National Aeronautics and Space Administration

Multi-Observation Imaging Spectroscopy

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Objectives

We develop and evaluate a framework to incorporate repeating observations of the same sites, by using a Kalman filter layer on top of an existing Optimal Estimation (OE) code, ISOFIT. This can significantly increase the accuracy of both surface reflectance retrievals and atmospheric-state retrievals. We will integrate this methodology into ISOFIT, an OE codebase for imaging spectroscopy that is being matured and enhanced for use with the EMIT investigation.

The specific capabilities offered by our work are: (1) a tunable Kalman filter layer to improve surface reflectance priors used by ISOFIT; (2) a reflectance basemap enabling an enhanced physical model that respects radiance adjacency effects; (3) validation and algorithm refinement using AVIRIS-NG campaigns.

Background

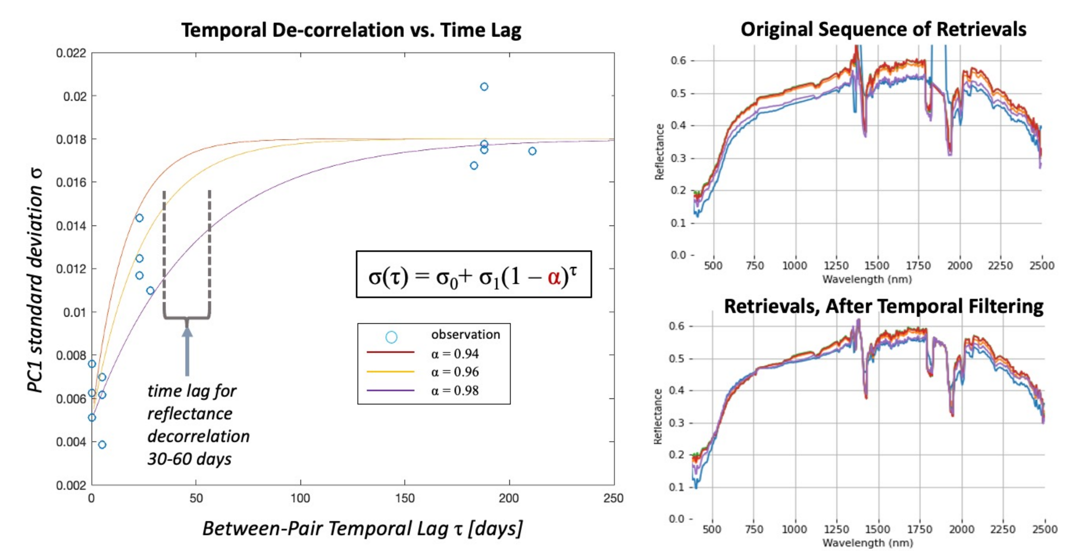
Current OE implementations use a general-purpose surface reflectance model. A pixel-specific surface reflectance prior, obtained from earlier retrievals, should improve the performance of the next retrieval.

Relatedly, current inversions simplify the physical model by assuming a flat and isotropic surface, leading to errors in conditions such as high surface contrast, rugged topography, or low zenith angles. In these cases, adjacency effects may contribute up to 50% of the recorded radiance, reducing the information available from the target pixel.

Using a surface reflectance map derived from temporal filtering, the isotropic-surface assumption can be removed, supporting an improved retrieval of surface and atmospheric properties.

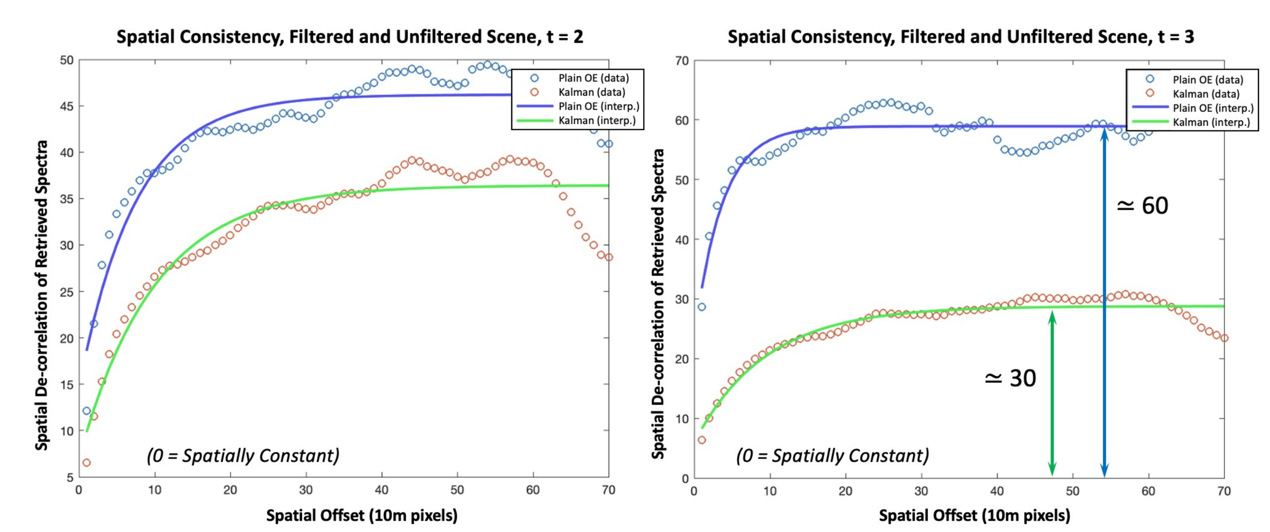
This enhanced surface-interaction model, together with the localized reflectance priors, will also improve the error characterization needed for new-generation level 2B and level 3 algorithms.

Figure 1



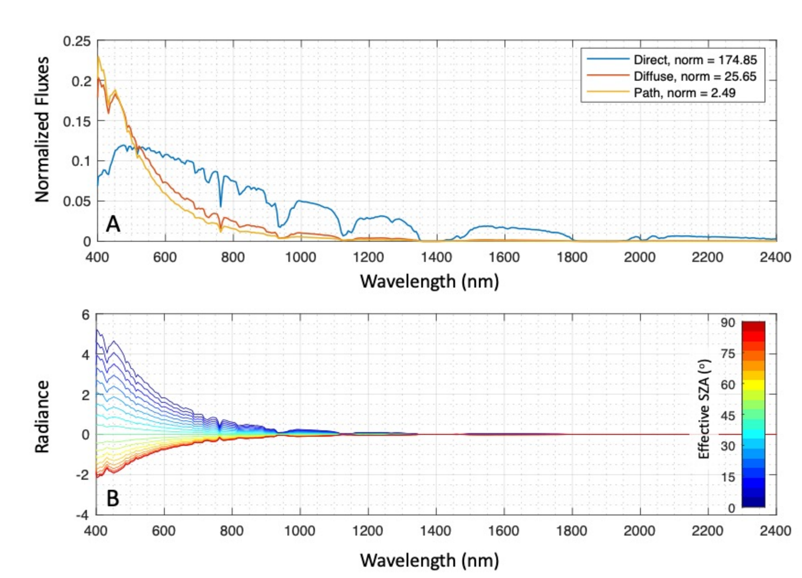
Left panel: recovery of temporal coherence of reflectance, the key Kalman filter parameter. Shown is a measure of difference between surface reflectances at various temporal separations for this desert scene, providing a fit to the filtering parameter. Top right: original sequence of five retrieved surface reflectance spectra from AVIRIS-NG over Ivanpah, CA. Bottom right: retrievals after temporal filtering, showing more consistent spectra.

Figure 2



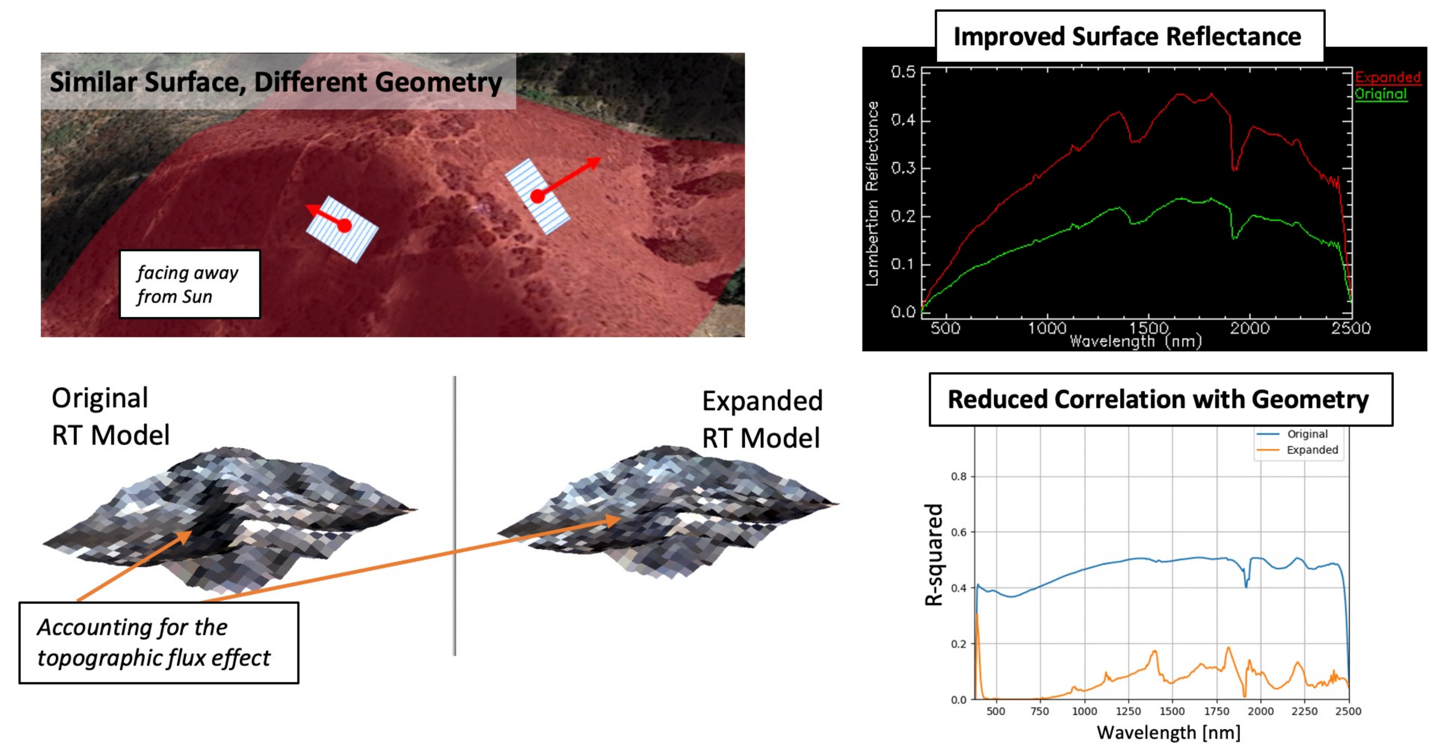
We used ordinary Optimal Estimation (OE) and the Kalman filter (OE-KF) to retrieve a sequence of 3 reflectance scenes from AVIRIS-NG over Ivanpah, CA. Plotted is the spatial decorrelation (the variogram) as a function of spatial offset for OE and for OE-KF, for two separate times. At distances more than ~200m within this spatially-homogenous scene, the OE reflectance is twice as variable as the OE-KF reflectance. Because no spatial information was used in either retrieval, this implies that the KF-OE approach is suppressing about half the noise in the reflectance it retrieves.

Figure 3



Ratio between radiances of the augmented to those of the original forward model, varying the effective solar zenith angle (SZA). When effective SZA = 45, the models are identical and the radiance ratio is unity (green line). As effective SZA changes, the radiance ratio changes non-linearly. To illustrate the radiance difference between a horizontal and a sloped surface, we simulated at-sensor radiance for a 50% surface reflectance spectrum, and a TOA SZA of 45 degrees. We calculate the ratio between the at-sensor vector-normalized radiance for the augmented model that of the original forward model.

Figure 4



Top left: Valencia, CA scene with varying aspect angle, and thus, varying effective SZA.
Top right: Accounting for geometry with DEM alters surface reflectance.
Bottom left: Improved spatial consistency of reflectance for similar surfaces at different aspect angles.
Bottom right: To first order, the correlation of reflectance with geometry is removed.

Approach and Results

We selected four separate regions with many AVIRIS-NG overflights. Of most interest: Ivanpah Playa, CA (homogenous, used for temporal filtering); and Valencia, CA (rugged, mixed terrain, used for radiative transfer modeling improvements). Both have about 40 flightlines at a variety of usable temporal offsets from a few days to several months.

We developed the filtering approach and software, and estimated the temporal coherence that filtering depends on (Figure 1, left). Results of the temporal filtering approach are in Figure 2, showing a variance reduction in Ivanpah Playa by approximately a factor of two has been achieved by temporal filtering.

Regarding radiative transfer, we extended the forward model to account for surface aspect angle and slope angle, separately from view angle (Fig. 3). At each site, we use the USGS DEM (1m resolution) and flight geometry to compute the aspect and slope angle. Figure 4 shows patches of similar surface material on a Valencia hillside with reflectance retrievals under the original forward model and the model expanded to include topographic effects. The surface reflectance exhibits a change by over a factor of two. We validated this change in part by showing that correlations between the retrieved reflectance and the sensor aspect angle decrease when the model is accounting for aspect. As shown in the figure, there remains very little correlation between the aspect angle and the retrieved reflectance, implying that the improved model is correct to first order.

Significance/Benefits to JPL and NASA

Plans for the SBG mission call for a regular cadence of measurements, giving a spectroscopic dataset with unprecedented power for analyzing the multiscale dynamics of Earth's ecosystems in response to seasons and extreme events. Algorithms are not yet ready to exploit this coming time series data, and we believe temporal filtering can both reduce noise in retrievals, and provide a path to improved forward modeling.

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