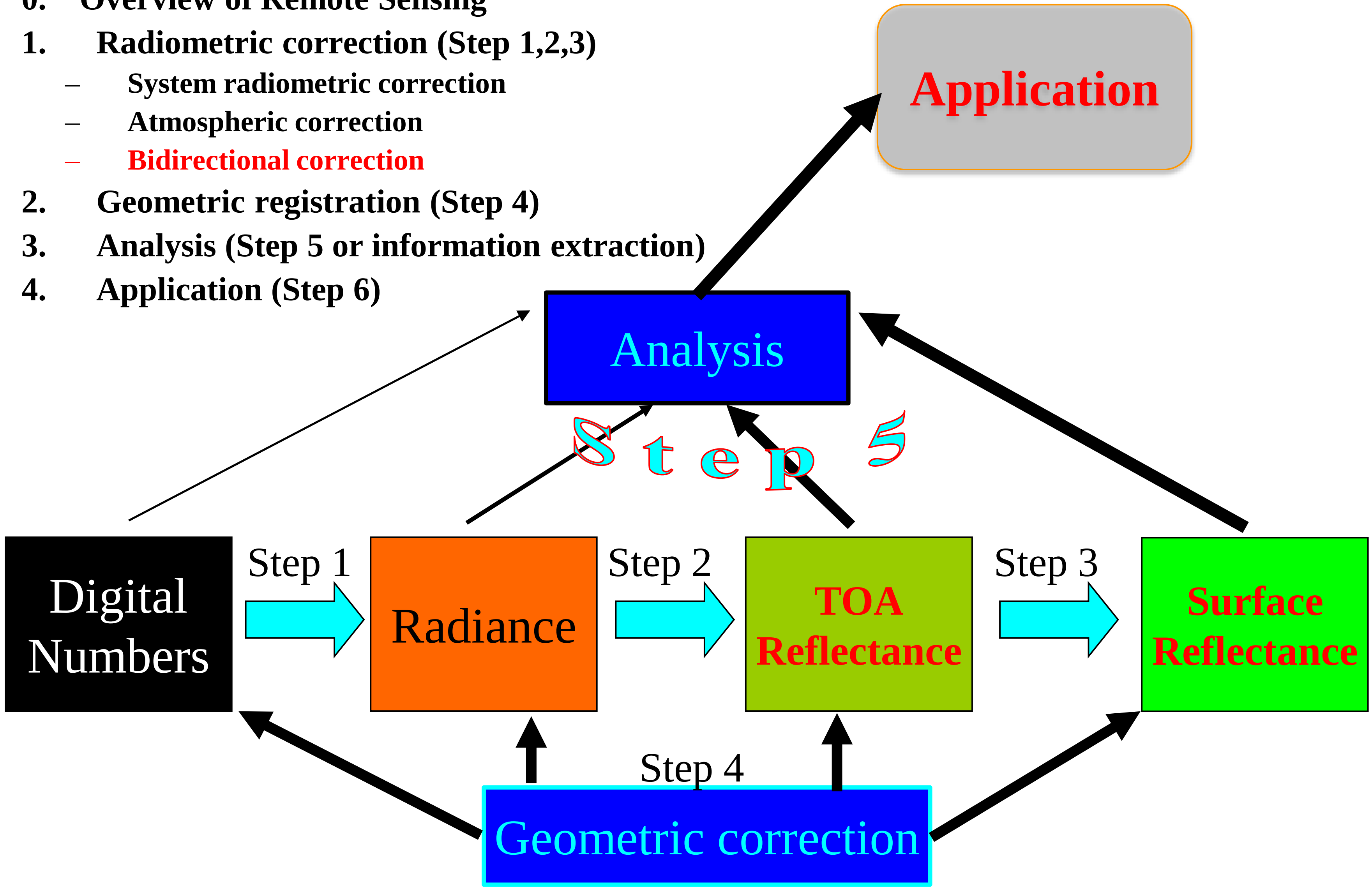
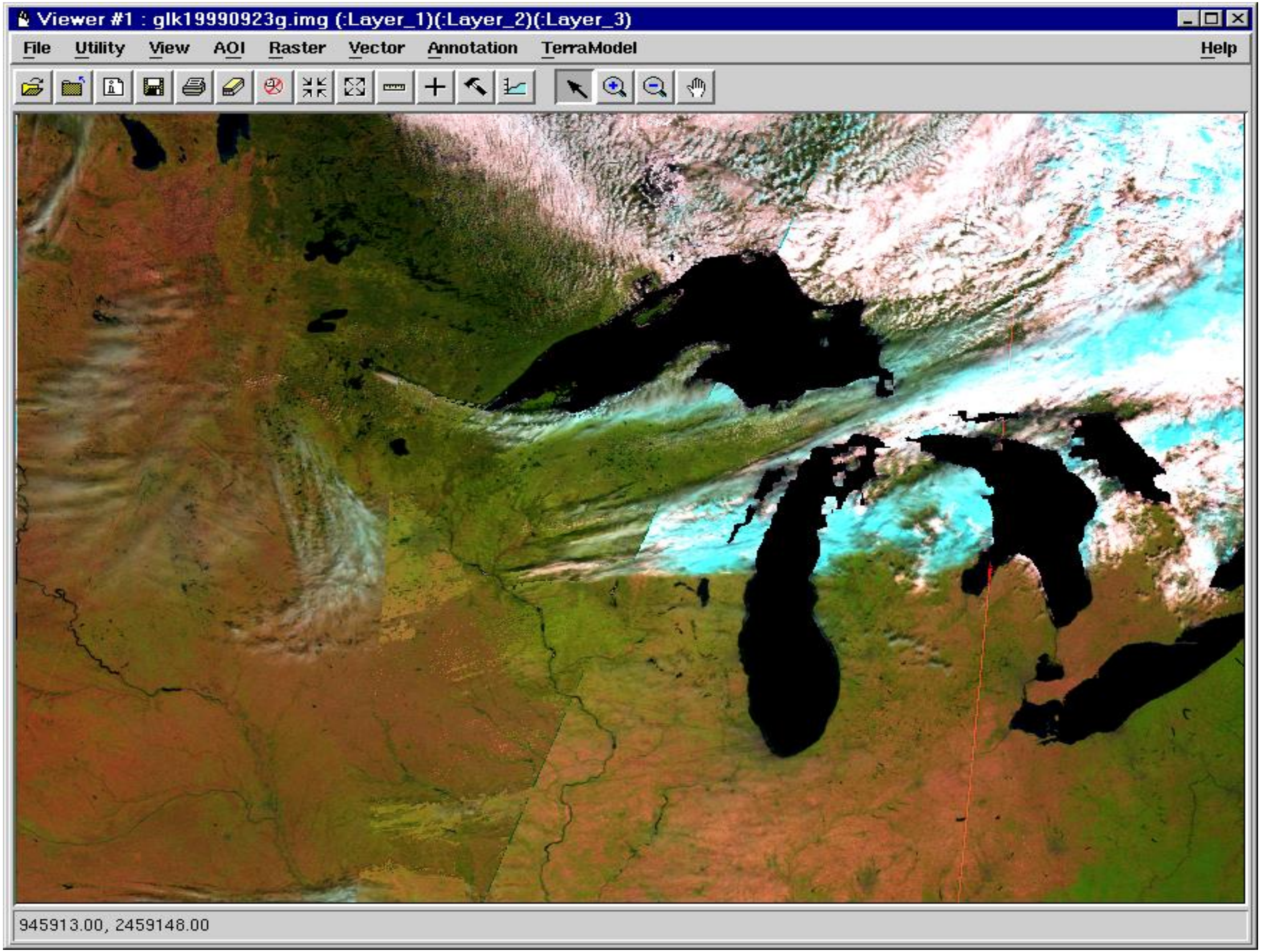
DIPA Flowchart – All you need to know

0. **Overview of Remote Sensing**
1. **Radiometric correction (Step 1,2,3)**
   - **System radiometric correction**
   - **Atmospheric correction**
   - **Bidirectional correction**
2. **Geometric registration (Step 4)**
3. **Analysis (Step 5 or information extraction)**
4. **Application (Step 6)**

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File
Utility
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Annotation
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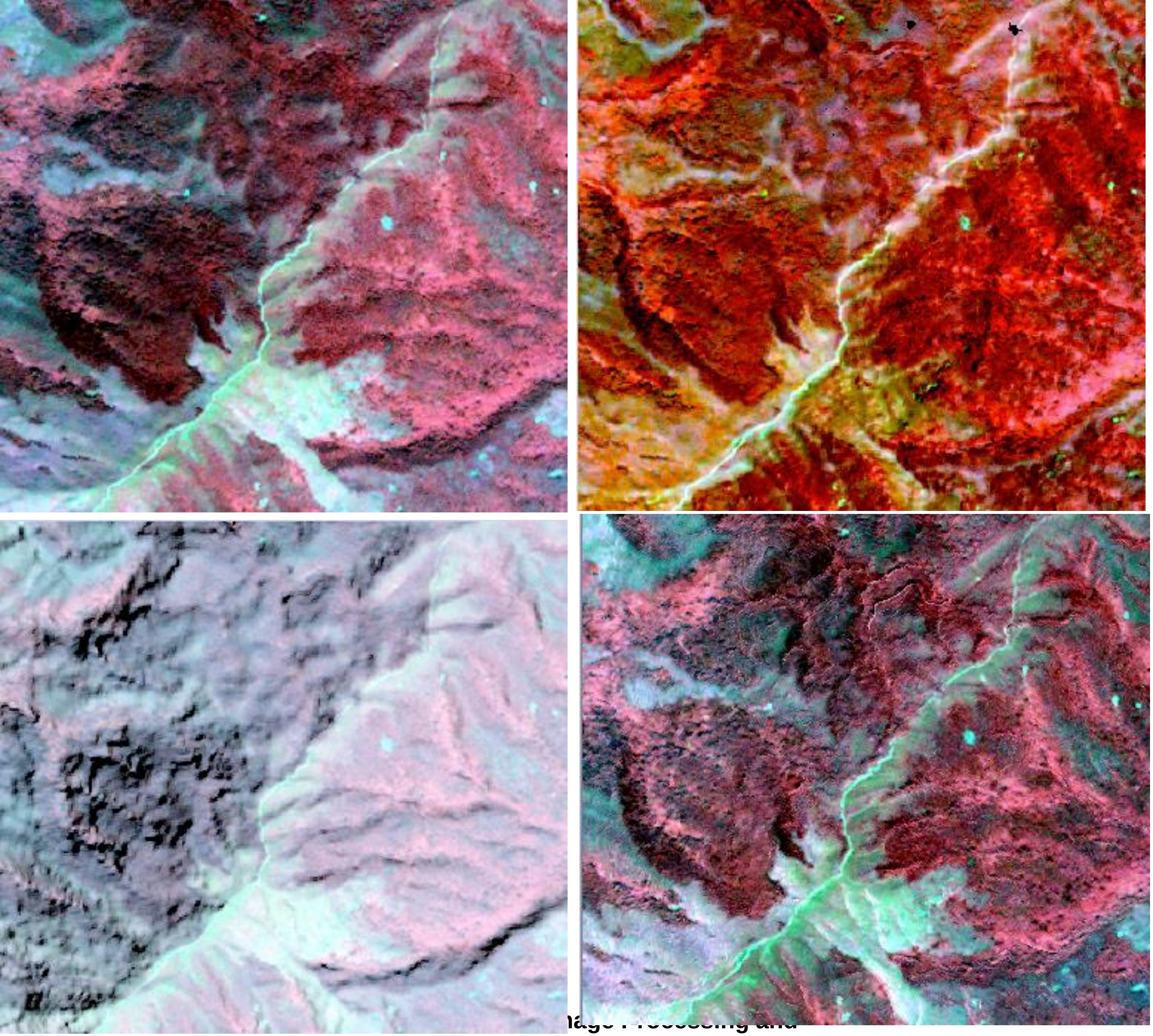
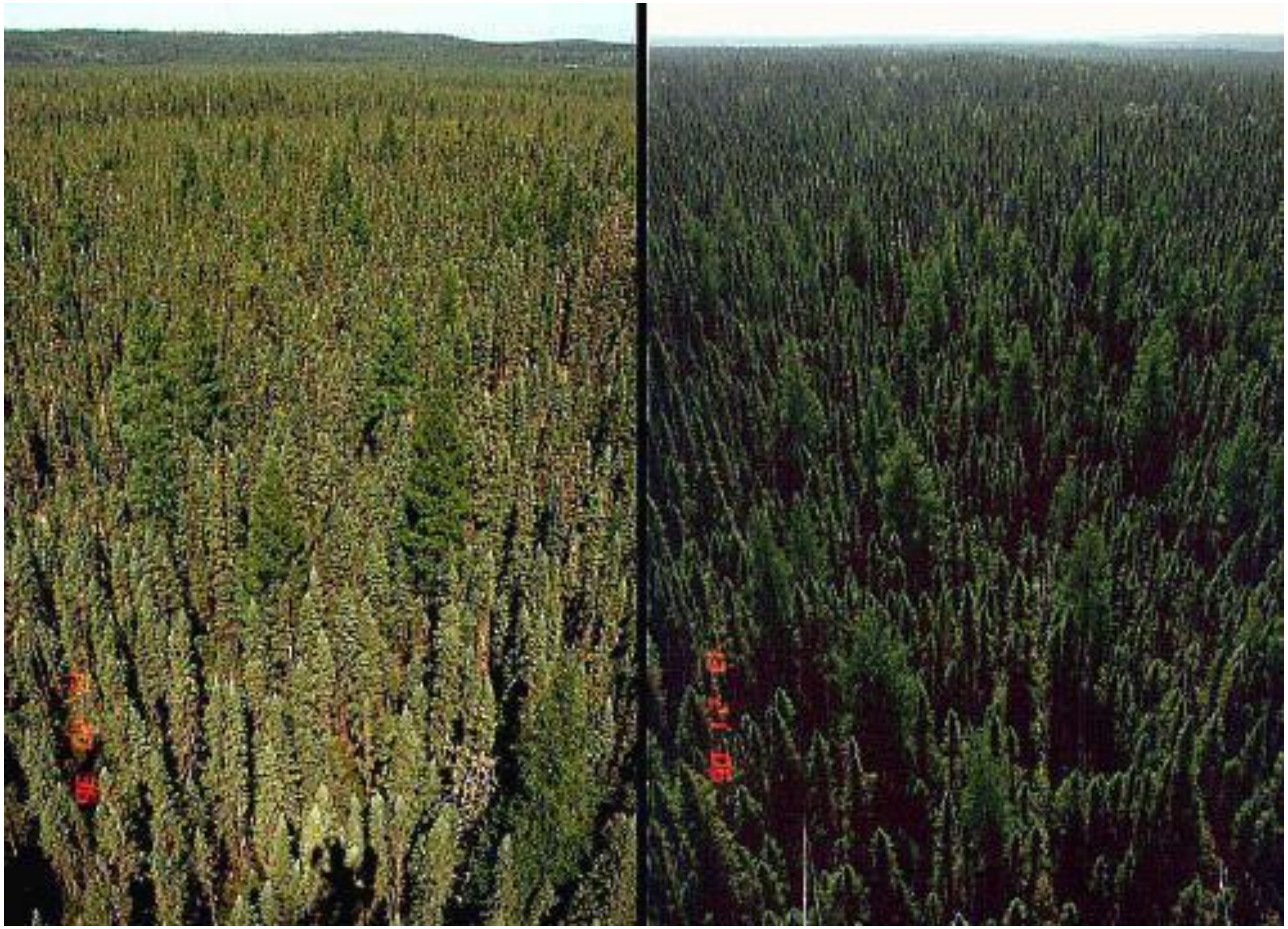


IKONOS False Colour Image, 7 Sept 2002, a ridge from top right to bottom left with sunlight coming from the bottom right, Lam Tseun Country Park. (a) Original image. (b) Result of cosine correction. (c) Result of Minnaert correction. (d) Result of 2-stage normalization Cosine Minnaert

From
Law & Nichol

BRDF



Backscatter direction   Forward scatter direction

cstars.ucdavis.edu/classes/ers186-w03/lecture11/lecture11.ppt

BRDF

Backscatter direction Forward scatter direction

cstars.ucdavis.edu/classes/ers186-w03/lecture11/lecture11.ppt

BRDF

Backscatter direction Forward scatter direction

cstars.ucdavis.edu/classes/ers186-w03/lecture11/lecture11.ppt

Bidirectional Effect, Modeling and Correction

Topics:

- Directional effect
- Modeling
- Correction

BRDF

BRDF: Bidirectional Reflectance Distribution Function

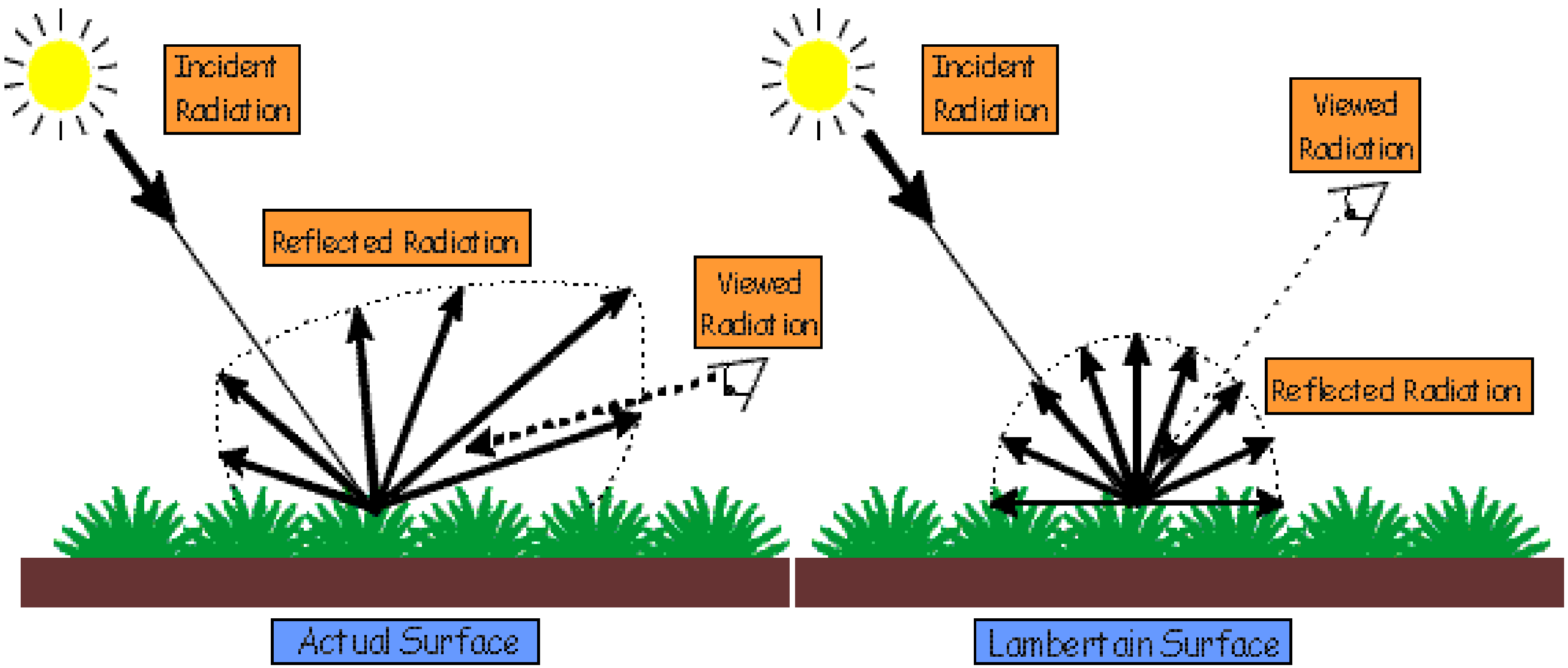
1. Illumination and viewing geometry
2. Wavelength
3. Structural and optical properties of the surface (shadow-casting, multiple scattering, mutual shadowing, transmission, reflection, absorption and emission by surface elements, facet orientation distribution and facet density).

BRDF is needed in remote sensing for the correction of view and illumination angle effects, for deriving albedo, for land cover classification, for cloud detection, for atmospheric correction and other applications.

It should not be overlooked that the BRDF simply describes what we all observe every day: that objects look differently when viewed from different angles, and when illuminated from different directions. For that reasons painters and photographers have for centuries explored the appearance of trees and urban areas under a variety of conditions, accumulating knowledge about "how things look", knowledge that today we'd call BRDF-related knowledge.

Bi-directional Reflectance Distribution Function (BRDF)

Light reflecting off of a surface is rarely isotropic. Most surfaces exhibit anisotropic reflectance (reflectance amount varies with direction).



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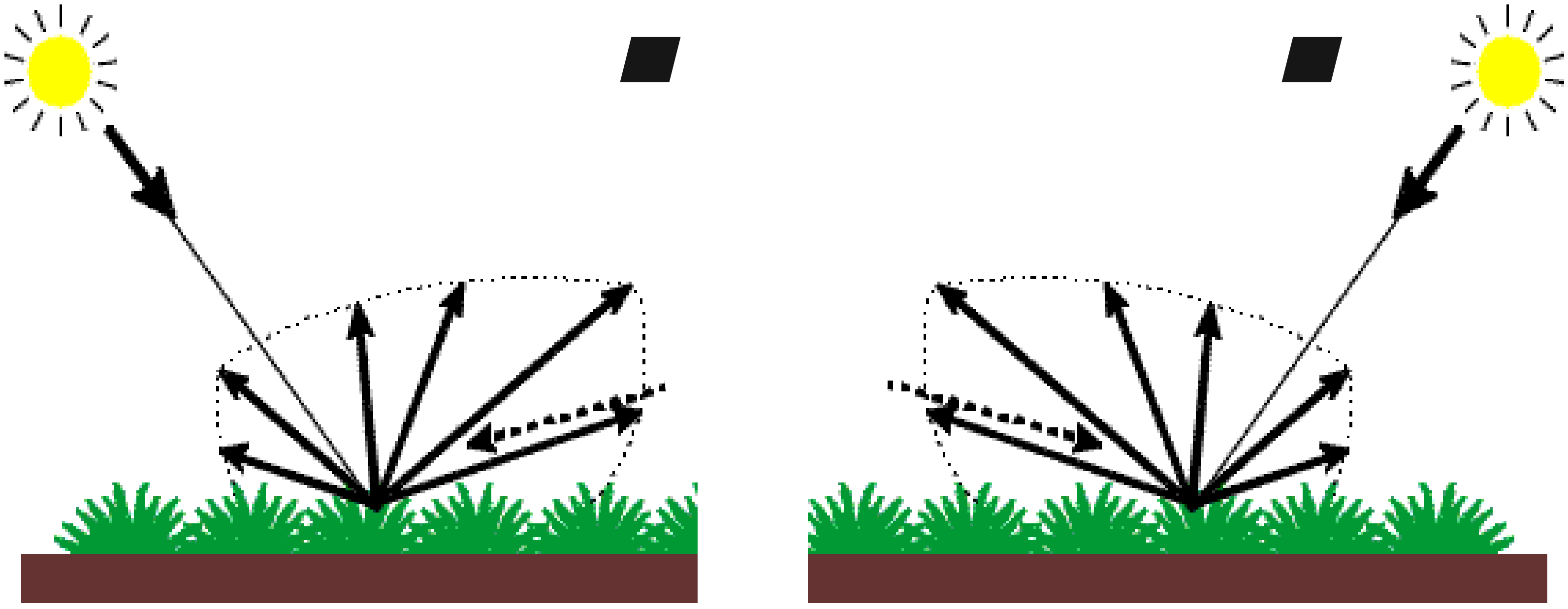
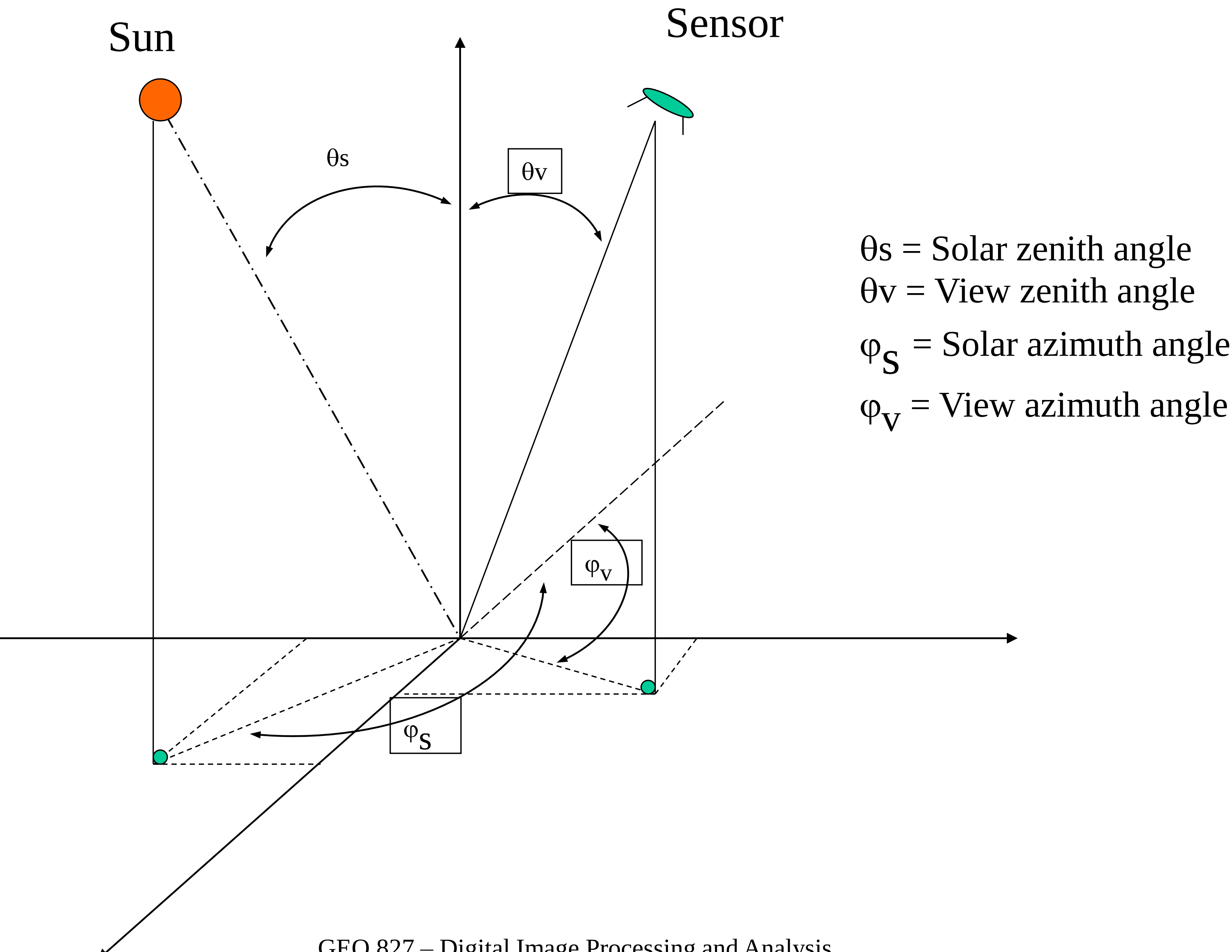


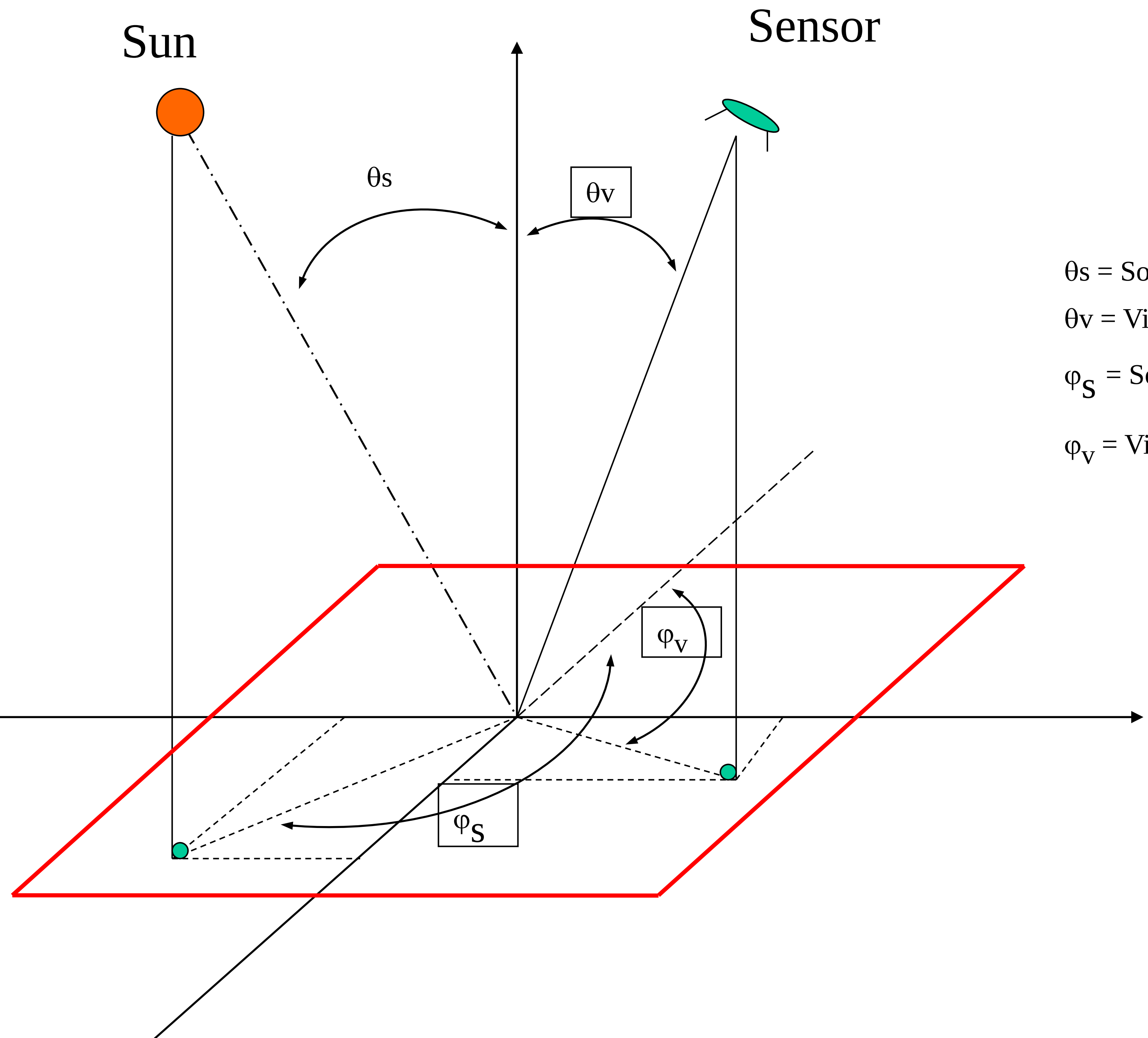
cstars.ucdavis.edu/classes/ers186-w03/lecture11/lecture11.ppt

Cotton field at ~80% cover
(Shadows)

How to Measure BRDF?

- Practically impossible to measure!
  - Would have to measure EVERY possible angle
- But can be approximated by discrete measurements,
- With BRDF models, bidirectional effect can be normalized.
- Every different surface/landscape should have a different BRDF


Sun
Sensor
θs
θv
φv
φS
θs = Solar zenith angle
θv = View zenith angle
φS = Solar azimuth angle
φV = View azimuth angle



θs = Solar zenith angle

θv = View zenith angle

φ_S = Solar azimuth angle

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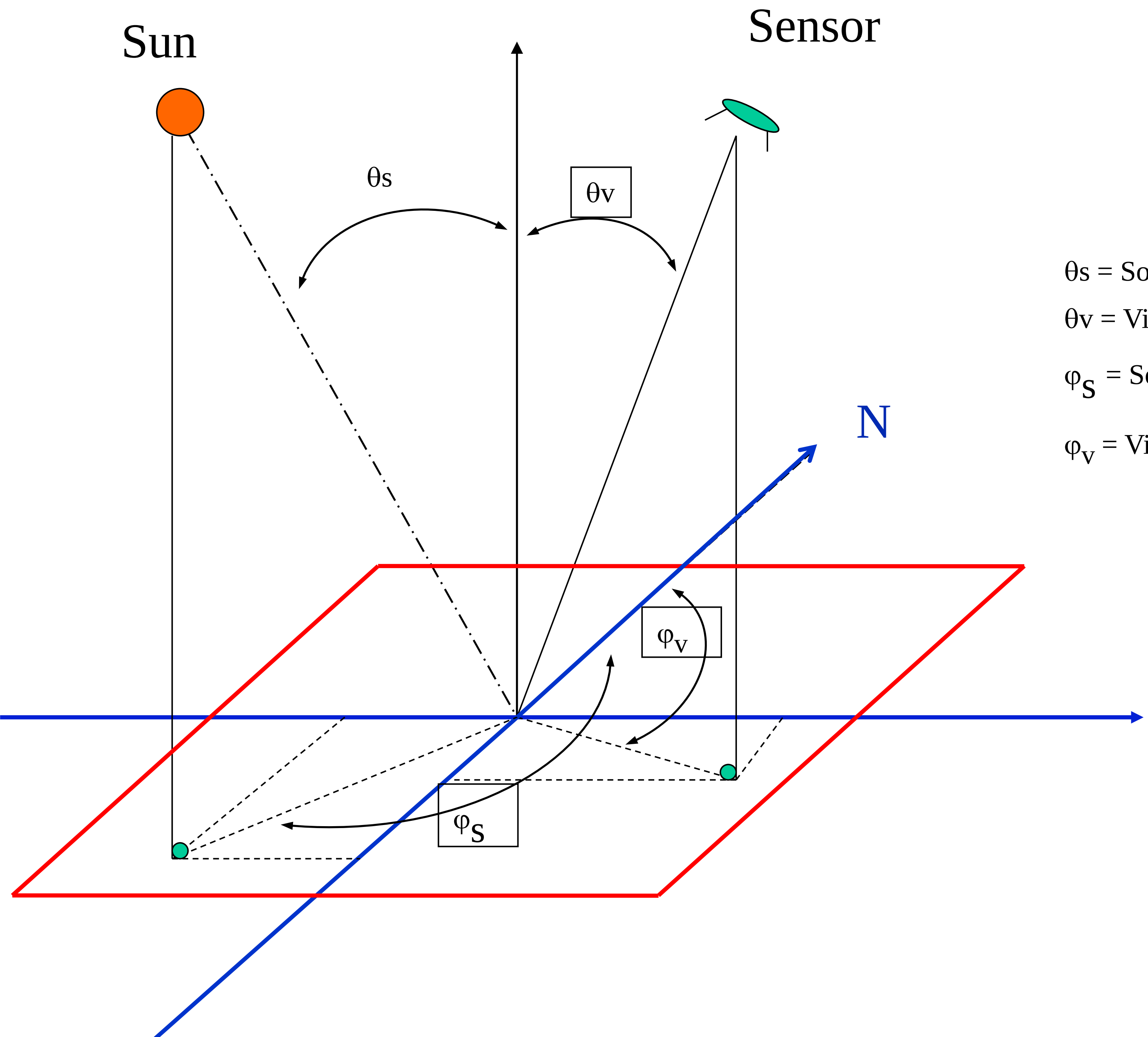

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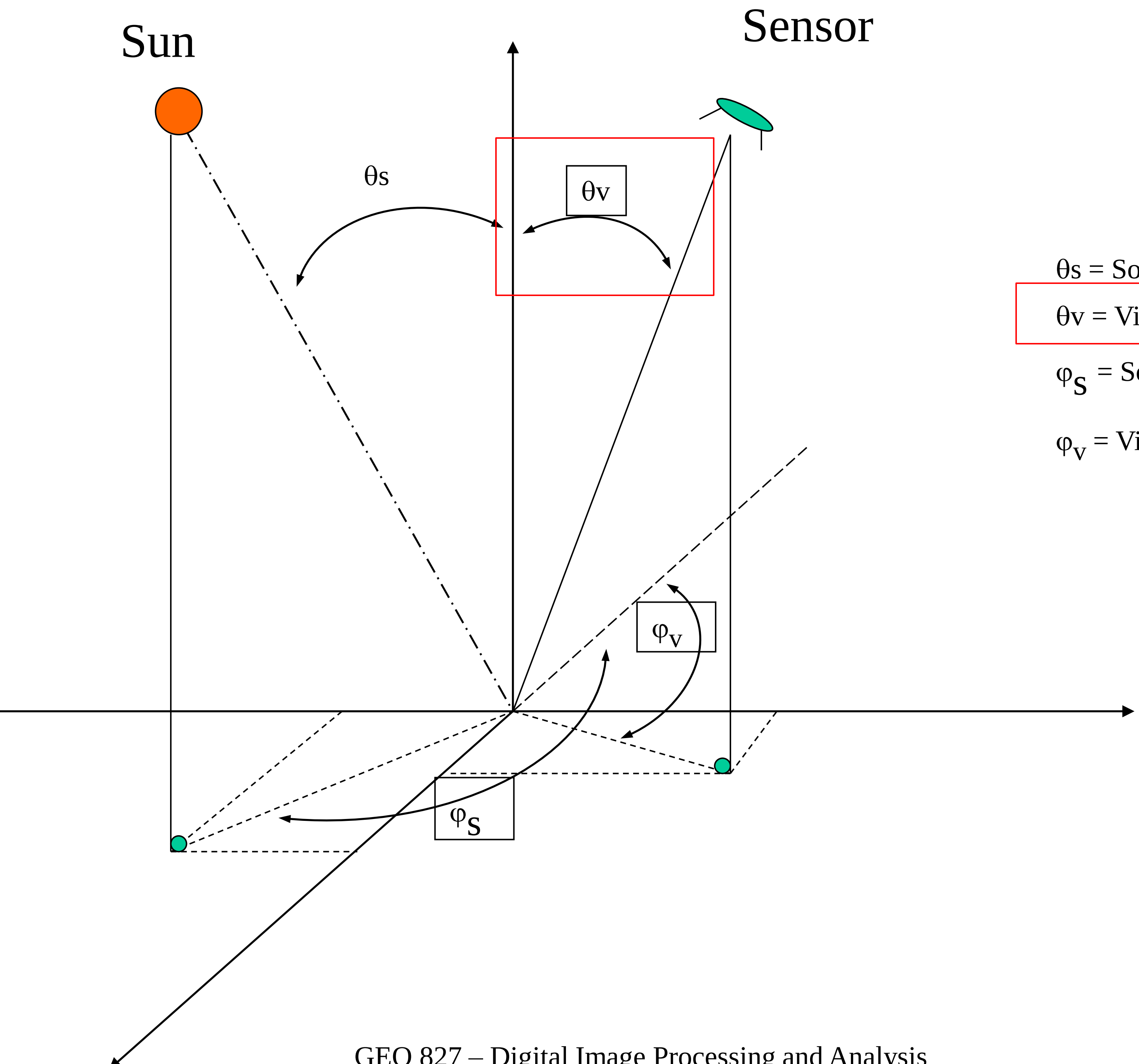

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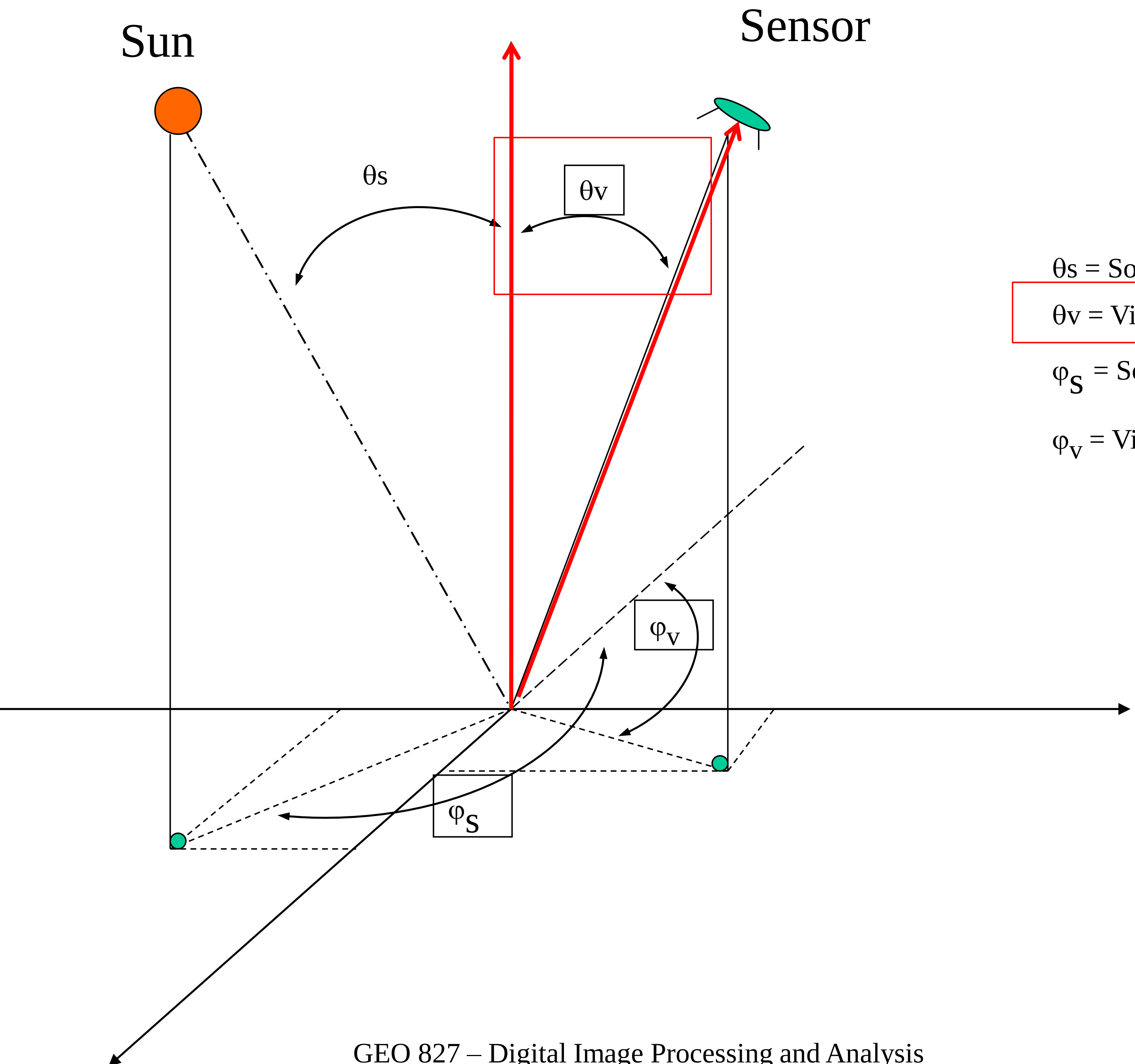

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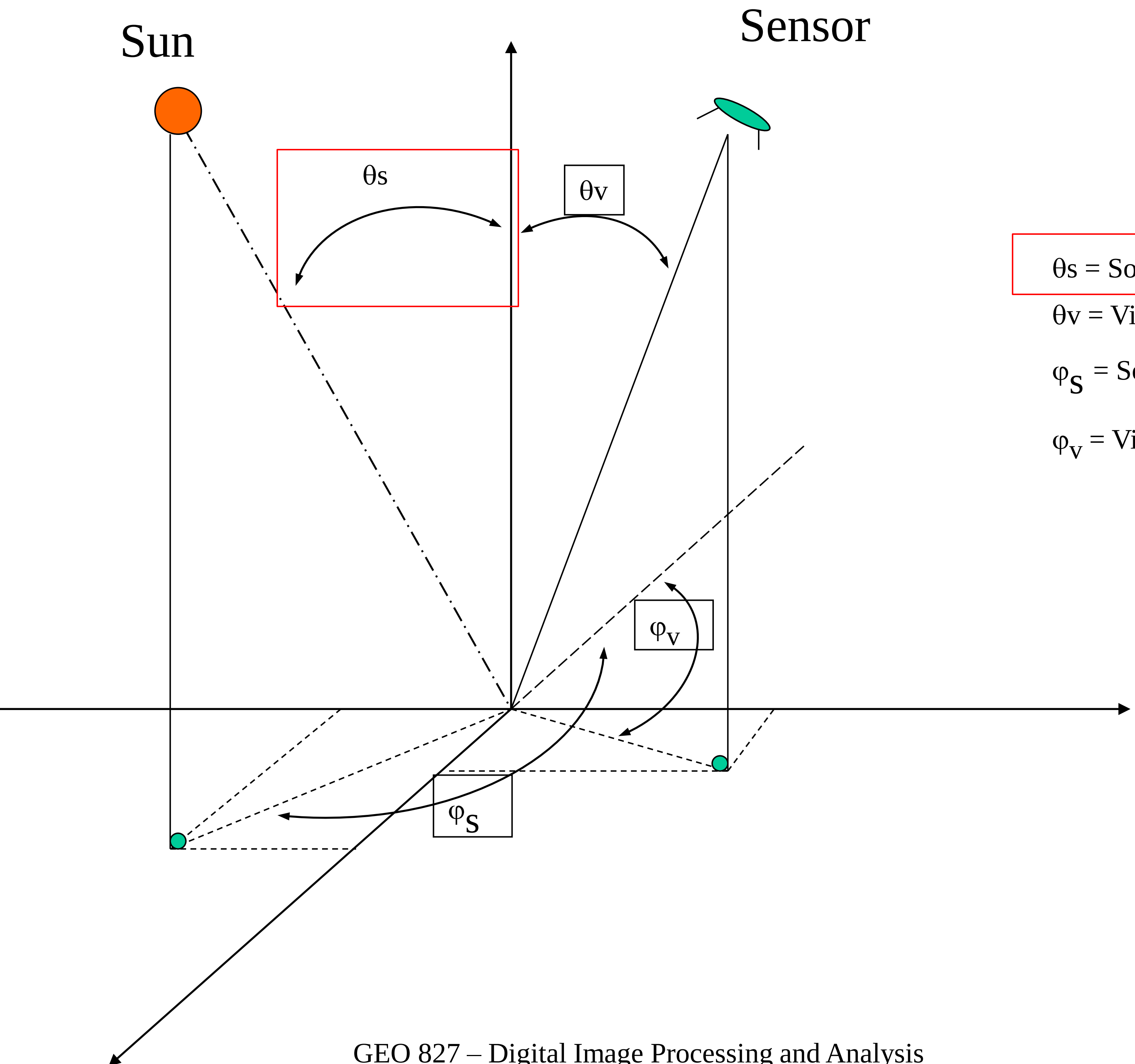

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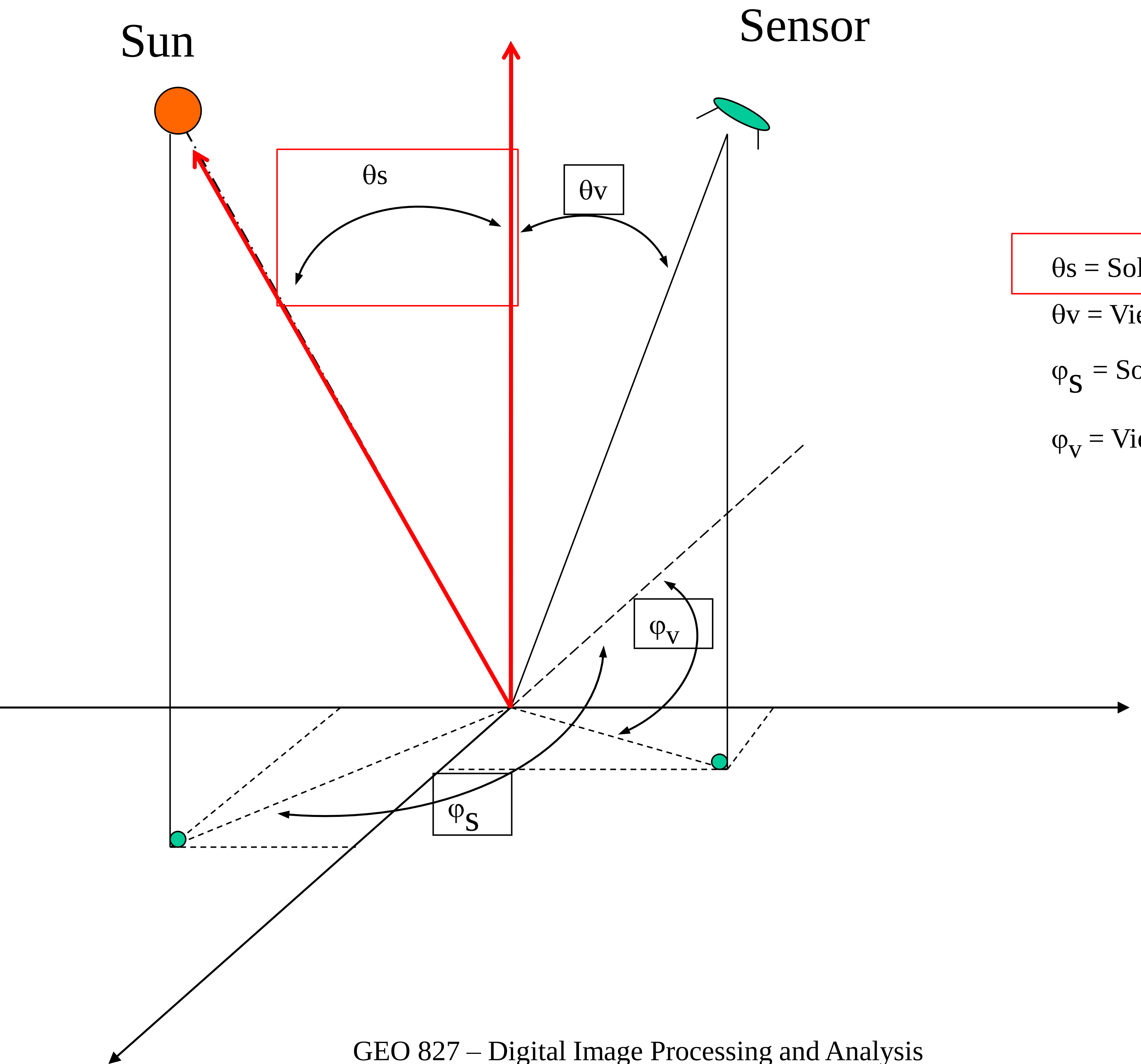

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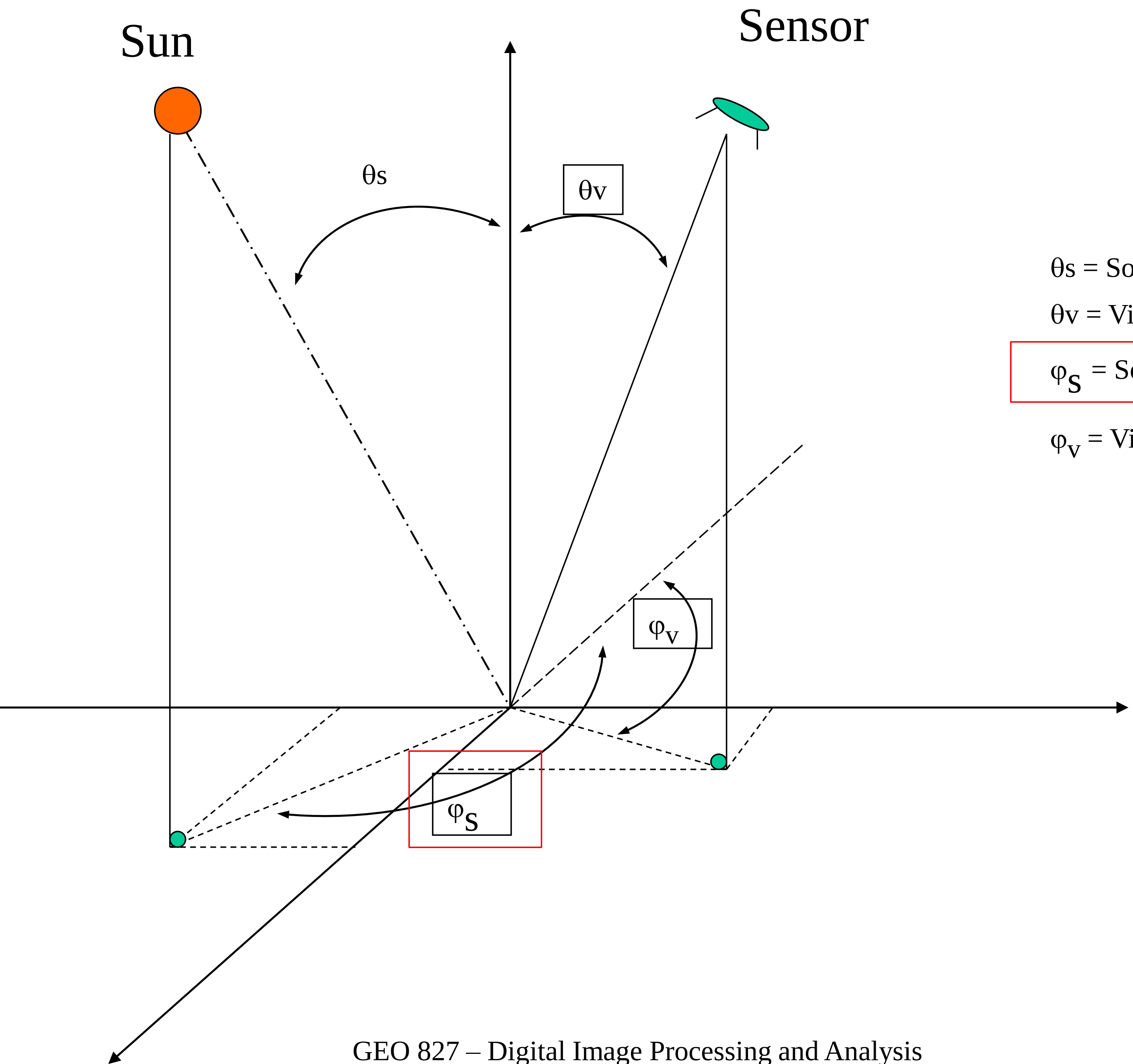

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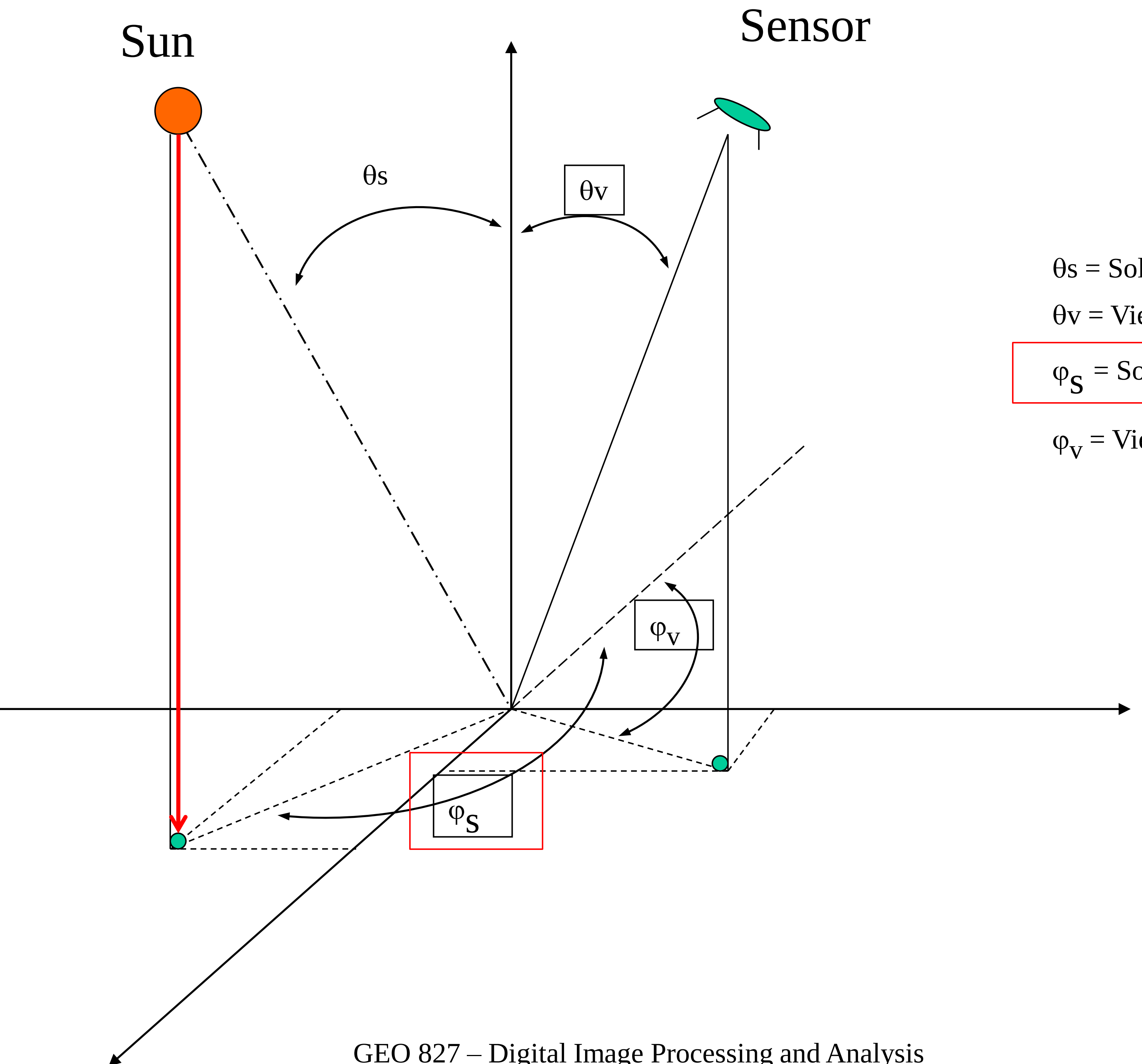

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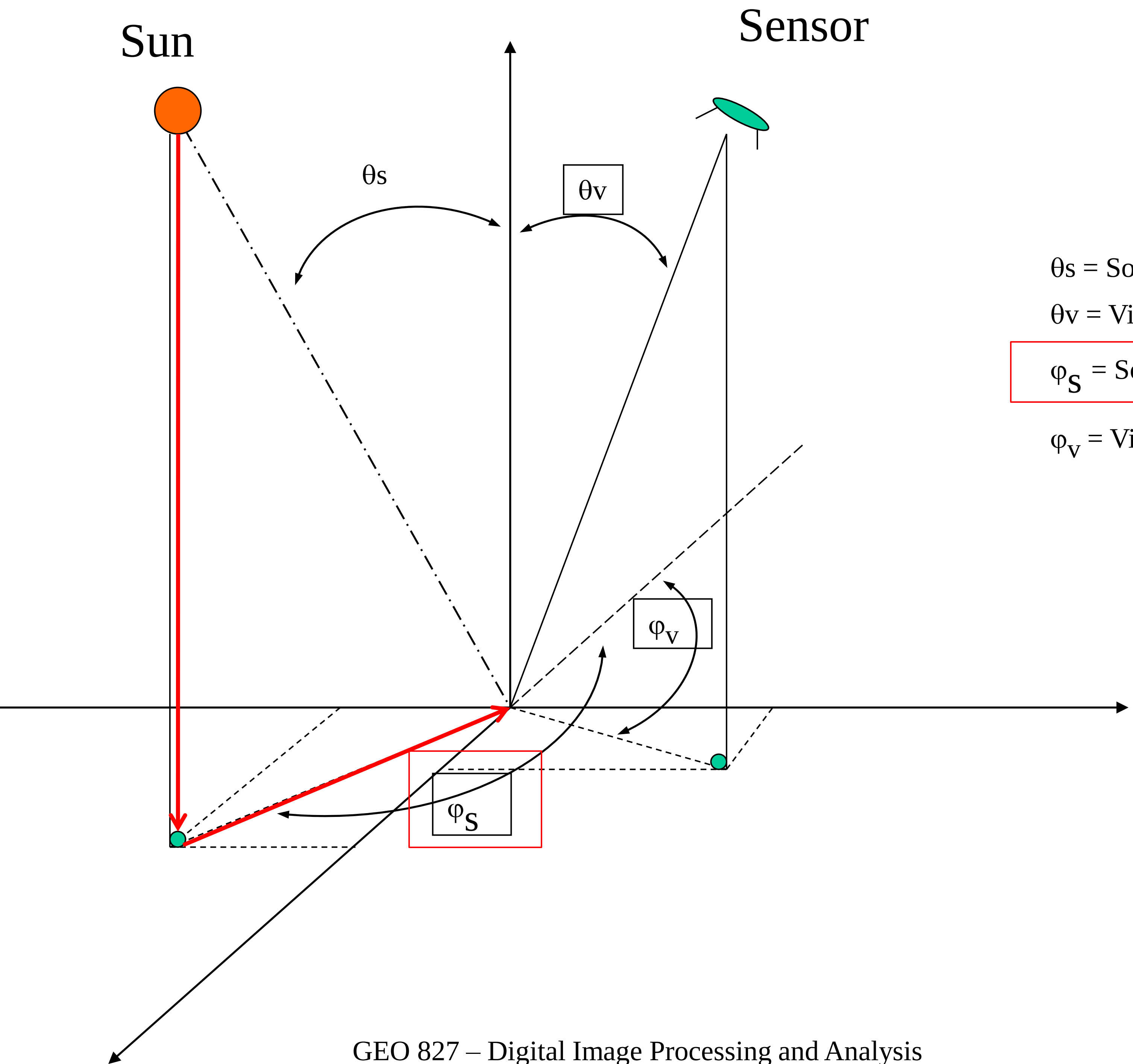

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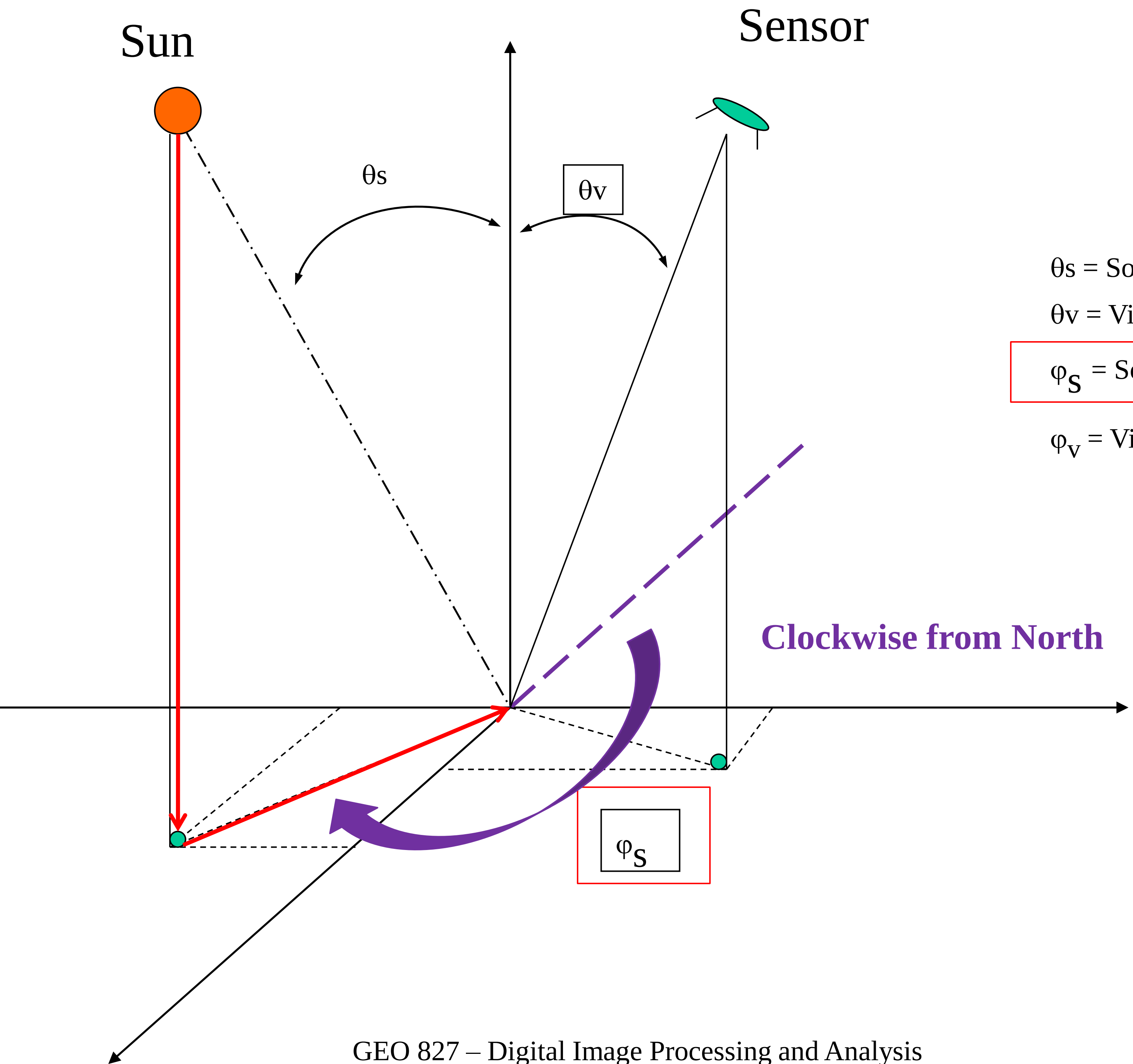

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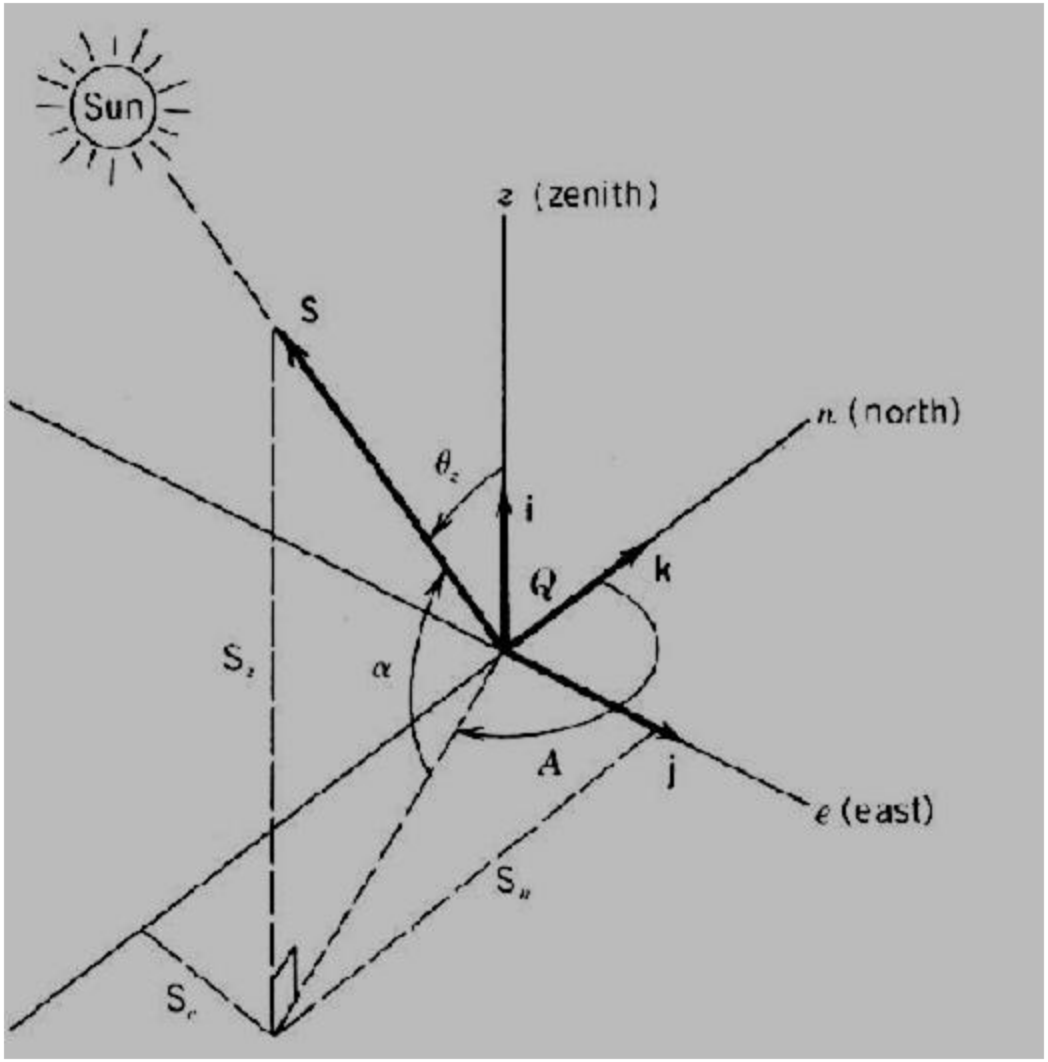

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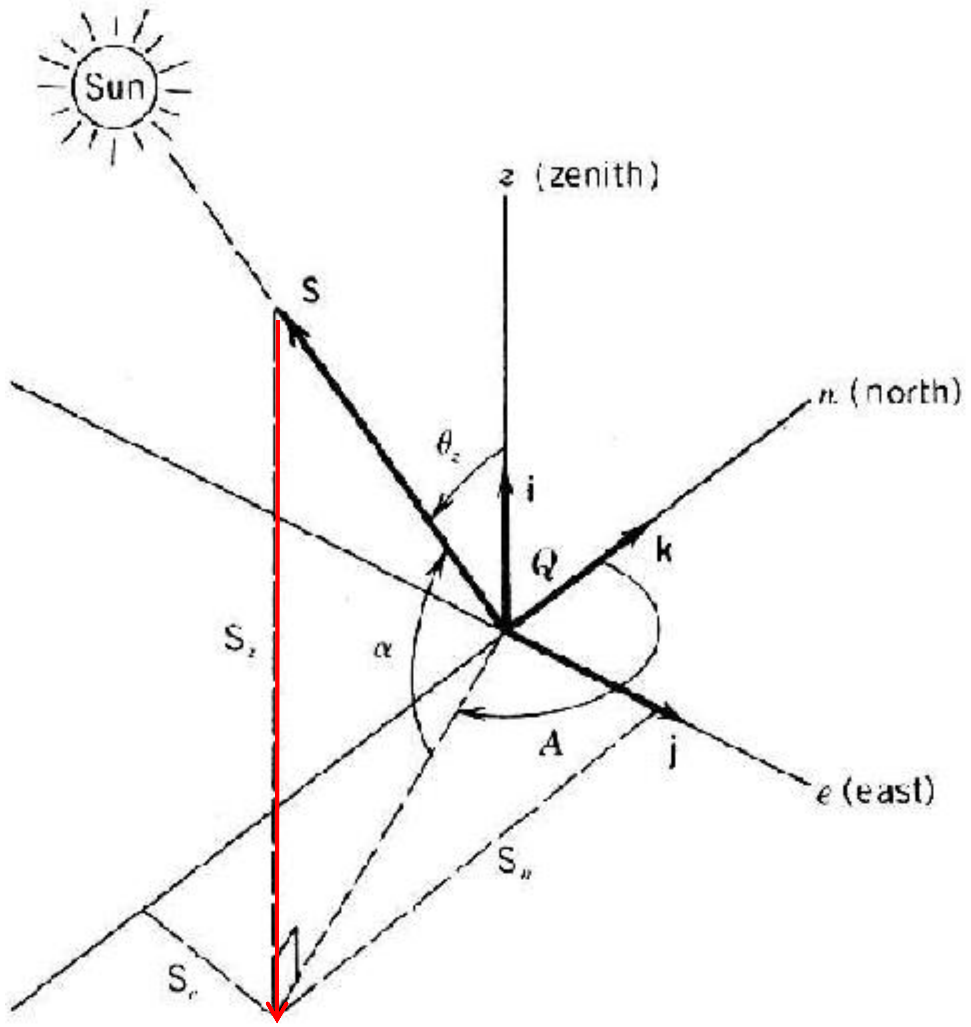
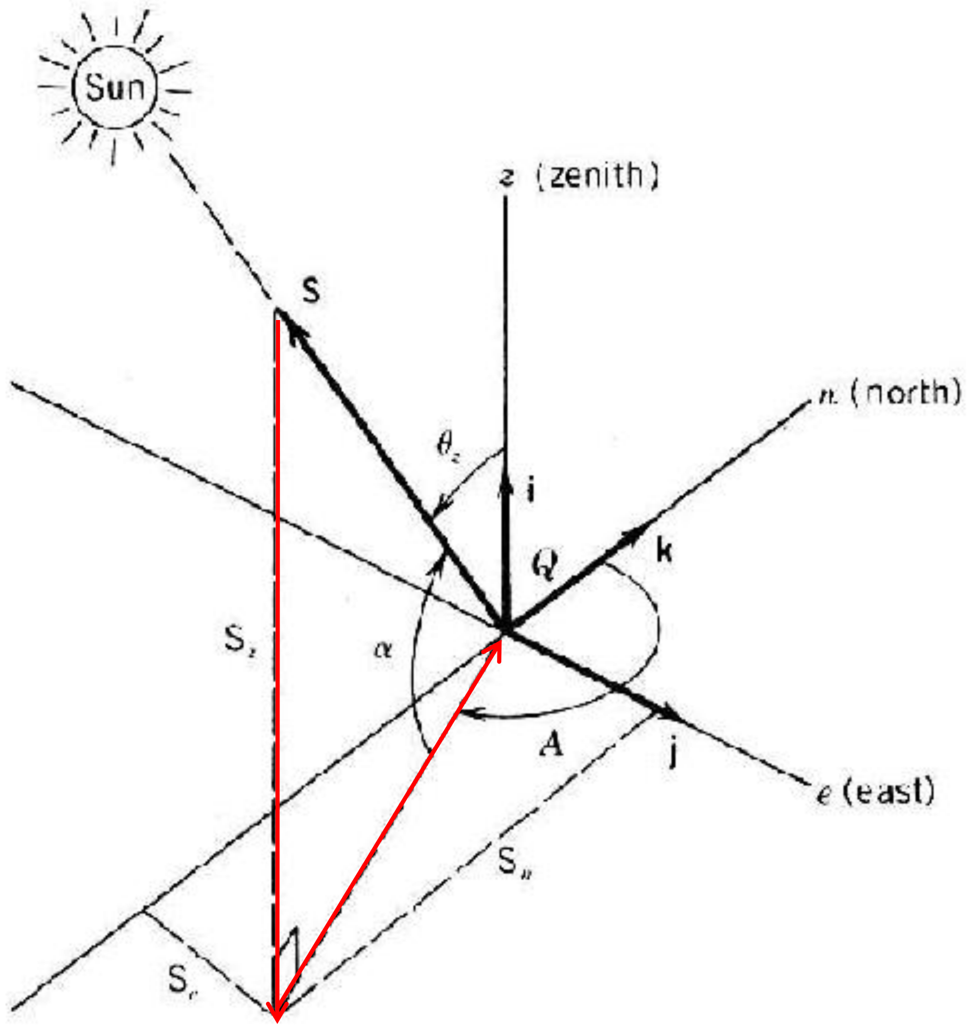


http://www.powerfromthesun.net/chapter3/Image61.jpg



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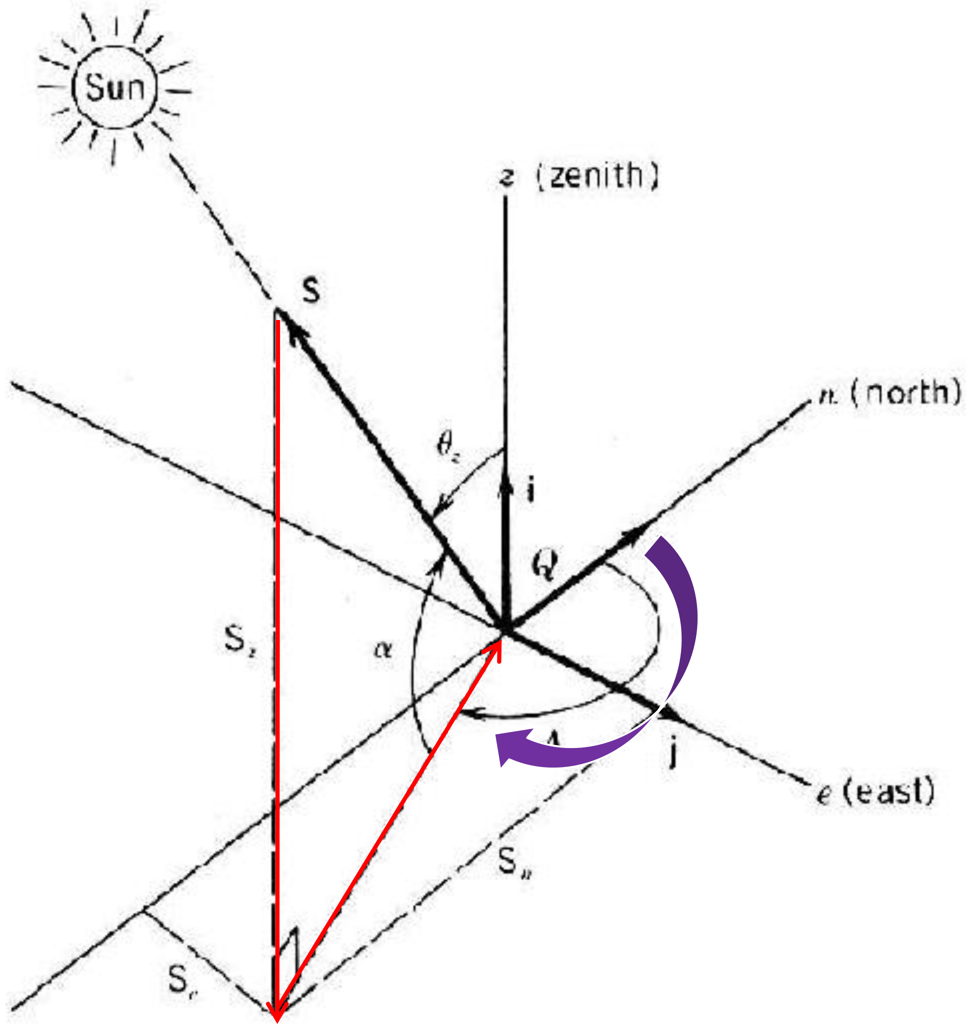

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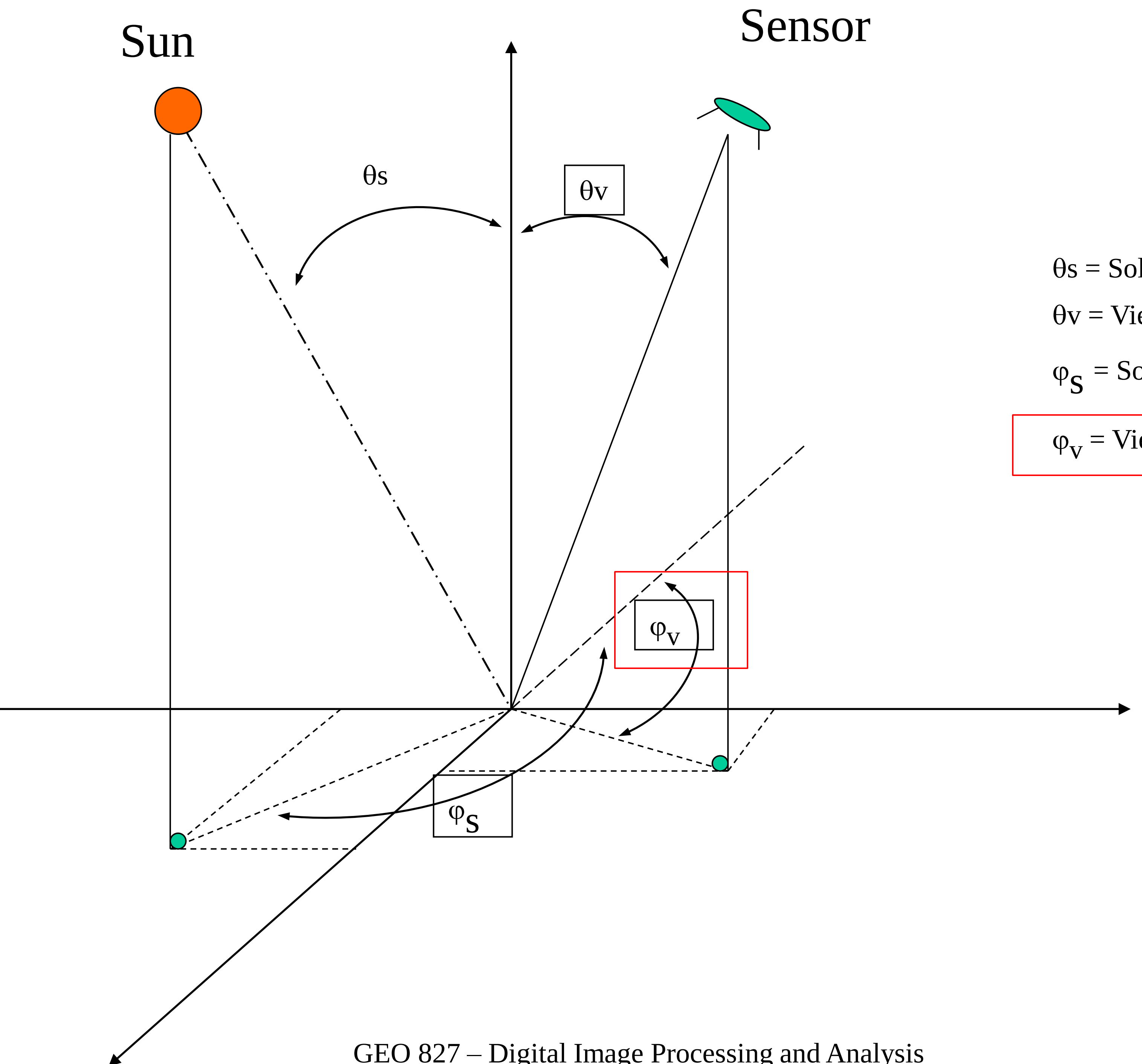

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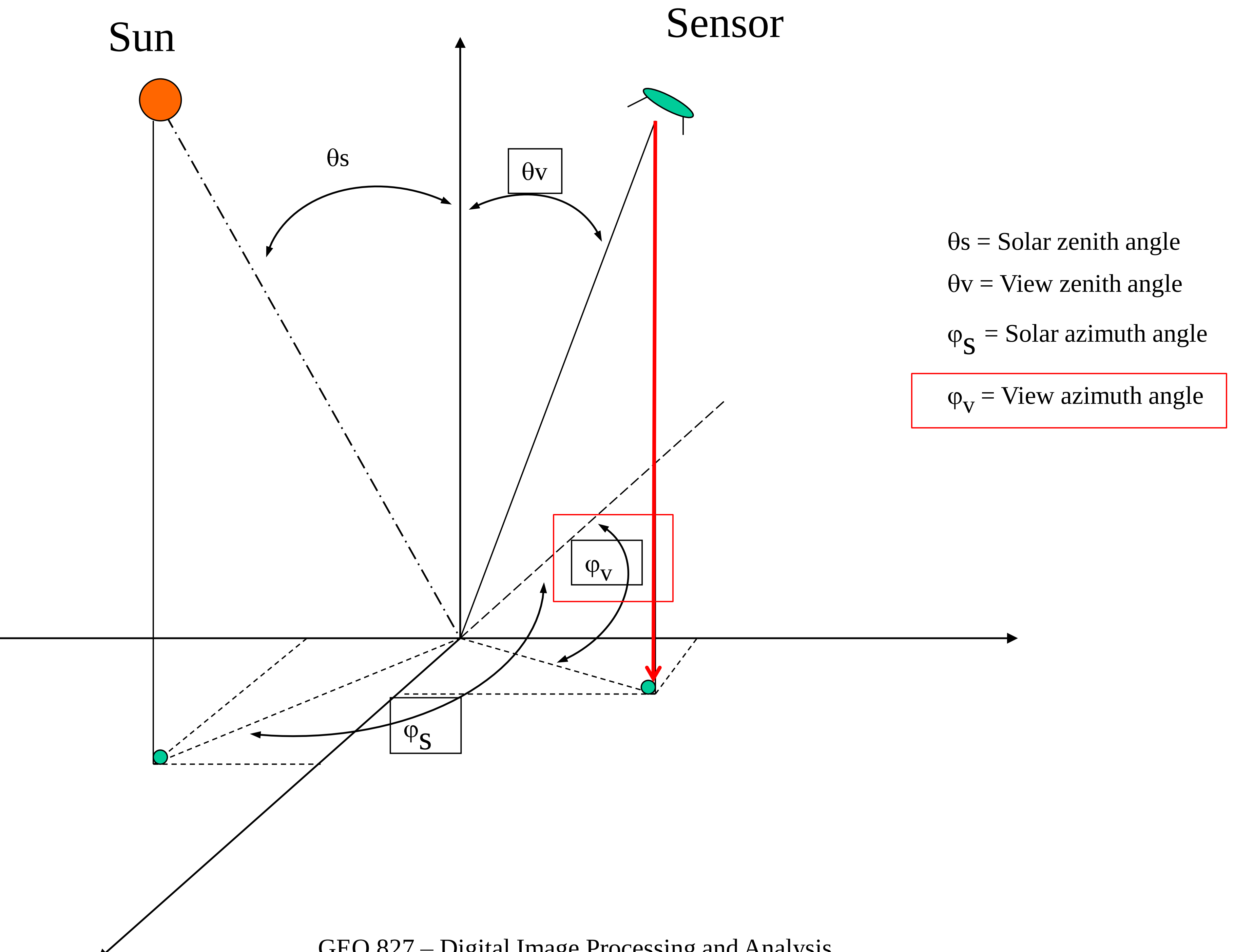
Sun
Sensor
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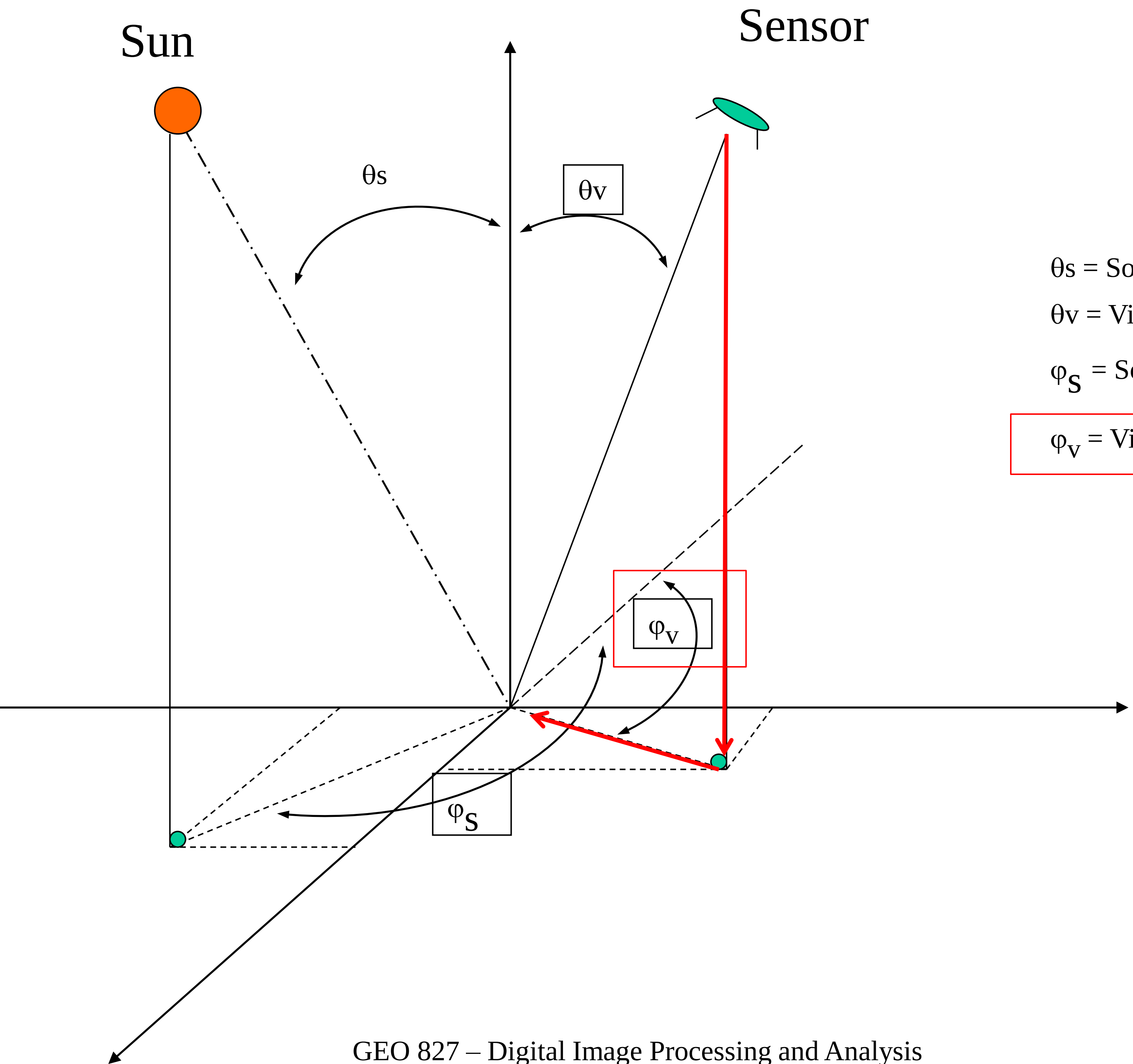

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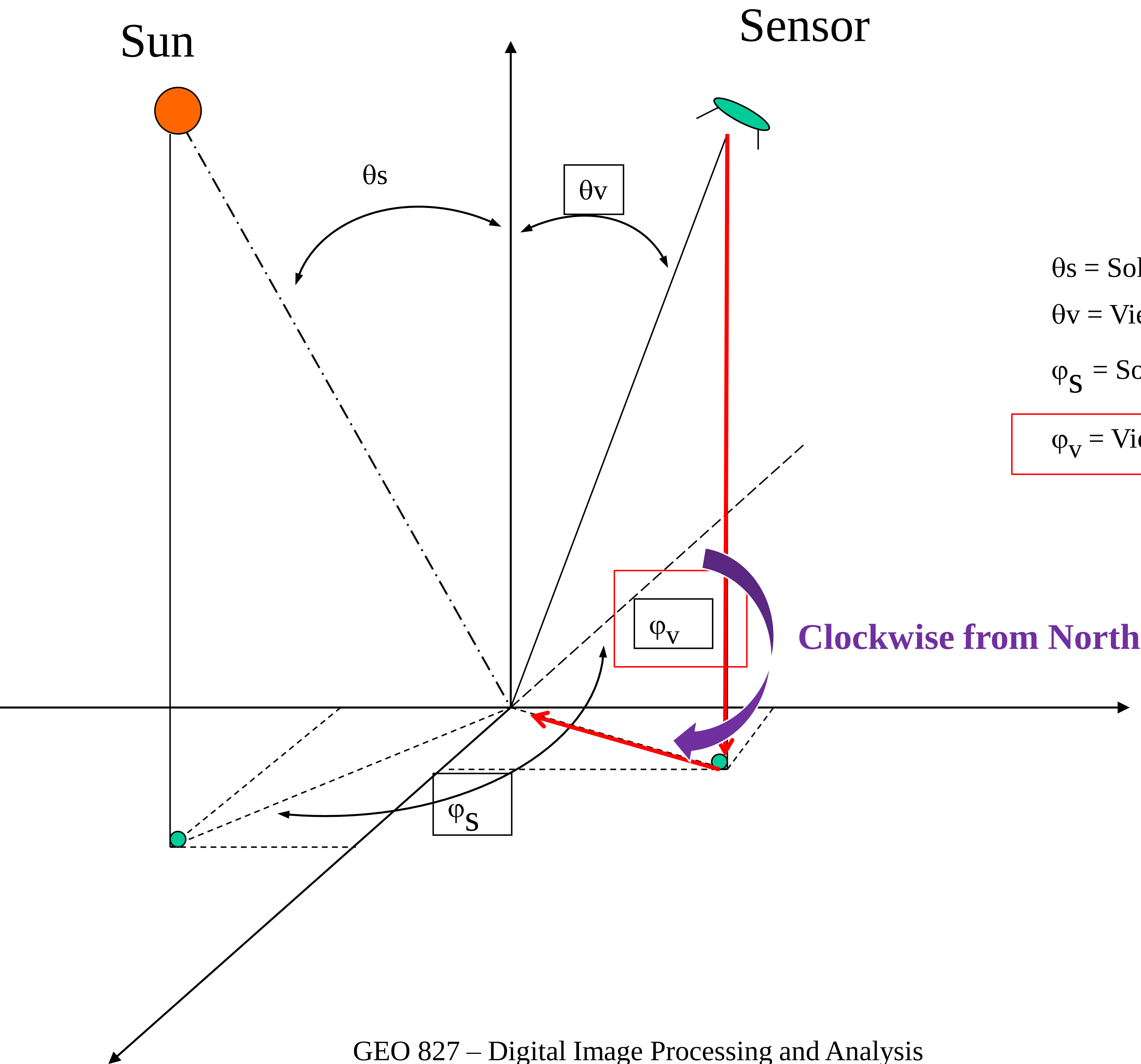

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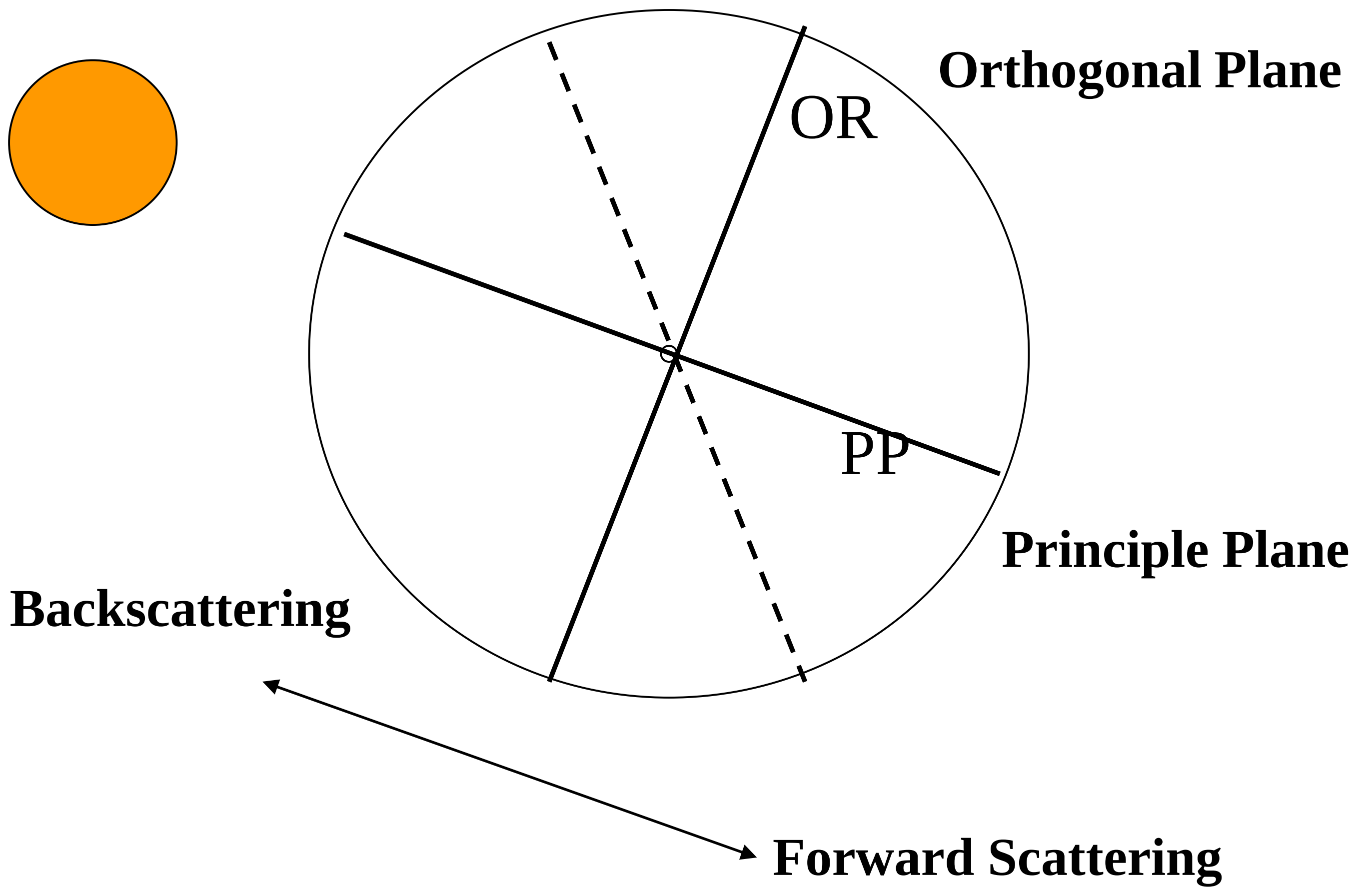
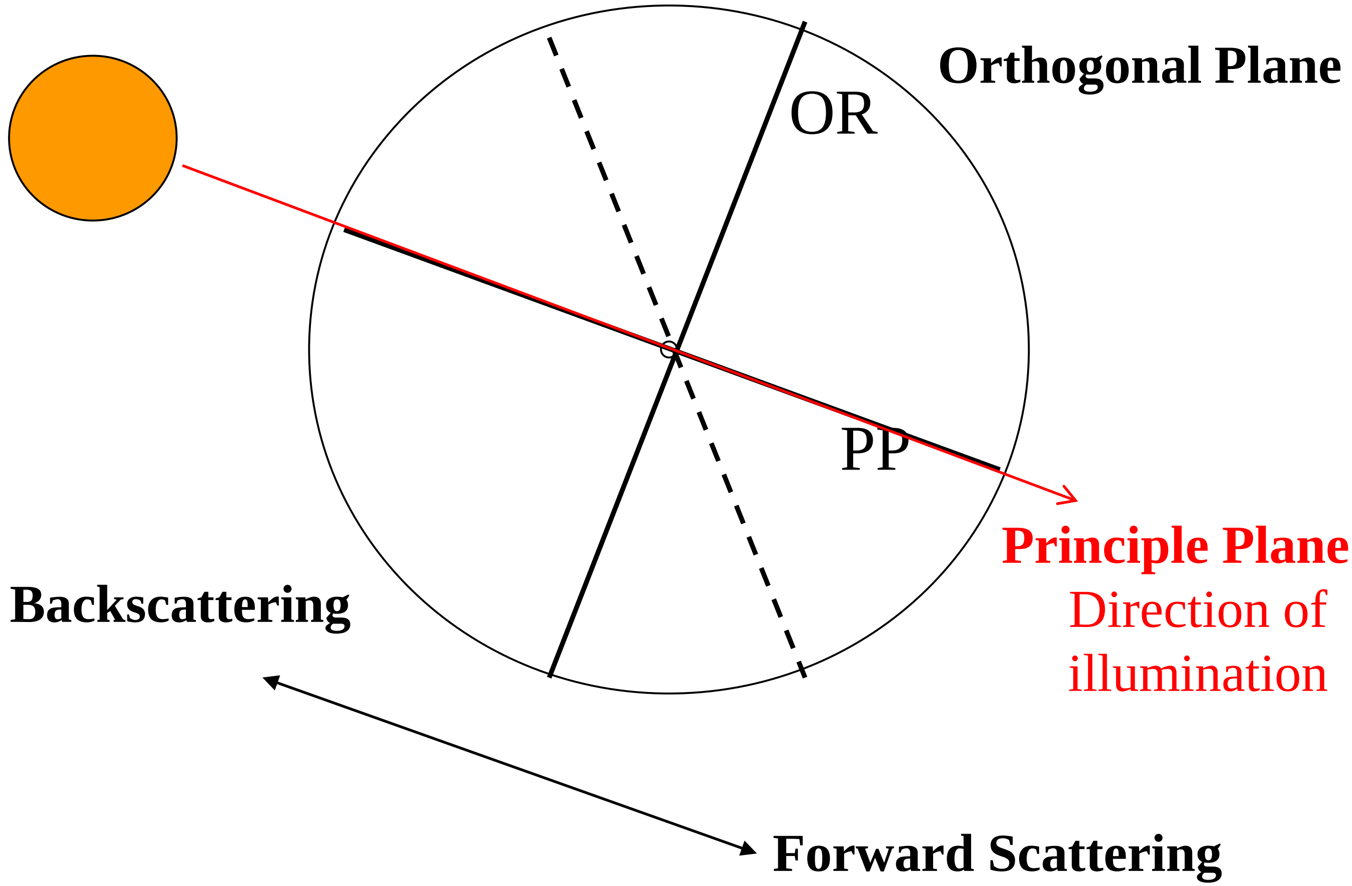
Relative Azimuth (φ) = Solar Azimuth-View Azimuth

Top View

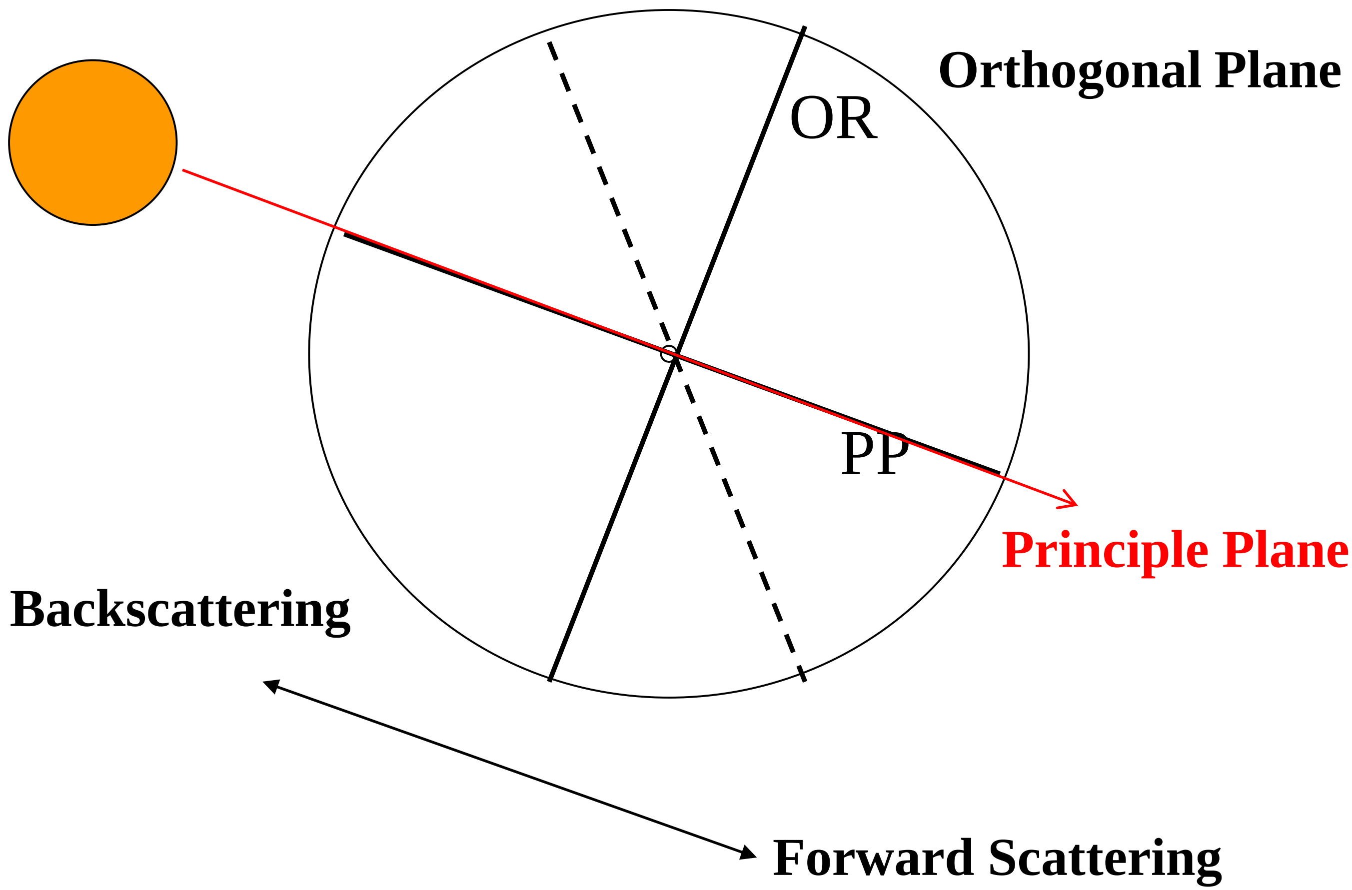

Orthogonal Plane
OR
PP
Principle Plane
Backscattering
Forward Scattering

Top View

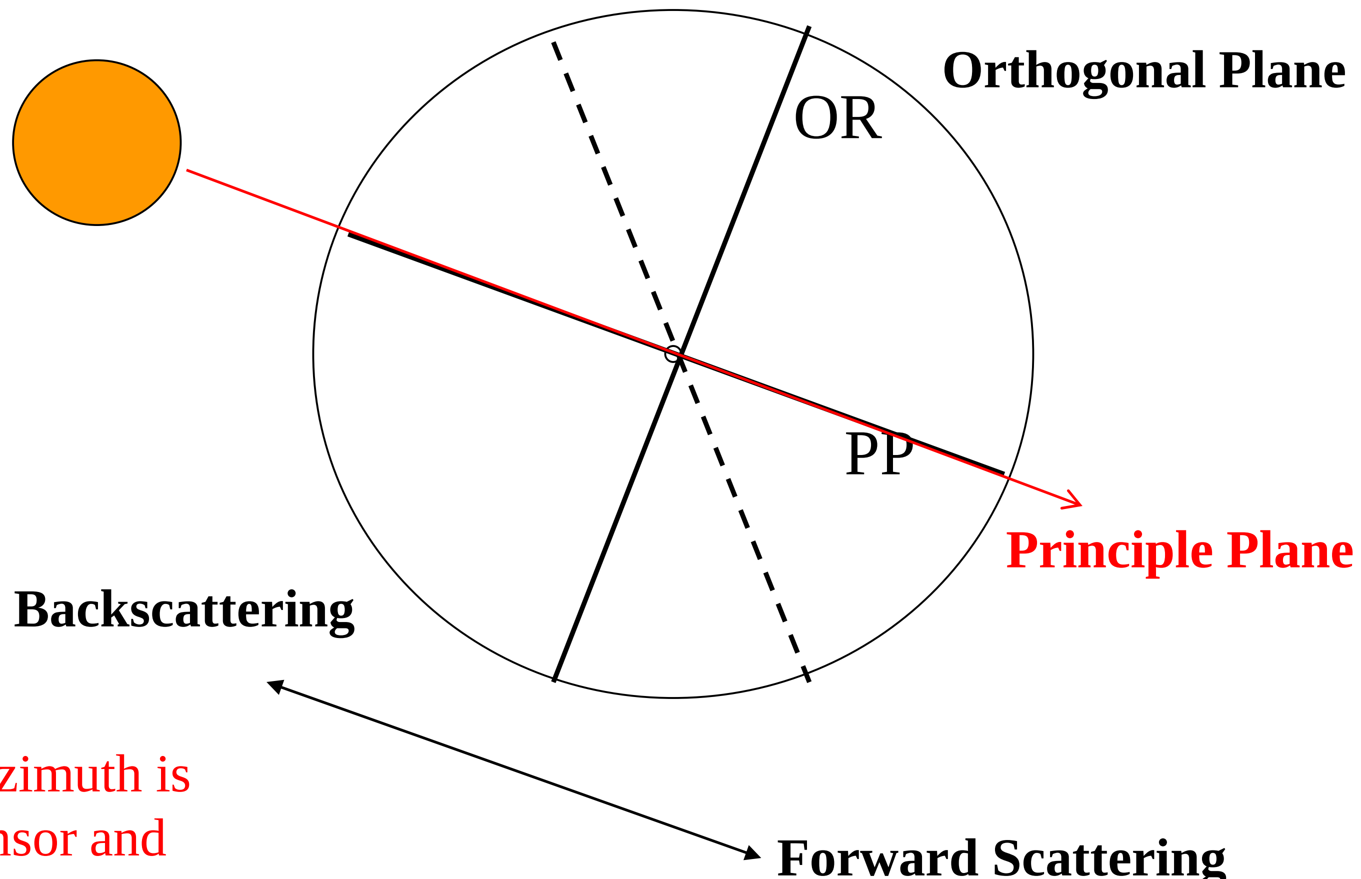

Orthogonal Plane
OR
PP
Principle Plane
Direction of
illumination
Backscattering
Forward Scattering

Top View

If relative azimuth is 180° then sensor is in principle plane

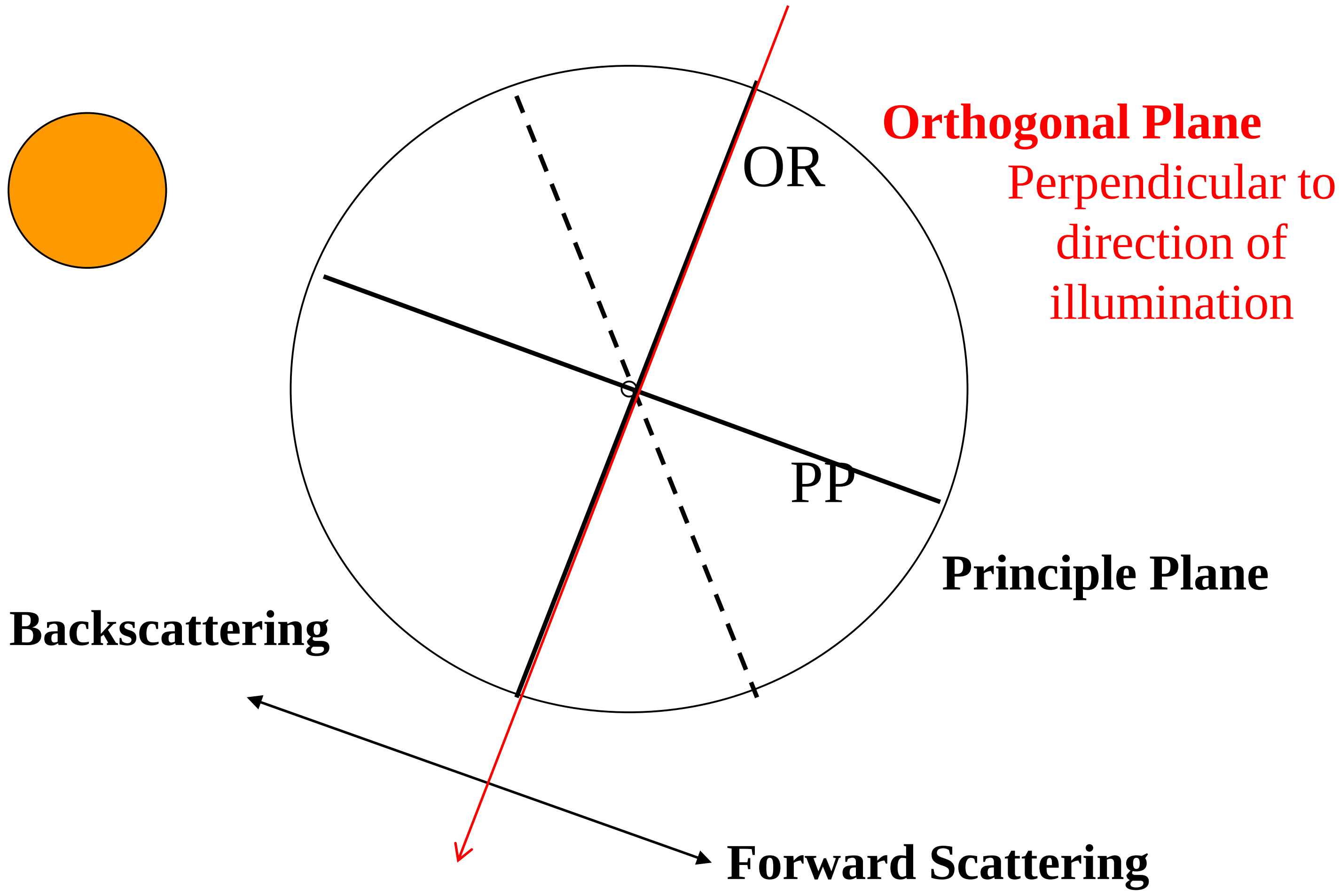


Top View



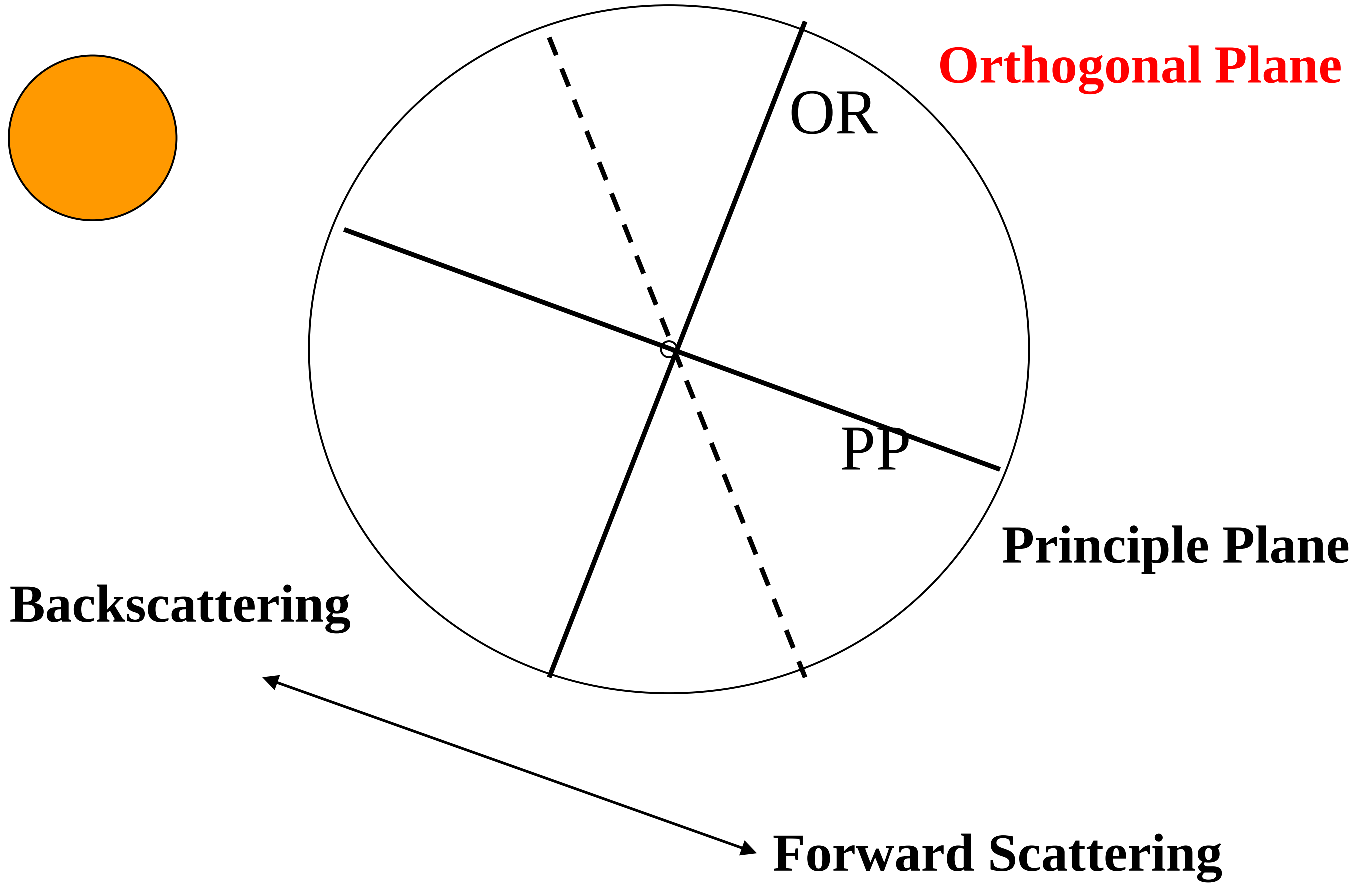
If relative azimuth is 0° then sensor and sun are on same side (direction) and in principle plane

Top View

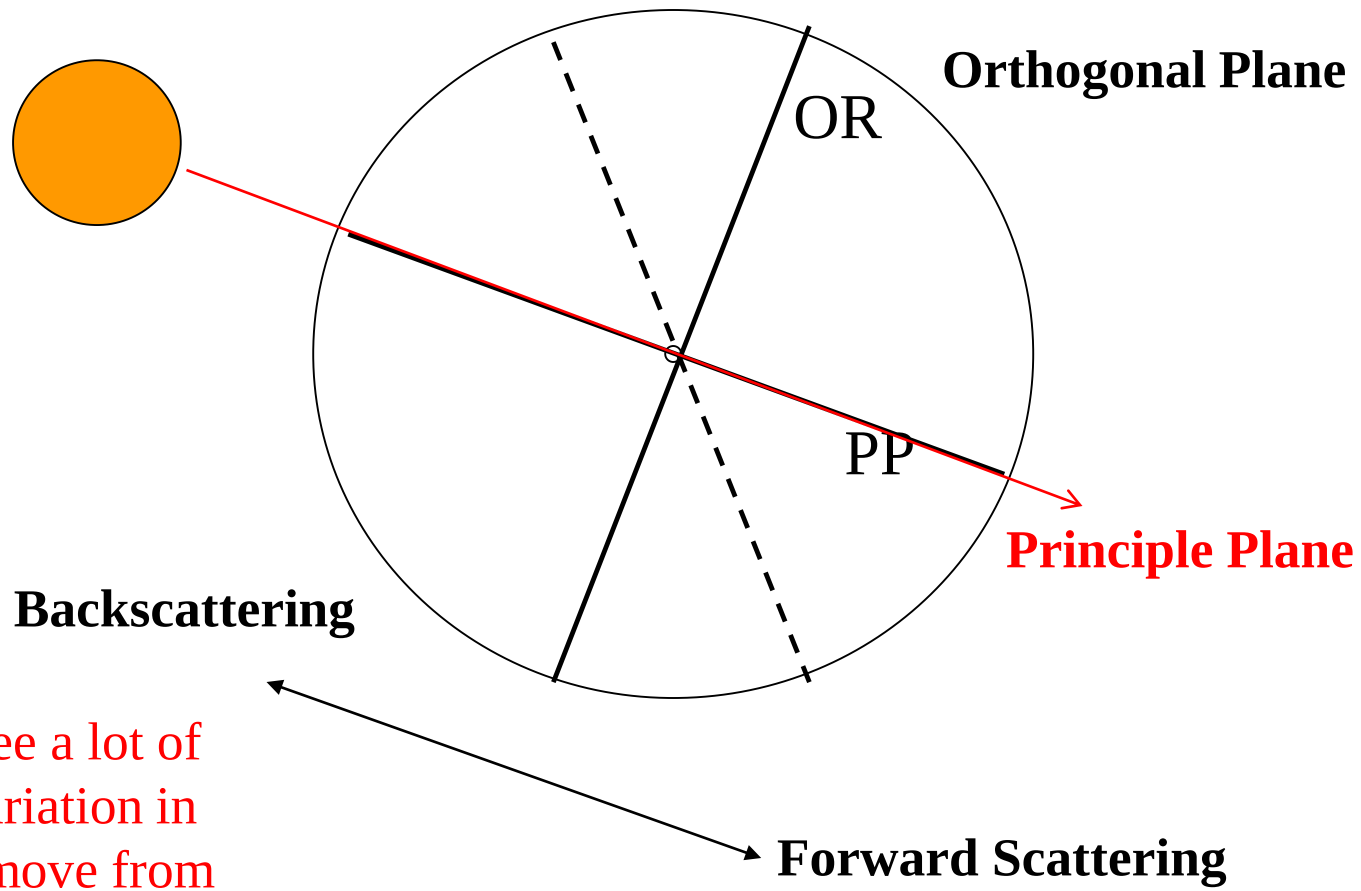

Orthogonal Plane
Perpendicular to direction of illumination
OR
PP
Principle Plane
Backscattering
Forward Scattering

Top View

If relative azimuth is 90° then sun and sensor are at adj. directions and in orthogonal plane



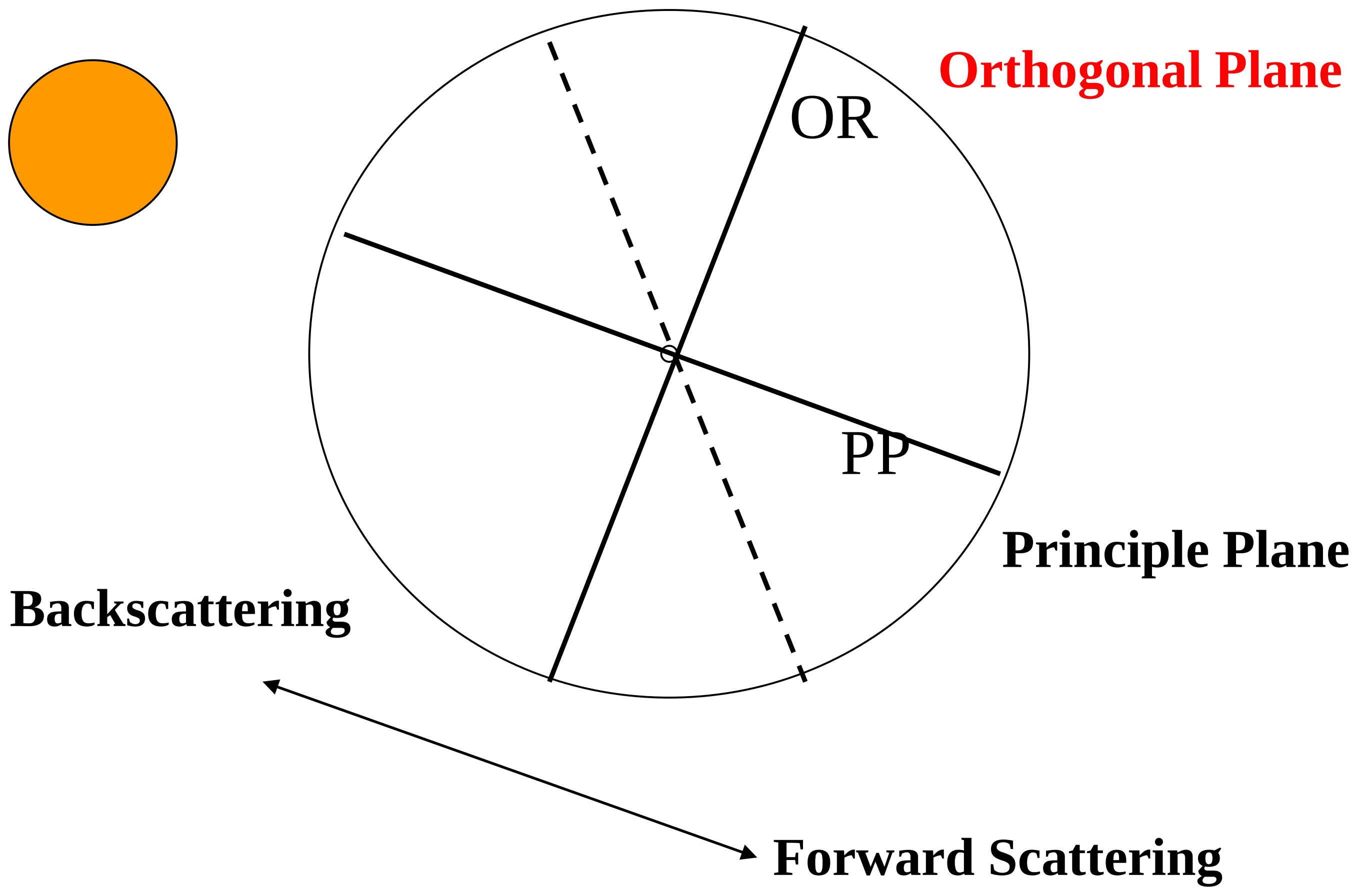
Top View



You will see a lot of shadow variation in PP as you move from one direction to another

Top View

You will see little shadow variation as you move from one direction to another in OR

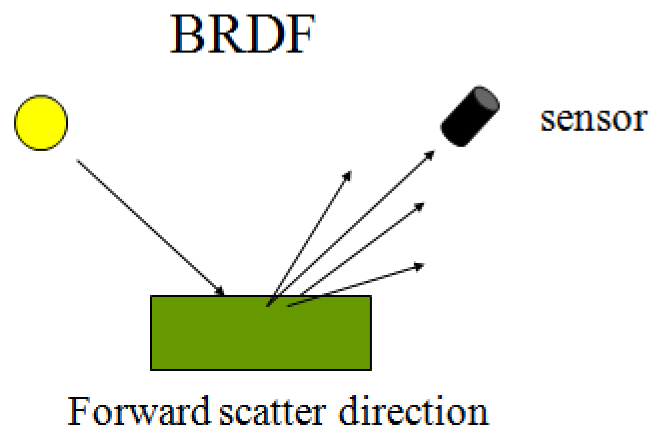


More terminology

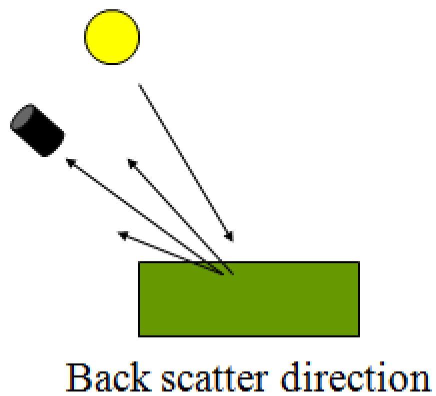
- Phase angle: angle between sensor and illumination source

- Hotspot: when phase angle equals 0
  - Sensor between sun and target
  - Zenith angles are equal
  - Rel. Azimuth is 0
  - No shadows, highest reflectance

Solar radiation scattered away from the sun



Solar radiation scattered back towards the sun



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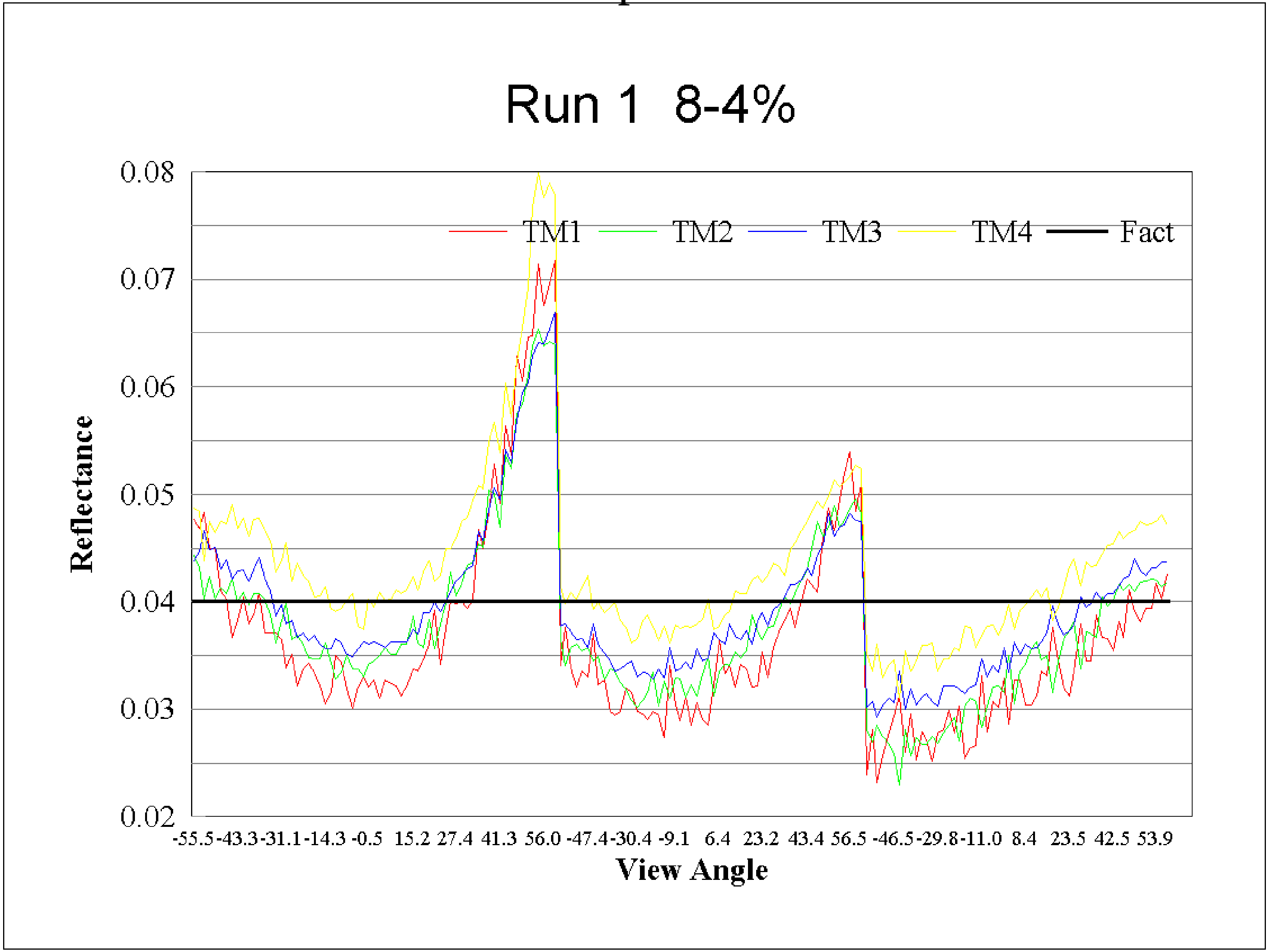
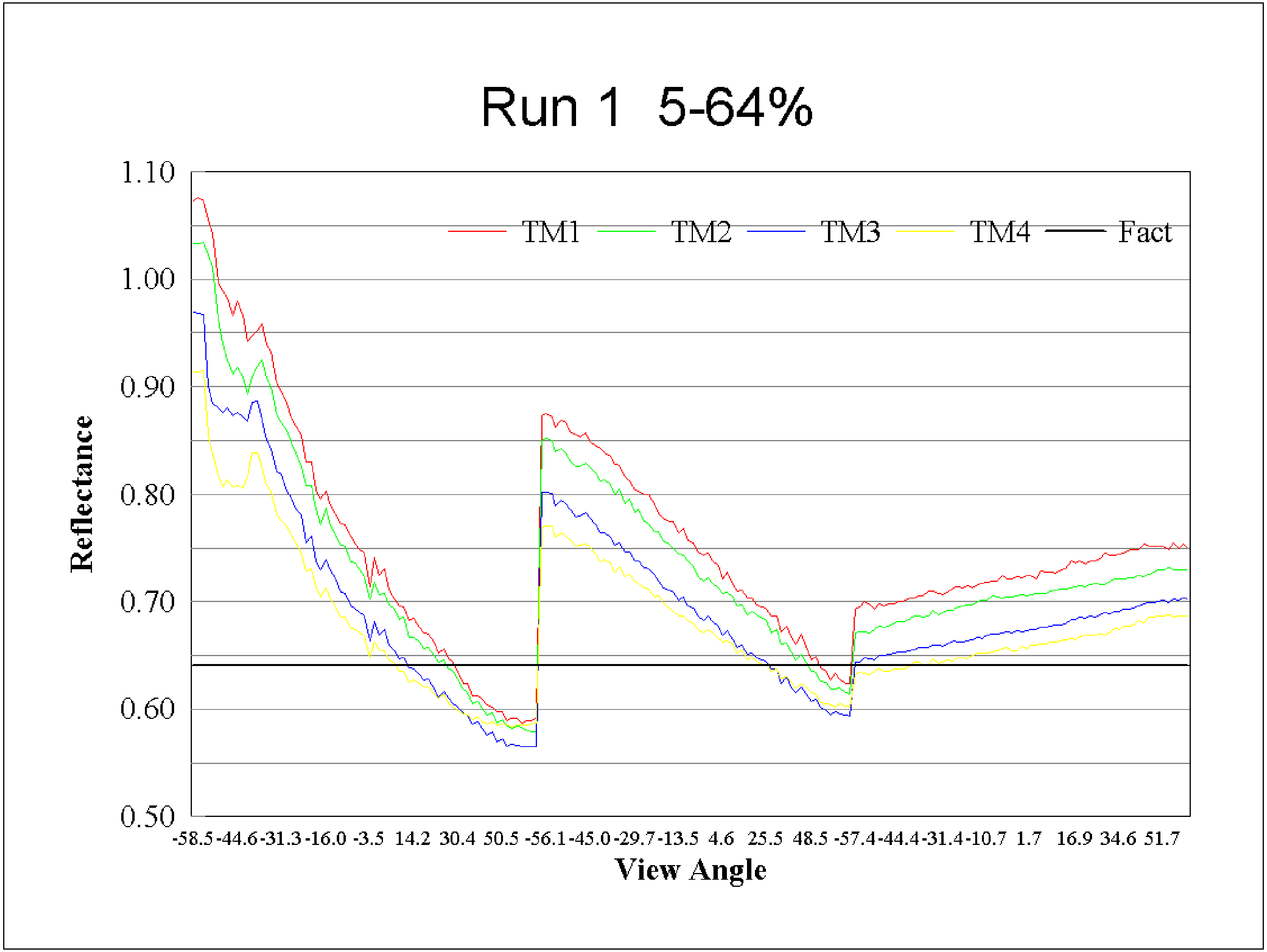
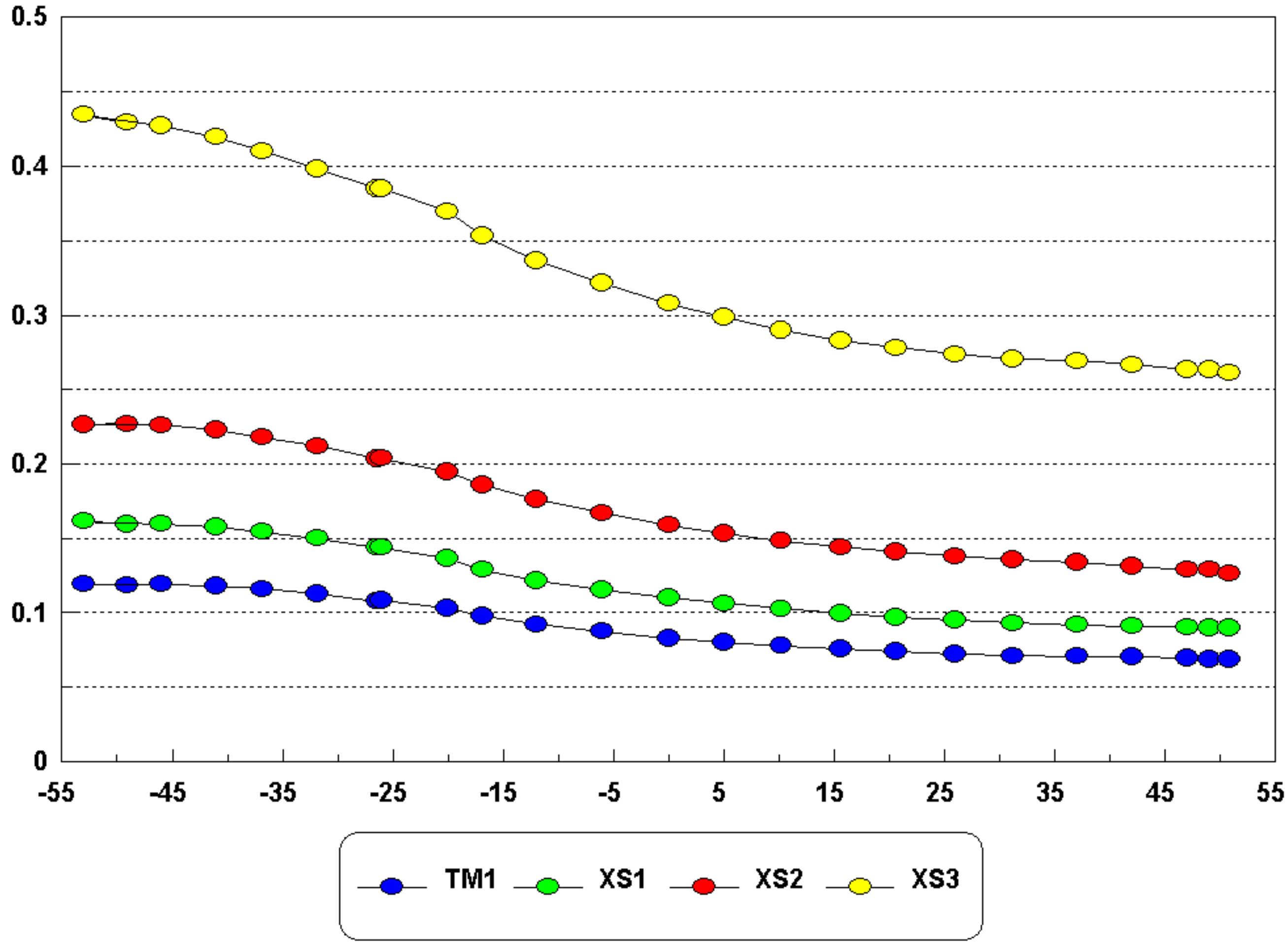
Artificial tarps at 4% reflectance

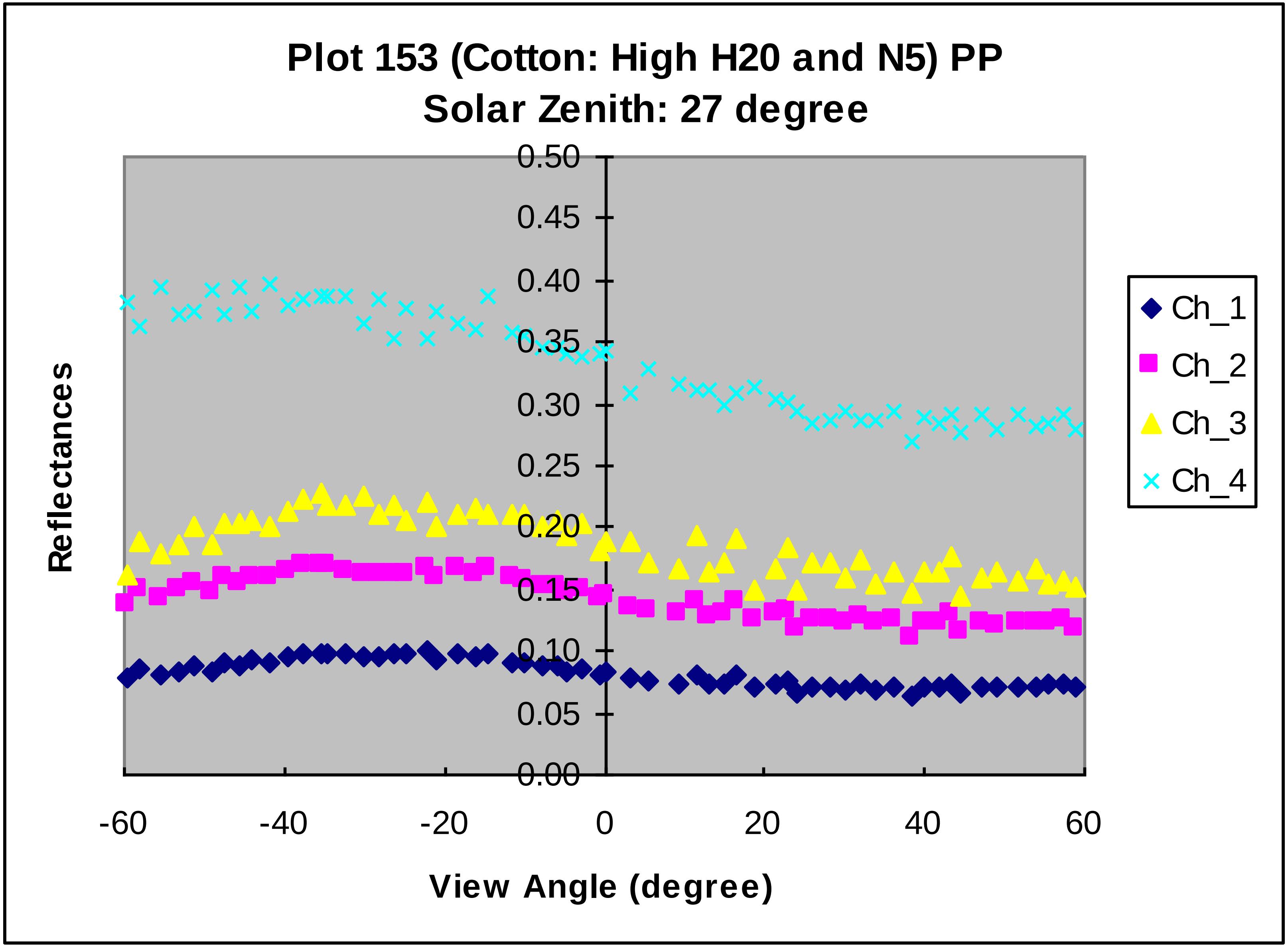


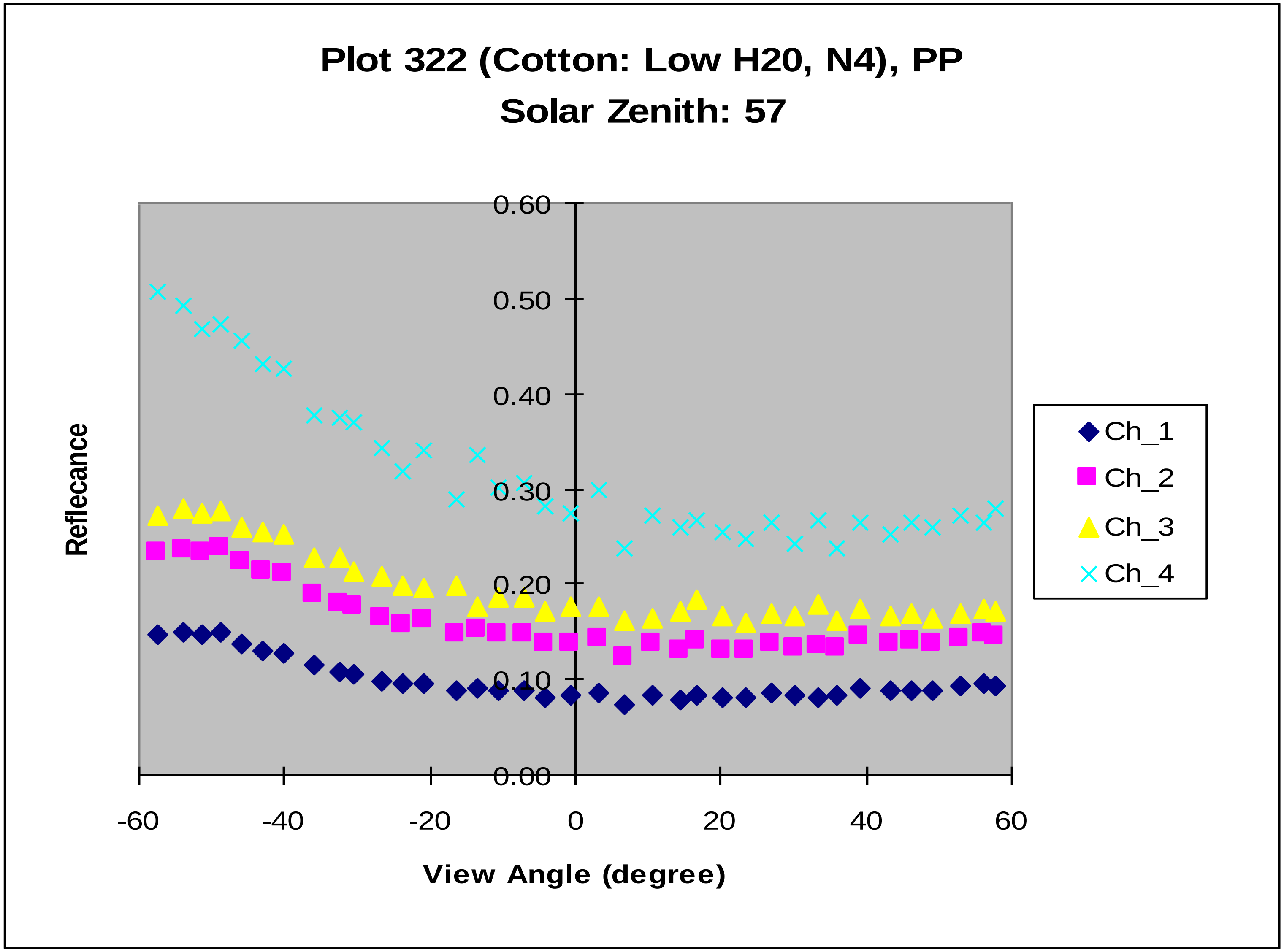
Artificial tarps at 64% reflectance



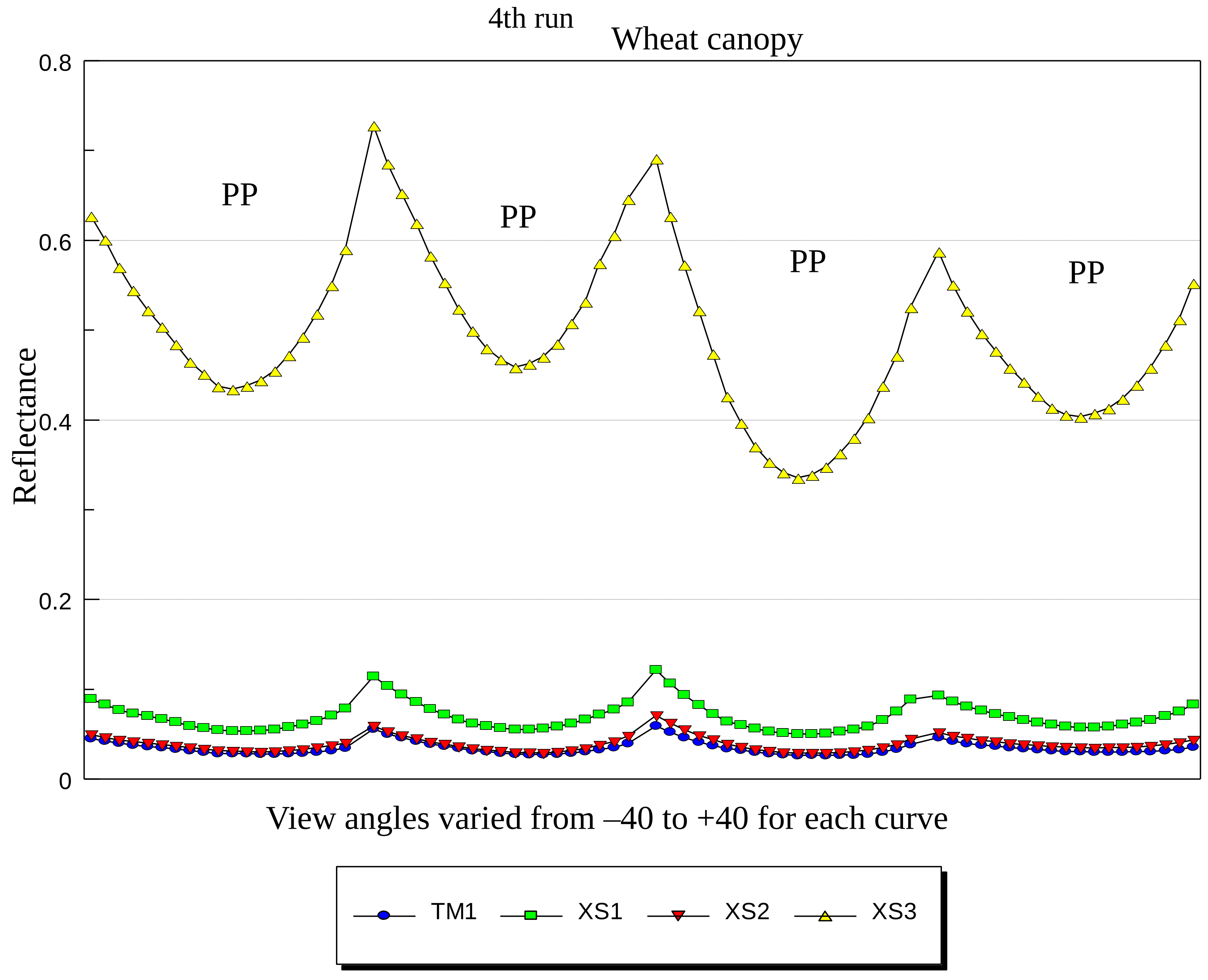
Young alfalfa canopy




Plot 153 (Cotton: High H20 and N5) PP
Solar Zenith: 27 degree
Reflectances
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
-60
-40
-20
0
20
40
60
View Angle (degree)
Ch_1
Ch_2
Ch_3
Ch_4

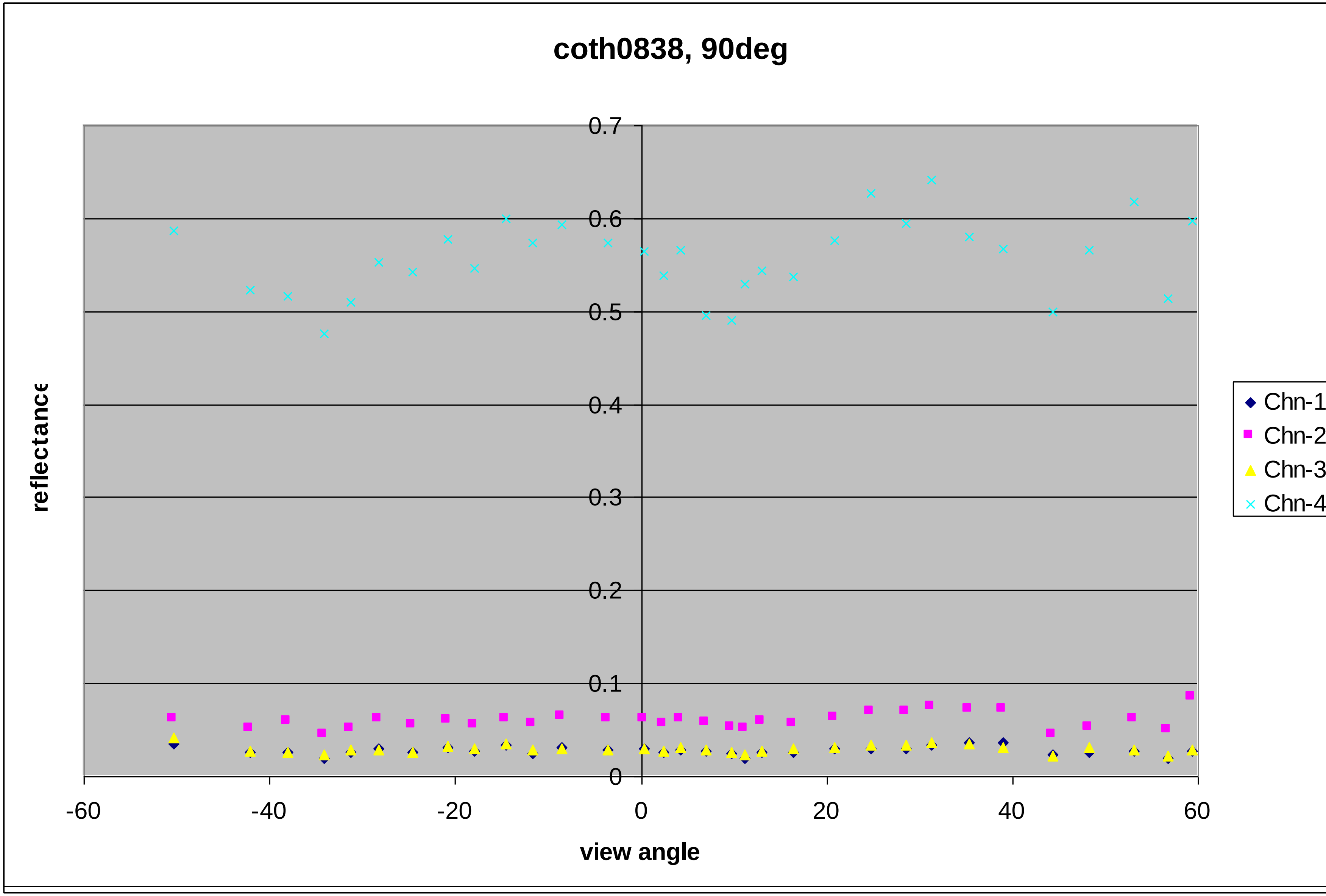


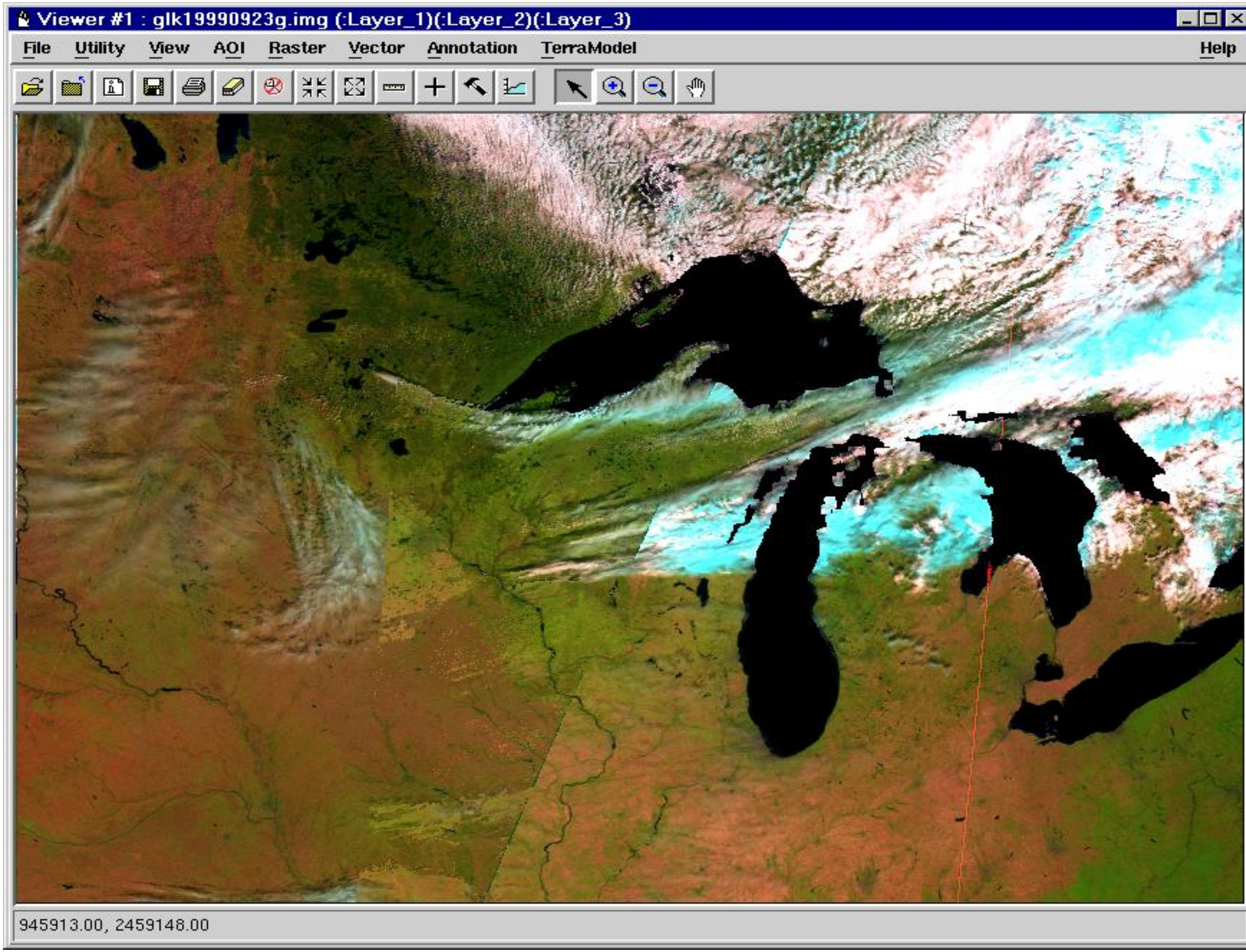
Plot 322 (Cotton: Low H20, N4), PP
Solar Zenith: 57
Reflecance
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-60
-40
-20
0
20
40
60
View Angle (degree)
Ch_1
Ch_2
Ch_3
Ch_4



4th run
Wheat canopy
0.8
0.6
0.4
0.2
0
Reflectance
PP
PP
PP
PP
View angles varied from –40 to +40 for each curve
TM1
XS1
XS2
XS3

BRDF Example 3 - Alfalfa


coth0838, 90deg
reflectance
view angle
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-60
-40
-20
0
20
40
60
Chn-1
Chn-2
Chn-3
Chn-4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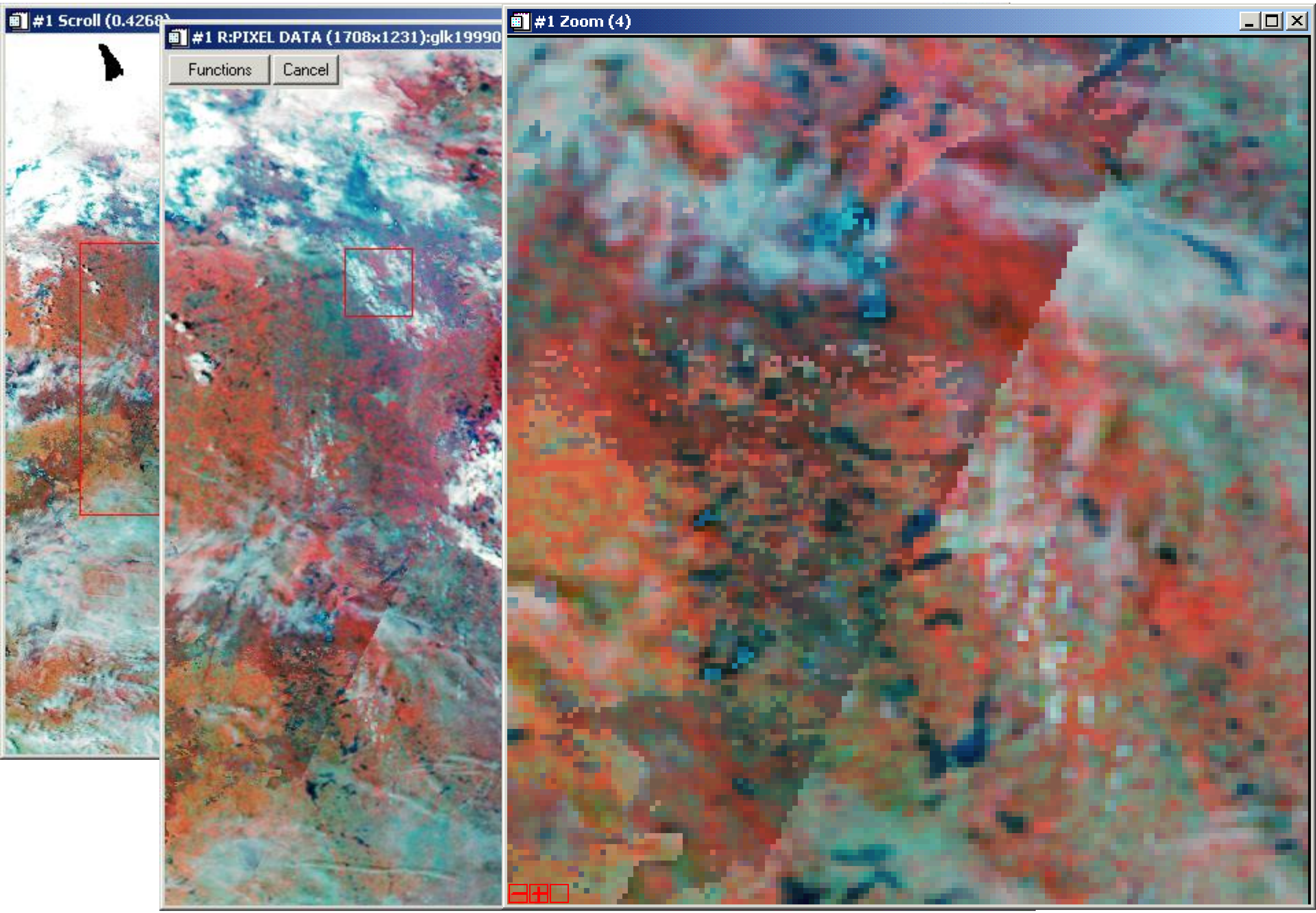
File Utility View AOI Raster Vector Annotation TerraModel Help
945913.00, 2459148.00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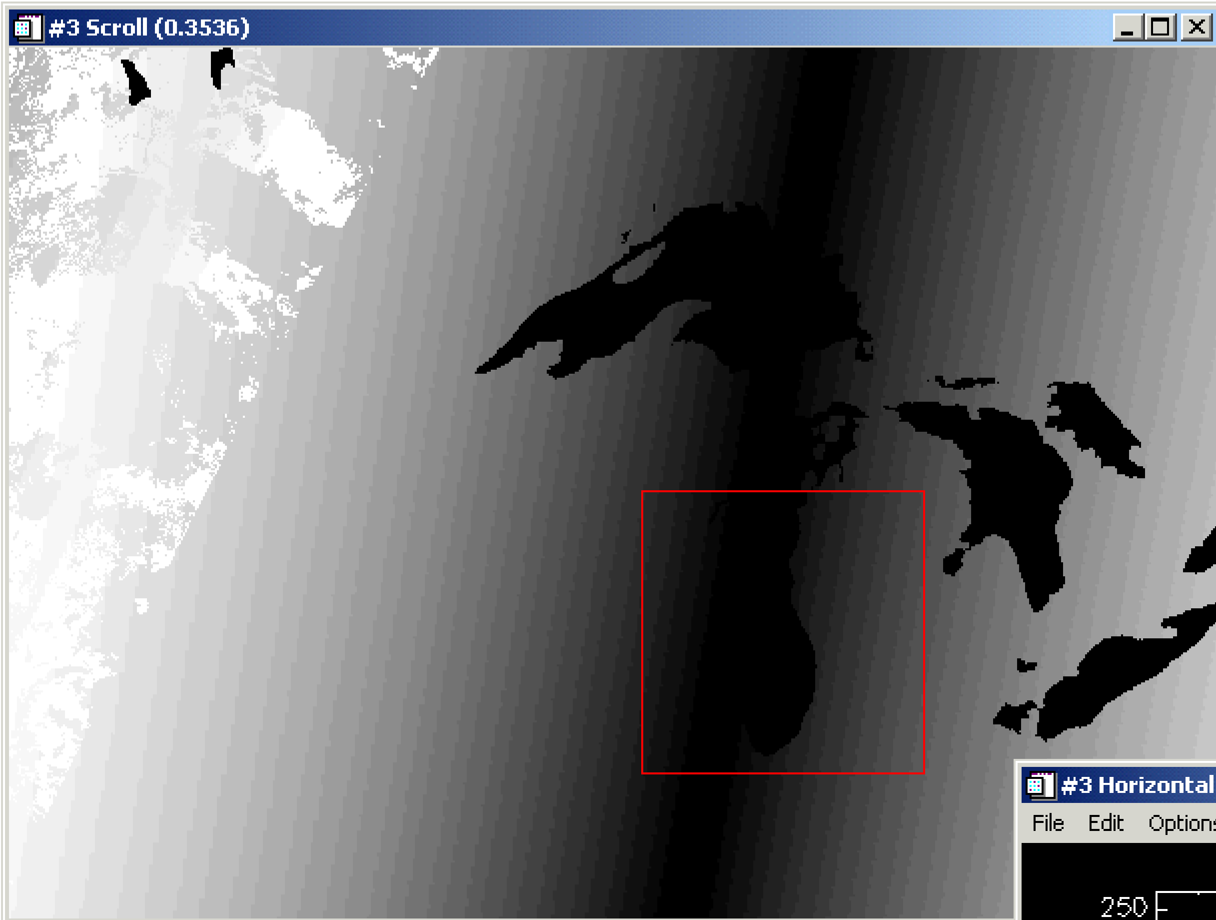
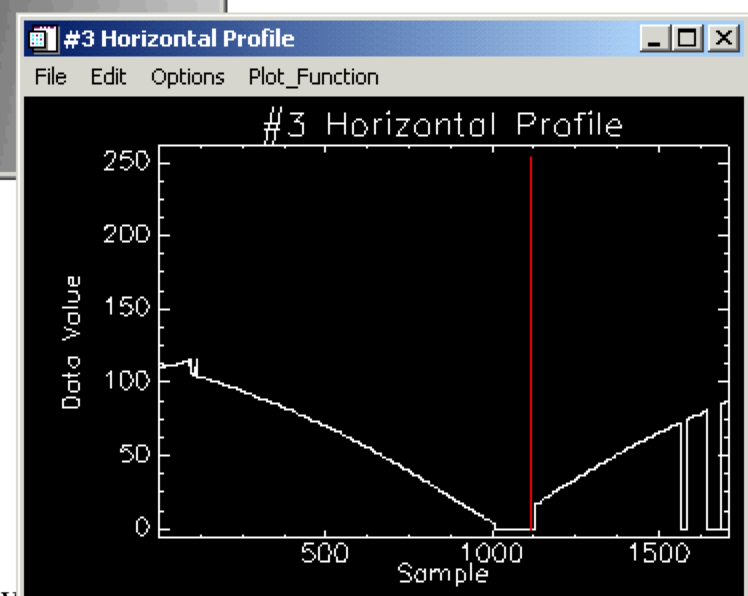
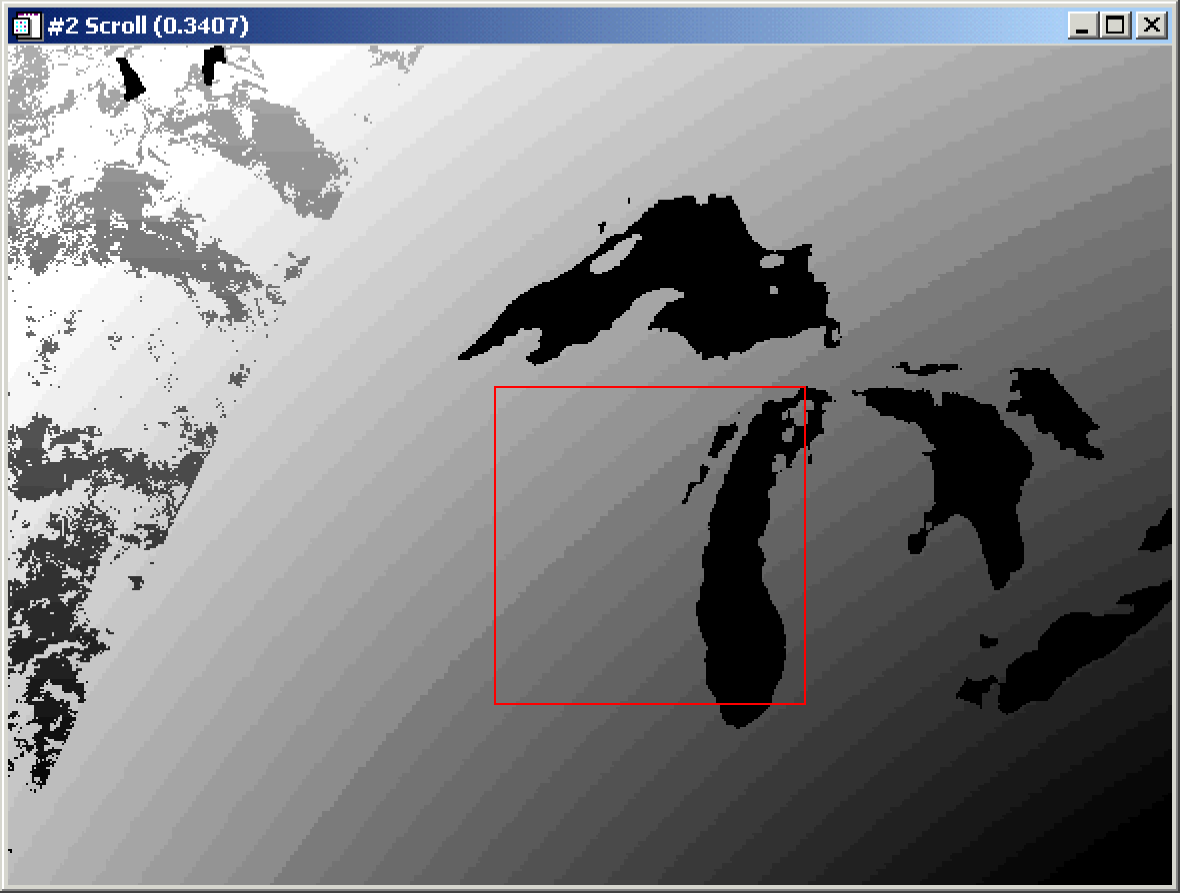
#1 R:PIXEL DATA (1708x1231):glk19990
Functions
Cancel
#1 Zoom (4)



#3 Scroll (0.3536)



#3 Horizontal Profile
File
Edit
Options
Plot_Function
#3 Horizontal Profile
Data Value
250
200
150
100
50
0
500
1000
1500
Sample


#2 Scroll (0.3407)

Issues

- Measurements at different view angles and directions can be substantially different;
- No standard viewing geometry, and sun elevation for remote sensing data acquisitions;
- Each senor from different direction sees different thing;
- How can images acquired with varying geometric configuration be compared?
- Comparison across geographic location is difficult, due to sun angle difference;
- Measurements made at different time of a day are also different. When is an optimal time?
- Should measurements be normalized to a single viewing geometry? If so, how?

Bidirectional Correction

- **Models must be established**
- Normalization standard must be determined
  - i. e., a set of sensor-target-sun geometry must be determined before correction is made
- Models vary with surface type
  - Ideally, different models (or same model but different coefficients) should be used for different surface types
- Many BRDF models exist and readily available
  - Challenges: Find appropriate model parameters for your crop type; even the same type crop, model parameters may vary depending on growth stage; select a model that best for your study

Modeling BRDF

- Empirical models:
  - Use empirical functions to simulate the shape of BRDF
  - For example, Shibayama and Wiegand (1985)
- Semi-empirical models
  - Radiative transfer schemes, but with empirical approximation
  - For example Roujean et al. (1992),
- Geometric models
  - For example, Li and Strahler (1985)
- Theoretical models
  - Canopy radiative transfer modeling
  - For example, Ross's model, SAIL, Myneni et al., Hapke, etc..
- Kernel Driven models:
  - Wanner et al., (1995)
  - MODIS product

Shibayama and Weigand Model

$$\rho = \rho_0 \left\{ 1 + \left(\beta_0 + \beta_1 \sin(\frac{\varphi}{2}) + \frac{\beta_2}{\cos\theta_s} \right) \sin\theta_v \right\}$$

Where ρ_0 is reflectance at nadir view, β_0, β_1, and β_2 are coefficients empirically derived.

Walthall Model 2001

$$r(q_s, q_v, f) = a_0 + a_1 q_s q_v \cos(f) + a_2 q_s^2 q_v^2 + a_3 (q_s^2 + q_v^2)$$

Boreal and Gerstl, 1994 and Gilabert et al., 2000

$$R(\lambda) = f_v R_v(\lambda) + f_{is} R_{is}(\lambda) + f_{ss} R_{ss}(\lambda)$$

$$R_v(\lambda) = R_\infty(\lambda) + [\rho_s(\lambda) - R_\infty(\lambda)] e^{-C \times LAI}$$

Roujean et al.,1992

Semi-empirical

$$\rho(\theta_s,\theta_v,\varphi) = k_0 + k_1 f_1(\theta_s,\theta_v,\varphi) + k_2 f_2(\theta_s,\theta_v,\varphi)$$

Roujean et al.,1992

Semi-empirical

$$\rho(\theta_s,\theta_v,\varphi)=k_0+k_1 f_1(\theta_s,\theta_v,\varphi)+k_2 f_2(\theta_s,\theta_v,\varphi)$$

These coefficients should be different for each band and each biome

Roujean et al.,1992

Semi-empirical

$$\rho(\theta_s,\theta_v,\varphi)=k_0+k_1 f_1(\theta_s,\theta_v,\varphi)+k_2 f_2(\theta_s,\theta_v,\varphi)$$

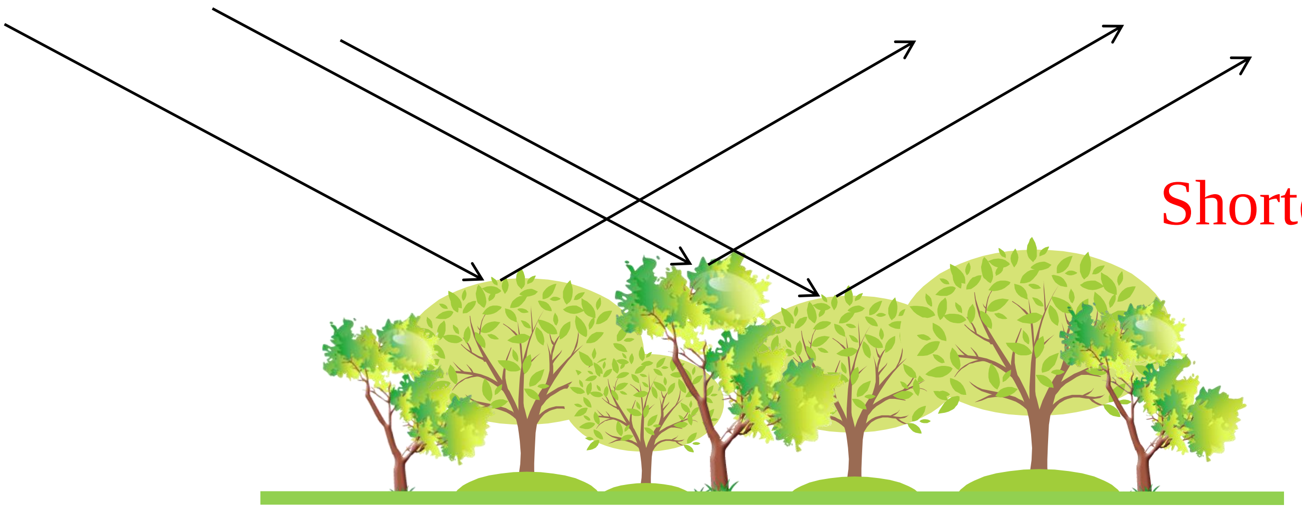
Related to albedo

Roujean et al.,1992

Semi-empirical

$$\rho(\theta_s,\theta_v,\varphi) = k_0 + \boxed{k_1 f_1(\theta_s,\theta_v,\varphi)} + k_2 f_2(\theta_s,\theta_v,\varphi)$$

Represents 1^{st} Order Scattering



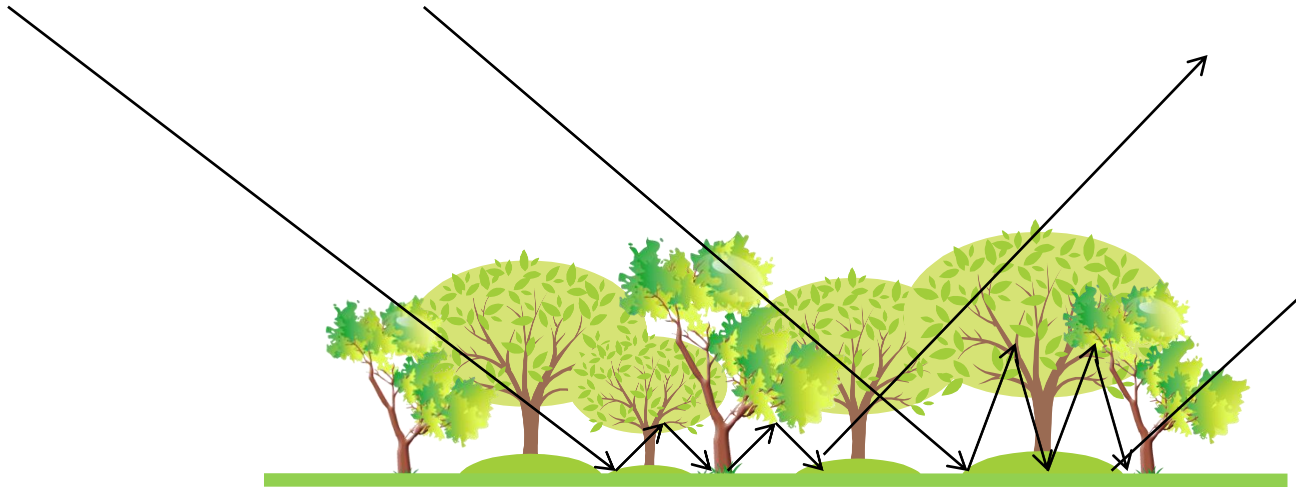
Shorter wavelengths

Roujean et al.,1992

Semi-empirical

$$\rho(\theta_s,\theta_v,\varphi)=k_0+k_1 f_1(\theta_s,\theta_v,\varphi)+k_2 f_2(\theta_s,\theta_v,\varphi)$$

Represents Volumetric Scattering



Longer wavelengths

Roujean et al.,1992

Semi-empirical

$$\rho(\theta_s,\theta_v,\varphi) = k_0 + k_1 f_1(\theta_s,\theta_v,\varphi) + k_2 f_2(\theta_s,\theta_v,\varphi)$$

$$f_1(\theta_s,\theta_v,\varphi) = \frac{1}{2\pi}\big((\pi-\varphi)\cos\varphi + \sin\varphi\big)\tan\theta_s \tan\theta_v - \frac{\tan\theta_s + \tan\theta_v + G}{\pi}$$

Roujean et al.,1992

Semi-empirical

$$\rho(\theta_s,\theta_v,\varphi) = k_0 + k_1 f_1(\theta_s,\theta_v,\varphi) + k_2 f_2(\theta_s,\theta_v,\varphi)$$

$$f_1(\theta_s,\theta_v,\varphi) = \frac{1}{2\pi}\big((\pi-\varphi)\cos\varphi + \sin\varphi\big)\tan\theta_s \tan\theta_v - \frac{\tan\theta_s + \tan\theta_v + G}{\pi}$$

$$f_2(\theta_s,\theta_v,\varphi) = \frac{4}{3\pi}\frac{1}{\cos\theta_s + \cos\theta_v}\left((\frac{\pi}{2}-\xi)\cos\xi + \sin\xi\right) - \frac{1}{3}$$

Roujean et al.,1992

Semi-empirical

$$\rho(\theta_s,\theta_v,\varphi)=k_0+k_1 f_1(\theta_s,\theta_v,\varphi)+k_2 f_2(\theta_s,\theta_v,\varphi)$$

$$f_1(\theta_s,\theta_v,\varphi)=\frac{1}{2\pi}\left((\pi-\varphi)\cos\varphi+\sin\varphi\right)\tan\theta_s\tan\theta_v-\frac{\tan\theta_s+\tan\theta_v+G}{\pi}$$

$$f_2(\theta_s,\theta_v,\varphi)=\frac{4}{3\pi}\frac{1}{\cos\theta_s+\cos\theta_v}\left((\frac{\pi}{2}-\xi)\cos\xi+\sin\xi\right)-\frac{1}{3}$$

$$\cos\xi=\cos\theta_s\cos\theta_v+\sin\theta_s\sin\theta_v\cos\varphi$$

Roujean et al.,1992

Semi-empirical

$$\rho(\theta_s,\theta_v,\varphi)=k_0+k_1 f_1(\theta_s,\theta_v,\varphi)+k_2 f_2(\theta_s,\theta_v,\varphi)$$

$$f_1(\theta_s,\theta_v,\varphi)=\frac{1}{2\pi}\big((\pi-\varphi)\cos\varphi+\sin\varphi\big)\tan\theta_s\tan\theta_v-\frac{\tan\theta_s+\tan\theta_v+G}{\pi}$$

$$f_2(\theta_s,\theta_v,\varphi)=\frac{4}{3\pi}\frac{1}{\cos\theta_s+\cos\theta_v}\left((\frac{\pi}{2}-\xi)\cos\xi+\sin\xi\right)-\frac{1}{3}$$

$$\cos\xi=\cos\theta_s\cos\theta_v+\sin\theta_s\sin\theta_v\cos\varphi$$

$$G=\sqrt{\tan^2\theta_s+\tan^2\theta_v-2\tan\theta_s\tan\theta_v\cos\varphi}$$

Roujean et al.,1992

Solar Zenith

$$\rho(\theta_s,\theta_v,\varphi)=k_0+k_1 f_1(\theta_s,\theta_v,\varphi)+k_2 f_2(\theta_s,\theta_v,\varphi)$$

$$f_1(\theta_s,\theta_v,\varphi)=\frac{1}{2\pi}\big((\pi-\varphi)\cos\varphi+\sin\varphi\big)\tan\theta_s\tan\theta_v-\frac{\tan\theta_s+\tan\theta_v+G}{\pi}$$

$$f_2(\theta_s,\theta_v,\varphi)=\frac{4}{3\pi}\frac{1}{\cos\theta_s+\cos\theta_v}\left((\frac{\pi}{2}-\xi)\cos\xi+\sin\xi\right)-\frac{1}{3}$$

$$\cos\xi=\cos\theta_s\cos\theta_v+\sin\theta_s\sin\theta_v\cos\varphi$$

$$G=\sqrt{\tan^2\theta_s+\tan^2\theta_v-2\tan\theta_s\tan\theta_v\cos\varphi}$$

Roujean et al.,1992

View Zenith

$$\rho(\theta_s,\theta_v,\varphi) = k_0 + k_1 f_1(\theta_s,\theta_v,\varphi) + k_2 f_2(\theta_s,\theta_v,\varphi)$$

$$f_1(\theta_s,\theta_v,\varphi) = \frac{1}{2\pi}\big((\pi-\varphi)\cos\varphi + \sin\varphi\big)\tan\theta_s \tan\theta_v - \frac{\tan\theta_s + \tan\theta_v + G}{\pi}$$

$$f_2(\theta_s,\theta_v,\varphi) = \frac{4}{3\pi}\frac{1}{\cos\theta_s + \cos\theta_v}\left((\frac{\pi}{2}-\xi)\cos\xi + \sin\xi\right) - \frac{1}{3}$$

$$\cos\xi = \cos\theta_s \cos\theta_v + \sin\theta_s \sin\theta_v \cos\varphi$$

$$G = \sqrt{\tan^2\theta_s + \tan^2\theta_v - 2\tan\theta_s \tan\theta_v \cos\varphi}$$

Roujean et al.,1992

Relative Azimuth

$$\rho(\theta_s,\theta_v,\varphi) = k_0 + k_1 f_1(\theta_s,\theta_v,\varphi) + k_2 f_2(\theta_s,\theta_v,\varphi)$$

$$f_1(\theta_s,\theta_v,\varphi) = \frac{1}{2\pi}\big((\pi-\varphi)\cos\varphi + \sin\varphi\big)\tan\theta_s \tan\theta_v - \frac{\tan\theta_s + \tan\theta_v + G}{\pi}$$

$$f_2(\theta_s,\theta_v,\varphi) = \frac{4}{3\pi}\frac{1}{\cos\theta_s + \cos\theta_v}\left((\frac{\pi}{2}-\xi)\cos\xi + \sin\xi\right) - \frac{1}{3}$$

$$\cos\xi = \cos\theta_s \cos\theta_v + \sin\theta_s \sin\theta_v \cos\varphi$$

$$G = \sqrt{\tan^2\theta_s + \tan^2\theta_v - 2\tan\theta_s \tan\theta_v \cos\varphi}$$

wak Model, 2001

$$\rho(\theta_s, \theta_v, \varphi) = S(H + H_i H_e - 1)$$

$$S = \frac{w \cos\theta_s}{4(\cos\theta_s + \cos\theta_v)}$$

$$H_i = \frac{1 + 2\cos\theta_s}{1 + 2\cos\theta_s \sqrt{1-w}}$$

$$H = \frac{8}{3\pi}\left(\alpha + (\pi - \alpha)e^{-k\xi}\right)$$

$$H_e = \frac{1 + 2\cos\theta_v}{1 + 2\cos\theta_v \sqrt{1-w}}$$

$$\cos\xi = \cos\theta_s \cos\theta_v + \sin\theta_s \sin\theta_v \cos\varphi$$

Rahman et al., 1993

$$\rho(\theta_s,\theta_v,\varphi) = \rho_0 \frac{(\cos\theta_s\cos\theta_v)^{k-1}}{(\cos\theta_s+\cos\theta_v)^{1-k}} \frac{1-\Theta^2}{\left[1+\Theta^2-2\Theta\cos(\pi-\xi)\right]^{3/2}} \left(1+\frac{1-\rho_0}{1+G}\right)$$

$$\cos\xi = \cos\theta_s\cos\theta_v + \sin\theta_s\sin\theta_v\cos\varphi$$

$$G = \sqrt{\tan^2\theta_s + \tan^2\theta_v - 2\tan\theta_s\tan\theta_v\cos\varphi}$$

Kuusk and Nilson, 2000

$$\rho(r_1, r_2) = \frac{I}{Q}\rho_1(r_1, r_2) + \frac{D}{Q}\rho_D(r_2)$$

$$\rho_D(r_2) = \frac{\int_{2\pi} d(r_1)\rho_I(r_1, r_2)\mu_1 dr_1}{D} \approx$$

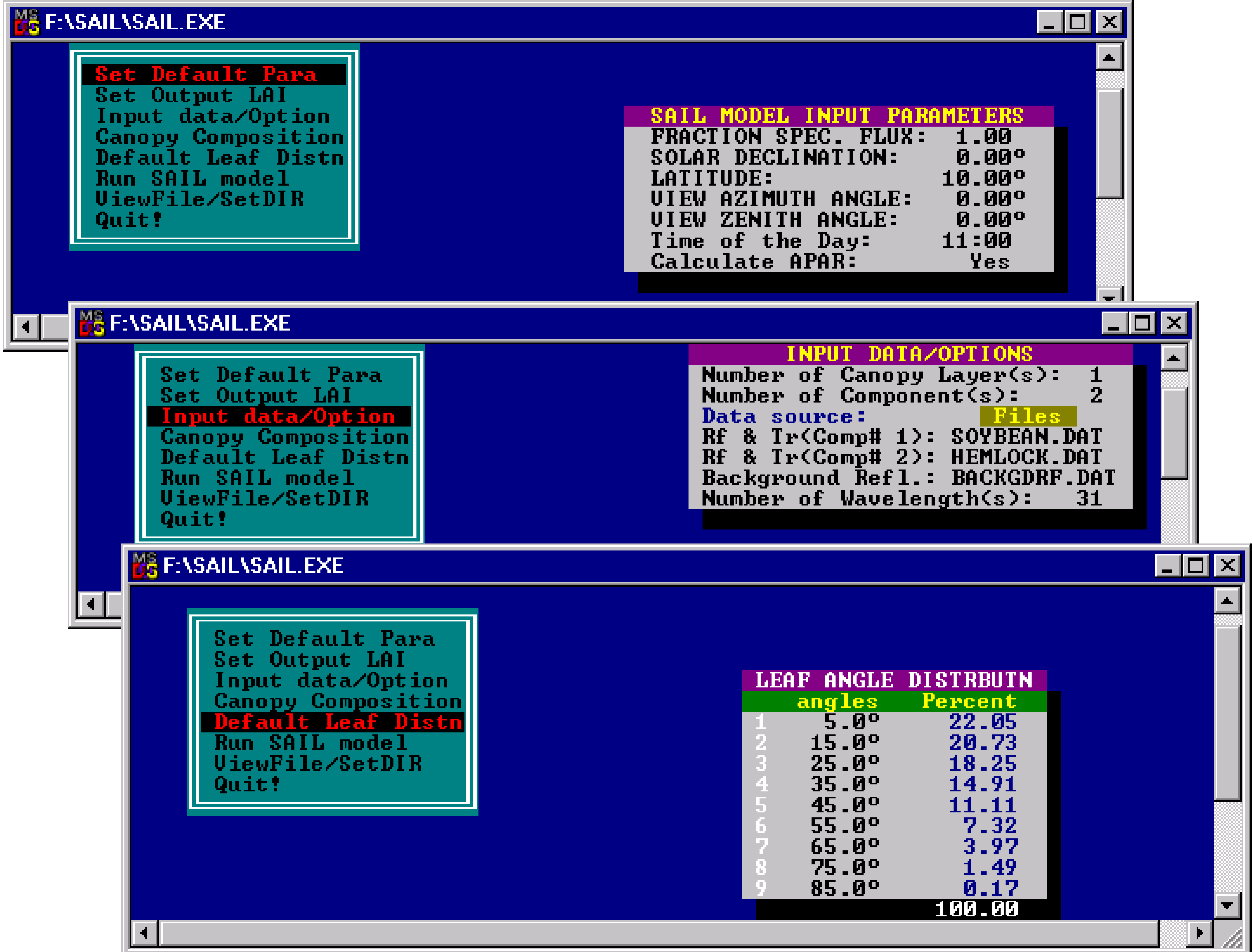
$$\frac{\int_0^{2\pi} d(\theta_1, \phi - \frac{\pi}{2})\rho_I(\theta_1, \theta_2, \phi - \frac{\pi}{2})\mu_1 d\theta_1}{D}$$

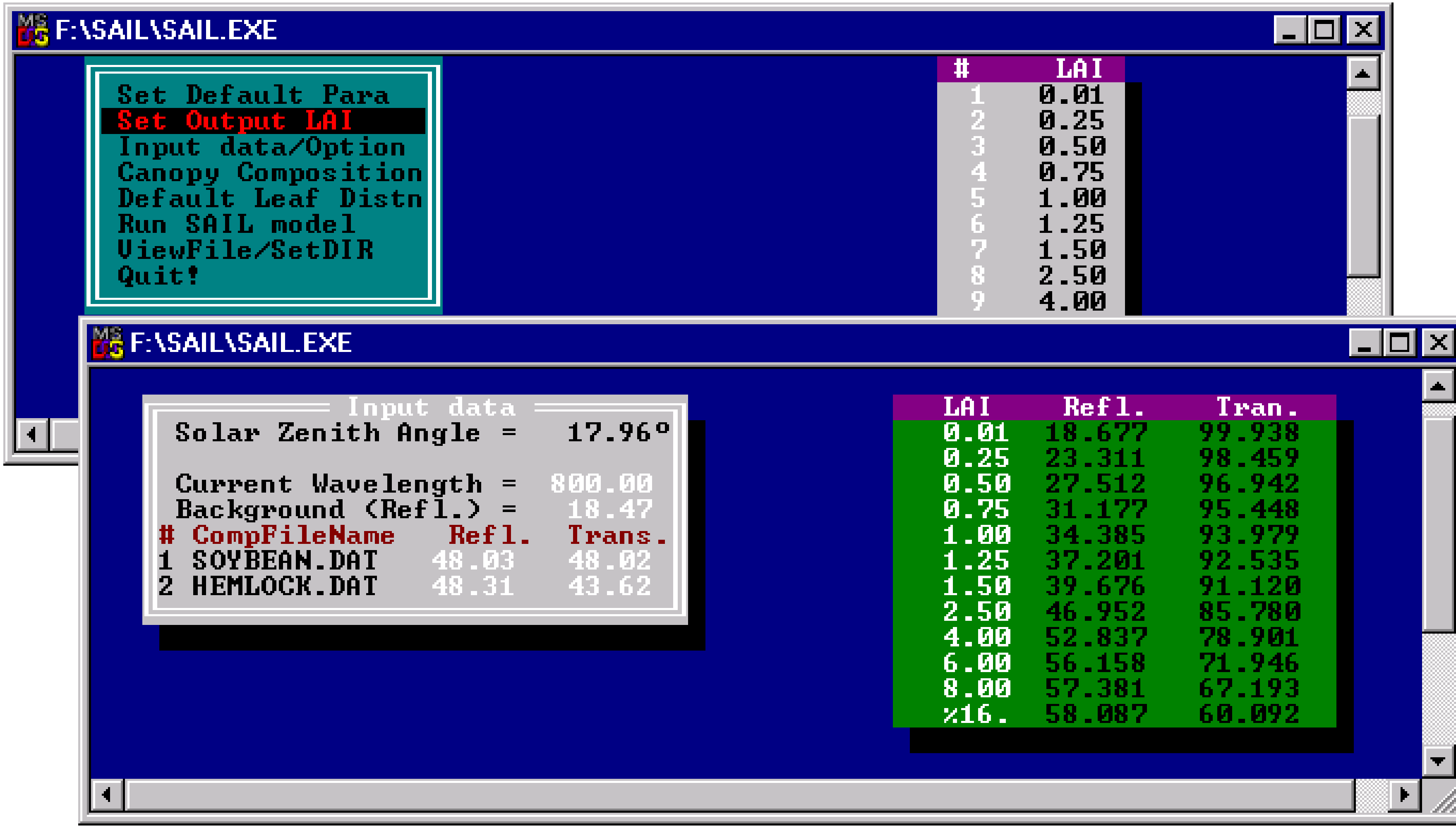
$$I(r_1, r_2) = \frac{I_0(r_1)\mu_L \Gamma(r_1, r_2)}{\pi}\int_V p(x, y, z, s_1, s_2, \alpha) dxdydz$$

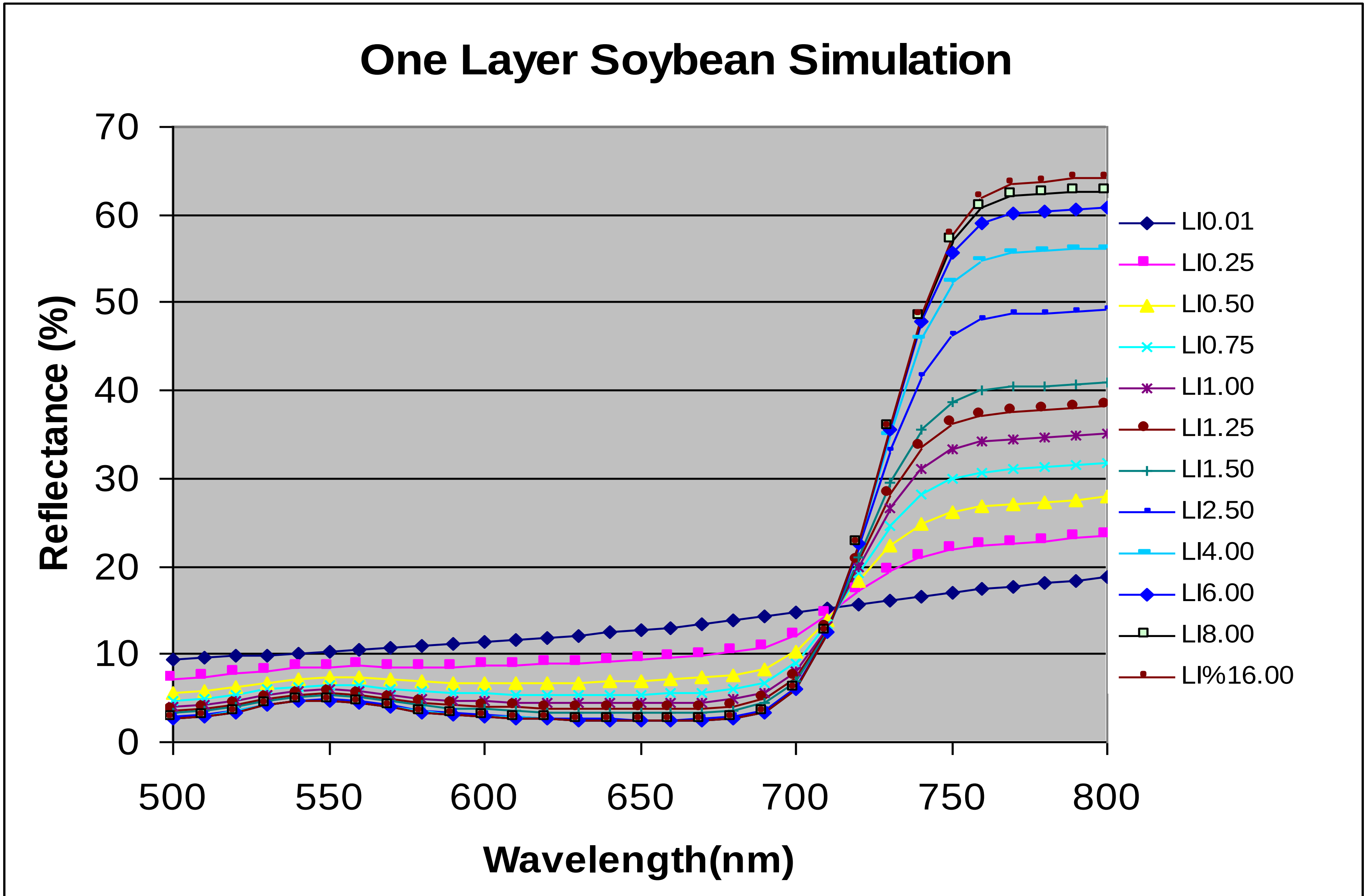
SAIL Model, Verhoef, 1984

$$dEs/dx = kEs$$
$$dE\_/dx = -s\,Es + a\,E\_ - E+$$
$$dE+/dx = s'\,Es + E\_ - a\,E+$$
$$dEo/dx = w\,Es + vE\_ + u\,E+ - KEo$$

where *Es* is direct solar flux, *E_* and *E+* are diffuse downward and upward flux, E*o* is total solar irradiance, K is extinction coefficient, and *k*, *s*, *s'*, *a*, are coefficients related to surface properties.

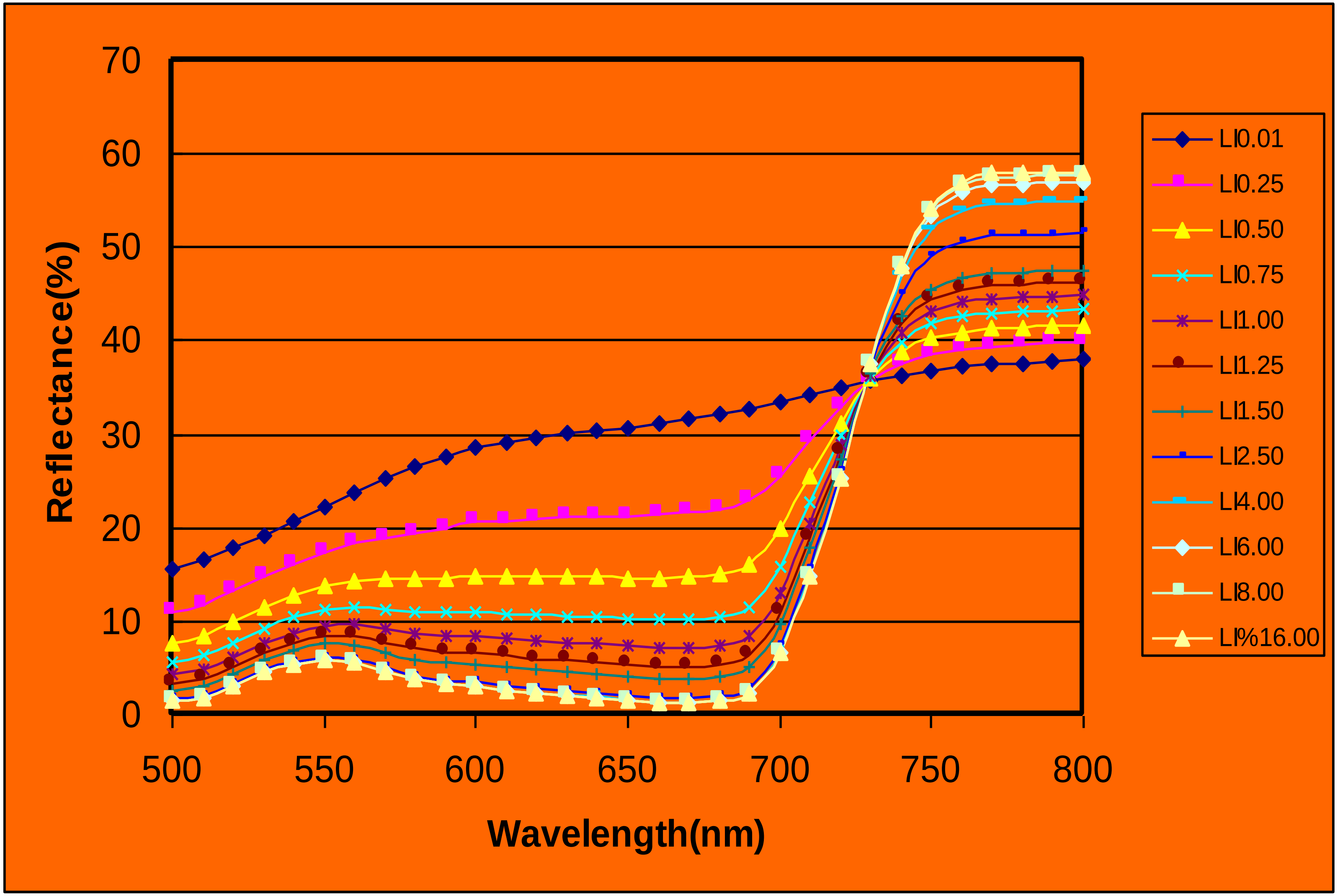

F:\SAIL\SAIL.EXE
Set Default Para
Set Output LAI
Input data/Option
Canopy Composition
Default Leaf Distn
Run SAIL model
ViewFile/SetDIR
Quit!
SAIL MODEL INPUT PARAMETERS
FRACTION SPEC. FLUX: 1.00
SOLAR DECLINATION: 0.00°
LATITUDE: 10.00°
VIEW AZIMUTH ANGLE: 0.00°
VIEW ZENITH ANGLE: 0.00°
Time of the Day: 11:00
Calculate APAR: Yes
F:\SAIL\SAIL.EXE
Set Default Para
Set Output LAI
Input data/Option
Canopy Composition
Default Leaf Distn
Run SAIL model
ViewFile/SetDIR
Quit!
INPUT DATA/OPTIONS
Number of Canopy Layer(s): 1
Number of Component(s): 2
Data source: Files
Rf & Tr(Comp# 1): SOYBEAN.DAT
Rf & Tr(Comp# 2): HEMLOCK.DAT
Background Refl.: BACKGDRF.DAT
Number of Wavelength(s): 31
F:\SAIL\SAIL.EXE
Set Default Para
Set Output LAI
Input data/Option
Canopy Composition
Default Leaf Distn
Run SAIL model
ViewFile/SetDIR
Quit!
LEAF ANGLE DISTRBUTN
angles Percent
1 5.0° 22.05
2 15.0° 20.73
3 25.0° 18.25
4 35.0° 14.91
5 45.0° 11.11
6 55.0° 7.32
7 65.0° 3.97
8 75.0° 1.49
9 85.0° 0.17
100.00


F:\SAIL\SAIL.EXE
Set Default Para
Set Output LAI
Input data/Option
Canopy Composition
Default Leaf Distn
Run SAIL model
ViewFile/SetDIR
Quit!
LAI
1 0.01
2 0.25
3 0.50
4 0.75
5 1.00
6 1.25
7 1.50
8 2.50
9 4.00
F:\SAIL\SAIL.EXE
Input data
Solar Zenith Angle = 17.96°
Current Wavelength = 800.00
Background (Refl.) = 18.47
CompFileName Refl. Trans.
1 SOYBEAN.DAT 48.03 48.02
2 HEMLOCK.DAT 48.31 43.62
LAI Refl. Tran.
0.01 18.677 99.938
0.25 23.311 98.459
0.50 27.512 96.942
0.75 31.177 95.448
1.00 34.385 93.979
1.25 37.201 92.535
1.50 39.676 91.120
2.50 46.952 85.780
4.00 52.837 78.901
6.00 56.158 71.946
8.00 57.381 67.193
∞16. 58.087 60.092



One Layer Soybean Simulation
Reflectance (%)
70
60
50
40
30
20
10
0
500
550
600
650
700
750
800
Wavelength(nm)
LI0.01
LI0.25
LI0.50
LI0.75
LI1.00
LI1.25
LI1.50
LI2.50
LI4.00
LI6.00
LI8.00
LI%16.00

SAIL model



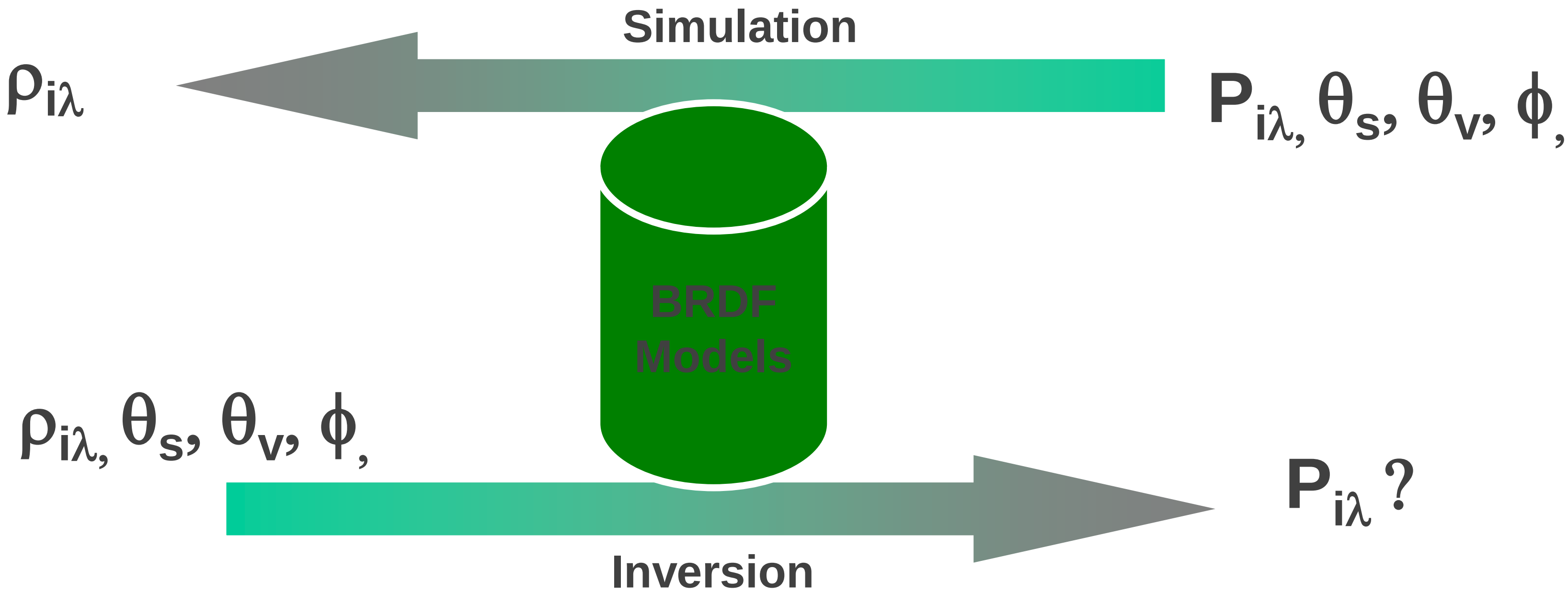
Reflectance(%)
70
60
50
40
30
20
10
0
500
550
600
650
700
750
800
Wavelength(nm)
LI0.01
LI0.25
LI0.50
LI0.75
LI1.00
LI1.25
LI1.50
LI2.50
LI4.00
LI6.00
LI8.00
LI%16.00

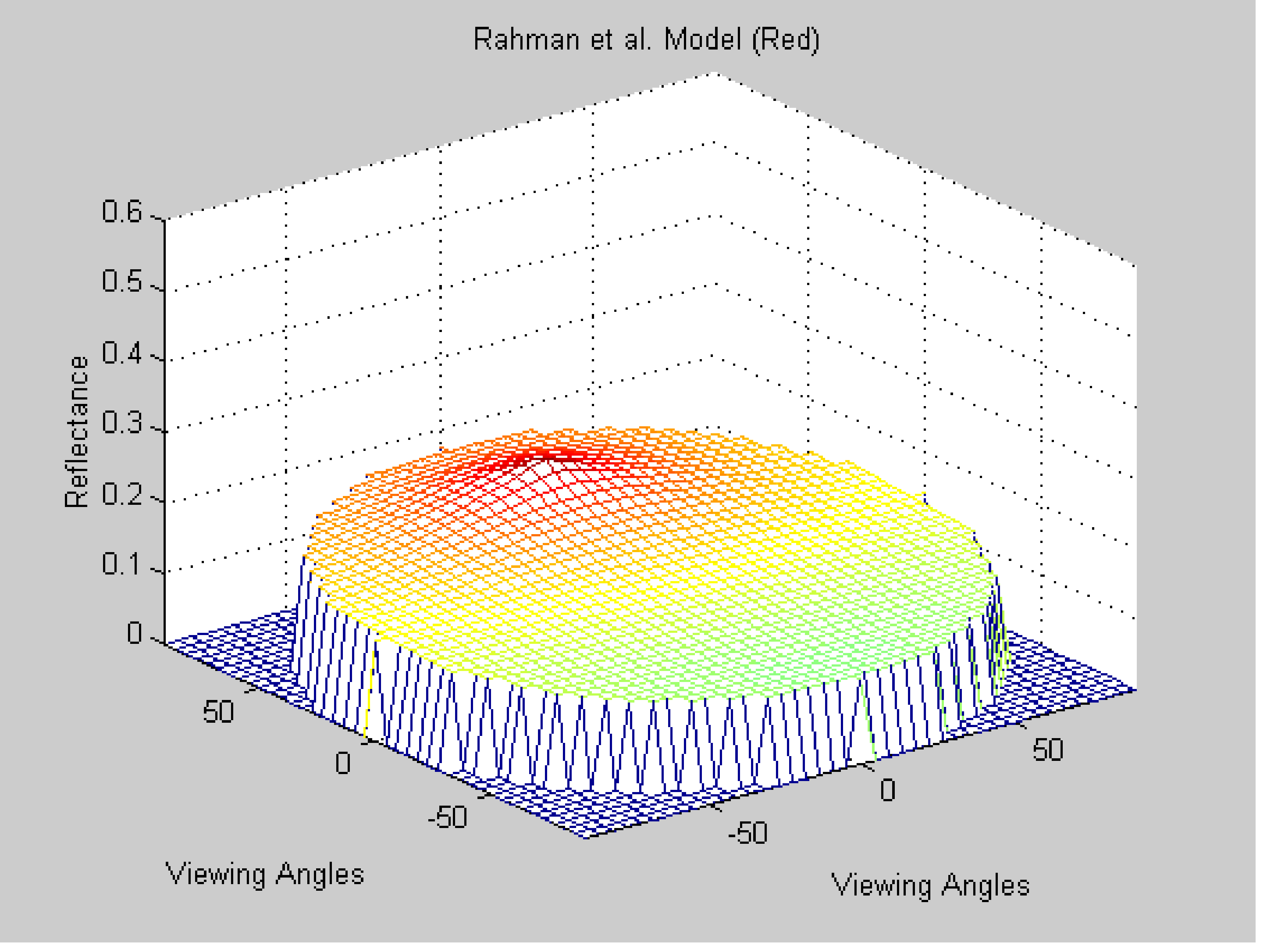
Model Summary

1. Model performance is very similar in many cases
2. Selection criteria:
   - Simple
   - Fewer model parameters
   - Multiplicative forms preferred
   - Computation time

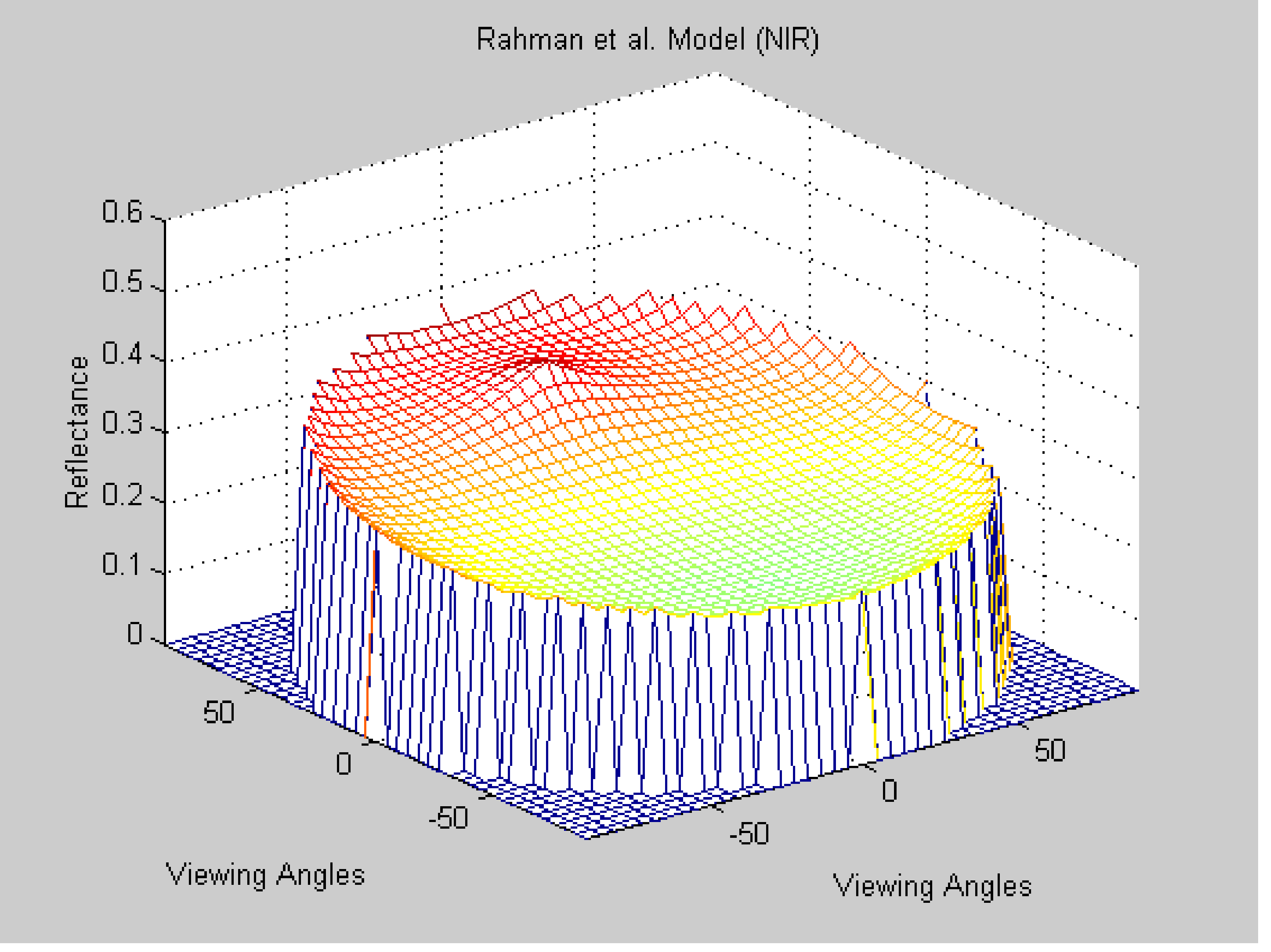
Simulation and Inversion

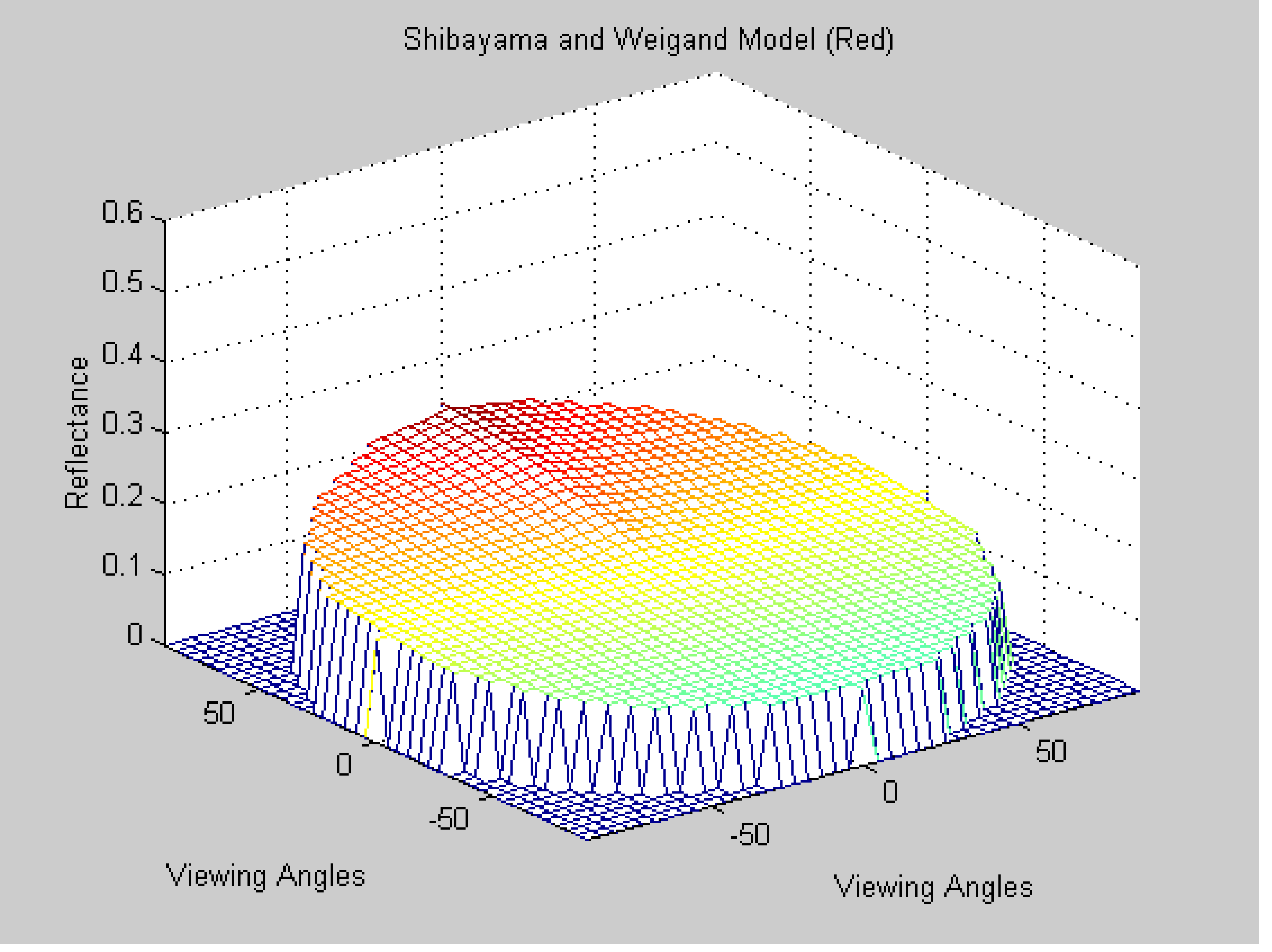
$$\rho = f(\mathrm{P}, \theta_s, \theta_v, \phi)$$



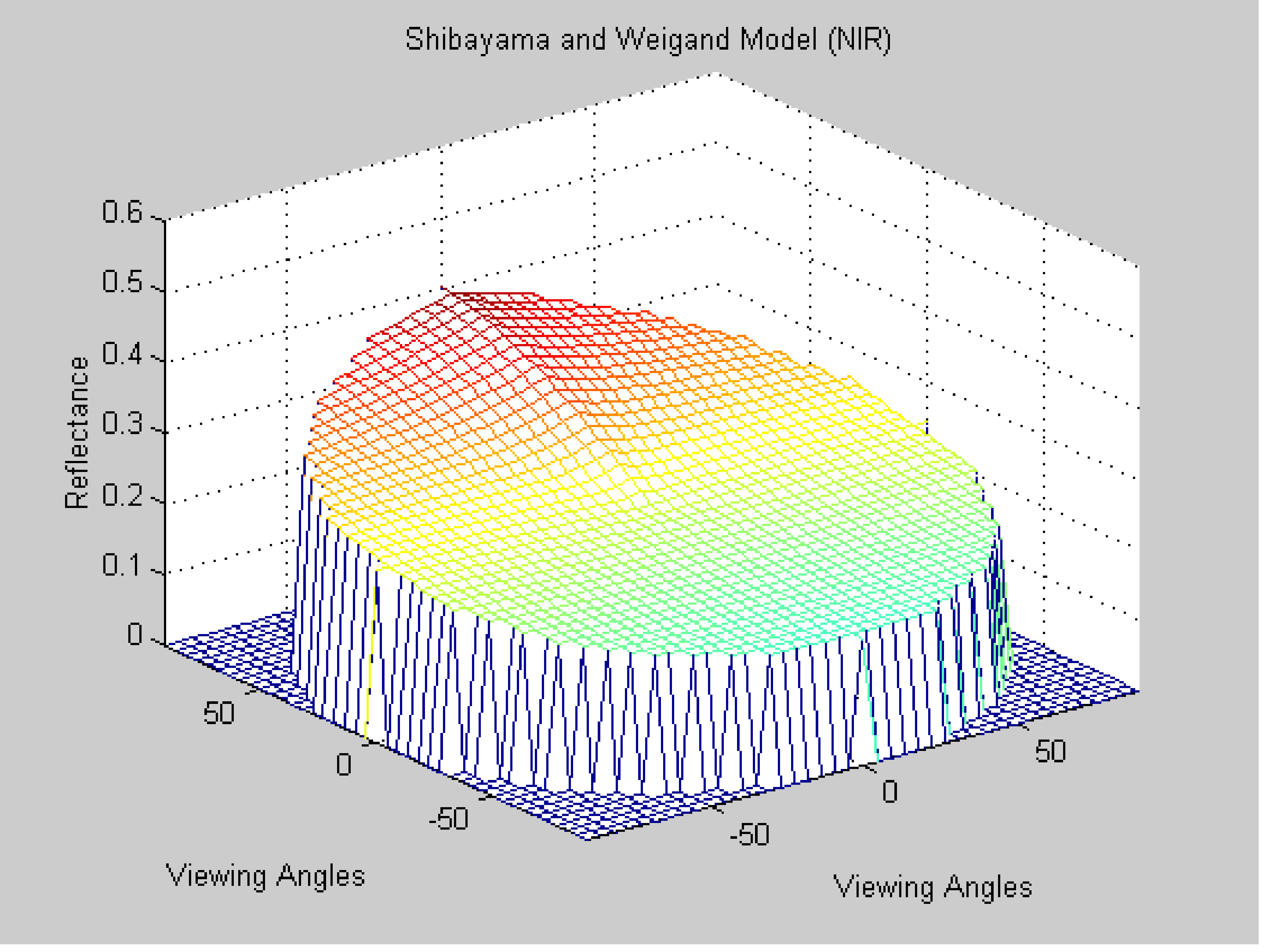


Rahman et al. Model (Red)
Reflectance
0.6
0.5
0.4
0.3
0.2
0.1
0
50
0
-50
Viewing Angles
50
0
-50
Viewing Angles

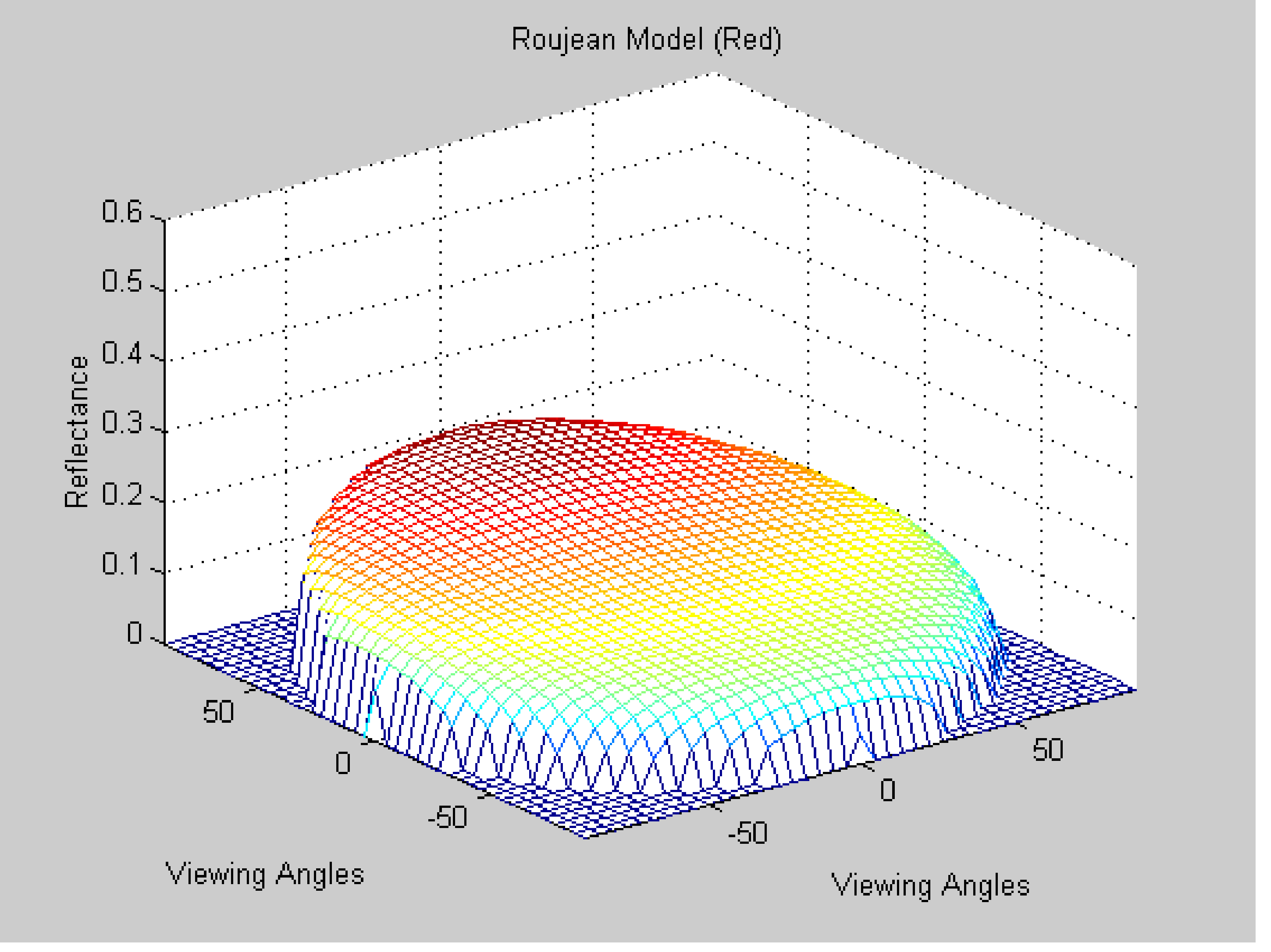

Rahman et al. Model (NIR)
Reflectance
0.6
0.5
0.4
0.3
0.2
0.1
0
50
0
-50
Viewing Angles
50
0
-50
Viewing Angles

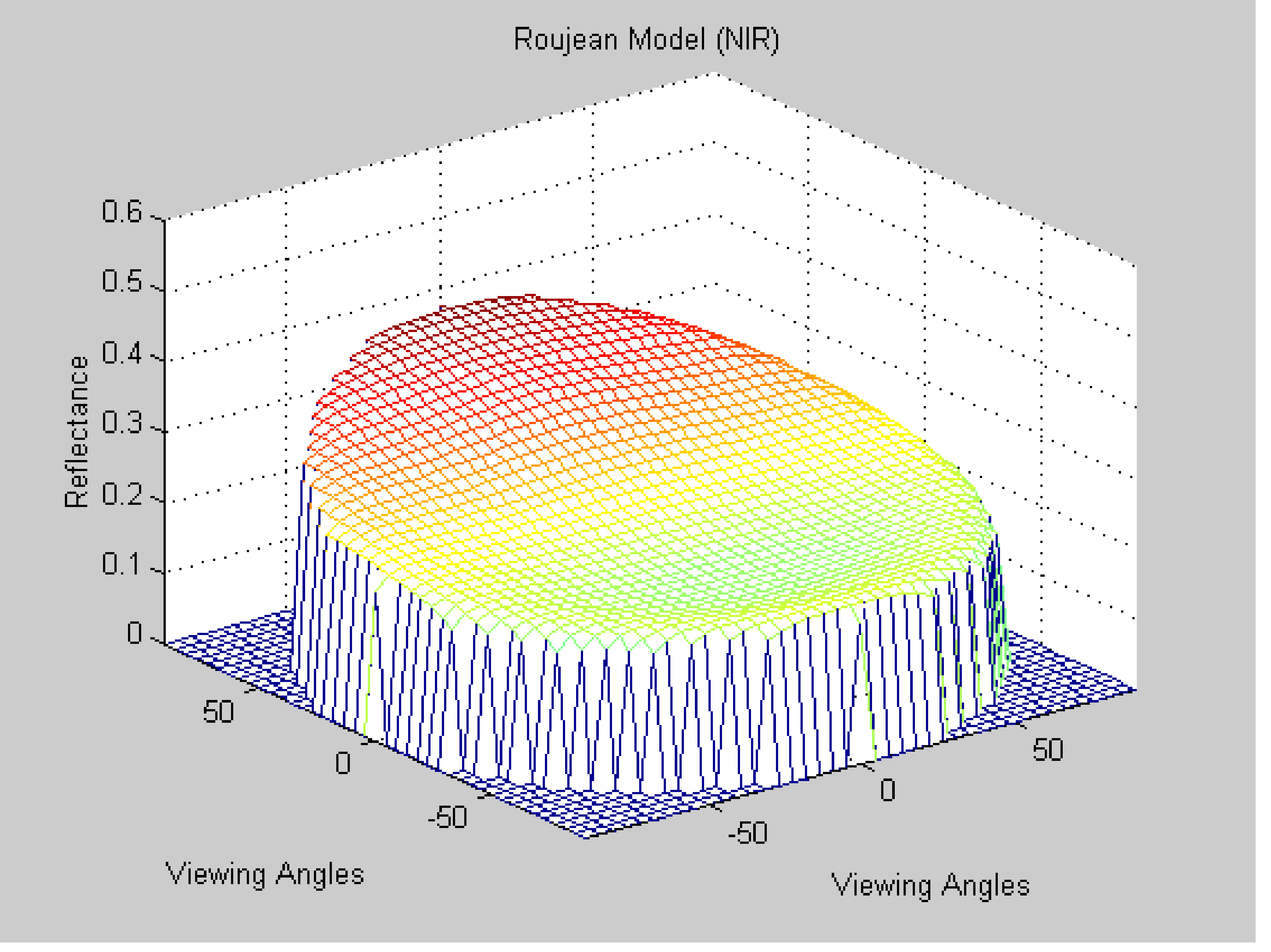


Shibayama and Weigand Model (Red)
Reflectance
0.6
0.5
0.4
0.3
0.2
0.1
0
50
0
-50
Viewing Angles
50
0
-50
Viewing Angles

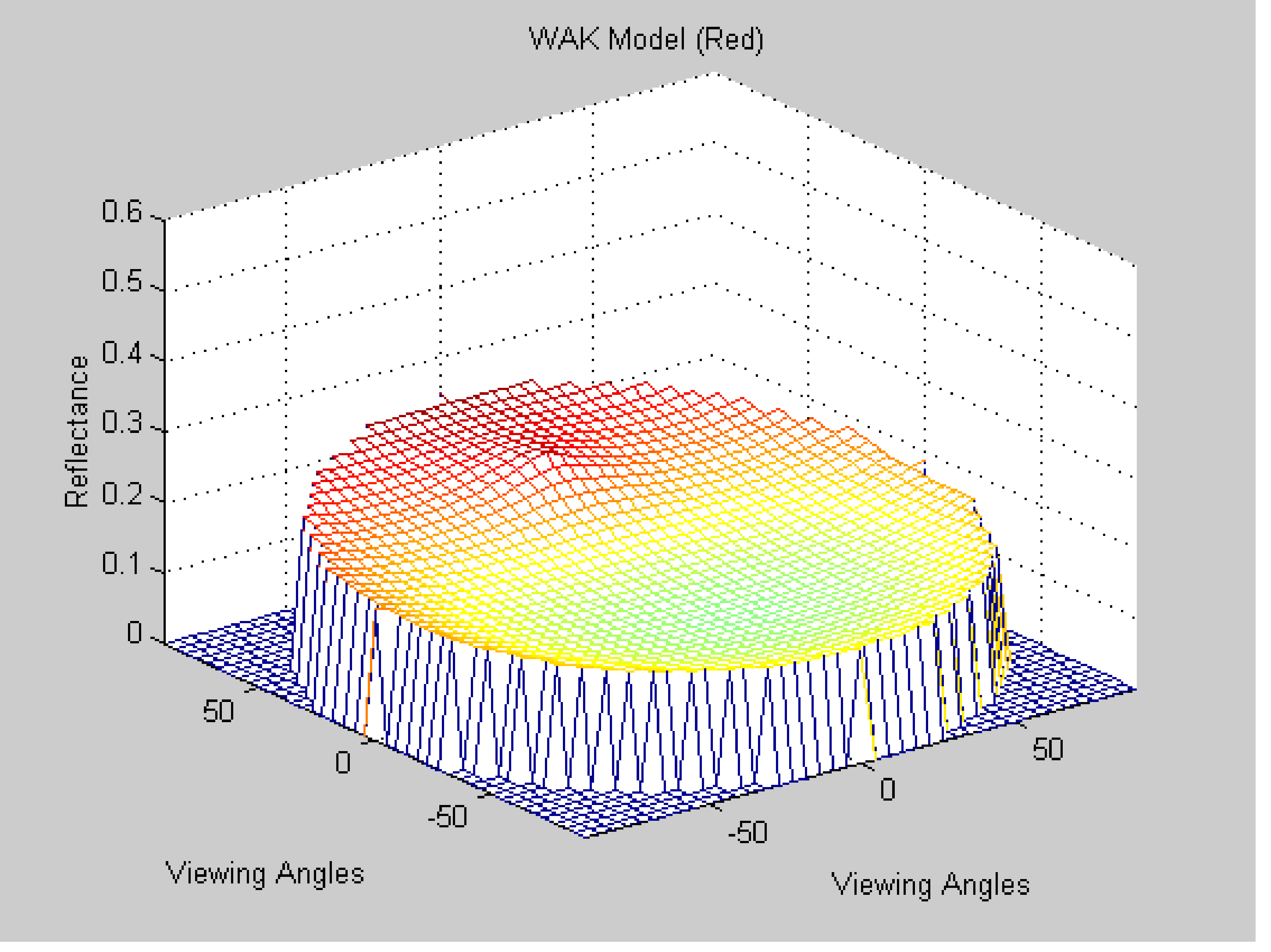


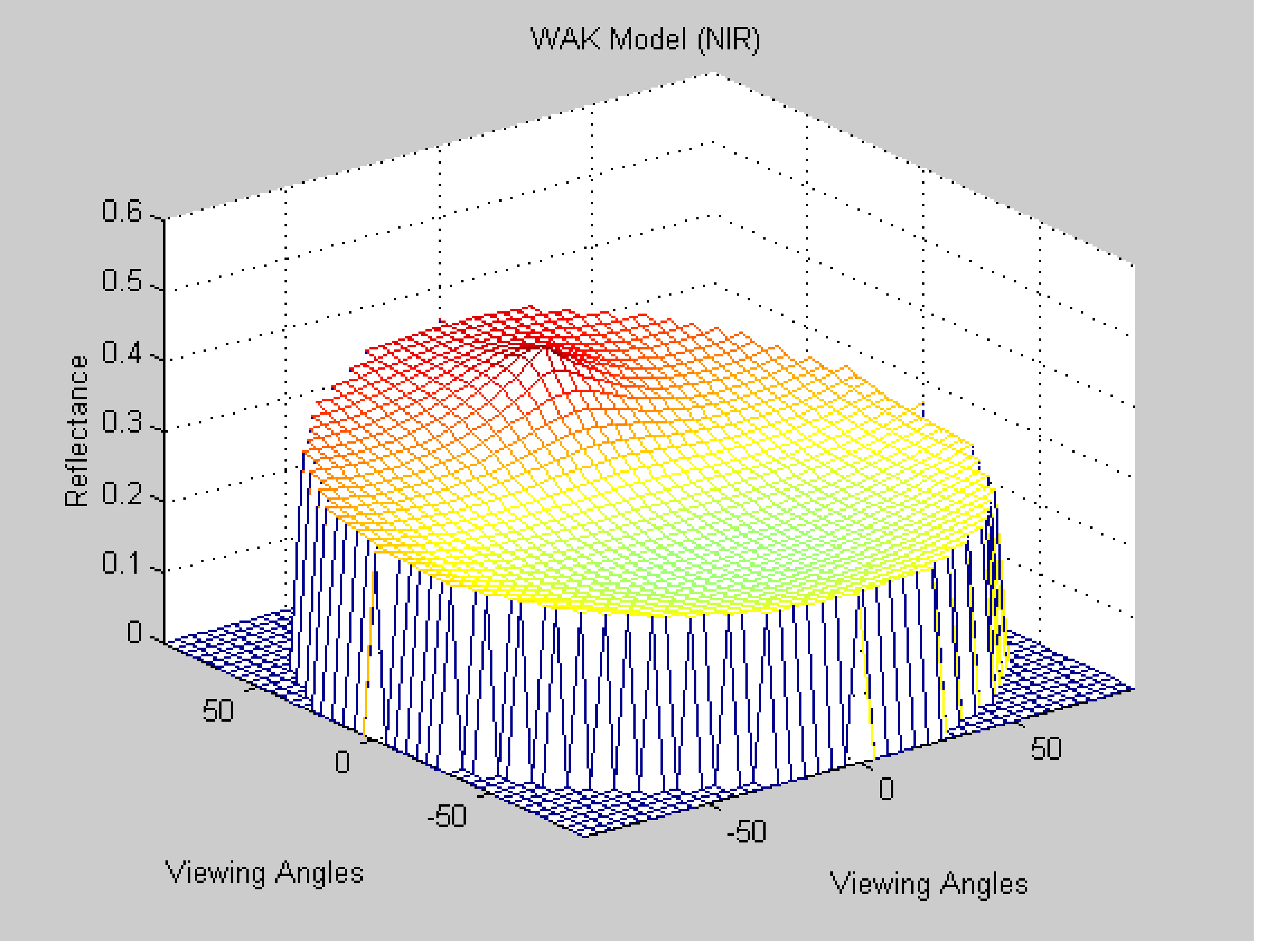
Shibayama and Weigand Model (NIR)
Reflectance
0.6
0.5
0.4
0.3
0.2
0.1
0
50
0
-50
Viewing Angles
50
0
-50
Viewing Angles


Roujean Model (Red)
Reflectance
0.6
0.5
0.4
0.3
0.2
0.1
0
50
0
-50
Viewing Angles
50
0
-50
Viewing Angles

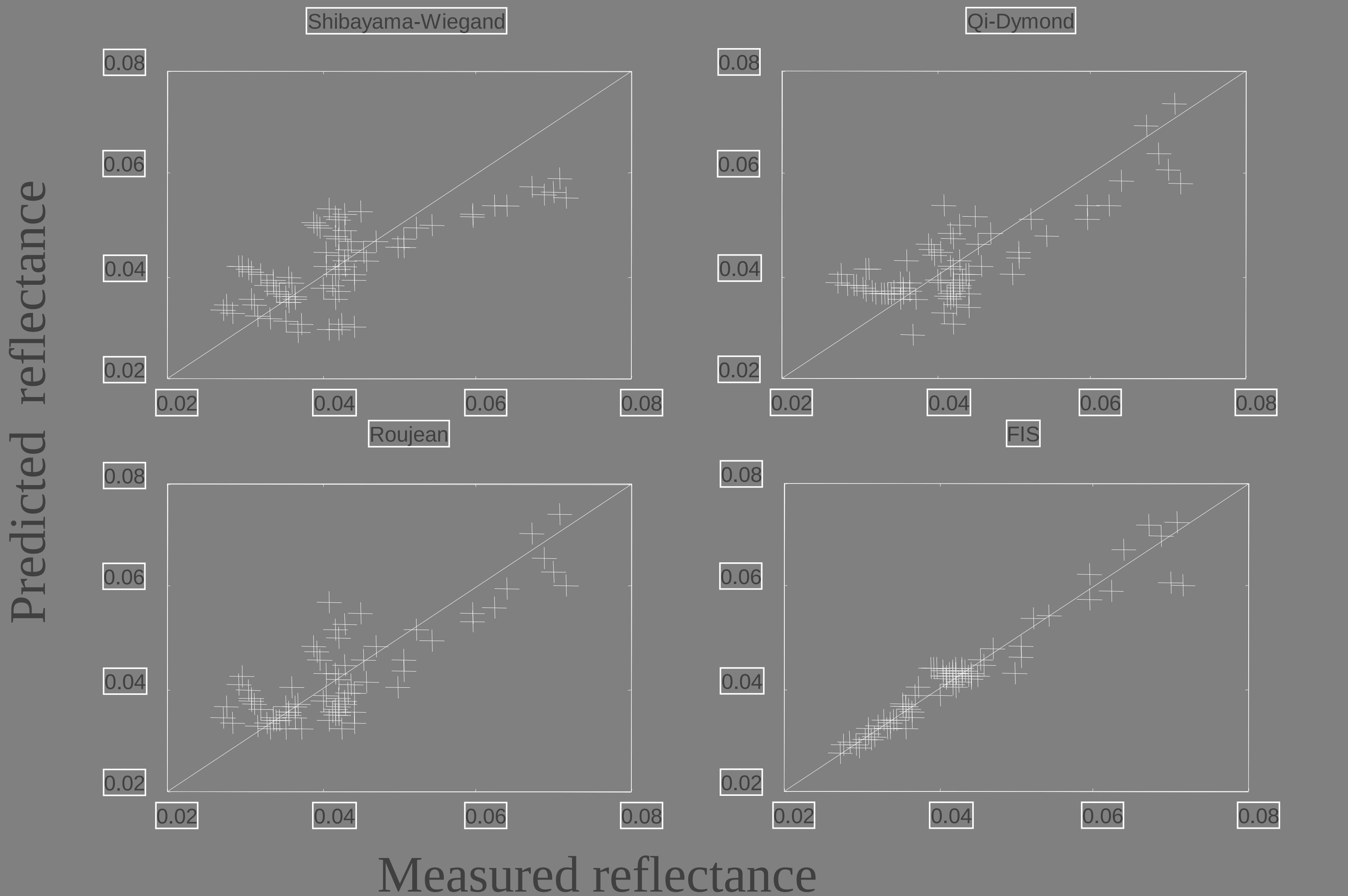


Roujean Model (NIR)
Reflectance
0.6
0.5
0.4
0.3
0.2
0.1
0
50
0
-50
Viewing Angles
50
0
-50
Viewing Angles

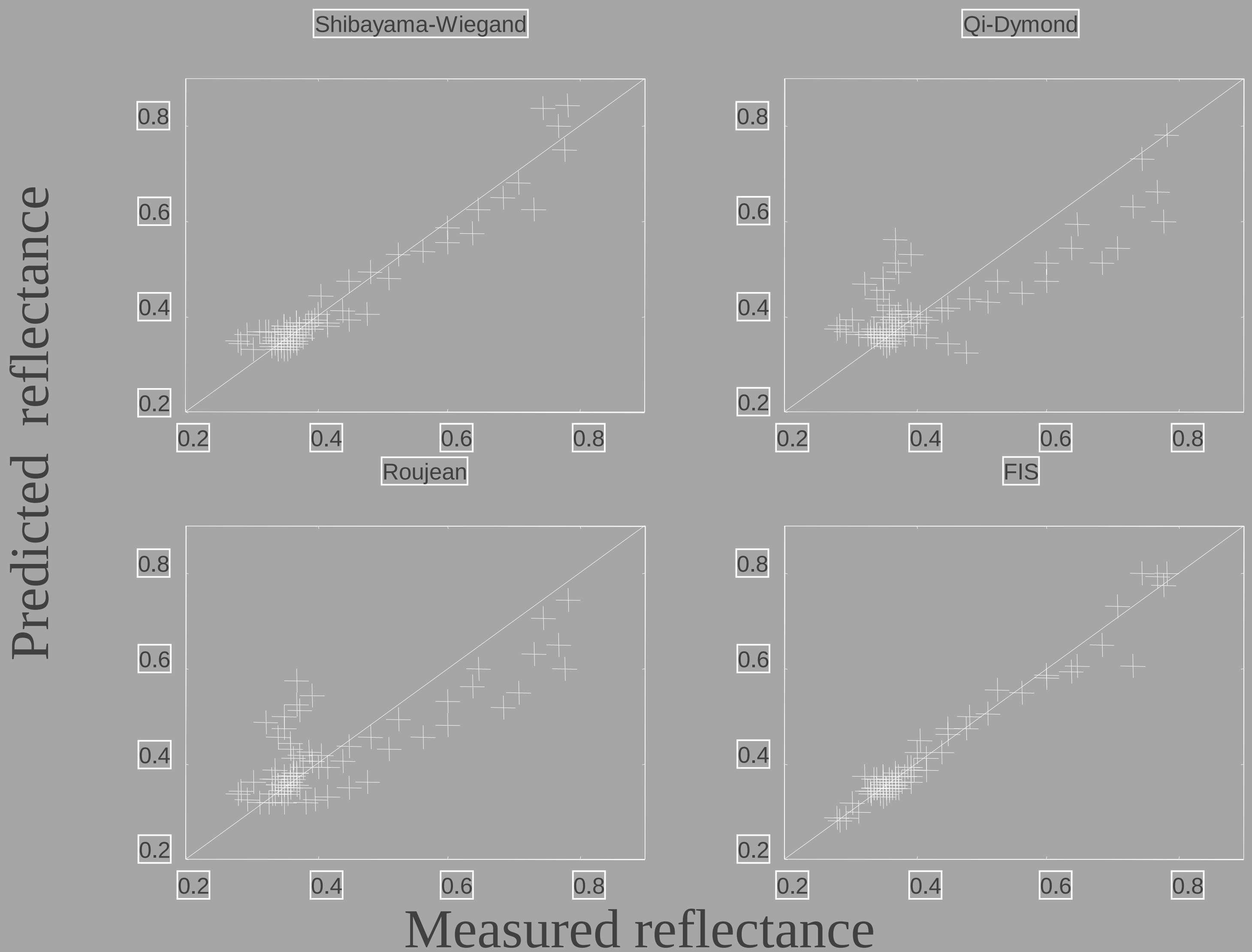

WAK Model (Red)
Reflectance
0.6
0.5
0.4
0.3
0.2
0.1
0
50
0
-50
Viewing Angles
50
0
-50
Viewing Angles


WAK Model (NIR)
Reflectance
0.6
0.5
0.4
0.3
0.2
0.1
0
50
0
-50
Viewing Angles
50
0
-50
Viewing Angles

Comparison with other models (TM Band 3)



Comparison with other models (TM Band 3)



BRDF Correction

$$\rho = \rho_0 \left\{ 1 + \left(\beta_0 + \beta_1 \sin(\frac{\varphi}{2}) + \frac{\beta_2}{\cos\theta_s} \right) \sin\theta_v \right\}$$

Two ways of using models:

1) Given ρ_o, $\beta_{\square}$, β_1, β_2 $\square$ one can simulate canopy reflectance and compute correction factors

2). Given canopy reflectance measurements, one can run the model in reverse model to obtain $\rho_{\square o}$, $\beta_{\square}$, β_1, and β_2 parameters and then compute correction factors

BRDF Correction

Once ρ_o, $\beta_{\square}$, β_1, β_2 are known, one can calculate correction factors:

$$f = \left\{ 1 + \left(\beta_0 + \beta_1 \sin(\frac{\varphi}{2}) + \frac{\beta_2}{\cos\theta_s} \right) \sin\theta_v \right\}$$

Note: ρ_0 is related to the magnitude of surface reflectances while *f* is related to the BRDF shape.

BRDF Correction

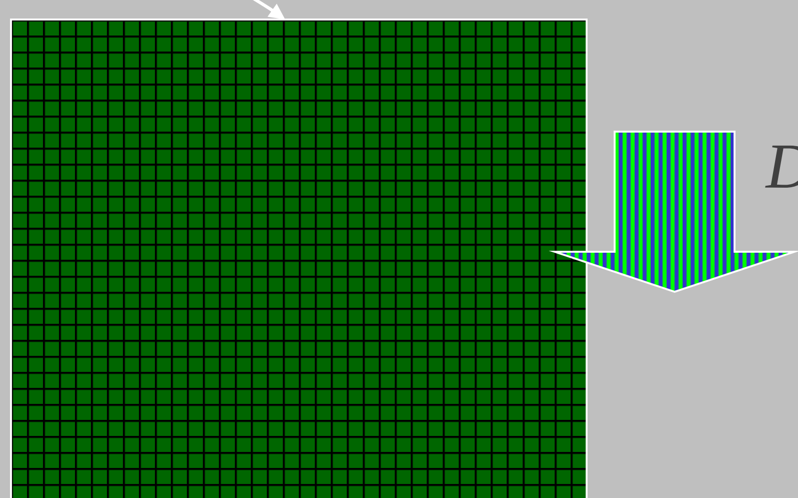
If a model can not be explicitly expressed as a function "correction factor" *f*, one can compute expected reflectance and the standardized reflectance

$$\rho(\theta_s,\theta_v,\varphi) = k_0 + k_1 f_1(\theta_s,\theta_v,\varphi) + k_2 f_2(\theta_s,\theta_v,\varphi)$$

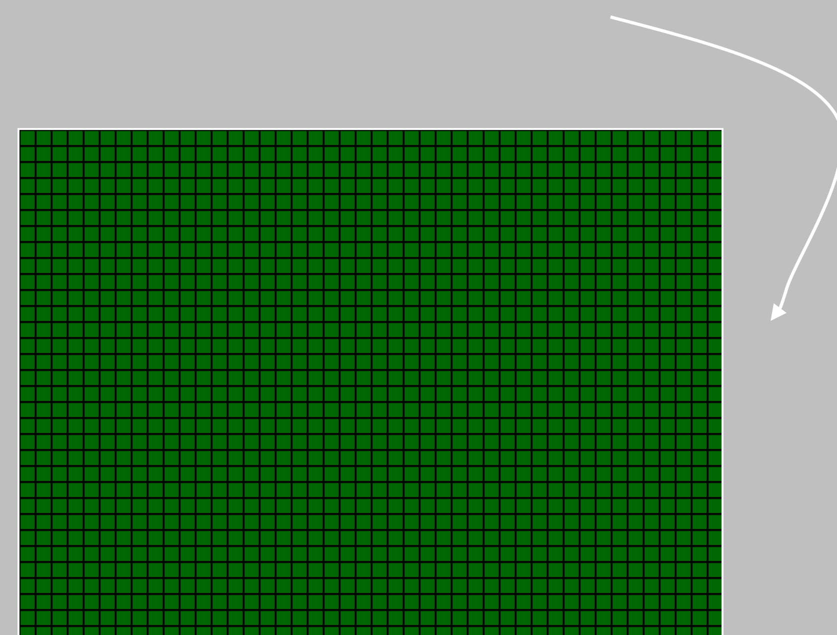
$$\rho(\theta_s,\theta_v,\varphi) = \rho_0 \frac{\left(\cos\theta_s \cos\theta_v\right)^{k-1}}{\left(\cos\theta_s + \cos\theta_v\right)^{1-k}} \frac{1-\Theta^2}{\left[1+\Theta^2 - 2\Theta\cos(\pi-\xi)\right]^{3/2}} \left(1 + \frac{1-\rho_0}{1+G}\right)$$

Correction Technique

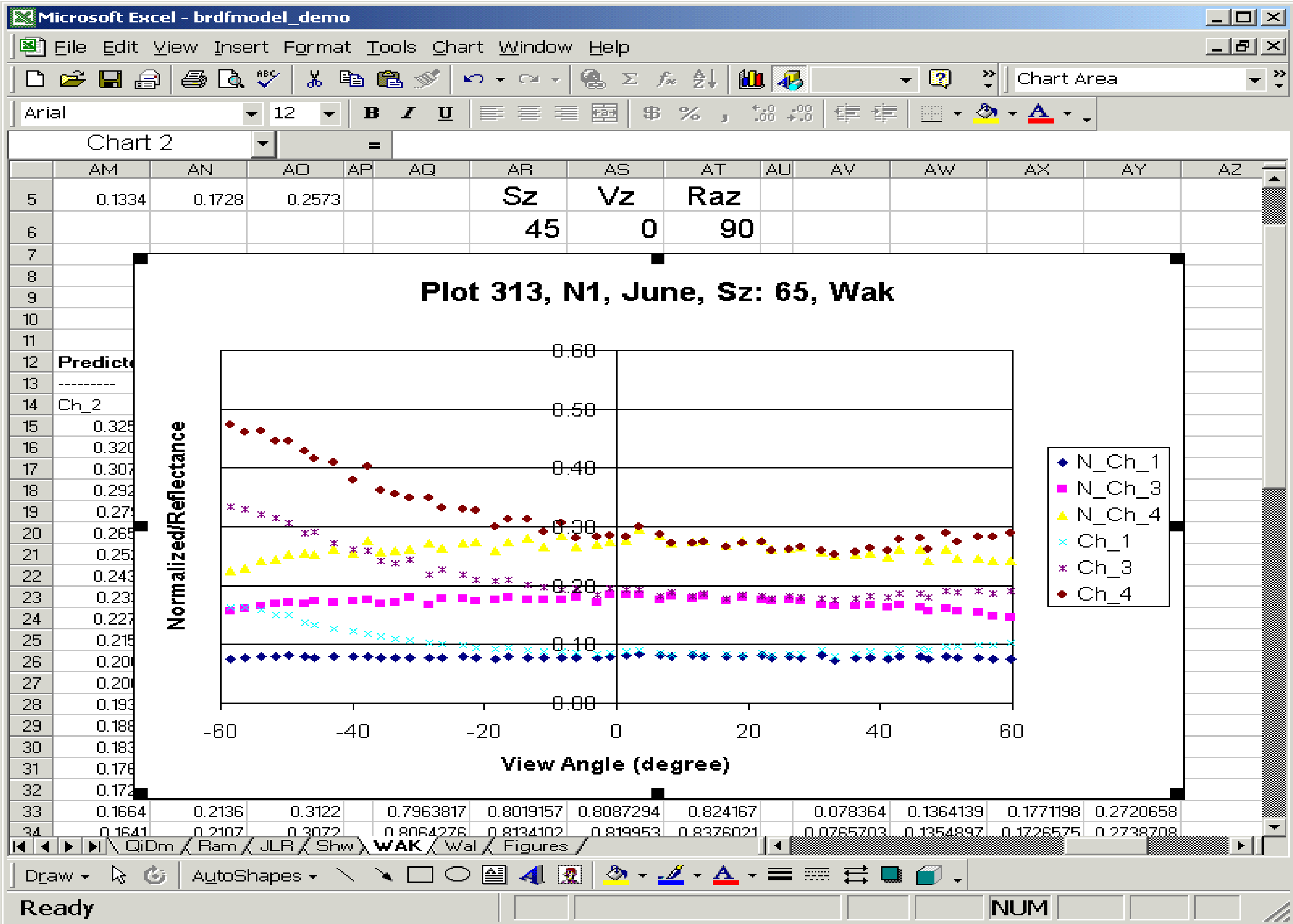
(i,j) For each pixel, compute $f\,(i,j) = \rho_o(i,j) \,/\, \rho\,(i,j)$



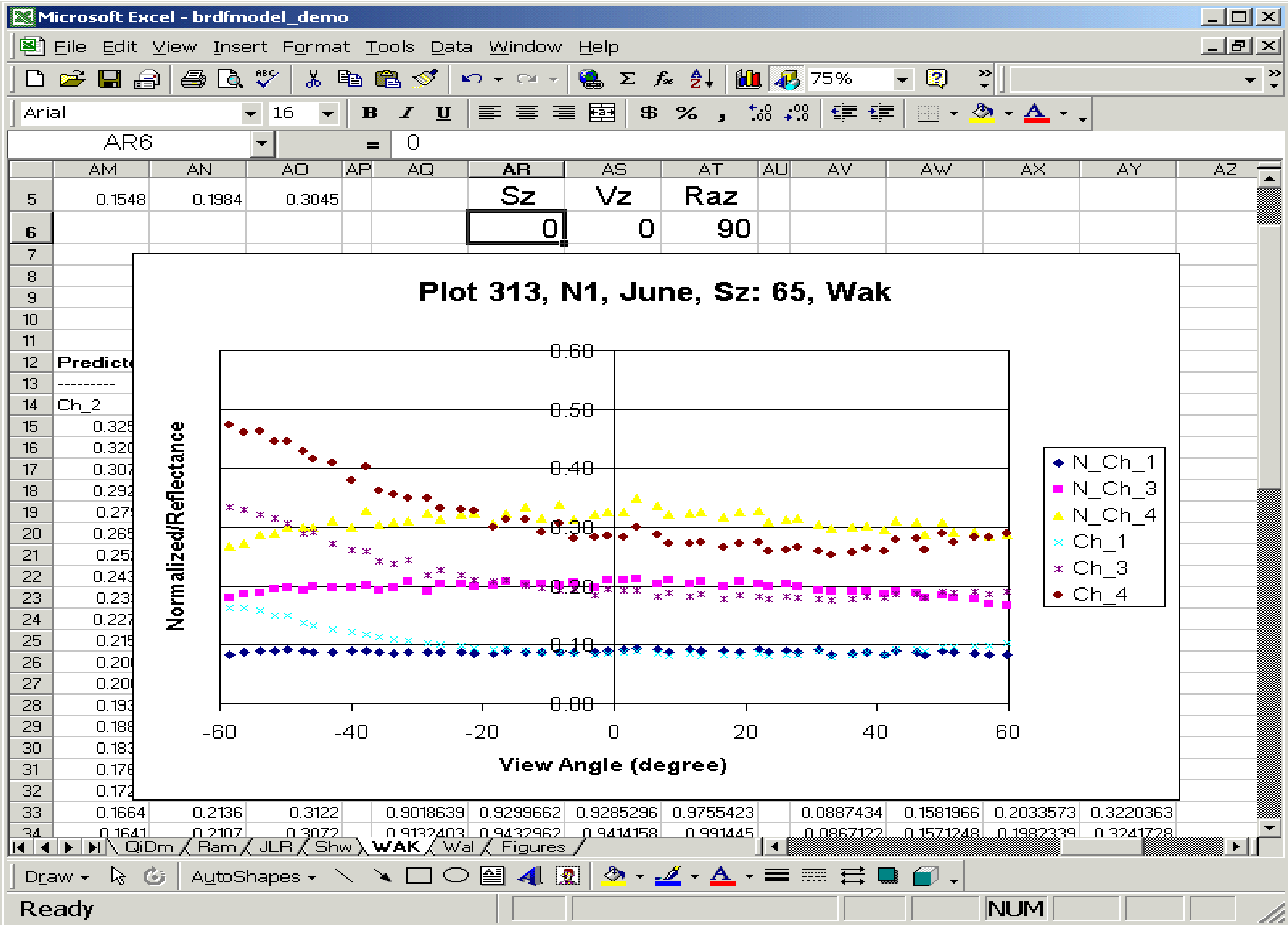
$DNnew\,(i, j) = DN(i, j) * \rho_o(i,j) \,/\, \rho\,(i,j)$



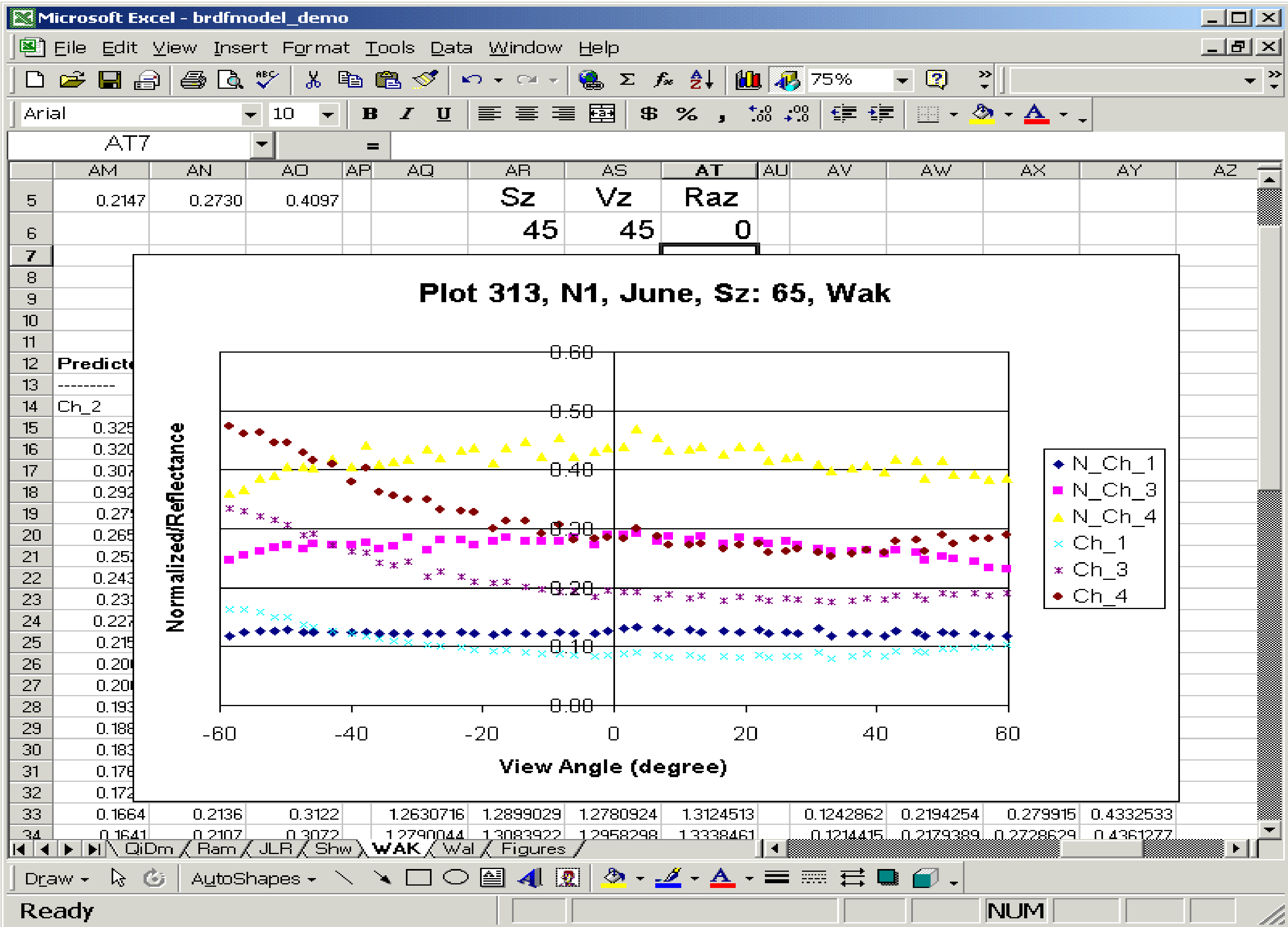
BRDF Correction Example



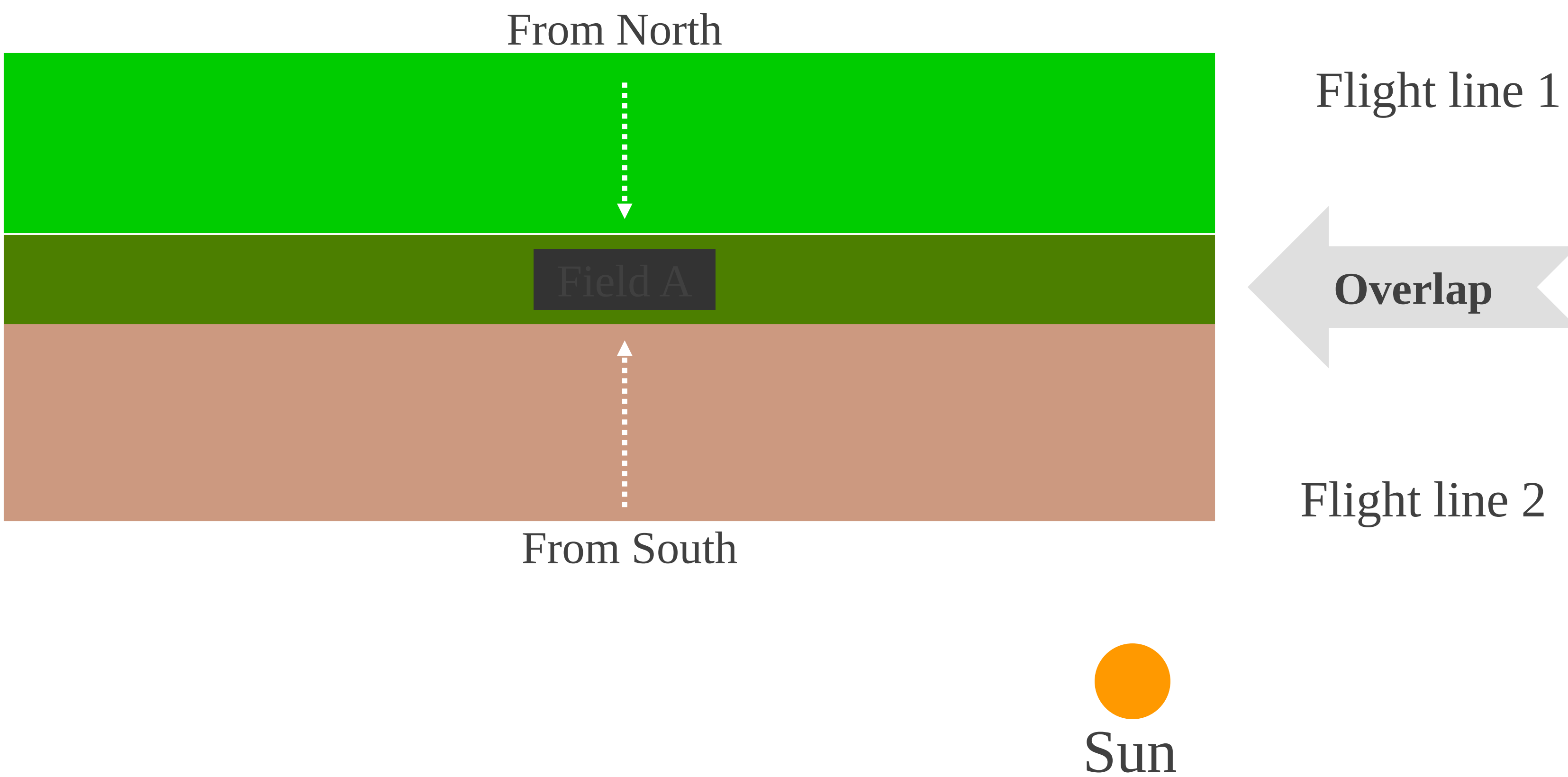
BRDF Correction Example



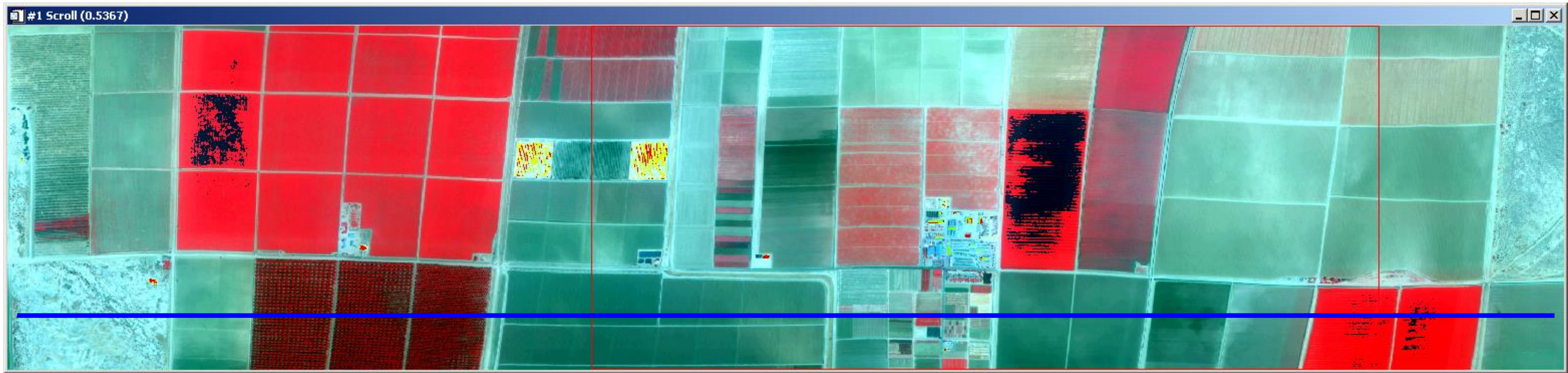
BRDF Correction Example

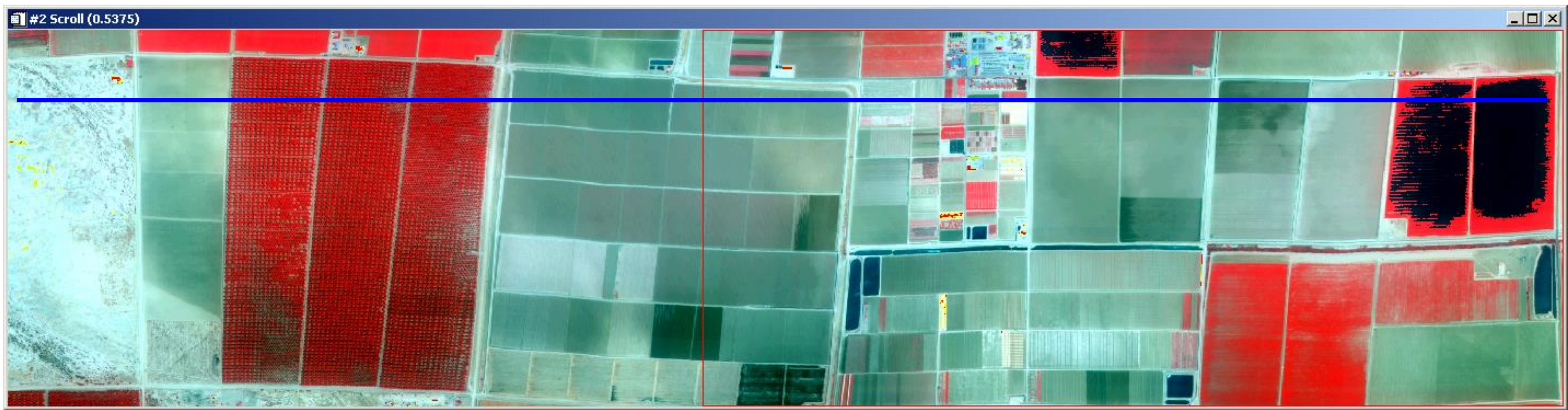


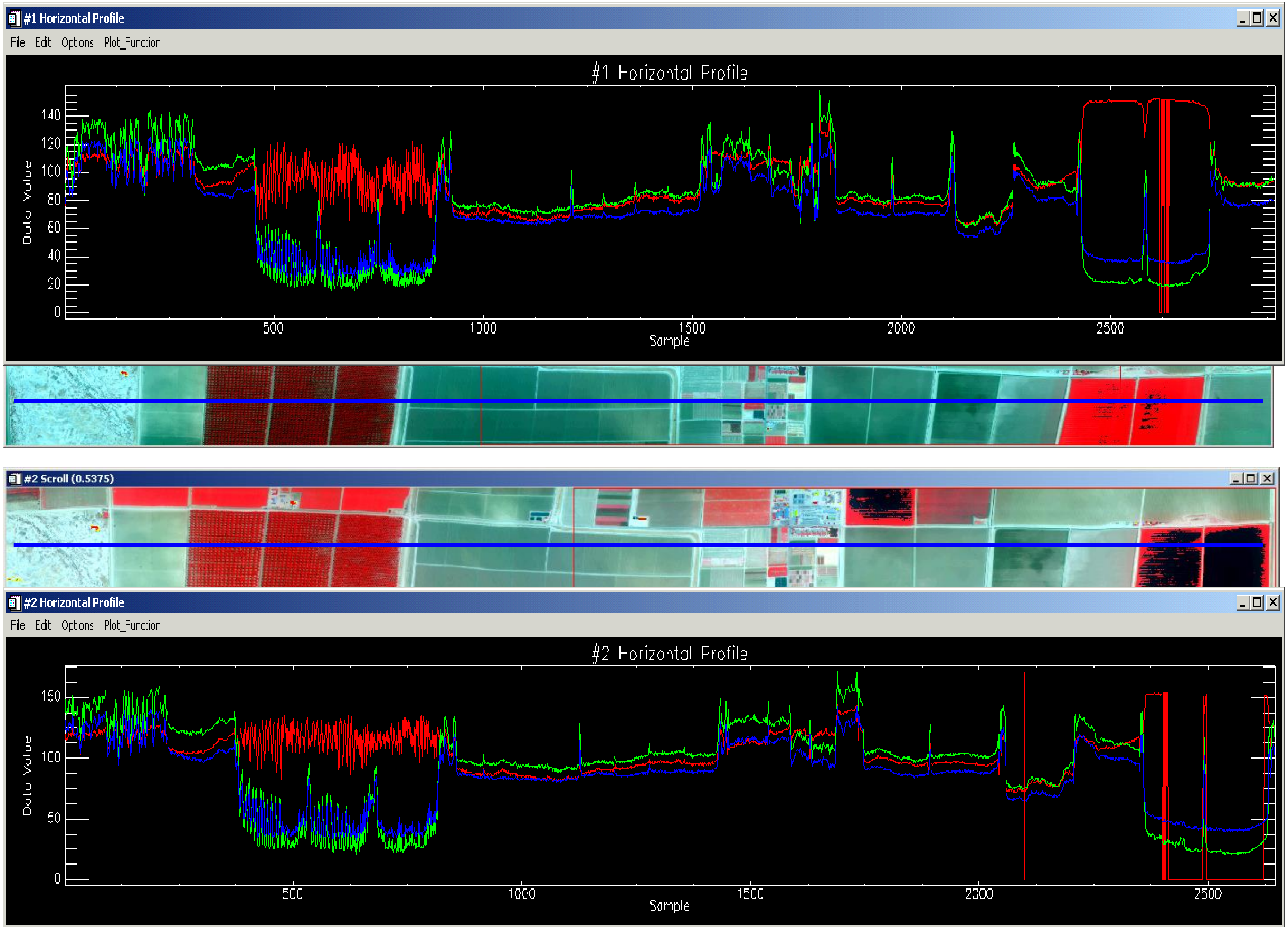
An Example



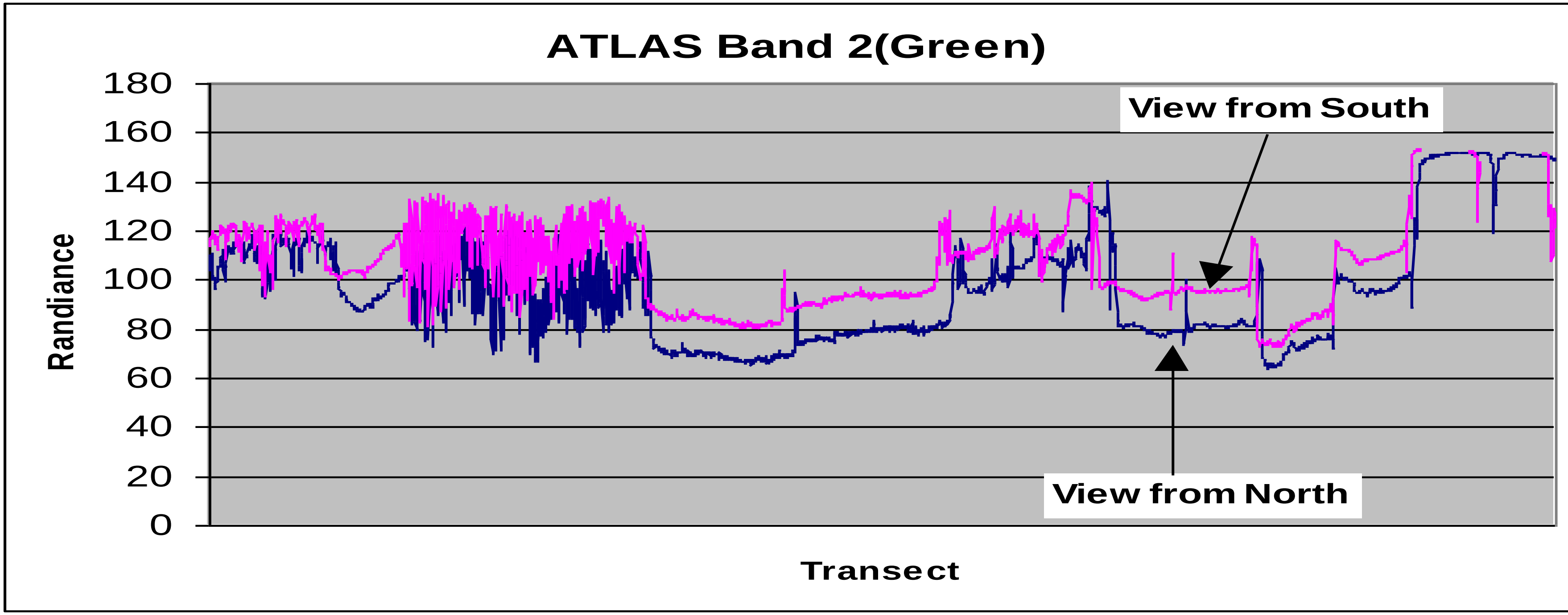
Field A is imaged twice: one from north and one from south

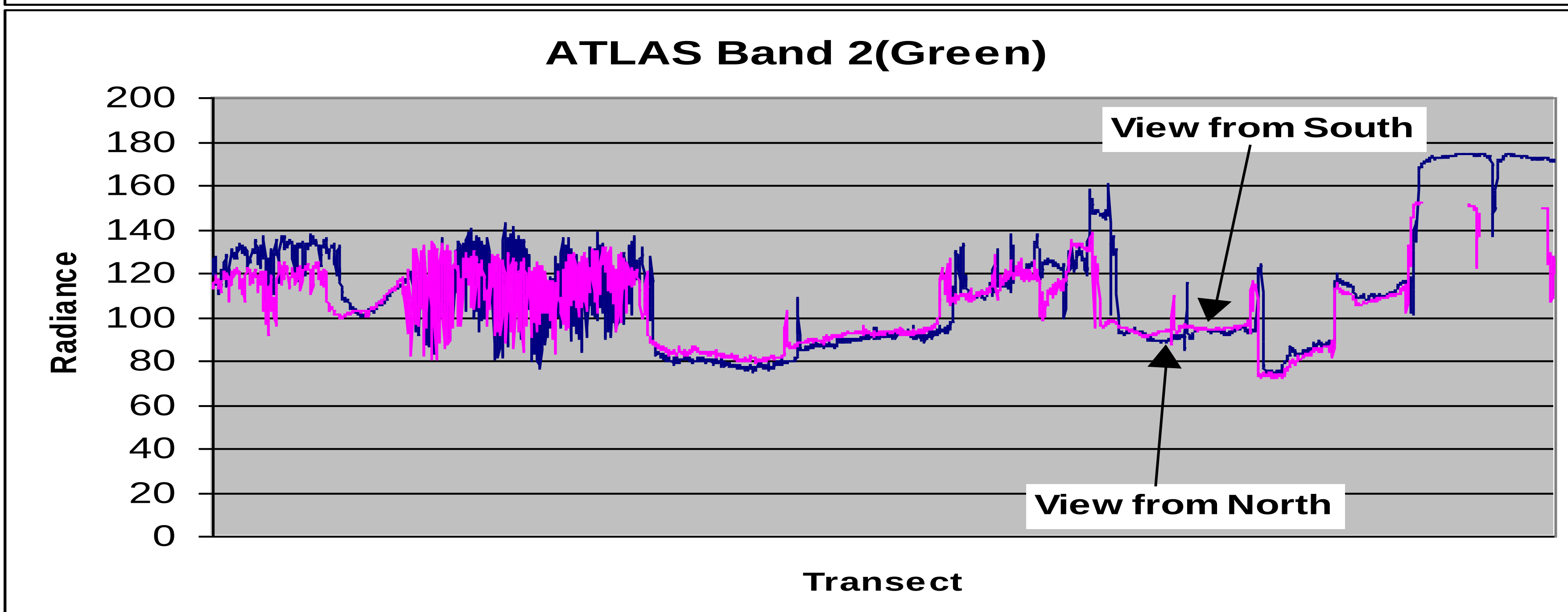

#1 Scroll (0.5367)

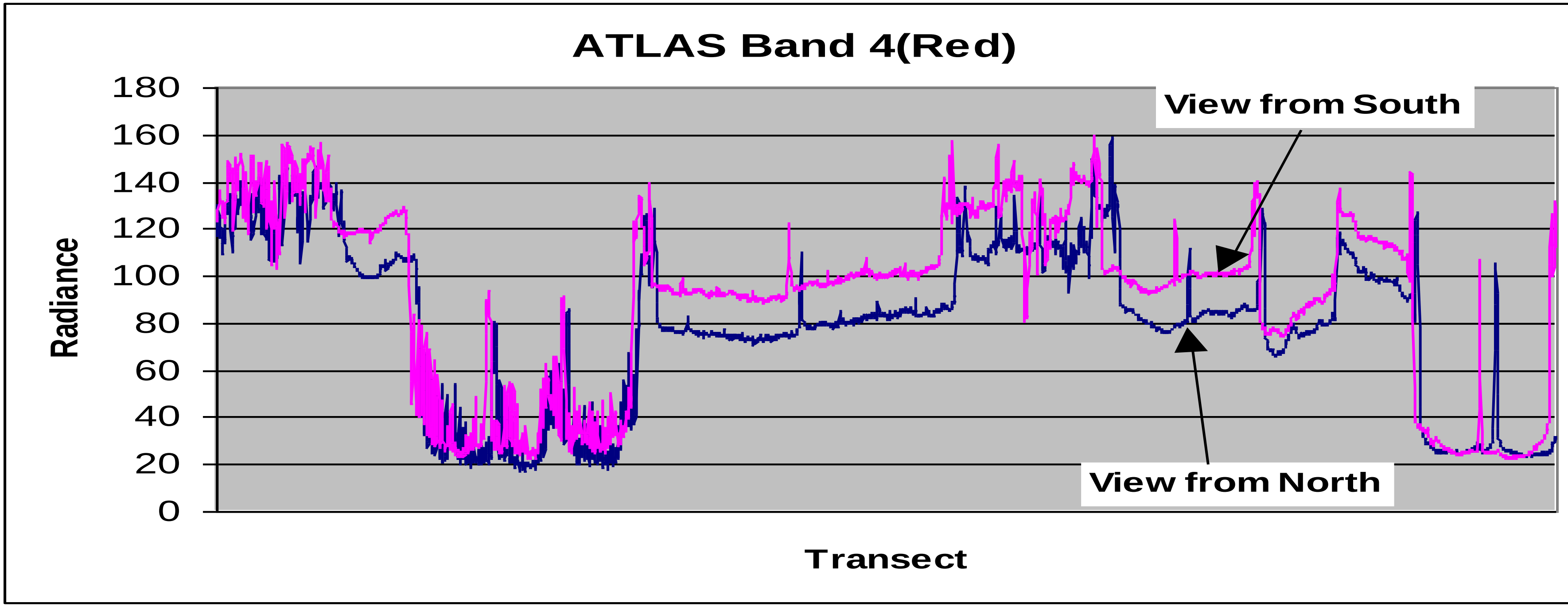

#2 Scroll (0.5375)



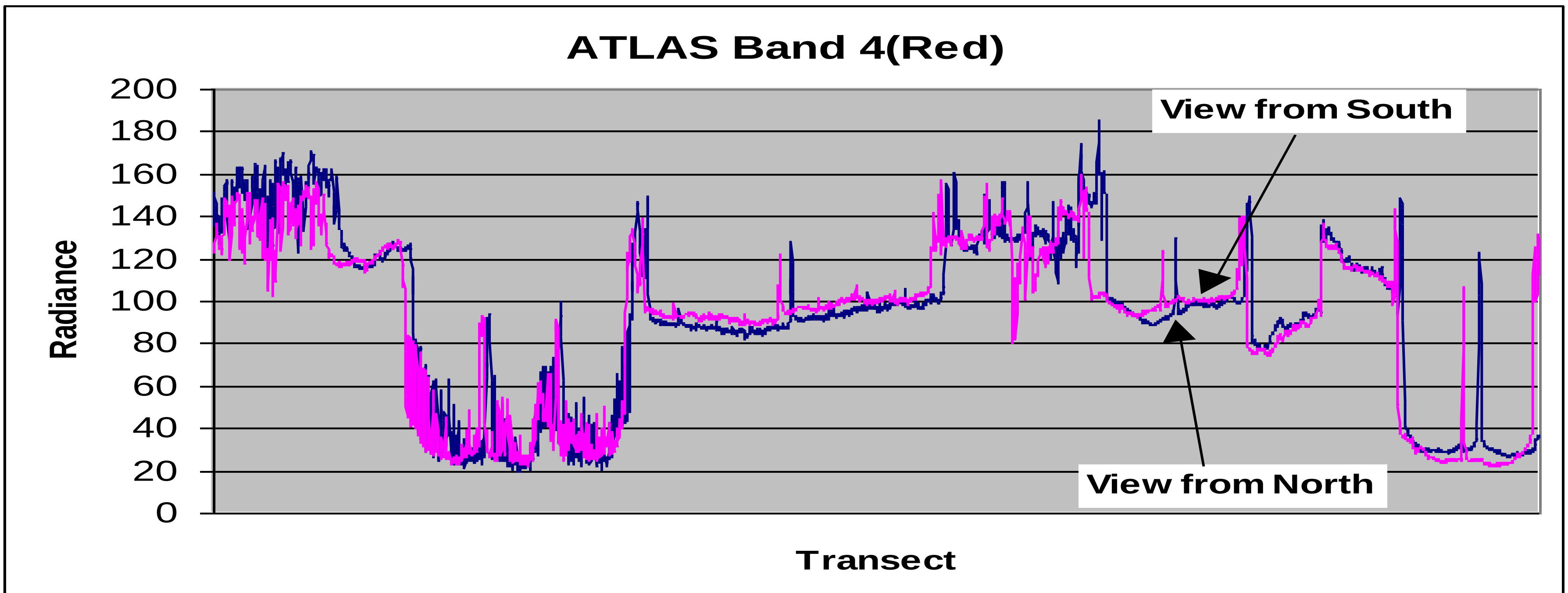
#1 Horizontal Profile
File Edit Options Plot_Function
#1 Horizontal Profile
140
120
100
80
60
40
20
0
Data Value
500
1000
1500
2000
2500
Sample
#2 Scroll (0.5375)
#2 Horizontal Profile
File Edit Options Plot_Function
#2 Horizontal Profile
150
100
50
0
Data Value
500
1000
1500
2000
2500
Sample


ATLAS Band 2(Green)
Randiance
180
160
140
120
100
80
60
40
20
0
View from South
View from North
Transect

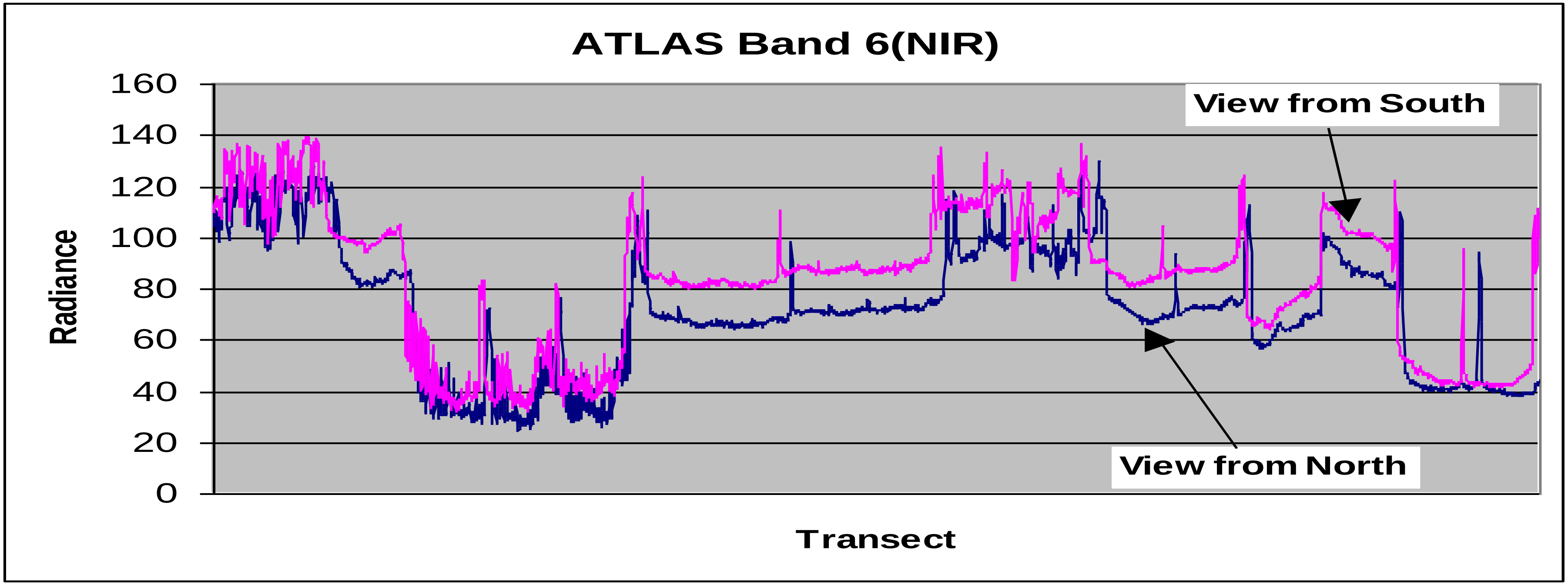

ATLAS Band 2(Green)
Radiance
200
180
160
140
120
100
80
60
40
20
0
View from South
View from North
Transect

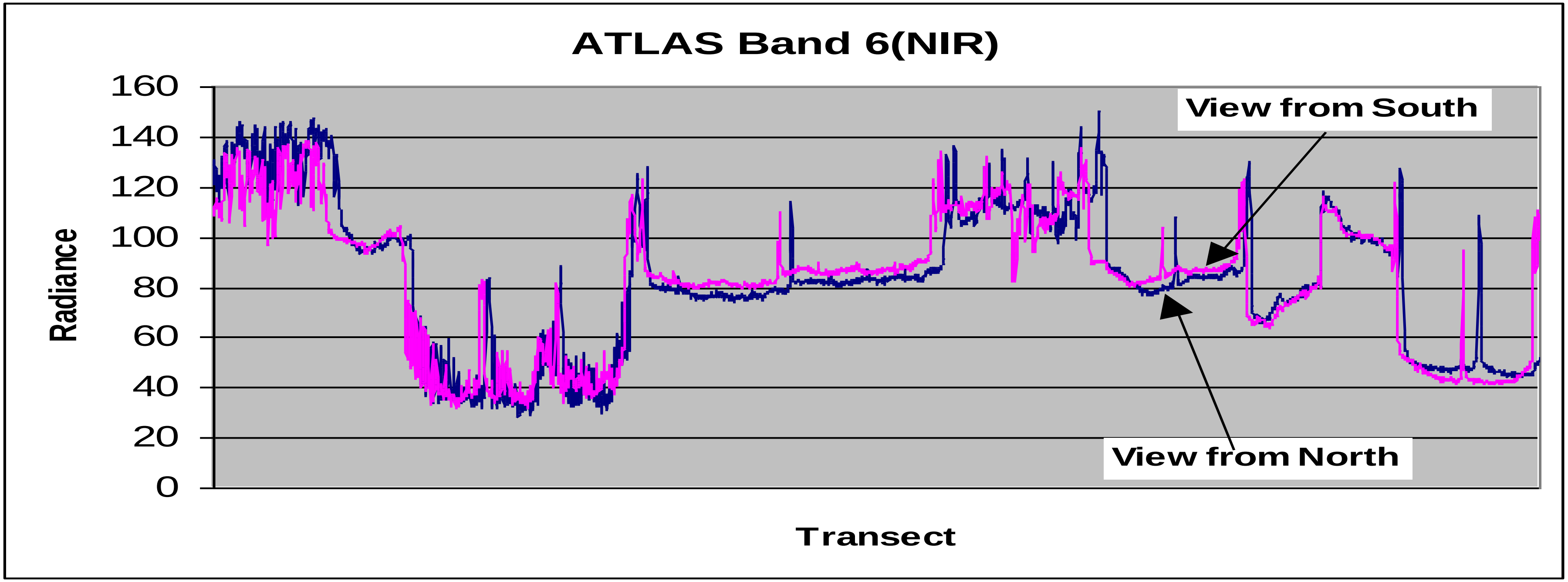


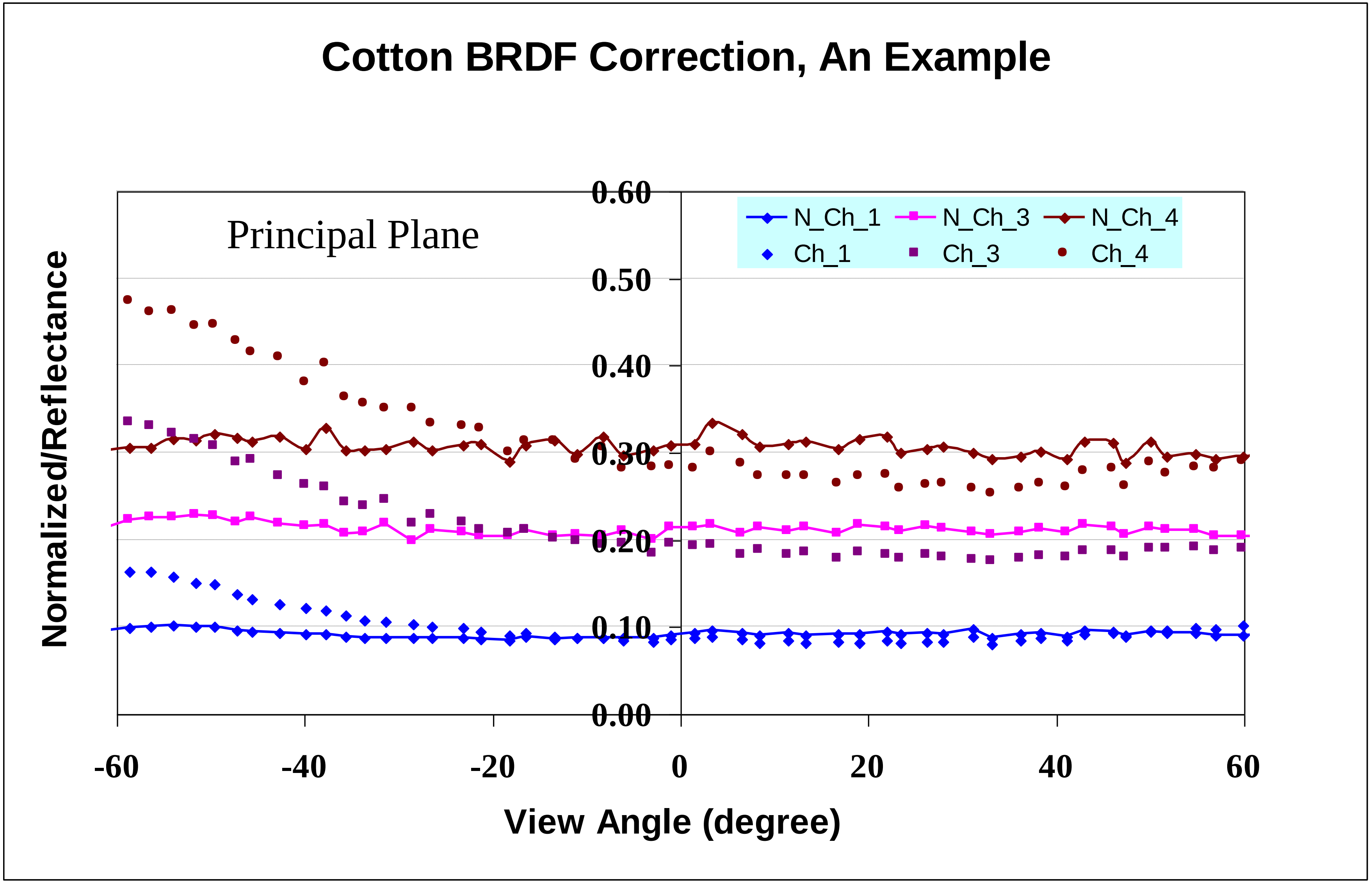
ATLAS Band 4(Red)
180
160
140
120
100
80
60
40
20
0
Radiance
View from South
View from North
Transect



ATLAS Band 4(Red)
200
180
160
140
120
100
80
60
40
20
0
Radiance
View from South
View from North
Transect


ATLAS Band 6(NIR)
Radiance
160
140
120
100
80
60
40
20
0
View from South
View from North
Transect


ATLAS Band 6(NIR)
Radiance
160
140
120
100
80
60
40
20
0
View from South
View from North
Transect



Cotton BRDF Correction, An Example
Principal Plane
N_Ch_1
N_Ch_3
N_Ch_4
Ch_1
Ch_3
Ch_4
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-60
-40
-20
0
20
40
60
Normalized/Reflectance
View Angle (degree)

SUMMARY

- Bidirectional effect on remote sensing images can be significant, depending on:
  - Spectral bands;
  - Crop type
  - Stage
  - Sensor-target-sun geometry
  - Surface heterogeneity
  - May be as high as 40% or even high

SUMMARY (*continued*)

- Bidirectional reflectance distribution function (BRDF) models exist and can be used to reduce such effect
  - Empirical models are simple and easy to use, but may have limitations
  - Physical models are preferred, but may require more model parameters
  - Semi-empirical models seem to be sufficient and easy to use
  - Neural network prove to be an easy way for non-modelers, but its accuracy depending on the training data sets
  - Their accuracy is often dictated by the inversion process, i.e., how representative your training data set is!

SUMMARY (*continued*)

- Bidirectional effect can be “reduced” or “normalized”
  - Select a model that works for your surface type (if necessary, classification may be needed)
  - Obtain model input parameters (often by inversion processes)
  - Determine your “standard” geometric configuration
  - Compute the correction factor for each pixel
  - Use LUT when necessary
  - Examine “effectiveness”
  - Try different models, if possible
  - May need to determine a correction limit (upper or lower limits), e. g., correction factor f should be $0.8 < f < 1.2$

SUMMARY (*continued*)

- For operational applications
  - A “generic” model or a “generic” set of model parameters may be sufficient
  - Make sure the sensor-target-sun geometry is correctly computed

Inverse Problems

- Obtain set of bidirectional measurements (can be field measurements, or satellite reflectance)
- Run the model in a reverse model using an optimization procedure
- Check the simulated verse the modeled results
- Make an assessment of accuracy by looking at the statistical agreement between the measured and simulated data
- Inversion may always converge!!
- How would you know if an inversion converged, i, e, inversion quality?

$$\rho(\theta_s,\theta_v,\varphi) = k_0 + k_1 f_1(\theta_s,\theta_v,\varphi) + k_2 f_2(\theta_s,\theta_v,\varphi)$$

$$\delta = \sum (\rho_o - \rho_m)^2$$