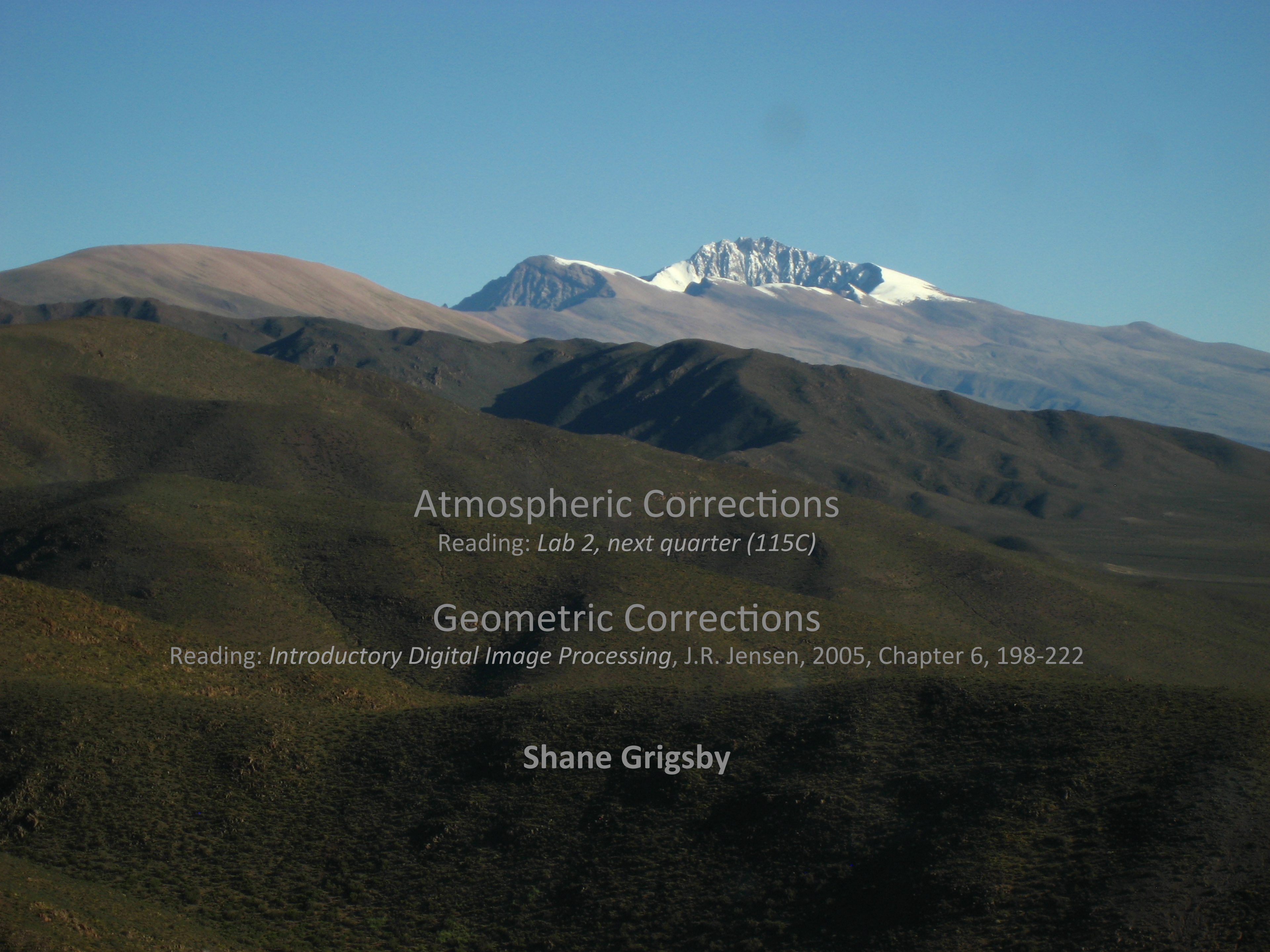


Atmospheric Corrections

Reading: *Lab 2, next quarter (115C)*

Geometric Corrections

Reading: *Introductory Digital Image Processing*, J.R. Jensen, 2005, Chapter 6, 198-222

Shane Grigsby

Agenda

- General Introduction
  - What do we mean by 'distortion'?
  - What do we correct? Why?

- Atmospheric Correction for the SWIR
  - Reflectances
  - Sources of error
  - Bulk atmospheric correction
  - Radiative transfer correction
    - Radiative transfer suites
    - Look up tables (LUT's)
    - Sensor convolution
    - Reflectance retrieval
    - Estimating atmospheric error terms
      - External model data
      - Direct inversion
- Atmospheric correction for Thermal data
  - Considerations
  - Sources of error
  - Radiance, Emissivity, Temperature
  - Separation: Classification based
    - Split window approach
  - Separation: Invariant targets
  - Separation: TES
- Geometric Correction
  - Review of photogrammetric distortion
  - Scan line distortion
    - Pixel size
      - Cross-track
      - Along-track
    - S-Bend distortion
    - Satellite considerations
      - Wide FOV distortion
      - Earth rotation
  - Radiometric distortion
    - The transfer function
    - Striping

Geometric and Atmospheric Correction

It would be useful if every remotely sensed image contained data that were already in their proper geometric x, y locations.

Unfortunately this is not the case. Instead, it is usually necessary to preprocess the RS data and remove geometric and atmospheric distortions.

Atmospheric correction: (In general) **Radiometric Correction**

RS data is influenced by atmospheric conditions, aerosols, pathway of EMR radiation

Removal through filtering and/or additional images

Geometric error: (in general) **Location/Size Correction**

RS data typically exhibits *internal* and *external* geometric error

Systematic (predictable) or nonsystematic (random) errors

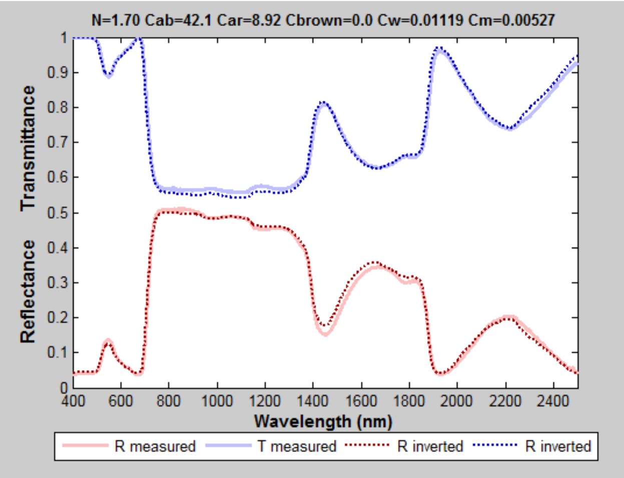
Distortion

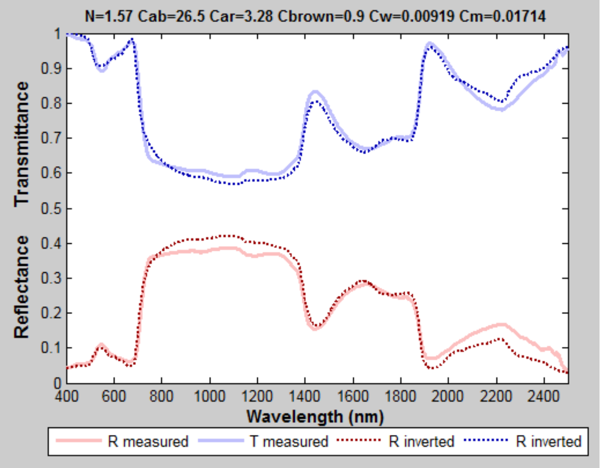
- Radiometric Distortion: Errors in pixel brightness values
  - Instrumentation
  - Wavelength dependence of solar radiation
  - Effect of atmosphere

- Geometric Distortion: Errors in image geometry, (location, dimensions, etc.)
  - Platform and instrument relative motions
  - Scan angles and scan patterns
  - Rotation of the Earth
  - Attitude and altitude variability

Why do we need to correct?

- Time Series and comparison
  - Geometric issues:
    - Tracking changes in time requires registration
    - Comparing regions/images requires areal consistency
  - Radiometric issues:
    - Different viewing geometries need to be normalized
    - Different seasons need to be normalized
- Physical inversions
  - Spectroscopy estimates chemical composition; radiometric errors propagate to quantity estimates

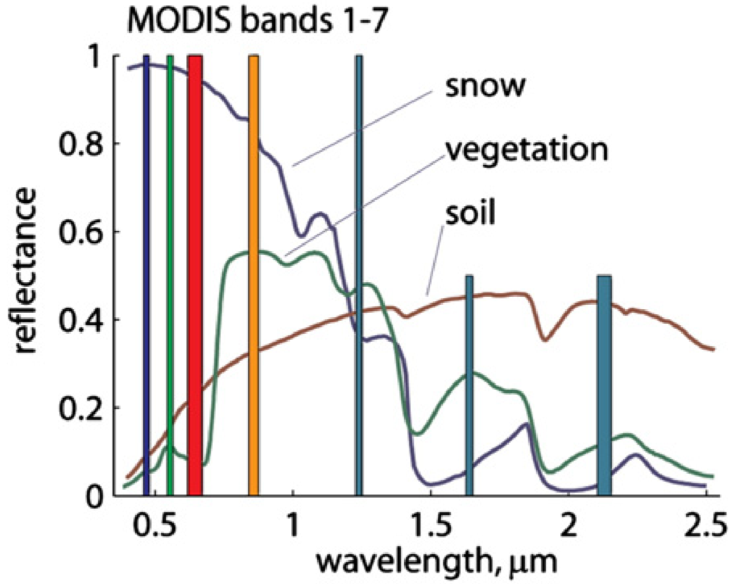


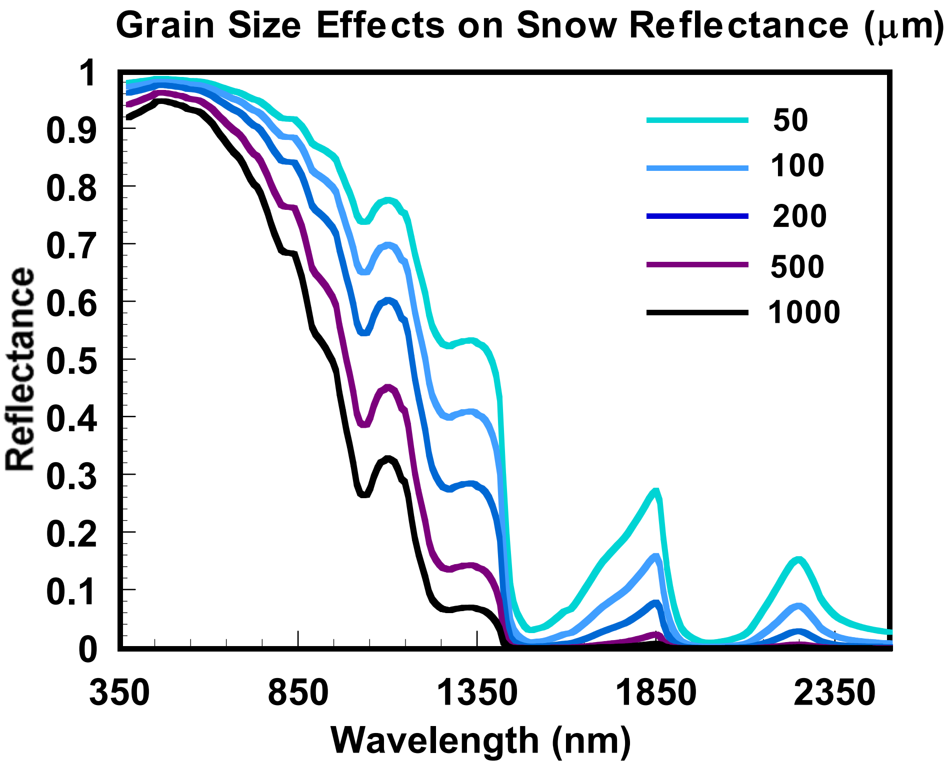


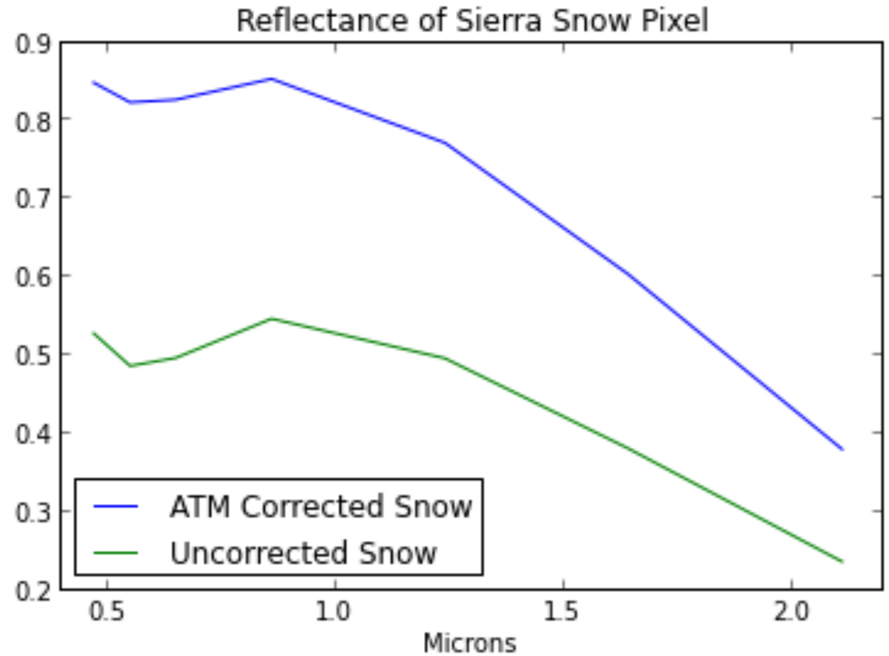
Examples: Remote sensing the Amazon, and the Sierras

Atmospheric Correction:

Essential for science



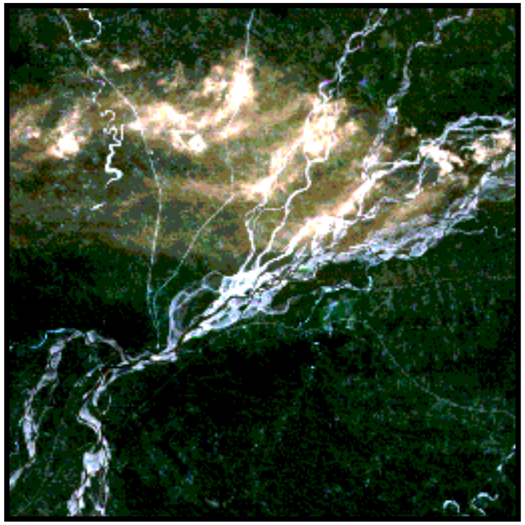




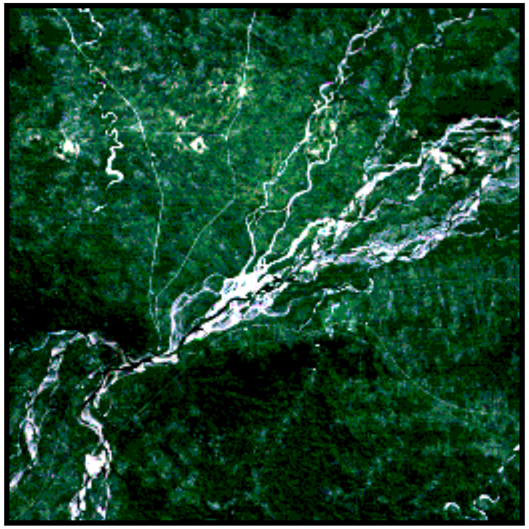
Atmospheric Correction

Atmospheric Correction is mostly applied to remove atmospheric moisture, aerosols, and other particles/clouds to create an homogenous picture.

Note: You will not be able to remove a thick cloud cover, but haze and similar low density effects can be removed.



pre-processing



post-processing

Effects of the Atmosphere

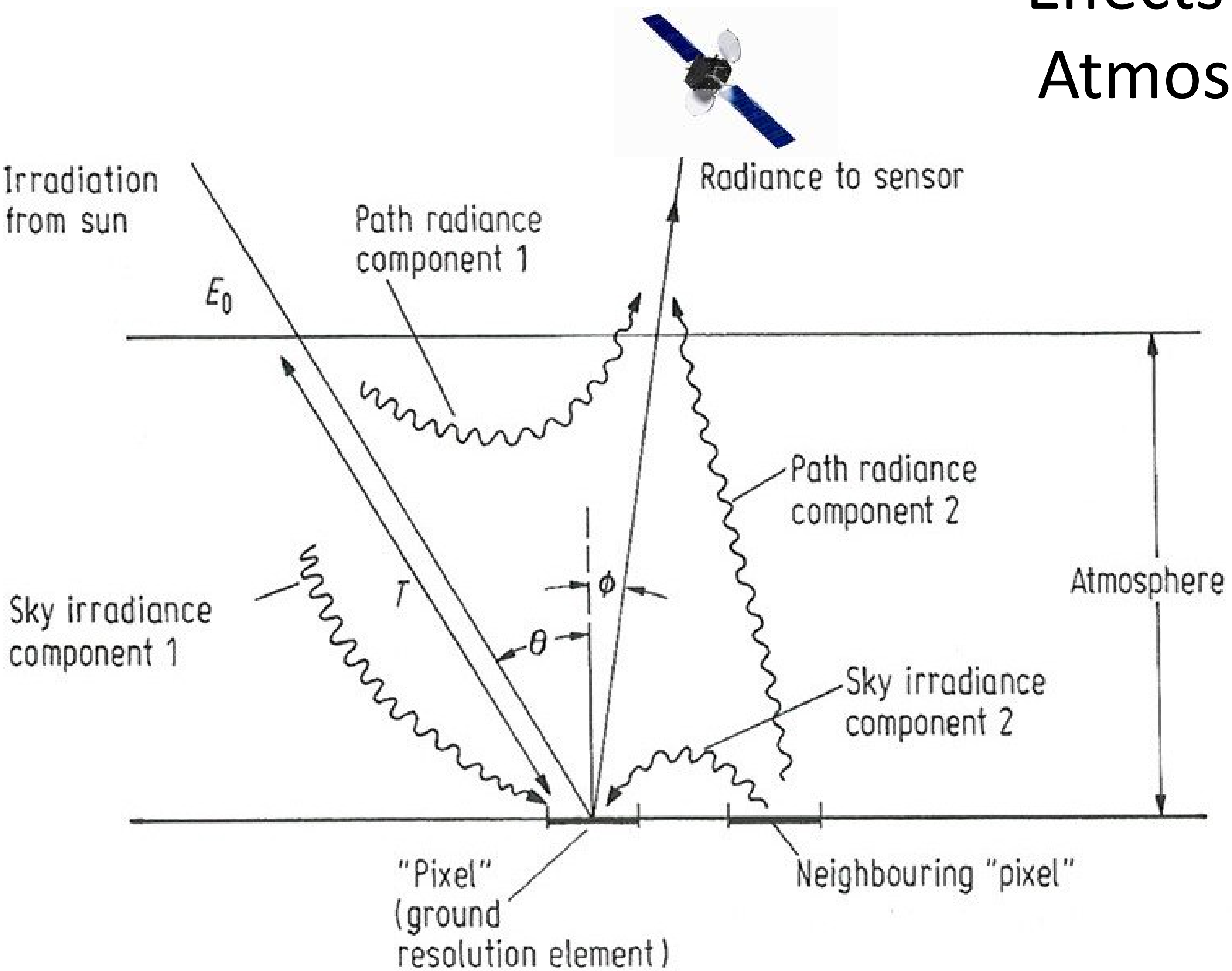


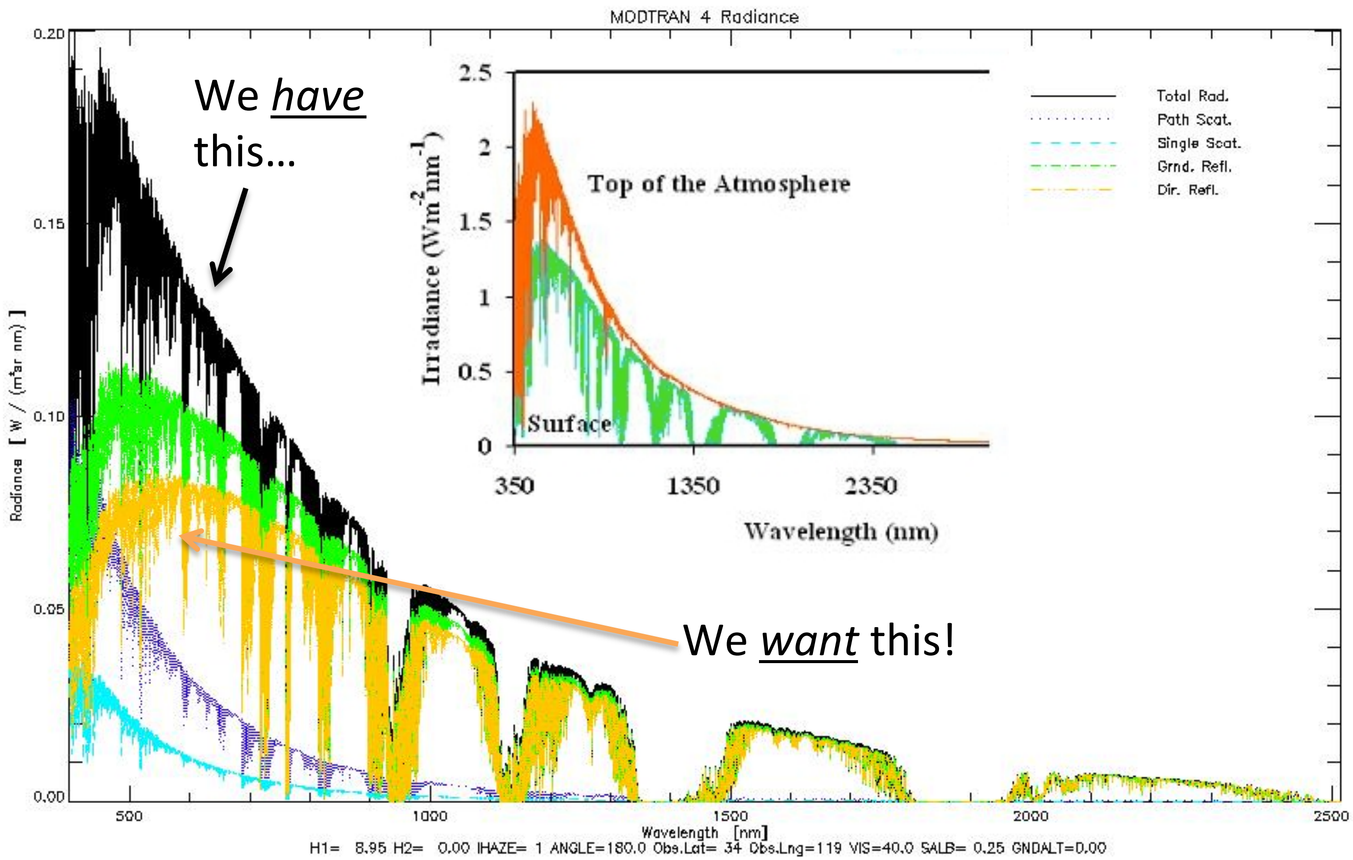
Fig. 2.1. The effect of the atmosphere in determining various paths for energy to illuminate a (equivalent ground) pixel and to reach the sensor

Atmospheric correction in the SWIR: Calculating Reflectances

We want:

- The amount of direct (non-scattered) energy from the sun that reaches the ground surface
- The amount of direct (non-scattered) energy from the ground that reaches the sensor

Reflectance is the ratio of these two quantities



- Top of Atmosphere, incoming (Solar spectrum)
- Total incident at surface
- Non-scattered at surface (direct)
- Path radiance at surface (yellow + blue = green)
- **Path scattered radiance at sensor**
- **Total radiance at sensor** ([*reflected* green] + **purple**)

Effects of the Atmosphere

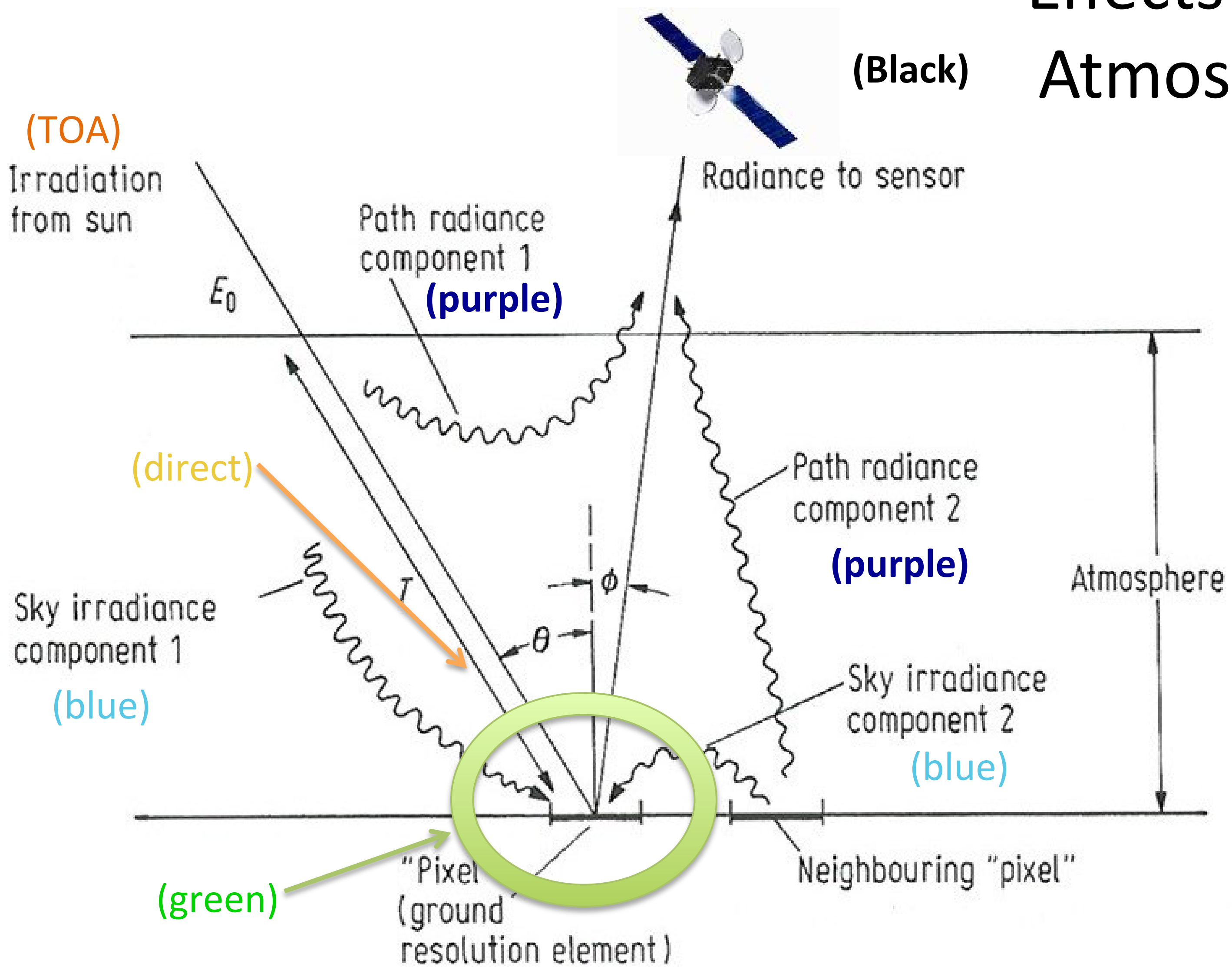


Fig. 2.1. The effect of the atmosphere in determining various paths for energy to illuminate a (equivalent ground) pixel and to reach the sensor

The simple correction:
Bulk Correction / Dark Object Subtract

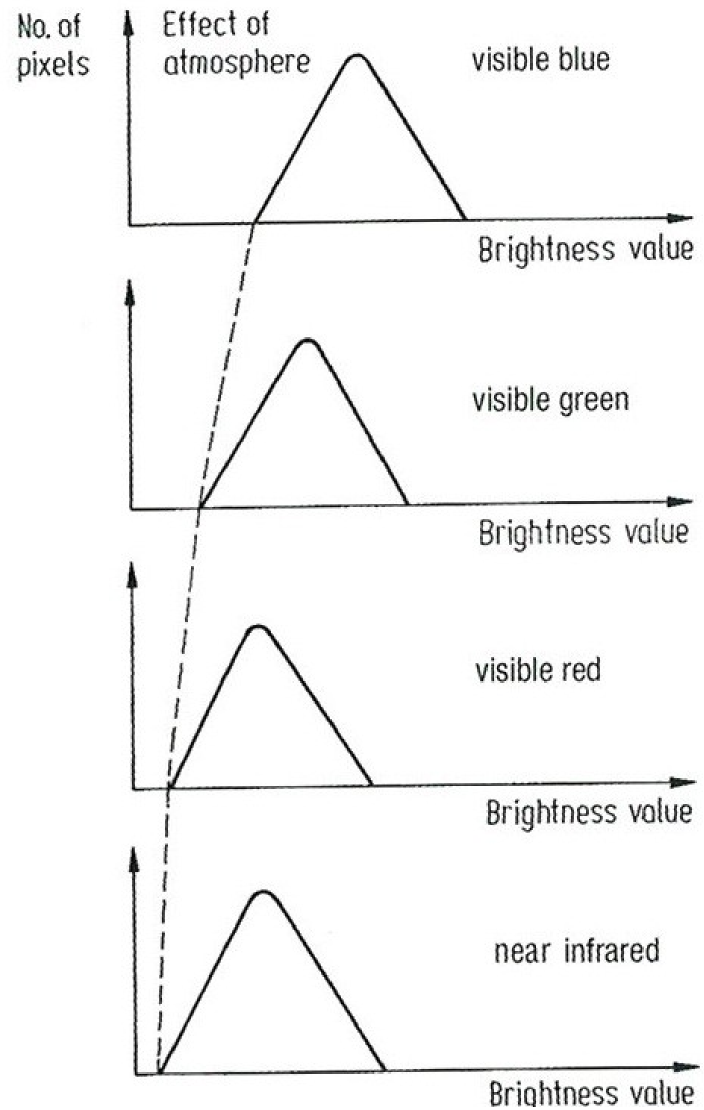
…i.e., what we did in 70’s…

“I don’t care what the noise is in my image—

I just want it gone”

Bulk Atmospheric Correction

- Often it is sufficient to assume there are pixel values close to zero in the imagery (e.g. water)
- In this case, any brightness observed will be a result of atmospheric contributions (Primarily L_P but also E_D)
- Histograms of each channel will show an offset from zero as a result
  - Wavelength dependent
- Subtracting this offset from the entire image will remove the vast majority of atmospheric effects

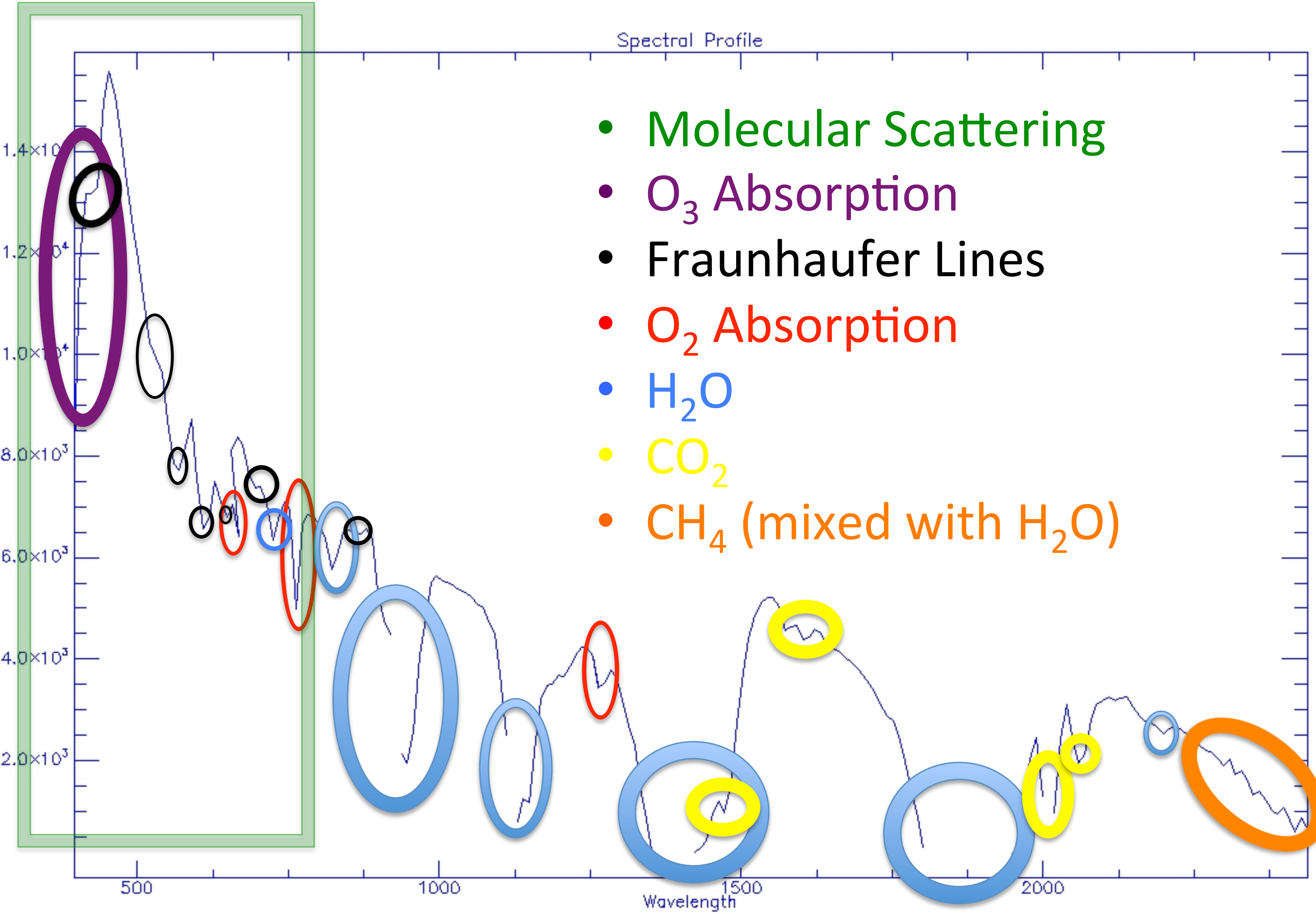


Option 2:
Physically based radiative transfer

…i.e., what we do now…

“Do the physics”

Estimate the amount of each atmospheric constituents…and model the atmospheric effects on our signal



Spectral Profile
1.4×10⁴
1.2×10⁴
1.0×10⁴
8.0×10³
6.0×10³
4.0×10³
2.0×10³
500
1000
1500
2000
Wavelength
• Molecular Scattering
• O_3 Absorption
• Fraunhaufer Lines
• O_2 Absorption
• H_2O
• CO_2
• CH_4 (mixed with H_2O)

Absolute atmospheric correction based on Radiative Transfer Modeling

Most current *radiative transfer-based atmospheric correction algorithms* can compute much of the required information if

a) the user provides fundamental atmospheric characteristic information to the program

b) certain atmospheric absorption bands are present in the remote sensing dataset.

Most radiative transfer-based atmospheric correction algorithms require that the user provide:

- latitude and longitude of the remotely sensed image scene
- date and exact time of remote sensing data collection
- image acquisition altitude (e.g., 20 km agl)
- mean elevation of the scene (e.g., 200 m asl)
- an atmospheric model (e.g., mid-latitude summer, mid-latitude winter, tropical)
- radiometrically calibrated image radiance data (i.e., data *must* be in the form W m^2 mm^{-1} sr^{-1})
- local atmospheric visibility at the time of remote sensing data collection (e.g., 10 km, obtained from a nearby airport if possible)

Radiative Transfer: Who and How

Three primary groups, one minor group:

JPL Group (ACORN)
Conel, Green, Roberts
MODTRAN LUT +
NLLSF and Full Spectrum Fitting

CIRES Group (ATREM)*
Bo-Cai-Gao, Goetz, Curtis Davis
S6 Radiative Transfer Model
Multiple band depth ratios (using multiple water bands)

Swiss/German Group (ATCOR)
Uses MODTRAN LUT

ENVI FLAASH
Uses MODTRAN LUT

Radiative transfer in summary…

- All atmospheric effects can be modeled using a radiative transfer model such as MODTRAN
- Most effects are per scene
- Non-well mixed gases (Water Vapor) are estimated separately, per pixel
- We take the bulk effects, apply a bulk correction to image, and then solve for per pixel effects separately

Modeling absorption and scattering

- How and why does this modeling work?
  - Two options: *a priori* knowledge
  - Direct estimation from remote sensing data
- All models estimate non-water scattering and absorption.
  - CO_2, CH_4, O_3, O_2, and other aerosols are considered ‘well mixed’, i.e., uniform in concentration over an area at most scales
  - This means that optical thickness effects (τ) are additive

First option: *a priori* knowledge

- We retrieve atmospheric constituents from other sources:
  - Field or other *in situ* data
  - Numerical weather models (NCAR / NCEP)
  - Take 'seasonal', 'regional', or 'best guess' estimates
  - <u>*Only works for well mixed gases—not water vapor!*</u>
- Forward model transmittance per 'estimated' constituent; sum transmittances

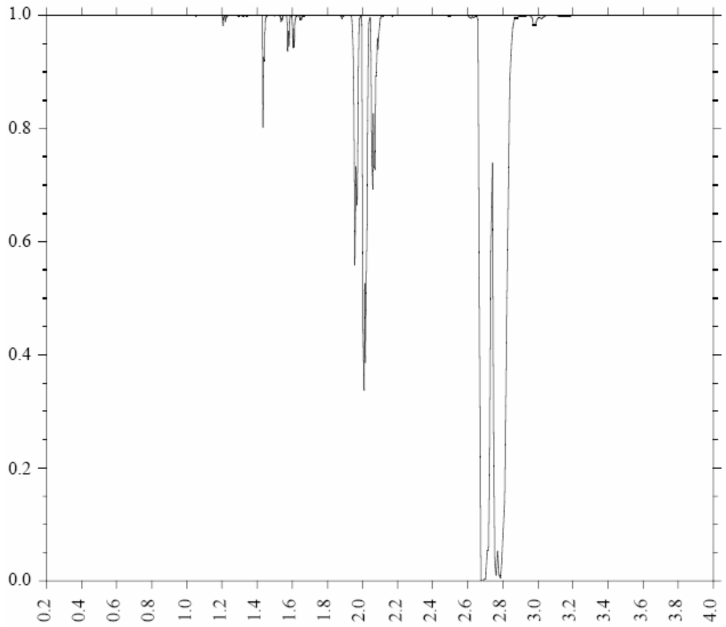


Fig. I-3. Spectral transmittance of CO_2.

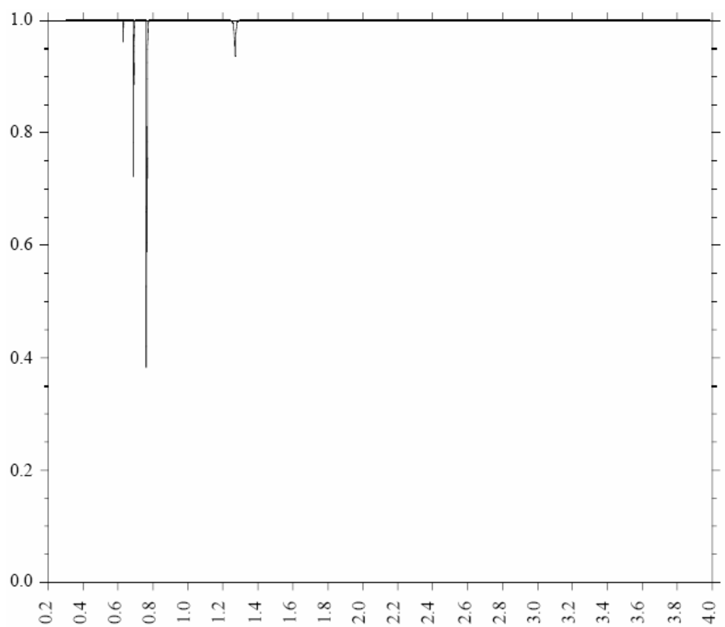


Fig. I-4. Spectral transmittance of O_2.

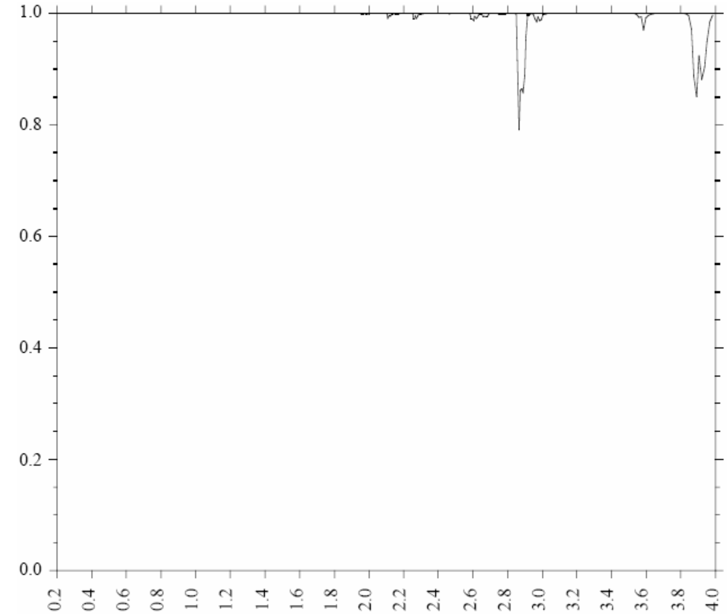


Fig. I-5. Spectral transmittance of N_2O.

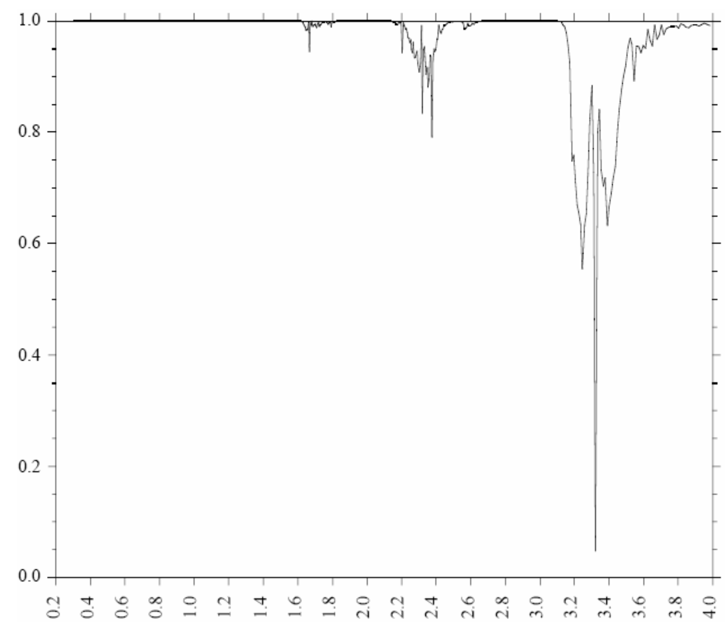
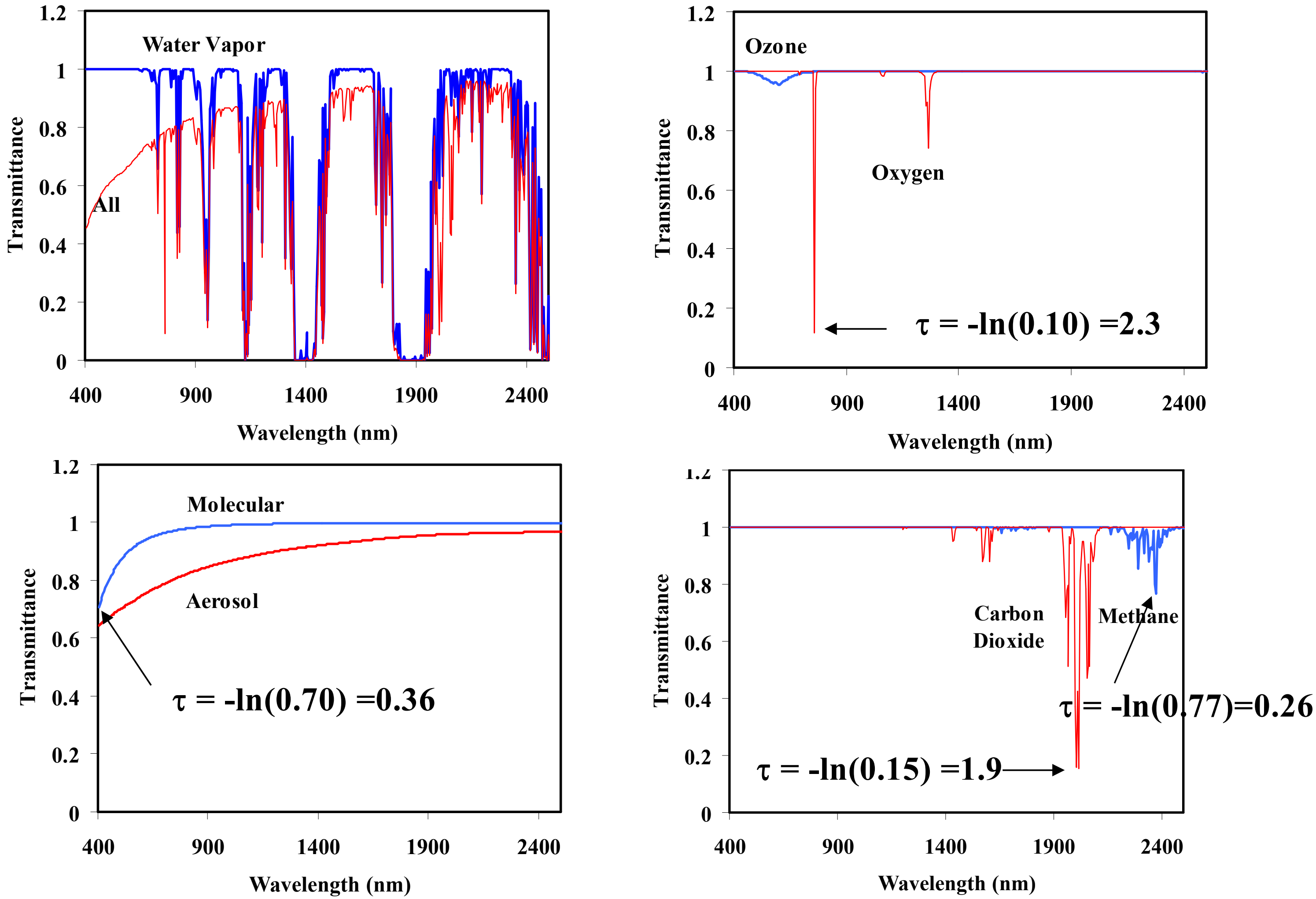


Fig. I-6. Spectral transmittance of CH_4.

Impact of Various Molecular Species on Atmospheric Transmittance (τ)



Modtran: March 21, 100 km elev, 1 atm

Second option:
Estimation from remote sensing data

Used for estimating water vapor and gases that are not well-mixed…

…but also works with well-mixed gases.

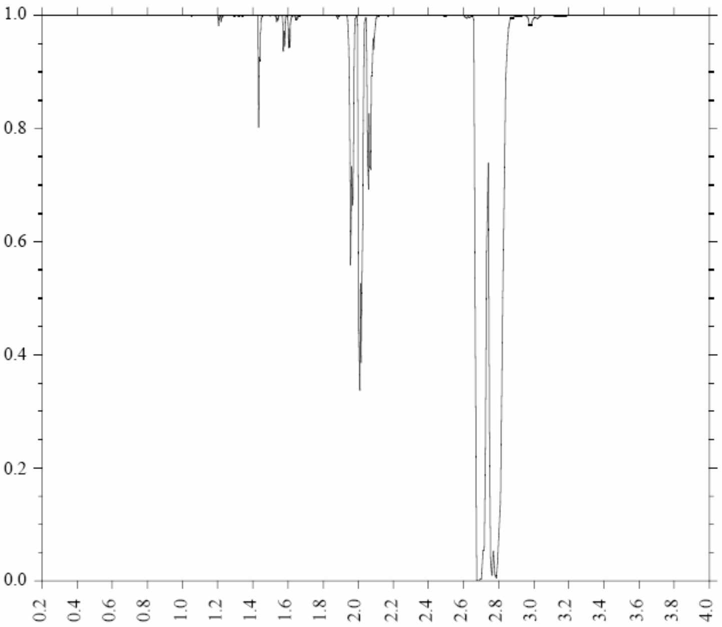


Fig. I-3. Spectral transmittance of CO_2.

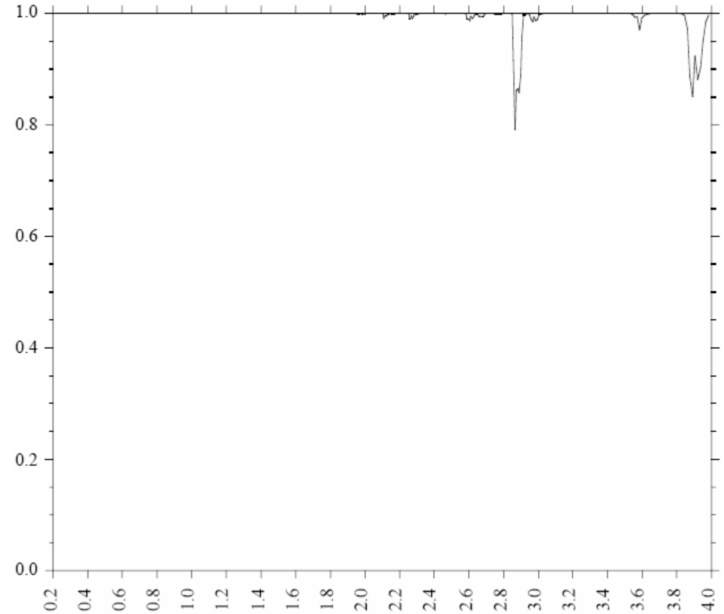


Fig. I-5. Spectral transmittance of N_2O.

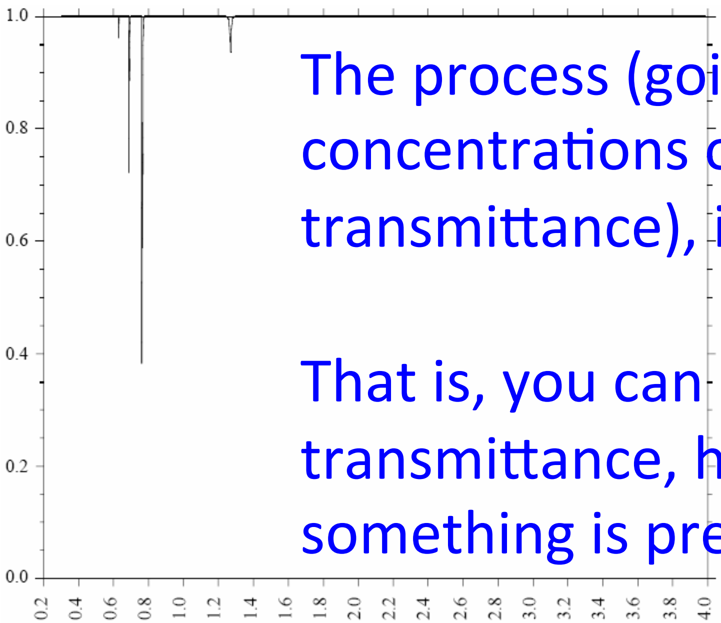


Fig. I-4. Spectral transmittance of O_2.

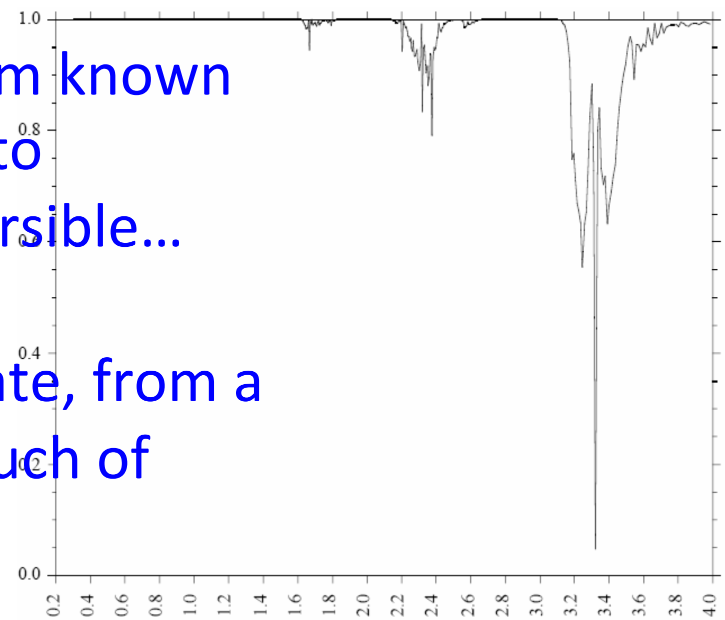


Fig. I-6. Spectral transmittance of CH_4.

The process (going from known concentrations of gas to transmittance), is reversible…

That is, you can estimate, from a transmittance, how much of something is present…

An in-depth example of inversion: Water vapor

THE dominant source of absorption and scattering in the atmosphere <u>is from water vapor</u>

- Water vapor is <u>*not*</u> well mixed
  - This is why bulk corrections are not high quality
- Keep in mind from earlier:
  - Most other constituents are well mixed, and can be modeled as constant for a scene
  - Atmospheric effects are additive
- Inversion methods:
  - CIBR, NW, APDA
  - Brute Force Lookup tables
  - Non-linear least squares estimation

Basic Procedure (using AVIRIS)

Commercial packages:

- All models estimate non-water scattering
- Most use lookup tables to fit

What do they do?

- Generate LUT from S6 or MODTRAN (e.g., N=32)
- Spline interpolate LUT, resample to AVIRIS (N=1000)
- Brute force solve for vapor, water, ice—per pixel
- Use vapor to select path and reflectance scaling radiance values, normalize for viewing geometry, and return reflectance per pixel

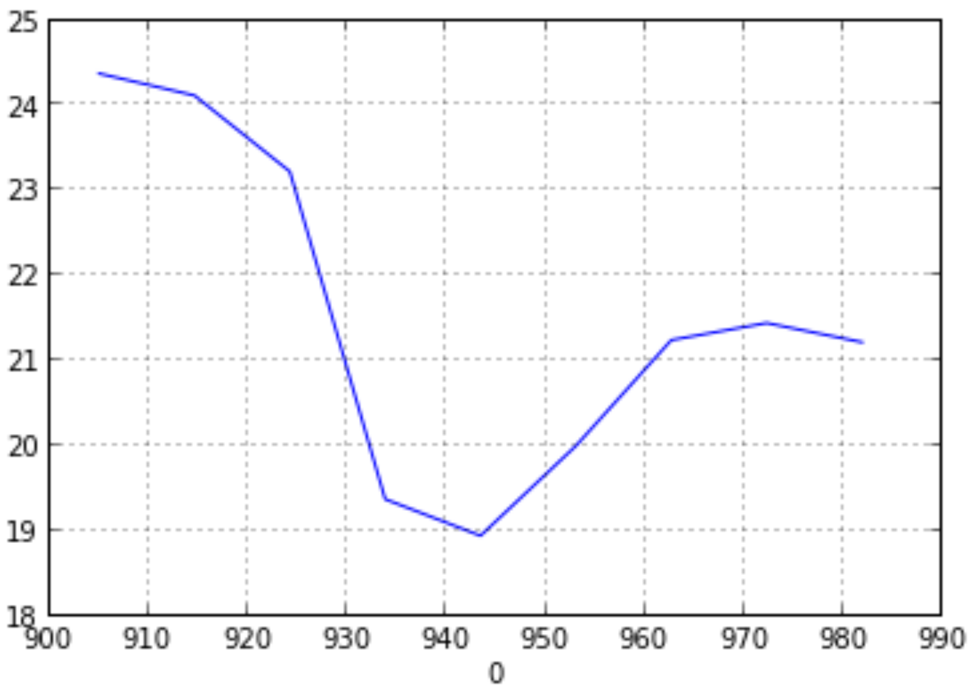
CIBR, NW, APDA

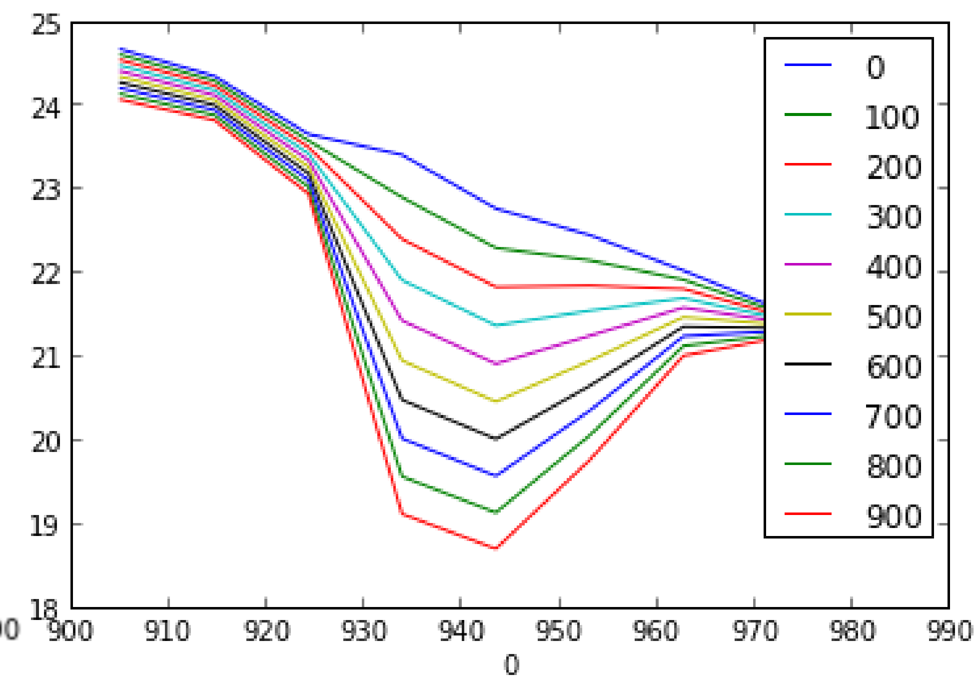
- Look at depth, or width, of feature

CIBR = exp(-α•Feature$^{\beta}$) CIBR = L / (A•C_1 + B•C_2)

Where 'Feature' is some physical quantity

$$\text{Feature}_{Ref} = \text{Feature} \bullet [\,(\cos\theta_0)^{-1} + (\cos\theta)^{-1}\,]^{-1}$$

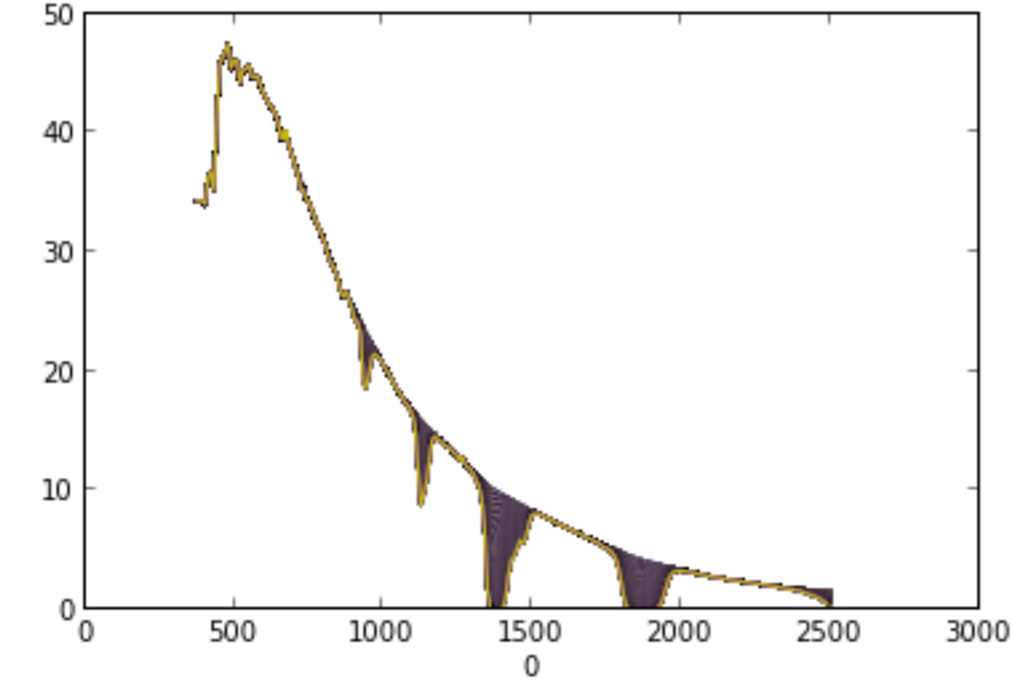




Continuum Interpolated Band Ratio

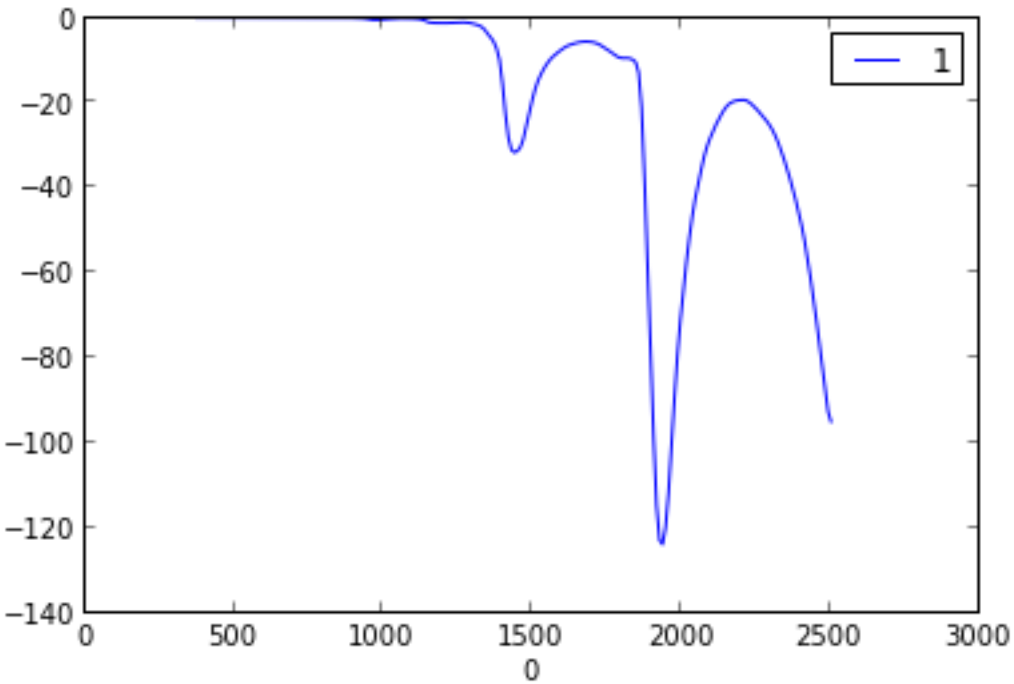
- Only need two ground reference values to solve the differential equation
- Applied to MODTRAN spectra (includes other atmospheric effects, other scattering)

- Why do we need a lookup table?



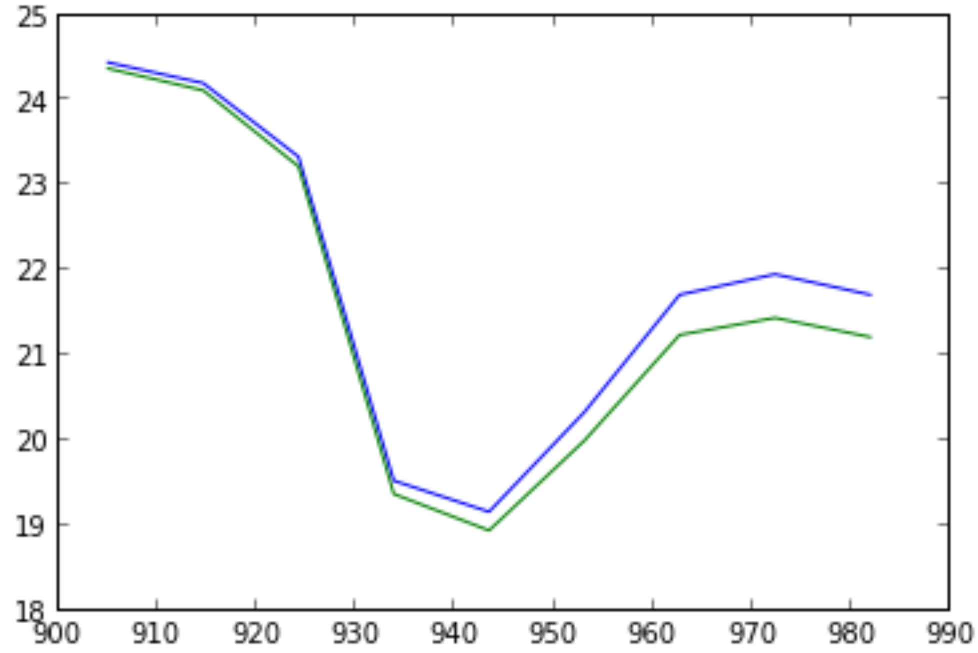
Issues with Spectral Mixing

Liquid water occupies an overlapping absorption band…

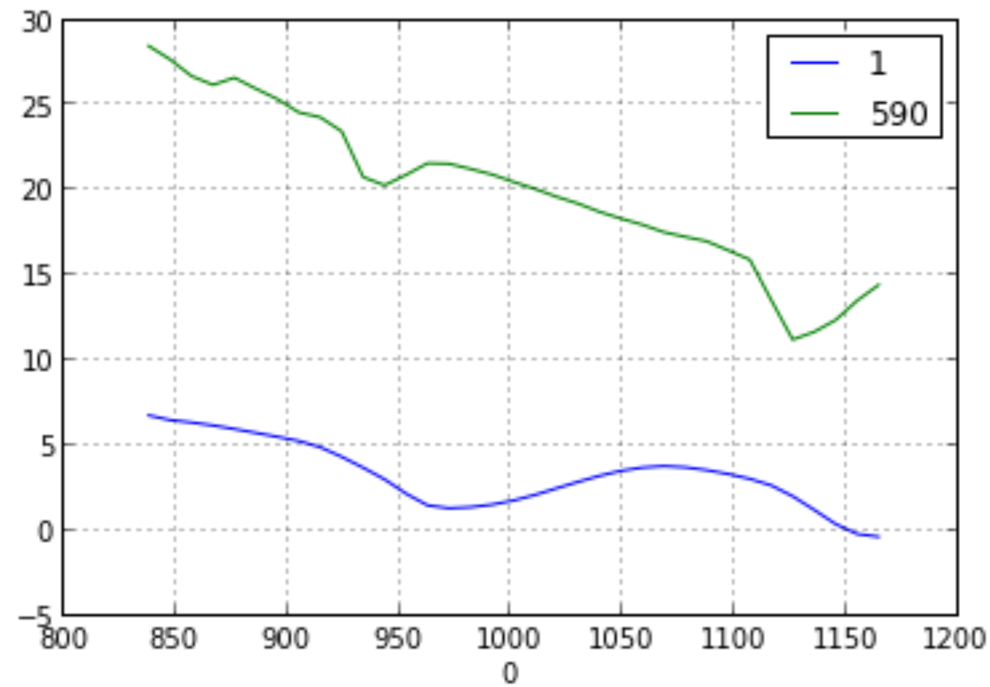


Note that we can actually apply the same CIBR to this absorption feature…

Spectral Mixing of Vapor and Liquid Water



Equivalent amounts of water vapor yield different at sensor values for differing pixel liquid water content (also, ice)



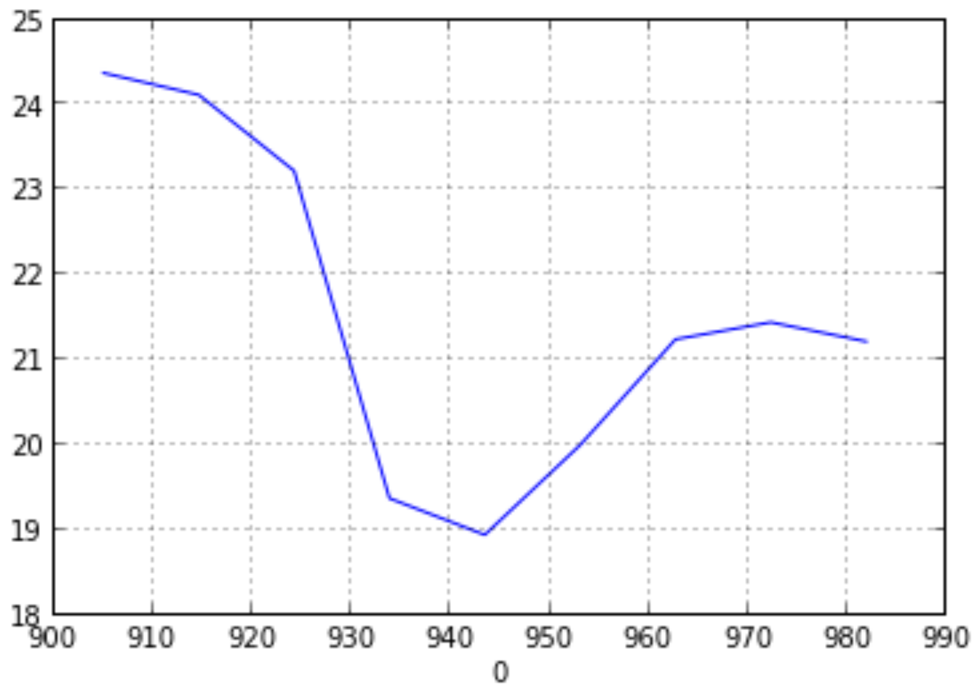
Thus, they must solved for simultaneously…

Separation of Vapor and Liquid Components of water

Our function on the right empirically solves for path-length, absorption, and scattering of a feature

$$CIBR = \exp(-\alpha \bullet \text{Feature}^{\beta})$$

For water, we can empirically derive the absorption coefficient per wavelength in the lab, disregard scattering, and solve for just path-length through water as a function of albedo



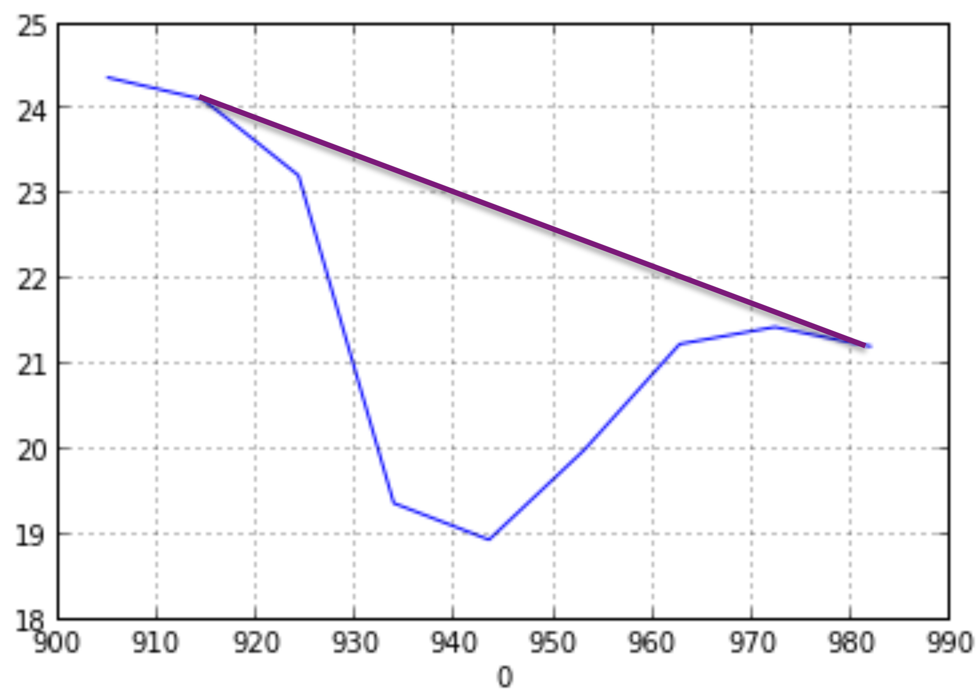
Solving for Separation

- We want a combination of path radiance, reflected radiance will ‘fill’ our absorption

--Note that reflected radiance is adjusted to at sensor

$\text{Path}_{\text{radiance}}$ is a function of water vapor

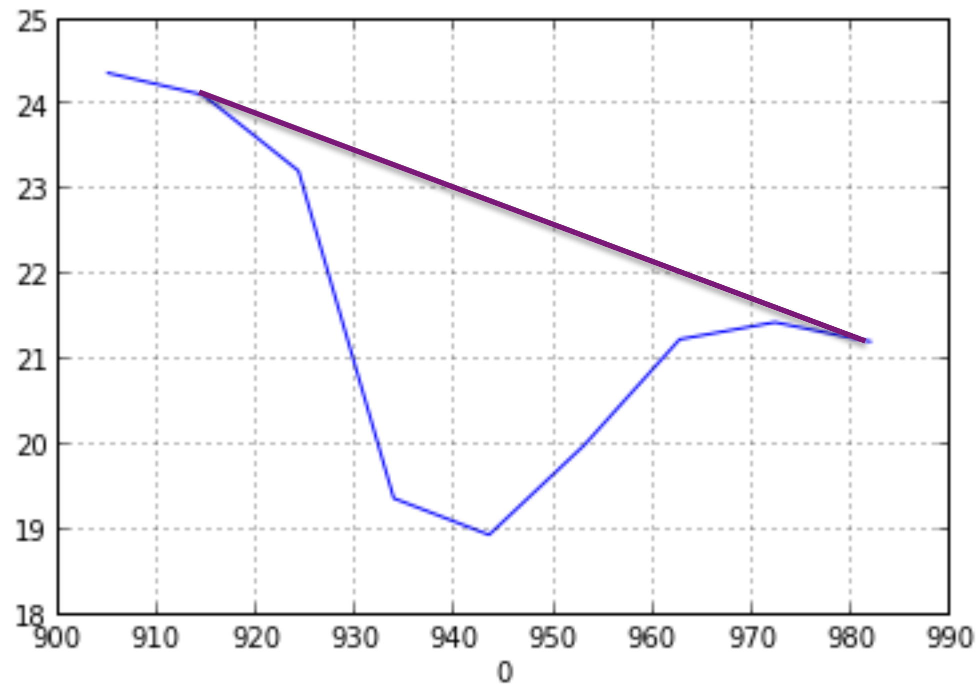
$\text{Reflected}_{\text{radiance}}$ is a function of water vapor, albedo, liquid water, and optical thickness as well as viewing geometry



Evaluating fit

We can formalize our fit by subtracting our modeled components to fill the gap. Fit is assessed by calculating the slope of the purple fitted line, then calculating the change in slope along the line.

We can then construct a multi-parameter nonlinear function that describes the change of slope of the purple line —and then minimize that function…

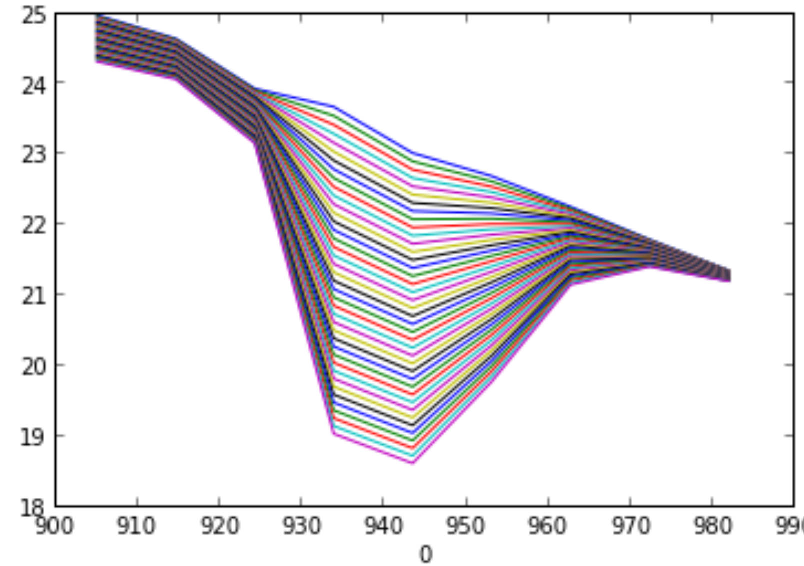


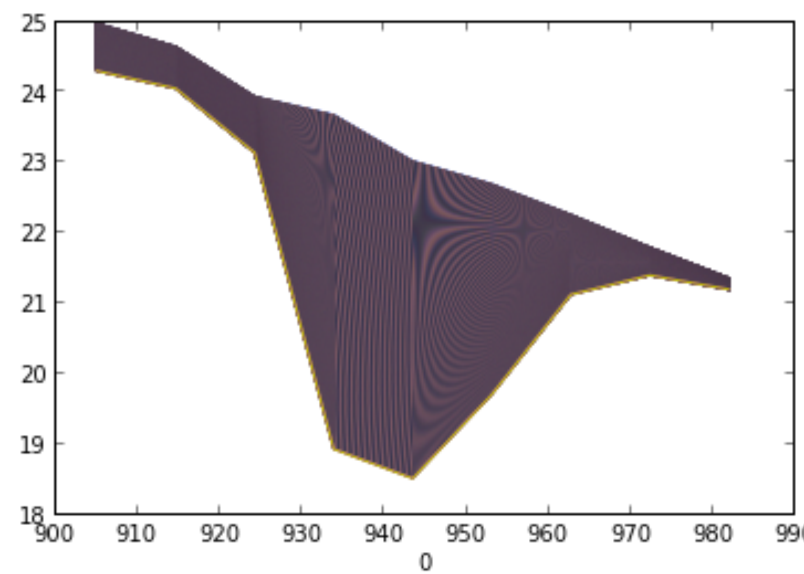
Downhill Simplex Method and NLLSF

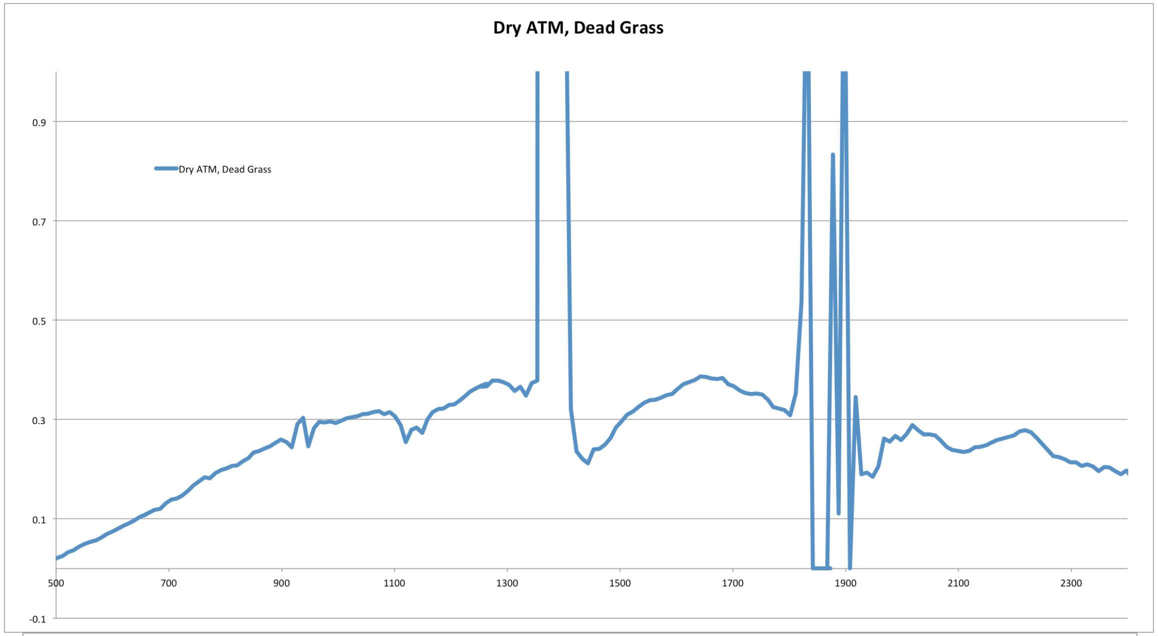
Doesn't require derivatives—just function evaluations

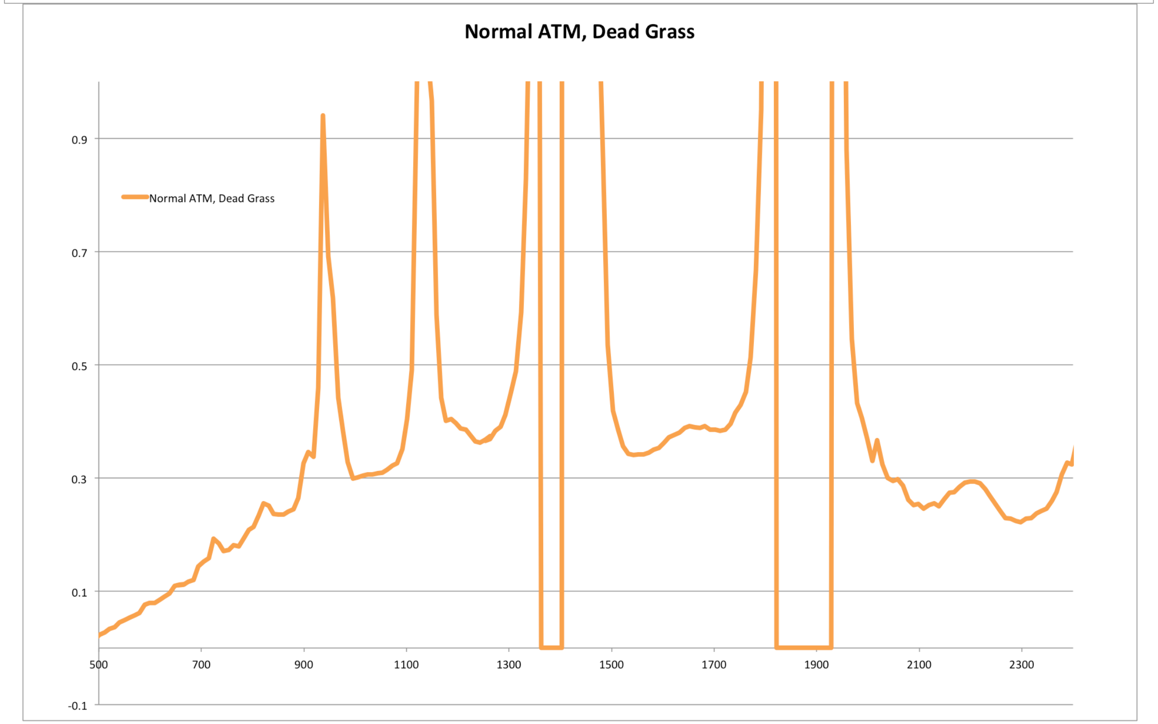
We set up the minimization equation, give an initial set of parameter 'guesses', and iteratively work to minimize the function in multi-dimensional parameter space

Basically, newton's method of steepest descents for discreet multi-parameter functions





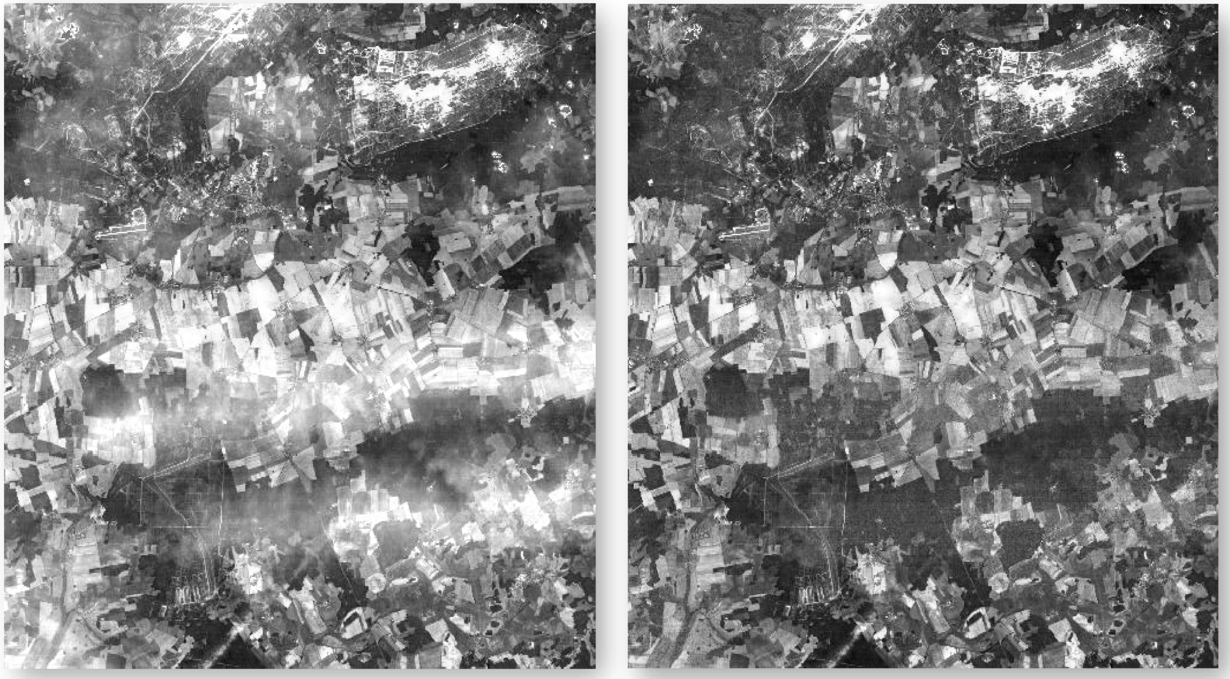

Dry ATM, Dead Grass
Dry ATM, Dead Grass
0.9
0.7
0.5
0.3
0.1
-0.1
500
700
900
1100
1300
1500
1700
1900
2100
2300


Normal ATM, Dead Grass
Normal ATM, Dead Grass
0.9
0.7
0.5
0.3
0.1
-0.1
500
700
900
1100
1300
1500
1700
1900
2100
2300

Questions?

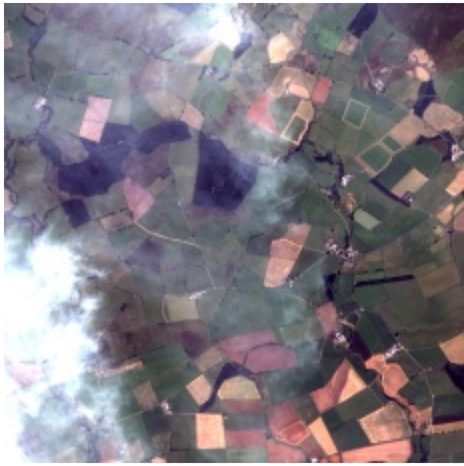
In practice, software will do the heavy lifting…

Atmospheric Correction using ATCOR – Atmospheric Correction and Haze Reduction



a. Before atmospheric correction.   b. After atmospheric correction.

a) Image containing substantial haze prior to atmospheric correction.
b) Image after atmospheric correction using ATCOR (Courtesy Leica Geosystems and DLR, the German Aerospace Centre).



IKONOS Raw Image (raw data values from sensor)
IKONOS Image after Haze Reduction (haze reduced data values)
IKONOS Image after Atmospheric Correction (true reflectance values)

Atmospheric Correction: Thermal

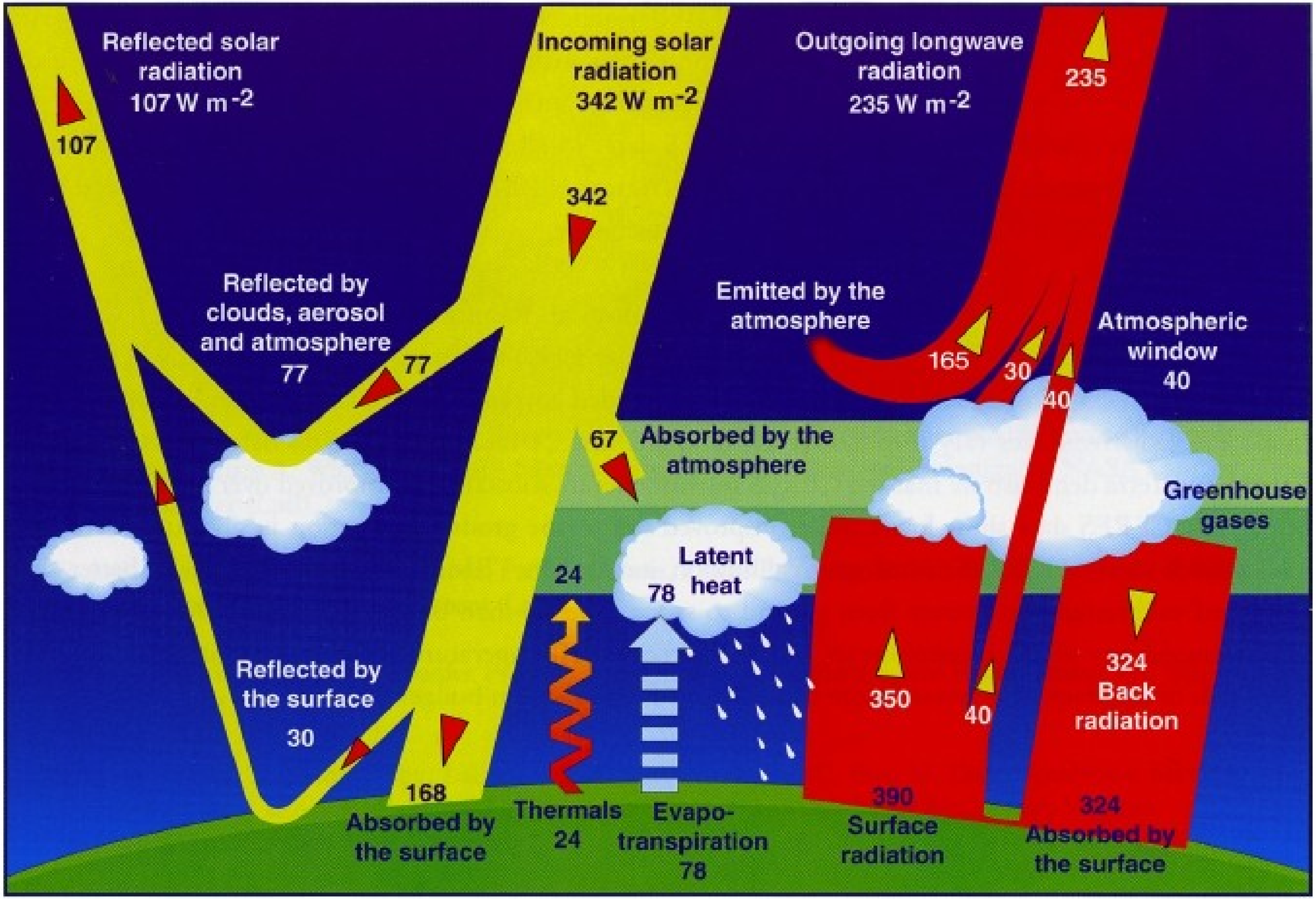
Thermal correction is a non-trivial problem:

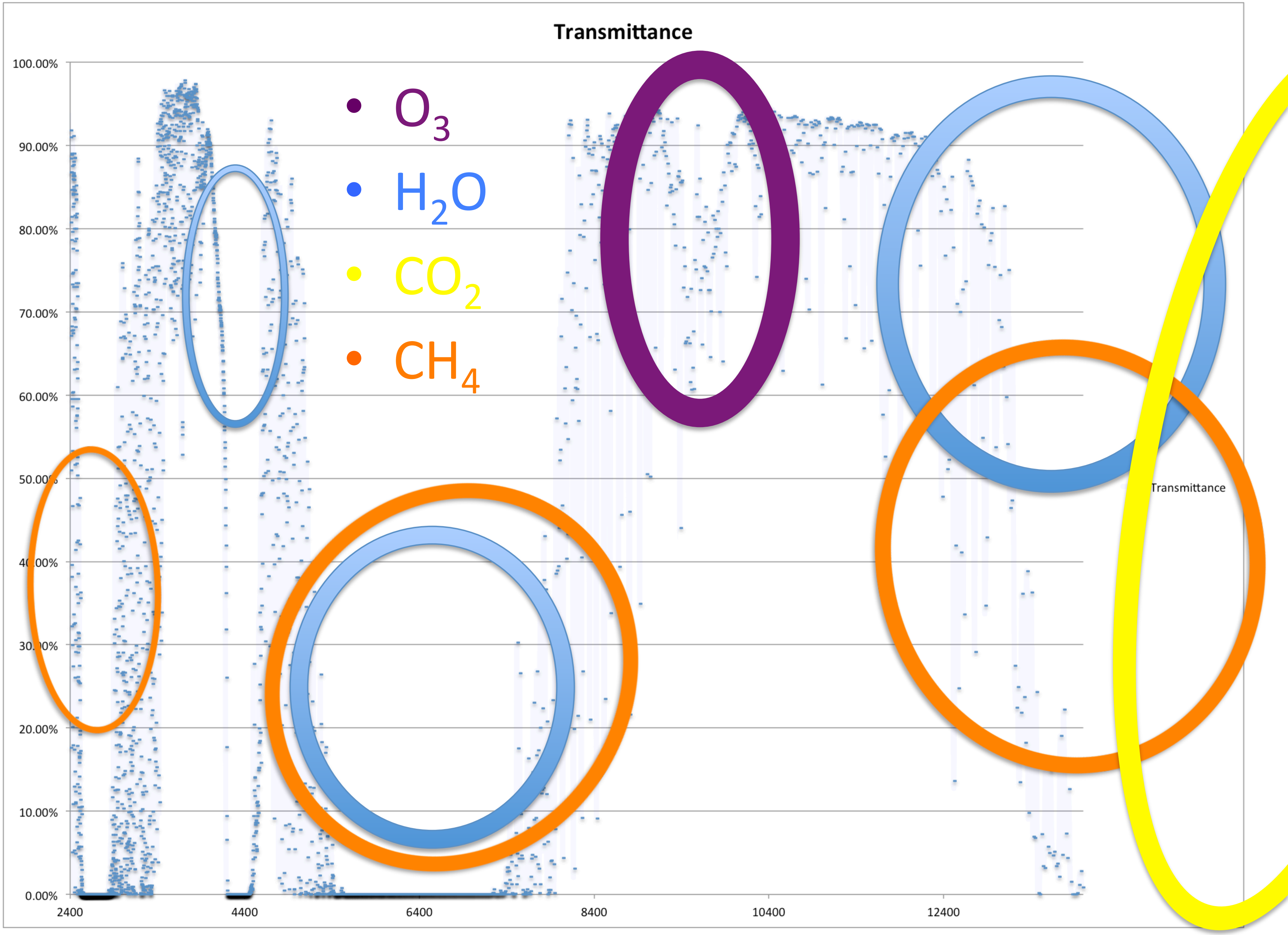
- Noisy, multisource portion of the EM spectrum
- Reflected *and* emitted terms
- Lower signal to noise ratios

Solving for temperature introduces additional complexities:

- Underdetermined problem mathematically
  - Have ‘n’ measurements, solving for ‘n+1’ terms

Contributions to Instrument Signal





Transmittance
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
2400
4400
6400
8400
10400
12400
O_3
H_2O
CO_2
CH_4
Transmittance

The thermal correction equation:

$$L_\lambda = [\varepsilon_\lambda B_\lambda(T_s) + (1-\varepsilon_\lambda)*L_{\lambda d}]*\tau_\lambda + L_{\lambda u}$$

…Or, equivalently…

$$[(L_\lambda - L_{\lambda u}) / \tau_\lambda] - (1-\varepsilon_\lambda)*L_{\lambda d} = \varepsilon_\lambda B_\lambda(T_s)$$

Where L_λ is the at sensor thermal radiance; ε_λ is an emissivity that we do not know, $B_\lambda(T_s)$ is the blackbody radiance at the surface temperature T_s; $L_{\lambda d}$ and $L_{\lambda u}$ are the downwelling and upwelling radiance from the atmosphere; and τ_λ is the transmittance from the ground to the sensor

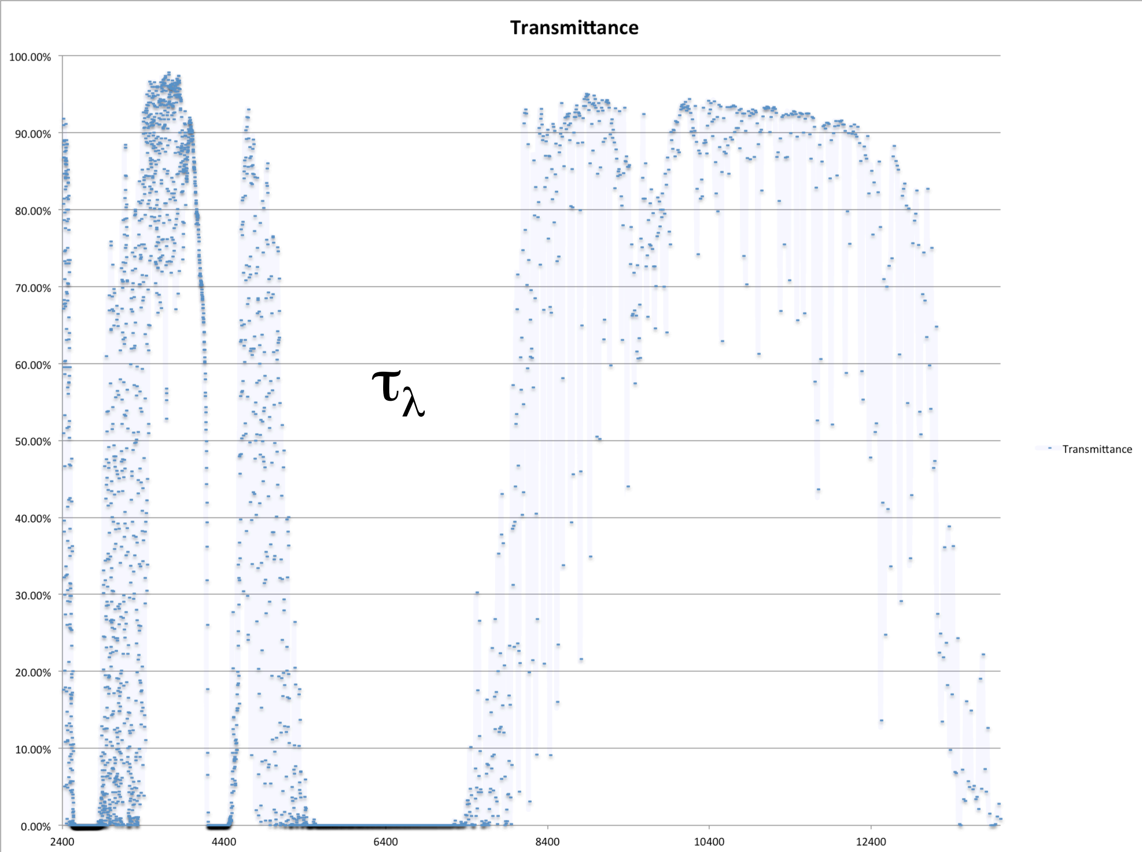
Considerations

$$L_\lambda = [\varepsilon_\lambda B_\lambda(T_s) + (1-\varepsilon_\lambda)*L_{\lambda d}]*\tau_\lambda + L_{\lambda u}$$

…Or, equivalently…

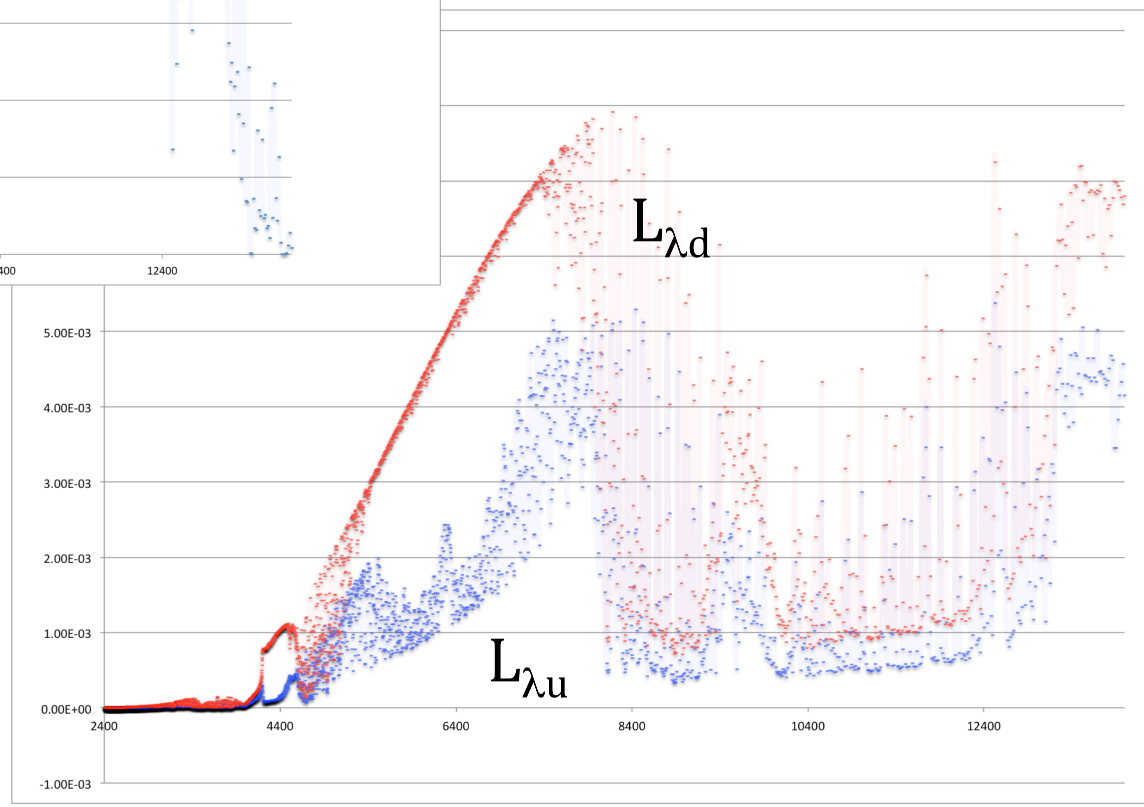
$$[(L_\lambda - L_{\lambda u}) / \tau_\lambda] - (1-\varepsilon_\lambda)*L_{\lambda d} = \varepsilon_\lambda B_\lambda(T_s)$$

- The surface temperature T_s is the only term that does not vary spectrally
- The at sensor radiance L_λ is the only term that is empirically acquired as part of data collection



...note we still do not have ε_λ

...or temperature...



From MODTRAN...

Estimating the Atmosphere: Thermal

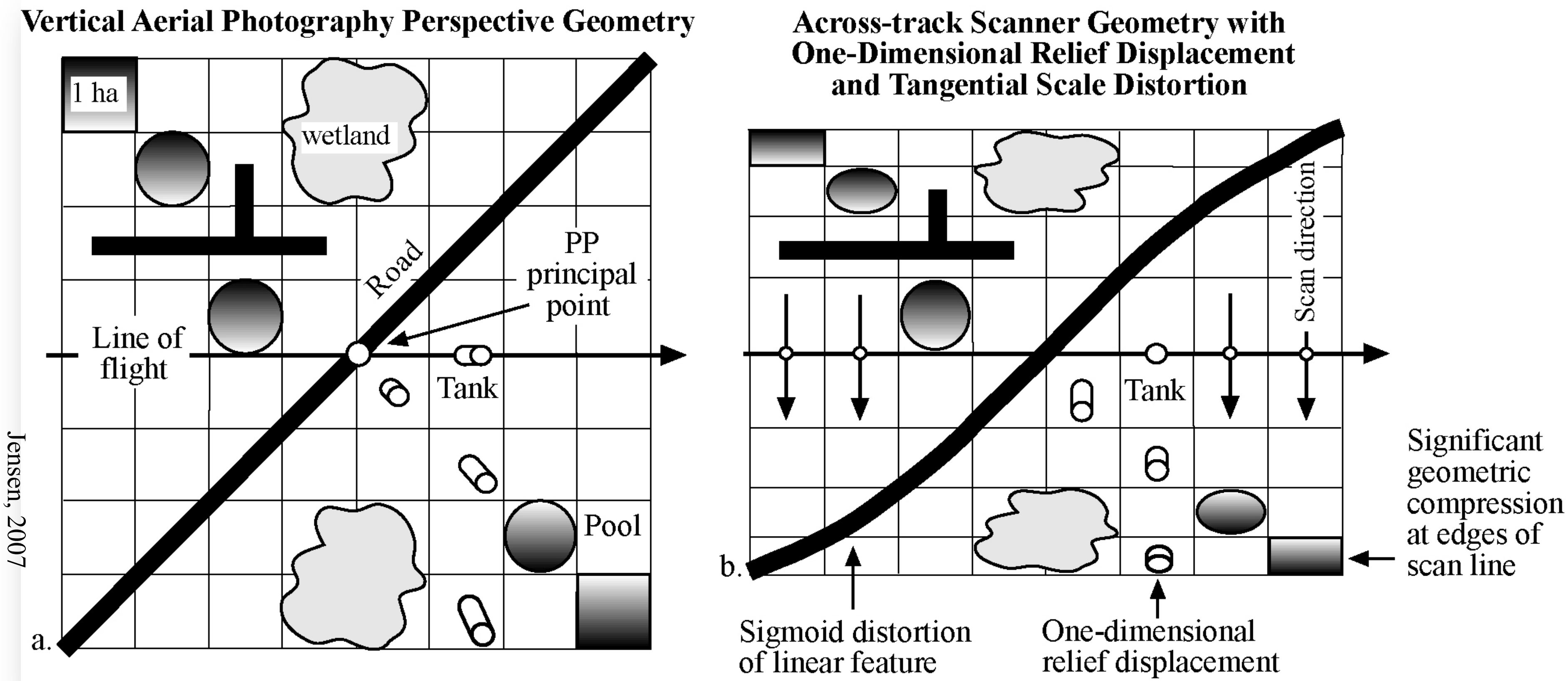
Same options as VSWIR:

- Get composition from external sources
  - Model data
  - *in situ* data
  - Other sensors, co-mounted on platform
    - MODIS and ASTER are co-mounted on Terra; VSWIR bands can be used to estimate water vapor, and used as input to the thermal atmospheric correction
- Direct inversion
  - Various absorption bands for atmospheric constituents

Solving for Emissivity

- Classification based
  - *a priori* knowledge based on classification
    - *i.e.,* emissivity of water is well known
    - Only works for emissive-invariant targets
  - Split window approach
- Invariant targets
  - Dual image acquisition: day and night
    - Assumes emissivity doesn't change diurnally (false for vegetation)
    - Two acquisitions result in 2*n observations for n+1 unknowns
- TES: Temperature Emissivity Seperation
  - Hybrid approach, relying on empirical regressions

Geometric Correction – Distortion



- Last quarter:
  - Yaw, pitch, roll (all types of imagery)
  - Photogrammetric effect: displacement from the principle plane

Computing pixel size

tan(angle)= opposite/adjacent

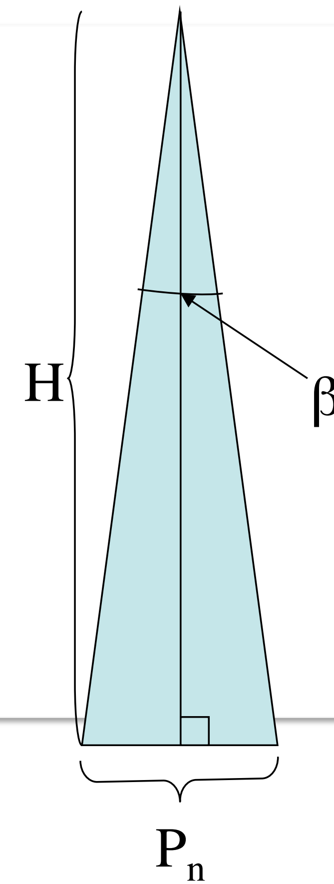
β = IFOV

P_n = pixel size at nadir

H = altitude of satellite

$\tan(\beta/2) = (P_n/2) / H$

$P_n = 2\ H \tan(\beta/2)$



Cross-track pixel size

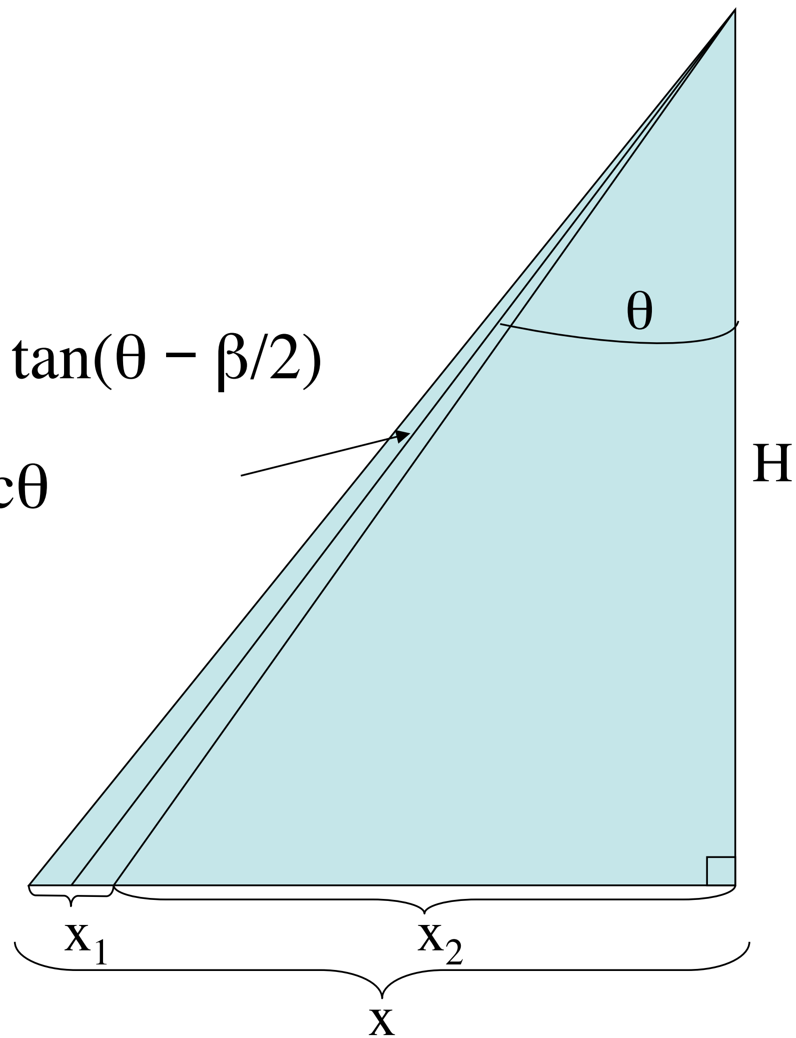
$x = H\tan(\theta + \beta/2)$

$x_2 = H\tan(\theta - \beta/2)$

$x_1 = x - x_2$

$P_c = H\tan(\theta + \beta/2) - H\tan(\theta - \beta/2)$

$H/\cos\theta = H\sec\theta$



Effect of Scan Angle

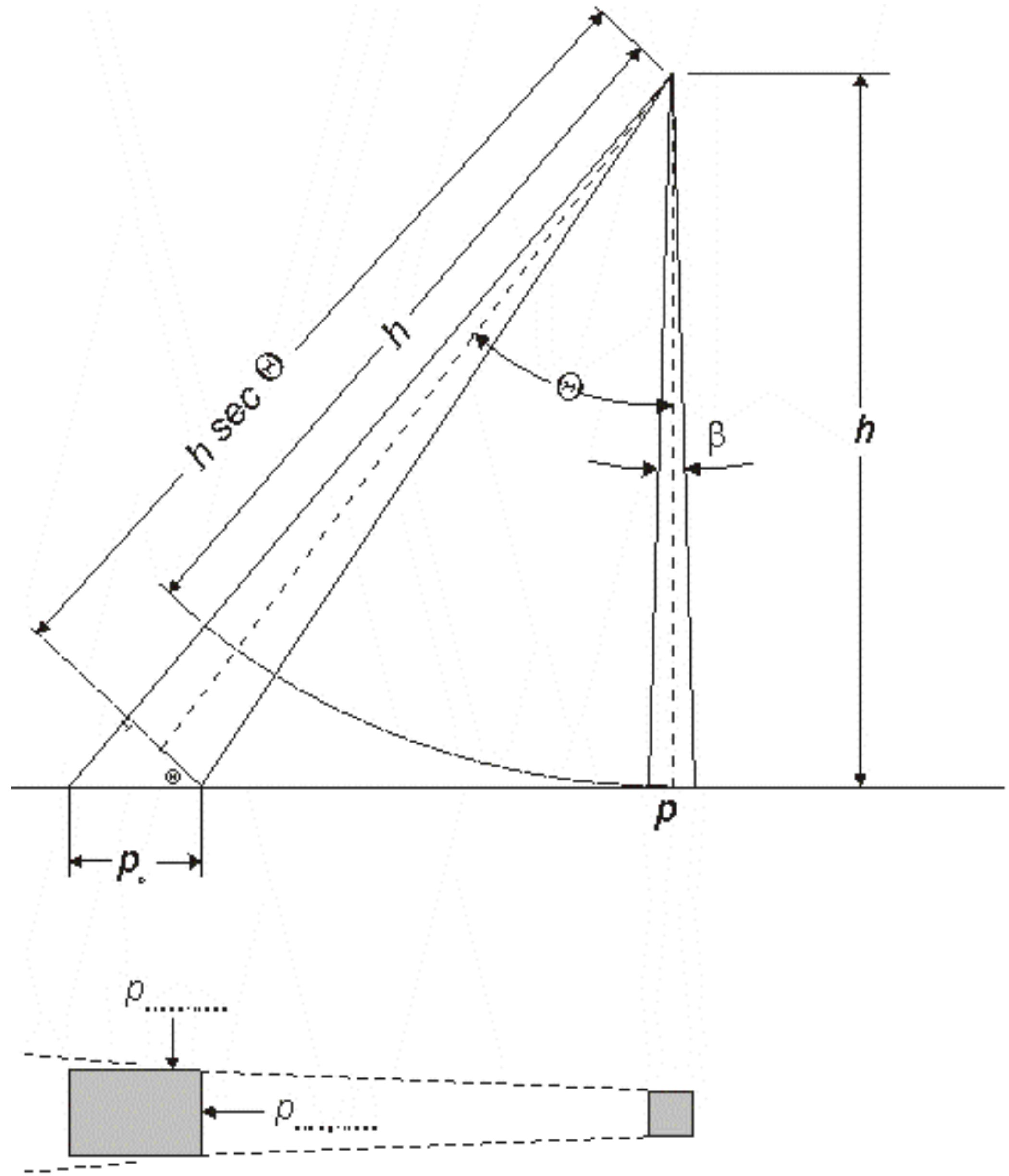
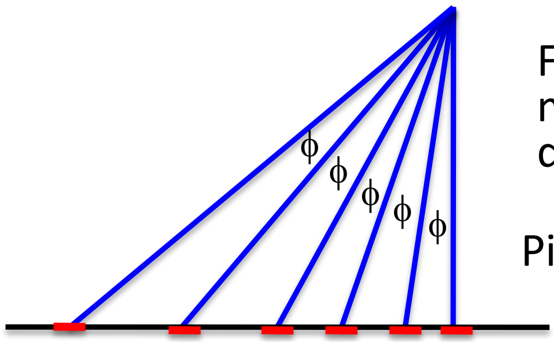


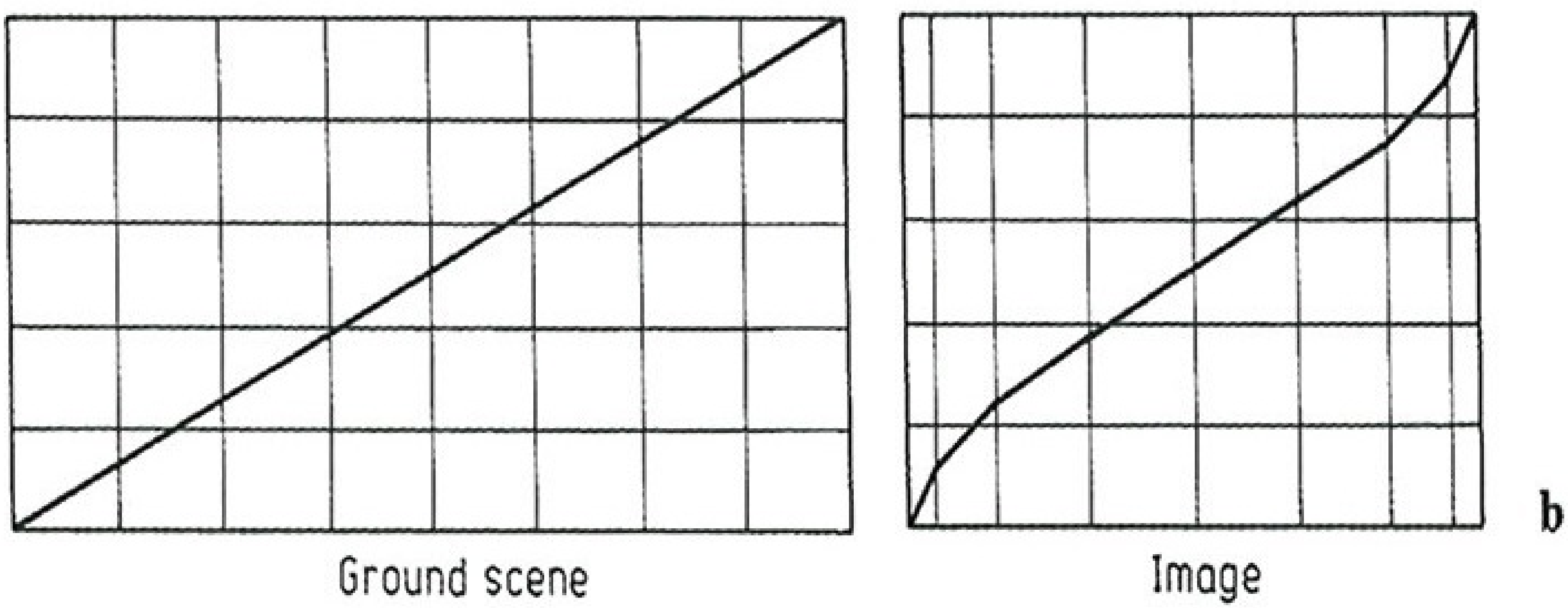
Image Edge Compression (S-Bend Distortion)



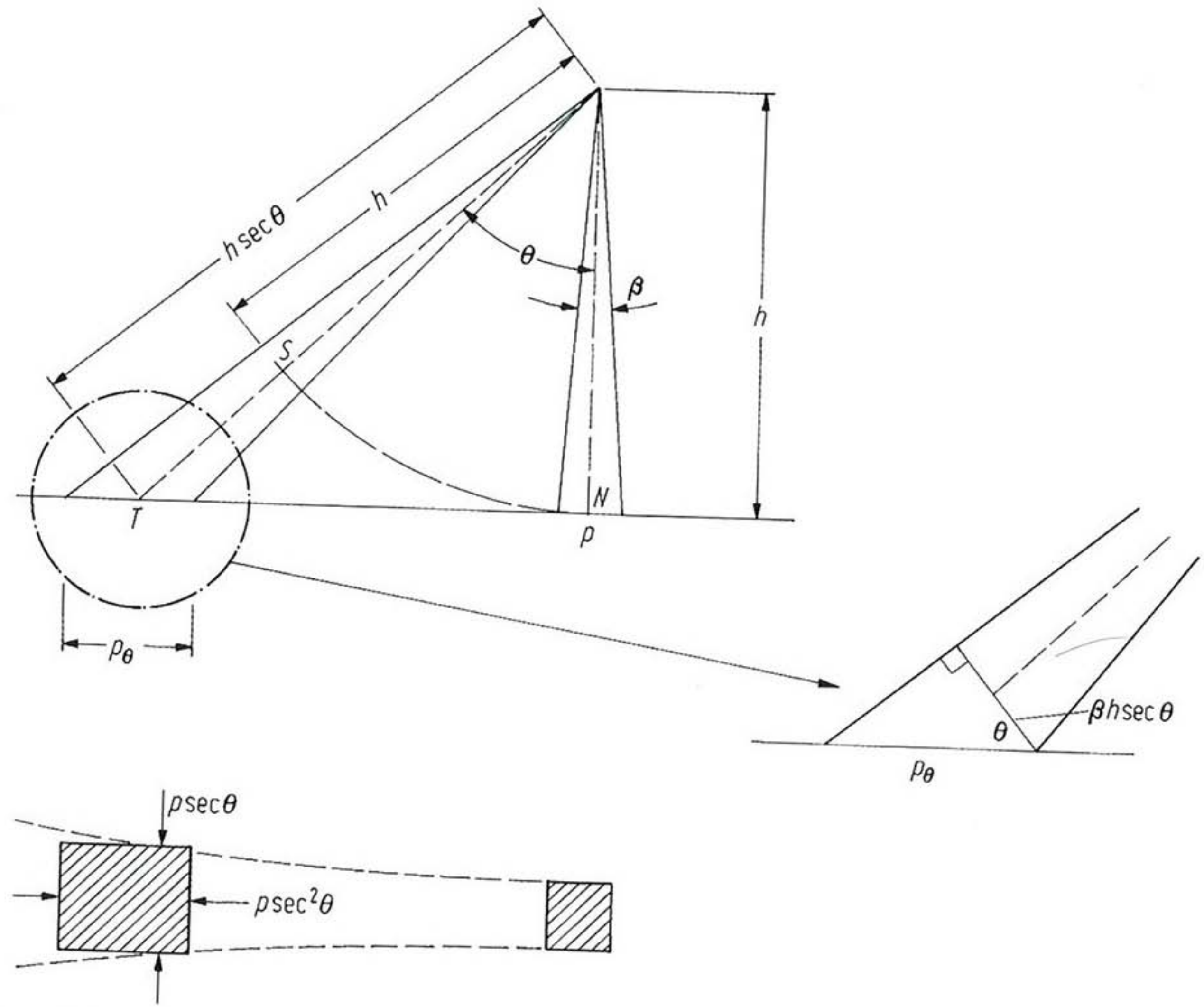
For constant angle increments (ϕ), pixels are offset more near the edge of a scan than near nadir (S-bend distortion)

Pixel spacing = $P/\cos^2\theta$

Resulting effect when pixels are placed on a uniform grid is cross-track compression



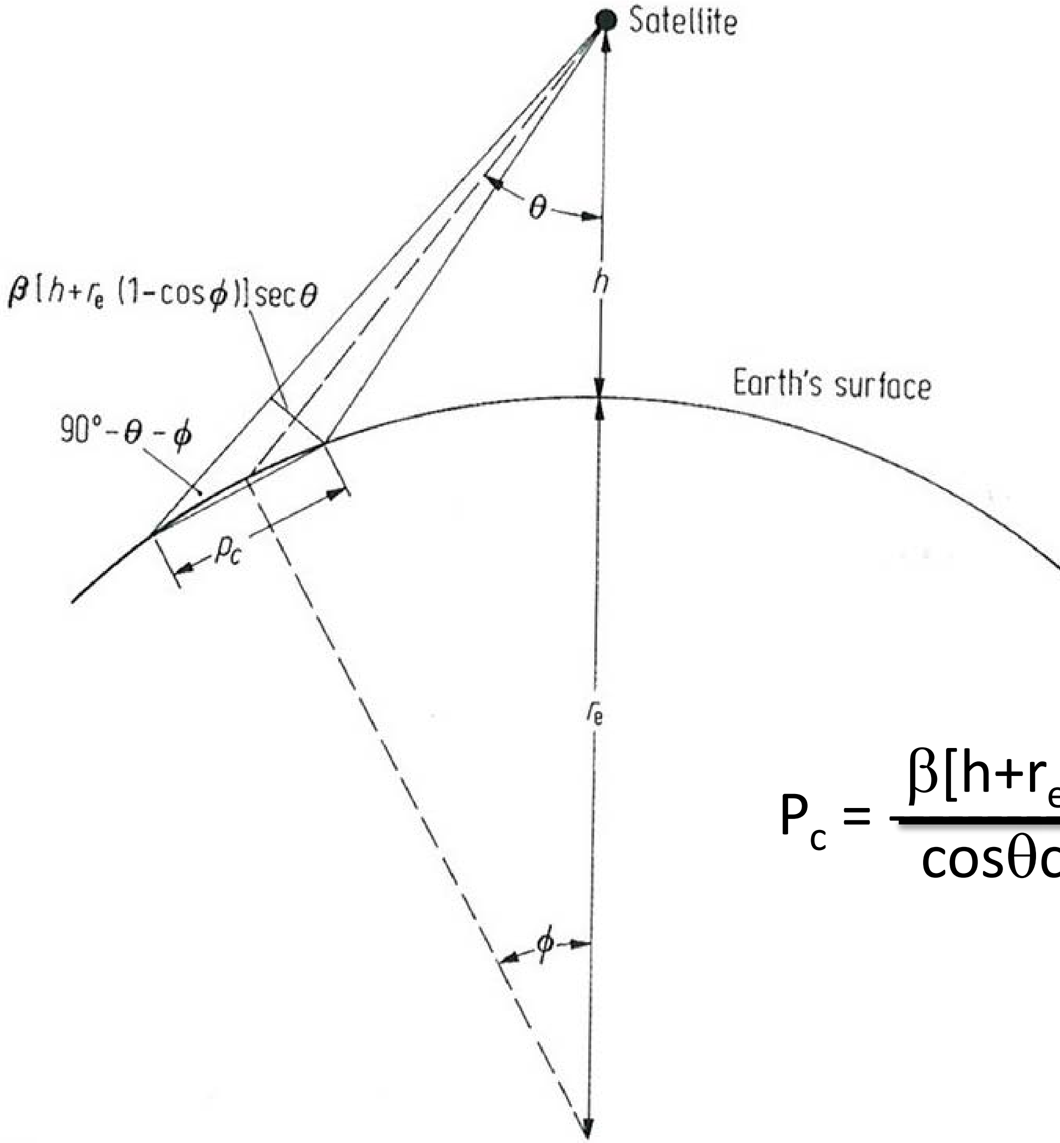
Distortion From Scan Geometry



- Pixels elongated significantly in the cross-track direction due to angular projection
- Pixels elongated slightly in the along-track direction due to increased distance from surface to sensor

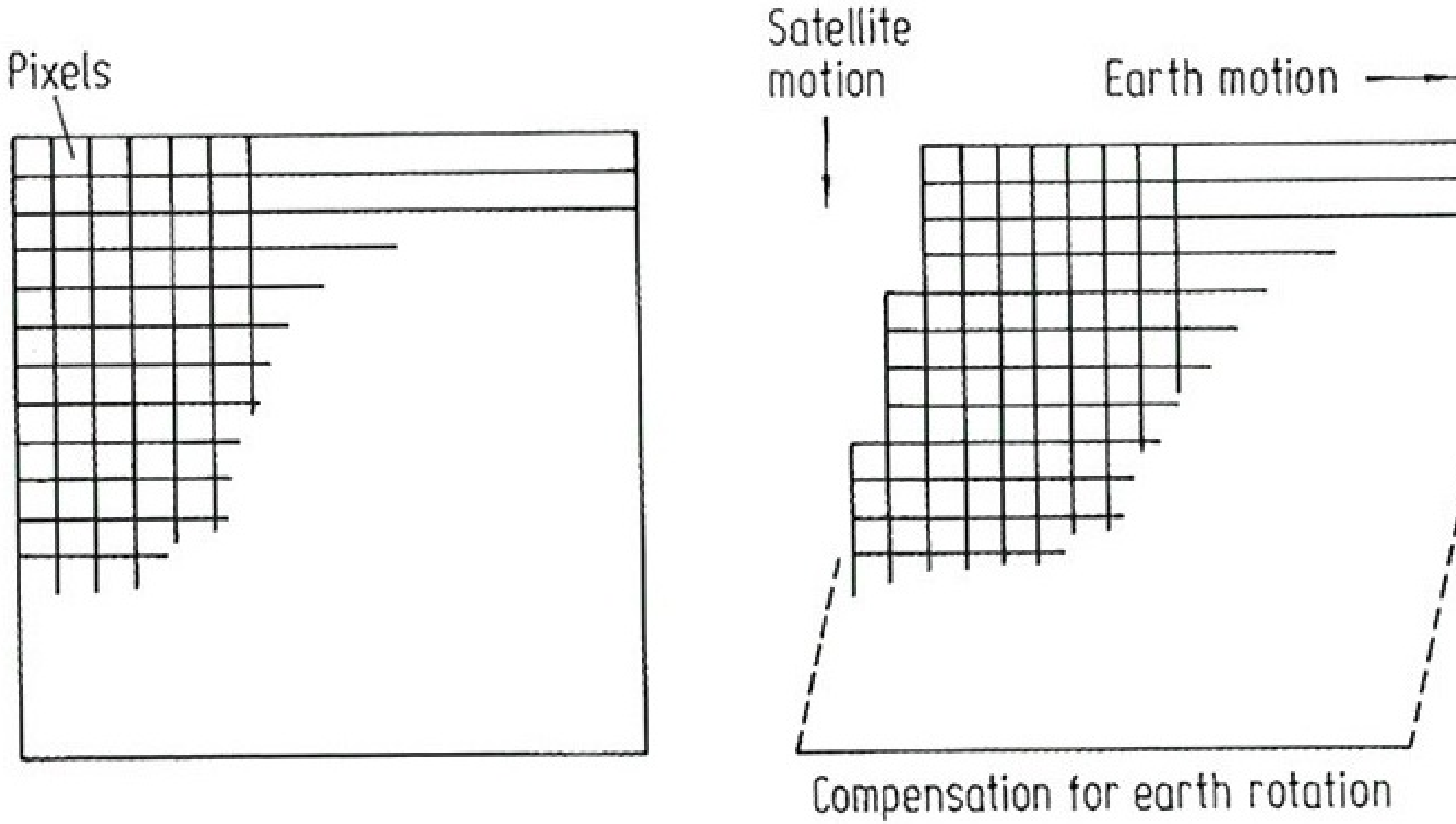
Additional effects: Satellites

Earth's Curvature



$$P_c = \frac{\beta[h+r_e(1-\cos\phi)]}{\cos\theta\cos(\theta+\phi)}$$

Earth Rotation Effect



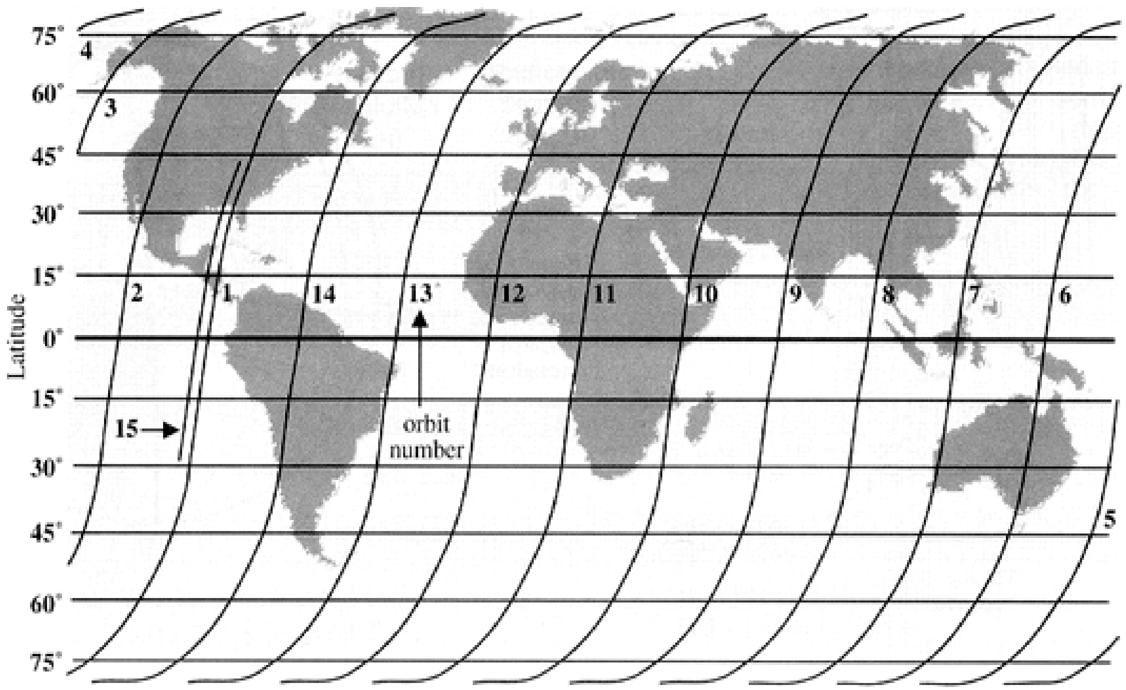
$v_e = \omega_e r_e \cos\lambda$ Surface velocity of the Earth

λ= 72.2 μrad/s; r_e = ~6378.1 km

At 40 Latitude, v_e = 355 m/s

Earth Rotation Effect at 40° Latitude

In the ~27.4 s it takes to acquire a Landsat scene, a point on the Earth's surface moves (Δx_e) 9.73 km, or 5.4% of the scene width



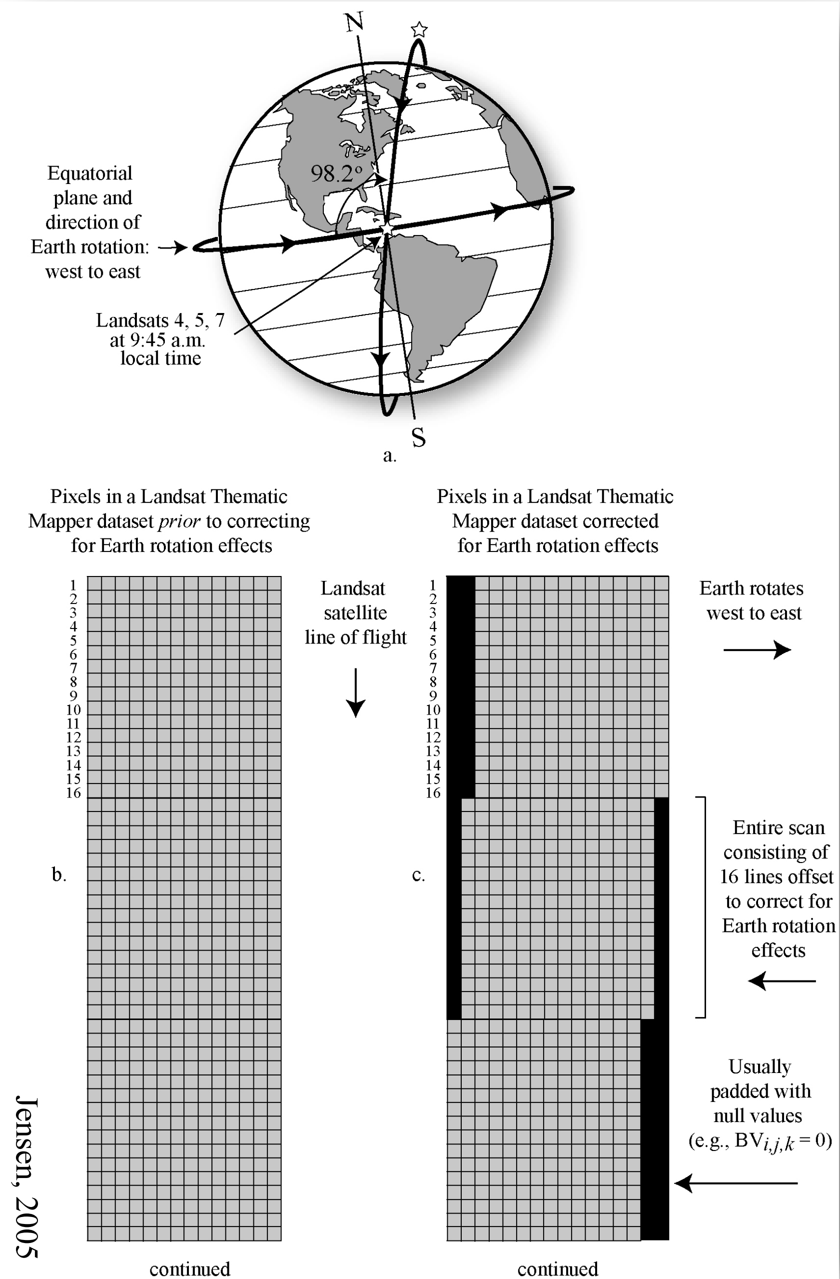
Orbital tracks of Landsat 1, 2, or 3 during a single day of coverage. The satellite crossed the equator every 103 minutes, during which time the Earth rotated a distance of 2,875 km under the satellite at the equator. Every 14 orbits, 24 hours clapsed.

$$\Delta x_e = v_e \quad \Delta T$$
$$= 355 \text{ m/s} \quad 27.4 \text{ s}$$
$$= 9727 \text{ m}$$

Accounting for ~13 angle N/S offset at 40 latitude associated with inclination:

$$\Delta_x = \Delta x_e \cos 13 \ = 9.48 \text{ km (5.3\% of scene width)}$$

Geometric Correction - Skew



- Landsat satellites 4, 5, and 7 are in a Sun-synchronous orbit with an angle of inclination of 98.2°.
    - Earth rotates on its axis from west to east as imagery is collected.
- pixels in three hypothetical scans (consisting of 16 lines each) of Landsat TM data.
    - matrix (raster) may look correct, it actually contains systematic geometric distortion caused by the angular velocity of the satellite in its descending orbital path
- result of adjusting (*deskewing*) the original Landsat TM data to the west to compensate for Earth rotation effects
- Landsats 4, 5, and 7 use a bidirectional cross-track scanning mirror.

Geometric Correction

Why geometric correction?

•Geometric correction allows remote sensing–derived information to be **related** to other thematic information in geographic information systems (GIS)

•Geometrically corrected imagery can be used to extract accurate distance, polygon area, and direction (bearing) information

•Two methods for correcting the types of the type of geometric distortion that we've discussed:

- Mathematical Modeling
- Empirical Registration

Mathematical Modeling

- Earth Rotation Skew Correction

$$\begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} 1 & \alpha \\ 0 & 1 \end{bmatrix} \begin{bmatrix} u \\ v \end{bmatrix} \qquad \begin{bmatrix} u \\ v \end{bmatrix} = \begin{bmatrix} 1 & -\alpha \\ 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix}$$

- North/South Orientation for an angle ζ

$$\begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} \cos\zeta & \sin\zeta \\ -\sin\zeta & \cos\zeta \end{bmatrix} \begin{bmatrix} u \\ v \end{bmatrix} \qquad \begin{bmatrix} u \\ v \end{bmatrix} = \begin{bmatrix} \cos\zeta & -\sin\zeta \\ \sin\zeta & \cos\zeta \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix}$$

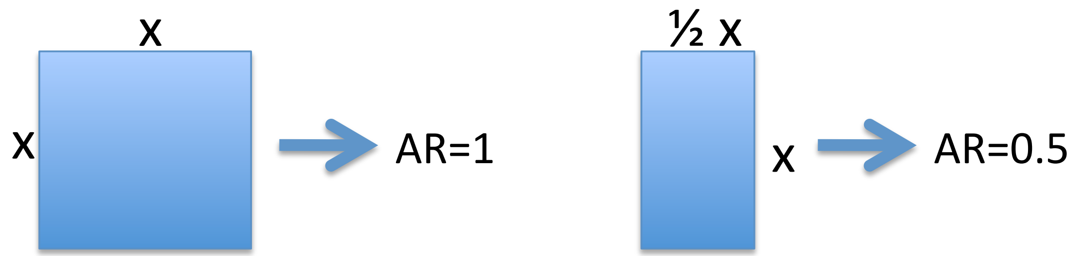
- Combined corrections for aspect ratio and Earth rotation skew

$$\begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} 0.709 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & \alpha \\ 0 & 1 \end{bmatrix} \begin{bmatrix} u \\ v \end{bmatrix}$$

…Additional Geometric Correction Slides…

Mathematical Modeling: Example
Aspect Ratio Distortion Correction

- Aspect Ratio: relative vertical and horizontal scales (width/heigh)



- Samples are sometimes acquired too quickly across a scan line compared to the instrument IFOV
  - e.g. Landsat MSS acquires pixels at 56 m intervals with an IFOV of 79 m
  - Landsat effective pixel size is 79 m x 56 m (along-track × across-track)
  - Image displayed on a square grid will be too wide for its height
  - Have to compress in width by a factor of 79/56 or 1.411
  - Another example is aircraft moving too slow or too fast compared to cross-track scan

Explicit Mapping Functions

- Ideally, we would like to know the function that allows us to map from known locations to image locations (x,y to u,v)

- Usually we don't, so we have to determine them by matching distinct features in image, to known location on map, e.g. Road intersections, bends in rivers, coastline features, etc.
  - ground-control points (GCPs)

- Generally chosen as simple polynomials of the first, second, or third degree
  - Requires 3, 6, and 10 GCPs respectively

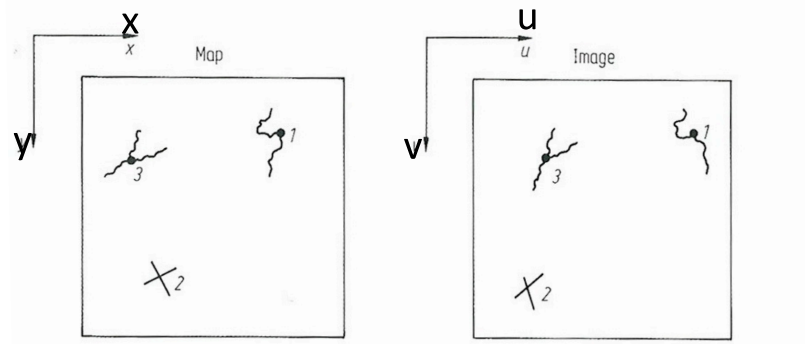


Fig. 2.12. Coordinate systems defined for the image and map, along with the specification of ground control points

$$u = a_0 + a_1x + a_2y + a_3xy + a_4x^2 + a_5y^2$$

$$v = b_0 + b_1x + b_2y + b_3xy + b_4x^2 + b_5y^2$$

Correction of Geometric Distortion

- Mapping Polynomials for Image Projection
  - Assumes geometrically correct map of image region is available
  - Need to map known locations (map) to corresponding locations in image

$$u = f(x,y)$$
$$v = g(x,y)$$

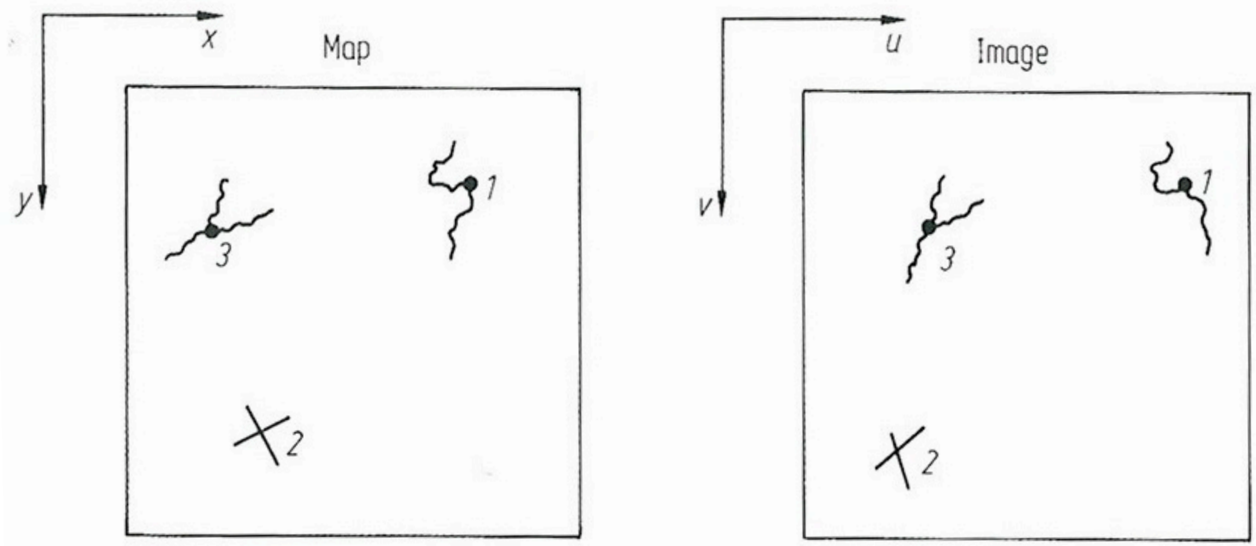
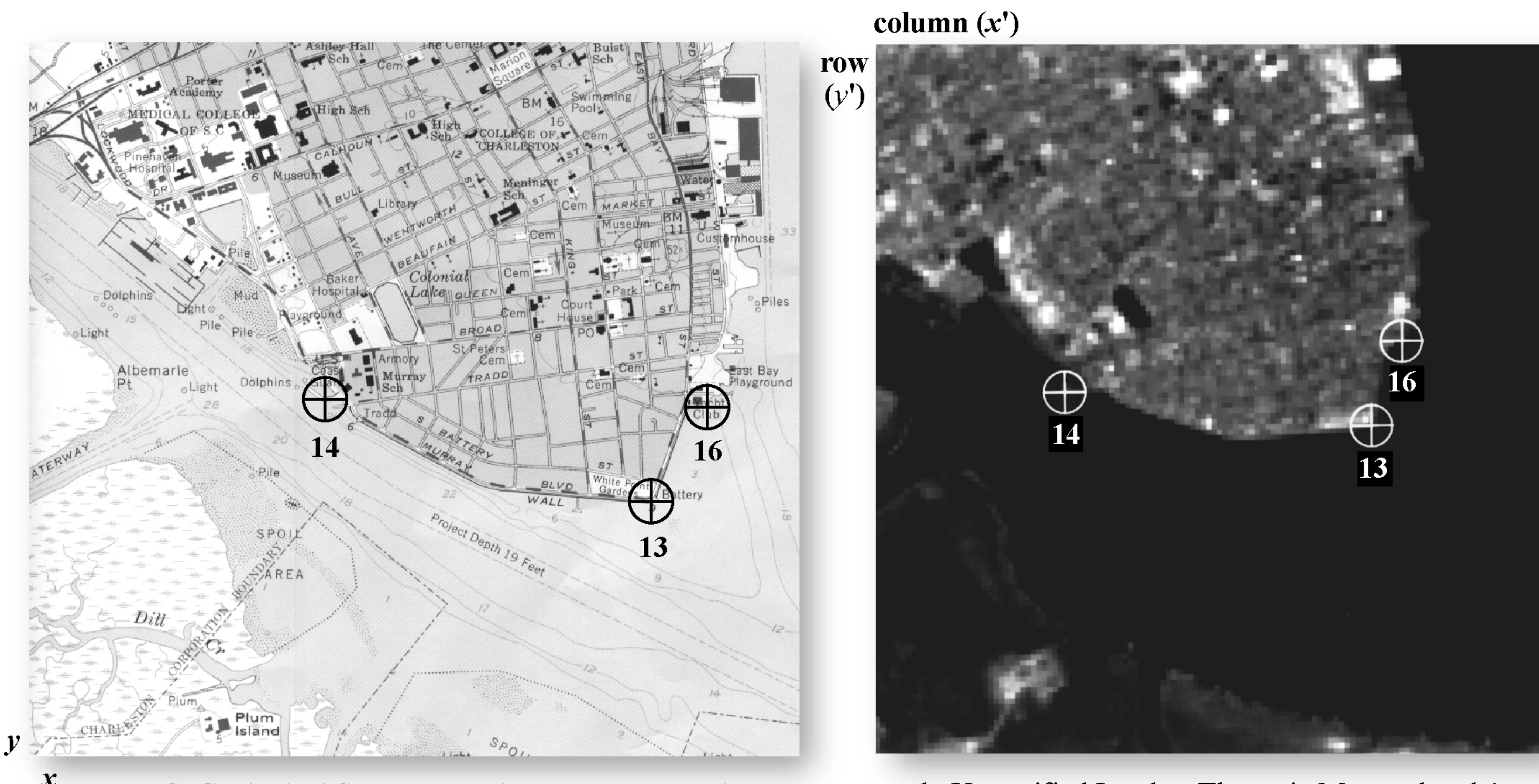


Fig. 2.12. Coordinate systems defined for the image and map, along with the specification of ground control points

Geometric Correction – Ground Control Point

Selecting Ground Control Points for Image-to-Map Rectification



a. U. S. Geological Survey 7.5-minute 1:24,000-scale topographic map of Charleston, SC, with three ground control points identified.

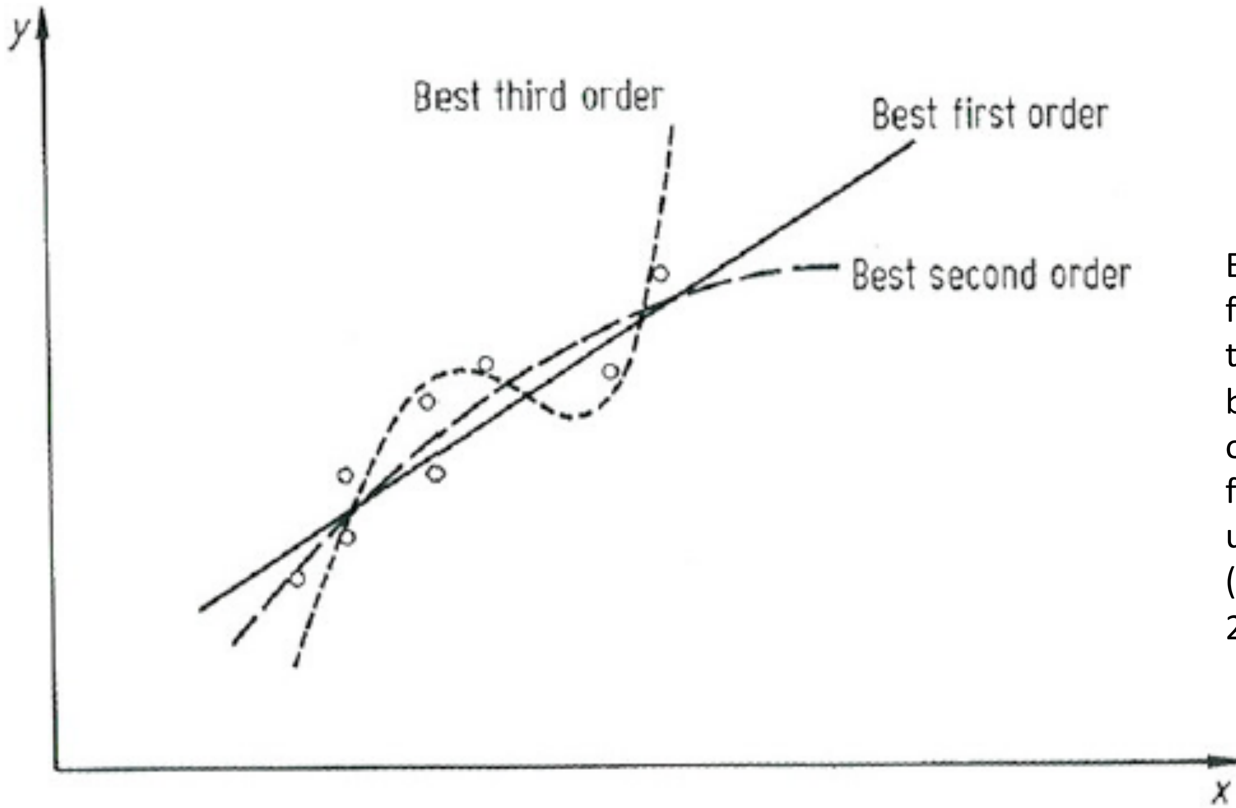
b. Unrectified Landsat Thematic Mapper band 4 image obtained on November 9, 1982.

Jensen, 2007

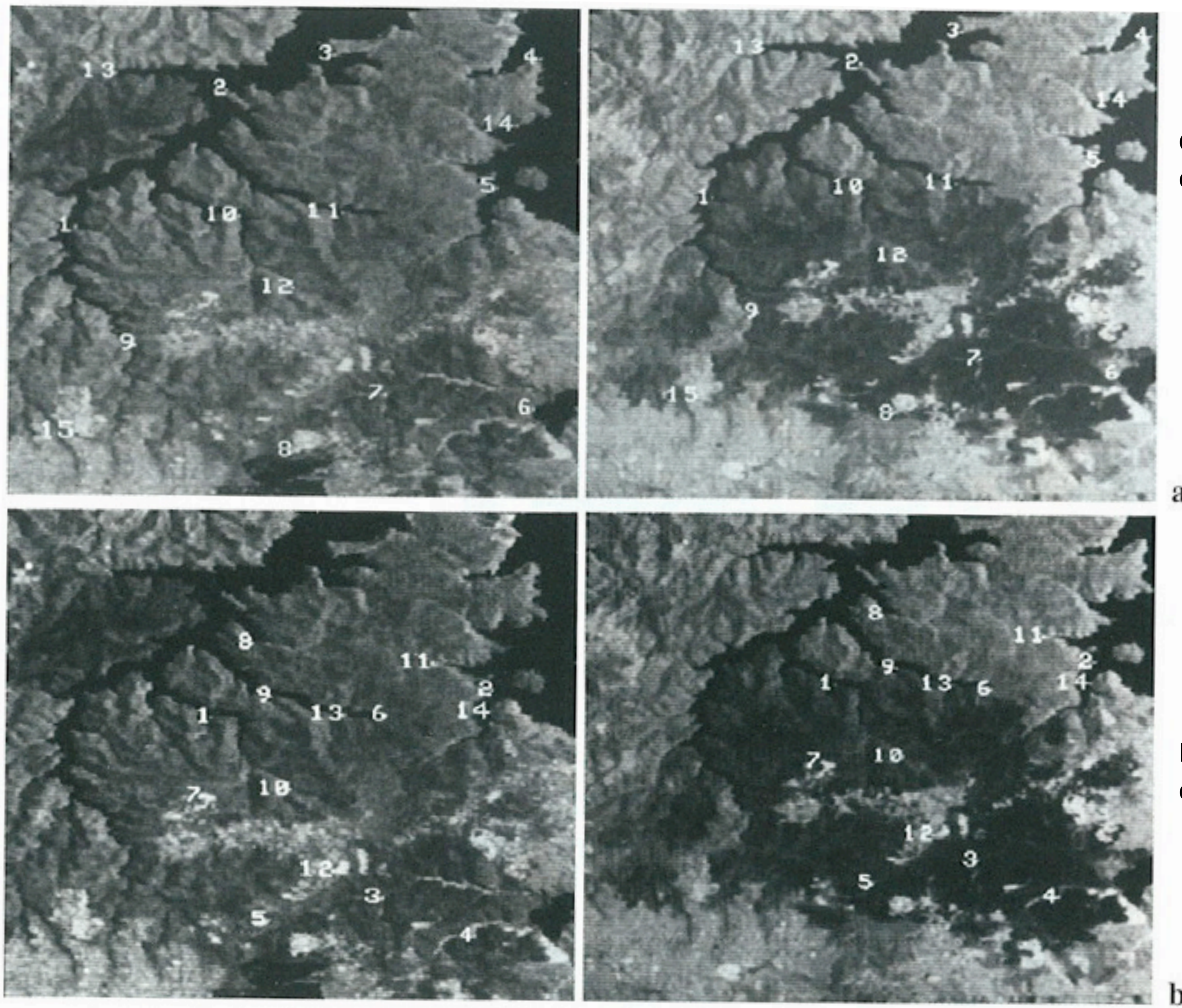
a) U.S. Geological Survey 7.5-minute 1:24,000-scale topographic map of Charleston, SC, with three ground control points identified (13, 14, and 16) in UTM coordinates.
b) Unrectified 11/09/82 Landsat TM band 4 image with the three ground control points identified. The image GCP coordinates are measured in rows and columns.

Choice of Control Points

- Sufficient number of well-defined control points needed to ensure generation of accurate mapping polynomials
- Must be sufficiently distributed so as to represent the full image and avoid large extrapolation errors.



Example of curve fitting to reinforce the potentially poor behavior of high order mathematical functions when used to extrapolate (Richards and Jia, 2006, Fig. 2.15)



Good point distribution

Bad point distribution

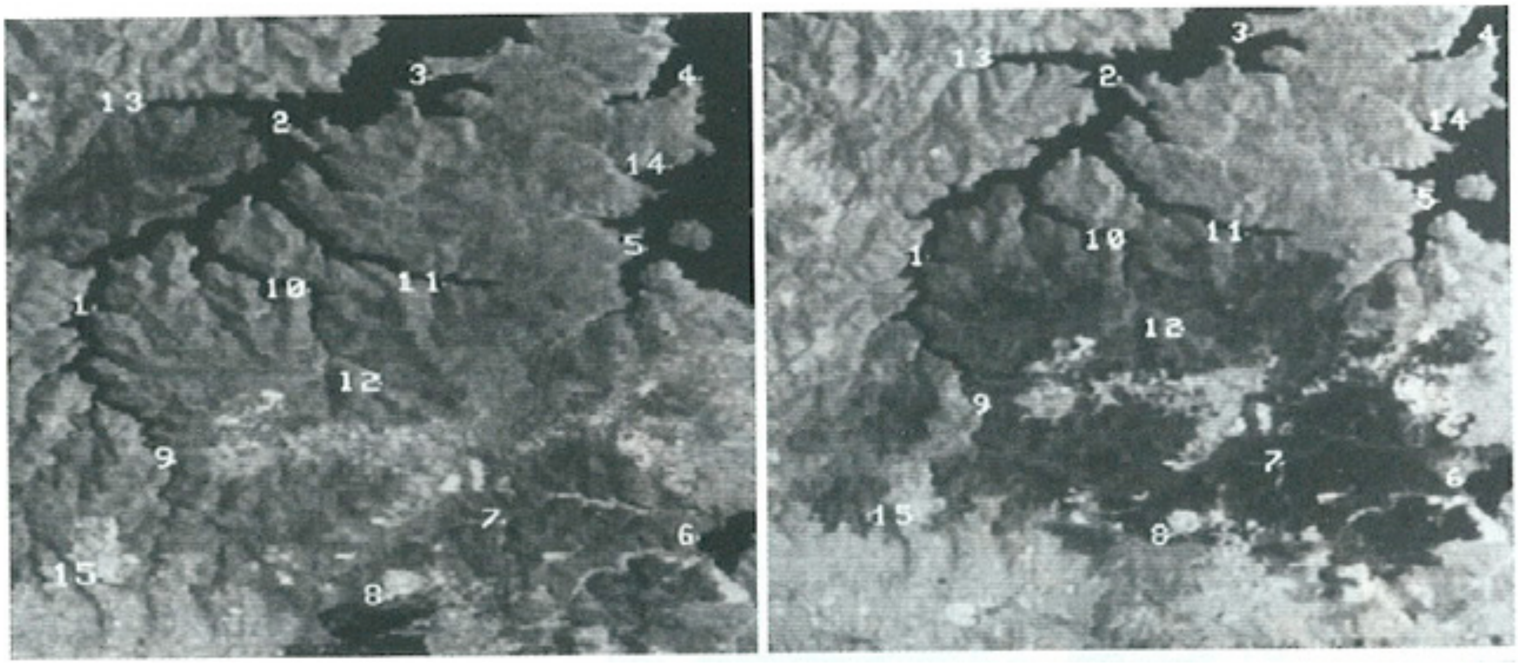
Fig. 2.17. Control points used in image to image registration example. **a** Good distribution **b** Poor distribution

Image Registration

- Georeferencing: registration of an image to a known map coordinate system
  - Pixels addressable in map coordinates such as lats and lons or Eastings or Northings
  - Enables comparisons to other data types registered similarly

- Image to image Registration
  - Multiple images registered to a single map
  - Image pairs registered to one another
    - Requires fewer steps
    - Relationships to only between image pairs or sets (not georeferenced to a geodetic coordinate system)
  - One image chosen as reference (master) image that remains unchanged; other (slave) images are "corrected" to match features to the reference image

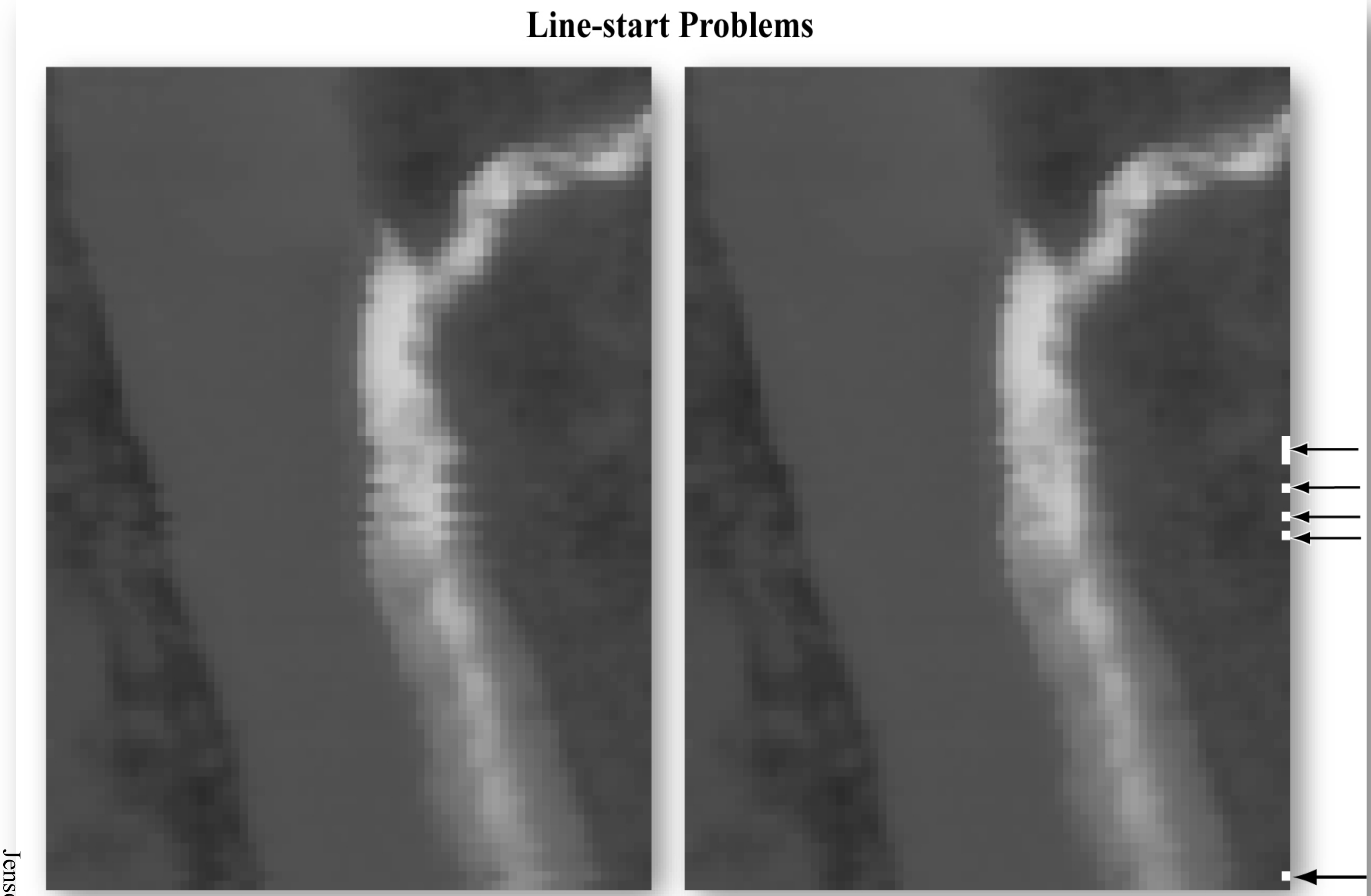
Image Registration



Line-start Problems I

- Occasionally, scanning systems fail to collect data at the beginning of a scan line
- Easy & fast to correct for, if we know where it occurs, but difficult & time consuming if random
- **A considerable amount of MSS data collected by Landsat 2 and 3 exhibit line-start problems.**

Line-start Problems II



a. Predawn thermal infrared imagery of the Savannah River with line-start problems.

b. Seven line-start problem lines were translated one column to the left.

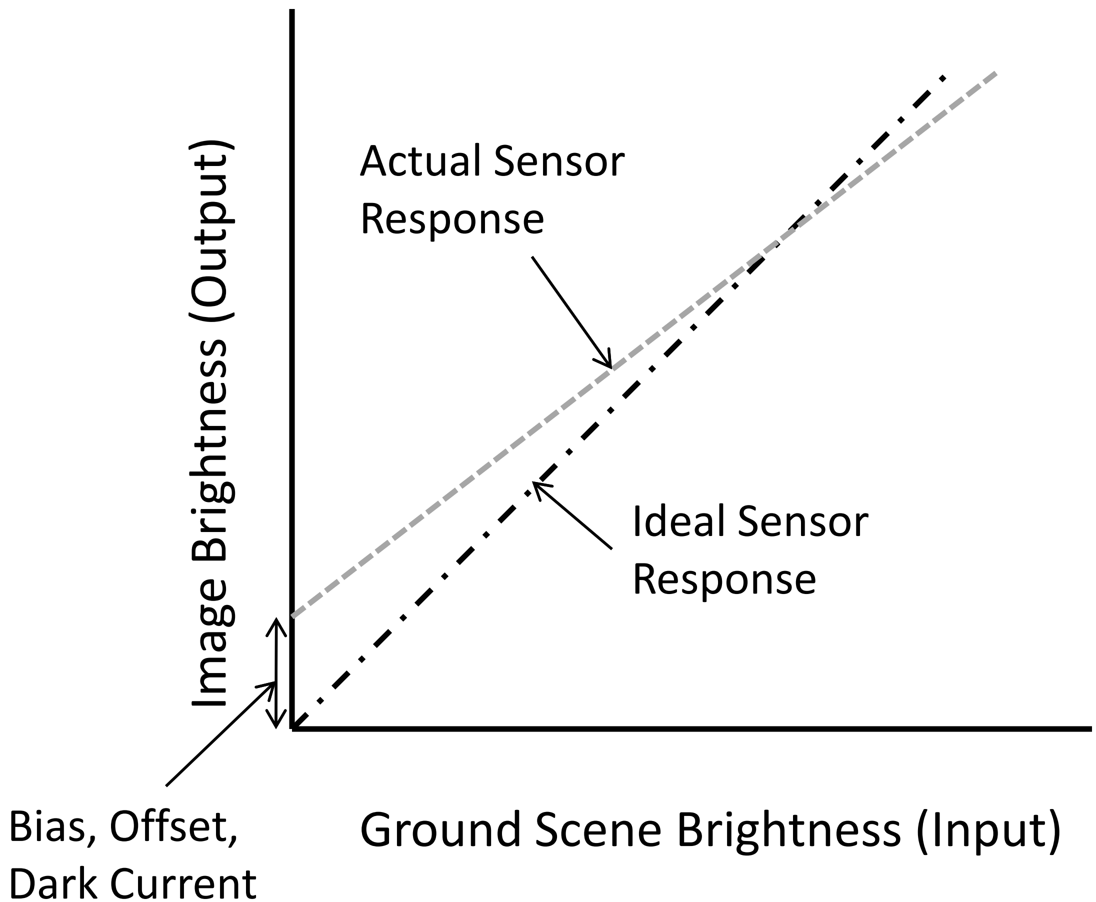
Jensen, 2005

n-line striping I

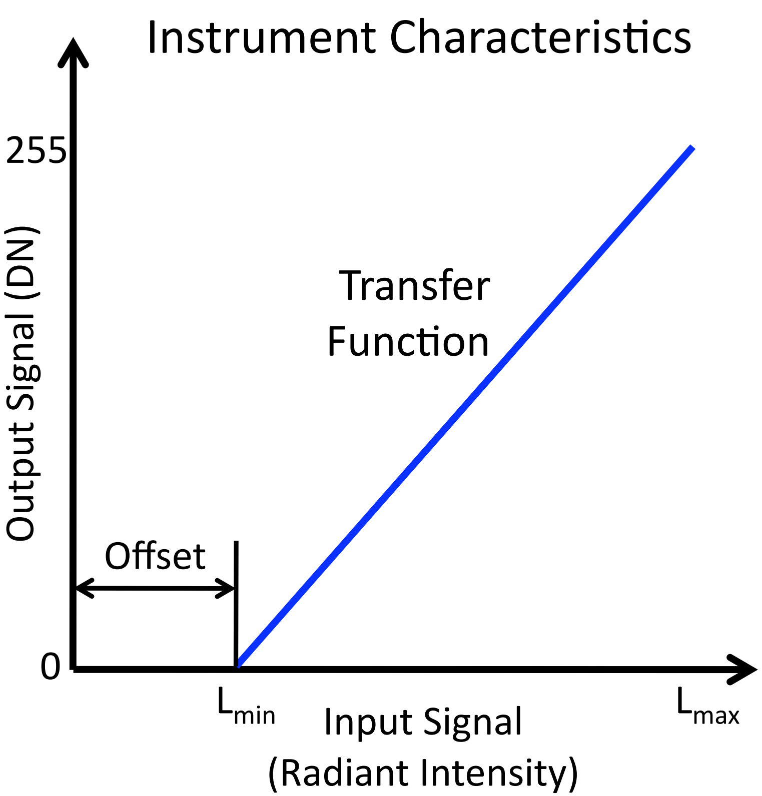
- Sometimes a detector does not fail completely, but simply goes out of radiometric adjustment
  - For example, spectral measurements may be uniformly 20 brightness values greater than the other detectors for the same band
- This results in systematic, noticeable lines that are brighter than adjacent lines: ***n-line striping***

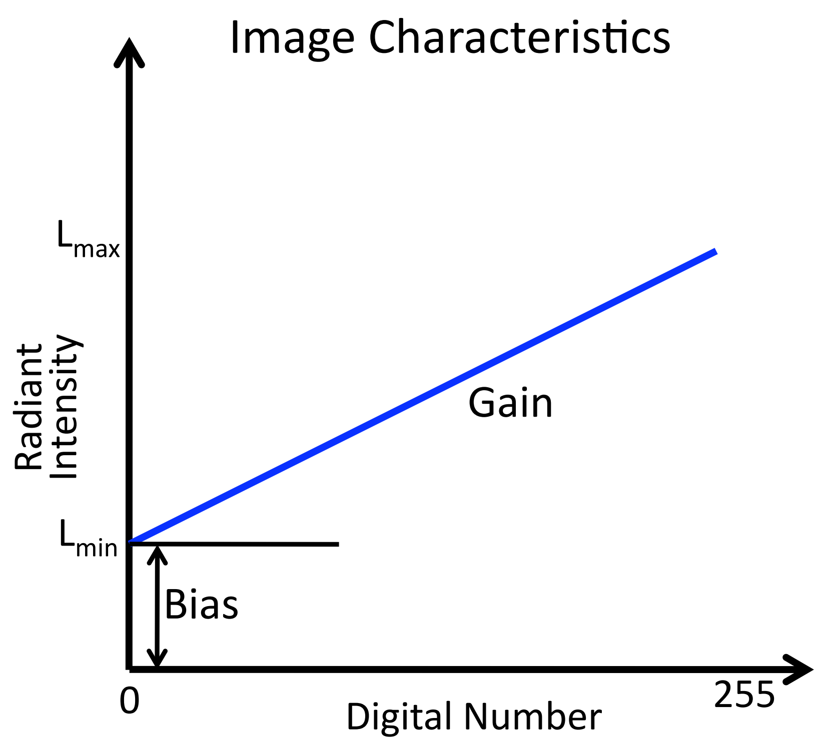
- *To repair:* First identify miscalibrated scan lines in the scene by computing a histogram of the values for each of the *n* detectors that collected data over the entire scene, preferable over a homogeneous area, such as a body of water
- If one detector's mean or median is significantly different from the others, it is probable that this detector is out of adjustment
- every line and pixel in the scene recorded by the maladjusted detector may require a *bias* (additive or subtractive) correction or a more severe *gain* (multiplicative) correction.
- This type of *n-line striping* correction a) adjusts all the bad scan lines so that they have approximately the same radiometric scale as the correctly collected data and b) improves the visual interpretability of the data.

Gain and Offset (Bias)



Apparent Surface Temperature

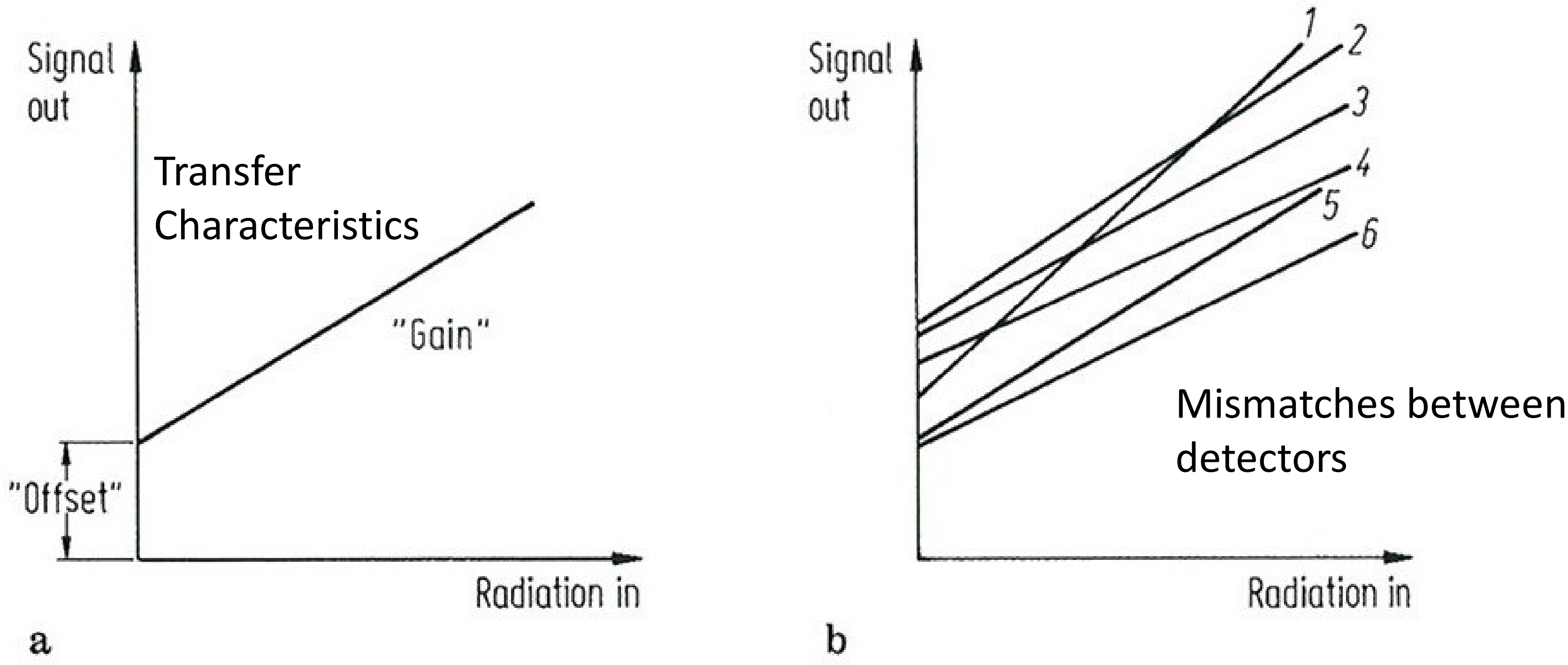




Radiometric Resolution/
Dynamic Range

L = Bias + (Gain × DN)

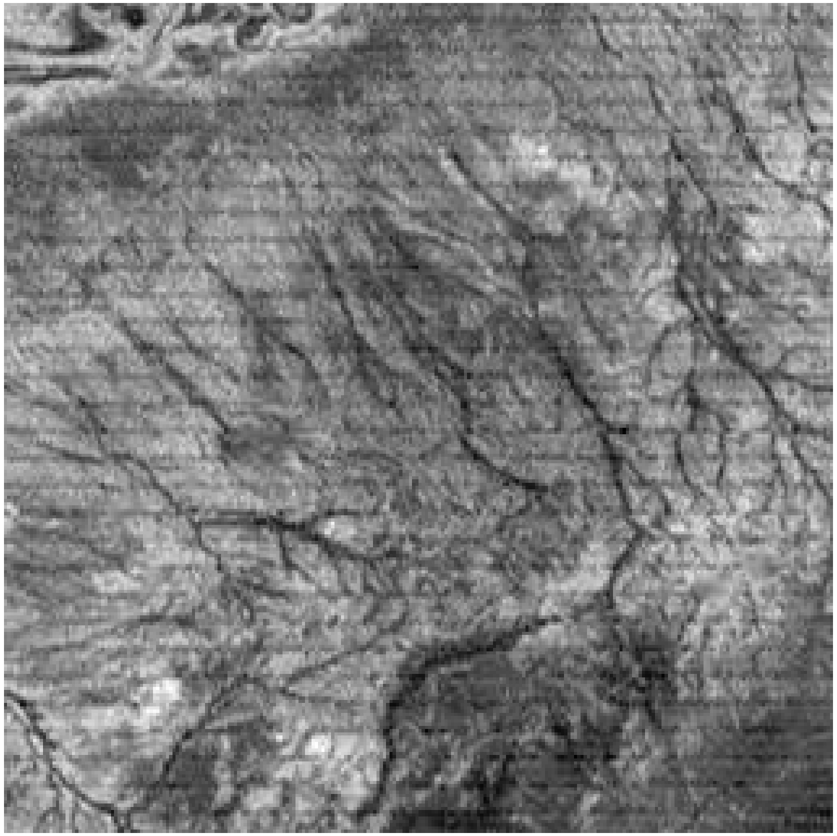
Striping



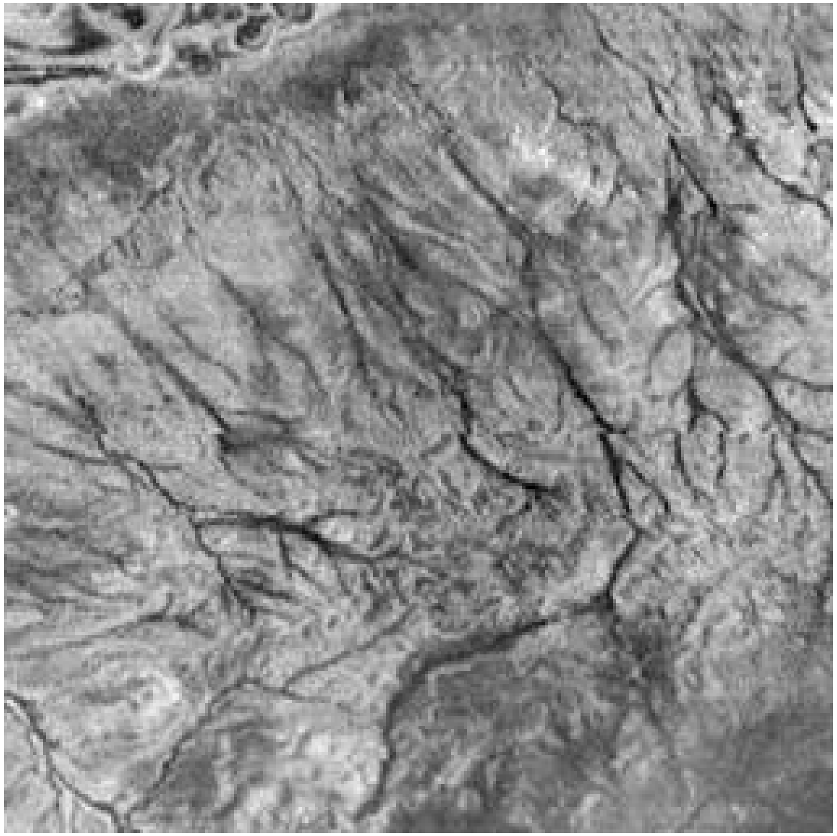
- Ideal radiation detector has a consistent transfer function (radiation in → radiation out)
- In reality, different detectors have different transfer functions
  - Same irradiance causes different brightnesses in different detectors
  - 6 detectors on MSS/band, 16 on TM, 6000 on SPOT HRV

Destriping

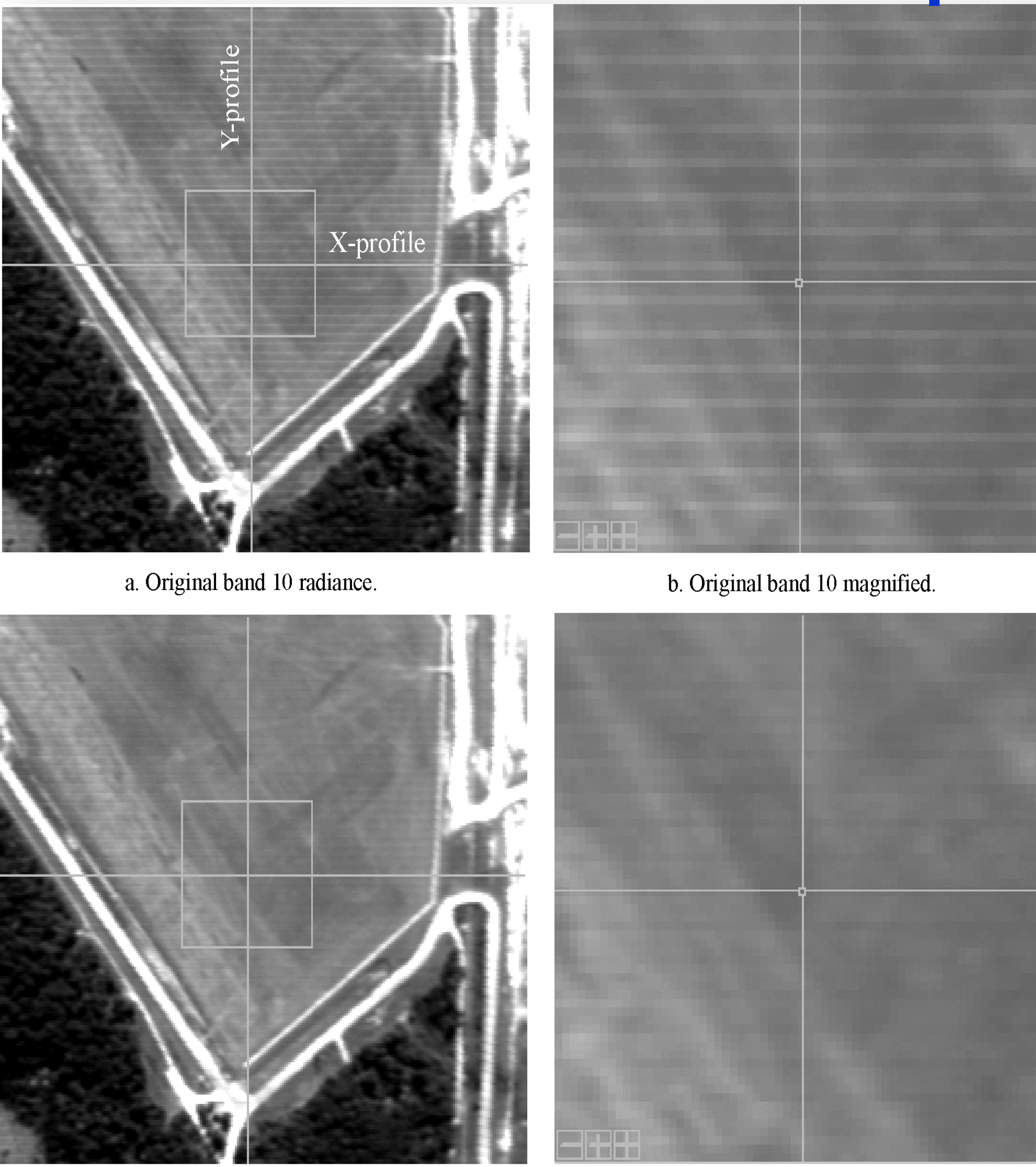
Original Band 1



Band 1 after destriping



n-line striping III



a. Original band 10 radiance.

b. Original band 10 magnified.

c. Destriped band 10 radiance.

d. Destriped band 10 magnified.

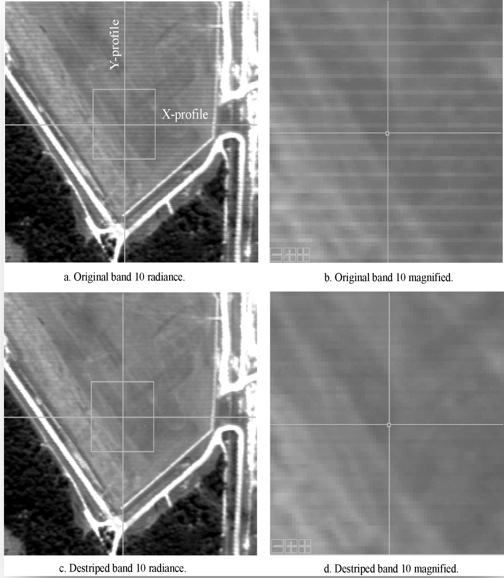
a) Original band 10 radiance (W m^{-2} sr^{-1}) data from a GER DAIS 3715 hyperspectral dataset of the Mixed Waste Management Facility on the Savannah River Site near Aiken, SC. The subset is focused on a clay-capped hazardous waste site covered with Bahia grass and Centipede grass. The 35-band dataset was obtained at 2 × 2 m spatial resolution.

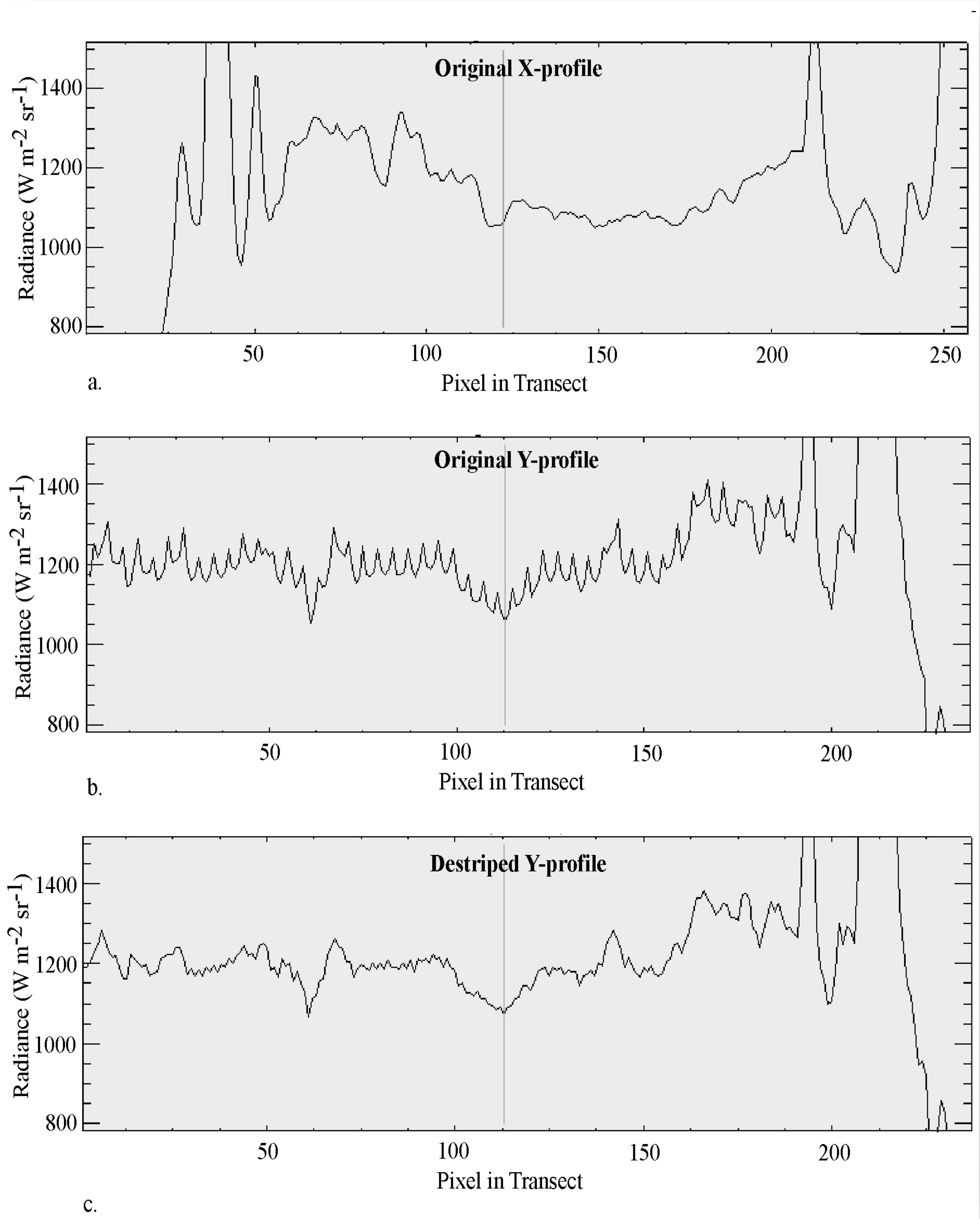
b) Enlargement of band 10 data.

c) Band 10 data after destriping.

d) An enlargement of the destriped data

n-line striping IV





a) The radiance values along the horizontal (*X*) profile of the original band 10 radiance values
b) The radiance values along the vertical (*Y*) profile of the original band 10 radiance values
c) The radiance values along the vertical (*Y*) profile of the destriped band 10 radiance values. Note the reduction of the saw-toothed pattern in the destriped data