VSWIR L1 & L2: Radiance and Reflectance Algorithm Maturity, Calibration, and Validation

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1. Instrument calibration: radiometric and spectral

2. Estimation of atmosphere and surface properties

3. Field validation methods and results
Typical Analysis Chain

Lambertian Reflectance (HDRF)

Radiance at sensor
mW/nm/cm²/sr

Raw Digital Numbers

[Gao et al., 1993; Green et al., 1998, Thompson et al., 2015]
Calibration Conventions

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1. **Electronic effects** - the time-dependent radiometric response of each detector

- Correct dark offset
- Correct pedestal shift
- Correct panel ghost
- Correct flat field
- Correct bad pixels
- Statistical destriping
Working backwards from the FPA

1. **Electronic effects** - the time-dependent radiometric response of each detector

   - Correct dark offset
   - Correct pedestal shift
   - Correct panel ghost
   - Correct flat field
   - Correct bad pixels
   - Statistical destriping
   - Correct crosstrack scatter
   - Correct spatial scatter

2. **Optical effects** - the spatial and spectral “view” of each detector
Working backwards from the FPA

1. **Electronic effects** - the time-dependent radiometric response of each detector
   - Correct dark offset
   - Correct pedestal shift
   - Correct panel ghost
   - Correct flat field
   - Correct bad pixels
   - Statistical destriping
   - Correct crosstrack scatter
   - Correct spatial scatter
   - Apply radiometric coefficients

2. **Optical effects** - the spatial and spectral “view” of each detector

3. **Calibration to the S.I.** (absolute spectroradiometry)
In-flight refinement of spectral calibration via atmospheric features

Feature positions provide accurate wavelength calibration

Depths and shapes provide refined information on spectral response function
In-flight refinement of spectral calibration via atmospheric features

Feature positions provide accurate wavelength calibration

Depths and shapes provide refined information on spectral response function
Empirical channel positions

[Thompson et al., Atmospheric Measurement Techniques 2015]
Empirical spectral response


Death Valley Transect, 2014 (visible RGB)
Empirical spectral response
[Thompson et al., Remote Sensing of Environment 2018]

Death Valley Transect, 2014 (visible RGB)
Empirical spectral response
[Thompson et al., Remote Sensing of Environment 2018]
Agenda

1. Instrument calibration: radiometric and spectral

2. Estimation of atmosphere and surface properties

3. Field validation methods and results
Atmospheric Correction

Rayleigh and molecular scattering

Gas and particle absorption

Surface reflectance
Atmospheric Correction

\[ \rho_{TOA} = \rho_{atm} + \frac{T \rho_s}{1 - S \rho_s} \]

- Top of atmosphere measurement
- Path reflectance
- Transmission
- Surface reflectance
- Spherical albedo

Radiance Spectrum

Reflectance Spectrum
H$_2$O Vapor maps
[Thompson et al., Surveys in Geophysics 2018]

Central Valley Agriculture (HyspIRI Santa Barbara Box)
Improving accuracy with simultaneous fitting of water vapor, ice, and liquid

[Thompson et al., Remote Sensing of Environment 2015]
[Green et al., Water Resources Research 2006]
Improving accuracy with simultaneous fitting of water vapor, ice, and liquid

[Thompson et al., Remote Sensing of Environment 2015]
[Green et al., Water Resources Research 2006]
Three phases of water
[Thompson et al., *Surveys in Geophysics* 2018]

Yosemite National Park (HyspIRI Sierra Box)
Agenda

1. Instrument calibration: radiometric and spectral

2. Estimation of atmosphere and surface properties

3. Field validation methods and results
Ivanpah field validation

[Thompson et al., *Surveys in Geophysics* 2018]
Spectral corrections improve atmosphere retrievals
[Thompson et al., Remote Sensing of Environment 2018]
Ongoing: *Optimal Estimation* for iterative fits of surface and atmosphere


Bayesian *Maximum a Posteriori* estimate using a combined model of surface, atmosphere, instrument

Improves atmospheric correction accuracy

Rigorous uncertainty accounting

Optimal weighting of information from instrument vs. domain knowledge

https://github.com/isofit/isofit
**Example:**

volcano observations

AVIRIS-C f170127t01p00r16
(subset, visible bands)

Combined estimate of H$_2$O vapor, AOT,
surface reflectance and temperature

Aerosol Optical Depth at 550 nm

Hot crater

Aerosol Optical Depth Uncertainty
Radiance at sensor:
$mW/nm/cm^2/sr$

Lambertian Reflectance (HDRF)

Raw Digital Numbers

[Gao et al., 1993; Green et al., 1998, Thompson et al., 2015]
Thanks!

NASA Earth Science Division and the HyspIRI preparatory campaign

The AVIRIS-NG Team, including Sarah Lundeen, Brian D. Bue, Winston Olson-Duvall, John Chapman, and others

NASA Program NNH16ZDA001N-AVRSN, “Utilization of Airborne Visible/Infrared Imaging Spectrometer – Next Generation Data from an Airborne Campaign in India.” Program manager Woody Turner
Stray SRF Measurement model
Adapted from [Zhong et al., 2006]

\[
\text{Measured Radiance} = \text{Stray Radiance} + \text{Nominal Radiance} + \text{Measurement Noise}
\]
Stray SRF Measurement model
Adapted from [Zhong et al., 2006]

\[
L_M = GHL_A + HLA + \epsilon
\]
Stray SRF Measurement model
Adapted from [Zhong et al., 2006]

\[
L_M = \begin{bmatrix} G + I \end{bmatrix} L_N + \epsilon
\]

\[
L_M = A L_N + \epsilon
\]
A Linear SRF Correction Matrix

Calculate a Moore-Penrose Pseudoinverse:

\[ A^+ = (A^T A)^{-1} A^T \]

This estimates the nominal SRF:

\[ \hat{L}_N = A^+ L_M \]

A similar correction fixes cross-track stray light
India Validation Results

- 26 of 37 flight days show significant improvements ($p < 0.001$)
- Typical improvement is 20-35%
- No flight day shows a statistically significant accuracy reduction

Fractional improvement for 277 scenes
Agreement with laboratory data

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Spatial dimension

- Exploit Near-Infrared (NIR) ocean reflectance
- Use a haze-free day to constrain path radiance and adjacency effects
- Use a wind-free day with nadir observations to limit glint
- Dark water should be highly absorbant in NIR
- Dataset: 2015 Greenland ice flow
“Halo” reduction

Original RGB

612 nm, equalization stretch (0-3 μW nm⁻¹ sr⁻¹ cm⁻²)

612 nm, after CRF correction
Retrieve Stray SRF from a “Calibration Scene”

Death Valley Transect, 2014 (visible RGB)

Predict A band radiances using a Digital Elevation Model

Nonlinear least squares optimization finds SSRF parameters
Estimation accuracy for Gaussian SSRF (simulated)
Estimation accuracy for Lorentz SSRF (simulated)

\[ \alpha \text{ (Stray light fraction)} \]

\[ \begin{align*}
\text{Lorentz half width} & \quad \text{SNR 400} \\
4.71 & \quad 8.2425 \\
5.8875 & \quad 7.065 \\
8.2425 & \quad 5.8875
\end{align*} \]
Fit error for candidate SSRF shapes

<table>
<thead>
<tr>
<th>Line shape</th>
<th>Error</th>
<th>$\alpha$</th>
<th>SSRF parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original</td>
<td>0.04482</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Pareto</td>
<td>0.004482</td>
<td>0.0805</td>
<td>x: 0.154, y: 0.0515</td>
</tr>
<tr>
<td>Lorentz</td>
<td>0.002059</td>
<td>0.0664</td>
<td>x: 1.018, y: 3.912</td>
</tr>
<tr>
<td>Voigt</td>
<td>0.001413</td>
<td>0.0639</td>
<td>$\sigma$: 5.477, $LHW$: 0</td>
</tr>
<tr>
<td>Gaussian</td>
<td>0.001413</td>
<td>0.0639</td>
<td>$\sigma$: 5.477</td>
</tr>
</tbody>
</table>
Improvement in O₂ A band fit

![Graph showing improvement in O₂ A band fit]
Radiometric calibration repeatability (hangar protocol)

Flat field: $\sigma < 0.14\%$ across most elements

Calibration coefficients: $\sigma < 0.05\%$ across most channels