Developing a spectral database of various land cover types to characterize land surface albedo for TEMPO

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Albedo/BRDF

- Land surface albedo/BRDF (Bi-directional reflectance function)
  - An important variable that characterizes solar illumination changes, vegetation growth and agricultural practices
- Provides useful Chappuis-band contributions for the retrieval of $O_3$ and chlorophyll fluorescence, e.g.

$$\rho_{tot}(\lambda) = \rho_s(\lambda)T(\lambda)\overline{T}(\lambda) + \frac{\pi F_s(\lambda)\overline{T}(\lambda)}{E(\lambda)\cos(\theta_0)}$$

Surface reflectance must be known

chlorophyll fluorescence (Joiner, et al 2013)
Methods for albedo estimation

- Physical approaches based of BRDF,
  - e.g., MODIS snow-free albedo products
  - BRDF is modeled by atmospheric correction and estimation of aerosol optical depth, transmittance, etc
  - Difficult to translate albedo from MODIS (0.5 – 1km) or other scales to TEMPO scale (4 km * 4 km) due to the lack of homogeneous pixels at coarser resolution.

- Direct estimation - data driven approach
  - Directly links broadband albedo to satellite observed TOA reflectance
  - Cannot estimate spectral albedos/BRDF

- Band reconstruction methods by fitting the satellite-derived BRDF
  - BRDF database in a sensor (e.g., VIIRS, RTTOV) is derived from MODIS BRDF/albedo (Wang et al. 2013; Vidot et al. 2014)
  - A conversion coefficient from field spectra to MODIS and then to VIIRS and RTTOV is estimated using USGS and ASTER spectral library
  - Limitations
    - Requires representative sets of hyperspectral spectra typically found in the landscape at different spatial and temporal scales
    - USGS and ASTER spectral data are mostly measured in the laboratory
    - Does not provide sufficient water, snow and ice reflectance
    - Assumes that there are some homogeneous pixels with coarser spatial resolution that correspond to the finer resolution data for each of the land cover (impact of scale is a problem!)
Ongoing efforts for albedo estimations

- Harvard Smithsonian
  - Band reconstruction method from Field-MODIS-TEMPO
    - Representative spectra found in Midwest is needed
    - Not just lab spectra but albedo/BRDF measured in the field, airborne

- Saint Louis University
  - Developing a database of spectral albedo/BRDF
  - Field-airborne data collection, more realistically reflect the land-cover and land-use
  - Impact of scale when spectra are converted from field to airborne, and then to MODIS and TEMPO
# Spectral profiles of several instruments

<table>
<thead>
<tr>
<th></th>
<th>MODTRAN</th>
<th>PSR-3500</th>
<th>Specim Camera</th>
<th>AVIRIS</th>
<th>TEMPO</th>
<th>PANDORA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Wavelength range</strong></td>
<td>0.2-100 um</td>
<td>0.35-2.5 um</td>
<td>0.35- 2.5 um</td>
<td>0.4-2.5um</td>
<td>0.29-0.69 um</td>
<td>0.29-0.52 um</td>
</tr>
<tr>
<td><strong>Spectral Resolution</strong></td>
<td>&gt; 0.1 cm⁻¹</td>
<td>3nm @700nm</td>
<td>1.5nm@ VNIR</td>
<td>10 nm</td>
<td>0.6 nm</td>
<td>0.6 nm</td>
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<tr>
<td>(0.08 nm @ 400 nm)</td>
<td></td>
<td>10nm @ 1500nm</td>
<td>12nm@SWIR</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>7nm @ 2100nm</td>
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<tr>
<td><strong>Spectral Sampling</strong></td>
<td></td>
<td>1.5nm @700nm</td>
<td></td>
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<td></td>
<td></td>
<td>3.8nm @ 1500nm</td>
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<tr>
<td></td>
<td></td>
<td>2.5nm @ 2100nm</td>
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<td></td>
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<td>~@ VNIR</td>
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<tr>
<td></td>
<td></td>
<td>5.6nm@SWIR</td>
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</tbody>
</table>
Test Site - MoBOT

Drought bed

Controlled bed

*Vitis riparia* (river bank grape); *Vitis rupestris* (sand grape)
Nine genotypes
Leaf and Canopy spectra – different

**Canopy**

**Mean canopy**

**Leaf**

**Mean leaf**
Rare earth minerals - the AVD

Examples of diatreme outcrops sampled in the AVD. Variation in mineralogy and resistance to weathering dictates the outcrop profile spanning preferentially resistant (left and right) to laterized.
At top right is the spectroradiometer set up for laboratory spectral measurements. Below the portable spectroradiometer being used to take VIS-NIR reflectance measurements of an AVD outcrop.
A representative group of spectra from various rare earth related minerals in Missouri (measured in the lab).
Lab and field spectra - different

Laboratory and field measured spectral albedo/BRDF from AVD samples displaying different VIS-NIR absorption features.

![Sample L6A, Field and Lab Measurements](image1)

![Sample L81A, Field and Lab Measurements](image2)

Highlights the impact of scale
Note: most of USGS spectra and ASTER library were measured in the lab
We need to know the scale effect

A very large hall?
We need to know the scale effect

Compared to what?
AmeriFlux network

AmeriFlux Site and Data Exploration System

Primary Site Information

Site name: All Sites
Primary Investigator(s): All PIs
Country: State/Province: All countries All States/Provinces
Measurement status: All
Data availability status: All
Types of available data products: L2 L3 L4 Bio data
Date available (mm/dd/yyyy): From 10/28/1991 To 12/31/2013
Vegetation (IGBP): All classes
Elevation (m): From 0 To 3190
Longitude (+/-, E/W): From -157.4089 To -54.9589
Latitude (+/-, N/S): From -3.0180 To 71.3225

Meteorological variables

- AdvTCFC
- CO*
- CO2
- DVO3*
- FH20*
- GEP
- H2Oden*
- NEE
- PARdif
- PRECcume
- PRESS
- Rgdir
- RgNIR*
- RgRedOut*
- SFC
- SH
- SLE
- SWDdepth*
- TExt*
- TMin*
- TMax*
- Tdew*
- Tskin*
- Tsonic*
- Ubar*
- WATERdepth*
- WATR*
- ZEC*
- ZL

Biological variables

- APAR
- APARpc
- CH4*
- CO2den*
- DryAirDen*
- FCH4*
- FG
- FO3*
- GC*
- H
- H2O
- LE
- Leafwetness*
- PAR
- PREC
- RE
- Rg
- Rgl
- RglOut
- RgRed*
- Rs*
- SFH2O*
- SHbole*
- SVP*
- SWC
- TA
- TAb*
- TADb*
- Tleaf*
- TS
- Tsk*
- Ten*
- WetAirDen*
- WS
AVIRIS data availability
AVIRIS spectral albedo

[Graph showing AVIRIS Spectral Library Plots and AVIRIS Spectra convolved to TEMPO wavelengths]
Future work – multi sensor fusion

- Tempo (4km res.)
- Numeric simulations
- Airborne (AVIRIS, Ball, SLU?)
  4 – 20m res.
- Field (0.13m res.)
- Mobile lab (0.5 m res.)
Future work – multi sensor fusion

Future work – multi sensor fusion

Kalman filter
Defining a slope across the Chappuis core region:
(is just a slope enough?)
R. Chatfield, NASA Ames

These are simple ratios of upward to downward:
all low altitude (0-500 m), minimal aerosol effect

Huge Credit to
S.-Schmidt/Pilewskie group
at CU Boulder, esp. Bruce Kindel
Solar spectrum flux radiometer (CU-Ames) provides the best-understood, most direct evidence about spectral shape.

“Half of SSFR’s signal (not an imager but irradiance radiometer) comes from within a cone that has a ground cross-section about the same as the flight altitude.”

Sebastian Schmidt

Flight path north of Houston, 2006, mostly vegetated.

Credit to S.-Schmidt / Pilewskie group at CU Boulder, esp. Bruce Kindel.
Examples of naïve albedo from SSFR data: ratio of upward flux to downward flux: this spotlights our concern: $\lambda$-variation

Vegetation $A(\lambda)$  
Soil/Road/Dry $A(\lambda)$  
$?$ Red Soil $?$

What happens with drought, Ozone damage? Yellowing?

These are simple ratios of upward to downward: all low altitude (0-500 m), minimal aerosol effect
Slopes can change very rapidly over < 6 km, but there are also broad regional patterns.

Variogram shows strong increase of variability of slope up to 10 km, ...then similar variability up to 40 km.
Analysis Overview

General direction of tasks:
• Identify “types” and “mixtures” using aircraft data to check and extend “pure-land-use” (lab) albedo. What might we be missing?
• Chose “components” method, paying attention to advice from MODIS land-use scientists.
• Produce sample dA/dλ descriptions with 2–3 degrees of freedom per description, or as TEMPO instrument error covariances mandate (do small 10-nm features matter?)

MAIAC: Repeat analysis Albedos in MODIS bands at 0.5–1 km resolution, with careful multi-footprint filtering and rationalization (in time and space domains). Lyapustin data will be available to GEO-CAPE (Aerosol) group by late March.

R.Chatfield, NASA Ames  Robert.B.Chatfield@nasa.gov
Usefulness of Some RT “Modeling”

SSFR and spectrum fitting

Houston NNW flight analysis, 2900 m at 19.19 UT
H$_2$O to zenith should be minimal for samples in this dataset.

Measured Downward (zenith) X 0.1 to fit scale

Measured upwards (nadir) (red dots) and “shift-Chappuis fit”

Downward – best-fit upward shifted +0.02 to fit scale (corresponds to ~0.10 to ~0.20 “albedo” in dataset)

Chappuis spectrum

Water spectrum (VPL plot)
Extra slides
Table 2
Relation of incoming and reflected radiance terminology used to describe reflectance quantities

<table>
<thead>
<tr>
<th>Incoming/Reflected</th>
<th>Directional</th>
<th>Conical–directional</th>
<th>Conical–hemispherical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Directional</td>
<td>Bidirectional</td>
<td>CASE 1</td>
<td>CASE 2</td>
</tr>
<tr>
<td></td>
<td>CASE 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conical</td>
<td>Conical–directional</td>
<td>CASE 4</td>
<td>CASE 5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hemispherical</td>
<td>Hemispherical–directional</td>
<td>CASE 7</td>
<td>CASE 8</td>
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<td></td>
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</tr>
</tbody>
</table>

The labeling with ‘Case’ corresponds to the nomenclature of Nicodemus et al. (1977). Grey fields correspond to measurable quantities (Cases 5, 8), the others (Cases 1–4, 6, 7, 9) denote conceptual quantities. Please refer to the text for the explanation on measurable and conceptual quantities.