Improved Atmospheric Correction for Imaging Spectroscopy Using Optimal Estimation

AGU FALL MEETING
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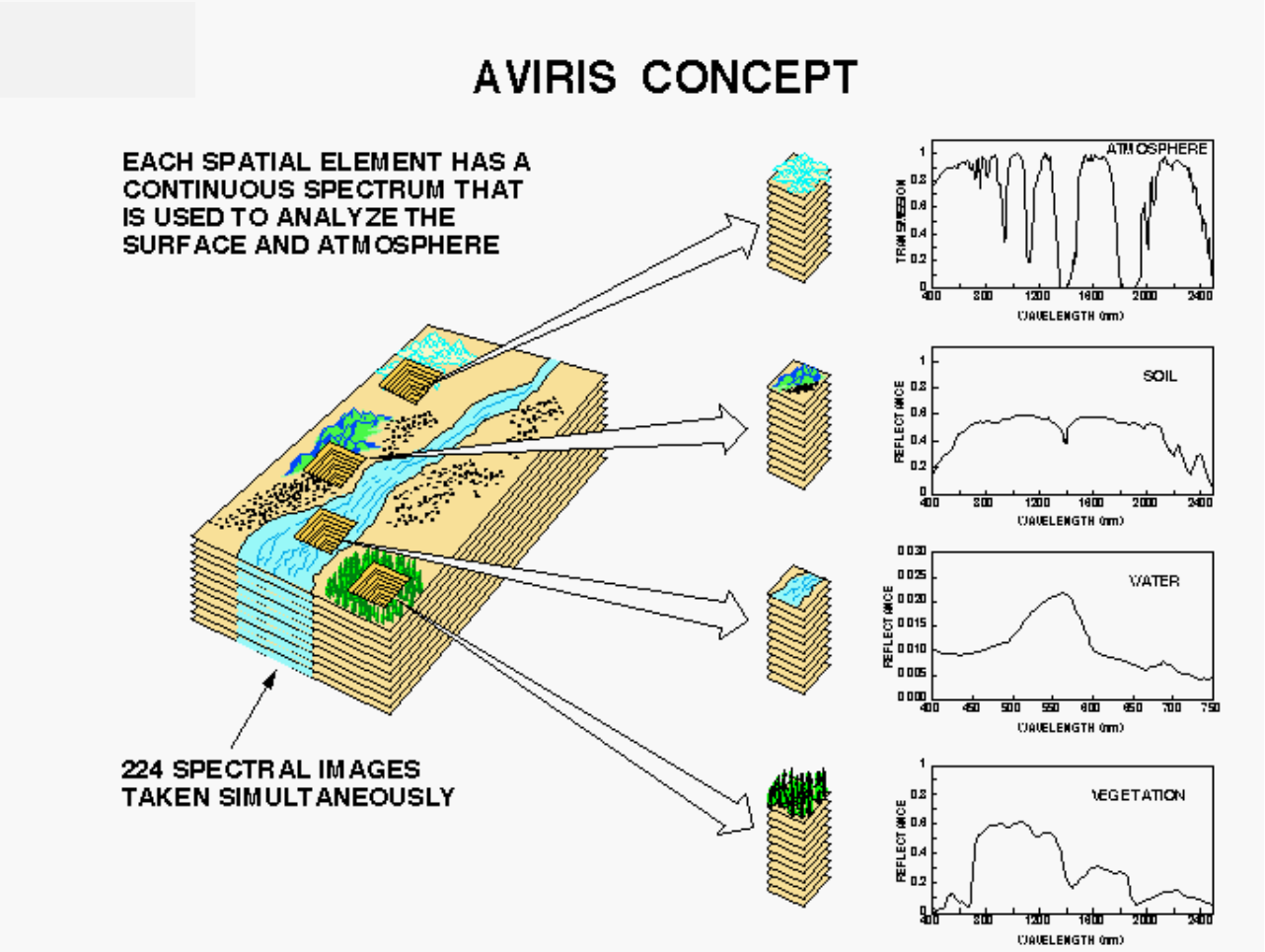
Imaging Spectroscopy: Concept

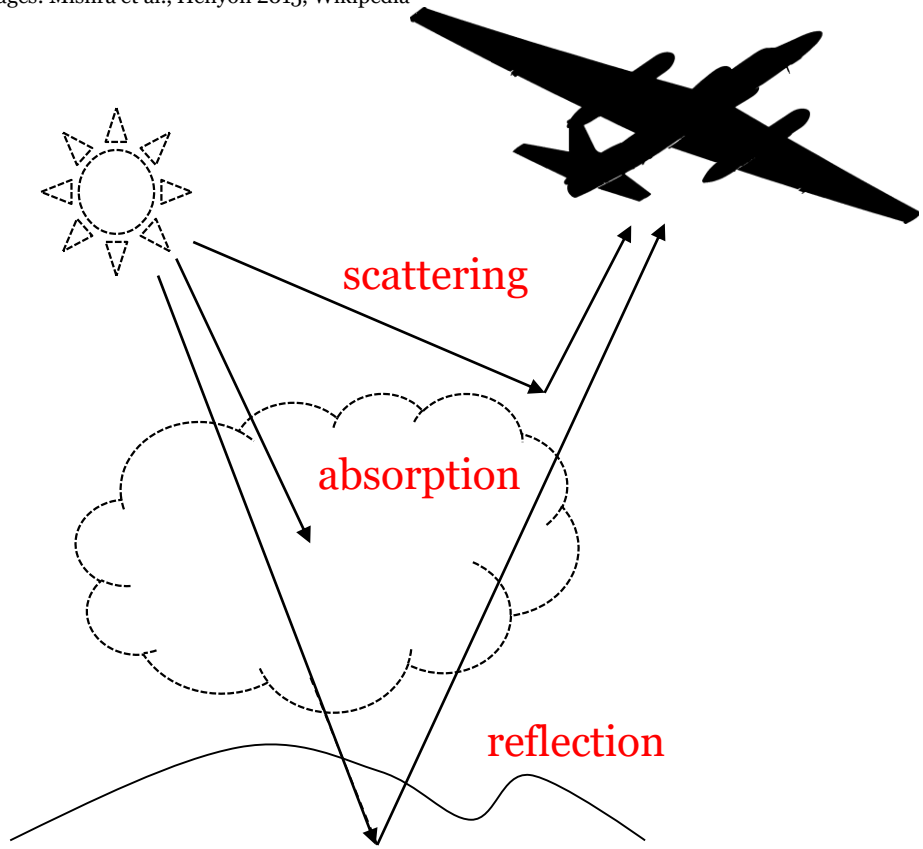


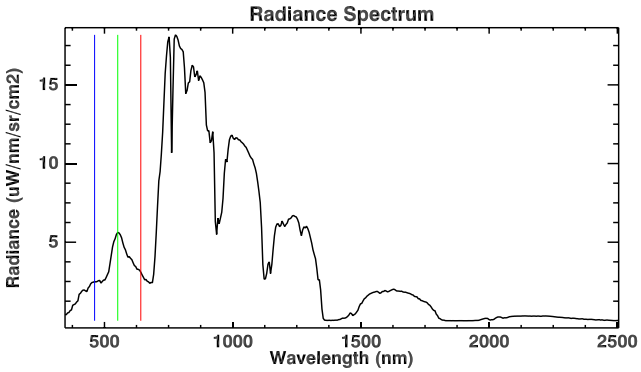
Applications

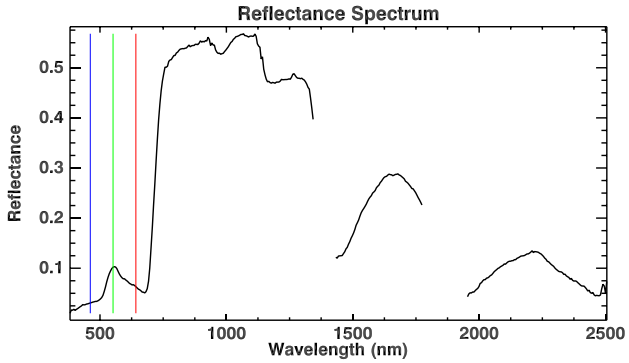
- Terrestrial domains
  - Ustin et al., 2004; Jetz et al., 2016; Asner et al., 2017
- Aquatic environments
  - Hochberg, 2011; Fichot et al., 2015
- Estimation of surface reflectance requires removal of atmospheric effects
- Atmospheric constituents typically estimated from radiance spectra
  - ACORN (Kruse, 2004), ATCOR (Richter & Schlapfer, 2002), FLAASH (Perkins et al., 2012), ATREM (Gao et al., 1993)
  - Atmospheric correction mature and performs well for many conditions (e.g. clear skies with near-nadir viewing)

Atmospheric Correction

Images: Mishra et al., Heliyon 2015, Wikipedia







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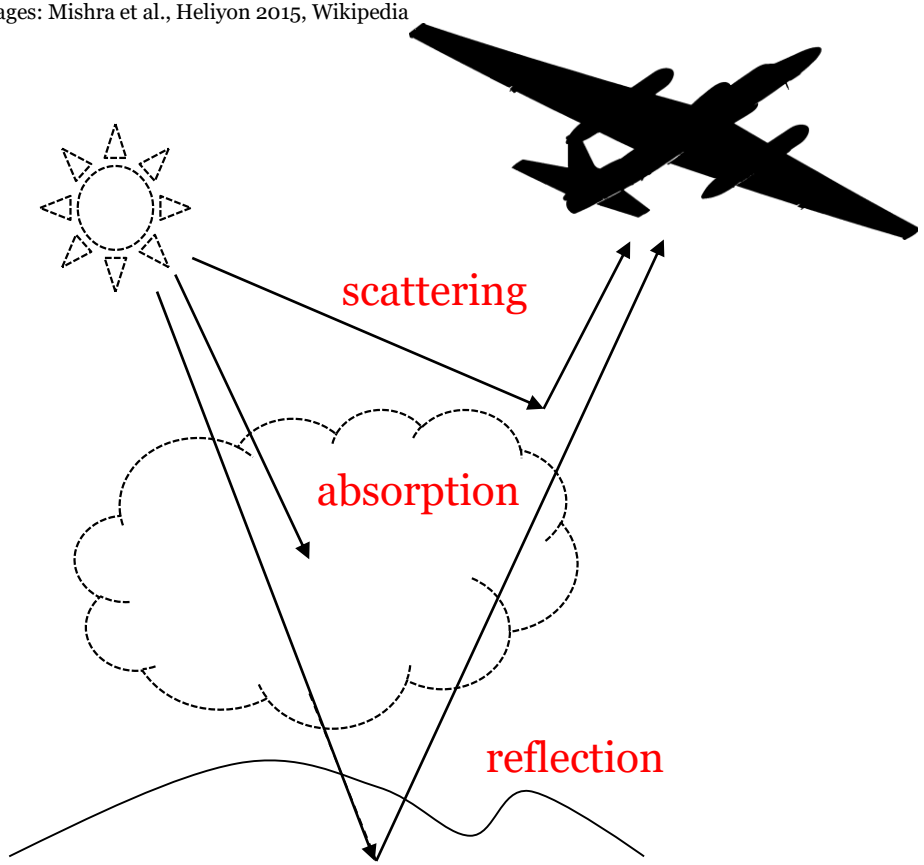
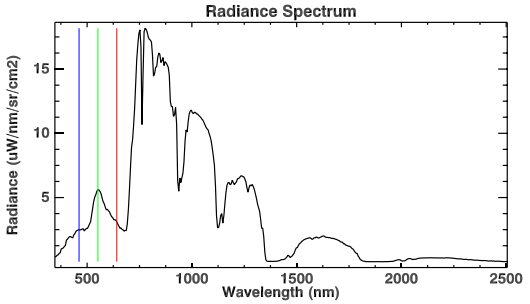
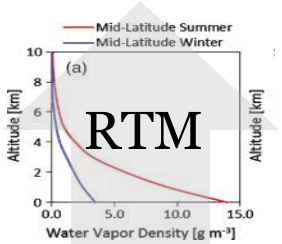
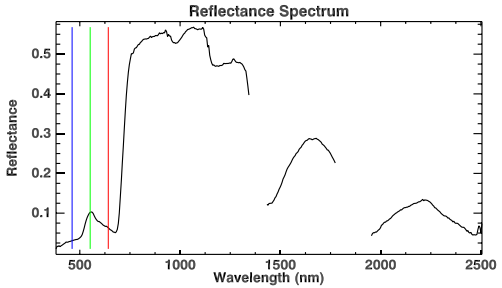


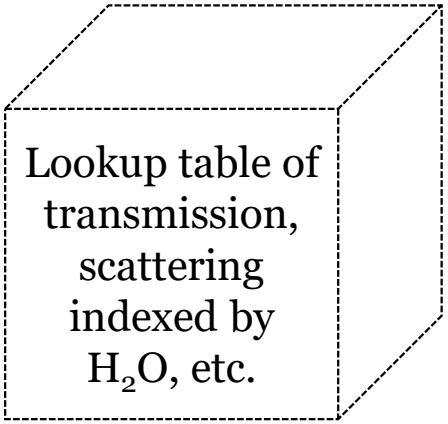






Sequential Estimation

1. In advance, do RTM calculations



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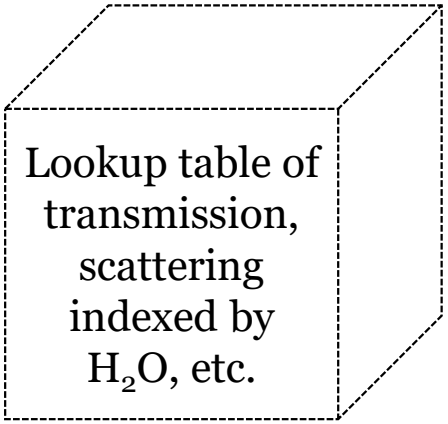

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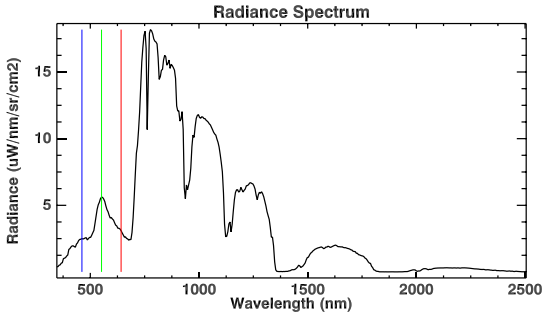

Sequential Estimation

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Lookup table of transmission, scattering indexed by H_2O, etc.

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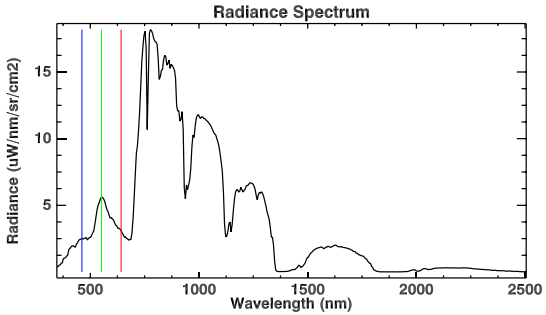
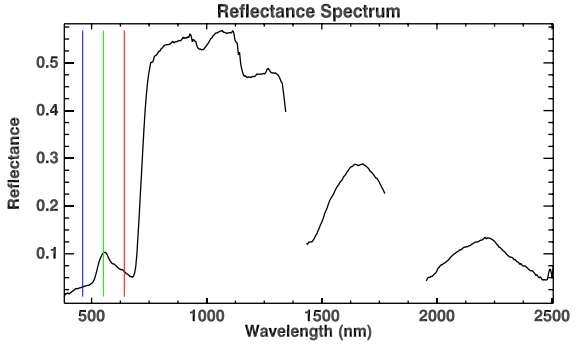


$$\rho^*_{obs} = \rho_a + \frac{T\rho_s}{1 - S\rho_s}$$

3. Algebraic inversion



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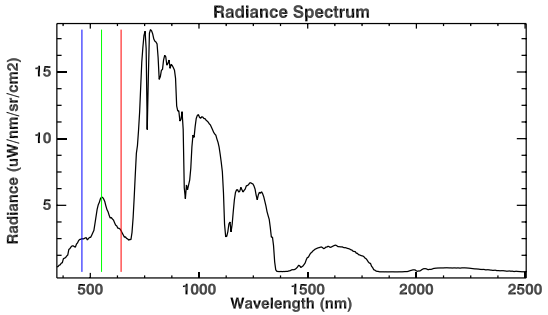

measurement reflectance

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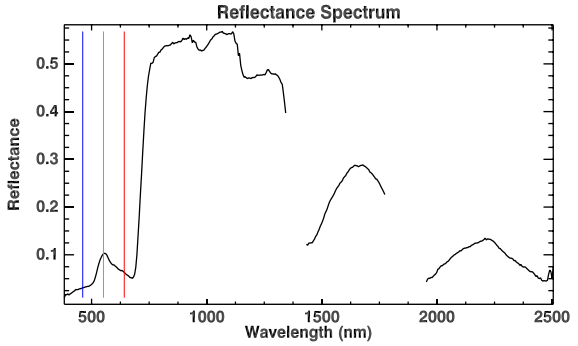

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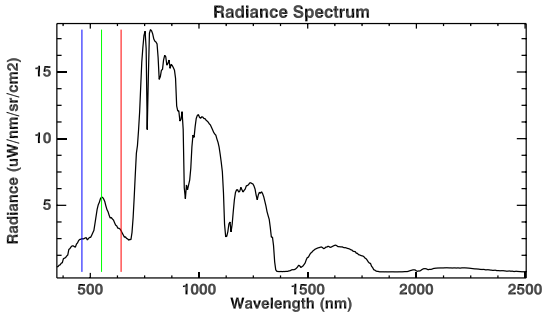

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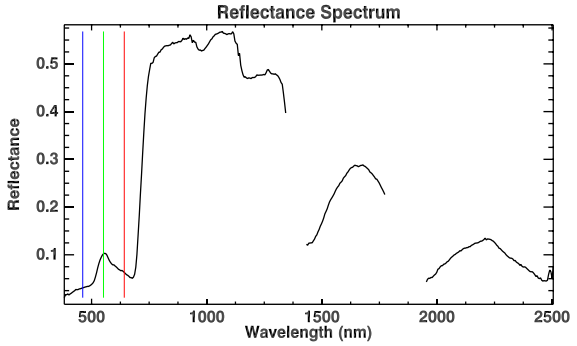


Challenging to disentangle atmosphere and surface effects

Problems with Current Approach

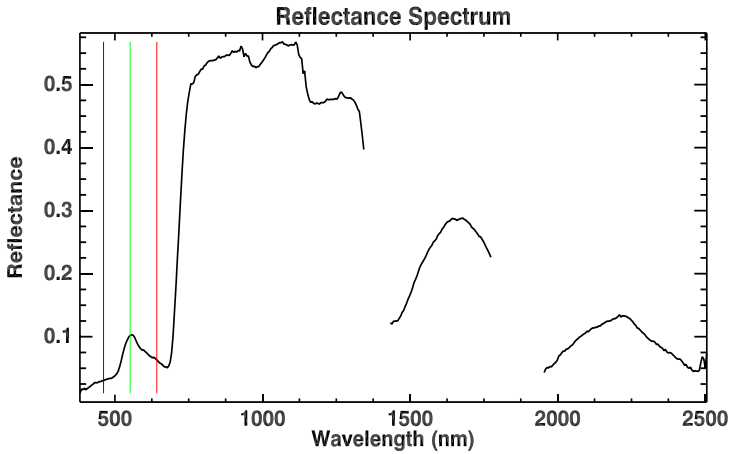
- Limits atmospheric information that can be recovered
- Less accurate for certain observing conditions
  - High water vapor, extreme viewing angles, high aerosol loading, non-Lambertian surfaces
- Orbital missions will not have flexibility to wait for optimal weather conditions
  - Tropical and subtropical environments often show extreme conditions that challenge existing approaches
- No uncertainty quantification

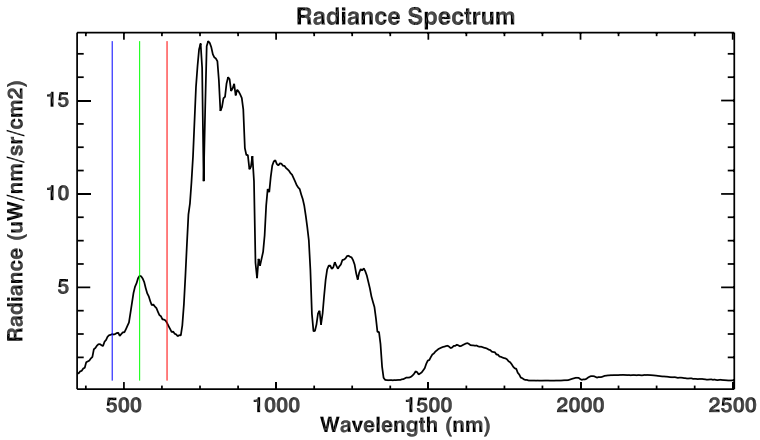
Simultaneous Estimation

1. Predict radiance

$$\mathbf{y} = \mathbf{F}(\mathbf{x}) + \epsilon$$

RTM





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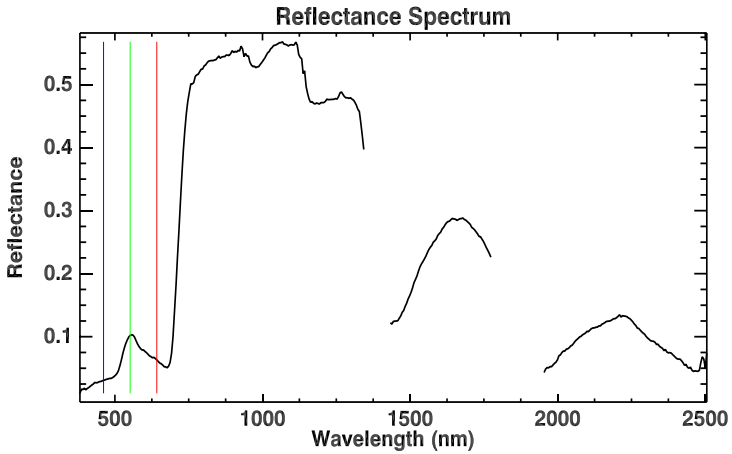
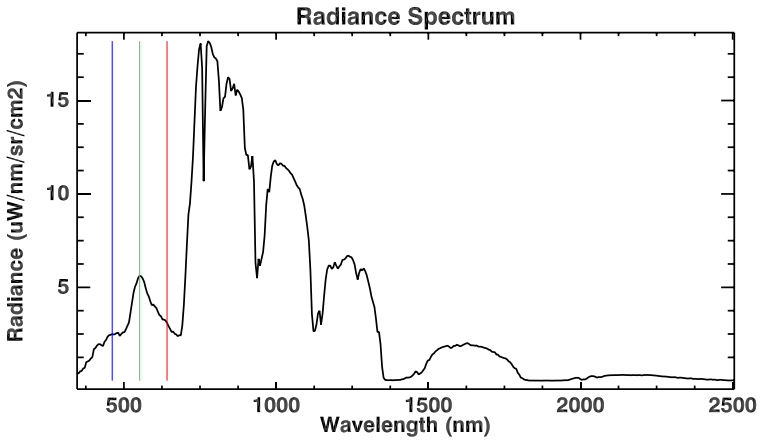




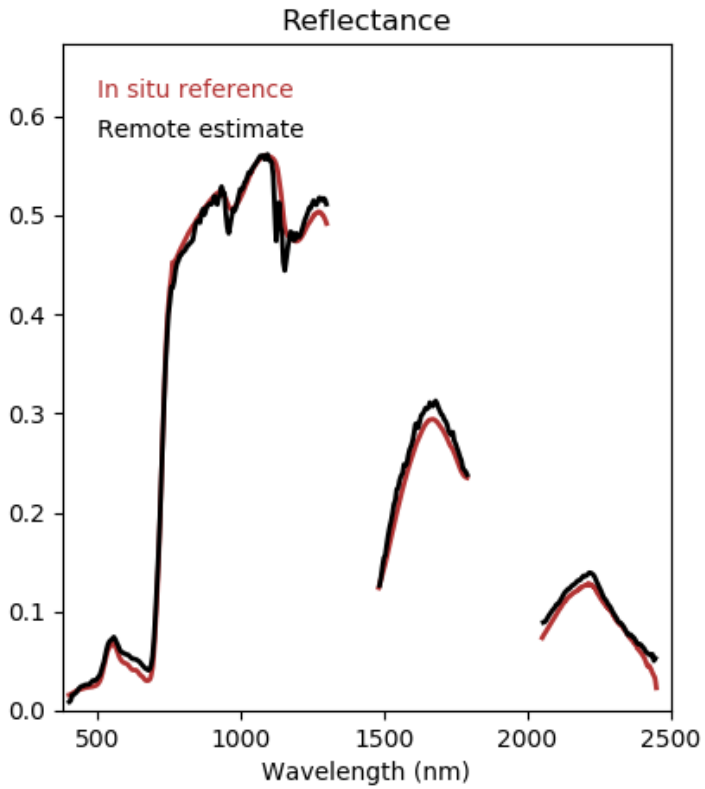
2. Optimize state vector

Minimize “cost function” by optimizing model-measurement mismatch and using Bayesian prior where there is no information from measurements

Advantages of Joint Estimation

- Permits atmosphere/surface coupling, relaxes Lambertian assumption
- Uses information across the VSWIR spectral range to characterize aerosols, water vapor and surface, improving accuracy of reflectance retrievals
- Rigorous probabilistic formulation incorporates ancillary measurements via the prior distribution
- Degree of Freedom (DOF) analysis permits evaluation of VSWIR atmospheric information content
- Posterior uncertainty estimates for use in downstream analyses

Retrieval Comparison



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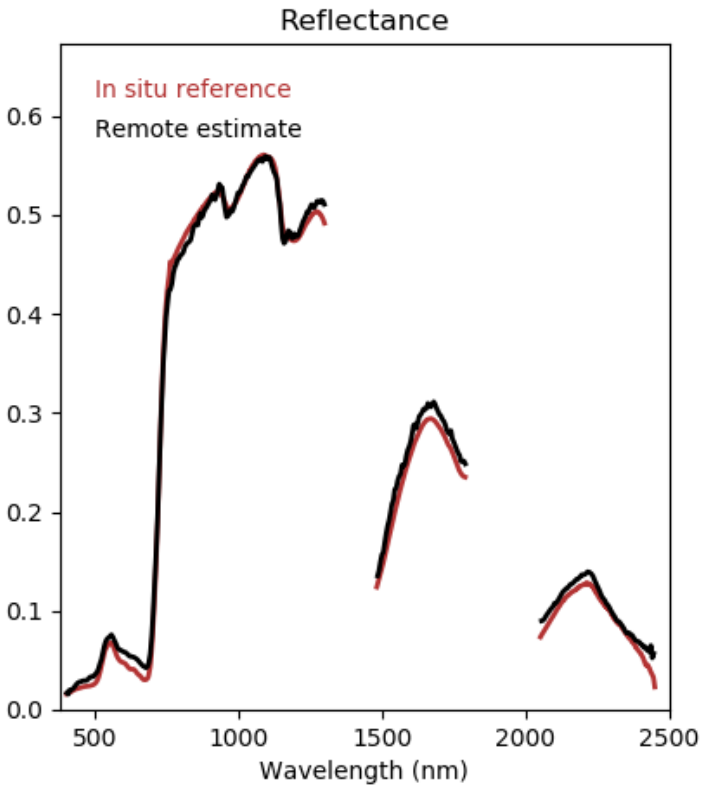

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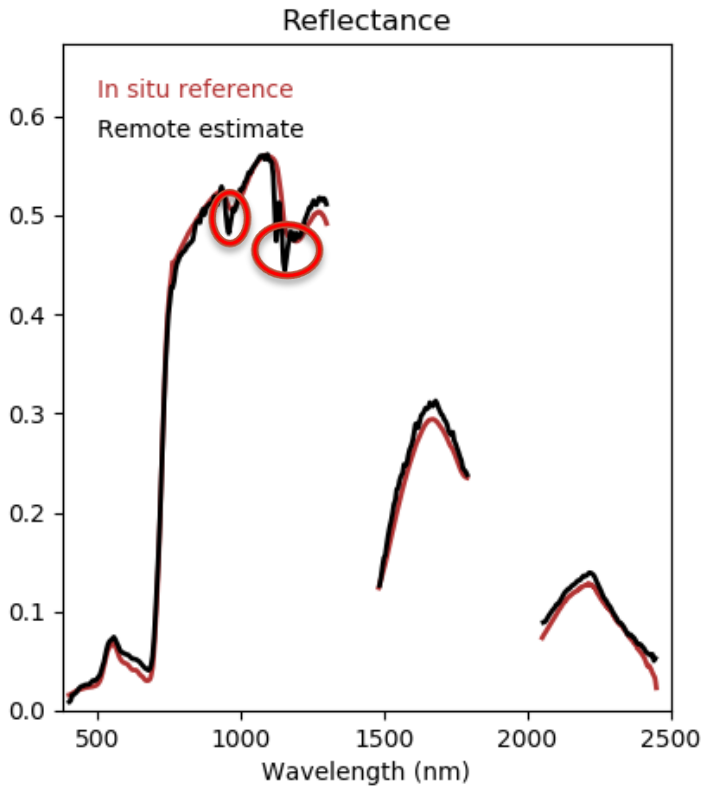

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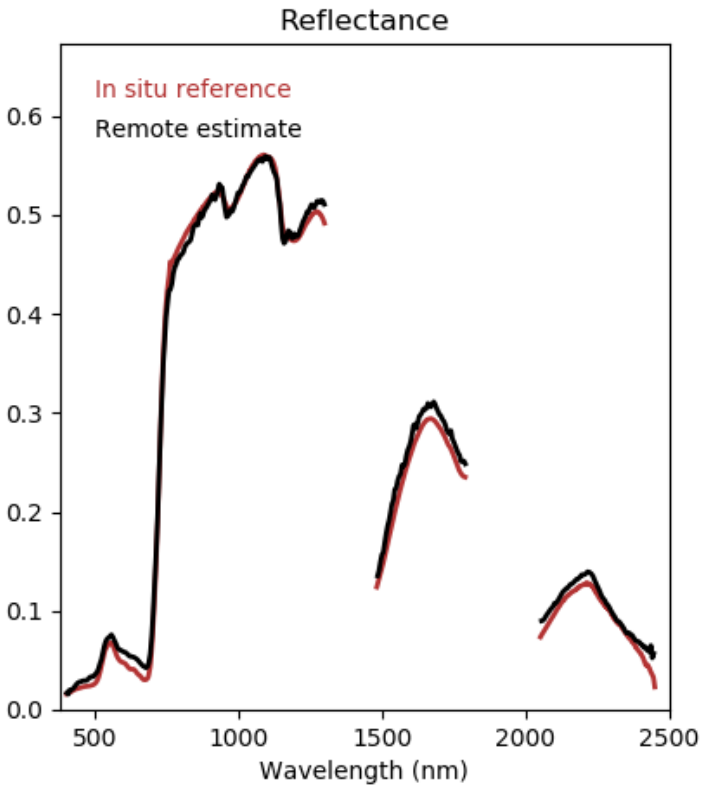
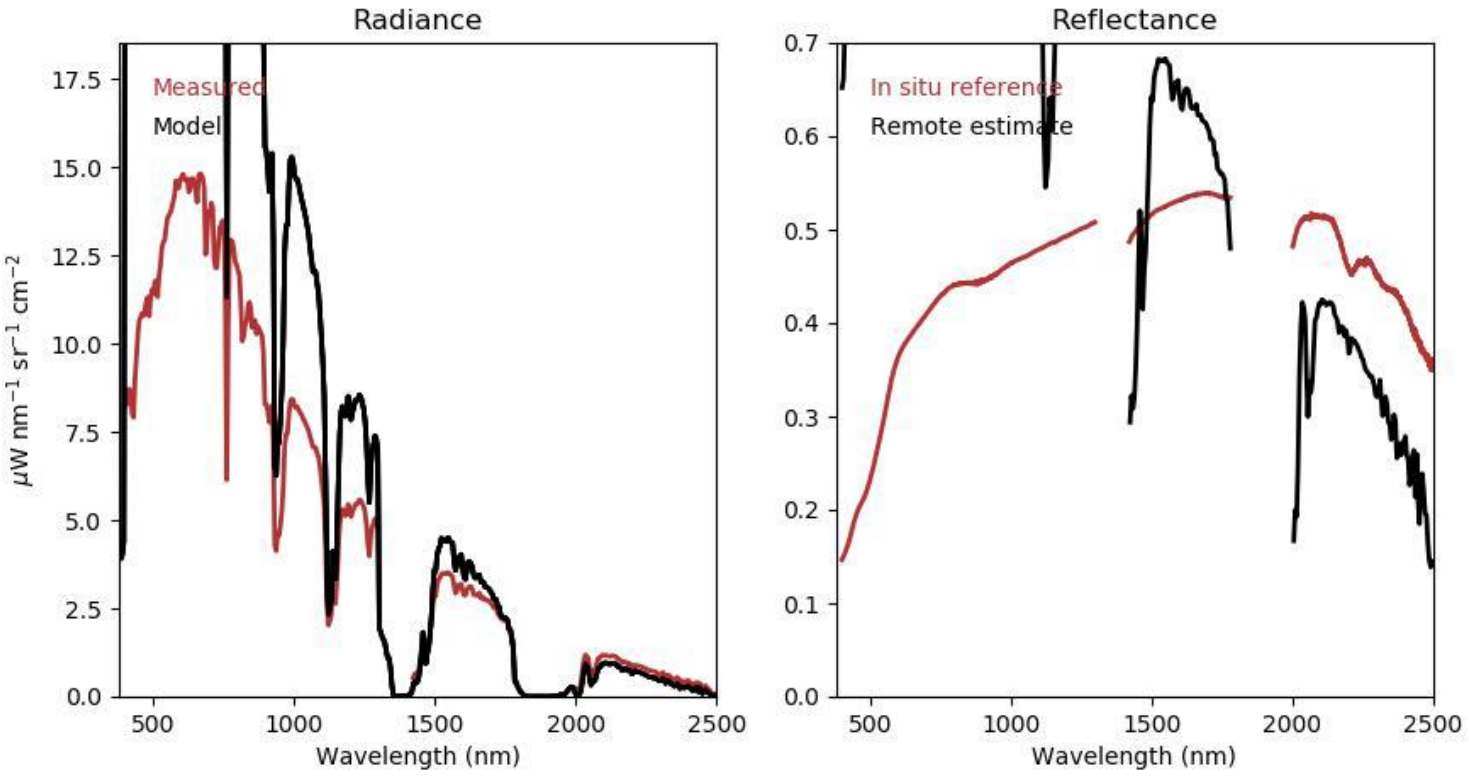
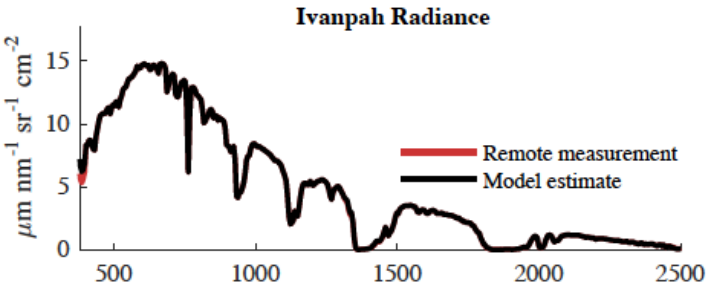


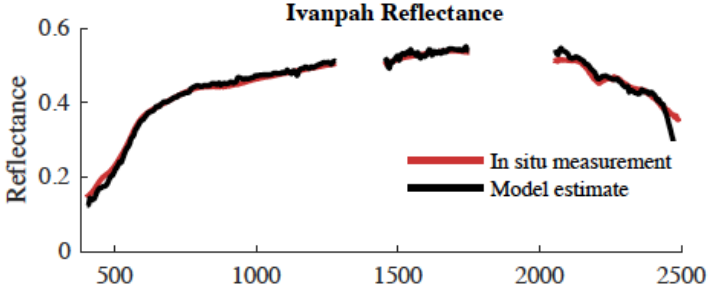
Simultaneous

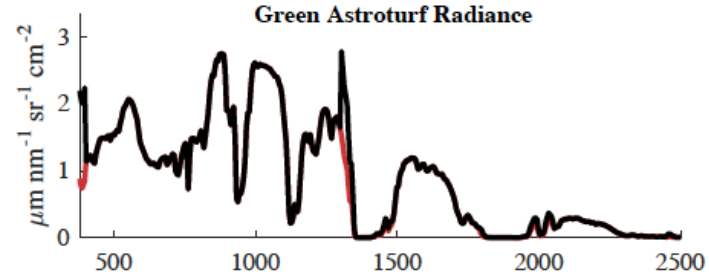
Iterative Retrieval

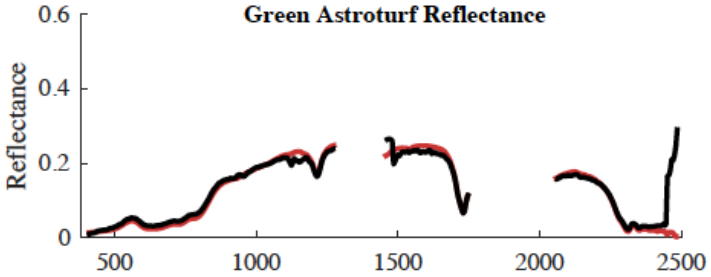


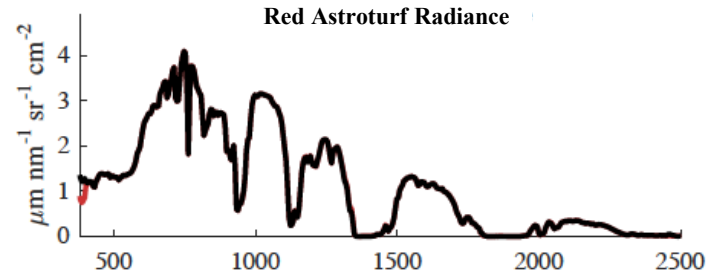
Retrieval Results

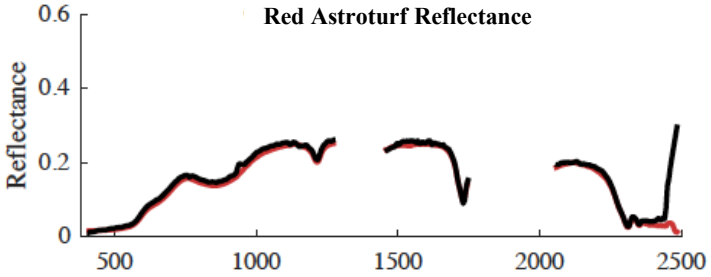












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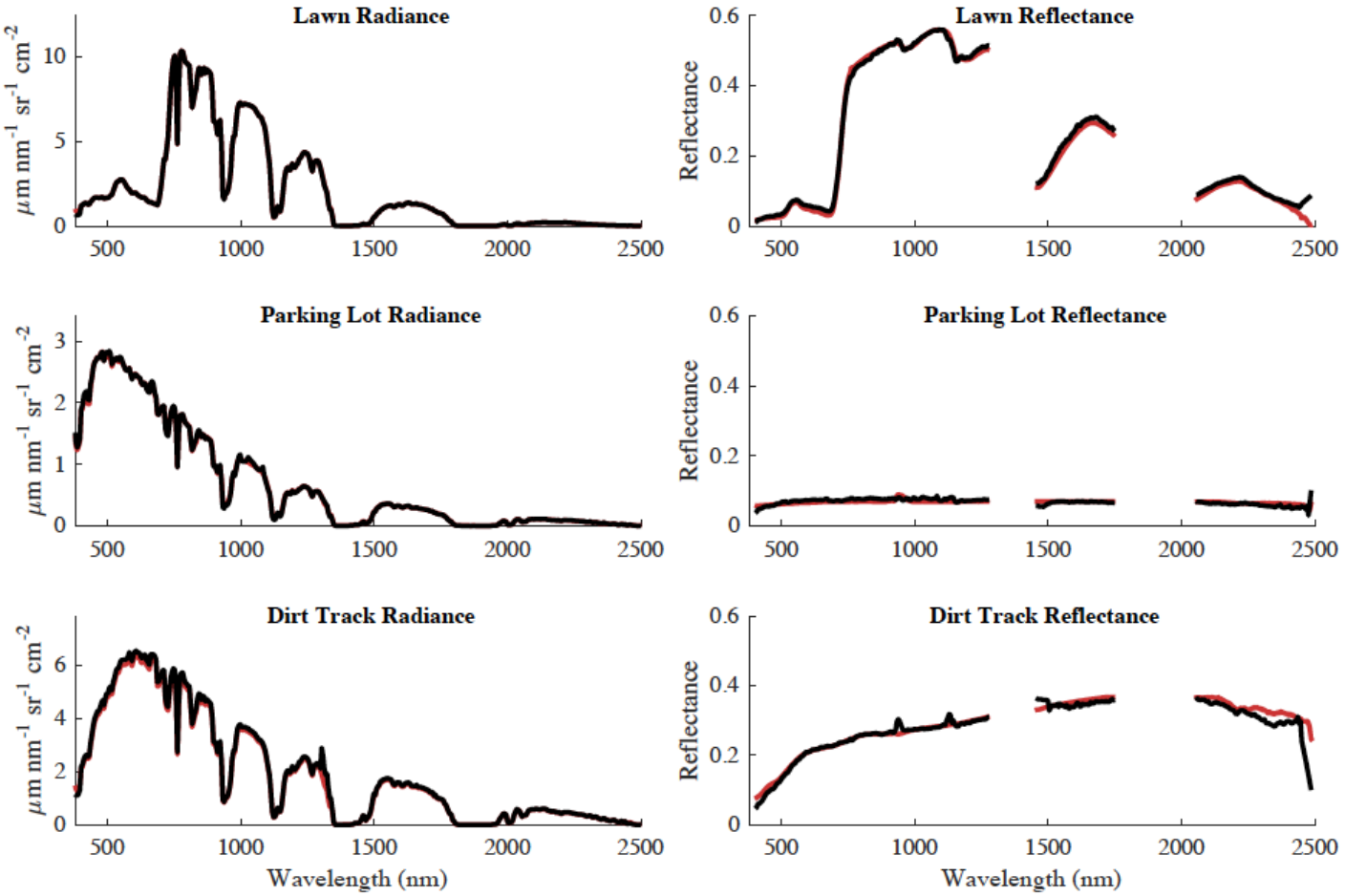

Fast "Full Physics" RT

- Two-stream exact-single-scattering (2S-ESS) model (Spurr and Natraj, 2011)
  - 2S computes multiple scattering field using two-stream approximation
  - ESS computes single scattering field accurately, including atmospheric sphericity effects
- Incorporates state-of-the-art representations
  - Delta-M scaling
  - Nakajima-Tanaka (N-T) correction
  - Surface BRDF
  - Analytic Jacobians
- For calculations in a 20-layer atmosphere with 100 spectral points, 2S-ESS is ~800 times faster compared to DISORT with eight discrete ordinates in the half-space
- Accurate to within 0.1% of an "exact" RT model, but with computational speed comparable to two-stream models

2S-ESS Model Benefits

- Can be used for scenarios with heavy aerosol loading
- Systematic errors due to cirrus can be accounted for
- Opens up avenues for simultaneous retrievals of surface, aerosols, water vapor and trace gases (e.g. NO_2, CH_4, CO_2)

Emulation of RTM Ouput

- Nonparametric regression model
- More accurate alternative to lookup tables
- Permits very high dimensional state vectors
- Neural network models should enable many-frames-per-second retrievals
- Five orders of magnitude speed improvement over MODTRAN-based model with negligible accuracy penalty

Future Work

- Improving aerosol retrievals by using better priors (Kindel and Massie)
- Improving surface retrievals by using BRDFs
- Testing model using extensive AVIRIS-NG India dataset
- Validation using in situ measurements

Acknowledgements

- AVIRIS-NG Team
- JPL Research and Technology Development Program
- NASA ROSES 2016: Utilization of Airborne Visible/Infrared Imaging Spectrometer – Next Generation Data from an Airborne Campaign in India NNH16ZDA001N-AVRSNG
- Indian Space Research Organisation (ISRO)
- NASA/ISRO AVIRIS-NG Campaign Team