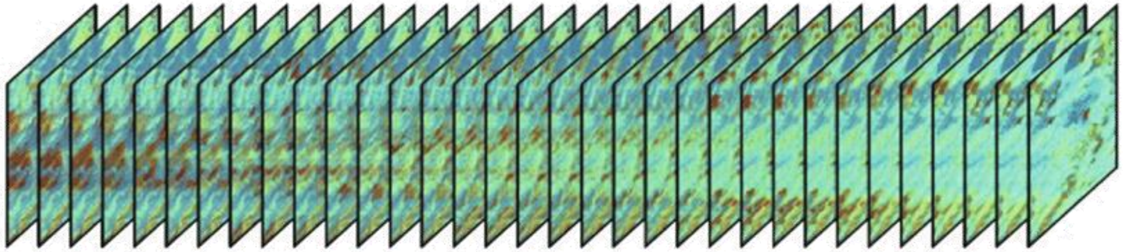
Making your Satellite Image Time Series (SITS) Analysis-ready

28 March 2022



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ITC
UNIVERSITY OF TWENTE.

Why do we need to correct SITS data prior to analysis?

Mentimeter

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low return frequency

sensor characteristics

atmospheric variability

geospatial mismatch

clouds

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Ensures like is to compared with like

Definition of Pre-Processing

Pre-processing of SITS concerns "the correction of geometric, radiometric, and atmospheric deficiencies, and removal of data error and flaws." (Mather and Koch 2010)

<u>There is no recipe for pre-processing</u>

Learning Objectives

By the end of this topic, you will be able to:

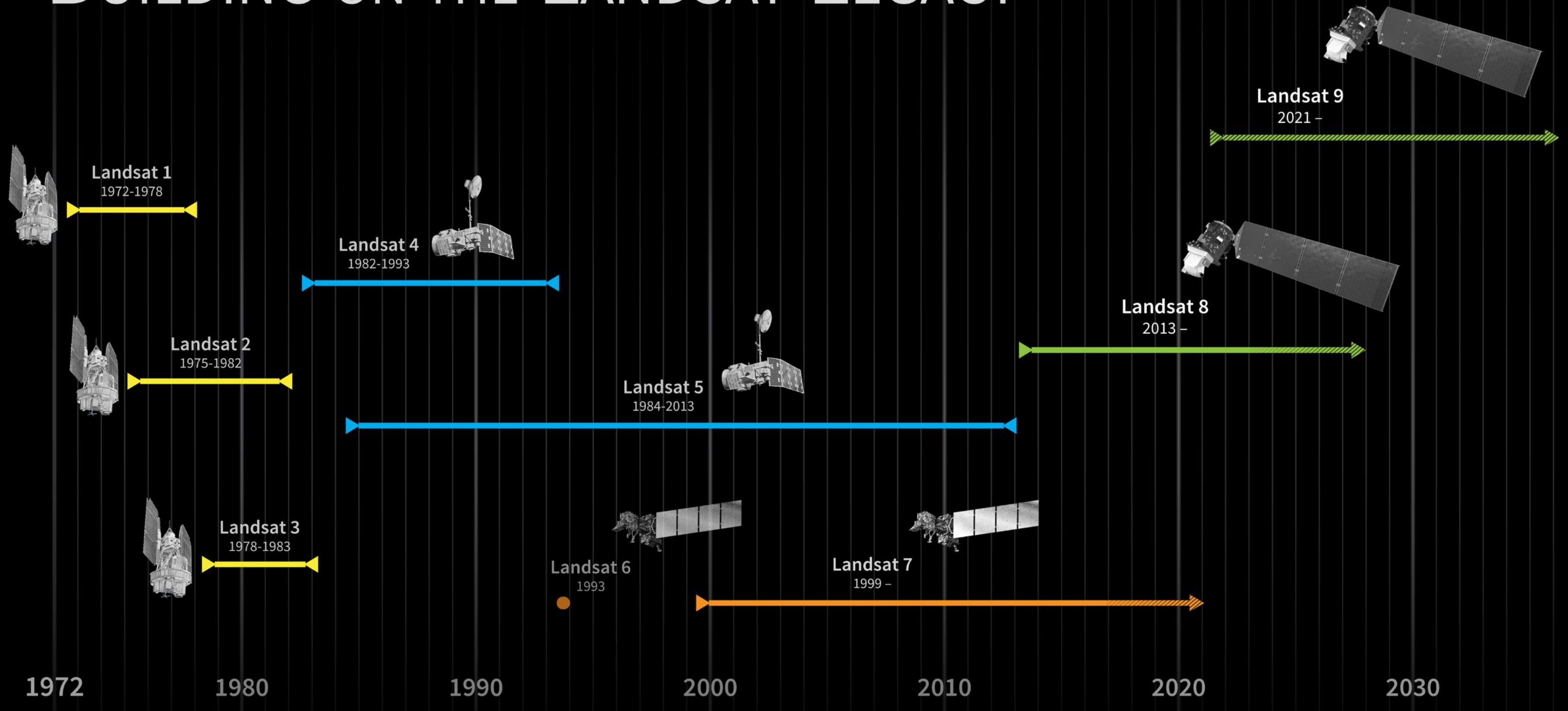
- Justify the use of one or more pre-processing techniques to make SITS analysis-ready
- Experiment with SITS pre-processing techniques in a cloud-based geospatial processing platform

Landsat Legacy

- Landsat Data Continuity Mission (LDCM)
- NASA-USGS Sustainable Land Imaging program
- Landsat Global Archive Consolidation (LGAC) initiative
- Landsat Analysis Ready Data (ARD) products

Michael A. Wulder, et al., Current status of Landsat program, science, and applications, Remote Sensing of Environment, Volume 225, 2019, Pages 127-147.

Building on the Landsat Legacy



Google Earth Engine

- Petabytes of remote sensing imagery and other ready-to-use products
- High-speed parallel processing and machine learning algorithms
- Application Programming Interfaces (APIs) in JavaScript or Python
- Free and open-access virtual environment
- Geared to geo-information processing/analysis

Table 1
A summary of the algorithms and capabilities available in code editor-Google Earth Engine.

Package	Capabilities
Machine learning	Supervised Classification Unsupervised Classification TensorFlow
Image	Image Visualization RGB composites Color plates Masking Mosaicking Clipping Rendering categorical maps Thumbnail images Operations (mathematical, Boolean, morphological, convolutions, relational, conditional) Edge detection Texture Spatial Transformation Object-based Methods Registration
Geometry, Feature, Feature Collection	Filtering Mapping Reducing Vector to raster Interpolation
Specialized algorithms	Landsat algorithms Sentinel-1 algorithms Resampling and Reducing Resolution

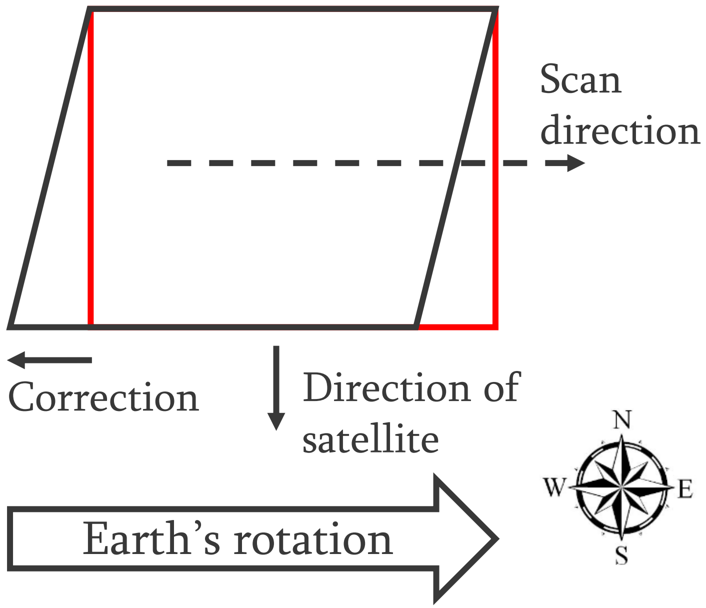
Haifa Tamiminia, Bahram Salehi, Masoud Mahdianpari, Lindi Quackenbush, Sarina Adeli, Brian Brisco, Google Earth Engine for geo-big data applications: A meta-analysis and systematic review, ISPRS Journal of Photogrammetry and Remote Sensing, Volume 164, 2020, Pages 152-170.

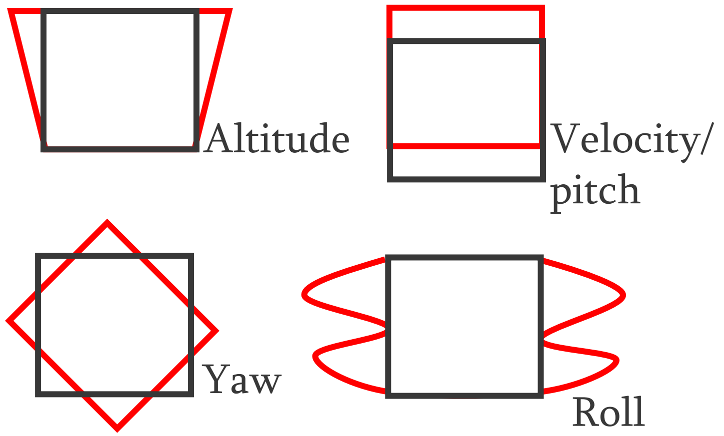
Geometric Correction / Geo-referencing

- Overlay temporal sequences of the same area

- Sources of error
  - Earth’s rotation
  - Platform altitude, attitude, and velocity
  - Wide field of view
  - Instrumentation

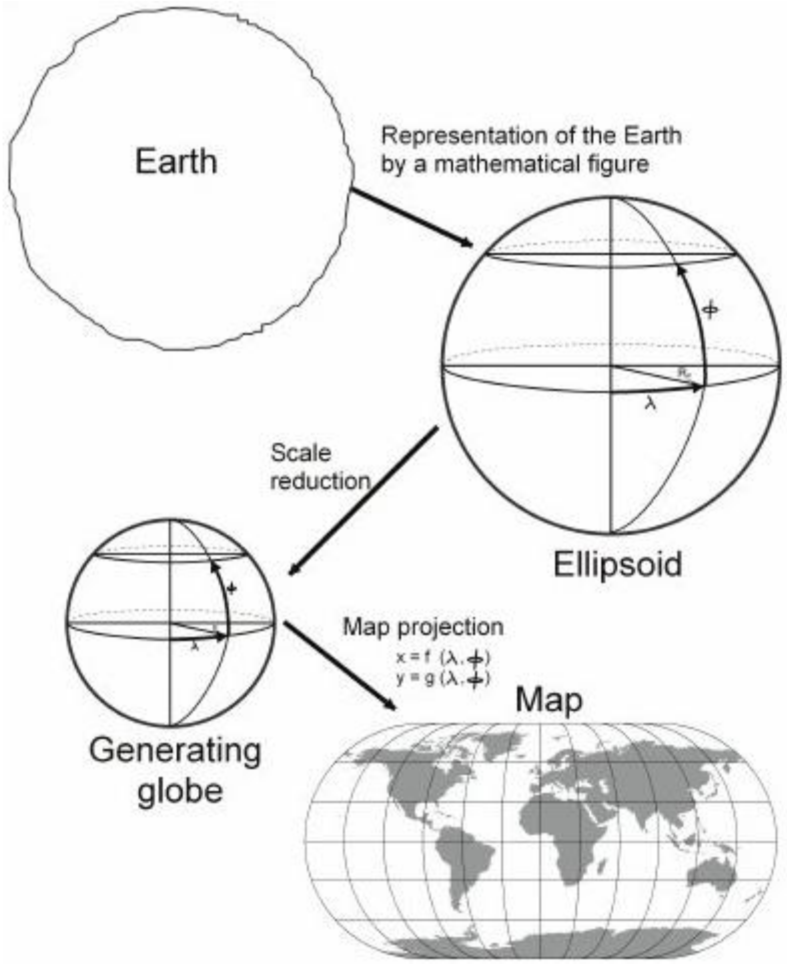
- Orbital geometry models





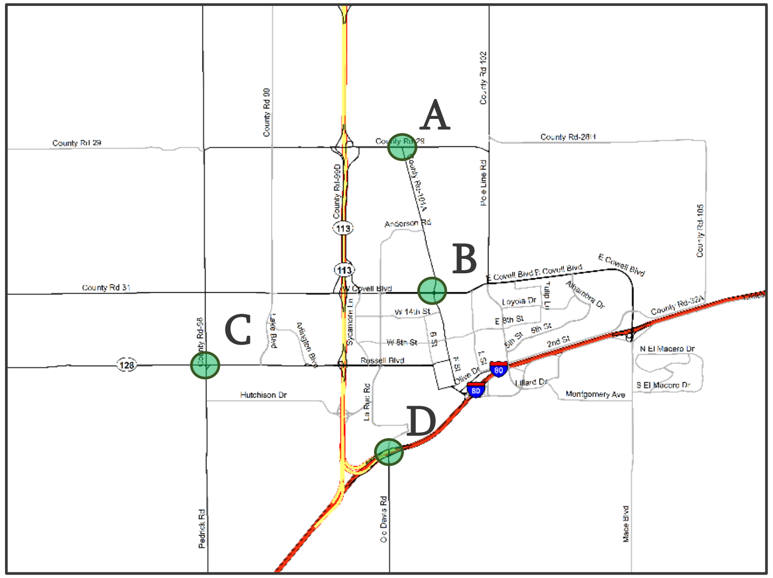
Defining a Coordinate System

- Representation of curved surface (Earth) on a plane
- [Map Projection visualizer]
- Earth's angular geographic coordinates converted to XY Cartesian coordinates
- Preserves one element at the cost of others
    - Shape (conformal)
    - Area (equal-area)
    - Distance (equidistant)
    - Direction (azimuthal)



Choosing Ground Control Points (GCPs)

- Map to image registration
- 1^{st}, 2^{nd}, 3^{rd} order polynomials
- Coefficients defined by GCPs
    - Road intersections
    - Street corners
    - Sharp bends in rivers
    - Prominent coastline features
- ~30 GCPs
- Evenly spaced
- Accuracy assessment (RMSE)
- Must be done for each image!



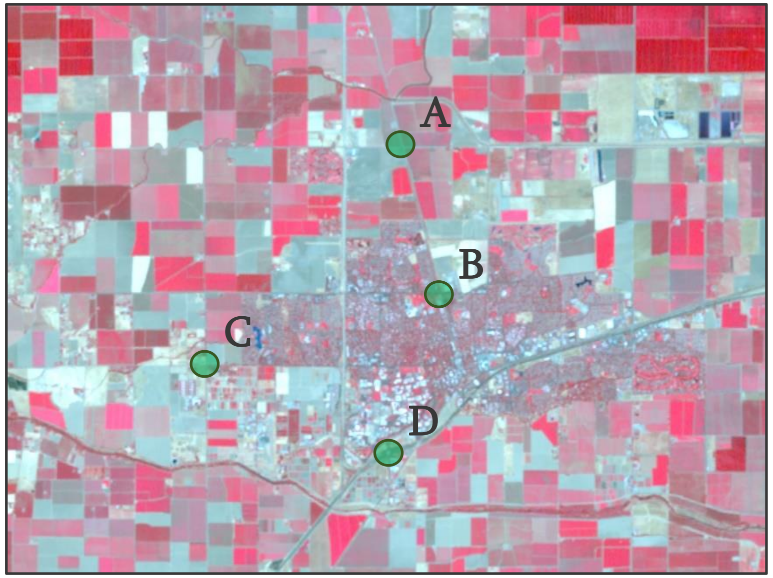
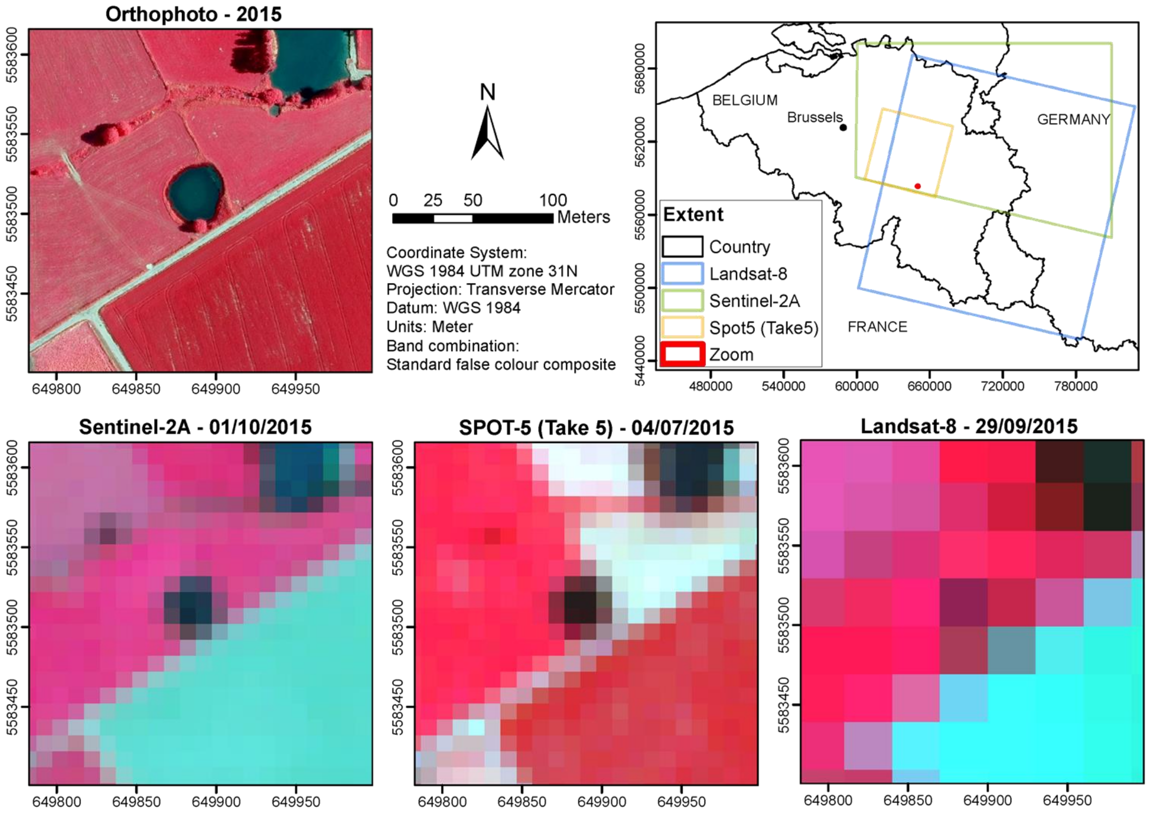


Image to Image Registration

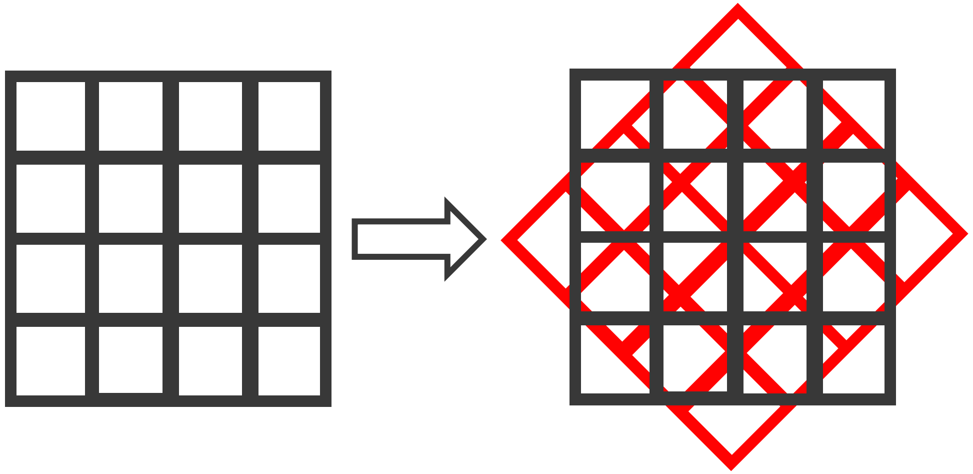
- Images through time and/or different sensors
- Similar to map to image registration
- More efficient
- Spatial correlation algorithms improve GCP selection

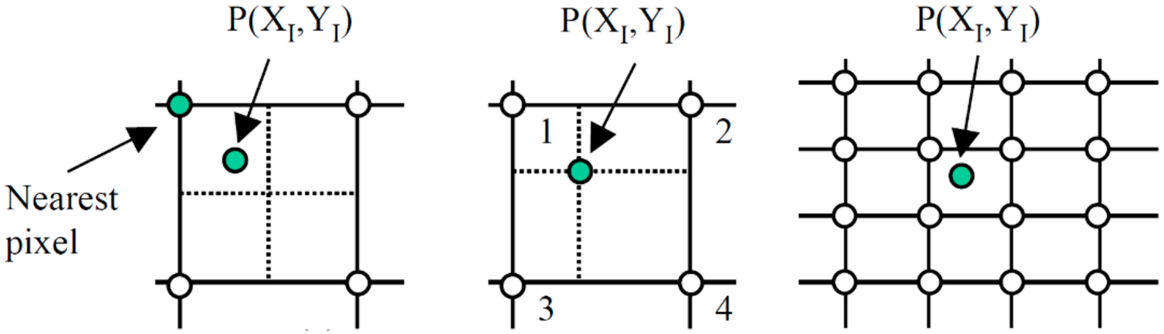


Radoux et l. (2016)

Resampling Images with GCPs

- Systematic correction of pixels
  - Image corners
  - Number of pixels
  - Pixel spacing
- Resampling (interpolation)
  - Nearest neighbor
  - Bilinear interpolation
  - Cubic convolution





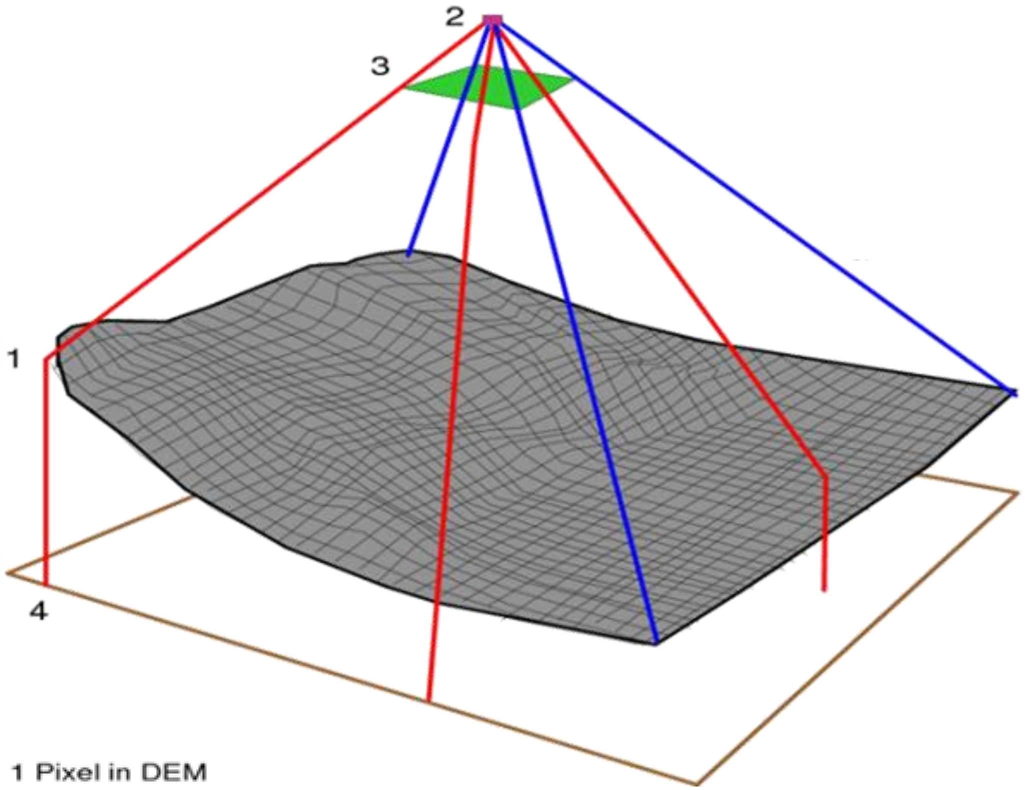
Rizeei and Pradhan (2019)

GEE: Landsat Collection 2 Raw Scenes

- Tier 2 includes Level-1 systematic terrain (L1GT) and systematic (L1GS)
  - RMSE > 12m and <30m

- Orthorectification corrects for distance-related changes in brightness
  - Topography
  - Sensor geometry

- Tier 1 includes Level-1 precision and terrain (L1TP)
  - RMSE < 12m



1 Pixel in DEM

2 Parameters in the exterior orientation

3 In the image the brightness value is determined based on the resampling of the surrounding pixels

4 Height, exterior orientation information and brightness values used to calculate equivalent location in the orthoimage

You have to register five images. You have a georeferenced map at your disposal. Would you...

Mentimeter

0	0	0
Register each image to the map seperately.	Register one "master" image to the map and the rest to the master image.	Register the second image to the master, third to second, etc.

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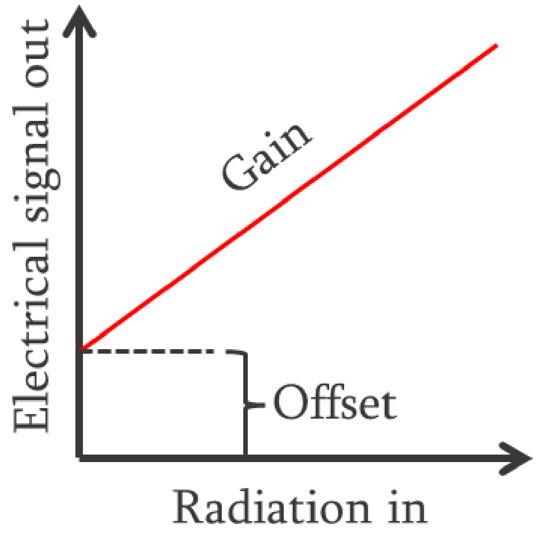
Mentimeter

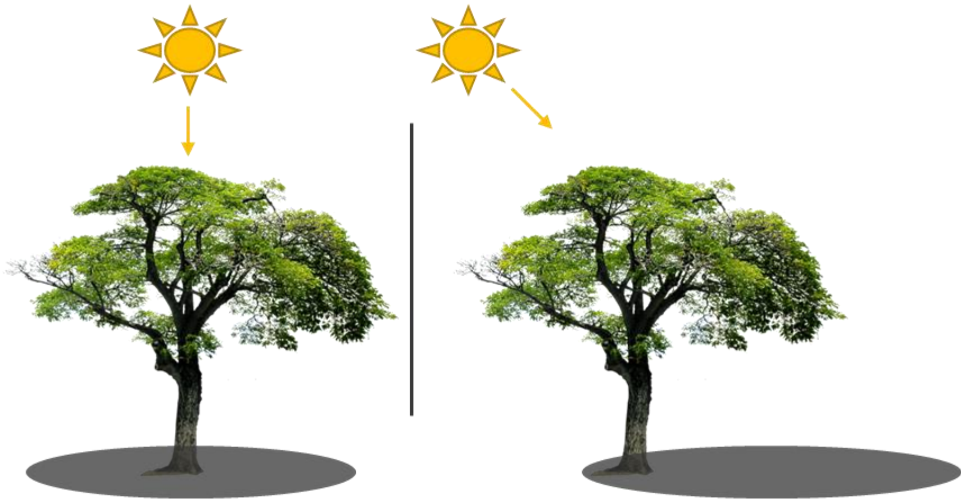
Register each image to the map seperately.	Register one "master" image to the map and the rest to the master image.	Register the second image to the master, third to second, etc.
1	0	0

Radiometric Correction

- Overlay temporal sequences of the same relative brightness

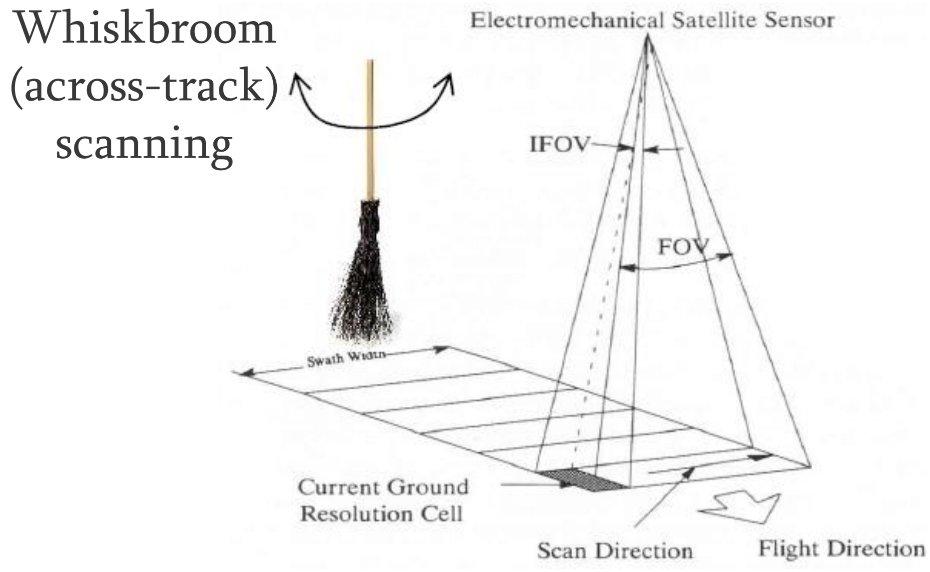
- Sources of error
    - Instrumentation
    - Illumination
    - Atmospheric constituents

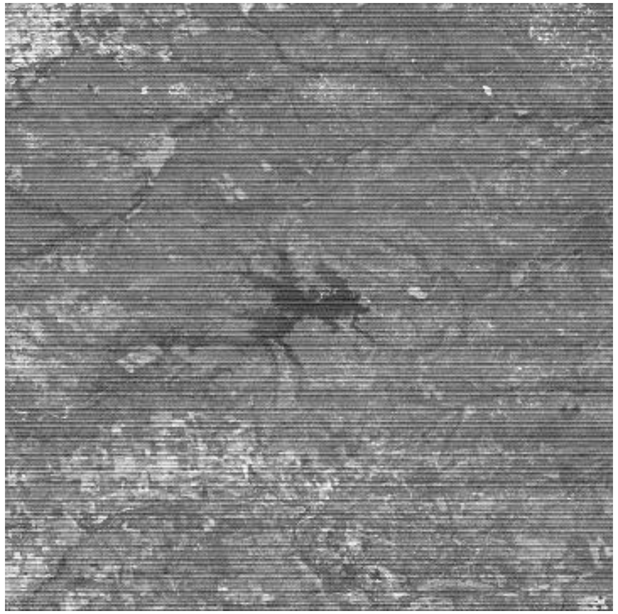




Radiometric Pre-processing

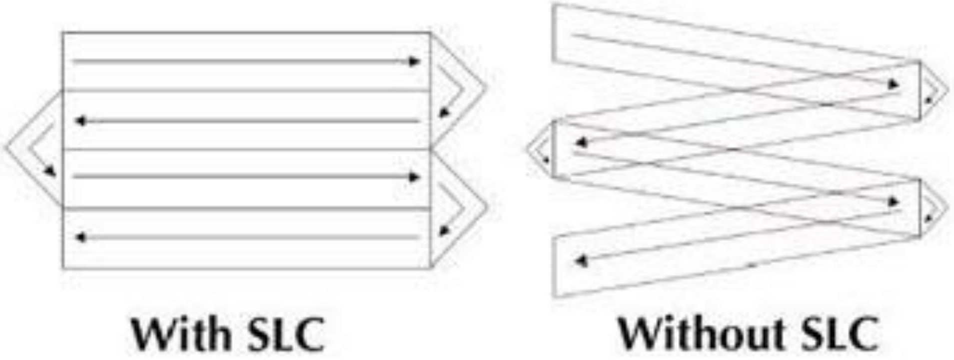
- "Cosmetic operations"
- Banding / de-striping
    - Histogram equalization
    - Histogram matching
- Missing scan lines
    - Replacement
    - Averaging
    - Band to band or sensor to sensor
- Salt and pepper

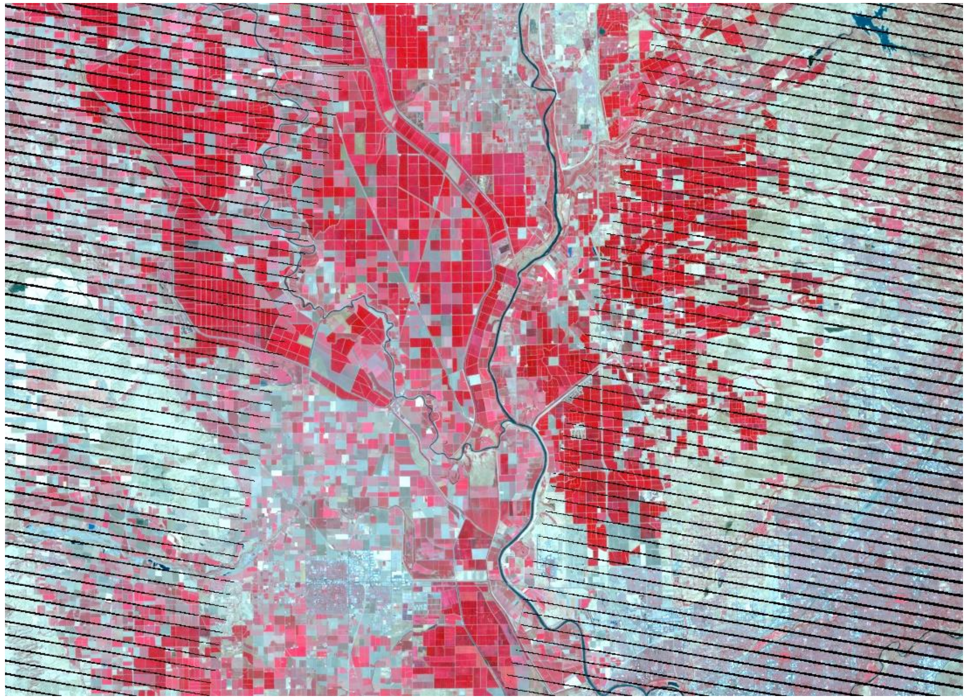




Example: Landsat 7 ETM+ SLC-off

- Scan-line corrector (SLC) failed in 2003
- Overlap toward image edges
- Gap filling methods
    - Spatial interpolation (e.g., histogram equalization or matching)
    - Temporary close image pairs
    - Other sensors (MODIS, Sentinel-2)

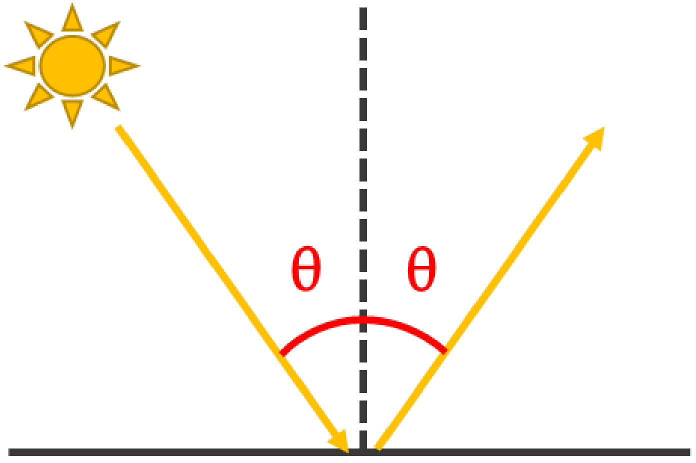




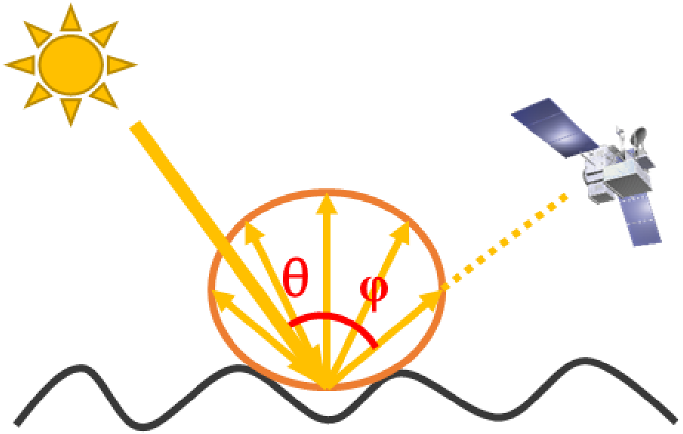
Qunming Wang, Lanxing Wang, Chao Wei, Yanmin Jin, Zhongbin Li, Xiaohua Tong, Peter M. Atkinson, Filling gaps in Landsat ETM+ SLC-off images with Sentinel-2 MSI images, International Journal of Applied Earth Observation and Geoinformation, Volume 101, 2021, 102365.

Illumination Effects

- View angle of the sensor
- Slope and aspect angles of target
- Solar elevation angle
  - Path length
  - Shadows
- Bidirectional reflectance distribution function (BRDF)
  - Lambert's cosine law



Specular surface
Radiance = cosθ / cosθ = 1



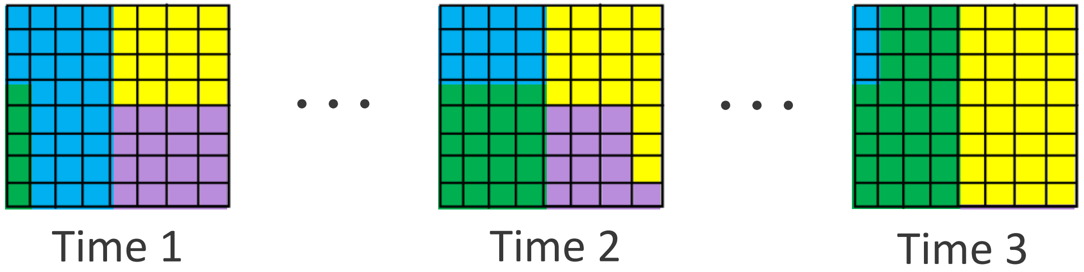
Diffuse surface
Radiance = cosφ / cosθ

At-sensor Radiance

- Light recorded as DNs by sensor
- Absolute calibration
  - RADIANCE_MULT_BAND_x
  - RADIANCE_ADD_BAND_x
- Radiometric normalization
  - Linear regression between master and slave images

Landsat (_MTL) metafile

```
GROUP = LEVEL1_RADIOMETRIC_RESCALING
  RADIANCE_MULT_BAND_1 = 7.7874E-01
  RADIANCE_MULT_BAND_2 = 7.9882E-01
  RADIANCE_MULT_BAND_3 = 6.2165E-01
  RADIANCE_MULT_BAND_4 = 9.6929E-01
  RADIANCE_MULT_BAND_5 = 1.2622E-01
  RADIANCE_MULT_BAND_6_VCID_1 = 6.7087E-02
  RADIANCE_MULT_BAND_6_VCID_2 = 3.7205E-02
  RADIANCE_MULT_BAND_7 = 4.3898E-02
  RADIANCE_MULT_BAND_8 = 9.7559E-01
  RADIANCE_ADD_BAND_1 = -6.97874
  RADIANCE_ADD_BAND_2 = -7.19882
  RADIANCE_ADD_BAND_3 = -5.62165
  RADIANCE_ADD_BAND_4 = -6.06929
  RADIANCE_ADD_BAND_5 = -1.12622
  RADIANCE_ADD_BAND_6_VCID_1 = -0.06709
  RADIANCE_ADD_BAND_6_VCID_2 = 3.16280
  RADIANCE_ADD_BAND_7 = -0.39390
  RADIANCE_ADD_BAND_8 = -5.67559
```



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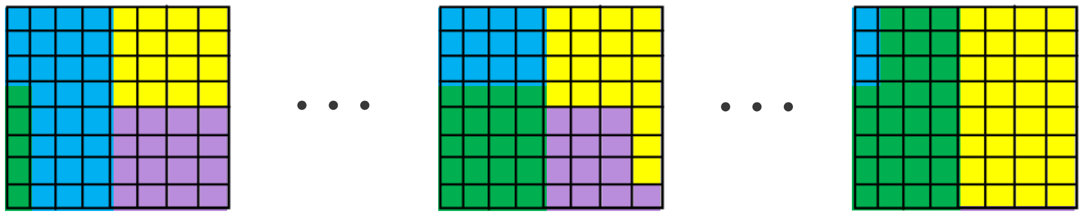
Gain

Offset



Time 1 Time 2 Time 3

At-sensor Radiance

- Light recorded as DNs by sensor
- Absolute calibration
  - RADIANCE_MULT_BAND_x
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  - Linear regression between master and slave images

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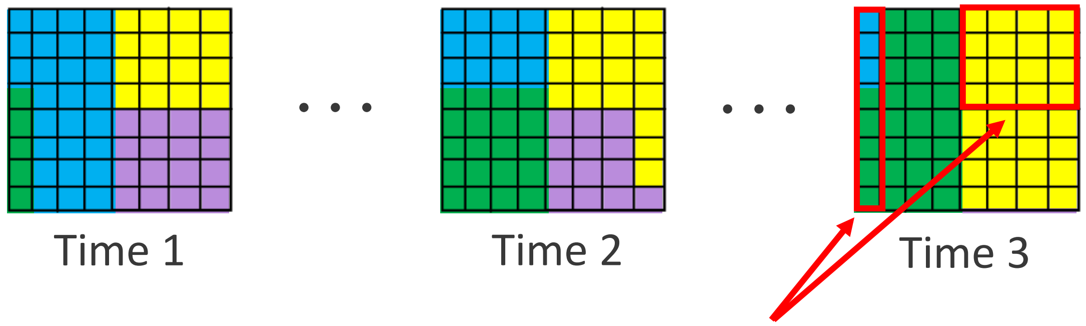


Pseudo-invariant features

At-sensor / Apparent Reflectance

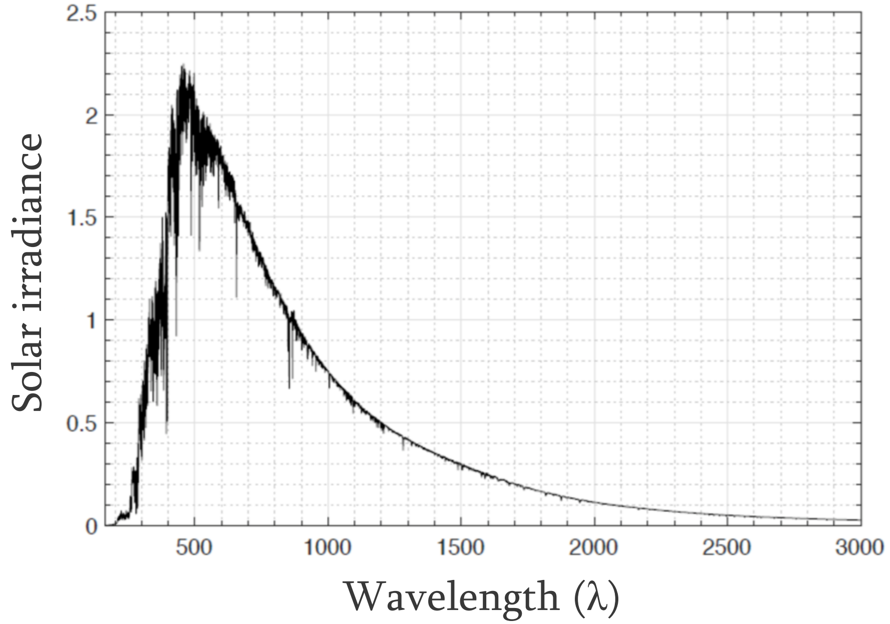
- Does not account for atmospheric absorption and scatter
- Corrects the time difference in solar zenith
- Compensates for differences in solar irradiance because of band differences

$$\text{Apparent reflectance} = \frac{\pi \cdot \text{radiance} \cdot \text{distance}^2}{E_{SUN} \cdot \cos(\underbrace{90 - \text{sun elevation}}_{\text{solar zenith}})}$$

E_{SUN} is exoatmospheric solar irradiance (band specific)

Landsat (_MTL) metafile

```
    SUN_AZIMUTH = 129.85770930
    SUN_ELEVATION = 63.99611450
    EARTH_SUN_DISTANCE = 1.0121280
    SENSOR_MODE = "BUMPER"
    SENSOR_MODE_SLC = "OFF"
    SENSOR_ANOMALIES = "NONE"
  END_GROUP = IMAGE_ATTRIBUTES
  GROUP = PROJECTION_ATTRIBUTES
    MAP_PROJECTION = "UTM"
    DATUM = "WGS84"
```



GEE: Landsat Collection 2 Top of Atmosphere (TOA)

- Onboard (IC) calibration system
- Gain and bias (linear regression) prelaunch correction
- Full and partial aperture solar calibrators (Landsat 7 ETM+…)
- At-sensor radiance calculated from DNs and coefficients in meta data
- At-sensor reflectance calculated from radiance and coefficients in meta data
- Tier 1 well-characterized radiometry and inter-sensor calibration (histogram equalization)

Gyanesh Chander, Brian L. Markham, Dennis L. Helder. 2009. Summary of current radiometric calibration coefficients for Landsat MSS, TM, ETM+, and EO-1 ALI sensors, Remote Sensing of Environment: 113, 893-903.

Landsat-7 and Landsat-8 Harmonization

- Different spectral response
- Atmospheric state and effects
- Imperfect atmospheric correction
- Edge effects (field of view)
- Temporal differences
- Harmonized Landsat/Sentinel-2 (HLS) project

Table 2
Surface reflectance sensor transformation functions (ETM+ to OLI and OLI to ETM+) derived by ordinary least squares (OLS) regression of the data illustrated in Fig. 8, reduced major axis (RMA) regression coefficients, the number of 30 m pixel values considered (n), the OLS regression coefficient of determination (r^2), the OLS regression F-test p-*value*, the mean difference [2], the mean relative difference [4], and the root mean square deviation [3], between the OLI and ETM+ surface reflectance data.

	Regression type	Between sensor OLS transformation functions and RMA regression coefficients	n	OLS r^2 (p-value)	Mean difference OLI–ETM+ (reflectance)	Mean relative difference OLI–ETM+ (%)	Root mean square deviation (reflectance)
Blue λ (~0.48 μm)	RMA	OLI = −0.0095 + 0.9785 ETM	29,607,256	0.750 (<0.0001)	−0.0110	−22.32	0.0313
	OLS	OLI = 0.0003 + 0.8474 ETM+					
	OLS	ETM+ = 0.0183 + 0.8850 OLI					
Green λ (~0.56 μm)	RMA	OLI = −0.0016 + 0.9542 ETM	29,670,363	0.790 (<0.0001)	−0.0060	−7.34	0.0317
	OLS	OLI = 0.0088 + 0.8483 ETM+					
	OLS	ETM+ = 0.0123 + 0.9317 OLI					
Red λ (~0.66 μm)	RMA	OLI = −0.0022 + 0.9825 ETM	29,505,658	0.848 (<0.0001)	−0.0041	−5.12	0.0333
	OLS	OLI = 0.0061 + 0.9047 ETM+					
	OLS	ETM+ = 0.0123 + 0.9372 OLI					
Near infrared λ (~0.85 μm)	RMA	OLI = −0.0021 + 1.0073 ETM	29,618,412	0.706 (<0.0001)	−0.0002	−0.19	0.0644
	OLS	OLI = 0.0412 + 0.8462 ETM+					
	OLS	ETM+ = 0.0448 + 0.8339 OLI					
Shortwave infrared λ (~1.61 μm)	RMA	OLI = −0.0030 + 1.0171 ETM	29,520,670	0.772 (<0.0001)	0.0009	0.03	0.0562
	OLS	OLI = 0.0254 + 0.8937 ETM+					
	OLS	ETM+ = 0.0306 + 0.8639 OLI					
Shortwave infrared λ (~2.21 μm)	RMA	OLI = 0.0029 + 0.9949 ETM	29,028,669	0.831 (<0.0001)	0.0021	1.52	0.0453
	OLS	OLI = 0.0172 + 0.9071 ETM+					
	OLS	ETM+ = 0.0116 + 0.9165 OLI					

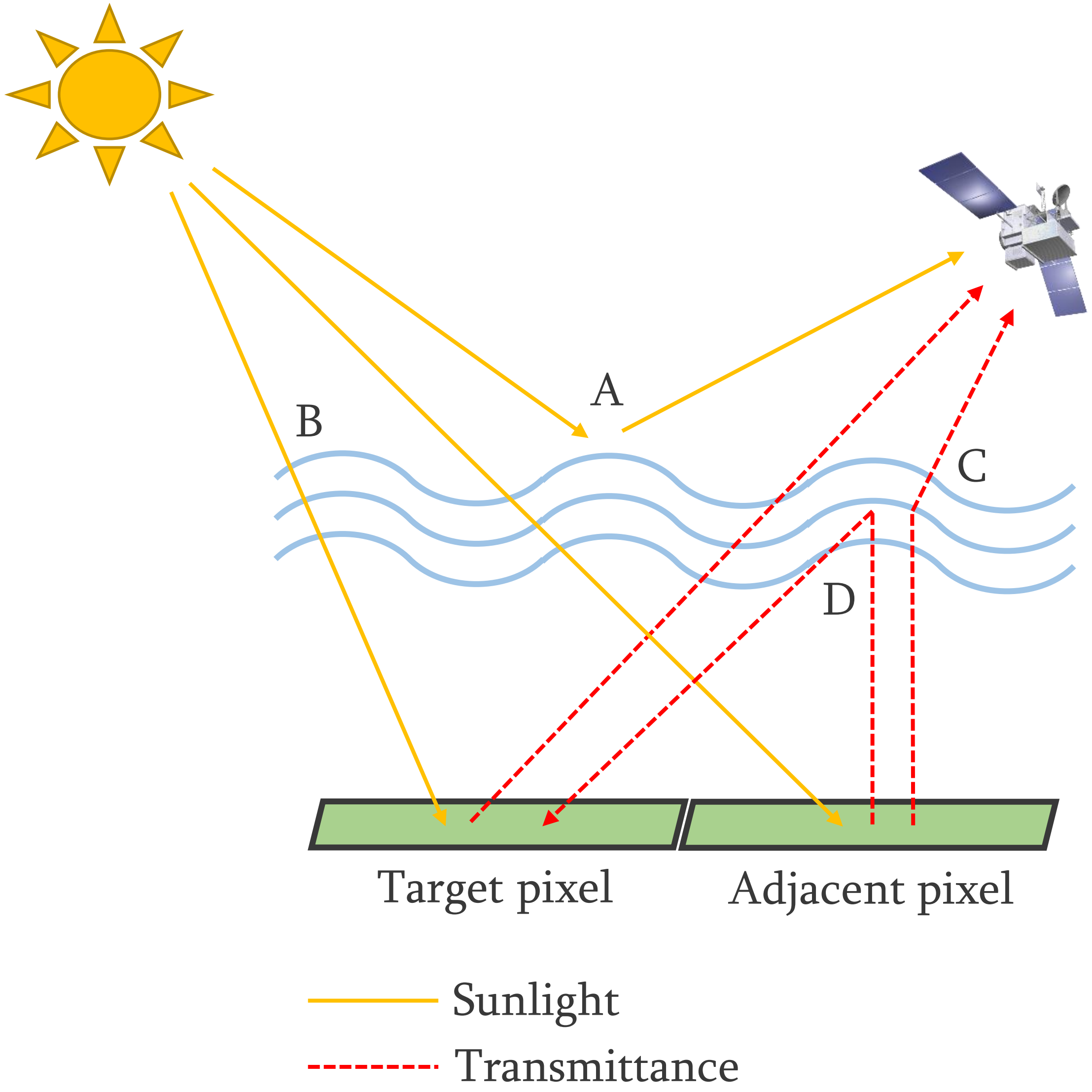
D.P. Roy, V. Kovalskyy, H.K. Zhang, E.F. Vermote, L. Yan, S.S. Kumar, A. Egorov, Characterization of Landsat-7 to Landsat-8 reflective wavelength and normalized difference vegetation index continuity, Remote Sensing of Environment, Volume 185, 2016, Pages 57-70.

Martin Claverie, Junchang Ju, Jeffrey G. Masek, Jennifer L. Dungan, Eric F. Vermote, Jean-Claude Roger, Sergii V. Skakun, Christopher Justice, The Harmonized Landsat and Sentinel-2 surface reflectance data set, Remote Sensing of Environment, Volume 219, 2018, Pages 145-161.

Influence of the Atmosphere

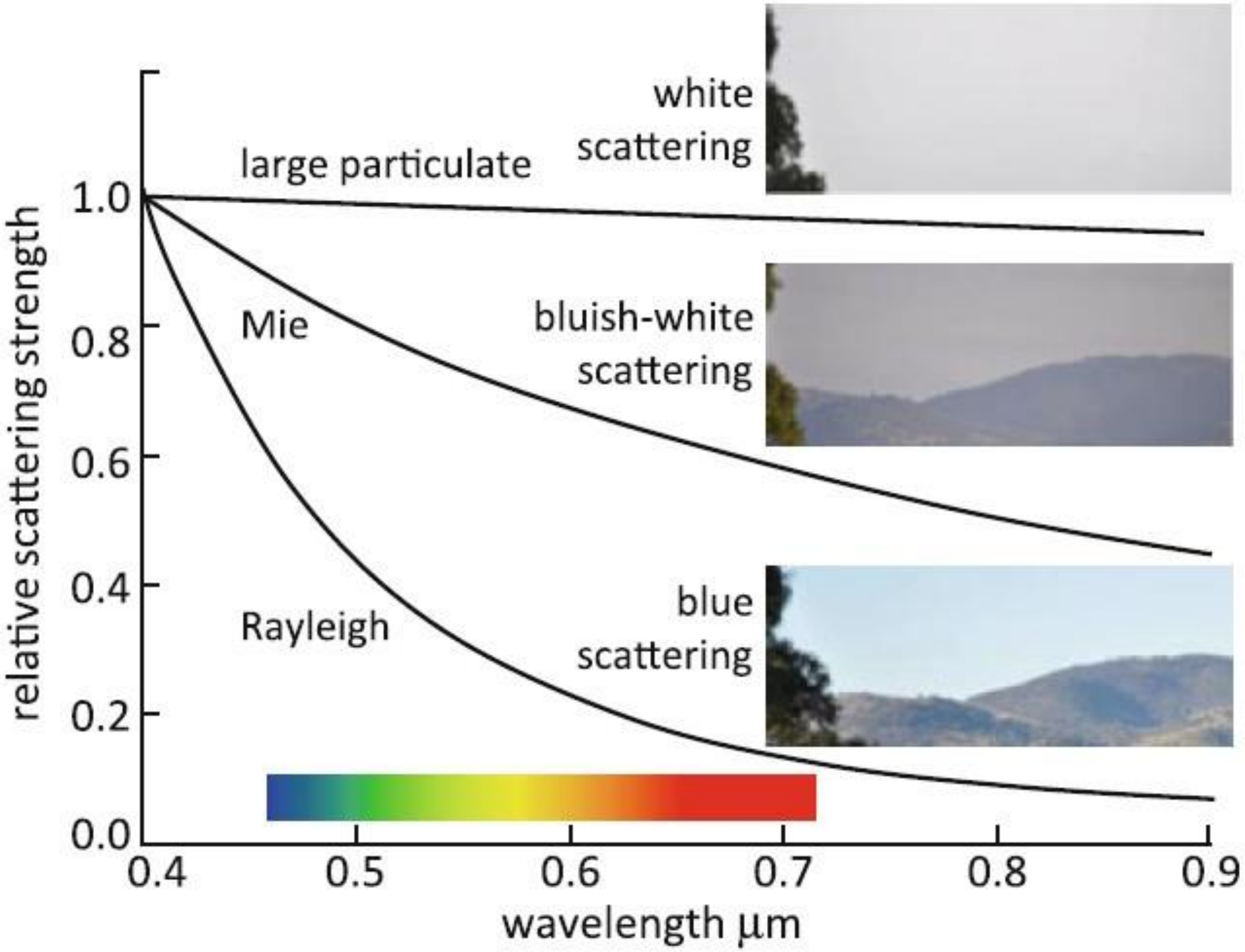
A. Path radiance 1
B. Sky radiance 1
C. Path radiance 2
D. Sky radiance 2

Diffuse versus direct beam



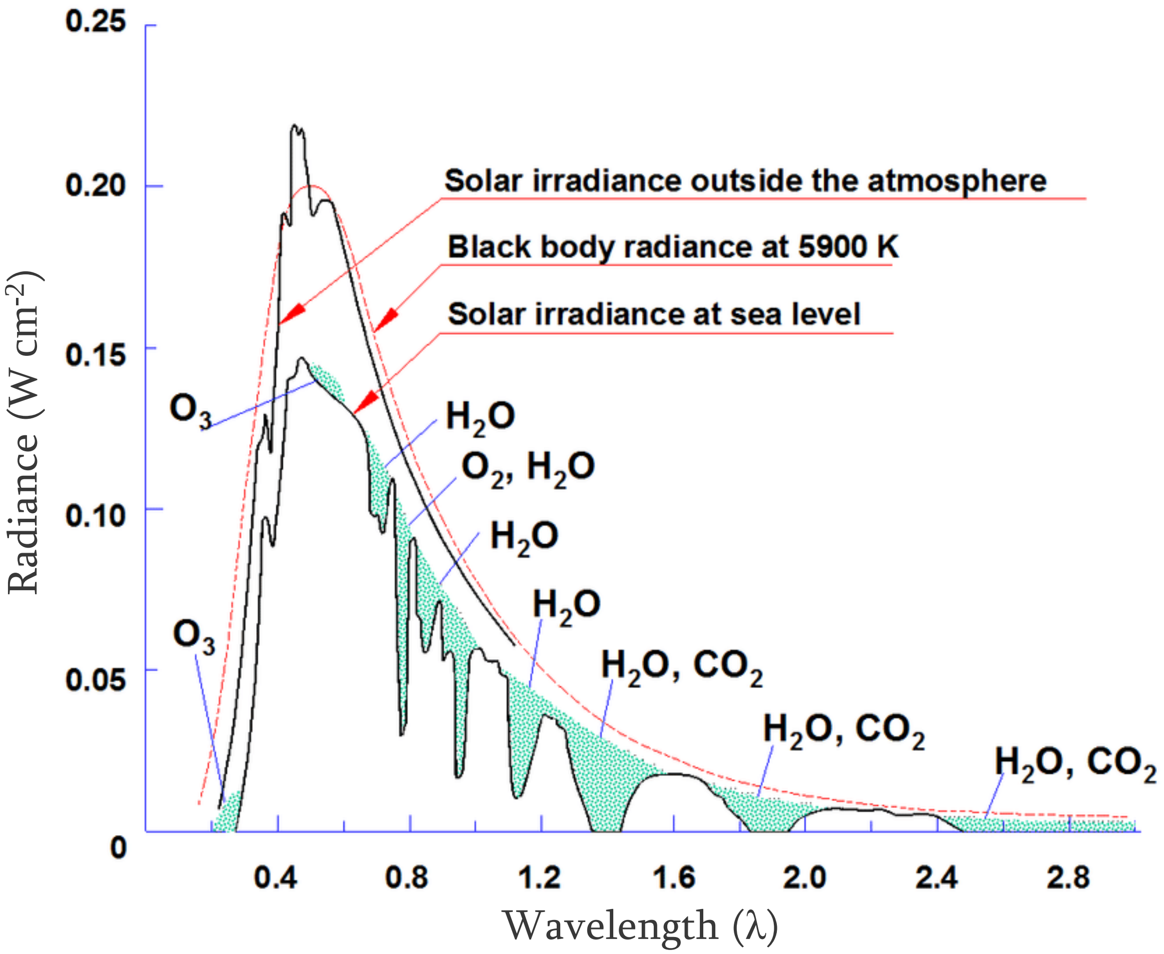
Scattering Mechanisms

- Rayleigh scattering
  - O_2, N_2
  - Higher at shorter λ
  - Primary path radiance
- Mie scattering
  - Aerosols, dust, pollen
  - Higher at shorter λ
- Non-selective scatter
  - Water, clouds, ice
  - Size dependent



Absorption

Ozone, water vapor, carbon dioxide also absorb radiation, which is converted to heat



Dark-Object Subtraction

- Early empirical method for atmospheric correction
- Corrects for path radiance
- Dark objects (e.g., water) should have zero brightness
- Attenuation higher for shorter λ
- "Excess" brightness removed uniformly over image
- Does not consider pixel-to-pixel variation

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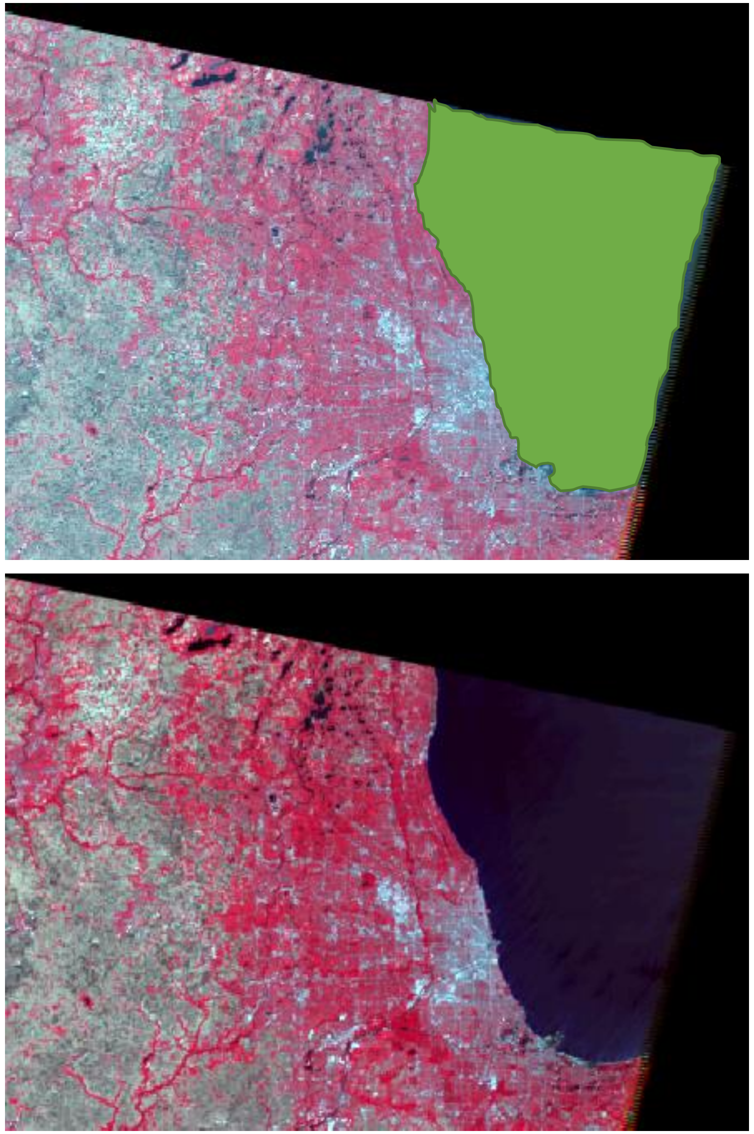
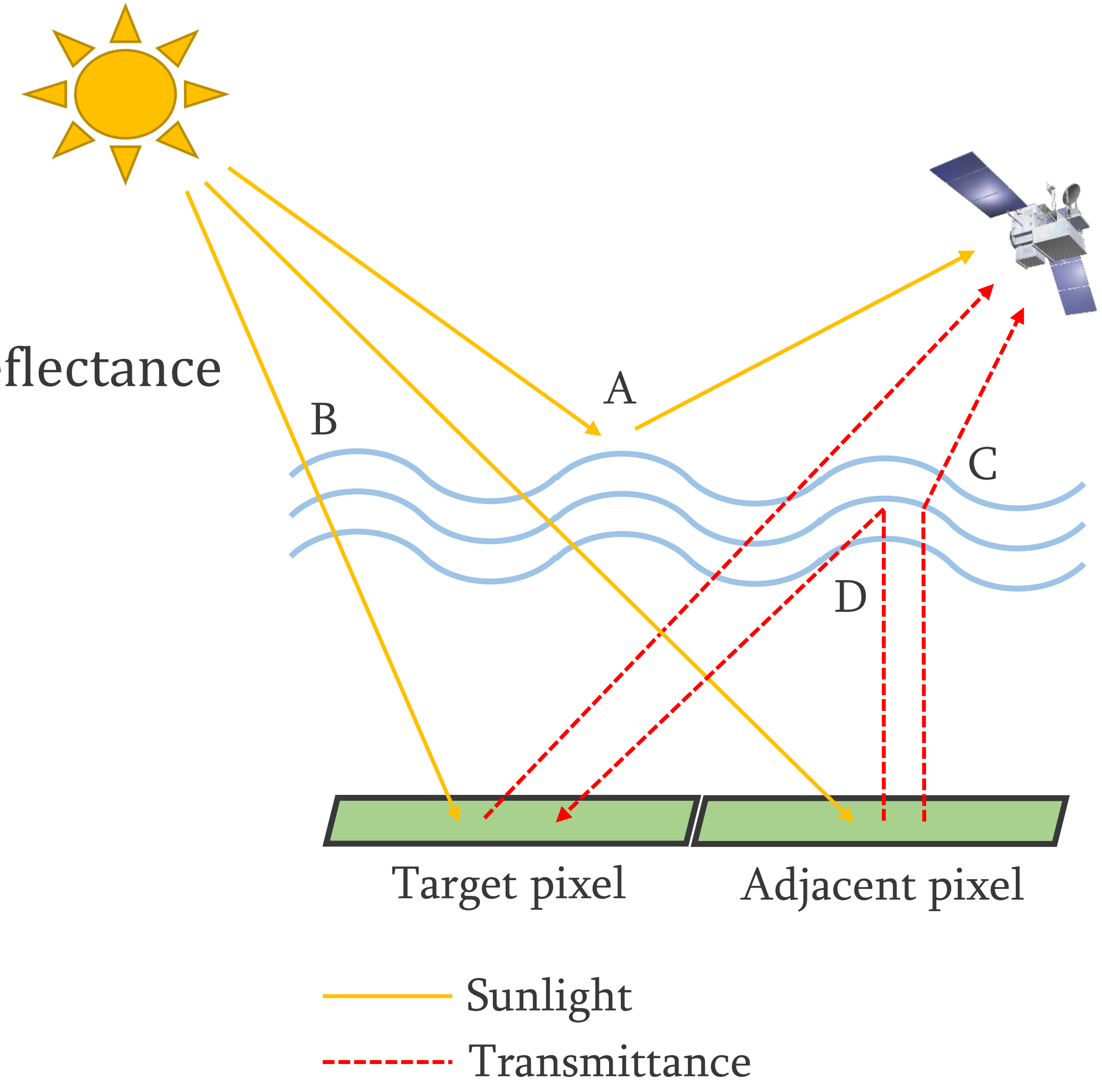


Quick Atmospheric Correction (QUAC)

Semi-physical approach

TOA reflectance=

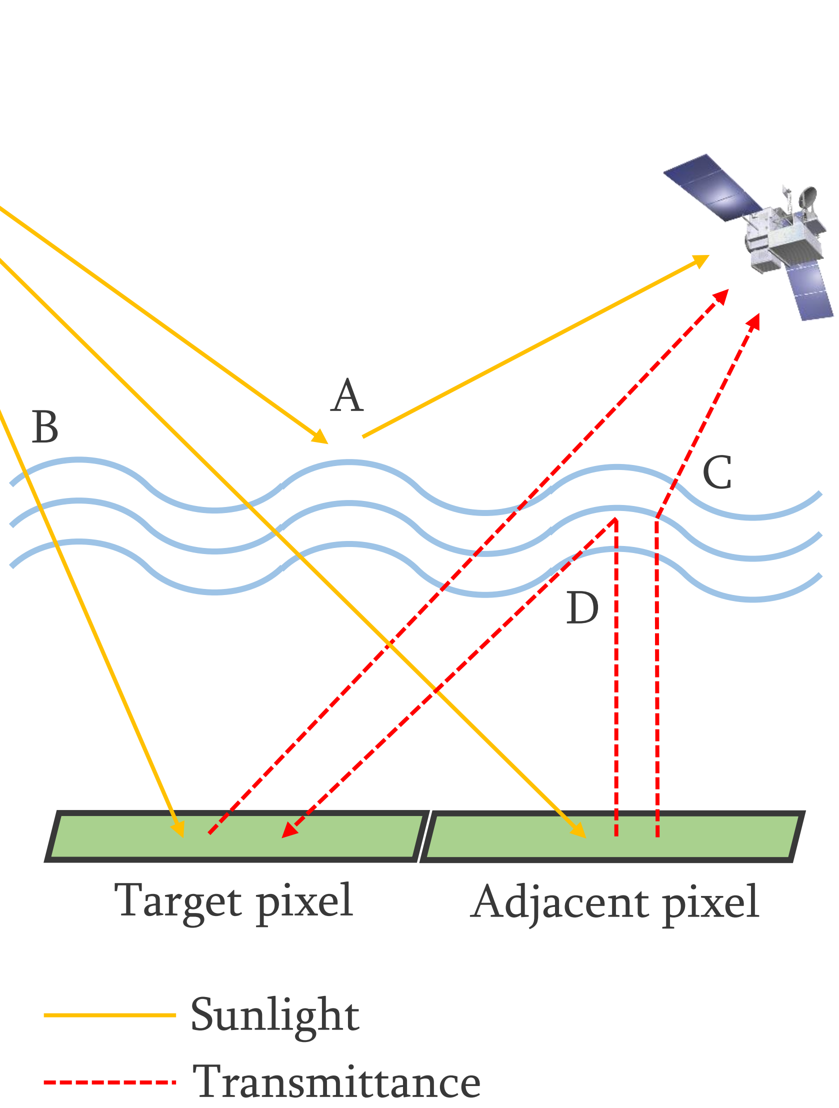
(A + C · adjacent reflectance) + B · target reflectance



Quick Atmospheric Correction (QUAC)

TOA reflectance=

$$\underbrace{(A + C \cdot \text{adjacent reflectance})}_{\text{Offset (constant)}} + \underset{\substack{\uparrow \\ \text{Gain}}}{B} \cdot \text{target reflectance}$$



Quick Atmospheric Correction (QUAC)

$$\text{TOA reflectance} =$$

$$\underbrace{(\text{A} + \text{C} \cdot \text{adjacent reflectance})}_{\text{Offset (constant)}} + \underset{\substack{\uparrow \\ \text{Gain}}}{\text{B}} \cdot \text{target reflectance}$$

$$\text{Target reflectance} =$$

$$\frac{1}{\text{B}} \cdot (\text{TOA reflectance} - \text{offset})$$

Dark-object subtraction

Spectral endmembers

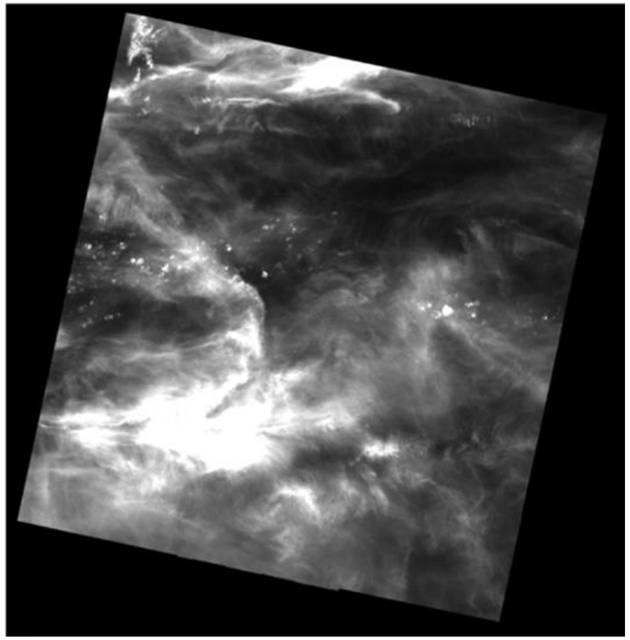
GEE: Landsat Collection 2 Surface Reflectance

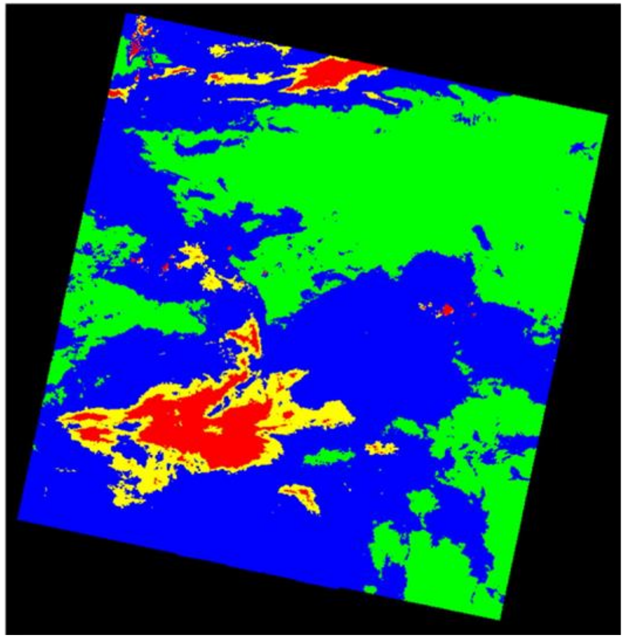
- Physical (radiative transfer) approaches (ATCOR, MODTRAN) have many complicated steps and manual operations
- Fully automated atmospheric correction…ALMOST!!!
    - Landsat 4-7: Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) software
    - Landsat 8-9: Land Surface Reflectance Code (LaSRC)
    - Still uses dark object subtraction
    - MODTRAN solar output model corrects for solar zenith, Sun–Earth distance, TM or ETM+ bandpass, and solar irradiance
    - 6S radiative transfer code
    - Model is calibrated with climate reanalysis and atmospheric sounders (aerosols)
- Tier-1: 6-10% error

J. G. Masek et al., "A Landsat surface reflectance dataset for North America, 1990-2000," in IEEE Geoscience and Remote Sensing Letters, vol. 3, no. 1, pp. 68-72, Jan. 2006, doi: 10.1109/LGRS.2005.857030.

Cloud and Cloud Shadow

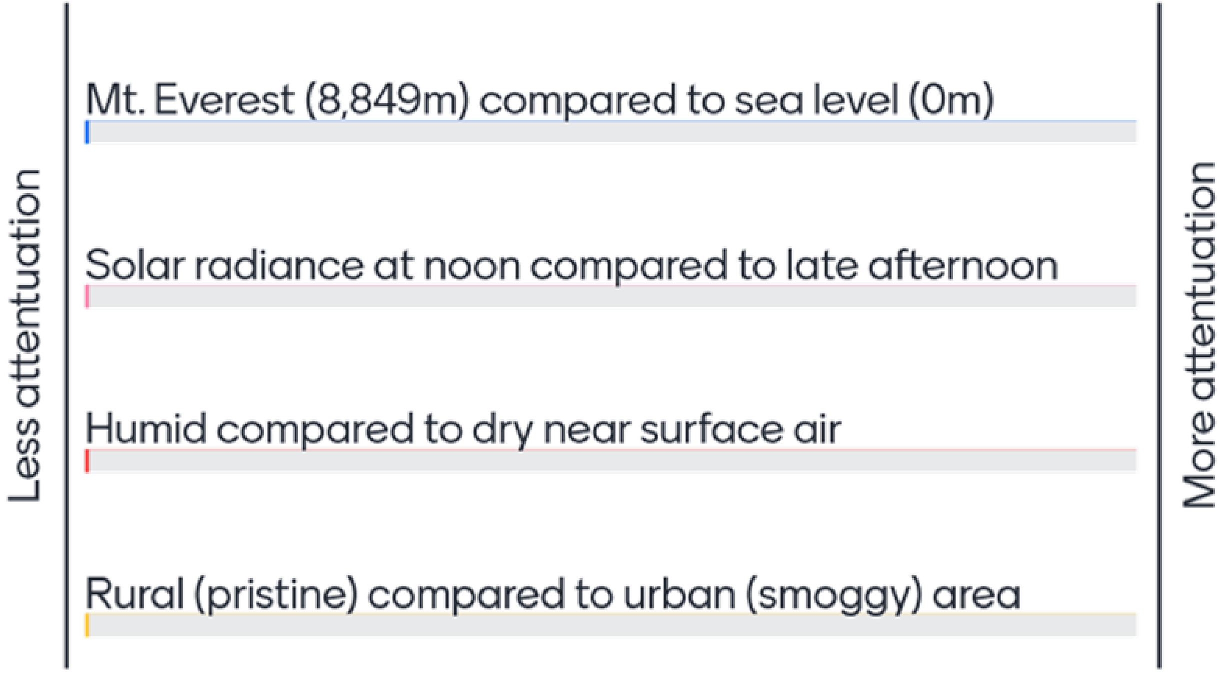
- Rules-based approaches
- LS 4-7: surface temperature from climate reanalysis and thermal band
- LS8-9: cirrus band and the new blue band
- Temperature normalized by DEM
- FMASK
  - Scene-based dynamic threshold
  - Shadows linked to clouds according to sun-sensor geometry
  - Reprogrammed in C language (CFMASK)
- Machine learning





Which scenario has more/less attentuation than its alternative?

Mentimeter



Which scenario has more/less attentuation than its alternative?

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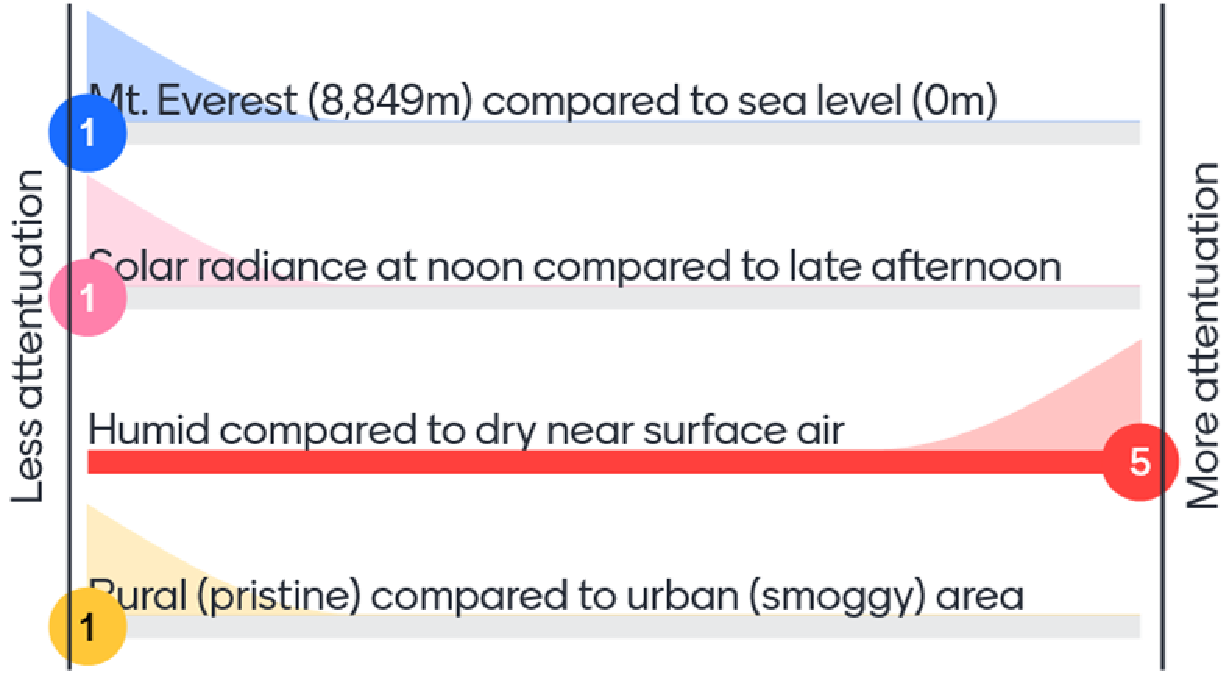
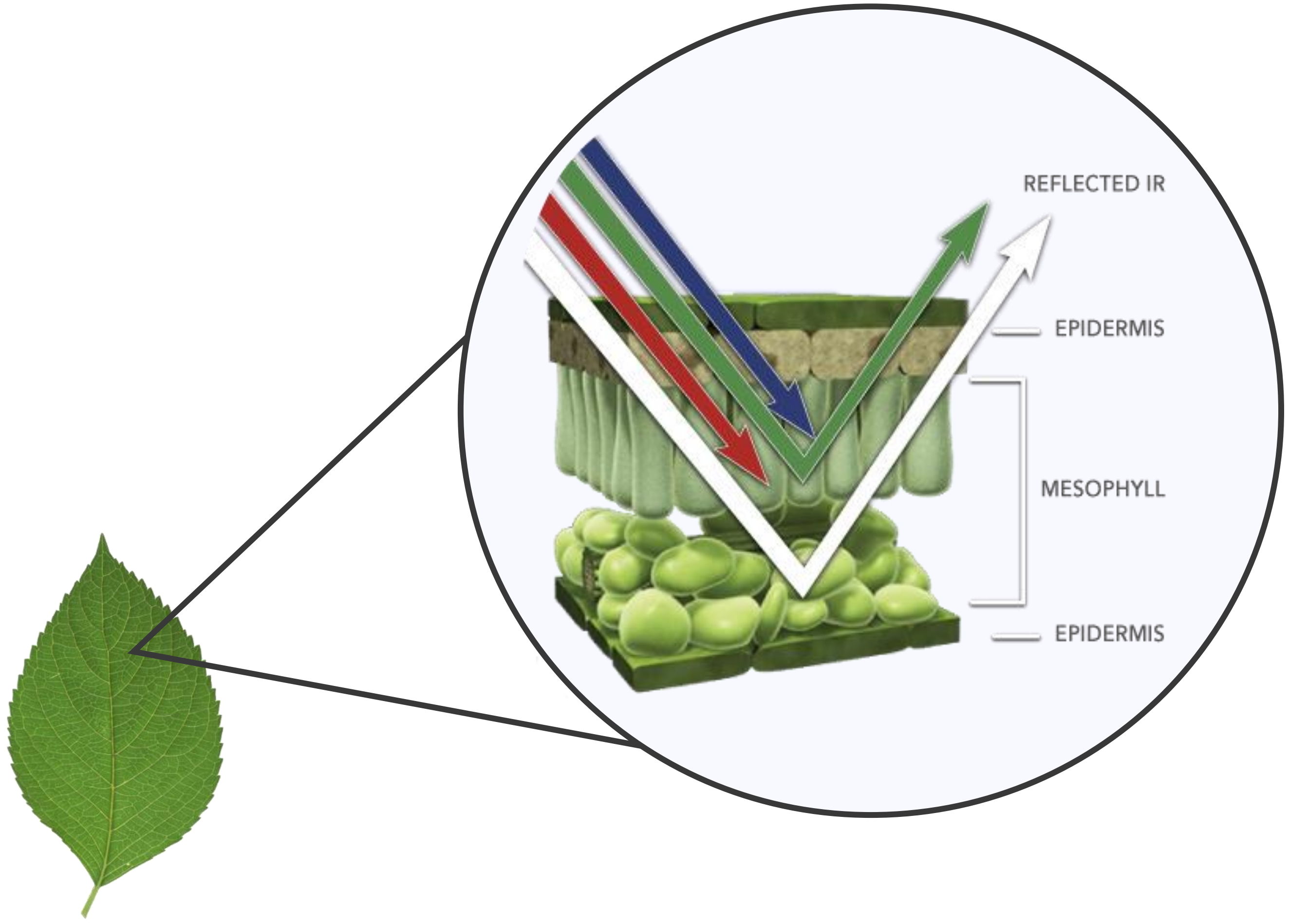


Metrics (e.g., NDVI)



Healthy plants

- Strong scatter in the green and NIR
- Strong absorption in the blue and red

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{red}}{\mathrm{NIR} + \mathrm{red}}$$

Tucker, C.J. 1979. Red and photographic linear combinations for monitoring vegetation, Remote Sensing of Environment, 8: 127-150.

Other Vegetation Indices

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GEOSPATIAL SOLUTIONS

Welcome to the L3 Harris Geospatial documentation center. Here you will find reference guides and help documents.

DOCS CENTER   IDL PROGRAMMING   ENVI   GSF   RESOURCES

> Docs Center > Using ENVI > Vegetation Indices

Vegetation Indices

Index Search   Keyword Search

EO-1 Hyperion Vegetation Indices Tutorial

Vegetation Indices (VIs) are combinations of surface reflectance at two or more wavelengths designed to highlight a particular property of vegetation. They are derived using the reflectance properties of vegetation. Each of the VIs is designed to accentuate a particular vegetation property.

More than 150 VIs have been published in scientific literature, but only a small subset have substantial biophysical basis or have been systematically tested. ENVI provides 27 vegetation indices to use to detect the presence and relative abundance of pigments, water, and carbon as expressed in the solar-reflected optical spectrum (400 nm to 2500 nm).

Selection of the most important vegetation categories and the best representative indices within each category was performed by Dr. Gregory P. Asner of the Carnegie Institution of Washington, Department of Global Ecology. The selections were based upon robustness, scientific basis, and general applicability. Many of these indices are currently unknown or under-used in the commercial, government, and scientific communities.

The indices are grouped into categories that calculate similar properties. The categories and indices are as follows:

- Broadband Greenness
- Narrowband Greenness
- Light Use Efficiency
- Canopy Nitrogen
- Dry or Senescent Carbon
- Leaf Pigments
- Canopy Water Content

Each category of indices typically provides multiple techniques to estimate the absence or presence of a single vegetation property. For different properties and field conditions, some indices within a category provide results with higher validity than others. By comparing the results of different VIs in a category, and correlating these to field conditions measured on site, you can assess which indices in a particular category do the best job of modelling the variability in your scene. By using the VI in any category that best models the measured field

Product ENVI

Version 5.5.2

Table of Contents

ENVI on GitHub

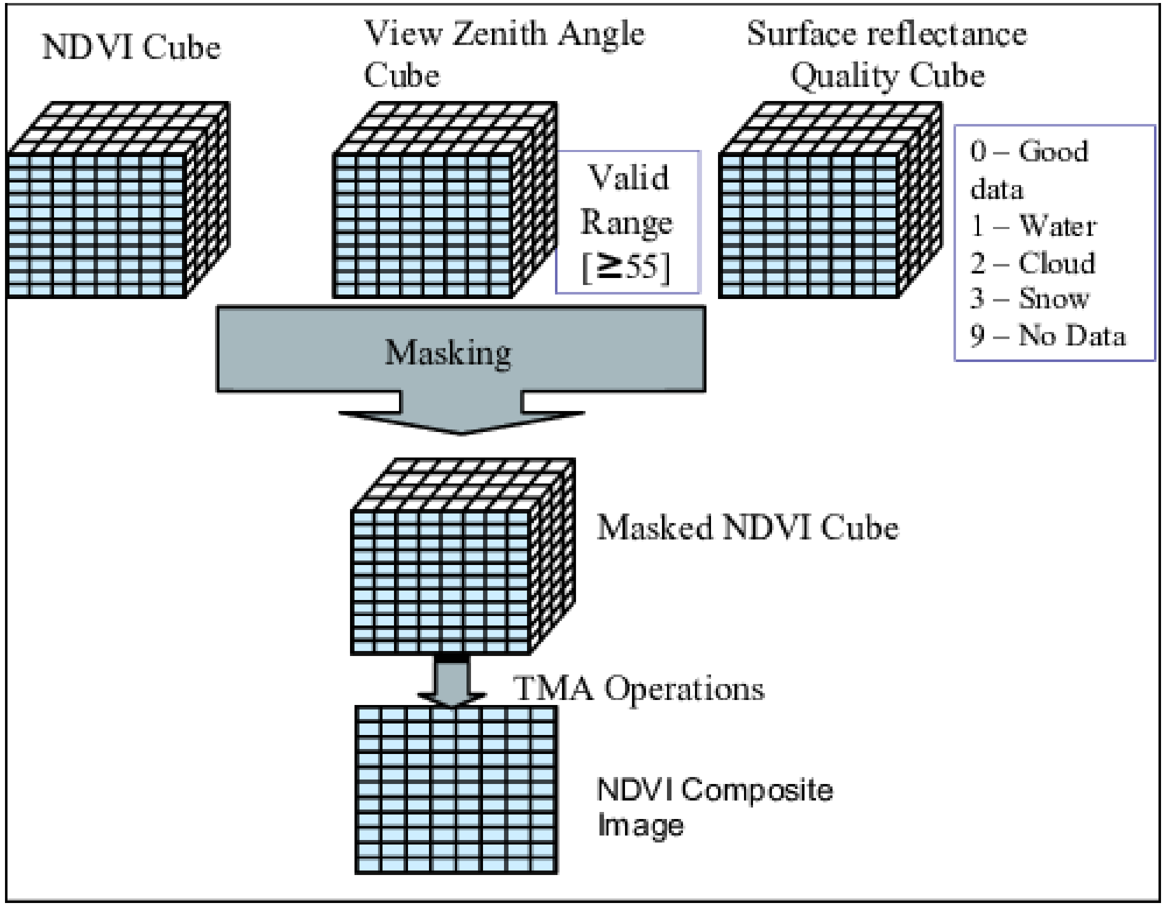
A collection of resources for ENVI users: custom tasks, extensions, and example models

Mosaicing

- Joins (geometrically) two or more images with overlapping areas
- Applied in GEE after atmospheric correction
- Steps
  - Feature extraction (Scale Invariant Feature Transform)
  - Correspondence between points
  - Image transformation (i.e., co-registration)
- Blending
  - Histogram matching, but does not change actual pixel values
  - Minimizes visual variations in brightness between images
- Image to image contrast matching
- Matching to a gaussian distribution or other mathematical reference

Compositing

- Selects "best" image or pixel over a period (7-day, 10-day, 16-day)
- Applied in GEE after atmospheric correction, cloud masking, quality assurance
- Reduces sun-sensor and atmospheric effects
- Mean / median / medoid
- Weighted averaging
- Time series fitted (harmonic) models



Summary

- Landsat Legacy
- Google Earth Engine and other cloud-computing environments
- Pre-processing essential to TSA
- Pre-processing compensates for:
    - Cosmetic defects
    - Geometric distortions
    - Atmospheric interference
    - Variations in illumination geometry
- Application specific

Practical Assignment

- Creating an GEE account
- Explanation of the interface
- Common data types in JavaScript in GEE
- Writing a Function
- Saving your outputs

- Image visualization
- Filtering image collections
- Creating mosaics and composites
- Cloud Masking
- Calculating Spectral Indices
- Plotting band histograms and spectral profiles
- Multi-sensor (Landsat) harmonization