National Aeronautics and Space Administration

Multi-observation Imaging Spectroscopy

Principal Investigator: Michael Turmon (398)
Co-Investigators: Nimrod Carmon, Hai Nguyen, Philip Brodrick (398); David Thompson (382); Olga Kalashnikova (329)

Program: FY22 R&TD Topics
Strategic Focus Area: Uncertainty Quantification

Objectives: We develop and evaluate a Kalman filter (KF) layer atop the existing Optimal Estimation (OE) code, ISOFIT. In parallel, we develop improved forward models to exploit information about observation context. Temporal filtering and improved forward modeling will increase the accuracy of surface reflectance retrievals and atmospheric-state retrievals. The specific capabilities we develop: (1) a Kalman filter layer to improve surface reflectance priors used by ISOFIT; (2) a reflectance basemap enabling an enhanced physical model that respects scene geometry; (3) validation via AVIRIS-NG campaigns with repeat observations.

Background: Current retrievals assume a broad reflectance prior distribution that spans a spectral library. The OE reflectance and atmospheric state estimates are both influenced by this prior – a pixel-specific surface reflectance prior from KF will improve performance. Also, current inversions simplify the physical model by assuming a flat, isotropic surface, leading to errors under high surface contrast or rugged topography. Our forward model, separating radiance due to direct versus diffuse and indirect illumination, removes the flat/isotropic assumption.

Approach and Results:
The KF was implemented within ISOFIT and tested using SHIFT campaign data. The KF reflectance was shown to be more consistent spatially over homogenous regions, despite using only temporal information (Fig. 1). To implement the KF at flightline scale, a method for compactly storing full posterior covariances was required, and we developed a principal-components based algorithm that proved quite effective (Fig. 2).

Several improvements in the formulation of the forward model were implemented within ISOFIT, in general by separating the contribution from direct illumination and reflected or downwelling diffuse illumination. Because these sources have different spectral shape (diffuse illumination is more blue, Fig. 3), geometry errors impose a spectral distortion on reflectances, harming downstream L2B processing (Fig. 4). Besides compensating for such effects, *we can harness them to accurately retrieve geometry* (Fig. 5).

Significance/Benefits to JPL and NASA: This capability will increase the utility of future NASA missions that use imaging spectroscopy, providing improvements in retrieval accuracy through modeling and estimation rather than costly hardware. It will directly benefit the Surface Biology and Geology (SBG) mission, and it will also benefit the Planetary Boundary Layer incubator. The approach is particularly valuable for global mapping investigations: it enables optimal synthesis of repeated acquisitions in the challenging atmospheres of Asia and Africa.

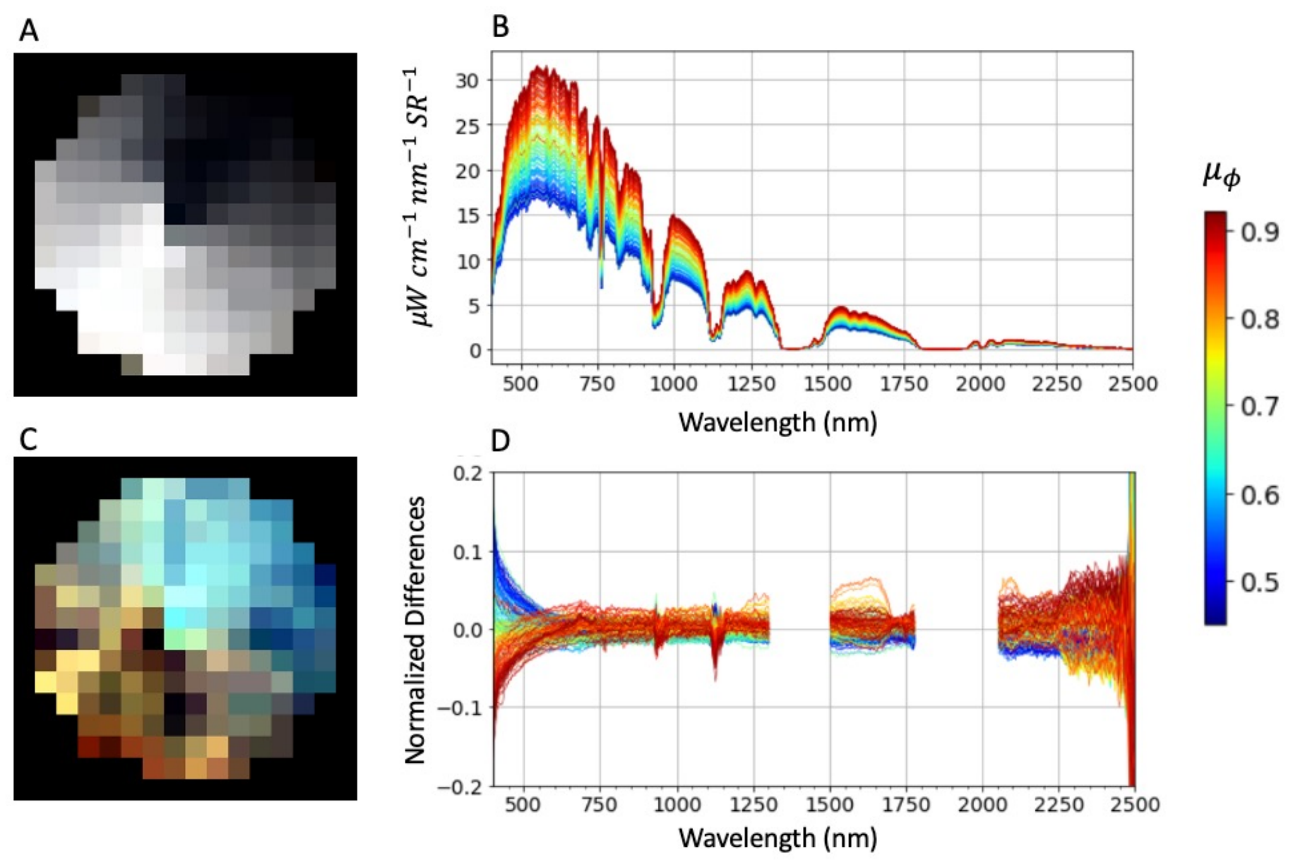
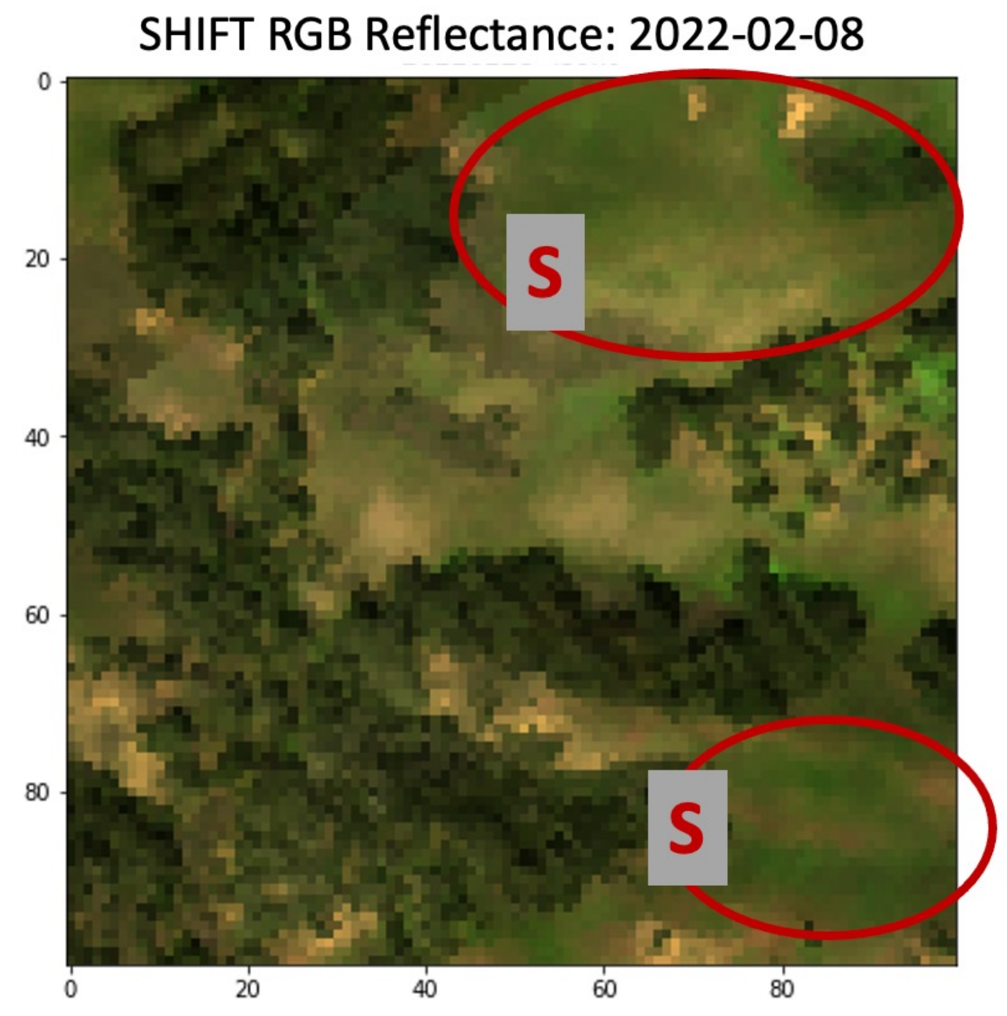


Figure 3: Panel A, white dome of CIT Beckman Auditorium. Its pixelwise spectra are in B, *colored by LIDAR topographic slope* (μ_ϕ). Panel C: *normalized differences* in radiance, with normalized spectra in panel D, illustrating the spectral shape effect. (Images have enhanced contrast.)



Variogram = spatial consistency of the reflectance ρ versus lag τ within set of sites S

$$V_v(\tau) = \frac{1}{N} \sum_{\substack{(i,j)\in S \\ (i,j+\tau)\in S}} \|\rho(i,j) - \rho(i,j+\tau)\|^2$$

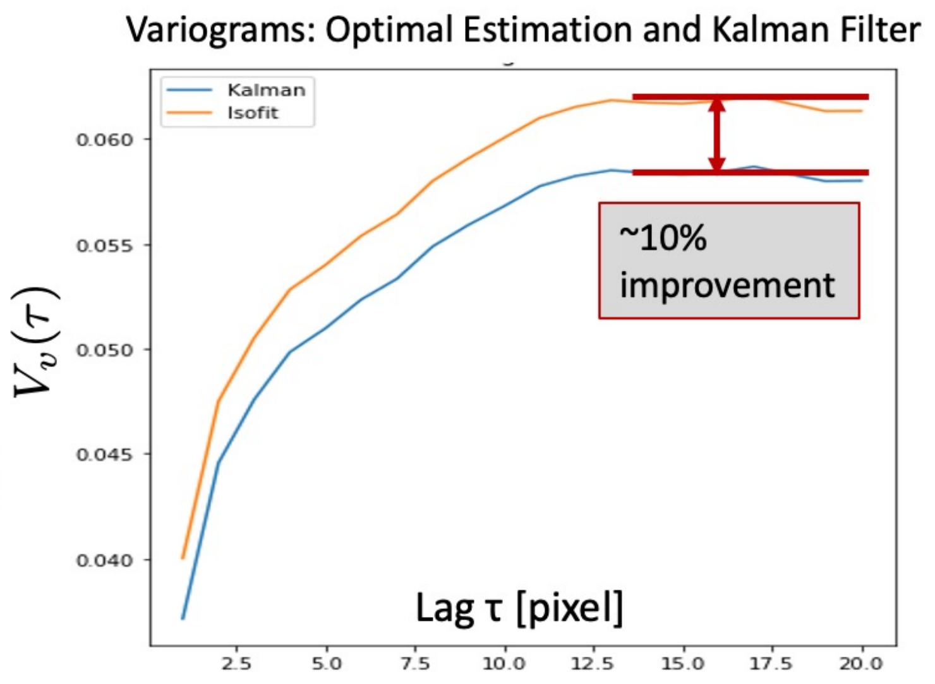


Figure 1: KF for the SHIFT field campaign. Left: representative reflectance – red ovals show a homogenous surface for validation. Right panel: Variogram of the OE and KF reflectances, as a function of lag.

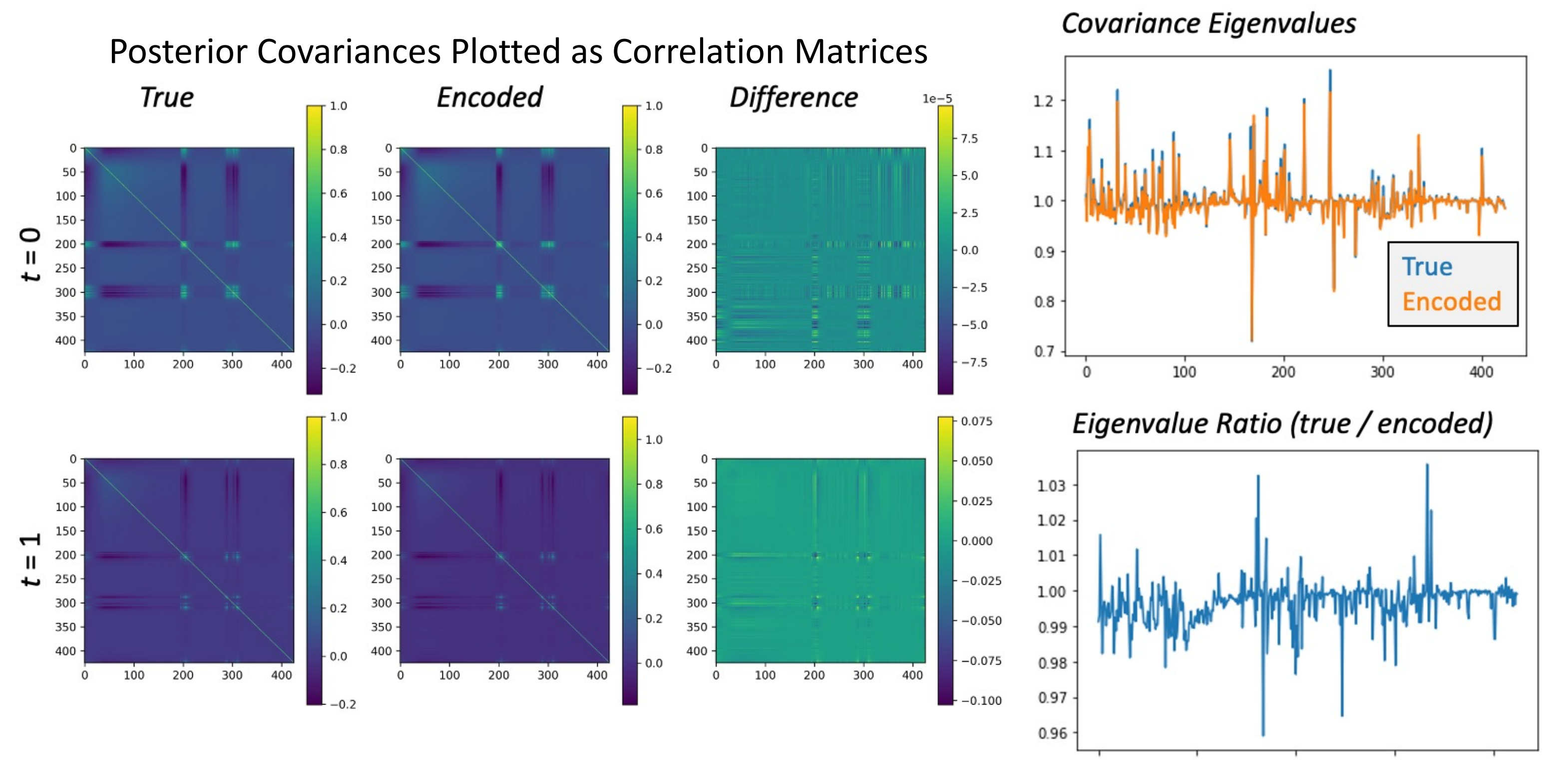


Figure 2: KF requires posterior covariance matrices. We compress a 425x425 matrix by about 100x using a principal components dictionary and Cholesky factorization (left panels), with an error <3% (right panels).

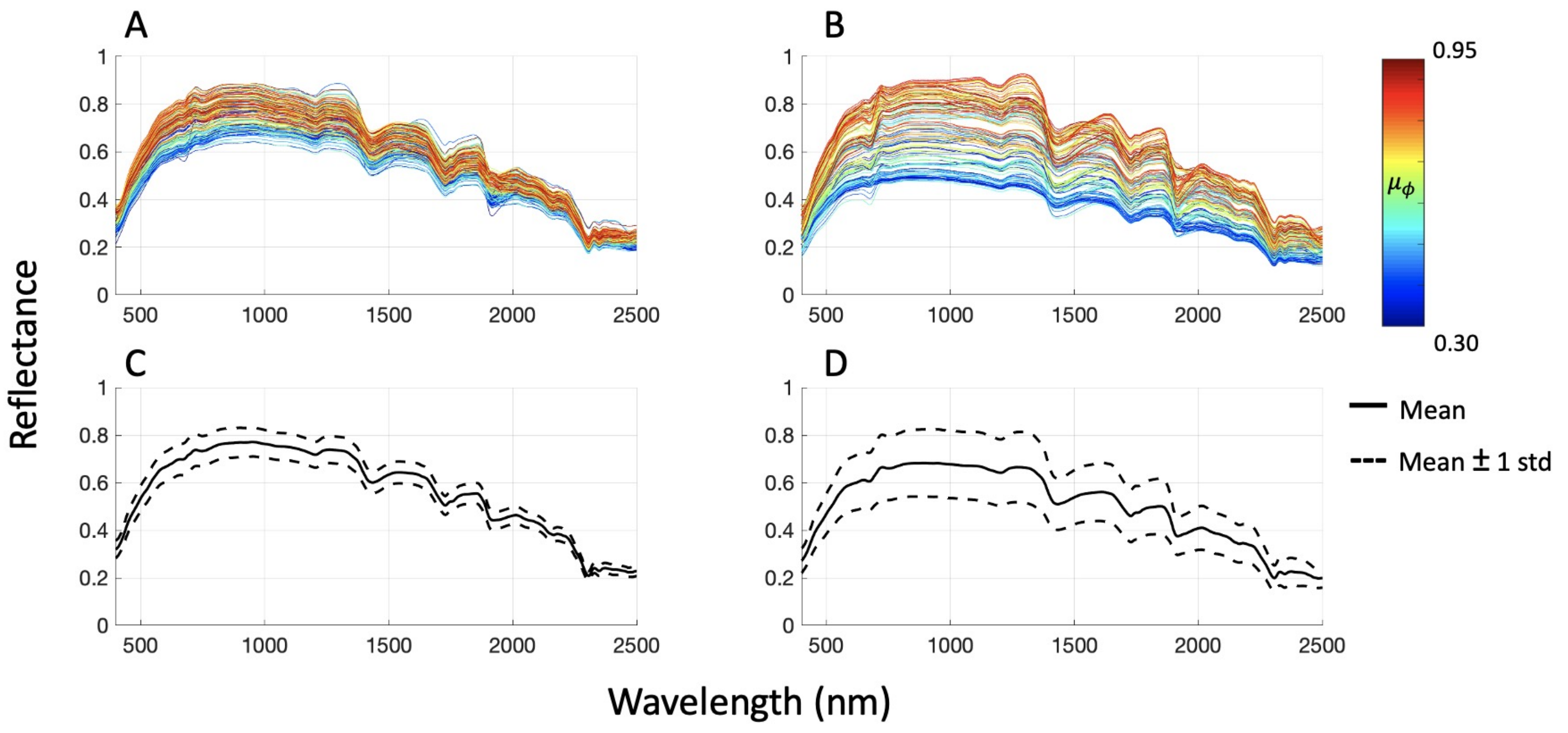
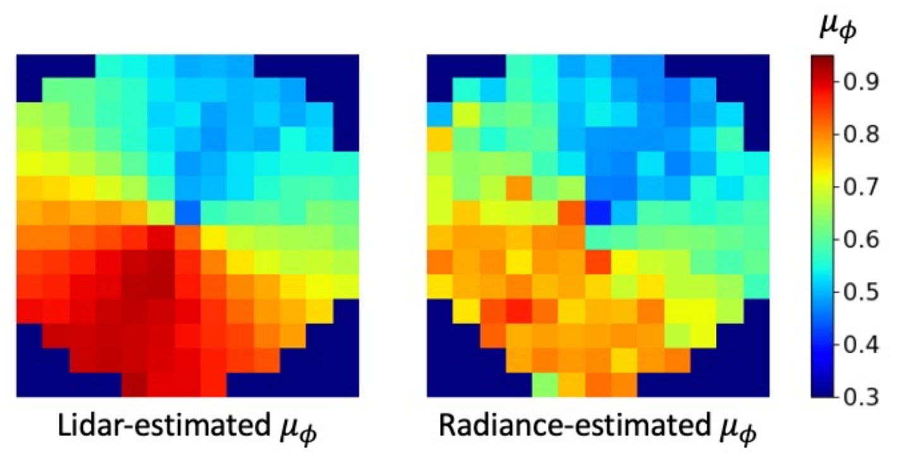


Figure 4: By estimating μ_ϕ within OE (panel A), retrieved reflectances are more consistent, and less-correlated with topography, than when assigning a best-guess constant value (B). The spectra are colored by the μ_ϕ value.



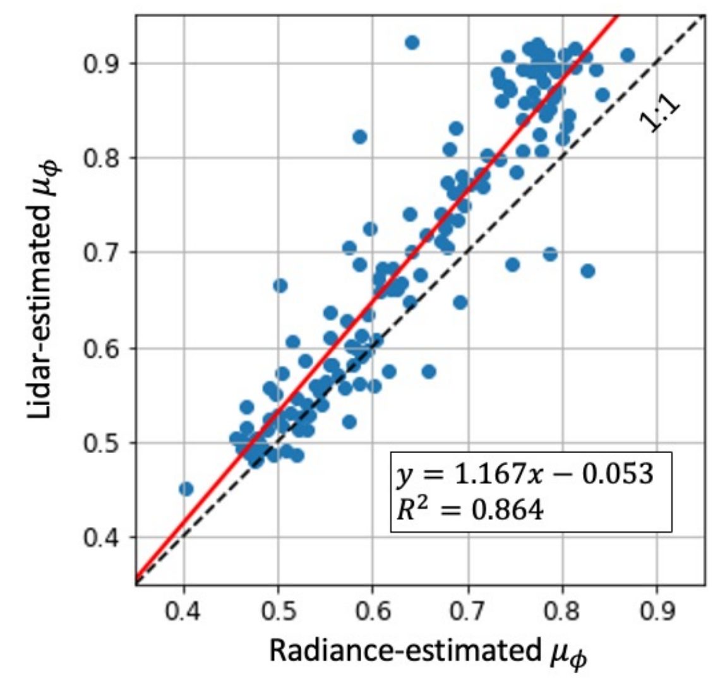


Figure 5: Dome geometry is accurately recovered by exploiting the spectral shift in radiances (scatter plot at right).

Publications:

N. Carmon et al., "Unified Topographic and Atmospheric Correction for Remote Imaging Spectroscopy," *Frontiers in Remote Sensing*, 2022.
N. Carmon et al., "Shape from Spectra," manuscript submitted to *RSE*, 2022.

PI Contact Information: Michael.J.Turmon@jpl.nasa.gov

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

Clearance Number: CL#22-5220
Poster Number: RPC#061