UCROSS
HIGH PLAINS STEWARDSHIP INITIATIVE

2014 Google Earth Engine Research Award Report

Title: Mapping Invasive Vegetation using Hyperspectral Data, Spectral Angle Mapping, and Mixture Tuned Matched Filtering

The members of the Ucross High Plains Stewardship Initiative (UHPSI) housed at the Yale School of Forestry and Environmental Studies have produced a Google Research Award Report to summarize our results and express feedback and reflections concerning our previous year's work. This document constitutes that report. We will be publishing our own version of this report on our website.

Section I: Background on our Lab and Grant

The Ucross High Plains Stewardship Initiative (UHPSI) is a research lab housed in the School of Forestry and Environmental Studies at Yale University. Under the direction of Dr. Chad Oliver, UHPSI conducts research and works with farmers, ranchers, and land managers in the American west to ensure environmentally sound, economically profitable, and holistically sustainable land management practices.

Goals:

- To provide land managers, students, and scholars with readily-available, open-access tools and resources for effective landscape-scale land management
- To act as conduits of communication and dialogue between all parties interested in land management, be they scholarly/academic, professional, or otherwise

Problem

Invasive species are a ubiquitous and recurrent problem for land managers in all parts of the world. Good land stewardship requires active management to mitigate the negative effects of invasive species on biodiversity and ecosystem stability. When managing across a wide land area, however, the actual detection of a given species, as well as the measurement of its abundance, becomes as crucial a problem as the management task itself.

Given recent advancements in remote sensing and imagery analysis, the detection of species and their distributions has become a much more realistic goal for managers with training and access to data. Two specific analytical techniques—Spectral Angle Mapping (SAM) and Mixture Tuned Matched Filtering (MTMF)—hold particular promise for the identification of invasive species and approximation of their abundance. However, the actual acquisition and analysis of remotely sensed data are still beyond the practical reach of many land managers.

Solution

Researchers from UHPSI have spent the last year adapting the SAM and MTMF algorithms into JavaScript scripts for use within Google Earth Engine. The successful adaptation of these algorithms addresses (1) the lack of easily-accessible satellite imagery, (2) the costs associated with using proprietary software to perform the analyses, and (3) the need for land managers to undergo intensive training and education to perform the work.

Per the details above, Google Earth Engine (a cloud-based platform available to anyone with an internet connection) has collected and organized a myriad of satellite imagery that is rapidly available to any user. Furthermore, UHPSI researchers have fully annotated each script to provide as much guidance to the user as possible. Additional Google Earth Engine training can be found here.

Though researchers have used the three algorithms described below to locate and map invasive species across landscapes, users can harness these algorithms for a variety of purposes other than invasive species detection. In fact, any land cover of interest can be quantified and mapped with the tools we have developed.

Section II: Results and Products

Minimum Noise Fraction (MNF) Transformation

Explained: The Minimum Noise Fraction Transformation (MNF) is used to reduce noise in an image. While it's not an actual classification algorithm like SAM or MTMF, its results directly feed into the MTMF code (i.e. performing the MNF transformation is one step of the MTMF process). Moreover, users can perform this transformation on any data they consider to be overly noisy, regardless of their eventual goals for analysis.

MNF works by estimating the minimum level of noise across a map, finding which bands of the satellite image contain this noise, and then formulating a new set of bands (based on the originals) that limit the amount of noise.

Our Results: We developed MNF as an input for the MTMF and (optionally) SAM classifications in order to reduce noise in our pilot data, which were originally 242-band Hyperion images with significant noise. The MNF script we have developed allows the user to input either their own data or that from the GEE data catalog. It outputs an MNF image with a number of transformed bands equal to the number of bands in the input image. The script also returns a chart of the eigenvalues for each MNF transformed band, allowing the user to visually inspect the noise level and decide how to subset the MNF data for further analysis. If using the MNF script to generate input data for time series-based classifications that rely on MTMF or SAM, we recommend applying the MNF transformation to each date separately before creating the time-series (version 2.0 of our MTMF script will implement the MNF transformation on each image within a time-series separately).

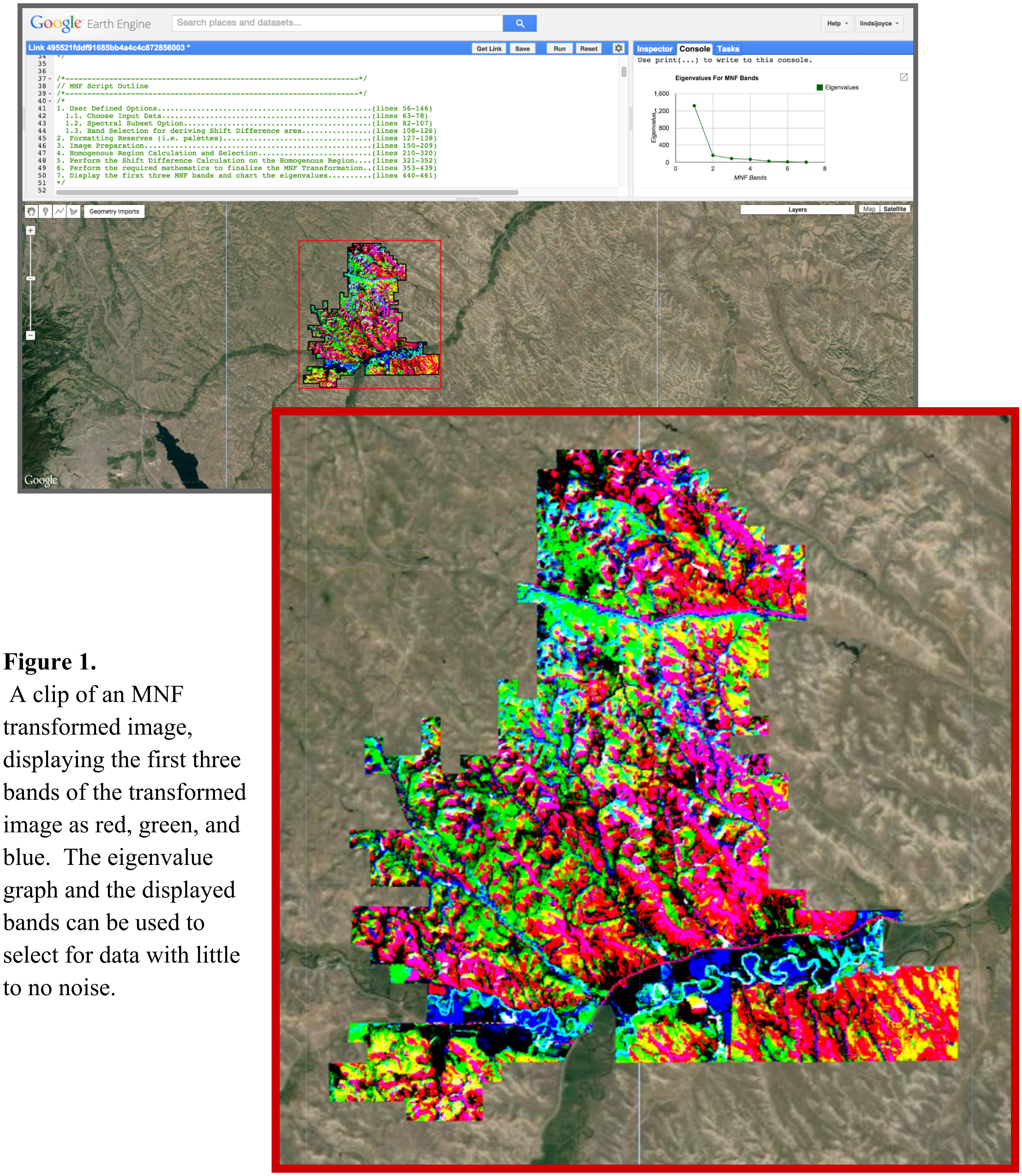


Figure 1.
A clip of an MNF transformed image, displaying the first three bands of the transformed image as red, green, and blue. The eigenvalue graph and the displayed bands can be used to select for data with little to no noise.

Spectral Angle Mapping

Explained: Spectral Angle Mapping (SAM) measures the degree of similarity between the spectral profile of each pixel in an image and one or more “pure” or idealized spectral signatures, termed “endmembers”. The SAM algorithm converts all pixel values and the endmember values to N-dimensional vectors (where N = the number of bands) then computes the angular distance (i.e. angle) between each pixel's vector and the endmember vector. Mathematically, this process is identical to finding the geometric angle between two lines that extend from a common origin to two different points on a 2-dimensional coordinate plane. The smaller the angle, the closer a match to the endmember. The SAM classification script produces a ‘rule’ image, where each pixel contains this angular distance value from 0-180 degrees. To obtain a classified image, a threshold angle is chosen based on training regions, ground-truthed data, or other observations. Pixels containing angular values equal to or less than the threshold will be classified as containing the endmember in the classified image.

Example Use: Spectral Angle Mapping is used for classification of one or more specific land cover types known to be in the study area. SAM is particularly useful when comparing images from multiple time periods, because changes in brightness depending on the day will not impact the results of the classification.

Our Results: Though we initially wrote SAM into GEE to classify the presence of Leafy Spurge (*Euphorbia esula*) on a test site in the High Plains of the American West, the algorithm can be used to evaluate many different land cover types using image- or field-collected endmembers from anywhere in the world. Our final script provides the user with the ability to classify user-supplied imagery as well as any data contained in the GEE data catalog, including stacked multi-temporal imagery and ancillary landscape data (e.g. digital elevation models). The script produces a rule image, a classified image with the option to modify the classification threshold, and a chart that visualizes the endmember spectral profile alongside the spectral profiles of three other sample pixels in the study area.

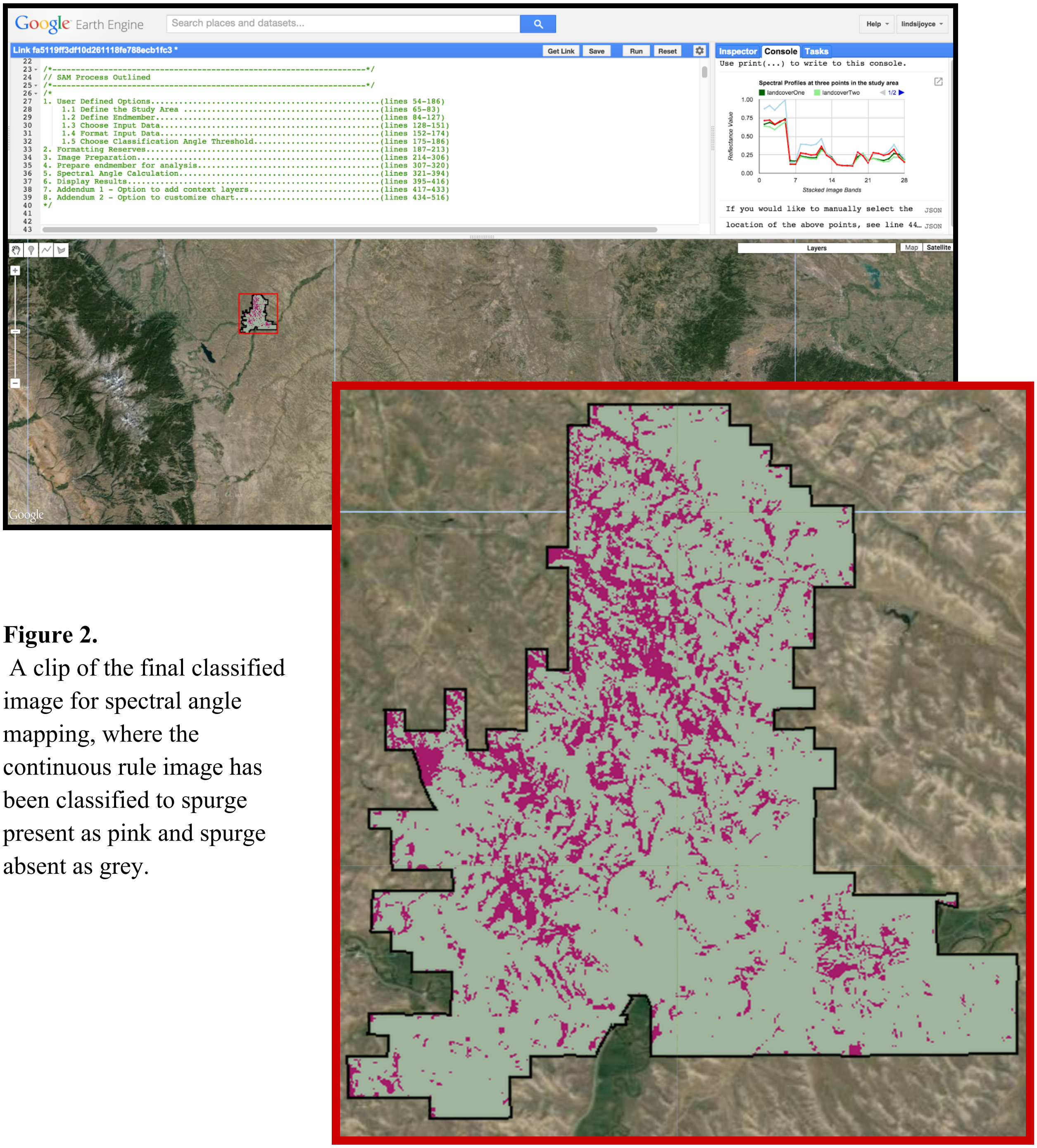


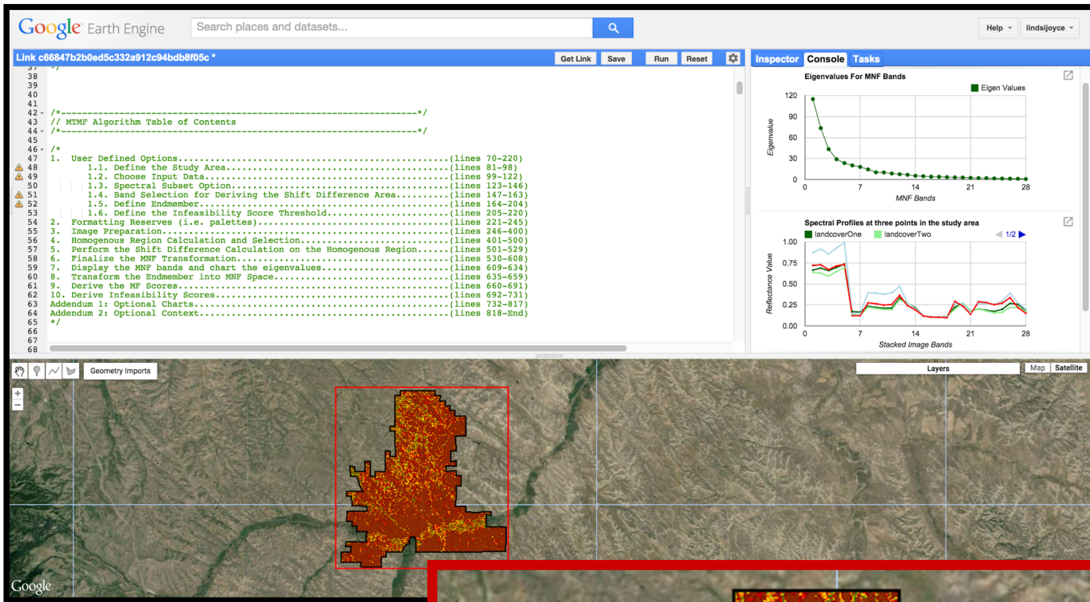
Figure 2.
A clip of the final classified image for spectral angle mapping, where the continuous rule image has been classified to spurge present as pink and spurge absent as grey.

Mixture Tuned Matched Filtering (MTMF)

Explained: Mixture-Tuned Matched Filtering is a multi-step process that produces (1) a map illustrating the degree of similarity between each pixel and an endmember, and (2) estimates of the actual reliability of these predictions. Using the MNF transformation described above, MTMF first reduces the noise in an image so as to make each feature more discernable to detection. Then, using linear algebra, the algorithm computes the similarity between the endmember of interest and each pixel, called the Matched Filtering (MF) image. Each pixel in the MF image contains a value between 0 and 1 (0 being the poorest match to the endmember and 1 being the best). The final step of MTMF involves determining the reliability of the MF score based on the underlying level of noise that the MNF transformation derived. This process is known as Mixture Tuning and produces an Infeasibility image. The Infeasibility image aids in the interpretation of the MF scores—the noisier the image (i.e. the higher the Infeasibility score), the greater the likelihood of a false positive MF score.

Example Use: The MTMF classification is most often used when working with hyperspectral imagery since the high number of narrow bands (as compared to most multispectral imagery) allows for better linear unmixing, which produces more useful MF predictions. MTMF works best in areas in which the endmember is particularly unique or rare.

Our Results: Similar to SAM, we initially wrote MTMF into GEE in order to classify the presence of Leafy Spurge on our pilot site in Wyoming. Like SAM, the algorithm for MTMF enables the use of image- or field-collected endmembers from many different landcover types for anywhere in the world. The final script provides the user with the ability to perform image classification on user-supplied imagery or on hyperspectral or multipsectral data contained in the GEE data catalog, including stacked multitemporal imagery and ancillary landscape data (e.g. digital elevation models). The script produces an MF image, an Infeasibility image, and a infeasibility mask for pixels deemed potential false positives (with the option to modify the thresholds that determine the infeasibility mask). Charts of the eigenvalues created during the MNF transformation in addition to the spectral profiles of the endmember and three sample points from the study area are also generated.



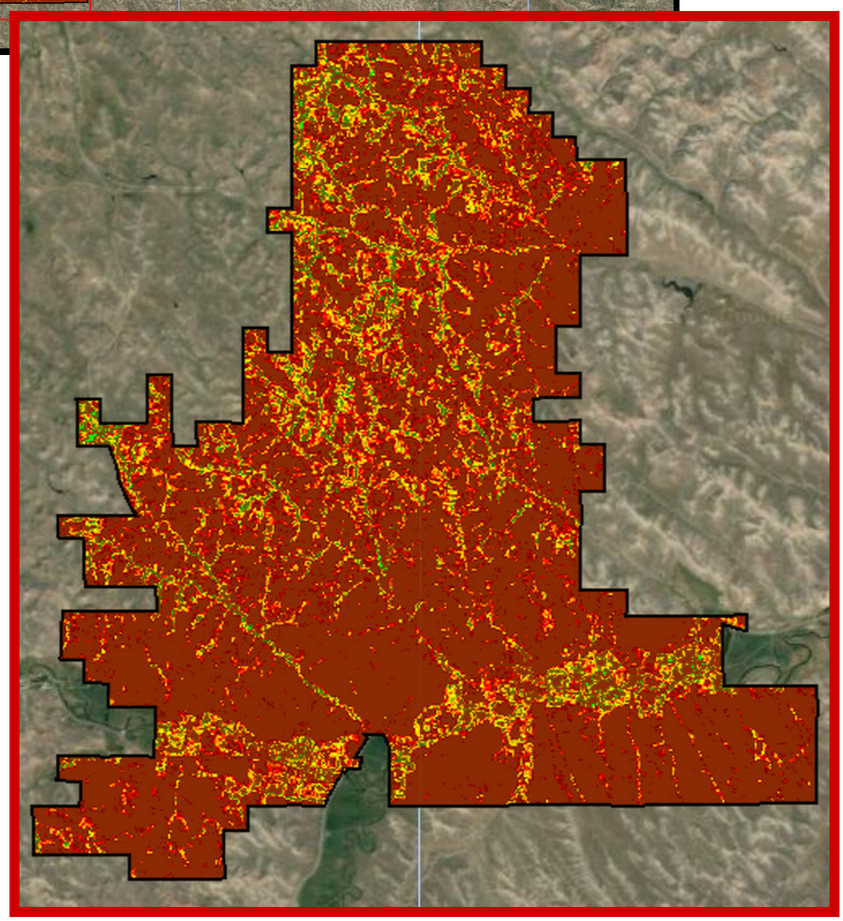


Figure 3.
A clip of the combined MTMF output images (MF and Infeasibility Scores) that displays the best match to leafy spurge as green and the worst match to leafy spurge as dark red.

Section III: Going forward and Final Note

To finalize this work, we will publish a grant report on our website, continue to present our work at conferences (including AAG 2015), and submit our related paper to a peer-reviewed academic journal for publication. We intend to combine GEE's reach, access, and ease-of-use with our on-the-ground connections to land managers to develop an online interface through which managers can quickly and easily perform analysis, get concrete numbers, and conduct adaptive management.

It has been a privilege to work with GEE over the past year, and while working on an ever-evolving platform created unique challenges, it also offered unique opportunities to elicit feedback and assistance directly from Google employees, to participate in an engaged community of users, and to make our own contributions to the platform's evolution. We are excited about the potential to share our work with people who can actually use the results and who can provide feedback as we move forward with additional research. As we take on new projects, we consistently find ourselves considering how to make the best use of GEE's power and accessibility.