Remote Sensing
Principles and Applications
Part I

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ETET Department, NYCCT/CUNY
Goal for this Lecture (2-hour course)

*Introduce the field of remote sensing*
- The electromagnetic spectrum
- Active sensors versus passive sensors

*Part I*

*Introduce the fundamental of lidar remote sensing atmosphere including :*
- Lidar technique and system
- Principle (physical process)
- Typical application (observation examples)

*Part II Remote Sensing from Space*
- Design considerations
Remote Sensing as an Information Source

Remote sensing has been defined as the science (and to some extent art) of acquiring information without actually being in contact with it. Applications of remote sensing information usually fall into one of the following categories:

1. Remote sensing is used as a tool to measure properties or conditions of the land, oceans, atmosphere or objects in space.
2. Images of remotely sensed information serve as base maps on which other information is overlaid for reference and enhanced interpretation.
3. Images of remotely sensed information are used to map and quantify the spatial distribution of features.
4. Multitemporal images can be compared to quantify changes in the area and spatial distribution of features.
Remote sensing advantages over traditional data sets

- It is unobtrusive;
- One can collect information simultaneously over a broad range of the electromagnetic spectrum;
- It is capable of making biophysical measurements; information can be acquired through clouds at long wavelengths;
- Data can be collected in a very short timeframe with aircraft platforms and frequently with satellite platforms;
- Data collection procedures are systematic thereby eliminating sampling bias introduced in some investigations;
- And analysis methods are relatively robust, objective, and repeatable.

This is not to say that remotely sensed data necessarily replaces existing data sets, but in many cases it provides supplemental information that can lead to improved assessments.
Applications of Remote Sensing

- Astronomical (Hubble Telescope, Very Large Array)
- Climate Change (Environmental monitoring, see the Dept. of Environmental Conservation, NOAA, Environmental Protection Agency, Dept of Energy, etc)
- Medical (Xray, Ultrasounds, etc)
- Military (surveillance and target detection, see Dept. of Defense, NASA)
- Communication systems (free space optical communications, wireless)
- Geoscience (natural hazards, earthquake and volcano monitoring etc)
- Transportation systems (GIS and aerial photography)
- Archeology (satellite images and aerial photography)
- And many more
# Electromagnetic Spectrum availability for Remote Sensing on Earth

<table>
<thead>
<tr>
<th>Region Name</th>
<th>Wavelength</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gamma Ray</td>
<td>&lt;0.03 nanometers</td>
<td>Entirely absorbed by the Earth's atmosphere and not available for remote sensing.</td>
</tr>
<tr>
<td>X-ray</td>
<td>0.03 to 30 nanometers</td>
<td>Entirely absorbed by the Earth's atmosphere and not available for remote sensing.</td>
</tr>
<tr>
<td>Ultraviolet</td>
<td>0.03 to 0.4 micrometers</td>
<td>Wavelengths from 0.03 to 0.3 micrometers absorbed by ozone in the Earth's atmosphere.</td>
</tr>
<tr>
<td>Photographic Ultraviolet</td>
<td>0.3 to 0.4 micrometers</td>
<td>Available for remote sensing the Earth. Can be imaged with cameras and sensors.</td>
</tr>
<tr>
<td>Visible</td>
<td>0.4 to 0.7 micrometers</td>
<td>Available for remote sensing the Earth. Can be imaged with cameras and sensors.</td>
</tr>
<tr>
<td>Near and Mid Infrared</td>
<td>0.7 to 3.0 micrometers</td>
<td>Available for remote sensing the Earth. Can be imaged with cameras and sensors.</td>
</tr>
<tr>
<td>Thermal Infrared</td>
<td>&lt;0.7 to 3.0 micrometers (and other windows available in LWIR)</td>
<td>Available for remote sensing the Earth. This wavelength cannot be captured by film cameras. Sensors are used to image this wavelength band</td>
</tr>
<tr>
<td>Micowave or Radar</td>
<td>0.1 to 100 centimeters</td>
<td>Longer wavelengths of this band can pass through clouds, fog, and rain. Images using this band can be made with sensors that actively emit microwaves.</td>
</tr>
<tr>
<td>Radio</td>
<td>&gt;100 centimeters</td>
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Passive Sensors
Passive sensors include different types of radiometers and spectrometers. Most passive systems used in remote sensing applications operate in the visible, infrared, thermal infrared, and microwave portions of the electromagnetic spectrum. Examples of Passive remote sensors are:

- **Accelerometer**—An instrument that measures acceleration (change in velocity per unit time). There are two general types of accelerometers. One measures translational accelerations (changes in linear motions in one or more dimensions), and the other measures angular accelerations (changes in rotation rate per unit time). Translational accelerations are proportional to the sum of the forces acting through the center of mass of the instrument, and rotational accelerations are proportional to the total torque acting to change the rotation of the instrument around its center of mass.

- **Radiometer**—An instrument that quantitatively measures the intensity of electromagnetic radiation in some bands within the spectrum. Usually, a radiometer is further identified by the portion of the spectrum it covers; for example, visible, infrared, or microwave. Microwave sensors are able to penetrate clouds and most rain, making them all-weather sensors.

- **Imaging radiometer**—A radiometer that has a scanning capability to provide a two-dimensional array of pixels from which an image may be produced. Scanning can be performed mechanically or electronically by using an array of detectors.

- **Spectrometer**—A device that is designed to detect, measure, and analyze the spectral content of incident electromagnetic radiation. Conventional imaging spectrometers use gratings or prisms to disperse the radiation for spectral discrimination.

- **Spectroradiometer**—A radiometer that measures the intensity of radiation in multiple wavelength bands (i.e., multispectral). Many times the bands are of high-spectral resolution, designed for remotely sensing specific parameters such as sea surface temperature, cloud characteristics, ocean color, vegetation, and trace chemical species in the atmosphere and in snow and sea ice data.

- **Hyperspectral radiometer**—An advanced multispectral sensor that detects hundreds of very narrow spectral bands throughout the visible, near-infrared, and mid-infrared portions of the electromagnetic spectrum. This sensor's very high-spectral resolution facilitates fine discrimination between different targets based on their spectral response in each of the narrow bands.

- **Sounder**—An instrument that measures vertical distributions of atmospheric parameters such as temperature, pressure, and composition from multispectral information.
• Active Sensors

The majority of active systems operate in the microwave portion of the electromagnetic spectrum, which makes them able to penetrate the atmosphere under most conditions. Examples of Active remote sensors are:

**Ranging Instrument**—A device that measures the distance between the instrument and a target object. Radars and altimeters work by determining the time a transmitted pulse (microwaves or light) takes to reflect from a target and return to the instrument. Another technique employs identical microwave instruments on a pair of platforms. Signals are transmitted from each instrument to the other, with the distance between the two determined for the differences between the received signal phase and transmitted (reference) phase. These are examples of active techniques. A passive technique views the target from either end of a baseline of known length. The change in apparent view direction (parallax) is related to the absolute distance between the instrument and target.

**Radar**—An active radio detection and ranging sensor that provides its own source of electromagnetic energy. An active radar sensor, whether airborne or space borne, emits microwave radiation in a series of pulses from an antenna. When the energy reaches the target, some of the energy is reflected back toward the sensor. This backscattered microwave radiation is detected, measured, and timed. The time required for the energy to travel to the target and return back to the sensor determines the distance or range to the target. By recording the range and magnitude of the energy reflected from all targets as the system passes by, a two-dimensional image of the surface can be produced. Because radar provides its own energy source, images can be acquired day or night. Also, microwave energy is able to penetrate clouds and most rain, making it an all-weather sensor.

**Scatterometer**—A high-frequency microwave radar designed specifically to measure backscattered radiation. Over ocean surfaces, measurements of backscattered radiation in the microwave spectral region can be used to derive maps of surface wind speed and direction.

**Lidar**—A light detection and ranging sensor that uses a laser (light amplification by stimulated emission of radiation) to transmit a light pulse and a receiver with sensitive detectors to measure the backscattered or reflected light. Distance to the object is determined by recording the time between transmitted and backscattered pulses and by using the speed of light to calculate the distance traveled. Lidars can determine atmospheric profiles of aerosols, clouds, and other constituents of the atmosphere.

**Laser altimeter**—An instrument that uses a lidar to measure the height of the platform (spacecraft or aircraft) above the surface. The height of the platform with respect to the mean Earth's surface is used to determine the topography of the underlying surface.

**Sounder**—An instrument that measures vertical distribution of precipitation and other atmospheric characteristics such as temperature, humidity, and cloud composition.
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Part I Outline

1. What is the lidar?
2. Lidar system and how it works
3. Principle of lidar remote sensing atmosphere (physical process)
4. Basic lidar returns equation
5. What can lidar measure in atmosphere?
6. Summary

*We only focus on atmospheric monitoring lidar.*
1. What is the lidar?

- **LIDAR: Light Detection And Ranging, or laser radar**
  An optical remote sensing technology that measures properties of scattered light to find range and/or other information of a distant target. It uses the same principle as RADAR except that it uses a laser instead of radio waves.

- **Lidar VS. Radar** *(different transmitting wavelength)*
  Radar: microwaves, wavelength: 0.3-10 cm, detect big particles and target (> 0.1 mm) such as rain and clouds droplet
  Lidar: shorter wavelength: 0.25-1μm, detect small particles such as aerosol and molecule

- **Active VS. Passive**
  Active: instruments generate their own illumination/radiation source. such as RADAR, LIDAR, SODAR
  Passive: The source of energy is the environment: naturally occurring radiation from the sun and the Earth, such as radiometer or sun-photometer
Passive remote sensing: Sun-photometer

Measure the whole column information of atmosphere (aerosol and water vapor)

Light source: Sun

No range-resolved information

No work in the night and overcast sky
A simple schematic diagram for LIDAR

The lidar's transmitter is a laser, while its receiver is an optical telescope.
Advantage of lidar remote sensing

- Active remote sensing
- Range-resolved information
- Highly temporal and spatial resolution

The term ‘aerosol in the atmosphere’,
A suspension of small particles in a gas.
The particles may be solid or liquid or a mixture of both.
How it works

**LIDAR: Light Detection And Ranging**

- Send light to the atmosphere
- Record light scattered by the atmosphere as function of time
- Convert time of flight to distance (1 ms ~ 150 km)

\[ R = c \Delta t / 2, \]

C: light speed, \(3 \times 10^8\) m/s
Active Remote Sensing

Interaction between radiation and objects

Step-1
Radiation Propagation Through Medium

Step-2
Signal Propagation Through Medium

Step-3
Transmitter (Radiation Source) → Receiver (Detector)

Step-4
System Control & Data Acquisition → Data Analysis & Interpretation

10/3/2013
Viviana Vladutescu, Ph.D., Assistant Prof. of Electrical Engineering
CEU meeting of IEEE Consultants Network of Long Island (LICN)
HOW IT WORKS:

1. Laser transmits beams to atmosphere
   A Photo-diode detects the start-time when laser beams go out, then make the trigger pulses to detector, data acquisition system
   Time-range relationship: \( Z = \frac{C \cdot t}{2} \),
   \( C \) is light speed, \( 3.0 \times 10^8 \) m/s
   \( t = 1 \) \( \mu \)s, \( Z = 150 \) m; \( t = 1 \) ms, \( Z = 150 \) km

2. Receiver telescope collects the atmospheric return signals, separate the different wavelength optical signals by delay-optics send them to detectors

3. Data acquisition samples the electrical signals from detectors output, then store data in computer
   Range resolution VS sampling rate: \( \Delta Z = C \cdot \frac{\Delta t}{2} \),
   10MHz---\( 10^{-7} \) sec=100 ns=0.1 \( \mu \)s; 10MHz----- 15 meter
   40MHz---3.75 meter

4. Analyze data for atmospheric research
2. Lidar system and main components

- **Laser transmitter: laser and steering mirrors**
  (Wavelength, pulse energy, repetition rate, divergence angle, pulse-width etc)

- **Optical receiver: telescope and delay-optics**
  (Newtonian/Cassegrain, diameter, Field-of-View)
  (narrowband filter, beam-splitter, collimator lens)

- **Signal detection**
  Detector PMT or APD (Avalanche photodiode) and pre-amplifier
  (spectral sensitivity, quantum efficiency, gain, dark-current)

- **Data acquisition and control**
  A/DC: Analogue to digital converter (8~32-bits, sampling rate)
  Photon-counter (count rate, dead time)
  Control: scanner, synchronizer and computer
Key component: Laser (light source) --- 1

- **Acronym** for *Light Amplification by Stimulated Emission of Radiation*
- Narrow, low-divergence monochromatic beam with a well-defined wavelength, high power/energy
- **Main specifications:**
  - wavelength, UV, visible, infrared
  - power, $\mu$J~J (joule) (issue: eye-safe)
  - repetition rate (1~KHz)
  - pulse width: ns
  - divergence angle: mrad
Fig. Powerlite Nd:YAG
Key component: Interference filter (suppress sky-light noise)

Main specifications:

• Center wavelength:
• Bandwidth (1.0~0.2 nm)
• Peak transmittance %: >30%
• Block ratio: 1e-7
Figure- Lidar system prototype
Figure- Micropulse lidar (commercial product)

1. ND:YLF Laser (523.5-nm) semiconductor laser,
   **Output Energy 10 µJ**
   **Pulse Repetition Frequency** 2500 Hz

2. **Transceiver:** diameter 20 cm
   **Beam Divergence** 50 µrad
   **Field-of-View** 100 µrad

3. Detector: Si:APD

4. Data acquisition:
   photon-counter
   **Vertical Resolution** 30 m - 300 m

5. Detection objective:
   aerosol, cloud and PBL

6. Working mode: 24-hr/7
   No operator

http://www.sigmaspace.com/sigma/micropulseLidar.php
Figure- Satellite-borne lidar CALIPSO
(launched in April 2006 by NASA to be part of the A-Train constellation at an altitude of 690 km).

Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO)

http://www-calipso.larc.nasa.gov/
3. Principle of lidar remote sensing atmosphere

Physical process of laser and atmosphere

• Elastic-scattering of molecule and particle (Rayleigh-Mie scattering)

• Raman-scattering (Water vapor, CH$_4$, N$_2$, O$_2$)

• Absorption of trace gas (Ozone, SO$_2$, NO$_2$ etc.)

• Fluorescent scattering (Na$^+$, Ca$^+$)

• Doppler shift
Lidar Interaction Elastic-scattering Mechanisms

- **Rayleigh Scattering** relevant for molecular gases including $N_2, O_2$ where $d\ll\lambda$
  - “Laser radiation elastically scattered from atoms or molecules is observed with no change of frequency”

- **Mie Scattering** for particulates (spherical) where $d\sim\lambda$
  - “Laser radiation elastically scattered from small particulates or aerosols (of size comparable to wavelength of radiation) is observed with no change in frequency”

**No wavelength Change in either mechanism**
Lidar Interaction **Inelastic-scattering Mechanisms**

- **Raman Scattering**
  
  “Laser radiation inelastically scattered from molecules is observed with a frequency shift characteristic of the molecule ($h\nu - h\nu^r = E$)”

Raman Transition radiation generated at longer wavelength from excitation

\[
\nu^r < \nu \quad \rightarrow \quad \lambda^r > \lambda
\]

\(\lambda = 355\) excitation

\[
\lambda_R^{N_2} = 387, \quad \lambda_R^{H_2O} = 407,
\]
Physical process between laser-beam and atmospheric medium

(\(\lambda_i\) incident laser wavelength (WL), \(\lambda_r\) receiving wavelength)

<table>
<thead>
<tr>
<th>Physical-process</th>
<th>Medium</th>
<th>WL</th>
<th>Cross-section (cm(^2))</th>
<th>Detection objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rayleigh-scat</td>
<td>molecule</td>
<td>(\lambda_i = \lambda_r)</td>
<td>(10^{-27})</td>
<td>Air density, temperature</td>
</tr>
<tr>
<td>Mie-</td>
<td>aerosol</td>
<td>(\lambda_i = \lambda_r)</td>
<td>(10^{-8} \sim 10^{-27})</td>
<td>Aerosol, cloud</td>
</tr>
<tr>
<td>Raman-</td>
<td>molecule</td>
<td>(\lambda_i \neq \lambda_r)</td>
<td>(10^{-30})</td>
<td>Trace-gas (H(_2)O, SO(_2), CH(_4))</td>
</tr>
<tr>
<td>Resonance-</td>
<td>atom &amp; mol</td>
<td>(\lambda_i = \lambda_r)</td>
<td>(10^{-14} \sim 10^{-23})</td>
<td>Metal atom and iron, Na(^+), K(^+), Ca(^+), Li</td>
</tr>
<tr>
<td>Fluorescence</td>
<td>molecule</td>
<td>(\lambda_i \neq \lambda_r)</td>
<td>(10^{-16} \sim 10^{-25})</td>
<td>Trace-gas (O(_3), SO(_2), NO(_2) etc)</td>
</tr>
<tr>
<td>Absorption</td>
<td>atom &amp; mol</td>
<td>(\lambda_i = \lambda_r)</td>
<td>(10^{-14} \sim 10^{-21})</td>
<td>Trace-gas (O(_3), SO(_2), NO(_2) etc)</td>
</tr>
<tr>
<td>Doppler-shift</td>
<td>atom &amp; mol</td>
<td>(\lambda_i \neq \lambda_r)</td>
<td></td>
<td>Wind-speed, direction</td>
</tr>
</tbody>
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10/3/2013

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Common types of Lidar & their application

1. **Mie-scattering lidar**: aerosol, clouds

2. **Raman-Lidar**: Vibrational and rotation-Raman lidar
   Aerosol, Cloud, Water vapor, Ozone, CH$_4$ and temperature

3. **DIAL(DIAL)**: trace-gas, Ozone, Water vapor, SO$_2$, NO$_2$, etc

4. **High-Spectral Resolution Lidar (HSRL)**: Separate molecular and aerosol scattering, aerosol & cloud

5. **Rayleigh-Lidar**: stratosphere-mesosphere temperature

6. **Resonance-fluorescence lidar**: metal atom Na, Fe, Ca

7. **Doppler-Lidar**: wind field
4. Elastic-scattering lidar returns equation

The reflected power from the atmosphere, \( P_r \), as a function of range, \( R \) and wavelength \( \lambda \), \( C \) (Callibration Constant:Includes Detector Area and Efficiencies, Field of View of Telescope etc.)

- \( \alpha_T = \alpha_M + \alpha_A \) : total atmospheric (molecular + aerosol) extinction including Absorption + Scattering coefficient (m\(^{-1}\)) (it is a function of object scattering or absorption properties and concentration)
- \( P_0 = \) transmitted peak power (W).
- \( \beta_T = \beta_M + \beta_A \) : Total Backscatter (m\(^{-1}\) sr\(^{-1}\))

\[
P_1(R) = P_0 e^{-\int_0^R [\alpha_T(r)] dr} \]

Atmospheric Extinction takes Energy out of the beam in both directions

\[
P_r(R, \lambda) = \frac{C P_0(\lambda) \beta_T(R, \lambda)}{R^2} e^{-2 \int_0^R [\alpha_T(R, \lambda)] dr} \]

Standard Lidar Equation

\[
d\Omega = \frac{A}{R^2} \]

\[
P_2 = (\beta_T(R) d\Omega) P_1 \]
1. Lidar returns (basic lidar equation, single scattering)

\[ P(\lambda, z) = EC \left[ \beta_m(\lambda, z) + \beta_p(\lambda, z) \right] T_m^2(\lambda, z) T_p^2(\lambda, z) / z^2 + P_{\text{noise}} \]

- \( P(\lambda, z) \): Lidar return signals intensity.
- \( E \): Laser pulse energy
- \( C \): System constant

\[ C(\lambda) = \eta_{\text{trans,opt}}(\lambda) \times A(\lambda) \times \eta_{\text{rec.opt}}(\lambda) \times \eta_{\text{electron}}(\lambda) \]

- \( \beta_{m,p} \): backscatter coefficient, \( m \)-molecule, \( p \)-particle or aerosol

- \( T^2_{m,p} \): two-way transmittance

\[ T^2_{m,p}(\lambda, z) = \exp(-2 \int \alpha_{m,p}(\lambda, z)dz) \]

Two unknown parameters: backscatter and transmittance (extinction)

- \( P_{\text{noise}} \): background and detector noise

\[ P_{\text{noise}} = P_{\text{sky}} + P_{\text{d-dark}} + P_{\text{d-thermo}} \]

Main factors to influence Signal-to-Noise Ratio (SNR):
Laser energy, telescope effective area, optical -electron efficiency, species contents
Each physical item in Lidar equation

\[ N_L(\lambda_L) \]

\[ T(\lambda_L, R) \]

\[ B(\lambda, \lambda_L, \theta, R) \]

Interaction between radiation and objects

Radiation Propagation Through Medium

\[ T(\lambda, R) \]

Signal Propagation Through Medium

\[ \eta(\lambda, \lambda_L)G(R) \]
N2-Raman (inelastic)-scattering lidar equation

\[ P(\lambda_n, z) = EC \beta_n(\lambda_n, z) T_m(\lambda_0, \lambda_n, z) T_P(\lambda_0, \lambda_n, z) / z^2 + P_{\text{noise}} \]

\( \beta_n \): N2-Raman backscatter coefficient, no aerosol

\( T_{m,p} \): One-way transmittance from both molecule and aerosol

Advantage:
Only extinction coefficient is unknown, easy solution

Disadvantage: weak signals
5. What can lidar measure?

Application in atmospheric remote sensing: observation examples

- Aerosol-cloud (particle) detection
- Planetary Boundary Layer detection
- Water vapor distribution
- Meteorological visibility
- Ozone and SO$_2$ detection
- Temperature profiles
Air pollutants affect climate by absorbing or scattering radiation.

Greenhouse gases absorb infrared radiation.

Aerosols interact with sunlight, "direct" + "indirect" effects composition matters!

- Smaller droplet size → clouds last longer → less precipitation
- More cloud droplets

Black carbon (soot)

Sulfates

Black carbon (soot) is an atmospheric cleanser.

Pollutant sources

Surface of the Earth
Radiative forcing of climate (1750 to present): Important contributions from air pollutants

<table>
<thead>
<tr>
<th>RF Terms</th>
<th>RF values (W m⁻²)</th>
<th>Spatial scale</th>
<th>LOSU</th>
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<tbody>
<tr>
<td><strong>Long-lived greenhouse gases</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>CO₂</strong></td>
<td>1.66 [1.49 to 1.83]</td>
<td>Global</td>
<td>High</td>
</tr>
<tr>
<td><strong>N₂O</strong></td>
<td>0.48 [0.43 to 0.53]</td>
<td>Global</td>
<td>High</td>
</tr>
<tr>
<td><strong>CH₄</strong></td>
<td>0.16 [0.14 to 0.18]</td>
<td>Global</td>
<td>High</td>
</tr>
<tr>
<td><strong>Halocarbons</strong></td>
<td>0.34 [0.31 to 0.37]</td>
<td>Global</td>
<td>High</td>
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<tr>
<td><strong>Ozone</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Stratospheric</strong></td>
<td>-0.05 [-0.15 to 0.05]</td>
<td>Continental</td>
<td>Med</td>
</tr>
<tr>
<td><strong>Tropospheric</strong></td>
<td>0.35 [0.25 to 0.65]</td>
<td>Continental</td>
<td>Med</td>
</tr>
<tr>
<td><strong>Stratospheric water vapour from CH₄</strong></td>
<td>0.07 [0.02 to 0.12]</td>
<td>Global</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Surface albedo</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Land use</strong></td>
<td>-0.2 [-0.4 to 0.0]</td>
<td>Local to</td>
<td>Med - Low</td>
</tr>
<tr>
<td><strong>Black carbon on snow</strong></td>
<td>0.1 [0.0 to 0.2]</td>
<td>continental</td>
<td>Low</td>
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<tr>
<td><strong>Total Aerosol</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Direct effect</strong></td>
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<td></td>
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</tr>
<tr>
<td><strong>Cloud albedo effect</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total net anthropogenic</strong></td>
<td>1.6 [0.6 to 2.4]</td>
<td>Global</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Natural</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Solar irradiance</strong></td>
<td>0.12 [0.06 to 0.30]</td>
<td>Global</td>
<td>Low</td>
</tr>
</tbody>
</table>

IPCC, 2007
Aerosol effects on Health

• Aerosols have been also linked to both cardiovascular and respiratory illness
  – PM2.5 (particulate matter less than 2.5 um diameter) is particularly a problem requiring Environmental Protection Agency health Standards to be set
  – New York City Metropolitan area has the largest frequency of problematic air-quality episodes and it is therefore extremely important to monitor, determine sources and predict air-quality
Figure- CCNY multiwavelength elastic-inelastic lidar

1. ND:YAG Laser (1064-532-355nm)
2. Telescope: diameter 500-mm
3. Detector: PMTs and Si-APD
4. Data acquisition: 12-bit ADC and Photon-counting
5. Detection range and objective: ~10 km altitude, aerosol, cloud, water vapor, PBL
6. Working mode: Only vertical pointing in the lab. Ancillary Radar for airplane (not eye-safe)
L = Lens – focus light
IF = Interference Filter – select the wavelength
NDF = Nurture Density Filter – attenuate the signal

Figure: A schematic of the optical receiver
Some typical observation examples
1-min average Lidar signals profiles
Case- Date=2006-08-23

- Raman signals (black & blue) are much smaller than elastic signals
- No strong cloud returns in Raman-channel
- Consistent H2O profile with radiosonde observation

![Graphs showing Lidar and H2O mixing ratio over altitude](image-url)
5.1 PBL variation (planetary boundary layer) or known as the atmospheric boundary layer (ABL), is the lowest part of the atmosphere and its behavior is directly influenced by its contact with a planetary surface. (Roles in air pollution, moisture and weather process etc.)

Stable PBL

Large variation with time (atmospheric process change)
5.2 Aerosol-plume

Asian dust or smoke-plume
Important to Air pollution & Climate Radiative Change

Cloud

Dust plume

PBL

enter PBL
5.3 Cloud-aerosol

Aerosol-cloud interaction at same level

2007 Apr 11 Logarithm of Range corrected Power (1064nm)

- Cloud
- Aerosol
- Thin Cloud
- EDT time [hr]
  No information due to cloud attenuation
- Before rain
CALIPSO- Spaceborne lidar (Mie-scattering+polarization lidar):

- Global-scale **vertical distribution** of aerosol and clouds
- **Aerosol types**: 2-wavelength channel
- **Cloud-phase**: water or ice clouds

http://www-calipso.larc.nasa.gov/products/
Passive Satellite remote sensing Aerosol

Column aerosol only
No altitude-information
No retrievals in cloudy-region
Influence by surface influence