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AN EXPERT SYSTEM SHELL FOR INFERRING VEGETATION CHARACTERISTICS - IMPLEMENTATION OF ADDITIONAL TECHNIQUES (TASK E)

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Prepared for:

National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, MD 20771

Prepared by:

JJM Systems, Inc.
One Ivybrook Boulevard, Suite 190
Ivyland, PA 18974

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LIST OF ACRONYMS

KEE	Knowledge Engineering Environment
VEG	VEGetation Workbench

SECTION 1.0

INTRODUCTION

The NASA VEGetation Workbench (VEG) infers vegetation characteristics from reflectance data. For a detailed description of VEG, see references 1 and 2. A number of subgoals are available in VEG. In the previous version of VEG, the subgoals DESCRIPTION.OF. SYSTEM, SPECTRAL.HEMISPHERICAL.REFLECTANCE, TOTAL.AND.SPECTRAL. HEMISPHERICAL.REFLECTANCE, and VIEW.ANGLE.EXTENSION were fully implemented. The subgoal LEARN.CLASS.DESCRIPTIONS was implemented in tasks C and D of the current contract. The basic framework for the subgoal PROPORTION.GROUND.COVER was developed as part of the previous version of VEG but no techniques were available. Several techniques to estimate the proportion ground cover were included in VEG. These were all dummy functions that returned the value one irrespective of the values of the arguments to the functions.

Three techniques that infer the proportion ground cover of a sample using data at a single wavelength have been fully implemented in VEG. In addition, the framework for the VEG subgoal PROPORTION.GROUND.COVER has been extended so that techniques can be applied to the data for a sample at multiple wavelengths. Two such techniques have also been implemented.

VEG can be operated in two different modes. In the "Research Mode," the scientist must separately execute each step in the processing of unknown cover type data. This mode allows the scientist to study the intermediate results in detail. VEG can also be operated in the "Automatic Mode." In this mode, the scientist selects the operations to be carried out. The cover type data is read from a file, processed and the results are written to another file without any further intervention from the user. The subgoal PROPORTION.GROUND.COVER was originally implemented in the VEG "Research Mode." This subgoal has now been implemented in the VEG "Automatic Mode."

Task E has been completed. Additional techniques to infer proportion ground cover have been implemented. The VEG subgoal PROPORTION.GROUND.COVER including the additional techniques is described in detail in this report. The code for the Lisp methods involved is included in Appendix A. A Sun cartridge tape containing these Lisp methods and the current version of VEG including the completed subgoal PROPORTION.GROUND.COVER has been delivered to the NASA GSFC technical representative.

SECTION 2.0

DESCRIPTION OF THE SUBGOAL PROPORTION.GROUND.COVER IN THE VEG "RESEARCH MODE"

The VEG subgoal that estimates the proportion ground cover is selected by left clicking on PROPORTION.GROUND.COVER in the VEG "Research Mode" top level menu. When this option is selected, the menu shown in Figure 2-1 is displayed. This menu enables the user to invoke the steps involved in processing unknown cover type data to estimate the proportion ground cover and estimate the error in the calculation. Before each step is carried out, a check is made to make sure that the necessary prerequisite steps have been carried out. For example, the results cannot be output before the techniques have been executed. If any prerequisite steps have not been carried out, a message is displayed and the user is prompted to complete the necessary prerequisite steps.

New rules and new methods for the techniques that estimate the proportion ground cover have been developed. However, many of the methods and screens that were originally developed for the VEG subgoal SPECTRAL.HEMISPHERICAL.REFLECTANCE, have been re-used for the subgoal PROPORTION.GROUND.COVER. The steps involved in estimating the proportion ground cover in the VEG "Research Mode" are briefly described in this section.

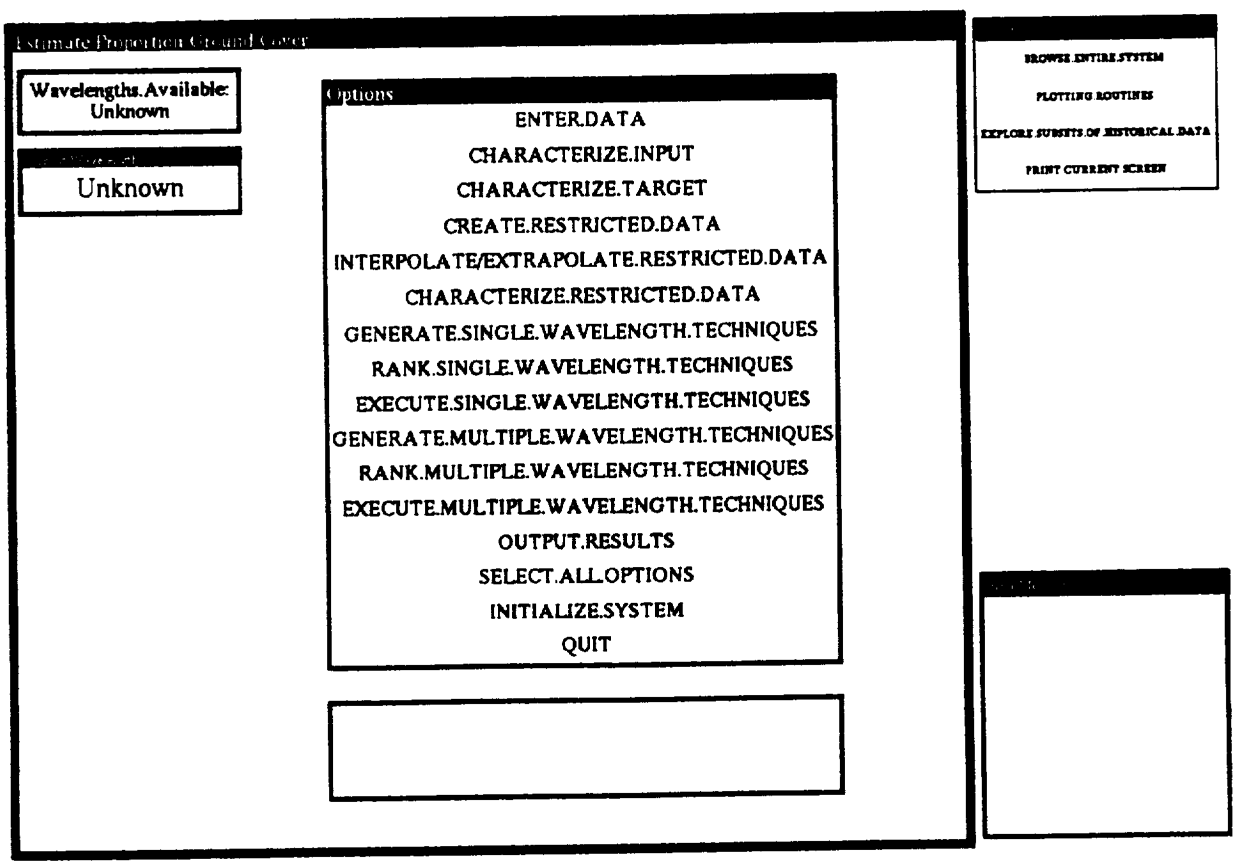

Figure 2-1

Menu for the VEG Subgoal PROPORTION.GROUND.COVER

2.1 ENTER DATA

The code and interface that were originally developed for the step ENTER.DATA for the VEG subgoal SPECTRAL.HEMISPHERICAL.REFLECTANCE have been modified for re-use in this step. When the user selects the step ENTER.DATA, an interface opens. This interface allows the user to either enter a new original set of data for an unknown cover type or select one of a number of samples of unknown cover type data already stored in VEG. If the user chooses to enter original data, another interface opens as shown in Figure 2-2. This interface allows the user to enter data for the new sample. Each value is checked as soon as it has been entered to make sure that it is of the correct type and is in the valid range for the data item it represents. The user can left click on the menu button "SAVE.DATA," at the bottom of the screen in Figure 2-2 to store the data. Before a set of cover type data is stored, the system checks that at least the solar zenith angle, wavelength and reflectance data have been entered. If any of these items is missing, the user is prompted to supply the missing items before storing the data. If the user elects to use one of the sets of sample cover type data already stored in VEG, a different screen is opened. This screen displays the name and a brief description of each available sample. The user can left click on the name of the sample to select it. Each set of unknown cover type data whether entered by the user or selected from the samples already in VEG can contain reflectance data at one or more wavelengths.

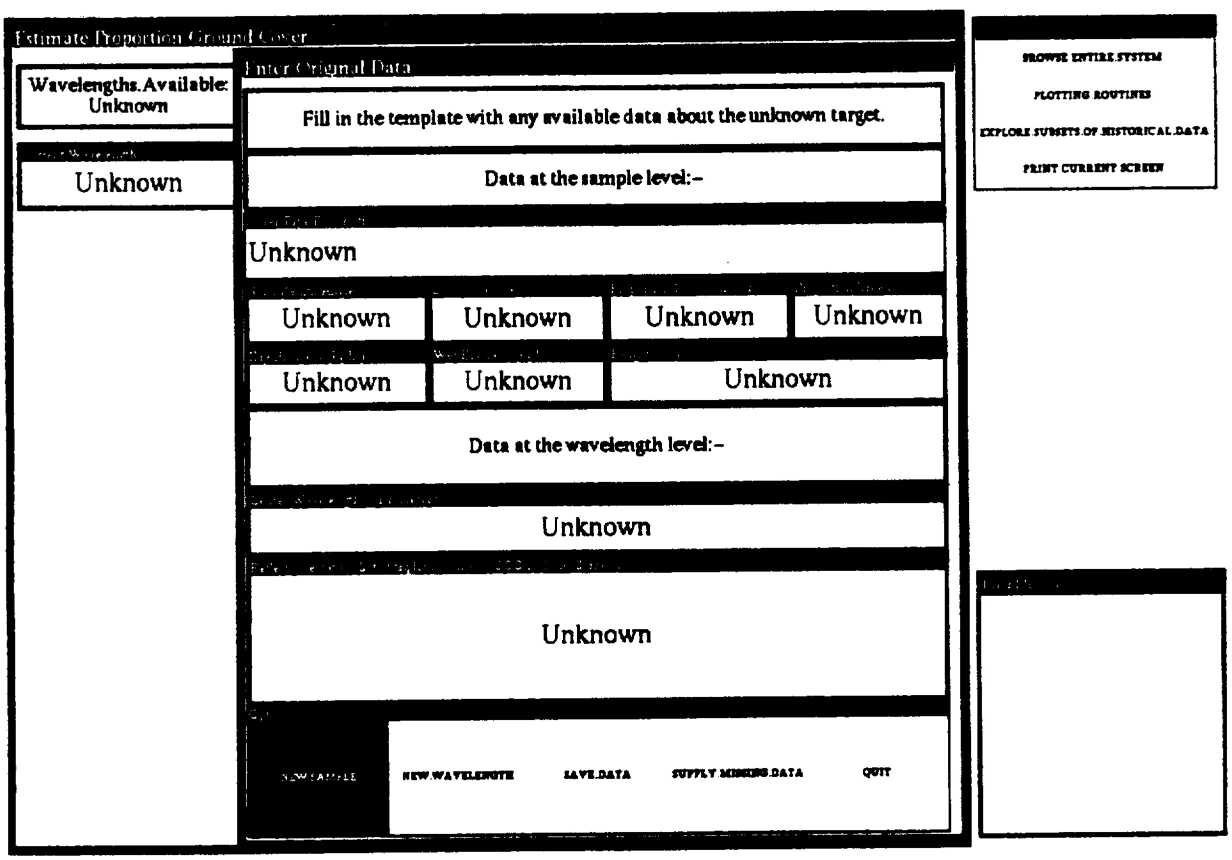

Figure 2-2

The Screen for Entering Original Cover Type Data

2.2 CHARACTERIZE INPUT

The unknown cover type data at each wavelength is characterized using code that was developed for the VEG subgoal SPECTRAL.HEMISPHERICAL.REFLECTANCE. Sets of view angles in the same azimuthal plane are identified as "strings." Strings are characterized as full-strings if they contain both forwardscatter and backscatter data and half-strings if they contain either backscatter or forwardscatter data.

2.3 CHARACTERIZE TARGET

If the sample data does not contain a value for ground cover or leaf area index, a crude estimation of these values is made. The code developed for the VEG subgoal SPECTRAL.HEMISPHERICAL.REFLECTANCE is re-used for this purpose.

2.4 CREATE RESTRICTED DATA

VEG contains a data base of historical cover type data. This data base is organized as a hierarchy of units that are subclasses and members of the unit HISTORICAL.COVER.TYPES. These units contain the results of previous experiments including values for the spectral hemispherical reflectance and the proportion ground cover. They are used in VEG to generate the coefficients needed in many of the technique methods. In several of the VEG subgoals, an estimate of the error term involved in applying a technique to the unknown cover type data is calculated. This is accomplished by applying the same technique to samples in the data base of historical cover types and measuring the error involved in each calculation. The error terms obtained by applying the technique to a number of historical data base samples are collected together and the root mean square value of the error terms is calculated. This value gives a measure of the error involved in applying the technique to the unknown cover type data.

In the step "CREATE.RESTRICTED.DATA," the data base of historical cover types is searched to find the sets of historical data that match the unknown cover type. This set of cover types is referred to as the "restricted data set." The selection of the restricted data set can either be made automatically by the system, or it can be made by the user. In the VEG subgoal SPECTRAL.HEMISPHERICAL.REFLECTANCE, the reflectance data at each wavelength is considered separately when searching the data base of historical cover types. However, some of the techniques for estimating proportion ground cover are multiple wavelength techniques. These techniques involve performing calculations on data in the red and near-infrared bands and then combining the results together to calculate the result. These techniques require a sample to have data in both bands. If these techniques are to be applied to historical cover type data, the data selected from the data base must also have data at multiple wavelengths. Thus the restricted data set is selected by considering the data at all the wavelengths together. The code originally developed for the VEG subgoal TOTAL.HEMISPHERICAL.REFLECTANCE is re-used for this purpose.

If the user elects to have the restricted data set selected automatically by the system, the data base of historical cover types is searched to find the cover types that best match the unknown cover type sample. The subset of historical cover types that have data that match all the wavelengths of the unknown cover type sample is first identified. From this subset, the cover types whose ground cover and solar zenith angle are within ten percent of the values for the unknown sample are then identified and pushed onto a list. If the list contains insufficient values, the search is then widened to include cover types whose sun angles and proportion ground cover are within 20 percent of the values for unknown cover type sample. The search criteria are progressively widened until either sufficient cover types have been identified or all cover types whose sun angle and proportion ground cover are within 100 percent of the values in the unknown cover type sample have been collected. In the search for the best matching cover types, the value for the proportion ground cover calculated in the step CHARACTERIZE.TARGET is used as the proportion ground cover of the unknown cover type sample.

The user can also manually select the restricted data set. In this case, the screen shown in Figure 2-3 is opened. This screen allows the user to enter the maximum and minimum values to be considered for parameters such as height and solar zenith angle. When the user left clicks on "MATCH.DATA," the data base of historical cover types is searched to find the cover types that match the criteria entered by the user and that also contain data at all the wavelengths present in the unknown cover type sample. The user can then select the matched cover types, enter new maximum and minimum values and match the data again or select a subset of the matched data using the screen shown in Figure 2-4.

When the search for the restricted data set has been completed, either manually or automatically, the cover type names are stored. The names of the historical cover types at the sun angle level (e.g. CT11-58) are stored in the slot R.D.S of the unknown cover type unit (e.g. the unit SAMPLE6). The names of the corresponding cover type units at the wavelength level such as CT11-58-1 and CT11-58-2 are stored in the slot R.D.S of the unknown cover types units at the wavelength level, for example W11 and W12.

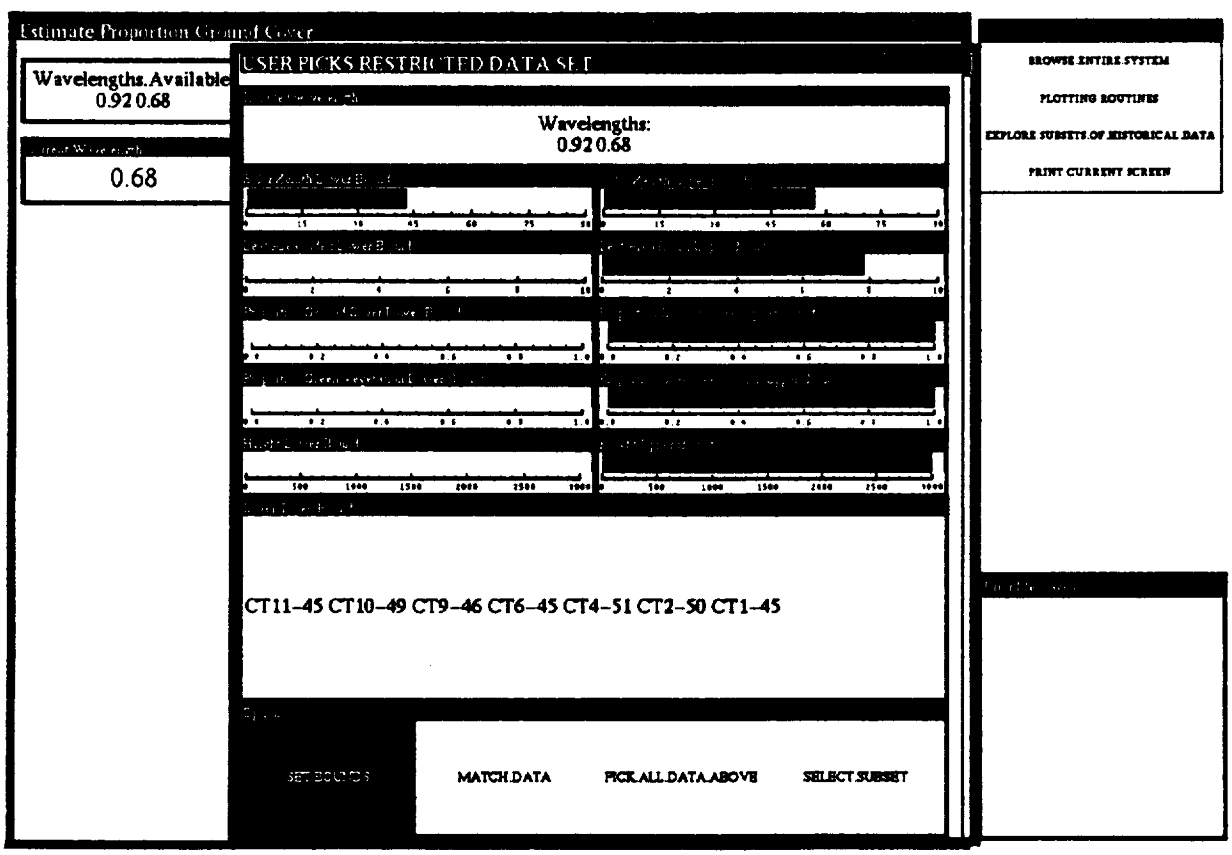

Figure 2-3

The Screen for Picking the Restricted Data Set

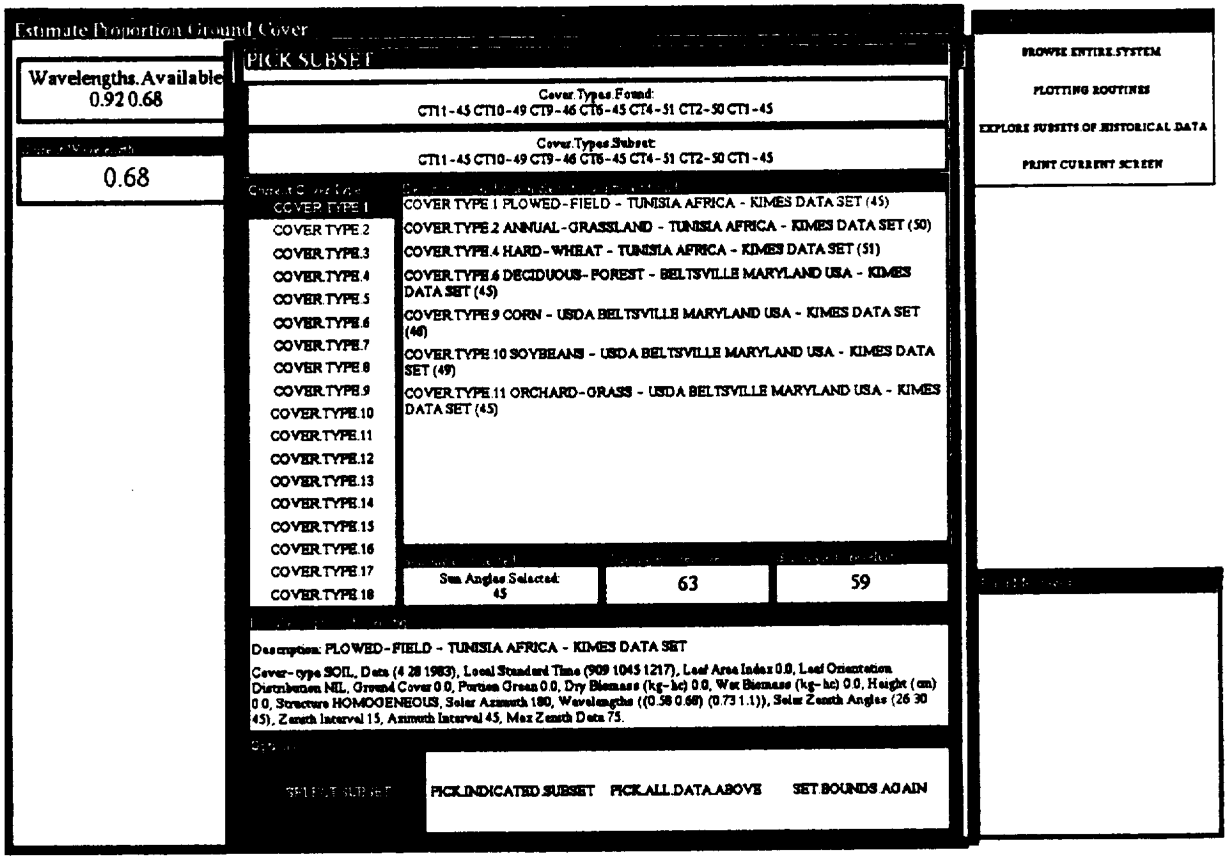

Figure 2-4

The Screen for Picking the Subset of the Matched Data

2.5 INTERPOLATE/EXTRAPOLATE RESTRICTED DATA

The code for this step in the VEG subgoal SPECTRAL.HEMISPHERICAL.REFLECTANCE is re-used for the subgoal PROPORTION.GROUND.COVER. In this step, the raw reflectance data for each cover type in the restricted data set is interpolated and extrapolated so that the view angles exactly match at each wavelength the view angles in the unknown cover type data. A unit such as RHD.SAMPLE6 is created as a subclass of the unit RESTRICTED.HISTORICAL.DATA. A hierarchy of units is set up as subclasses and members of the unit RHD.SAMPLE6 to store the data corresponding to SAMPLE6. A subclass unit such as RHD.SAMPLE6-CT11-58 is set up to correspond to each restricted data set cover type at the sun angle level. Member units of this unit such as R-4 and R-15 are created to store the reflectance data interpolated and extrapolated from the units CT11-58-1 and CT11-58-2. The class-member relationship between the units such as RHD.SAMPLE6-CT11-58, R-4 and R-15 is the same as the class member relationship between the units SAMPLE6, W11 and W12. This organization of units allows the same methods to be applied to the restricted historical data units and to the sample units.

2.6 CHARACTERIZE RESTRICTED DATA

The data in the restricted historical data units are characterized in the same way as the sample of unknown cover type data was characterized in the step CHARACTERIZE.INPUT. The code from the VEG subgoal SPECTRAL.HEMISPHERICAL.REFLECTANCE is re-used for this step.

2.7 GENERATE SINGLE WAVELENGTH TECHNIQUES

The single wavelength techniques can be generated automatically by the system or selected by the user. The code for generating techniques for the VEG subgoal SPECTRAL.HEMISPHERICAL.REFLECTANCE was copied and modified for this step towards the goal PROPORTION.GROUND.COVER. A new screen was created to allow the user to select the single wavelength proportion ground cover techniques, but many existing functions were used to operate this screen.

If the user elects to have the system generate the techniques, the rules in the rulebase PROPORTION.GROUND.COVER.SINGLE.WAVELENGTH.RULES are run. The rules operate on the unknown sample data at the wavelength level. All the techniques that are suitable for estimating the proportion ground cover of a sample at a particular wavelength are stored in the TECHNIQUES slot of the wavelength level unit. The rules are listed in Figure 2-5. The rule PGCSWR.10 selects the technique PGC.NEAR.NADIR if the reflectance data contains at least one view angle. The rule PGCSWR.11 fires and the technique PGC.NORMAN.PLUS is selected if the reflectance data contains three or more view angles. Rules PGCSWR.12, PGCSWR.13 and PGCSWR.14 fire if the reflectance data contains 2, 3 or 4 view angles respectively. These rules select the appropriate PGC.2.OFF.NADIR.ANGLE techniques, according to the number of view angles available.

If the user elects to choose the techniques manually, the screen shown in Figure 2-6 is opened. When the user left clicks on the name of a technique, a brief description of the technique is displayed in the box labelled "Description of Technique." A function is called to check whether the technique is suitable for the sample. For example, if the technique PGC.NORMAN.PLUS is selected, the function pgc.norman.plus.ok is called. This function returns T if the sample has at least 3 view angles and NIL otherwise. It the technique is suitable for the sample, the message "Technique is suitable for this sample" is displayed in the box labelled "Error Message," and the technique is selected. Otherwise an error message is displayed in the same box and the technique is not selected. When the user left clicks on PICK.SELECTED.TECHNIQUES, the selected techniques are stored in the TECHNIQUES slot of the wavelength level unknown cover type unit.

The NASA GSFC technical representative specified the single wavelength techniques that were to be implemented for estimating proportion ground cover. The maximum possible value for proportion ground cover is 1.0. It is possible for a technique to return a value for proportion ground cover that is greater than 1.0. In these cases, the value of the proportion ground cover was reported as 1.0.

The technique PGC.NEAR.NADIR uses the nearest view angle to the nadir and applies a simple linear regression (least squares) technique to calculate the proportion ground cover. This technique is similar to the technique NADIR which is used for estimating spectral hemispherical reflectance. It can be applied to any sample that has at least one view angle.

```
  (IF (THE CURRENT.SAMPLE.WAVELENGTHS
          OF ESTIMATE.HEMISPHERICAL.REFLECTANCE IS ?X)
      (LISP (CONSP (GET.VALUE ?X 'REFLECTANCE.DATA)))
      THEN
      (LISP (ADD.VALUES ?X
                        'TECHNIQUES
                        '(PGC.NEAR.NADIR))))
RULE: PGCSWR.10

  (IF (THE CURRENT.SAMPLE.WAVELENGTHS
          OF ESTIMATE.HEMISPHERICAL.REFLECTANCE IS ?X)
      (THE NUMBER.VIEW.ANGLES OF ?X IS ?Y)
      (LISP (AND (NUMBERP ?Y) (>= ?Y 3)))
      THEN
      (LISP (ADD.VALUES ?X
                        'TECHNIQUES
                        '(PGC.NORMAN.PLUS))))
RULE: PGCSWR.11

  (IF (THE CURRENT.SAMPLE.WAVELENGTHS
          OF ESTIMATE.HEMISPHERICAL.REFLECTANCE IS ?X)
      (THE NUMBER.VIEW.ANGLES OF ?X IS 2)
      THEN
      (LISP (ADD.VALUES ?X
                        'TECHNIQUES
                        '(PGC.2OFF.NADIR.ANGLE.0))))
RULE: PGCSWR.12

  (IF (THE CURRENT.SAMPLE.WAVELENGTHS
          OF ESTIMATE.HEMISPHERICAL.REFLECTANCE IS ?X)
      (THE NUMBER.VIEW.ANGLES OF ?X IS 3)
      THEN
      (LISP
      (ADD.VALUES ?X
                  'TECHNIQUES
                  (PGC.2OFF.NADIR.ANGLE.0 PGC.2OFF.NADIR.ANGLE.1
                   PGC.2OFF.NADIR.ANGLE.2))))
RULE: PGCSWR.13

  (IF (THE CURRENT.SAMPLE.WAVELENGTHS
          OF ESTIMATE.HEMISPHERICAL.REFLECTANCE IS ?X)
      (THE NUMBER.VIEW.ANGLES OF ?X IS 4)
      THEN
      (LISP
      (ADD.VALUES ?X
                  'TECHNIQUES
                  '(PGC.2OFF.NADIR.ANGLE.0 PGC.2OFF.NADIR.ANGLE.1
                    PGC.2OFF.NADIR.ANGLE.2 PGC.2OFF.NADIR.ANGLE.3
                    PGC.2OFF.NADIR.ANGLE.4 PGC.2OFF.NADIR.ANGLE.5))))
RULE: PGCSWR.14
```

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Figure 2-5

The Proportion Ground Cover Single Wavelength Rules

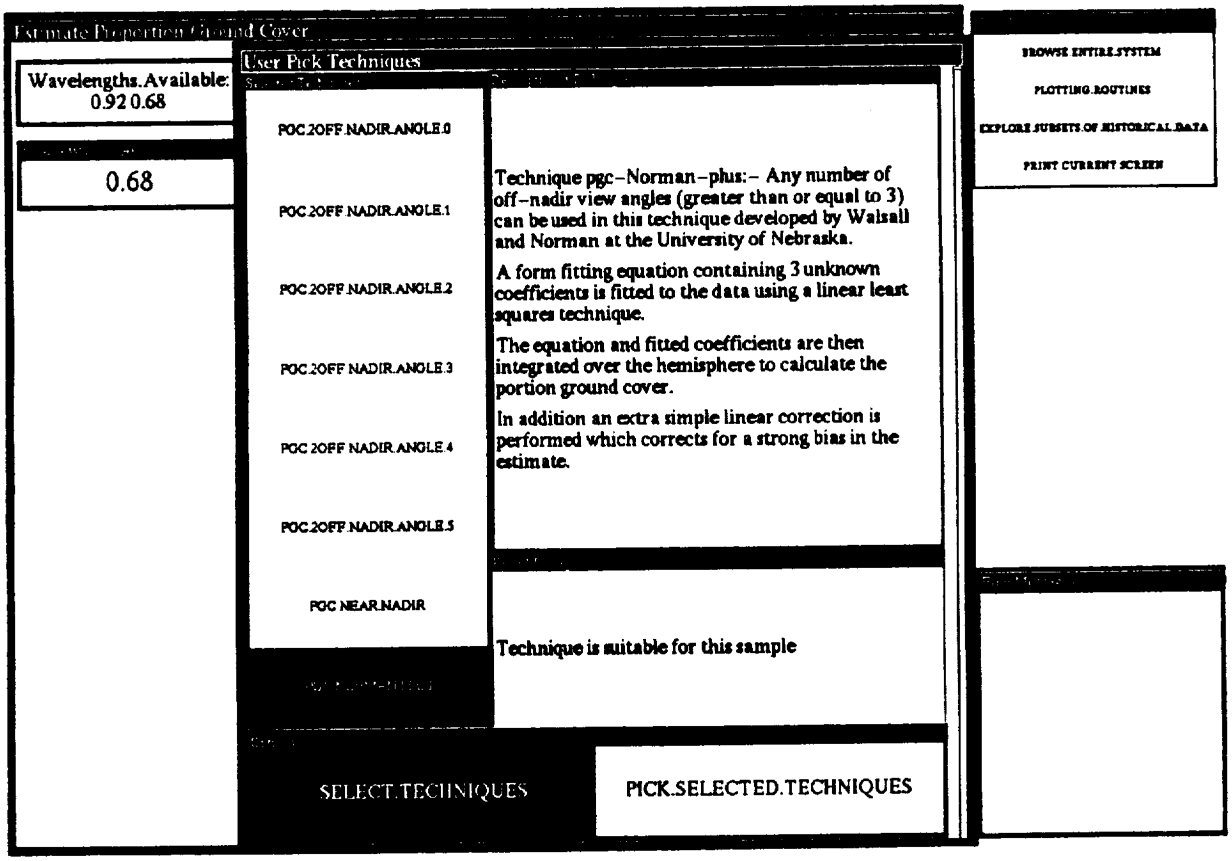

Figure 2-6

The Screen for Selecting the Single Wavelength Proportion Ground Cover Techniques

The technique PGC.2.OFF.NADIR.ANGLE can be applied to any two view angles in a set of reflectance data. A multiple regression (least squares) technique is applied to determine the proportion ground cover. This technique is similar to the technique 2.OFF.NADIR angle that was used to estimate the spectral hemispherical reflectance. The NASA GSFC technical representative advised that the technique should be applied to all samples with two, three or four view angles and it should be applied to every possible pair of angles in each suitable sample.

The technique PGC.NORMAN.PLUS is applied to samples with three or more view angles. The NORMAN technique is applied to the reflectance data to estimate the hemispherical reflectance. Then a simple linear regression is applied to estimate the proportion ground cover. This technique is similar to the technique NORMAN.PLUS for estimating spectral hemispherical reflectance.

2.8 RANK SINGLE WAVELENGTH TECHNIQUES

The code from this step in the subgoal SPECTRAL.HEMISPHERICAL.REFLECTANCE was re-used for this step. The techniques are ranked according to a simple weighting scheme and the ranked techniques at each wavelength are displayed on the screen. The user can select the best one, two or three techniques for each wavelength, pick all the selected techniques or repeat the previous step and generate the techniques again.

2.9 EXECUTE SINGLE WAVELENGTH TECHNIQUES

The code providing the framework for this step from the VEG subgoal SPECTRAL.HEMISPHERICAL.REFLECTANCE was re-used for this step. However, the methods for generating the coefficients and calculating the proportion ground cover for each technique are new. The code for these methods is included in Appendix A. When the step EXECUTE.SINGLE.WAVELENGTH.TECHNIQUES is selected, the techniques are applied to the data at each wavelength in the unknown cover type sample. If a technique requires coefficients, the user is asked whether all or half the restricted data set should be used for generating the coefficients and estimating the error. The appropriate coefficient methods are applied as necessary. The techniques are applied to the restricted historical data and the difference between the calculated proportion ground cover and the correct value for the proportion ground cover stored in the data base is calculated. Using the error measurements from several historical cover types, the root mean square error is calculated. This provides an estimate of the error involved in applying the technique to the sample of unknown cover type data. A hierarchy of units is set up to hold the results for each cover type in the restricted historical data and to hold the calculated proportion ground cover, error estimate and coefficients for each technique.

2.10 GENERATE MULTIPLE WAVELENGTH TECHNIQUES

The subgoal PROPORTION.GROUND.COVER includes techniques which are applied to a sample at multiple wavelengths. No other VEG subgoal has techniques of this type. The subgoal TOTAL.HEMISPHERICAL.REFLECTANCE has a technique which combines the spectral hemispherical reflectance results for several wavelengths to determine the total hemispherical reflectance. However, the multiple wavelength techniques for calculating the proportion ground cover operate on the raw reflectance data for the sample in the red (wavelength 0.63 μm - 0.68 μm) and near-infrared (wavelength 0.76 μm - 1.1 μm) bands. Because no techniques of this type had been included in the previous version of VEG, it was necessary to build the framework for these techniques. This included building the interfaces for generating, ranking and executing multiple wavelength techniques. The design of these interfaces was based on the interfaces that had previously been developed for the single wavelength techniques. Some of the existing code for the single wavelength techniques was copied and modified for use with the multiple wavelength techniques.

When the user selects the step GENERATE.MULTIPLE.WAVELENGTH.TECHNIQUES from the PROPORTION.GROUND.COVER main menu, the screen shown in Figure 2-7 is displayed. This screen enables the user to choose the method of selecting the techniques. The techniques can either be selected automatically by the system or selected manually by the user.

If the user elects to have the techniques selected by the system, the rules in the rulebase PROPORTION.GROUND.COVER.MULTIPLE.WAVELENGTH.RULES are run. These rules are shown in Figure 2-8. The rule PGCMWR1 fires if the unknown cover type has reflectance data in both the red and near-infrared bands. If this rule fires, the techniques PGC.NEAR.NADIR.ND is added to the slot MULTIPLE.WAVELENGTH.TECHNIQUES of the unit PROPORTION. GROUND.COVER. If the unknown cover type sample has reflectance data with at least three view angles in the red and near-infrared bands, the rule PGCMWR2 fires and the technique PGC.NORMAN.PLUS.ND is added to the slot MULTIPLE.WAVELENGTH.TECHNIQUES of the unit PROPORTION.GROUND.COVER. When the rules have run, the selected techniques are displayed on the screen as shown in Figure 2-7.

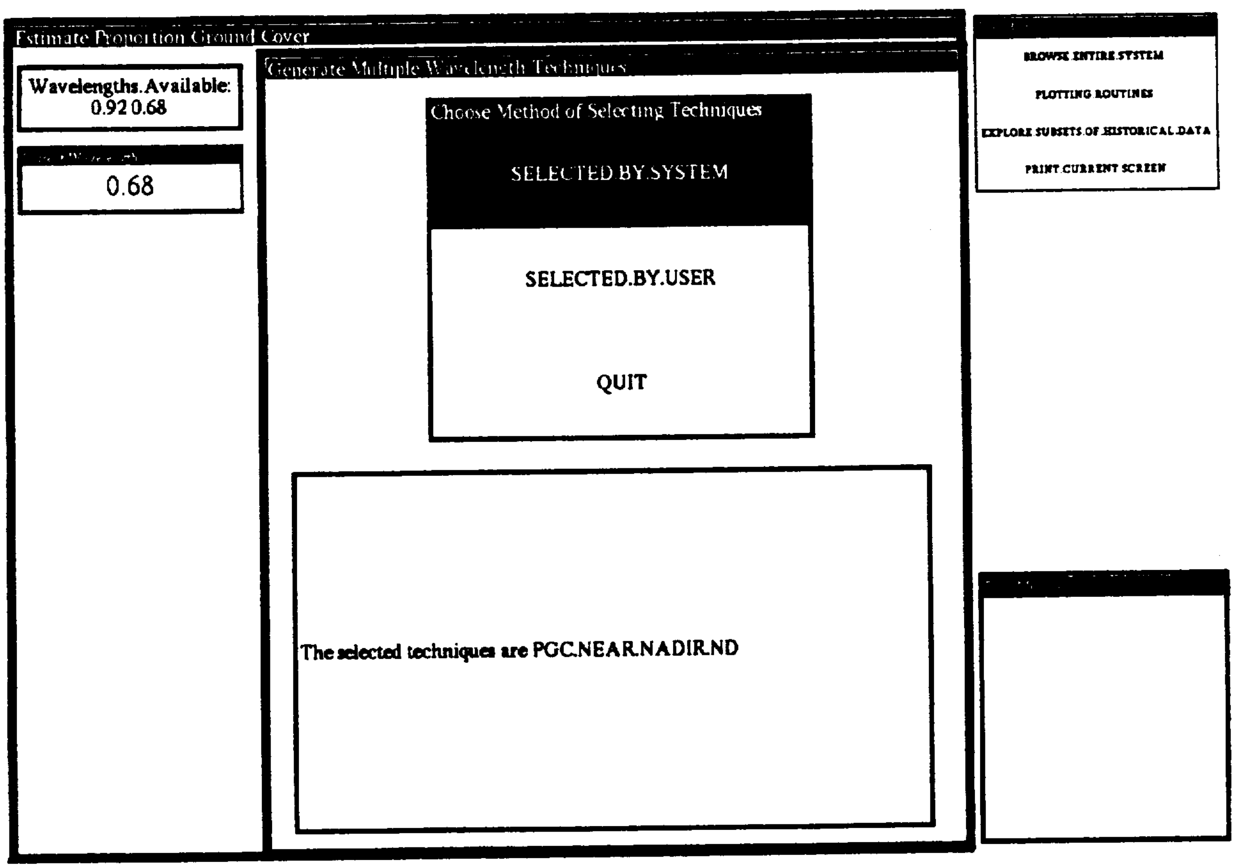

Figure 2-7

Choosing the Method of Selecting the Multiple Wavelength Techniques

The technique PGC.NEAR.NADIR.ND uses the reflectance value at the nearest view angle to the nadir in the red and near-infrared bands to calculate the normalized difference. A simple linear regression is then applied to calculate the proportion ground cover.

The technique PGC.NORMAN.PLUS.ND applies the Norman technique to three or more view angles in the red and near-infrared bands to estimate the spectral hemispherical reflectance in each band. The normalized difference is then calculated using these estimates. Finally, a simple linear regression is applied to calculate the proportion ground cover.

```
          (IF
            (THE CURRENT.SAMPLE.WAVELENGTHS
                 OF ESTIMA  TE.HEMISPHERICAL.REFLECTANCE IS ?X)
            (THE WAVELENGTH OF ?X IS ?RED)
            (LISP (AND (>= ?RED 0.63)
                       (<= ?RED 0.69)))
            (LISP (CONSP  (GET.VALUE ?X 'REFLECTANCE.DATA)))
            (THE CURRENT.SAMPLE.WAVELENGTHS
                 OF ESTIMATE.HEMISPHERICAL.REFLECTANCE IS ?Y)
            (THE WAVELENGTH OF ?Y IS ?NIR)
            (LISP (AND (>= ?NIR 0.76)
                       (<= ?NIR 1.1)))
            (LISP (CONSP  (GET.VALUE ?Y 'REFLECTANCE.DATA)))
            THEN
            (LISP
              (ADD.V ALUE  'PROPOR TION.GROUND.COVER
                           'MUL TIPLE.WAVELENGTH.TECHNIQUES
                           'PGC.NEAR.NADIR.ND)))
RULE :  PGCMWR1


          (IF
            (THE CURRENT.SAMPLE.WAVELENGTHS
                 OF ESTIMA  TE.HEMISPHERICAL.REFLECTANCE IS ?X)
            (THE WAVELENGTH OF ?X IS ?RED)
            (LISP (AND (>= ?RED 0.63)
                       (<= ?RED 0.69)))
            (THE NUMBER.VIEW.ANGLES OF ?X IS ?RED-VIEW)
            (LISP (>= ?RED-VIEW 3))
            (THE CURRENT.SAMPLE.WAVELENGTHS
                 OF ESTIMA  TE.HEMISPHERICAL.REFLECTANCE IS ?Y)
            (THE WAVELENGTH OF ?Y IS ?NIR)
            (LISP (AND (>= ?NIR 0.76)
                       (<= ?NIR 1.1)))
            (THE NUMBER.VIEW.ANGLES OF ?Y IS ?NIR-VIEW)
            (LISP (>= ?NIR-VIEW 3))
            THEN
            (LISP
              (ADD.V ALUE  'PROPOR TION.GROUND.COVER
                           'MUL TIPLE.WAVELENGTH.TECHNIQUES
                           'PGC.NORMAN.PLUS.ND)))
RULE :  PGCMWR2
```

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Figure 2-8

The Proportion Ground Cover Multiple Wavelength Rules

If the user elects to choose the multiple wavelength techniques manually, the screen shown in Figure 2-9 is opened. Left clicking on the name of a technique causes a brief description of the technique to be displayed in the box labelled "Description of Technique." A function such as the function pgc.near.nadir.nd.ok is called to determine if the sample has all the data required by the technique. In the case of the technique PGC.NEAR.NORMAN.ND, the sample must have reflectance data at the red and near-infrared bands. If the technique is suitable for the sample, the words "Technique is suitable for this sample" are displayed in the box labelled "Error Message," and the technique name is highlighted to show that the technique has been selected. Otherwise, an error message is displayed and the technique is not selected. The user must left click on "PICK.TECHNIQUES" to finish picking the techniques and close the screen. The message "Finished selecting techniques" is then displayed in the lower box on the screen shown in Figure 2-7. Left clicking on "QUIT" returns the user to the main menu for the subgoal PROPORTION.GROUND.COVER.

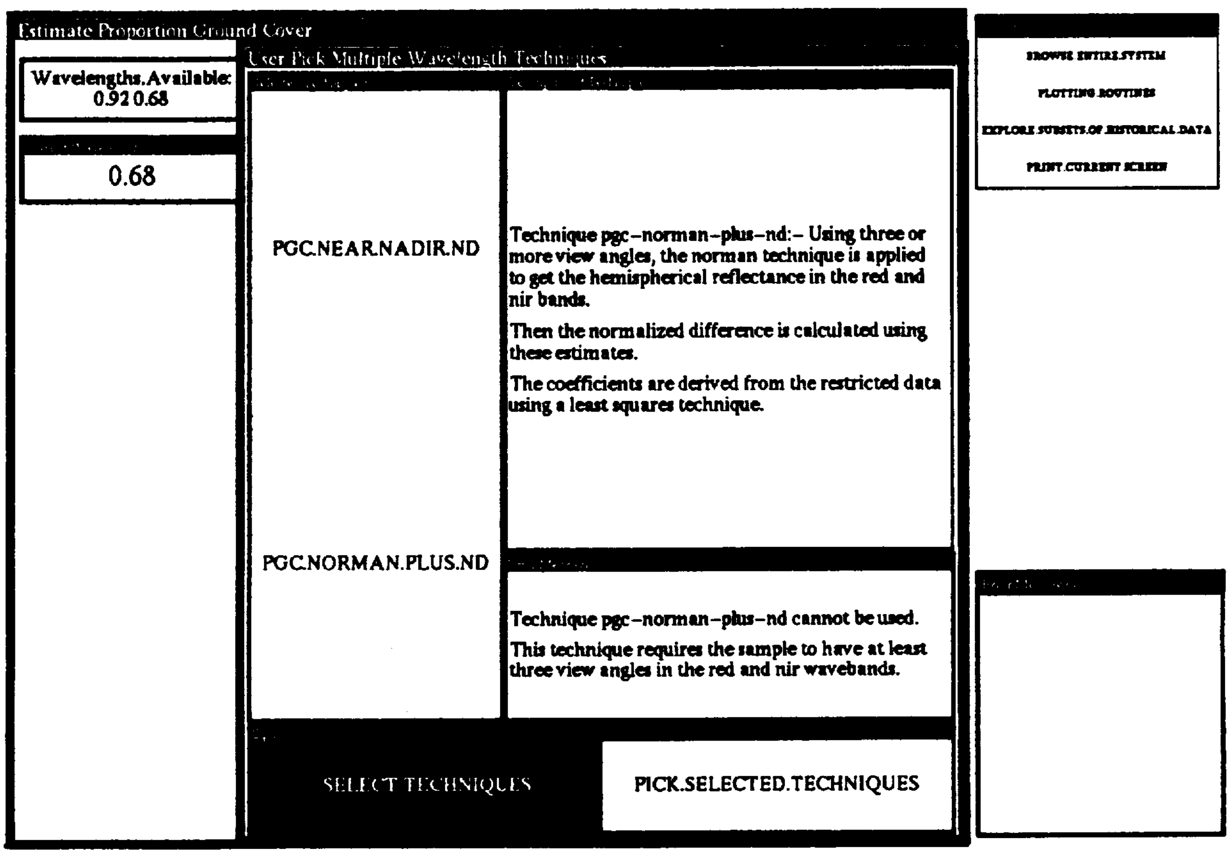

Figure 2-9

The Screen for Selecting the Multiple Wavelength Techniques

2.11 RANK MULTIPLE WAVELENGTH TECHNIQUES

The RANK.MULTIPLE.WAVELENGTH.TECHNIQUES interface has been implemented so that it is similar to the interface used for ranking the single wavelength techniques. When the user selects this step, the screen shown in Figure 2-10 is opened. The techniques that were generated in the previous step are ranked using a simple weighting scheme and then displayed on the screen. Even though VEG currently contains only two proportion ground cover multiple wavelength techniques, the interface has been implemented to allow for the addition of more multiple wavelength techniques at a later date. The user can choose the one, two, three best techniques, all the selected techniques or open the interface to generate the techniques again. If the user chooses the three best techniques and only two techniques have been generated, both techniques are used. When the user left clicks on a selection, the interface is closed and the main menu for the subgoal PROPORTION.GROUND.COVER is once again visible.

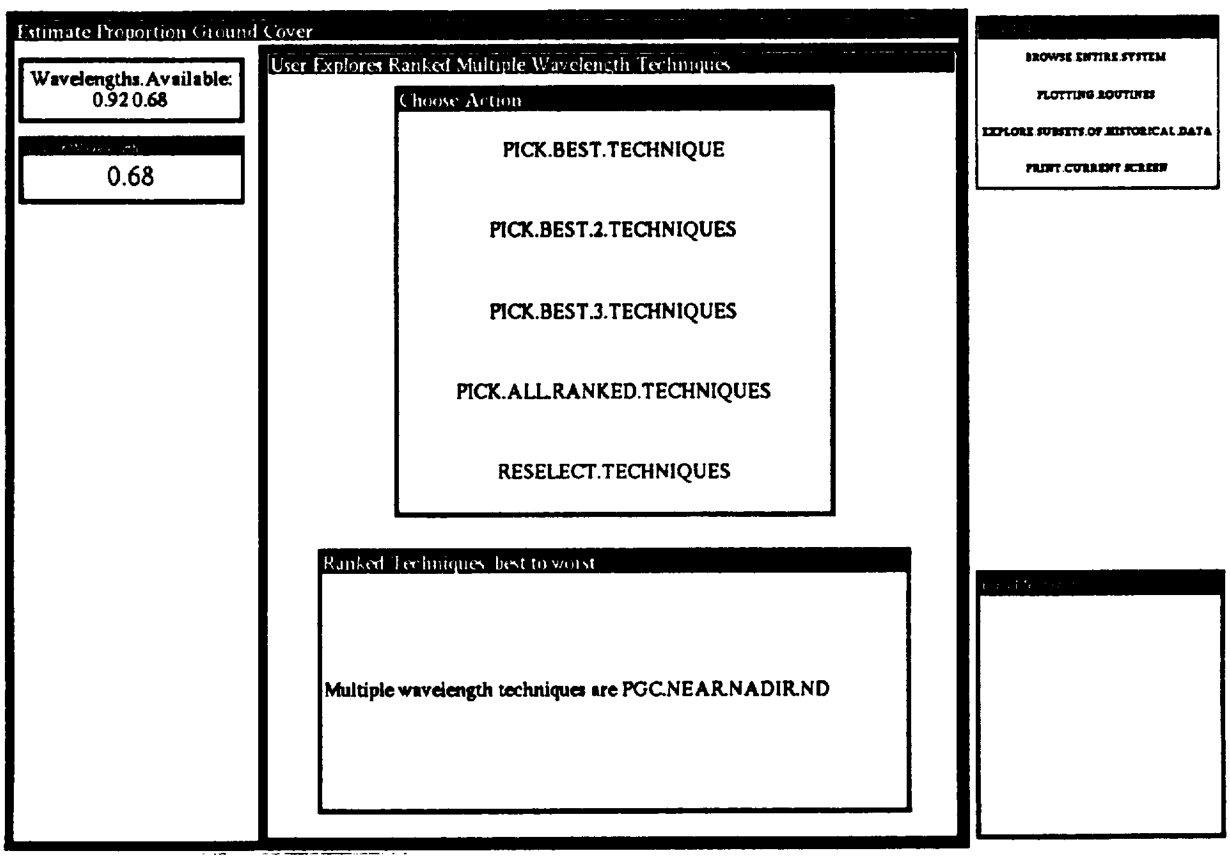

Figure 2-10

The RANK.MULTIPLE.WAVELENGTH.TECHNIQUES Interface

2.12 EXECUTE MULTIPLE WAVELENGTH TECHNIQUES

The Lisp code used for executing the single wavelength techniques and was modified to produce the code for executing the multiple wavelength techniques. When the user selects this step, the interface shown in Figure 2-11 is opened and the message "Executing multiple wavelength techniques - please wait........" is displayed. A check is made to make sure at least one multiple wavelength technique has been generated. If no techniques have been generated, an error message is displayed. Otherwise, the techniques are executed one at a time. If a technique requires coefficients, the user is asked whether all or half of the historical data units in the restricted data set should be used for calculating the coefficients and the error estimate. This step uses the screen shown in Figure 2-12. If the user left clicks on "HALF.OF. HISTORICAL.DATA," the list of restricted historical data units is divided into two lists. One list of units is then used in the function for calculating the coefficients for the technique. The other list is used for calculating the error estimate. The coefficients are calculated by applying the coefficient method for the technique to the appropriate list of restricted historical data units. Then the technique is applied to the unknown cover type data using the calculated coefficients. Next, the technique method is applied to each restricted historical data unit in the appropriate list. For each unit, the difference between the calculated value and the correct value for the ground cover (previously stored in the unit) is calculated. The root mean square of the error terms for all the appropriate restricted historical data units is calculated. This number provides an estimate of the error term involved in applying the technique to the sample.

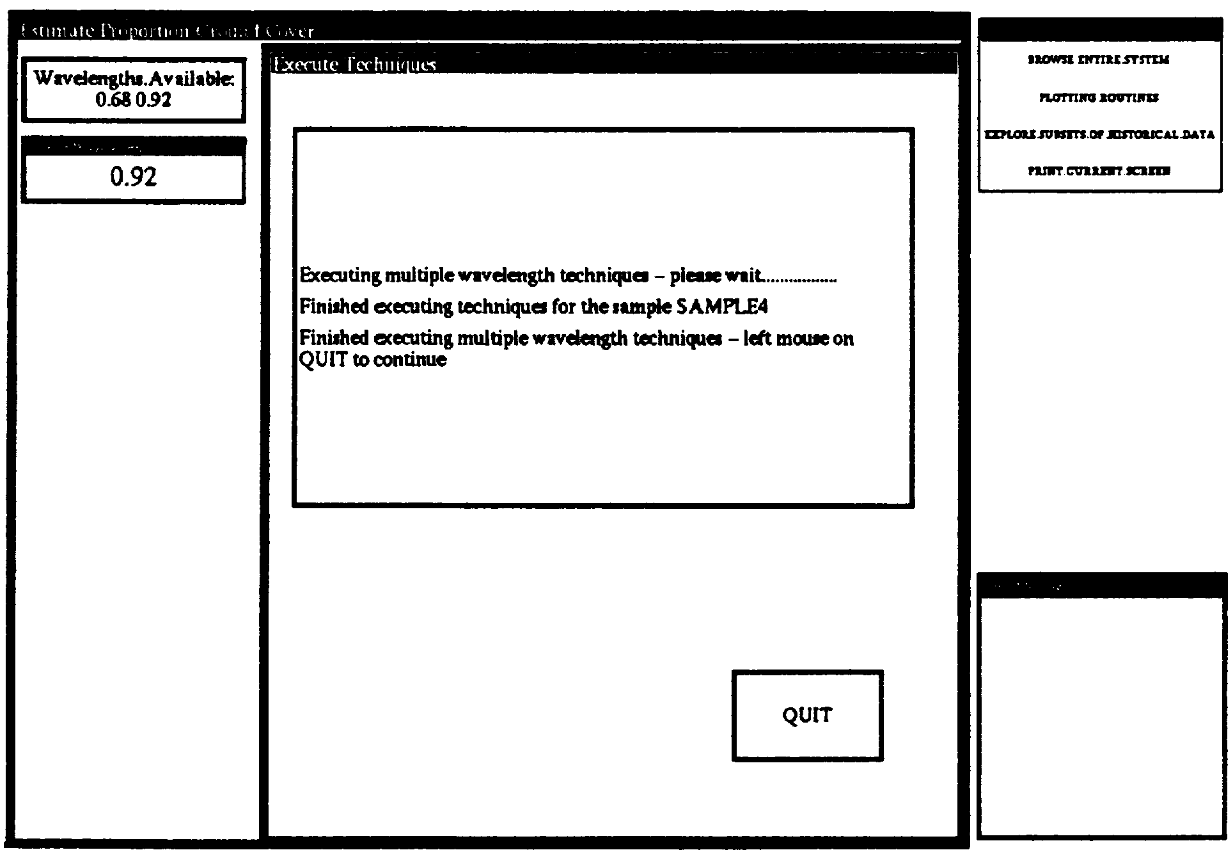

Figure 2-11

The EXECUTE.MULTIPLE.WAVELENGTH.TECHNIQUES Interface

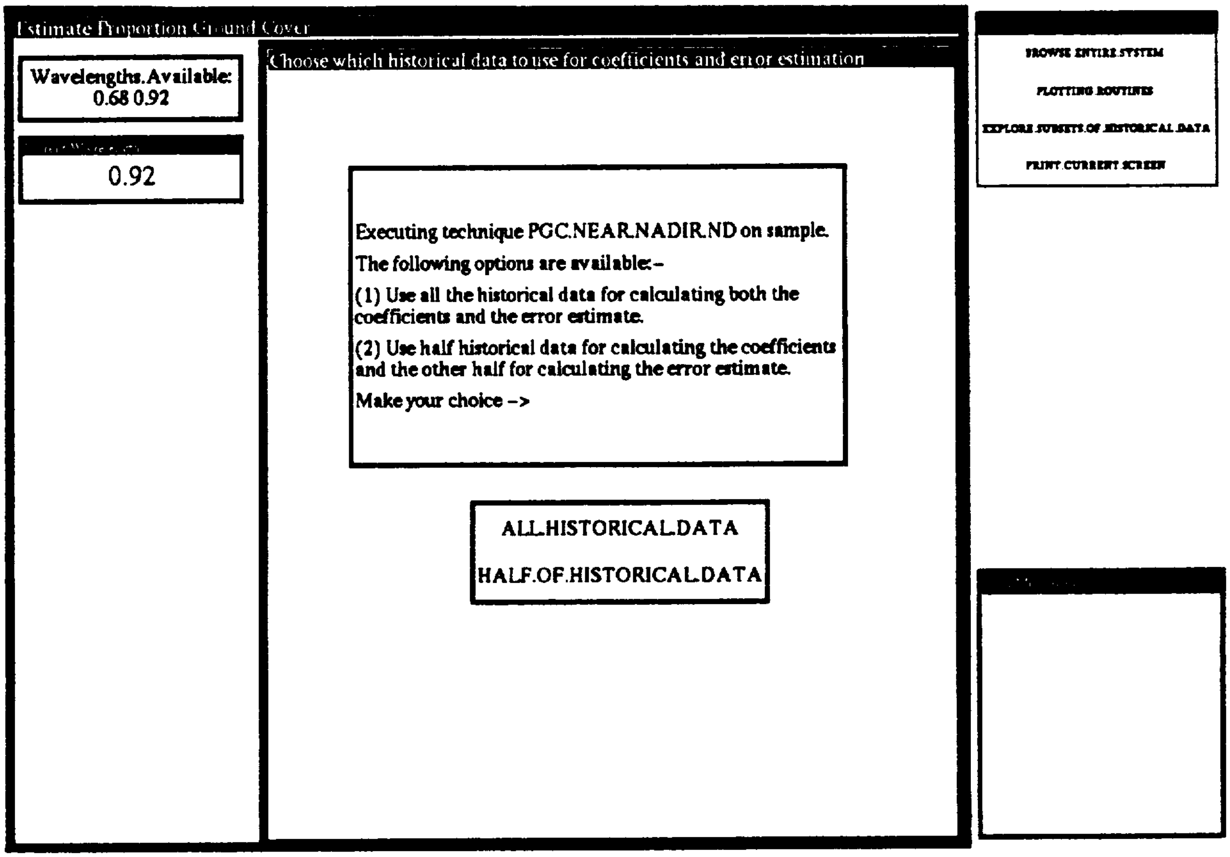

Figure 2-12

Choosing which Historical Data will be Used for Coefficients and Error Estimation

A hierarchy of units is created as subclasses and members of the unit RESULTS to hold the results of processing the multiple wavelength techniques. The results for each restricted historical data unit are stored as well as the results for the sample. This is to allow the scientist to study the intermediate results of processing the data in detail.

Each selected multiple wavelength technique is applied to the sample and the results are stored. When the execution of the multiple wavelength techniques has been completed, a message is displayed on the screen, and the user is prompted to left click on the box labelled "QUIT" to return to the main menu.

2.13 OUTPUT RESULTS

The results are displayed on the screen as shown in Figure 2-13. This screen was originally constructed for the VEG subgoal SPECTRAL.HEMISPHERICAL.REFLECTANCE. The title has been changed to "Proportion Ground Cover Results." The multiple wavelength results are displayed in the box labelled, "Sample Results." For each multiple wavelength technique, the estimate of the proportion ground cover, the error estimates and the coefficients are displayed. The multiple wavelength results apply to the entire sample, and they do not change when the user selects either the next or the previous wavelength. The single wavelength results are displayed in the box labelled, "Wavelength Results." For each single wavelength technique, the name of the technique is displayed together with the estimate of proportion ground cover, the error estimate and the coefficients. If the user left clicks on "NEXT.WAVELENGTH" or "PREVIOUS. WAVELENGTH," the wavelength level results for a different wavelength are displayed. When the user left clicks on "QUIT," another screen is opened. The user is asked whether the results should be written to a file. A detailed description of the interface for writing results from VEG was provided in the JJM Systems report B921016-U-2R02. The results for all the VEG subgoals, including the subgoal PROPORTION.GROUND.COVER, can be written to a file. Appendix B contains the listings of files that were produced when the subgoal PROPORTION.GROUND.COVER was tested.

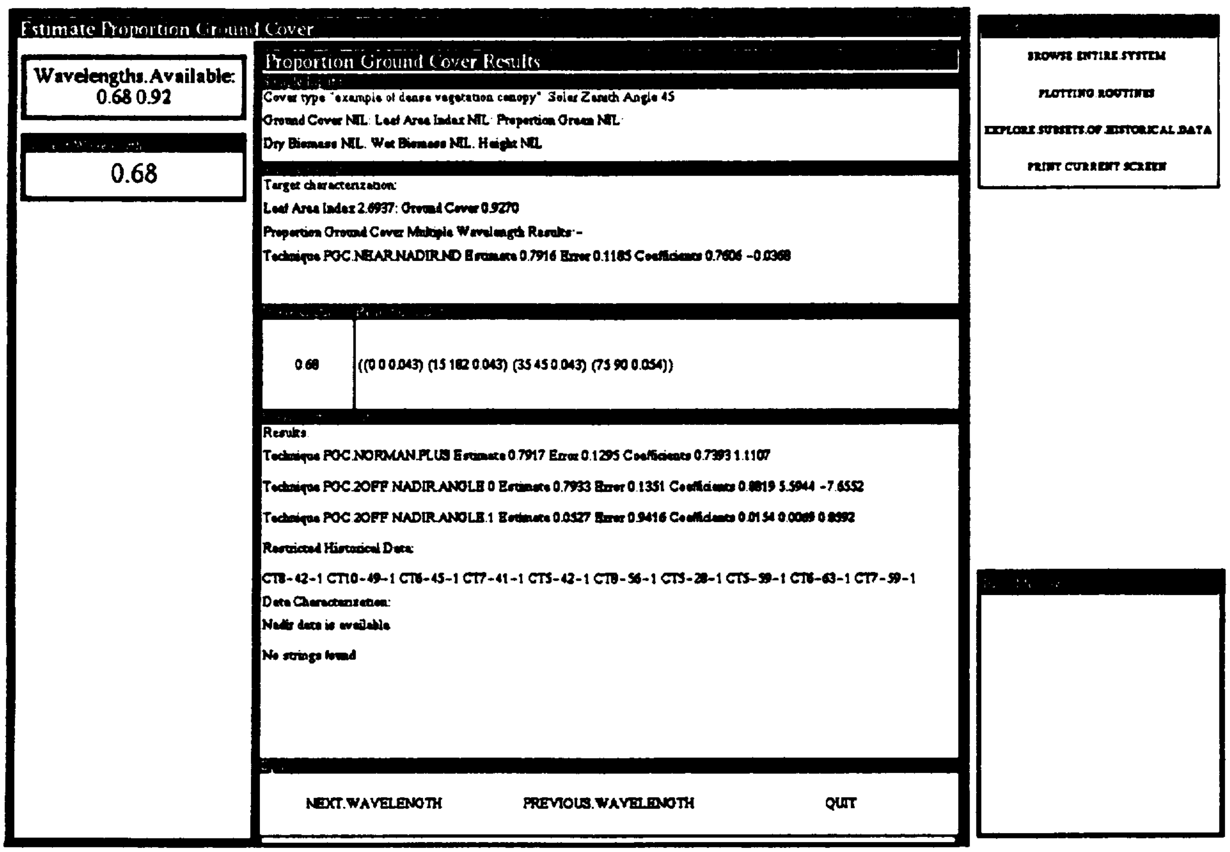

Figure 2-13

Displaying the Results of the VEG Subgoal PROPORTION.GROUND.COVER

SECTION 3.0

DESCRIPTION OF THE SUBGOAL PROPORTION.GROUND.COVER IN THE VEG "AUTOMATIC MODE"

When the user left clicks on the option PROPORTION.GROUND.COVER on the VEG "Automatic Mode" top level screen, additional boxes are opened, as shown in Figure 3-1. This screen enables the user to enter the name of the input file and specify the format for the file. When the user enters the name of the output file, he/she is prompted to specify the parameters to be written to the file and the format to be used. The interfaces that enable the user to specify the format of the input and output files were described in detail in the JJM Systems reports B921015-U-2R01 and B921016-U-2R02. The user can specify how many single wavelength techniques are to be applied to the sample at each wavelength and how many multiple wavelength techniques are to be applied to the entire sample by clicking on the required option in the box labelled, "How Many Techniques To Test." It should be noted that the interface does not allow the user to select a different number of single and multiple wavelength techniques. The user can also specify whether all or half the restricted historical data units should be used for calculating both the error term and the coefficients when the techniques are applied to the samples of unknown cover type data.

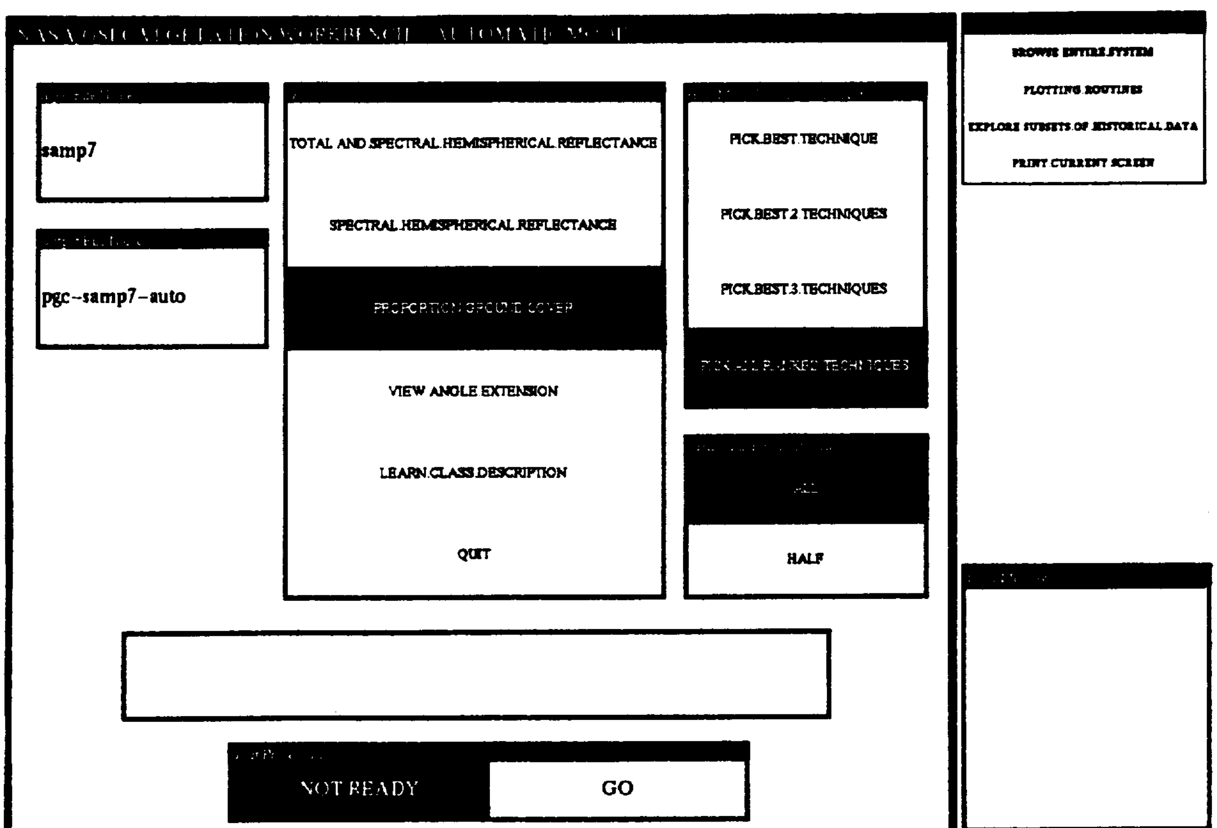

Figure 3-1

Selecting the Subgoal PROPORTION.GROUND.COVER from the VEG "Automatic Mode" Top Level Screen

When the user left clicks on "GO", the unknown cover type data is read from the file. The data is processed using the same sequence of steps as in the VEG "Research Mode." The results are written to the named file using the specified format.

SECTION 4.0

TESTING AND RESULTS

All the options of the VEG subgoal PROPORTION.GROUND.COVER were tested. These included testing the generation, ranking and execution of all the new single wavelength and multiple wavelength techniques. The selection of techniques both by the user and by the system were tested. In every test,the restricted data set was created automatically by the system. The tests included the subgoal PROPORTION.GROUND.COVER in the VEG "Automatic Mode" as well as the "Research Mode." All the tests were successful, showing that the system was working correctly. The tests are described in detail in this section. The output files produced by the test runs are presented in Appendix B.

4.1 TEST 1

The first test was designed to test the overall framework of the VEG subgoal PROPORTION.GROUND.COVER, and the operation of the rules to generate the single wavelength and multiple wavelength techniques. SAMPLE4 from the data base of unknown cover types within VEG was selected as the sample for this run. SAMPLE4 has four random view angles at wavelength 0.68 μm and a nadir view angle at wavelength 0.92 μm. All the single wavelength techniques are applicable to a sample with four view angles. This sample was selected so that the maximum number of techniques could be generated.

The data was processed by carrying out the steps in the PROPORTION.GROUND.COVER menu, as shown in Figure 2-1 and described in Section 2. The restricted data set was created automatically by the system.

The user opted to have the system generate the single wavelength techniques. The rules in the rulebase PROPORTION.GROUND.COVER.SINGLE.WAVELENGTH. RULES were run. The techniques PGC.NEAR.NADIR, PGC.NORMAN.PLUS, PGC.2OFF.NADIR.ANGLE.0, PGC.2OFF.NADIR.ANGLE.1, PGC.2OFF.NADIR.ANGLE.2, PGC.2OFF.NADIR. ANGLE.3, PGC.2OFF.NADIR.ANGLE.4 and PGC.2OFF.NADIR.ANGLE.5 were correctly chosen for the data at wavelength 0.68 μm. The technique PGC.NEAR.NADIR was the only technique selected for the data at wavelength 0.92 μm. This was as expected.

The single wavelength techniques were ranked, and the user chose to select the best three techniques at each wavelength. The best three techniques at wavelength 0.68 μm were PGC.NORMAN.PLUS, PGC.2OFF.NADIR.ANGLE.0 and PGC.2OFF.NADIR.ANGLE.1. The technique PGC.NEAR.NADIR was the only technique generated for the wavelength 0.92-μm. It was the only technique selected at this wavelength.

The techniques were executed by the system. In response to the question for each technique, the user indicated that half the restricted data set should be used for generating the coefficients and the other half should be used for estimating the error term.

The user elected to have the multiple wavelength techniques selected by the system. The rules in the rulebase PROPORTION.GROUND.COVER.MULTIPLE.WAVELENGTH.RULES were run. The technique PGC.NEAR.NADIR.ND was the only multiple wavelength technique generated for SAMPLE4. The technique PGC.NORMAN.PLUS.ND was not selected because the sample had only one view angle at wavelength 0.92 μm. The option PICK.BEST.TECHNIQUE was selected from the rank multiple wavelength techniques interface although selecting one, two, three or all techniques would have made no difference since only one technique was generated.

The technique PGC.NEAR.NADIR was executed on the sample. Half the restricted data set was used for generating the coefficients and the other half was used for estimating the error term.

The results were output on the screen. Figure 2-13 shows some of the results of this test. The proportion ground cover was estimated as 0.7916, with an error estimate of 0.1185 by the multiple wavelength technique PGC.NEAR.NADIR.ND. At wavelength 0.68 µm, the techniques PGC.NORMAN.PLUS, PGC.2OFF.NADIR.ANGLE.0 and PGC.2.OFF.NADIR.ANGLE.1 provided estimates of proportion ground cover of 0.7917, 0.7933 and 0.0527 with error estimate 0.1295, 0.1351 and 0.9416, respectively. At wavelength 0.92 using the technique PGC.NEAR.NADIR the proportion ground cover was estimated as 0.6124 with an error estimate of 0.2002. The NASA GSFC technical representative advised that errors as high as 45% are not uncommon in the measuring of reflectance data. Given the inherent inaccuracy of the reflectance data, most of the results were acceptable. The exception was the estimate of 0.0527 from applying the technique PGC.2OFF.NADIR.ANGLE1 to the data at wavelength 0.68 µm. Careful examination did not reveal any errors in coding. The result appears to have been calculated correctly. It has been referred to the NASA GSFC technical representative for interpretation. Test 1 provided evidence that all the steps in calculating the proportion ground cover were working correctly.

4.2 TEST 2

In test 1, all the single and multiple wavelength techniques were generated automatically by the system, by running rules. The purpose of test 2 was to test the interfaces that allow the user to select the techniques manually.

SAMPLE3 was chosen as the sample for test 2. This sample has three full strings at wavelength 0.68 µm and a nadir value at wavelength 0.92 µm. All the steps in the subgoal PROPORTION.GROUND.COVER were selected in turn. The "SELECTED.BY.USER" option was chosen for generating both the single wavelength and multiple wavelength techniques. In each case, the user attempted to select all the techniques. The system permitted the user to select the single wavelength techniques PGC.NORMAN.PLUS and PGC.NEAR.NADIR at wavelength 0.68 µm. It displayed an error message instead of selecting the technique when the user left clicked on each of the PGC.2OFF.NADIR.ANGLE techniques. These techniques were unsuitable for the sample because it had more than four view angles so the system was operating correctly. The user was only permitted to select the technique PGC.NEAR.NADIR at wavelength 0.92 µm, because the sample had only one view angle. The system allowed the user to select the multiple wavelength technique PGC.NEAR.NADIR.ND. It did not allow the user to select the technique PGC.NORMAN.PLUS.ND, because the sample had less than three view angles in the near-infrared band.

The results were displayed on the screen and output to a file which is listed in Appendix B. All the results were acceptable. This test showed that the interfaces for selecting the techniques manually were operating correctly.

4.3 TEST 3

This test was designed to test the subgoal PROPORTION.GROUND.COVER in the VEG "Automatic Mode." The proportion ground cover for SAMPLE7 was calculated using the VEG "Research Mode" and then using the VEG "Automatic Mode." The results were compared.

In the first part of this test, the VEG "Research Mode" was selected and SAMPLE7 was picked as the unknown cover type to be investigated. Each step in the VEG subgoal PROPORTION.GROUND.COVER was selected in turn.

A crude estimate of the proportion ground cover of a sample is calculated in the step CHARACTERIZE.TARGET. However, SAMPLE7 contains insufficient data for this crude estimate to be made. The restricted data set was created automatically. This operation uses the crude estimate of the proportion ground cover calculated in the previous step. When the estimate of ground cover is not available, the user is prompted to enter an estimate of the value. In test 3, the user entered the value 0.5 in response to this prompt. This value was chosen so that a direct comparison could be made between the results of this part of the test and running the same test in the VEG "Automatic Mode." If VEG is running in "Automatic Mode," and an estimate of proportion ground cover is required but it is not available, VEG uses the value 0.5.

Both the single wavelength and multiple wavelength techniques were generated by the system. In each case, all the ranked techniques were selected. The techniques were executed using half the restricted historical data units to calculate the coefficients and half the restricted historical data units to calculate the error estimate. The results were displayed on the screen and written to the file "pgc-samp7" which is listed in Appendix B.

In the second part of this test, VEG was run in the "Automatic Mode." The file "samp7" was selected as the input file. This file contains the same data as the VEG units SAMPLE7, W13 and W14. The output file was named "pgc-samp7-auto." The options "PICK.ALL.RANKED. TECHNIQUES" and "HALF" (see Figure 3-1) were selected. The user clicked on "GO," and the data was processed.

At the end of the run, the user compared the files "pgc-samp7" and "pgc-samp7-auto." These files were found to be the same. It was concluded that the subgoal PROPORTION.GROUND.COVER was working correctly in the VEG "Automatic Mode" since it gave the same results as the VEG "Research Mode."

4.4 TEST 4

This test was also run in both VEG modes as further proof that they were operating correctly. The test was designed primarily to test the multiple wavelength technique PGC.NORMAN.PLUS.ND. This technique was not generated in any of the previous tests. A new sample called SAMPLE10 was added to VEG. This sample contained data at more than four view angles in both the red and the near-infrared bands. The multiple wavelength technique PGC.NORMAN.PLUS.ND was suitable for this sample.

The test was run first in the VEG "Research Mode" and then in the "Automatic Mode." In both runs, the techniques were generated automatically, all the generated techniques were selected, and all the restricted historical data units were used for calculating both the coefficients and the error estimates. The results of the first and second runs were written to the files "pgc-samp10" and "pgc-samp10-auto," respectively.

In both runs, the multiple wavelength technique PGC.NORMAN.PLUS.ND was selected. Using this technique, the proportion ground cover was estimated as 0.7691 with an error estimate of 0.1438. This result compared with a proportion ground cover estimate of 0.7724 and an error estimate of 0.1182 using the multiple wavelength technique PGC.NEAR.NADIR.ND. This result was also similar to the results obtained using the single wavelength techniques on the same sample. It was concluded that the technique PGC.NORMAN.PLUS.ND was operating correctly. Both runs in this test produced the same results. This was further evidence that the subgoal PROPORTION.GROUND.COVER was working correctly in the VEG "Research Mode."

SECTION 5.0

CONCLUSIONS

The VEG subgoal PROPORTION.GROUND.COVER was completed in both the VEG "Research Mode" and the VEG "Automatic Mode." Several single wavelength techniques for estimating proportion ground cover were implemented. The framework to incorporate multiple wavelength techniques into VEG was constructed. Two multiple wavelength techniques for estimating ground cover were implemented.

All the options in the VEG subgoal PROPORTION.GROUND.COVER were tested. The tests were successful, showing that the system was working correctly.

REFERENCES

1. Kimes, D. S., Harrison, P. R. and Ratcliffe, P. A. 1991. A Knowledge-Based Expert System for Inferring Vegetation Characteristics. International Journal of Remote Sensing: Vol 12, 10, pp. 1987-2020.

2. Kimes, D. S., Harrison, P. A. and Harrison, P. R. 1992. New Developments of a Knowledge Based System (VEG) for Inferring Vegetation Characteristics. International Geoscience and Remote Sensing Symposium, Houston, Texas, May 1992.

APPENDIX A

LISP CODE FOR THE VEG SUBGOAL PROPORTION.GROUND.COVER

```
;;; veg-methods3.lisp
;;;
;;; Written by Ann Harrison
;;; Created 10th March 1992
;;; Last Modified 28th October 1992

(in-package 'kee)

(defun pgc.p ()
"Returns t if the subgoal PROPORTION.GROUND.COVER has been selected and nil
otherwise."
  (or (eq 'PROPORTION.GROUND.COVER (get.value 'methods 'goals))
      (eq 'PROPORTION.GROUND.COVER (get.value 'automatic.process 'auto.goals))))

(defun proportion-ground-cover ()
"Opens the panel to display the main menu for the subgoal
PROPORTION.GROUND.COVER."
  (remove.all.values 'proportion.ground.cover 'pgc.menu)
  (put.value 'proportion.ground.cover 'error.message "")
  (unitmsg 'viewport-portion.ground.cover.1 'open-panel!))

;;;---------------------------------------------------------------------------
;;; Methods for generating appropriate single wavelength techniques for
;;; proportion ground cover
;;;---------------------------------------------------------------------------

(defun user-pick-pgc-techniques ()
"Opens the panel that controls the selection of the single wavelength
techniques by the user. The panel contains a pushbutton. When the user left
clicks on the pushbutton, the system moves on to allow the user to select the
techniques at the next wavelength."
  (unitmsg 'viewport-6.generate.techniques.3 'open-panel!)
  (dolist (thisunit (get.values 'estimate.hemispherical.reflectance
                                'current.sample.wavelengths)
           (all-generate-techniques-finished-message))
    (put.value 'estimate.hemispherical.reflectance
        'current.wavelength thisunit)
    (user-pick-pgc-techniques-aux)
    (remove.all.values '6.generate.techniques 'push.button)
    (wait-for-mouse-gt)))

(defun user-pick-pgc-techniques-aux ()
"Calls a function to reset the values of images on the screen. Then opens the
screen that allows the user to select the single wavelength proportion ground
cover techniques."
  (reset-initial-values-pick-pgc-techniques)
  (unitmsg 'viewport-portion.ground.cover.5 'open-panel!))
```

```
(defun reset-initial-values-pick-pgc-techniques ()
"Resets the values of slots required by the screen that allows the user to
select the single wavelength proportion ground cover techniques."
  (remove.all.values 'proportion.ground.cover 'selected.techniques)
  (put.value '6.generate.techniques 'error.message "")
  (put.value '6.generate.techniques 'description.of.technique "")
  (put.value 'proportion.ground.cover 'action.on.selecting.techniques
     'select.techniques))

(defun pick-selected-values-pgc ()
"Stores the selected techniques in the current wavelength level unit.  Displays
a list of selected techniques on the screen.  Not - these techniques are
displayed until the user left clicks on the pushbutton."
  (let ((techs (get.values 'proportion.ground.cover 'selected.techniques))
        (current-wave (get.value 'estimate.hemispherical.reflectance
                         'current.wavelength)))
   (unless (null current-wave)
    (put.values current-wave 'techniques techs))
   (remove.all.values '6.generate.techniques 'automatic.or.manual)
   (tech-message (format ()
             "Techniques selected for sample at wavelength ~S are :-~{ ~S~}"
                (wav current-wave)(get-unit-names techs)))))

(defun pgc.near.nadir.ok (sample)
"Returns t if the techniques pgc.near.nadir is suitable for the sample and nil
otherwise.  The technique is suitable if the sample has at least one view
angle."
     (>= (get.value sample 'number.view.angles) 1))

(defun pgc.norman.plus.ok (sample)
"Returns t if the techniques pgc.nornam.plus is suitable for the sample and nil
otherwise.  The technique is suitable if the sample has at least three view
angles."
     (>= (get.value sample 'number.view.angles) 3))

;;;-------------------------------------------------------------------------------
;;; Basic functions required for calculating error proportion in proportion
;;; ground cover calculations
;;;-------------------------------------------------------------------------------

(defun get-pgc-error-prop (tech-method this-rhd coeffs)
"Returns the calculated result and error proportion after applying a proportion
ground cover technique to a sample of restricted historical data. Returns the
value 0 for the error proportion if the true result is zero."
  (let ((true-result (find-true-pgc this-rhd))
        (calc-result (funcall tech-method this-rhd coeffs)))
    (values calc-result
            (if (zerop true-result)
                0
                (/ (- true-result calc-result) true-result)))))
```

```
(defun find-true-pgc (this-rhd)
"Returns the true proportion ground cover for a restricted historical data
sample."
  (get.value (get.value this-rhd 'cover.type) 'ground.cover))

;;;------------------------------------------------------------------------
;;; Techniques to calculate proportion ground cover
;;;------------------------------------------------------------------------

(defun tech-pgc-near-nadir (thisunit coeffs)
"Method for the technique pgc.near.nadir.  The argument thisunit is a unit
containing reflectance data for an unknown cover type at the wavelength."
 (put-in-range (+ (aref coeffs 0)
                  (* (third (get-nearest-to-nadir
                             (get.value thisunit 'reflectance.data)))
                     (aref coeffs 1)))))

(defun coeffs-pgc-near-nadir (data)
"Method for calculating the coefficients for the technique pgc.near.nadir.
The argument data is a list of rhd units to be used for calculating the
coefficients."
 (let* ((nearest-to-nadir-position
          (get-nearest-to-nadir-position (first data)))
         (the-a-data
       (mapcar #'(lambda (unit)
               (third (nth nearest-to-nadir-position
                              (get.value unit 'reflectance.data))))
              data))
        (the-b-data (get-true-pgc-values data)))
   (least-squares (make-a-matrix the-a-data)
                  (make-array (length the-b-data)
                              :initial-contents the-b-data))))

(defun get-nearest-to-nadir-position (this-unit)
"Returns the position in the reflectance data of the nearest view angle to the
nadir."
 (let ((reflectance-data (get.value this-unit 'reflectance.data)))
   (position (get-nearest-to-nadir reflectance-data) reflectance-data
             :test #'equal)))

(defun get-nearest-to-nadir (reflectance-data)
"Returns the nearest view angle to the nadir in a set of reflectance data."
 (let* ((first-point (first reflectance-data))
         (best-distance (sqrt (+ (square (first first-point))
                                 (square (second first-point)))))
         (best-point first-point))
   (dolist (point (rest reflectance-data) best-point)
     (let ((this-distance (sqrt (+ (square (first point))
                                   (square (second point))))))
        (cond ((zerop this-distance)
              (return-from get-nearest-to-nadir point))
             ((< this-distance best-distance)
              (setf best-distance this-distance)
              (setf best-point point))))))
```

```
;;; The technique pgc-norman-plus uses the function tech-norman-plus from the
;;; file veg-methods.lisp, in the section containing the code for the
;;; techniques for estimating spectral hemispherical reflectance.

(defun tech-pgc-norman-plus (thisunit coeffs)
"Technique norman plus for proportion ground cover."
  (put-in-range (tech-norman-plus thisunit coeffs)))

(defun coeffs-pgc-norman-plus (data)
"Returns the coefficients for the technique norman plus for proportion ground
cover. The argument data is a list of rhd units to be used for calculating the
coefficients."
  (let* ((straight-norman-estimates (get-norman-estimates data))
        (the-b-data (get-true-pgc-values data)))
    (least-squares (make-a-matrix straight-norman-estimates)
                   (make-array (length the-b-data)
                               :initial-contents the-b-data))))


;;; The techniques pgc-2off-nadir-angle-* use the function tech-2off-nadir
;;; and related functions which can be found in the file veg-methods.lisp,
;;; in the section containing the code for the techniques for estimating
;;; spectral hemispherical reflectance.

(defun coeffs-pgc-2off-nadir (data m n)
"Returns the coefficients for a 2off nadir technique for calculating
proportion ground cover. The argument data is a list of rhd units to be used
for calculating the coefficients. The arguments m and n are the positions in
the list of reflectance data to be used in this technique."
   (let ((vector-1
        (mapcar #'(lambda (unit)
                (third (nth  m (get.value unit 'reflectance.data))))
                data))
      (vector-2
        (mapcar #'(lambda (unit)
                (third (nth n (get.value unit 'reflectance.data))))
                data))
      (the-b-data (get-true-pgc-values data)))
     (least-squares (make-a-matrix-3 vector-1 vector-2)
        (make-array (length the-b-data) :initial-contents the-b-data))))

(defun get-true-pgc-values (list-of-units)
"Returns a list of true proportion ground cover values for a list of units."
  (mapcar #'find-true-pgc list-of-units))

(defun tech-pgc-2off-nadir-angle-0 (thisunit coeffs)
"Technique 2 off nadir angle for proportion ground cover."
  (put-in-range (tech-2off-nadir-angle-0 thisunit coeffs)))

(defun coeffs-pgc-2off-nadir-angle-0 (data)
"Calls the function coeffs-pgc-2off-nadir to find the coefficients for applying
the function pgc-2off-nadir to the first and second view angles."
  (coeffs-pgc-2off-nadir data 0 1))
```

```
(defun tech-pgc-2off-nadir-angle-1 (thisunit coeffs)
"Technique 2 off nadir angle for proportion ground cover."
  (put-in-range (tech-2off-nadir-angle-1 thisunit coeffs)))

(defun coeffs-pgc-2off-nadir-angle-1 (data)
"Calls the function coeffs-pgc-2off-nadir to find the coefficients for applying
the function pgc-2off-nadir to the first and third view angles."
 (coeffs-pgc-2off-nadir data 0 2))

(defun tech-pgc-2off-nadir-angle-2 (thisunit coeffs)
"Technique 2 off nadir angle for proportion ground cover."
  (put-in-range (tech-2off-nadir-angle-2 thisunit coeffs)))

(defun coeffs-pgc-2off-nadir-angle-2 (data)
"Calls the function coeffs-pgc-2off-nadir to find the coefficients for applying
the function pgc-2off-nadir to the second and third view angles."
 (coeffs-pgc-2off-nadir data 1 2))

(defun tech-pgc-2off-nadir-angle-3 (thisunit coeffs)
"Technique 2 off nadir angle for proportion ground cover."
  (put-in-range (tech-2off-nadir-angle-3 thisunit coeffs)))

(defun coeffs-pgc-2off-nadir-angle-3 (data)
"Calls the function coeffs-pgc-2off-nadir to find the coefficients for applying
the function pgc-2off-nadir to the first and fourth view angles."
 (coeffs-pgc-2off-nadir data 0 3))

(defun tech-pgc-2off-nadir-angle-4 (thisunit coeffs)
"Technique 2 off nadir angle for proportion ground cover."
  (put-in-range (tech-2off-nadir-angle-4 thisunit coeffs)))

(defun coeffs-pgc-2off-nadir-angle-4 (data)
"Calls the function coeffs-pgc-2off-nadir to find the coefficients for applying
the function pgc-2off-nadir to the second and fourth view angles."
 (coeffs-pgc-2off-nadir data 1 3))

(defun tech-pgc-2off-nadir-angle-5 (thisunit coeffs)
"Technique 2 off nadir angle for proportion ground cover."
  (put-in-range (tech-2off-nadir-angle-5 thisunit coeffs)))

(defun coeffs-pgc-2off-nadir-angle-5 (data)
"Calls the function coeffs-pgc-2off-nadir to find the coefficients for applying
the function pgc-2off-nadir to the third and fourth view angles."
 (coeffs-pgc-2off-nadir data 2 3))

;;; ------------------------------------------------------------------------
;;; Multiple wavelength techniques
;;; ------------------------------------------------------------------------

;;;------------------------------------------------------------------------
;;; Generating Multiple Wavlength Techniques
;;;------------------------------------------------------------------------
```

```
(defun pgc.near.nadir.nd.ok (sample)
"Returns t if the selected sample is suitable for the technique
pgc.near.nadir.nd and nil otherwise.  A sample is suitable if it has
reflectance data in both the red and near infrared bands."
   (declare (ignore sample))
   (let ((waves (mapcar #'(lambda (unit) (get.value unit 'wavelength))
                        (get.values 'estimate.hemispherical.reflectance
                           'current.sample.wavelengths))))
     ; Check required data in red band is available
     (dolist (wav waves
           (return-from pgc.near.nadir.nd.ok nil))
        (when (and (>= wav 0.63)(<= wav 0.69))
          (return-from nil)))
     ; Check required data in nir band is available
     (dolist (wav waves nil)
        (when (and (>= wav 0.76)(<= wav 1.1))
          (return-from pgc.near.nadir.nd.ok t)))))

(defun pgc.norman.plus.nd.ok (sample)
"Returns t if the selected sample is suitable for the technique
pgc.norman.plus.nd and nil otherwise.  A sample is suitable if it has
at least three view angles in both the red and near infrared bands."
   (declare (ignore sample))
   (let ((wave-units (get.values 'estimate.hemispherical.reflectance
                        'current.sample.wavelengths)))
     ; Check required data in red band is available
     (dolist (wav-unit wave-units
           (return-from pgc.norman.plus.nd.ok nil))
        (let ((wav (get.value wav-unit 'wavelength)))
          (when (and (>= wav 0.63)(<= wav 0.69)
                  (>= (get.value wav-unit 'number.view.angles) 3))
           (return-from nil))))
     ; Check required data in nir band is available
     (dolist (wav-unit wave-units nil)
        (let ((wav (get.value wav-unit 'wavelength)))
          (when (and (>= wav 0.76)(<= wav 1.1)
                  (>= (get.value wav-unit 'number.view.angles) 3))
           (return-from pgc.norman.plus.nd.ok t))))))

(defun pick-selected-pgc-mw-techniques ()
"Puts the selected techniques into the slot multiple.wavelength.techniques of
the unit proportion.ground.cover."
   (put.values 'proportion.ground.cover 'multiple.wavelength.techniques
      (get.values 'proportion.ground.cover 'selected.mw.techniques))
   (put.value 'proportion.ground.cover 'message
      "Finished selecting techniques"))
```

```
(defun user-pick-mw-techniques ()
"Initializes values and opens the interface that allows the user to select
the multiple wavelength, proportion ground cover techniques."
  (put.value 'proportion.ground.cover 'action.on.selecting.mw.techniques
     'select.techniques)
  (remove.all.values 'proportion.ground.cover 'selected.mw.techniques)
  (put.value '6.generate.techniques 'description.of.technique "")
  (put.value '6.generate.techniques 'error.message "")
  (unitmsg 'viewport-portion.ground.cover.2 'open-panel!))

(defun open-generate-mw-techniques-interface ()
"Opens the interface for generating the multiple wavelength techniques."
   (remove.all.values 'proportion.ground.cover 'gen.mw.tech.auto.or.manual)
   (put.value 'proportion.ground.cover 'message "")
   (unitmsg 'viewport-portion.ground.cover.3 'open-panel!))

(defun display-selected-mw-techniques ()
"Displays the multiple wavelength, proportion ground cover techniques selected
by the rules."
  (put.value 'proportion.ground.cover 'message (format ()
     "The selected techniques are~{ ~S~}"
     (get-unit-names
         (get.values 'proportion.ground.cover
           'multiple.wavelength.techniques)))))

;;;------------------------------------------------------------------------
;;; Methods for Ranking the Multiple Wavelength Techniques
;;;------------------------------------------------------------------------

(defun open-rank-mw-techniques-interface ()
"Opens the interface that displays the ranked multiple wavelength techniques
and allows the user to specify how many techniques are to be used."
  (remove.all.values 'proportion.ground.cover 'action.on.ranking.mw.techniques)
  (unitmsg 'proportion.ground.cover 'evaluate.samples)
  (put.value 'proportion.ground.cover 'message (format ()
          "Multiple wavelength techniques are~{ ~S~}"
          (get-unit-names
           (get.values 'proportion.ground.cover
             'multiple.wavelength.techniques))))
  (unitmsg 'viewport-portion.ground.cover.4 'open-panel!))

(defun select-best-mw-techniques (num)
"Selects the best multiple wavelength techniques by reducing the set of
selected techniques as necessary."
  (let ((mw-techniques (get.values 'proportion.ground.cover
                          'multiple.wavelength.techniques)))
    (when (> (length mw-techniques) num)
      (put.values 'proportion.ground.cover 'multiple.wavelength.techniques
           (get-best num mw-techniques)))))

;;;------------------------------------------------------------------------
;;; Methods for Executing the Multiple Wavelength Techniques
;;;------------------------------------------------------------------------
```

```
(defun open-execute-mw-techniques-interface ()
"Opens the interface for executing the multiple wavelength techniques."
 (put.value '8.execute.techniques 'message "")
 (remove.all.values '8.execute.techniques 'push.button)
 (et-princ
"Executing multiple wavelength techniques - please wait................  ")
 (unitmsg 'viewport-8.execute.techniques.1 'open-panel!)
 (execute-mw-techniques)
 (et-princ
"Finished executing multiple wavelength techniques
- left mouse on QUIT to continue"))

(defun execute-mw-techniques()
"Displays an error message if no multiple wavelength techniques have been
selected.  Otherwise calls a function to execute the techniques."
 (let ((techs
         (get.values 'proportion.ground.cover
           'multiple.wavelength.techniques)))
   (if (null techs)
        (et-princ "No multiple wavelength techniques specified  ")
        (exe-mw-techniques techs))))

(defun exe-mw-techniques (techs)
"Creates the subclass unit to store the results for this sample - results for
different techniques will be subclasses of this unit. Controls the execution of
the different techniques on the sample."
  (let* ((current-sample (get.value 'estimate.hemispherical.reflectance
                                    'current.sample))
          (parent (e.t.find-parent current-sample))
          (sample-name (unit.name current-sample)))
    (if (not (unitp parent))
         (et-princ (format ()
                          "Results have already been stored for the sample ~S"
                          sample-name))
         (let ((thisunit-name (string sample-name)))
          (dolist (this-tech techs)
            (let* ((new-unit-name
                     (string-append thisunit-name "-"
                                    (string (unit.name this-tech))))
                    (new-unit (intern new-unit-name)))
              (create.unit new-unit 'veg parent)
              (apply-mw-tech this-tech current-sample new-unit)))
          (et-princ (format ()
                     "Finished executing techniques for the sample ~S  "
                     sample-name))))))
```

```
(defun apply-mw-tech (tech thisunit result-unit)
"Applies a multiple wavelength technique to a sample."
  (multiple-value-bind (i.e.rhd-use coeffs)
                (get-mw-coefficients tech thisunit)
    (let* ((tech-method (get.value tech 'technique.method))
          (result (funcall tech-method thisunit coeffs))
          (error-term (calc-mw-error tech-method i.e.rhd-use coeffs
                          result-unit)))
      (store-mw-results result error-term coeffs result-unit))))

(defun calc-mw-error (tech-method ie.rhd coeffs result-unit)
"Function to calculate the error term for all rhd samples and then the rms
error for the sample for the particular technique. The results for each rhd
sample are also stored in new units."
  (let ((error-terms ()))
     (dolist (this-rhd ie.rhd)
         (let* ((ct (get.value this-rhd 'cover.type))
               (ct-name (unit.name ct))
               (new-unit
                (create.unit (gentemp (string ct-name)) 'veg nil
                          result-unit)))
             (multiple-value-bind (calc-result error-prop)
                (get-pgc-error-prop tech-method this-rhd coeffs)
               (push error-prop error-terms)
               (put.value new-unit 'cover.type ct)
               (put.value new-unit 'calc.spectral.hem.result
                     calc-result)
               (put.value new-unit 'shr.error.prop error-prop))))
     (calc-rms-error error-terms)))

(defun store-mw-results (result error-estimate coeffs result-unit)
"Function to store the main results for a sample and technique in the result
unit."
  (put.value result-unit 'calc.spectral.hem.refl (round-to-4-dp result))
  (put.value result-unit 'coeffs coeffs)
  (put.value result-unit 'shr.error.estimate (round-to-4-dp error-estimate)))

(defun put-in-range (result)
"Returns one if the value of the result is greater than one."
  (if (> result 1)
     1
     result))
```

```
(defun get-mw-coefficients (tech sample-unit)
"Method to calculate the coefficients for a technique and sample. Returns
the list of cover-types to be used as historical data, and the appropriate
ceofficients for this technique."
  (let* ((coeffs-p (get.value tech 'coeffs.p))
       (i.e.rhd (get.values sample-unit 'sample.level.i.e.rhd)))
      (if (not coeffs-p)          ;No coefficients for this technique
        (values i.e.rhd nil)     ;Use all rhd for calculations
        (let ((coeff-method (get.value tech 'coeff.method)))
           (multiple-value-bind (i.e.rhd-set coeffs-set)
             (ask-user-about-mw-coeffs i.e.rhd
                          (unit.name tech))
             (values i.e.rhd-set
                 (funcall coeff-method coeffs-set)))))))

(defun ask-user-about-mw-coeffs (i.e.rhd tech-name)
"Asks the user which historical data to use for coefficients and error term
estimation."
(cond ((and
        (eq (get.value 'methods 'processing.mode) 'research) ;research mode
        (> (length i.e.rhd) 3))                     ;large enough rds
     (unitmsg 'viewport-8.execute.techniques.2 'open-panel!)
     (remove.all.values '8.execute.techniques 'reply)
     (put.value '8.execute.techniques 'prompt
         (format ()
             "Executing technique ~S on sample.  The following options are available:-  (1) Use all
the historical data for calculating both the coefficients and the error estimate.  (2) Use half historical
data for calculating the coefficients and the other half for calculating the error estimate.  Make your
choice ->"
             tech-name))
     (et-wait-for-mouse)
     (if (eq 'all.historical.data (get.value '8.execute.techniques 'reply))
         (values i.e.rhd i.e.rhd)
         (split-i.e.rhd i.e.rhd)))
    ((and (eq (get.value 'methods 'processing.mode) 'automatic)
          (eq (get.value 'automatic.process 'auto.all.or.half) 'half))
     (split-i.e.rhd i.e.rhd))
    (t (values i.e.rhd i.e.rhd)))) ;use all if <=3 or selected in auto mode

(defun tech-pgc-near-nadir-nd (thisunit coeffs)
"Function for the proportion ground cover, near nadir, normalized difference
technique ."
  (put-in-range (+ (aref coeffs 0)
                 (* (near-nadir-nd thisunit)
                   (aref coeffs 1)))))

(defun coeffs-pgc-near-nadir-nd (data)
"Function to calculate the coefficients for the proportion ground cover, near
nadir, normalized difference technique ."
  (let ((the-a-data (mapcar #'near-nadir-nd data))
        (the-b-data (get-true-pgc-values data)))
    (least-squares (make-a-matrix the-a-data)
                 (make-array (length the-b-data)
                          :initial-contents the-b-data))))
```

```
(defun near-nadir-nd (sample)
"Returns the near nadir normalized difference."
 (multiple-value-bind (red-unit nir-unit)
    (get-red-and-nir-units sample)
   (let ((red-near-nadir (third (get-nearest-to-nadir
                                  (get.value red-unit 'reflectance.data))))
         (nir-near-nadir (third (get-nearest-to-nadir
                                  (get.value nir-unit 'reflectance.data)))))
    (/ (- red-near-nadir nir-near-nadir)
       (+ red-near-nadir nir-near-nadir)))))

(defun get-red-and-nir-units (sample)
"Returns the names of the units that are members of the sample and contain
data in the red and nir bands."
 (let ((red-unit nil)
       (nir-unit nil))
   (dolist (uni (unit.children sample 'member))
    (let ((wave (get.value uni 'wavelength)))
       (cond ((and (>= wave 0.63)(<= wave 0.68))
              (setf red-unit uni))
             ((and (>= wave 0.76)(<= wave 1.1))
              (setf nir-unit uni)))))
   (values red-unit nir-unit)))

(defun tech-pgc-norman-plus-nd (thisunit coeffs)
"Function for the proportion ground cover, norman plus, normalized difference
technique ."
  (put-in-range (+ (aref coeffs 0)
                   (* (norman-plus-nd thisunit)
                      (aref coeffs 1)))))

(defun coeffs-pgc-norman-plus-nd (data)
"Function to calculate the coefficients for the proportion ground cover, norman
plus, normalized difference technique ."
 (let ((the-a-data (mapcar #'norman-plus-nd data))
       (the-b-data (get-true-pgc-values data)))
   (least-squares (make-a-matrix the-a-data)
                  (make-array (length the-b-data)
                              :initial-contents the-b-data))))

(defun norman-plus-nd (sample)
"Returns the norman plus normalized difference."
 (multiple-value-bind (red-unit nir-unit)
    (get-red-and-nir-units sample)
   (let ((red-norman (apply-norman
                      (get.value red-unit 'reflectance.data)))
         (nir-norman (apply-norman
                      (get.value nir-unit 'reflectance.data))))
    (/ (- red-norman nir-norman)
       (+ red-norman nir-norman)))))
```

```
;;;--------------------------------------------------------------------------
;;; Method for Forming the Multiple Wavelength Results into a String Ready for
;;; Output
;;;--------------------------------------------------------------------------

(defun get-pgc-mw-results (sample)
"Returns a string containing the multiple wavelength proportion ground cover
results."
  (let ((sample-name (unit.name sample))
        (results "Proportion Ground Cover Multiple Wavelength Results:-  "))
    (dolist (tech (get.values 'proportion.ground.cover
                              'multiple.wavelength.techniques)
          results)
     (let* ((tech-name (unit.name tech))
          (result-unit (intern (string-append (string sample-name)
                                              "-" (string tech-name)))))
        (setf results (string-append results
    (format () "Technique ~S Estimate ~,4F Error ~,4F Coefficients ~A  "
          tech-name
          (get.value result-unit 'calc.spectral.hem.refl)
          (get.value result-unit 'shr.error.estimate)
          (get-coeff-values result-unit))))))))
```

APPENDIX B

LISTINGS OF FILES PRODUCED BY THE TEST RUNS

Listing of the File pgc-samp4

Results for sample SAMPLE4
Sample input data:
Cover type "example of dense vegetation canopy": Solar Zenith Angle 45:
Ground Cover NIL: Leaf Area Index NIL: Proportion Green NIL:
Dry Biomass NIL: Wet Biomass NIL: Height NIL
Target characterization: Leaf Area Index 2.6937: Ground Cover 0.9270 Proportion Ground Cover Multiple Wavelength Results:- Technique PGC.NEAR.NADIR.ND Estimate 0.7916 Error 0.1185 Coefficients 0.7606 -0.0368

Wavelength 0.68
Reflectance data ((0 0 0.043) (15 182 0.043) (35 45 0.043) (75 90 0.054))
Results:
Technique PGC.NORMAN.PLUS Estimate 0.7917 Error 0.1295 Coefficients 0.7393 1.1107
Technique PGC.2OFF.NADIR.ANGLE.0 Estimate 0.7933 Error 0.1351 Coefficients 0.8819 5.5944 -7.6552
Technique PGC.2OFF.NADIR.ANGLE.1 Estimate 0.0527 Error 0.9416 Coefficients 0.0154 0.0069 0.8592
Restricted Historical Data:
CT8-42-1 CT10-49-1 CT6-45-1 CT7-41-1 CT5-42-1 CT8-56-1 CT5-28-1 CT5-59-1 CT6-63-1 CT7-59-1
Data Characterization:
Nadir data is available
No strings found
Wavelength 0.92
Reflectance data ((0 0 0.5))
Results:
Technique PGC.NEAR.NADIR Estimate 0.6124 Error 0.2002 Coefficients 1.1142 -1.0037
Restricted Historical Data:
CT8-42-2 CT10-49-2 CT6-45-2 CT7-41-2 CT5-42-2 CT8-56-2 CT5-28-2 CT5-59-2 CT6-63-2 CT7-59-2
Data Characterization:
Nadir data is available
No strings found

Listing of the File pgc-samp3

Results for sample SAMPLE3
Sample input data:
Cover type "example of dense vegetation canopy": Solar Zenith Angle 45:
Ground Cover NIL: Leaf Area Index NIL: Proportion Green NIL:
Dry Biomass NIL: Wet Biomass NIL: Height NIL
Target characterization: Leaf Area Index 2.6937: Ground Cover 0.9270 Proportion Ground Cover Multiple Wavelength Results:- Technique PGC.NEAR.NADIR.ND Estimate 0.7916 Error 0.1185 Coefficients 0.7606 -0.0368

Wavelength 0.92
Reflectance data ((0 0 0.5))
Results:
Technique PGC.NEAR.NADIR Estimate 0.6124 Error 0.2002 Coefficients 1.1142 -1.0037

Restricted Historical Data:
CT8-42-2 CT10-49-2 CT6-45-2 CT7-41-2 CT5-42-2 CT8-56-2 CT5-28-2 CT5-59-2 CT6-63-2 CT7-59-2
Data Characterization:
Nadir data is available
No strings found
Wavelength 0.68
Reflectance data ((0 0 0.043) (15 182 0.043) (15 7 0.043) (30 180 0.054) (30 5 0.043) (45 178 0.066) (45 356 0.044) (60 180 0.076) (60 355 0.054) (75 180 0.089) (75 2 0.067) (2 45 0.01) (15 46 0.03) (35 48 0.04) (50 45 0.05) (65 40 0.06) (15 225 0.02) (35 220 0.03) (50 227 0.04) (65 225 0.05) (2 90 0.01) (30 93 0.02) (45 85 0.03) (60 87 0.04) (15 270 0.02) (30 275 0.03) (45 270 0.05) (60 275 0.06))
Results:
Technique PGC.NORMAN.PLUS Estimate 0.7908 Error 0.1647 Coefficients 0.6443 3.0988
Technique PGC.NEAR.NADIR Estimate 0.7808 Error 0.1156 Coefficients 0.8480 -1.5625
Restricted Historical Data:
CT8-42-1 CT10-49-1 CT6-45-1 CT7-41-1 CT5-42-1 CT8-56-1 CT5-28-1 CT5-59-1 CT6-63-1 CT7-59-1
Data Characterization:
Nadir data is available
Strings:
COMPLETE FULL-string with 0 degrees azimuth
COMPLETE FULL-string with 45 degrees azimuth
INCOMPLETE FULL-string with 90 degrees azimuth

Listing of the File pgc-samp7

Results for sample SAMPLE7
Sample input data:
Cover type "Dense green vegetation canopy": Solar Zenith Angle 45:
Ground Cover NIL: Leaf Area Index NIL: Proportion Green NIL:
Dry Biomass NIL: Wet Biomass NIL: Height NIL
No target characterization Proportion Ground Cover Multiple Wavelength Results:- Technique PGC.NEAR.NADIR.ND Estimate 0.6463 Error 0.3210 Coefficients -0.2311 -1.1676

Wavelength 0.92
Reflectance data ((0 0 0.31))
Results:
Technique PGC.NEAR.NADIR Estimate 0.6697 Error 0.6921 Coefficients 0.4351 0.7567
Restricted Historical Data:
CT11-45-2 CT11-58-2 CT5-28-2 CT5-42-2 CT5-59-2 CT5-26-2 CT7-23-2 CT7-41-2 CT7-59-2 CT9-46-2
Data Characterization:
Nadir data is available
No strings found
Wavelength 0.68
Reflectance data ((45 0 0.044) (45 180 0.066) (60 0 0.054) (60 180 0.076))
Results:
Technique PGC.NORMAN.PLUS Estimate 0.6914 Error 0.4951 Coefficients 0.9188 -3.9599
Technique PGC.2OFF.NADIR.ANGLE.0 Estimate 0.7412 Error 0.4693 Coefficients 0.9112 4.2767 -5.4267
Technique PGC.2OFF.NADIR.ANGLE.1 Estimate 0.0645 Error 0.8630 Coefficients 0.0064 1.4208 -0.0817

Technique PGC.2OFF.NADIR.ANGLE.2 Estimate 0.7297 Error 0.4872 Coefficients 0.8634 -4.6006 3.1480
Technique PGC.2OFF.NADIR.ANGLE.3 Estimate 0.7312 Error 0.8346 Coefficients 0.8264 2.3740 -2.6269
Technique PGC.2OFF.NADIR.ANGLE.4 Estimate 0.6956 Error 0.1260 Coefficients 0.9684 -7.2136 2.6751
Technique PGC.2OFF.NADIR.ANGLE.5 Estimate 0.7821 Error 1.0843 Coefficients 0.7050 7.7256 -4.4745
Technique PGC.NEAR.NADIR Estimate 0.6633 Error 0.5509 Coefficients 0.8403 -4.0226
Restricted Historical Data:
CT11-45-1 CT11-58-1 CT5-28-1 CT5-42-1 CT5-59-1 CT5-26-1 CT7-23-1 CT7-41-1 CT7-59-1 CT9-46-1
Data Characterization:
Nadir data is not available
Strings:
NIL NIL-string with 0 degrees azimuth

Listing of the File pgc-samp7-auto

Results for sample FILE-SAMPLE-399
Sample input data:
Cover type NIL: Solar Zenith Angle 45:
Ground Cover NIL: Leaf Area Index NIL: Proportion Green NIL:
Dry Biomass NIL: Wet Biomass NIL: Height NIL
No target characterization Proportion Ground Cover Multiple Wavelength Results:- Technique PGC.NEAR.NADIR.ND Estimate 0.6463 Error 0.3210 Coefficients -0.2311 -1.1676

Wavelength 0.68
Reflectance data ((45 0 0.044) (45 180 0.066) (60 0 0.054) (60 180 0.076))
Results:
Technique PGC.NORMAN.PLUS Estimate 0.6914 Error 0.4951 Coefficients 0.9188 -3.9599
Technique PGC.2OFF.NADIR.ANGLE.0 Estimate 0.7412 Error 0.4693 Coefficients 0.9112 4.2767 -5.4267
Technique PGC.2OFF.NADIR.ANGLE.1 Estimate 0.0645 Error 0.8630 Coefficients 0.0064 1.4208 -0.0817
Technique PGC.2OFF.NADIR.ANGLE.2 Estimate 0.7297 Error 0.4872 Coefficients 0.8634 -4.6006 3.1480
Technique PGC.2OFF.NADIR.ANGLE.3 Estimate 0.7312 Error 0.8346 Coefficients 0.8264 2.3740 -2.6269
Technique PGC.2OFF.NADIR.ANGLE.4 Estimate 0.6956 Error 0.1260 Coefficients 0.9684 -7.2136 2.6751
Technique PGC.2OFF.NADIR.ANGLE.5 Estimate 0.7821 Error 1.0843 Coefficients 0.7050 7.7256 -4.4745
Technique PGC.NEAR.NADIR Estimate 0.6633 Error 0.5509 Coefficients 0.8403 -4.0226
Restricted Historical Data:
CT11-45-1 CT11-58-1 CT5-28-1 CT5-42-1 CT5-59-1 CT5-26-1 CT7-23-1 CT7-41-1 CT7-59-1 CT9-46-1
Data Characterization:
Nadir data is not available
Strings:
NIL NIL-string with 0 degrees azimuth
Wavelength 0.92
Reflectance data ((0 0 0.31))

Results:
Technique PGC.NEAR.NADIR Estimate 0.6697 Error 0.6921 Coefficients 0.4351 0.7567
Restricted Historical Data:
CT11-45-2 CT11-58-2 CT5-28-2 CT5-42-2 CT5-59-2 CT5-26-2 CT7-23-2 CT7-41-2 CT7-59-2 CT9-46-2
Data Characterization:
Nadir data is available
No strings found

Listing of the File pgc-samp10

Results for sample SAMPLE10
Sample input data:
Cover type "NIL": Solar Zenith Angle 42:
Ground Cover NIL: Leaf Area Index NIL: Proportion Green NIL:
Dry Biomass NIL: Wet Biomass NIL: Height NIL
Target characterization: Leaf Area Index 1.6186: Ground Cover 0.8256 Proportion Ground Cover Multiple Wavelength Results:- Technique PGC.NORMAN.PLUS.ND Estimate 0.7691 Error 0.1438 Coefficients -0.0316 -1.0491 Technique PGC.NEAR.NADIR.ND Estimate 0.7724 Error 0.1182 Coefficients 0.0124 -0.9994

Wavelength 0.68
Reflectance data ((0 0 0.0425) (15 0 0.0433) (15 45 0.0443) (15 90 0.0461) (15 135 0.0443) (15 180 0.0424) (15 225 0.0397) (15 270 0.0415) (15 315 0.0406) (30 0 0.0433) (30 45 0.0461) (30 90 0.0461) (30 135 0.0516) (30 180 0.0535) (30 225 0.0507) (30 270 0.0461) (30 315 0.0443) (45 0 0.0443) (45 45 0.048) (45 90 0.0507) (45 135 0.0553) (45 180 0.0664) (45 225 0.0599) (45 270 0.0507) (45 315 0.0461) (60 0 0.0535) (60 45 0.0581) (60 90 0.0627) (60 135 0.063599996) (60 180 0.0756) (60 225 0.0655) (60 270 0.059) (60 315 0.0535) (75 0 0.0673) (75 45 0.0738) (75 90 0.0775) (75 135 0.0821) (75 180 0.0894) (75 225 0.0793) (75 270 0.0728) (75 315 0.0784))
Results:
Technique PGC.NORMAN.PLUS Estimate 0.7637 Error 0.1896 Coefficients 0.9323 -3.0073
Technique PGC.NEAR.NADIR Estimate 0.7813 Error 0.1476 Coefficients 1.0488 -6.2942
Restricted Historical Data:
CT6-45-1 CT7-41-1 CT5-42-1 CT8-42-1 CT10-49-1 CT5-26-1 CT5-28-1 CT8-56-1 CT10-28-1 CT11-58-1
Data Characterization:
Nadir data is available
Strings:
COMPLETE FULL-string with 0 degrees azimuth
COMPLETE FULL-string with 45 degrees azimuth
COMPLETE FULL-string with 90 degrees azimuth
Wavelength 0.92
Reflectance data ((0 0 0.3124) (15 0 0.3236) (15 45 0.3275) (15 90 0.31689999) (15 135 0.3002) (15 180 0.3242) (15 225 0.3258) (15 270 0.3125) (15 315 0.3242) (30 0 0.3426) (30 45 0.3593) (30 90 0.3549) (30 135 0.3515) (30 180 0.3699) (30 225 0.3683) (30 270 0.3549) (30 315 0.3482) (45 0 0.3805) (45 45 0.4028) (45 90 0.4129) (45 135 0.39) (45 180 0.4592) (45 225 0.4252) (45 270 0.4006) (45 315 0.39) (60 0 0.4586) (60 45 0.4726) (60 90 0.4771) (60 135 0.4854) (60 180 0.5451) (60 225 0.4938) (60 270 0.462) (60 315 0.4536) (75 0 0.5278) (75 45 0.5451) (75 90 0.5401) (75 135 0.5546) (75 180 0.5741) (75 225 0.5479) (75 270 0.5022) (75 315 0.5122))

Results:
Technique PGC.NORMAN.PLUS Estimate 0.7926 Error 0.1734 Coefficients 0.4582 0.8010
Technique PGC.NEAR.NADIR Estimate 0.7625 Error 0.1803 Coefficients 0.5751 0.6000
Restricted Historical Data:
CT6-45-2 CT7-41-2 CT5-42-2 CT8-42-2 CT10-49-2 CT5-26-2 CT5-28-2 CT8-56-2 CT10-28-2 CT11-58-2
Data Characterization:
Nadir data is available
Strings:
COMPLETE FULL-string with 0 degrees azimuth
COMPLETE FULL-string with 45 degrees azimuth
COMPLETE FULL-string with 90 degrees azimuth

Listing of the File pgc-samp10-auto

Results for sample FILE-SAMPLE-629
Sample input data:
Cover type NIL: Solar Zenith Angle 42:
Ground Cover NIL: Leaf Area Index NIL: Proportion Green NIL:
Dry Biomass NIL: Wet Biomass NIL: Height NIL
Target characterization: Leaf Area Index 1.6186: Ground Cover 0.8256 Proportion Ground Cover Multiple Wavelength Results:- Technique PGC.NORMAN.PLUS.ND Estimate 0.7691 Error 0.1438 Coefficients -0.0316 -1.0491 Technique PGC.NEAR.NADIR.ND Estimate 0.7724 Error 0.1182 Coefficients 0.0124 -0.9994

Wavelength 0.92
Reflectance data ((0 0 0.3124) (15 0 0.3236) (15 45 0.3275) (15 90 0.31689999) (15 135 0.3002) (15 180 0.3242) (15 225 0.3258) (15 270 0.3125) (15 315 0.3242) (30 0 0.3426) (30 45 0.3593) (30 90 0.3549) (30 135 0.3515) (30 180 0.3699) (30 225 0.3683) (30 270 0.3549) (30 315 0.3482) (45 0 0.3805) (45 45 0.4028) (45 90 0.4129) (45 135 0.39) (45 180 0.4592) (45 225 0.4252) (45 270 0.4006) (45 315 0.39) (60 0 0.4586) (60 45 0.4726) (60 90 0.4771) (60 135 0.4854) (60 180 0.5451) (60 225 0.4938) (60 270 0.462) (60 315 0.4536) (75 0 0.5278) (75 45 0.5451) (75 90 0.5401) (75 135 0.5546) (75 180 0.5741) (75 225 0.5479) (75 270 0.5022) (75 315 0.5122))
Results:
Technique PGC.NORMAN.PLUS Estimate 0.7926 Error 0.1734 Coefficients 0.4582 0.8010
Technique PGC.NEAR.NADIR Estimate 0.7625 Error 0.1803 Coefficients 0.5751 0.6000
Restricted Historical Data:
CT6-45-2 CT7-41-2 CT5-42-2 CT8-42-2 CT10-49-2 CT5-26-2 CT5-28-2 CT8-56-2 CT10-28-2 CT11-58-2
Data Characterization:
Nadir data is available
Strings:
COMPLETE FULL-string with 0 degrees azimuth
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The Lisp and KEE code for this work is available on a Sun Cartridge Tape.

16. Abstract

The NASA VEGetation Workbench (VEG) is a knowledge based system that infers vegetation characteristics from reflectance data. The VEG subgoal PROPORTION.GROUND.COVER has been completed and a number of additional techniques that infer the proportion ground cover of a sample have been implemented. Some techniques operate on sample data at a single wavelength. The techniques previously incorporated in VEG for other subgoals operated on data at a single wavelength so implementing the additional single wavelength techniques required no changes to the structure of VEG. Two techniques which use data at multiple wavelengths to infer proportion ground cover were also implemented. This work involved modifying the structure of VEG so that multiple wavelength techniques could be incorporated. All the new techniques were tested using both the VEG "Research Mode" and the "Automatic Mode."

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