SUMMARY
Introduction to Earth Observation

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Lecture overview 2010

1- Introduction

Why satellite observation?

- Synoptic observations: being able to look at a large region at the same time
- Global perspective
- Convenient for inaccessible regions
- Short term application (tsunami)
- Long term application (global warming)

Three basic physical properties

1. **Potential field**
- Source: object, info about mass distribution or magnetic behavior; passive instruments
2. **Electromagnetic field**
- *Visible and near-IR*: source; reflected sunlight, info about chemical composition and physical structure of object; passive instruments
- *Thermal IR and passive microwave*: source; object, info about thermal properties and composition of objects; passive instruments
- *Active microwave*: source; sensor, info about physical structure and electrical properties of object; active instruments
3. **Acoustic field**: source; object or sensor, information on propagating and reflecting media

Gravity and magnetic forces are known as conservative forces: the amount of work performed is path-independent.

Different platforms for Earth Observations

Ground platforms

Issues:

- Required infrastructure
- Remote or human operation, maintenance
- Data transmitting

Marine platforms

Pros:

- Multidisciplinary payloads
- High spatial resolution
- Ideal for seafloor mapping

Cons:

- Limited spatial coverage
- Platform dynamics (tides, vibrations)
- High costs/day

Aircraft platforms

Pros:

- Flexible in operation and payload
- Wide range of altitudes and speeds
- High spatial resolution

Cons:

- Short mission duration
- Smaller spatial coverage
- Platform dynamics (atmosphere, vibrations)

Combination with satellites to calibrate satellite data pr to fill in data gaps

Satellite platforms

Pros:

- Provides almost global coverage
- Homogeneous spatial coverage
- Continuous data stream in time
- Rapid data delivery
- Homogeneous accuracy

Cons:

- More expensive (both launch and maintenance)
- Long development time
- Limited spatial and temporal resolution
- Instrument accessibility
- Potential launch failure

Considerations:

Space environment very different than the Earth's:

- Near-zero gravity
- Temperature extremes
- Exposed to radiation

2 - GPS System

It is the workhorse for navigation techniques.

For EO:

- Positioning of platforms
- Post processing for enhanced precision
- Differential positioning (relative to known position)
- Satellite orbit precision up to cm accuracy, ground station coordinates up to mm accuracy

How it works:

- Receiver identifies each GPS sat signal through PRN
- Position of GPS satellites known through broadcast ephemeris (updated every 4 hours)
- Travel time of signal determined by comparing received and internally generated PRN codes
- Receiver clock often not that accurate, so need to track an additional satellite to estimate clock error → 4 satellites needed in total to determine position
- Uses two frequencies (L1 and L2) by which ionospheric errors are corrected.

Differential GPS

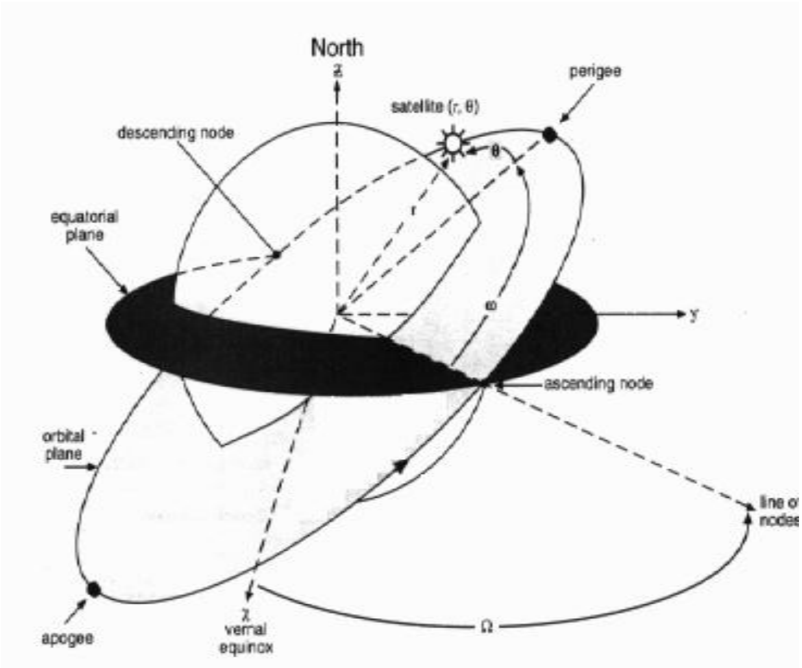
Many EO applications require highly accurate positioning measurements. In order to increase the accuracy, post processing is used by incorporating the precise locations of known GPS stations into the measurements. It results in an accuracy <1m.

Errors by which GPS cannot be 100% accurate:

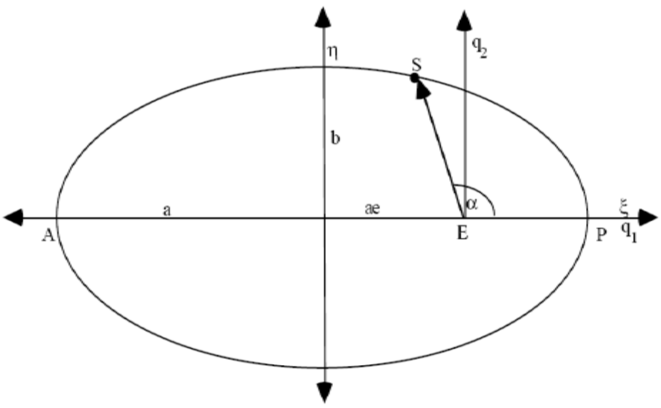
- Clock errors
- Atmospheric effects
- Imprecise knowledge of GPS orbits
- Relativistic effects
- Encryption (data travel protection)
- Dilution of precision (i.e. geometry)
- Multipath

3 - EO mission design

Satellite orbits for EO purposes



I	inclination
Ω	longitude of the ascending node
e	eccentricity
ω	argument of perigee
a	semimajor axis
M	mean anomaly



S	-	satellite
E	-	Earth
A	-	apogee
P	-	perigee
a	-	semimajor axis
b	-	semiminor axis
e	-	eccentricity

$$e^2 = \frac{a^2 - b^2}{a^2}$$

Complications due to earth flattening

Gravitational potential changes through orbit due to the oblate earth.

Leads to:

- Increased orbital period
- Precession of orbital plane
- Change of the longitude of the ascending node
- Change of the argument of the perigee
- Change of the mean motion

Special orbits

Polar orbits

- Inclination is 90 deg, orbital plane does not change w.r.t. inertial space
- Low Earth Orbit, approximate orbit time of 90 minutes.
- Satellite passes the poles
- Ground tracks covers Earth homogeneously
- Used for mission where inertial attitude control is important.

Sun-synchronous orbits

A spacecraft in sun-synchronous orbit is at the same latitude as at the same solar time every day. This implies an inclination larger than 90 degrees. It is caused by the oblateness of the earth: The Earth's oblateness causes the line of nodes to precess, and for specific orbits, this precession can be timed to be the same as the Earth's rotation about the Sun.

Repeat orbits

- A given position can be observed periodically
- Aliasing is important (see chapter 7)
- Altimetry satellites use sun-synchronous and repeat orbits of the same time.

Geostationary orbits

- Orbit period the same as earth rotation rate.
- 36000 km height
- Covers almost 1/3 of Earth's surface
- It is used for telecommunication, meteo, and relay.

Molniya orbits

- Orbit must not rotate in its own plane
- e = 0.7460
- orbital period is 12 hours
- Used for telecommunication.
- Since the satellite remains longer at 'the desired side' of the Earth due to its elliptical form

Altimetric orbits

Altimetric orbits are designed such that pass-lines will intersect each other at 90 deg angles so orthogonal slopes measurements are possible.

Main disturbances for orbits

- Drag (Atmospheric, Solar, ...)
- Orbital Period Increases
- Orbital Plane Precesses with respect to Polar Axis
- Orbital Ellipse Rotates in own Plane

4 - Reference system

A reference system is a complete specification of how a coordinate system is to be formed. It defines:

- Origin
- Axis
- Constants, models, algorithms to transform between observables and reference data that can conform the reference system

Reference system + coordinates = coordinate system

A reference system can have different coordinate systems and reference frames.

Reference frame: realization of a reference system through accessible physical objects along with their coordinates.

Different types:

Celestial system (space fixed)
- Origin is barycentre of the solar system
- Z-axis: (Mean) Celestial Pole (CEP) at 1 jan 2000 12h = (Mean) Earth rotation axis at 1 jan 2000 12h
- X-axis: (Mean) Vernal Equinox = intersection ecliptic - equator at 1 jan 2000 12h (zero-direction for right ascension)
- Governed by the International Astronomical Union
- Uses spherical coordinates

Terrestrial system (Earth fixed)
- Origin is the earth centre of mass
- Z-axis: (Mean) rotation axis
- X-axis: Mean Greenwich Observatory Meridian

Motion of the Earth's rotation axes in space
- Rotation axis never fixed with respect to nor fixed with respect to the Earth's crust
- Motion with respect to space:
    - Precession
    - Nutation
    - Residual motion (pole off sets)
- Motion with respect to Earth's crust:
    - Polar motion
- Changes in angular velocity

Pole is where rotation axis intersects Earth surface

Local system (observation point fixed)
- Origin is observation point
- Z-axis: up
- X-axis: East

- Y-axis: North
- Coordinates can either be Cartesian or Spherical
- A reference frame is realized by a leveled instrument or antenna

Platform system

- Origin is platform used (e.g. airplane)
- Axis with respect to platform
- Coordinates Cartesian
- Reference frame realized by platform structure

The earth is not static. Changes include (usually as a result of mass transfer):

- Change of polar axes
- Length of day
- Variance of magnetic field

Measuring Earth's rotation

Ground stations (terrestrial reference system) rotate with Earth. Measurements to extra-terrestrial objects provide orientation with respect to these objects.

Instruments:

- GPS
- Laser ranging to satellites and moon
- Very Long Baseline Interferometry
- Ring lasers

4 – 2 Time scales

Why important?

- Fast moving platforms (satellites) require high accurate time-keeping
- For frequency dependent measurements (laser, radio waves) small timing off sets can lead to large errors

Absolute time measurements:

- Epoch (event, observation)

Relative time measurements:

- Intervals (signal travel times)

Required accuracies to measure a position error of 1 cm

1. Earth's rotation: 2*10^-5 s (absolute)
2. Light/microwave time: 1*10^-10 s (relative)
3. LEO motion: 1*10^-6 s (absolute)

For scientific observation a different time scale is needed because:

- Humans operate on time based on the Earth's rotation
- But Earth does not rotate uniformly!
- Just after 1920 an atomic clock was more accurate the Earth's rotation.

Universal Time

- Based on Earth's rotation
- Most commonly used
- Also called GMT

International Atomic Time TAI

- Uses the current definition of the second
- Initial phase coincides with UT1

Coordinated Universal Time

- Official time of the world
- Uses same time interval as TAI
- Differs from TAU by integer number of seconds
- Initial phase adjusted by leap seconds to keep UTC within one second of UT1
- Coordinated Universal Time is always within one second of Universal Time

4- 3 Sea level and vertical reference systems

The equi-potential surface of the Earth's gravity field at mean sea level is the most natural choice of a height reference surface: it is called the geoid.

h = H + N, with

h = ellipsoid height

H = orthometric height

N = geoid height

From GPS we always find height w.r.t ellipsoid (h)

Maps always shows height w.r.t. the geoid (H)

A geoid model explains the difference N

Why is geoid interesting?

- Level surface (engineering purposes)
- Allows connecting worldwide sea level measurements
- Enables use of GPS for height determination
- Oceanography

Aspect that effect the realization of vertical reference systems:

- Sea level changes
- Ocean tides
- Post-glacial rebound
- Physical access to sea level
- Potential differences between local mean sea levels

Earth & Ocean tides

Earth tides and reference system

- Periodical deformation of Earth crust
- Periodical (reference) station movements <0,3m

Ocean tides and reference system

- Periodical change in actual sea level → to be removed in the processing e.g. of satellite altimetry

5- Gravity field

Some facts:

- Plays an important role in our universe
- Is an always existing force between particles of matter
- Has an infinite range through space
- Weakens at the inverse square of the distance between the bodies
- It travels no faster/slower than the speed of light
- Without gravity there is no space and time
- Much weaker than other forces like electromagnetic forces, but it is much stronger over a larger distance.

Why observe?

- Gravity field is a mirror of density
- Time-varying gravity as indicator of global change
- Motion of platforms are governed by gravity field
- Gravity is an indicator of oil/gas reserves
- Gravity determines in which direction water flows
- Height measurements with GPS require knowledge about gravity
- Gravity concerns ocean currents

Gravity = gravitational acceleration + centrifugal acceleration

Gravity potential = gravitational potential + centrifugal acceleration

Gravity potential field is dominated by the monopole (l=1)

Gravity irregularities disturb satellite orbits. Satellites serve as a sensor for the gravity field

Airborne gravimetry

- Airborne gravimetry is commercially applied for geophysical exploration
- It is an operational tool in local gravity field modeling
- Main problem: remove high-frequency vibrations from data. Filter design and signal processing is an issue.

Bathymetry from satellite altimetry

Principle: If sea surface topography (or marine gravity anomalies) is caused solely by seamount mass surplus, and density is known, we can invert this relation

Rule of thumb

In general the sea surface bows upward 1 m for every rise in the seafloor of 1000 m (a ratio of 1 to 1000)

5-2 - Geomagnetic field

Why observe?

- Local surveys, e.g. locating underground objects
- Mapping, e.g. archeology, minerals, geological structures
- Navigation, e.g. spacecraft stabilization (magnetic torquer)
- Research
- Hazard of geomagnetic storms prediction

Sources

The earth is composed of: solid crust; semi-solid mantle; liquid iron outer core; solid iron inner core

From which the magnetic field is for 97/99% caused by the core field.

- Internal field = core field + lithospheric field
- External field (caused by electric currents in ionosphere)
- Induced field (caused by magnetic variations of external field)

Applications

- Magnetic polarity reversals
- Sea floor age determinations

6 - Data processing

Preprocessing: removal of systematic errors

- Calibration
  - Radiometric correction
  - Atmospheric correction
  - Geometric correction
- Geocoding

Image enhancement: improving intelligibility

Classification: extracting meaningful patterns

Radiometric correction/calibration:

- Striping
- Missing lines
- Angular effects
- Sensor calibration
- Terrain effects

Sun angle correction

- Position of the sun relative to the earth changes depending on time of the day and the day of the year
- In the northern hemisphere the solar elevation angle is smaller in winter than in summer

Sensor calibration

- Necessary to generate absolute data on physical properties:
  - Reflectance
  - Temperature
  - Emissivity
  - Blackscatter
- Values provided by data provider/agency

Terrain effects

- Cause differential solar illumination
  - Some slopes receive more sunlight than others
- Magnitude of reflected radiance reaching the sensor
  - Topographic slope and aspect

Image enhancement

Images may suffer from the following degradations:

- Poor contrast due to poor illumination or finite sensitivity of the imaging device
- Electronic sensor noise or atmospheric disturbances leading to broad band noise
- Aliasing effects due to inadequate sampling
- Finite aperture effects or motion leading to spatial disturbance

Contrast enhancement: consider simple algorithms for image enhancement based upon lookup tables

Noise removal: consider simple linear filtering algorithms

Image filtering

- Simple image operators can be classified as ‘point wise’ or ‘neighborhood’ filtering operators
- Histogram equalization is a point wise operation
- More general filtering operations use neighborhoods’ of pixels

Types of noise

- Additive, noise v and signal g are independent
- Multiplicative, noise is a function of signal magnitude
- Impulse noise

Additive noise types:

White noise: constant power spectrum

Gaussian noise: good approximation of actual noise

7 - Electromagnetic fields

Important terms

Signal: data, something that carries information

- A continuous time signal is often sampled (divided in discrete sequence)
- A signal is represented as a summation of sinusoids with different amplitudes, frequencies and phases

System: something that can manipulate, change, record or transmit signals

Fourier's theorem: adding many sinusoids (harmonic waves) with varying amplitudes, frequencies and phases can build any signal.

Harmonic addition theorem: we can always write the sum of sinusoidal functions as a new sinusoidal function

The Fourier transform is a decomposition of a complex signal in harmonic components (spectral components)

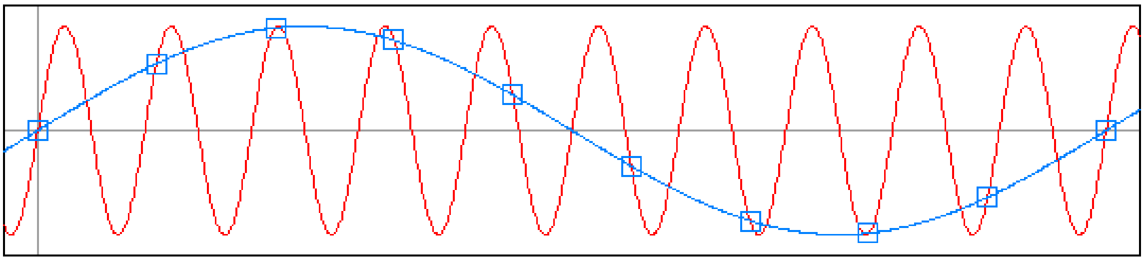
Relation to Earth and Planetary observation:

- Reflected or penetrating waves are the superposition of many spectral components
- This is dependent of material properties (spectral properties of material)

Sampling

Aliasing

Aliasing refers to the difference between observation frequency and frequency of the occurrence of an event. When the frequency of the observation is too small a wrong signal can be read:



Red: actual signal **Blue**: received signal due to low frequency of observation

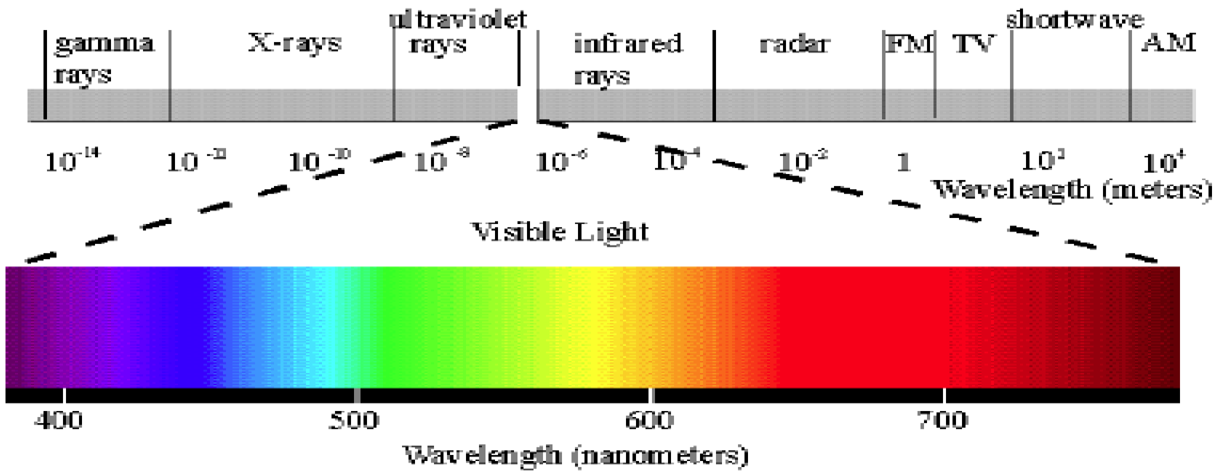
To be able to reconstruct a signal:

The sampling rate should exceed Nyquist frequency, which is twice the bandwidth (= usually the highest frequency) of the signal.

Spectral resolution

Spectral resolution is usually achieved with filters (high band-width signals) or prisms/diffracting grating (low band width). Diffraction grating generates spectrum of order n with radiation lines separated by a distance d: $\sin\theta = \frac{n\lambda}{d}$.

Electromagnetic spectrum



Diffraction grating achieves better line-spread than a prism. It is used primarily for color (wavelength) separation.

Over sampling

Oversampling occurs when the distance between different measurements (as defined, in a push broom system, by the projections of neighboring sensors in the terrain) is smaller than the result of diffraction effects. This is not necessarily beneficial, since it does not lead to additional information. Neighboring measurements will be correlated (but this could be simply eliminated by down sampling). Sometimes over-sampling can be beneficial, to be able to compensate for specific effects. For example, radar systems usually apply oversampling to compensate for spectral effects related to the motion of the sensor.

Overlap

Overlap yields independent measurements of the same distance, which can be used to reduce noise (by averaging).

Electricity, magnetism, gravity

Electric forces are similar to gravitational forces

Faraday: there are electric and magnetic fields, extending in space, able to carry forces

Fields are created by charges and the fields cause forces on other charges:

1. **Coulomb's law:** relates electric fields to charges
2. **Ampere's law:** a moving charge (or a changing electric field) generates a magnetic field
3. **Faraday's law:** changing a magnetic field generates an electric field

Maxwell's equations

$$\nabla \cdot \mathrm{E} = 0$$

$$\nabla \cdot \mathrm{B} = 0$$

$$\nabla \times \mathrm{E} = -\frac{\partial \mathrm{B}}{\partial t}$$

$$\nabla \times \mathrm{B} = \varepsilon_0 \mu_0 \frac{\partial \mathrm{E}}{\partial t}$$

- E: electric field
- B: magnetic field
- ε_0: electric permittivity
- μ_0: magnetic permeability

Consequences from Maxwell's equations

- They describe **all** EM waves, including light
- Electric and magnetic forces are not instantaneous, but travel at a definite predicted speed
- They predict the velocity of light
- All EM waves propagate with the same velocity
- Nothing can travel faster than light

Polarization

Polarization is a property of certain types of waves that describes the orientation of their oscillations. Electromagnetic waves, such as light, and gravitational waves exhibit polarization; acoustic waves (sound waves) in a gas or liquid do not have polarization because the direction of vibration and direction of propagation are the same.

Phase velocity versus group velocity

- Phase plane perpendicular to the direction the wave is travelling
- Line of equal phase propagates with phase velocity
- Suppose series of plane waves of slightly different frequencies travel in the same direction, than
- The energy contained in the waves propagates not with the phase velocity but with the group velocity

Quantum properties of EM radiation

- For smooth waves, Maxwell's equations describe EM radiation
- For small wavelengths and certain effects in interaction with matter, these equations fail
- EM waves appear to occur in short wave trains, or bursts of radiation
- Each burst carries a radiant energy, *Q*, which is proportional to the frequency *f* (Planck's law):

$Q = h f$

- *h* is Planck's constant *(=6.626 x 10-34 Js)*

Generation of EM radiation is caused by:

Kinetic energy, chemical energy, thermal energy, electrical energy, magnetic energy or nuclear energy transformed into electromagnetic radiation.

Thermal energy ←→ kinetic energy:

Random motion of particles of matter. This results in excitation due to collisions, followed by decay. The decay causes random emission of EM waves. Random nature, so a wide spectral band.

Electrical energy:

Periodic currents of electrical charges in wires, electron tubes (microwave), or antenna surfaces. Specific nature, so small band width.

Nuclear energy:

Radioactive decay of, e.g. , uranium, potassium, thorium, causing gamma radiation. Wide spectrum of frequencies.

Planks equations – implications

- Short wave lengths contain higher energy
- Long wavelengths contain lower energy
- Are therefore more difficult to measure
- Very short wave-lengths even destroy sensors
- Only valid for pure blackbodies

Planck's equation

$$Q = h\,f \quad \left(= \frac{h\,c}{\lambda}\right)$$

where

Q radiant energy [Joules]

h Planck's constant, 6.626×10^{-34} [joule sec]

f frequency of radiation [Hz]

Result:

Increase the temperature, and you will get

1. higher emitted radiation energy
2. Peak energy shifts towards smaller wavelengths

Stefan's law:

Relation between temperature T and how much power is emitted by a black body, integrated over all wavelengths: M=σ T4 (σ is constant)

For a perfect emitter (black body): σ is (Stefan's) constant, T is temperature in K. and M is the radiant exitance; energy radiated per unit time per unit area of the surface of the body. [W /m2] (=J/s/m2).

Kirchoff's law:

Black bodies do not exist: no real body is a perfect emitter. Thus, the radiant exitance M of a real body is less or equal to the hypothetical radiant exitance Mb of a blackbody.

- The ratio M/Mb is referred to as the emissivity:
- ε = M/Mb
- The emissivity 0 ≤ ε ≤ 1 and
- Thus, the combination of Stefan's and Kirchhoff's law yields:
- M=εσ T4

At thermal equilibrium, the emissivity of a body (or surface) equals its absorptivity

The Rayleigh-Jeans approximation is an approximation of Planck's law valid for larger wave lengths.

Radiant energy: the capacity of radiation to do physical work

Radiant flux: rate at which photons strike a surface measured in watts (amount of energy delivered per unit time)

Irradiance: incoming radiant flux per unit area

Radiant exitance: the rate at which radiation is emitted from a unit area

Blackbody: hypothetical entity, absorbs all energy, reflects none, emits energy with perfect efficiency

Emissivity: the ratio of emittance of a given object and a blackbody at the same temperature

White body: reflects all energy and does not heat up

Greybody: constant emissivity

Selective radiator: wavelength dependent emissivity

Quantity	Usual symbol	Defining equation	Units
Radiant energy	Q		[J]
Radiant flux	Φ	$\Phi = \frac{dQ}{dt}$	[J s^{-1}]=[W]
Radiant flux density	E (irradiance)	$E = \frac{d\Phi}{dA}$	[W m^{-2}]
	M (radiant exitance)	$M = \frac{d\Phi}{dA}$	[W m^{-2}]
Radiant intensity	I	$I = \frac{d\Phi}{d\Omega}$	[W sr^{-1}]
Radiance	L	$L = \frac{dI}{dA \cos\theta}$	[W sr^{-1}m^{-2}]

Solid Angle [steradian]

- Solid (or Cone) angle, extension of the radian in 2D
- Unit: steradian [sr]
- Solid angle = spherical cap area A / R2
- Total surface sphere: 4πR2
- (Thus, solid angle of full sphere is 4πR2 / R2 = 4π)

Brightness temperature

A body that is emitting thermal radiation has a brightness temperature (Tb)

Definition:

Tb is temperature of equivalent black body with the same radiation

Thermal radiation

Objects absorb visible and near infrared radiation (coming from the sun) and emit this energy at longer wavelengths in the mid and far infrared regions.

Intensity of emitted thermal radiation depends on

- Object properties
- Viewing angle
- Object temperature

Complications for remote sensing:

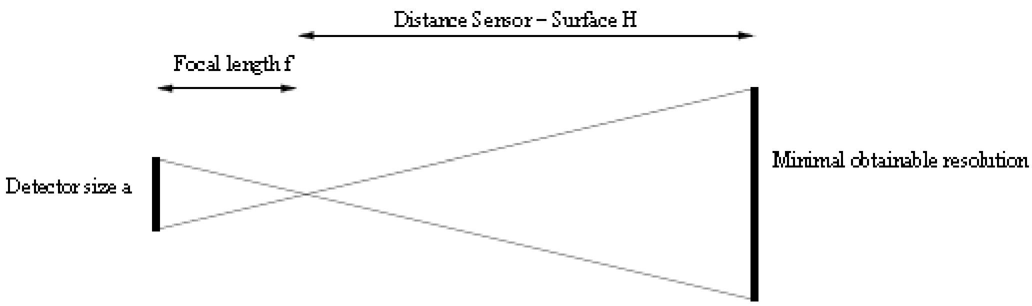
- Absorbed and emitted energy have to be distinguished from geothermal energy, fires and sources of man-made thermal energy (power stations, etc.)
- Energy absorbed and emitted by the atmosphere may change sensed temperatures by up to 15 degrees

Spatial resolution and its link with Fraunhofer diffraction

- A perfect lens will display a point source of the focal plane as a bright circular zone surrounded by concentric bright and dark rings.
- Pattern is due to diffraction and the lens is said to be diffraction limited. The image of the point source is called an Airy Disk

- Lens is source of infinite number of spherical wave fronts that constructively and destructively interfere

Calculating the resolution of an optical image system



Resolving power

Two point sources are resolved if they are separated by at least the radius of the dark ring

The Rayleigh-criterion is the limit at which two Airy-disks can be resolved into separate entities.

Diffraction is normally taken to refer to the various phenomena which occur when a wave encounters an obstacle. It is described as the apparent bending of waves around small obstacles and the spreading out of waves past small openings.

Refraction is fundamental phenomenon in the interaction of matter and radiation, along with reflection, absorption and scattering. When a ray of light traveling through a medium A of refractive index n1 arrives at a medium B (e.g. glass) of refractive index n2, it is refracted at the interface. All kinds of waves refract.

EM wave interaction with matter

Physics of the electromagnetic interaction:

- *Diffraction*
- *Transmission*
- *Refraction*
- *Absorption*
- *Reflection*
- *Scattering*
- *Emission*

8 - Laser remote sensing

LASER: light amplification by stimulated emission of radiation

- Coherent light, (often) monochromatic, polarized, strongly bundled
- Stimulated emission: process by which, when perturbed by a photon, matter may lose energy resulting in the creation of another photon with the same phase and frequency as the original

Properties in remote sensing

- active technique ("own energy")
- laser 300nm – 10µm
- often on moving platform and scanning
- observables
  - Range
  - Intensity
  - Waveform
  - Backscatter
  - Dopplershift

Air- and satellite borne laser ranging

- Determine platform position and attitude
- Measure range along profiles

Laser equation (= radar equation)

$$P_r = \frac{P_t D_r^4}{4\pi R^4 \beta_t^2} \cdot \eta_{sys} \eta_{atm} \cdot \sigma$$

where
P_r = received signal power (watt)
P_t = transmitted signal power (watt)
D_r = diameter of receiver aperture (meter)
R = range from sensor to target (meter)
β = laser beamwidth (radian)
η_{sys} = system transmission factor
η_{atm} = atmospheric transmission factor
σ = target cross section (square meters)

Backscatter

- Laser light reflected on particles in atmosphere
- Scattering inversely proportional to the 4th power of the wavelength
- Direct detection: signal strength is a measure of particle concentration

Doppler effect

If a source of electromagnetic radiation of frequency *f* is in motion with respect to an observer (sensor), the observer will (in general) detect the radiation at a different frequency *f′*

Application to Laser RS

1. emitted pulse (energy)
   - frequency *f*
   - time *t*
2. Detect returning energy frequency
   - *f′*
   - time $t+\Delta t$

Laser Scanning

- Limitation of pure ranging only profiles →fly parallel
- expensive
- different resolution along/across track
- Use a *scanner* = beam deflection device

Laser scan system

1. laser ranger on platform
2. satellite positioning system (GPS) for platform position
3. inertial measurement unit (IMU) for attitude determination (roll, pitch, yaw)
4. scanner for periodic beam deflection
5. aircraft for (linear) platform motion

Gated Viewing

Principle

1. Emit a laser flash (short pulse) frequency *f* at time *t*
2. Energy travels through atmosphere and get reflected on obstacles (trees, persons, cars, ...)
3. CCD camera placed next to flash sensitive at *f* record backscattered energy (take image) between $t+\Delta t1$ and $t+\Delta t2$

9 – Radar

A radar measures distances, optical methods measures angles

Bistatic-monostatic radar

- **Monostatic:** same antenna for transmitting and receiving
- **Bistatic:** different antennas for transmitting and receiving

Radar types

- **Continuous wave radar:** transmits and receives continuously. Usually bistatic. Velocity measurements
- **Pulse radar:** common radar type. It sends the signal in pulses. Measures range and velocities.

Sources of noise

The most important source of noise in a radar system is the one produced by the device itself, the thermal noise. It is determined by:

$$P_n = k \cdot T_{sys} \cdot B$$

- P_n : Noise power
- k : Boltzmann's constant (1.38 10-23 [J/K]
- T_{sys} : Noise temperature [K]
- B : System bandwidth [Hz]

SNR (signal to noise ratio)

- SNR is an expression of the quality of a radar measurement
- For imaging radar, SNR > 10 is required
- Determined by power of the signal divided by the power of the noise

Scattering

- Scattering is dominated by wave-length scale structures
- Wavelength shorter: image brighter
- Specular and Bragg scattering
- Speckle

Radar pixel phase is superposition of near-random scattering elements:

➔ Unpredictable!

Radar signal return depends on:

- Slope
- Roughness
- Dielectric constant

Speckle

For a single resolution cell, the coherent summation of elementary scatterers will lead to a 'speckled' signal.

Sidelooking

Used to avoid ambiguous returns at the same range.

Real aperture radar

Resolution is dependent on antenna dimension/pulse length. The beam width is the ratio of wavelength over antenna size.

Calculate Ground Resolution [example]

C-band λ= ~0.05 m
D=10 m antenna
Beam angle = 5.10-2/10 = 5.10-3 rad (0.3deg)
R=850 km
times 8.5.105 = 42.102[m] = 4.2 km

Possible problems when using

- If the distance between two scatters is shorter than the coherence length (lc) / coherence width wc, interference of the signals is possible, yielding it to be noisy.

- If the surface is rough, the power receiving pattern will change. In fact, it is a function of the variance of the roughness of the surface.

- Loss of Lock can occur. That is, the signal is bouncing back another way or too early when the return signal is not yet expected and the receiver if off.

- Use dual-frequency systems to correct for ionosphere errors.

- An application is the determination of the long term average of the mean sea level for geoid determination. This may be subject to aliasing!

Synthetic Aperture Radar

- Is a form of radar in which multiple radar images are processed to yield higher-resolution images than would be possible by conventional means.
- Resolution of SAR is inversely proportional with bandwidth.
- Azimuth resolution SAR: half antenna size! (No influence of satellite height on azimuth resolution SAR image. So it is only dependent on the antenna size!
- Range resolution improvement using chirp waveform.

Satellite Radar Altimetry

From the received waveform we can deduce

- • Two-way signal travel-time
- • Sea surface roughness

From the two-way travel-time we get the

- geometric distance (requires corrections:
- Ionospheric, tropospheric signal delay, tides,
- IB-effect)
- Sea surface roughness can be converted to wind
- speed, wave height

10 – Sound

- Sound is of high importance for remote sensing of the underwater environment. It actually is the main technique
- Reason is the low absorption coefficient and
- Due to the sound speed profile channeling occurs, thereby keeping the (geometrical) propagation loss limited (cylindrical spreading instead of spherical spreading).
- The decibel is defined as: $L = 20^{10} \log \frac{p}{p_{ref}}$

  with p the pressure due to the sound
- The speed at which sound travels is dependent on salinity, temperature and pressure in water and on temperature in air. Here also wind affects the propagation of sound.

Propagation loss

$$PL = 10\ {}^{10}\log \frac{p^2(1)}{p^2(r)}$$

Multibeam system

Pros:

- better resolution
- more measurements per ping along a swath perpendicular to the sailing direction (i.e. much better coverage)

Cons:

- more expensive

Sea floor classification: why?

- Supporting dredging operations
- Marine geology
- Marine biology (fisheries)
- Coastal engineering

Is possible because the interaction of sound with the seafloor is dependent on seafloor type. Therefore, the received signal (shape, strength) will be affected by the seafloor type. The received signals therefore contain information about seafloor type.