GEOL 1460/2461 Ramsey
Introduction to Remote Sensing Fall, 2023

Multispectral/hyperspectral remote sensing systems
Image processing: data transforms & classifications

Week #4: September 20, 2023

I. Class Information:

- both textbooks should now be available for 2-hour reserve in the Engineering Library

II. Review: Last Lecture Two Weeks Ago

- atmospheric principles
  - types of scattering, definitions
  - atmospheric windows

- cameras
  - relief displacement
  - stereo-pairs → DEM's

- imaging systems
  - types of scanners, dwell time
  - *did you solve the multispectral scanner question??*

- EM principles
  - spectral resolution
  - spectroscopy

III. Tonight: digital image processing *(continued)*

- introduction to image processing
  - we will go over: (1) data transforms and (2) image classifications

- data transforms *(geometric)*
  - corrections to the data due to scan errors, sensor position, motion
  - transformations (new coordinate systems, image mosaics)

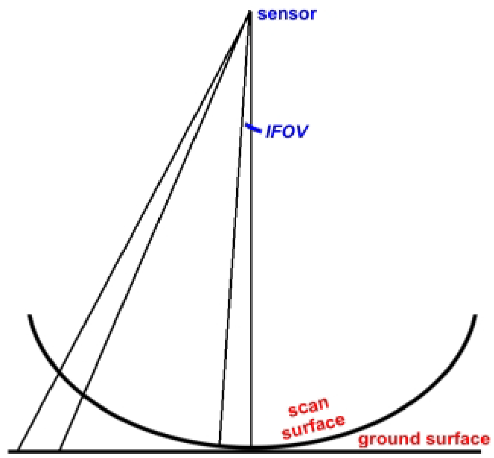
  - non-systematic distortions
    - uncontrolled variations
    - much more complicated to correct

  - systematic distortions
    - regular occurrence
    - example: edge foreshortening due to scan angle
    - easier to correct

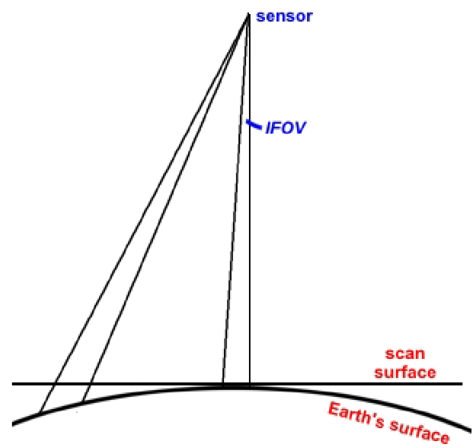
- *panoramic distortion*
  - systematic error in whiskbroom style instruments
  - gets worse away from the nadir (non-vertical position)
  - true size and position of ground objects lie along a circular arc described by the scanning motion of the instrument

  - this scan arc intercepts the ground at one point, called *nadir*
  - elsewhere, objects on the ground are compressed perpendicular to the flight direction

- *distortion due to the Earth's curvature*
  - systematic error seen in geostationary sensors (further from the Earth)
  - effects images covering a large portion of the Earth's surface (i.e., weather satellites)
  - produces the opposite effect as panoramic distortion
  - images are elongated with respect to the image center



panoramic distortion



distortion due to Earth's curvature

- over/under sampling
  - **non**-systematic error
  - function of the sensor velocity vs. scan rate
  - most common on aircraft scanners
    - if sensor is moving too fast for scan rate, then under-sampling occurs and there are gaps in the data (image appears compressed in the flight direction)
    - if sensor is moving too slow for scan rate, then over-sampling occurs and there are scanned more than once (image appears elongated in the flight direction)

- Image Classifications *(slightly more advanced topic)*
  - series of algorithms designed to categorize or "clump" data into certain classes in order to minimize scene variability and extract certain user-defined parameters
  - focus of machine learning algorithms more recently

- two primary types of classification:
    - unsupervised (can be defined automatically)
    - supervised (defined by the user)

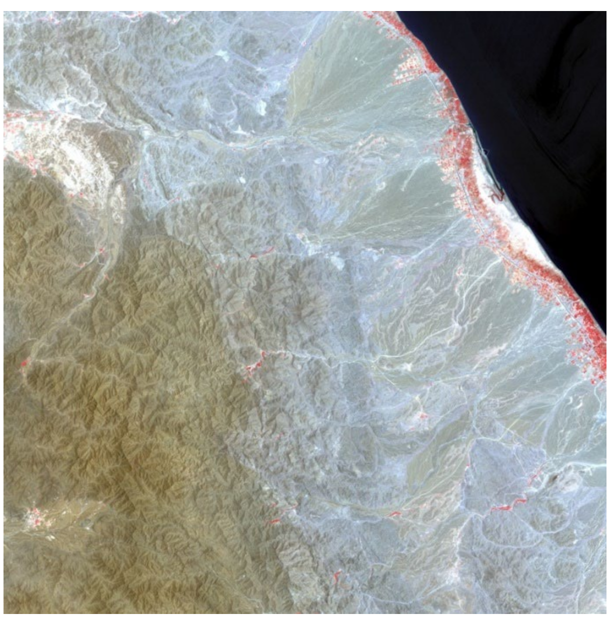
    - what determines a "good" class or target?
        1. covers more than one pixel (mathematically valid) – *see below*
        2. class is well represented in the scene
        3. overlap with other classes is minimal
        4. able to define enough training pixels per class

    - need approximately **10 × (n+1)** pixels per class to give good statistics
        - where, n = number of spectral bands of the instrument

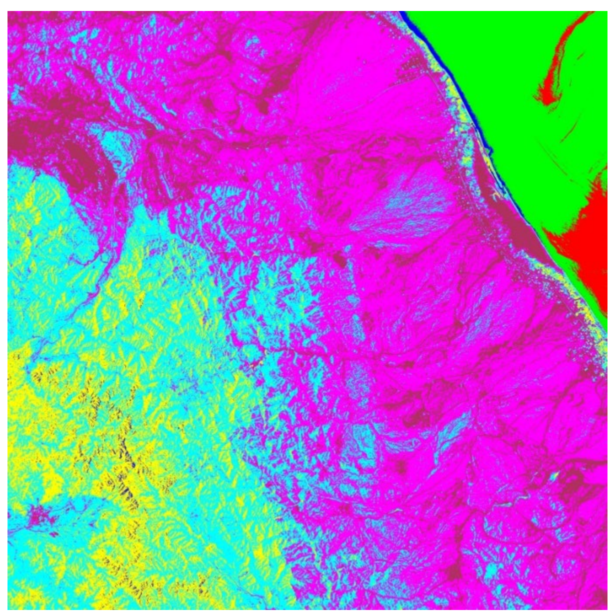
    - <u>unsupervised classifications:</u>
        - limitation: all unsupervised classifications may produce non-intuitive classes
            - user must still interpret the results

        - different algorithms for unsupervised classifications
            - k-means approximation
                - algorithm locates a number of data clusters and their centers
                - computes statistically significant number of classes

            - iso-approximation
                - users seeds the algorithm with some number of data clusters
                - then a k-means (or other rule) is performed
                -



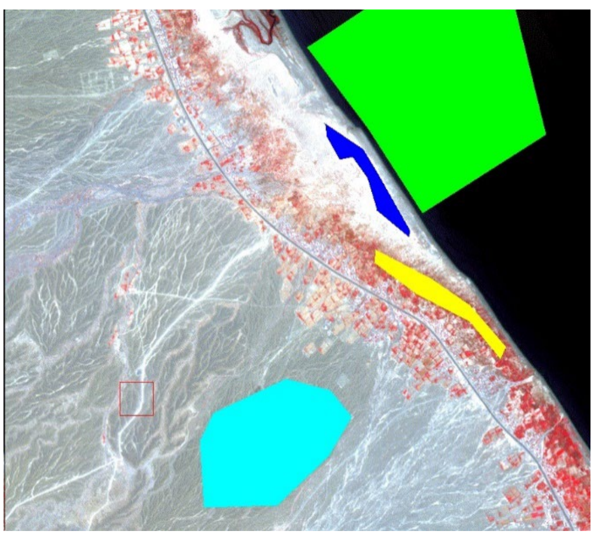
ASTER bands 3,2,1 in R,G,B



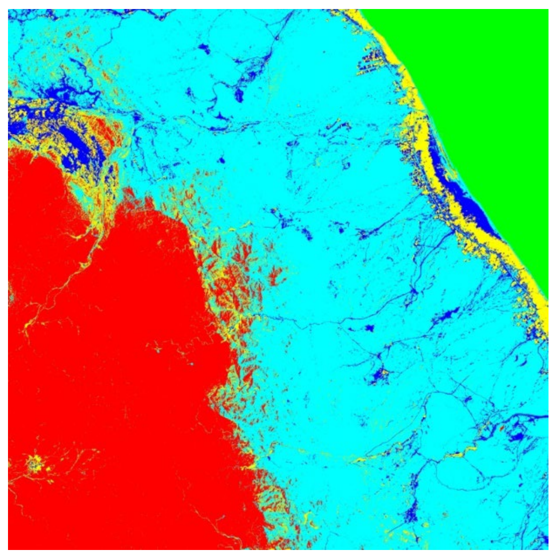
unsupervised classification (7 classes)

- <u>supervised classifications:</u>
  - minimum distance *(to means)*
    - simplest method
    - determines the distance to the mean DN value (in n dimensional space) of each class and assigns unknown pixels to the class with a mean closest to that pixel
    - limitation – ignores the shape (variance) of the data cloud
      - can cause errors if an unknown pixel lies near/within one class, but is closer to the mean of another class

  - maximum likelihood
    - more complex method
    - creates an n-dimensional parallelepiped or ellipsoid around the DN values of each class
    - statistically determines whether an unknown pixel falls within that shape
    - generally, the most accurate method of classification
    - limitations - longer computer run time, requires a large number of pixels to accurately define your classes



4 of 5 training regions (classes)



max. likelihood supervised class.

  - accuracy assessment
    - user validation and check of the classification accuracy is critical
    - without it, the results of the classification could be wildly incorrect
    - check can be performed via field work, use of higher spatial resolution data, or other (non-raster) datasets

IV. History of visible to short-wave infrared (VSWIR) sensors: Landsat

- ***http://landsat.gsfc.nasa.gov/***
- first “open” data source from space – still in use today

- *Landsat 1 launched in 1972*
  - primary instrument: Multispectral Scanner (MSS)
    - 4 bands (VIS - NIR)
    - 79m ground resolution (pixel size)
    - ceased operation: 1978

- *Landsat 2 (1975), Landsat 3 (1978)*
  - also contained the MSS instrument

- *Landsat 4 (1982)*
  - some important differences from the first three
    - lower orbit (higher spatial resolution) and later overpass time (less shadows)
    - began to transmit data to numerous ground receiving stations and via TDRS satellites (expanded coverage, less reliance on tape drive)

  - new instrument: **Thematic Mapper (TM)**
    - 7 bands (including 1 TIR band, 120m/pixel)
    - Band numbers are out of order (naming convention remains)
    - 30m/pixel resolution
    - dual-scan motion (longer dwell time, less noise)

- *Landsat 5 (1984)*
  - operational for 29 years!
  - officially retired in 2013

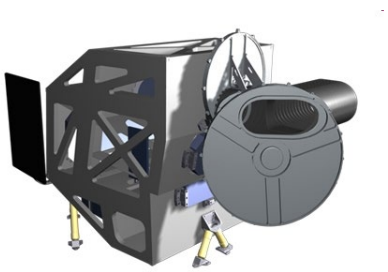
- *Landsat 6 (1993)*
  - failed to reach orbit

- *Landsat 7 (1999):* ***https://www.usgs.gov/landsat-missions***
  - new instrument: **Enhanced TM (ETM+)**
    - doubled the resolution of the thermal IR band (60m)
    - added a new “pan-band”
      - averages the wavelengths of bands 2, 3, 4
      - 15m/pixel

Band	Spectral Range (µm)	Ground Res. (m)
1	.45 to .52	30
2	.53 to .61	30
3	.63 to .69	30
4	.78 to .90	30
5	1.55 to 1.75	30
6	10.4 to 12.5	60
7	2.09 to 2.35	30
Pan	.52 to .90	15

        - data compromised after only a few years in orbit due to a mechanical part failure called the scan line corrector (SLC)

- *Landsat 8 (2013):*
    - new instrument: **Operational Land Imager (OLI)**
        - push broom rather than whiskbroom
        - 7000 detectors per spectral band!
        - 5 to 10-year life
        - 2 additional bands from the TM instruments

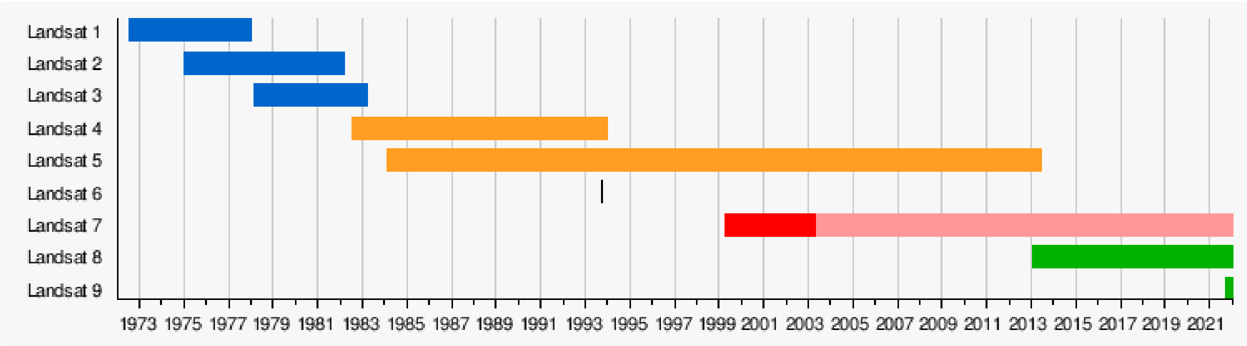


    - new instrument: **Thermal Infrared Sensor (TIRS)**
        - also push broom
        - new array material
        - only a 3-year life *(stopped working well after 1 year)*
        - 1 additional band from the TM instrument

    - *differences* from Landsat 7:

Band	Spectral Range (µm)	Ground Res. (m)
1	0.433 – 0.453	30
5	0.845 – 0.885	30
8	0.500 – 0.680	15
9	1.36 – 1.39	30
10	10.30 – 11.30	100
11	11.50 – 12.50	100

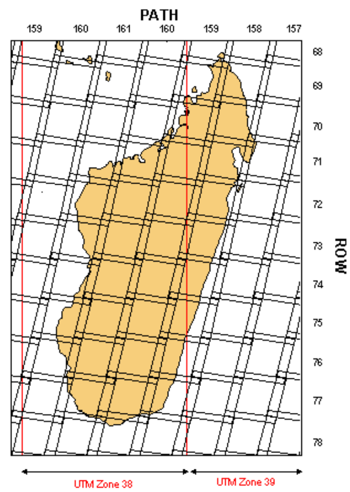
- *Landsat 9 (2021):*
    - duplicate of Landsat 8



- Landsat orbits
  - inclined polar orbit
    - sun-synchronous
    - meaning the same overpass time (~ 10:15 am/pm) at the equator every time

  - repeat cycle of 16 days (233 distinct orbital paths)

  - all images are referenced to specific Row (N-S) and Path (E-W) grid system



V. Other VNIR sensors

- *TIROS weather satellites (1960's)*
  - Television Infrared Observation Satellite
  - VIS and TIR instruments
  - cloud and surface temperatures
  - images of large storms
  - 11 satellites in all
  - precursors to the current GOES weather satellites
    - now used for daily weather in the northern hemisphere

  - geostationary satellites
    - stay in an orbit with a fixed view of the surface

- *AVHRR (1981)*
  - followed from TIROS program
    - 5-6 channels
    - two VNIR bands (green and blue)
    - 1.1 km/pixel resolution
    - used for weather patterns, thermal anomaly monitoring, vegetation health, sea surface temperatures

- *SPOT (1986 – present):* ***http://www.geo-airbusds.com/en/143-spot-satellite-imagery***
  - French/ESA program
    - 5 satellites launched thus far
    - VNIR bands
    - spatial resolution: 2.5 – 20 m/pixel
    - repeat time: 1-3 days

- *Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)*
  - ***http://asterweb.jpl.nasa.gov/***
  - built by Japan
  - launched in 1999 on the Terra spacecraft

- part of NASA Earth Observing System (EOS)
- highly successful thus far
- can also generate DEM's from its near infrared data

- *MODIS instrument (NASA)*
  - ***https://modis.gsfc.nasa.gov/***
  - two instruments (on the Terra & Aqua satellites)
    - 1999 (Terra spacecraft), 2002 (Aqua spacecraft)

  - 26 bands (0.41 – 6.8 μm)
  - 250 m to 1 km/pixel resolution
  - used for land, atmosphere, and sea applications

- Sentinel
  - ***https://www.esa.int/Applications/Observing_the_Earth/Copernicus/The_Sentinel_missions***
  - many different Sentinel missions launched by the European Space Agency (ESA)
  - improved temporal resolution (revisit time) by launching 2 satellites in opposing orbits
    - Sentinel-1: radar (Sentinel-1A launched on 3 April 2014 and Sentinel-1B on 25 April 2016)
    - Sentinel-2: imager similar to Landsat (Sentinel-2A launched on 23 June 2015 and Sentinel-2B on 7 March 2017)
      - 13 bands in the VSWIR region
      - spatial resolution: 10 m, 20 m and 60 m/pixel
      - 10-day revisit
      - 10-11am local time equator crossing

Band	**Band Center (μm)**	**Ground Res. (m)**
Band 1 – Coastal aerosol	0.4422	60
Band 2 – Blue	0.4921	10
Band 3 – Green	0.559	10
Band 4 – Red	0.6649	10
Band 5 – Vegetation red edge	0.7038	20
Band 6 – Vegetation red edge	0.7391	20
Band 7 – Vegetation red edge	0.7797	20
Band 8 – NIR	0.8329	10
Band 8A – Narrow NIR	0.864	20
Band 9 – Water vapor	0.9432	60
Band 10 – SWIR – Cirrus	1.3769	60
Band 11 – SWIR	1.6104	20
Band 12 – SWIR	2.1857	20

- Others: *commercial*
  - *Satellite Imaging Corporation:* ***http://www.satimagingcorp.com/***
  - purchased rival, *Digital Globe (now called Maxar):* ***https://www.maxar.com/***
  - all their satellites are combined under one system now, examples:

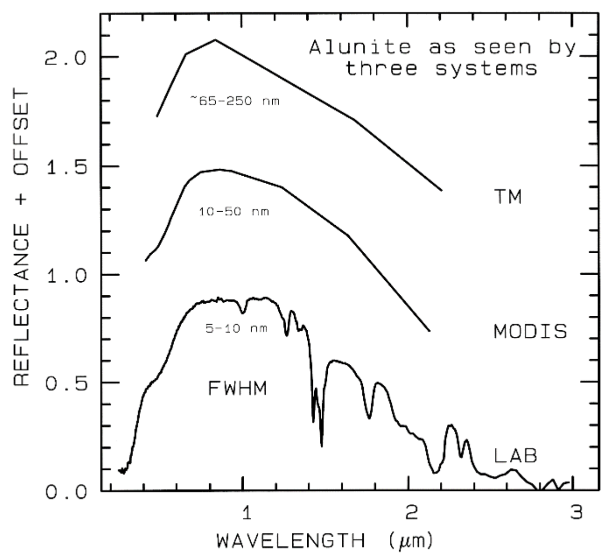
- IKONOS:
  - 4 band VNIR sensors with 4 m/pixel resolution
  - 1 pan-band at 1 m/pixel
  - sun-synchronous
  - 10-11am local time equator crossing

- GeoEye-1:
  - 4 band VNIR sensor with 1.65 m/pixel resolution
  - 1 pan-band at 41 cm/pixel

- QuickBird
  - 4 band VNIR sensors with 2.4 m/pixel resolution
  - 1 pan-band at 0.6 m/pixel
  - not sun-synchronous

- *AVIRIS (1990's - present)*
  - ***http://aviris.jpl.nasa.gov/***
  - NASA *airborne* instrument
  - Silicon (Si) detectors for the visible range
  - indium-antimonide (InSb) detectors for the near infrared
  - "whisk broom" scanning
  - 10 nm nominal channel bandwidth, calibrated to within 1 nm
    - 224 spectral bands (hyperspectral)
  - 30 degrees total field of view (full 614 samples)

examples of spectral resolution for several different VNIR instruments



- *VIIRS (2011)*
  - ***https://jointmission.gsfc.nasa.gov/viirs.html***
  - Visible/Infrared Imager Radiometer Suite (VIIRS)
  - provide advanced imaging on the National Polar-orbiting Operational Environmental Satellite System (NPOESS)
    - civil and national security requirements of current NOAA and DOD polar-orbiting satellites
    - NPOESS satellites will be designed to last nearly twice as long on orbit as the current satellites
    - will pick up capabilities of the aging AVHRR system as well as MODIS

- spectral bands
  - Visible/Near IR: 9 + Day/Night Pan Band
  - Mid-Wave IR: 8
  - Thermal IR: 4
- 3000 km swath width, 650 m pixel size