Satellite sensor radiometric calibration

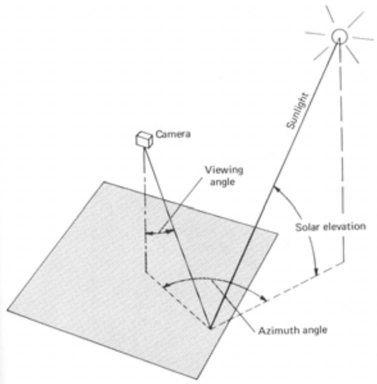


Figure 2.8 Sun–object–image angular relationship.

Background

- Working Group on Calibration & Validation (WGCV) – International Committee on Earth Observation Satellites (CEOS)
- *Remote sensing calibration* – process of quantitatively defining the system response to known controlled signal inputs

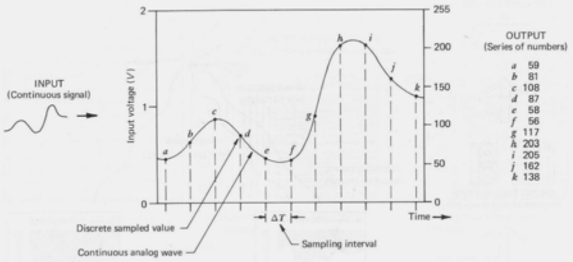


Figure 1.13 Analog-to-digital conversion process.

(Lillesand & Kiefer, 2000)

Fundamental aspects to be calibrated

- Sensor system's response to EMR as a function of:
  - Wavelength and/or spectral band (spectral response)
  - Intensity of input signals (radiometric response)
  - Different locations across the IFOV and/or the overall scene (spatial response, uniformity)
  - Different integration times & lens or aperture settings
  - Unwanted signals – stray light & leakage – from other spectral bands

Why is this important?

- Estimating land surface bio/geophysical variables accurately from RS data relies largely on quality of the data
- Depends on accuracy of radiometric calibration

Terminology

- Radiometric calibration
  - Process that converts recorded sensor voltages or digitized counts to an absolute scale of radiance – independent of image forming characteristics of the sensor
  - Relative or absolute calibration

Terminology

- Absolute calibraion
  - Linear sensor: performed by ratioing the digital numbers from the sensor with the value of an accurately known, uniform radiance field at its entrance
- Relative calibration
  - Normalizing the outputs of the detectors to a given, often average, output from all detectors in the band

Preflight calibration

- Calibration may change in space – response to variations in the environment surrounding the sensor in a spaceborne environment
  - Outgassing
  - Bombardment by energetic particles from space
  - Variation in the filter transmittance & spectral response
  - Slow deterioration of the electronic system

In-flight absolution calibration

- Performed on a routine basis for thermal IR bands – allows for precise temperature information
- Solar channels for imaging – don't have onboard calibration capabilities because of limitations in satellite power, weight & space

Post-launch calibration data

- Need to obtain from vicarious calibration techniques
  - Vicarious calibration – techniques that make use of natural or artificial sites on the surface of the Earth for post-launch calibration of sensors

Approach to sensor calibration

- Formulate a sensor calibration model
- Simplest form:

  $Y = A L$

  where Y represents the DN values, A is the matrix of absolute calibration coefficients, L is radiance
- To determine matrix A:
  - Accurate preflight measurements, then monitored on orbit by onboard calibration devices (secondary or tertiary standard light sources – lamps or the Sun)
  - Vicarious methods – images of specific well-known ground targets or the Moon

Post-launch calibration methods

- Radiance-based calibration method
  - Fly an aircraft with a calibrated radiometer
  - Measure the spectral radiance of the target observed by the satellite in the same illumination & observing directions – simultaneous measurements
- Reflectance-based calibration method
  - Accurate measurement of spectral reflectance of the ground target
  - Measurement of spectral extinction depths & other meteorological variables
- See Figure 5.1

Post-launch calibration methods

- These calibration methods - most direct – relatively expensive & complex
- Can’t calibrate historical data

Post-launch calibration methods

- Another technique: compare observed radiance with radiative transfer calculations using physical characteristics of atmosphere & surface targets – see Chapter 2
- Surface targets: ocean, desert, cloud, snow, dry lake, ice sheet, Moon

Ocean calibration

- Relies on molecular scattering in the atmosphere over the ocean
  - Conditions: cloudless air mass, small amount of haze far away from the ocean glint – major contribution (70-80%) to upward radiance over deep oceans in the visible part of the spectrum is from molecular scattering in the atmosphere
  - Viewing conditions: deep oceans to get clear water, large viewing & solar zenith angles to increase the photon travel path length, viewing the western direction to avoid specular reflection

Ocean calibration

- Glint radiance – 87% is due to specular reflectance
- Depends on wind speed & wave structure
- Independent of wavelength – determine relative calibration of near IR bands to visible bands
- Good conditions – 2-5 m/sec wind speed

Desert calibration

- Advantages
  - Stable spectral response over time
  - With their high reflectance, atmospheric effect on upward radiance is minimal
  - Spatially uniform
- Typical desert sites
  - Libyan desert for AVHRR
  - North Africa desert for SPOT
  - Egyptian desert for int’l sensor intercalibration
  - White Sands Missile Range for high resolution imagery, used since the 1980s

Clouds

- Very-high-altitude (10-km) bright clouds used for good validation targets
  - Visible & near IR spectral
  - High spectrally consistent reflectance
- With clouds high, don't need to correct for aerosol scattering & water vapor absorption (these are distributed near the surface)
- Consider only Rayleigh scattering & ozone absorption

Other calibration sites

- Dry lakes & other large homogenous areas – Railroad Valley Playa (clay), Rogers Dry Lake (Edwards AFB)
- Permanent ice sheets – Greenland & Antarctica
- Cloud shadows over water – calibrate high-resolution sensors

Other calibration sites

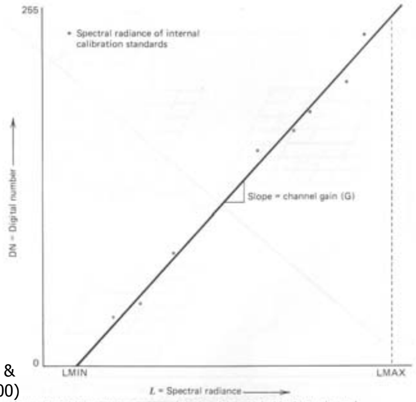
- Moon – stability of reflectance is extremely high
  - Check in-flight stability of a solar diffuser
  - Provide a direct calibration of the sensor
- Flagstaff, AZ – making long-term radiometric measurements of the Moon
  - EOS calibration – radiometric stability of the lunar surface to give long-term, on-orbit calibration & cross-calibration of EOS and non-EOS sensors flown on similar & different platforms
- See Table 5.1

Linear radiometric response

- Each spectral band has its own response function
- Band characteristics monitored using onboard calibration lamps (temperatures references for thermal band)
- Absolute spectral radiance output of calibration sources known from prelaunch calibration – assume stable over life of sensor

Figure 7.4

- Linear fit to the calibration data – radiance & DN values related by:
  - DN = GL + B
    DN = digital number value recorded
    G = slope of response function (channel gain)
    L = spectral radiance measures (spectral bandwidth of channel)
    B = intercept of response function (channel offset)
- Slope & intercept – *gain* & *offset* of the response function

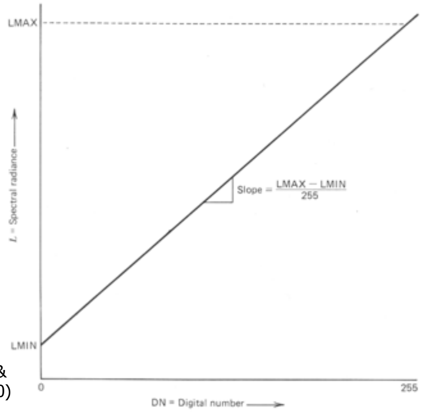


(Lillesand & Kiefer, 2000)

Figure 7.4 Radiometric response function for an individual TM channel.

Figure 7.4

- LMIN – spectral radiance corresponding to a DN response of 0
- LMAX – minimum radiance required to generate the maximum DN (255)
    - LMAX – radiance at which the channel saturates
- Range from LMIN to LMAX is the dynamic range of the channel



(Lillesand & Kiefer, 2000)

Figure 7.5 Inverse of radiometric response function for an individual TM channel.

Figure 7.5

- Inverse of the radiometric response
- Interchanged the axes from Fig. 7.4
- L = (LMAX – LMIN / 255) DN + LMIN
- Can convert any DN in a particular band to absolute units of spectral radiance in the band, if LMIN & LMAX are known from sensor calibration
- LMIN & LMAX values – mW cm^{-2} sr^{-1} μm^{-1}
- To estimate total within-band radiance, multiply by width of spectral band

Calibration coefficients

- Landsat TM
- NOAA AVHRR
- See Section 5.3 for details