Geography 403
Lecture 7
Scanners, Thermal, and Microwave

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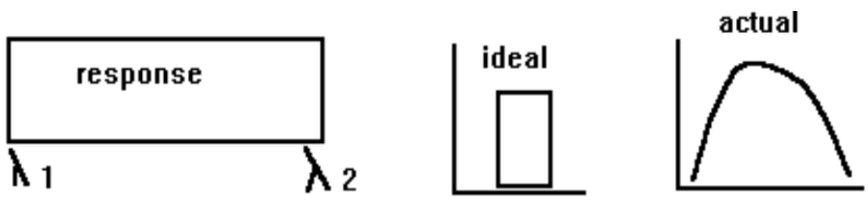
Key Terms and Concepts
Basics of Passive Electric Sensors (esp. quantum sensor types)
Features of Electric Sensors (Instantaneous Field of View, Response Time)
Scanners (Electric-Optical, Optical-Mechanical, "Pushbroom", "Area")
Thermal Remote Sensing (components, imagery interpretation, issues)
Active Microwave/Radar (Basic Characteristics, Return Factors, SLAR System)
Passive Microwave Radiation and Imaging Systems
LIDAR



A. Basics of Passive Electric Sensors
PP1 1. Sensors absorb EMR and produce some sort of response, such as voltages differences which generate electric current
   a. Photos produce chemical reaction in film emulsion
2. Sensors allow us to work with EMR outside the range that film can record
PP2 3. "Ideal sensor"
   a. Response should be uniform over entire band, with no response outside band, but this is never achieved
   b. Need to compare sensor response to original EMR spectrum over a discrete band where:
      Sensor Signal $\Delta\lambda$ = response constant $\Delta\lambda$ * EMR Intensity $\Delta\lambda$
   c. Electric sensors have relatively even response curves, while film emulsions are rarely uniform
4. Quantum type electric sensors--photon hits detector and produces changes in the electric qualities of the material
   a. Photemissive--causes detection material to emit photons which can be measured (not effective at λs higher than NIR)...too few photons produced--LANDSAT RBV a variation of this type of sensor)
   b. Photoconductors (semiconductors)--EMR modifies electrical resistance of detector so a current is generated (e.g. solar cell), different substances used in different bands, some new sensors effective to very long λs
   c. Problems--must be kept cool, or else they produce electric signals internally, also usually need filter to limit spectral range
5. Thermal Sensor (thermopile) measures EMR indirectly by heating that is caused by absorption--need to know band response to calibrate

a. Not very spectrally selective--use filters
b. Must "subtract out" EMR from instrument and solar if working in the FIR (thermal bands)--can be a big source of error

B. Other features of electric sensors

PP3 1. Instantaneous field of view (IFOV), D = Hβ (in radians)
a. Extended sources (larger than IFOV, separately detected)
b. Point sources (smaller than IFOV, merge with background)
c. Wide IFOV (low resolution, used for hemispheric energy)
d. Narrow IFOV (higher resolution, but less energy)

PP4 original LANDSAT (β = 9 x 10^{-5} radians)
at 915 km, D = 79 m

2. Response time
a. Photo emitter and photo conductor (1 x 10^{-9} s)
b. Thermopile SLOW 1-3 s

C. Scanners--way to generate images in parts of the spectrum not sensitive to film emulsions

PP5 1. Electric Optical (E-O) type, really electric camera, as it converts radiation image into electric signal, which can be stored
a. Plate, which becomes charged when light, is absorbed, resulting in an electric "picture"
b. RBV systems shoot electrons at the plate, and scan across, measuring the response, which can be stored on tape or viewed on a TV screen
c. Pictures can be transmitted back to earth
d. Limitation--uses lens, only works in UV, VIS, and NIR

PP6-7 2. Optical Mechanical (O-M) type sense target in scan lines, sensor moves back and forth, platform moves forward between scan lines ("whiskbroom")
a. Movement of scanner produces some distortions

3. "Pushbroom" scanners (newer, aboard SPOT & IKONOS) platform moves as in O-M, but now have a line of charge-coupled devices to image entire scan line at once
a. Advantage--no moving parts
b. Disadvantage--calibration of a larger number of detectors, no longer a problem

4. Newest "Area" devices can operate like E-O and record images of an entire scene all at once

D. Thermal Remote Sensing

PP8-9 1. Thermal radiometer components
a. Collecting optics
b. Filter
c. Detector
d. "chopper"--calibration

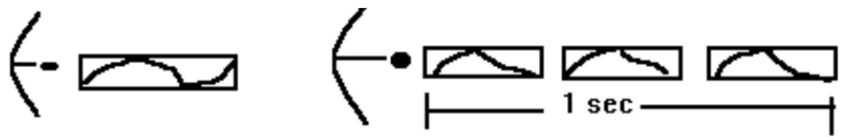
2. Thermal scanners--imaging devices (O-M or "whiskbroom")

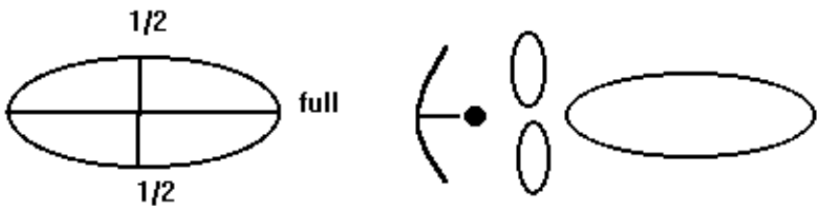
a. contain a rotating "mirror" assembly that moves the IFOV along scan lines that run perpendicular to the flight line

3. Newest Thermal Scanners–linear “pushbrooms”
   a. Eliminates much of the geometric distortion of “whiskbrooms”
4. Image interpretation (almost always using emitted energy)
   a. IR divided into:
      i. Near .7-1.5μm (reflected IR, can record on film)
      ii. Mid 1.5-5.5μm (scanners, both reflected and EMITTED)
      iii. Far 5.5-1000μm (region of earth's emission)
   b. Imagery and energy exchange theory
      i. A black body curve would be produced by a perfect emitter
      ii. With internal calibration, can produce "brightness" temperatures
      iii. $E = \varepsilon\sigma T^4$ so emissivity affects apparent temperatures
5. Atmospheric effects
   a. Gases in the atmosphere absorb and emit energy in narrow bands of λs determined by molecular structure--combined effect produces "windows", i.e., we cannot use entire spectrum for R.S.
   b. Solar window (allows UV, VIS, and NIR in)
   c. Terrestrial window (around 10.5-12.5μm) allows earth emitted energy out
   d. Possible geographic variations due to water vapor and suspended material in column of air
   e. Usual method of correcting is to use some kind of "ground truth", but this is difficult, can also compare same object with several different passes of the plane (if a plane) at different heights
   f. Viewing angle is also important, as ε usually decreases as viewing angle decreases
6. Distortion--fairly high due to system factors
   a. Scale changes away from nadir along scan lines
   b. Several other causes of distortion or signal loss
7. Environmental factors
   a. Clouds or rain can obscure surface
   b. Winds can produce "smears"
   c. Small objects below system resolution can produce "hot spots"

PP10-15 d. IMPORTANT--time of day and season is critical for interpretation

   e. Nighttime TIR is probably superior to daytime for contrast
8. Example applications (interpretation difficult without ground truth)
   a. Relative ice thickness
   b. Soil surface temperature (air temperature more difficult)
   c. Thermal pollution monitoring
   d. Residential thermal energy surveys--building heat loss
   e. Distinguish rock types by heat holding characteristics
   f. Urban heat island studies





E. Microwave-RADAR interactions in the atmosphere

PP16 1. Two major systems
- a. Passive Microwave--earth emitted
- b. RADAR--active, send and then "listen"
- c. Both subject to some similar limitations

PP17 2. Characteristics and Terms
- a. 1-25 cm λ common
- b. Pulse--packet of EMR (1μs)
- c. Pulse repetition frequency PRF (1000/s)
- d. Beam width (angular distance between ½ power points)
- e. Power pattern (main and side lobes)

PP18
- f. Radar Equation $Pr \approx Pt\ Ga\ R\ \sigma$
  - where:
    - Pr = power returned
    - Pt = power transmitted
    - Ga = gain or amplification factor of antenna
    - R = distance to target
    - σ = scattering characteristics of target
- g. Return is determined by a number of characteristics of the target and the radar system

PP19 3. Return factors
- a. Geometry--shape of material (snow vs. rain)
- b. Type of scattering (volume or surface)
- c. Polarization (HH VV HV VH)
- d. Dielectric constant ($\approx$ water content of target) reason microwave oven works
- e. Viewing angle--changes what radar "sees", i.e. top as opposed to sides of trees
- f. Resolution--half power angular width determines this
- g. Wavelength--longer the λ the farther below the surface it will view

4. Example radar returns from different surfaces
    a. Water--mostly specular, roughness can change
    b. Land--penetrates below highest level (e.g., vegetation) so both surface and volume scattering present in return
    c. Soil--highly moisture dependent, and some other props.
    d. Snow--air-water mixture, depends on age, etc.
    e. Plants--more sensitive to leaves than stalks, time of year important as it determines volume scattering (how many leaves present, etc.)

F. Radar Systems

PP20 1. Resolution--smallest object resolved is related to beam width
    a. Beam width is inversely prop. to number of λs across antenna
    b. For conventional systems need to either decrease λ or increase antenna size for improved resolution
    c. There are synthetic aperture processing techniques that can get around this for imaging systems

2. Basic forms and applications
    a. Range discrimination--a function of pulse length, time to return give distance
    b. Speed measurement--Doppler principle, produces change of phase in return signal
    c. Imaging systems

PP21 3. SLAR Systems (contrast **real** and **synthetic** apertures) displays radar "backscatter" of the earth's surface as a strip "map"

PP22 a. A scanning system, displayed in either slant range or (more useful) ground range

b. "Look direction"-direction that radar is sending out energy toward

PP23 c. Range resolution ("look" direction, at 90° to aircraft flight line) size decreases with distance away from aircraft (near range resolution not as good as far range resolution, see pages 301-304 in Jensen)

PP24 d. Azimuth resolution (along the direction of aircraft flight line) size increases with distance from aircraft (better in near range and worse in far range)

e. Image must be rectified to produce "vertical" view from side imaged information

f. Dual systems can produce information for terrain contour mapping, due to knowledge of time traveled by EMR

g. SLARs taken at two different altitudes can be used to produce stereo views

h. Geometric distortions
    i. Radar relief displacement–unlike vertical air photos, it is TOWARD the sensor, because the higher the object the closer it is to the sensor–called "foreshortening or layover"
    ii. shadows–help or hinder as in air photos
    iii. "speckle"–random constructive and destructive interference in the coherent radar beam

G. Passive Microwave Radiation

PP25 1. Similar to TIR, observations in the 1-30 cm λ range

2. Can approximate energy produced in this band with the Rayleigh-Jeans formula

Brightness (Blackbody in W/m^2) = $2\ k\ T / \lambda^2$

where:

$k = 1.38 \times 10^{-23}$ j/°K (Boltzman constant)

λ = wavelength in m

T = temp. in °K

3. Radiometric or "brightness" temperature will be related to:
   a. Brightness of total scene (how warm is everything viewed)
   b. Atmospheric loss
   c. Scattered energy to sensor
   d. Emitted energy by the atmosphere reaching sensor
   e. Desired emitted energy by target

H. Passive Microwave Systems (relatively new and developing area)

PP26 1. Antenna patterns determine resolution as in radar

2. Many sources of "noise" from space, and even the antenna itself
3. About 10% of an average signal will be emission by atmosphere, and must also consider atmospheric attenuation
4. Emissivity varies more than in TIR
5. Atmosphere more transparent than in TIR
6. Little energy available, so need large "pixels", hence poorer resolution
7. Applications in oceanography, related to sea surface physical and chemical conditions; meteorology (tropical rainfall), wind speeds from sea surface state; hydrology, snowpack and soil moisture assessment

I. LIDAR (Light Detection and Ranging, with lasers, a relatively new technology)

PP27 1. A scanning mirror directs pulses of laser light across-track perpendicular to the flight line

2. LIDAR is based on the accurate measurement of the laser pulse travel time from the transmitter to the target and back to the receiver.
3. Processing is complex: need to know x,y,z location; attitude (roll, pitch, and heading); scan angle; atmospheric refraction effects on the speed of light; and pulse travel time.
4. Multiple returns from the same laser pulse can allow determination of canopy heights as well as ground elevation (digital elevation models).
5. LIDAR-derived vertical accuracies are usually in the range of 5 to 30 cm.