

EAS 8803

FALL 2017

Satellite Data Analysis (Satellite Remote Sensing)

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Meeting Time: Monday/Wednesday: 4:30-5:45 PM L1116

Lecture 1

A. Introduction and Logistics

B. The nature of electromagnetic radiation

Introduction and Logistics

Objectives:

1. What this course is about.
2. How the course is organized:
 - Lectures
 - Computer Modeling Laboratories
 - Class Research Project
3. Reading.
4. Grading.
5. Course outline, lecture schedule, and reading assignments.

1. What this course is about

General definition:

Remote sensing is the collection of information about an object without coming into physical contact with it.

Definition used in this course:

Remote sensing is characterization of an object based on measurements of electromagnetic radiation.

- This course provides a foundation for understanding the physical principles of remote sensing of the atmosphere and oceans.
- The main goal of the course is to build a broad conceptual framework for physical understanding the methodology and various applications of remote sensing in studying the atmosphere and oceans.

NOTE: This course does NOT include remote sensing of land and vegetation, image processing, or instrumentation development.

- The course is designed as a collection of lectures and computer modeling laboratories.
- The lectures focus on the fundamentals of the interactions between electromagnetic radiation and atmospheric gases, aerosols and clouds, and ocean surfaces, covering the spectrum from the ultraviolet through the microwave.
- The labs provide hands-on experience in using remote sensing data for various applications in atmospheric and oceanic sciences. Topics to be covered include aerosol and cloud property retrievals, ozone and air pollution characterization, vertical temperature and humidity profile retrievals, sea ice characterization, and retrievals of ocean color and sea surface temperature, among others.

2. How this course is organized:

➤ **Lectures:**

Lectures are developed to provide the most critical material.

Lecture notes will be posted before the lectures (in PDF format) at the course website:

http://irina.eas.gatech.edu/EAS8803_Fall2015.htm

!!!! Please review lecture materials before coming to the class.

➤ **Computer Modeling Laboratories**

Will be posted at the course web and available on-line. Your written report will be required by the time of the following lab.

➤ **Exam:**

Date of the exam will be posted later.

➤ **Class Research Project**

Goal is to perform an analysis and interpretation of remote sensing data in a well-defined problem.

Plan of a research project must be prepared by a student but discussed with and approved by me. Try to select a topic of your class project as close as possible to your research.

Deadline for the title and abstract is the end of the second week of the course.

Research project must be prepared as a research paper and presented in the class.

Presentations will be scheduled for the last week of the classes.

General guidelines for preparing your class project:

1) Define a topic of your project by selecting a specific atmospheric or oceanic parameter and remote sensing technique(s) used to retrieve this parameter.

For instance, characterization of ozone from OMI observations.

2) Identify and study at least 3-5 papers dealing with the selected topic.

3) Perform an original analysis of the remote sensing data in a well-defined problem.

For instance, interannual variability of O₃ over the Northern America.

4) Your paper (about 20 – 25 pages) should show

the importance of the atmospheric or oceanic parameter selected;

brief description of a remote sensor;

explanation of a retrieval algorithm;

results of your analysis;
validation of retrieved data against independent measurements and/or modeling;
brief summary (e.g., advantages and disadvantages of the retrieval technique, etc.)

3. Reading.

Remote Sensing of the Lower Atmosphere: An Introduction.

Stephens G. Oxford Univ. Press 1994.

A First Course in Atmospheric Radiation.

Petty G.W., Sundog Publishing. Second Edition.

Online tutorials:

Canada Centre for Remote Sensing (CCRS) remote sensing tutorial:

<http://www.nrcan.gc.ca/earth-sciences/geomatics/satellite-imagery-air-photos/satellite-imagery-products/educational-resources/9309>

NASA remote sensing tutorial:

<http://fas.org/irp/imint/docs/rst/>

Univ. of Illinois tutorial: remote sensing for meteorology:

[http://ww2010.atmos.uiuc.edu/\(Gh\)/guides/rs/home.rxml](http://ww2010.atmos.uiuc.edu/(Gh)/guides/rs/home.rxml)

Additional Text:

An introduction to atmospheric radiation.

Liou, K.N., Academic Press, Second Edition, Chapter 7, 2002.

Satellite meteorology: An Introduction.

Kidder S.Q. and Vonder Haar T.H., Academic Press, 1995.

Physical principles of remote sensing.

Rees W.G., Cambridge Univ. Press, Second Edition, 2001.

Introduction to the physics and techniques of remote sensing.

Elachi, C. New York : Wiley, 1987

Remote sensing: Principles and interpretation.

Sabins, F.F., 1997.

NOTE: The various textbooks might have somewhat different terminology and use very different notations.

4. Grading.

Exam	20%
Computer modeling labs	40%
Research project	40%

The nature of electromagnetic radiation.

1. Basic introduction to the electromagnetic field:

- Dual nature of electromagnetic radiation
- Electromagnetic spectrum

2. Basic radiometric quantities: intensity and flux.

Required reading:

S: 2.1-2.2

Recommended reading:

Petty: Chapters 2-3

1. Basic introduction to electromagnetic field.

Electromagnetic (EM) radiation is a form of energy propagated through free space or through a material medium in the form of electromagnetic waves.

EM radiation is so-named because it has electric and magnetic fields that simultaneously oscillate in planes mutually perpendicular to each other and to the direction of propagation through space.

- ✓ Electromagnetic radiation has the **dual nature**:
its exhibits **wave properties** and **particulate (photon) properties**.
- **Wave nature of radiation**: Radiation can be thought of as a **traveling transverse wave**.

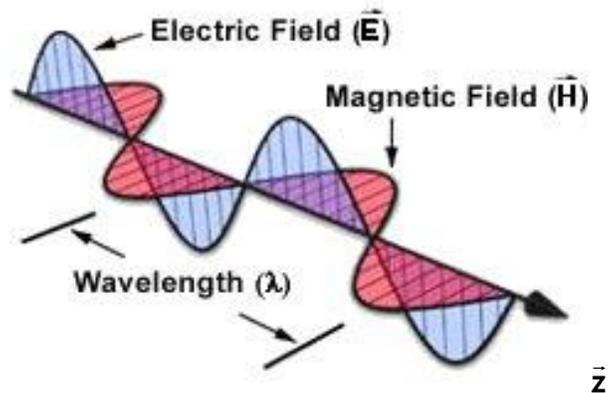


Figure 2.1 A schematic view of an electromagnetic wave propagating along the \vec{z} axis. The electric \vec{E} and magnetic \vec{H} fields oscillate in the x-y plane and perpendicular to the direction of propagation.

- As a transverse wave, EM radiation can be polarized. **Polarization** is the distribution of the electric field in the plane normal to propagation direction.

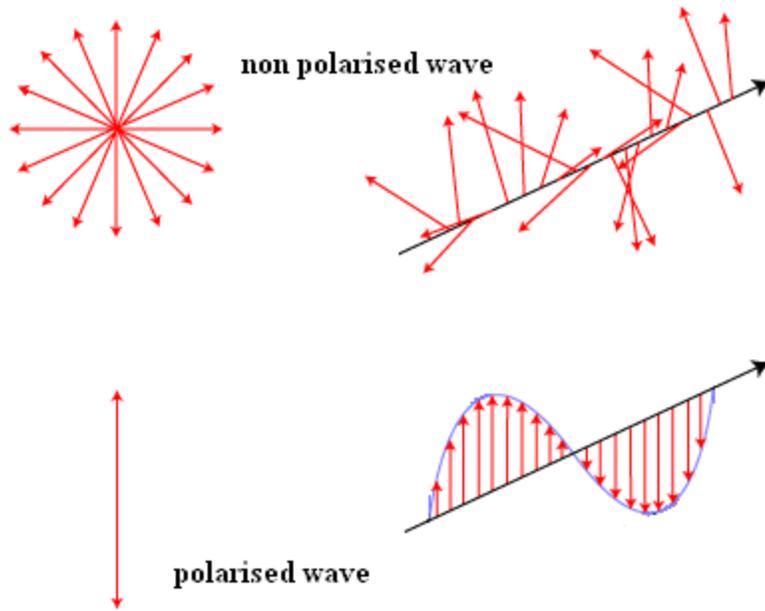


Figure 2.2 Electric field \vec{E} orientation for polarized and non polarized electromagnetic waves.

Poynting vector gives the flow of radiant energy and the direction of propagation as (in the cgs system of units)

$$\vec{S} = c^2 \epsilon_0 \vec{E} \times \vec{H} \quad [2.1]$$

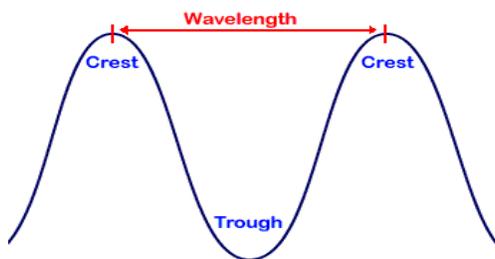
here c is the speed of light in vacuum ($c = 2.9979 \times 10^8 \text{ m/s} \cong 3.00 \times 10^8 \text{ m/s}$) and ϵ_0 is vacuum permittivity (or dielectric constant). \vec{S} is in units of energy per unit time per unit area (e.g., W m^{-2})

NOTE: $\vec{E} \times \vec{H}$ means a **vector product** of two vectors.

- \vec{S} is often called **instantaneous Poynting vector**. Because it oscillates at rapid rates, a detector measures its average value $\langle S \rangle$ over some time interval that is a characteristic of the detector.
- **Waves** are characterized by **frequency, wavelength, speed and phase**.

Frequency is defined as the number of waves (*cycles*) per second that pass a given point in space (symbolized by $\tilde{\nu}$).

Wavelength is the distance between two consecutive peaks or troughs in a wave (symbolized by the λ).



Relation between λ and $\tilde{\nu}$: $\lambda \tilde{\nu} = c$ [2.2]

- Since all types of **electromagnetic radiation** travel at the speed of light, short-wavelength radiation must have a high frequency.
- Unlike speed of light and wavelength, which change as electromagnetic energy is propagated through media of different densities, frequency remains constant and is therefore a more fundamental property.

$\nu = \tilde{\nu} / c = 1/\lambda$ [2.3]

UNITS:

Wavelength units: length
 Angstrom (Å) : 1 Å = 1×10^{-10} m;
 Nanometer (nm): 1 nm = 1×10^{-9} m;
 Micrometer (μm): 1 μm = 1×10^{-6} m;

Wavenumber units: inverse length (often in cm^{-1})

NOTE: Conversion from the wavelength to wavenumber:

$$\nu[\text{cm}^{-1}] = \frac{10,000 \text{cm}^{-1} \mu\text{m}}{\lambda[\mu\text{m}]} \quad [2.4]$$

Frequency units: unit cycles per second 1/s (or s^{-1}) is called hertz (abbreviated Hz)

Table 2.1 Frequency units

Unit	Frequency, (cycles/sec)
------	-------------------------

Hertz, Hz	1
Kilohertz, KHz	10 ³
Megahertz, MHz	10 ⁶
Gigahertz, GHz	10 ⁹

➤ **Particulate nature of radiation:**

Radiation can be also described in terms of particles of energy, called **photons**

The energy of a **photon** is given as:

$$\mathcal{E}_{\text{photon}} = h \tilde{\nu} = h c/\lambda = hc\nu \quad [2.5]$$

where **h** is Plank's constant ($h = 6.6256 \times 10^{-34}$ J s).

- Eq. [2.5] relates energy of each photon of the radiation to the electromagnetic wave characteristics ($\tilde{\nu}$ and λ).
- Photon has energy but it has no mass and no charge.

NOTE: The quantized nature of light is most important when considering absorption and emission of electromagnetic radiation.

PROBLEM: A light bulb of 100 W emits at 0.5 μm . How many photons are emitted per second?

Solution:

Energy of one photon is $\mathcal{E}_{\text{photon}} = hc/\lambda$, thus, using that 100 W = 100 J/s, the number of photons per second, N, is

$$N(s^{-1}) = \frac{100(Js^{-1}) \lambda(m)}{h(Js) c(ms^{-1})} = \frac{100 \times 0.5 \times 10^{-6}}{6.6256 \times 10^{-34} \times 2.9979 \times 10^8} = 2.517 \times 10^{20}$$

NOTE: Large number of photons is required because Plank's constant **h** is very small!!!

The electromagnetic **spectrum** is the distribution of electromagnetic radiation according to energy or, equivalently, according to the wavelength or frequency.

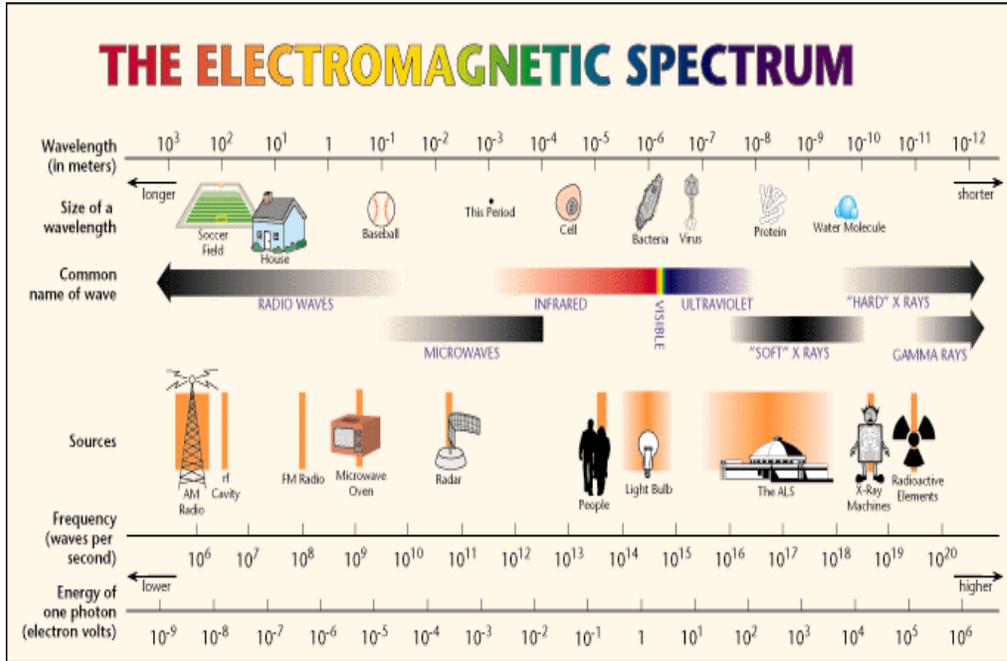


Figure 2.3 Schematic representation of the electromagnetic spectrum.

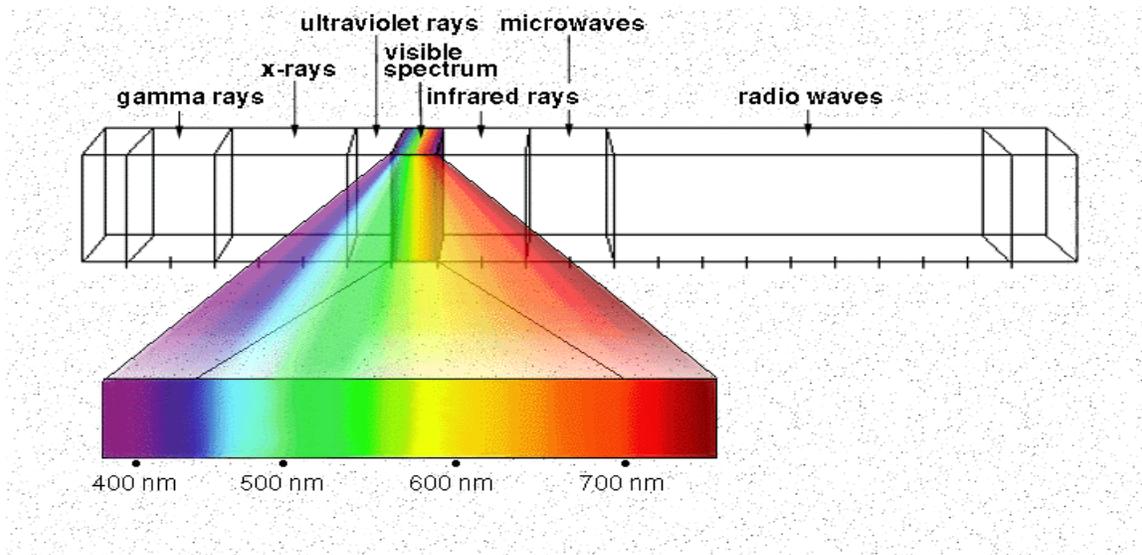


Figure 2.4 Visible region of the electromagnetic spectrum.

NOTE: In remote sensing, sensor's spectral bands in the visible are often called by their color (e.g., blue, green, and red channels)

Effects of atmospheric gases:

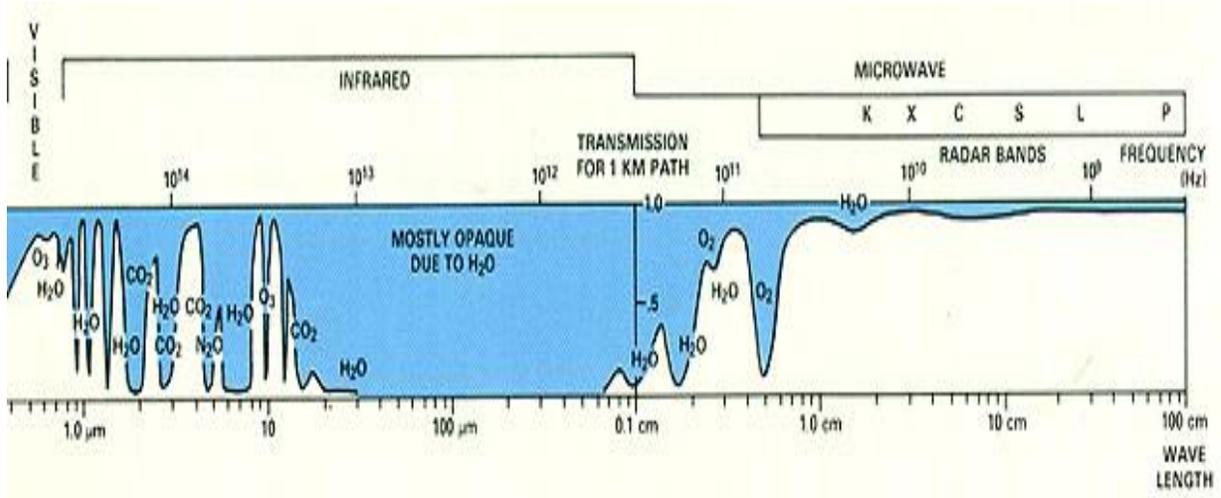


Figure 2.5 A generalized diagram showing relative atmospheric radiation **transmission** at different wavelengths. Blue zones show low passage of incoming and/or outgoing radiation and white areas show atmospheric windows, in which the radiation doesn't interact much with air molecules and hence, isn't absorbed.

Table 2.2 Common names and relationships between radiation components.

Name of spectral region	Wavelength region, μm	Spectral equivalence
Solar	0.1 - 4	Ultraviolet + Visible + Near infrared = Shortwave
Terrestrial	4 - 100	Far infrared = Longwave
Infrared	0.75 - 100	Near infrared + Far infrared
Ultraviolet	0.1 - 0.38	Near ultraviolet + Far ultraviolet = UV-A + UV-B + UV-C + Far ultraviolet
Shortwave	0.1 - 4	Solar = Near infrared + Visible + Ultraviolet
Longwave	4 - 100	Terrestrial = Far infrared
Visible	0.38 - 0.75	Shortwave - Near infrared - Ultraviolet
Near infrared	0.75 - 4	Solar - Visible - Ultraviolet = Infrared - Far infrared
Far infrared	4 - 100	Terrestrial = Longwave = Infrared - Near infrared
Thermal	4 - 100 (up to 1000)	Terrestrial = Longwave = Far infrared
Microwave	$10^3 - 10^6$	Microwave
Radio	$> 10^6$	Radio

Table 2.3 Microwave frequency bands used in remote sensing

<i>Bands</i>		<i>Frequency</i>
“Old”	“New”	[GHz]
L	D	1-2
S	E, F	2-4
C	G, H	4-8
X	I, J	8-12
Ku	J	12-18
K	J	18-26
Ka	K	26-40

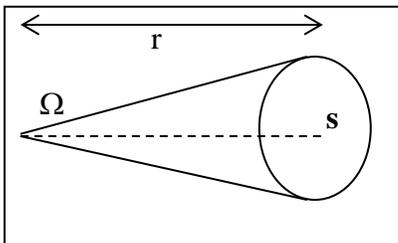
Example: L-band is used onboard American SEASAT and Japanese JERS-1 satellites.

2. Basic radiometric quantities: intensity and flux.

Solid angle is the angle subtended at the center of a sphere by an area on its surface numerically equal to the square of the radius

$$\Omega = \frac{s}{r^2} \quad [2.6]$$

UNITS: of a solid angle = steradian (sr)



A differential solid angle can be expressed as

$$d\Omega = \frac{ds}{r^2} = \sin(\theta) d\theta d\phi,$$

using that a differential area is

$$ds = (r d\theta) (r \sin(\theta) d\phi)$$

Example: Solid angle of a unit sphere = 4π

PROBLEM: What is the solid angle of the Sun from the Earth if the distance from the Sun to the Earth is $d=1.5 \times 10^8$ km? Sun's radius is $R_s = 6.96 \times 10^5$ km.

SOLUTION: $\Omega = \frac{\pi R_s^2}{d^2} = 6.76 \times 10^{-5} \text{ sr}$

Intensity (or radiance) is defined as radiative energy in a given direction per unit time per unit wavelength (or frequency) range per unit solid angle per unit area perpendicular to the given direction:

$$I_\lambda = \frac{d\varepsilon_\lambda}{ds \cos(\theta) d\Omega dt d\lambda} \quad [2.7]$$

I_λ is referred to as the **monochromatic** intensity.

- Monochromatic does not mean at a single wavelength λ , but in a very narrow (infinitesimal) range of wavelength $\Delta\lambda$ centered at λ .

NOTE: same name: intensity = specific intensity = radiance

UNITS: from Eq.[2.7]:

$$(\text{J sec}^{-1} \text{ sr}^{-1} \text{ m}^{-2} \mu\text{m}^{-1}) = (\text{W sr}^{-1} \text{ m}^{-2} \mu\text{m}^{-1})$$

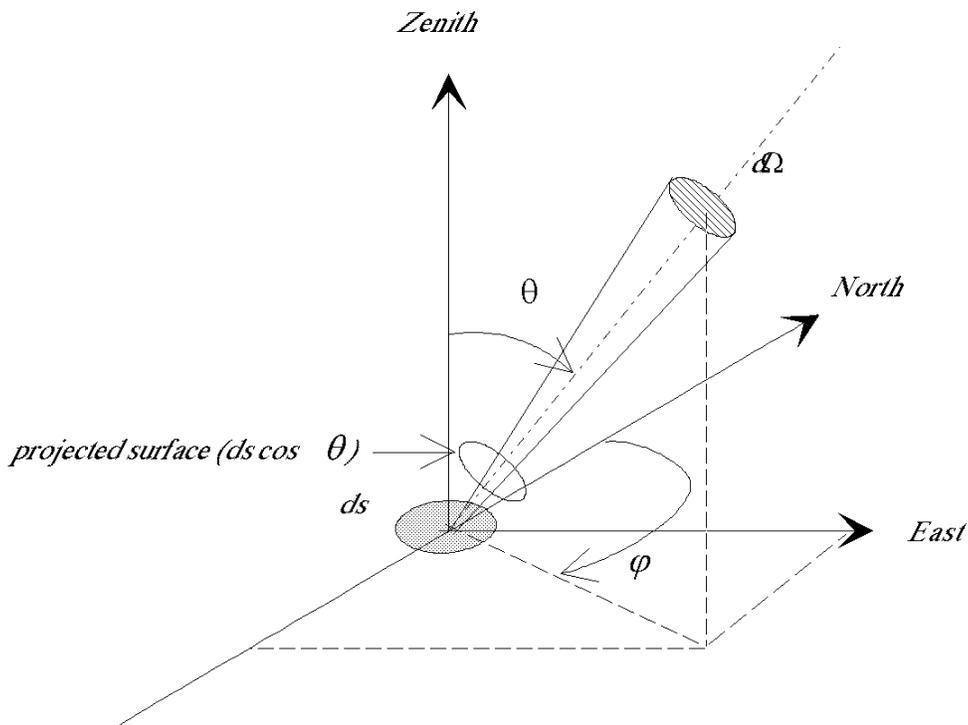


Figure 2.6 Intensity is the flow of radiative energy carried by a beam within the solid angle $d\Omega$.

Properties of intensity:

- a) In general, intensity is a function of the coordinates (\vec{r}), direction ($\vec{\Omega}$), wavelength (or frequency), and time. Thus, it depends on seven independent variables: three in space, two in angle, one in wavelength (or frequency) and one in time.
 - b) In a transparent medium, the intensity is constant along a ray.
- If intensity does not depend on the direction, the electromagnetic field is said to be **isotropic**.
 - If intensity does not depend on position the field is said to be **homogeneous**.

Flux (or irradiance) is defined as radiative energy in a given direction per unit time per unit wavelength (or frequency) range per unit area perpendicular to the given direction:

$$F_{\lambda} = \frac{d\varepsilon_{\lambda}}{dtdsd\lambda} \quad [2.8]$$

UNITS: from Eq.[2.8]:

$$(\text{J sec}^{-1} \text{ m}^{-2} \mu\text{m}^{-1}) = (\text{W m}^{-2} \mu\text{m}^{-1})$$

From Eqs. [2.7]-[2.8], the flux is integral of normal component of radiance over some solid angle

$$F_{\lambda} = \int_{\Omega} I_{\lambda} \cos(\theta) d\Omega \quad [2.9]$$

NOTE: Many satellite sensors have a narrow viewing angle and hence measure the intensity (not flux). To measure the flux, a sensor needs to have a wide viewing angle.

- Depending on its **spectral resolution**, a detector measures electromagnetic radiation in a particular wavelength range, $\Delta\lambda$. The intensity $I_{\Delta\lambda}$ and flux $F_{\Delta\lambda}$ in this range are determined by integrating over the wavelength the monochromatic intensity and flux, respectively:

$$I_{\Delta\lambda} = \int_{\lambda_1}^{\lambda_2} I_{\lambda} d\lambda \qquad F_{\Delta\lambda} = \int_{\lambda_1}^{\lambda_2} F_{\lambda} d\lambda \qquad [2.10]$$