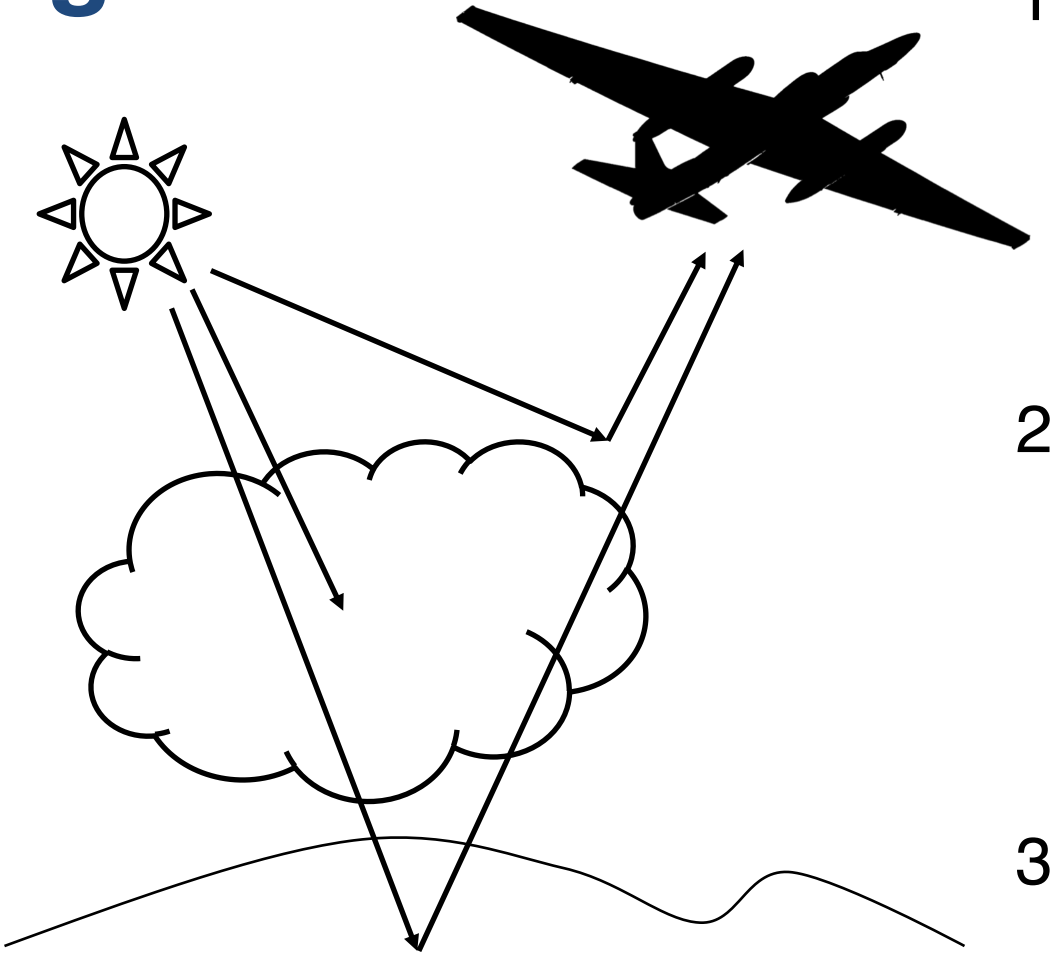
VSWIR L1 & L2: Radiance and Reflectance Algorithm Maturity, Calibration, and Validation

David R. Thompson[1]
Robert O. Green
Bo-Cai Gao[2]
Brian D. Bue
John Chapman
Michael L. Eastwood
Mark Helmlinger
Sven Geier
Yumi Iwashita
Sarah Lundeen
Ian McCubbin
Vincent Realmuto
Winston Olson Duvall

Jet Propulsion Laboratory,
California Institute of Technology
[1]david.r.thompson@jpl.nasa.gov
[2]Naval Research Laboratory

Source:
Wikimedia
commons

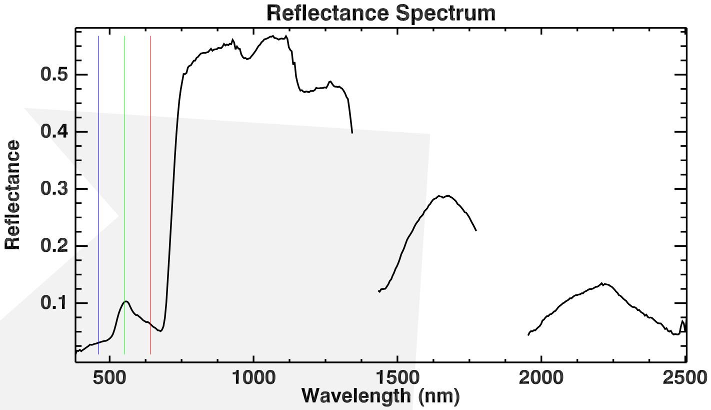
Agenda



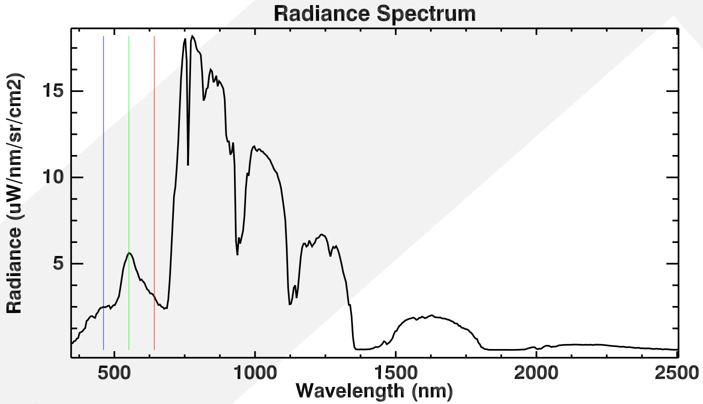
1. Instrument calibration: radiometric and spectral
2. Estimation of atmosphere and surface properties
3. Field validation methods and results

david.r.thompson@jpl.nasa.gov

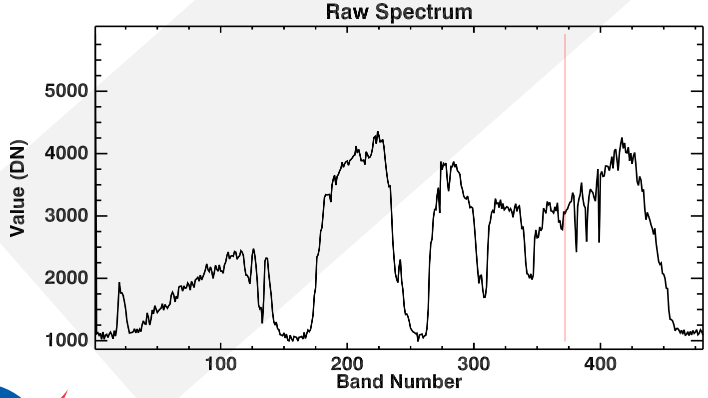
Typical Analysis Chain



Lambertian Reflectance (HDRF)



Radiance at sensor mW/nm/cm²/sr



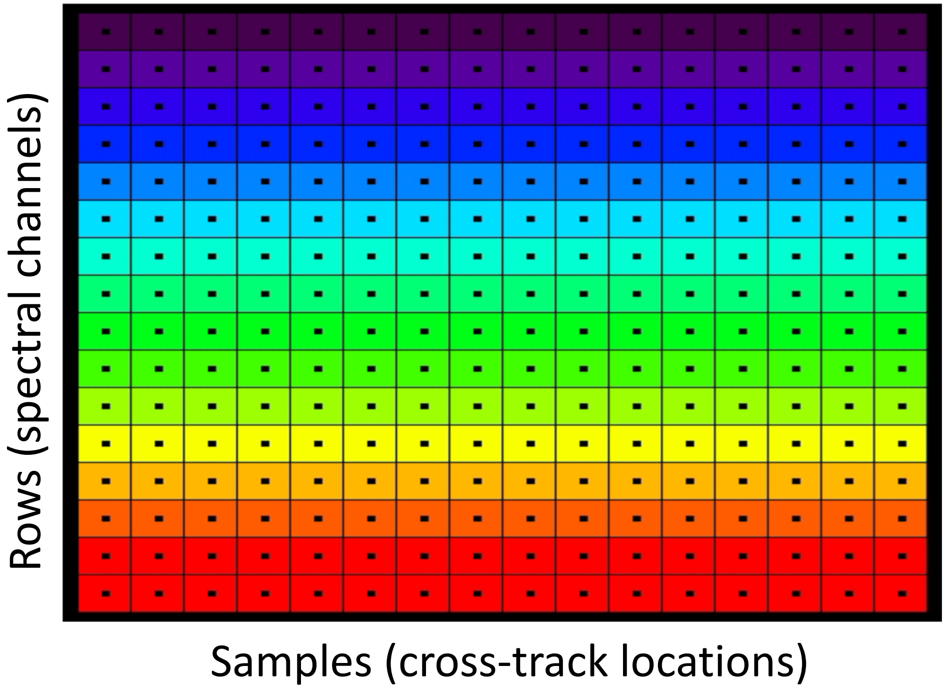
Raw Digital Numbers

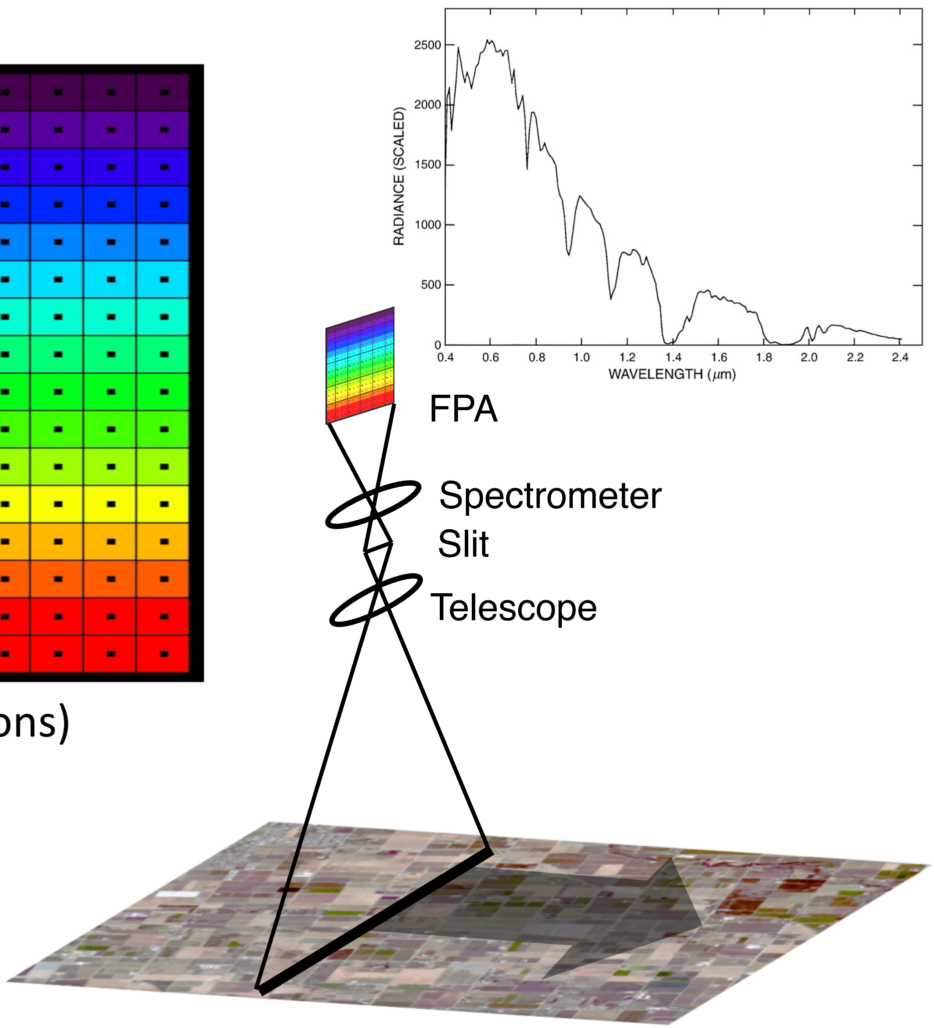
[Gao et al., 1993; Green et al., 1998, Thompson et al., 2015]

9/20/18

david.r.thompson@jpl.nasa.gov

Calibration Conventions

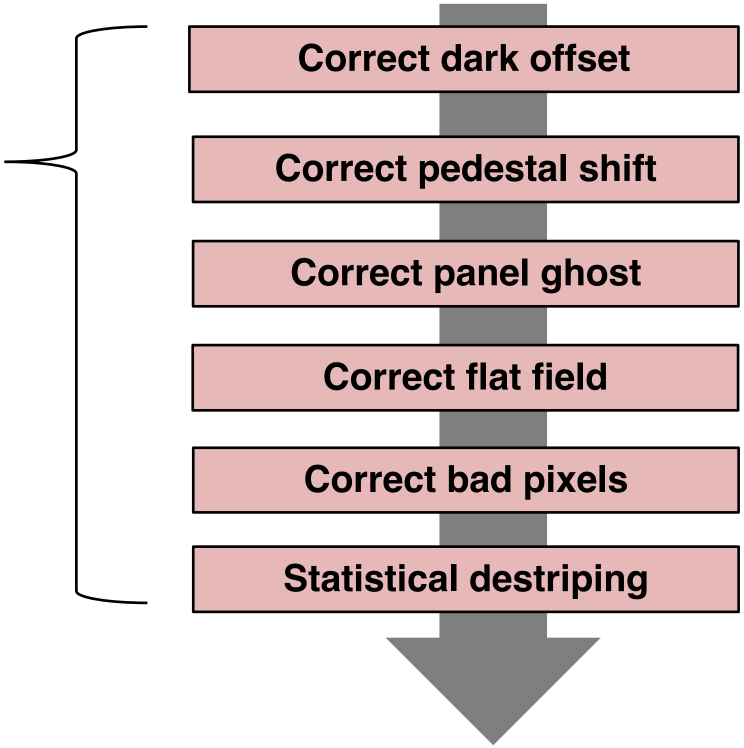



B.-C. Gao et al. / Remote Sensing of Environment 113 (2009) S17–S24

david.r.thompson@jpl.nasa.gov

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

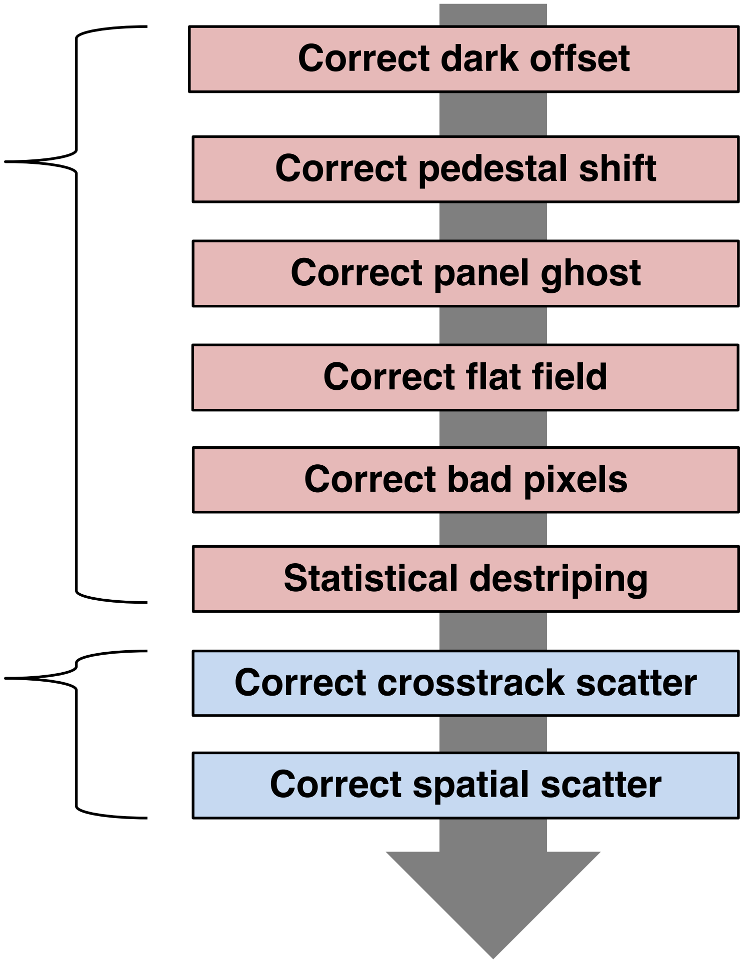
Statistical destriping

david.r.thompson@jpl.nasa.gov

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



Correct dark offset

Correct pedestal shift

Correct panel ghost

Correct flat field

Correct bad pixels

Statistical destriping

Correct crosstrack scatter

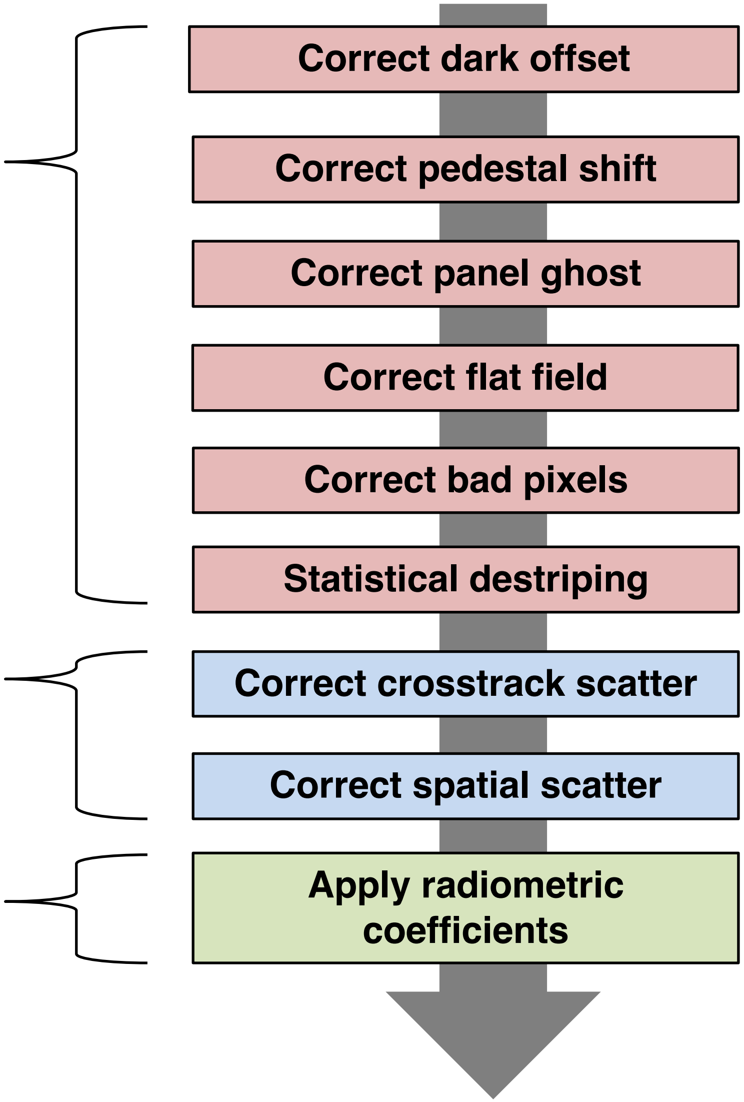
Correct spatial scatter

9/20/18

david.r.thompson@jpl.nasa.gov

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)



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

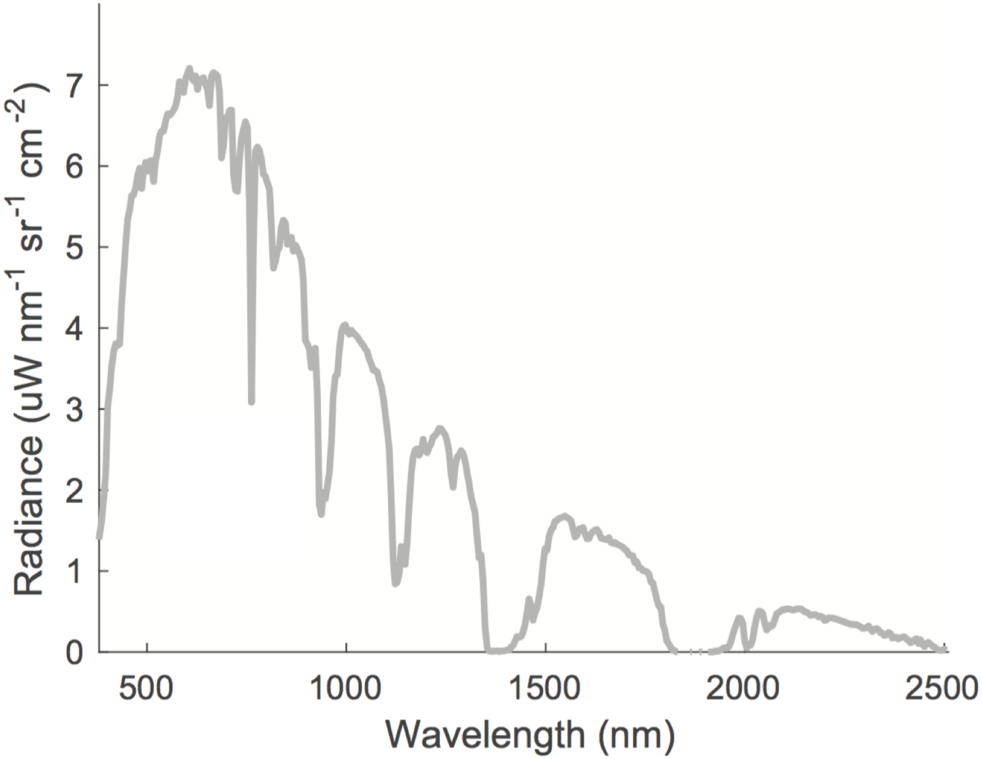
9/20/18

david.r.thompson@jpl.nasa.gov

In-flight refinement of spectral calibration via atmospheric features

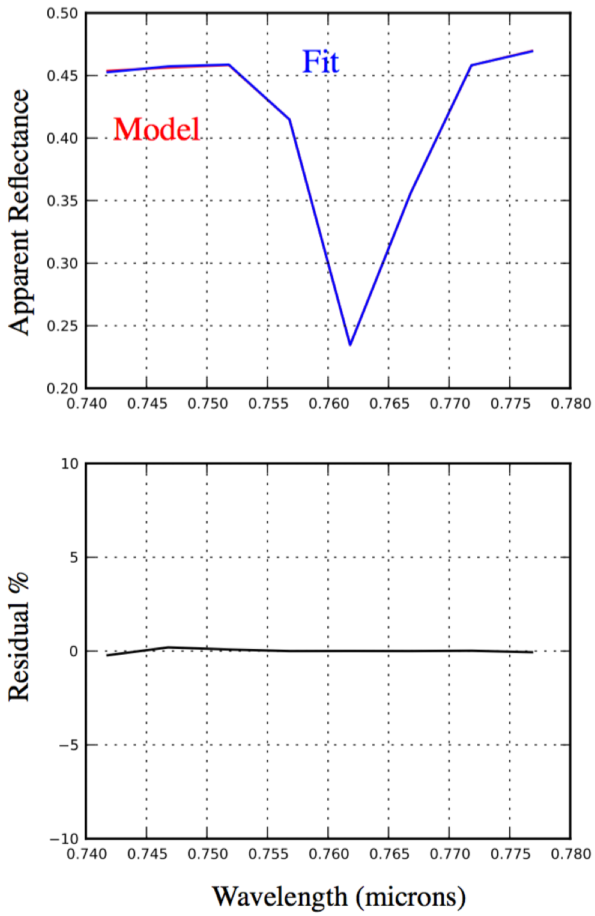
Feature positions provide accurate wavelength calibration

Depths and shapes provide refined information on spectral response function



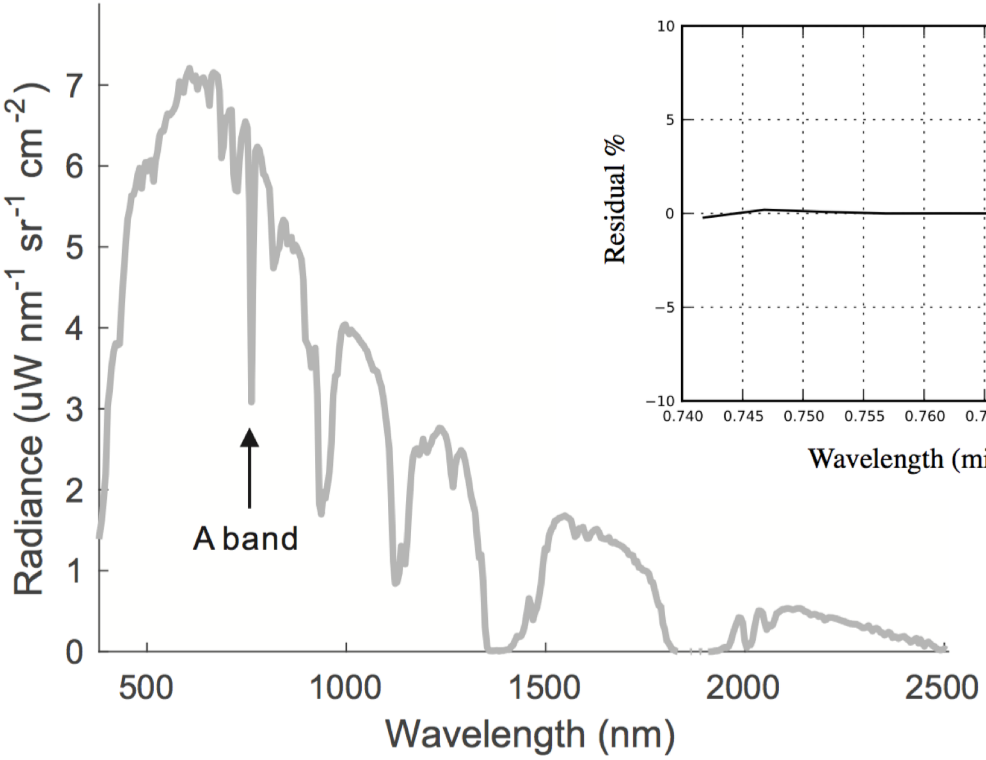
david.r.thompson@jpl.nasa.gov

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

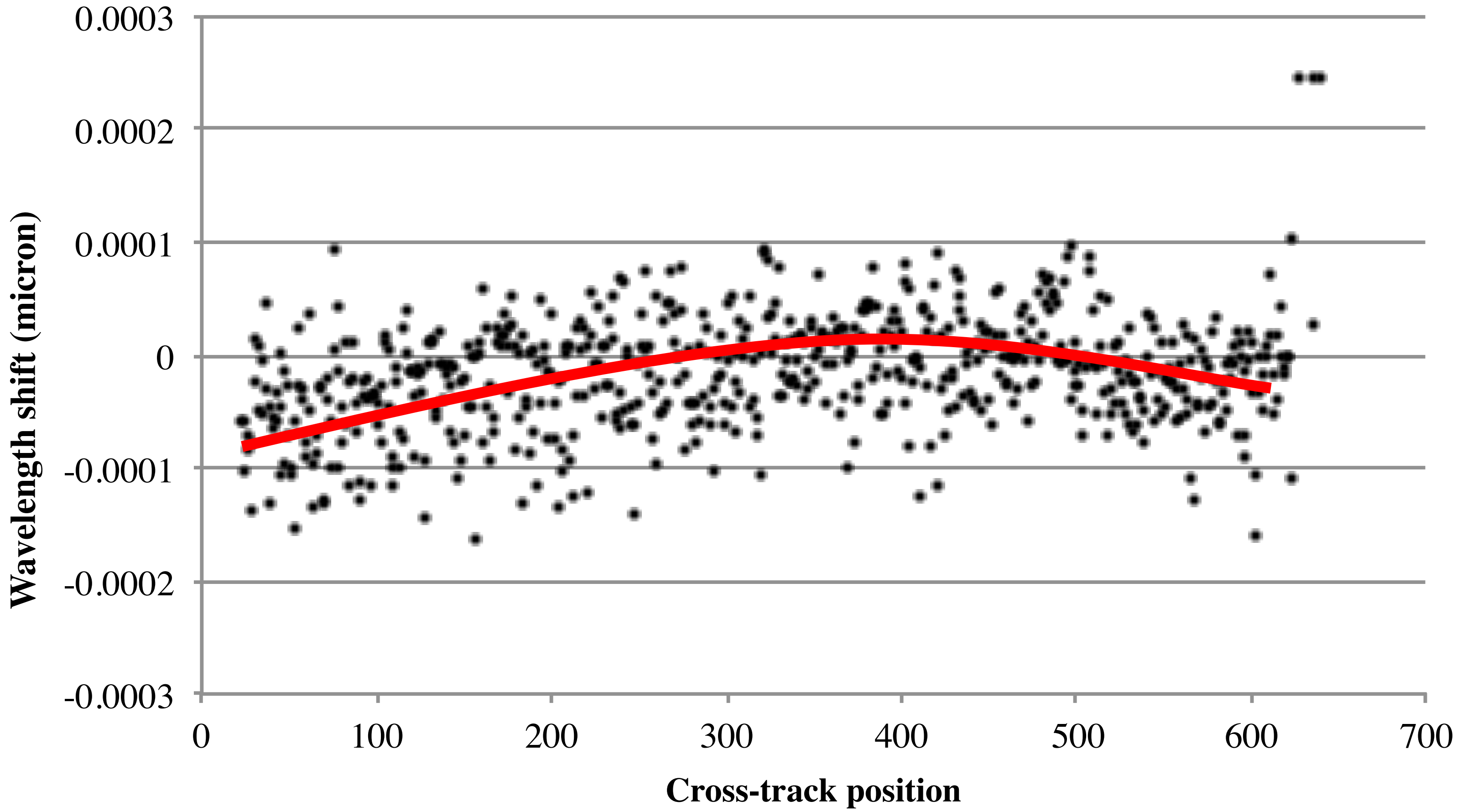


9/20/18

david.r.thompson@jpl.nasa.gov

Empirical channel positions

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

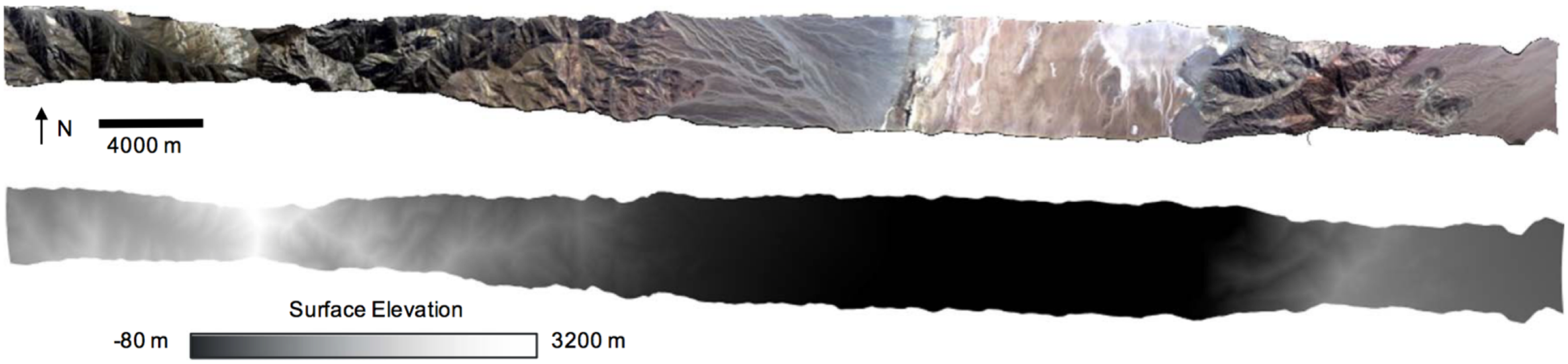


david.r.thompson@jpl.nasa.gov

Empirical spectral response

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

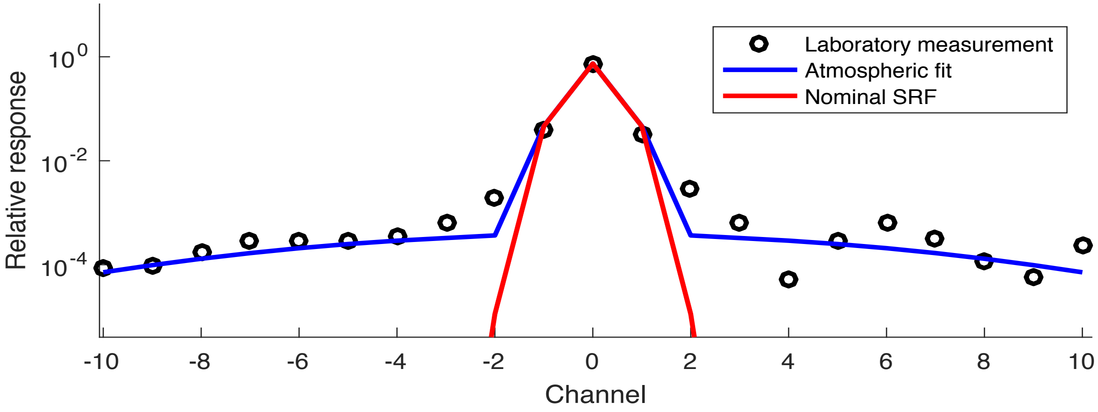
Death Valley Transect, 2014 (visible RGB)



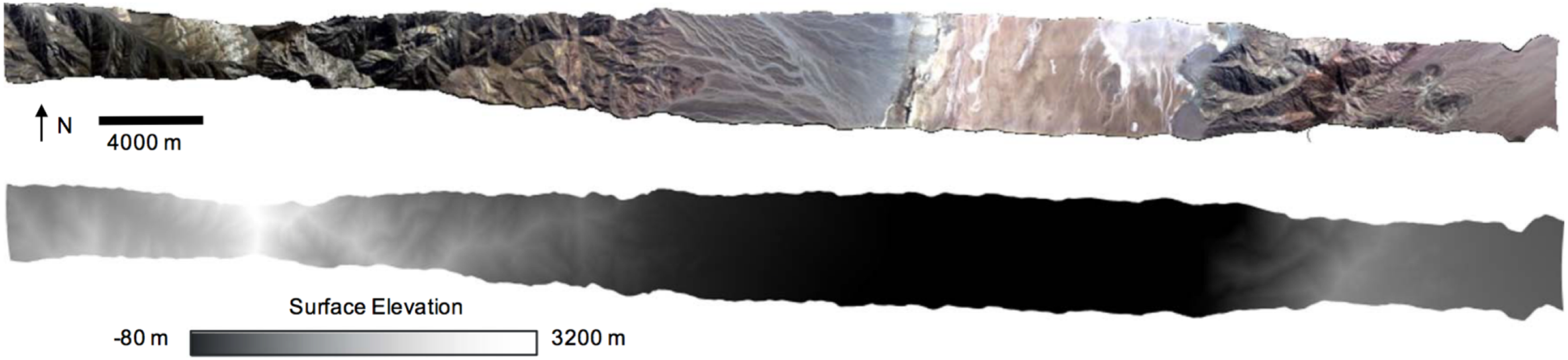
david.r.thompson@jpl.nasa.gov

Empirical spectral response

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



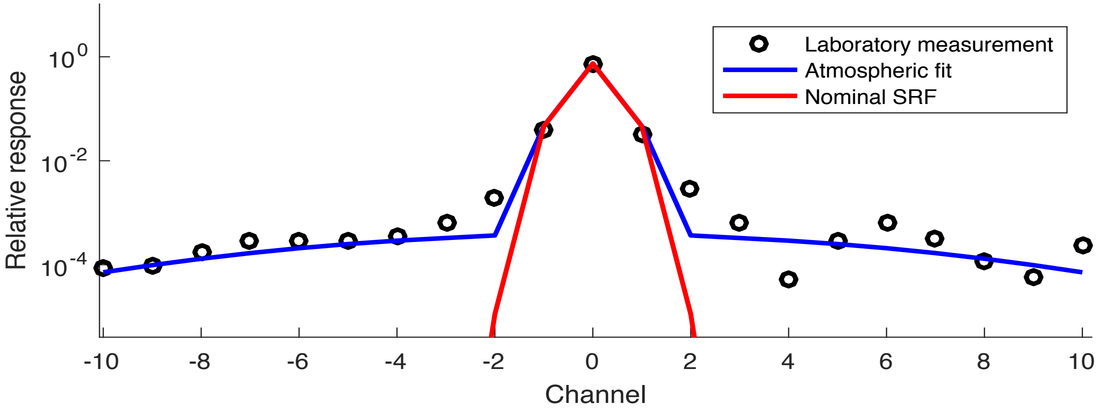
Death Valley Transect, 2014 (visible RGB)

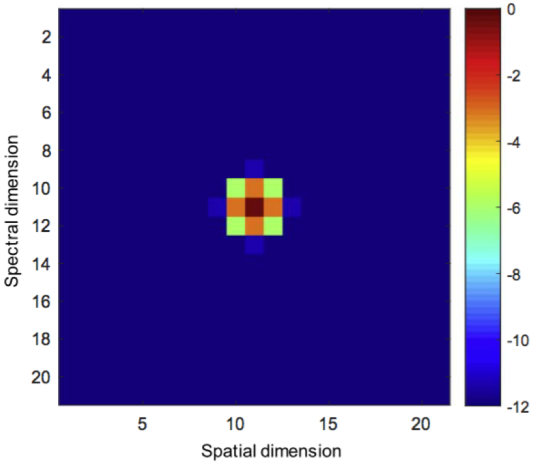


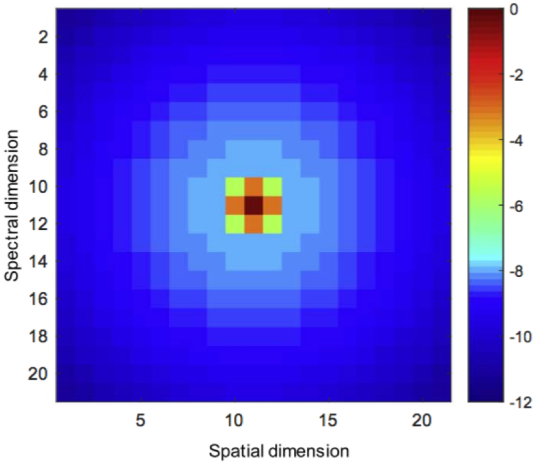
david.r.thompson@jpl.nasa.gov

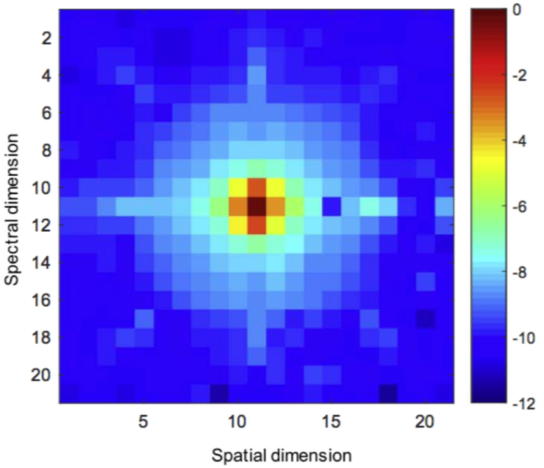
Empirical spectral response

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

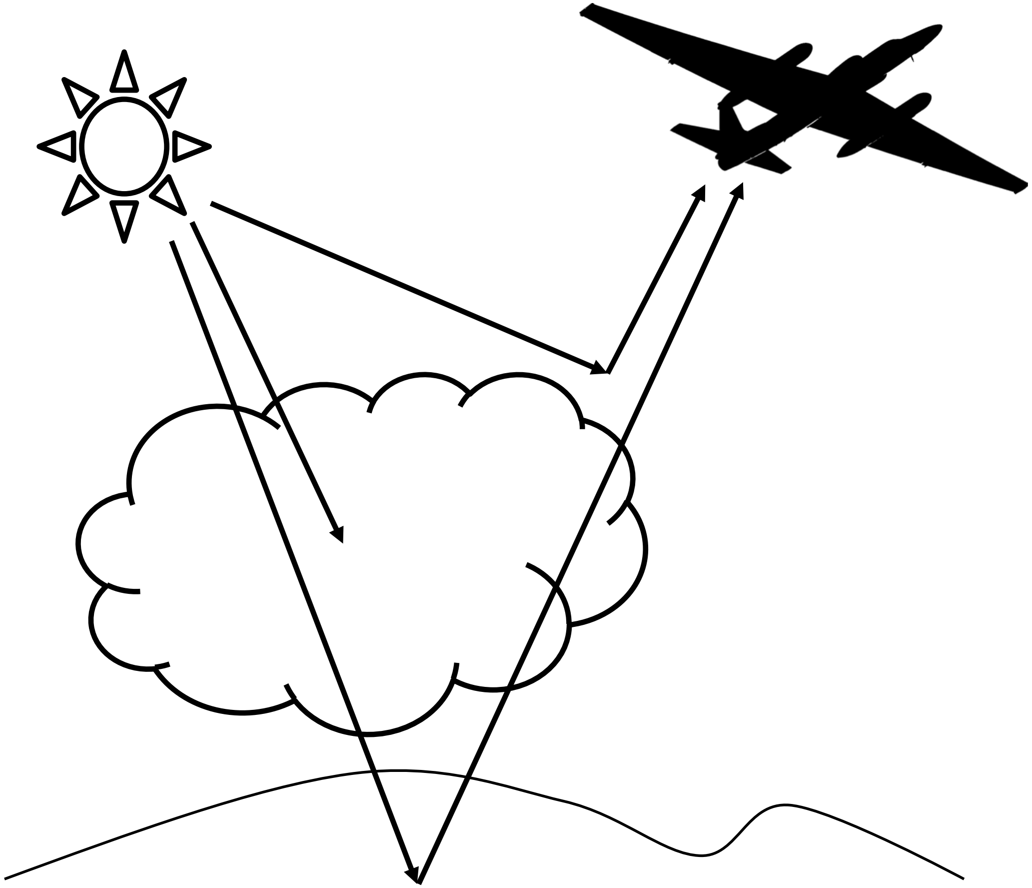



Nominal response


Atmospheric fit


Laboratory measurement

Agenda

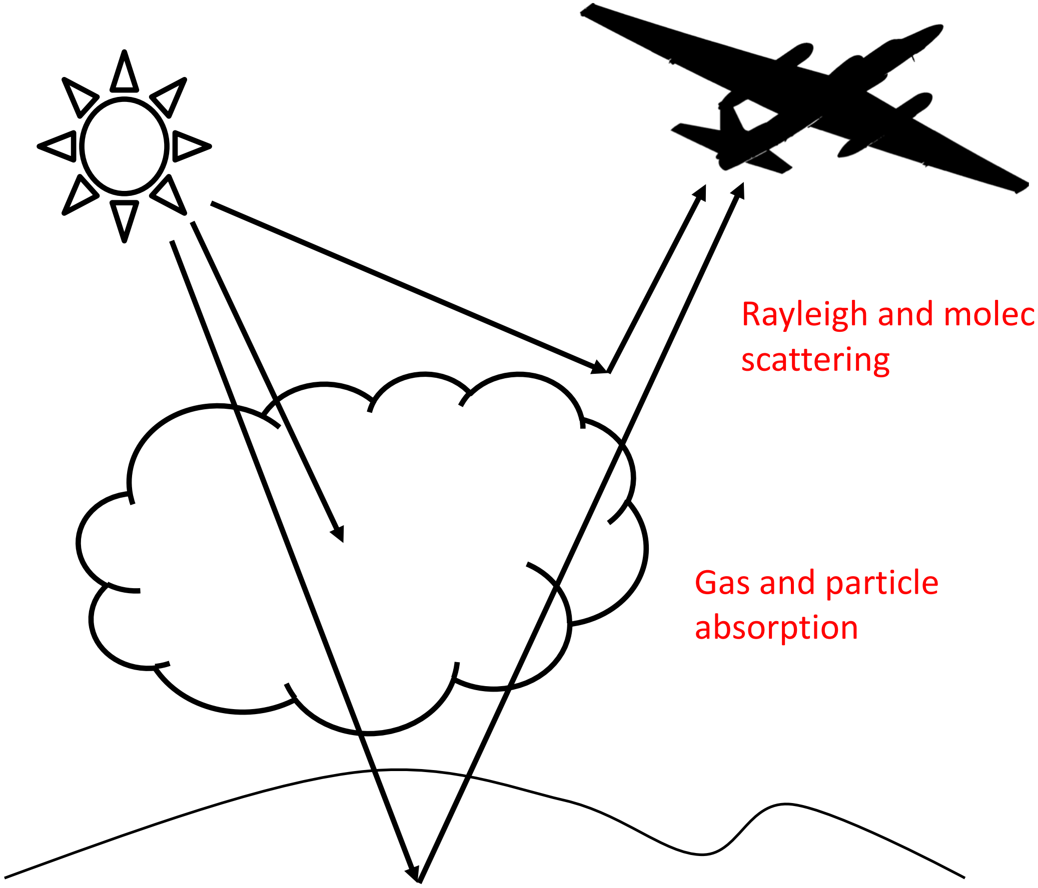


1. Instrument calibration: radiometric and spectral
2. Estimation of atmosphere and surface properties
3. Field validation methods and results

9/20/18

david.r.thompson@jpl.nasa.gov

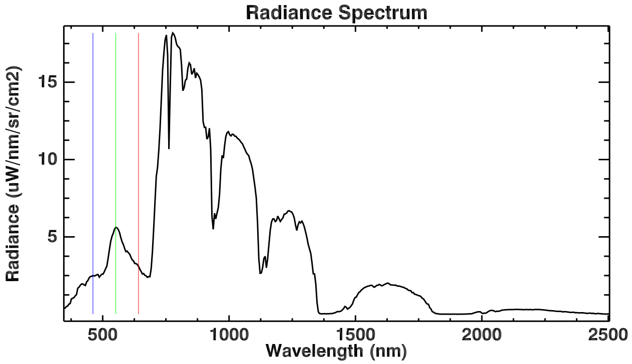
Atmospheric Correction

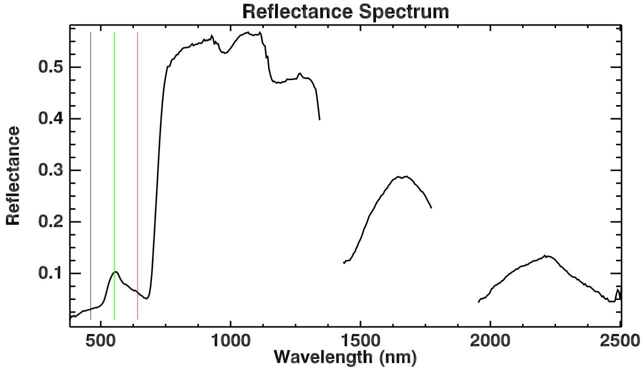


Rayleigh and molecular scattering

Gas and particle absorption

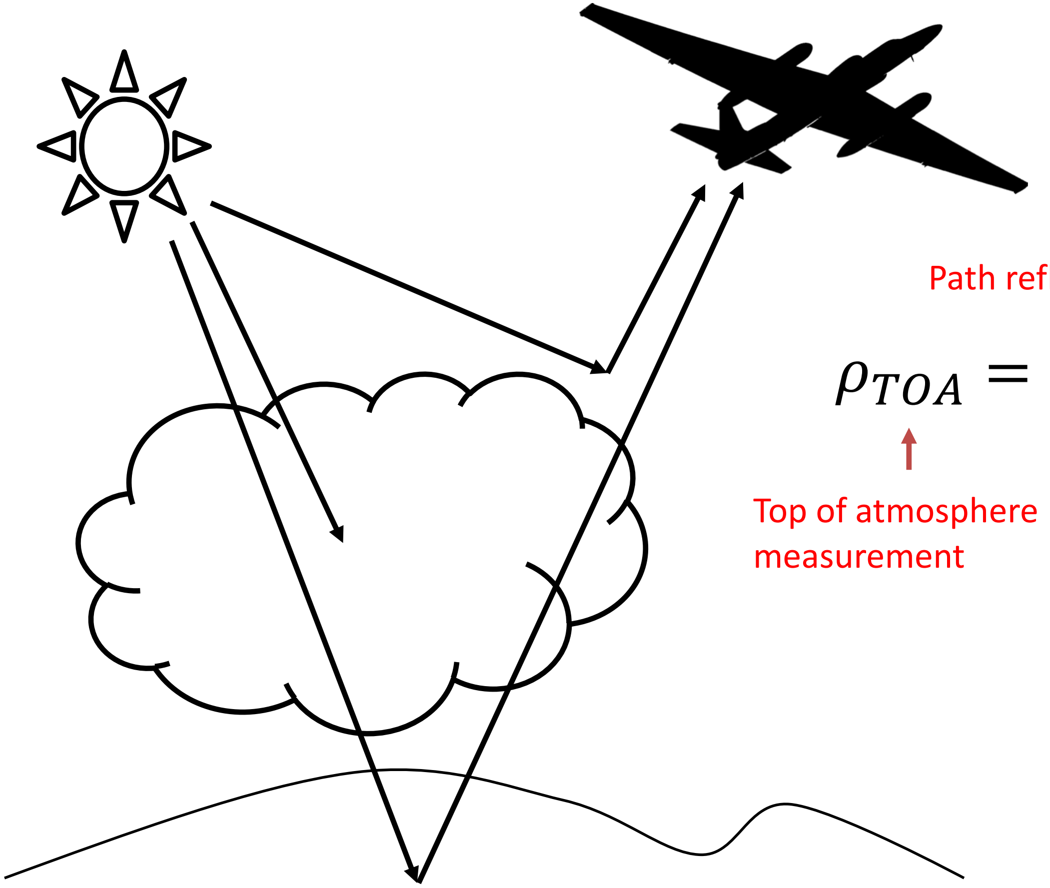
Surface reflectance

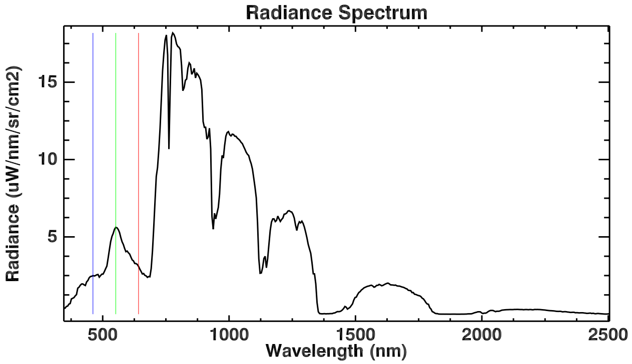




david.r.thompson@jpl.nasa.gov

Atmospheric Correction





Transmission

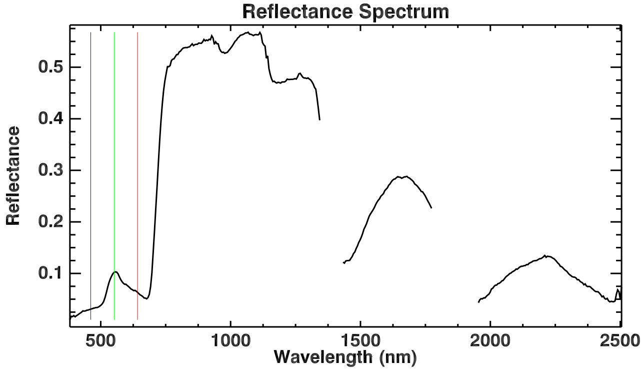
Path reflectance

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

Surface reflectance

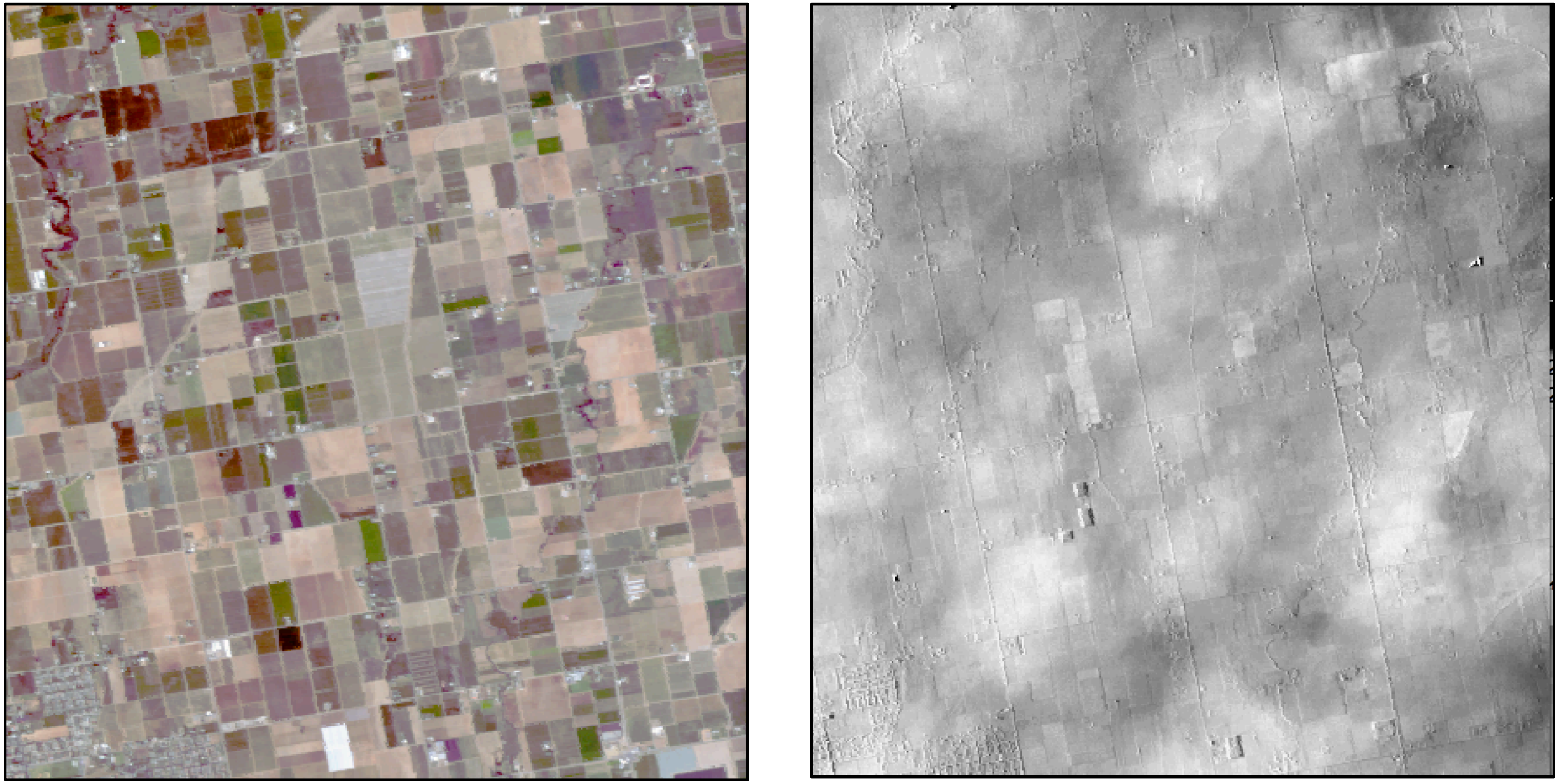
Top of atmosphere measurement

Spherical albedo



H_2O Vapor maps

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

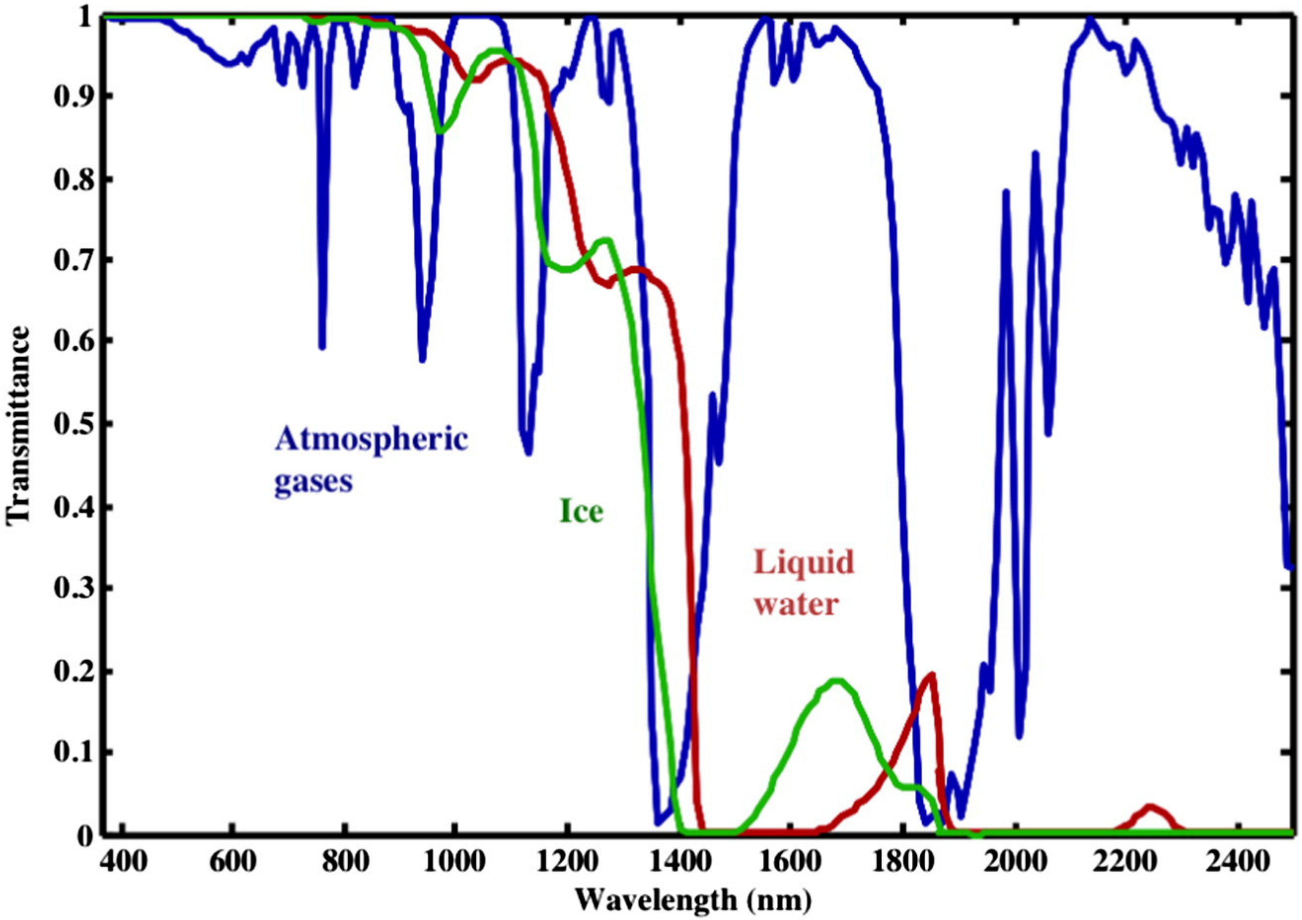


Central Valley Agriculture (HyspIRI Santa Barbara Box)

david.r.thompson@jpl.nasa.gov

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

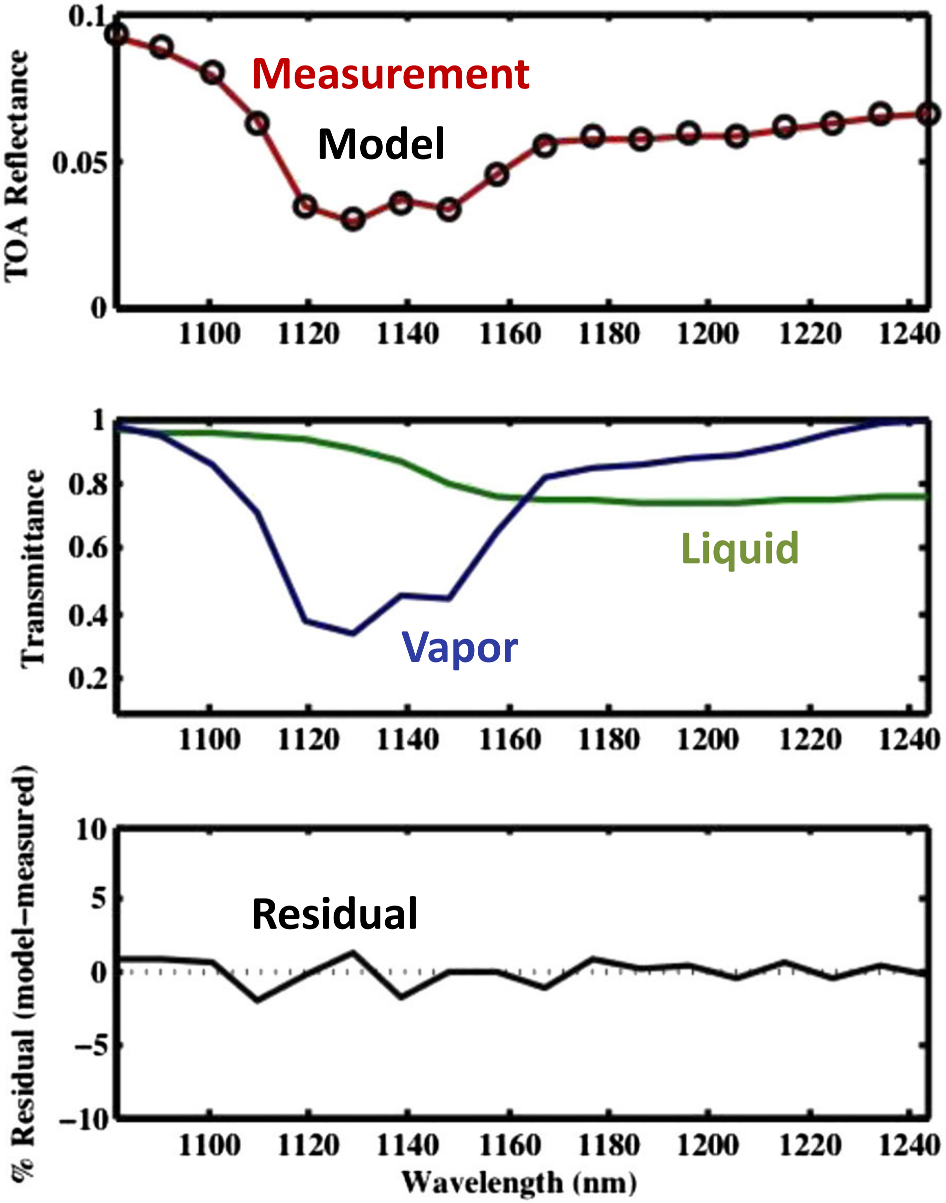
[Thompson et al., *Remote Sensing of Environment* 2015]
[Green et al., *Water Resources Research* 2006]



david.r.thompson@jpl.nasa.gov

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]

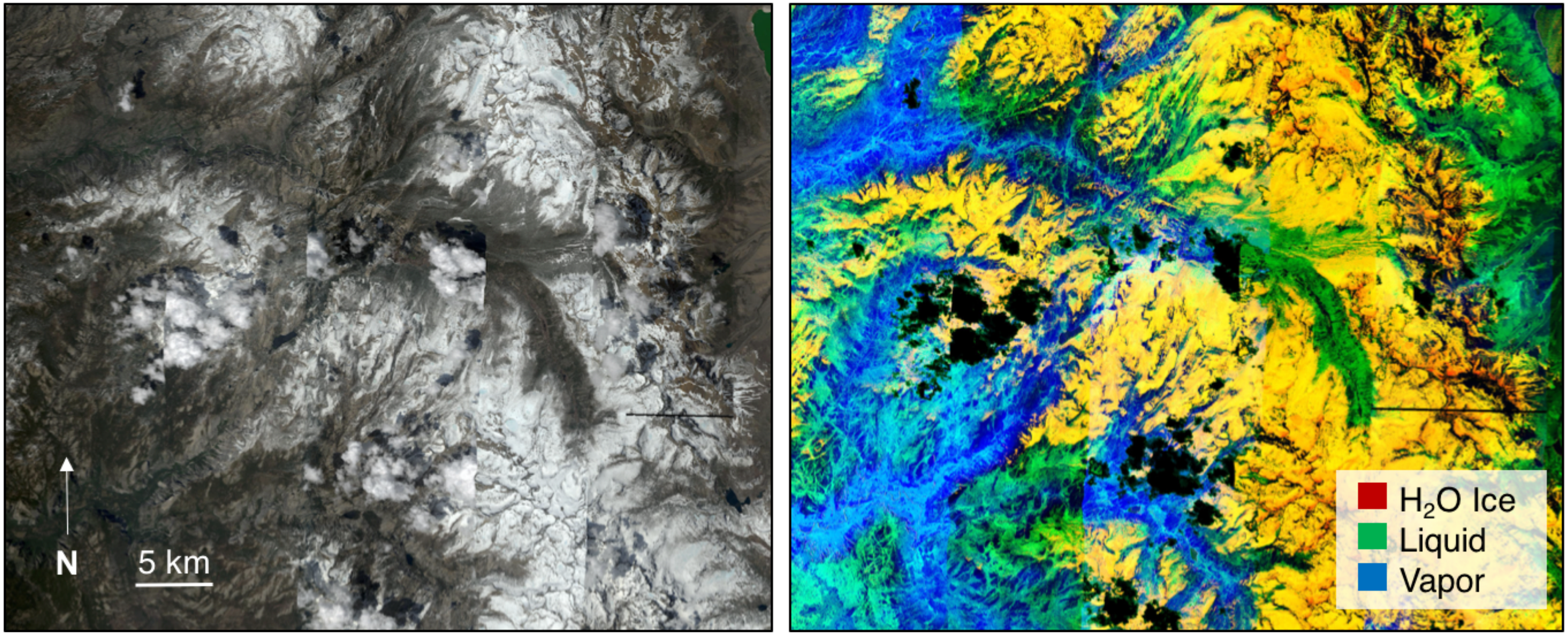


david.r.thompson@jpl.nasa.gov

Three phases of water

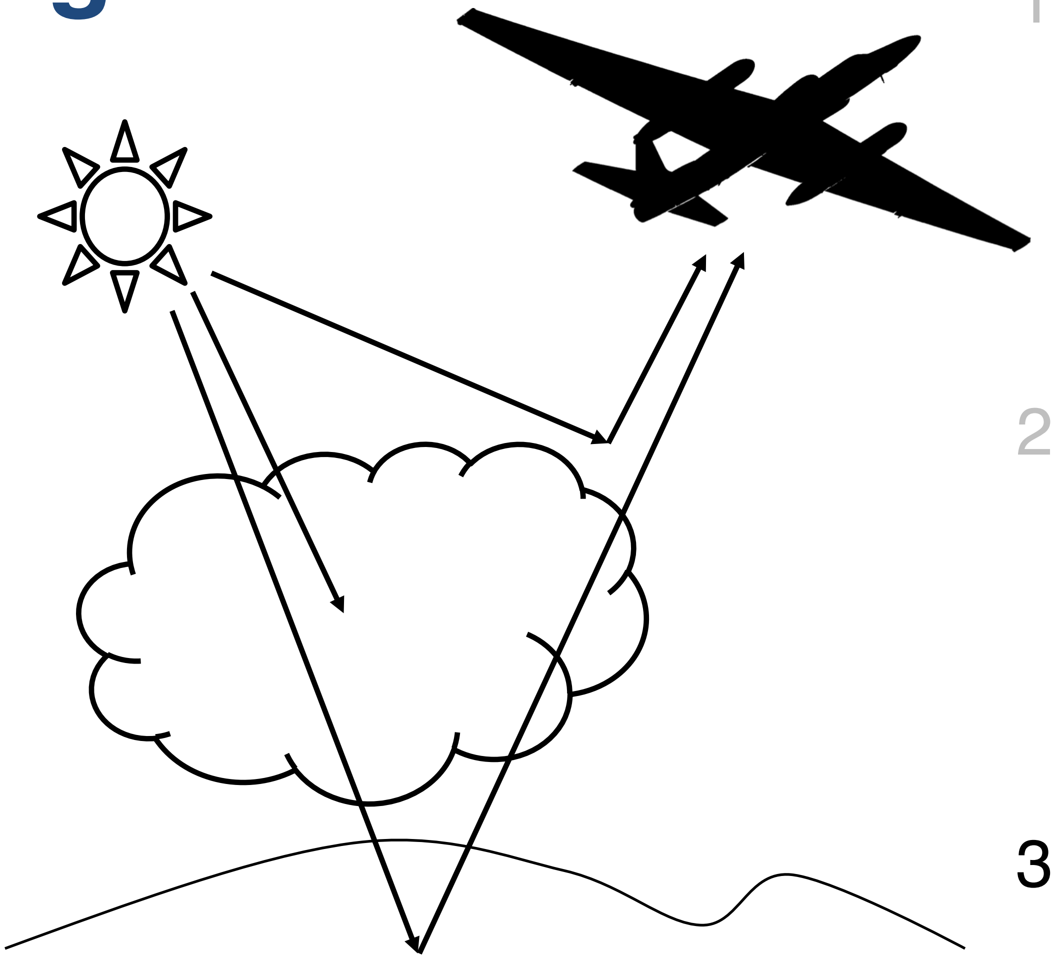
[Thompson et al., *Surveys in Geophysics* 2018]

Yosemite National Park (HyspIRI Sierra Box)



david.r.thompson@jpl.nasa.gov

Agenda



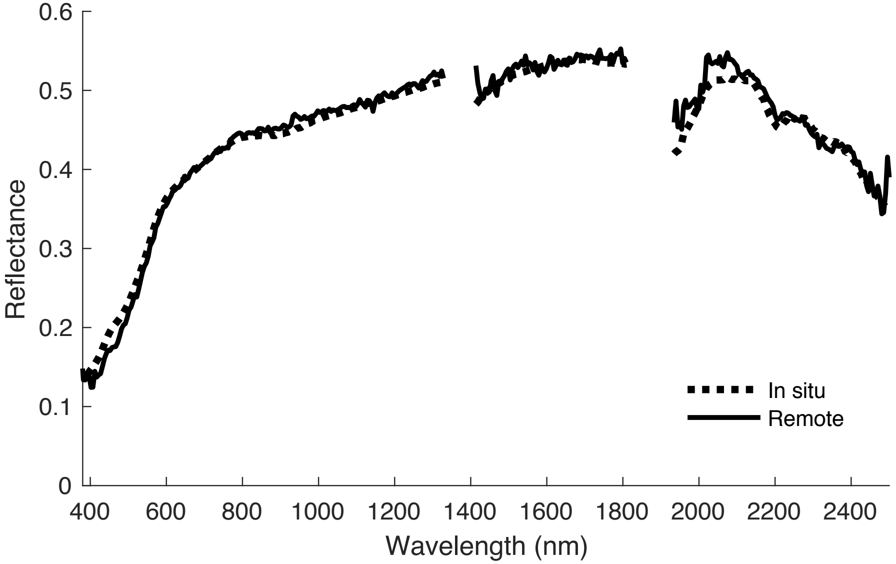
1. Instrument calibration: radiometric and spectral
2. Estimation of atmosphere and surface properties
3. Field validation methods and results

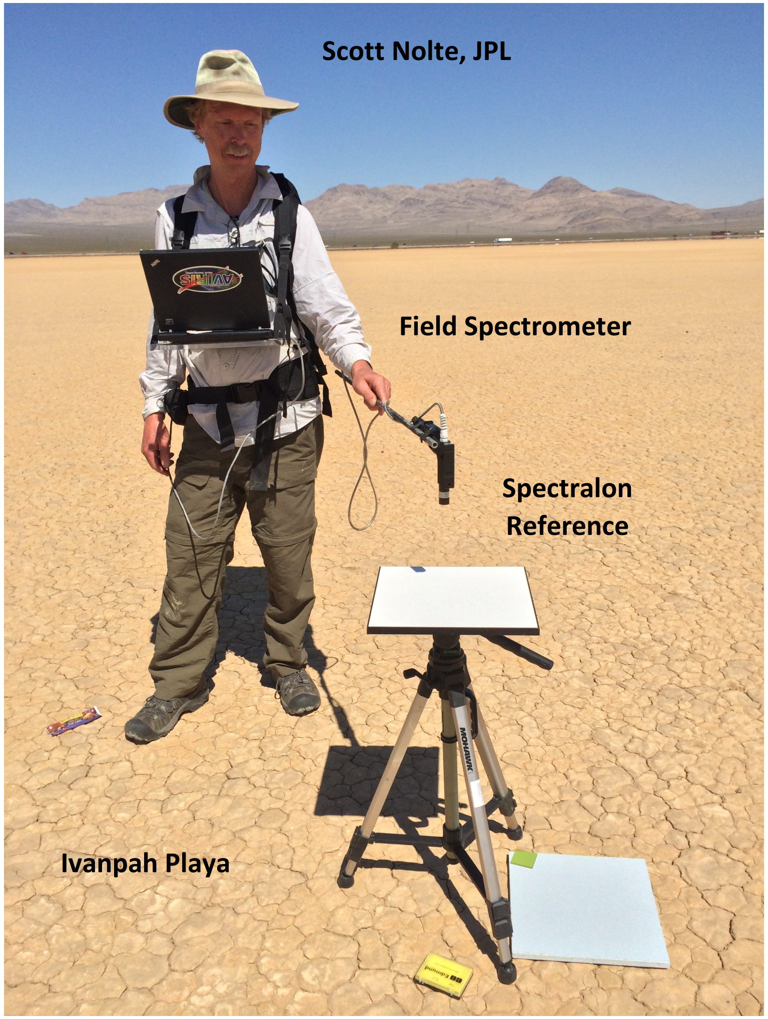
9/20/18

david.r.thompson@jpl.nasa.gov

Ivanpah field validation

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



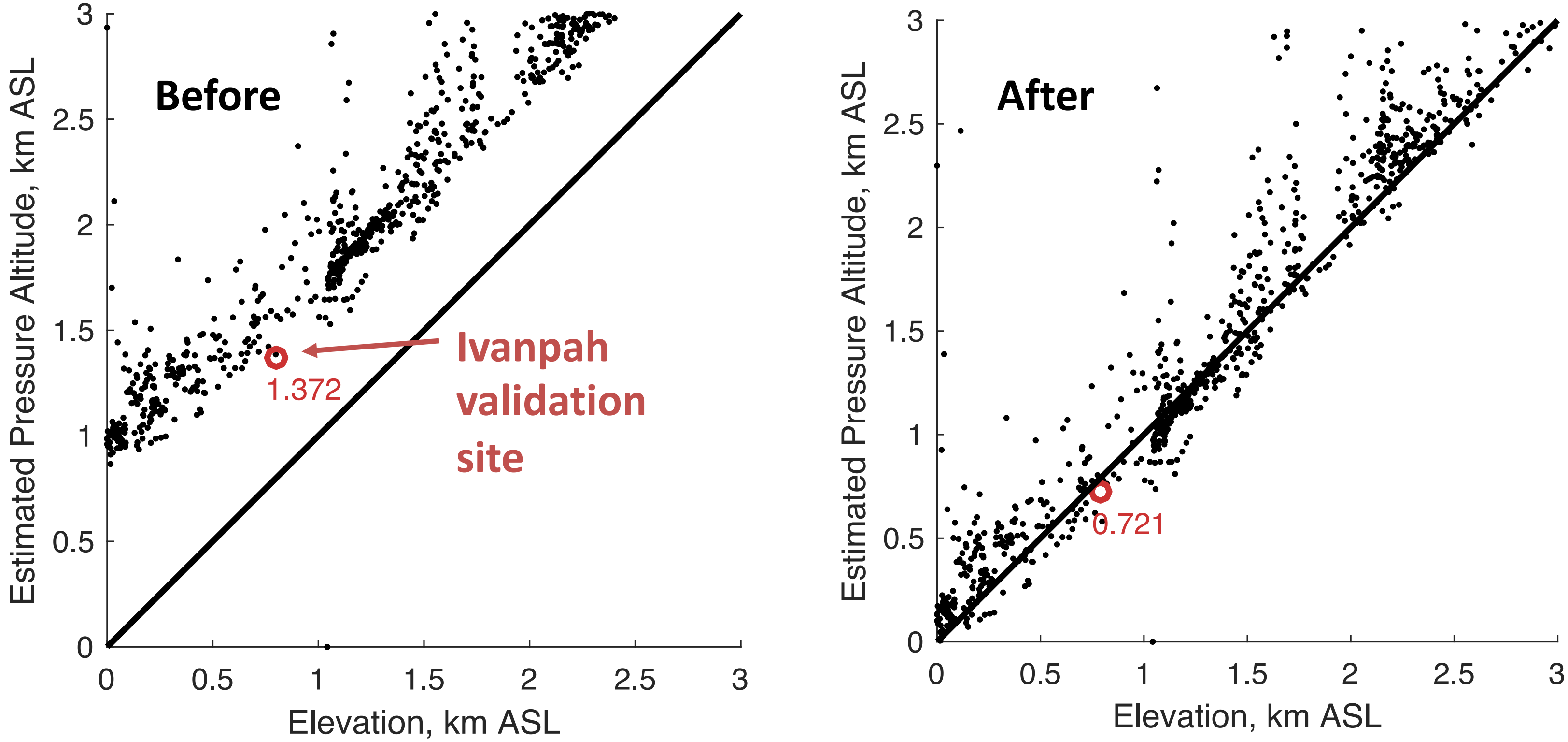


9/20/18

david.r.thompson@jpl.nasa.gov

Spectral corrections improve atmosphere retrievals

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



9/20/18

david.r.thompson@jpl.nasa.gov

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

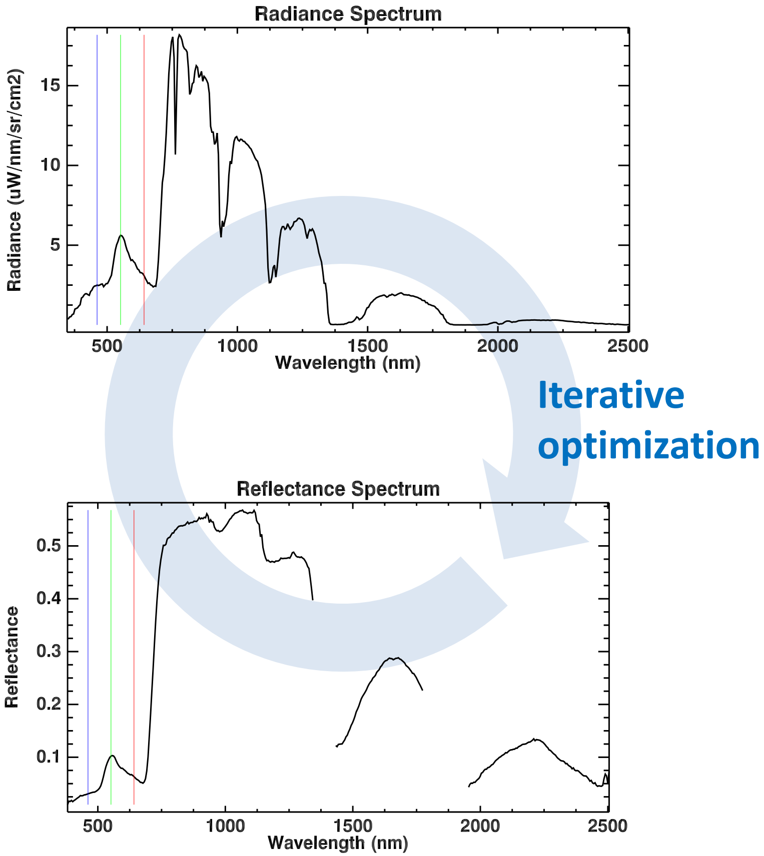
[Thompson et al., *Remote Sensing of Environment* 2018]

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

Improves atmospheric correction accuracy

Rigorous uncertainty accounting

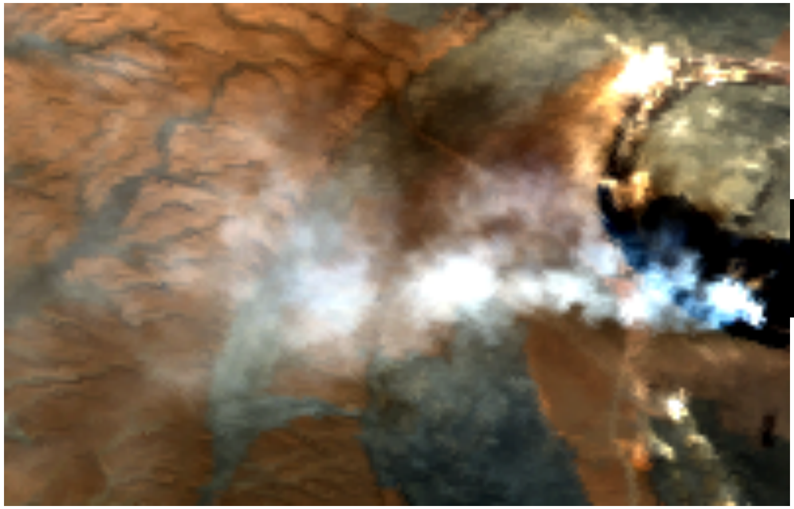
Optimal weighting of information from instrument vs. domain knowledge



https://github.com/isofit/isofit

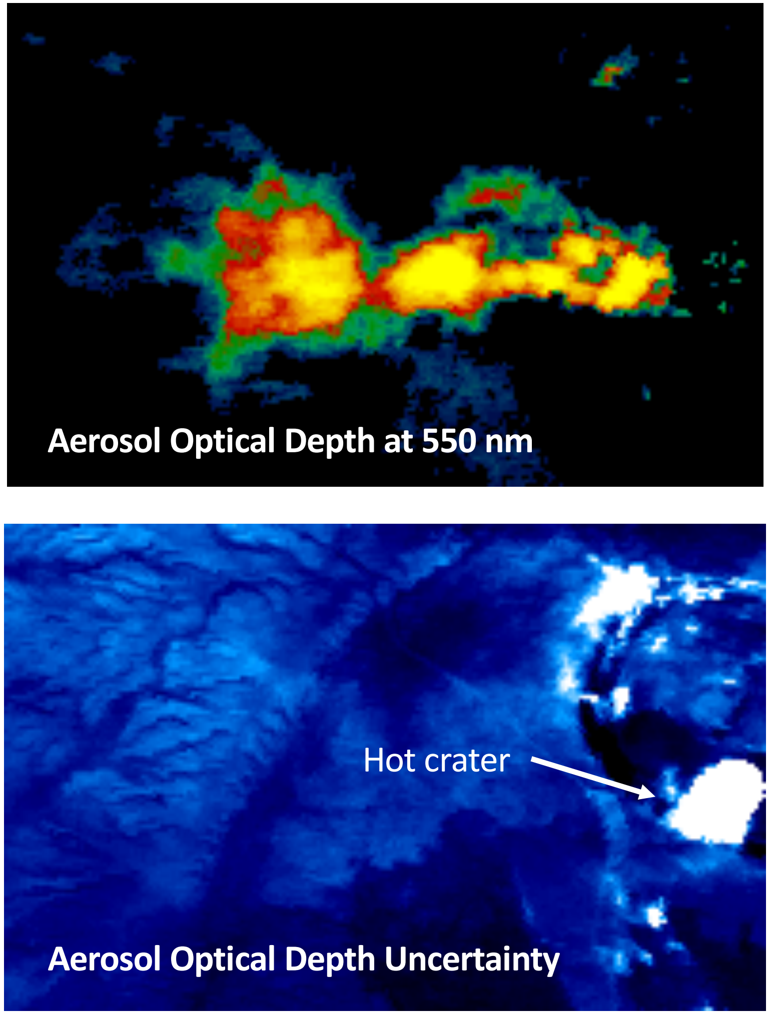
david.r.thompson@jpl.nasa.gov

Example: volcano observations



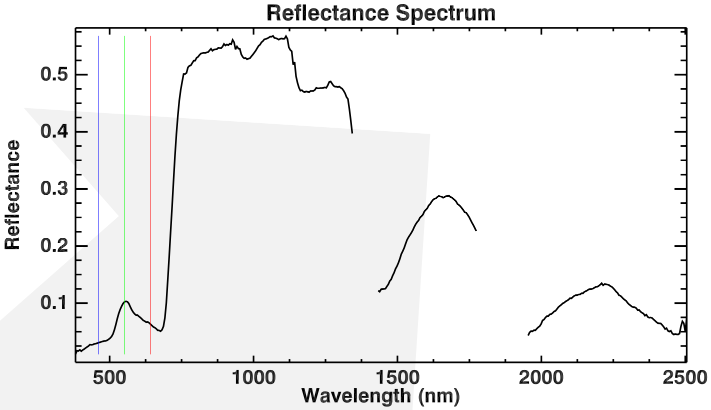
AVIRIS-C f170127t01p00r16
(subset, visible bands)

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

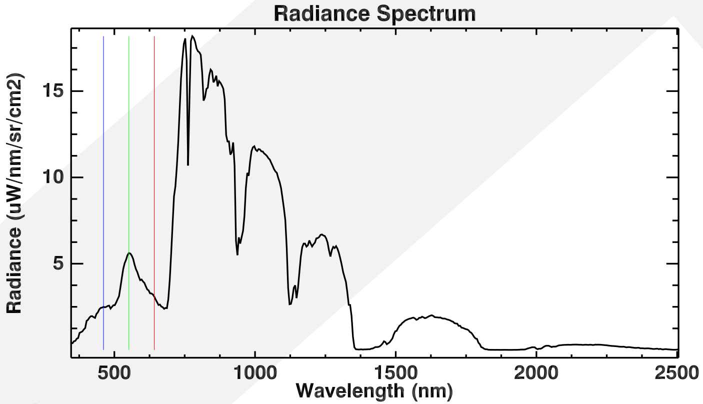


david.r.thompson@jpl.nasa.gov

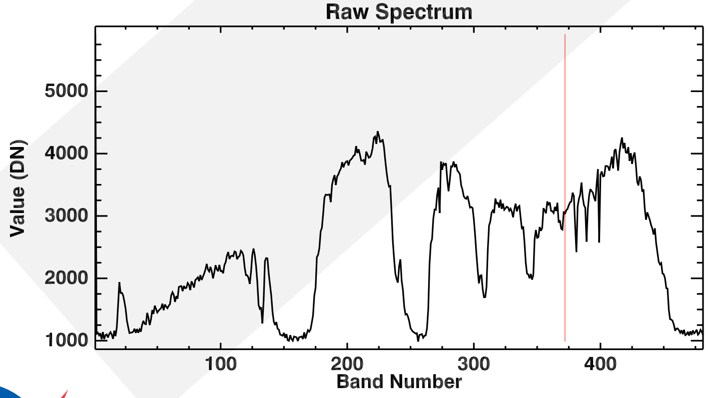
Summary



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

david.r.thompson@jpl.nasa.gov

BACKUP

Stray SRF Measurement model

Adapted from [Zhong et al., 2006]

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

david.r.thompson@jpl.nasa.gov

Stray SRF Measurement model

Adapted from [Zhong et al., 2006

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

$$L_M = \underset{\substack{\uparrow \quad \uparrow \\ \text{Stray SRF} \quad \text{Nominal SRF}}}{GH}L_A + H\underset{\substack{\uparrow \\ \text{Radiance at sensor}}}{L_A} + \epsilon$$

david.r.thompson@jpl.nasa.gov

Stray SRF Measurement model

Adapted from [Zhong et al., 2006]

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

$$\mathbf{L}_M = \overset{\Downarrow}{\underset{\substack{\uparrow \\ \text{Stray SRF}}}{\mathbf{G}}\underset{\substack{\uparrow \\ \text{Nominal SRF}}}{\mathbf{H}}\mathbf{L}_A} + \overset{\Downarrow}{\mathbf{H}\underset{\substack{\uparrow \\ \text{Radiance at sensor}}}{\mathbf{L}_A}} + \overset{\Downarrow}{\epsilon}$$

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

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

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

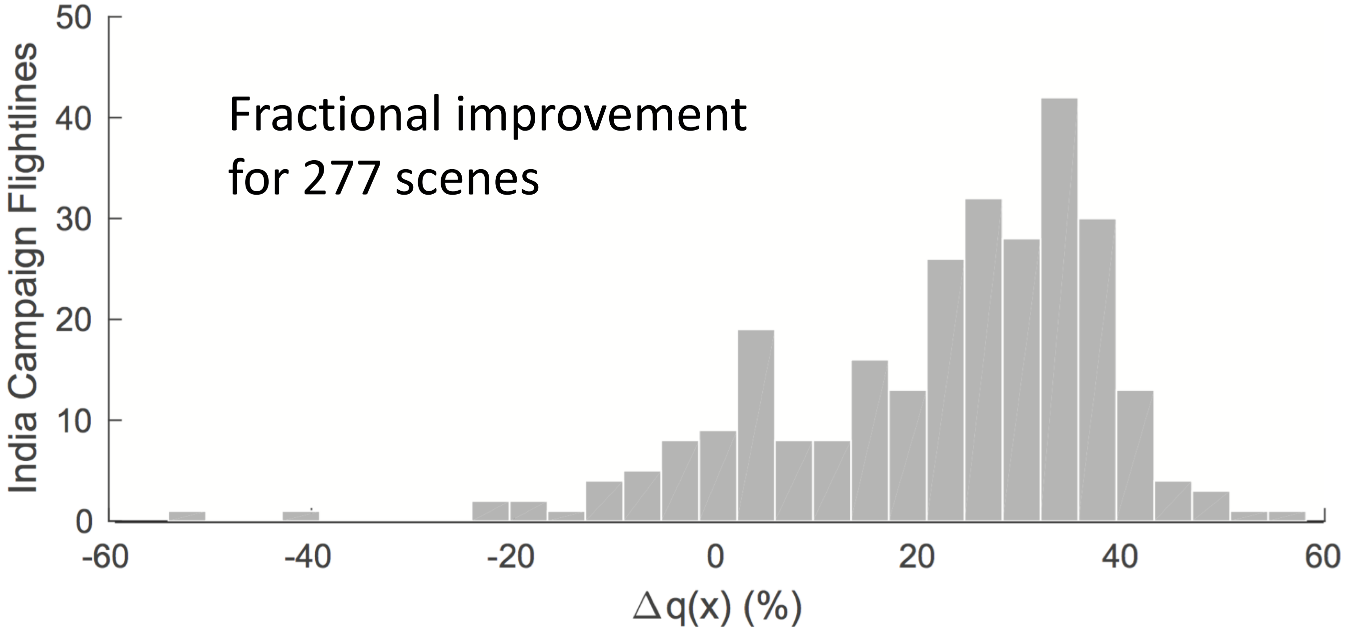
Distorted Measurement

A similar correction fixes cross-track stray light

david.r.thompson@jpl.nasa.gov

India Validation Results

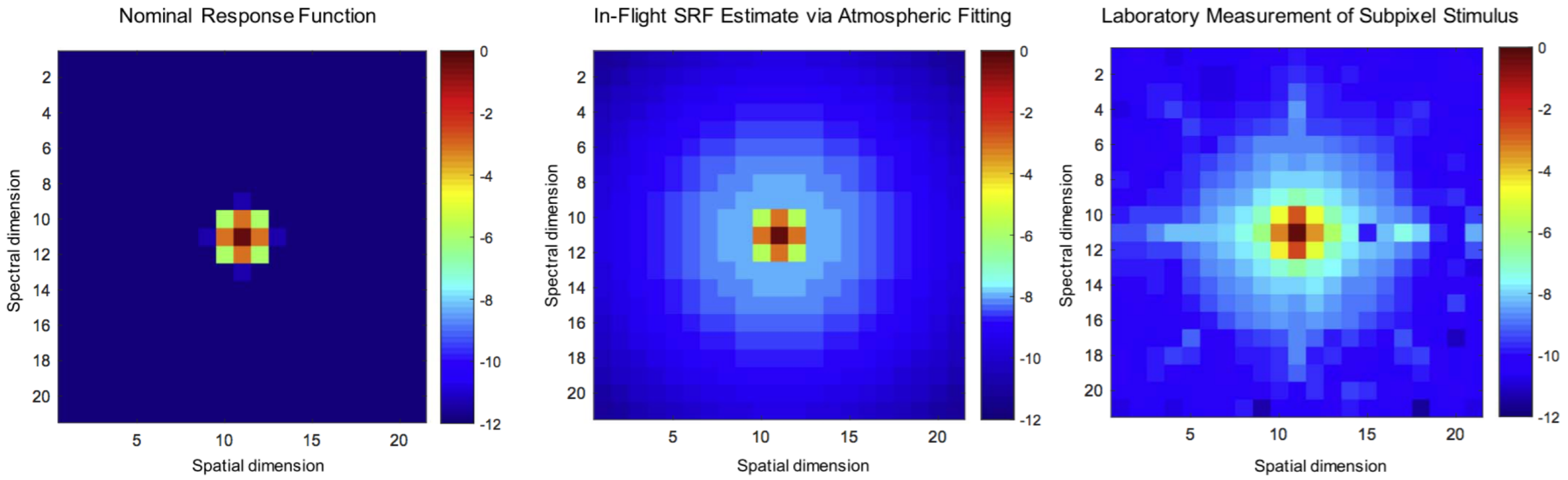
- 26 of 37 flight days show significant improvements ($p < 0.001$)
- Typical improvement is 20-35%
- No flight day shows a statistically significant accuracy reduction

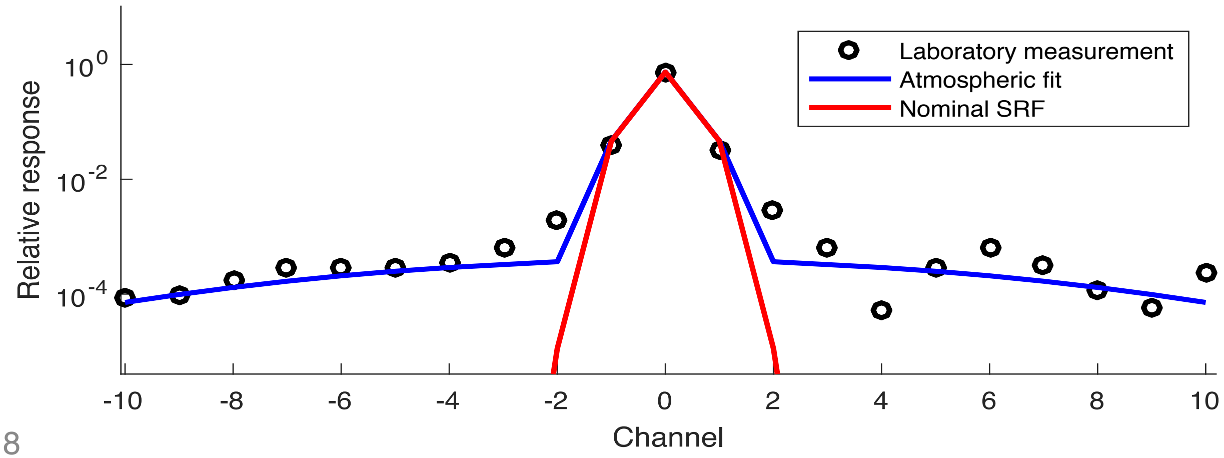


9/20/18

david.r.thompson@jpl.nasa.gov

Agreement with laboratory data

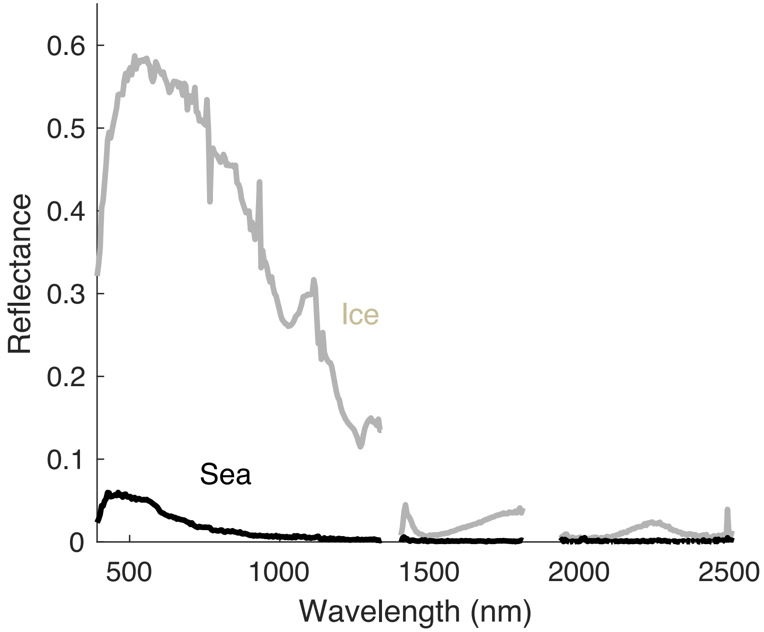




david.r.thompson@jpl.nasa.gov

Spatial dimension

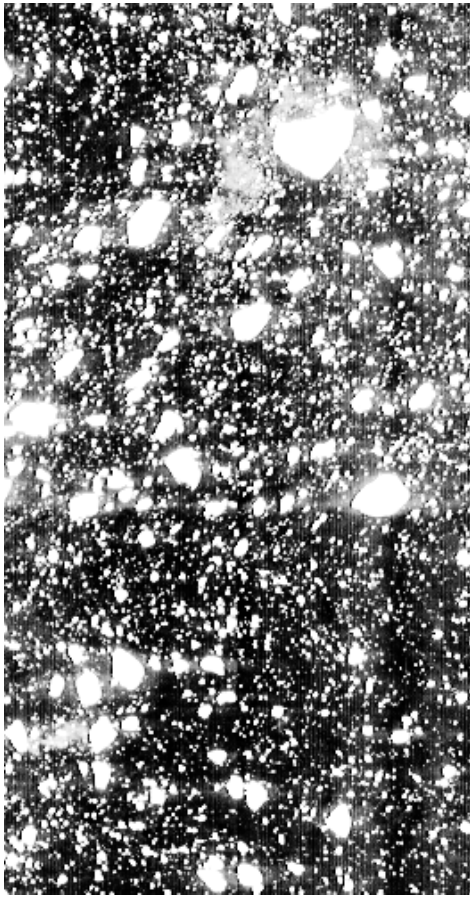
- Exploit Near-Infrared (NIR) ocean reflectance
- Use a haze-free day to constrain path radiance and adjacency effects
- Use a wind-free day with nadir observations to limit glint
- Dark water should be highly absorbant in NIR
- Dataset: 2015 Greenland ice flow



“Halo” reduction

Original RGB

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



612 nm, after CRF correction

Retrieve Stray SRF from a “Calibration Scene”

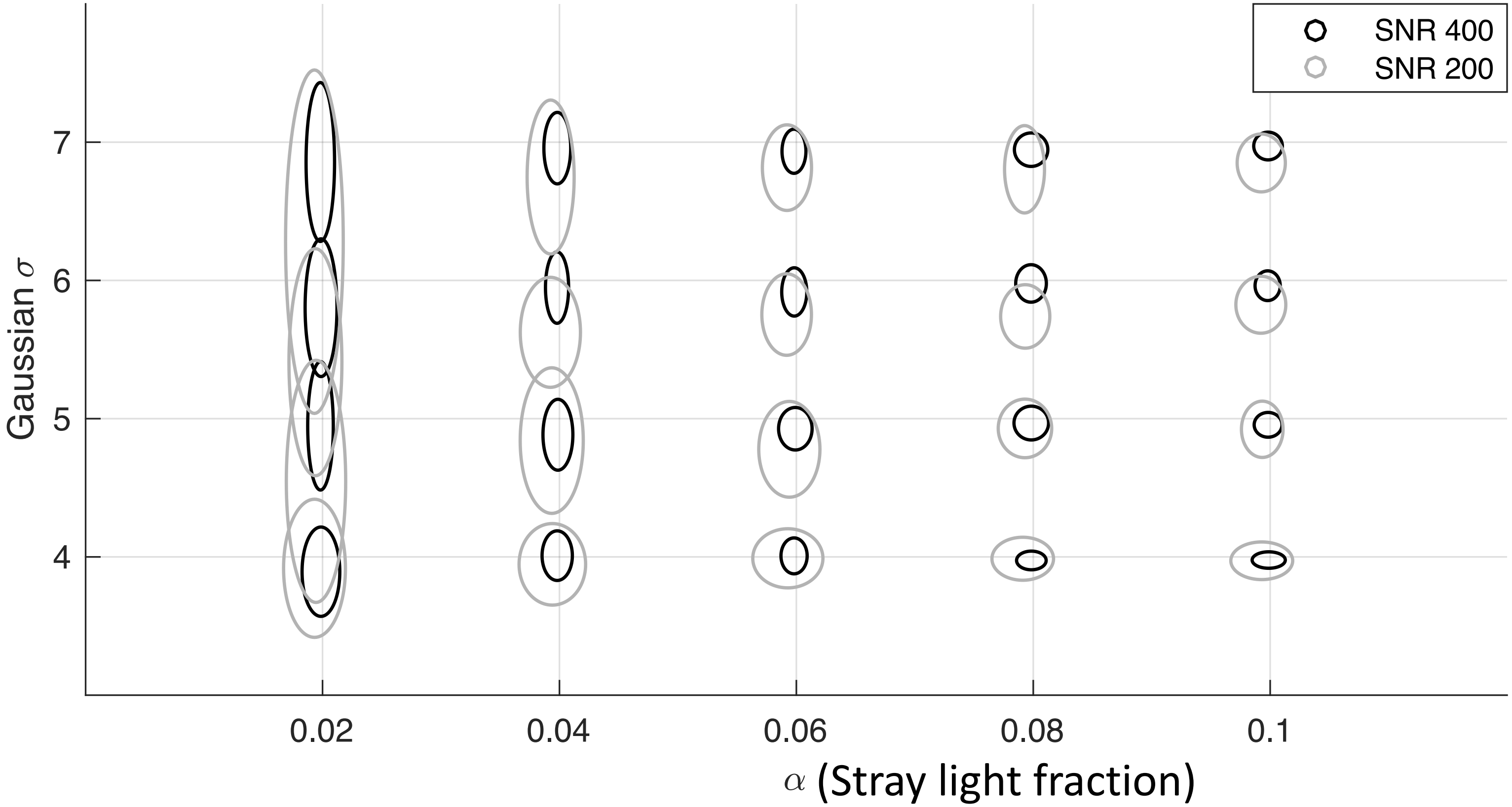
Death Valley Transect, 2014 (visible RGB)

Predict A band radiances using a Digital Elevation Model

Nonlinear least squares optimization finds SSRF parameters

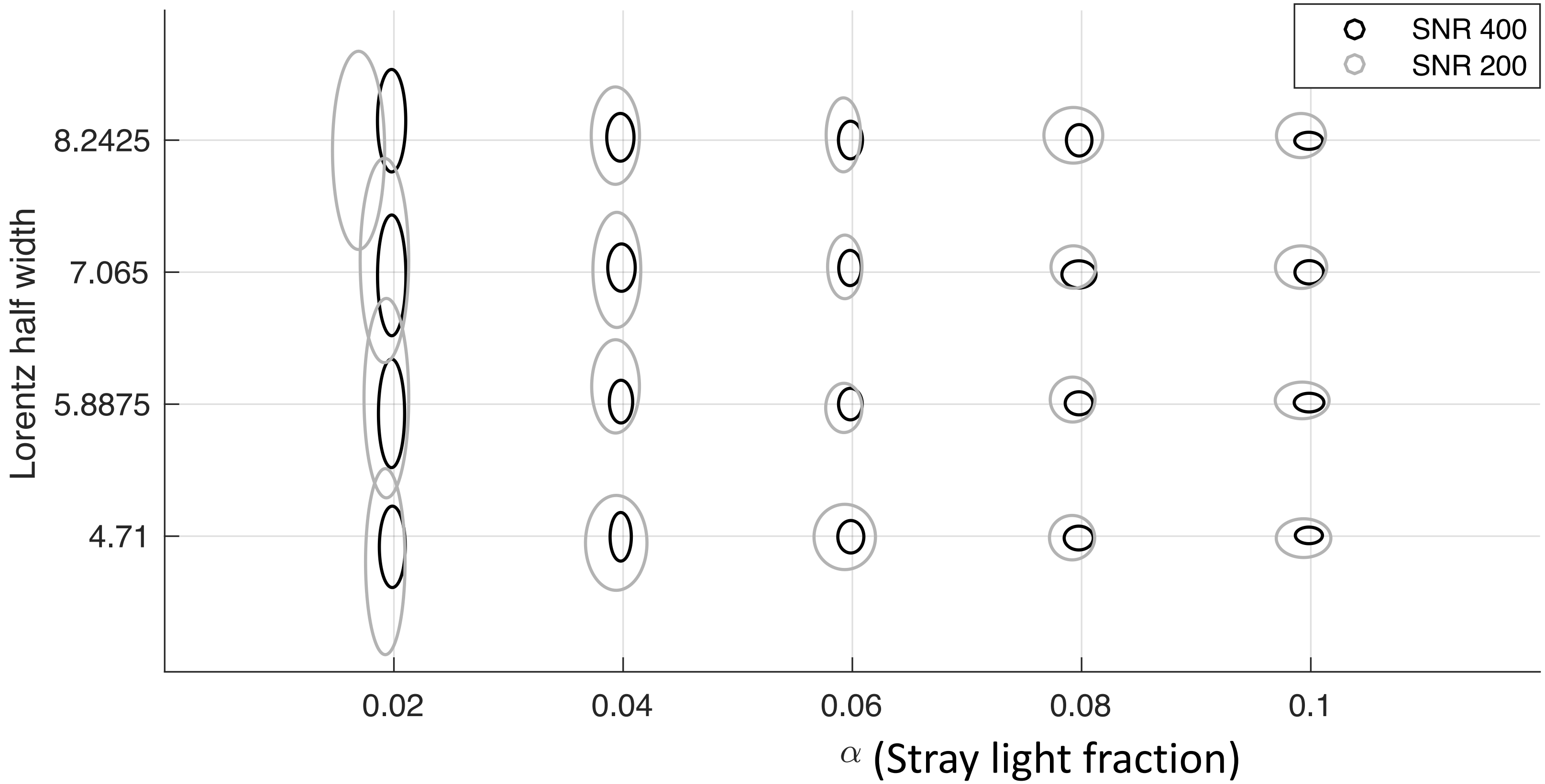
david.r.thompson@jpl.nasa.gov

Estimation accuracy for Gaussian SSRF (simulated)



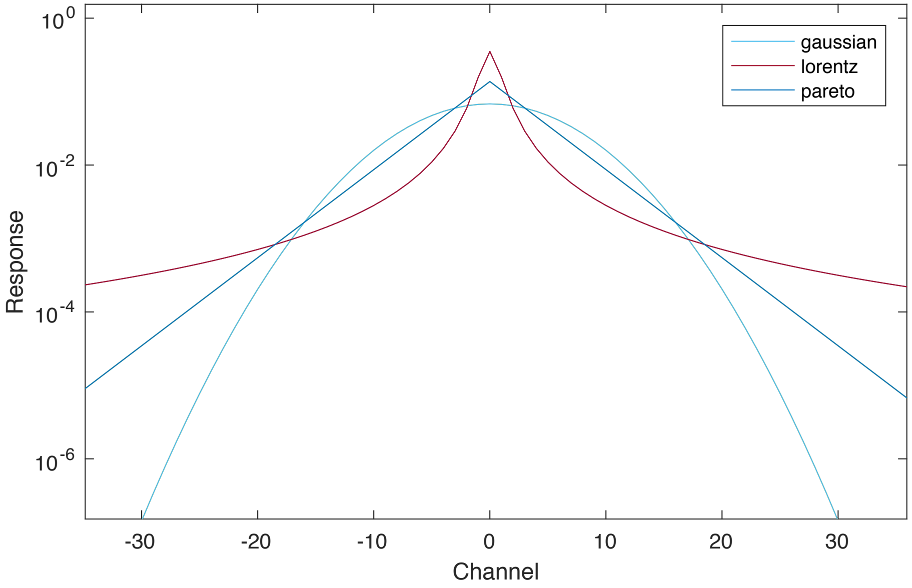
david.r.thompson@jpl.nasa.gov

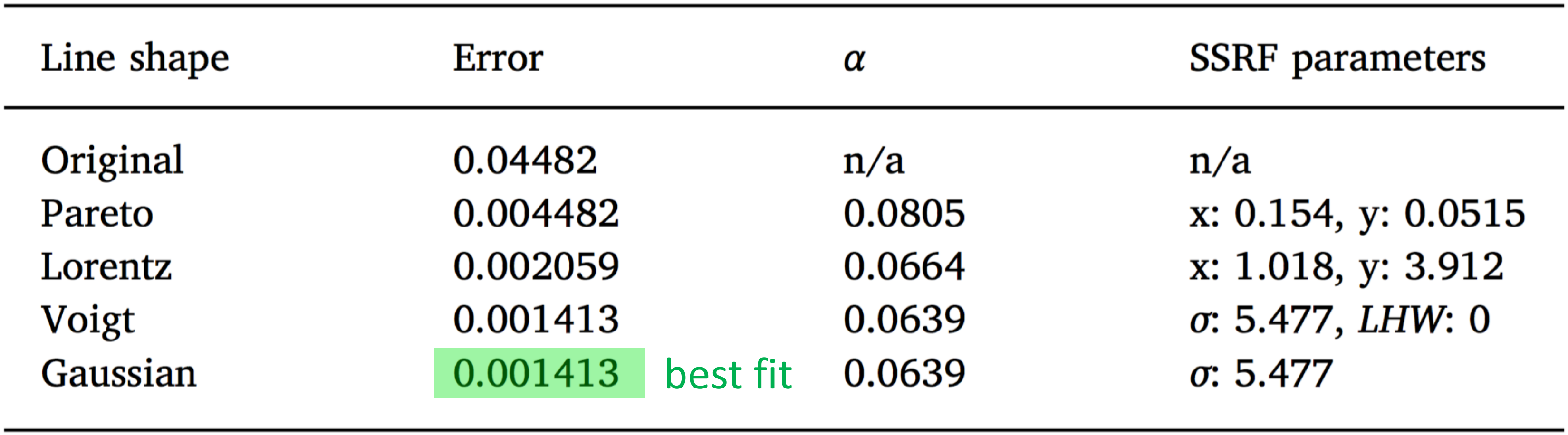
Estimation accuracy for Lorentz SSRF (simulated)



david.r.thompson@jpl.nasa.gov

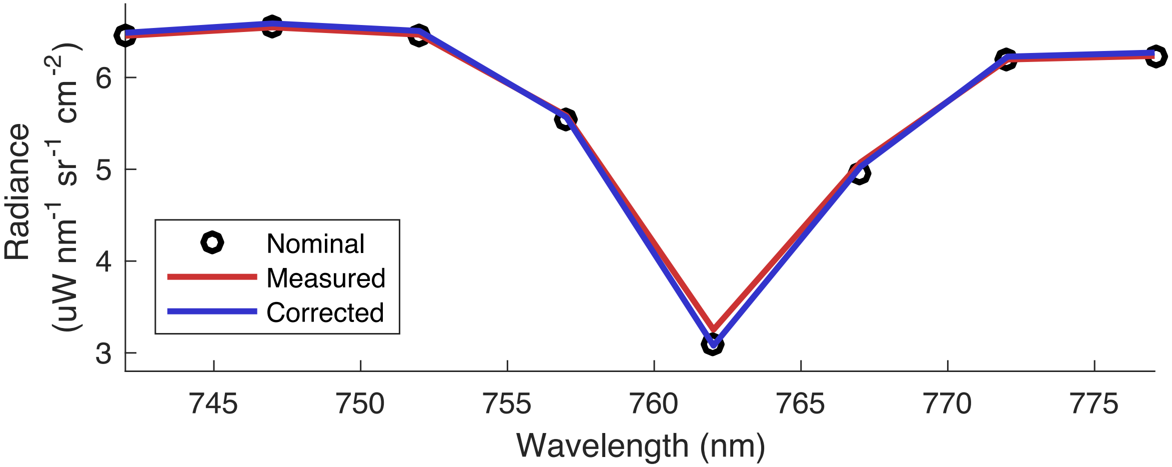
Fit error for candidate SSRF shapes

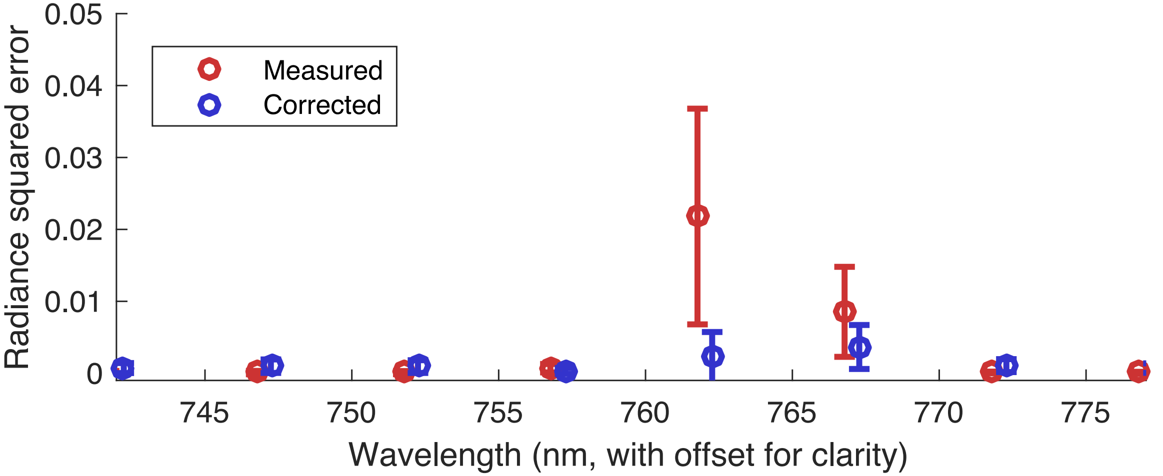




Line shape	Error	α	SSRF parameters
Original	0.04482	n/a	n/a
Pareto	0.004482	0.0805	x: 0.154, y: 0.0515
Lorentz	0.002059	0.0664	x: 1.018, y: 3.912
Voigt	0.001413	0.0639	σ: 5.477, *LHW*: 0
Gaussian	0.001413 best fit	0.0639	σ: 5.477

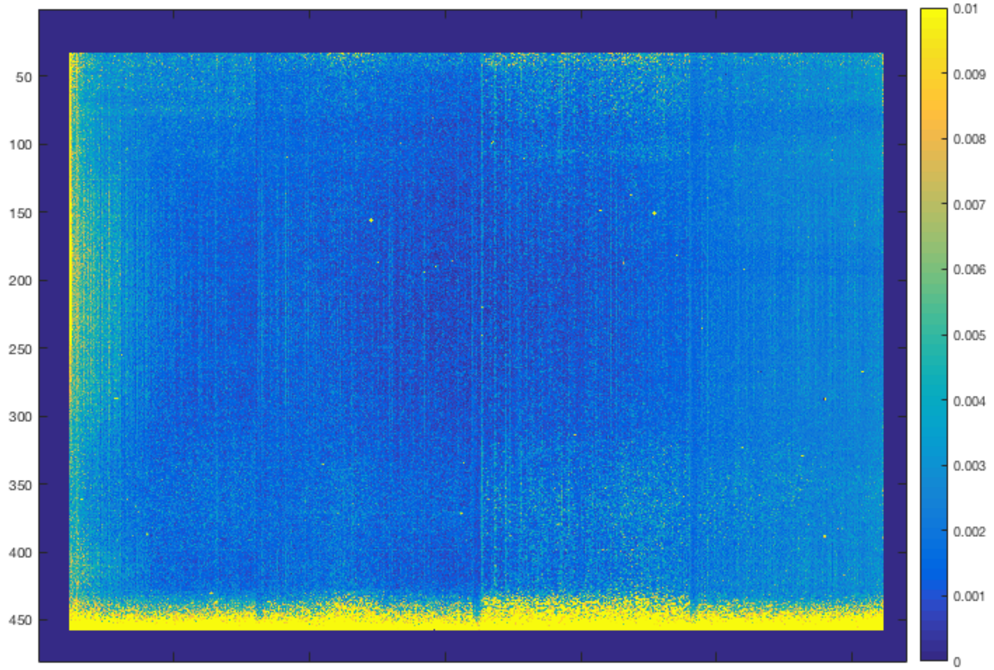
Improvement in O_2 A band fit





david.r.thompson@jpl.nasa.gov

Radiometric calibration repeatability (hangar protocol)



Flat field: σ < 0.14% across most elements

Calibration coefficients: σ < 0.05% across most channels