

Jet Propulsion Laboratory
California Institute of Technology

Imaging Spectrometer Stray Spectral Response: In-Flight Characterization and Correction

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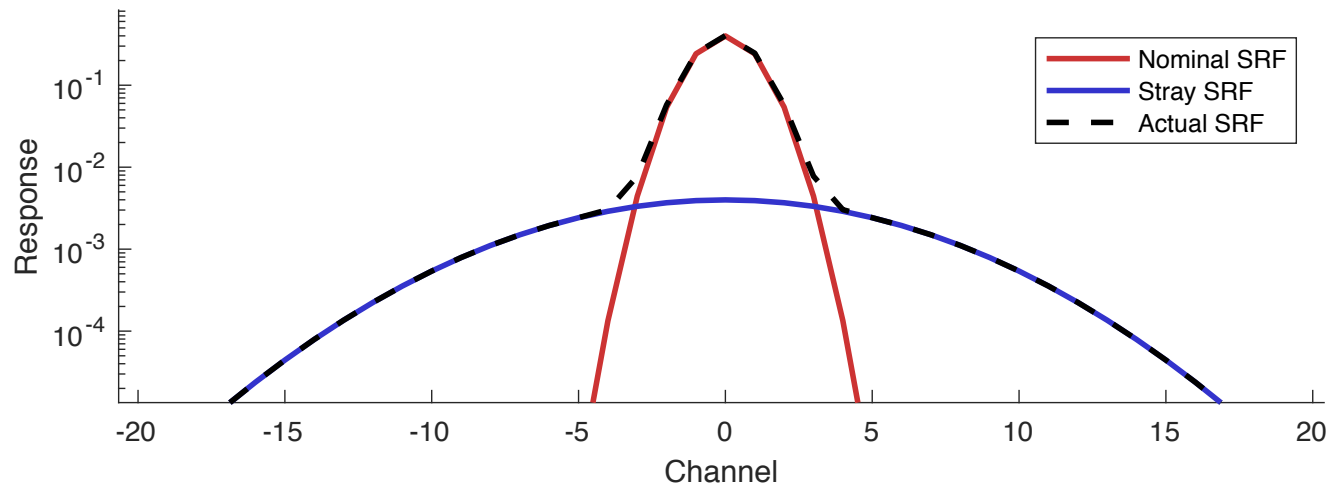
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Motivation

- Non-Gaussian tails of spectral response functions can be difficult to characterize in the laboratory
- Calibration can shift during deployment
- Small SSRF contributions can damage downstream atmospheric correction
- In-flight techniques are useful for validating and updating laboratory measurements.

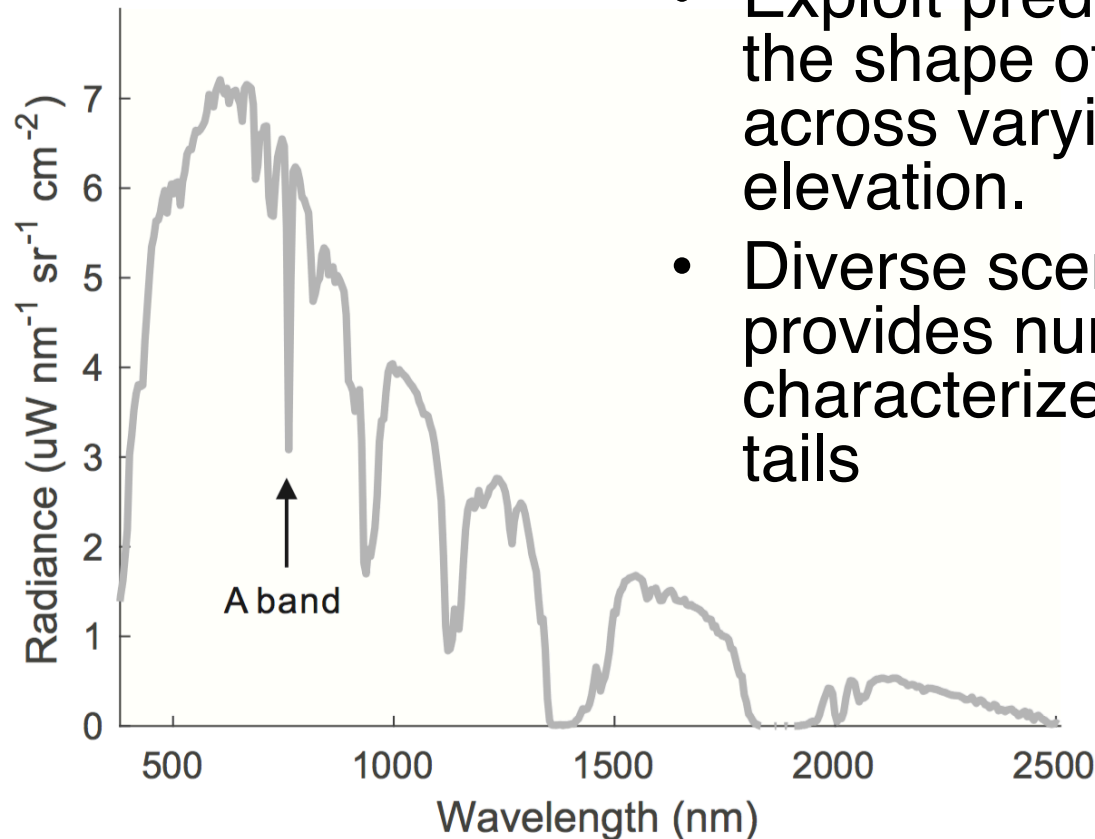


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Method

- Sequential estimation of Nominal and Stray SRF parameters.
- Exploit predictable changes in the shape of the A band across varying surface elevation.
- Diverse scene content provides numerical leverage to characterize spectral response tails



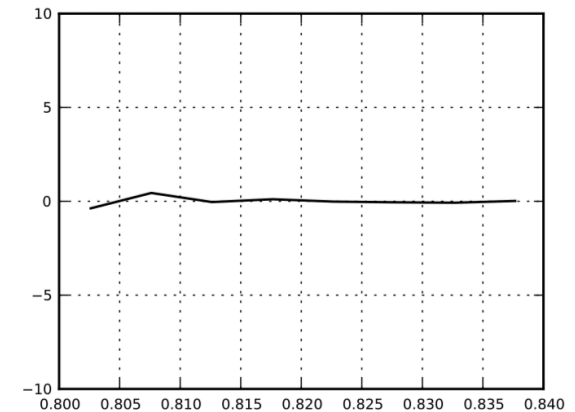
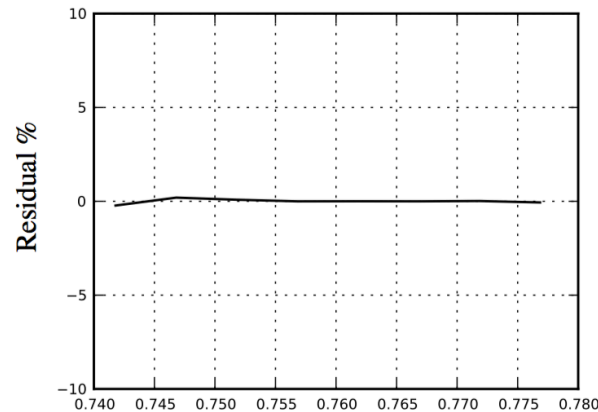
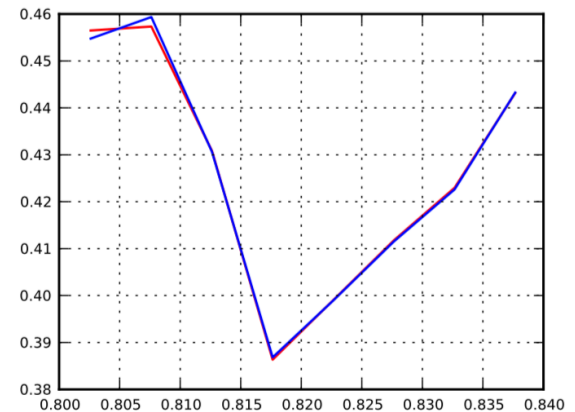
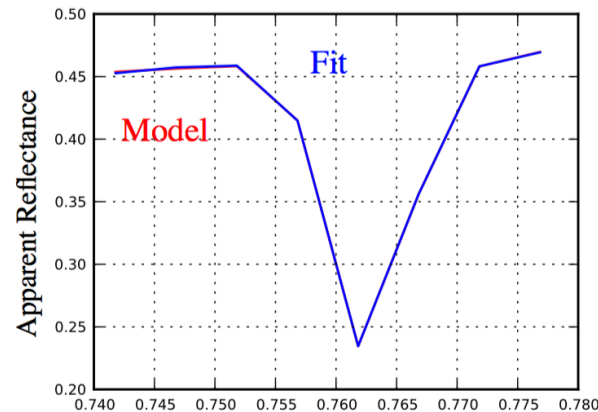
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Estimation of nominal SRF

[Thompson et al., Atmos. Meas. Tech 2015]

Optimize a wavelength shift to match high-contrast atmospheric absorption features

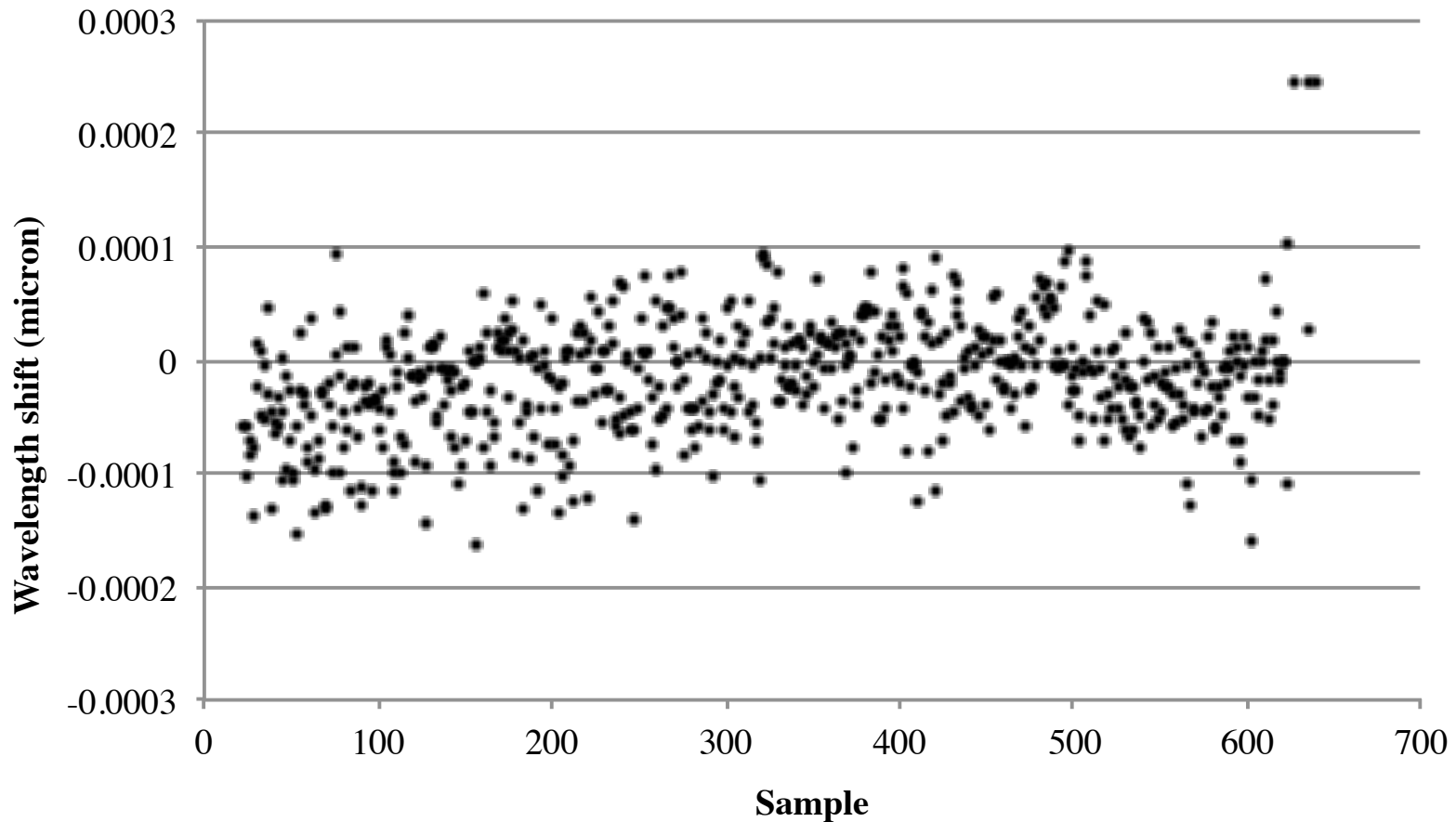


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Estimation of nominal SRF

[Thompson et al., Atmos. Meas. Tech 2015]



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Stray SRF Measurement model

Adapted from [Zhong et al., 2006]

$$\text{Measured Radiance} = \text{Stray Radiance} + \text{Nominal Radiance} + \text{Measurement Noise}$$



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Stray SRF Measurement model

Adapted from [Zhong et al., 2006]

$$\begin{array}{ccccccc} \text{Measured} & = & \text{Stray} & + & \text{Nominal} & + & \text{Measurement} \\ \text{Radiance} & & \text{Radiance} & & \text{Radiance} & & \text{Noise} \\ & & \downarrow & & \downarrow & & \downarrow \\ L_M & = & GHL_A & + & HL_A & + & \epsilon \\ & & \uparrow \quad \uparrow & & \uparrow & & \\ & & \text{Stray SRF} \quad \text{Nominal SRF} & & \text{Radiance at sensor} & & \end{array}$$



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Stray SRF Measurement model

Adapted from [Zhong et al., 2006]

$$\begin{array}{ccccccc} \text{Measured} & & \text{Stray} & & \text{Nominal} & & \text{Measurement} \\ \text{Radiance} & = & \text{Radiance} & + & \text{Radiance} & + & \text{Noise} \\ & & \downarrow & & \downarrow & & \downarrow \\ \mathbf{L}_M & = & \mathbf{GHL}_A & + & \mathbf{HL}_A & + & \epsilon \\ & & \uparrow & & \uparrow & & \uparrow \\ & & \text{Stray SRF} & & \text{Nominal SRF} & & \text{Radiance at sensor} \end{array}$$

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

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



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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:

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

Corrected
Radiance

Correction
matrix

Distorted
Measurement

A similar correction fixes cross-track stray light



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Retrieve Stray SRF from a “Calibration Scene”

Death Valley Transect, 2014 (visible RGB)



Predict A band radiances using a Digital Elevation Model



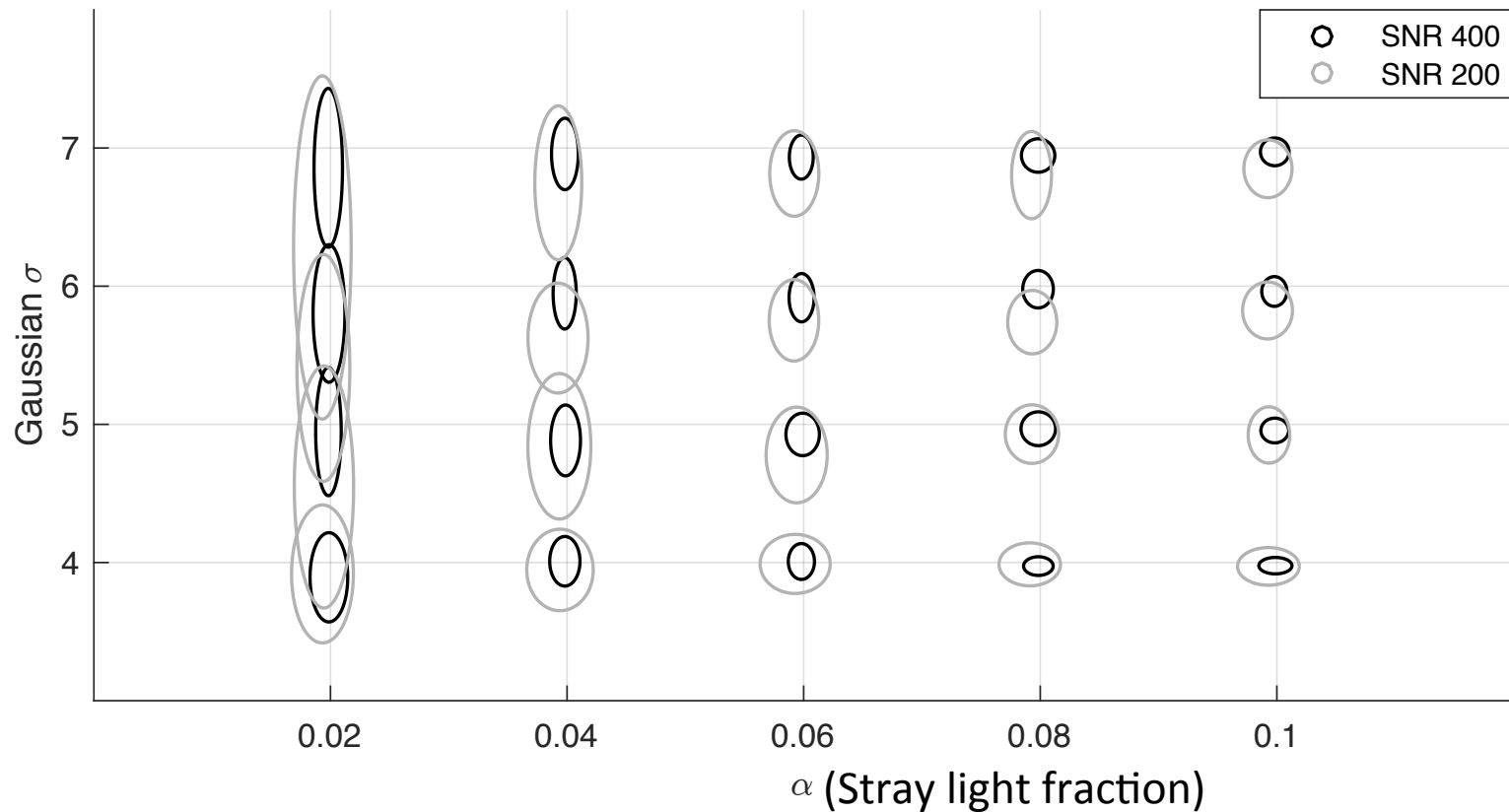
Nonlinear least squares optimization finds SSRF parameters



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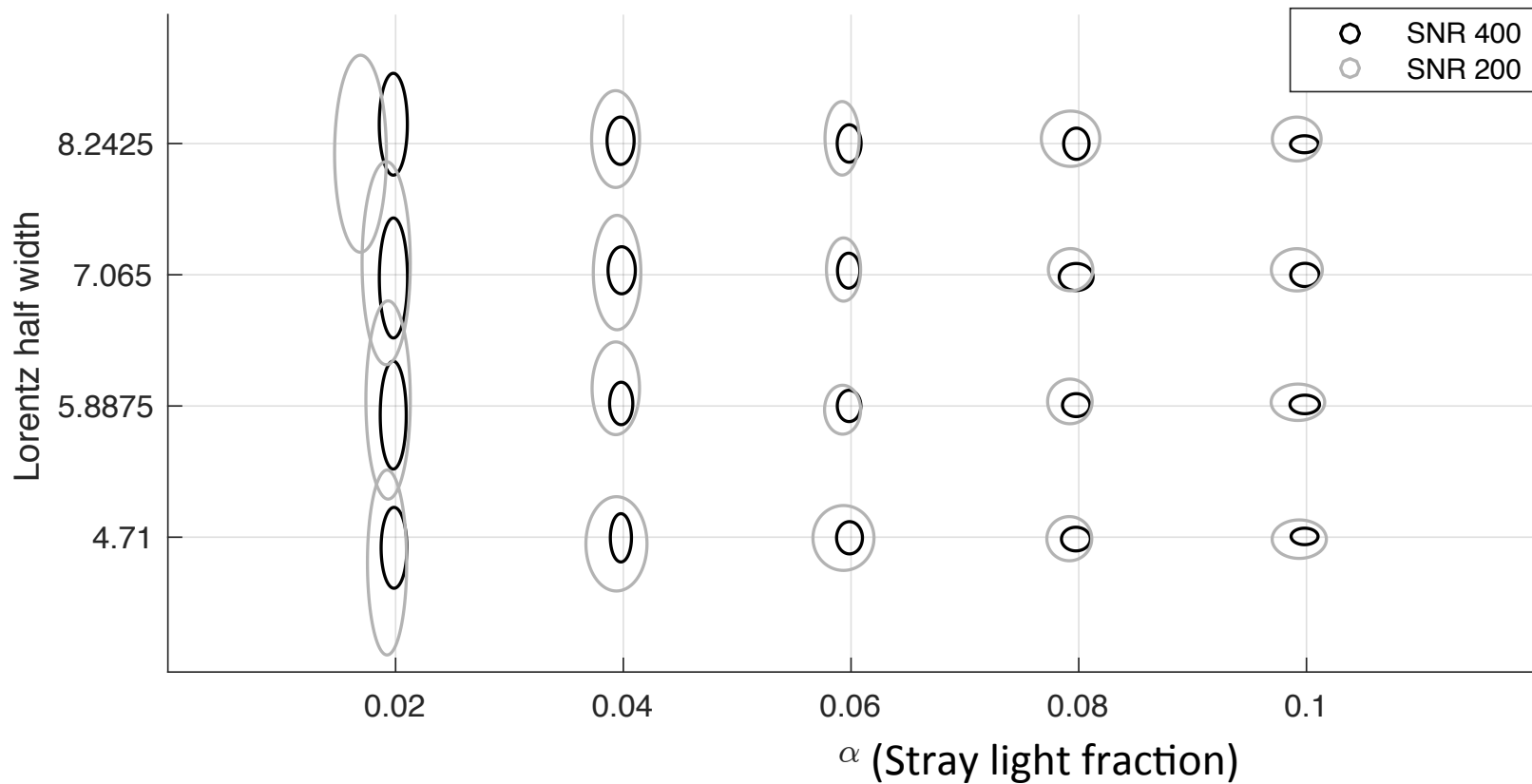
Estimation accuracy for Gaussian SSRF (simulated)



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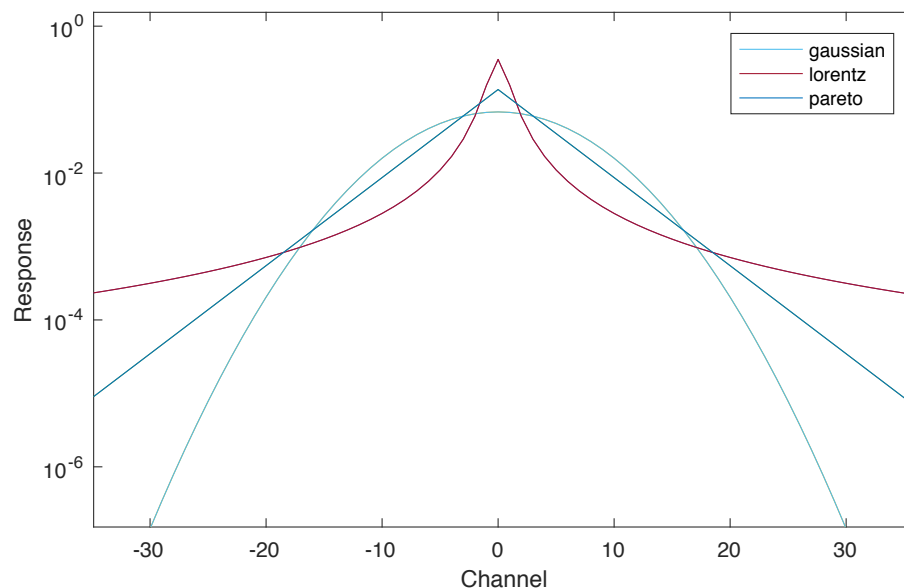
Estimation accuracy for Lorentz SSRF (simulated)



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Fit error for candidate SSRF shapes



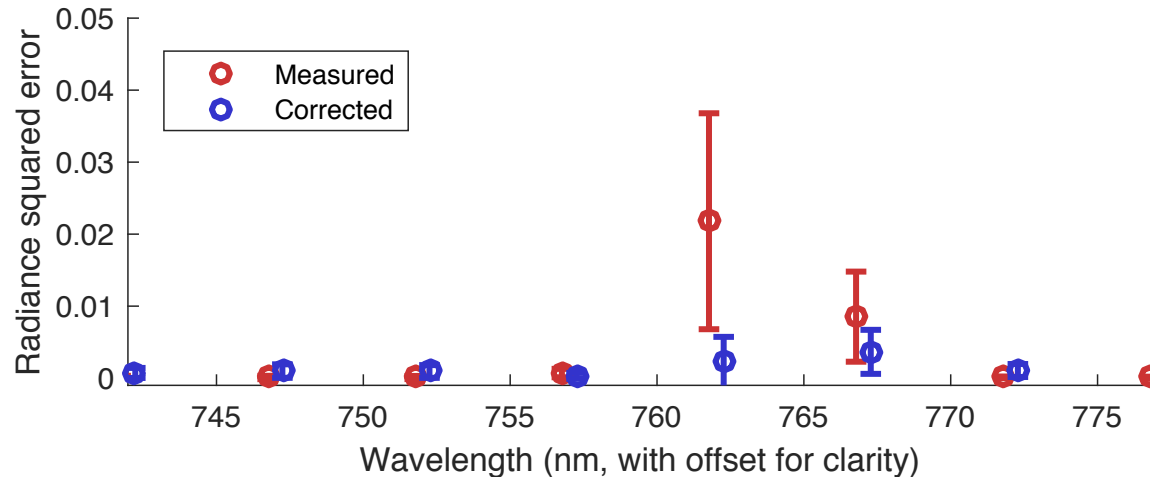
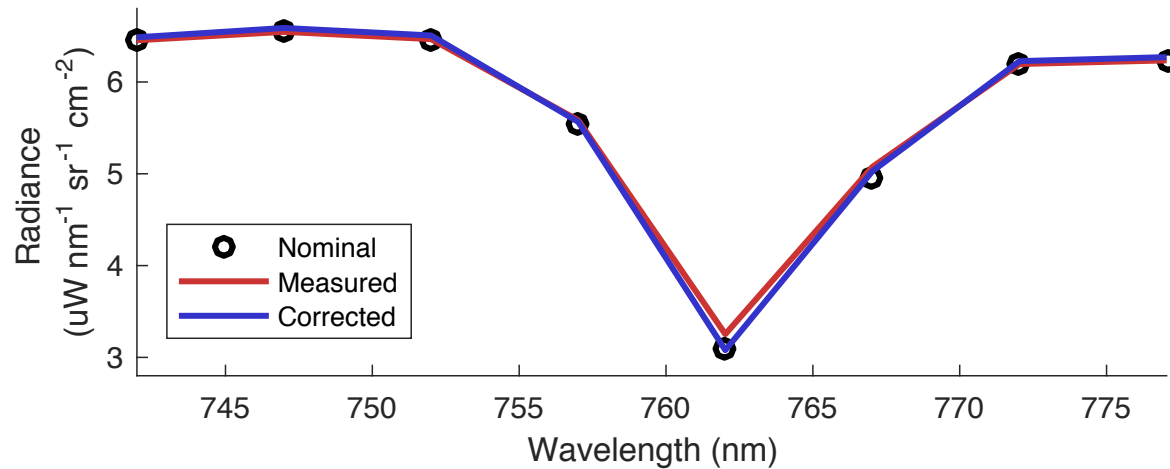
Line shape	Error	α	SSRF parameters
Original	0.04482	n/a	n/a
Pareto	0.004482	0.0805	x: 0.154, y: 0.0515
Lorentz	0.002059	0.0664	x: 1.018, y: 3.912
Voigt	0.001413	0.0639	σ : 5.477, <i>LHW</i> : 0
Gaussian	0.001413	0.0639	σ : 5.477



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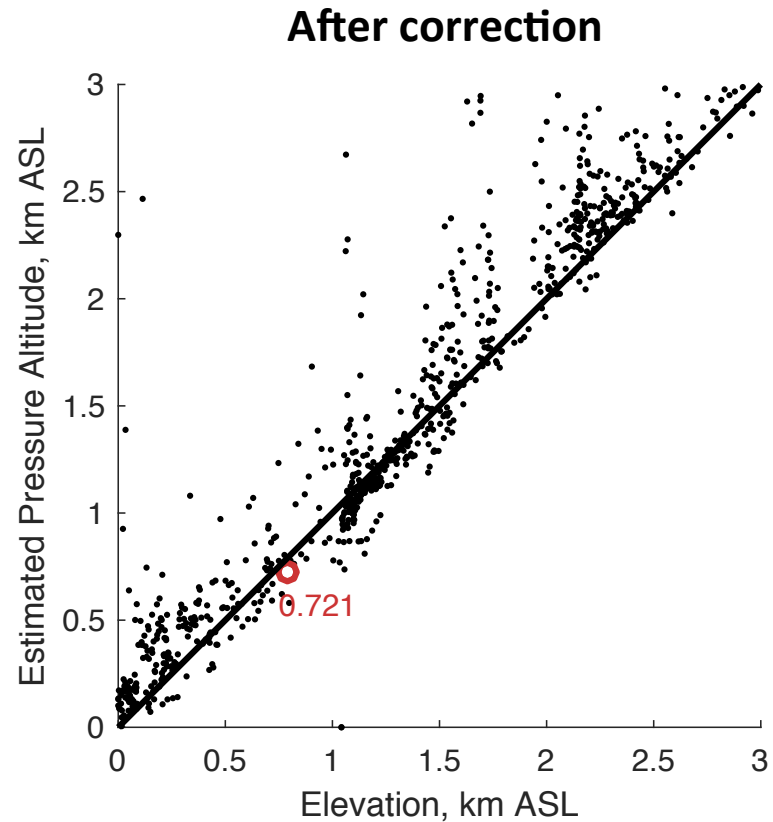
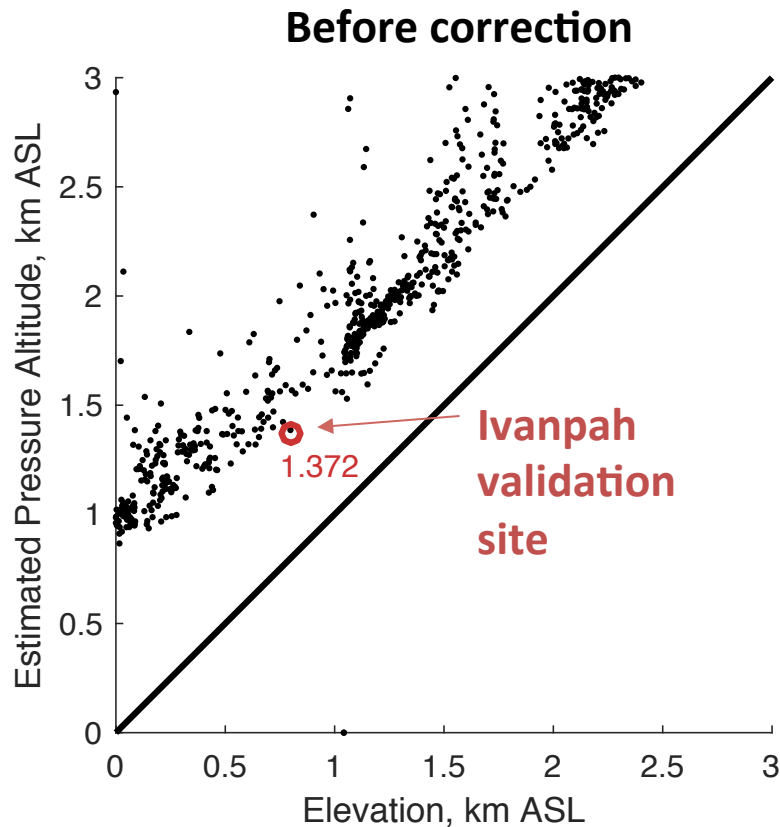
Improvement in O₂ A band fit



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Correction fixes a bias in pressure altitude estimates

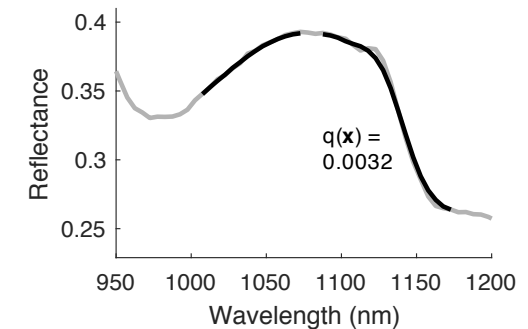
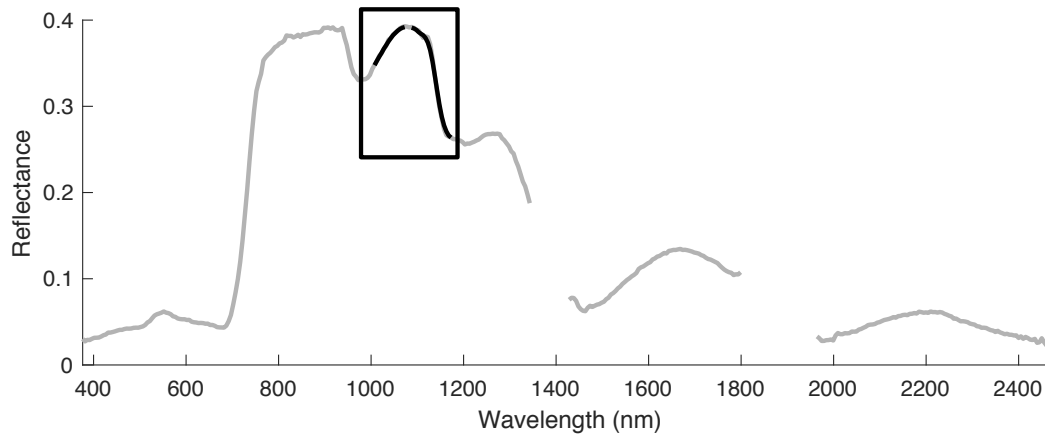
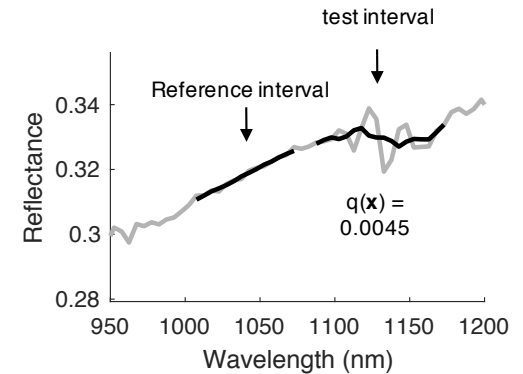
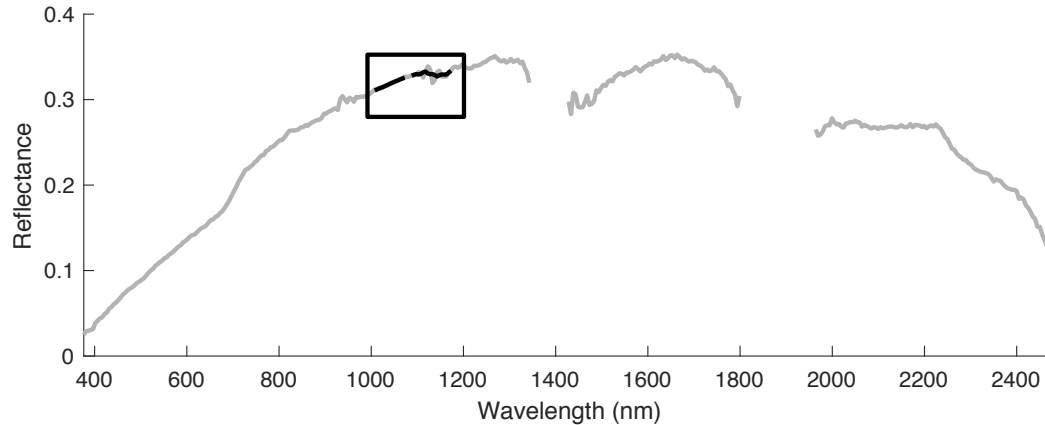


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Reflectance validation

Reflectance quality metric: $q(\mathbf{x}) = \sqrt{\sigma_{H_2O}^2 - \sigma_{REF}^2}$

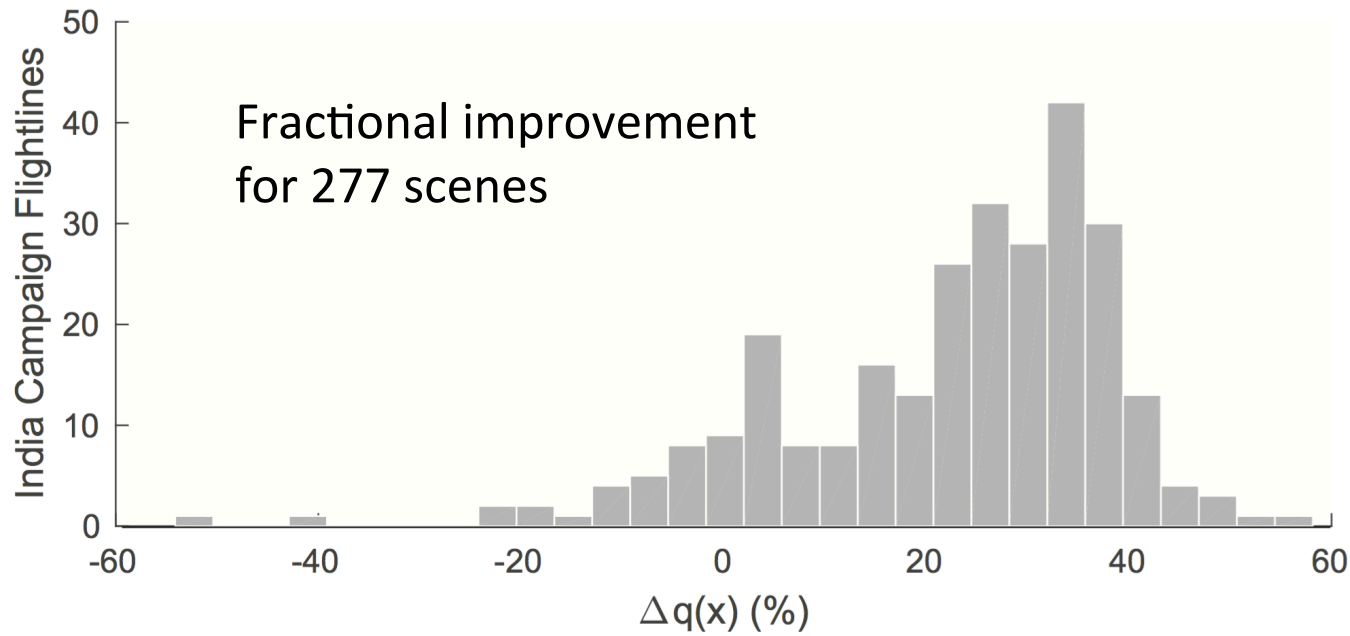


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India Validation Results

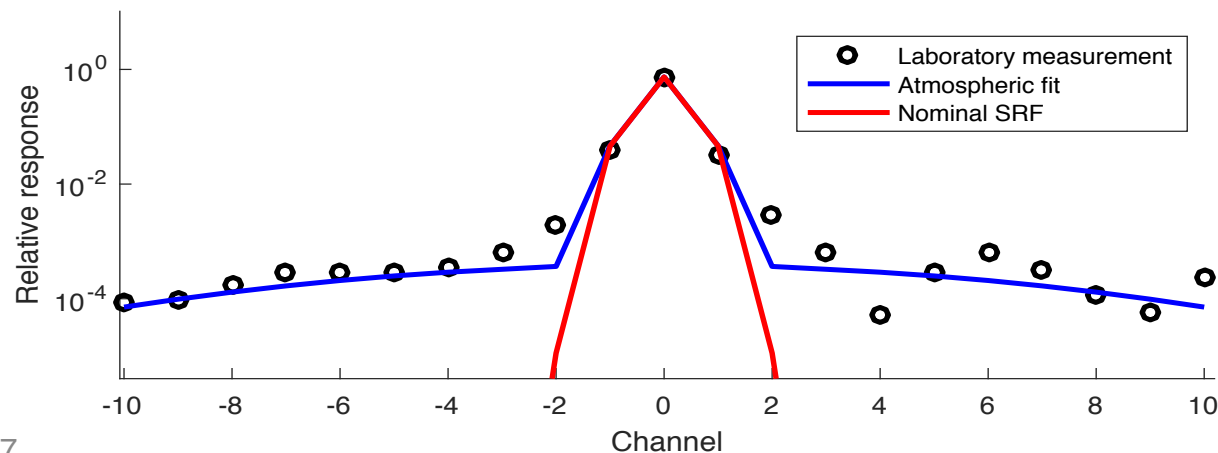
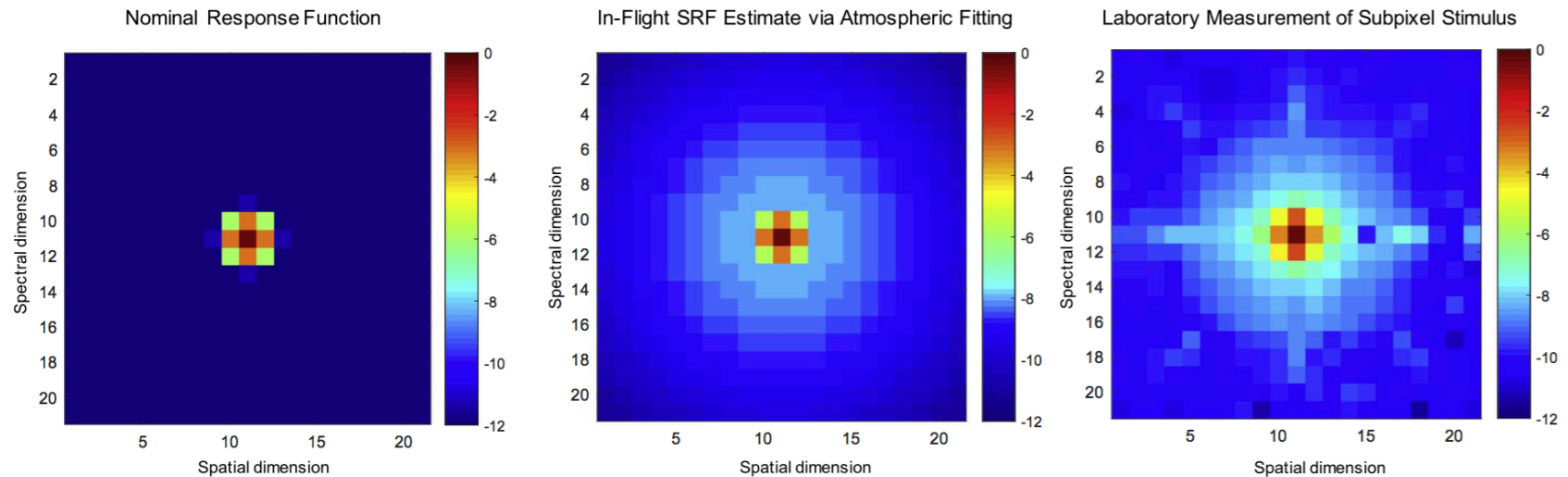
- 26 of 37 flight days show significant improvements ($p < 0.001$)
- Typical improvement is 20-35%
- No flight day shows a statistically significant accuracy reduction



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Agreement with laboratory data

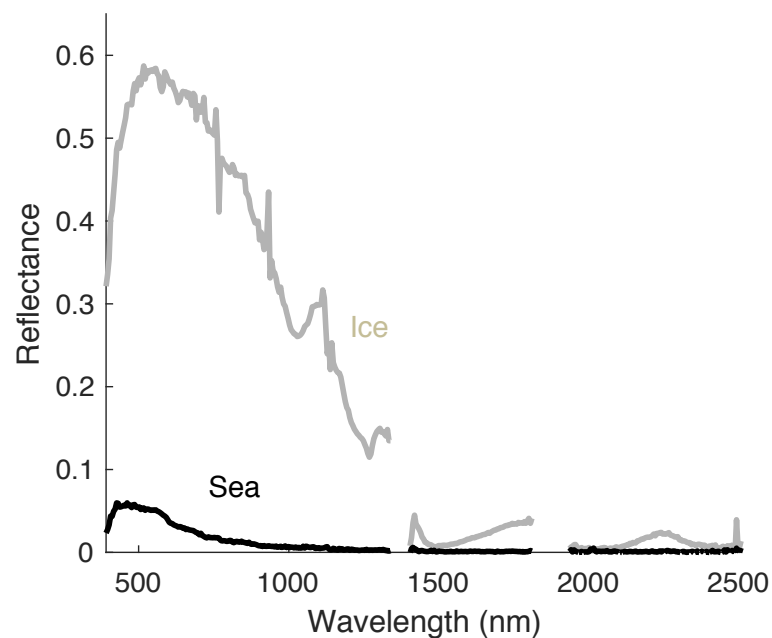


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Spatial dimension

- 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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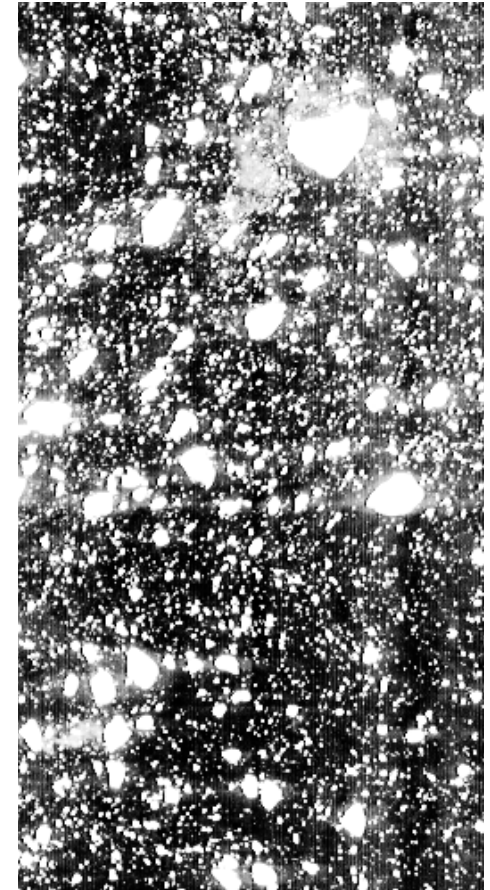
“Halo” reduction



Original RGB



612 nm, equalization stretch
(0-3 $\mu\text{W nm}^{-1} \text{sr}^{-1} \text{cm}^{-2}$)



612 nm, after CRF correction



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Discussion

- Can leverage scene invariant properties to fit PSFs
- Some advantages to using separable functions
 - Numerical stability, fairly easy to prevent ringing & overcorrection
 - Can model CRF or SRF or both, and fit them independently
- Positive results on held-out validations
 - Appears to fix our pressure altitude bias
 - Improves H₂O residuals
 - Improves spatial halos
- Implemented in latest India release, and all AVIRIS-NG datasets starting from 2016



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Thanks!

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