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DRDC Bathymetry: a Bootstrap Calibration Procedure

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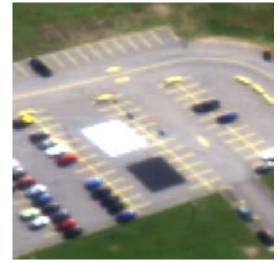
Canada

Outline

- WISE original radiometric calibration and atmospheric correction
- Proposed combined bootstrap method for simultaneous optimization
- Proposed criteria for optimum model performance evaluation

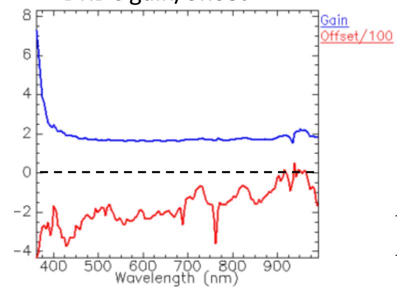
WISE Original Radiometric Calibration Issue

190820_MC-C1A-WI-1x1x1_v01
Calibration targets

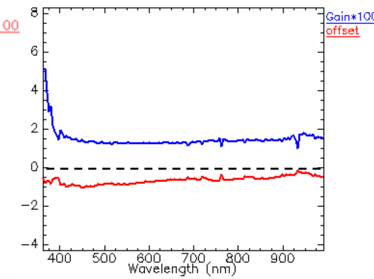


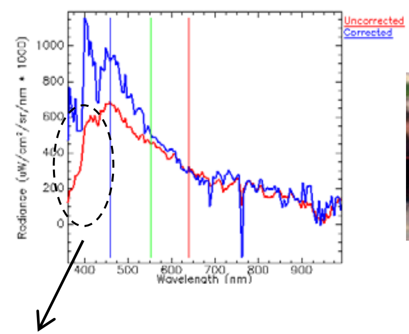
- WISE original radiometric calibration was incorrect
  - FLAASH and DRDC MUSIC would not give correct reflectance
  - Issue also apparent in path radiance (over dark target) between 360-430nm
- NRC installed calibration targets in Baie Comeau
  - Flight Line 190820_MC-C1A-WI-1x1x1_v01 (time 2019/08/20 13:29:55 GMT)
- Radiance correction: $L_{corrected}$ = gain * $L_{original}$ + offset
- NRC computed the correction using Atcor4 « Inflight radiometric calibration module” combined with the NRC spectra of the calibration targets. (Atcor4 comparison between MODTRAN and WISE radiance)
- DRDC developed code to find gain/offset correction by iteratively calling FLAASH until it converges to the calibration target reflectance
- Good radiometric calibration is critical to obtain accurate atmospheric correction over water (low reflectance)

DRDC gain/offset

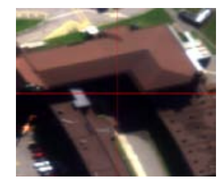


NRC Atcor4 gain/offset



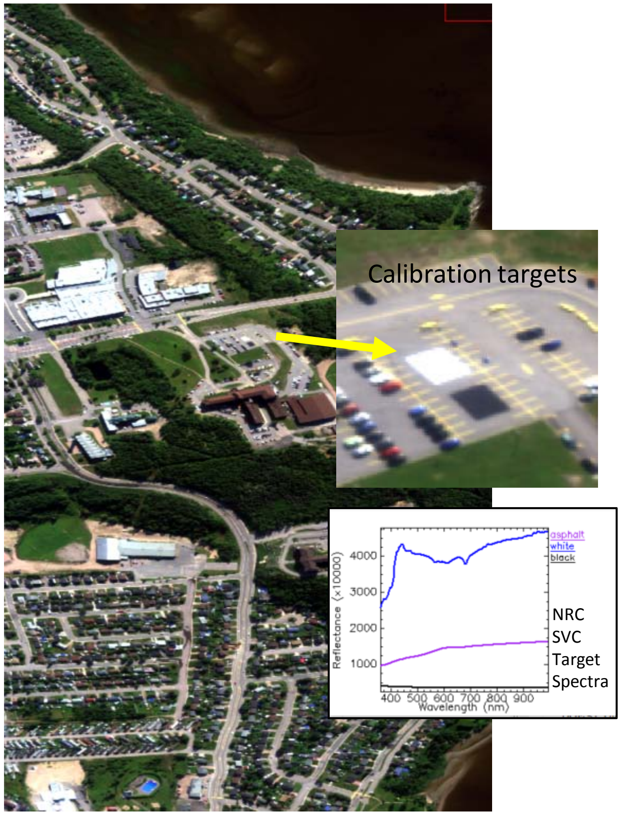


This radiance drop is incorrect



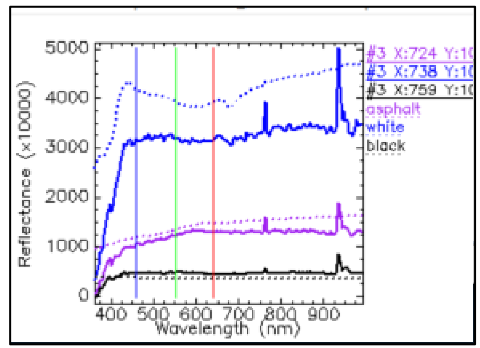
WISE Radiometric Calibration Issue – Atmospheric Correction

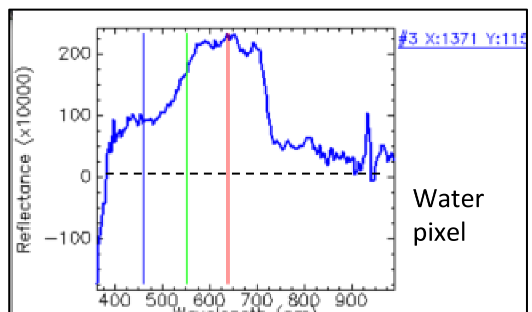
190820_MC-C1A-WI-1x1x1_v01



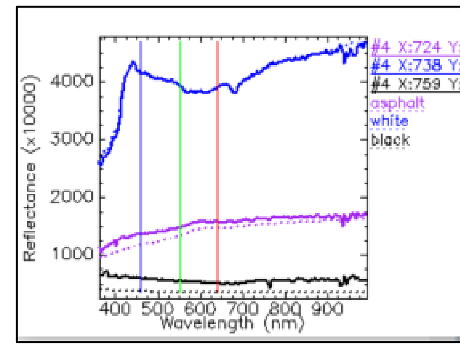
Atmospheric Correction with FLAASH

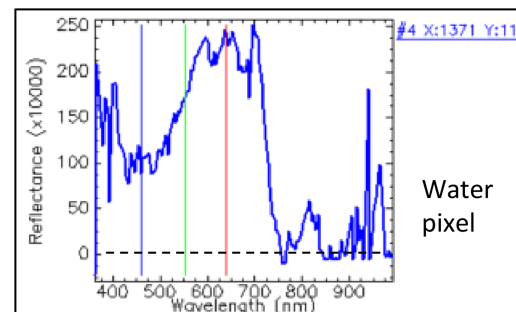
Before Radiometric Calibration Correction



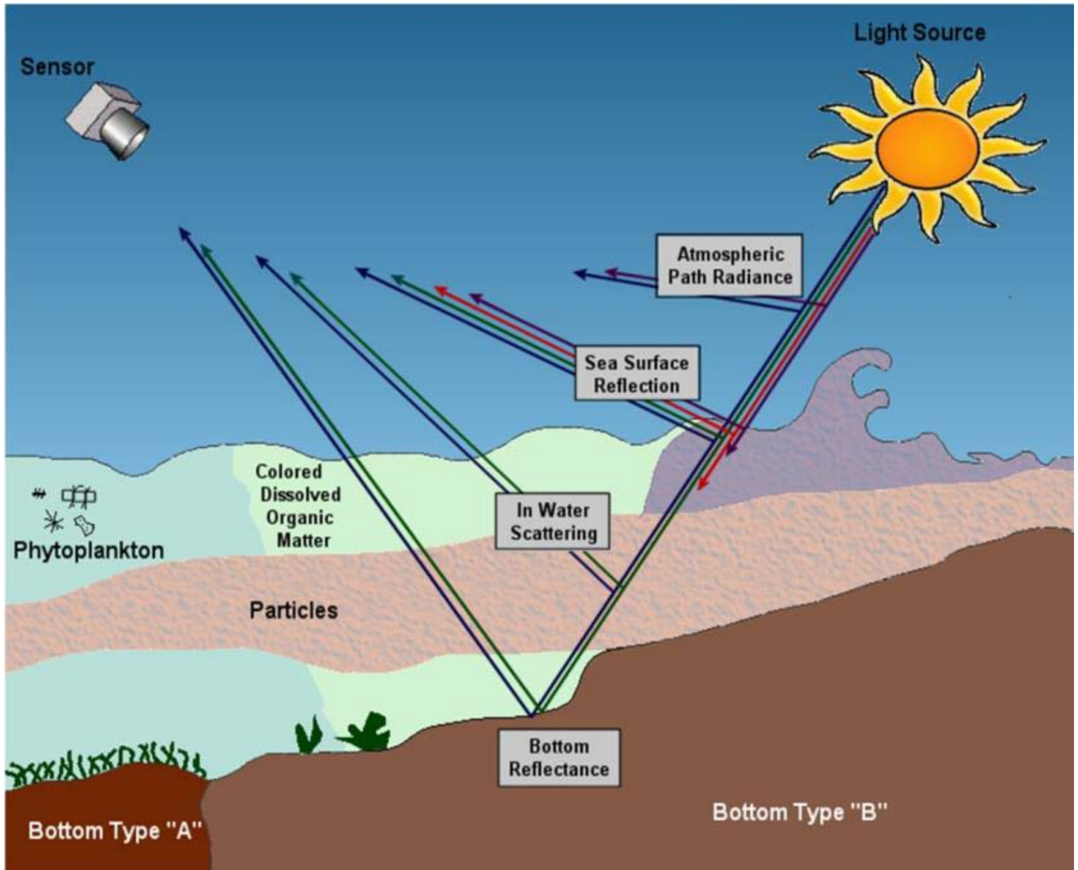


After Radiometric Calibration Correction

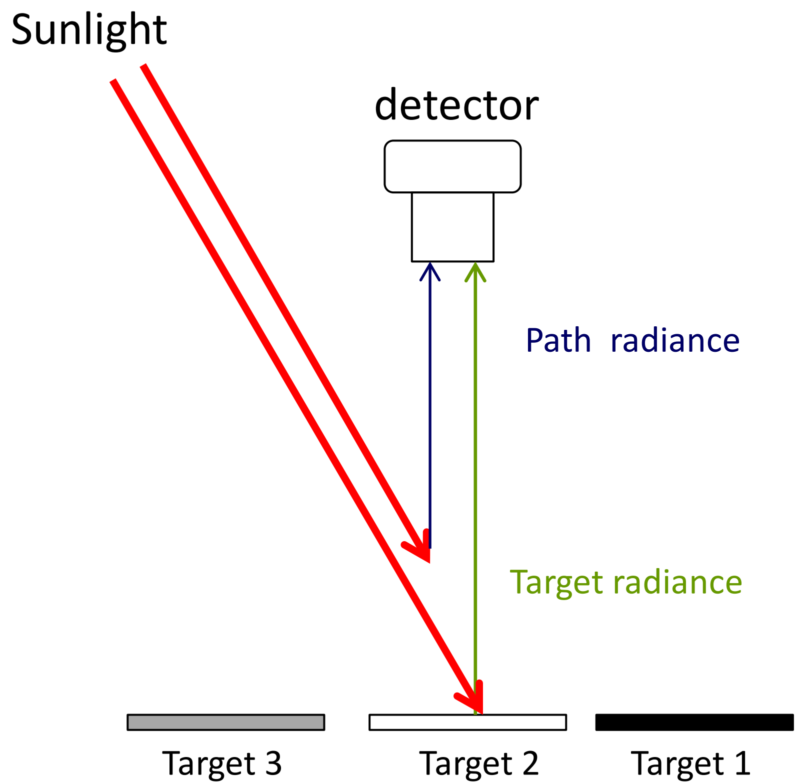




Bootstrap Radiometric Calibration – Atmospheric Correction



Bootstrap Radiometric Calibration – Atmospheric Correction



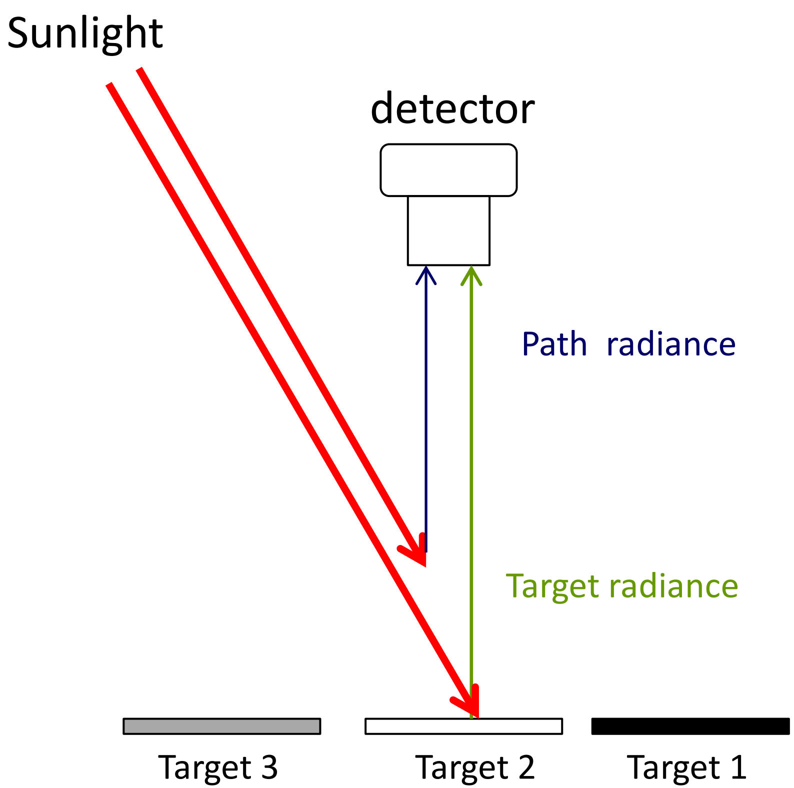
Ideal case

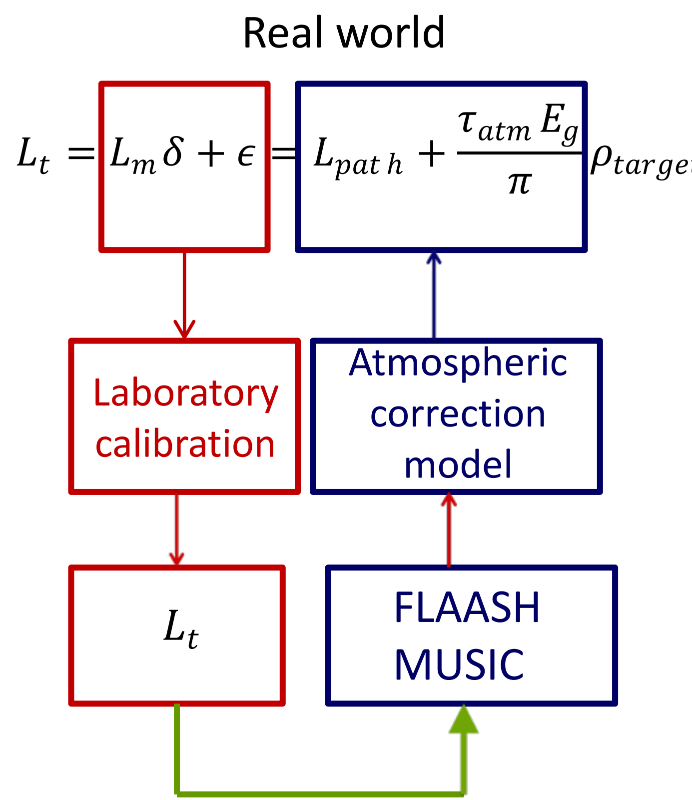
$$L_t = L_m = L_{path} + \frac{\tau_{atm} E_g}{\pi} \rho_{target}$$

Real world

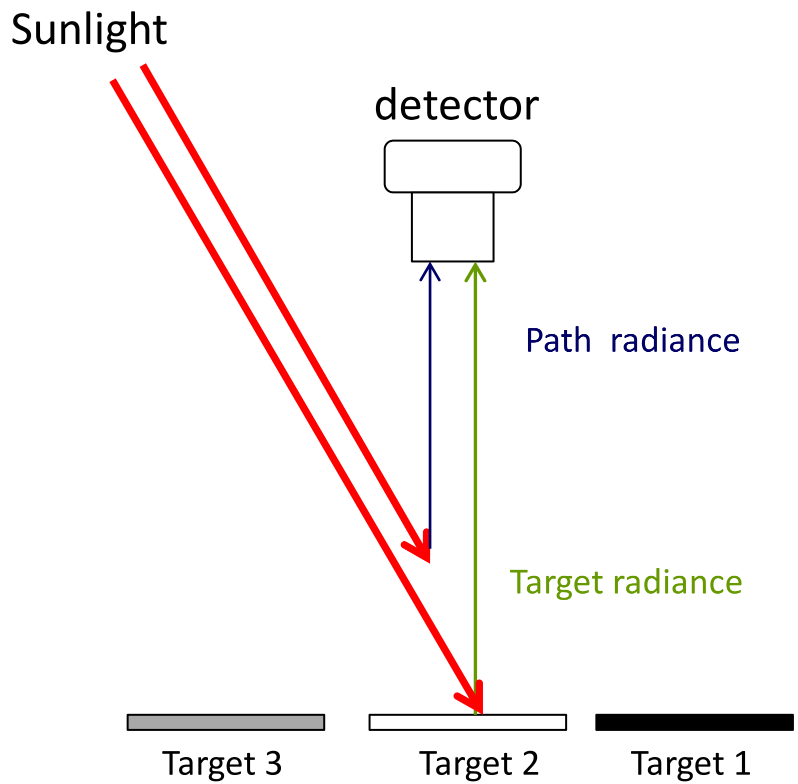
$$L_t = L_m \delta + \epsilon = L_{path} + \frac{\tau_{atm} E_g}{\pi} \rho_{target}$$

Bootstrap Radiometric Calibration – Atmospheric Correction





Bootstrap Radiometric Calibration – Two Known Target Case



$$L_{t1} = L_{m-t1}\delta + \epsilon = L_{path1} + \frac{\tau_{atm} E_g}{\pi}\rho_{t1}$$

$$L_{t2} = L_{m-t2}\delta + \epsilon = L_{path2} + \frac{\tau_{atm} E_g}{\pi}\rho_{t2}$$

Given target measurements close in space and time

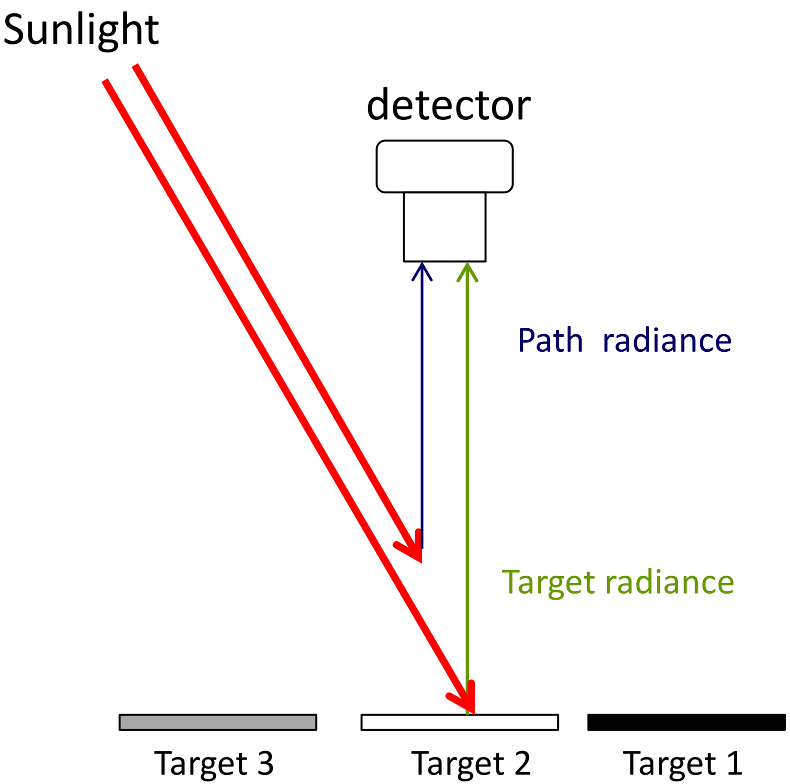
$$L_{path2} = L_{path2} = L_{path}$$

$$(L_{m-t2} - L_{m-t1})\delta = \frac{\tau_{atm} E_g}{\pi}(\rho_{t2} - \rho_{t1})$$

$$\delta = \left[\frac{\tau_{atm} E_g}{\pi}\right]\frac{(\rho_{t2} - \rho_{t1})}{(L_{m-t2} - L_{m-t1})}$$

Note that δ is completely independent of the offset ϵ

Bootstrap Radiometric Calibration – Two Known Target Case



Compute initial gain correction estimate

$$\delta_1 = \left[\frac{\tau_{atm} E_g}{\pi}\right]_0 \frac{(\rho_{t2} - \rho_{t1})}{(L_{m-t2} - L_{m-t1})}$$

Re-compute scene irradiance with gain correction estimate

$$L_s = L_m \delta_1$$

Re-compute atmospheric correction

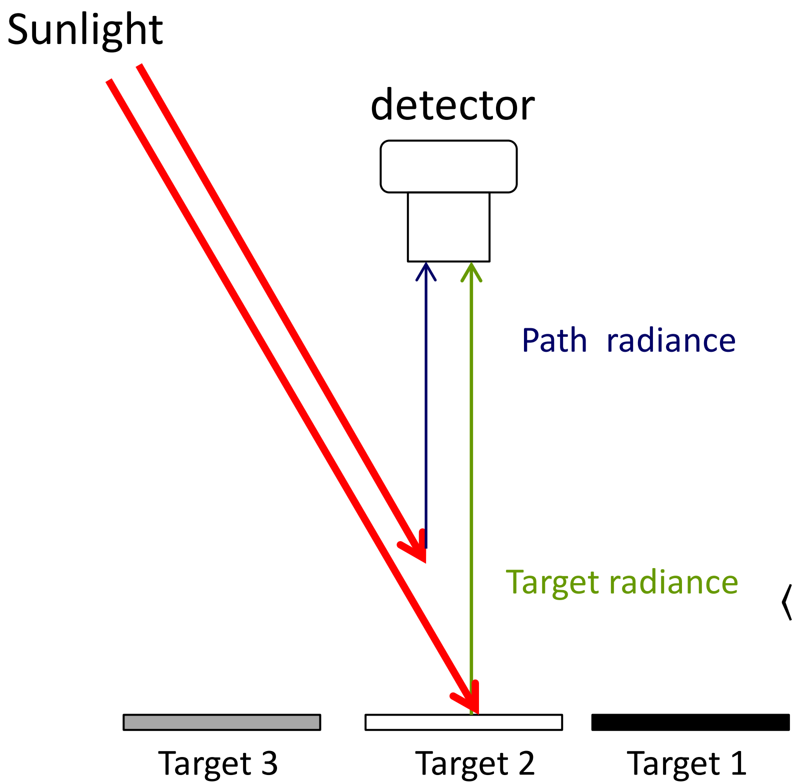
FLAASH
MUSIC

$$\left[\frac{\tau_{atm} E_g}{\pi}\right]_1$$

Use new atmospheric correction to update gain

$$\delta_{i+1} = \left[\frac{\tau_{atm} E_g}{\pi}\right]_i \boxed{\frac{(\rho_{t2} - \rho_{t1})}{(L_{m-t2} - L_{m-t1})}}$$

Bootstrap Radiometric Calibration – Two Known Target Case



Once the gain correction has stabilized
we initialize the offset correction estimate

$$\epsilon_1 = \left[L_{path}\right]_n + \left[\frac{\tau_{atm} E_g}{\pi}\right]_n \rho_{t1} - L_{m-t1}\delta_n$$

$$\epsilon_2 = \left[L_{path}\right]_n + \left[\frac{\tau_{atm} E_g}{\pi}\right]_n \rho_{t2} - L_{m-t2}\delta_n$$

Since the offset is independent of the gain we can use
the average value as the optimum estimate

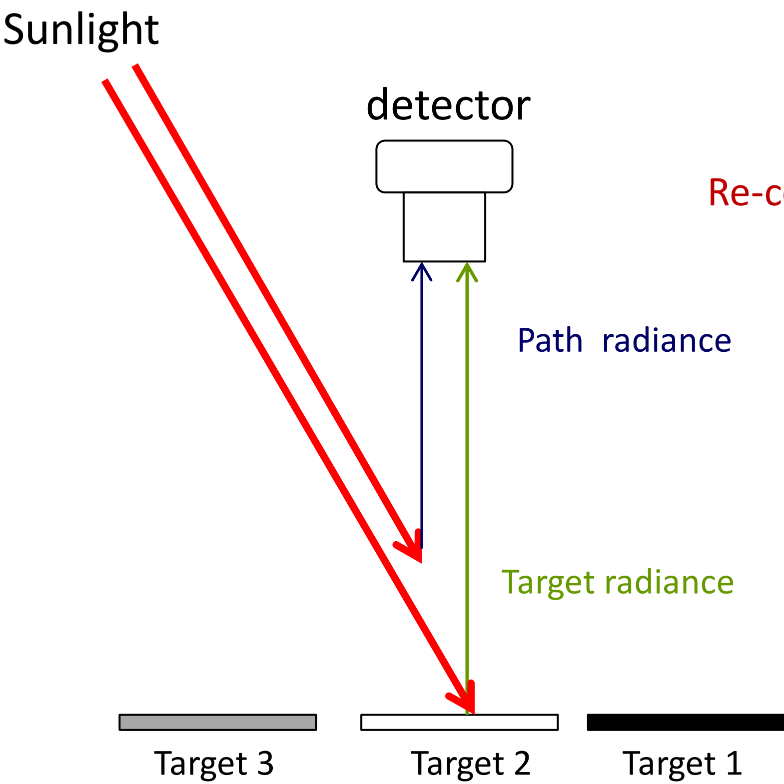
$$\langle\epsilon\rangle = \frac{(\epsilon_2 + \epsilon_2)}{2}$$

$$\langle\epsilon\rangle = \left[L_{path}\right]_n + \left[\frac{\tau_{atm} E_g}{\pi}\right]_n \frac{(\rho_{t2} + \rho_{t1})}{2} - \frac{(L_{m-t2} + L_{m-t1})}{2}\delta_n$$

$$\langle\epsilon\rangle = \left[L_{path}\right]_n + \left[\frac{\tau_{atm} E_g}{\pi}\right]_n \left[\frac{(L_{m-t2}\,\rho_{t1} - L_{m-t1}\rho_{t2})}{(L_{m-t2} - L_{m-t1})}\right]$$

$$\langle\epsilon\rangle = \left[L_{path}\right]_n + \delta_n \left[\frac{(L_{m-t2}\,\rho_{t1} - L_{m-t1}\rho_{t2})}{(\rho_{t2} - \rho_{t1})}\right]$$

Bootstrap Radiometric Calibration – Two Known Target Case



Compute initial offset correction estimate

$$\langle\epsilon\rangle_0 = \left[L_{path}\right]_n + \delta_n \left[\frac{(L_{m-t2}\,\rho_{t1} - L_{m-t1}\rho_{t2})}{(\rho_{t2} - \rho_{t1})}\right]$$

Re-compute scene irradiance with offset-gain correction estimates

$$L_s = \langle\epsilon\rangle_0 + L_m\,\delta_n$$

Re-compute atmospheric correction

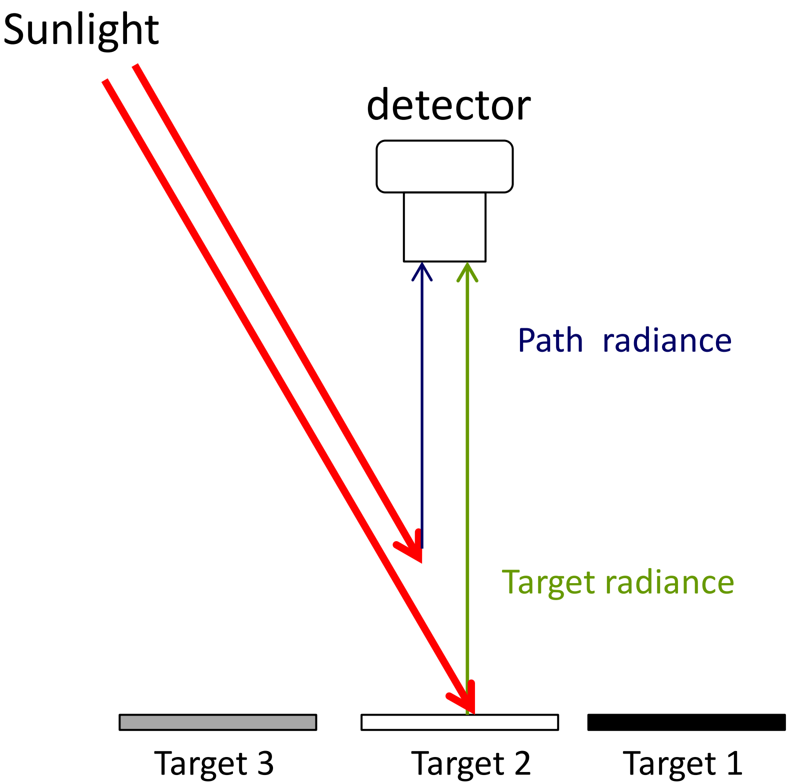
FLAASH
MUSIC

$$\left[L_{path}\right]_{n+1} \quad \text{and} \quad \left[\frac{\tau_{atm}\,E_g}{\pi}\right]_{n+1}$$

Use new atmospheric correction to update offset-gain and repeat procedure until convergence of offset correction

$$\langle\epsilon\rangle_i = \left[L_{path}\right]_{n+i} + \delta_{n+i} \left[\frac{(L_{m-t2}\,\rho_{t1} - L_{m-t1}\rho_{t2})}{(\rho_{t2} - \rho_{t1})}\right]$$

Bootstrap Radiometric Calibration – Multiple Known Target Case



Given N targets, for each distinct combination of a pair of targets we have a separate estimate of the gain

$$\delta_{i,j} = \left[\frac{\tau_{atm} E_g}{\pi}\right] \frac{(\rho_{tj} - \rho_{ti})}{(L_{m-tj} - L_{m-ti})} = \left[\frac{\tau_{atm} E_g}{\pi}\right] \frac{\Delta\rho_{t\,j,i}}{\Delta L_{m-tj,ti}}$$

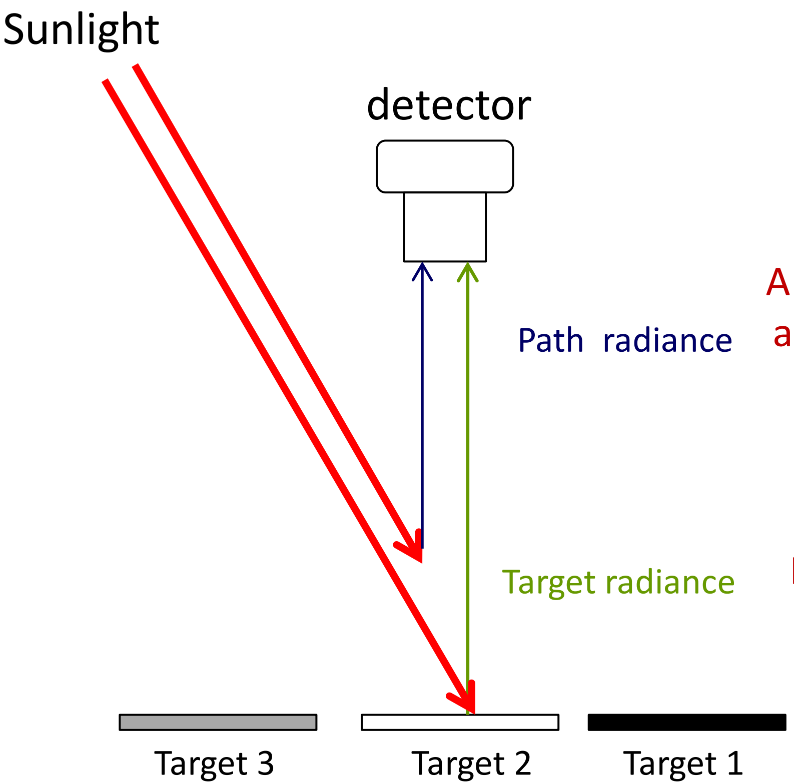
Since $\delta_{i,j} = \delta_{j,i}$

the number of distinct pairs is given by the upper triangular part of the difference matrix

$$\begin{pmatrix} \delta_{1,1} & \delta_{1,2} & \delta_{1,3} & \delta_{1,4} \\ \dots & \delta_{2,2} & \delta_{2,3} & \delta_{2,4} \\ \dots & \dots & \delta_{3,3} & \delta_{3,4} \\ \dots & \dots & \dots & \delta_{4,4} \end{pmatrix}$$

$$N_p = \frac{(N^2 - N)}{2} = \frac{N(N-1)}{2}$$

Bootstrap Radiometric Calibration – Multiple Known Target Case



Number of distinct estimate for gain and offset

N=2 targets -> 1 estimate

N=3 targets -> 3 estimates

N=4 targets -> 6 estimates

N=5 targets -> 10 estimates

A larger number of targets improves significantly the accuracy and may give the capability of handling non-linear gain terms

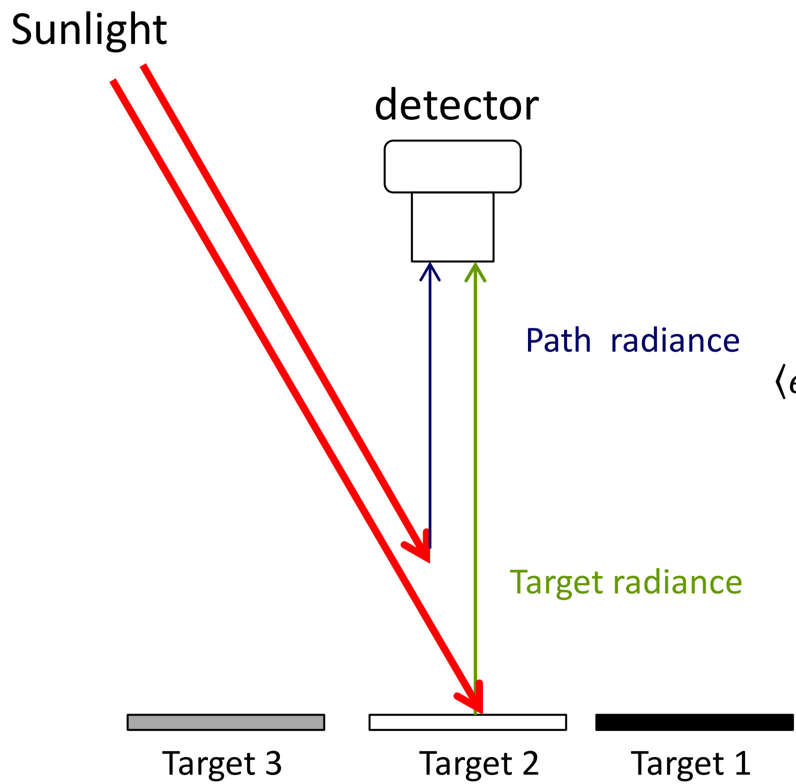
Since δ is completely independent of the offset ϵ the least squares estimates of each variable must be carried out separately for gain and offset terms

For more than two targets we have the measured matrices

$$\Delta\rho_{t\,j,i} = (\rho_{tj} - \rho_{ti})$$

$$\Delta L_{m-tj,ti} = (L_{m-tj} - L_{m-ti})$$

Bootstrap Radiometric Calibration – Multiple Known Target Case



For N targets the least squares estimate of the gain and offset corrections are given by the following expressions

$$\langle \delta \rangle = \left[\frac{\tau_{atm} E_g}{\pi} \right] \boxed{ \frac{\sum_{i=1}^{i=N} \sum_{j=i+1}^{j=N} \Delta\rho_{t\,j,i}\, \Delta L_{m-tj,ti}}{\sum_{i=1}^{i=N} \sum_{j=i+1}^{j=N} \Delta L_{m-tj,ti}^2} }$$

$$\langle \epsilon \rangle = L_{path} + \langle \delta \rangle \boxed{ \frac{2}{N(N-1)} \sum_{i=1}^{i=N} \sum_{j=i+1}^{j=N} \left[\frac{\left(L_{m-tj}\, \rho_{ti} - L_{m-ti}\, \rho_{tj} \right)}{\left(\rho_{tj} - \rho_{ti} \right)} \right] }$$

Using these expressions for estimated gain and offset corrections we then carry out exactly the same successive convergence bootstrap procedure we used for two targets

Bootstrap Radiometric Calibration – Model Quality Estimate

The feedback, stability and convergence of the bootstrap method is controlled only by the atmospheric correction model.

$$\langle\delta\rangle = \left[\frac{\tau_{atm} E_g}{\pi}\right] \frac{\sum_{i=1}^{i=N} \sum_{j=i+1}^{j=N} \Delta\rho_{t\,j,i}\, \Delta L_{m-tj,ti}}{\sum_{i=1}^{i=N} \sum_{j=i+1}^{j=N} \Delta L_{m-tj,ti}^{2}}$$

Feedback by Atmospheric model

Given by initial target conditions

$$\langle\epsilon\rangle = L_{path} + \langle\delta\rangle \frac{2}{N(N-1)} \sum_{i=1}^{i=N} \sum_{j=i+1}^{j=N} \left[\frac{(L_{m-tj}\,\rho_{ti} - L_{m-ti}\,\rho_{tj})}{(\rho_{tj} - \rho_{ti})}\right]$$

Feedback by Atmospheric model

Given by initial target conditions

This implies that the accuracy of the bootstrap method could be used as one measure of the performance of the atmospheric correction model.

Bootstrap Radiometric Calibration – Model Quality Estimate

Potential use of the bootstrap calibration procedure as quality metric for atmospheric correction algorithms

For a target i with a measured reflectivity ρ_{ti} and a modeled reflectivity ρ_{mi} the spectral cosine is defined as:

$$\cos\theta_i = \frac{\sum_j \rho_{ti}(\lambda_j)\rho_{mi}(\lambda_j)}{\sqrt{\sum_j \rho_{ti}^2(\lambda_j)}\ \sqrt{\sum_j \rho_{mi}^2(\lambda_j)}}$$

Given N measured reference targets the criteria for goodness of fit we propose is that the best and most consistent model is the one that leads to the minimum value of the following function.

$$G = \frac{1}{N}\sum_{i=1}^{N}(1-\cos\theta_i)$$

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