Appendix I.
AVIRIS Reflectance Retrievals: UCSB Users Manual

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Introduction

The following write-up is designed to help students and researchers take Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) radiance data and retrieve surface reflectance. In the event that the software is not available, but a user has access to a reflectance product, this document is designed to provide a better understanding of how AVIRIS reflectance was retrieved. This guide assumes that the reader has both a basic understanding of the UNIX computing environment, and that of spectroscopy. Knowledge of the Interactive Data Language (IDL) and the Environment for Visualizing Images (ENVI) is helpful. When acknowledging the technique, cite Green et al., 1993 and Roberts et al., 1997. This is a working document, and many of the fine details described in the following pages have been previously undocumented. After having read this document the reader should be able to process AVIRIS to reflectance, provided access to all of the code is possible. The AVIRIS radiance data itself is pre-processed at the Jet Propulsion Laboratory (JPL) in Pasadena, California.

AVIRIS data are comprised of a series of "scenes" (614 x 512 pixel arrays), which make up a flight line called a "run." A group of runs flown during one flight is known as a "take." Quite commonly, the nomenclature of an AVIRIS data granule will be given in the following fashion; YYMMDD Run X Scene Z, where YY represents the last two digits of the year, MM is the month, DD is the day of the data take, and X and Z are integers. In many cases, there will not be a Run 1, and the last scene of any run is usually a fraction of a full scene (x,y) array (e.g., 614 x 262).

Each radiance image is comprised of 224 bands, stored in band-interleaved-by-pixel (BIP) format, and each pixel value is stored as a 16-bit integer. Therefore, a full-scene radiance file is over 140 megabytes.

The first section of this paper describes how to read data from tape and byte-swap the data. This write-up is most pertinent to recent data (1994 or newer) transferred via the UNIX `tar` command. For older data sets (processed by the facility prior to late 1997) data must be read in using the UNIX command `dd`.

Section II describes the procedure in preparing support files before running the "h2o" suite of programs. This is one of the most difficult steps, in particular convolving the appropriate absorption coefficients and dealing with spectral calibration.

Section III describes the four programs used in the process, `h2olut9.f`, `h2ospl9.f`, `vlsfit9.f` and `rfl9.f` (hereafter denoted without their file extensions). If ground spectra are available, `vlsfit9` and `rfl9` are run a second time using ground reflectance to correct for high-frequency errors in reflectance. The general procedure is to:

> 1) Use MODTRAN (Berk et al., 1989; Anderson et al., 1995) to build a series of look-up tables for path radiance and reflected radiance over a range of water vapor conditions for a specific place, time, sensor elevation and visibility. This step is usually performed once for each run using `h2olut9`.
> 2) Spline interpolate the 15 or so models from Step1 into a finer interval of water vapor values. This is done using `h2ospl9`.
> 3) Retrieve water vapor and liquid water on a per pixel basis using the appropriate spline-interpolated tables. This has to be done for each scene, but need be done twice only for the scene containing the calibration target. Once correction factors have been produced, those factors can be applied to the whole flight. The program is `vlsfit9` (`vlsfit9-2` is used for atmospheres with particularly high specific humidity).
> 4) Retrieve surface reflectance with `rfl9`. Measured radiance and modeled path and reflected radiance are used to retrieve surface reflectance on a per-pixel basis.

Section IV covers references, and Section V describes common problems encountered while processing AVIRIS data, along with known remedies. A set of four sample input files applicable to a BOREAS AVIRIS data run is included in Section VI. Finally, the last section provides a table of metadata for the AVIRIS data takes of the Boreal Atmosphere-Ecosystem Study (BOREAS).

Examples shown in this document are derived from, or applied to, AVIRIS data acquired for BOREAS in 1994. In many cases, examples refer to computers specific to UCSB and software that may or may not be distributed. In particular the AVIRIS reflectance retrieval code (`h2olut9`, `h2ospl9`, `vlsfit9` and `rfl9`) are not for general distribution and can only be accessed either from UCSB or by contact with its designer, Robert O. Green. The intent of this document is, in part, to provide a detailed description of how the data are processed so that a user (even if he/she cannot access the code) may understand how the process works and thereby understand the power and limitations of the technique. It is also assumed that the user is likely to have accessed AVIRIS reflectance data either through a data distribution system such as the BOREAS Information System (BORIS) or directly from UCSB. Specific references to computers and directories at UCSB have been replaced with generic terms including:

host: (Login Host Computer)
source: (Source Code directory)
data_directory: (Data directory)

As the document evolves, examples from Washington State, Southern California, the Sierra Nevada and the Midwest - areas where the UCSB Geography Department has active research programs - will be added. Each time AVIRIS from a new geographic region is processed in this manner, environmental differences from one place to the next may force slight, but important modifications in the way the data are treated. During this time, potentially the most important component to understand is in the first step, where the choice of an appropriate visibility and set of initial water vapor runs can have a large impact on the final result. Incidentally, of these areas, processing BOREAS AVIRIS data has proven to be the most challenging.

Section I: Handling the AVIRIS data

The following section describes the process where by AVIRIS data delivered from JPL are downloaded from tape. It assumes that the data are delivered on 8 millimeter tape using `tar`. Although the write up is most pertinent to older, non-georeferenced data, it can be used with slight modification to view georeferenced data as well. The most significant difference is that the browse image will have a different name, and that the sample dimension is not fixed at 614 samples.

a) Downloading From Tape

1) Login to *host*

2) Locate a minimum of 1.5 gigabytes of disk space

3) Load the tape in **hosts** 8 mm tape drive

4) Create your directory (e.g., */data_directory*/boreas/940721r2). Note: it is best to keep the data and flight-line information in the same directory.

5) Download the data: `%tar xvf /dev/8mm`

6) Select the scenes you wish to process and delete the rest. To do this, use IDL and read in the browse image (e.g., `f940721t01p02_r02_s02.c.brz`)

Example:

`%ls -l f940721t01p02_r02_s02.c.brz` ; (Find the file size)
`%IDL` ; Start IDL

```
IDL>openr,1,' f940721t01p02_r02_s02.c.brz'  ; Open the file
IDL>print,(size in bytes)/(4.0*614.0*2.0) ; print the number of lines
IDL>brz=intarr(4,614,nl) ; Note, the data are BIP
IDL>readu,1,brz
IDL>byteorder,brz  ; byte-swap the data to DEC
IDL>window,xs=614,ys=512
IDL>for i=0,nl,512 do begin print,i& tvscl,brz(1,*,i:i+511)& wait,2&
        ; Skim through the Browse Image
```

Or visit the AVIRIS Internet website at JPL to view the "quicklook" JPEG images of selected runs at:

http://makalu.jpl.nasa.gov/html/view.html

The browse image is a 4-band file, containing bands 10 (460 nm), 33 (666 nm), 128 (1.56 µm) and 192 (2.19 µm).

b) Byte-swapping data

1) Byte-swap the AVIRIS images, if necessary. AVIRIS images we request from JPL come in the big-endian/Motorola/most-significant-byte-first format, which is compatible with Sun machines. If the processing procedure is to take place on a Digital Electronics Corporation (DEC) machine, these data will have to be byte-swapped into the little-endian/Intel/least-significant-byte-first format. In UNIX, this can be done with the `dd` command. The user may also have to call upon the `gzip` command if free disk space is at a minimum:

```
%dd if=f940721t01p02_r02_s02.c.img of=940721r2sc2.swp conv=swab
%rm f940721t01p02_r02_s02.c.img
%gzip -9 940721r2sc2.swp
```

This can typically be done with a script file, in which deletion of the `.img` files are performed after the byte-swapped versions are written to disk. Alternatively, if large amounts of disk space are available to the user, it is recommended that the `.img` files are instead compressed and saved to disk, and later removing them when the user is absolutely certain that the end products are satisfactory.

Section II. Assembling the input files

The following section describes the steps necessary to develop ancillary files needed for reflectance retrieval. As previously noted, this write-up is most pertinent to data from 1994 to 1998. Newer JPL products have a slightly different format and thus must be treated differently.

A) Preparing the spectral calibration file

1) Locate the spectral calibration file (e.g., `f940721t01p02_r02_s02.c.spc`)

2) Revise the spectral calibration file to save only the first three columns. In IDL:
```
IDL>openr,1,'f940721t01p02_r02_s02.c.spc'
IDL>spc=fltarr(5,224)
IDL>readf,1,spc
IDL>openw,2,'940721.spc'
IDL>for i=0,223 do begin printf,2,i,spc(0,i),spc(1,i)
IDL>close,2
IDL>close,1
```

B) Generating the water and ice absorption files

1) Convolve the water and ice absorption coefficients to AVIRIS

    a) transfer the spectral calibration file to */source*
    (alternatively, transfer avrgss and wtrandice.txt to your directory)

    b) run avrgss
ENTER THE INPUT DATA FILE (FIRST COLUMN WVL):wtrandice.txt
ENTER THE NUMBER OF COLUMNS IN THE INPUT FILE:3
ENTER THE OUTPUT SPECTRAL FILE (WVL,WDT):940721.spc
ENTER THE OUTPUT DATA FILE:wtrandice-940721.txt

`wtrandice.txt`; file containing most recent absorption coefficients, stored as wavelength, ice, water.
`940721.spc`; spectral calibration file (first two columns from original `.spc` file is safest).
`wtrandice-940721.txt`; output file, wavelength, ice and water.

2) Extract spectra for ice and water absorptions and store in separate files called `wtrabsxx.flt` and `iceabsxx.flt`., where xx = last two digits of year. In IDL, in this case:

```
IDL>openr,1,'wtrandice-940721.txt'
IDL>spc=fltarr(3,224)
IDL>readf,1,spc
IDL>openw,2,'wtrabs94.flt'
IDL>openw,3,'iceabs94.flt'
IDL>for i=0,223 do begin printf,2,spc(0,i),spc(2,i)& printf,3,spc(0,i),spc(1,i)&
IDL>close,2
IDL>close,3
```

3) Copy the `.flt` files to the run directory (/*data_directory*). A useful strategy is to keep all input files (`*.in`) and copies of all support files (`*.flt`, etc.) in one directory that is backed up routinely, thus preserving all metadata.

C) Preparing the inputs for the h2o series files

      1) View the AVIRIS header file and record latitude, longitude, date and time. This information needs to be entered in the input file for `h2olut9`. In UNIX;

```
%more f940721t01p02_r02_s02.c.avhdr
```

*** Enter for every run:

```
site_name       = SSA-Cal -W
location        = Saskatchewan

investigator    = sellers/green

pilot_st_lat    = 53 08 00
pilot_end_lat   = 53 21 00

pilot_st_long   = -105 41 48
pilot_end_long  = -105 41 48

pilot_st_date   = 490721
pilot_end_date  = 940721
pilot_st_time   = 16 29 00
pilot_end_time  = 16 31 00
```

Taking an average of the start and end values of these for the input files is a common and acceptable technique, provided that the run is less than 20 scenes long.

      2) Locate the elevation of the calibration target (or average terrain). An exact value is not necessary; within a tenth of a kilometer is satisfactory.

Section III: Reflectance retrieval

The `h2o` series for reflectance retrieval uses four programs to generate a series of files used to retrieve water vapor, map liquid water and retrieve surface reflectance from AVIRIS. The general source code is located in **/source/robcode96** (for `h2olut9` and `h2ospl9`) and the **/source/robcode96/latest** subdirectory for `vlsfit9` and `rfl9`. When dealing with a very wet atmosphere, it is necessary to run `vlsfit9-2` and `rfl9-2`.

h2olut9

The general procedure uses MODTRAN3.5 to generate look-up tables for radiance reflected from 0% and 25% reflectant targets. The program `h2olut9` calls MODTRAN as a subroutine, and may take up to an hour or less than 10 minutes depending on the processor and number of models run. The input file used to run `h2olut9` tells the program:

1) Which model to run (tropical, mid-latitude summer, winter continental, etc.). See the example input file below for options.

2) Horizontal atmospheric visibility; 30 km is a good starting place. For a winter scene or high elevation scene, 35 to 50 km is good. For a hazy scene 25 km or less is good. It should not be necessary to have to go below 20 km. Visibility sometimes has to be chosen iteratively, after viewing retrieved reflectance. Evidence of scattering in the reflectance spectra (increasing reflectance towards shorter wavelengths) means visibility was too high (~50km). Negative reflectance at shorter wavelengths means it was too low (~25km).

3) Latitude, longitude, date, time and ground elevation (in km). Longitude values west of the Prime Meridian (i.e., negative) should actually be entered as positive in the input file.

4) Spectral calibration. This should be a file consisting of two columns, wavelength center and corresponding full-width half-maximum (FWHM). Preparing the correct file is critical.

5) Water vapor intervals. This is probably the most important component of the program. The program runs two sets of MODTRAN runs (25% and 0% surface reflectance) for each water vapor value in the `.int` file. The numbers correspond to multipliers against a standard atmosphere for that geographic place and time. The corresponding output file (e.g., `h2olut940721r2-2-35.val`), gives the equivalent values in atm-cm. Note, the same `.int` file can produce very different values in atm-cm at different elevations and seasons.

The objective is to populate the look-up table densely where the actual column water vapor varies in the image, but weakly outside the region. This look-up table will be subsequently spline-interpolated over a specified range (in atm-cm) at a specified interval (in atm-cm) in `h2ospl9`. It is important to bracket the high and low values. Most importantly, it is not desirable to generate many values of atm-cm below 1.0. The spline-interpolation routine operates at an integer step no lower than 1 with a minimum of 1. As a result, by supplying several reference points less than 1, it will extrapolate poor values that guarantee poor water vapor retrievals. Below is a successful example for the Saskatchewan site that uses `walutwtr.int` for 940721r2.

Table 1. Example *.int file for Saskatchewan.

Interval	Atm-cm of water	Micrometers (μm) of water
0.001	0.314	2.523
0.020	0.629	5.047
0.050	0.943	7.570
0.150	1.257	10.094
0.300	1.571	12.615
0.400	2.514	20.188
0.500	3.142	25.231
0.650	15.710	126.154
0.800	31.420	252.309
0.900	78.560	630.852
1.000	157.100	1261.543
1.125	314.200	2523.087
1.250	785.600	6308.520
1.375	1571.000	12615.434
1.500	3142.000	25230.868

To convert from atm-cm to μm, use

μm =(10000*atm-cm)/1245.3

Note that in this case, 3142 atm-cm is the upper limit of meaningful data, but higher values still help in the interpolation.

6) Output `.pth` and `.rfl` files. These are floating point arrays consisting of a specified number of wavelengths for each interval value. In this case, MODTRAN was instructed to start at 4000 cm^{-1} and model to 25000 cm^{-1} at 10 cm^{-1} intervals (`4000,25000,10,5`). The resulting output file consists of an array with 15 columns and 2100 rows. A useful step during early processing (when facing problems) is to view the file in IDL:

```
IDL>openr,1,'h2olut940721r2-1-30.rfl'
IDL>rfl=fltarr(15,2100)
IDL>readu,1,rfl
IDL>plot,rfl(0,*) ; this plots the driest atmosphere.
```
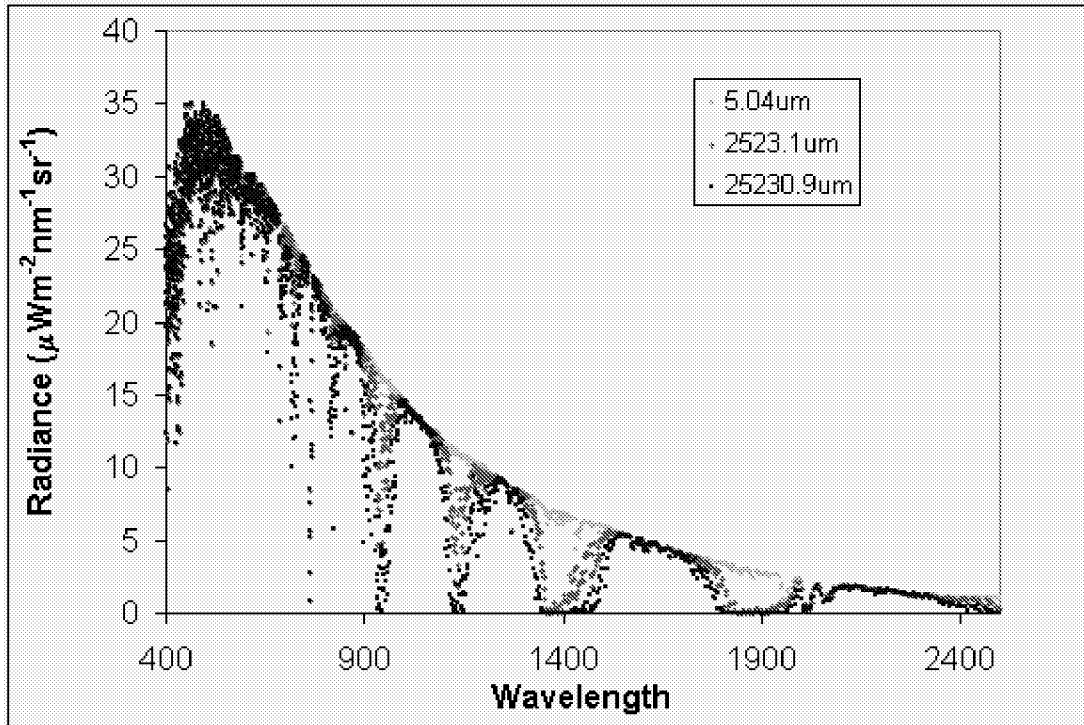
h2ospl9

Once the look-up tables are generated, intermediate values are generated at finer vapor resolution using spline-interpolation. The program that does this is `h2ospl9`, which may take a few minutes to complete. The procedure is generally pretty straightforward. However, there are caveats.

1) Make sure that the applied interpolation range makes sense. For example, it does not make sense to interpolate beyond the original look-up table, nor does it make sense to interpolate atmospheres that do not exist. For very dry atmospheres, interpolation may be as low as a few thousand atm-cm (i.e., `1,1500,3`) or for very wet atmospheres, interpolation of much higher values (i.e., `1,3500,3`). In any event, it is crucial that the input file passed to `vlsfit9` has the same ranges.

2) Shifting the MODTRAN spectrum to account for spectral-miscalibration of the spectrometers may be necessary. This is done on the first lines. It is usually only needed in older data (1993 or older).

Again, as before, it is useful to look at the output `.pth` and `.rfl` files in IDL to make sure they are good. These files consist of 224 bands, for anywhere between 500 and 1500 atmospheres. In IDL, the format is ncolumns = nwater, nrows = number of bands. That is,
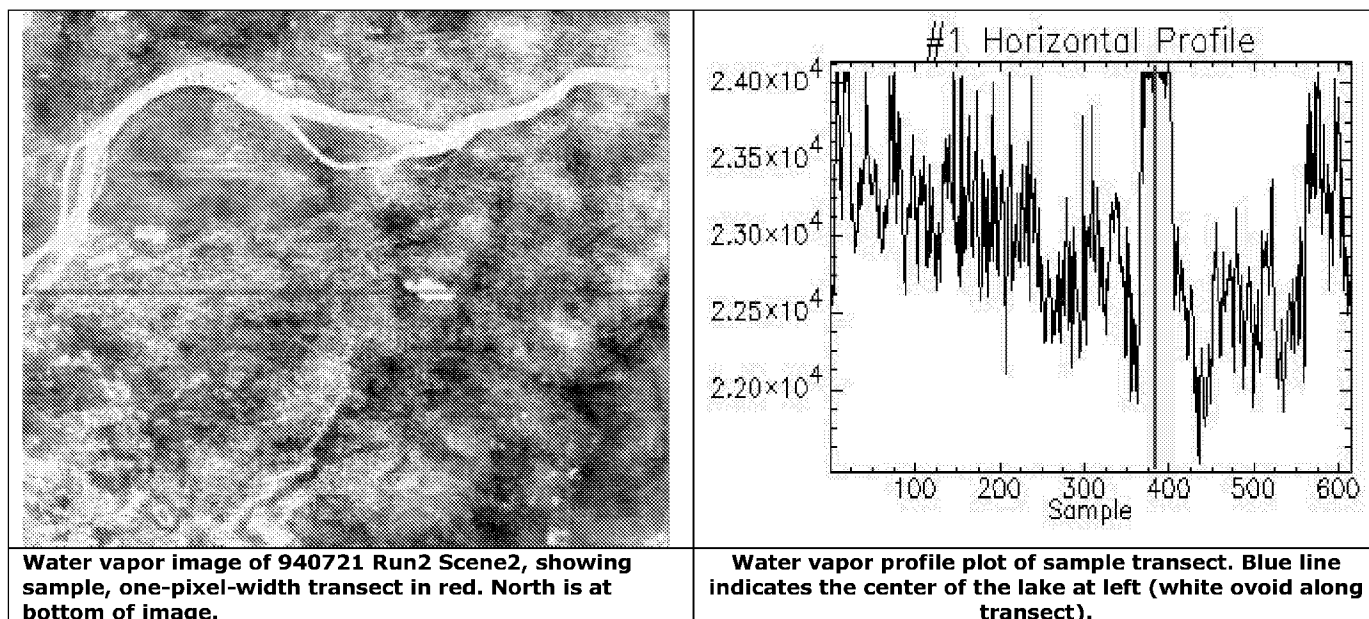
```
IDL>openr,1, 'h2ospl940721r6-5-30.rfl'
IDL>spl=fltarr(1000,224)
IDL>readu,1,spl
IDL>plot,spl(0,*) ; plots the driest atmosphere interpolated to AVIRIS
```
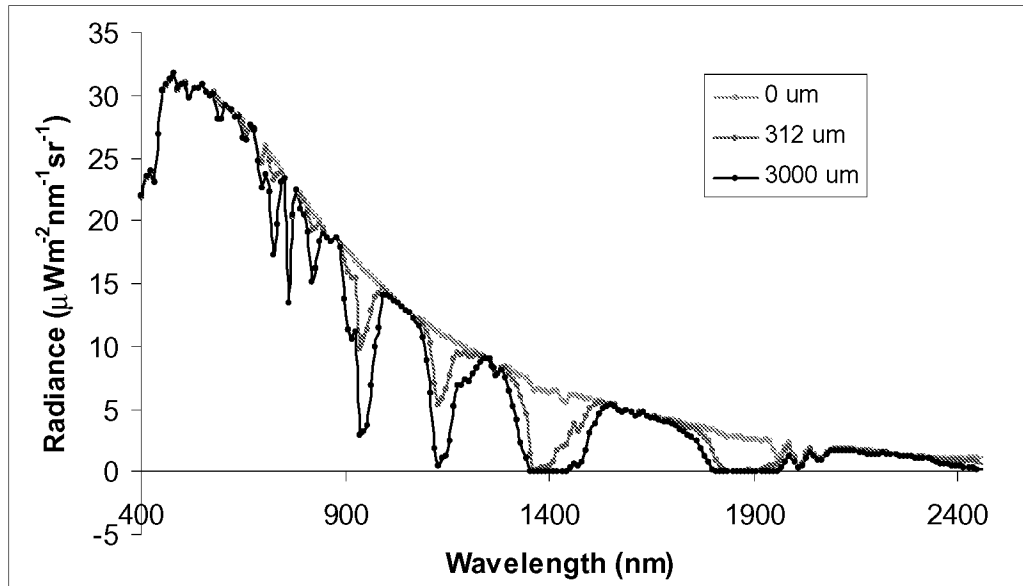
vlsfit9

After the interpolated look-up tables are generated, they are used to retrieve apparent surface reflectance from AVIRIS. With access to ground targets, the `vlsfit9` and `rfl9` programs are generally run twice. The first run is only performed on the scene that has a ground target in it, while the correction files are used for the whole flight line. This program runs for approximately 30 minutes.

The program `vlsfit9` uses a non-linear fitting routine, called the amoeba (Press et al., 1986), to input measured radiance and fit it against modeled radiance (in the look-up tables). Additional modifying parameters include albedo, reflectance slope, liquid water absorption depth and ice absorption on icy terrain. The amoeba is initialized using prior values and simpler vapor estimates such as the CIBR. The output file includes images of albedo, water vapor (in μm; band 2), liquid water (band 3) ice (band 4) amongst other outputs (such as NDVI). Incidentally, the water vapor and liquid water images can be extracted from the 10-band integer output file and saved separately as valuable maps. The output 10-band `.vls` image is used as an input to `rfl9`. In order to use `vlsfit9`, the images must be properly byte-swapped.

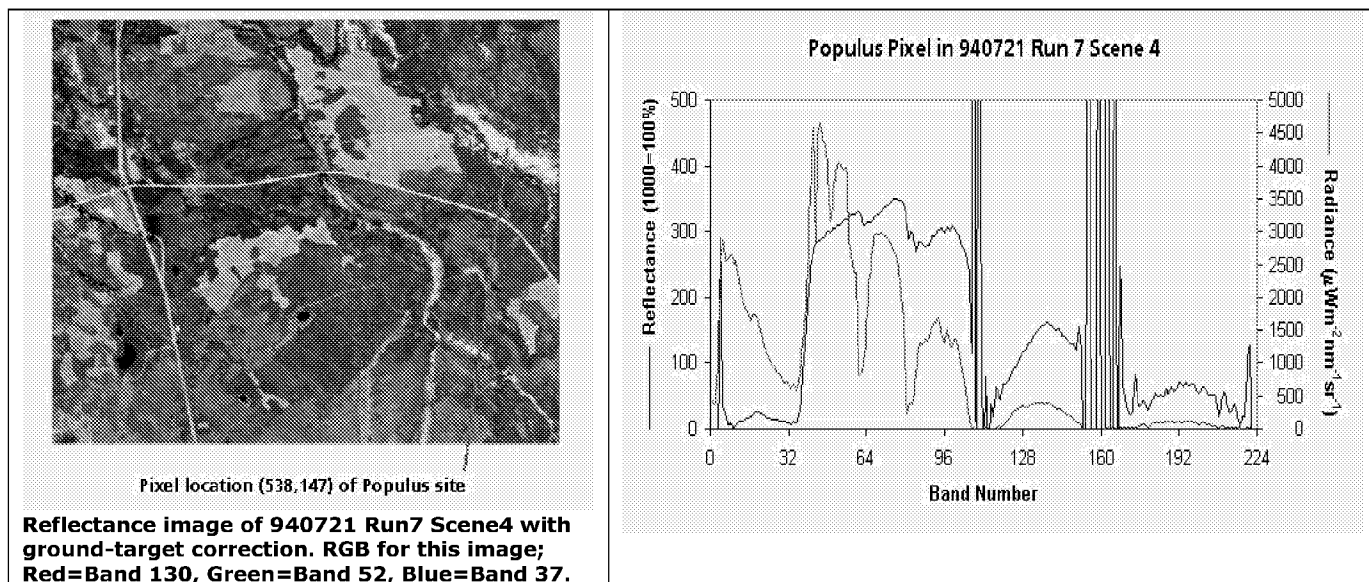| Water vapor image of 940721 Run2 Scene2, showing sample, one-pixel-width transect in red. North is at bottom of image.	Water vapor profile plot of sample transect. Blue line indicates the center of the lake at left (white ovoid along transect).

rfl9

Once look-up tables for reflected radiance and path radiance are generated (`h2osp19`) and water vapor is mapped (`vlsfit9`), these provide all of the information needed to calculate reflectance. The run time for this step takes just a few minutes. Reflectance is calculated as:

refl   =   [(Measured - path)/(modeled -path)]/4

Reflectance images are stored as 1000 = 100% reflectance.

Pixel location (538,147) of Populus site

Reflectance image of 940721 Run7 Scene4 with ground-target correction. RGB for this image; Red=Band 130, Green=Band 52, Blue=Band 37.
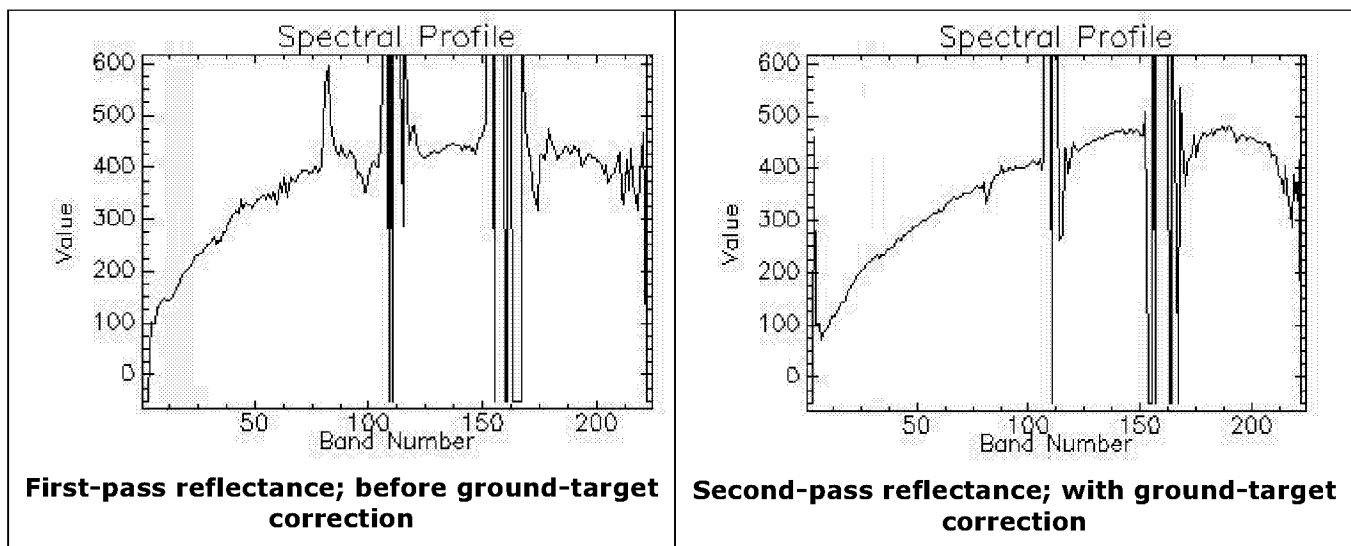
vls9 & rfl9; Second pass.

Typically, AVIRIS reflectance retrievals need slight corrections to remove high-frequency errors in reflectance. These errors originate because of imperfections in MODTRAN, errors in radiometric calibration of AVIRIS and, most importantly, minor wavelength shifts that occur in AVIRIS (even in 1999). The errors effect both reflectance and water vapor/liquid water retrievals. Corrections are applied using a ground reflectance target as described originally by Roger Clark. The general procedures include:

1) Locate ground targets in image data. Extract image reflectance.
2) Measure ground reflectance. This can commonly use historical measurements of airport tarmacs, beaches etc. In the case where no ground targets are available for a specific date, it is commonly possible to use temporally-invariant targets and extract reflectance from prior AVIRIS flights that have high-quality reflectance. We have used this approach in the BOREAS (Saskatchewan, Canada) and WESTGEC (Washington State) campaigns.
3) Convolve ground reflectance to AVIRIS.
4) Adjust ground reflectance if necessary. Our main goal is to remove high-frequency errors, not grossly alter reflectance retrieved from AVIRIS. Provided that the ratio of modeled reflectance to measured reflectance is within 90 to 110% correspondence, the ground target can be used as is. However, commonly the ground target differs by more than this factor, especially at shorter wavelengths. If improper estimates of visibility have been removed as a potential cause of the error, it may be necessary to adjust ground reflectance up or down to preserve shape, but not albedo. This was the approach used in Washington State and BOREAS, where the ground targets had reflectance that was too low in the visible, resulting in over-correction when applied to AVIRIS.
5) Build libraries. These should have the format wavelength (first column), reflectance (second column). Make sure reflectance units match (i.e., if AVIRIS =1000 for 100%, so should the field spectra).
6) Rerun `vlsfit9` and `rfl9`.

vlsfit9-2 and rfl9-2.

On occasion, we encounter very wet atmospheres. These are atmospheres that have more than 25,000 micrometers of column water vapor. In the event that a target scene has these properties, `vlsfit9-2` and `rfl9-2` replace `vlsfit9` and `rfl9` respectively. These two programs can handle atmospheres with up to 32,678 micrometers of water vapor. In the event that an atmosphere containing more than this amount is encountered (i.e., Brazil, Hawaii), a new version of `vls9-2` and `rfl9-2` will need to be written to accommodate this contingency.

| First-pass reflectance; before ground-target correction | Second-pass reflectance; with ground-target correction |

Section IV: References

Anderson, G. P., J. Wang and J. Chetwynd, An Update and Recent Validations Against Airborne High Resolution Interferometer Measurements, Summaries of the Fifth Annual JPL Airborne Earth Science Workshop, JPL 95-1, Vol. 1,AVIRIS Workshop, Jet Propulsion Laboratory, Pasadena, CA., January 23, 1995.

Berk, A., L. S. Bernstein, and D.C. Robertson, (1989), "MODTRAN: A Moderate Resolution Model for LOWTRAN 7," Final report, GL-TR-0122, AFGL, Hanscomb AFB, MA., 42 pp.

Green, R.O., Conel, J.E. and Roberts, D.A., 1993, Estimation of Aerosol Optical Depth, Pressure Elevation, Water Vapor and Calculation of Apparent Surface Reflectance from Radiance Measured by the Airborne Visible-Infrared Imaging Spectrometer (AVIRIS) Using MODTRAN2, *SPIE Conf. 1937, Imaging Spectrometry of the Terrestrial Environment*, 2-5.

Roberts, D.A., Green, R.O., and Adams, J.B., 1997,Temporal and Spatial Patterns in Vegetation and Atmospheric Properties from AVIRIS, *Remote Sens. Environ* 62: 223-240.

Section V: Troubleshooting

There are more ways to run into problems then can be imagined. The process is very complex and involves careful development of all support files and input files. Even under the ideal case when reflectance retrieval has been successful in one geographic area for one season, changes in environmental properties (humidity, water vapor lapse rate, visibility etc.) can lead to poor results. An experienced user is likely to

succeed with few problems about half the time. An inexperienced user rarely succeeds the first time. There are many ways to make a mistake. The following section describes some common ones.

A) All outputs look bad.

1) The program `vlsfit9` crashes early in the run. A view of the radiance data shows that it is highly speckled.
Likely cause: Incorrect byte-order. Byte-swap the image, and start again.

2) The water vapor or liquid water maps seem to be getting confused, with plants showing high values of water vapor. Reflectance looks okay in places.
Likely cause: The spectral calibration is wrong. You may have to reconvolve new ice and liquid water filters. A 1-nanometer shift in spectral calibration will have its greatest impact on liquid water, which can shift by a factor of 2.

B) Liquid water and water vapor seem to saturate. Reflectance shows obvious absorption at all water vapor bands.
Likely cause: Your model is unable to account for enough water vapor in the image. The water vapor look-up table peaks (at say 25,000). The remaining water vapor is allocated to liquid water. Measured radiance has deeper water vapor features than the model, creating troughs. Examples where this occurs is in any tropical forest scene or summer scenes over the mid-western United States. Use `vlsfit9-2` and `rfl9-2`.

C) Reflectance looks good, but water vapor and liquid water look bad. The water vapor is very speckly showing high-frequency jumps by a factor of 4 or even 2.
Likely cause: Look at the `.int` (e.g. `940721.int`) and `.val` (`h2ospl940721r2-2-35.val`) files. If more than 2 lower vapor values are below 1.0, the spline-interpolated table is bad. The `.int` file needs a more reasonable distribution of water vapor. This happens in winter scenes and high-elevation targets. A sample `.int` file range applied to a set of winter scenes from the BOREAS south study area (SSA) is shown in Table 2.

Table 2. Sample interval file for the April 19, 1994 data take over the BOREAS SSA.

Interval

```
0.001
0.005
0.010
0.025
0.050
0.100
0.250
0.500
0.750
1.000
1.250
1.500
1.750
2.000
2.500
```

D) `h2olut9` crashes with "IOT Trap" or similar error message.

Likely cause: Invalid date or time entered in the input file. Date must be entered as DD MM YY. Time must be entered as HH MM SS. If the date and time are correct, try setting the SS to "00." Accidental swapping of DD and MM values will not cause `h2olut9` to crash, but the routine will wrap any inappropriate value (e.g., MM=14 will be calculated as February) and continue. Therefore, keep in mind that this can be a transparent source of error, even if the output products visually appear to make sense with cursory inspection.

E) `Vlsfit9` or `rfl9` crashes. A perusal of the radiance shows whole spectrometers with negative radiance.

Likely cause: Bad radiometric calibration from JPL. Only occurs in 1994 data.

F) Reflectance looks strange. Water vapor and liquid water maps make no sense.

Likely cause: After exhausting options 1 to 3, it is best to compare radiance for your scene to one that worked. If you see major differences that cannot be accounted for by season, location or time, radiometric calibration is the likely culprit. Contact JPL with example radiance spectra in hand.

G) The tape bombs with "tar: offset error." There are two potential problems.

Likely cause: The tape drive at JPL and the tape drive used to extract the data may not be compatible. You may be able to read the tape using the UNIX command `dd`:

```
%dd if=/dev/8mm of=outfile.tar bs=10240
```

Likely cause: The tape itself is bad. Tapes sent by surface mail commonly have this problem. If they cannot be read by `dd`, contact JPL.

Section VI: Example Input Files

h2olut9

Example: h2olut940721-2-2-35.in

; Changeable Parameters

```
qmodtran model (1=Tropical, 2=MidlatSummer, 3=MidlatWinter, 4=SubarcticSummer, 5=SubarcticWinter)
2                                                    ; Model #
type of atmospheric path (1=HorizontalPath, 2=Path between two altitudes, 3=PathToSpace)
2
mode of execution (0=TransmittanceMode, 2=radiance mode, 3=DirectSolarIrradiance)
2
scattering mode (0=NoMultipleScattering, 1=MultipleScattering)
1
problem boundary temperature in kelvin (0=default profile)
0
spectral reflectance file name
25.rfl
discrete ordinate scattering (1=yes), number of streams
0,4
updated solar irradiance (1=yes),cm-1 resolution
1,5
h2o, co2,  o3, n2o,  co, ch4,  o2,  no, so2, no2, nh3,hno3 scaling
0.50,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00
aerosol model (0=None, 1=Rural23km, 2=Rural5km, 4=Maritime23km, 5=Urban5km, 8=AdvFog0.2km, 9=RadFog0.5km)
1
volcanic stratospheric aerosols (0,1=background, 2=background, 8=extreme)
1
visibility (0=default, >0=km)
35                                                   ; Visibility, generally 20 to 50 km
ground altitude in km
0.5                                                  ; Elevation of average ground or target
platform, ground elevation (km), observation angle (180)
20,0.3,180                                           ; Sensor elev, ground elev - change for hi-res
long path = 1 , short path =0
0
day,month,year
21 07 94                                             ; Date - beware y2k, no leap year
latitude
53 13 43                                             ; Latitude, use negative for southern hemisphere
longitude
105 41 58                                            ; Longitude, use negative for east of Greenwich
time
16 30 33                                             ;UTC
observation azimuth
0
start,end,delta,fwhm wave number
4000,25000,10,5                                      ; Generally keep
spctral calibration file
94.spc                                               ; Wavelength, FWHM. Major source of error if incorrect even by 1 nm
water vapor interval in percent
walutwtr.int                                         ; Make require fine tuning, major source of error if in correct
output vapor interval value in atm cm
h2olut940721r2-1-35.val                              ; Equivalent atm-cm. To convert to micrometers *10000/1254.3
output path radiance
h2olut940721r2-1-35.pth                              ; Output path radiance. Floating array Nmodels columns, N intervals rows
output reflected radiance
h2olut940721r2-1-35.rfl                              ; Output rfl radiance. Floating array Nmodels columns, N intervals rows
output transmission
h2olut940721r2-1-35.trn                              ; Output transmittance. Floating array Nmodels columns, N intervals rows
output wavelengths
h2olut940721r2-1-35.wvl
output report f-2ile
h2olut940721r2-1-35.rpt
```

h2ospl9

Example: h2ospl940721-2-1-35.in

```
WAVELENGTH SHIFTS A,B,C,D SPECTROMETERS
0,0,0,0                                    ; Wavelength shift, usually unnecessary for modern data
FWHM CHANGE A,B,C,D SPECTROMETERS
0,0,0,0
WATER VAPOR INTERVALS
h2olut940721r2-1-35.val                    ; From h2olut9
WATER VAPOR SPLINED RANGE
1,3000,3                      ; Spline-interpolation range. 1 is a minimum interval. Maximum should not exceed the table
SPECTRAL CALIBRATION FILE
94.spc
OUTPUT SPECTRAL CALIBRATION FILE
940721r2_o.spc
CHANNELS TO SPLINE OVER
1,224
INPUT WAVELENGTHS
h2olut940721r2-1-35.wvl                    ; From h2olut9
INPUT PATH RADIANCE
h2olut940721r2-1-35.pth                    ; From h2olut9
INPUT REFLECTED RADIANCE
h2olut940721r2-1-35.rfl                    ; From h2olut9
OUTPUT PATH RADIANCE
h2ospl940721r2-1-35.pth                    ; Output spline-interpolated. Format  n-atm,n-band
OUTPUT REFLECTED RADIANCE
h2ospl940721r2-1-35.rfl                    ; Output spline-interpolated. Format  n-atm,n-band
OUTPUT TEST OF OUTPUT VERSUS WATER
h2ospl940721r2-1-35.twtr
OUTPUT TEST OF OUTPUT VERSUS WAVELENGTH
h2ospl940721r2-1-35.twvl
```

vlsfit9

Example: vls940721-2-2-35.in

```
NUMBER OF LINES, SAMPLES, CHANNELS, RADIANCE FACTOR
512,614,224,500,1                          ; Nlines, n-columns,n-bands
INPUT IMAGE
940721/940721r2sc2.swp                     ; byte swapped input AVIRIS radiance image
OUTPUT IMAGE
940721/940721r2-2-35.vls                   ; output vls file. IDL Band 2=watervap, 3=liqwater, 4=ice, 7=NDVI
SPECTRAL CALIBRATION FILE
940721r2_o.spc
DARK SIGNAL FILE
0.drk
RADIOMETRIC CALIBRATION COEFFICIENTS
1.rcc
GAIN FILE
97.gain                                    ; Gain file. Use 94.gain for older, unreprocessed data.
                                           otherwise, use 95.gain and up for newer data (including
                                           reprocessed 1994 data).
INFLIGHT CALIBRATION FILE
940721.avr      ; 1.clb for 1ˢᵗ pass. Substitute with field spectra convolved to AVIRIS on 2nd pass
INFLIGHT CALIBRATION OBC FILE
940721.inf      ; 1.clb for 1ˢᵗ pass. Substitute with first pass AVIRIS reflectance retrieval
OBC FILE 1
```

```
1.clb
OBC FILE 2
1.clb
LIQUID WATER ABSORPTION
wtrabs94.flt
SOLID WATER ABSORPTION
iceabs94.flt
WATER VAPOR RANGE
1,3000,3
WATER VAPOR TO ELEVATION FILE
km.wtr
BAND CONTINUA VAPOR, LIQUID, SOLID CENTERS
868,935,973,1025,1085
PATH RADIANCE LIBRARIES
h2ospl940721r2-1-35.pth
REFLECTED RADIANCE LIBRARIES
h2ospl940721r2-1-35.rfl
STARTING LINE, SAMPLE, ??,1=no ice,??
1,1,1,1,20
FIT TEST
vls940721r2-1-35.fit
NDVI TEST
vls940721r2-1-35.ndvi
```

rfl9

Example: rfl940721-2-2-35.in

```
NUMBER OF LINES, SAMPLES AND CHANNELS
512,614,224,1,1,0
INPUT IMAGE
940721/940721r2sc2.swp
INPUT WATER VAPOR
940721/940721r2-2-35.vls
OUTPUT REFLECTANCE
940721/940721r2-2-35.rfl
LOOK UP TABLE WATERVAPOR RANGE
1,3000,3
LEAVE AT 1
1.0
BAND THAT CONTAINS THE WATER VAPOR MAP
3,10
PATH RADIANCE LOOK UP TABLE
h2ospl940721r2-1-35.pth
REFLECTED RADIANCE L.OOK UP TABLE
h2ospl940721r2-1-35.rfl
INPUT SPECTRAL CALIBRATION
940721r2_o.spc
INFLIGHT CALIBRATION MODTRAN
940721.avr      ; 1.clb for 1st pass. Substitute with field spectra convolved to AVIRIS on 2nd pass
INFLIGHT CALIBRATION AVIRIS
940721.inf      ; 1.clb for 1st pass. Substitute with first pass AVIRIS reflectance retrieval
OBC  MASTER CALIBRATION
1.clb
OBC LOCAL CALIBRATION
1.clb
RADIANCE GAIN FACTOR FILE
97.gain
REFLECTANCE MULTIPLIER
1000.0
OUTPUT TEST A
rfl940721r2-1-35.rfla
OUTPUT TEST B
rfl940721r2-1-35.rflb
OUTPUT TEST C
rfl940721r2-1-35.rflc
```

Section VII. Metadata for BOREAS

Flight#	Run TotalRun	#Lines	Site_Name	Study Area	Avg_Lat Entered	Avg_Long Entered	AvgTime Entered	Elevation (m)	Visibility (km)	NumLines LastScene	#Scenes in run	Scenes Completed	Spectra File of GBT	Comments
940419B	2	1954	SSA-cal-W	S	53:14:03	105:41:58	18:02:55	500	50	432	3	ALL	940419.avr	
940419B	3	5769	SSA-West-B	S	53:53:16	106:15:54	18:14:20	500	50	151	11	ALL	940419.avr	
940419B	4	3334	SSA-West-Thaw	S	53:48:59	106:09:39	18:24:10	500	50	276	6	ALL	940419.avr	Eq to THAW-Z
940419B	5	5761	SSA-West-C	S	53:53:26	106:06:50	18:35:53	500	50	143	11	ALL	940419.avr	R4 param used
940419B	6	3258	SSA-East-Thaw	S	53:56:14	104:57:48	18:48:18	500	50	200	6	ALL	940419.avr	Eq to THAW-Y
940419B	7	4245	SSA-East-J	S	53:54:16	104:40:59	19:01:51	500	50	163	8	ALL	940419.avr	
940419B	8	4447	SSA-East-H	S	53:53:46	104:58:07	19:12:53	500	50	365	8	ALL	940419.avr	
940419B	9	4266	SSA-East-F	S	53:54:16	105:15:26	19:23:30	500	50	184	8	1,2,3	940419.avr	
940419B	10	4381	SSA-East-K	S	53:53:46	104:32:25	19:36:00	500	50	299	8	ALL	940419.avr	
940419B	11	4290	SSA-EAST-I	S	53:54:16	104:49:33	19:46:47	500	50	208	8	2,3,4	940419.avr	
940419B	12	4382	SSA-EAST-G	S	53:53:46	105:06:42	19:57:14	500	50	300	8	ALL	940419.avr	R11 paramUsed
940419B	13	4331	SSA-East-E	S	53:54:16	105:24:10	20:10:18	500	50	249	8	ALL	940419.avr	
940419B	14	5679	SSA-West-D	S	53:53:26	105:57:47	20:25:08	500	50	61	11	1,2,3,4	940419.avr	
940420B	3	8294	Transect-T	N	55:27:02	100:57:51	17:57:57	300	50	116	16	ALL	940419.avr	
940420B	4	8960	Transect-U	N	55:54:43	99:02:40	18:16:52	300	50	270	17		940419.avr	
940420B	5	2342	NSA-Q	N	55:53:54	98:07:27	18:31:59	300	50	308	4		940419.avr	
940420B	6	2550	NSA-O	N	55:53:25	98:25:25	18:39:53	300	50	516	4		940419.avr	
940420B	7	2315	NSA-M	N	55:53:44	98:44:12	18:48:00	300	50	281	4		940419.avr	No QL at JPL
940420B	8	2556	NSA-L	N	55:53:25	98:52:56	18:56:48	300	50	522	4		940419.avr	No QL at JPL
940420B	9	2360	NSA-N	N	55:54:04	98:35:08	19:04:44	300	50	326	4		940419.avr	No QL at JPL
940420B	10	2537	NSA-P	N	55:53:25	98:16:21	19:12:57	300	50	503	4		940419.avr	No QL at JPL
940420B	11	2415	NSA-R	N	55:54:03	97:58:14	19:20:57	300	50	381	4		940419.avr	
940420B	12	3514	NSA-thaw-X	N	55:53:14	98:29:43	19:31:20	300	50	456	6		940419.avr	
940420B	13	13829	Transect S	T		103:19:05	19:58:45	400	50	19	27		940419.avr	
940428B	2	3567	NSA-Thaw	N	55:53:14	98:31:01	17:02:27	300	50	509	6	ALL	940419.avr	
940428B	3	1597	NSA-Q	N	55:52:25	98:07:17	17:13:07	300	50	75	3		940419.avr	
940428B	4	1923	NSA-O	N	55:53:35	98:25:35	17:20:23	300	50	401	3		940419.avr	
940428B	5	1777	NSA-M	N	55:53:54	98:44:02	17:27:25	300	50	255	3		940419.avr	
940428B	6	1869	NSA-L	N	55:53:44	98:53:06	17:34:40	300	50	347	3		940419.avr	
940428B	7	1861	NSA-N	N	55:53:54	98:34:49	17:41:46	300	50	339	3		940419.avr	
940428B	8	1876	NSA-P	N	55:53:35	98:16:31	17:49:02	300	50	354	3		940419.avr	
940428B	9	1789	NSA-R	N	55:53:54	97:58:14	17:56:28	300	50	267	3		940419.avr	
940428B	10	1804	NSA -Q	N	55:53:35	98:07:08	18:04:11	300	50	414	3		940419.avr	
940428B	11	9125	Transect-U	N	55:54:53	99:02:20	18:18:54	300	50	435	17		940419.avr	Clouds/Smoke
940428B	12	8112	Transect-T	N	55:27:22	100:57:31	18:37:15	300	50	446	15		940419.avr	Clouds sc4,5
940428B	13	5764	Transect-S	N	54:49:58	102:18:36	18:53:24	300	50	146	11		940419.avr	
940608B	2	4241	NSA-Thaw-X	N	55:53:14	98:34:19	16:01:40	300	35	159	8		940721.avr	
940608B	3	2842	NSA-R	N	55:55:53	97:57:44	16:13:55	300	35	296	5		940721.avr	
940608B	4	1872	NSA-P	N	55:54:03	98:16:31	16:21:03	300	35	350	3		940721.avr	
940608B	5	2101	NSA-N	N	55:52:45	98:34:49	16:28:26	300	35	67	4		940721.avr	
940608B	6	1867	NSA-L	N	55:54:23	98:53:16	16:36:08	300	35	345	3		940721.avr	
940608B	7	2076	NSA-M	N	55:53:04	98:44:02	16:44:55	300	35	42	4		940721.avr	
940608B	8	1890	NSA-O	N	55:54:23	98:25:55	16:52:17	300	35	368	3		940721.avr	
940608B	10	10479	Boreas	N	55:54:53	99:14:51	17:16:36	300	35	253	20		940721.avr	
940608B	11	7267	Boreas	N	55:23:25	101:03:57	17:35:22	300	35	113	14		940721.avr	Clouds/Smoke
940721B	2	1995	SSA-Cal-W	S	53:13:43	105:41:58	16:30:33	500	35	473	3	ALL	940721.avr	No QL at JPL
940721B	3	3757	SSA-Thaw-Y	S	53:55:25	104:53:21	16:56:39	500	35	187	7	ALL	940721.avr	
940721B	4	4485	SSA-East-G	S	53:50:48	105:06:42	17:08:41	500	35	403	8	ALL	940721.avr	
940721B	5	4138	SSA-East-I	S	53:53:07	104:49:33	17:18:14	500	35	56	8		940721.avr	Clouds
940721B	6	3741	SSA-East-K	S	53:54:55	104:32:25	17:28:14	500	35	171	7		940721.avr	Clouds
940721B	7	4040	SSA-East-J	S	53:53:36	104:40:59	17:38:22	500	35	470	7	ALL	940721.avr	Clouds
940721B	8	3630	SSA-East-H	S	53:53:46	104:58:07	17:48:54	500	35	60	7	ALL	940721.avr	Clouds
940721B	9	4171	SSA-East-F	S	53:52:57	105:15:16	17:58:57	500	35	89	8	ALL	940721.avr	
940721B	10	3514	SSA-Thaw-Z	S	53:49:39	106:09:29	18:10:13	500	35	456	6		940721.avr	
940721B	11	5207	SSA-West-B	S	53:55:35	106:15:54	18:32:24	500	35	101	10	ALL	940721.avr	Clouds in sc9?
940721B	12	5495	SSA-West-D	S	53:53:56	105:57:17	18:44:27	500	35	389	10		940721.avr	
940721B	13	5511	SSA-West-C	S	54:05:38	106:07:00	18:58:54	500	35	405	10		940721.avr	No QL at JPL
940804B	2	3905	NSA-Thaw-x	N	51:55:46	109:22:07	17:41:06	300	35	335	7	ALL	940721.avr	
940804B	3	2139	NSA - R	N	55:52:25	97:57:54	15:40:48	300	35	105	4		940721.avr	
940804B	4	1978	NSA - P	N	55:54:43	98:16:21	15:48:39	300	35	456	3	ALL	940721.avr	
940804B	5	2065	NSA - N	N	55:52:55	98:34:49	15:56:02	300	35	31	4	ALL	940721.avr	
940804B	6	1875	NSA - L	N	55:54:03	98:53:16	16:03:24	300	35	353	3		940721.avr	

940804B	7	1904	NSA - M	N	55:53:35	98:44:02	16:10:47	300	35	382	3	ALL	940721.avr	
940804B	8	1835	NSA - O	N	55:54:23	98:25:45	16:17:49	300	35	313	3	ALL	940721.avr	
940804B	10	9352	Transect U	N	55:54:53	98:59:52	16:40:04	300	35	150	18	1,2,3,4,5	940721.avr	Clouds/Smoke
940804B	11	8296	Transect T	N	55:34:37	100:46:29	16:58:06	300	35	118	16		940721.avr	Clouds/Smoke
940808B	1	3889	NSA-Thaw-X	N	55:53:14	98:33:00	15:25:58	300	35	319	7		940721.avr	Clouds/Smoke
940808B	2	2262	NSA_R	N	55:52:05	97:58:04	15:37:33	300	35	228	4		940721.avr	Clouds/Smoke
940808B	3	2180	NSA-P	N	55:55:22	98:16:11	15:45:22	300	35	146	4		940721.avr	Clouds/Smoke
940808B	4	2292	NSA-N	N	55:52:15	98:34:49	15:53:45	300	35	258	4		940721.avr	Clouds/Smoke
940808B	5	2175	NSA-L	N	55:54:54	98:53:26	16:02:34	300	35	141	4		940721.avr	Clouds/Smoke
940808B	6	2120	NSA-M	N	55:52:45	98:44:02	16:12:59	300	35	86	4		940721.avr	Clouds/Smoke
940808B	7	1973	NSA-O	N	55:53:14	98:25:45	16:21:26	300	35	451	3		940721.avr	Clouds/Smoke
940808B	8	2105	NSA-Q	N	55:52:25	98:07:17	16:29:45	300	35	71	4		940721.avr	Clouds/Smoke
940808B	9	8967	Transect U	N	55:55:03	98:42:04	16:43:35	300	35	277	17		940721.avr	Clouds/Smoke
940808B	10	8290	Transect-T	N	55:27:52	100:57:02	17:04:20	300	35	112	16		940721.avr	Clouds/Smoke
940916B	2	1760	SSA-Cal-W	S	53:14:52	105:41:48	16:40:07	500	35	238	3	ALL	940916.avr	
940916B	3	3953	SSA-East-K	S	53:54:45	104:34:53	16:49:43	500	35	383	7		940916.avr	
940916B	4	4061	SSA-East-I	S	53:54:55	104:49:33	17:04:50	500	35	491	7	ALL	940916.avr	
940916B	5	3883	SSA-East-G	S	53:53:56	105:06:42	17:17:11	500	35	313	7	ALL	940916.avr	
940916B	6	3726	SSA-East-F	S	53:53:36	105:15:36	17:30:53	500	35	156	7	ALL	940916.avr	
940916B	7	3875	SSA-East-H	S	53:54:25	104:57:58	17:43:33	500	35	305	7		940916.avr	
940916B	8	4003	SSA-East-J	S	53:54:55	104:40:59	17:55:51	500	35	433	7	ALL	940916.avr	
940916B	9	3391	SSA-East-Thaw-Y	S	53:56:14	104:57:37	18:07:50	500	35	333	6	ALL	940916.avr	
940916B	10	5165	SSA-West-D	S	53:54:25	105:58:07	18:22:09	500	35	59	10		940916.avr	
940916B	11	5088	SSA-West-B	S	53:54:45	106:15:45	18:35:56	500	35	494	9	ALL	940916.avr	
940916B	12	5077	SSA-West-C	S	53:54:26	106:07:00	18:51:32	500	35	483	9	ALL	940916.avr	
940917B	3	8423	Transect-T	N	55:26:43	100:58:20	15:59:46	300	35	245	16		940916.avr	
940917B	4	1615	NSA - L	N	55:53:05	98:53:16	16:15:13	300	35	93	3		940916.avr	
940917B	5	2237	NSA - N	N	55:51:55	98:34:39	16:22:21	300	35	203	4		940916.avr	
940917B	6	1877	NSA - P	N	55:54:34	98:16:31	16:29:38	300	35	355	3		940916.avr	
940917B	7	2091	NSA - R	N	55:52:35	97:57:44	16:36:47	300	35	57	4		940916.avr	
940917B	8	2105	NSA - M	N	55:55:23	98:44:12	16:55:31	300	35	71	4		940916.avr	
940917B	9	2061	NSA - O	N	55:52:35	98:25:35	17:02:49	300	35	27	4		940916.avr	
940917B	10	2098	NSA - Q	N	55:55:23	98:07:27	17:10:19	300	35	64	4		940916.avr	
940917B	11	9914	NSA-Thaw-X/Tran	N	55:53:14	99:00:11	17:27:42	300	35	200	19		940916.avr	
940917B	12	30000	Transect S	T	54:22:46	103:56:19	17:59:26	400	35	318	58?		940916.avr	
960307C	3	6376	Prince Albert	S	53:51:54	106:16:56	19:13:41	500		246	12			
960307C	4	5463	Prince Albert	S	53:55:05	105:57:47	19:26:28	500		357	10			
960307C	5	6478	Prince Albert	S	53:51:38	106:06:35	19:40:30	500		348	12			
960307C	6	4260	Prince Albert	S	53:55:22	105:06:40	19:54:18	500		178	8			
960307C	7	5143	Prince Albert	S	53:51:48	104:57:47	20:06:59	500		37	10			
960307C	8	4703	Prince Albert	S	53:50:09	104:49:22	20:19:30	500		109	9			
960307C	9	5225	Prince Albert	S	53:51:42	104:32:13	20:29:04	500		119	10			
960307C	10	5148	Prince Albert	S	53:52:31	104:40:55	20:41:24	500		42	10			
960814B	1	5945	Prince Albert West	S	53:52:25	106:24:36	16:28:23	500		327	11	Missing		
Missing	2	5565	Prince Albert West	S	53:54:44	106:06:52	16:40:46	500		459	10	Missing		
960814B	3	5830	Prince Albert West	S	53:53:29	106:15:37	16:53:03	500		212	11	Missing		
960814B	4	5593	Prince Albert West	S	53:54:33	105:57:48	17:05:14	500		487	10	Missing		
960814B	5	4566	Prince Albert East	S	53:55:42	105:23:52	17:25:13	500		484	8	Missing		
960814B	6	4428	Prince Albert East	S	53:53:28	105:06:32	17:36:37	500		346	8			
960814B	7	4486	Prince Albert East	S	53:59:05	105:15:13	17:45:13	500		404	8			
960814B	8	4535	Prince Albert East	S	53:48:39	104:57:55	17:55:26	500		453	8			
960814B	9	4476	Prince Albert East	S	53:55:13	104:40:53	18:06:15	500		394	8			
960814B	10	4512	Prince Albert East	S	53:49:09	104:49:11	18:16:36	500		430	8			