Remotely Identifying Geomorphic Processes on Alluvial Fans Using the Bidirectional Reflectance Distribution Function (BRDF)

Sarah Doyle and Louis Scuderi

Department of Earth and Planetary Sciences, The University of New Mexico, Albuquerque, NM, USA, 87131

sld474@unm.edu

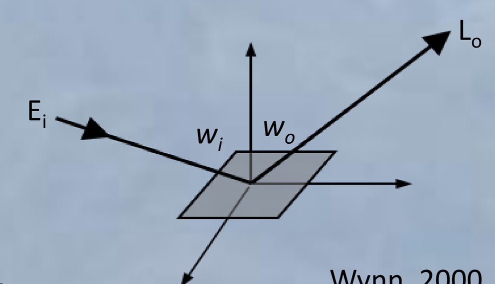
I. Abstract

The aim of this study is to develop an accurate, reproducible and low cost technique to map the surface roughness of alluvial fans using a Bidirectional Reflectance Distribution Function (BRDF) algorithm on Landsat 7 imagery. This technique, using multiple images from a single year to find roughness-based differences in directional radiance across sparsely vegetated fan surfaces, may provide accurate assignments of deposit types and locations of secondary alteration that can be used on arid zone fans. The applicability of a BRDF approach to delineate the surface roughness of facies on alluvial fans in Death Valley will be investigated. Alluvial fans can be described by the mass movement deposits that form them, and the secondary processes that modify them, such as gullying and desert pavement formation. These different processes result in quantifiable variability in fan surface roughness. Death Valley contains examples of different fan morphologies and many of the fans have a range of surface characteristics that can be differentiated independently of color and clast lithology. Readily available satellite imagery of earth's surface and application of a BRDF approach may allow understanding of geomorphic processes on large scales and in inaccessible areas.

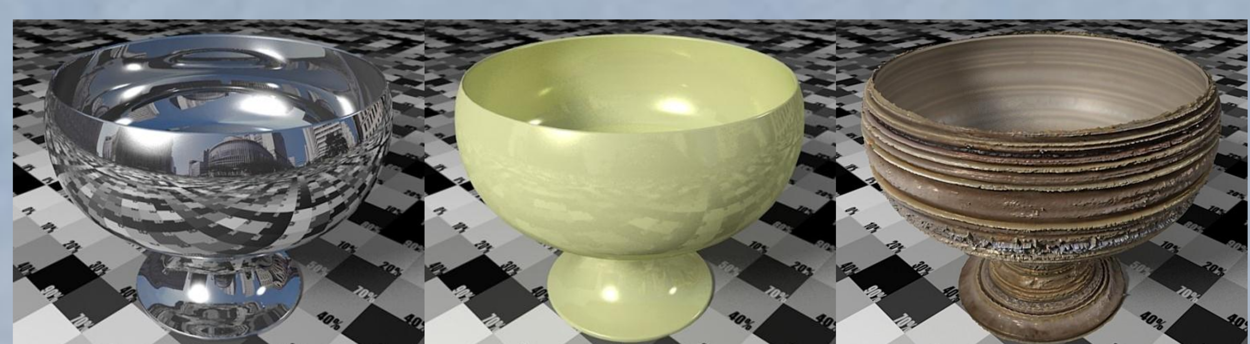
II. What is the Bidirectional Reflectance Distribution Function (BRDF)?

BRDF is the ratio of reflected light (L_o) in direction w_o to incoming light (E_i) from direction w_i :

$$BRDF_\lambda = \frac{L_o}{E_i}$$



Wynn, 2000


Turbosquid.com, 2011 – Architecture and Design Collection

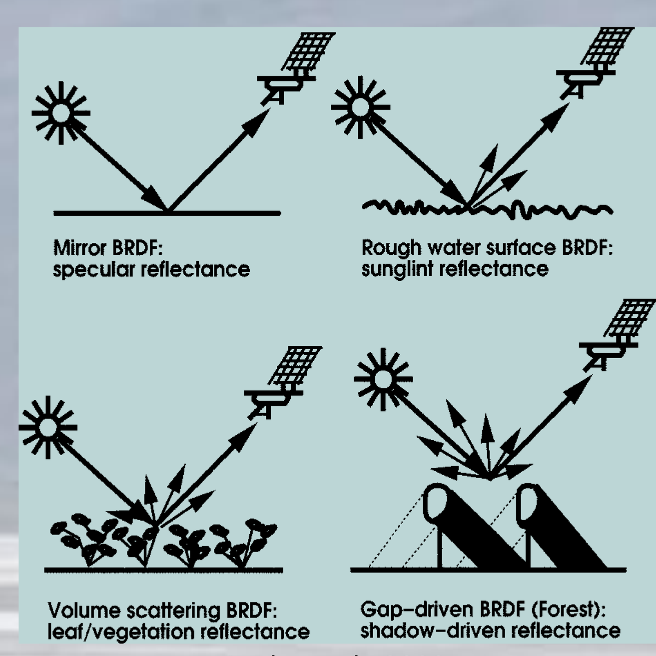
These computer animated bowls appear to have different textures based on the amount of reflected light perceived by the viewer

Having a constant view angle, such as the satellite in the figure below (Lucht et.al., 2000), surface roughness changes the amount of reflection received.

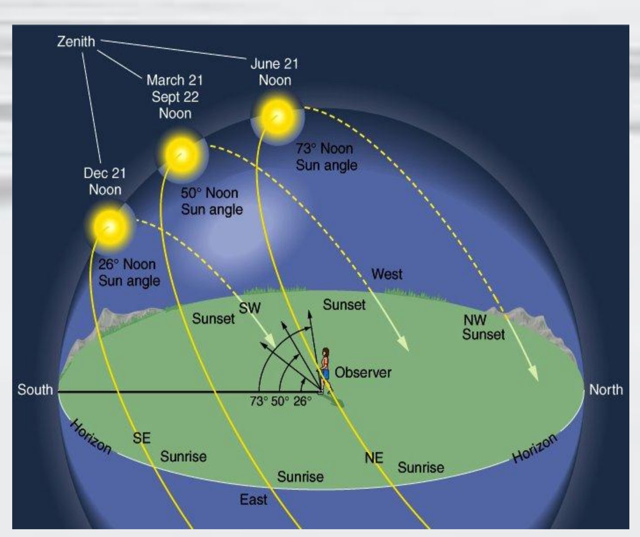
For each wavelength of radiation, the scale of surface roughness determines the amount and angle of reflection.


Shorter wavelengths will pick up clast size differences


Longer wavelengths will pick up larger topography changes



Lucht et.al., 2000



With adequate spatial resolution and spectral resolution images, surface roughness of fan surfaces can be delineated with knowledge of the BRDF

The tilt of the earth's axis causes annual changes in incoming solar angle (figure to the left). Since the Landsat imagery satellite collects data from a consistent angle, it will observe different amounts of reflected radiation at different times of the year. For each image, the observed reflection over each 30 m pixel is averaged. Images from different times of the year will have different reflection values at a specific pixel.

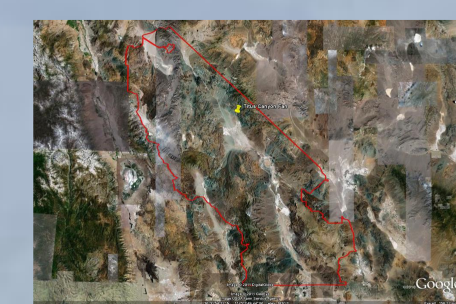
Analyzing these changes in reflection for different wavelengths can help to interpret the scale of roughness on the earth's surface. For alluvial fans, this may correspond to deposit types (debris flows, fluvial deposition) and types of secondary alteration (gullies, pavement, etc.).

III. Methods

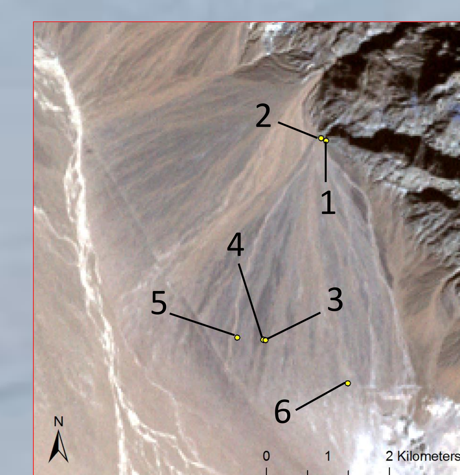
1. Landsat 7 Enhanced Thematic Mapper Plus (ETM+) imagery acquisition - USGS Global Visualization Viewer (GLOVIS)
   - Moderate spatial resolution, high spectral resolution
     - 60m – thermal infrared band (high and low gain)
     - 30m – 3 visible bands, 1 near-infrared, and 2 mid-infrared
     - 15m – panchromatic band
   - Set path/rows with images taken ~16 days apart at ~10:00 am from same angle
   - Cloudless (<10%) images can be selected
2. Clipping and other analyses done within image processing software: ArcGIS and ERDAS
3. ISODATA classifications created by isoclustering in n-dimensional space
   - Creation of Maximum Likelihood Classifications (MLC) and Principal Components Analyses (PCA)
   - Unsupervised classification – each classification is not assigned an interpretation
4. Fieldwork – Looking at different scales of roughness on fan surface locations
   - Measuring ranges of clast sizes on surfaces
   - Larger topography changes – bar and swale relief; gullies; desert pavement
   - Percent vegetation cover
5. Comparison with mapping techniques and descriptions by others (Blair, 1999; Frankel and Dolan, 2007)

IV. Preliminary Fieldwork

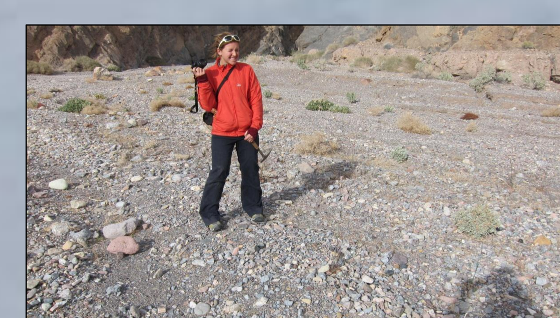
February 25th-27th, 2011 – Death Valley Natl. Park
- GPS locations taken on multiple fans
- Surface features described and photographed


Death Valley Natl. Park outline with Titus Canyon marked


1 – Older surface with well-developed desert pavement and some rock varnishing. Smooth surface with pebble/cobble sized clasts

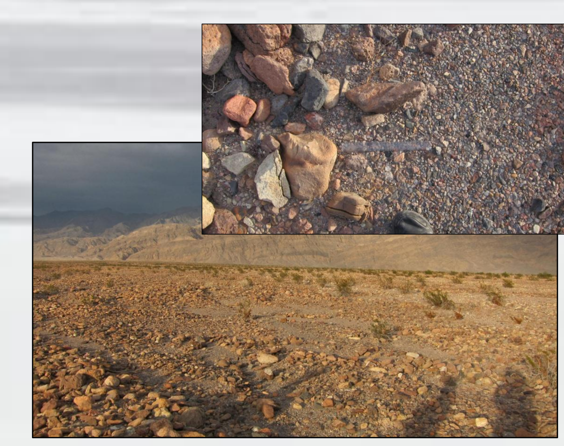


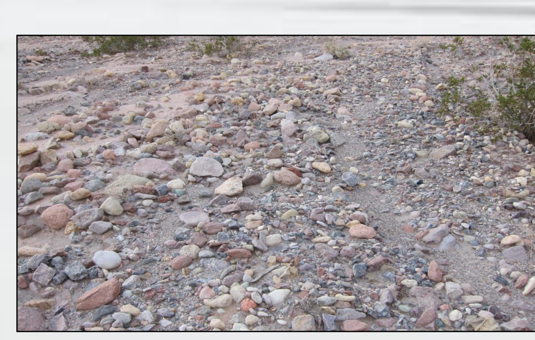
Titus Canyon Fan


2 – Within the incised channel cutting the surface of 1. Bar and channel topography wide range in clasts (pebbles to boulders)


3 – Paved surface and varnished clasts. Pebbles to boulders. Subdued bar and swale topography.


4 – Noticeably less varnished and paved than 3. Bar and swale topography. ~5% vegetated.


5 – Heavily paved and varnished. Very subdued topography. Pebbles to cobbles. Many disintegrating clasts.

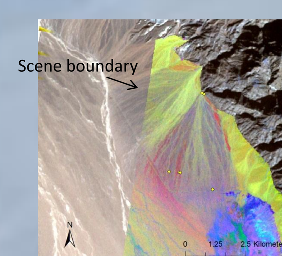

6 – At the toe of the fan. Some fine material collected in channels. Coarse (pebble to boulder) bars.

V. Preliminary Results

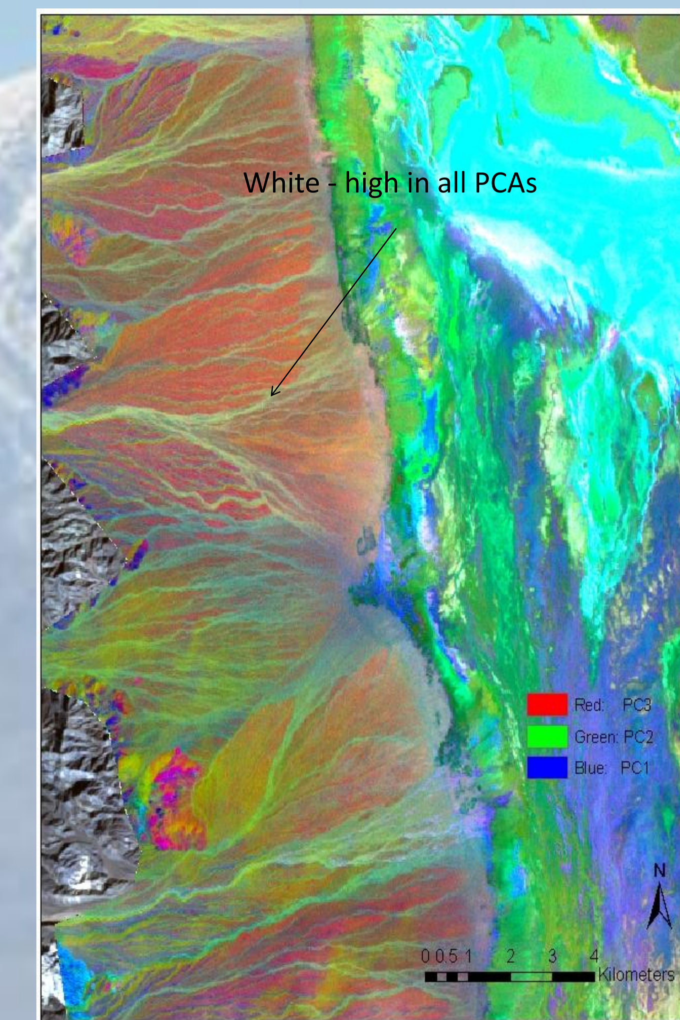
Principal Components Analyses (PCA) use Landsat 7 bands to isolate wavelength relationships that can be interpreted as different surface characteristics. In a composite image, the areas with high values in all PCA's appear white. The most active channels are white most likely because they have many different scales of roughness.

Multiple Maximum Likelihood Classifications (MLC) have been made to compare the features brought out by different wavelength bands. An example MLC shown here, shows the difference in detail for increasing wavelengths of light. This shows that this method will work to identify roughness at different scales.

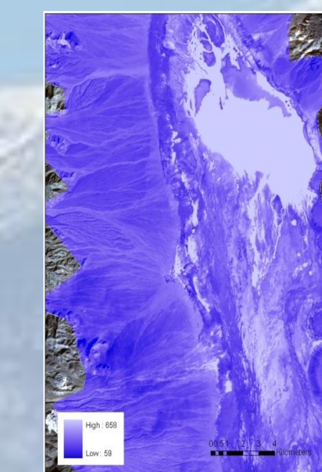
Fieldwork will help to interpret these analyses. Our preliminary trip gave us an idea of what we should see. Vegetation is minimal and so should not affect our analyses.

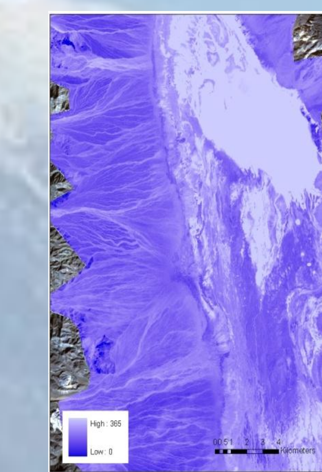


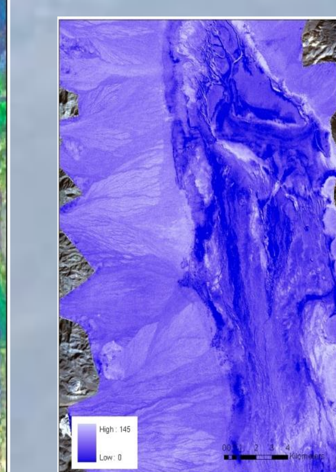
PCA for Titus Canyon Fan

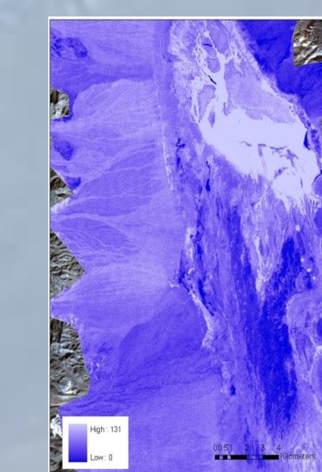


Principal Component Analysis: PC1 is Blue, PC2 is Green, and PC3 is Red

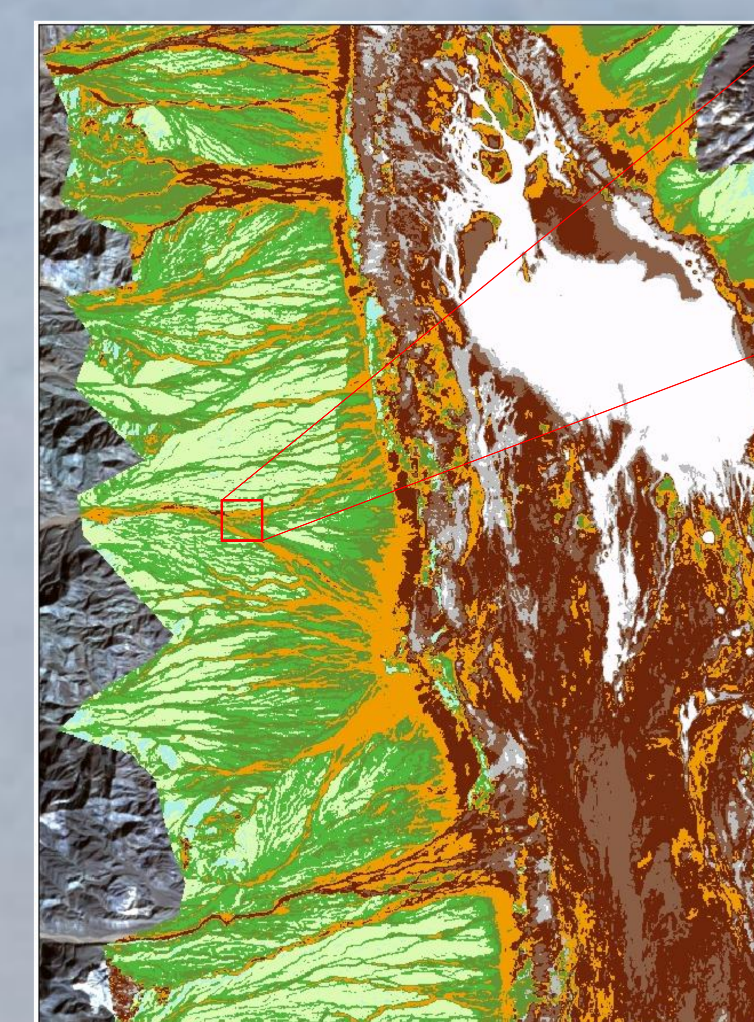

PCA1

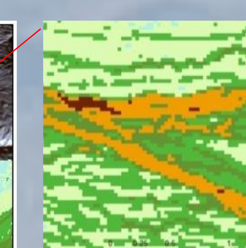

PCA2

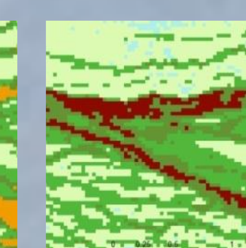

PCA3

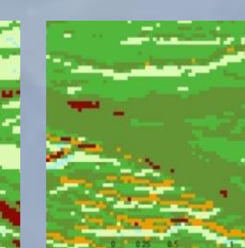

PCA4

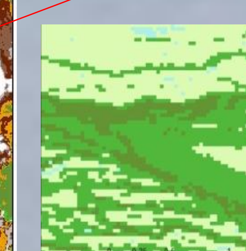
First 4 axes: High values within PCA are lighter and low values are darker. Each axes represents some feature (i.e. vegetation, clays, different scales of roughness)

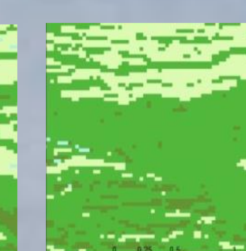


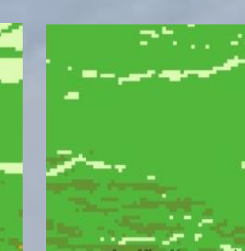

Band 1 (shortest)


Band 2


Band 3


Band 4


Band 5


Band 7 (longest)

Wavelength

0.45 µm ⟶ 2.35 µm

Band 1 ⟶ Band 7

Short ⟶ Long

Maximum Likelihood Classification: MLC's created for each Landsat band with images over the course of a year. Band 1 MLC, shown in the large image, is the blue visible light wavelength (shortest). The next 5 bands used are the Green, Red, Near-Infrared, and 2 Mid-Infrareds, going from shortest to longest wavelengths.

VI. Future Work and Significance

Future Work and Goals:
- -Make comparisons of field locations to imagery
- -Interpret analyses using statistical tests
- -Additional fieldwork
- -Look at the effects of a wet year vs. a dry year on classifications
- -Compare active lobes to altered, older surfaces
- -Be able to make interpretations of unvisited fans using this approach

This work will help to study fans in remote places (Gobi Desert, Mars) and to compare large datasets of alluvial fans without extensive fieldwork. Understanding the spatial variability of deposit types will be beneficial to many hydrogeologic and petroleum studies.

References

Blair, T.C., 1999, Cause of dominance by sheetflood vs. debris-flow processes on two adjoining alluvial fans, Death Valley, California: Sedimentology, v. 46, p. 1015- 1028.

Frankel, K.L., and Dolan, J.F., 2007, Characterizing arid region alluvial fan surface roughness with airborne laser swath mapping digital topographic data: Journal of Geophysical Research, v. 112, 14 p.

Lucht, W., Schaaf, C.B., and Strahler, A.H., 2000, An algorithm for the retrieval of albedo from space using semiempirical BRDF models: IEEE Transactions on Geoscience and Remote Sensing, v. 38, n.2, p. 977-997.

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Distributive Fluvial Systems (DFS)

CREATE Center for Rapid Environmental Assessment & Terrain Evaluation