A Synthetic Sensor/Image Simulation Tool to Support the Landsat Data Continuity Mission (LDCM)

Digital Imaging and Remote Sensing Lab
Chester F. Carlson Center for Imaging Science
Rochester Institute of Technology

John R. Schott ,Rolando V. Raqueno,
Nina Raqueno, Mike Gartley, Scott Brown…

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First Results of a Spiral Development Project

LDCM Algorithm Development Team

Landsat Calibration Team

Image Assessment System: NASA/USGS

Landsat Science Community

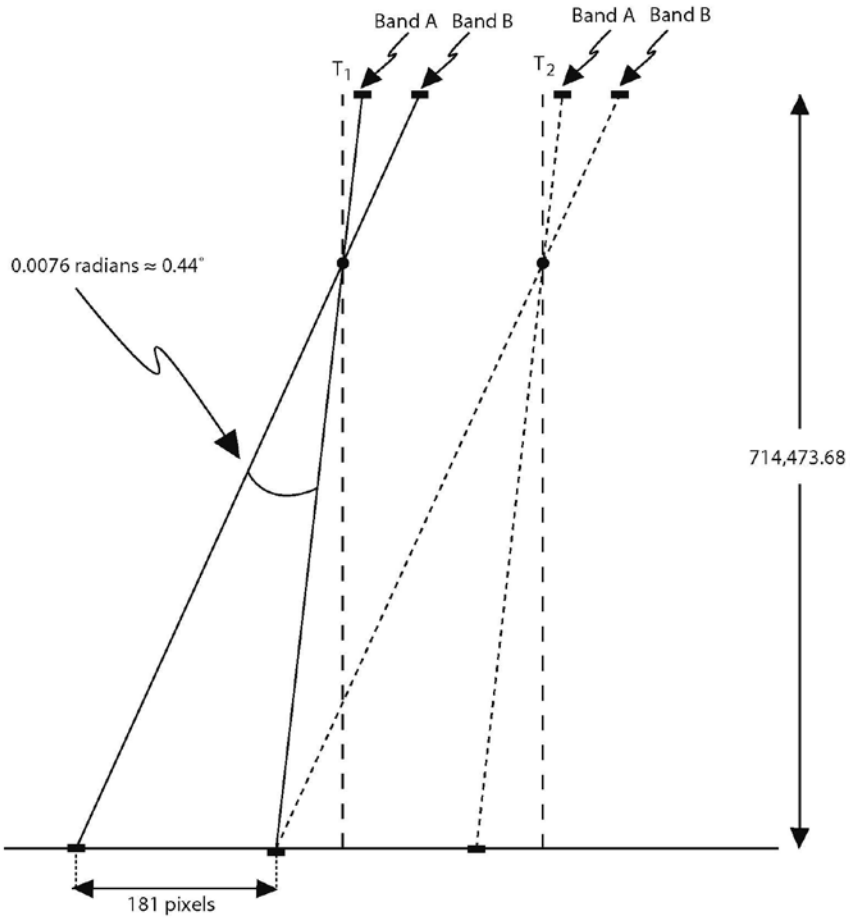


Figure 1: At nominal flying height (AGL) Bands A and B require 181.0 pixels of offset to exactly register A to B.

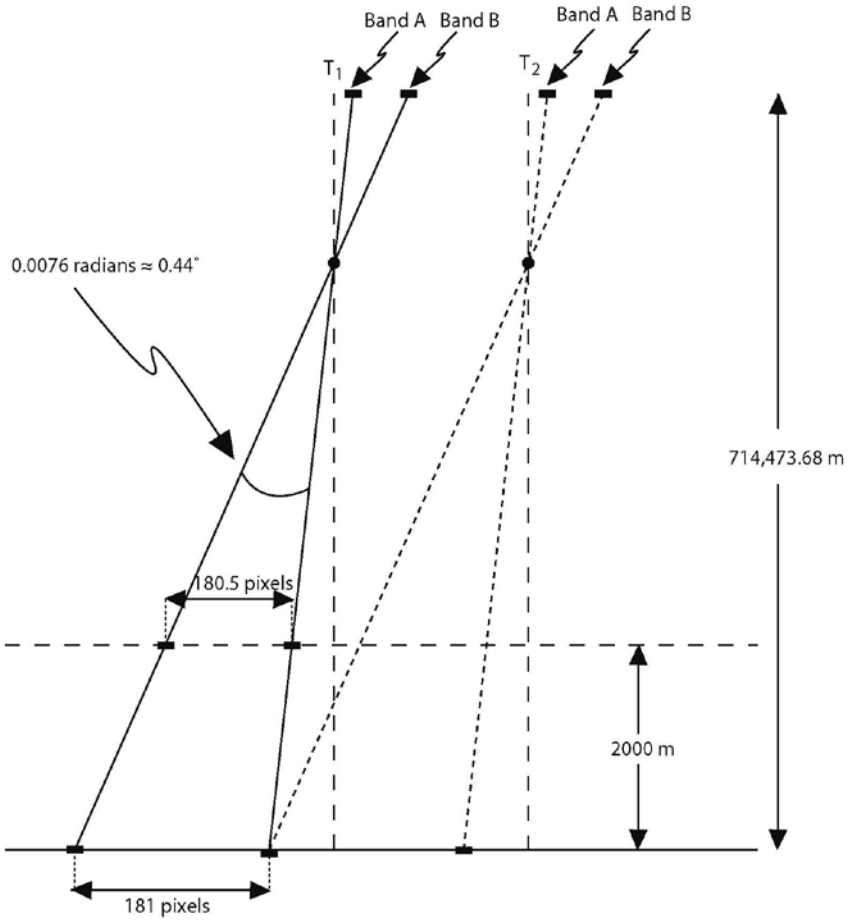
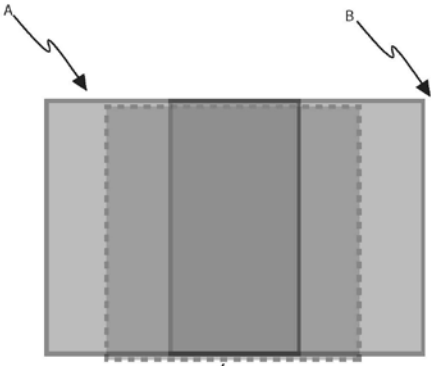


Figure 2: For a target at 2000m AGL Bands A and B are offset by 180.5 pixels

First Priority

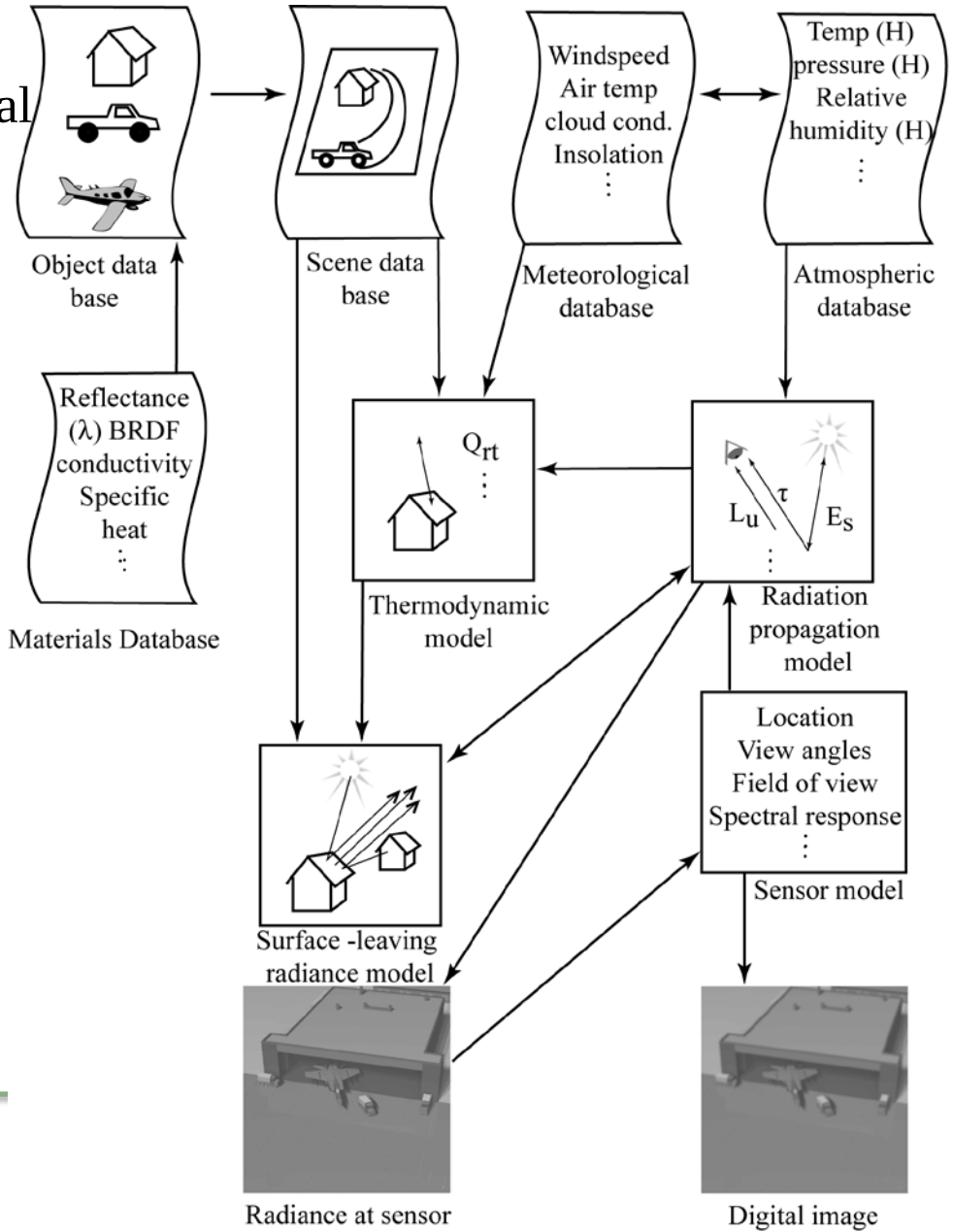


Parallax

Note that this problem is exaggerated by the non spherical nature of the Earth which introduces up to 20 km of variability in effective flying height (i.e., it is not just a terrain elevation problem). As a result, it will require continuous adjustment to account for elevation and effective altitude change (i.e., we need to adjust for the Geoid , the elevation (DEM) and the orbit ellipse).

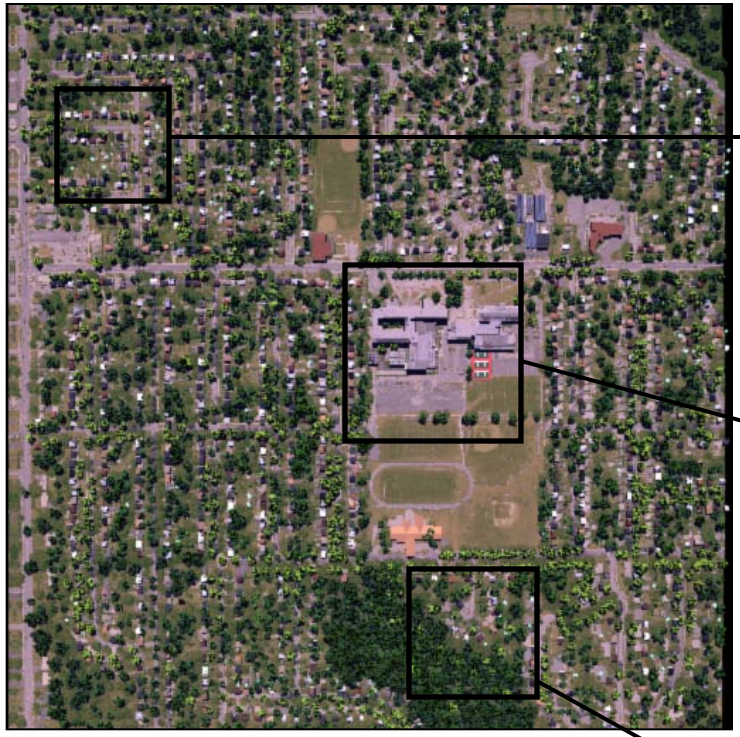
DIRSIG

Diagram of conceptual data flow and interaction mechanisms in a generic SIG model.



DIRSIG

Megascene 1, Tile 1



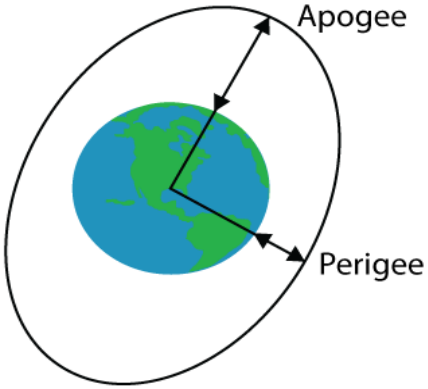
- 5,000+ objects
- 500+ million facets
- 1.6 km^2 (0.6 mi^2)

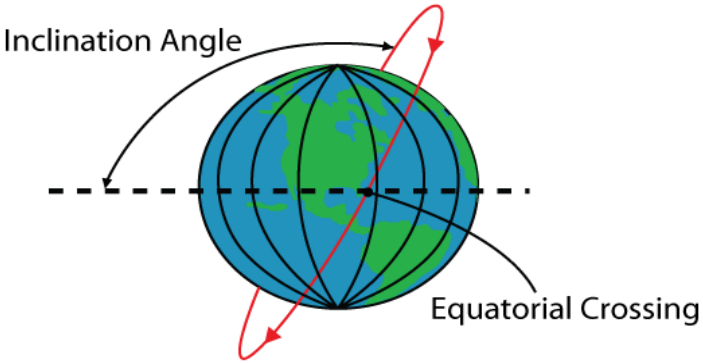
OLI Sensor Modeling in DIRSIG

Use of NORAD Two Line Element (TLE) orbital descriptors in DIRSIG

TLE → Orbital Discriptors → SGP4 Translator → TEME → TEME to ECEF Translator → ECEF

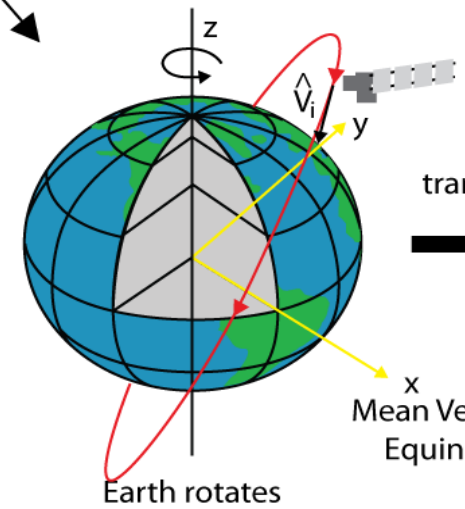
TLE Describes Orbit



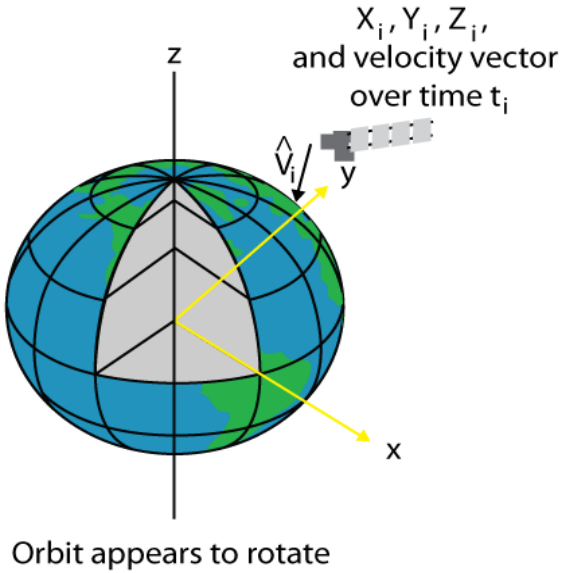


SGP4

Translator yields location and velocity vector for time t_i

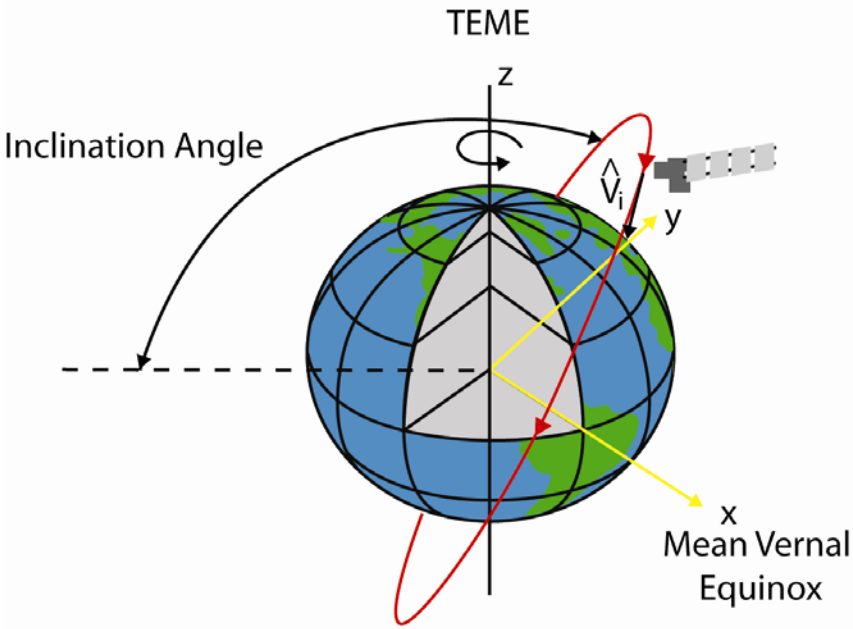


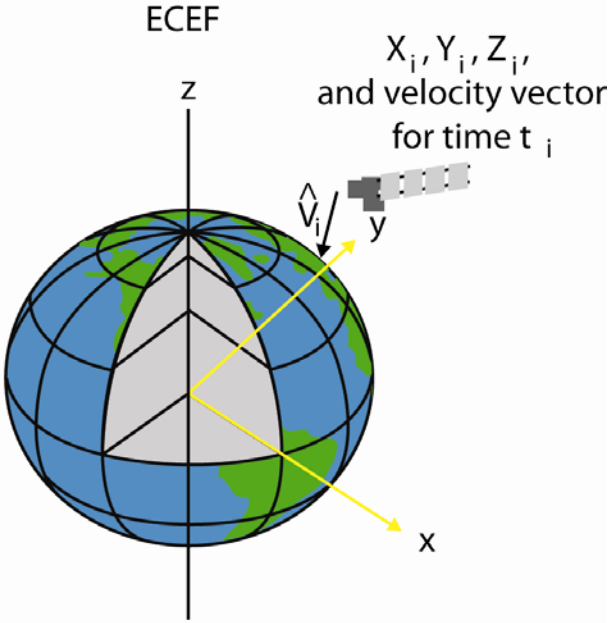
translator

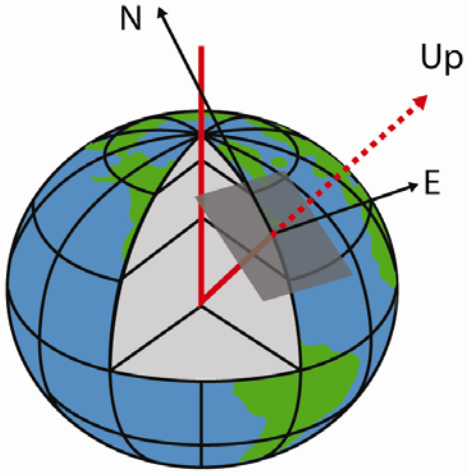


TEME Coordinate System
(True Equator Mean Equinox)

ECEF Coordinate System
(Earth Centered Earth Fixed)







ENU (0,0,0) <=> ECEF (X,Y,Z)

$$\begin{bmatrix} E \\ N \\ U \end{bmatrix} = \begin{bmatrix} \quad \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

Geometry Verification: Platform Position

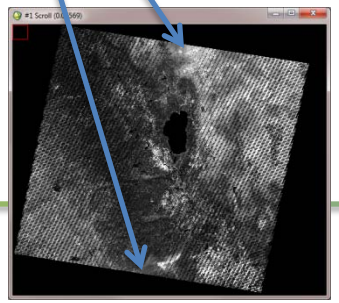
- Compared DIRSIG platform position (via SGP4 orbtial model wizard) against Vallado book example
- Verified DIRSIG derived ECEF positions against Vallado provided MATLAB code
- Current Approach Incorporates all First Order Effects, Several second order effects not considered worth while at present. The result is a realistic Orbit that may be shifted from actual by fractions of a kilometer.

Geometry Verification: Geolocation Accuracy of Tahoe Imaged with L7 TLE

- **Utilize LANDSAT-7 TLE from same date as actual LANDSAT-7 collection over Lake Tahoe (7/27/2009)**
- **Perform DIRSIG simulation with actual TLE and scan start and stop UTC**
- **Compare L7 metadata against geolocation of center of first and last DIRSIG scan line**

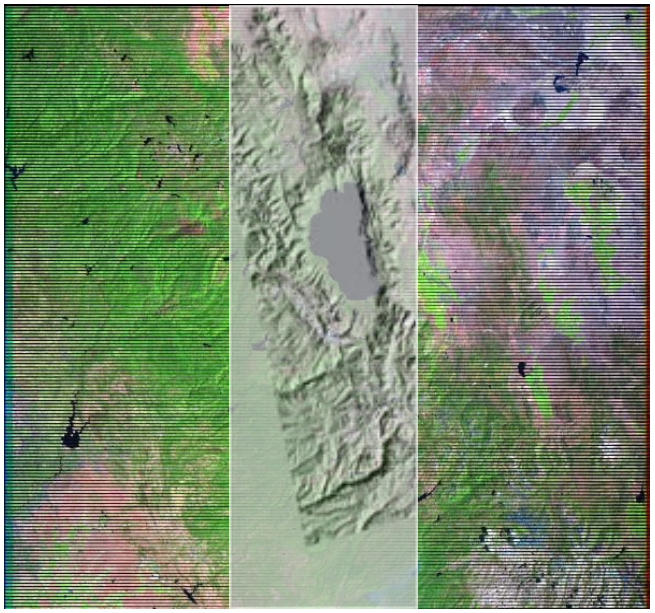
Dataset Attribute	Attribute Value
Product Download	http://edcsns17.cr.usgs.gov/cgi-bi
Landsat Scene Identifier	LE70430332009208EDC00
Station Identifier	EDC
Day Night	DAY
WRS Path	043
WRS Row	033
Date Acquired	2009/07/27
Start Time	2009:208:18:29:32.2742499
Stop Time	2009:208:18:29:59.0282499
Image Quality VCID 1	9
Image Quality VCID 2	9
Gap Phase Source	DE
Gap Phase Statistic	-5.303652
Cloud Cover	0.15
Cloud Cover Quadrant Upper Left	0.00
Cloud Cover Quadrant Upper Right	0.00
Cloud Cover Quadrant Lower Left	0.00
Cloud Cover Quadrant Lower Right	0.59
Sun Elevation	61.07777405
Sun Azimuth	126.37123871
Full Aperture Calibration	N
Scene Center Latitude	38.90137 (38°54'04.93"N)
Scene Center Longitude	-120.15545 (120°09'19.62"W)
Corner Upper Left Latitude	39.85583 (39°51'20.99"N)
Corner Upper Left Longitude	-121.00538 (121°00'19.37"W)
Corner Upper Right Latitude	39.53743 (39°32'14.75"N)
Corner Upper Right Longitude	-118.81339 (118°48'48.20"W)
Corner Lower Left Latitude	38.25100 (38°15'06.48"N)
Corner Lower Left Longitude	-121.47383 (121°28'25.79"W)
Corner Lower Right Latitude	37.94038 (37°56'25.37"N)
Corner Lower Right Longitude	-119.32983 (119°19'47.39"W)
Gain Band 1	H

		L7 Metadata		DIRSIG		Northing error	Easting error
reference point	UTC	latitude	longitude	latitude	longitude	[km]	[km]
center of first scan line	18:29:32.2742499	39.69663	-119.90939	39.69823	-119.91418	0.178	-0.534
center of last scan line	18:29:59.0282499	38.09609	-120.40183	38.09817	-120.40682	0.232	-0.555



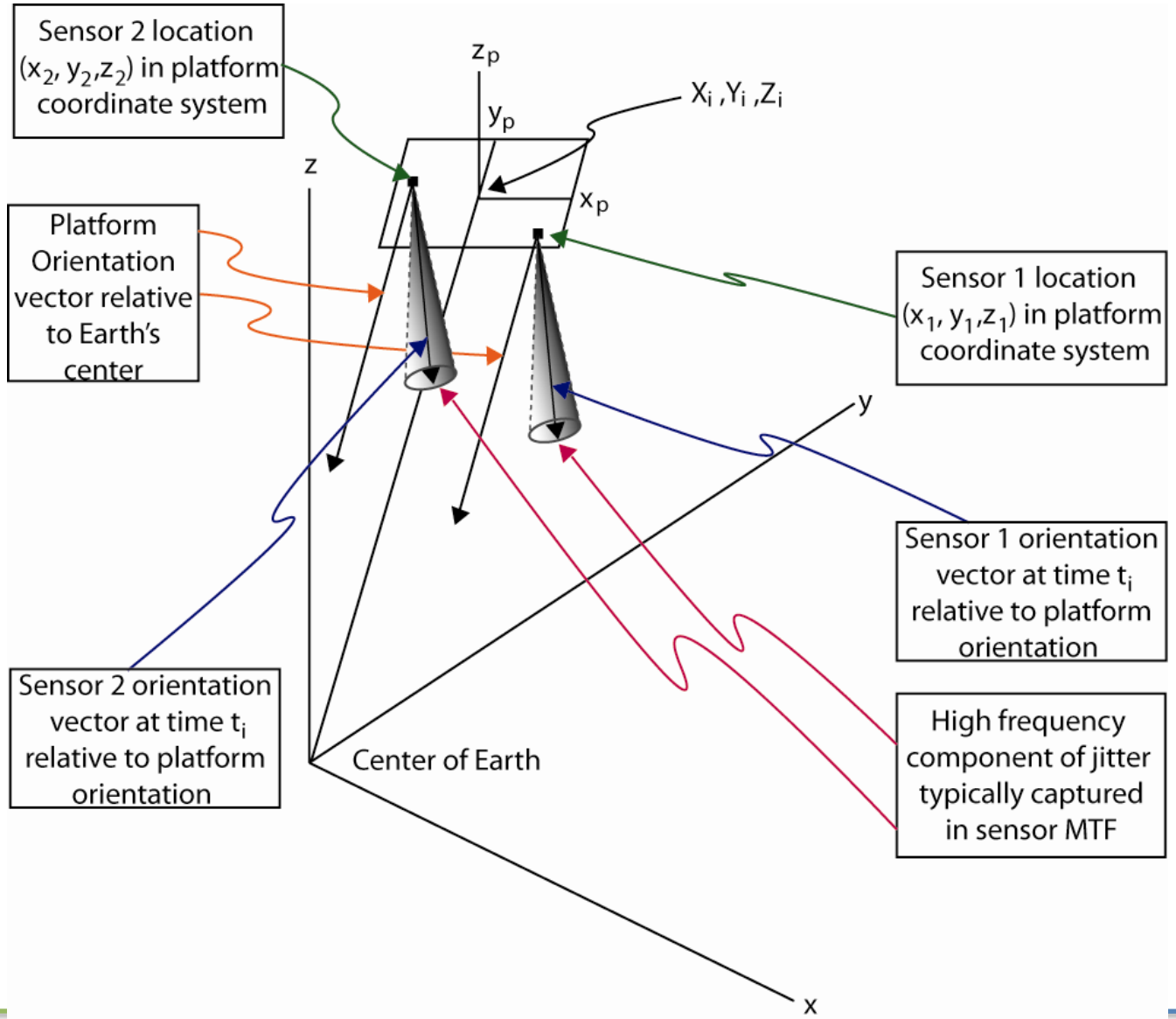
Geometry Verification: Geolocation Accuracy of Tahoe Imaged with L7 TLE

- **Visual comparison of 7/27/2009 LANDSAT-7 collection over Lake Tahoe**
- **Modeled L7 as a linear pushbroom system in DIRSIG**
- **DIRSIG simulation starts and stops at the UTC specified in L7 metadata and utilizes TLE for 7/27/2009 retrieved from spacetrack.org**



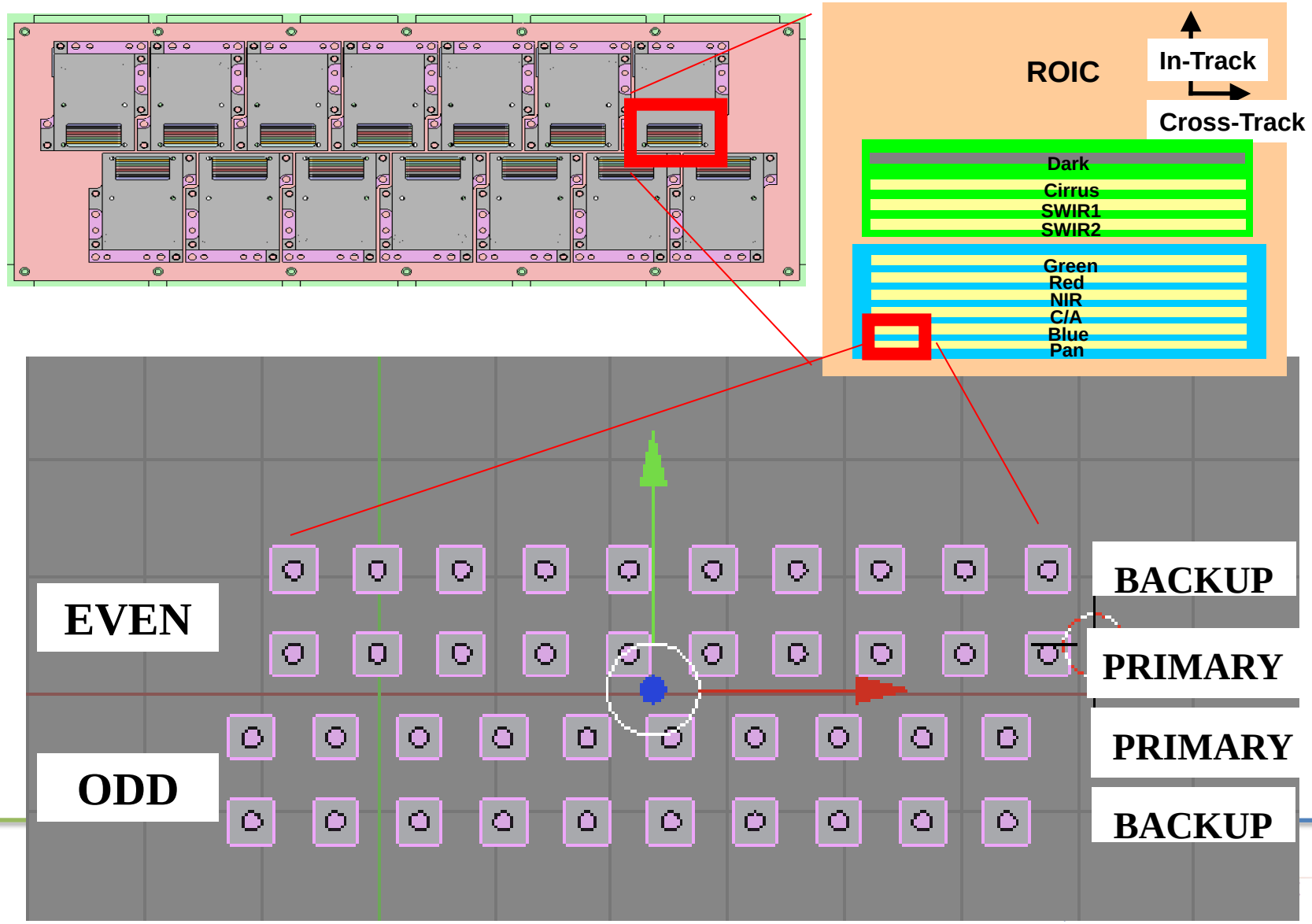
- **Full color image extent is actual L7 data, gray 2048 pixel across-track subset is DIRSIG simulation over unity albedo terrain**

DIRSIG Platform/Sensor Model

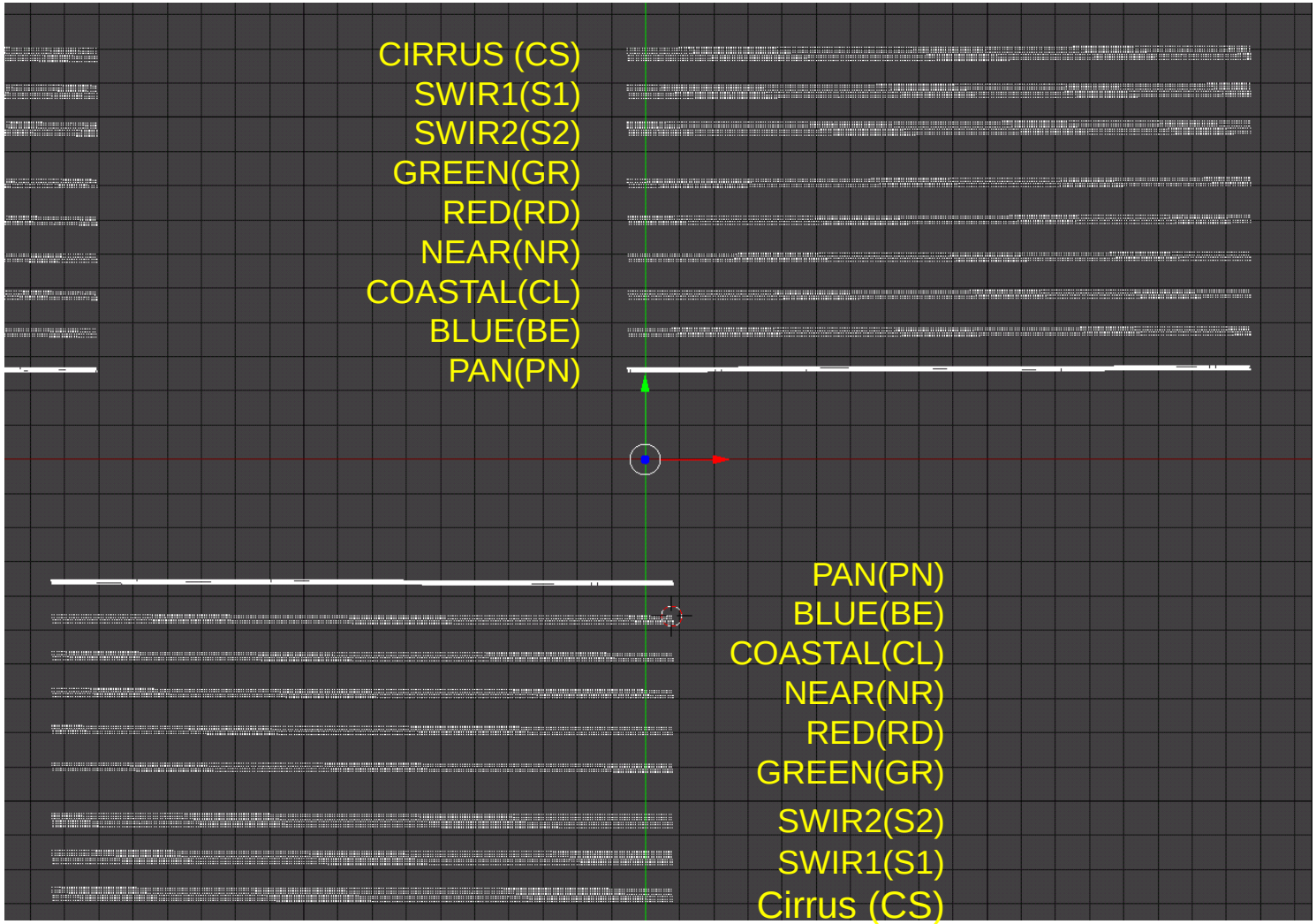


Sensor Design 14 FPA

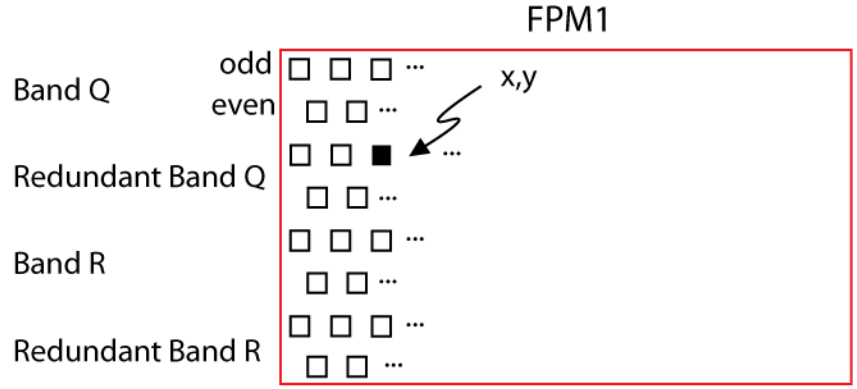
Blue Array Pixels Arrangement 36 um detectors, 72 um pitch (xy)

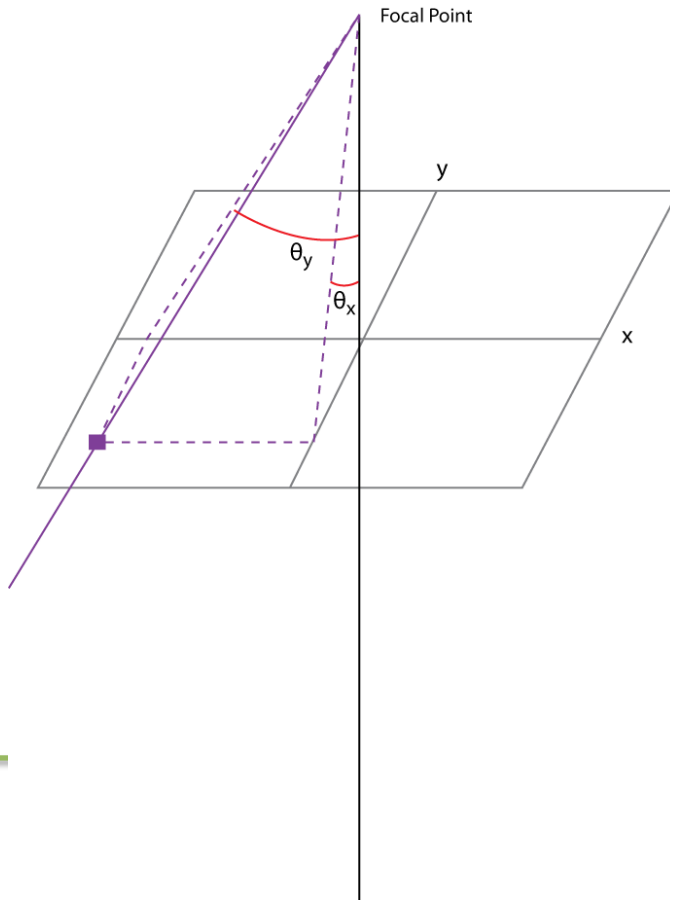


Layout of Bands



Pixel locations are designated by angle pairs accessed by a user controlled look-up-table



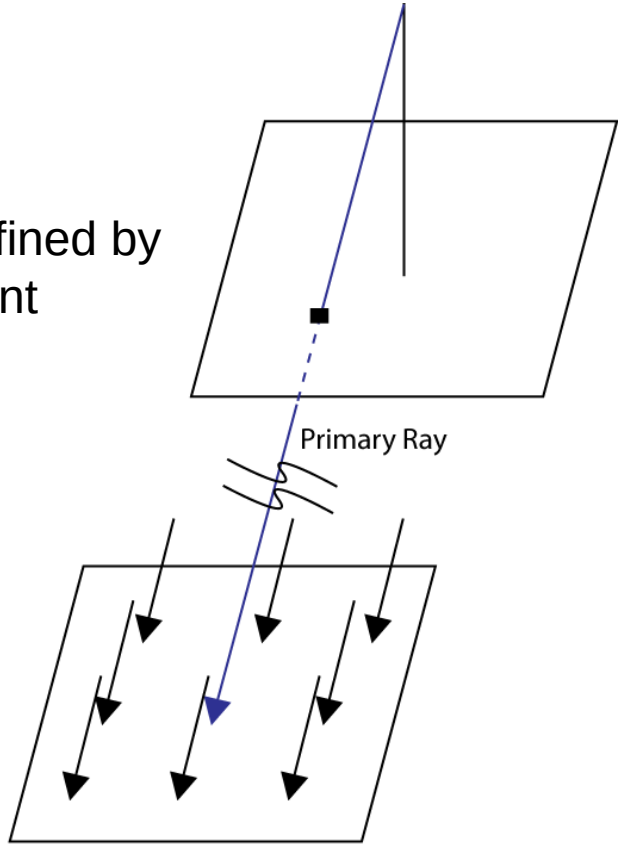


Focal Plane Module	Band	Primary/ Redundant	Odd/Even	Detector
1	1	Primary	Odd	1
1	1	Redundant	Even	1
1	1	Primary	Odd	2

Look Up Table

Designator	θ_x	θ_y
11P01	0.0071	0.0072
11P02	0.0076	0.0076
11P03	0.0072	0.0074

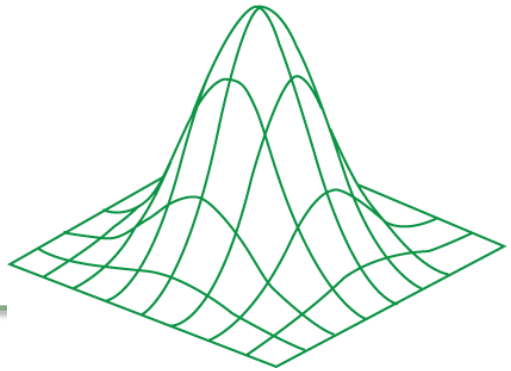
Primary ray defined by detector element angle-angle designation



User defined level of oversampling about primary ray

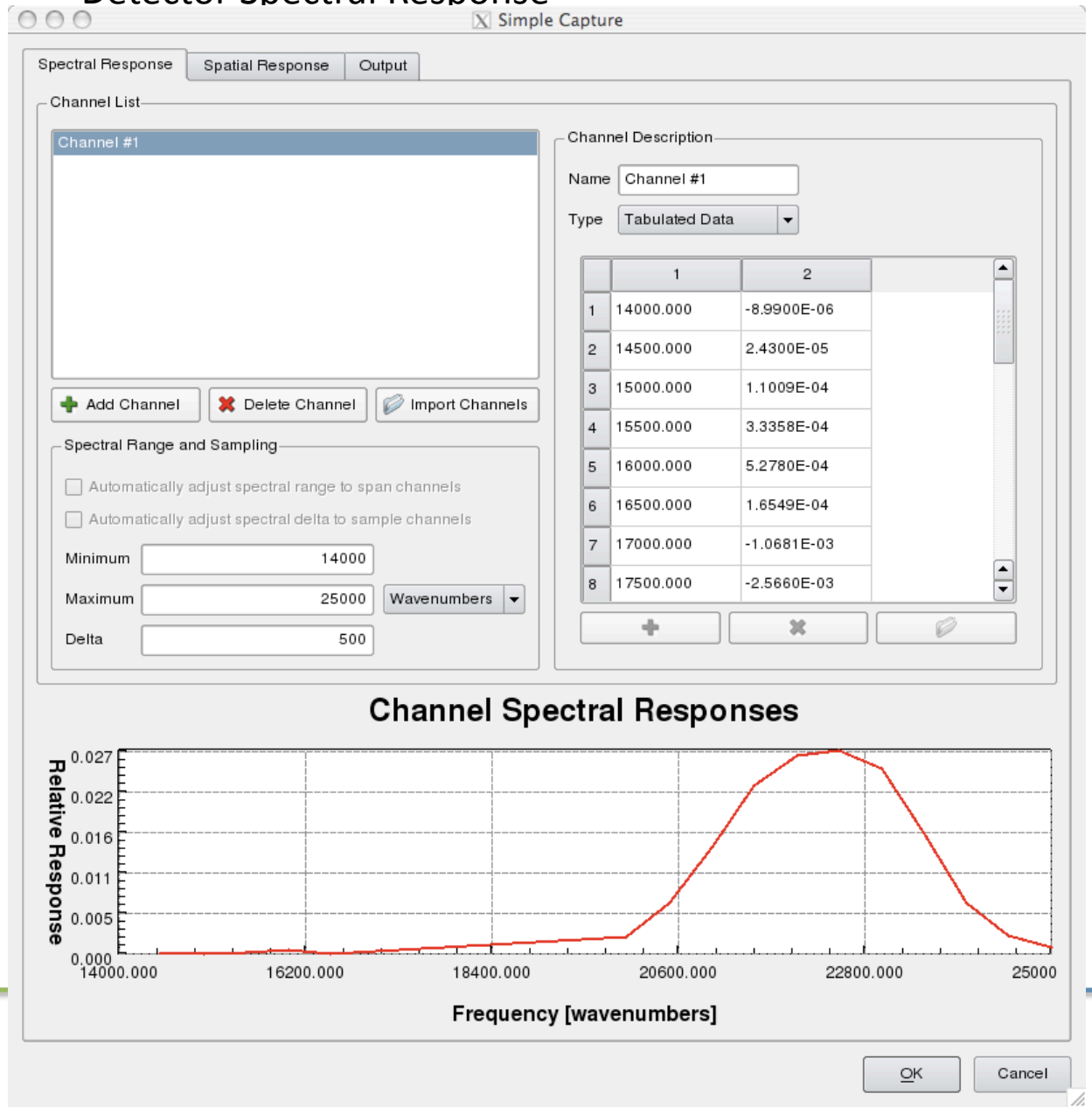
*

Convolution of oversampled radiance values with band specific or focal plane array specific instrument PSF



Sensor Design

Detector Spectral Response



Landsat Scene Model in DIRSIG

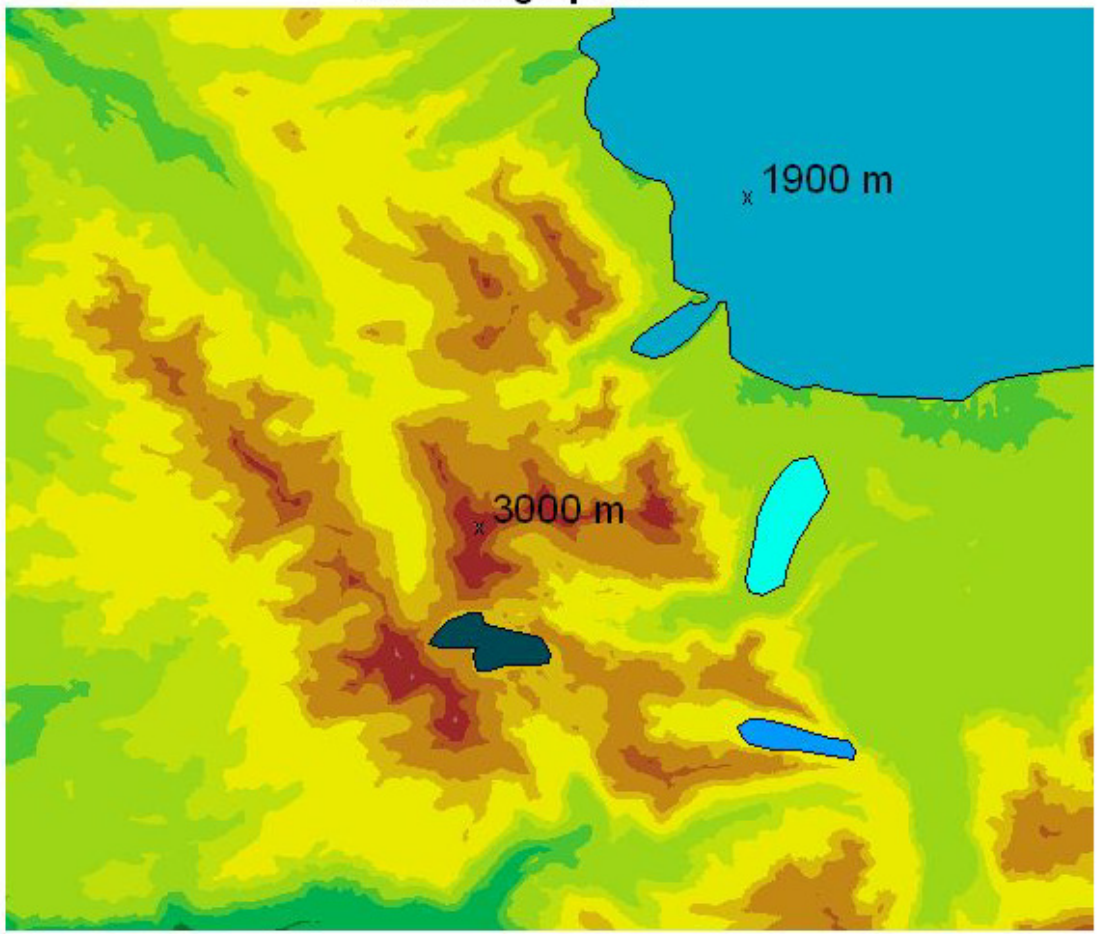
Quickbird 4 band MSI

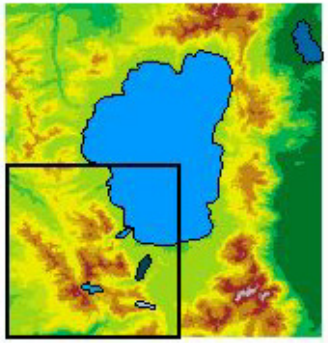
Sensor: Tahoe Area
AcqDate: Jun 28, 2007 Sensor: QB02
Format: NITF
Geo-spatial:Geographic WGS84

QB Dimensions: 17km x 47km
compared to 30m pixel * 500 detectors = 15km
GSD=3m.(current texture maps=6m.).

Lake Tahoe Area Elevation [meters]

National Elevation Dataset (NED) 1/3 Arc Second
X Ycell size ~10 meters or 0.00009 Degrees
NAD Geographic





Waterbodies
- Fallen Leaf Lake
- Lake Aloha
- Lake Tahoe
- Lower Echo Lake

Elevation [meters]
- 1400 - 1500
- 1500 - 1600
- 1600 - 1700
- 1700 - 1800
- 1800 - 1900
- 1900 - 2000
- 2000 - 2100
- 2100 - 2200
- 2200 - 2300
- 2300 - 2400
- 2400 - 2500
- 2500 - 2600
- 2600 - 2700
- 2700 - 2800
- 2800 - 2900
- 2900 - 3000
- 3000 - 3100
- 3100 - 3200
- 3200 - 3300
- 3300 - 3400
- No Data

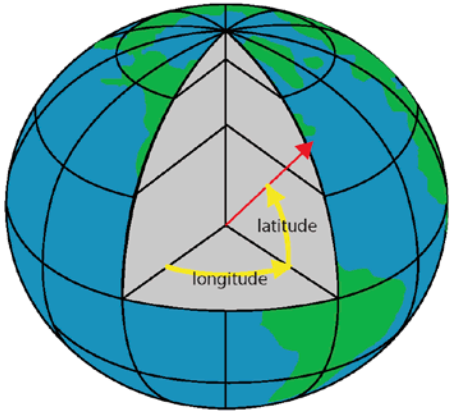
10 0 10 Miles

N W E S

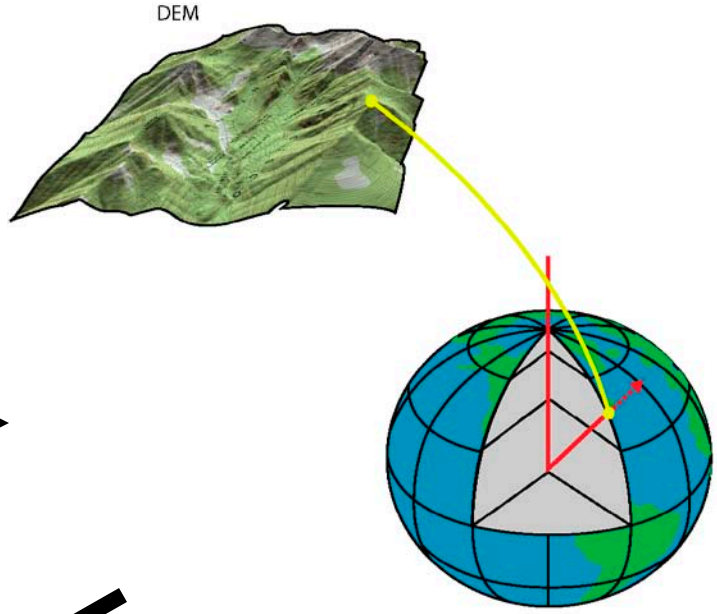
DIRS Digital Imaging and Remote Sensing Lab

R·I·T

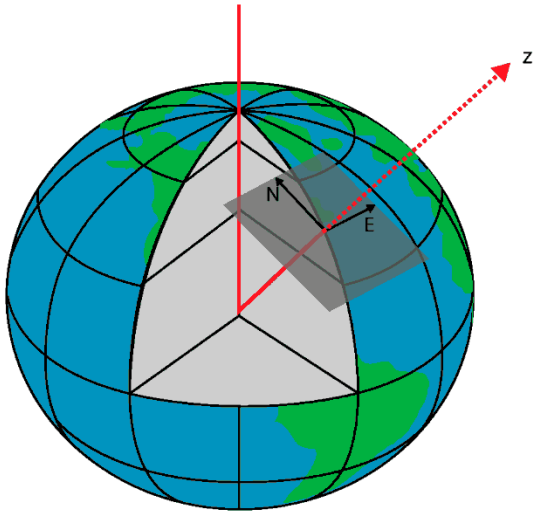
IMAGING SCIENCE



Angle, angle, distance describes any point on the surface.



DEM is height above or below WGS 84.



DIRSIG NATIVE Format is Euclidian with x,y plane tangent to Earth.

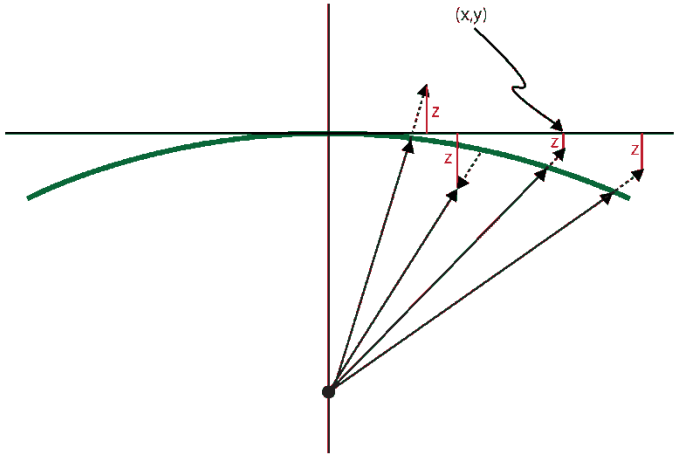


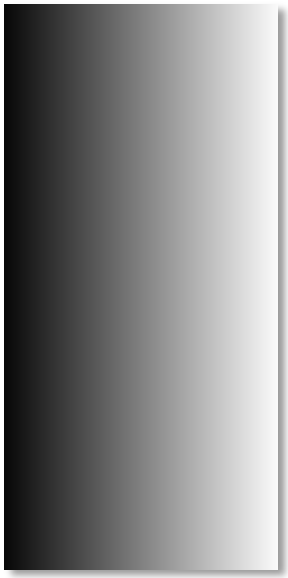
Illustration of how angle, angle, distance (DEM) is converted to NATIVE DIRSIG geometry.

http://www.cis.rit.edu/~mgg3357/ldcm/movie.mpg

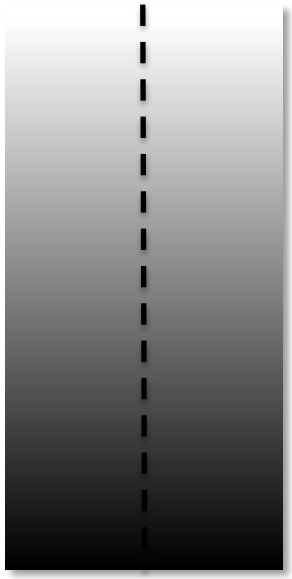
Geometry Verification: Earth Curvature

- Push DEM filled with geodetic height values of 0.0 through TIN processing chain
- Render flat DEM in DIRSIG ENU coordinates
- Compare resulting ENU coordinates against expected ellipsoidal earth shape

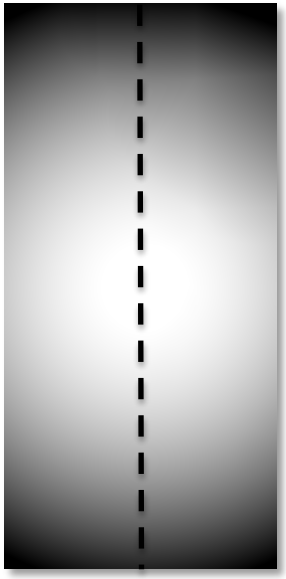
DIRSIG ENU_x truth

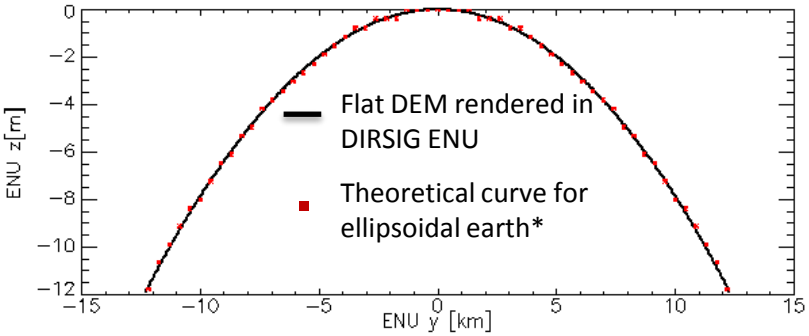


DIRSIG ENU_y truth



DIRSIG ENU_z truth

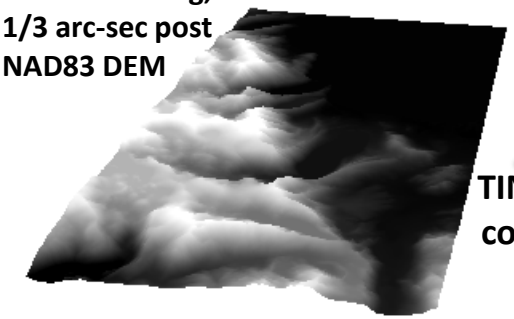




*slight quantization noise due to precision of sin and cos in IDL (i.e. z = 6378d3 * [1.0 - cos(lat – lat_{ENU_center})]

Geometry Verification: DEM Placement

0.125x0.25 deg, 1/3 arc-sec post NAD83 DEM



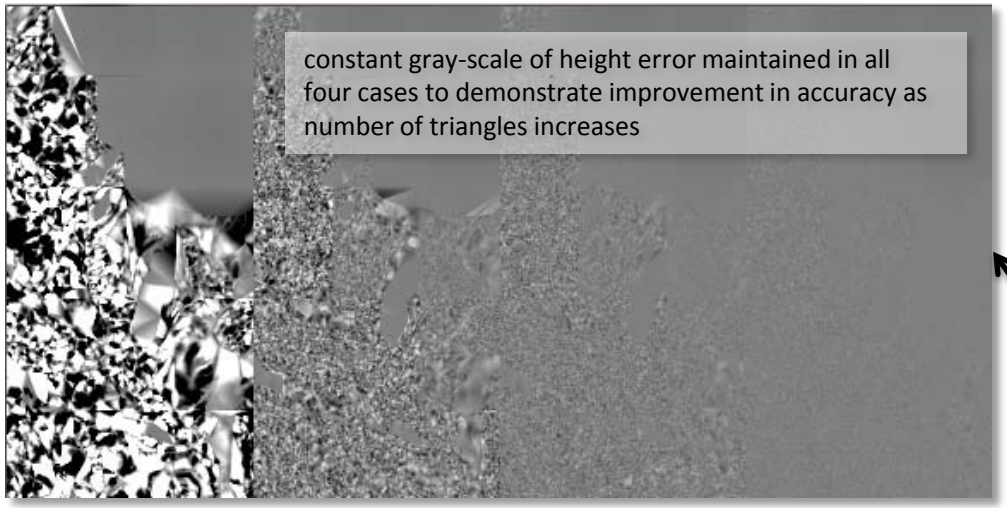
TIN in geodetic, convert to ENU

3x5 OBJ geometry tiles converted to ENU coordinates

DIRSIG simulation in ENU coordinates

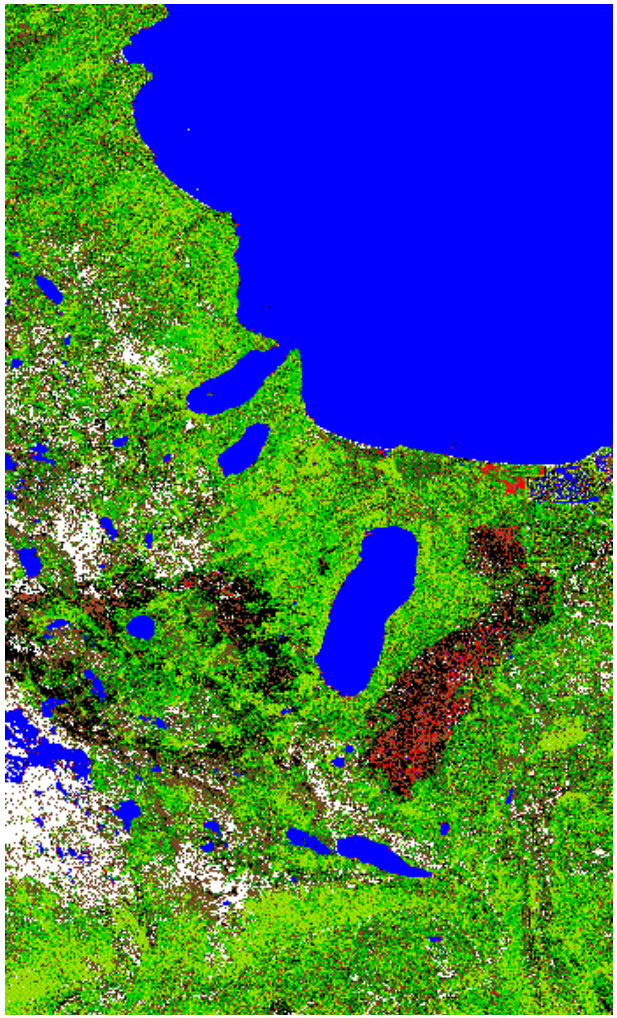
Convert DIRSIG ENU intersection truth to ECEF to geodetic coordinates

Generate map of the difference between DIRSIG intersection truth derived geodetic height to DEM

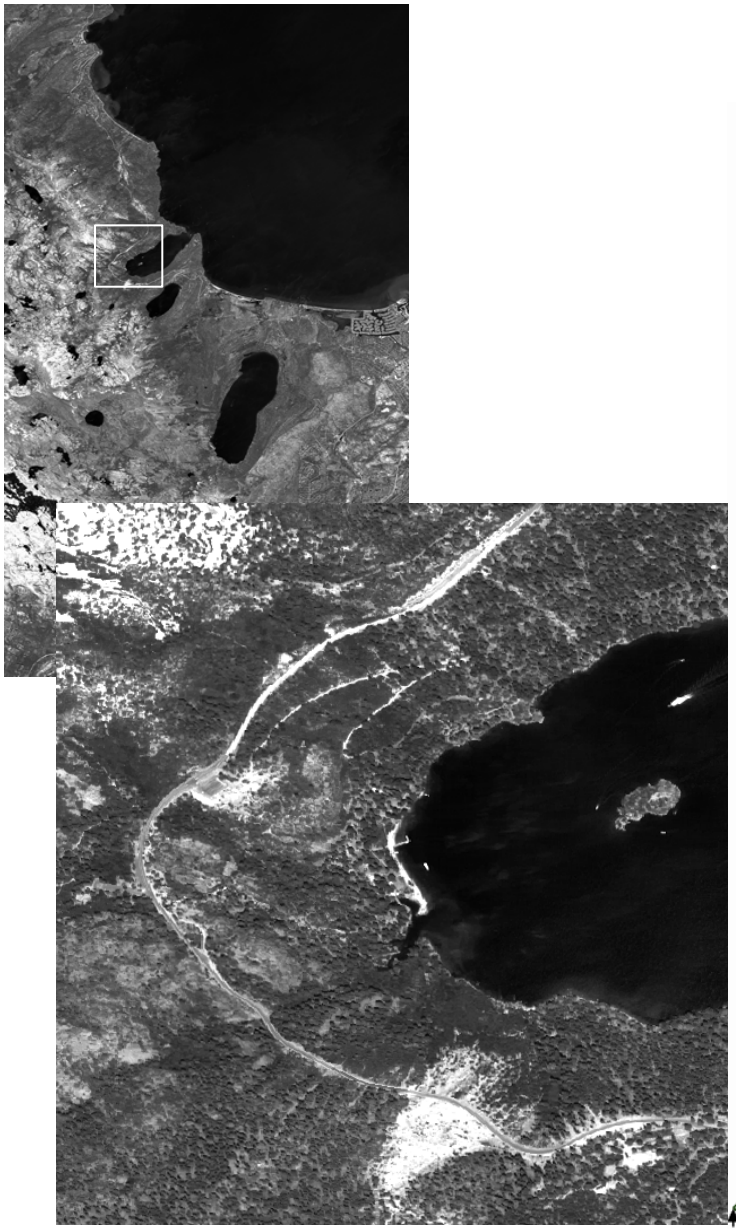


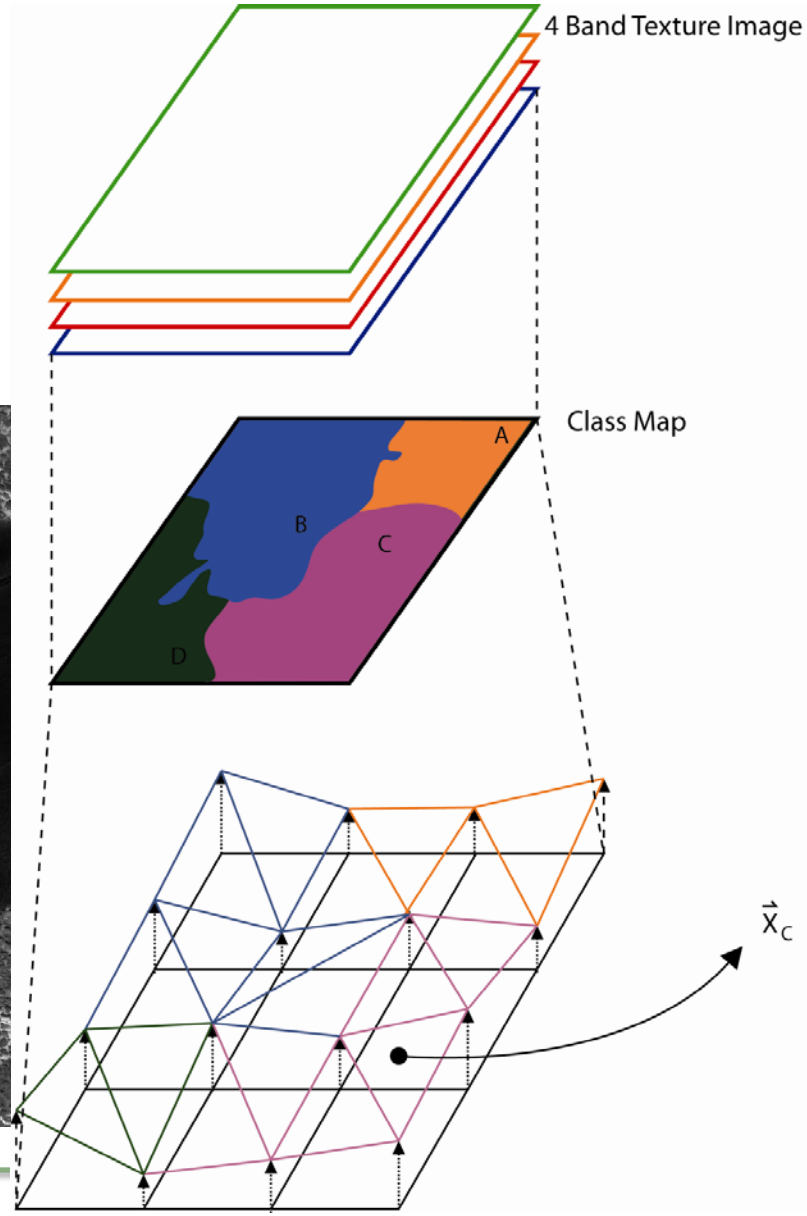
3k triangles	30k triangles	90k triangles	300k triangles
Δh_{rms}= 16.7m	Δh_{rms}= 3.1m	Δh_{rms}= 1.4m	Δh_{rms}= 0.6m
run time = 24s	run time = 28s	run time = 31s	run time = 36s

Quickbird Classification
9 classes



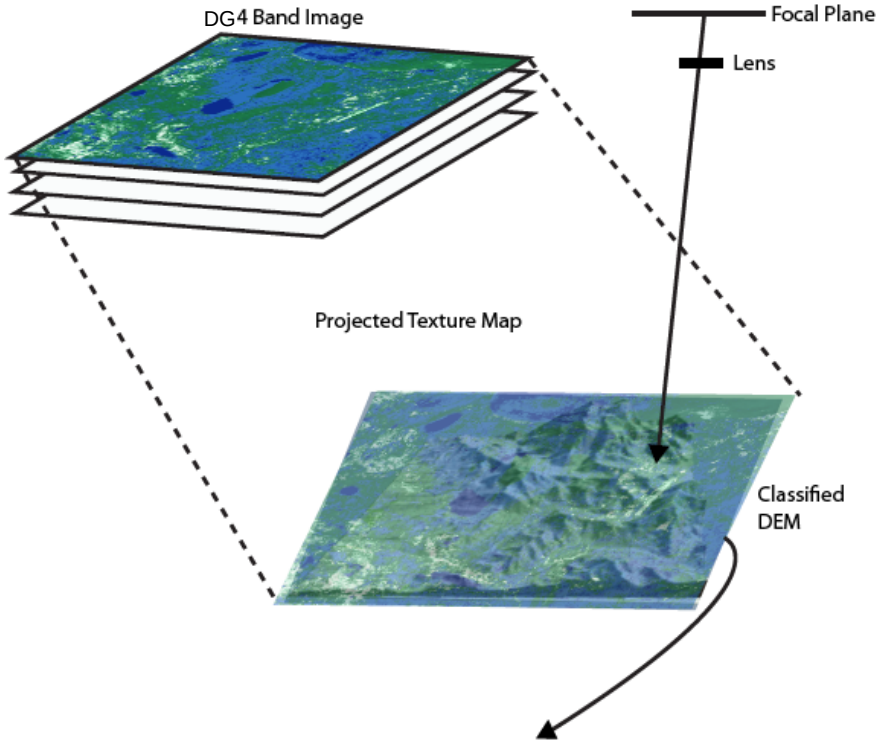
Class ID	Class Item	Colormap
Class 1	Water	blue
Class 3	Wetland/Water Fringe	red
Class 4	soil	sienna
Class 5	rock	black
Class 6	veg1	dark green
Class 7	veg2	bright green
Class 8	veg3	yellow green
Class 9	soil/rock	dark brown
Class 10	rock	white

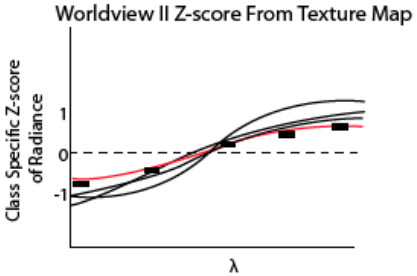


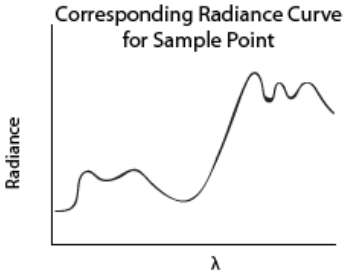


$$\vec{X}_C = \begin{bmatrix} X_{C1} \\ X_{C2} \\ X_{C3} \\ X_{C4} \end{bmatrix} \Rightarrow \vec{Z}_C \begin{bmatrix} Z_{C1} \\ Z_{C2} \\ Z_{C3} \\ Z_{C4} \end{bmatrix}$$

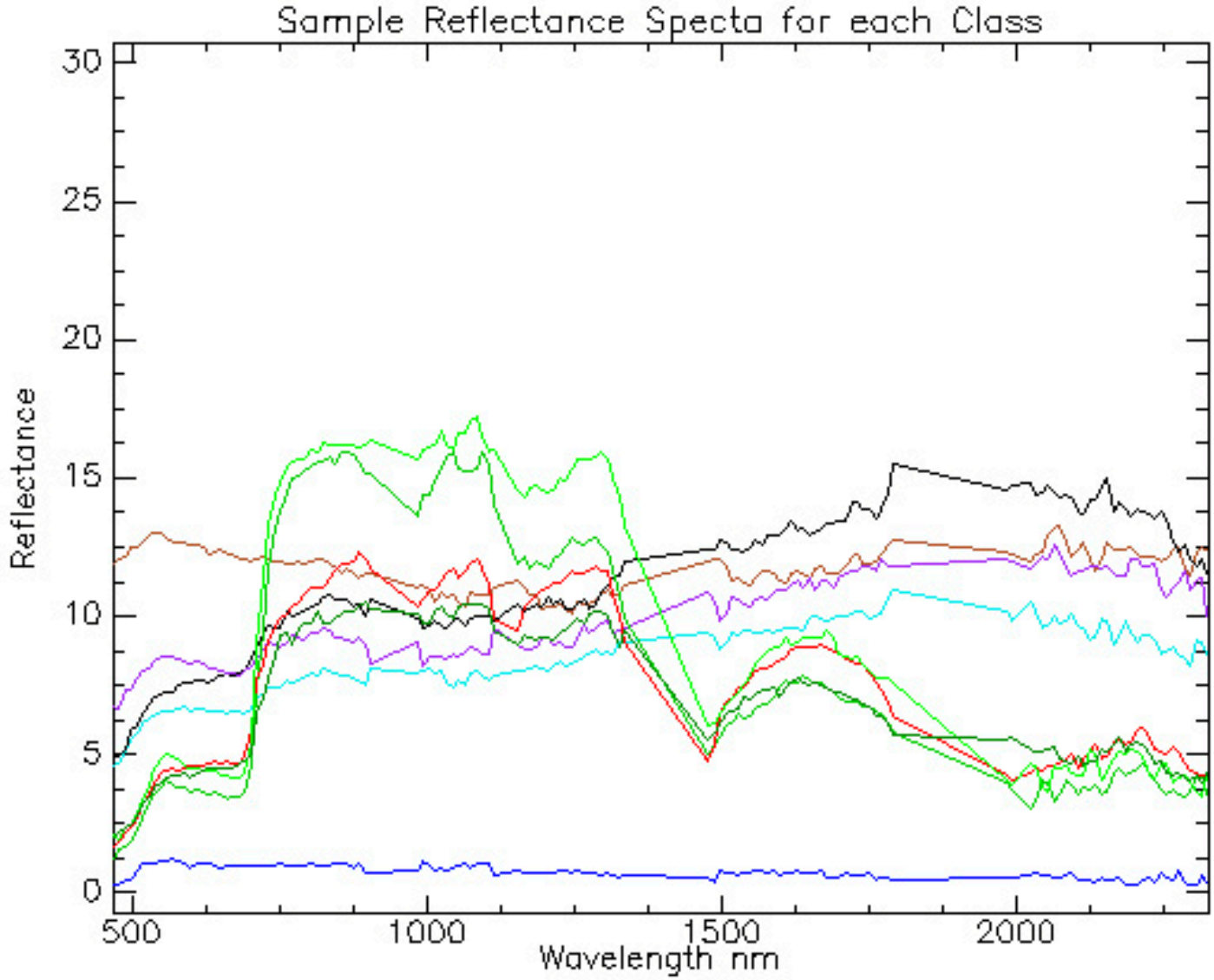
Conceptual Implementation

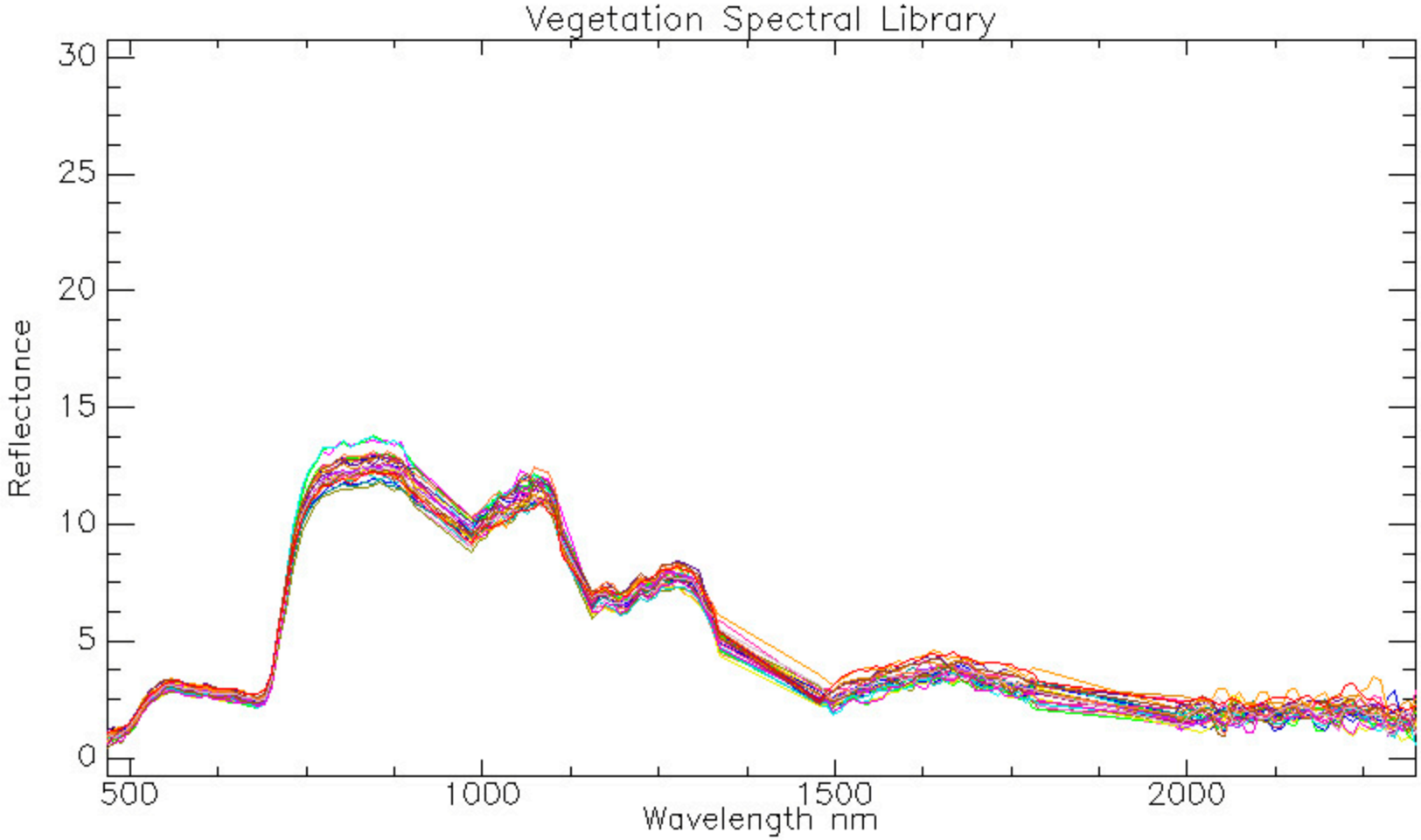




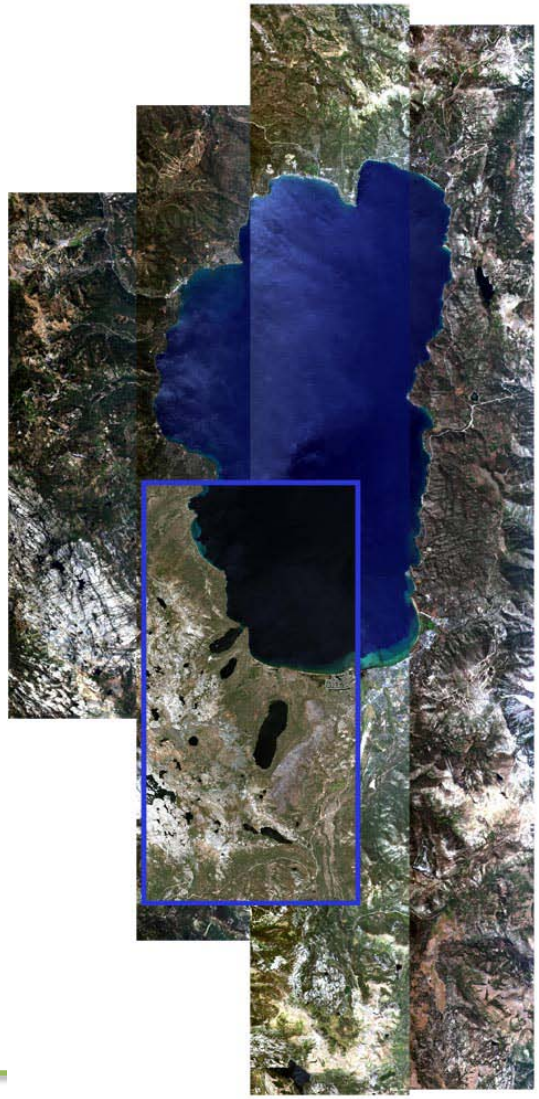


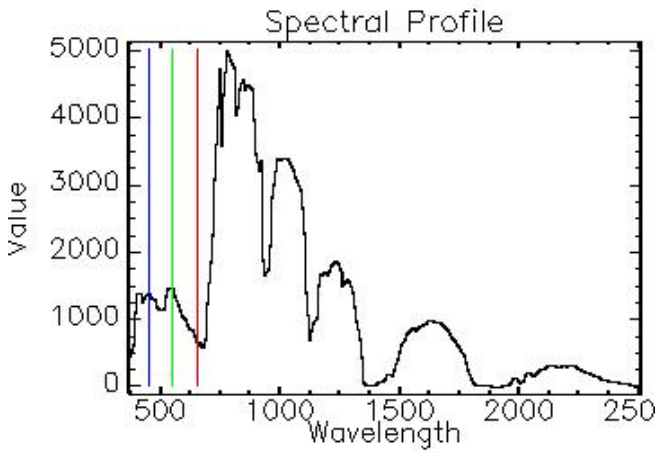
Initial Hyperion Derived Spectra




Vegetation Spectral Library
Reflectance
30
25
20
15
10
5
0
500
1000
1500
2000
Wavelength nm

AVIRIS for improved spectral content

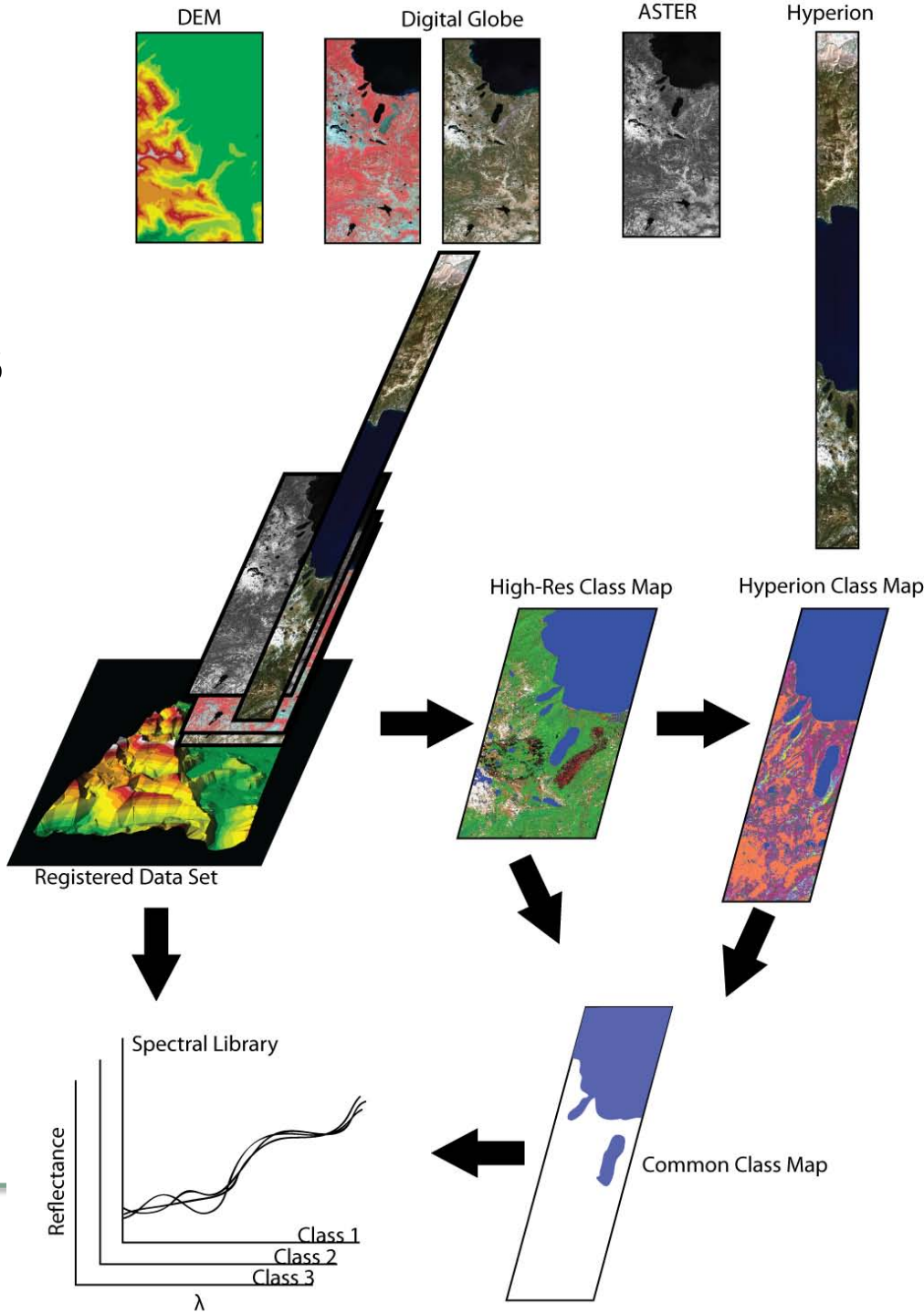


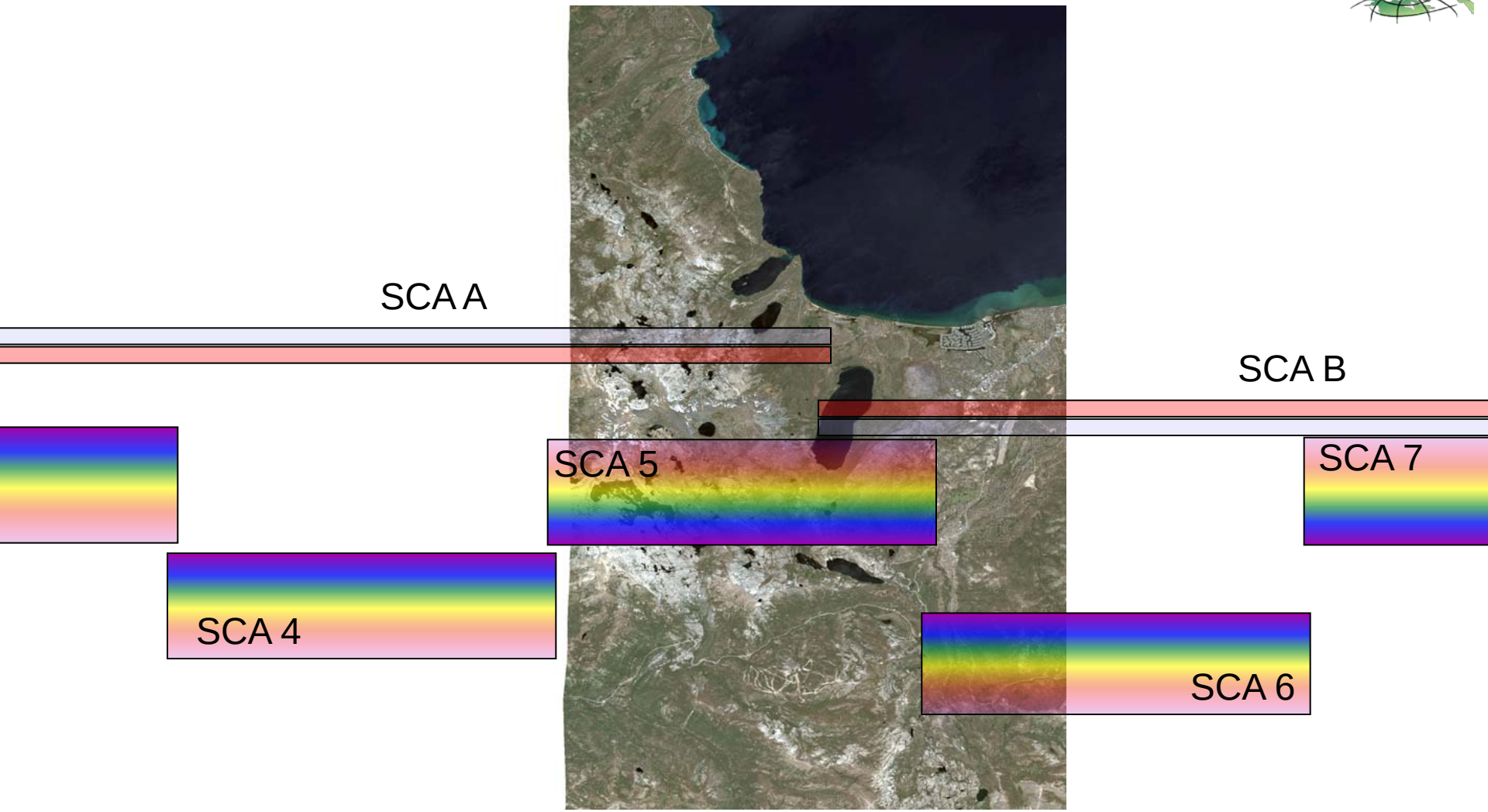


- AVIRIS Lake Tahoe Coverage
- Date: August 28, 1997
- Spectral Range: 369nm-2506nm
- Spatial Resolution: 20m

- Use fused data sets to establish a **virtual truth**
  - DEMs: scene geometry
  - Quickbird: MSI high spatial resolution Initial Landcover Class.
  - Hyperion: Spectral Resolution 196 bands-Moving to AVIRIS
  - LANDSAT thermal texture
  - ASTER emissivity map

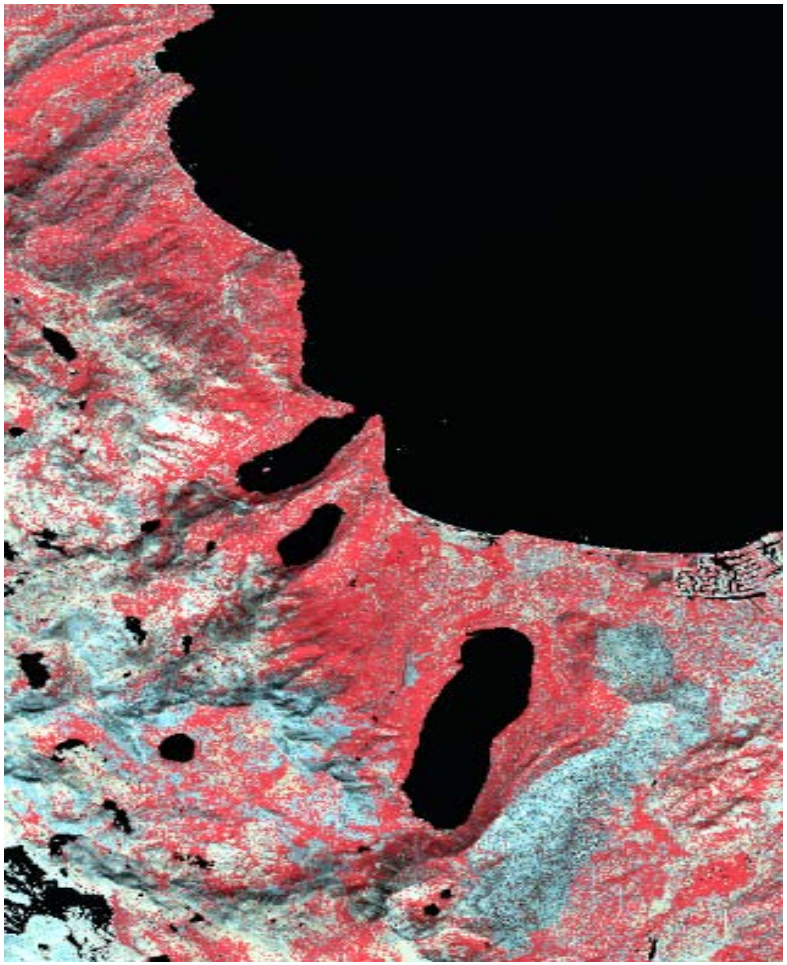
- Register QuickBird image to DEM
- Register Hyperion and ASTER to QB
- TIN DEM and format for use in DIRSIG




SCA A
SCA B
SCA 5
SCA 7
SCA 4
SCA 6

Lake Tahoe

- Used Landsat 7 TLE from July 27, 2009 to determine the orbital parameters for an OLI model.
- OLI's spectral response and modules 7 and 8 on the focal plane used in the OLI model.
- Flew for 5 seconds over the scene at 11:30 am local time.

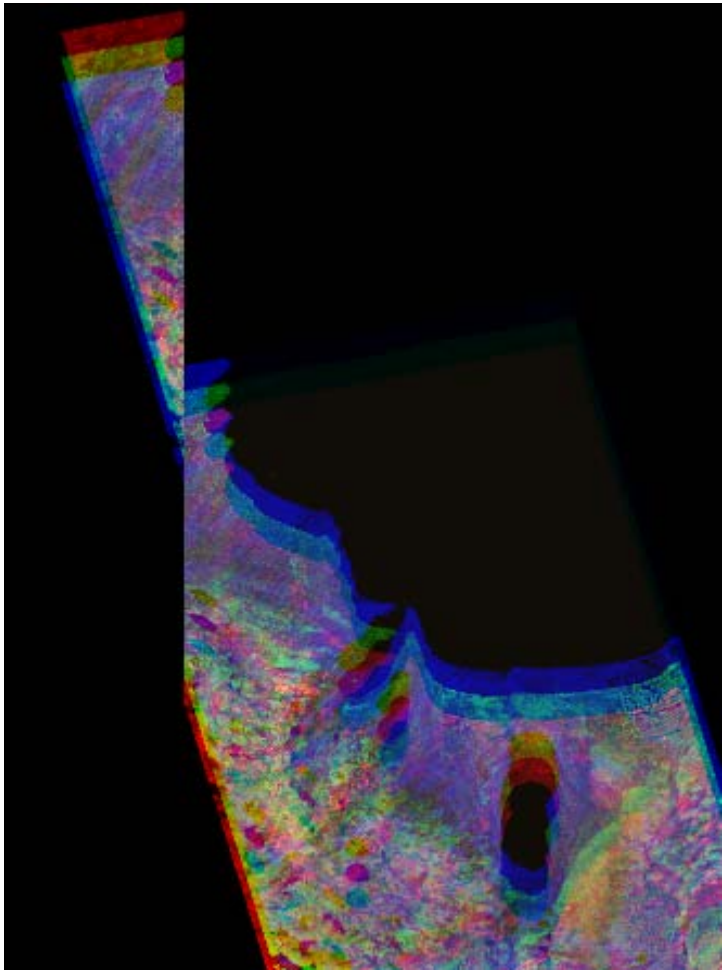


Framing Camera, False Color Image of Lake Tahoe.

- 3x3 oversampling used.

False Color Image

- Bands 3, 4, and 5 of OLI used to image Lake Tahoe.
- Offset in north-west corner due to module 7 collecting data ahead of module 8.
- 30 pixel offset between adjacent bands on focal plane.



OLI bands 3, 4, 5 used to image Lake Tahoe.

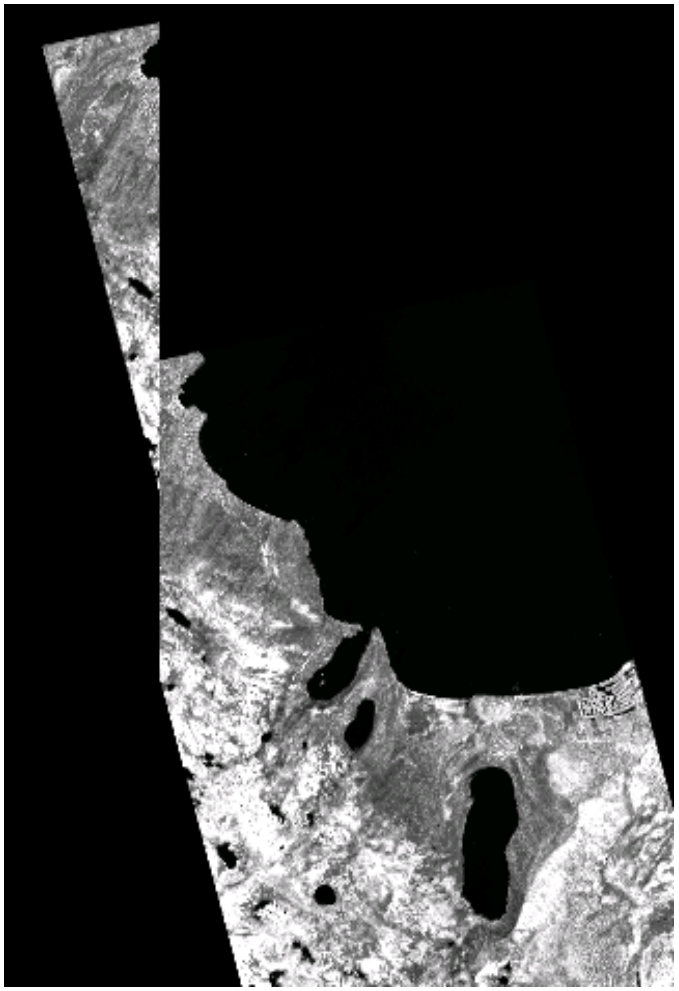
False Color Image

- Bands 3, 4, and 5 of OLI used to image Lake Tahoe.
- Offset in north-west corner due to module 7 collecting data ahead of module 8.
- 30 pixel offset between adjacent bands on focal plane.
- Performed simple shift of data to obtain a false color image.

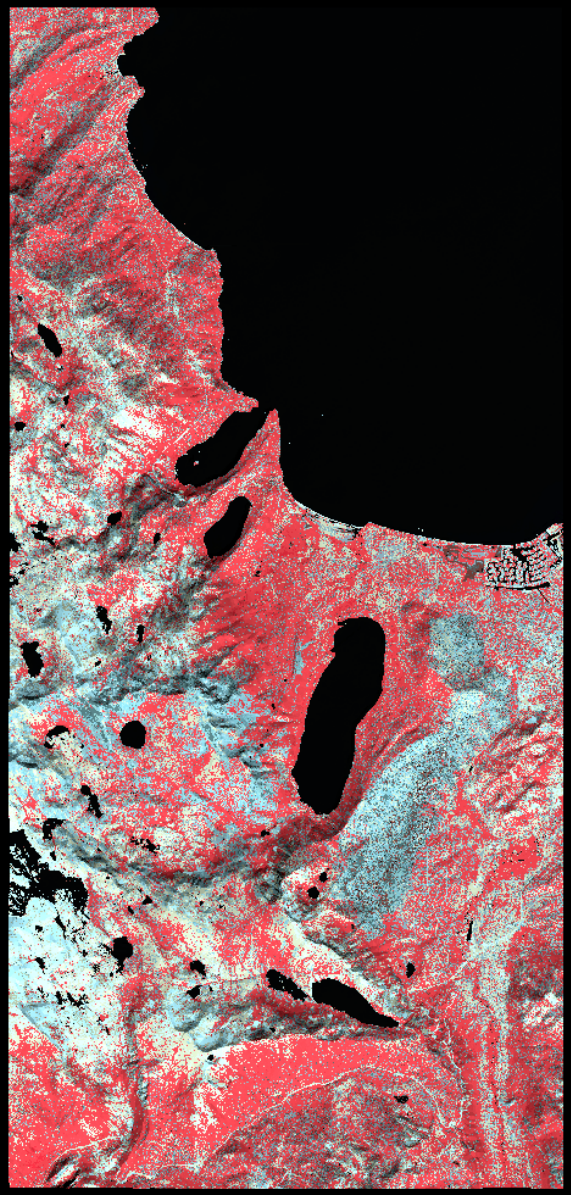
OLI bands 3, 4, 5 used to image Lake Tahoe.

OLI Green Band

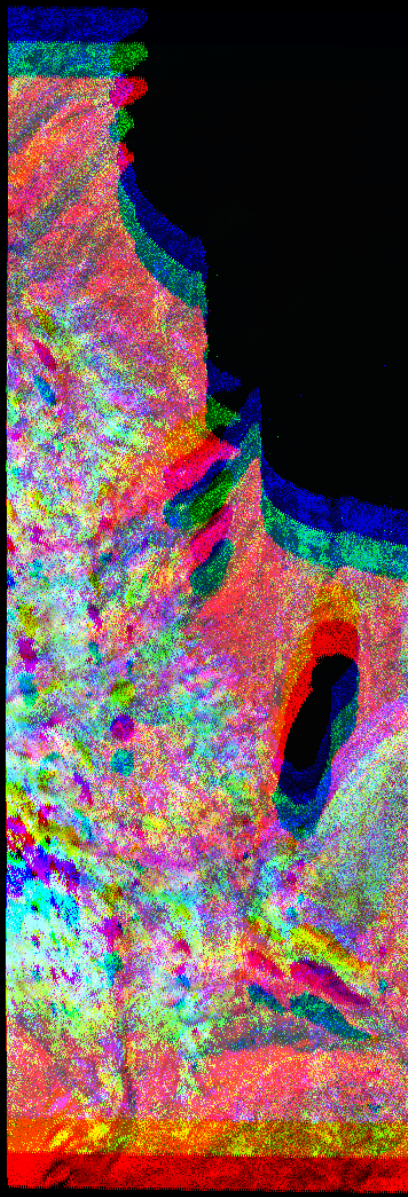
OLI Red Band



OLI NIR Band

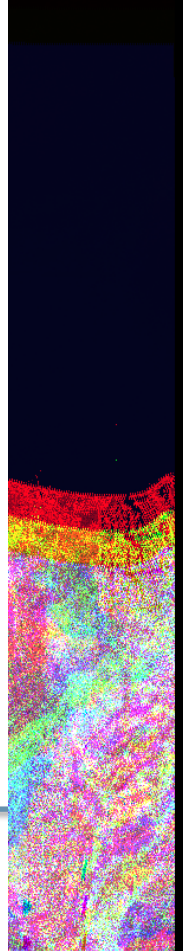


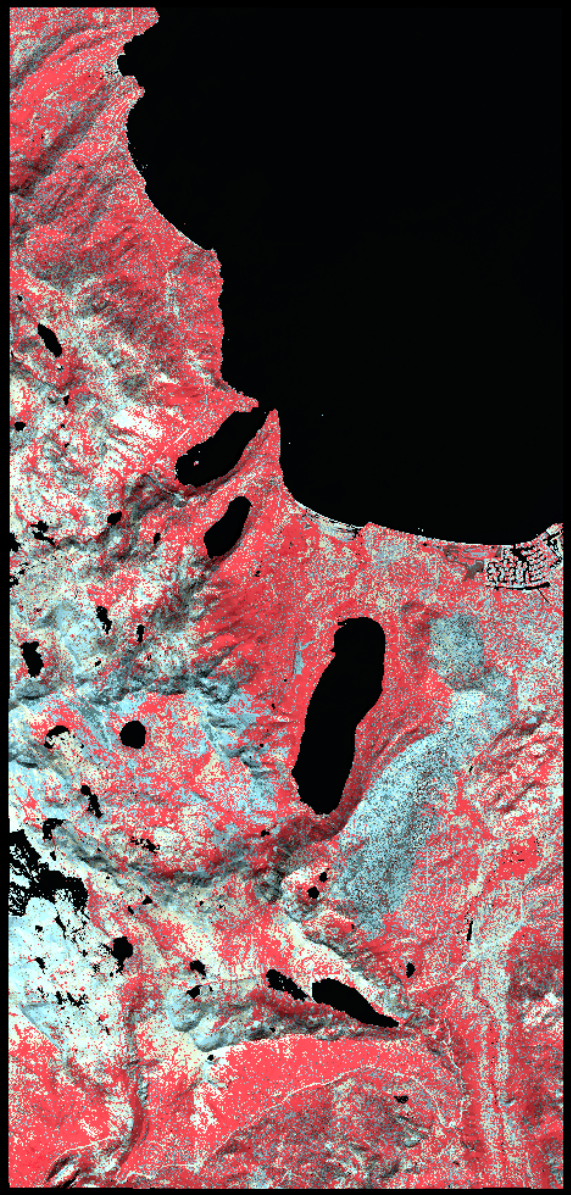
Frame CIR



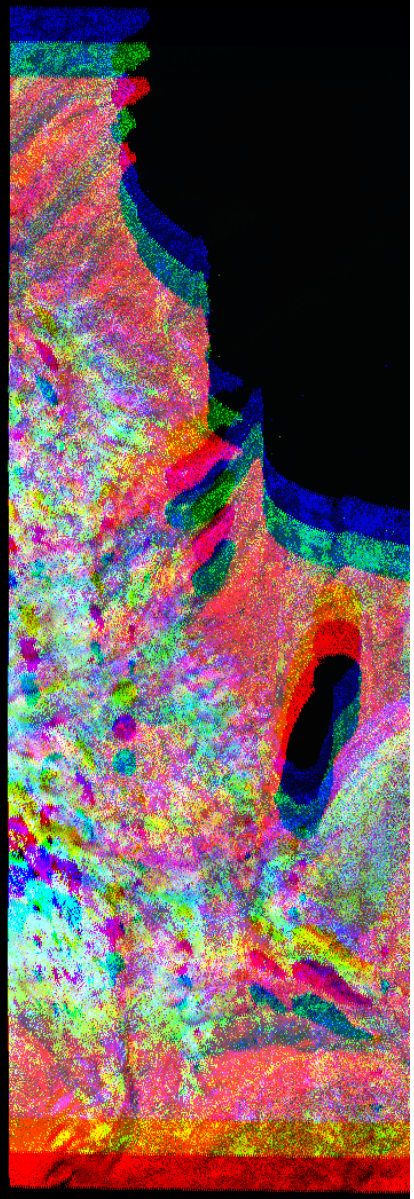
SCA 05

SCA 06

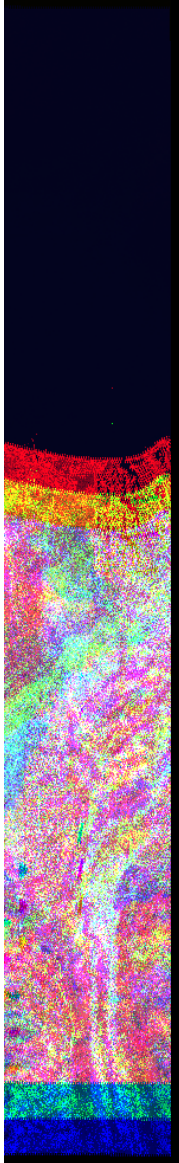




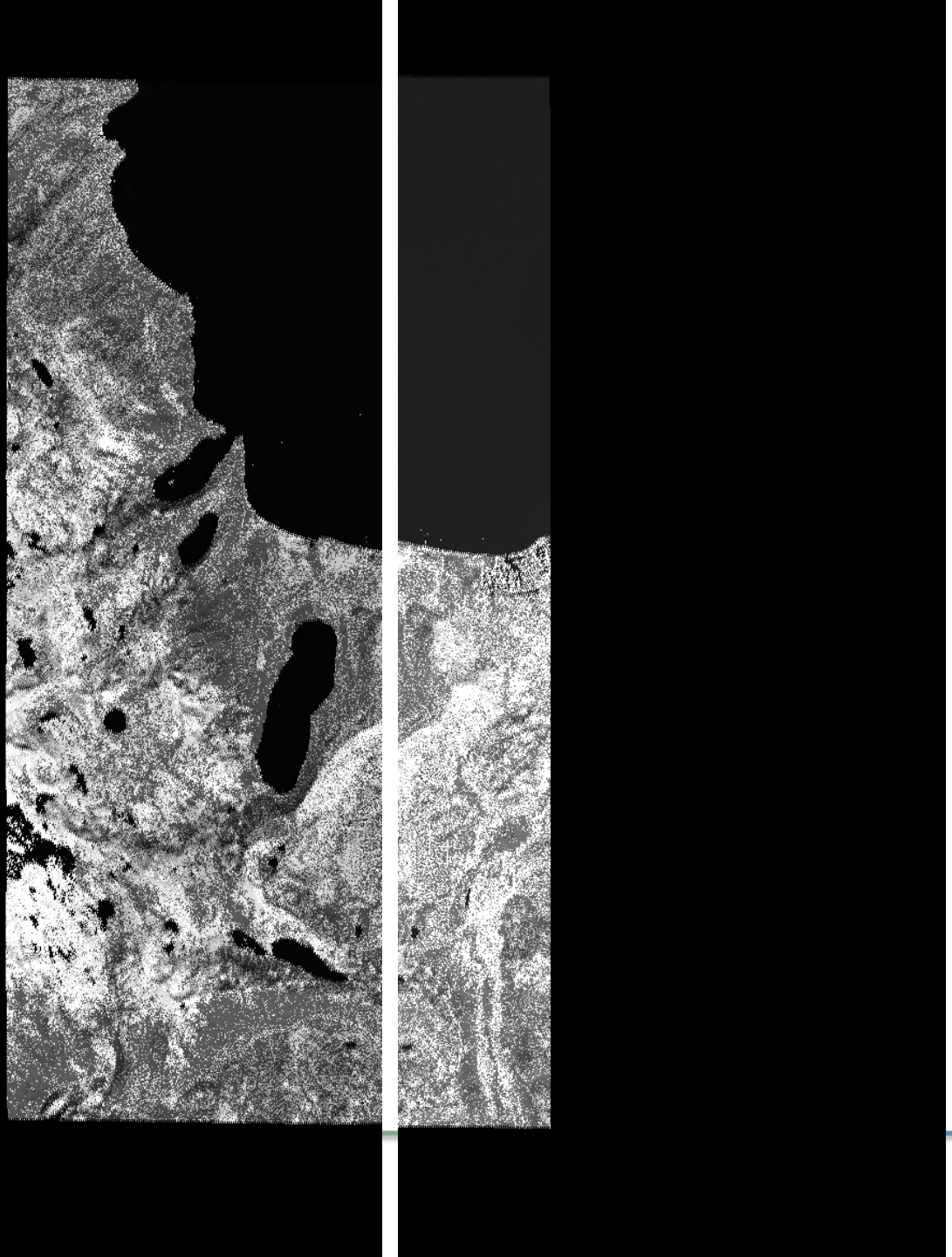
Frame CIR



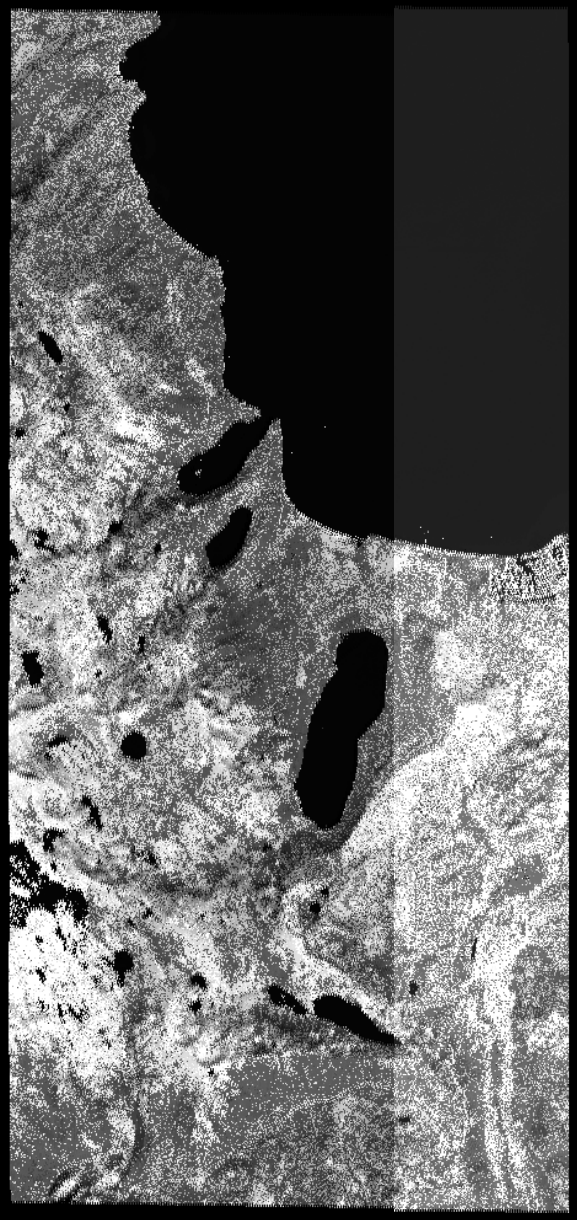
SCA 05



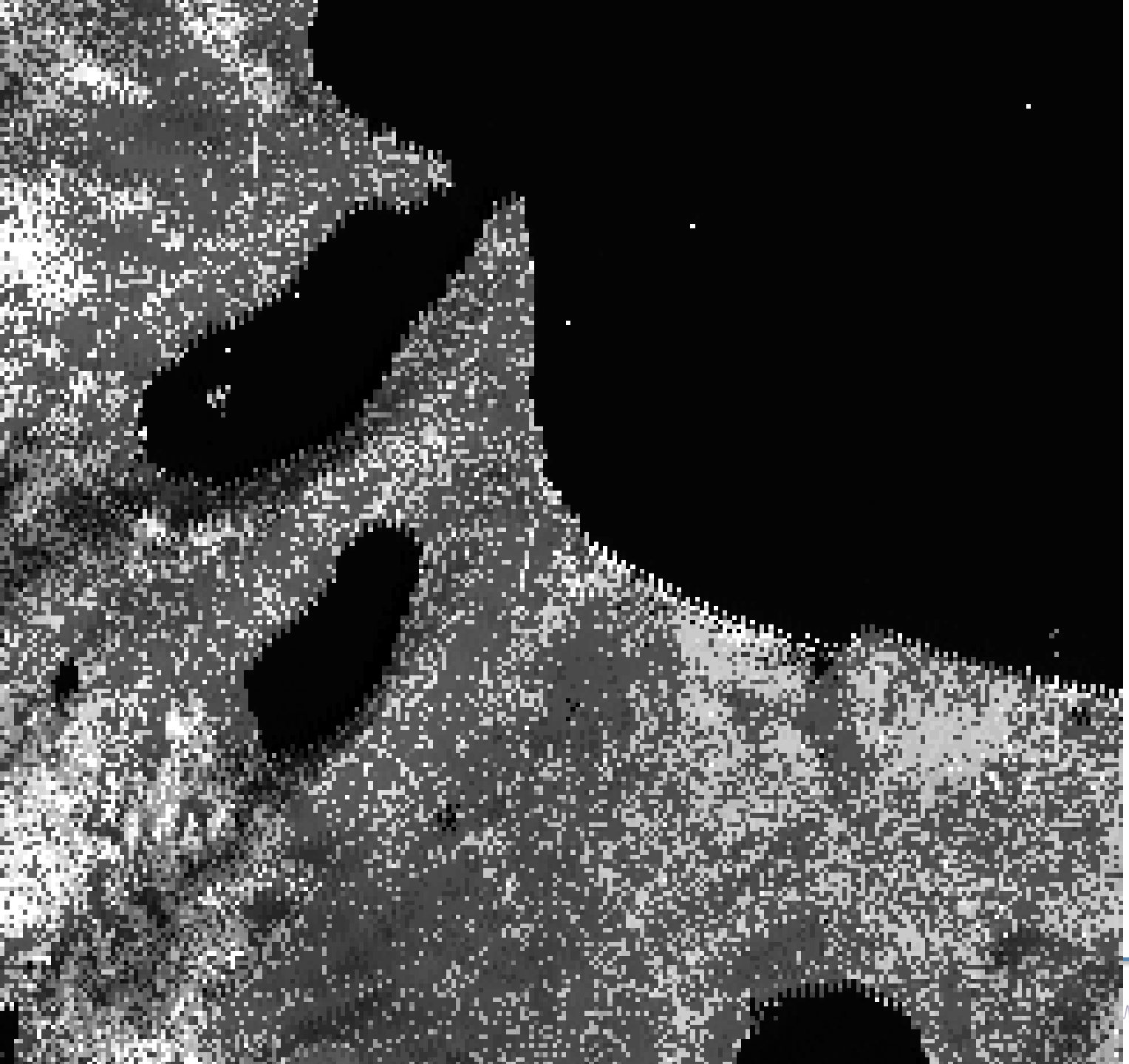
SCA 06



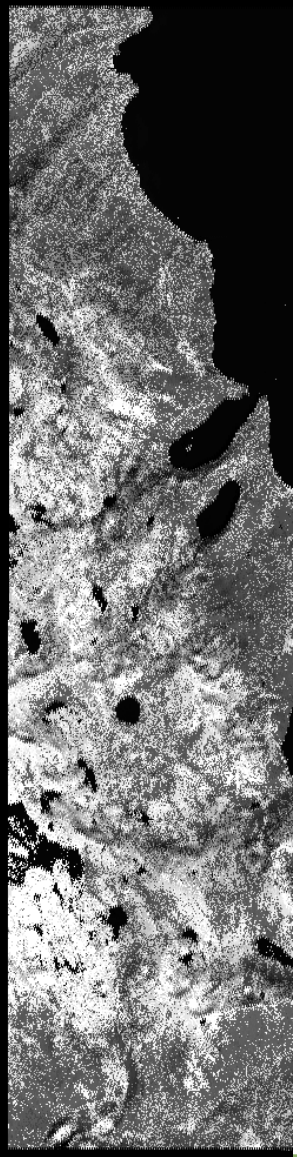
SCA 05 &06
Green



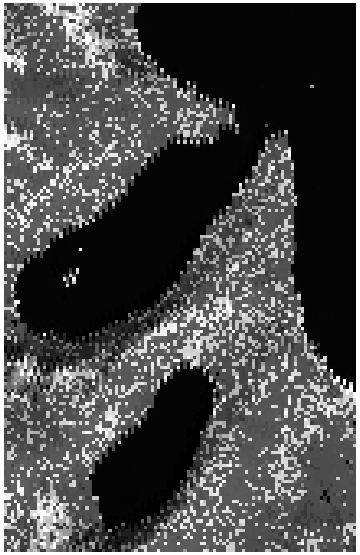
SCA 05 &06
Green

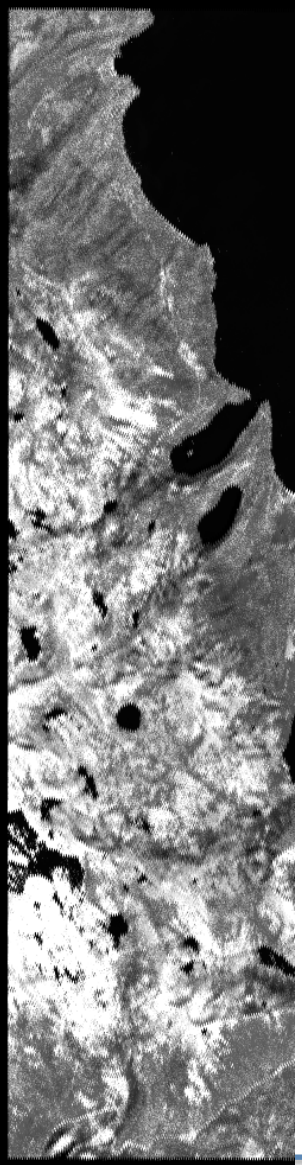


SCA 05
Green zoom

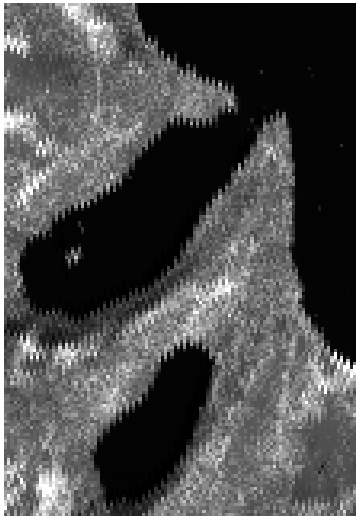


Green band delta function sampling





Green band three by three oversampling



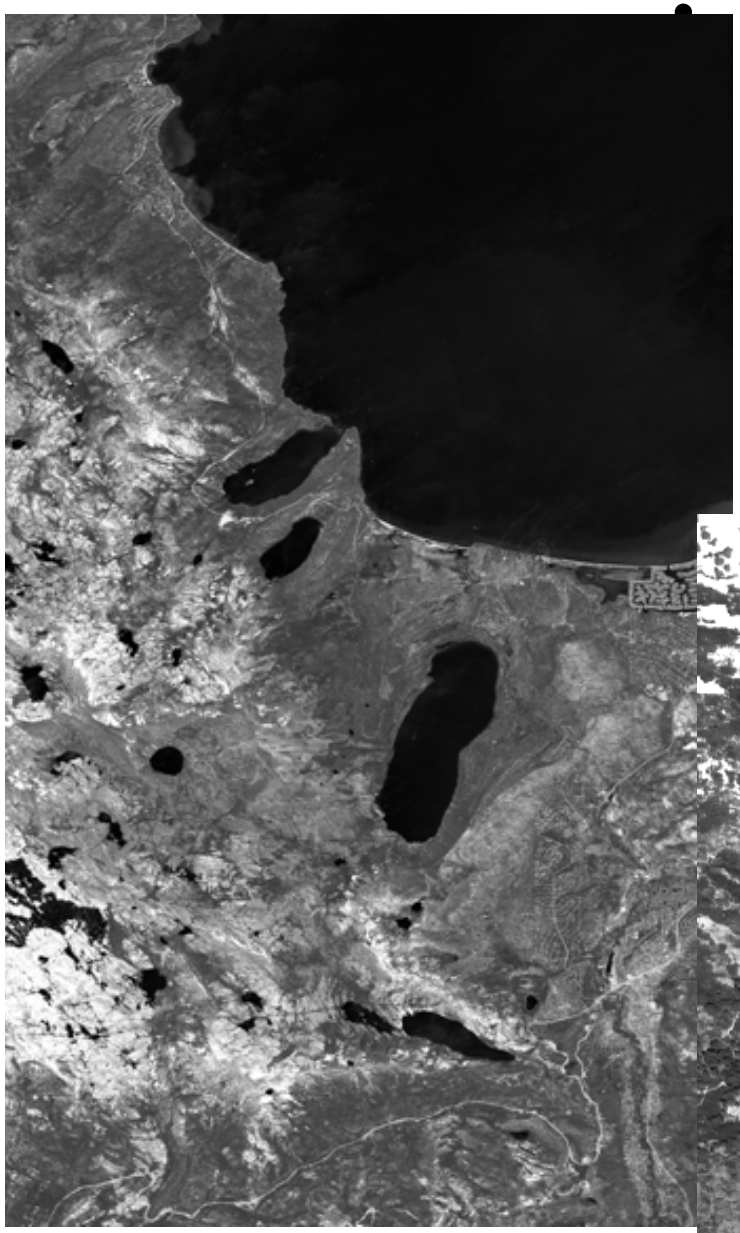
Status: About to release first images to USGS for initial geometric analysis.

Shifting emphasis to TIRS and other scene (eg. Clouds) and sensor (eg. Noise , Jitter , Spectral Response Variation…)characteristics.

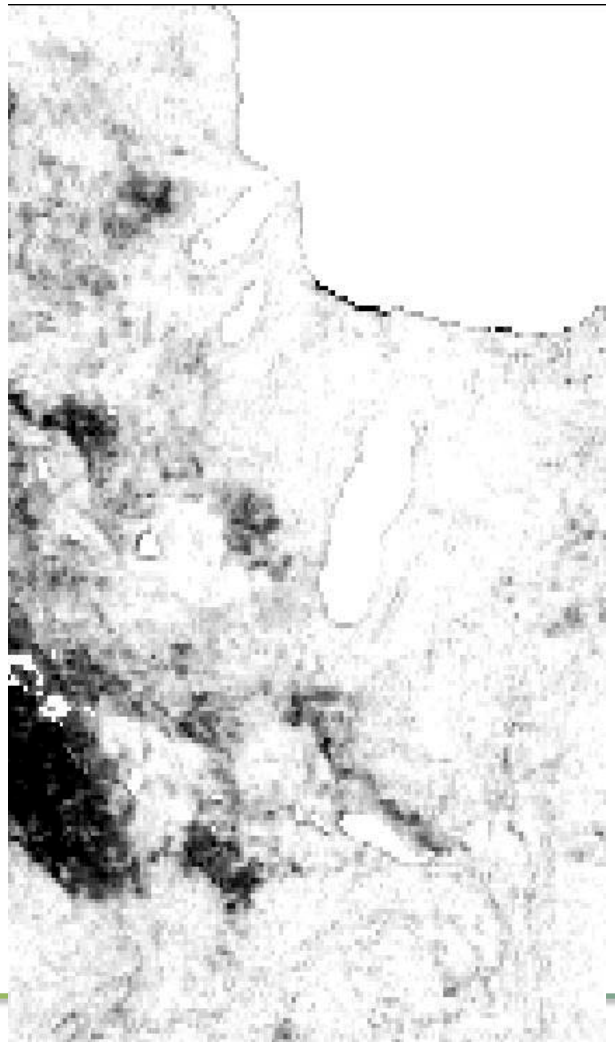
Questions?

- 3meter texture map produced from Quickbird2 scene from Jun 28, 2007

Average of RGB bands

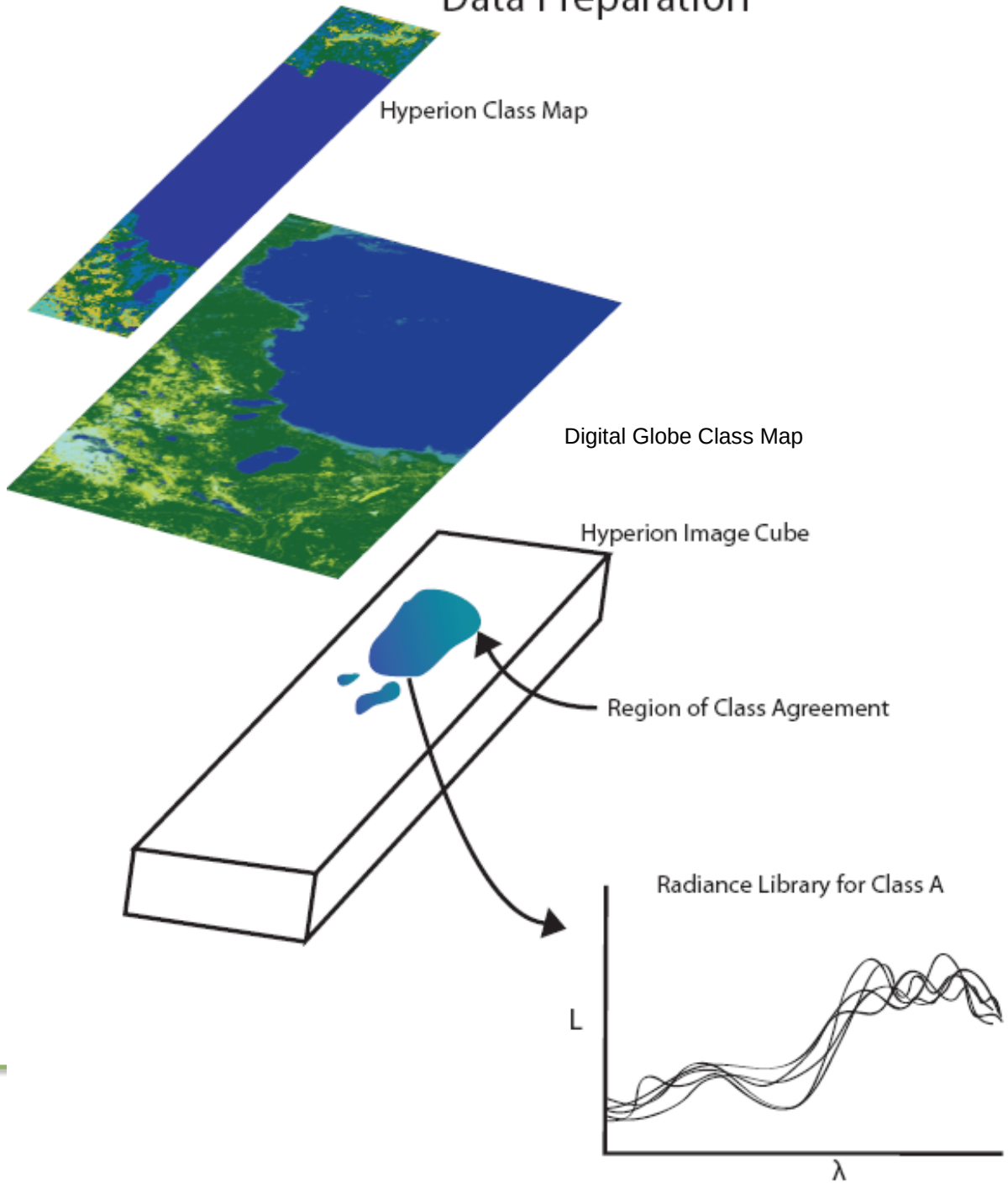


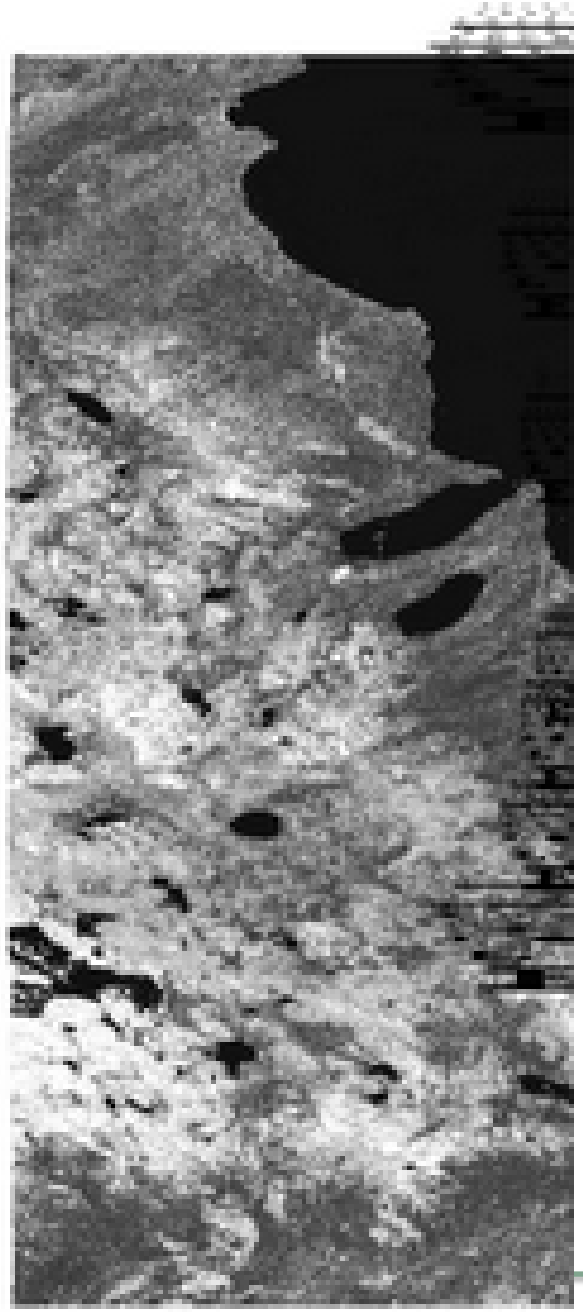
ASTER NAALSED for surface emissivity



Band 10 8.3
Band 11 8.6
Band 12 9.1
Band 13 10.6
Band 14 11.3

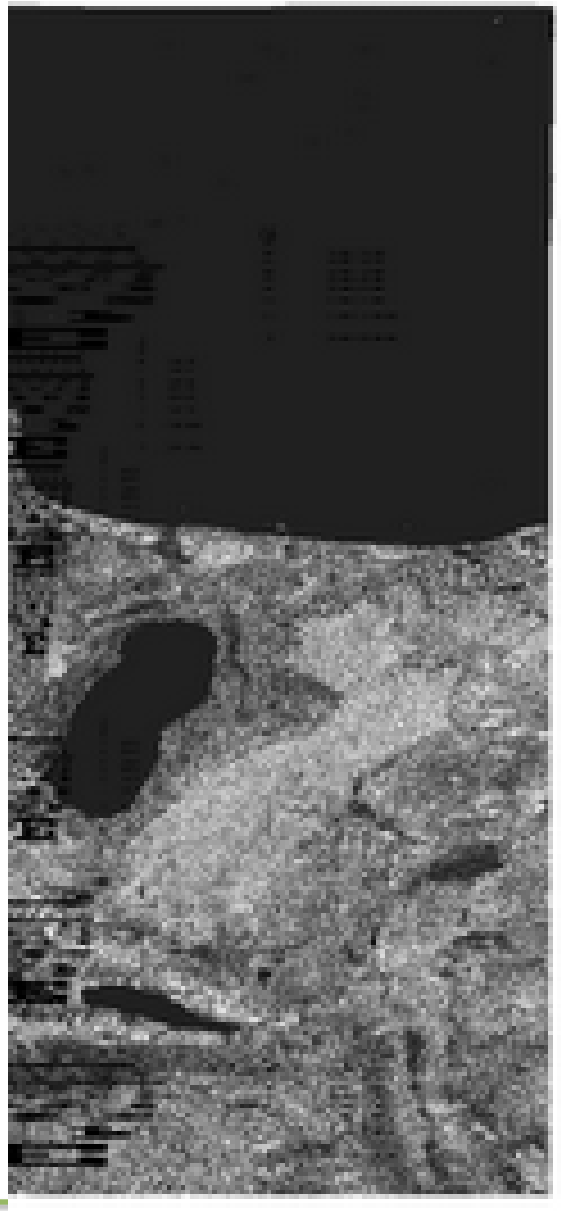
Data Preparation





Test Image
Focal Plane 07 red
Odd-even interleaved
Grid detectors
One spectrum per class

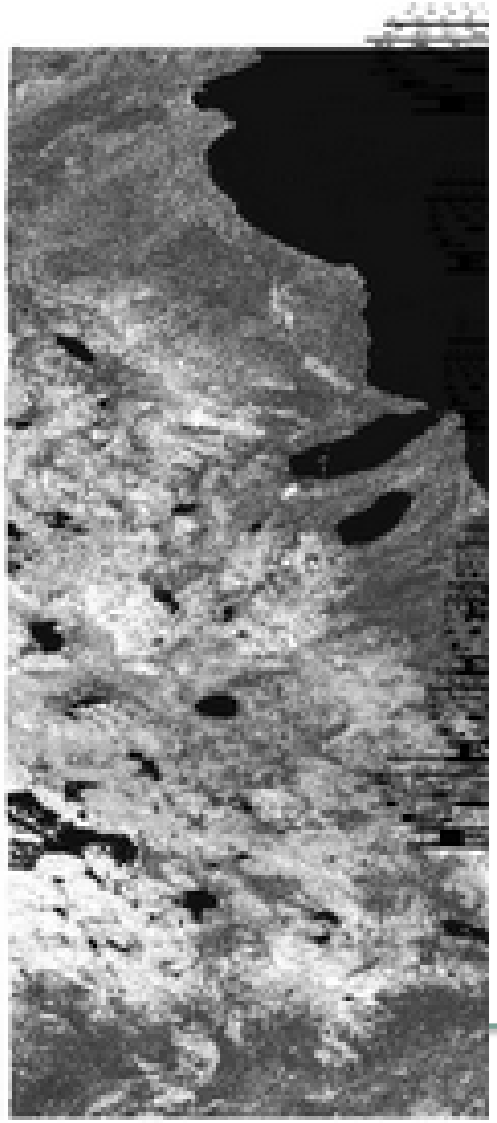
Snellen eye chart flooting
Over image at various heights

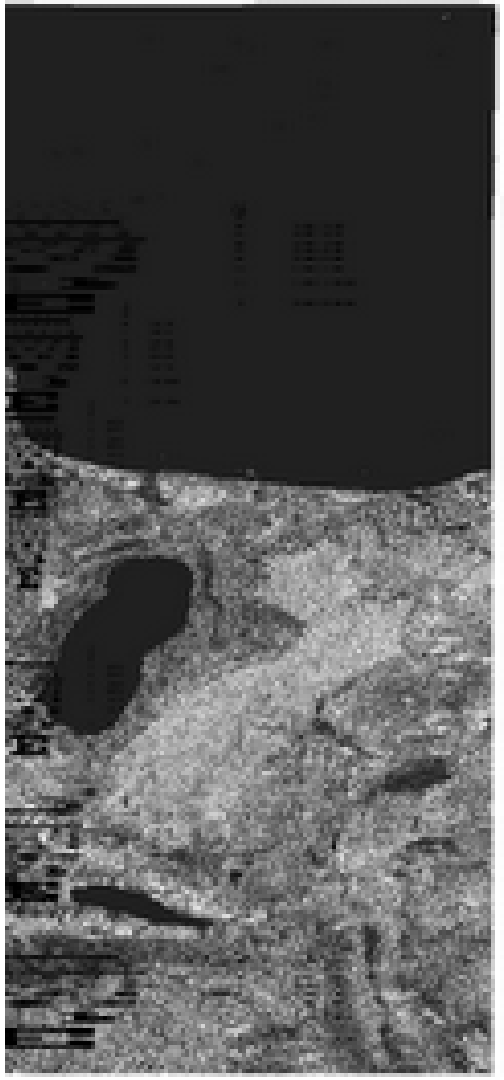


Test Image
Focal Plane 08 blue
Odd-even interleaved
Grid detectors
One spectrum per class

Snellen eye chart flooting
Over image at various heights

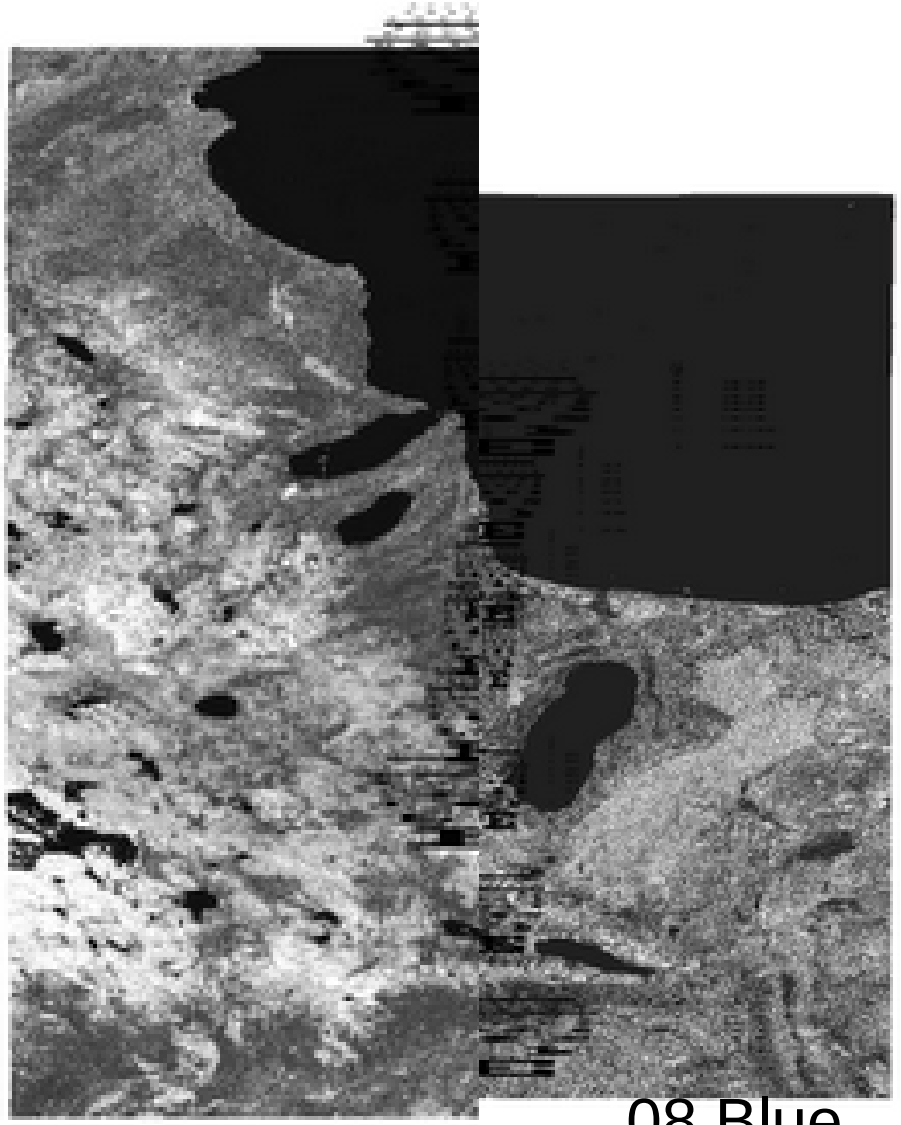
07 red





08 Blue

07 red



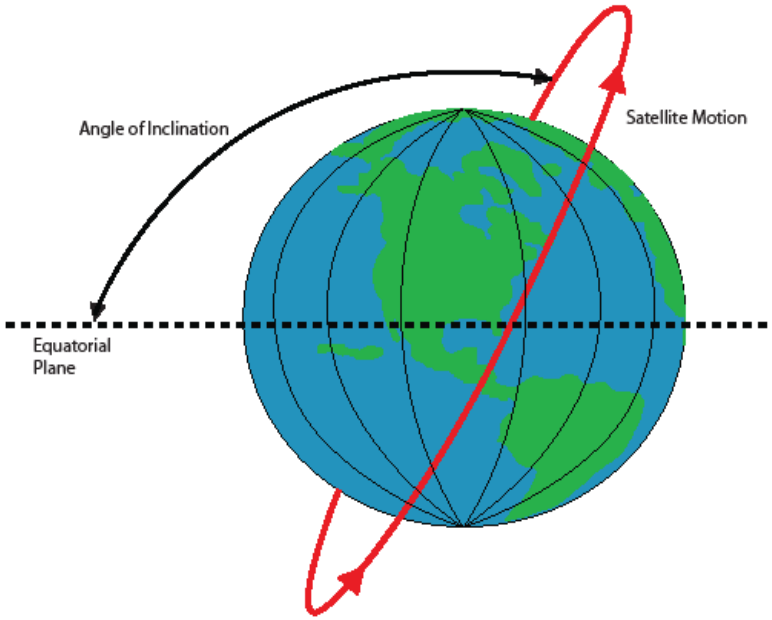
08 Blue

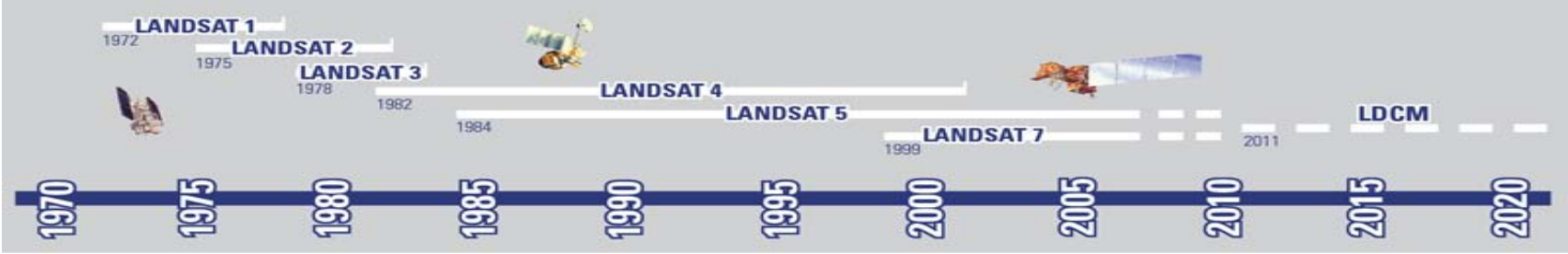
Orbitology

- Uses the NORAD Two-Line Element (TLE) format for describing the Orbit (Keplerian Elements). This is information on Inclination, Eccentricity, Drag, etc.). TLE are readily available for all NASA satellites (Note they are updated regularly (e.g., weekly) to adjust for orbital perturbations.

- Feed DIRSIG satellite TLE, start time, end time and sample clock rate.

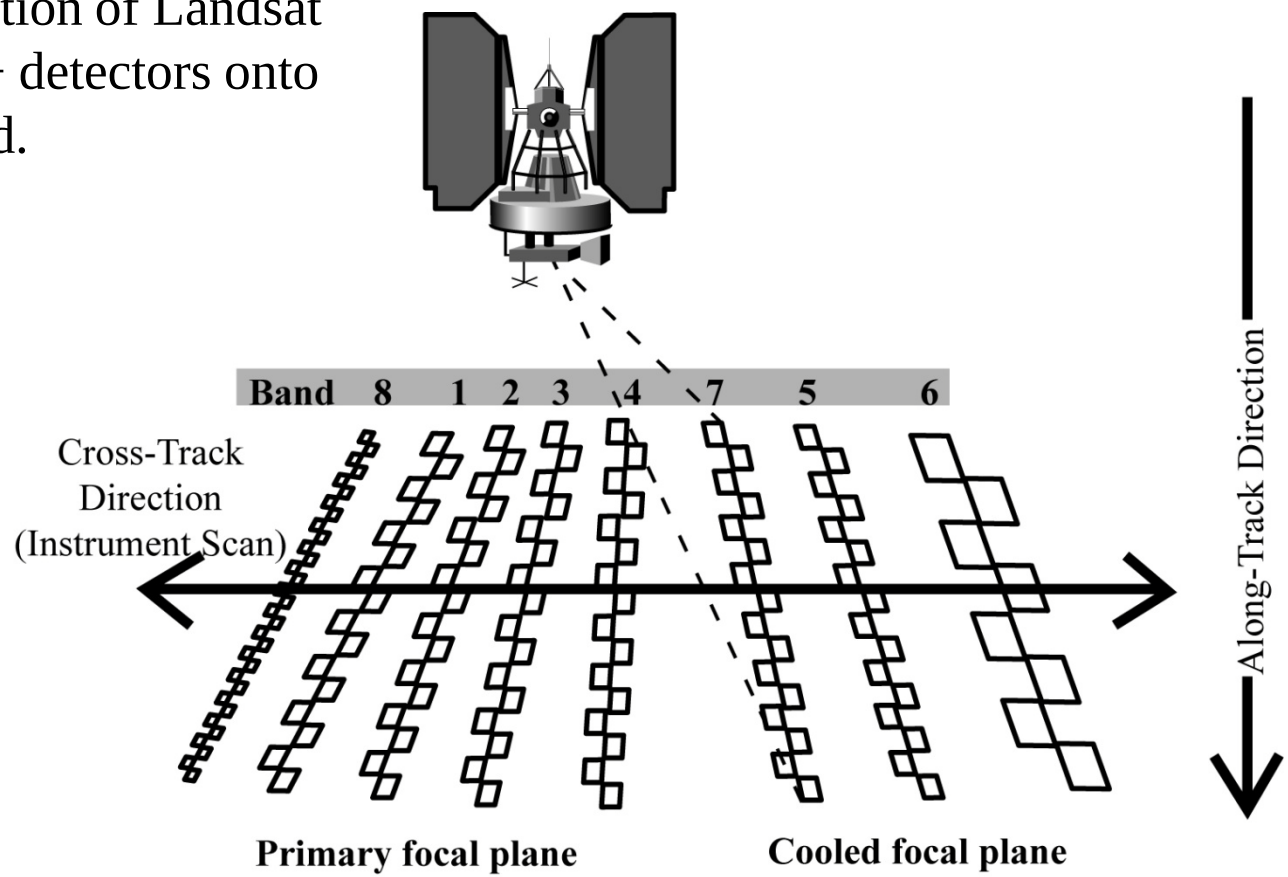
- Use SpaceCom's Simplified General Perturbations version 4 (SGP4) orbital propagator to convert to position and velocity for any given time (we use SGP4-Celestrak).
- Output is in True Equator and mean Equinox (TEME) format . We need to convert to Earth Centered-Earth Fixed (ECEF) format. (North =z, sun at Noon on vernal Equinox is x and right hand rule yields y). Note that the vector from the location x, y, z to the origin (Earth's center) is the nominal line of sight (LoS) of the instrument. Finally we convert to DIRSIG's native East North Up (ENU) format.

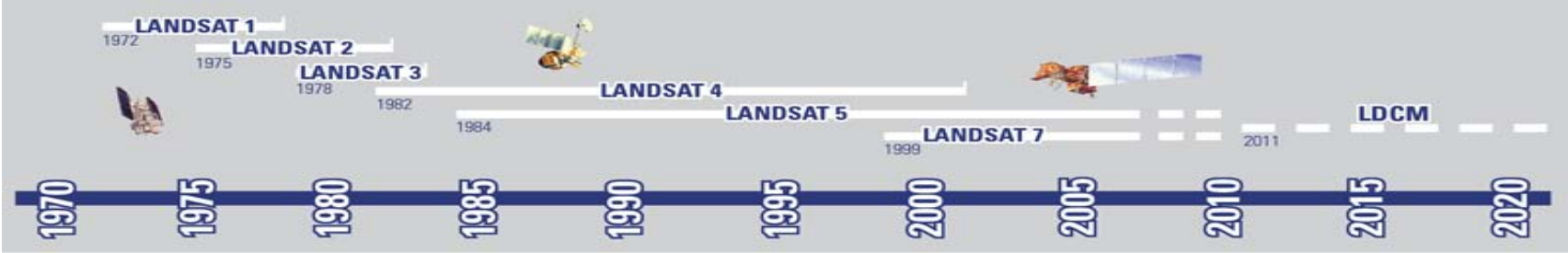




Multispectral Sensors

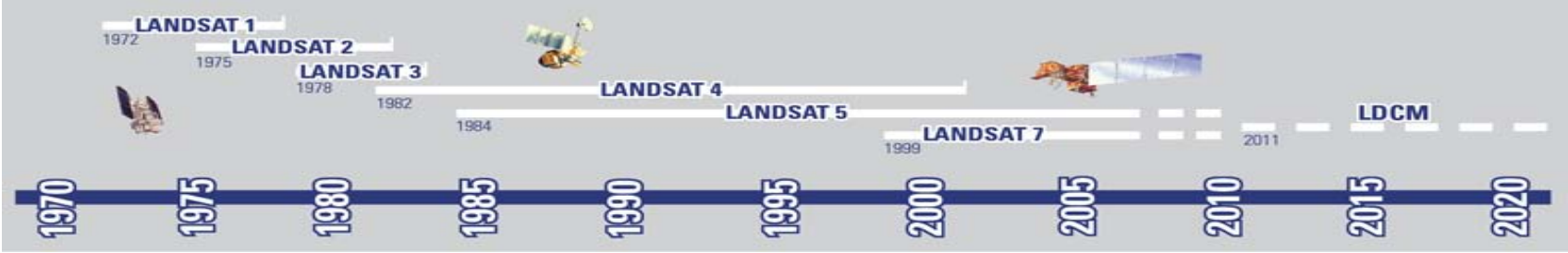
Projection of Landsat ETM+ detectors onto ground.



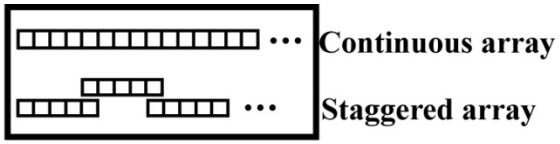
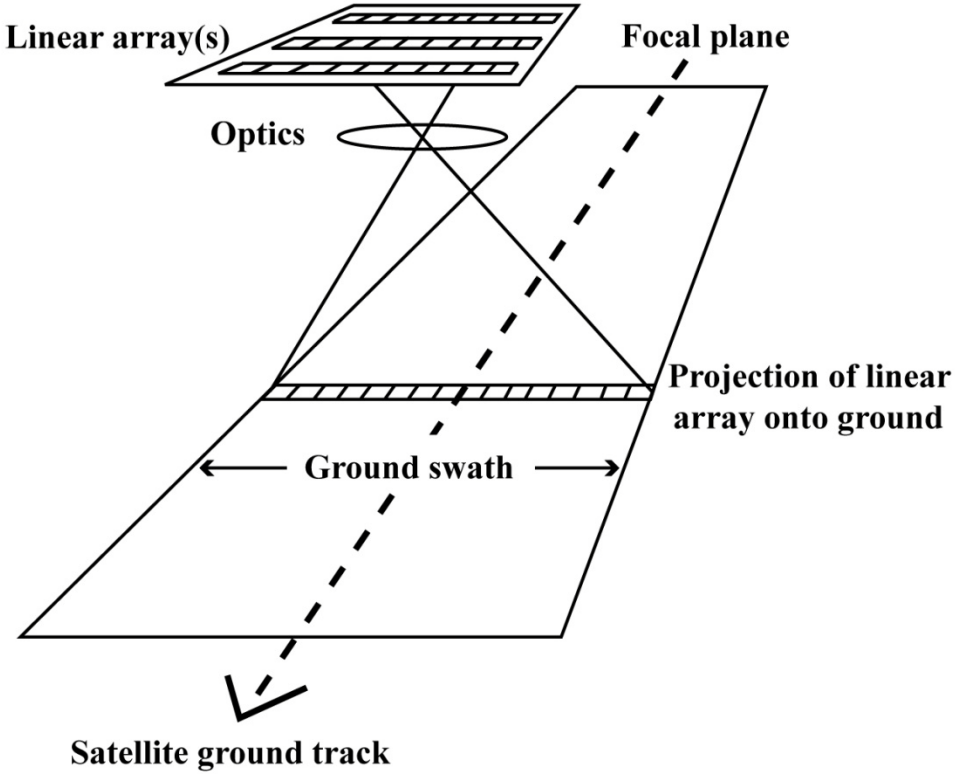


Multispectral Sensors

Landsat TM full-scene of Eastern Lake Ontario and the Finger Lakes region of New York State.



Push-broom sensor operation.



LDCM will have two Pushbroom Imagers: OLI and TIRS