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IIT Bombay Winter School

Data Models 2 Session 3

Agenda

Time	Session	Speakers
0930-1000	Recap	Sumit Sen
1000-1100	Earth Observation Background	Paul Churchyard, Ajay Gupta
1100-1145	Activity 1: Create a Data Model for Identifing Flood Extent, Contaminated Water, & Impacted Population	Paul Churchyard, Ajay Gupta
1145-1200	Tea	
1200-1300	First Discussion Session	Paul Churchyard, Ajay Gupta, Sumit Sen
1300-1400	Lunch	
1400-1500	Final Activity: Create your own Data Model	Paul Churchyard, Ajay Gupta
1500-1545	Final Discussion / Presentation part 1	Paul Churchyard, Ajay Gupta, Sumit Sen
1545-1600	Tea	
1600-1700	Final Discussion / Presentation part 2	Paul Churchyard, Ajay Gupta, Sumit Sen

Agenda

- Background on Remote Sensing
    - Types of Imagery
    - Types of Resolution
        - Spatial
        - Temporal
        - Radiometric
        - Spectral
    - How Analysis is conducted on Imagery
    - Well Known Indices for EO
        - NDVI
        - NDWI
        - NDFI
    - Data Model Example for flood extent
- Lab
- Discussion

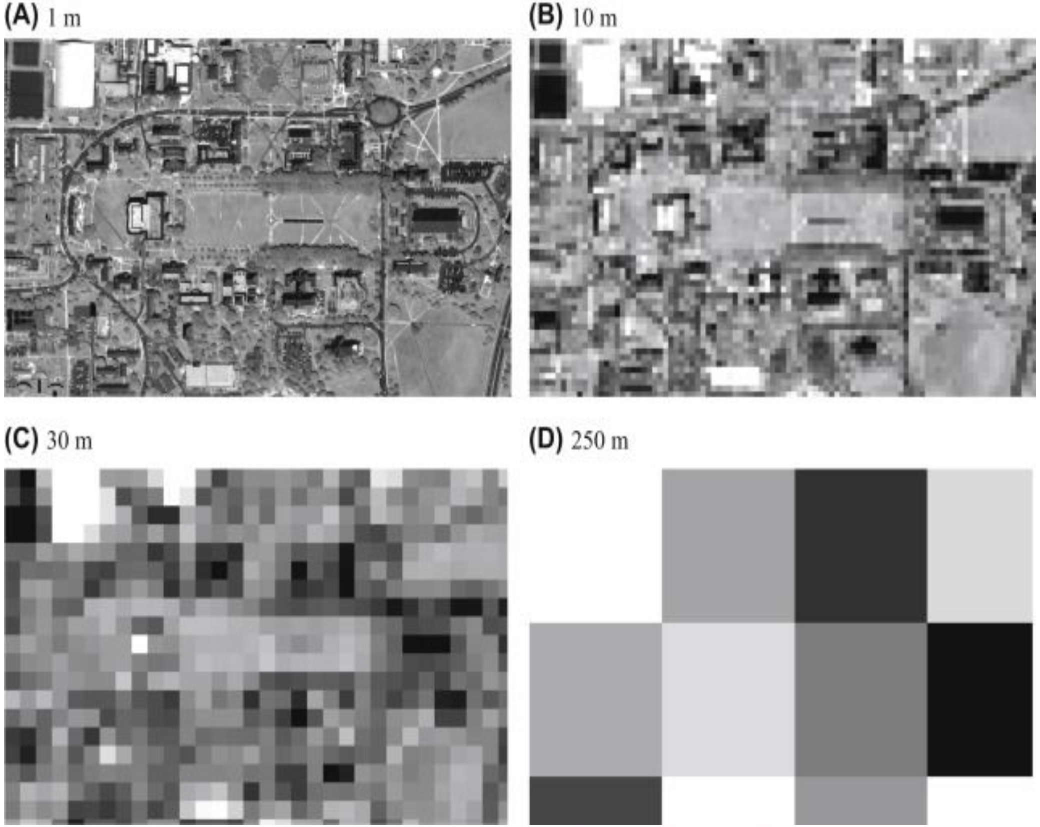
What is Remote Sensing?

Remote sensing is the process of detecting and monitoring the physical characteristics of an area by measuring its reflected and emitted radiation at a distance (typically from satellite or aircraft). Special cameras collect remotely sensed images, which help researchers "sense" things about the Earth.

Ways Remote Sensing Data is Captured

Spatial Resolution

- Spatial Resolution is the ground area covered by one pixel in the image



Temporal Resolution

Temporal resolution is the time it takes for a satellite or constellation of satellites to acquire an image of the same area.

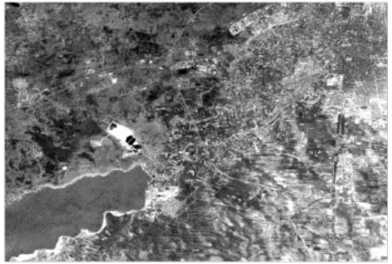
Satellites have a fixed temporal resolution due to their orbits so if small temporal resolution to near real time resolution is needed then aerial imagery is the way to go

Mission	Number of satellites	Temporal resolution (single satellite)	Temporal resolution (constellation)
SENTINEL-1	2	12 days	6 days
SENTINEL-2	2	10 days	5 days
LANDSAT 7	1	16 days	16 days
WorldView-3	1	1 day	1 day
Terra	1	16 days	16 days

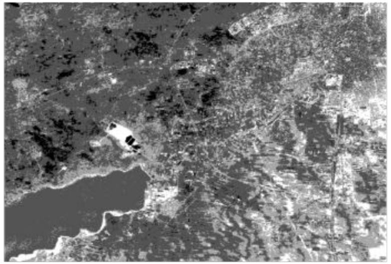
Radiometric Resolution

Radiometric resolution is the bit rate of the image data stored in the image.

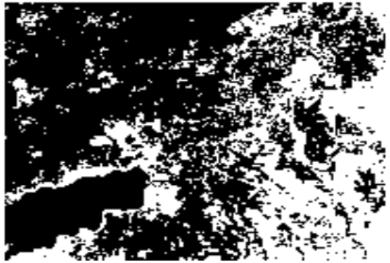
16 Values (4 bit)



8 Values (3 bit)



4 Values (2 bit)



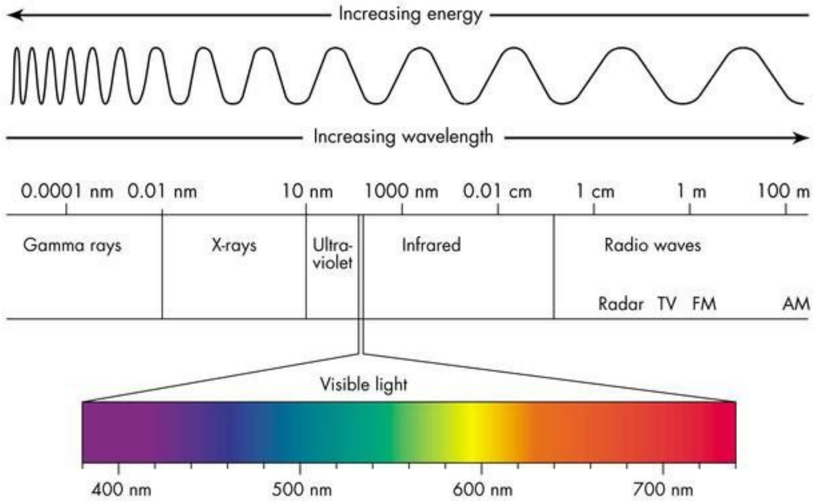
2 Values (1 bit)

Spectral Resolution

Spectral resolution is the number of spectral bands that an imaging satellite or aerial camera captures.

General Classification of Sensors:

- Multispectral Imagery - ~8 broad bands
- Hyperspectral Imagery - >30 narrow bands



Landsat 8 Reflective Bands

Band #	Band Name	Wavelength (micrometers)
Band 1	Coastal aerosol	0.43 - 0.45
Band 2	Blue	0.45 - 0.51
Band 3	Green	0.53 - 0.59
Band 4	Red	0.64 - 0.67
Band 5	Near Infrared (NIR)	0.85 - 0.88
Band 6	Shortwave Infrared (SWIR1)	1.57 - 1.65
Band 7	Shortwave Infrared (SWIR2)	2.11 - 2.29

Some Current Satellite Constellations

US Constellations

- Landsat
  - Used for general imagery analysis
  - Moderate Spatial Resolution 15-30m & ~ 8 - 16 Day Temporal Resolution
- MODIS (Moderate Resolution Imaging SpectroRadiometer)
  - Primarily Used for Weather, Atmospheric, and Oceanic observations
  - Low Spatial Resolution 250m - 1km & 16 Day Temporal Resolution

European Constellations

- Sentinel
  - Used for general imagery analysis
  - Has some specialized bands for atmospheric composition detection like pollutants
  - Low Spatial Resolution ~300m & 1 Day Temporal Resolution

Indian Constellation

- Cartosat
  - General imagery analysis
  - High Spatial Resolution < 1m

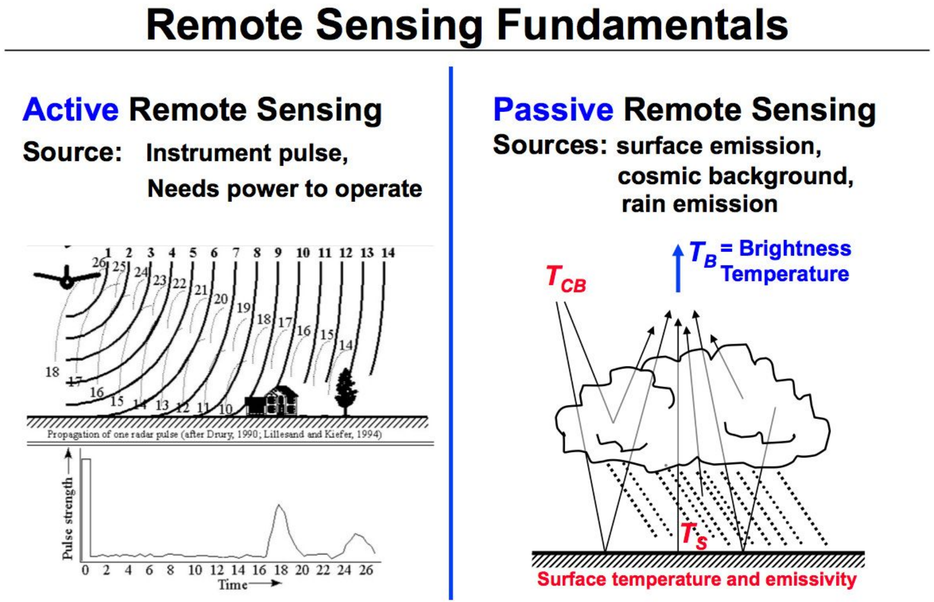
Passive vs Active Remote Sensing

Passive Remote Sensing Examples:

- Multispectral Imaging
- Hyperspectral Imaging
- Thermal Imaging (Long-Wave IR)

Active Remote Sensing:

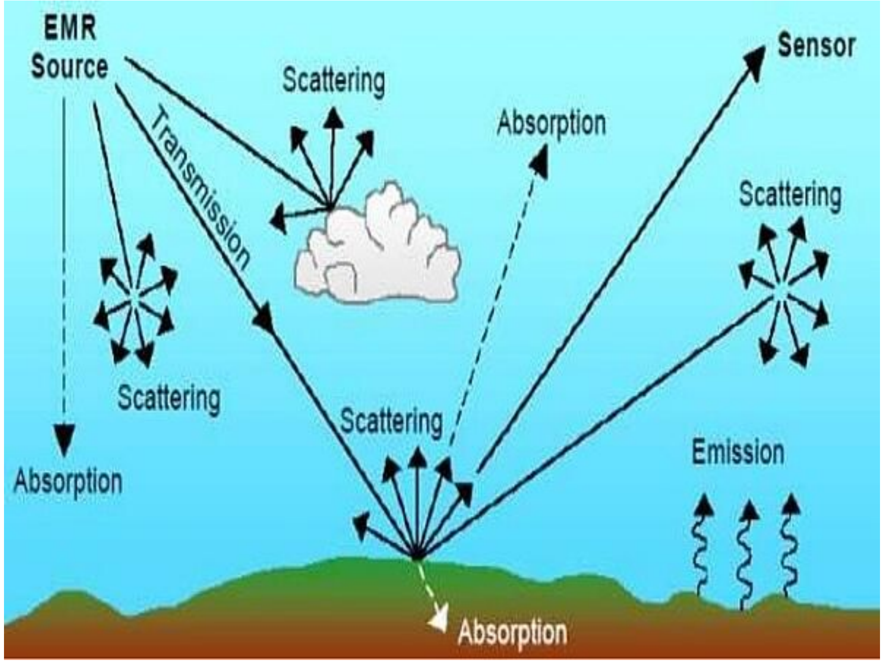
- Radar (Radio Waves / Microwave Waves)
- LiDAR (Light Detecting and Ranging, IR)



Atmospheric Correction of Imagery

Due to the natural scattering of light from the composition of the atmosphere the raw image from a sensor has to correct the blue band range.

This scattering is also why the sky appears blue.

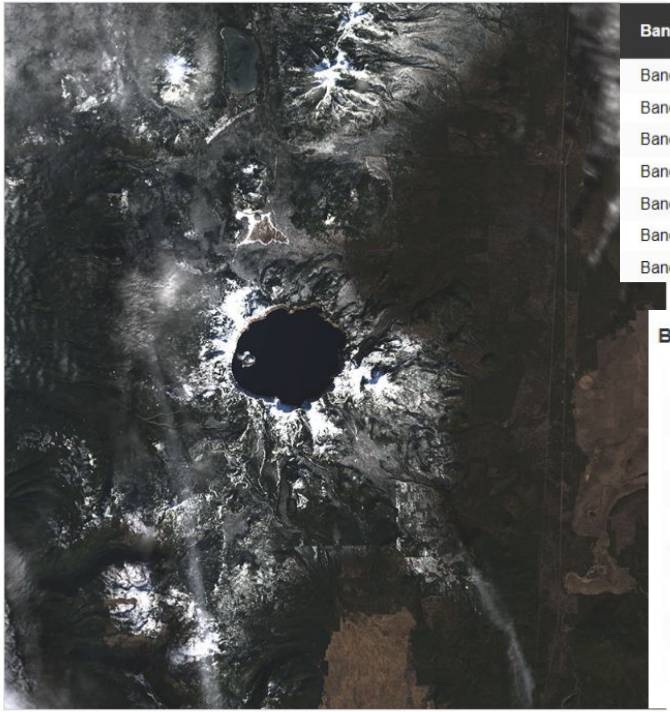


How Imagery is Visualized

Red: Band 4 (Red) Green: Band 3 (Green) Blue: Band 2 (Blue)

Red: Band 5 (NIR) Green: Band 4 (Red) Blue: Band 3 (Green)

Natural Color Composite



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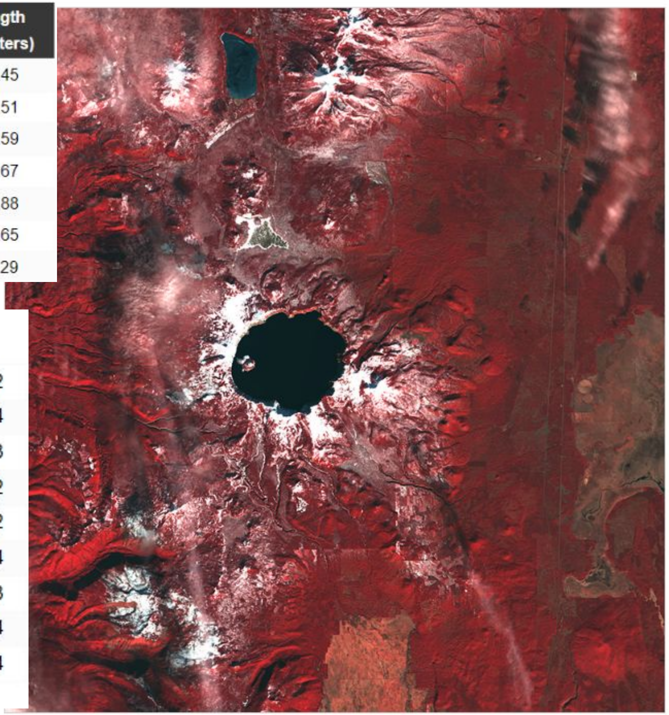
Band Combinations for Landsat 8

Natural Color	4 3 2
False Color (urban)	7 6 4
Color Infrared (vegetation)	5 4 3
Agriculture	6 5 2
Healthy Vegetation	5 6 2
Land/Water	5 6 4
Natural With Atmospheric Removal	7 5 3
Shortwave Infrared	7 5 4
Vegetation Analysis	6 5 4

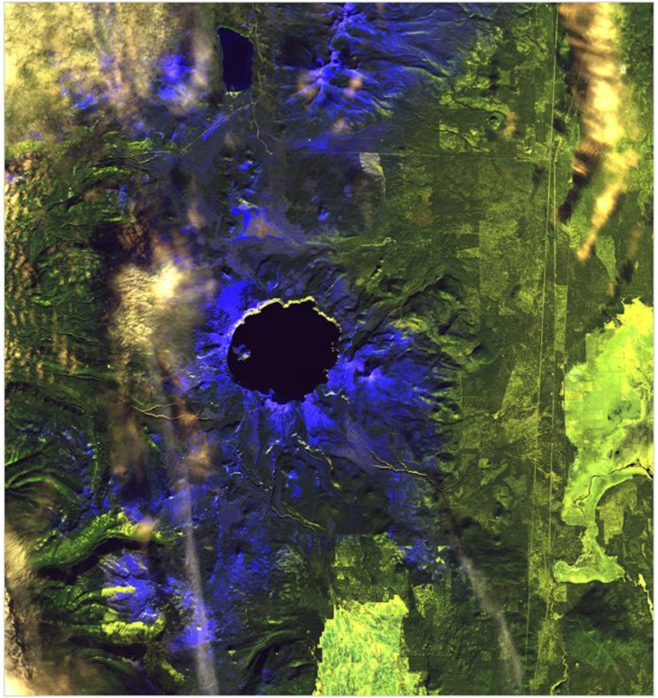
Color Infrared Composite



How Imagery is Visualized (Continued)

Red: Band 7 (SWIR2) Green: Band 6 (SWIR1) Blue: Band 4 (Red)

Urban False Color Composite



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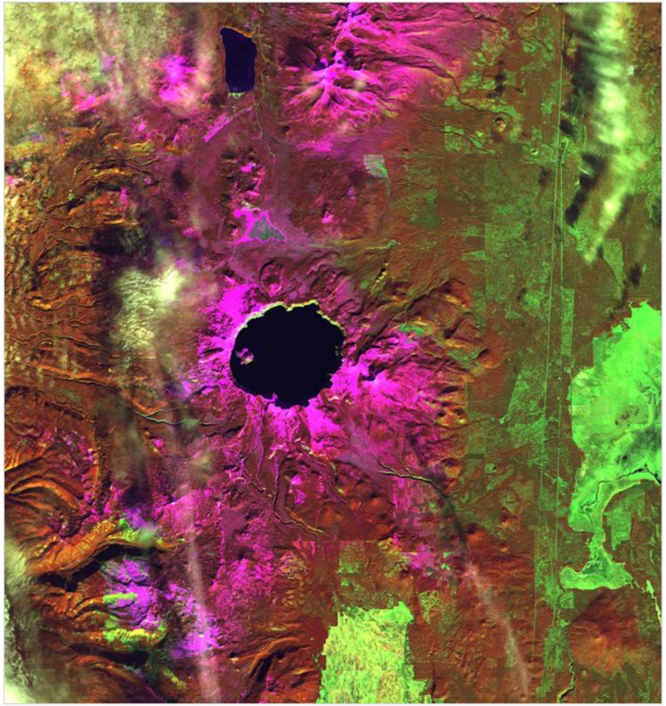
Shortwave Infrared	7 5 4
Vegetation Analysis	6 5 4

How Imagery is Visualized (Continued)

Red: Band 5 (NIR) Green: Band 6 (SWIR1) Blue: Band 4 (Red)

Land / Water Composite



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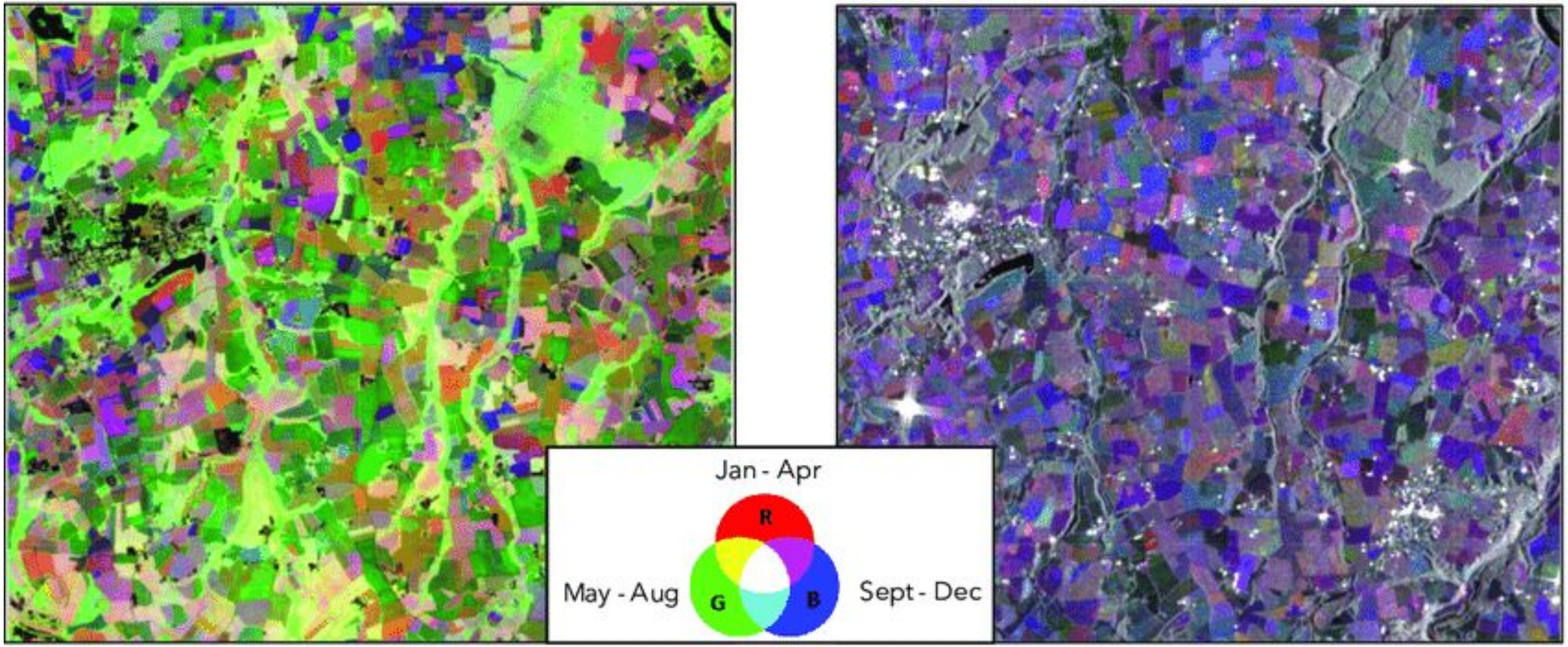
Shortwave Infrared	7 5 4
Vegetation Analysis	6 5 4

Temporal Composites



Multi-temporal RGB composite. Sentinel-2 NDVI (left). Sentinel-1 VV (right).

Map Algebra (Raster Math)

Operations

- Addition
- Subtraction
- Multiplication
- Division
- Exponentiation
- etc..

How Operations are Applied

- Local (Cell by Cell)
- Global (Entire Raster)
- Neighborhood
- Zonal

Map Algebra (Local Operation)

1. Local Operations

The simplest approach is map algebra on a cell-by-cell basis. For example, you have 2 rasters stacked on top of each other. Then, you add each cell one-by-one.

If raster cells represent temperature, you can subtract them both at different time periods. By using a local operation, you can find the difference in temperature for each cell.

1	4	5
5	3	2
2	5	2

\+

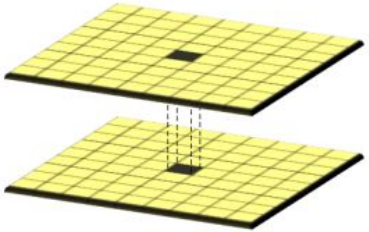
5	1	3
1	2	1
1	4	2

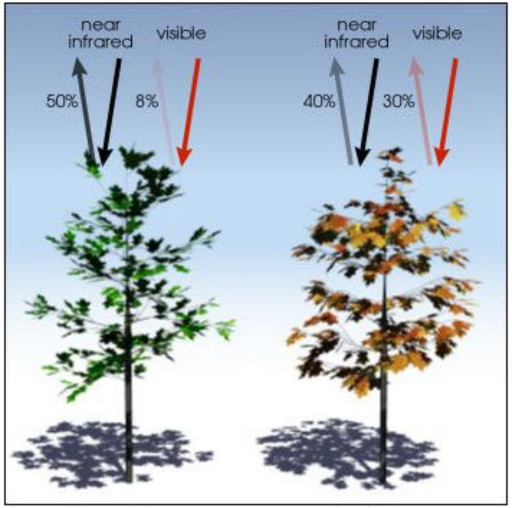
=

6	5	8
6	5	3
3	9	4

Example: Normalized Difference Vegetation Index

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)}$$





$$\frac{(0.50 - 0.08)}{(0.50 + 0.08)} = 0.72 \qquad \frac{(0.4 - 0.30)}{(0.4 + 0.30)} = 0.14$$

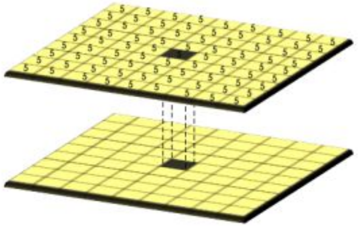
Image courtesy of NASA.

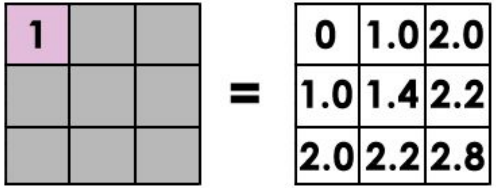
Map Algebra (Global Operation)

2. Global Operations

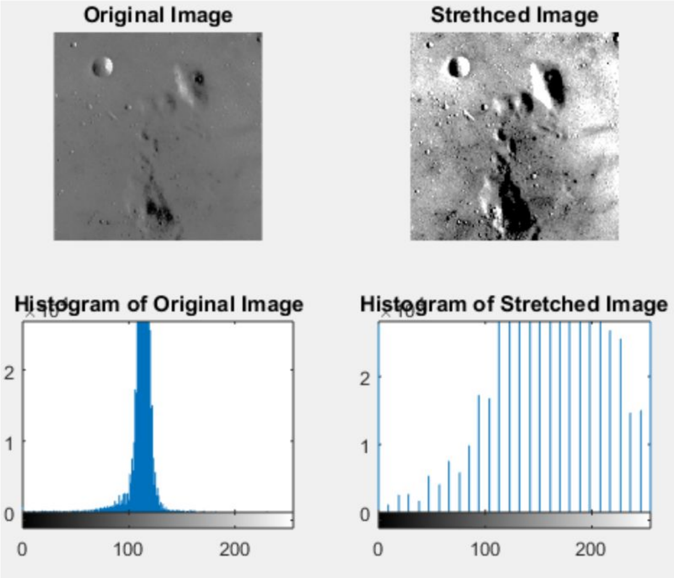
Global operations apply a bulk change to all cells in a raster. If you want to add a value of 1 to all grid cells, this is a global operation.

For example, Euclidean distance is an example of a global operation. By calculating the closest distance away from a source, it applies the function globally in a raster.





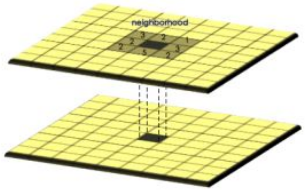
Example: Image Stretching Enhancement



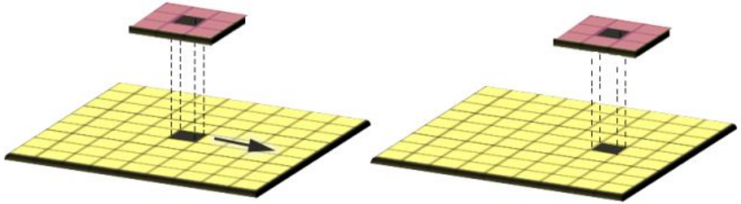
Map Algebra (Neighborhood Operation)

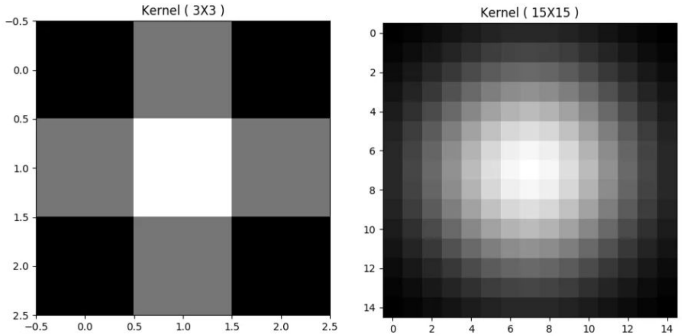
3. Focal Operations

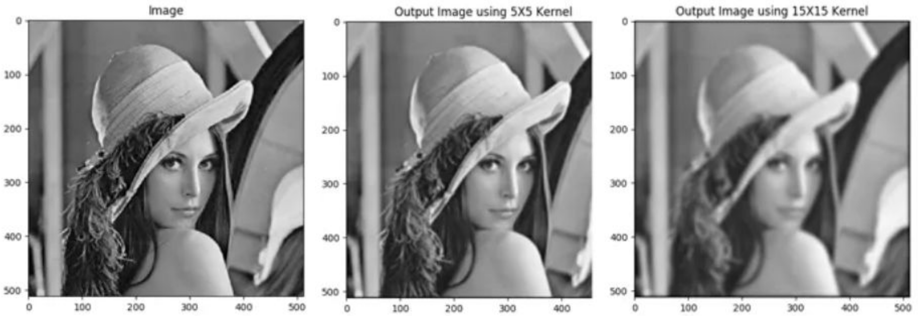
Focal operations are spatial functions that compute an output value of each cell using neighborhood values. For example, convolution, kernel, and moving windows are focal operations.



MOVING WINDOW: A moving window is a rectangular arrangement of cells that shifts in position. By applying an operation to each cell from a moving window, it commonly smooths values in a raster.







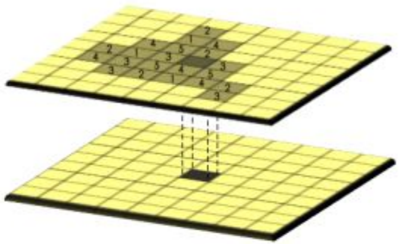
Example: Gaussian Smoothing Operation

Map Algebra (Zonal Operation)

4. Zonal Operation

Zonal operations apply a math function to a group of cells within a specified zone. For example, a zone could be a vector or raster format.

If you want to find out how much rain is in a watershed, you can use a zonal operation. By using a raster with precipitation, you can set your zone as a watershed with a sum function.



Common Local Operation Indices

Normalized Difference Vegetation Index

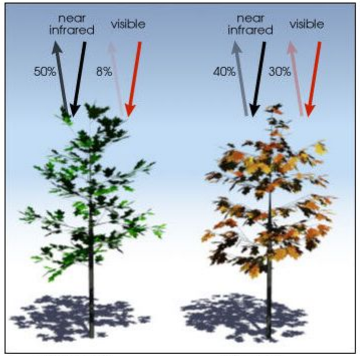
$$NDVI = \frac{(NIR - Red)}{(NIR + Red)}$$

Normalized Burn Ratio

$$NBR = \frac{(NIR - SWIR)}{(NIR + SWIR)}$$

Normalized Difference Water Index

NDWI = (Green-NIR) / (Green + NIR)



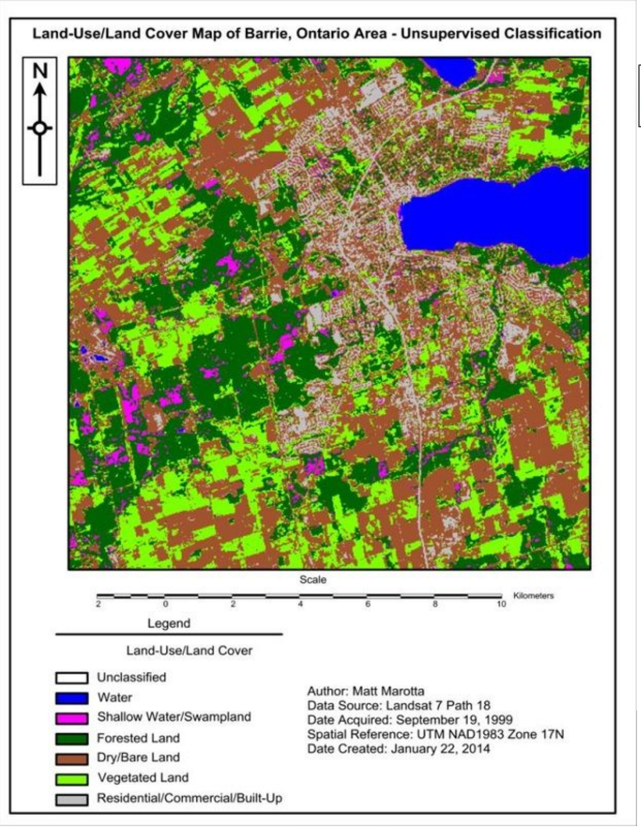
$\frac{(0.50 - 0.08)}{(0.50 + 0.08)} = 0.72$ $\frac{(0.4 - 0.30)}{(0.4 + 0.30)} = 0.14$

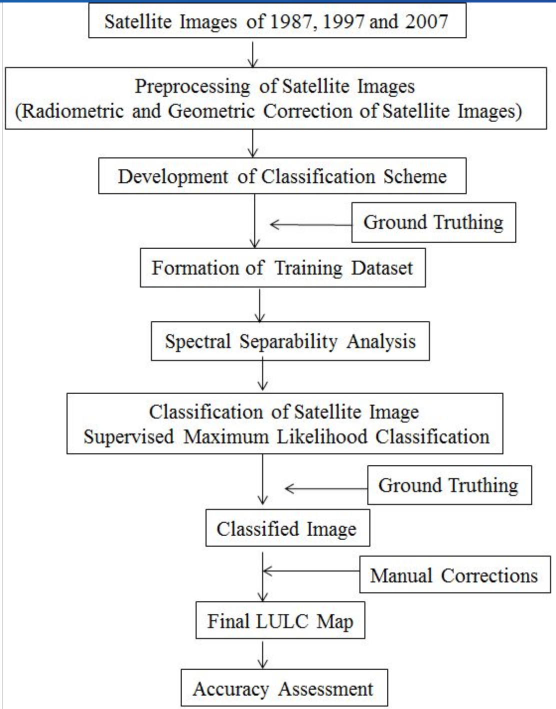
Image courtesy of NASA.

There are also more complex difference indices as well such as the MSAVI2

$$MSAVI2 = \frac{(2 * NIR + 1 - \sqrt{(2 * NIR + 1)^2 - 8 * (NIR - RED)}}{2}$$

Land Cover Classification

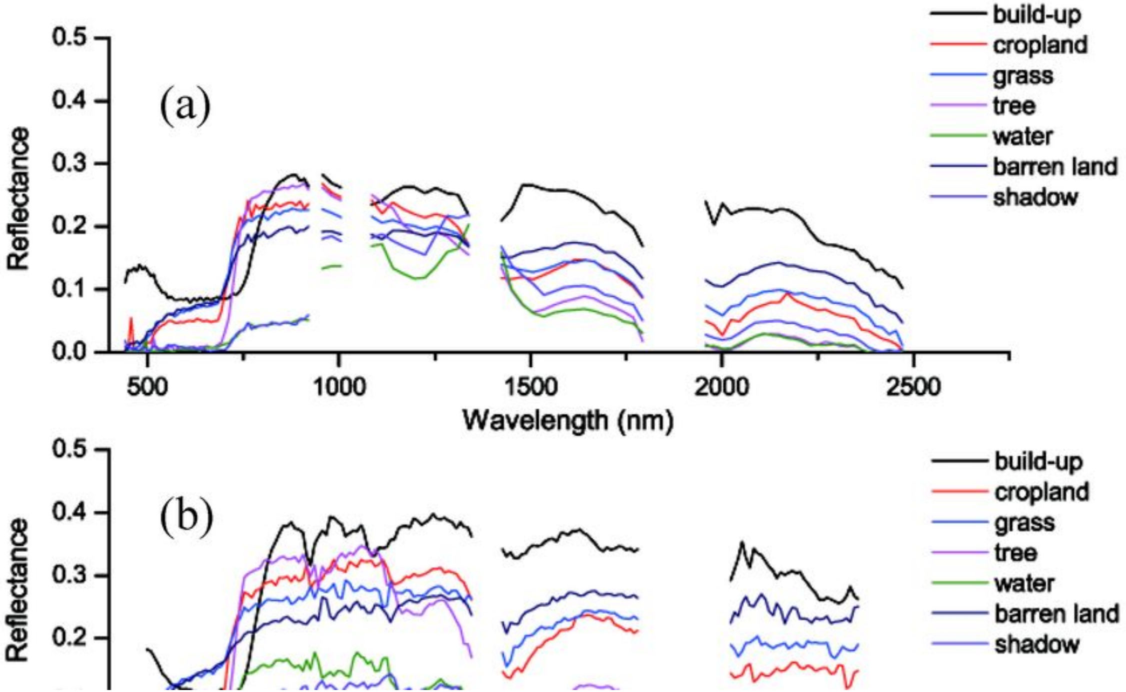




Classification Types:

- Supervised
- Unsupervised

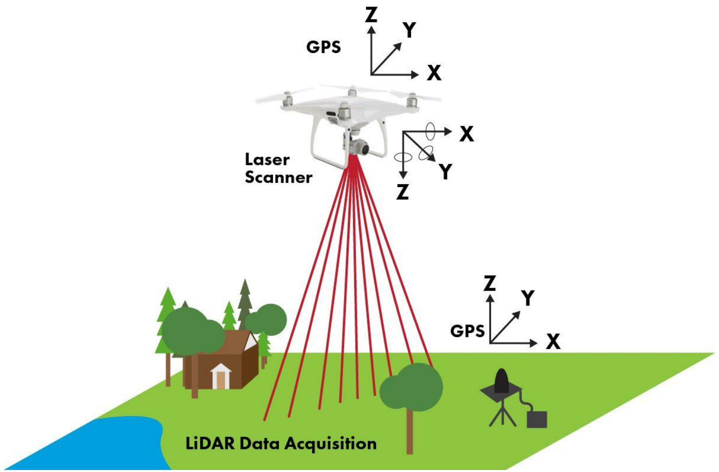
Land Cover Classification (with Hyperspectral Imagery)

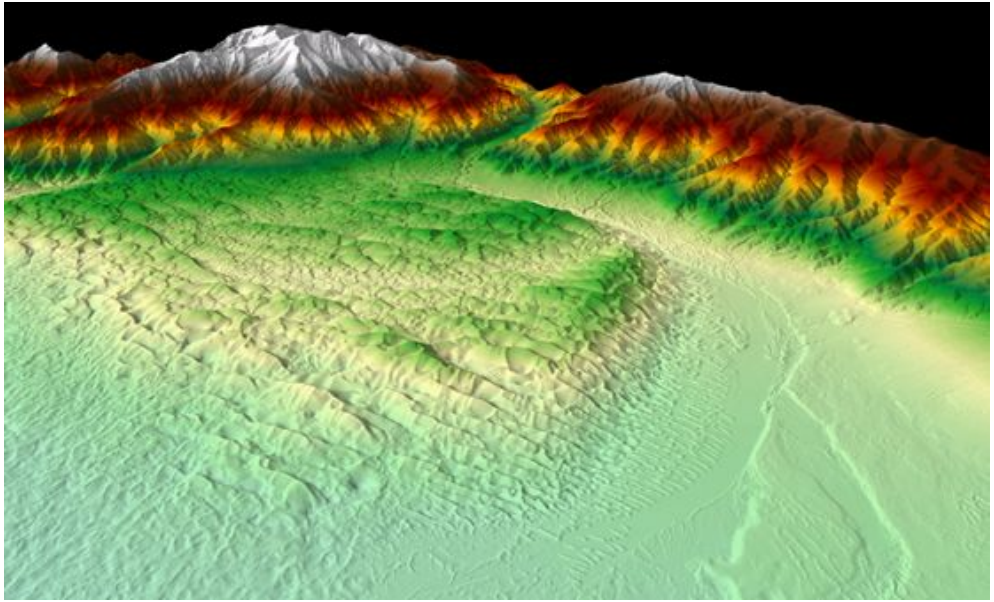


Special Remote Sensing Application LiDAR

Light Detection and Ranging utilizes NIR to create a point cloud by identifying the return time of a laser. (active remote sensing)

It has applications in 3D modeling and creating digital elevation models of terrain





Also has applications in self-driving cars!

Infrastructure Considerations

For processing Remote Sensing Imagery you will need access to a decent amount of storage space, memory, and compute resources.

Each satellite image can be over 300mb of data

There are some programming / cloud based applications that allow you to bring your analysis to the data instead of needing to download the data in order to process it which can help with some of the infrastructure needs

Example Workflow Identification of Coal Mine Expansion

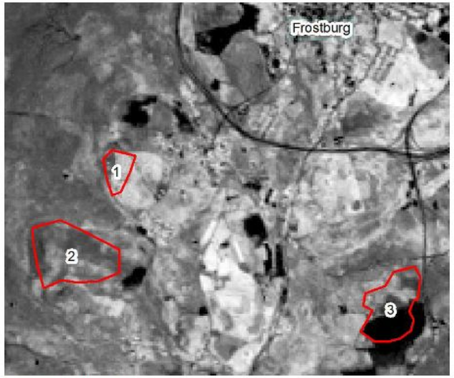
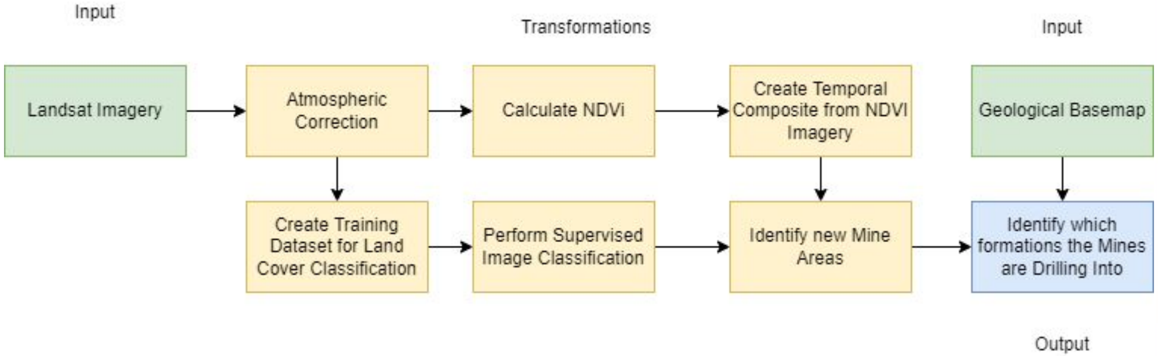


Figure 5: 2005 NDVI



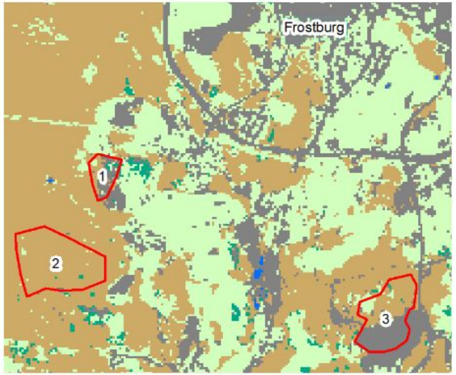


Figure 4: 2005 Land Cover

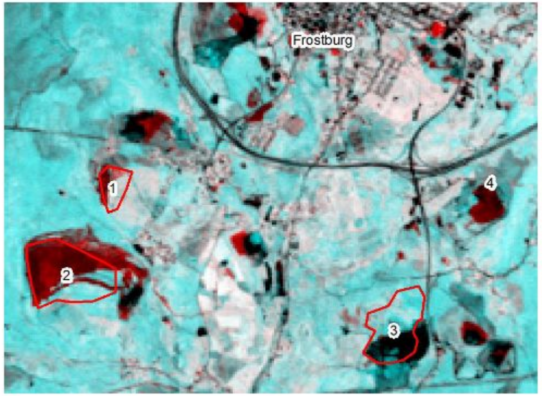


Figure 6: 2005 to 2010 Time Composite

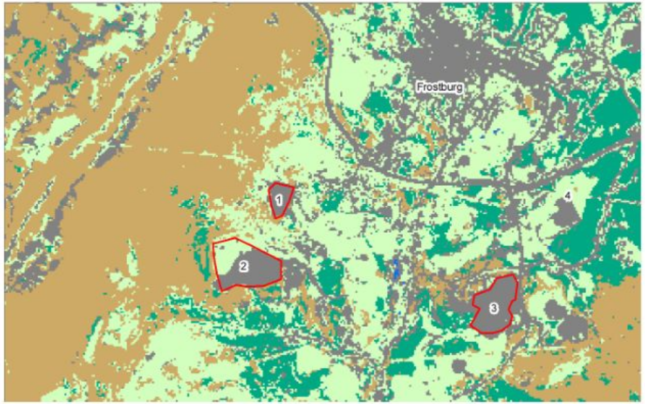


Figure 9: 2017 Land Cover

Example Workflow Identification of Coal Mine Expansion

The Evolution of Coal Mining in Frostburg Maryland, from 2005 to 2012
Paul Churchyard

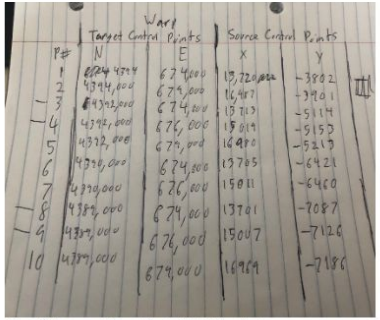


Figure 2: Source and Target Control Point Coordinates

Finally a geological map of the Avilton and Frostburg quadrangles was re-projected using the warp feature and the provided graticules on the map, with ten control points used to perform the warp, see figure 2 and 3. The vertical datum for the map was provided however unfortunately, the coordinate system was not included on the map and as the map was created using the National Geodetic Vertical Datum of 1929, the coordinate system for the map was assumed to be the North American Datum of 1927.

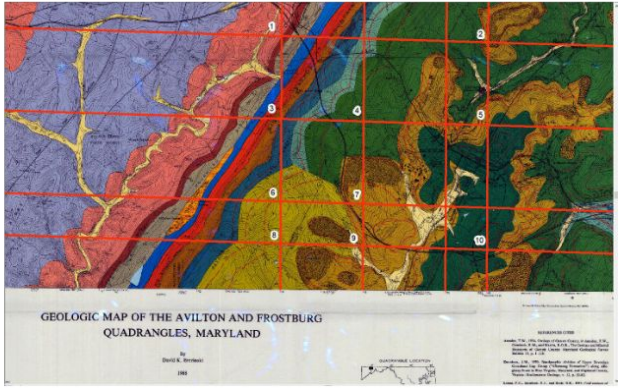


Figure 3: Frostburg Geologic Map Control Points (Brezinski 1988)

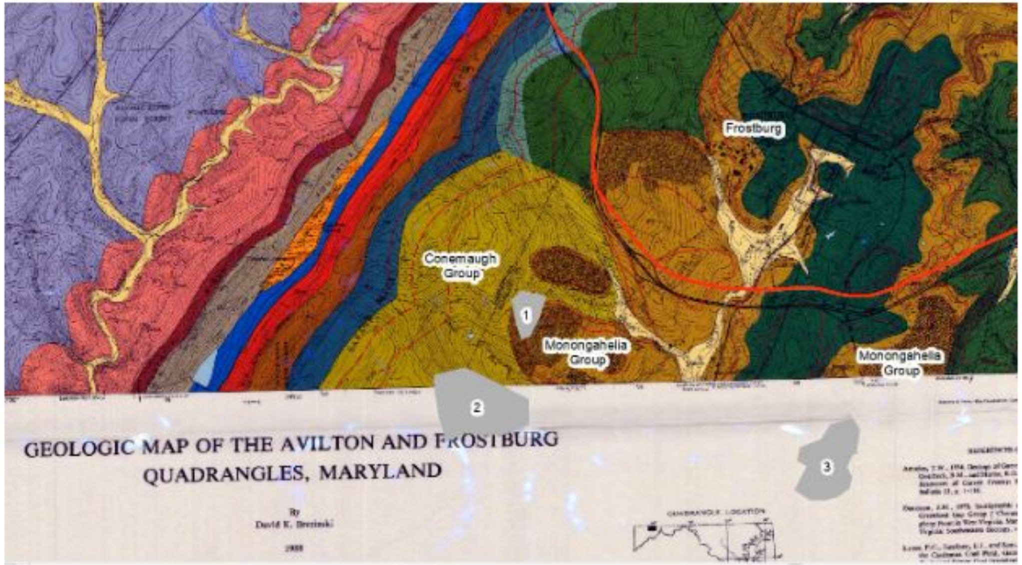
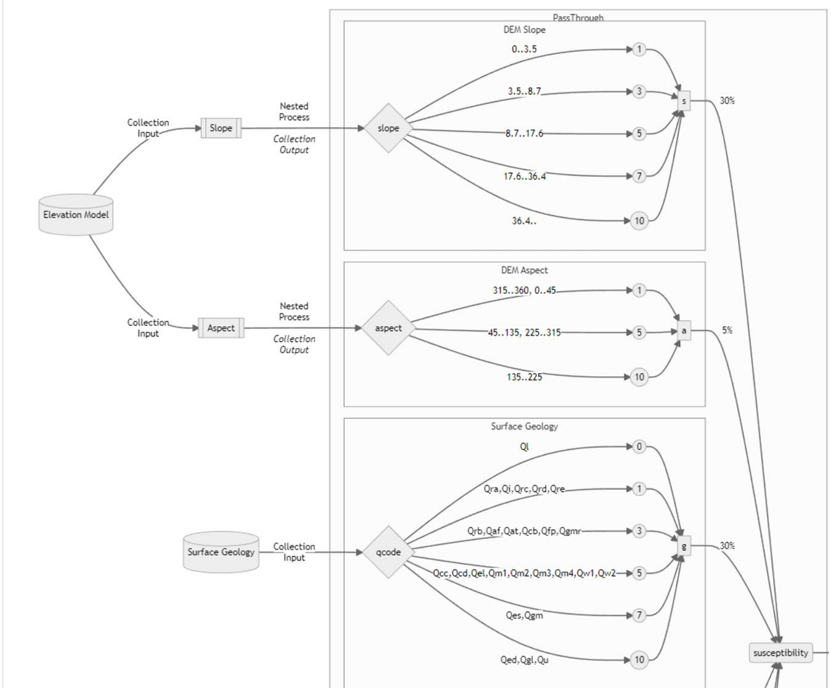
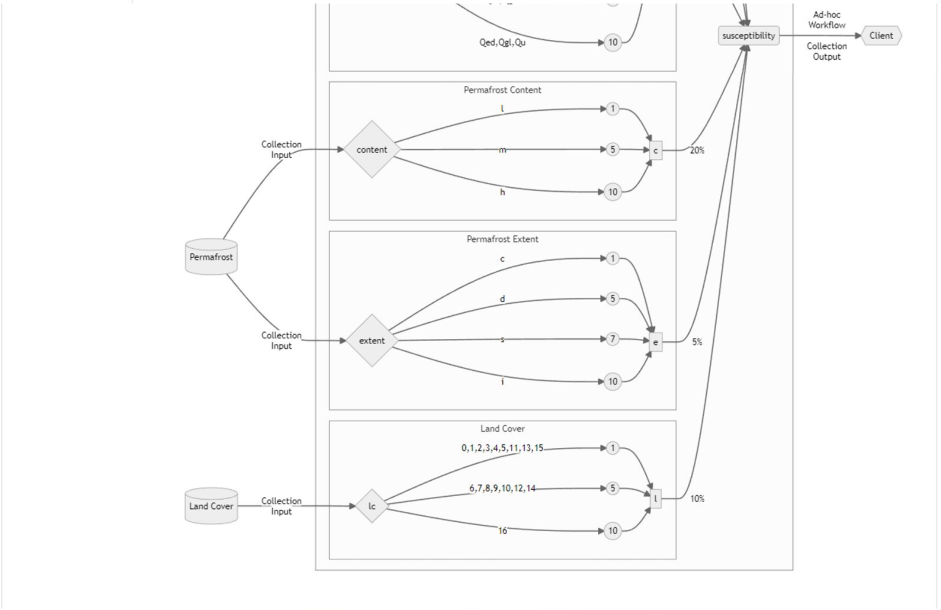


Figure 11: Mine Geology (Brezinski 1988)

Example Workflow 2 Coastal Erosion Workflow





Activity: Identify Flood Extent, Contaminated Water, & Impacted Population

Activity 1: Identify Flood Extent, Contaminated Water, and Impacted Population

Task: Identify Flood Extent, Contaminated Water, and Impacted Population Demographics

Source:

- What are the relevant factors?
  - Elevation of the Area (DEM) - How can you obtain this data from EO data?
  - Population characteristics
    - Age
    - Comorbidities
  - Flood Extent
  - Where are water treatment facilities?
- Where are they coming from?

Transformation:

- How can you combine to relevant factors to identify
  - Flood Extent
  - Area Impacted by contaminated water / no access to potable water
  - Who are the most vulnerable populations?

Output:

- What does the output mean?
- Who and how could use the output?
- What is the best way to display the output?

To get you started:

https://www.jadelearning.com/blog/mitigating-flooding-impacts-on-drinking-water-treatment-systems/

https://www.epa.gov/sites/default/files/2017-06/documents/004_drinking_water_advisory_-_vulnerable.pdf

https://link.springer.com/article/10.1007/s13753-021-00377-z

Bibliography

- https://sites.google.com/a/coe.edu/principles-of-structural-chemistry/relationship-between-light-and-matter/electromagnetic-spectrum
- https://gpm.nasa.gov/education/images/active-and-passive-remote-sensing-diagram
- https://gsp.humboldt.edu/olm/Courses/GSP_216/lessons/composites.html
- https://www.researchgate.net/figure/Multi-temporal-RGB-composite-Sentinel-2-NDVI-left-Sentinel-1-VV-right_fig3_356393443
- http://www.adeveloperdiary.com/data-science/computer-vision/applying-gaussian-smoothing-to-an-image-using-python-from-scratch/
- https://www.nzfaruqui.com/contrast-stretching-in-image-processing-using-matlab/
- https://gisgeography.com/ndvi-normalized-difference-vegetation-index/
- https://blog.vito.be/hs-fs/hubfs/marketing/BLOG%20POSTS/1805_PV.LAC/BLOG_PV.LAC_pic2.jpg?width=600&name=BLOG_PV.LAC_pic2.jpg
- https://mattmarotta.weebly.com/uploads/2/7/4/7/27472547/5033088_orig.jpg
- https://www.researchgate.net/figure/Flowchart-shows-methodology-adopted-for-LULC-mapping-9_fig3_276733978
- https://flyguys.com/5-industry-use-cases-for-lidar/
- https://www.usgs.gov/news/science-snippet/earthword-lidar

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Data Models 2 Session 4

Activity: Final Data Model

Activity 2: Utilize the knowledge you have gained over the past 4 days in addition to your own domain knowledge to create a data model for a specific topic of your interest

Key Points to Remember

Source:

- What are the relevant factors?
- What are the data sources for these factors?

Transformation:

- How can you combine to relevant factors?

Output:

- What does the output mean?
- Who and how could use the output?
- What is the best way to display the output?

Time to complete: 1 hour
2 hour discussion / presentation afterwards