Introduction to calibration

In-flight characterization and calibration methodologies
Postlaunch calibration

The launch and operating environment are harsh and thus there is a benefit to having postlaunch calibrations

- To monitor sensor degradation with time is also a good motivation for postlaunch calibration
- Philosophy is the same as the prelaunch calibration
  - Lamp-based calibration
  - Solar-diffusers
  - Blackbodies
- Unfortunately, onboard calibration approaches have problems
  - Lamp output changes over time
  - Diffusers degrade
  - May not cover full optical path or fully simulate operation of the sensor
- Vicarious calibration methods are those that use a radiance source that is not part of the sensor
Need for inflight calibration

Inflight calibration is needed due to the uncertainties in going to orbit

- Difficult to predict fully the inflight behavior using laboratory approaches
  - Size of source
  - Spectral effects
- Behavior of the sensor is different on orbit
  - Sensor degradation
  - Lack of gravity
On-board lamps

Lightweight, compact in size, and excellent repeatability

- TM and ETM+ case, lamps are used before and after every scan line
- Pushbroom sensors typically must stop collecting data to view the lamps
  - Can be done on dark side for cases of reflective-only sensors
  - However, this consumes power when the system is not generating power
- Problems with lamp approaches
  - Do not simulate the solar spectrum very well
  - Degrade and burn out over time
  - Absolute accuracy cannot be better than the preflight calibration
- Availability of diffuser materials are making lamps less desirable
- Detector-based approaches allow the lamps to be used in an absolute calibration scheme
Solar diffusers can be full aperture and have a spectral shape similar to that seen by the operating sensor.

- Characterized prior to launch and coupled with an assumed solar irradiance gives an at-sensor radiance:
  - Directionality
  - Level of reflectance
- Exposure to solar irradiance causes degradation
- Scrubbing by atomic oxygen causes degradation
- Mechanical movement causes change of incident angle and view angle
- Panels often mounted with large incident angles to reduce irradiance
- Have to wait for the appropriate geometry in the orbit and limit exposure of the panel
MODIS calibration example

MODIS scan cavity contains multiple calibration approaches for the full spectral range of bands.
Vicarious approaches

Vicarious approaches are useful for inflight calibration since they won’t degrade over time

- Vicarious calibration refers to any method that does not rely on sensor-based equipment
  - Lunar approaches
  - Rayleigh scattering
  - Desertic scenes
  - Deep space views
  - Cloud-top methods
  - Simultaneous nadir observations (SNOs)

- Other advantages are
  - Independent of preflight calibration
  - Independent of onboard calibrators

- Disadvantages tend to be
  - Low precision for high accuracy methods
  - Poor accuracy for high precision methods
Why bother with vicarious?

Radiance validation is most critical for the accurate retrieval of geophysical parameters from temporal data sets with little to no overlap

- Realistically, absolute radiometric calibration may not be needed for some specific cases
  - Data from a single sensor with focus on change analysis
  - Multiple sensors for which significant overlap exists
- Temporal studies and inter-sensor measurements, however, critically require validated sensors
  - Biases between sensors need to be removed
  - Temporal changes in response must be tracked
- Temporal studies using multiple sensors with little to no overlap in data MUST have accurate absolute radiometric calibration
Why bother with vicarious?

Results shown are for ETM+ band 3.
These data show the onboard calibrator data.
Note the difference between the lamp-based results and solar diffuser.

![Landsat-7 ETM+ Band 3 Radiometric Calibration Results](chart)

Scaled to High Gain

- FASC angle/position adjusted
- Internal Calibrator
- Pre-launch
- Linear Fit FASC

Responsivity (DN/radiance)

Time Since Launch (Days)
Why Bother with vicarious?

Many current and future sensors are tending towards smaller size and pushbroom technology

- Even wide swath sensors are using pushbroom approaches which does not easily allow onboard approaches
- Days of calibration information on every scan line are numbered
- Collection of calibration data on these newer systems can mean loss of data thus calibration is less frequent
- New approaches are being developed that should be evaluated for their accuracy
- Some newer systems forgo onboard calibration for cost and weight savings
- Numerous other motivations for vicarious approaches such as source spectra, simulates use, etc.
Vicarious methods

The critical aspect of calibration is to ensure multiple independent methods to gain an accurate assessment of the sensor’s behavior

- Vicarious methods are rarely tied to the laboratory preflight calibration
  - Diffusers are characterized for BRDF in the laboratory and assumed constant
  - Onboard lamps are calibrated using the sensor as a transfer radiometer
- Detector-based and blackbody approaches can be independent of the laboratory calibration
- Vicarious methods suffer from lower precision and temporal sampling than onboard approaches
- Major advantage to vicarious approaches is that they typically calibrate the sensor in the same mode in which data are collected
  - Similar source spectrum
  - Illumination conditions are similar
Basic philosophy

The philosophy in all vicarious approaches is that the radiance at the sensor can be predicted

- Concept is identical to that in the laboratory with a sphere source
- Methods can be both relative and absolute
- Relative methods typically rely on temporal overlap of the data sets
  - Determining temporal changes in one band relative to another for a given sensor
  - Sensor to sensor effects
- Absolute methods attempt to place a value on the predicted radiance
  - Independent calibration from laboratory
  - Better accuracy
Vicarious approaches without in situ data

Vicarious approaches that provide the highest temporal sampling are those not relying on in situ data

- Lack of in situ data does not imply the method has to be a relative calibration
- Models can be used to predict the radiance at the sensor
- These approaches tend to suffer from poor absolute accuracy
- Repeatable processing and large number of data points typically give high precision
- Examples are
  - Sky scattering or Rayleigh approach
  - Sun glint
  - Lunar calibration
  - Invariant test sites
  - Simultaneous nadir observations
Test site selection

Proper selection of test sites will determine the accuracy of the results from a ground-truth approach

- True for both geometric and radiometric calibration
- There are both natural and man-made scenes
- Most important factor is site accessibility by the imaging sensor
  - Frequency of scene collection
  - Typical view angles
- Other factors that will be discussed here are
  - Temporal stability
  - Size
  - Location
Lunar calibration

Moon is a stable reflectance surface with the sun as the source so spectral character is similar to terrestrial scenes

- Point the sensor such that an image of the moon can be taken
- Characterize and calibrate the moon spectrally to remove phase angle and libration effects
  - Moon has directional reflectance effects
  - Moon is not homogeneous
  - We see different parts of the moon over time (libration cycle)
- May provide point-spread function data
- Risk of pointing at the moon and reflectance is low
Rayleigh Scattering

One of the earliest vicarious approaches modeled the scattering by the atmosphere to predict band ratios:

- Over water, or other dark surface, the reflected energy becomes negligible.
- Dominant source of energy is scattering by the atmosphere.
  - Can be modeled based on atmospheric pressure and wavelength.
  - Assume that the scattering follows a Rayleigh scatter model.
  - Works much better at short wavelengths.
- Originally used to calibrate Band 1 of AVHRR.
  - Large view angles of AVHRR improved results.
  - Daily collections reduced errors due to sea foam and aerosol effects.
- Method also used for laser-based,
Sun Glint

Rayleigh scattering approaches led to a large number of ocean scenes where sun glint was visible

- The reflection of sunlight from the water is effectively independent of wavelength
  - Still need a spectral correction due to solar spectrum
  - Requires a correction for atmospheric transmittance

- First used to calibrate AVHRR band 2 relative to band 1
  - Longer wavelength of band 2 made the Rayleigh method less accurate
  - Rayleigh method used to determine any temporal degradation in band 1
  - Allowed for band 2 degradation to be determined independent of band 1

- Problems with approach are
  - Sun glint can saturate
  - Need to have the appropriate geometry to see the sun glint
Invariant scene approaches

- Some ground areas are treated as not changing with time
  - Desert scenes
  - Glaciers and snow fields
- First used for AVHRR over Saharan Desert
On-orbit summary

Best sensors have reflectance accuracy of 3.6% (k=2) in mid-visible [4.2% in radiance]

Terra sensors linked vicarious, onboard, prelaunch calibrations to data products

Laboratory 4.2% (k=2) absolute

In situ 5% (k=2) absolute

Intercomparisons 1.0% (k=2) relative

Lunar 0.2% (k=2) relative