Lecture 13

Multi-Spectral Remote Sensing - System Considerations

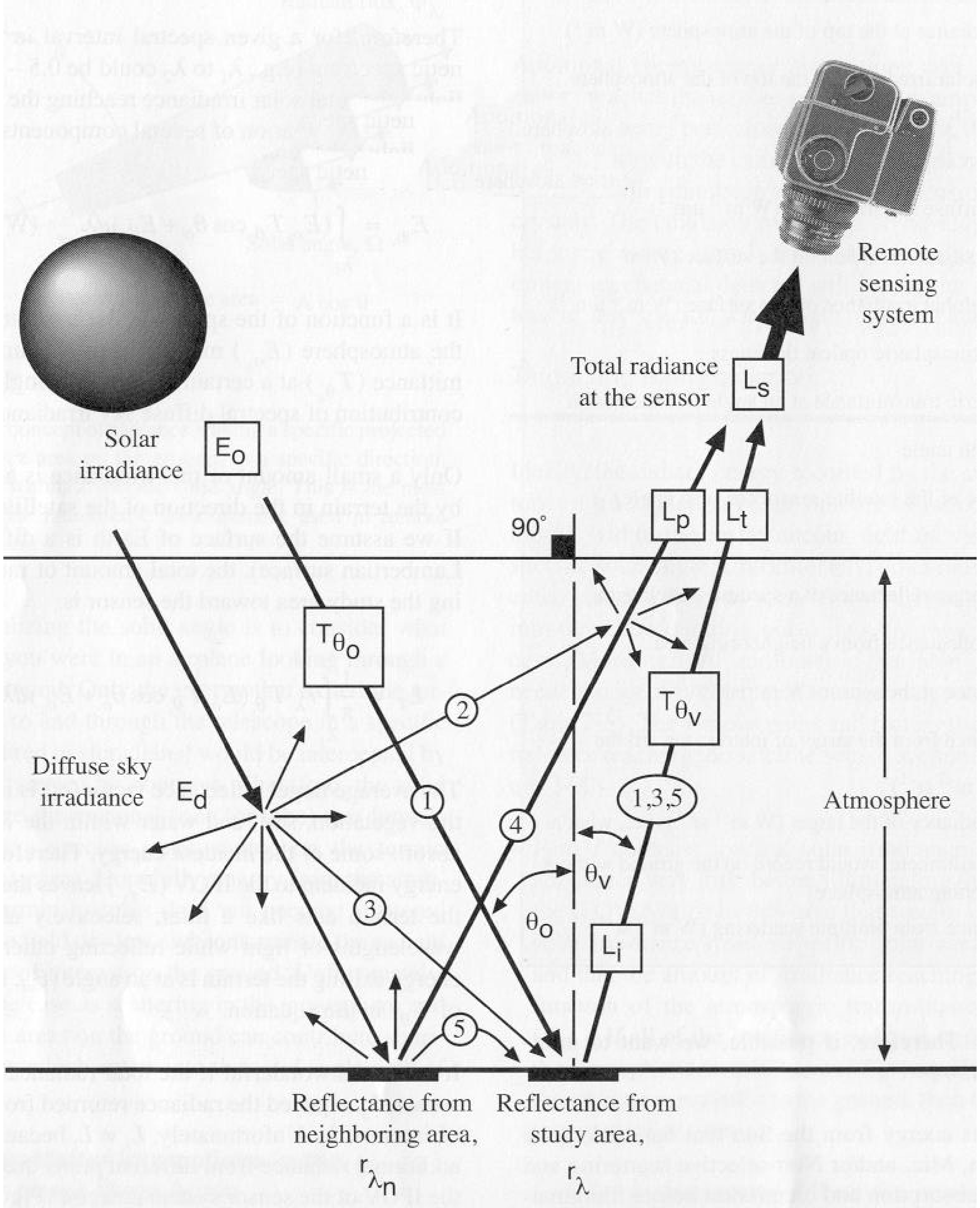
21 October 2004

Reading Assignment

- Jensen – Chapter 7

Unless otherwise noted, all images in this lecture are from

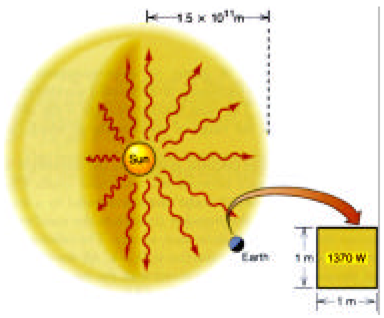
- Jensen, J.R., *Remote Sensing of the Environment - An Earth Resource Perspective*, 544 pp., Prentice Hall, Upper Saddle River, NJ, 2000.



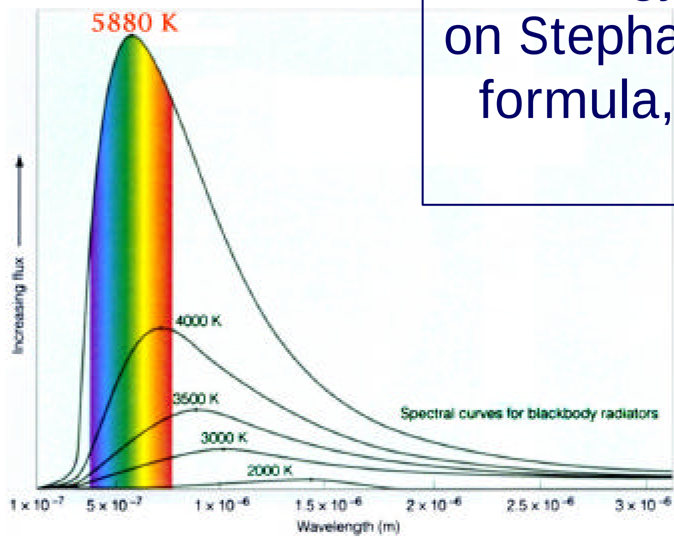
Remote sensing system
Total radiance at the sensor
L_s
Solar irradiance
E_o
90°
L_p
L_t
T_{θ_o}
T_{θ_v}
2
Diffuse sky irradiance
E_d
1
4
1,3,5
Atmosphere
θ_v
θ_o
3
L_i
5
Reflectance from neighboring area, $r_{\lambda n}$
Reflectance from study area, r_λ

Key components of VIS/RIR remote sensing

1. Sun is EM Energy Source



EM energy



2. Energy emitted from sun based on Stephan/Boltzman Law, Planck's formula, and Wein Displacement Law (Lecture 2)

VIS/NIR Satellite

EM energy

3. EM Energy interacts with the atmosphere

5. EM Energy interacts with the atmosphere

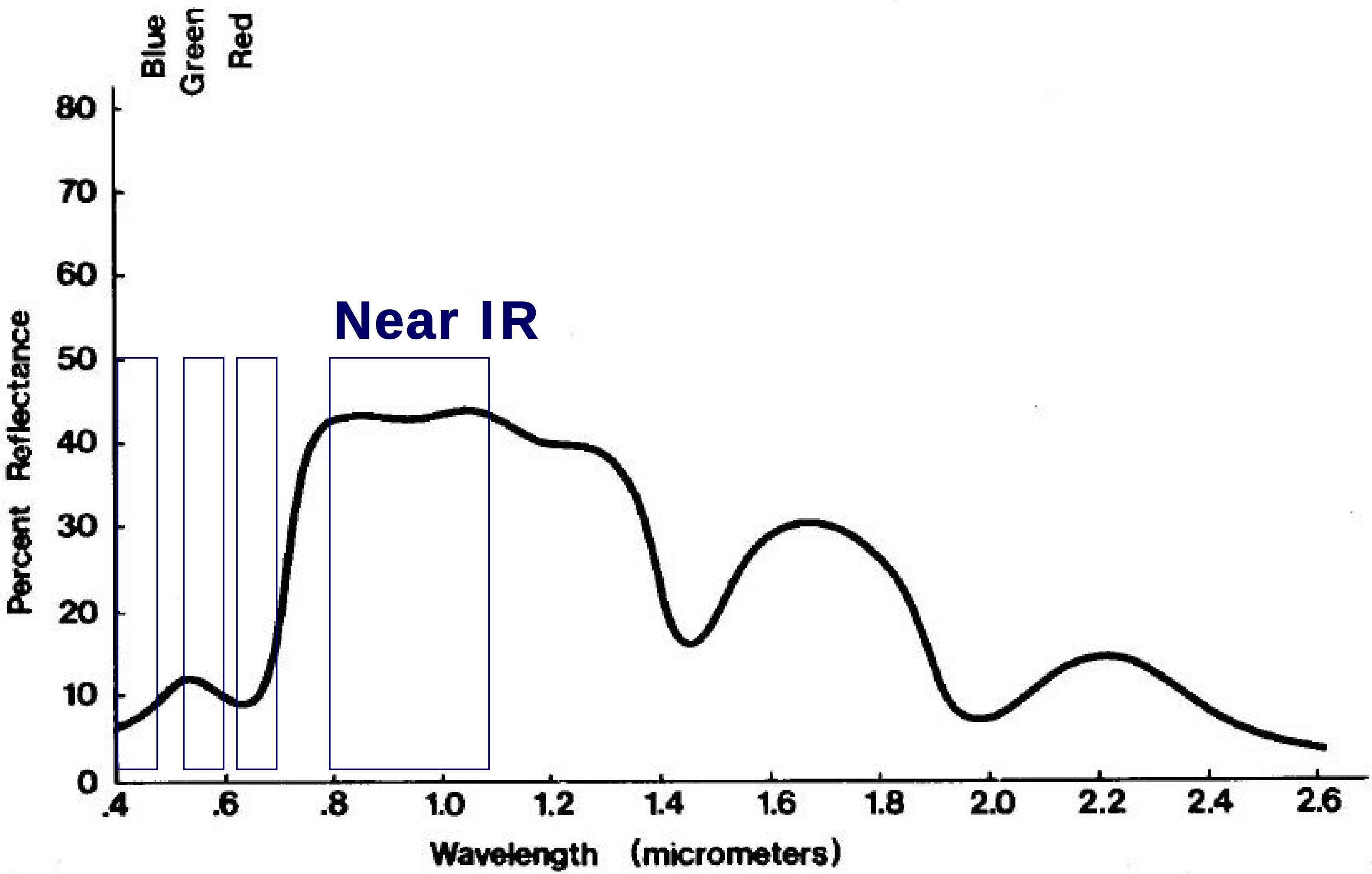
4. EM energy reflected from Earth's Surface

Lecture Topics

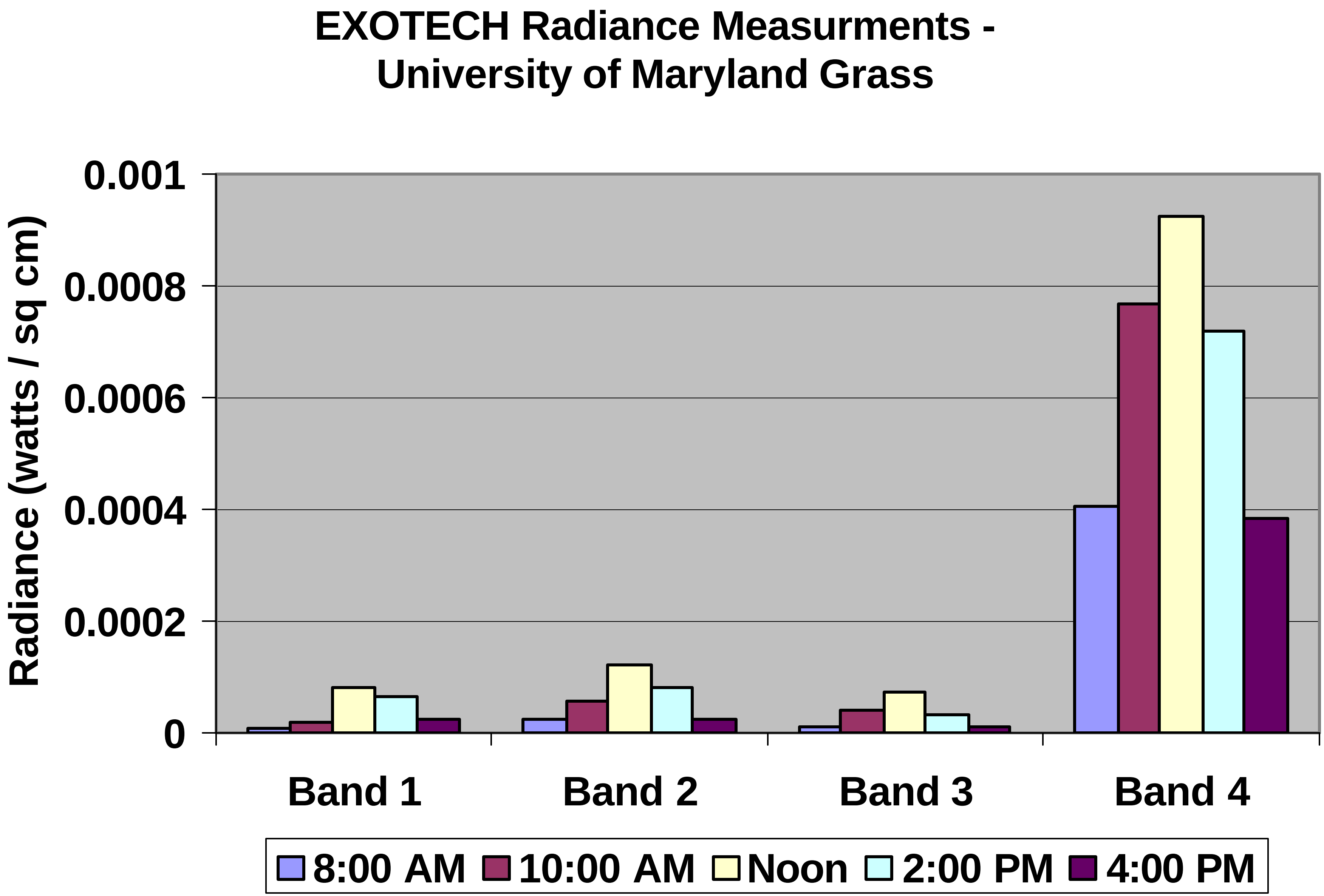
1. Instruments for measuring radiance
2. Key questions for designing spaceborne radiometers
3. Considerations for deploying a spaceborne radiometer
4. Problems in imaging over wide swaths
5. Summary of system tradeoffs
6. Categories of satellite radiometers

Radiometers and Spectrometers

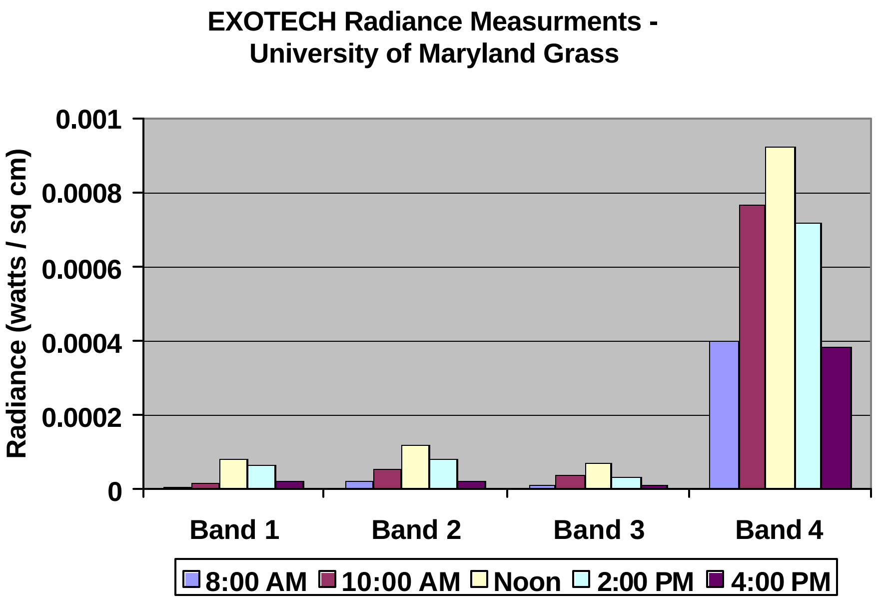
- *Radiometer – An instrument that measures radiance in a specified wavelength region*
- *Spectroradiometer or spectrometer – An instrument that measures radiance continuously across a region of the EM spectrum or in multiple-bands across a region of the EM spectrum*



Blue
Green
Red
Near IR
Percent Reflectance
80
70
60
50
40
30
20
10
0
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
Wavelength (micrometers)



EXOTECH Radiance Measurments -
University of Maryland Grass
Radiance (watts / sq cm)
0.001
0.0008
0.0006
0.0004
0.0002
0
Band 1
Band 2
Band 3
Band 4
8:00 AM
10:00 AM
Noon
2:00 PM
4:00 PM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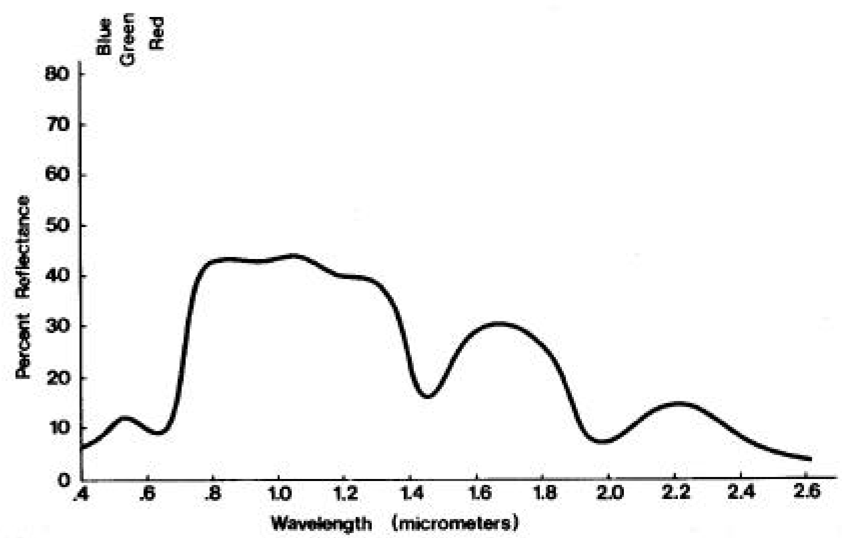
Blue
Green
Red
Percent Reflectance
80
70
60
50
40
30
20
10
0
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
Wavelength (micrometers)

Lecture Topics

1. Instruments for measuring radiance
2. Key questions for designing spaceborne radiometers
3. Considerations for deploying a spaceborne radiometer
4. Problems in imaging over wide swaths
5. Summary of system tradeoffs
6. Categories of satellite radiometers

Questions to ask when designing a multi-channel spaceborne radiometer

- What reflectance characteristics are you trying to measure? *Spectral resolution*
- How precisely do you have to measure these characteristics? *Radiometric resolution*
- How large are the features of interest? *Spatial resolution*
- How frequently and when do you have to measure the features of interest? *Temporal resolution*

Resolution

- *Spectral Resolution* – the wavelength regions of and bandwidths for a radiometer
- *Radiometric Resolution* - the sensitivity of a remote sensing detector to variations in the emitted, reflected or scattered EM energy that is being detected
- *Spatial Resolution* - The measure of the smallest distance (linear or angular separation) between objects that can be resolved by the sensor
- *Temporal Resolution* – the timing and frequency for collection of data by a satellite system

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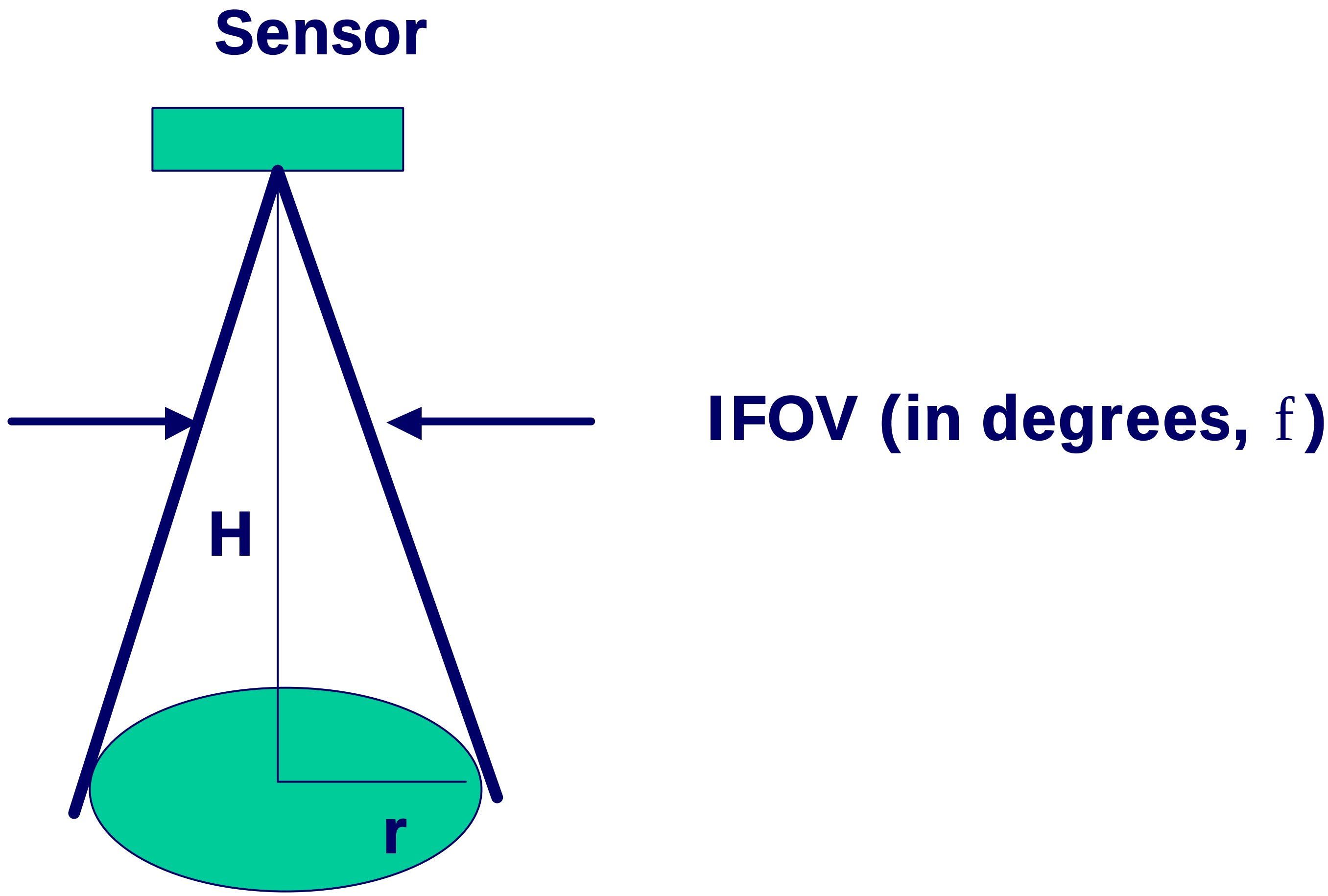
CONSIDERATIONS FOR SATELLITE DEPLOYMENT OF A RADIOMETER

1. What is the size of the patch being detected by the satellite?
2. How frequently can a satellite view the same piece of ground on the earth's surface?
3. How large an area is imaged by the sensor?
4. How much data are being recorded by the radiometer and how do we retrieve these data?
5. How do variations in surface and atmospheric conditions affect the data quality?

Instantaneous Field of View- IFOV

- All radiometers have an instantaneous field of view, e.g., the angular dimension over which radiation is detected



Radius of circle within IFOV, $r = H \tan \phi/2$

For very small IFOV, e.g., <<< 0.01º,
$r = H \phi/2$, where ϕ is in radians

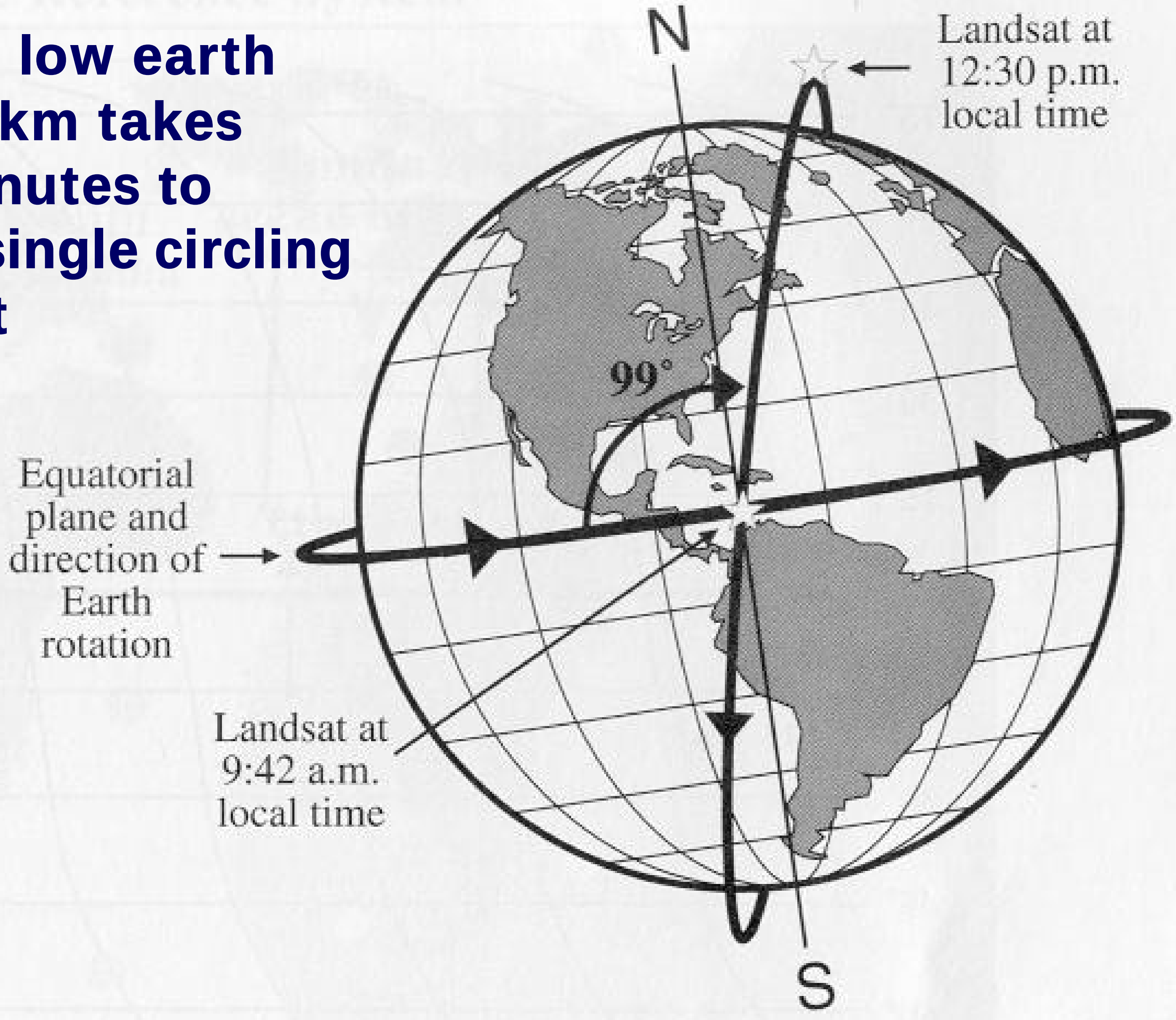
CONSIDERATIONS FOR SATELLITE DEPLOYMENT OF A RADIOMETER

1. What is the size of the patch being detected by the satellite?
2. How frequently can a satellite view the same piece of ground on the earth's surface?
3. How large of an area is imaged by the sensor?
4. How much data are being recorded by the radiometer and how do we retrieve these data?
5. How do variations in surface and atmospheric conditions affect the data quality?
6. How do you record/transmit the data being detected/recorded by the systems

Controls on Frequency of Coverage by a Satellite

1. The orbital time of the satellite
2. The width of the area being imaged by a satellite when it passes over the earth

A satellite in low earth orbit (~800 km takes about 90 minutes to complete a single circling of the planet



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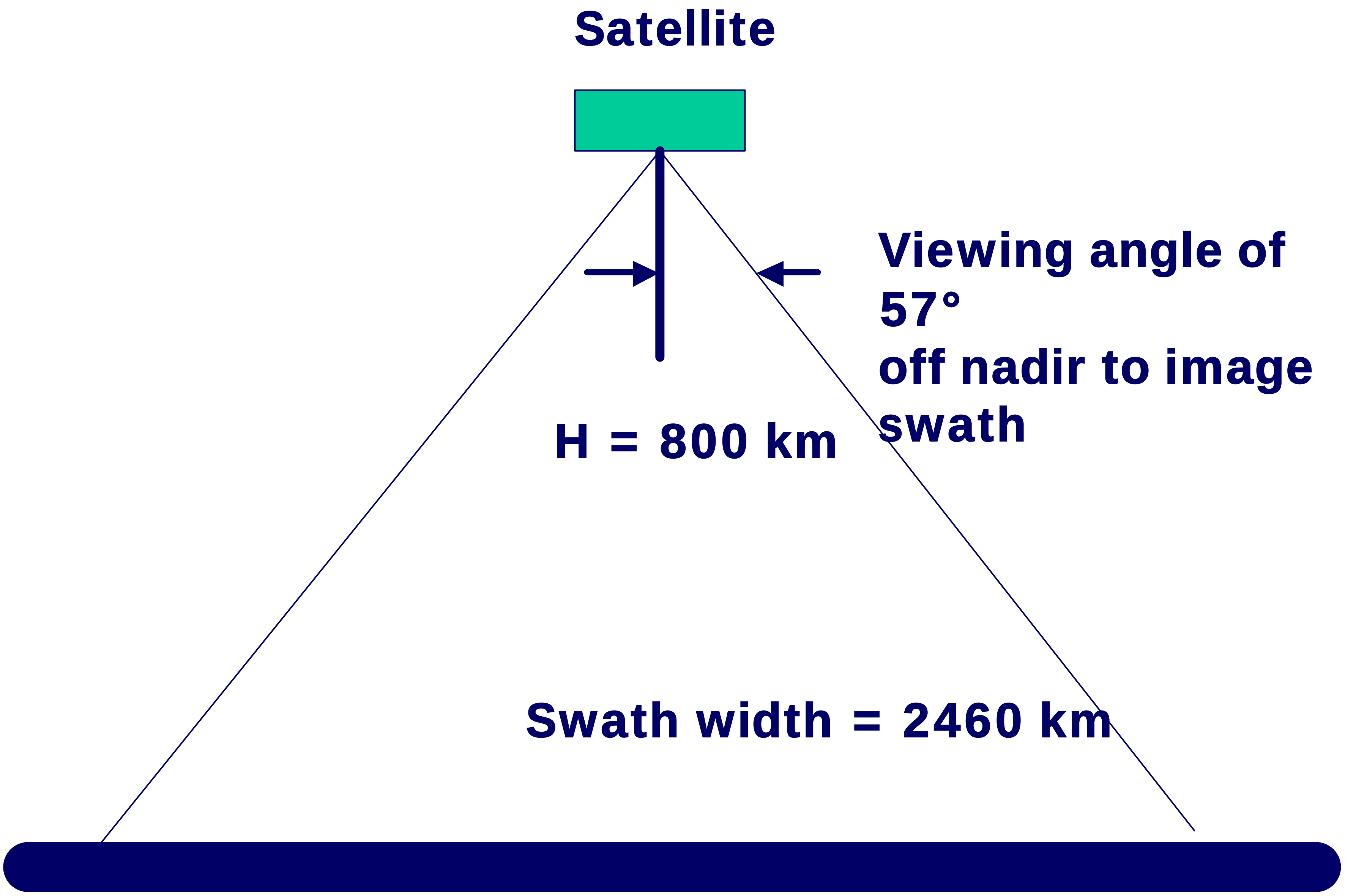
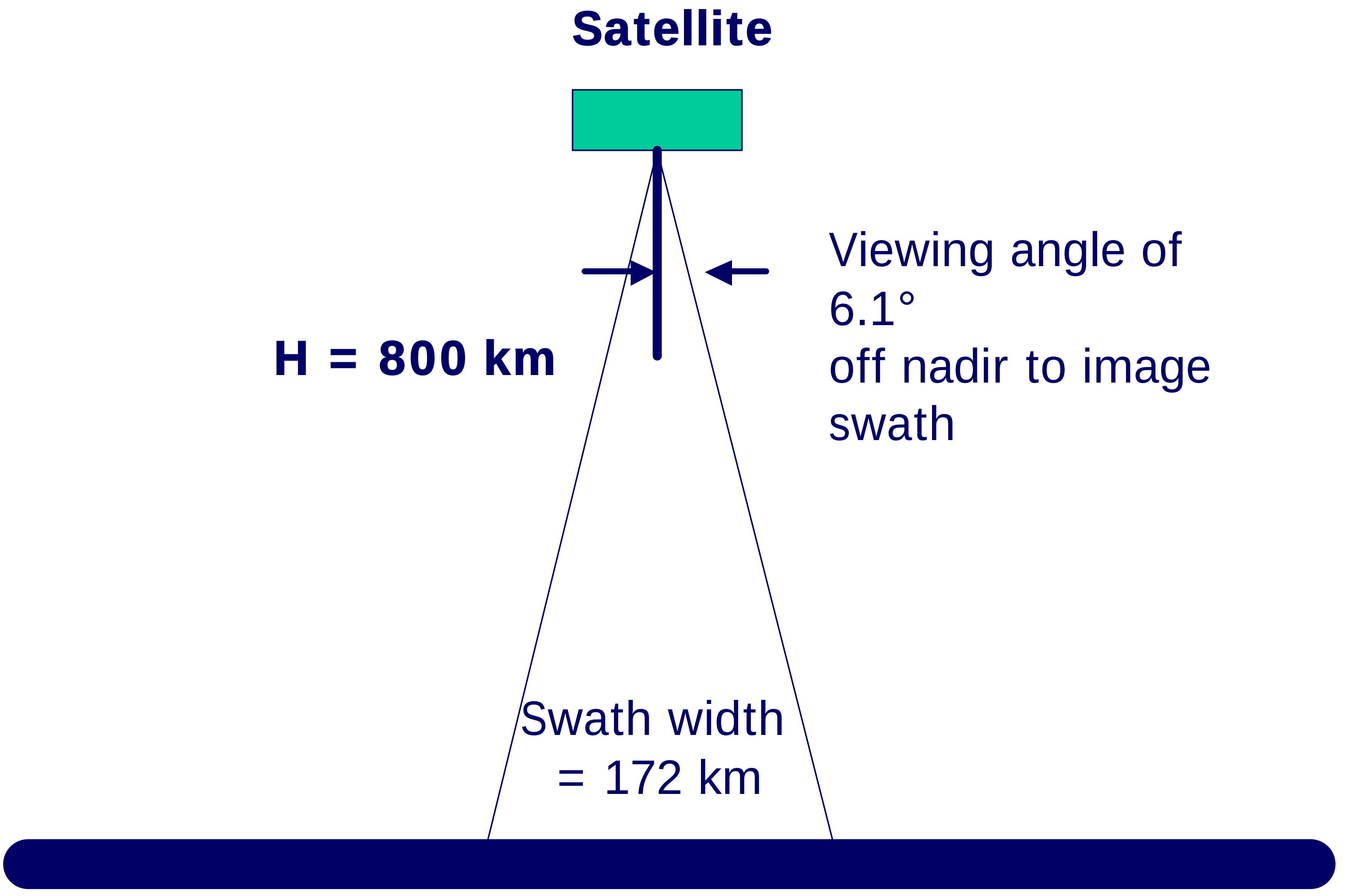

Satellite
Viewing angle of 57°
off nadir to image swath
H = 800 km
Swath width = 2460 km


Satellite
H = 800 km
Viewing angle of 6.1°
off nadir to image swath
Swath width
= 172 km

CONSIDERATIONS FOR SATELLITE DEPLOYMENT OF A RADIOMETER

1. What is the size of the patch being detected by the satellite?
2. How frequently can a satellite view the same piece of ground on the earth's surface?
3. How large an area is imaged by the sensor?
4. How much data are being recorded by the radiometer and how do we retrieve these data?
5. How do variations in surface and atmospheric conditions affect the data quality?

	Wide Swath / Low Resolution	Narrow Swath / High Resolution
Image Size	2460 by 2460 km	172 by 172 km
Ground area size (resolution or pixel size)	1 by 1 km	0.05 by 0.05 km (50 by 50 m)
Number of radiometer channels	4	4
Images per orbit	16	228.8
Pixels per image per channel	6 million	11.8 million
Pixels per orbit per channel	96 million	2.7 billion
Pixels per orbit for all channels	384 million	10.8 billion
High resolution, wide swath – pixels per orbit for all channels	155 billion	
Data per day	2.5 trillion	
Data per month	743 trillion	

CONSIDERATIONS FOR SATELLITE DEPLOYMENT OF A RADIOMETER

1. What is the size of the patch being detected by the satellite?
2. How frequently can a satellite view the same piece of ground on the earth's surface?
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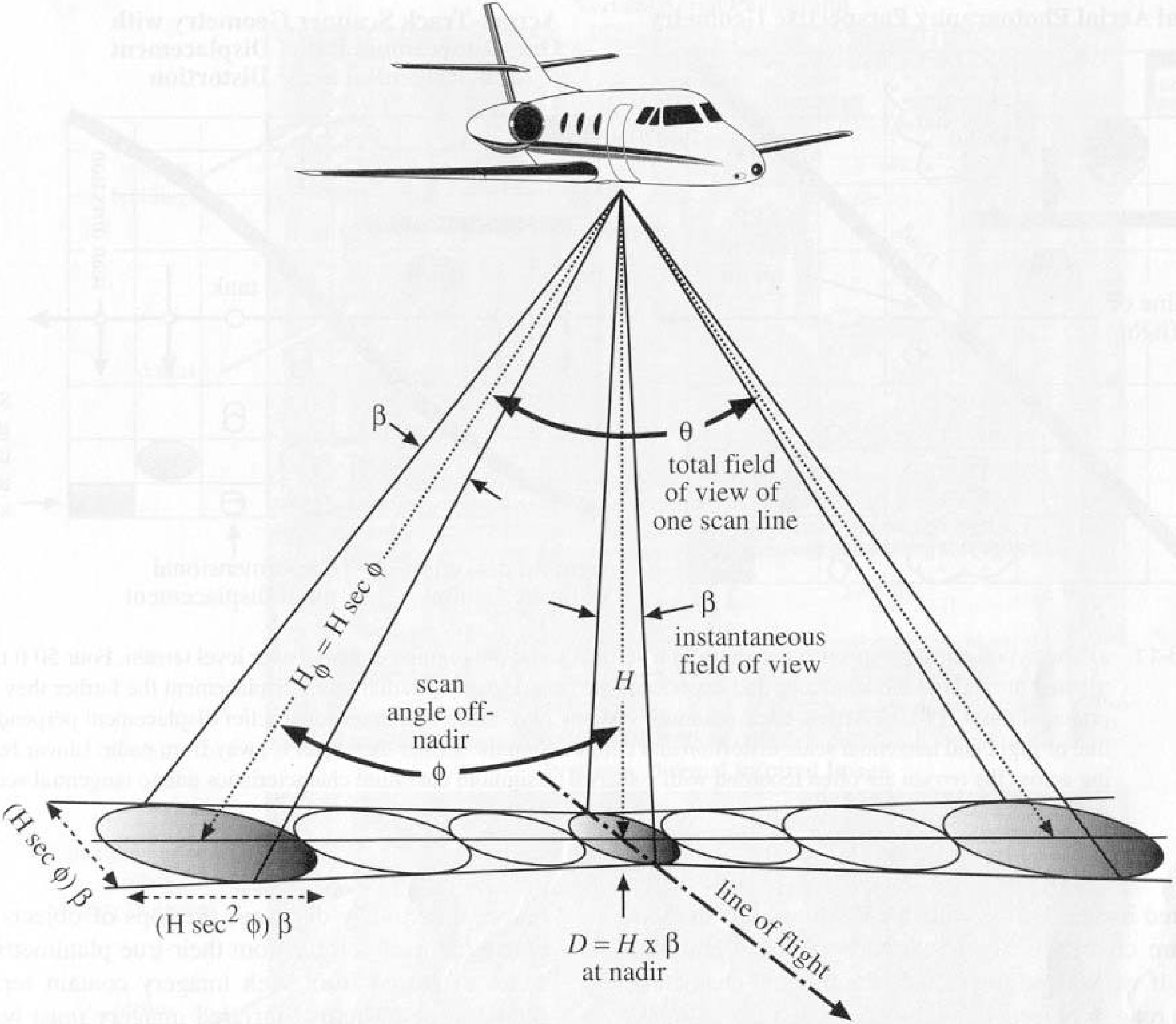
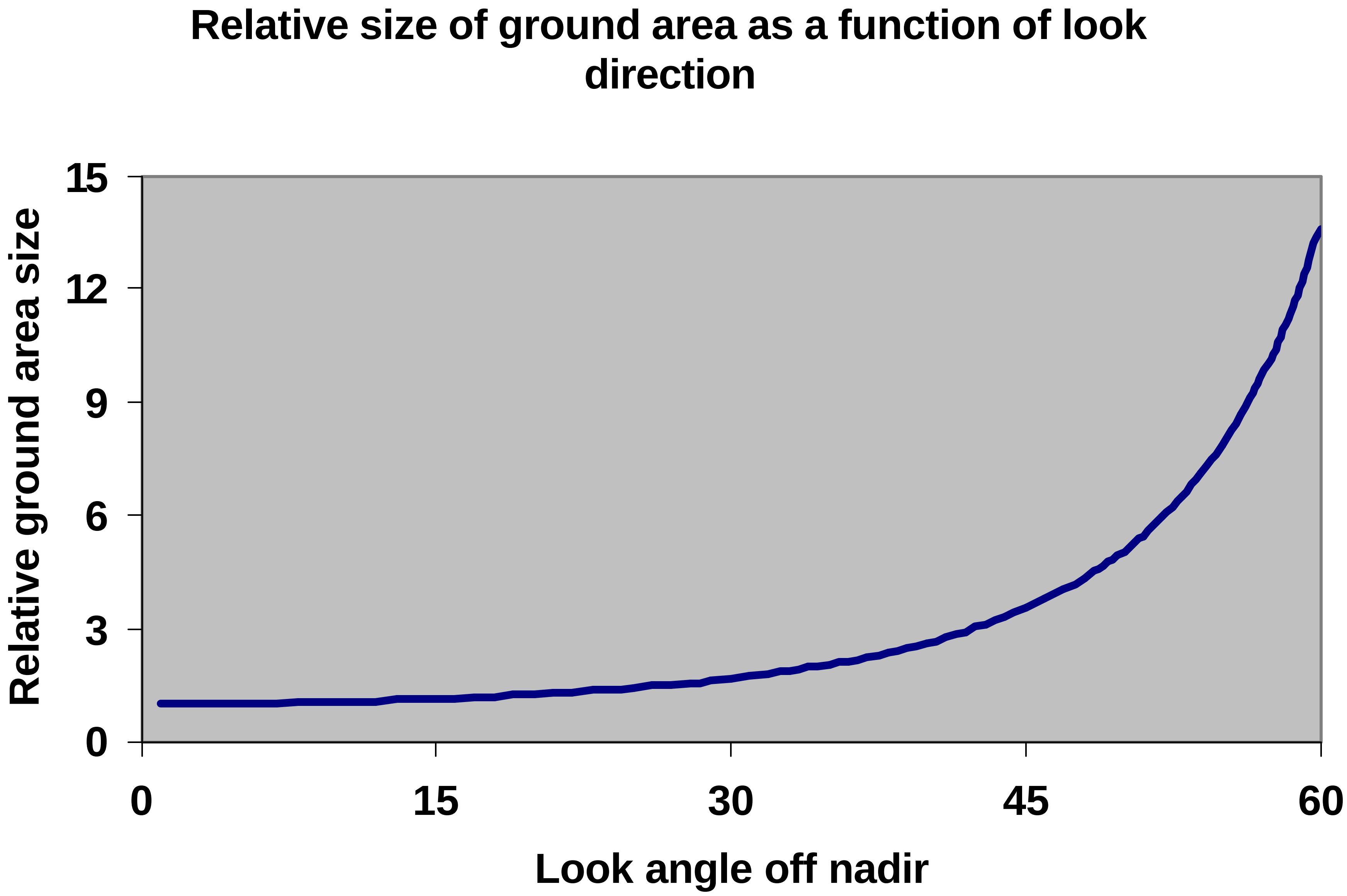
Problems with imaging over wide swaths

1. The size of your ground footprint gets bigger as the angle off nadir gets large
2. Atmospheric effects increase
3. The bidirectional reflectance at the surface often changes, e.g., the emittance from the surface for the same surface cover type changes



β
θ
total field of view of one scan line
β
instantaneous field of view
H
Hφ = H sec φ
scan angle off-nadir
φ
(H sec φ) β
(H sec2 φ) β
D = H x β at nadir
line of flight

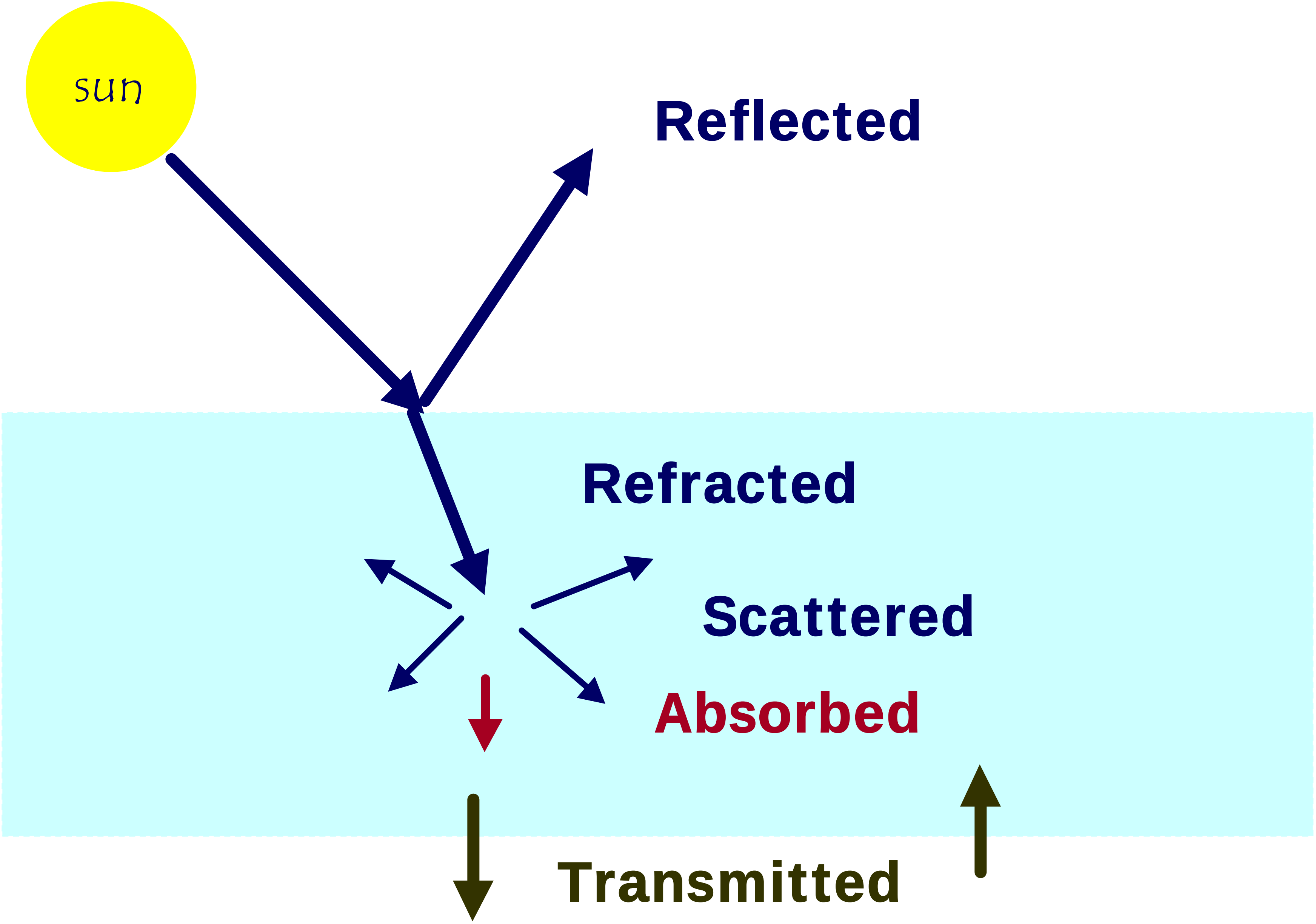

Relative size of ground area as a function of look direction
Relative ground area size
15
12
9
6
3
0
0
15
30
45
60
Look angle off nadir

Problems with imaging over wide swaths

1. The size of your ground footprint gets bigger as the angle off nadir gets large
2. Atmospheric effects increase
3. The bidirectional reflectance at the surface often changes, e.g., the emittance from the surface for the same surface cover type changes

Atmospheric effects

- Effects of atmosphere on incoming/outgoing EM energy is proportional to distance traveled through the atmosphere
- As incidence angle increases, atmospheric effects (scattering, absorption, attenuation) increase
- Using wide swath width increases the requirements for precise atmospheric correction of the data


sun
Reflected
Refracted
Scattered
Absorbed
Transmitted

Problems with imaging over wide swaths

1. The size of your ground footprint gets bigger as the angle off nadir gets large
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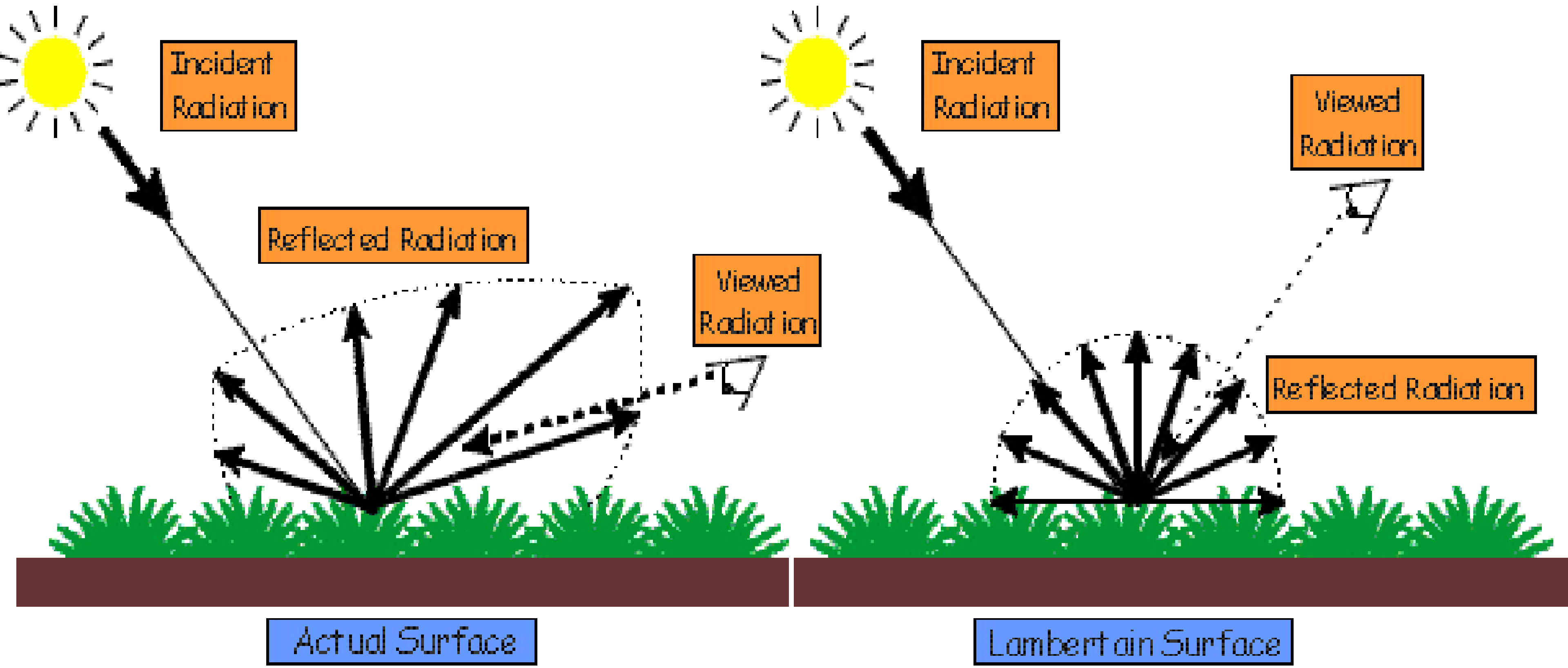
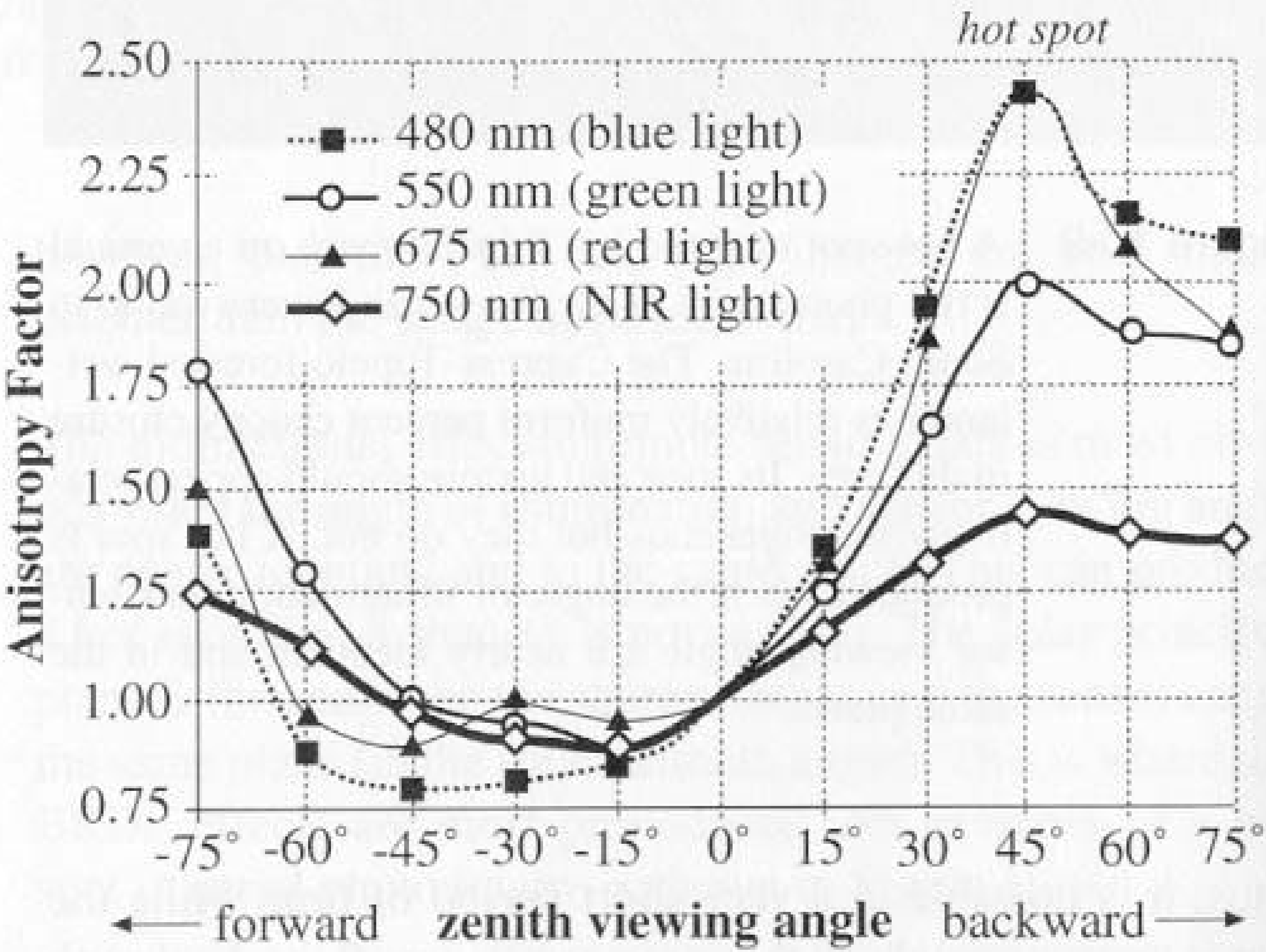
3. The bidirectional reflectance at the surface often changes, e.g., the emittance from the surface for the same surface cover type changes



Further information on this slide can be viewed at http://snrs.unl.edu/agmet/908/brdf_definition.htm


hot spot
480 nm (blue light)
550 nm (green light)
675 nm (red light)
750 nm (NIR light)
Anisotropy Factor
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
-75° -60° -45° -30° -15° 0° 15° 30° 45° 60° 75°
← forward zenith viewing angle backward →

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Summary of System Tradeoffs

Narrow-Swath, Higher Resolution	Wide-Swath, Lower Resolution
-Coverage only every 15 to 20 days (less if cloud cover exists)	+Daily coverage of area
+High resolution imagery	-Low resolution imagery
-Higher data volumes requires on-board recording or direct transmission	+Lower data volumes result in less stringent recording/direct transmission requirements
+Narrow viewing angle results in lower atmospheric / bi-directional scattering effects, and consistent across-swath resolution	-Wider viewing angle results in greater atmospheric / bi-directional scattering effects, and variable across-swath resolution

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Categories of satellite radiometers

1. Wide swath, low resolution
   - *1000-2600 km swath, 500 to 1100 m*
2. Moderate swath, moderate resolution
   - *100 to 200 km swath, 10 to 50 m resolution*
3. Narrow swath, fine resolution
   - *5 to 15 km swath, 1 to 4 m resolution*

Key points for Lecture 13

- Key questions for designing spaceborne radiometers
- Considerations for deploying a spaceborne radiometer
- Problems in imaging over wide swaths
- System tradeoffs