Final Report
Hyperspectral Imaging and Related Field Methods: Building the Science
NAG5-6651

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Proposed Tasks

The proposal requested funds for the computing power to bring hyperspectral image processing into undergraduate and graduate remote sensing courses. This upgrade made it possible to handle more students in these oversubscribed courses and to enhance CSES' summer short course entitled "Hyperspectral Imaging and Data Analysis" provided for government, industry, university and military. Funds were also requested to build field measurement capabilities through the purchase of spectroradiometers, canopy radiation sensors and a differential GPS system. These instruments provided systematic and complete sets of field data for the analysis of hyperspectral data with the appropriate radiometric and wavelength calibration as well as atmospheric data needed for application of radiative transfer models.

The proposed field equipment made it possible to team-teach a new field methods course, unique in the country, that took advantage of the expertise of the investigators rostered in three different departments, Geology, Geography and Biology.

Results

The following is a list of equipment purchased under this contract:

1) 12 Dell Workstation 400 Personal Computers 300MHz 128MB 9GB 1GB JAZ Drive and 24 1GB JAZ diskettes
2) 2 ASD-FR Spectroradiometers temperature stabilized, with complete foreoptics Spectralon, batteries, notebook computers.
3) Complete radiometric calibration set-up including: Newport Optical Bench, Optronic 83A precision DC current source, 1 calibrated Optronic FEL Irradiance source, 3 seasoned uncalibrated FEL irradiance sources, 1 GuildLine NIST calibrated precision current shunt, 1 5 ½ digit HP Digital Volt Meter, alignment jig and kinematic FEL mount, Newport HeNe laser, 1 12x12 Spectralon panel, assorted Newport optical bench accessories, UltraPol flat black shielding.
4) Acton .5m monochromator with tungsten and low-pressure mercury light sources and silicon detector
5) IBM PC 167MHz for monochromator control
6) 2 Li-Cor Plant Canopy Analyzers

7) 2 Li-Cor Line Quantum Sensors
8) 2 Li-Cor 1400 Data Loggers
9) 4 Trimble GeoExplorer II GPS receivers with software for differential correction
10) 6 Garmin III hand held GPS receivers
11) 1 Reagan 10 channel Solar radiometer
12) 1 Panasonic Field Laptop computer
13) 1 custom built Goniometer for use with ASD-FR
14) 3 LowelPro DC light sources

Course development

A new course entitled "Remote Sensing Field Methods" was developed by the PI and Co-I's. and is given for credit in three departments, Geology, Geography and EPO Biology.The attached pages are the syllabus and lab exercises for the course. Ten students completed the course. It will be repeated in the fall of 2001. The purchase of the above equipment was key to being able to offer the course.

GEOL 5700, GEOG 6181, EPOB 5460
Remote Sensing Field Measurements
Thursday 12:30-3:30 PM, Rm. Ekeley W240

Welcome to a brand new course, probably unique in the country if not the world. We have developed this course with funds provided by NASA for our "center of excellence in hyperspectral imaging". The emphasis of this course isn't on hyperspectral imaging, but rather on measurements and methods of field verification, otherwise known as "ground truth". The course is being team-taught by CSES/CIRES Profs. Alexander Goetz, Carol Wessman and Konrad Steffen, with emphasis on rocks, vegetation and snow and ice respectively. Atmospheric measurements will also play a part. The equipment we will use are spectrometers, radiometers and specialized measurement devices, all are state-of-the-art. You will learn not only how to use the instruments but how to calibrate them and understand their shortcomings.

Lectures/Labs

- Aug 27 General introduction and overview.
- Sept 3 Field spectrometry, design and function of spectrometers, lab measurements, calibration.
- Sept 10 Canopy structure, direct and indirect
- Sept 17 APAR
- Sept 24 Spectrometer outside. Radiance and irradiance. Natural Surfaces
- Oct 1 Canopy structure, direct measurement
- Oct 8 GPS, single and differential
- Oct 15 Bi-directional reflectance distribution function (BRDF).
- Oct 22 Catch-up day
- Oct 29 Solar and terrestrial radiation, pyranometer, pyroheliometer, data loggers, global radiation balance.
- Nov 5 Atmosphere scattering and absorption. Solar measurements, Langley method
- Nov 12 Spectral reflectance of snow and clouds
- Nov 19 BRDF of snow
- Dec 3 Student presentations

Expectations and Grading

Measurements will be made in groups depending on the number of instruments available. Each student will keep a lab notebook to be handed in at the end of the course. There will be homework each week consisting of working up the data and answering questions. Each student will choose one of the labs, no overlap, on which to expand into a 5-8 page paper, researching the literature, etc. On Dec 3 each student will give a 10 minute presentation. There will not be a final exam. Students are expected to attend all class meetings. Grading: 60% homework, 20% lab notebook, 20% paper and presentation.

GEOL 5700, GEOG 6181, EPOB 5460
Remote Sensing Field Measurements
Field Spectrometry – Laboratory Measurements
September 3, 1998

Exercise 1 - ASD-FR Basics

Introduction – From the lecture you should understand the basic steps in acquiring data with ASD Full Range (ASD-FR) spectroradiometer. Begin by adjusting the configuration of the instrument and changing the number of spectra to average for the measurement, the dark current, and the white reference. After the desired configuration is entered, optimize the instrument for the current lighting conditions. When the ASD-FR has optimized, focus the tungsten light source until the instrument saturates (flat lines) in some channels to see how the saturation manifests itself. Finally put the ASD-FR into reflectance mode. Run through this entire process several times with averaging of 10, 20, 40 and 80 spectra, dark current and white reference. Record a white reference spectrum at each level of integration.

Task 1 – Create a plot of the white reference spectra averaging at the various levels of averaging (10,20,40...). You need not make a separate plot for each value, use the offset for clarity function in the ENVI plotting window and create one plot for all the spectra. Clearly label each spectrum with its averaging value.
Task 2- From these spectra estimate the noise for each spectrometer (350-1000nm, 1000nm-1850nm and 2500nm). Estimate by eye, the average noise (average peak to peak not maximum peak to peak) in units of reflectance. Make a plot of these noise estimates versus spectrum averaging value.

Exercise 2 - Laboratory Reflectance Measurements

The next exercise involves making laboratory reflectance measurements of various samples to gain some insight into the spectral variability of materials and the underlying causes of the variability. Begin with the three mineral samples provided. Record several spectra from each sample.

Task-3 Create a plot of each of the reflectance spectra (one per sample) and label the various absorption features and explain the processes that produce these features. You'll need refer to the Clark and Hunt papers for this task. Another excellent reference is the USGS spectroscopy page, try http://speclab.cr.usgs.gov/browse.html

Next record several spectra of the three unidentified mineral samples provided.

Task-4 Using the USGS spectral library provided in ENVI, plot your sample and the library spectrum which you believe matches it. Make sure to include the name of the matching spectrum. Label the matching absorptions and the reasons (e.g. shape, position, etc) why you believe the spectra match.

Record the spectrum of a single fresh leaf while on top of a piece of Spectralon. Record additional spectra (one per leaf) as you stack one leaf on top of another until the spectra no longer changes shape or magnitude.

Task 5 – Plot a single fresh leaf spectrum and explain the various absorption features.
Task 6 – Plot the stacked leaf spectra on top of one another (no offsets) and explain the changes in the spectra as you go from one leaf to several stacked leaves.

Exercise 3 - Spectroradiometer Calibration: Radiometric & Spectral

In this exercise you will perform a radiometric calibration of the ASD-FR. You will calibrate the instrument in radiance, viewing a Spectralon panel illuminated by a NIST traceable bulb and irradiance, directly viewing the NIST traceable bulb with a cosine receptor. You will also produce a "Noise Equivalent Change in Radiance (NEΔL)" plot for the ASD-FR, an important measure of noise characteristics of a spectroradiometer.

Radiometric Calibration

Take a series of spectra collected with the bare fiber optic viewing the 2x2 Spectralon panel illuminated by the NIST traceable bulb, average 25 spectra and save three. Next configure the instrument to average 10 spectra. Record 30 spectra as quickly as possible.

Task 7 – From the DN response of the ASD-FR and the published values of the NIST traceable bulb, make a plot of radiometric coefficients versus wavelength. Because there aren't as many published NIST values, as there are channels in the ASD-FR you'll need to interpolate the intermediate channels with a cubic spline. Please see the attached note on how to perform a cubic spline in IDL.

Task 8– From the 30 spectra saved very rapidly, plot the NEΔL of the ASD-FR (in units of radiance).

Finally, replace the Spectralon panel with the remote cosine receptor (RCR) and align with the laser. Record three spectra, again each one an average of 25 spectra.

Task 9 – In nearly the same manner of task 8, create a plot of the radiometric coefficients (irradiance) versus wavelength.

Spectral Calibration

In this final exercise you will evaluate the spectral calibration of the ASD-FR as well as determine the Full Width Half Maximum (FWHM) of the instrument both in the array (350-1000nm) and scanning (1000-2500nm) portions of the instrument.

Begin with the tungsten light source on the Acton .5m monochromator. Tune the Acton monochromator to 696nm of light, step the monochromator to 704 nm in increments of .2nm. Record a spectrum at each step. Next change the grating on the monochromator and tune the monochromator to 1100 nm. Record a spectrum every 100 nm. until you reach 2400 nm.

Task 10 – Plot the response of the ASD-FR *at 700 nm.* for the wavelengths recorded from 696-704 nm. From this plot estimate the FWHM of the instrument in the 350-1000 nm range.

Task 11 – Plot the response of the instrument for the wavelengths 1100-2400 at every 100 nm. These can all be plotted on the same graph. Estimate the FWHM and the accuracy of the wavelength calibration for all 14 of the measurements.

Replace the tungsten light source on the Acton .5m monochromator with the low-pressure mercury lamp. With the monochromator tuned to 0 nm, record a single spectrum.

Task 12 – Plot the mercury lines spectrum and estimates the FWHM in both 350-1000nm and 1000-2500nm regions. Does the FWHM differ from the tungsten source and the mercury source? Why?

GEOL 5700, GEOG 6181, EPOB 5460
Remote Sensing Field Measurements
Canopy Structure - Indirect Measurements
10 September 1998

This lab will involve the use of the LICOR LAI-2000 (Plant Canopy Analyzer) and hemispherical photography for measurements of the plant canopy leaf area. The lab will be conducted in two sessions: the first during normal lab time Thursday (10 Sept) to learn the instruments and the second at dawn Friday (11 Sept) for actual measurements with diffuse skies.

Session 1 - Basics of the LICOR LAI-2000 Plant Canopy Analyzer and Hemispherical Photography

PCA:

- Sensor Checklist: Become familiar with the operations for setting up the LA-2000 to make measurements in the 1-Sensor mode. See attached pages on operating summaries.

- Practice measurements under different canopy types (tree, grass, shrub) and observe variations in calculated values of LAI and MTA.

- At the end of the Thursday lab have the dataloggers set up for Friday's measurements.

Hemispherical Photography

- Demonstration of camera's use.
- Processing of final canopy pictures (acquired Friday) will be discussed and completed in Lab #3, 17 September 1998

Session 2 - Sunrise Field Measurements

We will meet at 5:30 am Friday at the Chatauqua parking lot. (Sunrise is at 6:37am) This will give us time to get to the sites and set up transects, etc. Each of three groups will be assigned to a cover type (grass, conifer trees and deciduous trees) and will be responsible for the measurements of that type. A couple of people will be working on the photography at the same time. At a minimum, three transects will be run in each of the grassland and deciduous tree sites, both types representing "continuous" canopy. Because of the discontinuous distribution of ponderosa trees, each of three trees (minimum) will be measured three times. It's suggested that different people make each set of measurements (i.e. each transect and each set of trees by different people). We'll have approximately 30 minutes to work with; you'll need to be efficient in both your operation of the instrument and the trade-off between individuals.

Hemispherical photography will be obtained during this time in the conifer and deciduous canopies. Discussion and processing will occur in Lab #3.

Measurements will begin when light is sufficient enough for a signal and will continue until the solar disk is above the horizon. Note that accurate estimates of LAI require fully diffuse sky conditions.

Task 1: Immediately following the Friday measurements, take 10 minutes with your group to list what you consider to be the principal needs and concerns for measurements in your designated cover type. Also, list what you would consider the problems encountered by the other groups in their respective cover types.

Task 2: Process the data for your cover type and make them available to the other groups.

Task 3: Retrieve the data for all three cover types. Plot the individual LAI points with respect to position (transects) or count (conifers). This will give you an idea of canopy variation in space for the transects and variation among individuals for the conifers. Calculate the mean and coefficient of variation (standard deviation/mean) for each cover type.

Task 4: Answer the following questions:

a. Do you have reasonable numbers (LAI, MTA) for each cover type?
b. How do the data vary within each cover type? What are the likely sources of variation?
c. How do the data vary between cover types? What are the likely sources of variation?
d. Do you see variation among measurements made by different individuals?

Techniques for Each Cover Type

Each set of measurements will require 3 people dedicated to, respectively, the PCA, the datalogger, and recording LAI, MTA, and SEM values. We will continue making measurements until the sun is up.

Transects in Grass:

1. Mark beginning and end of a 50-m transect with flagging. . (First readings can be made while this is being done.)
2. Make above-canopy measurement. (A)
3. Drop down and position end of instrument under the canopy directly in front of you and level. (B1)
4. At the same location, turn 90°, 180°, and 270° from your first measurement for B2, B3, B4.
5. Pace off about 5 meters and repeat 2-4.
6. Continue for about 10 meters for a transect length of 50 meters.
7. Rotate to another combination of individuals and instruments.

Transects in Deciduous Trees:

1. Mark beginning and end of a 50-m transect with flagging; make the beginning and end to the nearest tree trunk. (First readings can be made while this is being done.)
2. Make the above-canopy measurement (A) in the clearing to the east of the stand. Be sure to have the forest to your back to get a full-sky measurement.
3. Return to the beginning of the transect. Make measurements from the base of the tree outward. Drop down and position end of instrument under the canopy directly in front of you and level. (B1)
4. At the same location/tree trunk, turn 90°, 180°, and 270° from your first measurement for B2, B3, B4.
5. Pace off about 5 meters. Choose the nearest tree trunk. Have someone wait at this position while the PCA/datalogger individuals acquire the A reading east of the stand.
6. Repeat 3-5.
6. Continue for a transect length of 50 meters (ten stopping points).
7. Rotate to another combination of individuals and instruments.
8. Hemispherical photographs should be taken at 3 points along the transect where LAI-2000 measurements are being made.

Conifers:

Trees are best measured using a 180° or smaller view cap, and placing the sensor next to the trunk below the crown for the B readings. The view cap prevents the sensor from seeing the trunk of the tree. Usually the largest branches are where you'd want to put the sensor at the bottom center of the crown, but it is important to avoid having these dominate the sensor's view.

1. Make your above-canopy measurement in a clearing facing away from the trees for a full-sky view.

2. If the tree is symmetric, 8 B readings spaced 45° apart will obtain a good average. (even better would be 12 B readings 30° apart).

3. With the same combination of individuals, work through 3-4 trees. Then rotate to another combination of individuals and instruments to measure the same trees

4. Hemispherical photos should be made at 2 or 3 of the trees for later comparisons.

GEOL 5700, GEOG 6181, EPOB 5460
Remote Sensing Field Measurements
Canopy Function – Fraction of Absorbed/Intercepted Radiation
17 September 1998

This lab will involve the use of point and line quantum sensors for measurements of PAR (photosynthetically active radiation). We will concern ourselves with measurements of the fraction of absorbed or intercepted PAR (fAPAR and fIPAR, respectively). Measurements of PAR have been used for canopy gap fraction measurements and, in turn, to calculate LAI. We will only be considering the fAPAR as a measurement of canopy function, that is as it relates to photosynthetic activity as determined by amount of PAR absorbed. After a <u>brief</u> introduction to the theory behind measurements of PAR, we will return to our sites at Chatauqua to learn the instruments and dataloggers.

Field Measurements

One point quantum sensor and datalogger will be set up in the open to measure incident PAR (PAR_i) throughout the field exercise. Everyone will use these data. The three groups from last week (grass, conifer, deciduous) will re-establish their transects/tree sites in each cover type for the measurements of canopy-transmitted radiation, PAR_t.

Instruments will be calibrated to one another using simultaneously acquired PAR_i measurements immediately before and after the suite of PAR_t measurements. The line quantum measurements (PAR_t) will be made in a similar fashion to the LAI-2000 measurements:

- Grassland and deciduous sites will work along transects at 5 m intervals. Measurements should be made in 4 directions at each point.

- Conifer measurements will be made at the same trees as last week, with approximately 8 measurements made radially from the trunk of the tree.

- Each group will need someone to hold the sensor, someone to hold the datalogger, and a recorder to note the time, transect location, direction, and DN value of the measurement. The recorder will use a GPS for the exact time to facilitate matching with PAR_i values.

9. Rotate personnel in a manner consistent with last week to ensure everyone has an opportunity at all roles.

<u>Task 1:</u> Process the data for your cover type and make them available to the other groups.

<u>Task 2:</u> Retrieve the data for all three cover types. As with the LAI data, plot the fIPAR values with respect to position (transects) or count (conifers). (These points will be the four averaged values acquired at each transect position and the average of all measurements for each individual conifer tree.) This will give you an idea of canopy variation in space for the transects and variation among individuals for the conifers. Calculate the mean and coefficient of variation (standard deviation/mean) for each cover type.

<u>Task 3:</u> Answer the following questions:

a. How do the data vary within each cover type? What are the likely sources of variation?
b. How do the data vary between cover types? What are the likely sources of variation?
c. Do you see variation among measurements made by different individuals?

Task 4: LAI and fIPAR data set comparisons:

a. Plot the LAI and fIPAR values for each cover type. While you only have 3 data points, look at the general relationship across cover types. (You may also want to plot the individual conifer trees (averaged across reps) since their LAI and fIPAR measurements are discrete.) Is there some trend between LAI and fIPAR?

b. Basic plant physiology: the chlorophyll in green leaves is absorbing PAR wavelengths to drive the photosynthetic process. However, stem and litter material will intercept PAR to some degree. Moreover, from a remote sensing platform, the high albedo of stem and litter will contribute a significant signal to measured reflectance. What do you expect the relative contributions of non-photosynthetic material to be for each cover type, namely grasses, conifers and deciduous trees?

c. **Optional:** Take a look at the SAIL (Scattering Arbitrarily Inclined Leaves) model described by F.M. Danson ("Teaching the physical principles of vegetation canopy reflectance using the SAIL model", PER&S 64(8):809-812) and found at the web site http://www.salford.ac.uk/geog/staff/sail.html. Use it to explore the complex of variables which control vegetation canopy reflectance, and the relative influence on NDVI.

These labs (2&3) are due Thursday, 24 September. I will grade them and return them on Thursday, 1 October, for our discussion of these techniques. (We will also be analyzing the hemispherical photography for the 1 Oct lab)

GEOL 5700, GEOG 6181, EPOB 5460
Remote Sensing Field Techniques
Field Spectrometry – Field Measurements
September 24, 1998

Exercise 1 - Measuring Atmospheric Short-wave Radiance and Irradiance

In the first part of the lab we will make measurements of down-welling solar irradiance as well as radiance.
Begin by setting up the ASD-FR with the 2x2 Spectralon panel with 45^{o} arm. Collect 10 minutes of data sampling every 30 seconds for a total of 20 spectra. Configure the instrument to average 25 spectra to improve SNR. Next use the occulting disk to measure the diffuse component of solar radiation. Record five diffuse spectra. After completing this task, switch the instrument foreoptic to the remote cosine receptor as quickly as possible as record five spectra with the RCR.

Task 1 – Create a plot of the down-welling radiance and label the prominent absorption features (e.g. water vapor, oxygen, carbon dioxide, ozone and Fraunhofer lines). Include the diffuse component on the same plot (use the average of the five measurements).

Task 2 – Ratio the first spectrum to each subsequent spectrum to determine the change in atmospheric conditions over the relatively short ten -minute period.

Task 3 – Plot the ratio of radiance as measured with Spectralon panel to the irradiance as measured with the RCR. Make sure to use the two measurements closest in time to mitigate the effects of changing atmosphere.

Exercise 2 - Characterizing a field site for calibration/comparison with an airborne/spaceborne sensor

In this exercise we will characterize the grass of Norlin Quad to gain some insight into the variability of even "uniform" natural surfaces like grass fields or playas. Record several transects across the field collecting spectra as you walk across. Configure the instrument to average 50 spectra and save the spectra as quickly as possible. Setup a Spectralon panel at the end of each transect to perform a white reference at the end of each transect. Stop after collecting one hundred spectra have been collected.

Task 4 – Plot all of the spectra you've collected on one plot. On a second graph, plot the mean spectrum and +/- one standard deviation.

Exercise 3 – Collecting Field Spectra

Take twenty minutes and collect a spectrum for the various materials found around Norlin Quad. Make sure to include man-made materials as well as natural ones. Take careful notes of both the materials and in the case of leaf spectra, the material beneath the canopy. Make comparisons of whole canopy spectra to single leaf spectra of the same canopy.

Task 5 – Plot the various spectra you've collected. Comment on the differences between single leaf versus whole canopy spectra.

Exercise 4 – Scattering into the Field of View

Reconfigure the instrument with the 45° radiance arm and the 2x2 Spectralon panel. Optimize and white reference in the center of Norlin Quad. Immediately record a white reference spectrum. Quickly move the instrument closer to a nearby tree recording a spectrum each couple of steps. Do not perform another white reference at any point during these measurements. Time permitting, repeat the measurement with a group of people as the scatterer.

Task 6 – Ratio each white reference spectrum to the first spectrum and plot the result. How does the spectrum change as you move closer to the tree?

GEOL 5700, GEOG 6181, EPOB 5460
Remote Sensing Field Measurements
Global Positioning System - GPS
8 October 1998

This lab will involve the introduction to and use of the Global Positioning System (GPS), a satellite-based positioning system operated by the U.S. Department of Defense (DoD). Exact coordinates can be calculated for any position on earth by measuring the distance from a group of satellites (of known location) to the ground position (satellite trilateration).

Following the overview of the GPS, you will learn the operation of Garmin (not differentially-correctable) and Trimble (differentially-correctable) receivers. After an appropriate "familiarization" period, you will be provided with a georegistered SPOT image of the Boulder area. Each of four groups will be given two receivers (one of each kind) and assigned to an area of Boulder. By bus or car, you will be expected to find and determine the coordinates of a minimum of 3 points (and no more than 8) that can be easily located in the scene. It's recommended that you spend 10 minutes on the computer screen to determine good points. The hard-copy images provided will be useful for general directions.

Upon your return to CSES, Bruce will download the Trimble data, differentially correct them, and make them available to you.

<u>Task 1:</u> Once you've located a point, you'll make measurements with both receivers. Take 180 points (Trimble), approximately 3 minutes. All values from the Garmin will need to be written down. Make a note of the pixel you're in (e.g. intersection of Broadway and Baseline) and note the Trimble file #. (Bruce will need this information.)

<u>Task 2:</u> Retreat to the lab and extract the coordinates from the georegistered image (registered on a map with UTM (NAD-27)).

<u>Task 3:</u> In ENVI, convert the lat/long values from the differentially-corrected and the uncorrected coordinates to UTM. Compute the distance between the differentially-corrected and the uncorrected coordinates to determine the "real error" of the undifferentially-corrected data. How does it compare with the Garmin estimated error?

<u>Task 4:</u> Perform a thorough comparison of image versus ground coordinates. Make a table of the coordinates and through whatever means you chose, determine the actual error of the georegistration process.

<u>Task 5:</u> Study the set of coordinates and their associated error in their relative geographic orientation. Is there any systematic error in space that occurs in the image coordinates? Have the ground control points used in the georegistration adequately addressed any variation in registration across the image? If so, what are the sources of error? What improvements could be made in the georegistration process?

GEOL 5700, GEOG 6181, EPOB 5460
Remote Sensing Field Techniques
Field Spectrometry – BRDF
October 22, 1998

In this lab you will learn how to make measurements of the BRDF (bidirectional reflection function) of some natural surfaces. We will set up a custom-made field goniometer designed especially for use with an ASD-FR field spectroradiometer. The goniometer allows the user to change the view zenith and view azimuth of the ASD-FR foreoptic with respect to the sun angle and azimuth. Although we will go outside and attempt some measurements, the processing part of the lab will use measurements made previously of three different surfaces (green grass, bare soil and a small bush).

Exercise 1 - Setup the ASD-FR with the goniometer on a section of green grass. We will use the 5^0 field of view foreoptic. Use the 12x12 Spectralon panel to reference and collect reflectance spectra. Move the foreoptic through the various view zenith angles both in and perpendicular to the principal plane of the sun. Observe and record the changes in the reflectance for the various view angles, remember to also think (record) about the position of the sun (zenith and azimuth).

Exercise 2 - On cses-nt-0 in the geo5700 folder you will find the data for the BRDF analysis. There are six files, two of each kind of surface. For instance, the file called "grass_30_150.img" is an array of 25 ASD-FR spectra. The first line of data is a spectrum taken at –60 degrees (30 elevation) in the retro-solar direction (backscatter direction). The last spectrum, grass_30_150.img (*, 25) in IDL parlance, is 60 degrees from the 0 zenith in the forward scattering direction from the sun. There are 25 measurements, one every 5 degrees from –60 to +60. The other file for grass is called "grass_30_90.img". It is 13 measurements taken from -60 in the plane perpendicular to the principle plane of the sun. It extends only from –60 to 0 degrees. Each surface is identical in its array dimensions and naming scheme.

Attached to this sheet is an example of making the plots in IDL.

Questions:

1. Plot the data acquired for soil, grass and bush at 4 wavelengths: 680, 1050, 1500 and 2200 nm. Using a Cartesian system plot the angles (-60 to +60) on the x-axis and the reflectance value on the y-axis. Create separate plots for the measurements in the principal plane and those measurements perpendicular to the principal plane of the sun. You should have a total of six plots, 2 azimuths (principal plane and perpendicular to the principal plane) for each surface type (3 types). Each plot should have four lines for the four wavelengths.

2. Discuss the overall differences in the BRDF shapes among the surfaces and suggest causes.

3. Discuss the differences among wavelength bands for each of the materials individually.

GEOL-5700, GEOG 6181, EPOB 5460
Remote sensing Field Methods: Atmospheric path length
November 5

Analyze the sun photometer measurements made for the wavelength region 400 – 550 nm in Greenland 69 34.425' N, 49 18' W and plot the data according to the Langley method [ln(V) vs. sec(solar zenith)], whereas sec is the inverse of the cosine.

Estimate the total atmospheric optical depth for the wavelength region 400 – 550 nm.

Derive the solar signal in volts at the top of the atmosphere for this instrument

Review the literature and discuss and propose different wavelength regions, which could be use measure the water vapor concentration, the ozone concentration, the aerosol concentration with a sun photometer.

Discuss the accuracy of sun photometer measurements.

Lit:

Ehsani, A.R., J.A. Reagan, W.H. Erxleben, Design and performance analysis of an automated 10-channle solar radiometer instrument. J. Atm. and Oceanic Technology, 15, 697-707, 1998.

Regan, J., K. Thome, B. Herman, R. Stone, J. DeLuisi, and J. Snider. A comparison of columnar water vapor retrieval obtained with near-IR solar radiometer and microwave radiometer measurements, J. Appl. Meteorology, 34, 1384-1391, 1995.

Reagan, J., L. Thomason, B. Herman, and J. Palmer, Assessment of atmospheric limitations on the determination of the solar spectral constant from ground-based spectroradiometer measurements, IEEE Trans. Geosc. And Rem. Sens., 24(2), 258-266, 1986.

GEOL-5700, GEOG 6181, EPOB 5460
Remote sensing Field Methods: Snow reflectance
November 12, 19

Field measurements

1. Measure the spectral reflectance of different snow types (e.g., zero zenith angle reading of clean snow, icy snow, new snow, dirty snow).

2. Measure the bi-directional spectral reflectance of clean snow for reflectance zenith angles, ranging from 80 to 0 degrees.

Analysis

Discuss the snow reflectance spectra compared to other surface types (e.g., water, sea ice, vegetation, soil and others).

Use this information to analyze the Landsat TM scene from the Beaufort Sea, which has different ice types (with and without snow cover), open water, and clouds. Classify the different clouds based on the spectral difference. Map the different ice types based on their albedo (thinner ice has lower albedo). Provide a map that displays the clouds, and the different ice types, and the open water. Summarize the percentage of the different surface types in that scene in a table. Discuss a method to classify clouds over sea ice by using different TM channels or their ratio.

Literature

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