Radiometric Correction

**Radiometric Correction:** Operations intended to remove systematic or random noise affecting the amplitude (brightness) of an image.

Radiometric defects may be introduced during:
- imaging (atmosphere, optics, detector, …)
- digitization or
- transmission.

The goal of correction procedures is to restore an image to the condition it would have been in if the imaging process were flawless.

Data Processing Levels

<table>
<thead>
<tr>
<th>Level</th>
<th>Description</th>
<th>AVHRR 1B; ASTER; MODIS; Landsat:</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Reconstructed, unprocessed instrument and payload data at full resolution, with any and all communications artifacts (e.g., synchronization frames, communications headers, duplicate data) removed.</td>
<td></td>
</tr>
<tr>
<td>1a</td>
<td>Reconstructed, unprocessed instrument data at full resolution, time-referenced, and annotated with ancillary information, including radiometric and geometric calibration coefficients and georeferencing parameters (e.g., platform ephemeris) computed and appended but not applied to the Level 0 data (or if applied, in a manner that level 0 is fully recoverable from level 1a data).</td>
<td></td>
</tr>
<tr>
<td>1b</td>
<td>Level 1a data that have been processed to sensor units (e.g., radiance, radar backscatter cross section, brightness temperature, etc.); generally includes a geometric correction (UTM co-ordinates); not all instruments have Level 1b data; level 0 data is not recoverable from level 1b data.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Derived geophysical variables (e.g., ocean wave height, soil moisture, ice concentration) at the same resolution and location as Level 1 source data.</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Variables mapped on uniform spacetime grid scales, usually with some completeness and consistency (e.g., missing points interpolated, complete regions mosaicked together from multiple orbits, etc.).</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Model output or results from analyses of lower level data (i.e., variables that were not measured by the instruments but instead are derived from these measurements).</td>
<td></td>
</tr>
</tbody>
</table>
Units

- **DN (Digital Number) values:**
  Standard form for raw data.
  byte, unsigned integer

- **Radiance (mw cm$^{-2}$ sr$^{-1}$ μm$^{-1}$)**
  Calibrated value at the detector.
  • conversion from DN to radiance is typically linear
  • different for each detector and each spectral band
  • may change over time.
  signed integer (scaled)

- **Reflectance**
  • Albedo, $A$, (dimensionless) – The ratio of the upwelling irradiance to the downwelling irradiance
  • Remote Sensing reflectance, $R_{rs}$, (sr$^{-1}$) – the ratio of upwelling radiance to the downwelling irradiance.
  • Exoatmospheric reflectance is reflectance at the satellite and includes reflectance from the earth’s atmosphere.
  signed integer, floating point

**Impulse noise:** Isolated pixels which are anomalously dark or bright.
Impulse noise may arise in several ways:
- a faulty detector (in an array)
- data dropouts during transmission, compression, decompression.
- electronic noise

Examples: Ikonos pan image: London

1) isolated pixels that are anomalously dark or bright (often black or saturated).

2) Line dropouts
Impulse noise: correction

• With impulse noise the original cannot be recovered.

• Instead, the anomalous gray values can either be
  – labeled so that it can be ignored in later processing, or
  – replaced with a more reasonable value. Typically, the gray value of the faulty pixel is replaced by an average gray value of its nearest neighbors.

For example, for individual points, replace the noise point with an average of the 8 nearest neighbors:

\[
26 \quad 22 \quad 23 \quad 24 \quad 23 \\
25 \quad 23 \quad 25 \quad 24 \quad 22 \\
24 \quad 22 \quad 255 \quad 25 \quad 23 \\
24 \quad 25 \quad 23 \quad 23 \quad 22 \\
25 \quad 26 \quad 24 \quad 22 \quad 23 \\
\]

\[
\begin{array}{cccccc}
26 & 22 & 23 & 24 & 23 & 25 \\
25 & 23 & 25 & 24 & 22 & 21 \\
24 & 22 & 23 & 24 & 23 & 25 \\
26 & 22 & 23 & 24 & 23 & 25 \\
25 & 26 & 24 & 22 & 23 & 24 \\
\end{array}
\]

\[
23 + 25 + 24 + 22 + 25 + 25 + 23 + 23 = 23.75
\]

\[
255 \Rightarrow 24
\]

For line dropouts, replace the noise line with averages of the nearest neighbors from adjacent lines:

\[
\begin{array}{ccccccccc}
26 & 22 & 23 & 24 & 23 & 25 & 26 & 22 & 23 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
24 & 25 & 23 & 23 & 22 & 21 & 24 & 22 & 24 \\
25 & 26 & 24 & 22 & 23 & 21 & 22 & 23 & 23 \\
24 & 25 & 23 & 24 & 25 & 21 & 24 & 22 & 24 \\
\end{array}
\]

\[
\begin{array}{ccccccccc}
26 & 22 & 23 & 24 & 23 & 25 & 26 & 22 & 23 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
24 & 25 & 23 & 23 & 22 & 21 & 24 & 22 & 24 \\
25 & 26 & 24 & 22 & 23 & 21 & 22 & 23 & 23 \\
24 & 25 & 23 & 24 & 25 & 21 & 24 & 22 & 24 \\
\end{array}
\]

\[
255 \Rightarrow 24
\]

Problems:

• The user must identify the anomalous pixel or line.

• The filter should be applied only to the anomalous points.

• If there are more than a few pixels in the image to deal with, identifying the anomalous pixels will be a very tedious process.

• Automating the process is difficult. It is particularly difficult to define a procedure which will alter only the anomalous pixels.

Global filters: Mean filter

The mean is computed as the average of all the pixels within a user-specified window

• replaces the gray value of the pixel at the center of the window with the local mean.

• includes the anomalous pixel in the average and will generally do a poor job of substitution.

\[
\begin{array}{cccccccc}
26 & 22 & 23 & 24 & 23 & 25 & 24 \ \\
25 & 23 & 25 & 24 & 22 & 23 \ \\
24 & 23 & 22 & 255 & 26 & 25 & 23 \ \\
24 & 25 & 23 & 23 & 22 & 23 & 24 \ \\
25 & 26 & 24 & 22 & 26 & 23 & 24 \ \\
\end{array}
\]

\[
\begin{array}{cccccccc}
26 & 22 & 23 & 24 & 23 & 25 & 24 \ \\
25 & 23 & 25 & 24 & 22 & 23 \ \\
24 & 23 & 22 & 49 & 26 & 25 & 23 \ \\
24 & 25 & 23 & 23 & 22 & 23 & 24 \ \\
25 & 26 & 24 & 22 & 26 & 23 & 24 \ \\
\end{array}
\]
Global filters: Median filter

The median is the middle value of a set. Half of the selected pixels will have a greater (or equal) gray value and half the pixels have a smaller (or equal) gray value.

- will replace the gray value of a target pixel with the median gray value of the pixels within a window centered on the target pixel.
- will also include the anomalous pixel, but will not be skewed by it.

Consider the sequence:

| 21 | 18 | 14 | 26 | 100 | 23 | 37 | 28 | 29 |
where 100 is the center pixel.

Sort them into increasing order (rank order):

| 14 | 18 | 21 | 23 | 26 | 28 | 29 | 30 | 100 |

Select the middle value in the sequence: 26

The median filter is a special case of a general class of rank-order filters.

- An adaptive median filter will impose less change on the image by applying an extra condition: Do not change the center pixel if the original value is within n steps of the median value.

Impulse noise: correction example

In this example, the filters are applied to the entire image and affect all points.

Image with seven anomalous pixels

Mean filter

Median filter

Despeckle filter
**Random noise** • Random noise implies local variability in gray value that is **not** related to changes in the signal from the target.

• The pixel-to-pixel variability suggests that random noise is, by nature, a high spatial frequency phenomenon.

• Thus, an operation which damps out high frequencies should also damp out random noise.
  
  \[ \Rightarrow \text{Mean, median, despeckle filters} \]

**Systematic, non-periodic noise**

\[ I(x,y) = M(x,y) F(x,y) + A(x,y) \]

- \( F(x,y) = \) noise-free image function
- \( A(x,y) = \) additive noise  
  - detector offset (dark current)
  - surface reflection
  - atmospheric (path radiance)
- \( M(x,y) = \) multiplicative noise factor  
  - detector gain
  - illumination variations
  - transmission of optical system
- \( I(x,y) = \) observed, digitized image function

**Transillumination**

\[ M(x,y) = \text{position dependent variation in light intensity and vignetting of the optical system} \]

**Transillumination: correction procedure**

1. Determine \( A(x,y) \) (or turn off the room light)
   a. Replace the film transparency with a uniformly black \( F(x,y) = F_0 = 0 \) piece of the same type of film.
   b. Turn off the primary light source.
   c. Collect an image, \( A(x,y) \)

2. Determine \( M(x,y) \)
   a. Use a clear piece of the same film: \( F(x,y) = F_c = \text{constant} \)
   b. Turn the primary light back on
   c. Collect an image: \( I_c(x,y) = M(x,y) F_c + A(x,y) \)

\[ M(x,y) = \frac{I_c(x,y) - A(x,y)}{F_c} \]

\[ F(x,y) = \frac{I(x,y) - A(x,y)}{M(x,y)} \]
d. Solve for $M(x,y)$:

**Reflective Illumination**

![Diagram of reflective illumination](image)

$I(x,y) = M(x,y) F(x,y) + A(x,y)$

$M(x,y) = $ illumination (irradiance) at the photo surface

$F(x,y) = $ image function (photo density)

$A(x,y) = $ surface reflection at the film surface

**Reflective illumination: correction procedure**

1. Determine $A(x,y)$
   a. replace the film transparency with a uniformly black [$F(x,y) = F_0 = 0$] piece of the same type of film.
   b. collect an image, $I_0(x,y) = A(x,y)$

2. Determine $M(x,y)$
   a. use a uniform piece of the same film (constant density is all that is really necessary), i.e., $F(x,y) = F_c = $ constant.
   b. collect an image: $I_c(x,y) = M(x,y) F_c + A(x,y)$
   c. Solve for $M(x,y)$:

$$M(x,y) = \frac{I_c(x,y) - A(x,y)}{F_c}$$

$$F(x,y) = \frac{I(x,y) - A(x,y)}{M(x,y)}$$
Radiometric Correction

Atmospheric Correction

\[ I(x,y) = M(x,y) F(x,y) + A(x,y) \]

\( M(x,y) \) = illumination (irradiance) at the earth's surface due to sunlight and skylight 
\( (\text{includes transmissive losses}) \).

\( F(x,y) \) = reflectance of the earth's surface

\( A(x,y) \) = path radiance (atmospheric scattering)

1. Dark object subtraction
   - If the atmosphere is uniform over the scene \([A(x,y) = A]\), and
   - if a black (zero reflectance) object exists in the scene then one may correct the image for path radiance by subtracting the gray value of the dark object pixel from every pixel in the image:

\[ I(x,y) - A_0 = M(x,y) F(x,y) \]

- Water (clear, deep water) is frequently chosen as the dark target in the infrared.
- Dense vegetation will approximate a dark object in the red and blue (chlorophyll absorption).

Problems:
- does not account for atmospheric variations
- Truly "dark" pixels are rare, and dark pixels in all spectral bands are even more rare.

Ad hoc solutions:
- water (presumably clear, deep water) is frequently chosen as the dark target, particularly in the infrared.
- dense vegetation will approximate a dark object in the red and blue (chlorophyll absorption).

2. Ratioing
   Suppose that, although the atmosphere is spatially uniform, the illumination is spatially variable, but differs only by a constant factor, \( c \), from band to band then:

\[ M_2(x,y) = c M_1(x,y) \] (subscripts refer to spectral bands)

then dividing (pixel by pixel) the first band by the second yields a new image:

\[ I_3(x,y) = \frac{I_1(x,y)}{I_2(x,y)} = \frac{M_1(x,y) F_1(x,y) + A_1(x,y)}{c M_1(x,y) F_2(x,y) + A_1(x,y)} \]

If the path radiance is negligible \([A_1 = A_2 = 0]\) or can be removed by another method then

\[ I_3(x,y) = \frac{I_1(x,y)}{I_2(x,y)} = \frac{F_1(x,y)}{c F_2(x,y)} \]

and the new image will be insensitive to variations in illumination and atmosphere.
2. Simple Radiative Transfer Model

\[ E_o = \text{solar constant (solar irradiance outside the earth's atmosphere)} \]

\[ \tau_o = \text{atmospheric transmission along the solar path (accounts for absorption and scattering)} \]

\[ \theta_o = \text{solar zenith angle} \]

\[ E_{sky} = \text{Irradiance at the earth's surface due to skylight} \]

\[ E_d = \text{total irradiance at the earth's surface} \]

\[ = \tau_o E_o \cos \theta_o + E_{sky} \]

\[ L_v = R_{RS}(\theta_v) E_d = R_{RS}(\theta_v) \left( \tau_o E_o \cos \theta_o + E_{sky} \right) \]

\[ L_* = \text{Path radiance} \]

\[ L_{sat} = \tau_v L_v + L_* \]

\[ L_{sat} = \left[ \tau_v (\tau_o E_o \cos \theta_o + E_{sky}) \right] R_{RS}(\theta_v) + L_* \]
Atmospheric Correction:

digitized scene, $I(x,y)$

illumination fn, $M(x,y)=E_d$

path radiance, $A(x,y) = L_e$

corrected image $f(x,y)$
**Atmospheric Correction – examples**

The objective of atmospheric correction is to retrieve the *surface reflectance*. The result may not always be visually apparent.

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**Aviris Data, Pocomoke City, MD**

http://www.umiacs.umd.edu/labs/GC/atmo/

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http://www.ncaveo.ac.uk/special_topics/atmospheric_correction/example3/
Banding: **TM 16 detectors per scan**

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Match means & standard deviations