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

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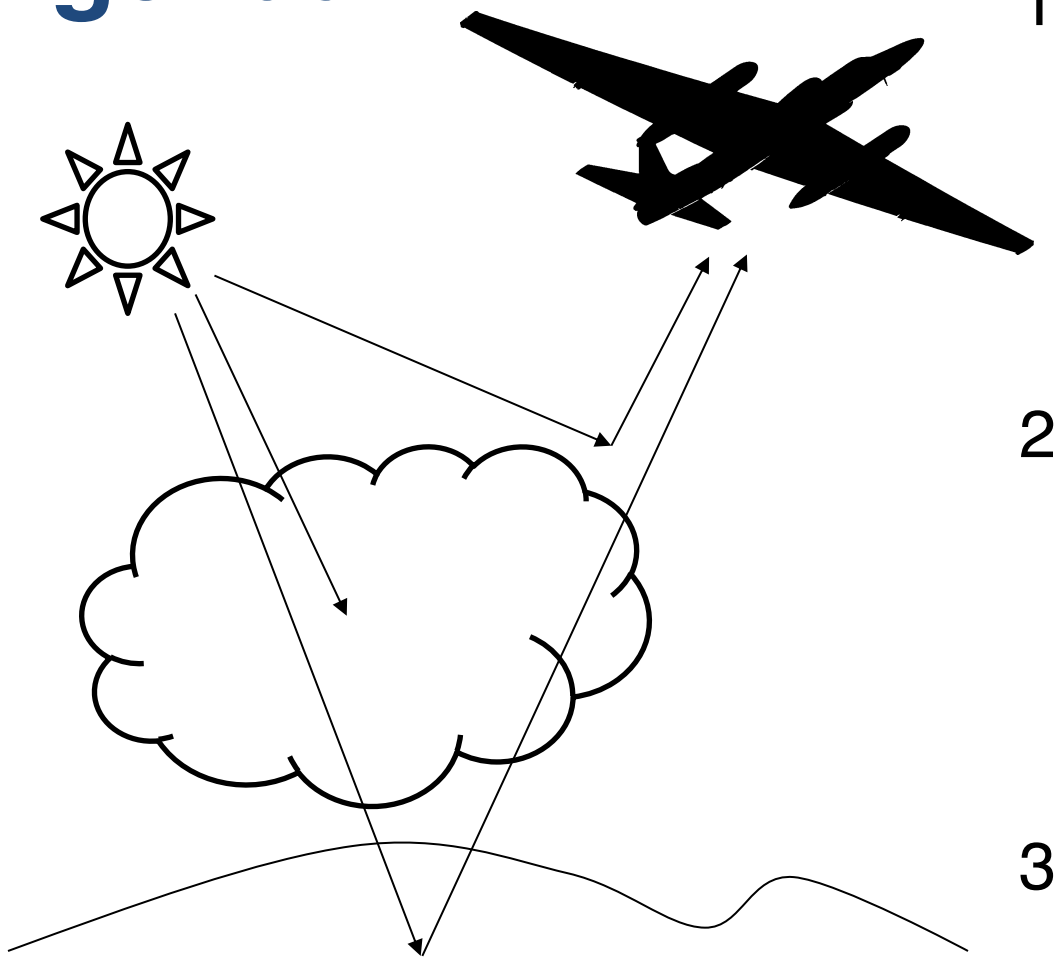
Agenda



1. Instrument calibration: radiometric and spectral
2. Estimation of atmosphere and surface properties
3. Field validation methods and results

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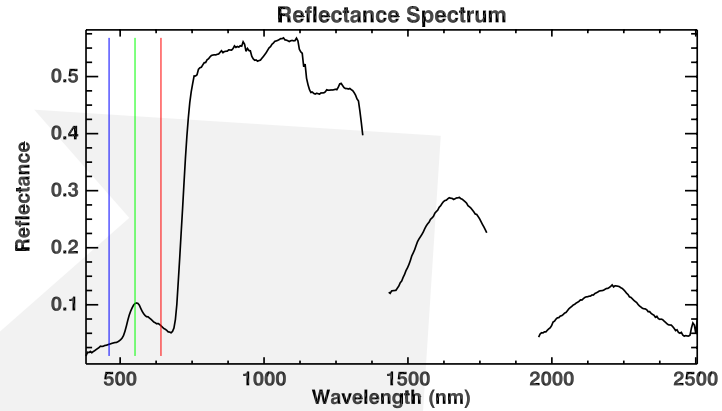
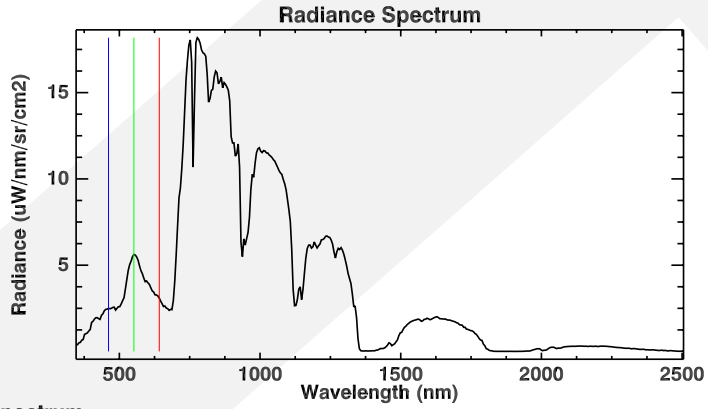
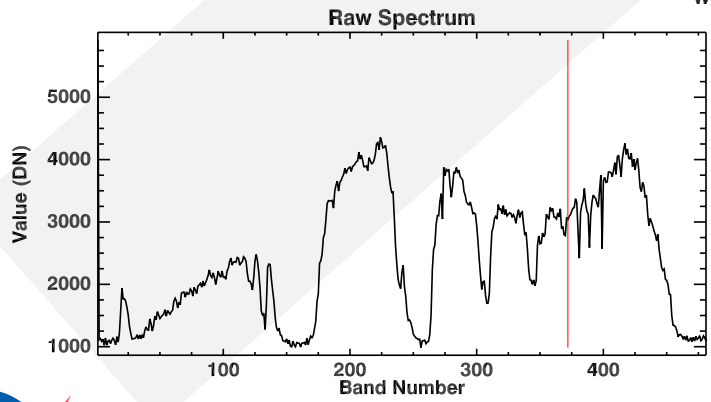
Typical Analysis Chain



Lambertian Reflectance (HDRF)



Radiance at sensor mW/nm/cm^2/sr



Raw Digital Numbers

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

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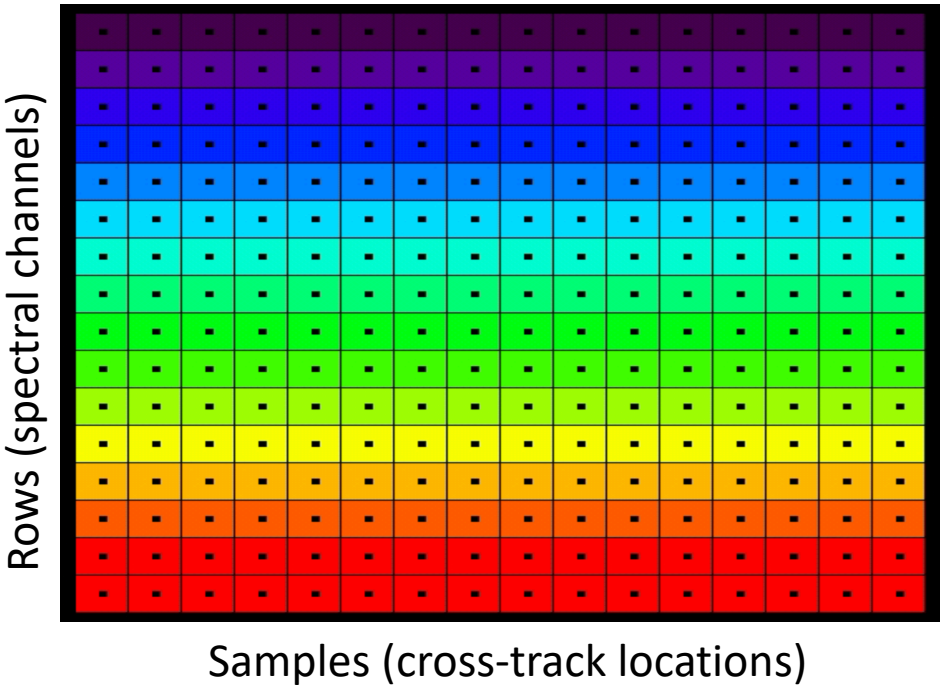
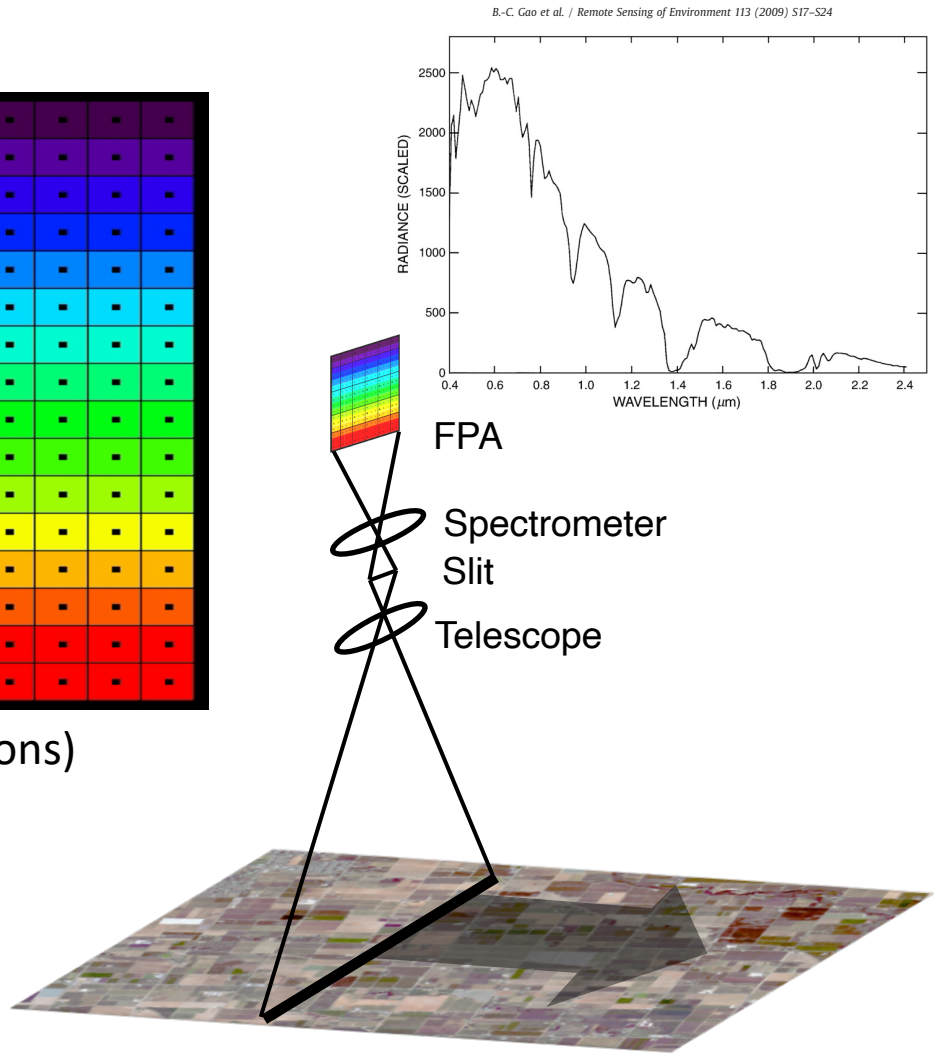
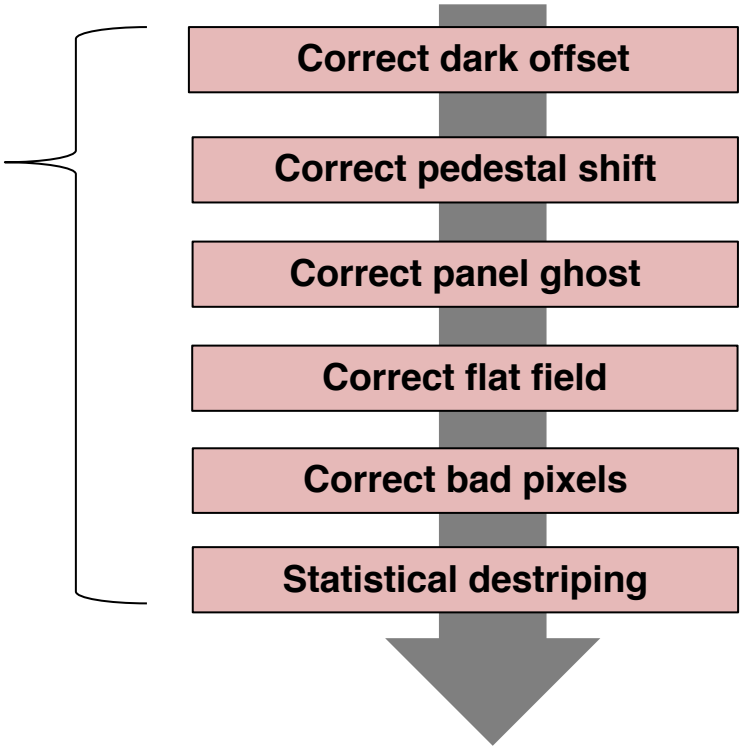
Calibration Conventions





Working backwards from the FPA

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



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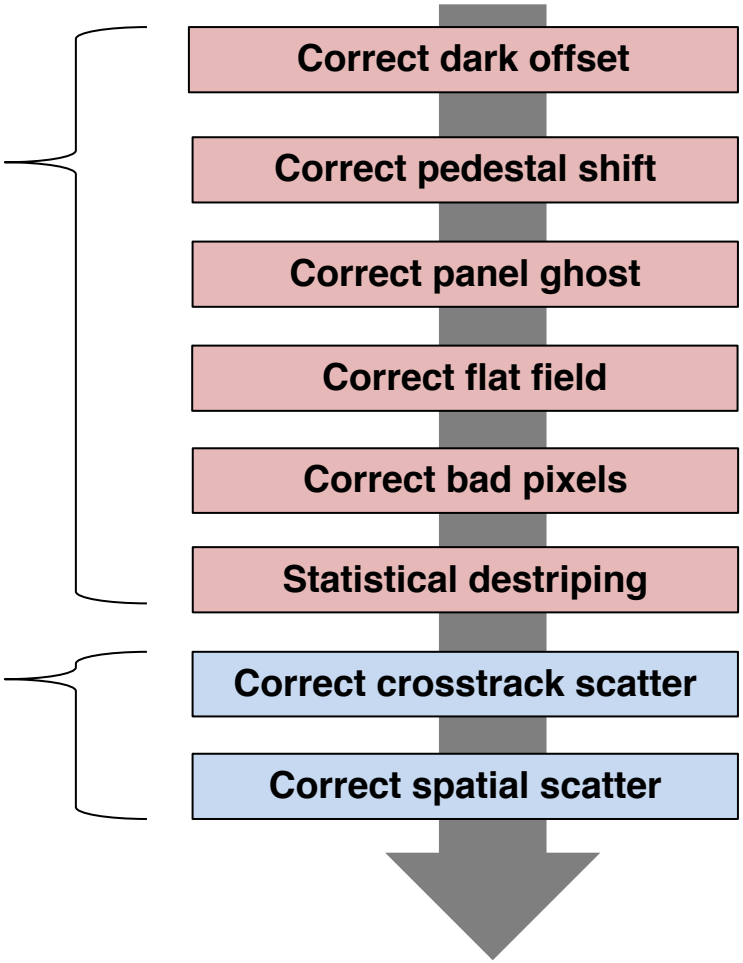
Working backwards from the FPA

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

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



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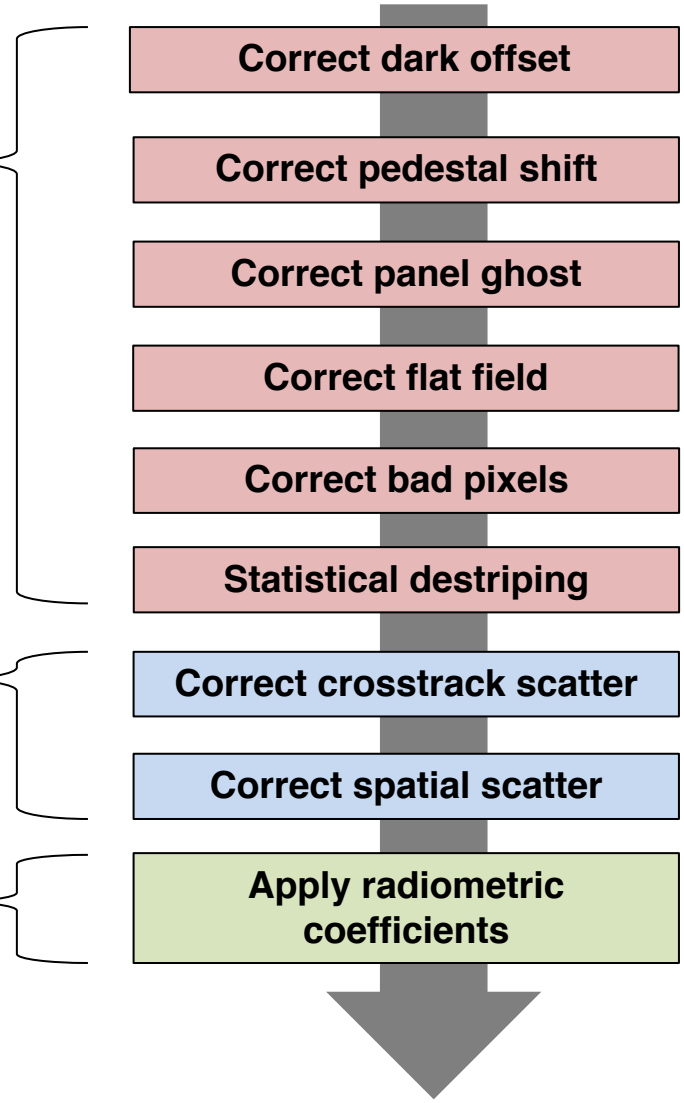
Working backwards from the FPA

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

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

3. **Calibration to the S.I.** (absolute spectroradiometry)



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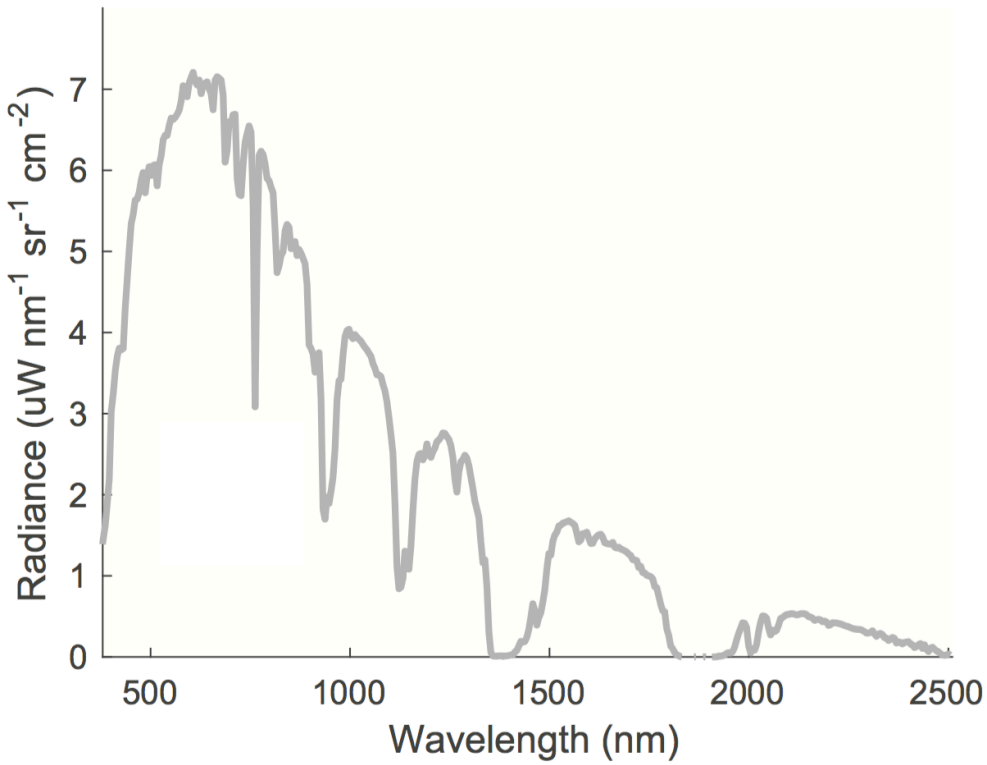
In-flight refinement of spectral calibration via atmospheric features

Feature positions provide accurate wavelength calibration

Depths and shapes provide refined information on spectral response function



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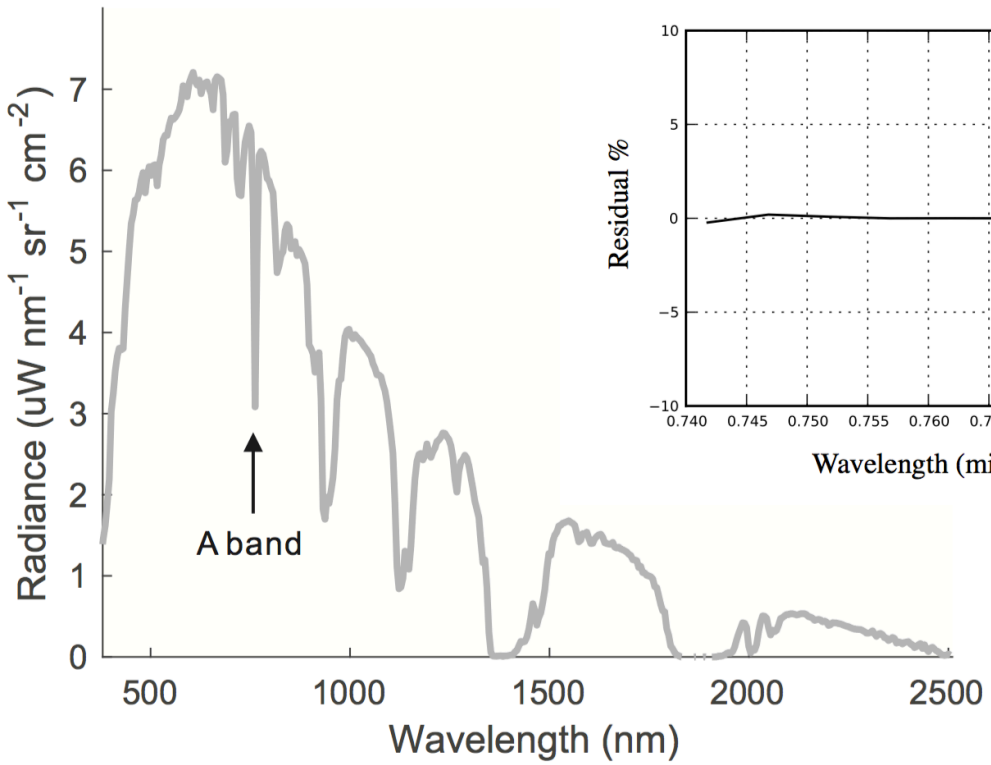

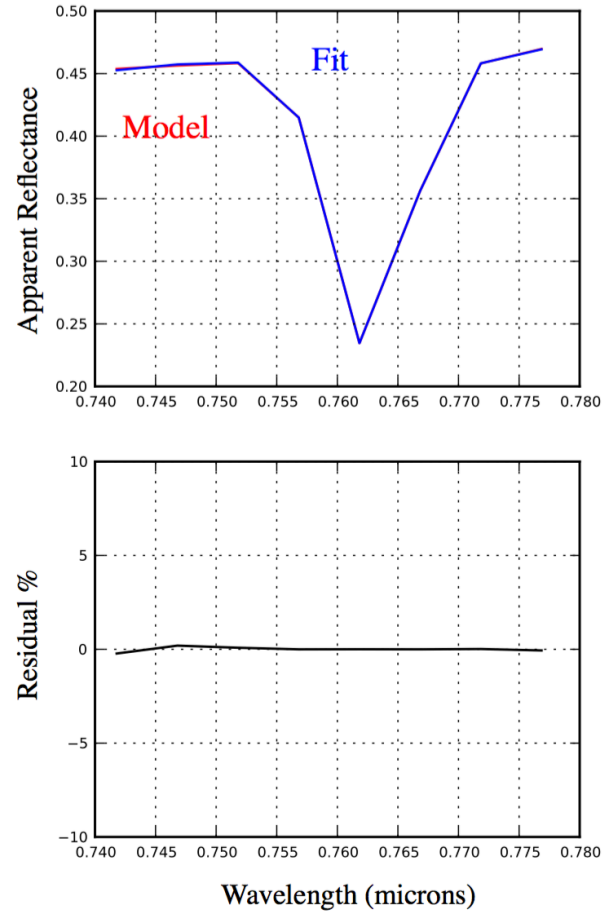

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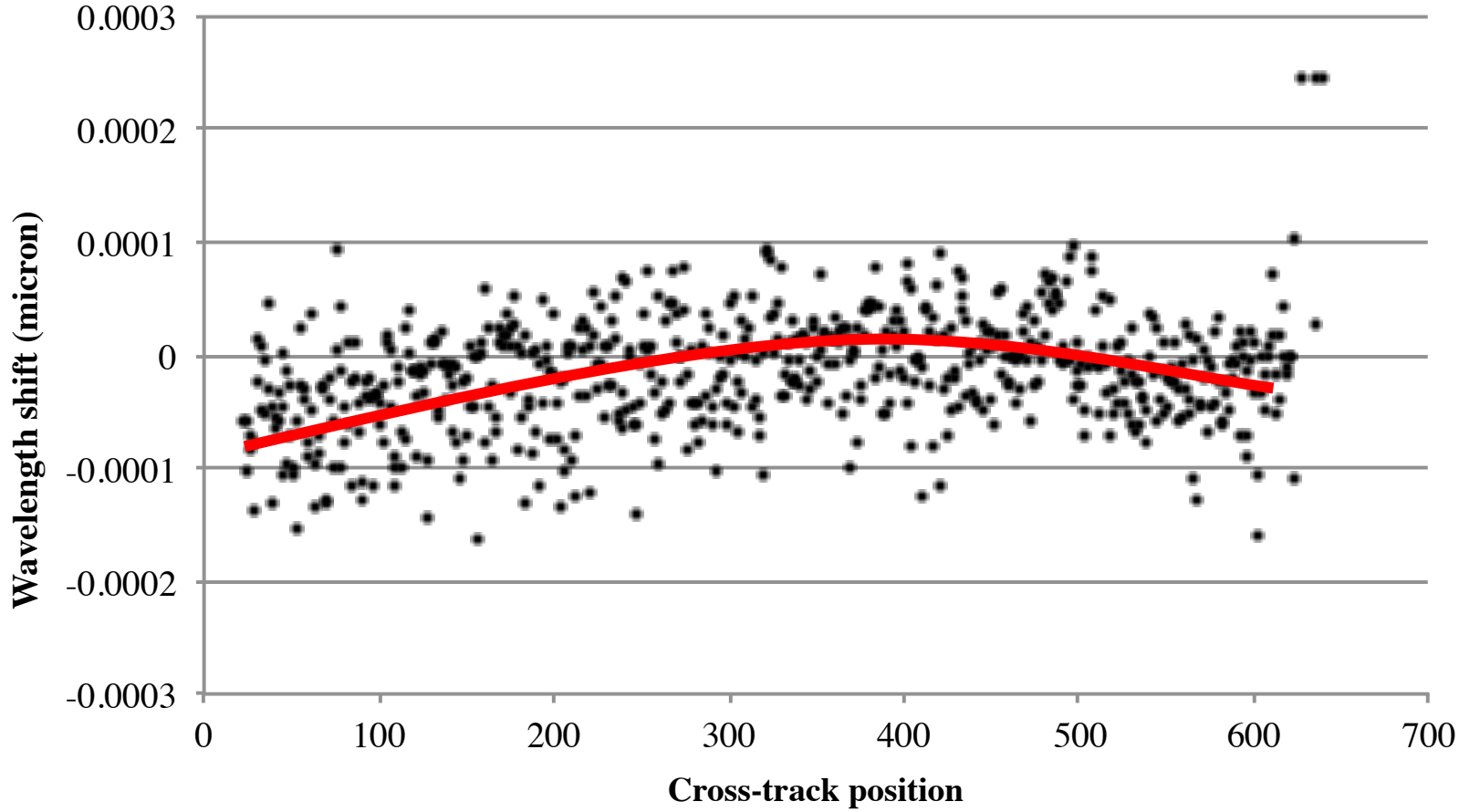
Empirical channel positions

[Thompson et al., *Atmospheric Measurement Techniques* 2015]



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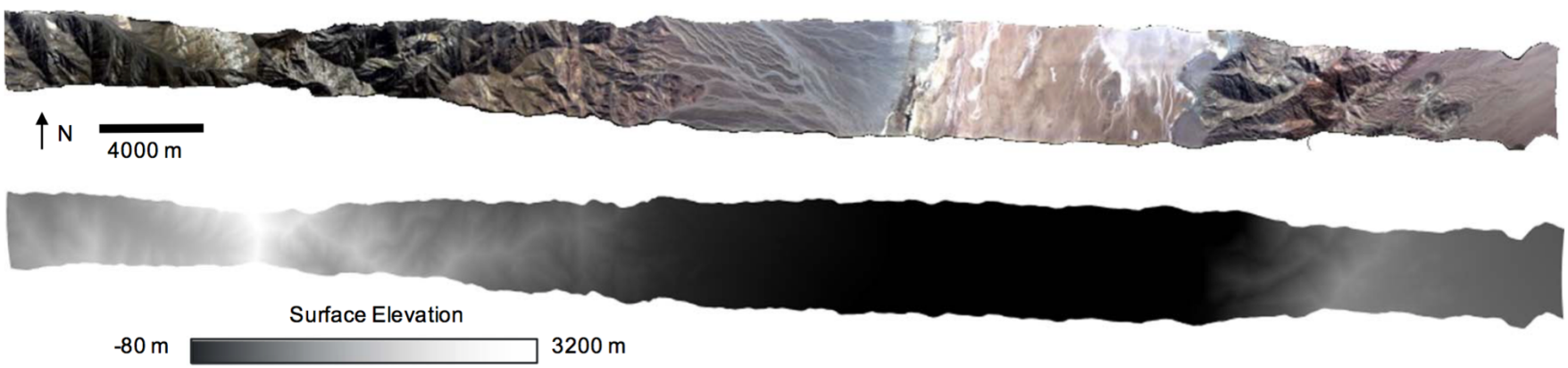
Empirical spectral response

[Thompson et al., *Remote Sensing of Environment* 2018]

Death Valley Transect, 2014 (visible RGB)



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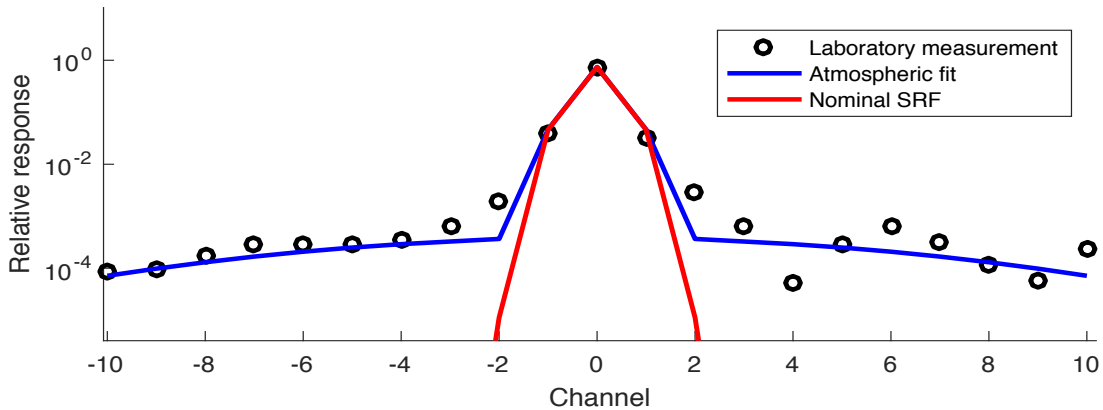
Empirical spectral response

[Thompson et al., *Remote Sensing of Environment* 2018]



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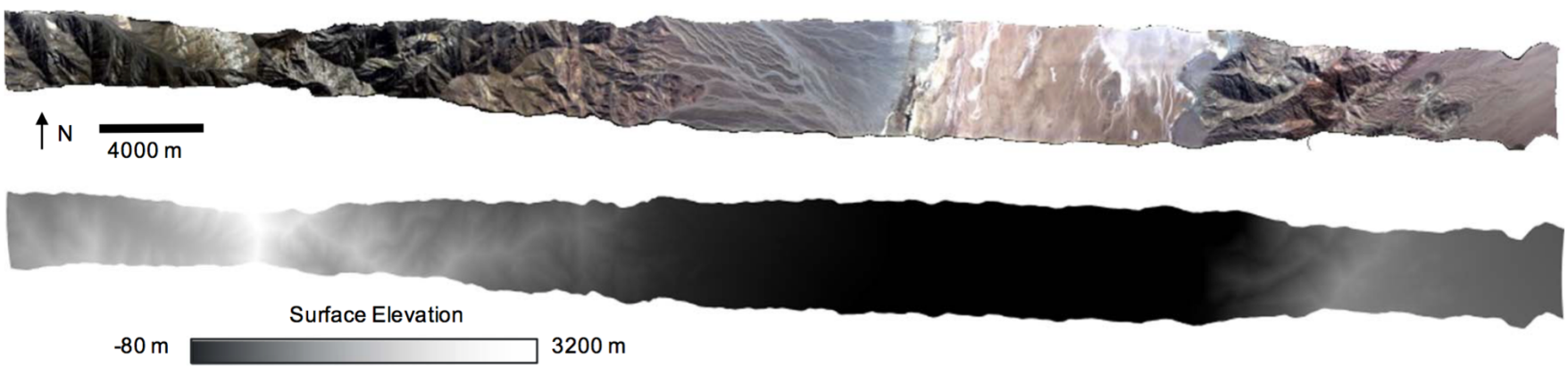

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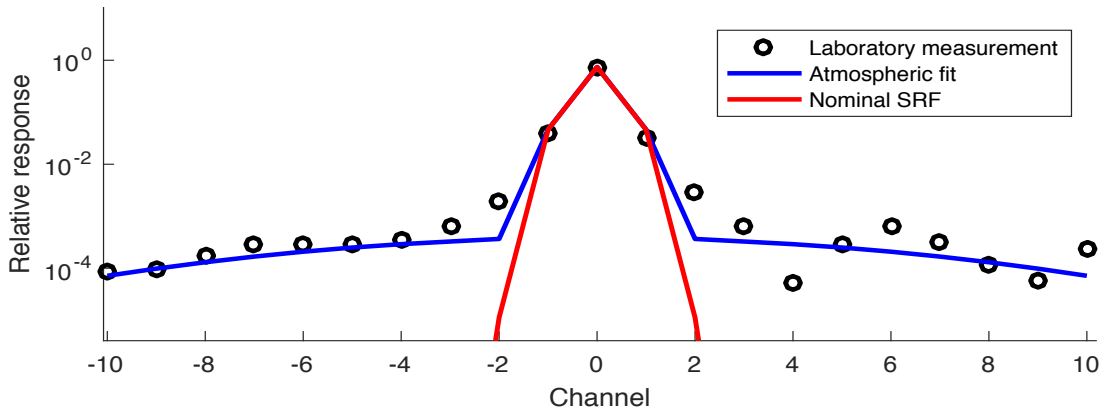
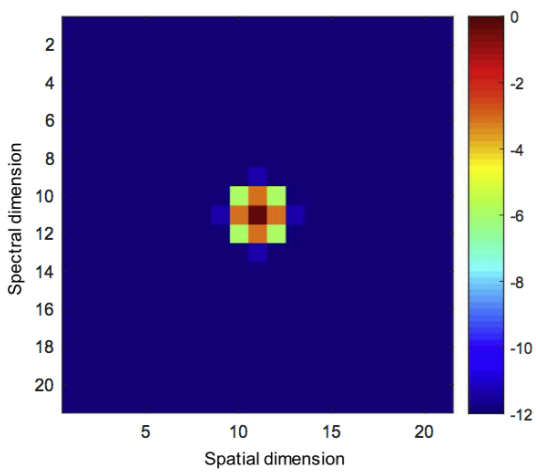
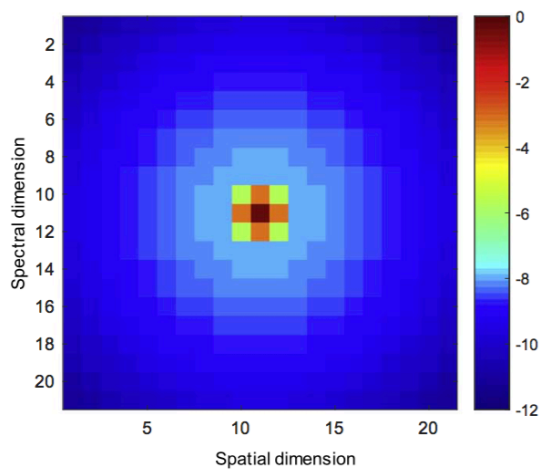


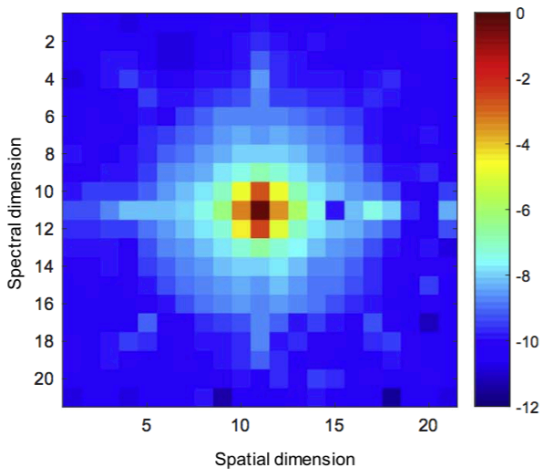
Nominal response



Atmospheric fit



Laboratory measurement



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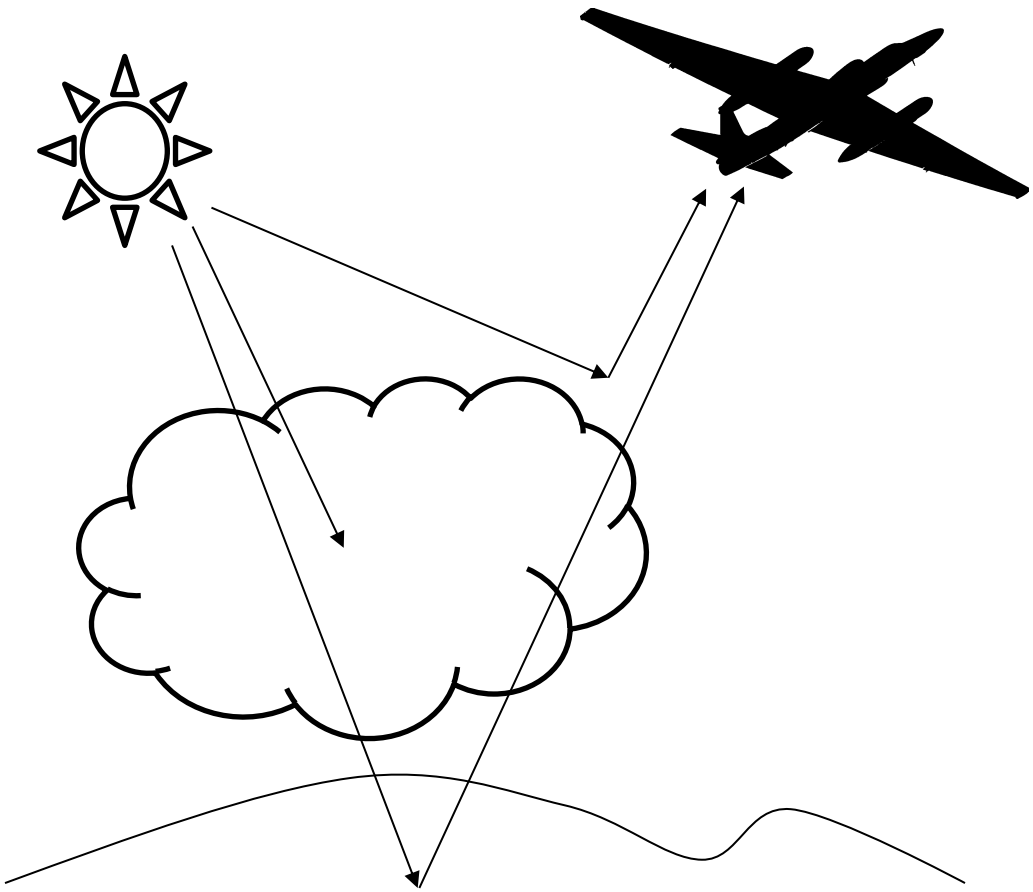
Agenda



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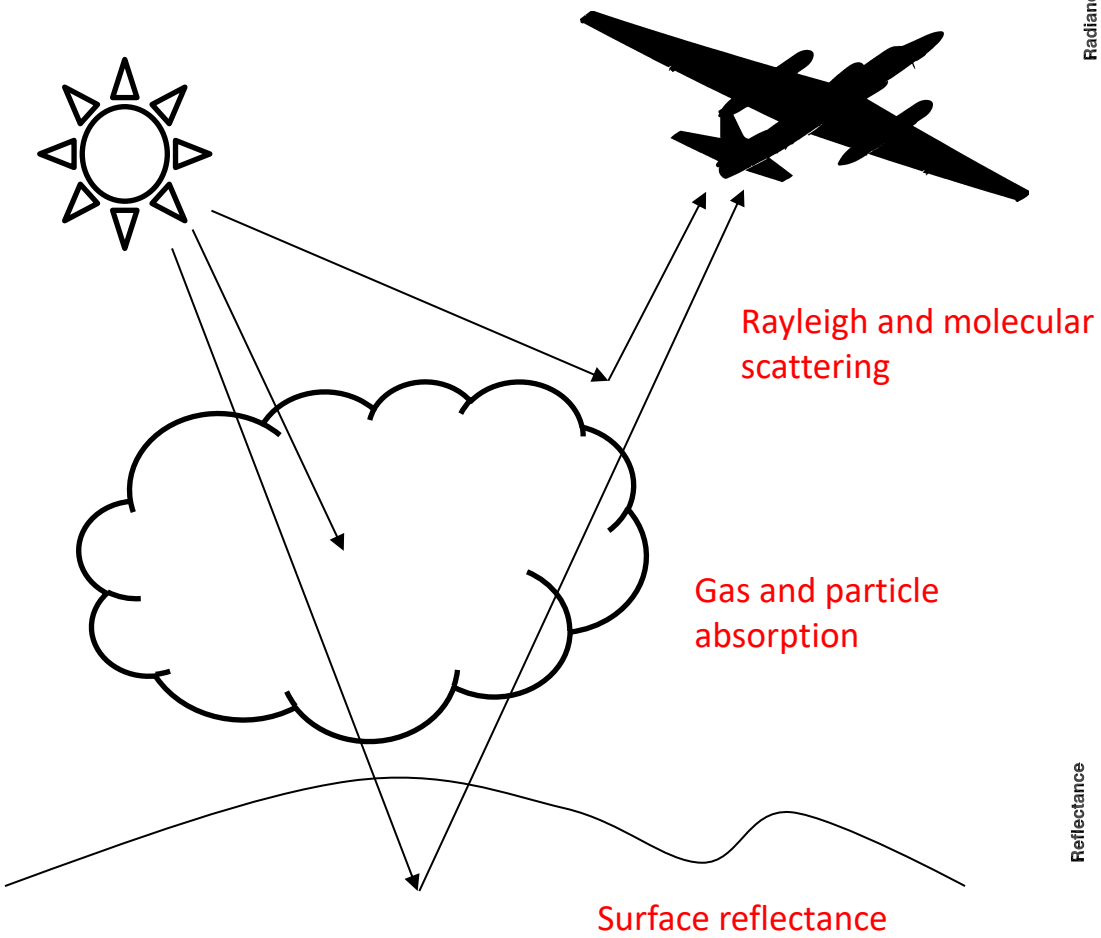
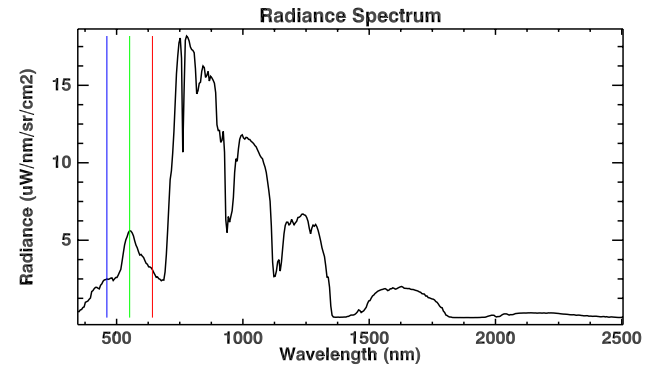
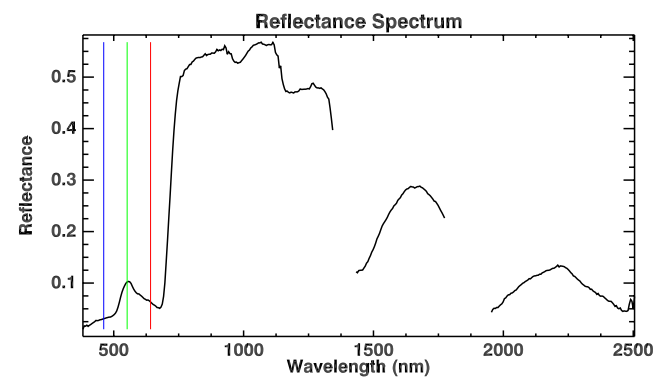
Atmospheric Correction







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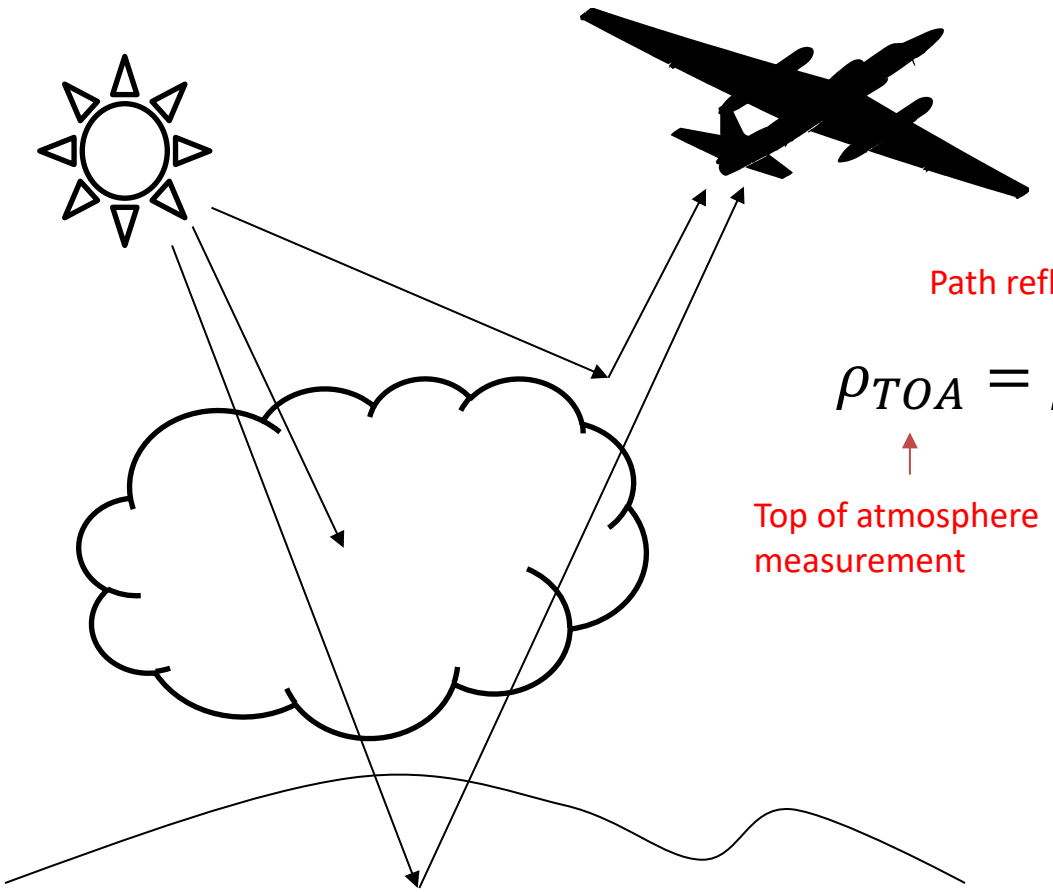
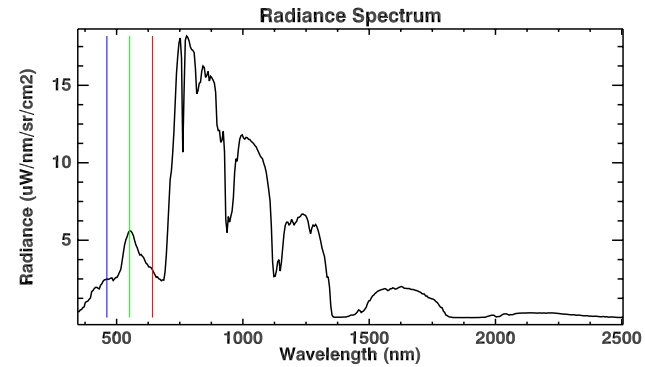




Transmission

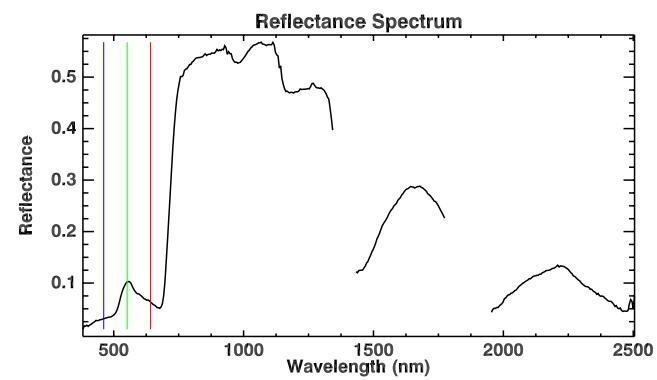
Path reflectance

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

Surface reflectance

Top of atmosphere measurement

Spherical albedo



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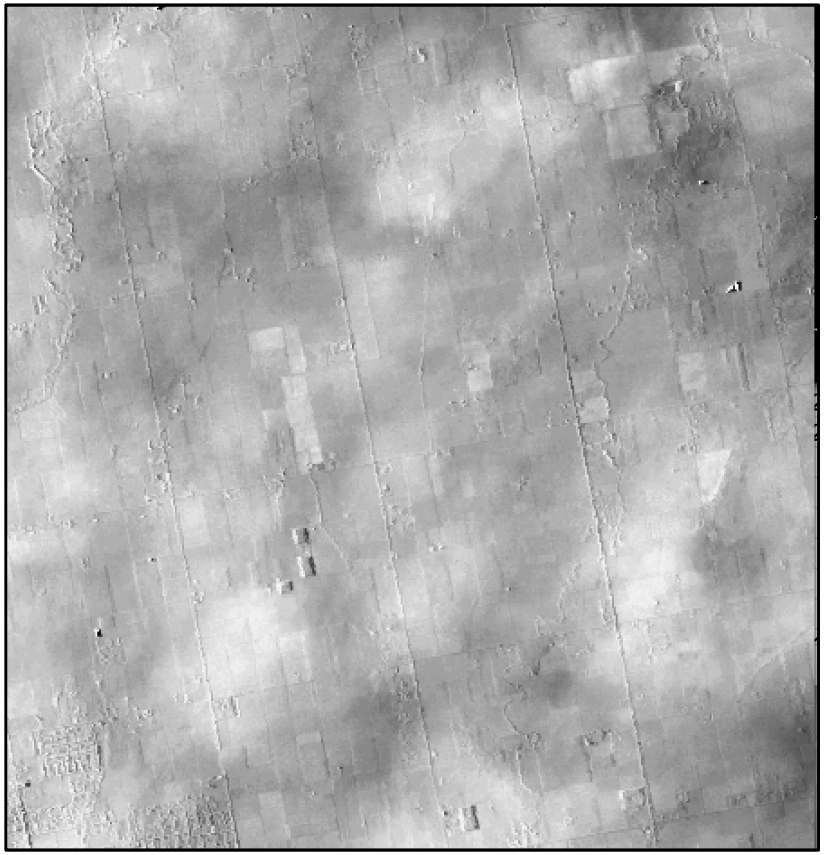
H_2O Vapor maps

[Thompson et al., *Surveys in Geophysics* 2018]



Central Valley Agriculture (HyspIRI Santa Barbara Box)

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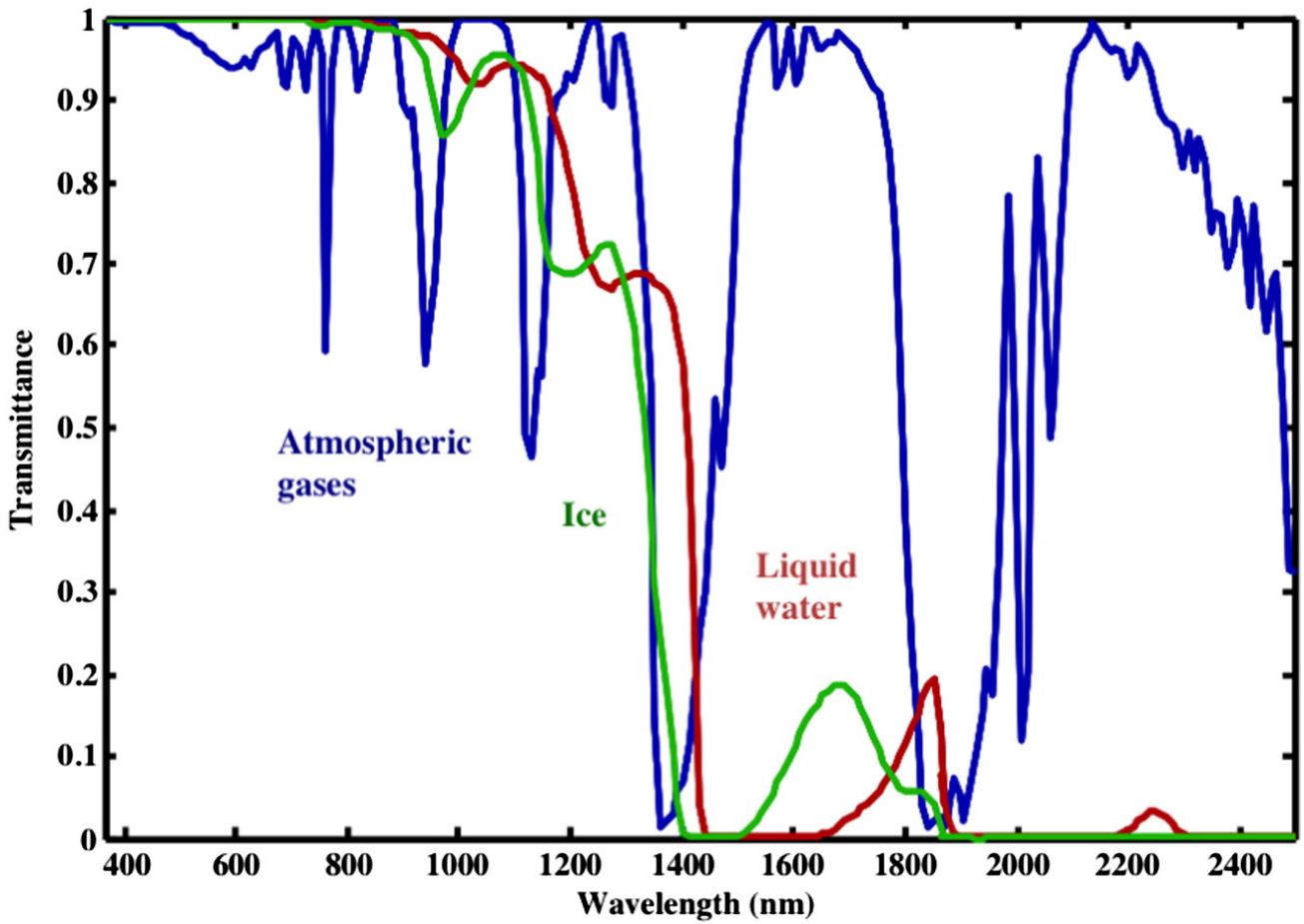
Improving accuracy with simultaneous fitting of water vapor, ice, and liquid

[Thompson et al., *Remote Sensing of Environment* 2015]
[Green et al., *Water Resources Research* 2006]



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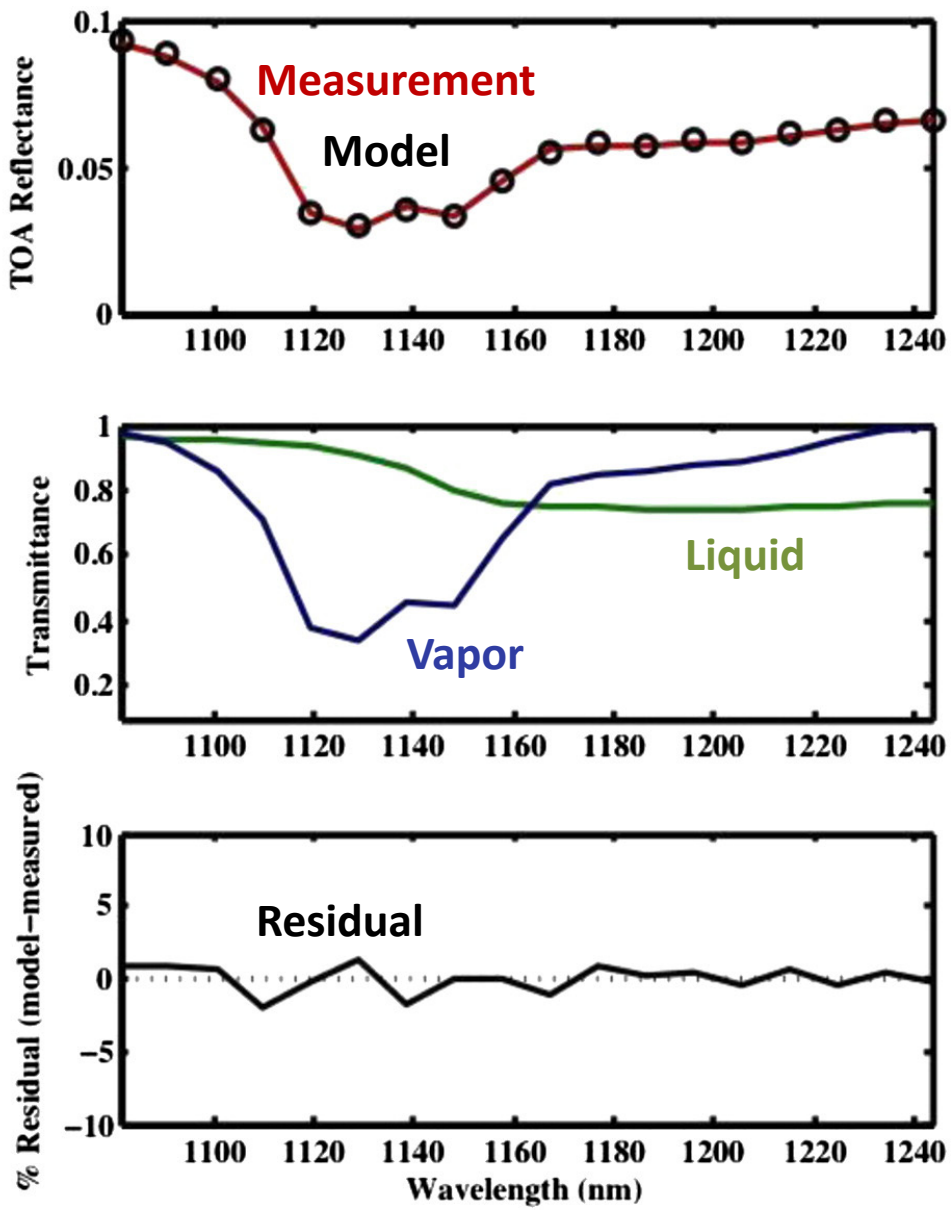

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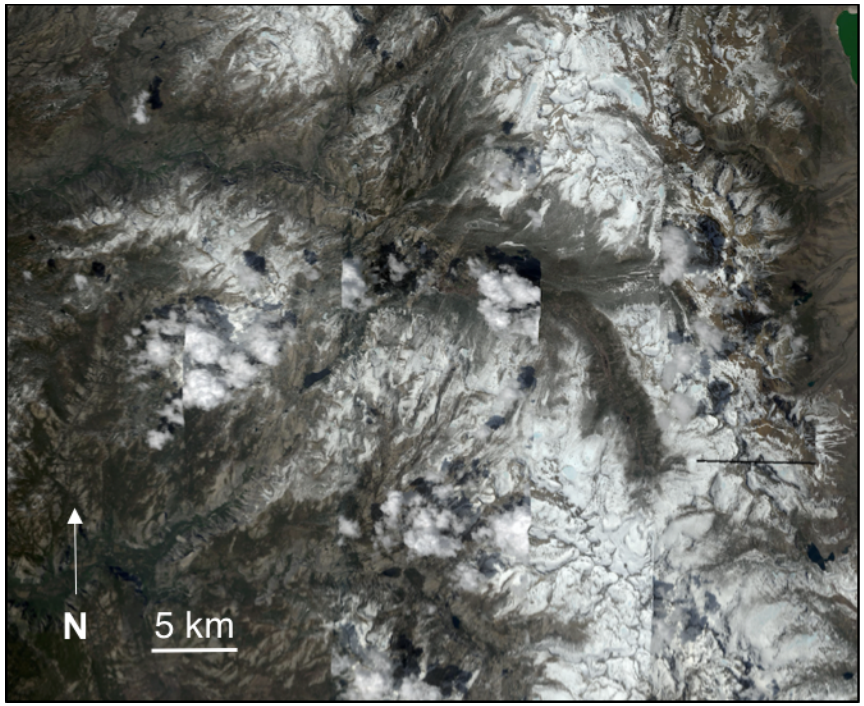
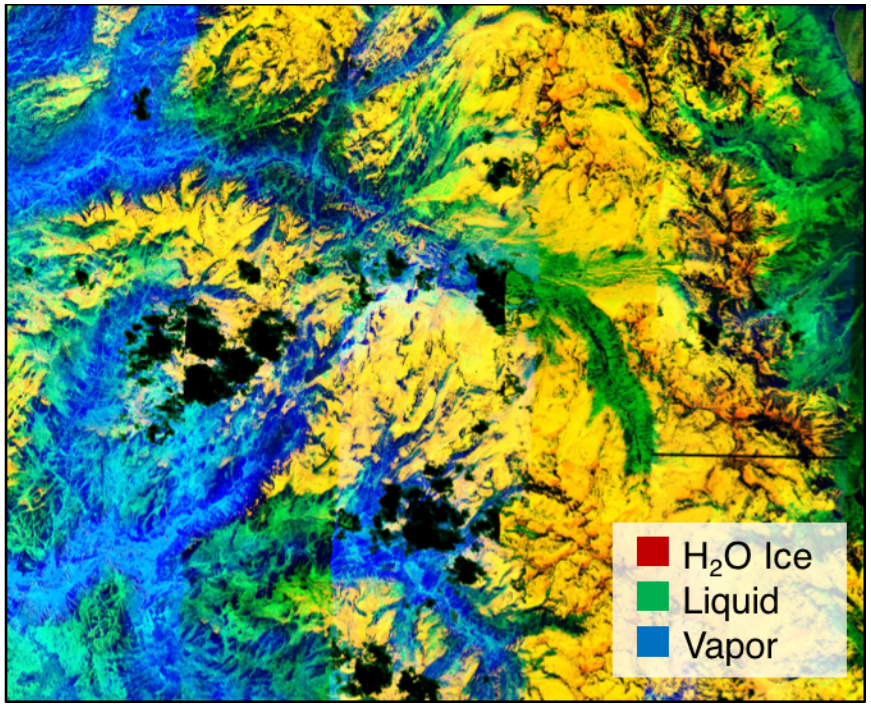
Three phases of water

[Thompson et al., *Surveys in Geophysics* 2018]

Yosemite National Park (HyspIRI Sierra Box)





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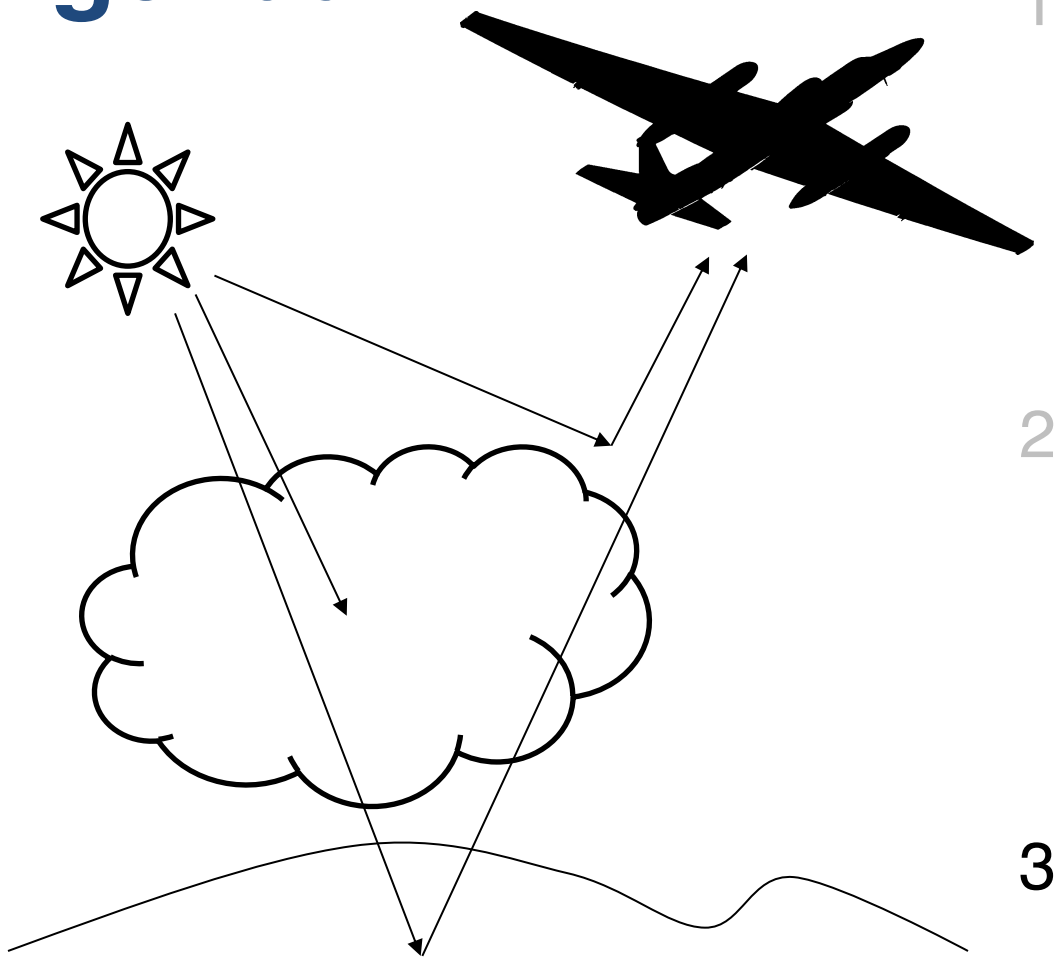
Agenda



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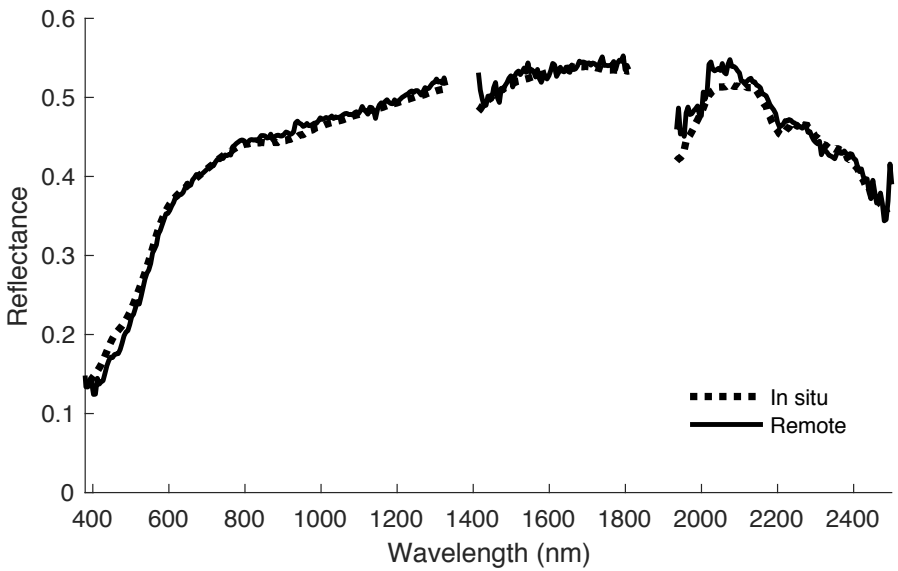
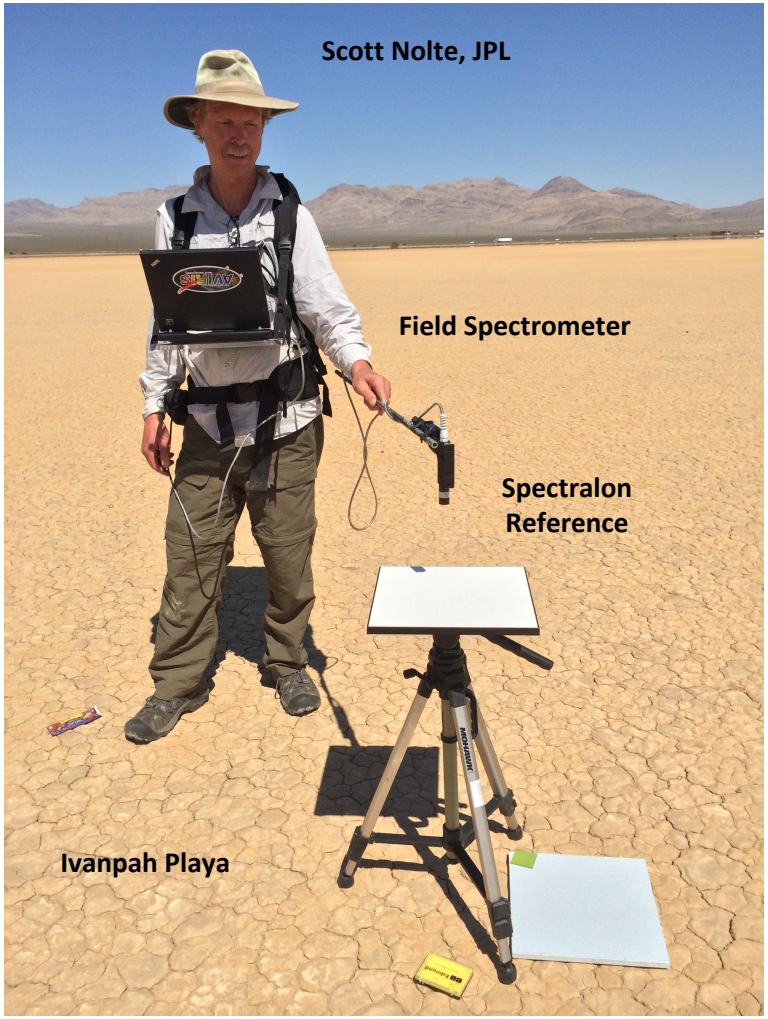
Ivanpah field validation

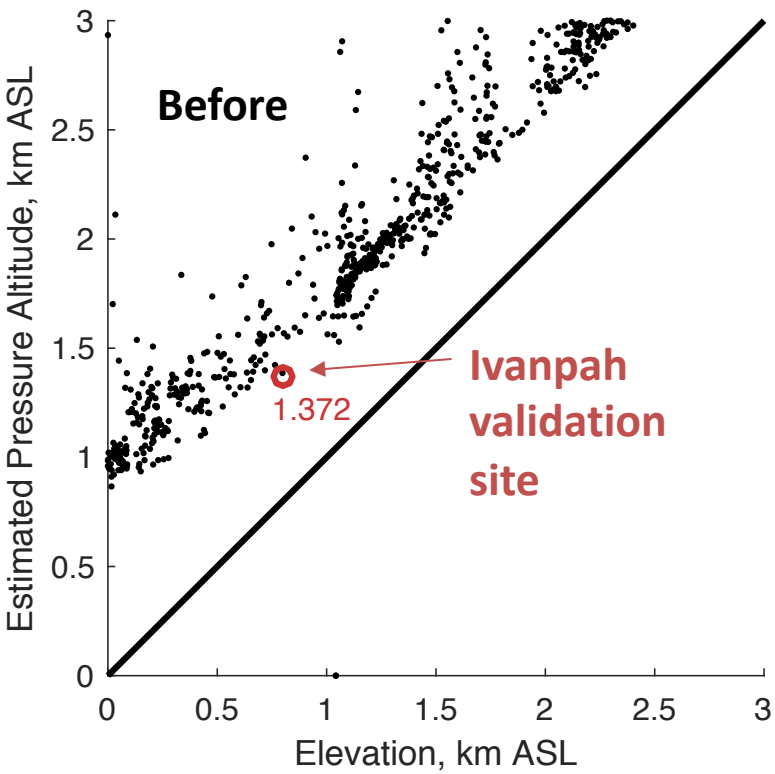
[Thompson et al., *Surveys in Geophysics* 2018]

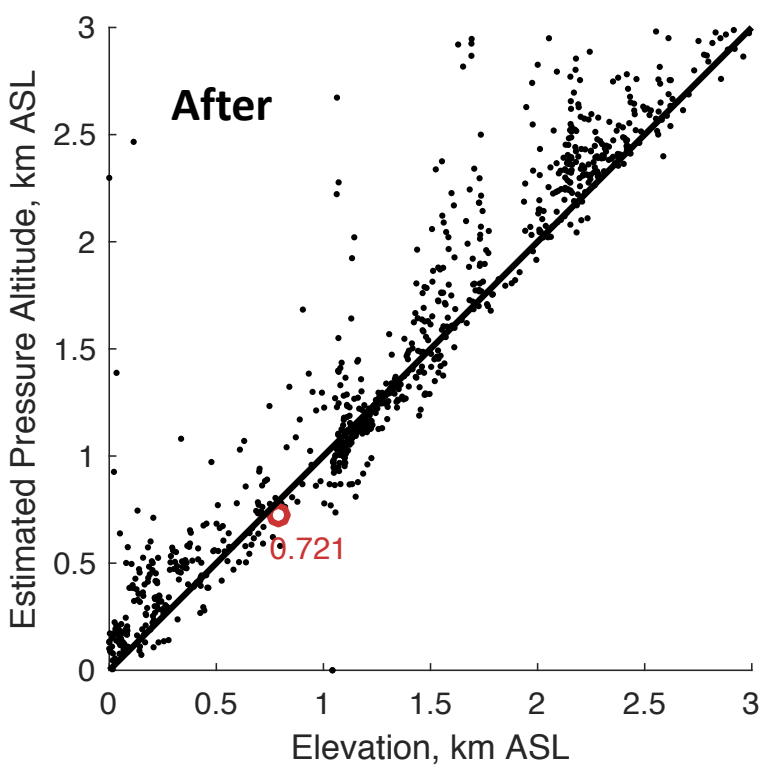




Spectral corrections improve atmosphere retrievals

[Thompson et al., *Remote Sensing of Environment* 2018]





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Ongoing: *Optimal Estimation* for iterative fits of surface and atmosphere

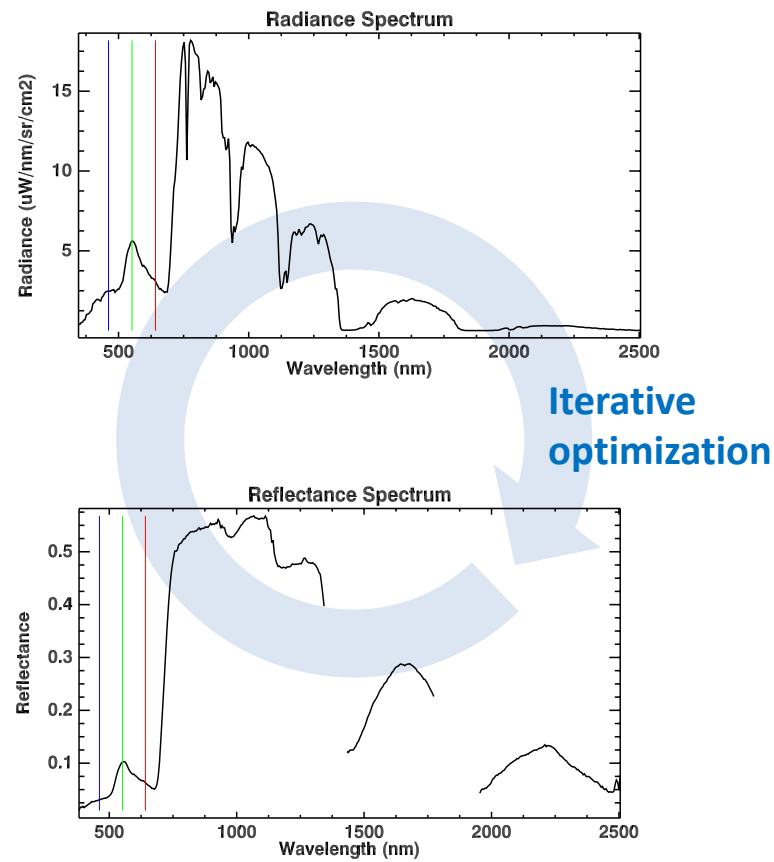
[Thompson et al., *Remote Sensing of Environment* 2018]

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

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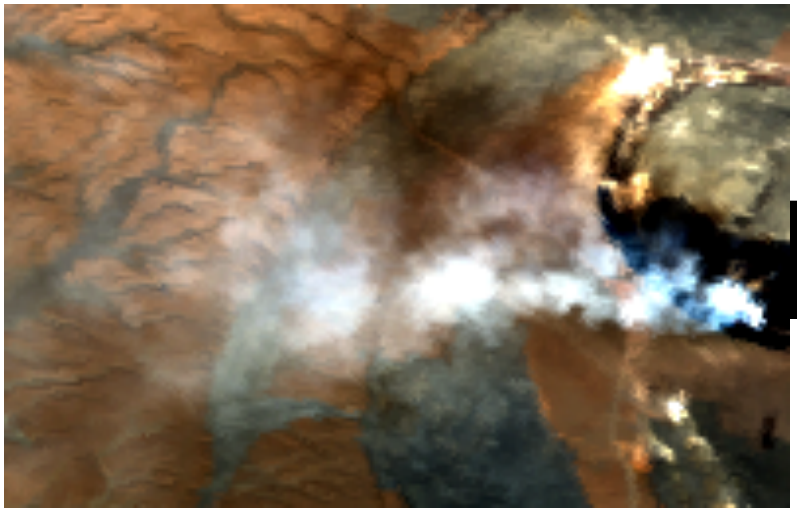
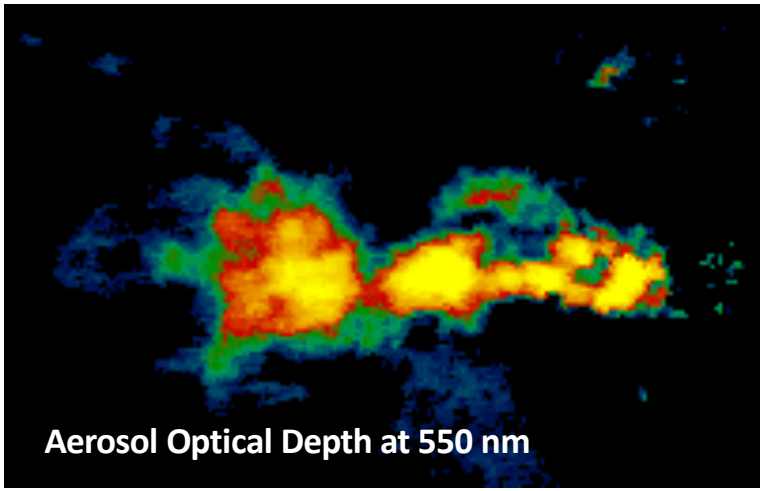
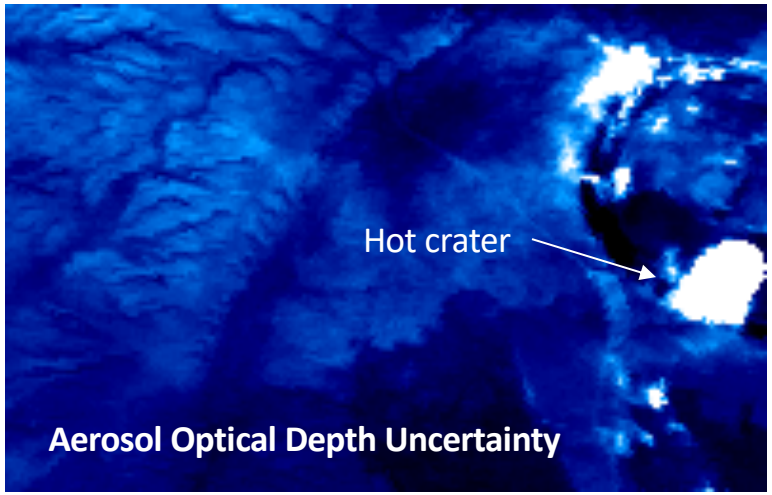
Example: volcano observations



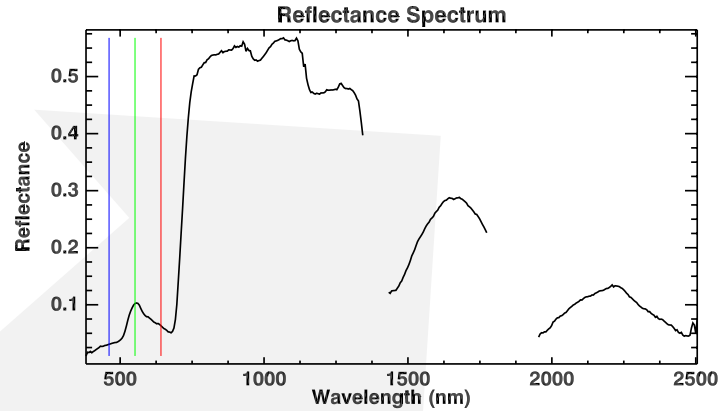
AVIRIS-C f170127t01p00r16
(subset, visible bands)

Combined estimate of H_2O vapor, AOT, surface reflectance and temperature

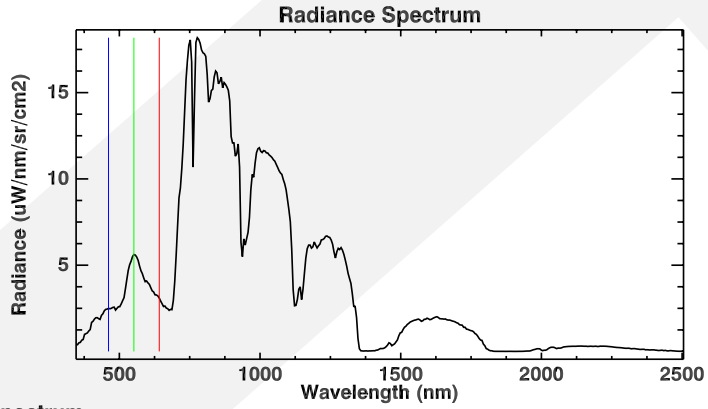




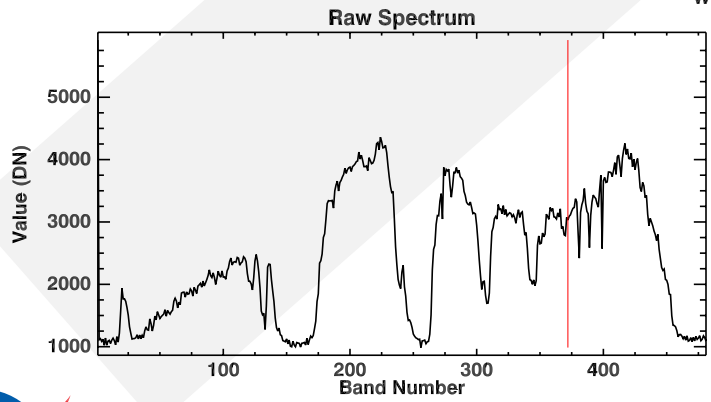
Summary



Lambertian Reflectance (HDRF)



Radiance at sensor mW/nm/cm^2/sr



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

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BACKUP

Stray SRF Measurement model

Adapted from [Zhong et al., 2006]

Measured Radiance = **Stray Radiance** + **Nominal Radiance** + **Measurement Noise**

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Stray SRF Measurement model

Adapted from [Zhong et al., 2006

Measured Radiance	=	Stray Radiance	+	Nominal Radiance	+	Measurement Noise
		⇩		⇩		⇩
$\mathbf{L}_M$	=	$\mathbf{GHL}_A$	+	$\mathbf{HL}_A$	+	ϵ

Stray SRF ↑ Nominal SRF ↑ Radiance at sensor ↑

Stray SRF Measurement model

Adapted from [Zhong et al., 2006]

Measured Radiance = Stray Radiance + Nominal Radiance + Measurement Noise

$$\mathbf{L}_M = \mathbf{G}\mathbf{H}\mathbf{L}_A + \mathbf{H}\mathbf{L}_A + \epsilon$$

Stray SRF

Nominal SRF

Radiance at sensor

$$\mathbf{L}_M = [\mathbf{G}+\mathbf{I}]\mathbf{L}_N + \epsilon$$

$$\mathbf{L}_M = \mathbf{A}\mathbf{L}_N + \epsilon$$

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A Linear SRF Correction Matrix

Calculate a Moore-Penrose Pseudoinverse:

$$\mathbf{A}^{+} = (\mathbf{A}^{T}\mathbf{A})^{-1}\mathbf{A}^{T}$$

This estimates the nominal SRF:

$$\widehat{\mathbf{L}}_N = \mathbf{A}^{+}\mathbf{L}_M$$

Corrected Radiance

Correction matrix

Distorted Measurement

A similar correction fixes cross-track stray light

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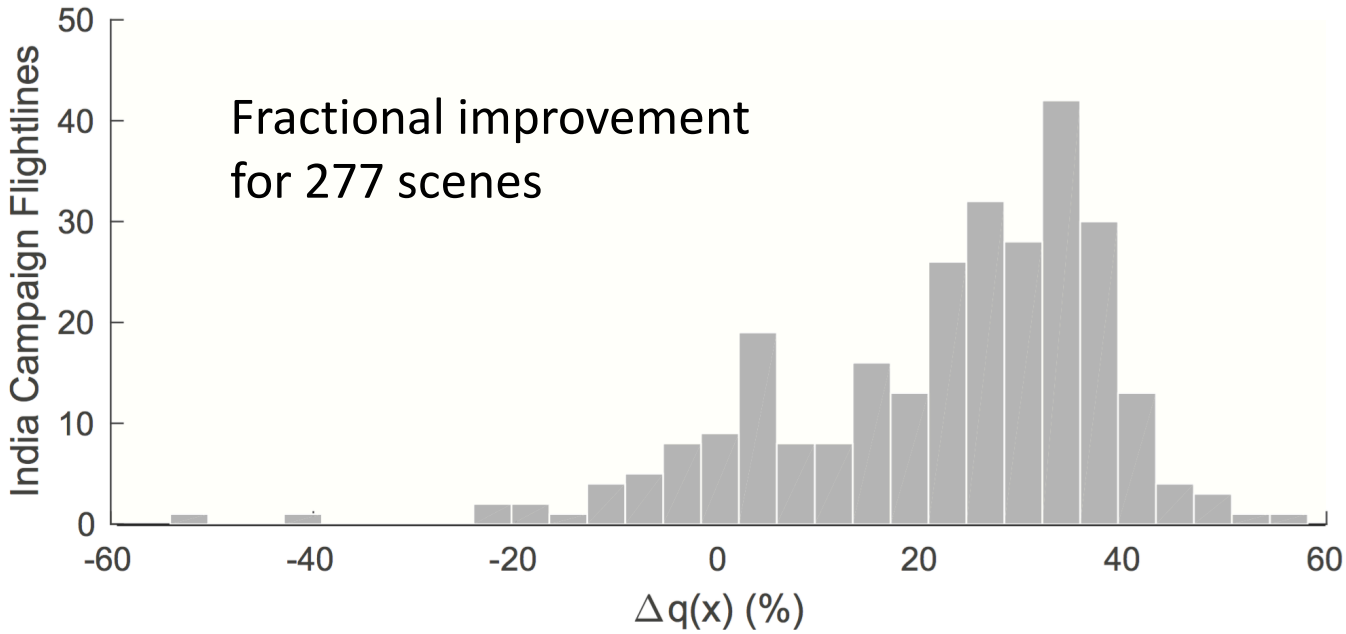
India Validation Results

- 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



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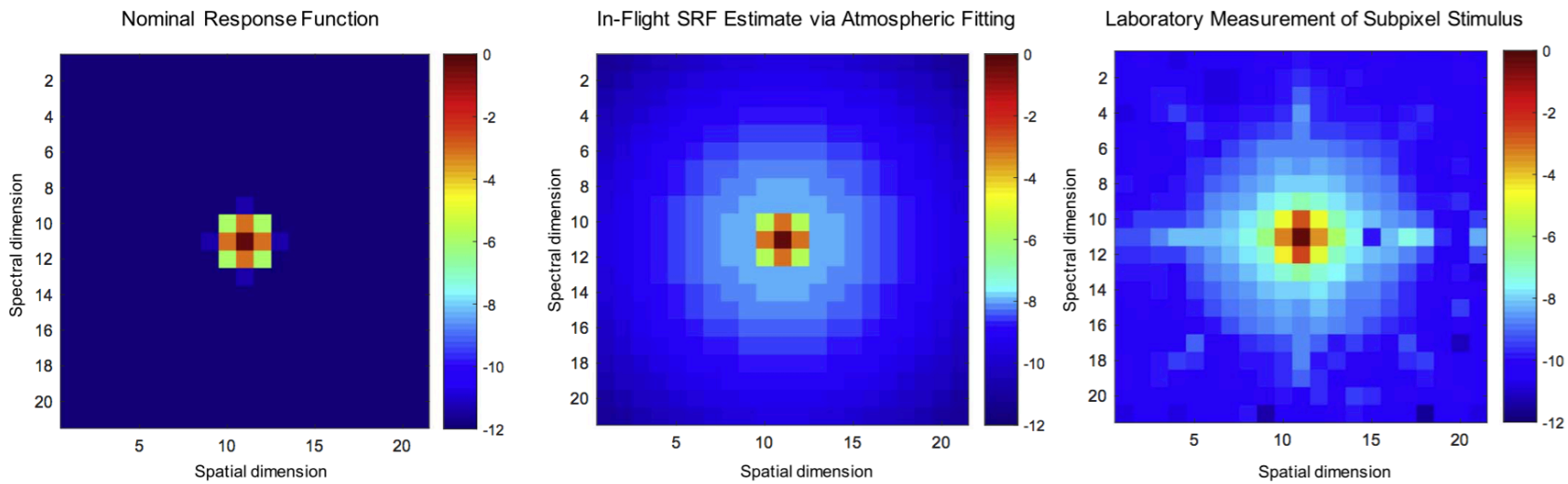
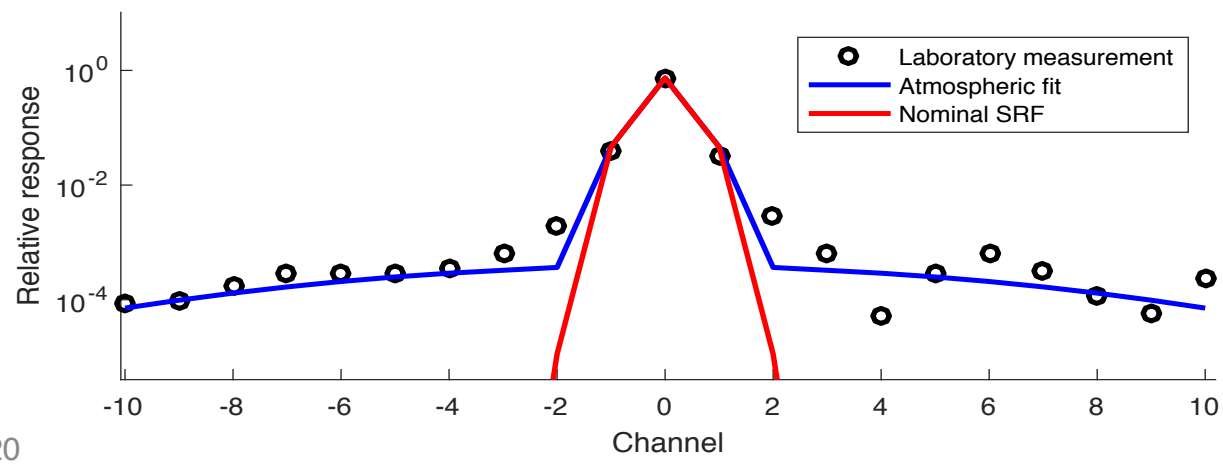
Agreement with laboratory data





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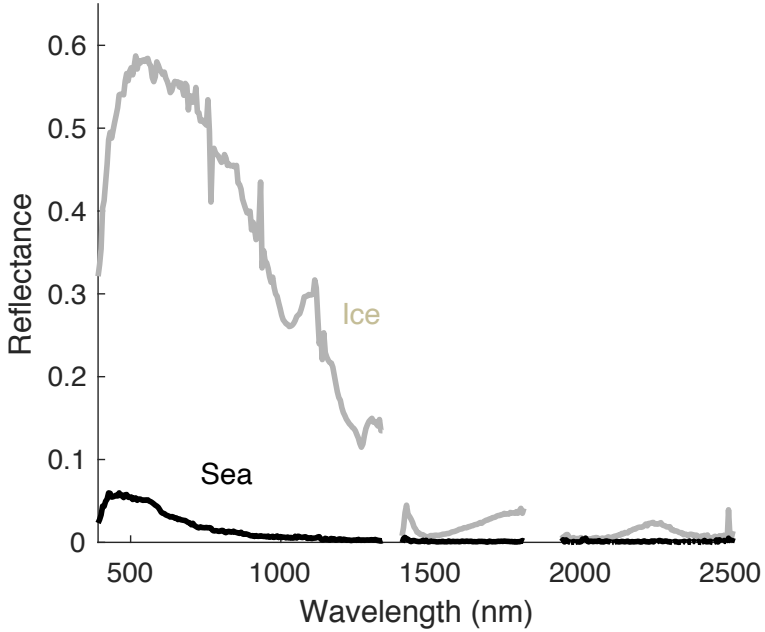
Spatial dimension

- 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



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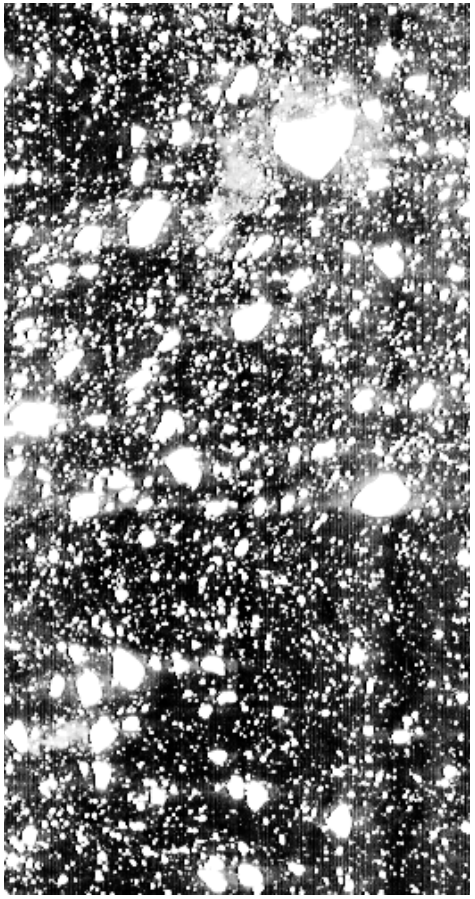
“Halo” reduction

Original RGB

612 nm, equalization stretch (0-3 uW nm^{-1} sr^{-1} cm^{-2})



612 nm, after CRF correction

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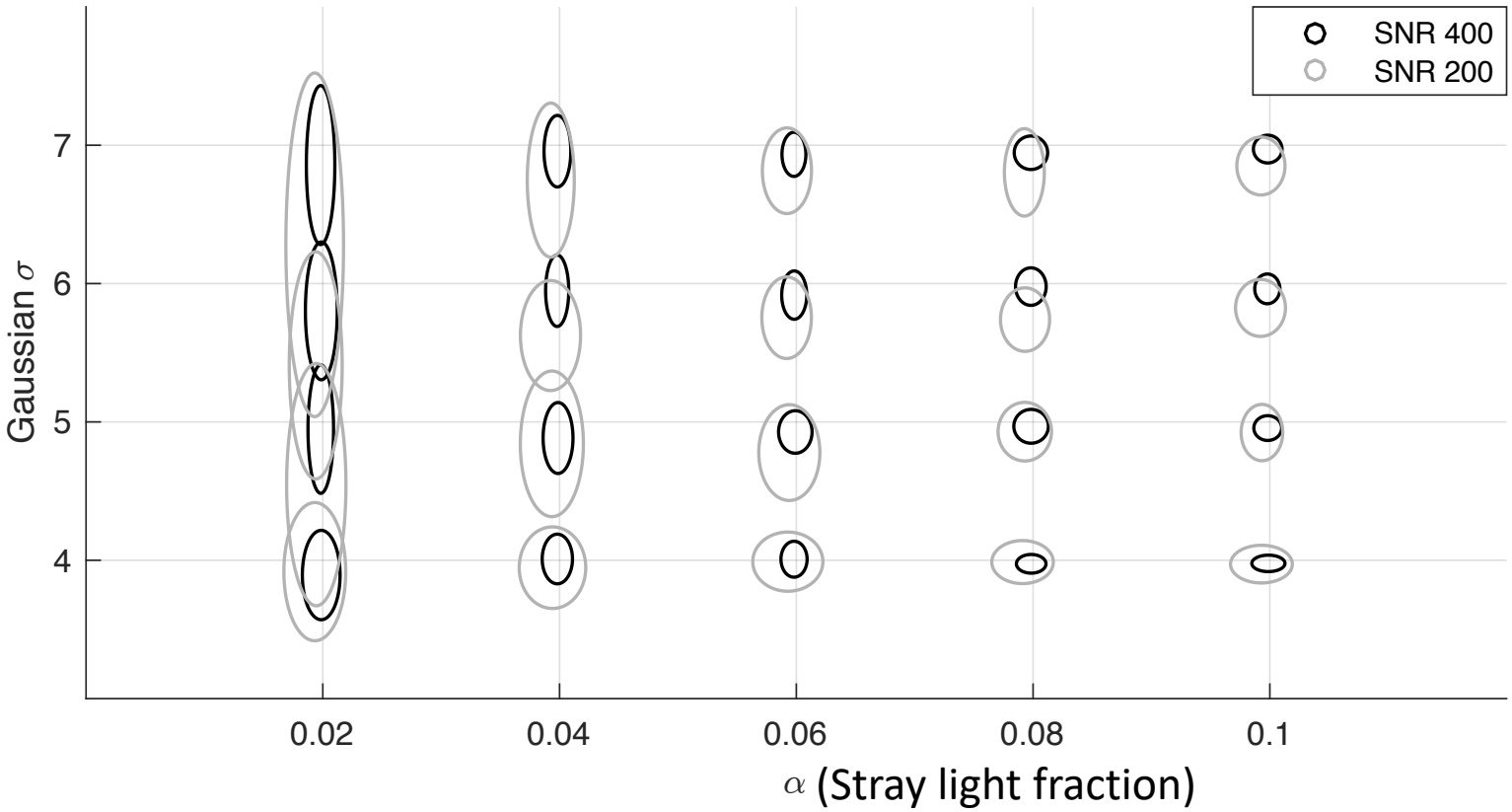
Retrieve Stray SRF from a "Calibration Scene"

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)



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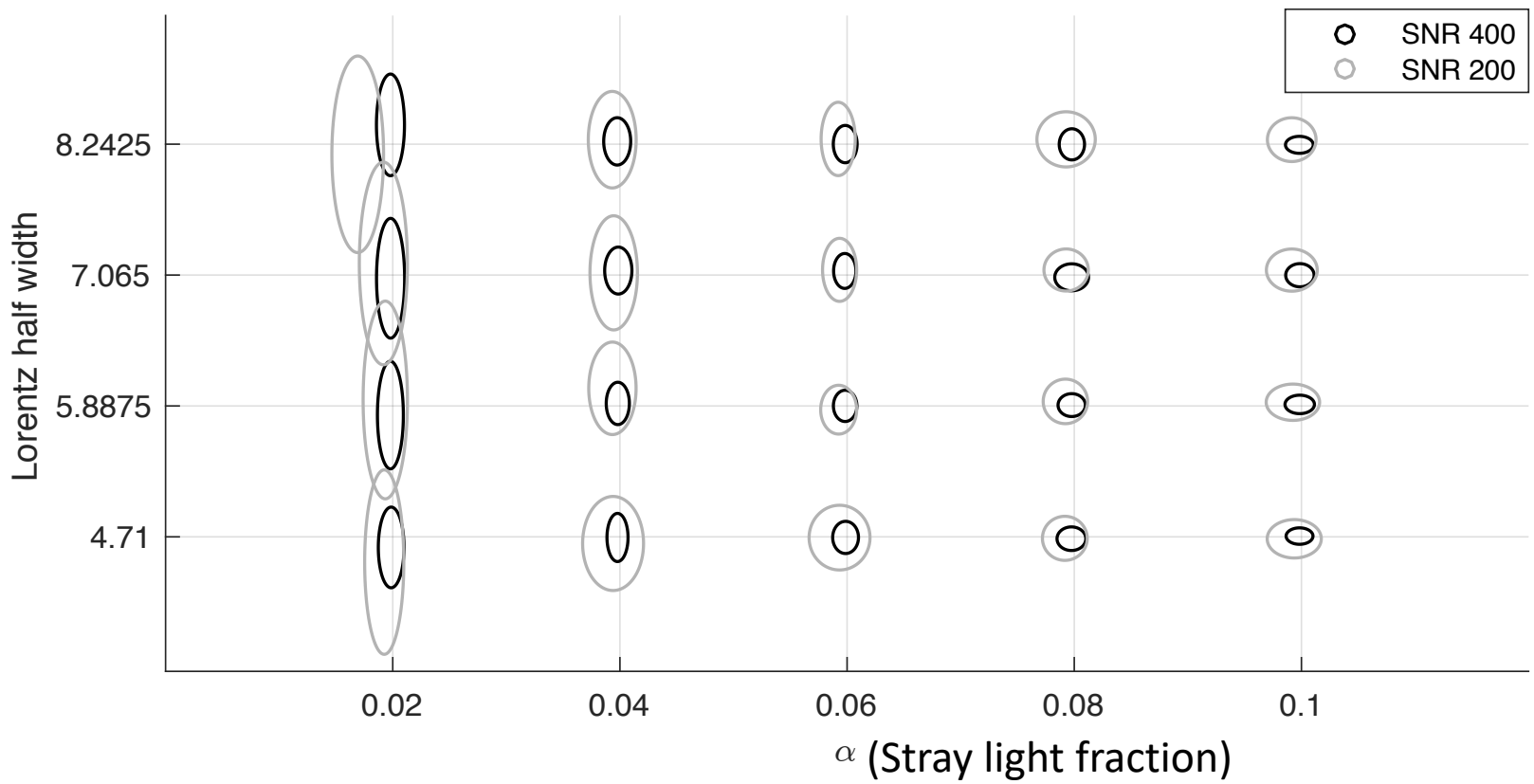
Estimation accuracy for Lorentz SSRF (simulated)



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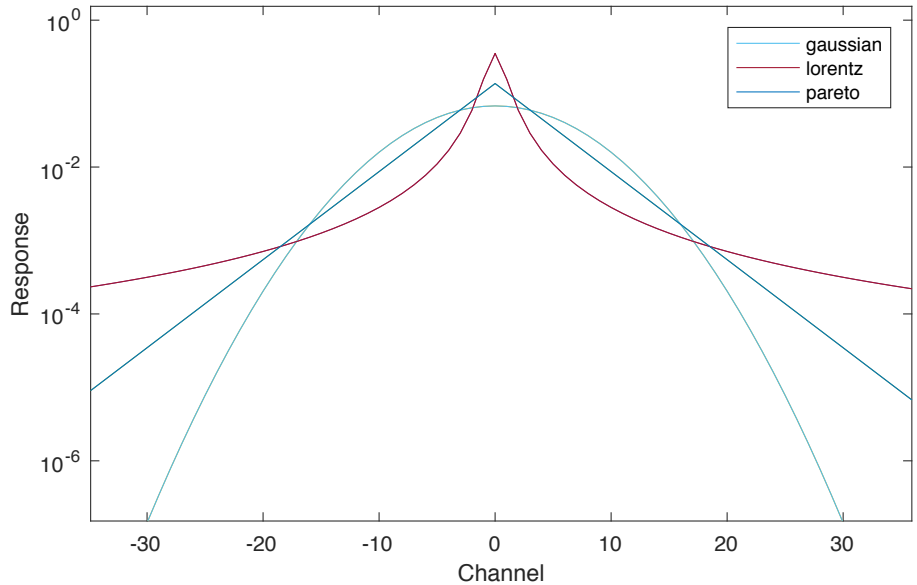
Fit error for candidate SSRF shapes



Line shape	Error		α	SSRF parameters
Original	0.04482		n/a	n/a
Pareto	0.004482		0.0805	x: 0.154, y: 0.0515
Lorentz	0.002059		0.0664	x: 1.018, y: 3.912
Voigt	0.001413		0.0639	σ: 5.477, *LHW*: 0
Gaussian	0.001413	best fit	0.0639	σ: 5.477

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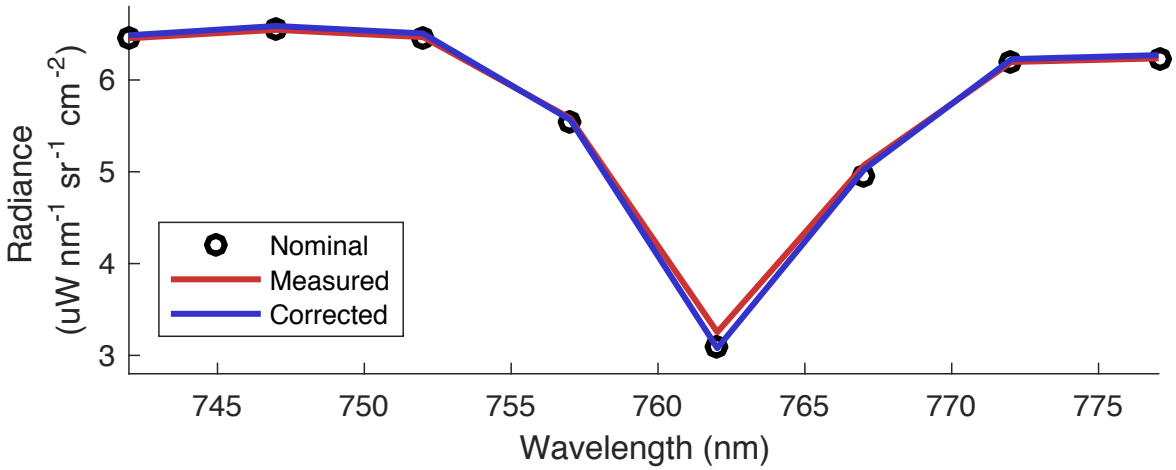
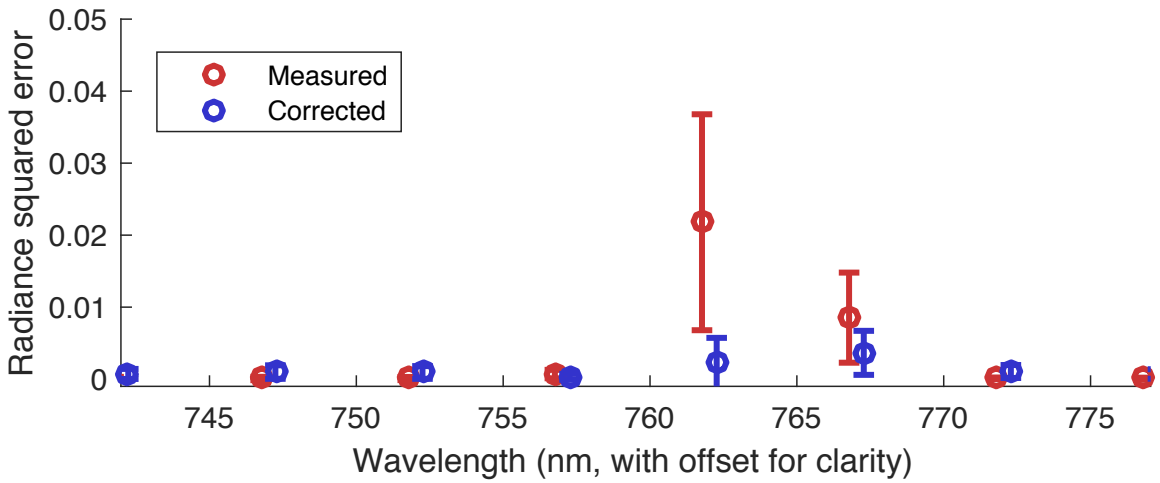
Improvement in O_2 A band fit





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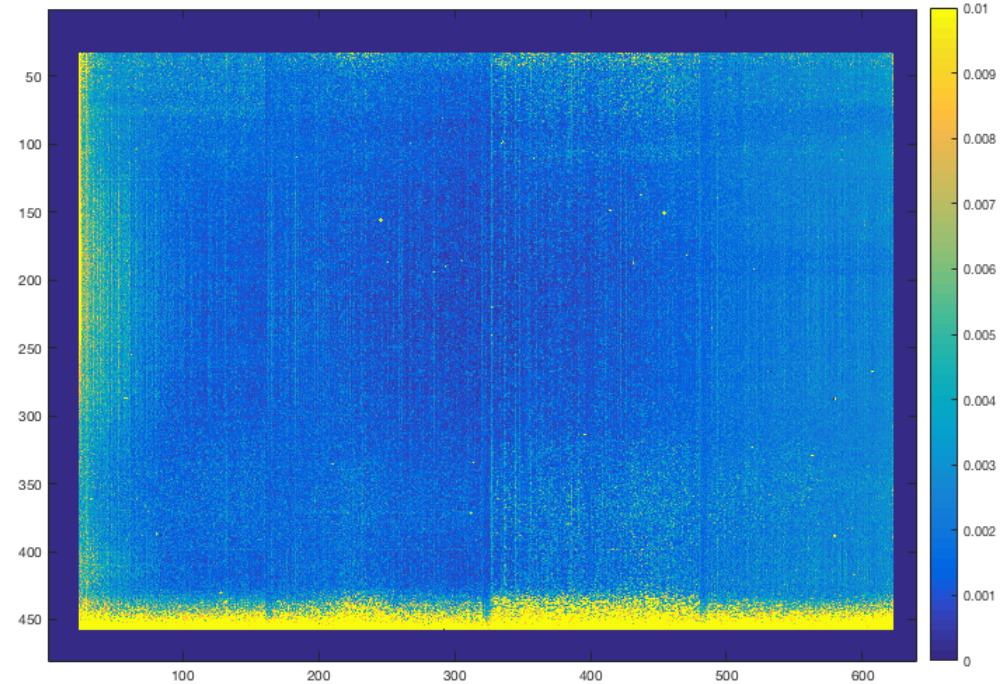
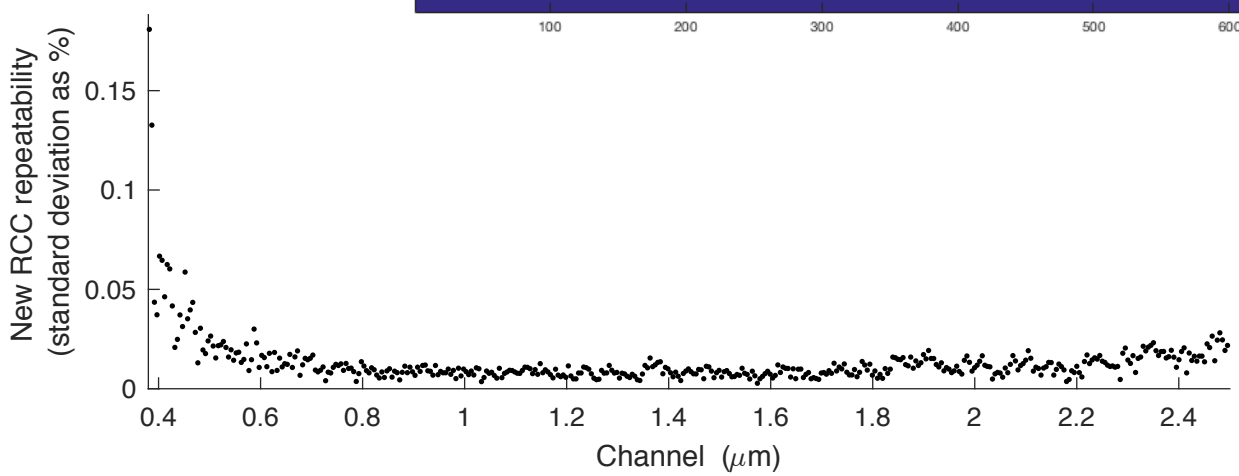
Radiometric calibration repeatability (hangar protocol)

Flat field: σ < 0.14% across most elements



Calibration coefficients: σ < 0.05% across most channels



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