Joint Estimation of Atmosphere and Surface Reflectance: Initial Results from the AVIRIS-NG India Campaign

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Agenda

1. Joint retrieval of surface and atmosphere
2. Examples from the AVIRIS-NG India campaign
3. Going beyond lookup tables
Atmospheric correction
Atmospheric correction

\[ \rho_{\text{TOA}} = \rho_{\text{atm}} + T \rho_{\text{s}} / (1 - S \rho_{\text{s}}) \]

Transmission

Path reflectance

Top of atmosphere reflectance

Spherical albedo

Surface reflectance
Conventional approach: sequential estimation of atmosphere and surface

1. In advance, do RTM calculations

   Lookup table for $T$, $S$, $\rho_{atm}$ indexed by $H_2O$, etc.

2. Estimate atmospheric state from radiance

3. Algebraic Inversion

Radiance Spectrum

Reflectance Spectrum
Conventional approach: sequential estimation of atmosphere and surface

1. In advance, do RTM calculations

2. Estimate atmospheric state from radiance

3. Algebraic Inversion

Challenging to disentangle atmosphere & surface effects

Lookup table for $T$, $S$, $\rho_{atm}$ indexed by $H_2O$, etc.
Simultaneous estimation of atmosphere & surface

1. In advance, do RTM calculations

Lookup table for T, S, $\rho_{atm}$ indexed by $H_2O$, etc.

2. Iterative optimization of surface & atmosphere model
Simultaneous estimation of atmosphere & surface

1. In advance, do RTM calculations

Lookup table for T, S, $\rho_{atm}$ indexed by H$_2$O, etc.

Can estimate spectrally-smooth atmospheric effects

2. Iterative optimization of surface & atmosphere model
Enables Optimal Estimation
[Rodgers et al., 2000]

• Measurement model:

\[ y = F(x) + \epsilon \]

- Radiance measurement
- RTM prediction
- random error

• For covariances \( S \), the iterative loop minimizes the error:

\[
\chi^2 (x) = (F(x) - y)^T S^{-1} (F(x) - y) + (x - x_a)^T S a^{-1} (x - x_a)
\]

- Model match to measurement
- Bayesian prior
Advantages

- Permits atmosphere/surface coupling, relaxes Lambertian assumption
- **Retrieve aerosol parameters** using information across the VSWIR range, improving accuracy of aerosol correction.
- **Incorporates ancillary measurements** in a principled way via the prior distribution
- **Degree of Freedom (DOF) analysis** permits a rigorous analysis of VSWIR atmospheric information content
- **Posterior uncertainty estimates** for use in downstream analyses.
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1. Joint retrieval of surface and atmosphere

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Hyderabad spectrum fit example
ang20151218t105122

Atmospheric H₂O vapor, surface water and ice thickness, aerosol visibility

Surface (linear mixture)

Surface (linear mixture)

Surface (linear mixture)
Hyderabad spectrum fit example

ang20151218t105122
Desalpar calibration / validation site
ang20160210t061239

Iteration 1

Radiance (µW nm⁻¹ sr⁻¹ cm⁻²)

Wavelength (nm)

H₂O STR: 1.1000
SURF_LQD_PTH: 0.0000
SURF_ICE_RTH: 0.0000
MIX_6: 0.0351
MIX_1: 0.0123
MIX_2: 0.0000
MIX_3: 0.0077
MIX_4: 0.0087
MIX_5: 0.0000
MIX_6: 0.0038
MIX_7: 0.0014
MIX_8: 0.0000
Desalpar calibration / validation site
ang20160210t061239

No residual correction or smoothing applied
Ivanpah calibration / validation site
ang20170328t212316

No residual correction or smoothing applied
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Fast Radiative Transfer

• Two-stream exact-single-scattering (2S-ESS) model (Spurr and Natraj, 2011)
  1. 2S computes the approximate multiple scattering field
  2. ESS calculates the single-scatter field.

• Incorporates state of art representations
  – Nakajima-Tanaka (N-T) correction
  – Delta-M scaling

• For calculations in a 20-layer atmosphere with 100 spectral points, 2S 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.
Joint surface and atmosphere estimation

- Elegant unified model
- Flexibility for large, diverse state vectors
- Can model coupled atmosphere & surface, non-Lambertian reflectance
- Can estimate spectrally-smooth atmospheric effects
- Principled statistical foundation, uncertainties
- Path to overcome lookup table simplifications thanks to emerging RTM technologies
Thanks!

NASA Program NNH16ZDA001N-AVRSN, “Utilization of Airborne Visible/Infrared Imaging Spectrometer – Next Generation Data from an Airborne Campaign in India.” Program manager Woody Turner

The AVIRIS-NG Team, including Sarah Lundeen, Brian Bue, Winston Olson-Duvall, Ian McCubbin, Mark Helmlinger, and others