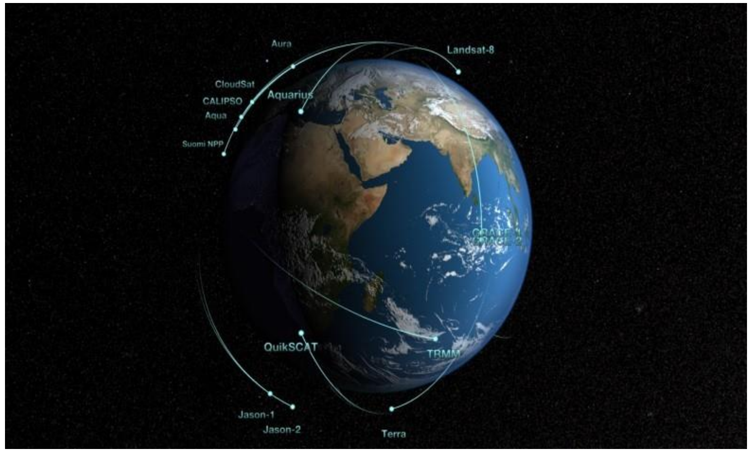
  - Landsat-8 OLI:
    - 16-bit, level of quantization = 65536= 2^{16}, DN range: 0-65535.

  - Significant increase in bit depth as a result of improvement in sensor quality over the 40+ years.

How has the image file size changed?

- WorldView-2: 11-bit; QuickBird: 11-bit; RapidEye: 12-bit

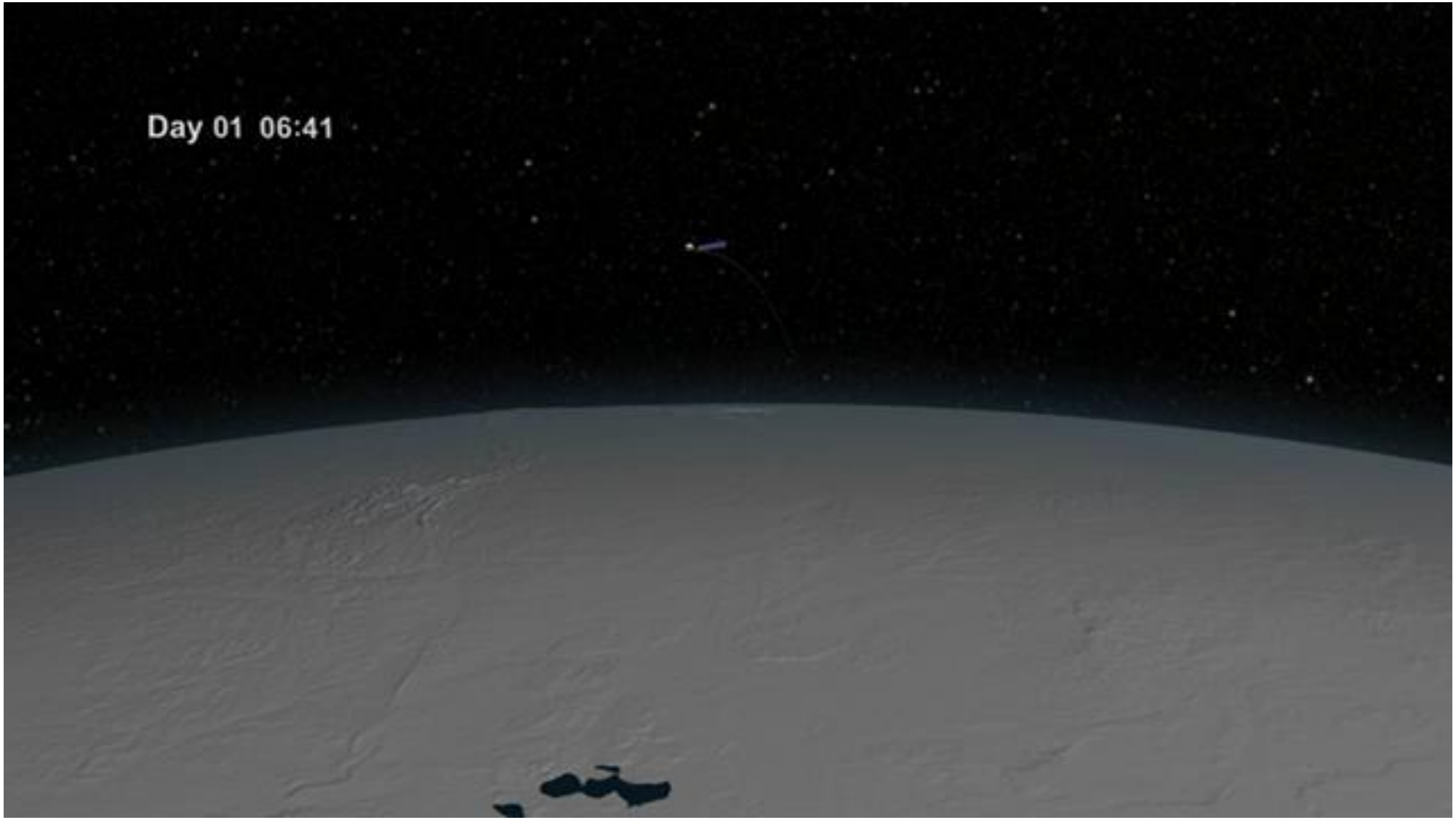
Temporal resolution



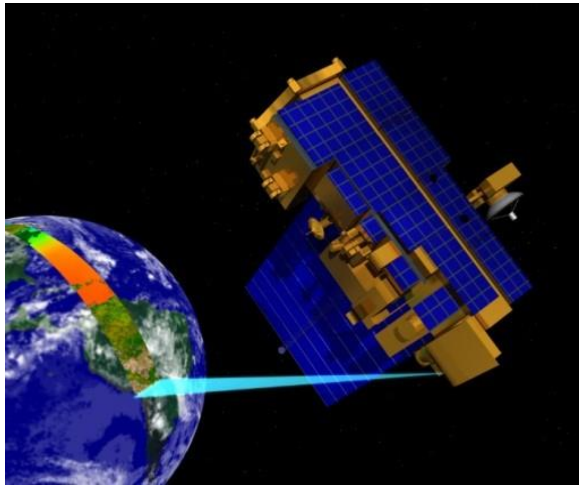
Play video clip

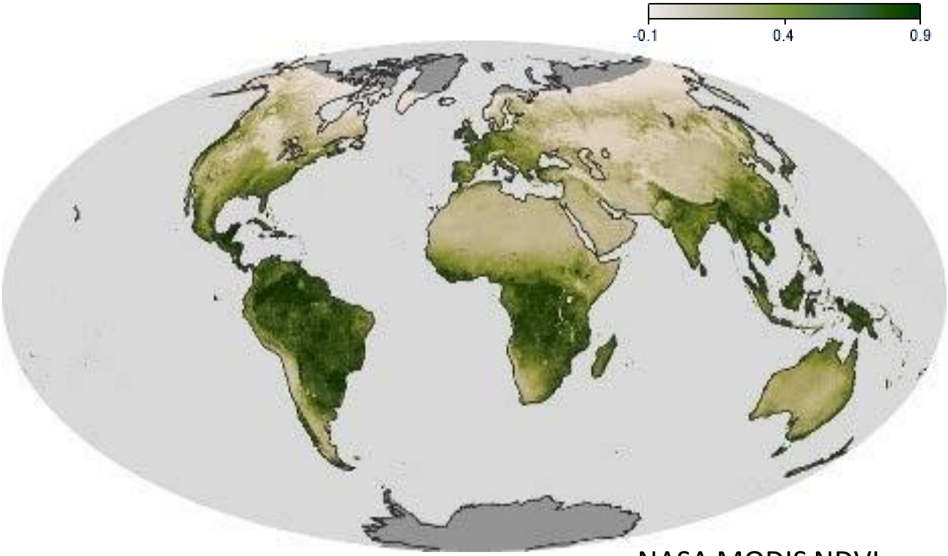
- The amount of time it takes for a sensor to return to a previously imaged location (Weng, 2012)
- Repeat cycle or revisit time
  - Satellites: 15 min to >10 days
  - Airborne remote sensing: customized
- Important for vegetation change detection and monitoring
- May be subject to weather conditions

Landsat satellite orbiting



MODIS data products at various temporal resolutions





NASA MODIS NDVI

Short Name	Platform	MODIS Data Product	Raster type	Res (m)	Temporal Granularity
MCD12C1	Combined	Land Cover Type	CMG	5600m	Yearly
MCD12Q1	Combined	Land Cover Type	Tile	500m	Yearly
MCD12Q2	Combined	Land Cover Dynamics	Tile	500m	Yearly
MCD15A2	Combined	Leaf Area Index - FPAR	Tile	1000m	8 day
MCD15A3	Combined	Leaf Area Index - FPAR	Tile	1000m	4 day
MCD43A1	Combined	BRDF-Albedo Model Parameters	Tile	500m	16 day
MCD43A2	Combined	BRDF-Albedo Quality	Tile	500m	16 day
MCD43A3	Combined	Albedo	Tile	500m	16 day
MCD43A4	Combined	Nadir BRDF-Adjusted Reflectance	Tile	500m	16 day
MCD43B1	Combined	BRDF-Albedo Model Parameters	Tile	1000m	16 day
MCD43B2	Combined	BRDF-Albedo Quality	Tile	1000m	16 day
MCD43B3	Combined	Albedo	Tile	1000m	16 day
MCD43B4	Combined	Nadir BRDF-Adjusted Reflectance	Tile	1000m	16 day
MCD43C1	Combined	BRDF-Albedo Model Parameters	CMG	5600m	16 day
MCD43C2	Combined	BRDF-Albedo Snow-free Quality	CMG	5600m	16 day
MCD43C3	Combined	Albedo	CMG	5600m	16 day
MCD43C4	Combined	Nadir BRDF-Adjusted Reflectance	CMG	5600m	16 day
MCD45A1	Combined	Thermal Anomalies & Fire	Tile	500m	Monthly
MOD09A1	Terra	Surface Reflectance Bands 1–7	Tile	500m	8 day
MOD09CMG	Terra	Surface Reflectance Bands 1–7	CMG	5600m	Daily
MOD09GA	Terra	Surface Reflectance Bands 1–7	Tile	500/1000m	Daily
MOD09GQ	Terra	Surface Reflectance Bands 1–2	Tile	250m	Daily
MOD09Q1	Terra	Surface Reflectance Bands 1–2	Tile	250m	8 day
MOD11A1	Terra	Land Surface Temperature & Emissivity	Tile	1000m	Daily
MOD11A2	Terra	Land Surface Temperature & Emissivity	Tile	1000m	8 day

Rice planting in northeast China (1986-2010) as detected from Landsat

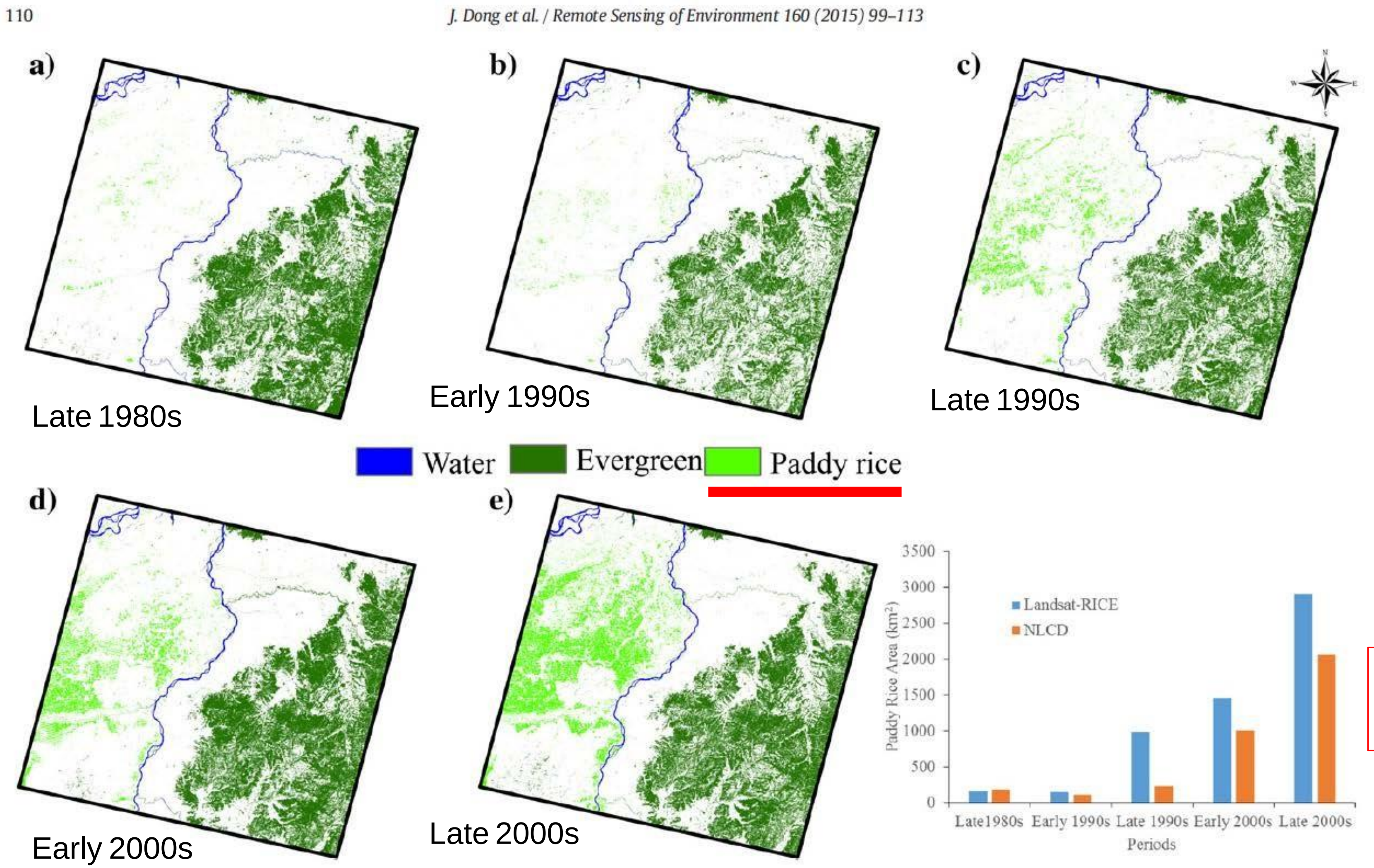
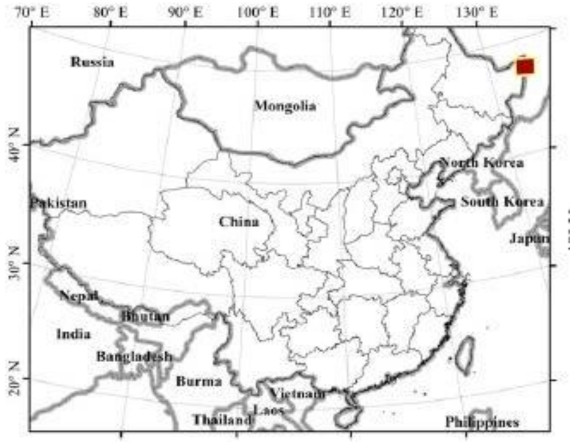


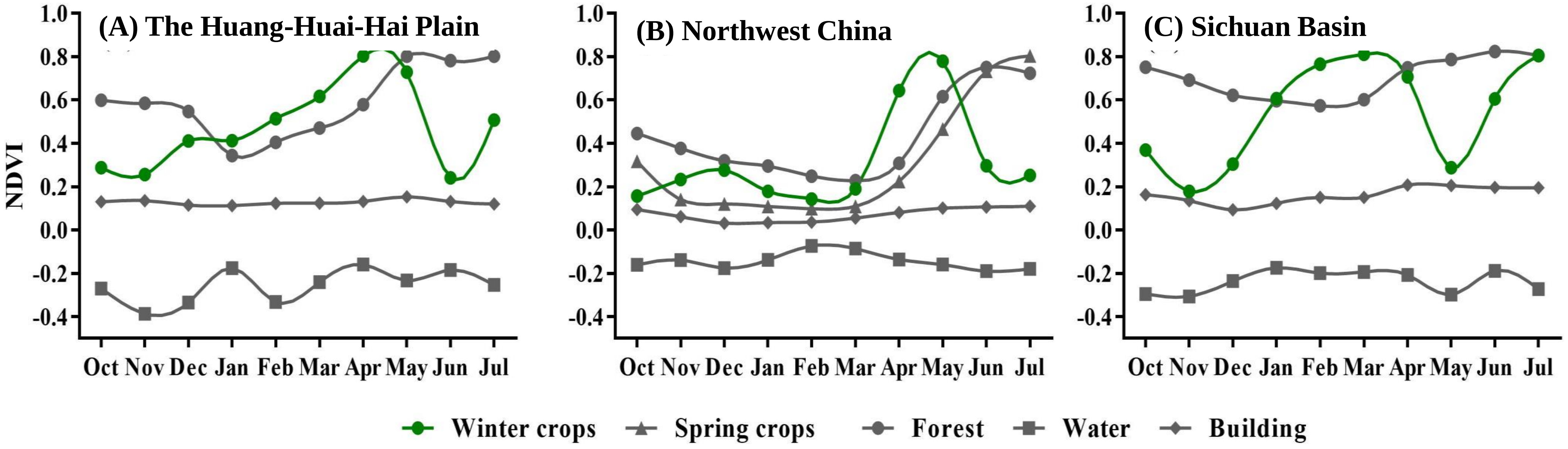
Fig. 8. Resulted maps of paddy rice planting areas for the scene (path/row 113/27) in five epochs: a) late 1980s, b) early 1990s, c) late 1990s, d) early 2000s, and e) late 2000s. f) The temporal dynamic of paddy rice areas according to the five epochs of Landsat-RICE maps and NLCD-based paddy rice maps.



Q6：what has changed in rice planting area?

Dong et al., (2015), Remote Sensing of Environment, 160, 99-113.

Within-season temporal profiles

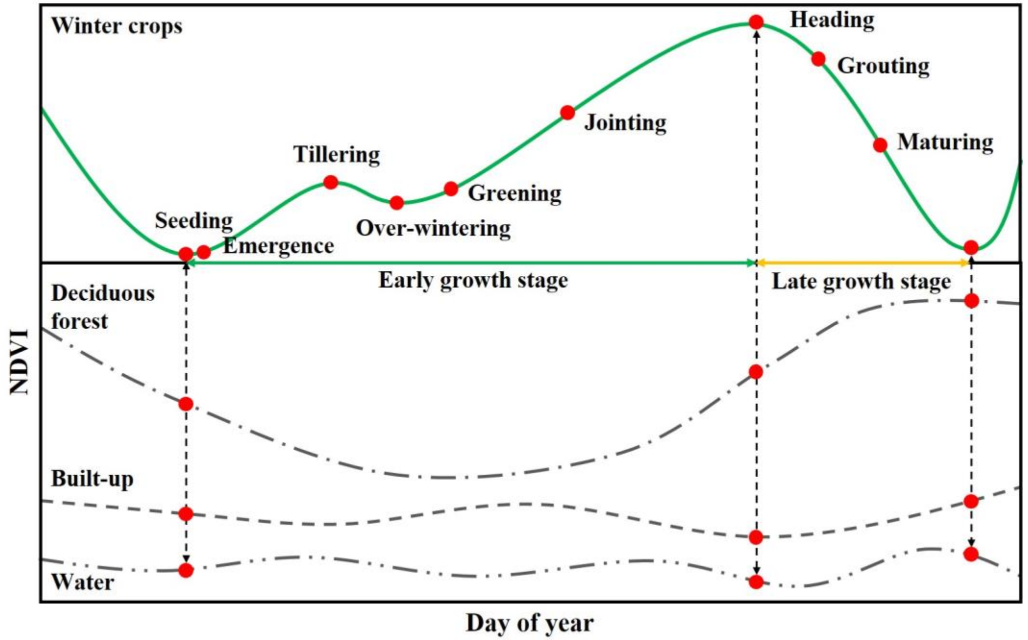


- Winter crops exhibit different temporal patterns in NDVI from spring crops and non-crop land cover classes
- Typical temporal feaures are often used to identify winter wheat

Q7: what can we derive from these time series curves?

28

Within-season temporal profiles



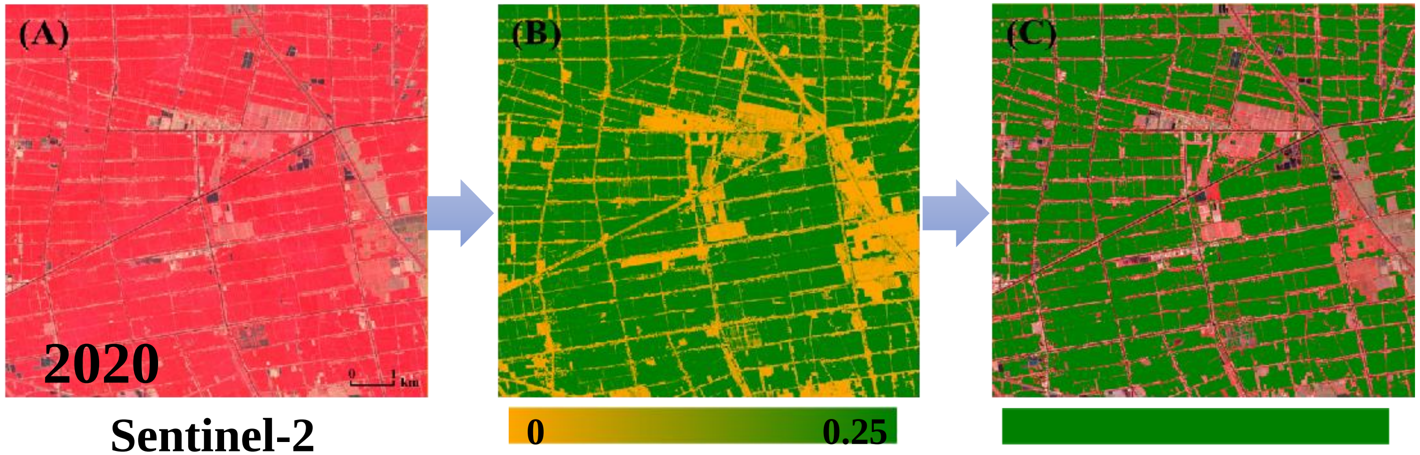
- A spectral index could be developed to identify target crops
- Early growth stage: sowing → grain filling

  $\Delta\, EGS = NDVI_{Heading} - NDVI_{Seeding}$

- Late growth stage: grain filling → harvest

  $\Delta\, LGS = NDVI_{Harvesting} - NDVI_{Heading}$

$WCI = \Delta\, EGS \times \Delta\, LGS$



Sentinel-2 (NIR，R，G)

Winter crop idnex (WCI)

Winter crops

Intraannual temporal profiles

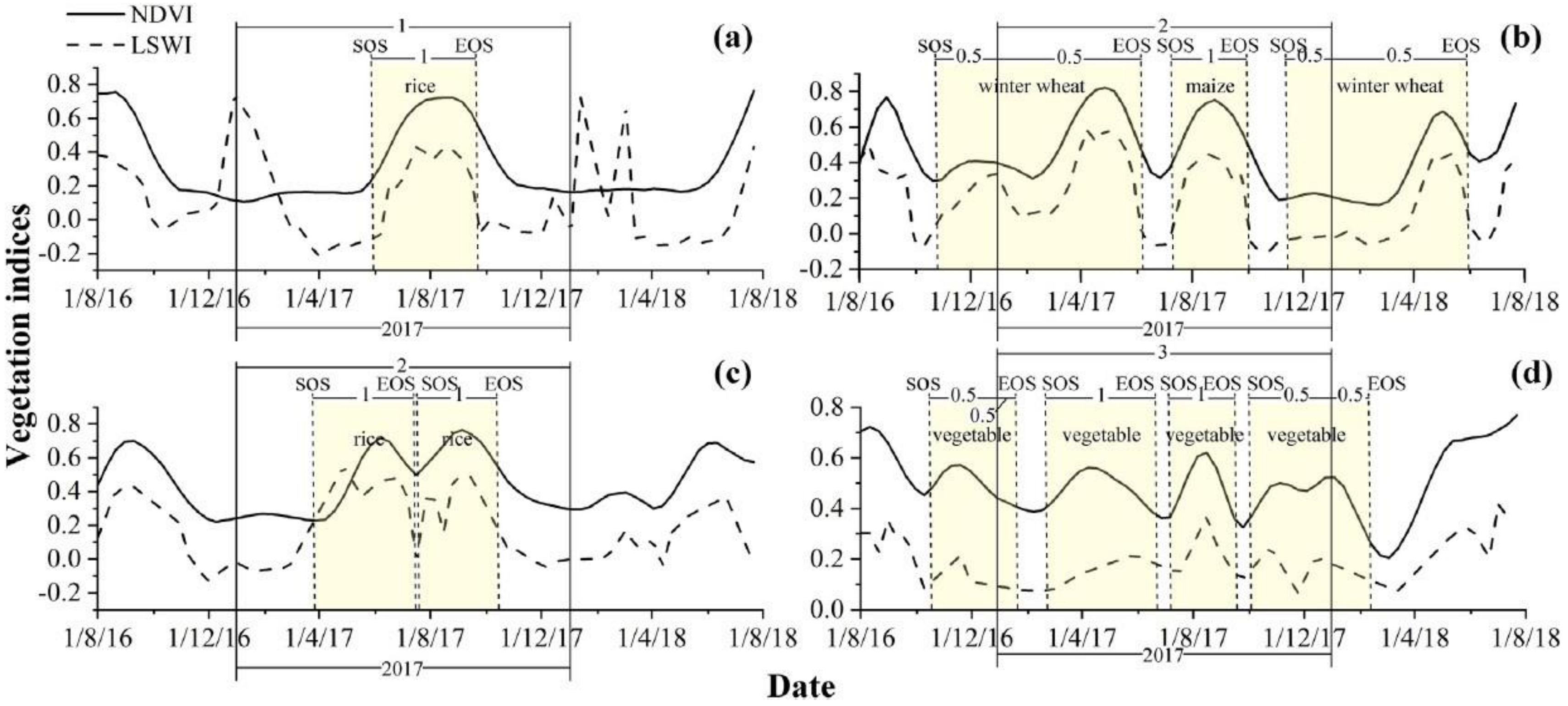


Fig. 6. Temporal profile of vegetation indices (NDVI and LSWI) for cropping intensity sample sites with (a) single cropping (124.7143°E, 43.6478°N), (b) double cropping (114.8321°E, 37.3673°N), (c) double cropping (113.2629°E, 29.1703°N), and (d) triple cropping (109.2024°E, 24.1904°N).

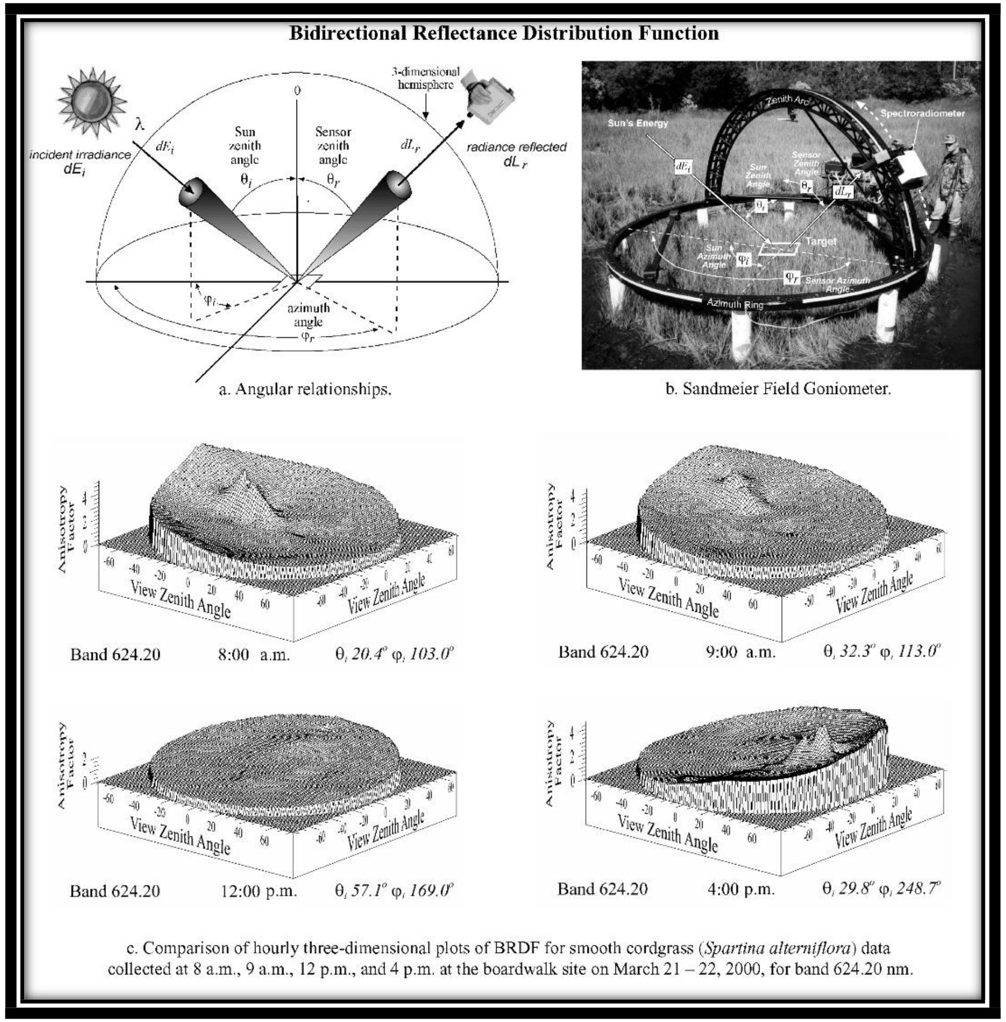
$$\text{NDVI} = \frac{NIR - RED}{NIR + RED}$$

$$\text{LSWI} = \frac{NIR - SWIR}{NIR + SWIR}$$

- Intraannual temporal profiles are useful for detecting cropping intensity.

Liu et al., (2020), Remote Sensing of Environment, 239, 111624.

Angular information



c. Comparison of hourly three-dimensional plots of BRDF for smooth cordgrass (*Spartina alterniflora*) data collected at 8 a.m., 9 a.m., 12 p.m., and 4 p.m. at the boardwalk site on March 21 – 22, 2000, for band 624.20 nm.

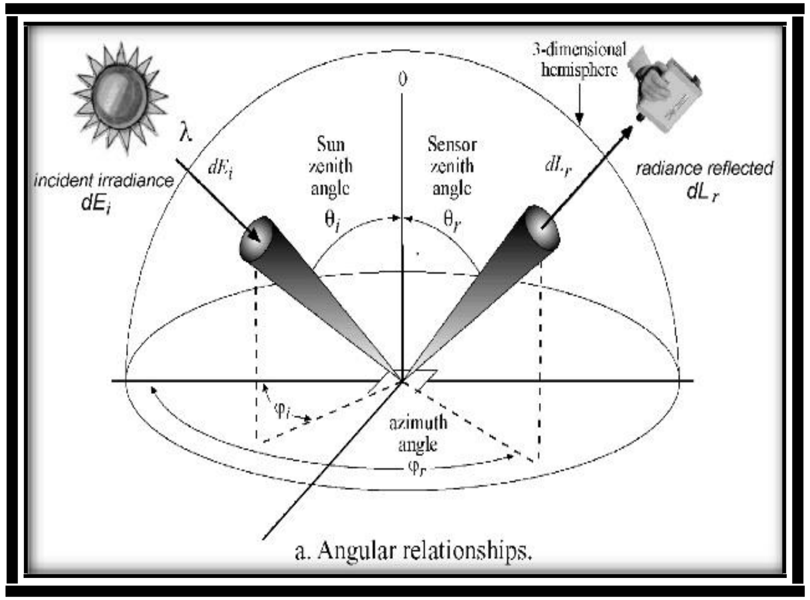
Jensen (2006)

- To minimize spectral variation due to differences in observation angles, we prefer to observe in the nadir direction and the common solar position (around noon time).

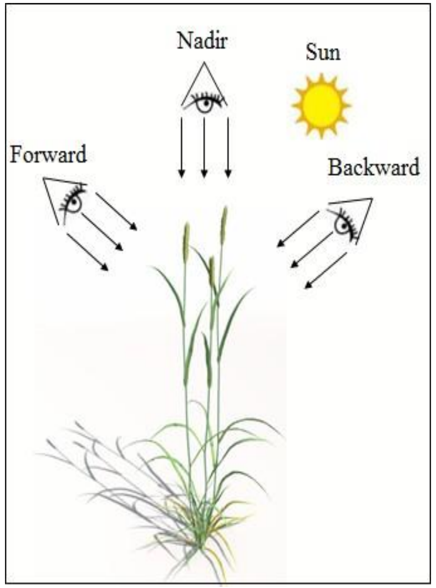
$$BRF(\theta_i, \varphi_i; \theta_r, \varphi_r; \lambda) = \frac{dL_r(\theta_i, \varphi_i; \theta_r, \varphi_r; \lambda)}{dL_{ref}(\theta_i, \varphi_i; \theta_r, \varphi_r; \lambda)} \times R_{ref}(\theta_i, \varphi_i; \theta_r, \varphi_r; \lambda)$$

Information gain from multiple view angles

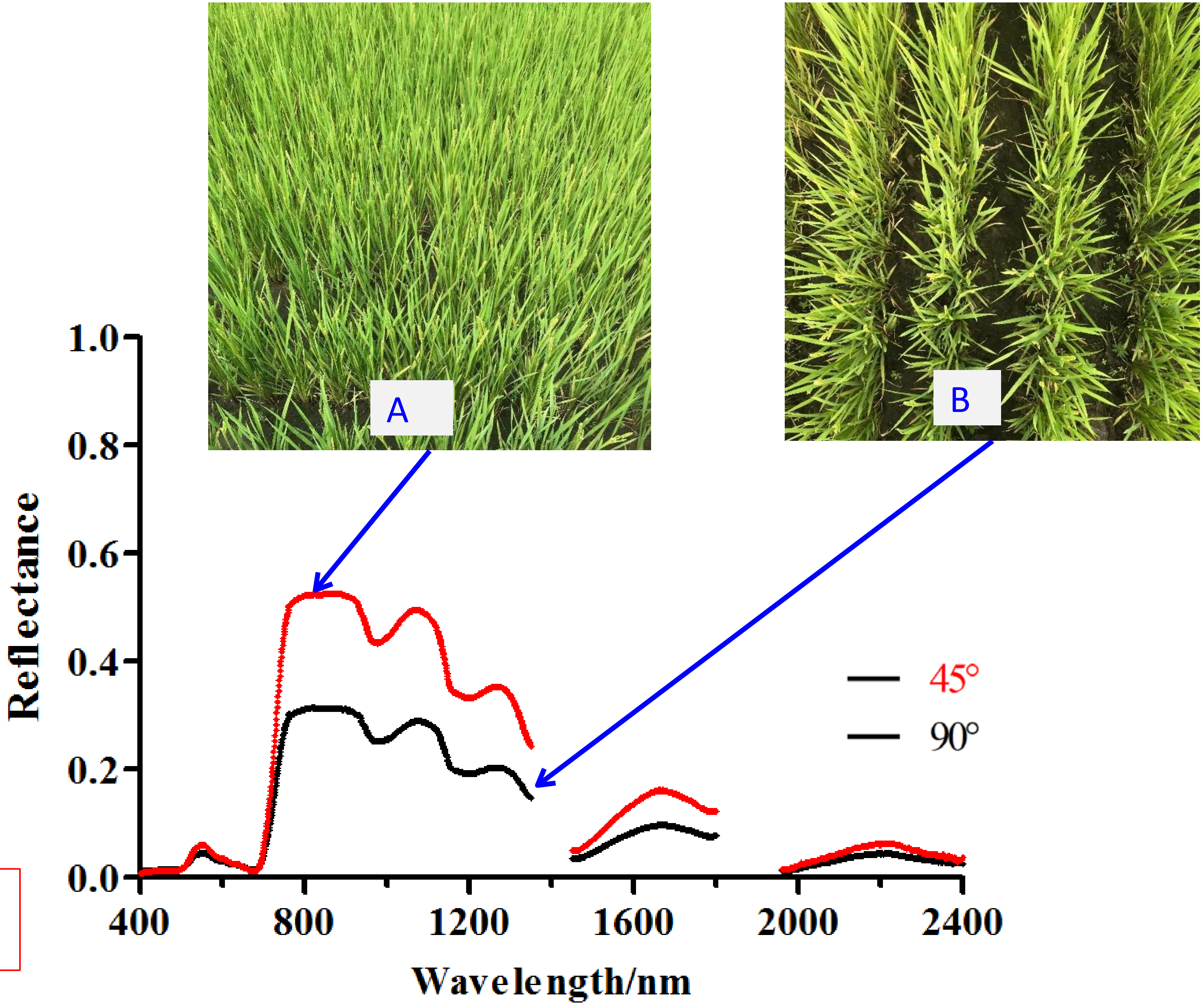
- While UAV images are often acquired from the top view, they can also be acquired efficiently from the oblique view.
- Oblique-angle images with weaker background effects may be beneficial to the estimation of canopy chemistry (e.g., LNC).
- Use of oblique observations is well supported by BRDF theories.



a. Angular relationships.

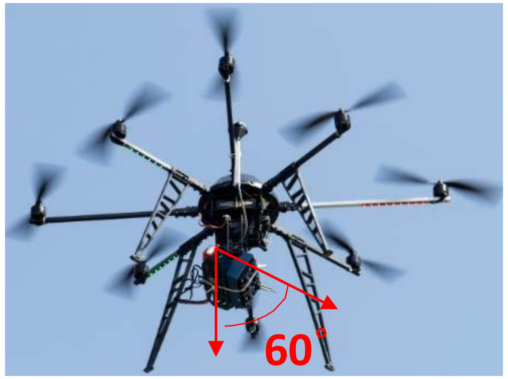


Observations from different angles

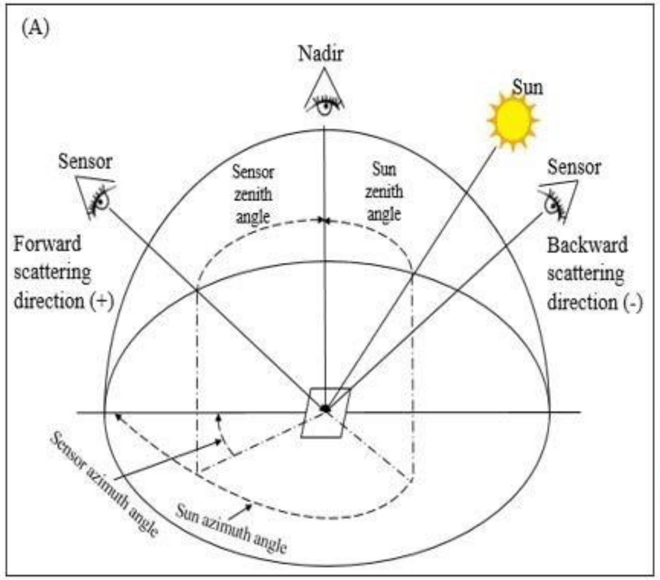


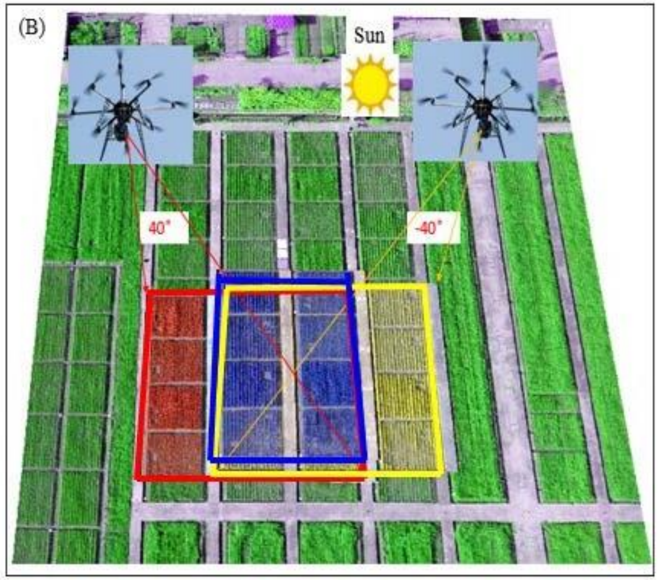
Q8: which spectrum corresponds to figure A? Why?

Multi-angle observations from an UAV



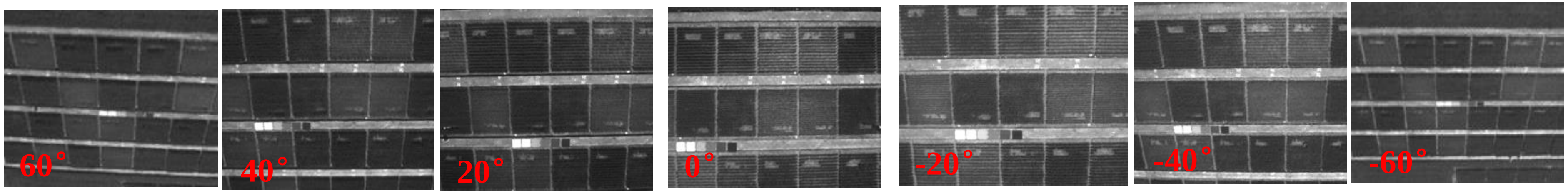
Oblique viewing from an unmanned aerial vehicle (UAV)





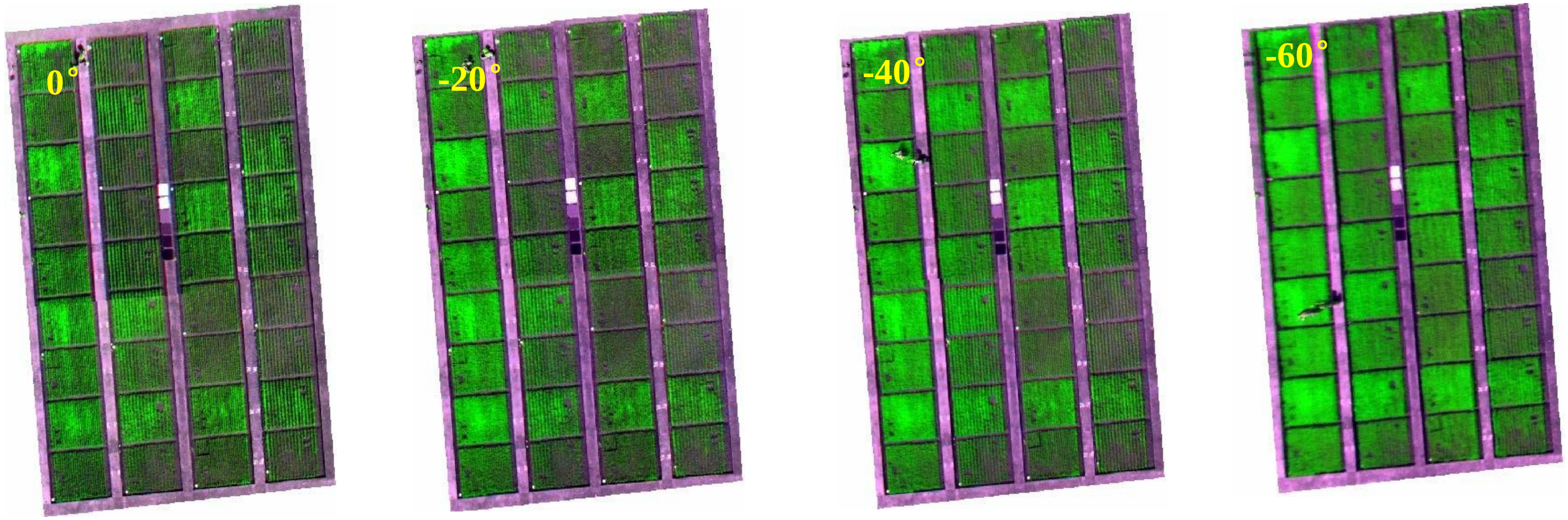
Acquisition of multi-angular images

- Camera captures from different angles

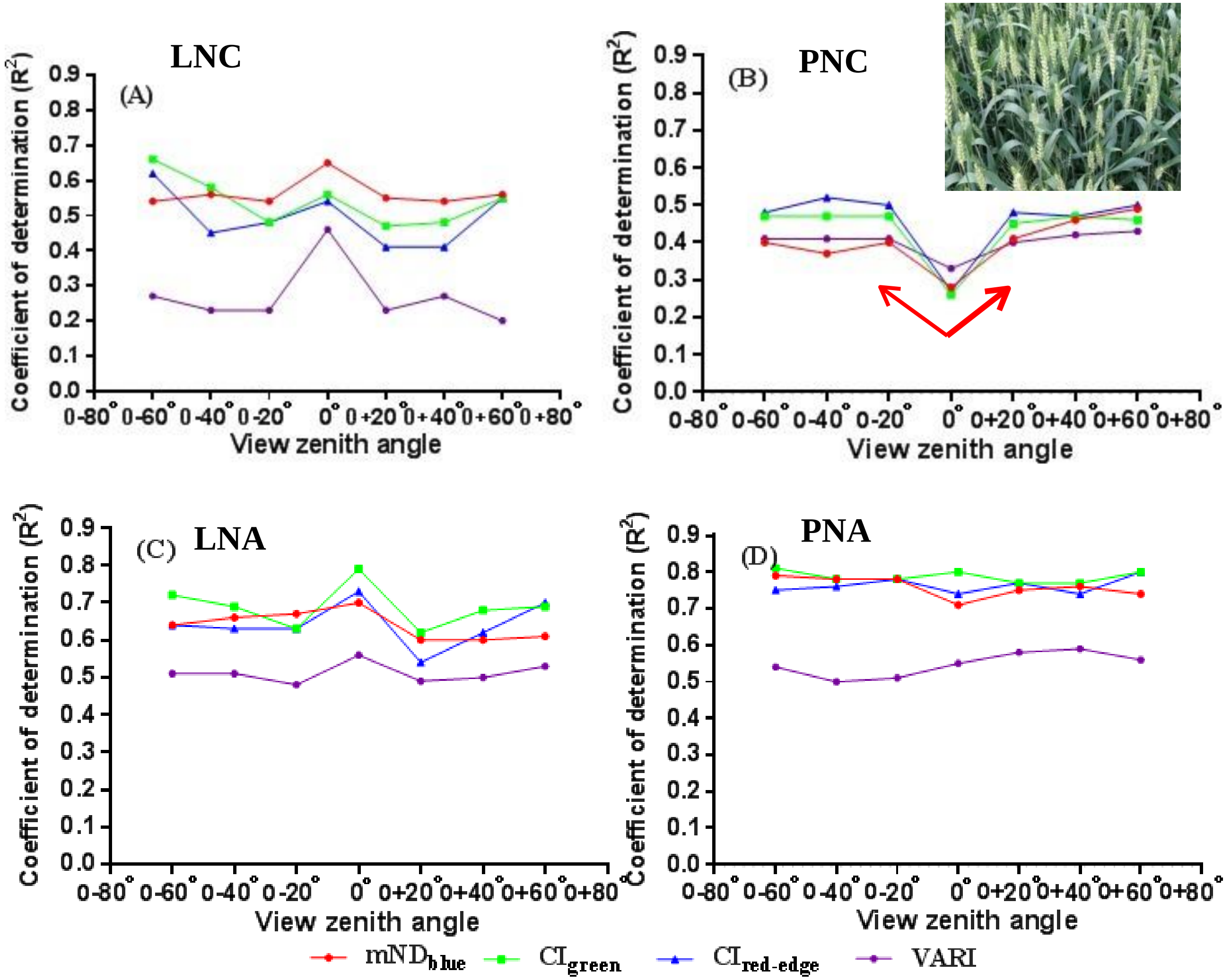


- Image mosaics for the experimental site (36 plots)
  - Oblique images appear to be brighter and more homogeneous, with more signals from the leaves

Jointing stage of winter wheat



Estimation of N nutrition status from nadir + oblique observations



- PNC: estimation was improved with $CI_{red\text{-}edge}$ (R^2: 0.36 → 0.52) by combining any off-nadir image and the 0° image.
- Improvement from the use of dual-angle images was not so significant for LNC, especially for LNA and PNA.

Lu et al., Frontiers in Plant Science, 2019

Categories of remotely sensed data

- Optical imagery: acquired in the visible-infrared and thermal region (0.35-1000 μm)
  - Aerial color photos
  - Panchromatic images
  - Multispectral images
  - Hyperspectral images
  - Thermal images
- Microwave imagery: acquired in the microwave region (1 mm~1 m)
  - Radar images
  - LiDAR images (or point cloud)
- Spectra

False color photos

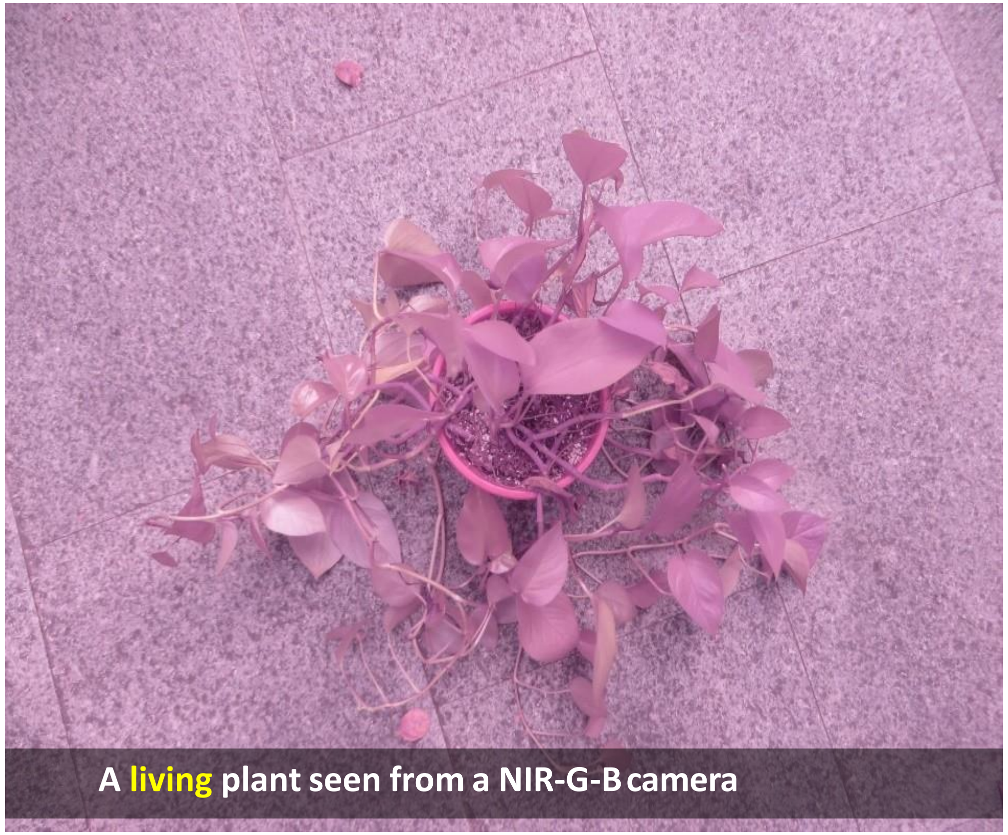
- Traditional data
- Mainly used for making color composites

True color

False color

(Jensen, 2000)

False color photos



A **living** plant seen from a NIR-G-B camera

An **artificial** plant seen from a NIR-G-B camera

Q9: Why do they show different colors? Are green leaves true?

Panchromatic images

- In single band
- Usually at high spatial resolution
- Bundled with multispectral images

Pan Multispectral Fused

QuickBird images

Source: www.geosage.com

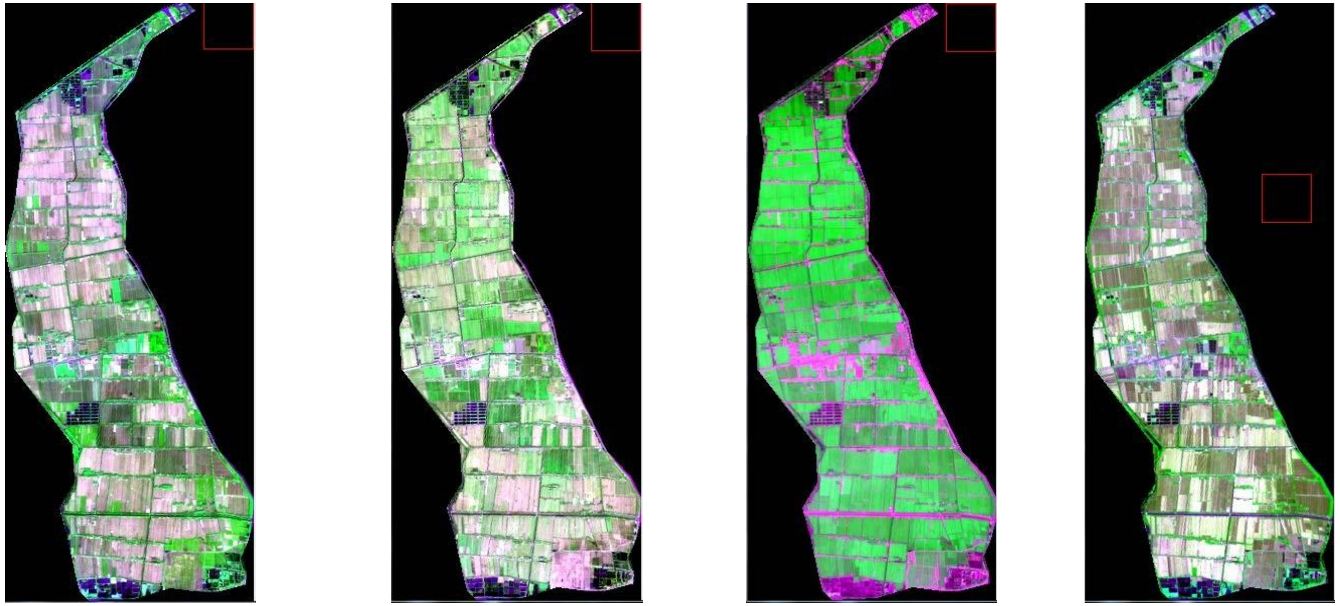
Multispectral images

- Composed of less than 10 bands
- The most popular category
- Available for many satellites

  -- Landsat

  -- MODIS

  -- HJ-1A/B, ZY-3, GF-1



The 2013-2014 wheat season of Baima Lake Farm as seen from Landsat 8

Hyperspectral images

- Very few data from satellite platforms (GF-5)
- Mostly acquired from aircrafts

    -- AVIRIS, HyMap, CASI, …

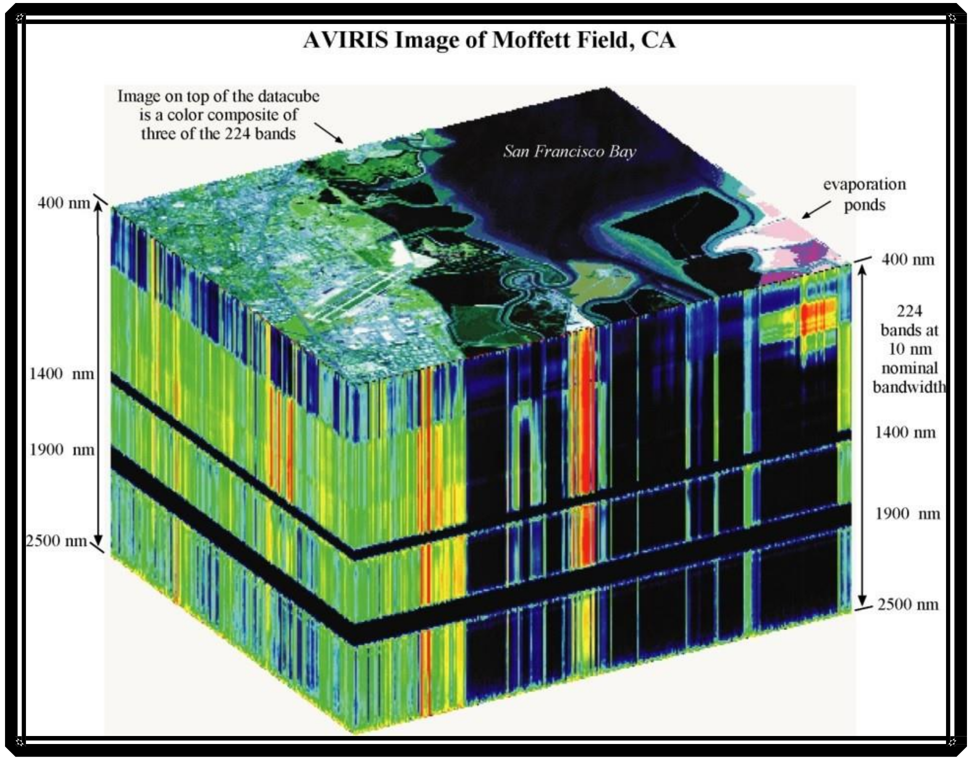


Figure from Jensen (2006)

Hyperspectral images

Specification	Value
Wavelength range	450–950 nm
Sampling interval	4 nm
Spectral resolution	8 nm at 532 nm
Channels	125
Detector	Si CCD
Weight	470 g

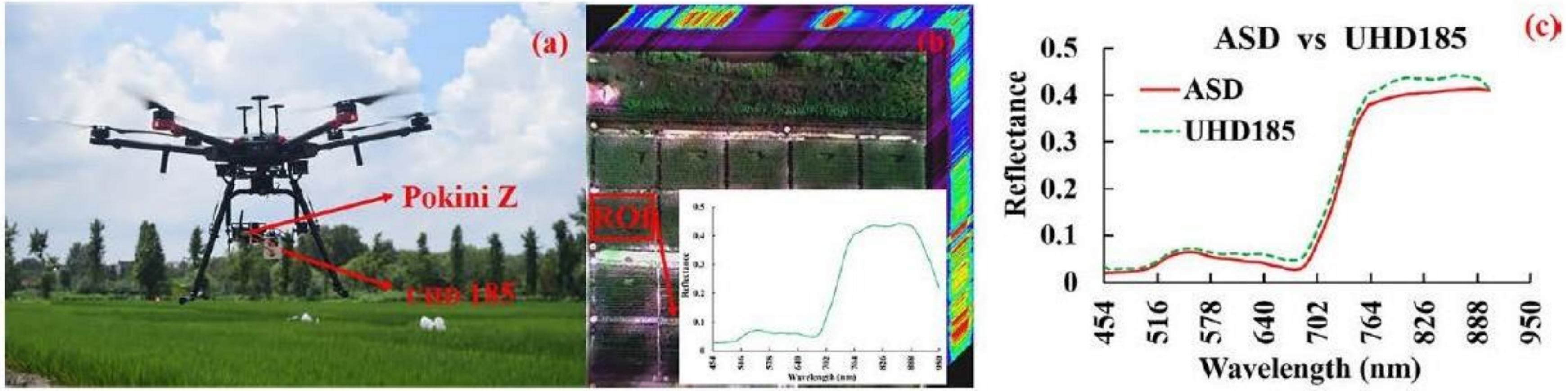
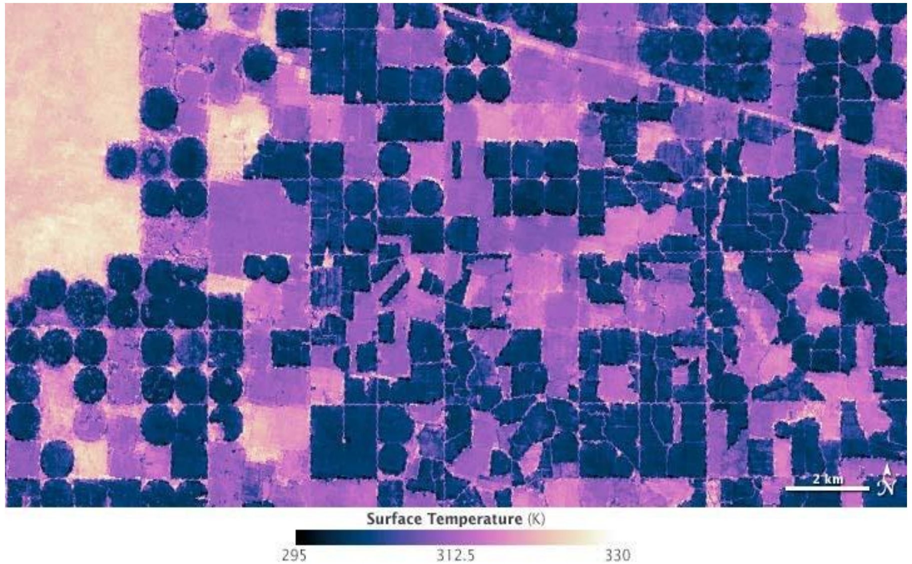


Fig. 2 UAV with a hyperspectral imaging system (**a**), reflectance obtained from one plot in one single hyperspectral image cube (**b**) and the comparison of spectral reflectance between ASD (Analytical Spectral Devices, Boulder, CO, USA) and UHD 185 (**c**)

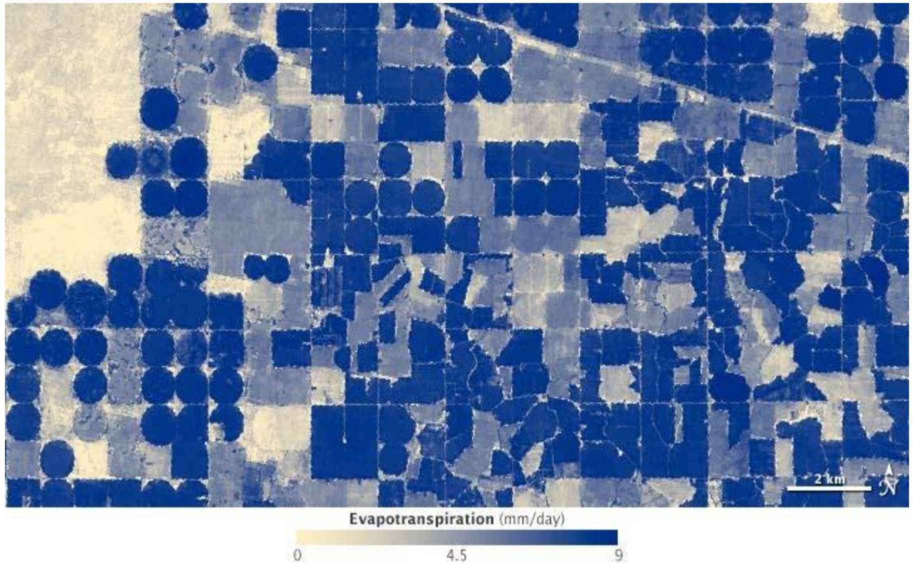
Lu et al., (2020), Precision Agriculture, https://doi.org/10.1007/s11119-020-09729-z

Thermal images

- Lower resolution than VNIR images
- Not many sources, and only in several bands(1-2）
  - — Landsat 7 ETM+ band 6
  - — Landsat 8 TIRS bands 10, 11
- Very useful for studying land surface temperature and energy radiation



Land surface temperature



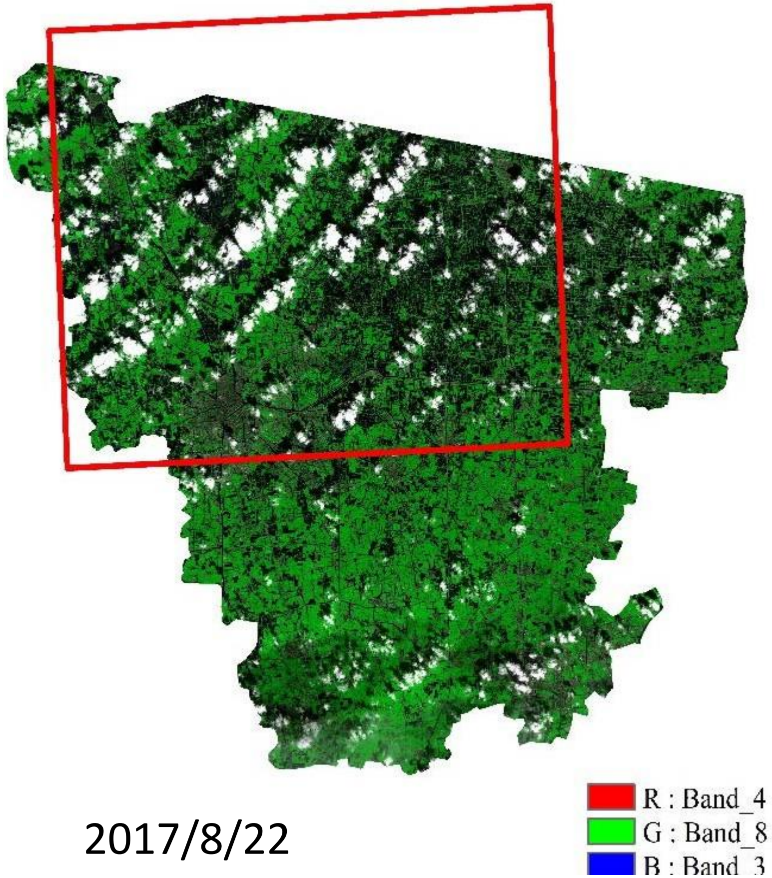
Evapotranspiration

Source：Idaho water resources dept.

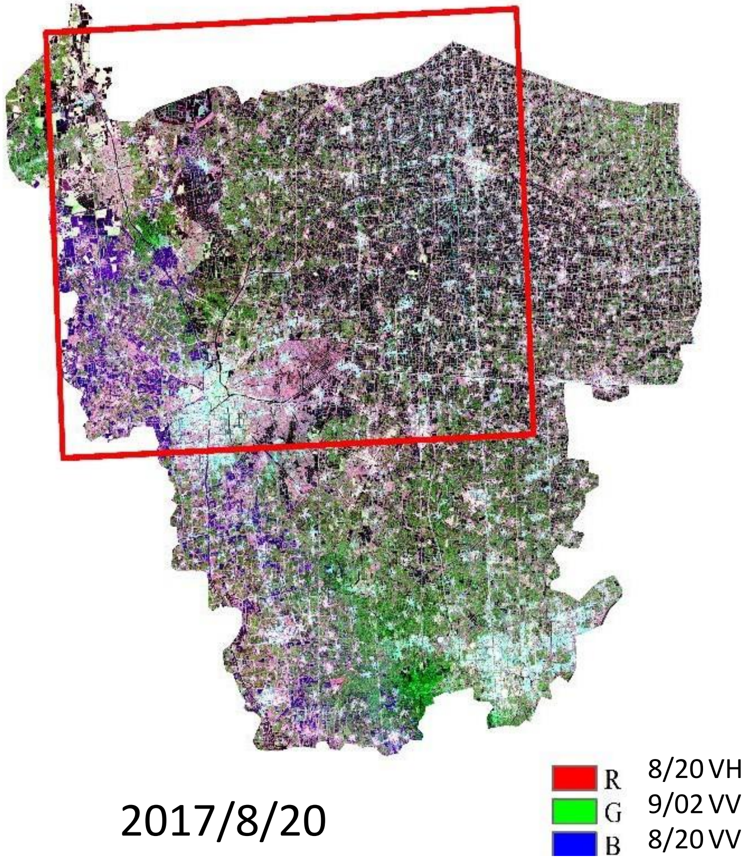
Radar images

- Synthetic aperture radar (SAR), with a different imaging mode
- Satellite sensors
  - — Europe ERS-1/2, ENVISAT-1, Sentinel-1
  - — Japan JERS-1, ALOS-PALSAR
  - — Germany TerraSAR-X
  - — Canada RadarSat
  - — China HJ-1C
- Advantages
  - —not affected by cloud
  - —can penetrate vegetation and bare soil in the top layer
  - —sensitive to surface roughness

Radar images



2017/8/22



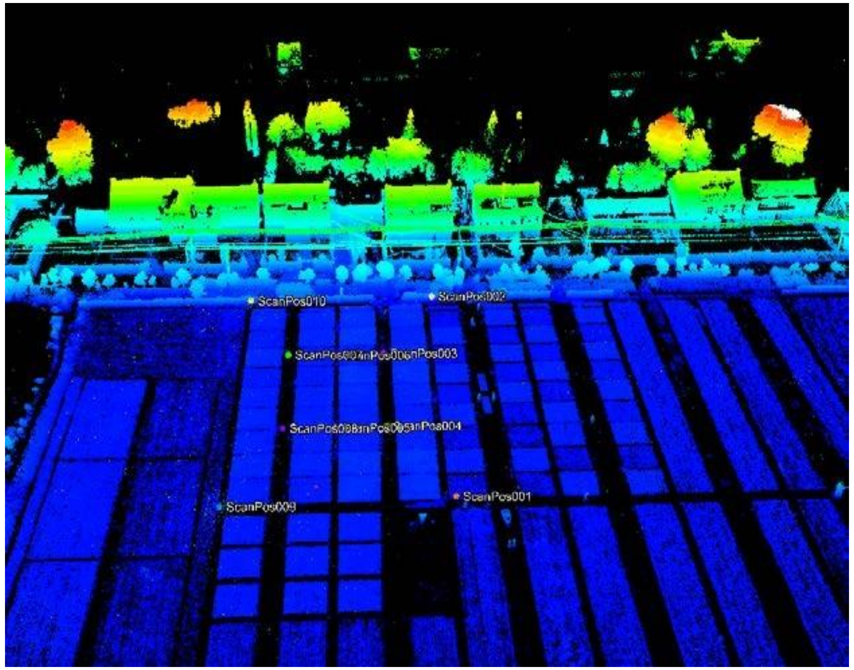
2017/8/20

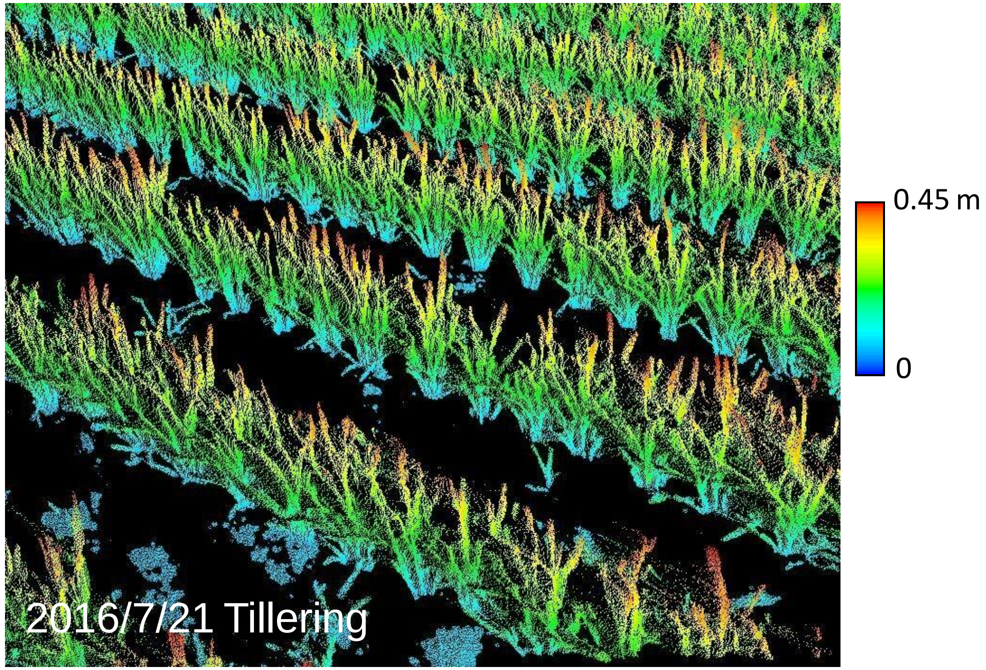
Landsat 8 OLI (optical) and Sentinel-1 (SAR) imagery for the same area

Q10：what is the visual difference between Landsat 8 and Sentinel-1 images?

LiDAR data

- LiDAR (Light Detection and Ranging)
- Acquired with laser beams
- Acquisition wavelength at visible and NIR bands
- Raw data in point cloud and transferrable to image data

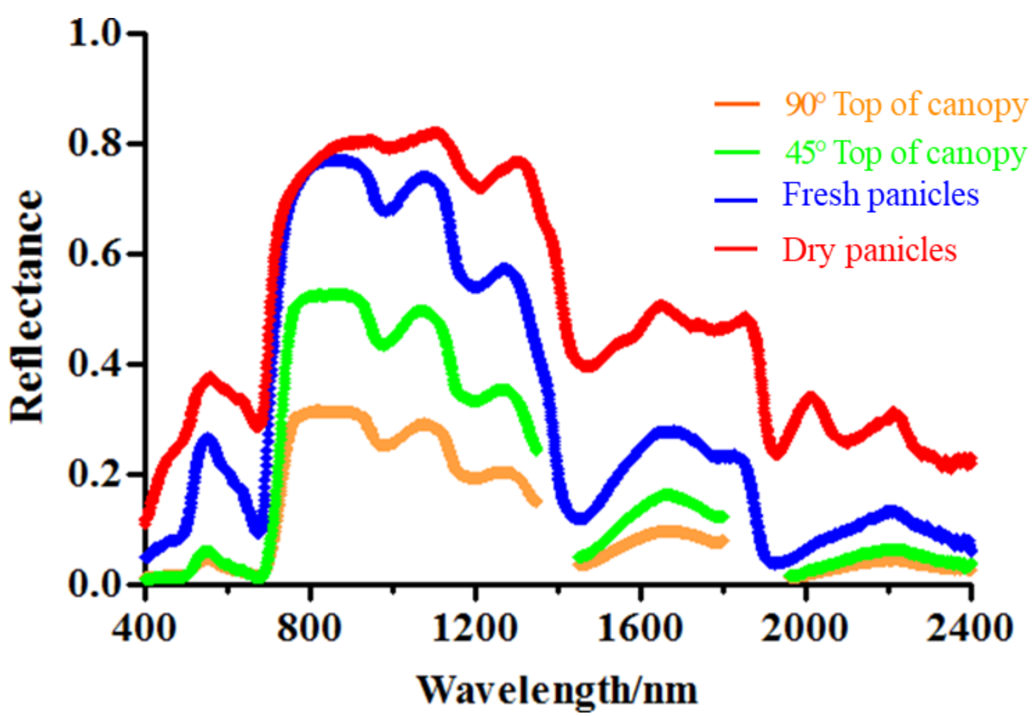


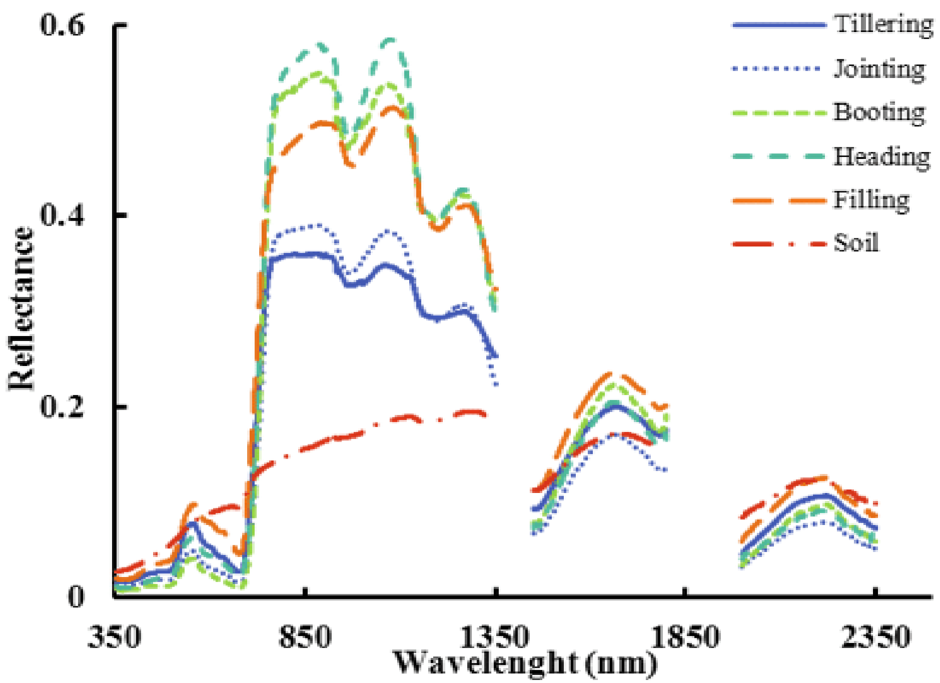


Point cloud of rice fields in Rugao, Jiangsu

Field spectra

- Acquired with spectrometers in the field or laboratory
- Non-imaging one dimensional data
- Used for surface material identification, cal/val, etc





Data resources

- Landsat:
  - http://landsat.usgs.gov/Landsat_Search_and_Download.php
- Land remote sensing data:
  - https://lpdaac.usgs.gov/data_access/
- Chinese Resources Satellite Data:
  - http://www.cresda.com/CN/

Further reading

- DIP Chapter 1