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BACKSCAT Lidar Backscatter Simulation: User's Guide for Version 2.0

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13. ABSTRACT *(Maximum 200 words)*

BACKSCAT is a computer simulation of atmospheric backscatter from a laser radar (lidar) system. The computer code can simulate operating conditions for a variety of viewing, laser system, and atmospheric conditions.

BACKSCAT Version 2 0 has been totally redesigned. The redesign effort has included the addition of several new features as well as improvements to the code. As with Version 1.0, BACKSCAT Version 2.0 is modular in fashion. This allows for further expansion and growth in the code.

Wind dependent desert aerosols and cirrus clouds have been added. Both are based on formulations used in LOWTRAN 7. The cirrus cloud models include standard cirrus clouds as well as subvisual clouds.

An all new User Interface System has also been developed. The new interface is designed to be easy to use while providing the operator with maximum flexibility. The interface system includes a built-in graphics package that permits the user to display the results from a simulation. The interface system also permits the user to include molecular scattering profiles based on a library of built-in model atmospheres or a user-supplied radiosonde profile.

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1 INTRODUCTION

Backscatter from atmospheric aerosols can produce significant returns in monostatic laser radar (lidar) systems. The Optical Environment Division of the Geophysics Directorate of the Phillips Laboratory (PL/OP) is developing lidar systems that will measure this backscatter. To aid in the design and use of such systems, SPARTA has developed a simulation program, BACKSCAT, that calculates the backscatter return for various lidar systems, viewing aspects, and atmospheric conditions.[1] This report describes the features of a new version of the code, BACKSCAT Version 2.0.

BACKSCAT Version 2.0 has been totally redesigned. As with Version 1.0, BACKSCAT Version 2.0 is modular in fashion, as shown in Figure 1. This allows for further expansion and growth in the code. Additional aerosol models have been added and an all new user interface developed. The new interface is designed to be easy to use while providing the operator with maximum flexibility. As with Version 1.0, all simulation and configuration parameters can be changed interactively through an integrated menu interface. The simulation output is written in tabular form to a data file that can be read by standard plotting programs. A log file is

[1] Guivens, Jr., N.R., Rafuse, S.E., Hummel, J.R., and Cheifetz, M.G. (1988) "BACKSCAT Lidar Backscatter Simulation User's Manual for Version 1.0," Air Force Geophysics Laboratory, Hanscom AFB, Massachusetts, AFGL-TR-88-0331, 27 December,ADA 219487.

also generated during the execution of the simulation that provides for verification of simulation inputs and traceability of results.

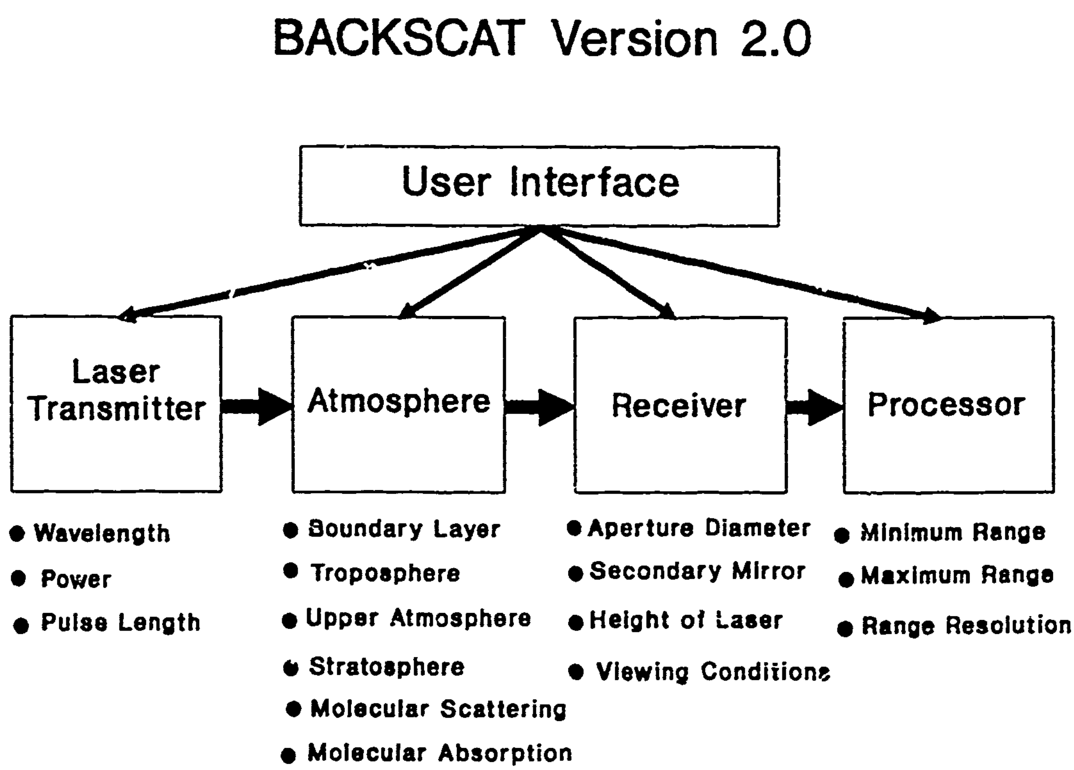

Figure 1. Schematic Representation of BACKSCAT Version 2.0

1.1 Organization of Report

This manual is a user's guide to the operation of BACKSCAT Version 2.0. Section 2 describes the modifications and enhancements made to Version 1.0. Section 3 describes the steps required to install and run the code on a computer system. Section 4 describes the main menu options that are available while Sections 5 and 6 describe how to edit the lidar system and atmospheric parameters, respectively. Section 7 describes how the user can enter radiosonde data for use by the code. Section 8 provides information on running BACKSCAT Version 2.0 in a batch mode and Section 9 provides information on compiling the code. Finally, Section 10 summarizes the results of this effort and provides recommendations for additional developments.

2 DESCRIPTION OF BACKSCAT VERSION 2.0

2.1 Overview of Physics

BACKSCAT Version 2.0 simulates the return from a monostatic lidar through a solution of the lidar equation (*eg.* Klett[2]). The backscatter return observed by a lidar system operating at the wavelength λ is given by

$$P_R(\lambda,r) = P_T\tau c A_R[\beta_m(\lambda,r) + \beta_a(\lambda,r)]\frac{1}{2r^2}\exp\left(-2\int_0^r[\alpha_a(\lambda,r) + \alpha_m(\lambda,r)]dr\right) \quad (1)$$

where $P_R(\lambda, r)$ is the power received from range r, P_T is the transmitted power, τ is the pulse length, c is the speed of light, A_R is the collecting area of the receiver aperture, $\beta_a(\lambda, r)$ is the aerosol backscatter coefficient at range r, $\beta_m(\lambda, r)$ is the molecular backscatter coefficient at range r, $\alpha_a(\lambda, r)$ is the aerosol attenuation coefficient at range r, and $\alpha_m(\lambda, r)$ is the molecular attenuation coefficient at range r.

The lidar return can be normalized by dividing by the transmitter power to obtain the fractional power returned as a function of range. The lidar return can also be range compensated by multiplying by the square of the range to obtain a measure of the actual aerosol levels. Both of these values are calculated and produced by BACKSCAT Version 2.0.

BACKSCAT can be run with molecular backscatter and attenuation contributions included or excluded. One can also selectively include molecular backscattering and neglect molecular absorption and vice versa.

BACKSCAT contains a database of attenuation and backscatter coefficients developed by PL/OP to model atmospheric attenuation properties.[3] The user can also supply a specific set of aerosol and molecular attenuation and backscattering coefficients. The BACKSCAT simulation obtains the attenuation and backscatter coefficients by linear interpolation of an altitude index into a propagation profile table.

2.2 Modifications and Enhancements

BACKSCAT has been extensively modified and enhanced. These changes included the addition of new features and improvements to the old version. The new features added to the code are:

[2] Klett, J.D. (1981) Stable Analytical Inversion Solution for Processing Lidar Returns, *Applied Optics*, 20:211.

[3] Fenn, R.W., Clough, S.A., Gallery, W.O., Good, R.E., Kneizys, F.X, Mill, J.D., Rothman, L.S., Shettle, E.P., Volz, F.E. (1985) "Optical and Infrared Properties of the Atmosphere," Chapter 18 in *Handbook of Geophysics and the Space Environment*, A.S. Jursa Scientific Editor, Air Force Geophysics Laboratory, Hanscom AFB, Massachusetts, AFGL-TR-85-0315, ADA167000.

- Addition of Cirrus Cloud Models
- Addition of Wind Dependent Desert Aerosols
- A Built-In Graphics Package
- User-Defined Molecular Scattering Profiles Based on:
  - Built-in Model Atmospheres
  - User-Supplied Radiosonde Data

Improvements to the code include:

- Improved Method of Computing the Lidar Returns
- Increased Error Checking
- Improvement in Overall Scientific Integrity
- Code Consolidation

2.2.1 Inclusion of Cirrus Cloud Models

Users can now include a single cirrus cloud layer in their BACKSCAT calculations. Currently, cirrus clouds are modeled in the same way as in LOWTRAN 7.[4] Two types of cirrus cloud models are available, a standard cirrus model having a mode radius of 64 μm and a subvisual cirrus model having a mode radius of 4 μm. The attenuation properties of the cloud layer are defined by the cirrus cloud thickness, the cloud base altitude, and the cirrus cloud extinction coefficient at 0.55 μm. Backscattering by cirrus clouds as a function of wavelength has been computed using Mie theory. Table 1 gives a summary of the parameters used to describe cirrus clouds in BACKSCAT Version 2.0. For reference, Figure 2 shows the extinction coefficients for cirrus clouds as a function of wavelength.

2.2.2 Inclusion of a Wind Dependent Desert Aerosols

Desert aerosols in the boundary layer can now be included in BACKSCAT simulations. The attenuation properties of the desert aerosol are taken from Longtin *et al.*[5] Their model gives extinction and backscattering by desert aerosols for wind speeds of 0, 10, 20 and 30 m/s (see Figure 3). Backscattering by desert aerosols is approximated by the Henyey-Greenstein expression for the phase function.

In BACKSCAT Version 2.0, the user is given three options on how to define the extinction and backscattering by desert aerosols:

---

[4] Kneizys, F.X, Shettle, E.P., Abreu, L.W., Anderson, G.P., Chetwynd, J.H., Gallery, W.O., Selby, J.E.A., and Clough, S.A. (1983) "Users Guide to LOWTRAN 7," Air Force Geophysics Laboratory, Hanscom AFB, MA, AFGL-TR-88-0177, ADA206773.

[5] Longtin, D.R., Shettle, E.P., Hummel, J.R., Pryce, J.D. (1988) "A Wind Dependent Desert Aerosol Model: Radiative Properties," Air Force Geophysics Laboratory, Hanscom AFB, MA, AFGL-TR-0112, ADA206164.

Table 1. Parameters Used To Describe Cirrus Clouds in BACKSCAT Version 2.0

PARAMETER	DEFAULTS/OPTIONS
Type	Standard Subvisual
Thickness	1.0 km (Standard) 0.2 km (Subvisual)
Base Altitude	10.0 km
Extinction at 0.55 μm*	0.14 km^{-1}(Standard) 0.028 km^{-1}(Subvisual)

* If the user sets the cirrus extinction to 0.0, BACKSCAT Version 2.0 internally sets the cirrus cloud extinction to a value given by 0.14 $\times$ the cloud thickness.

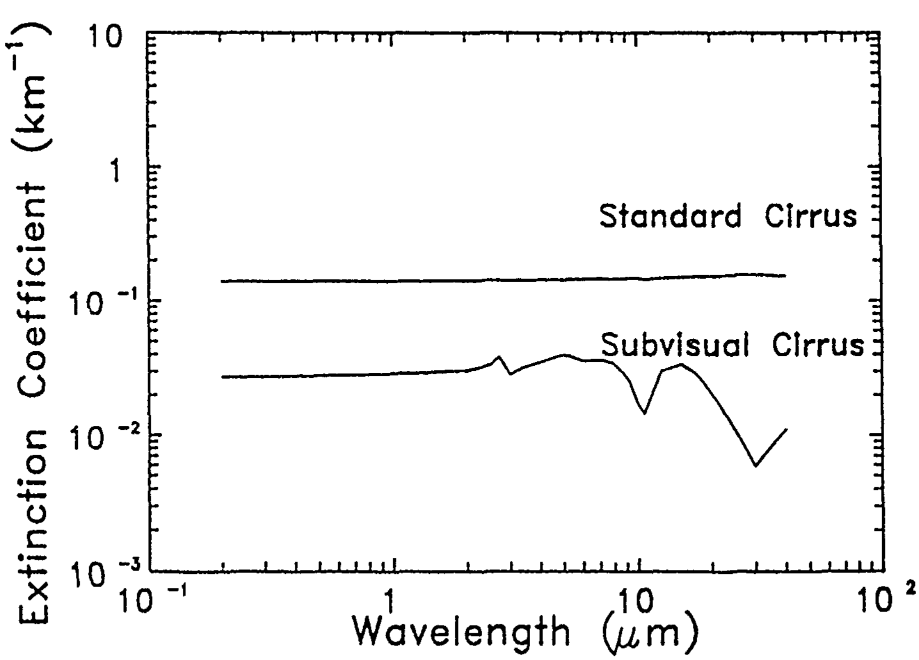

Figure 2. Extinction Coefficients as a Function of Wavelength for Standard and Subvisual Cirrus Cloud Models in BACKSCAT Version 2.0. The values represent standard and subvisual cirrus having thicknesses of 1.0 and 0.2 km, respectively

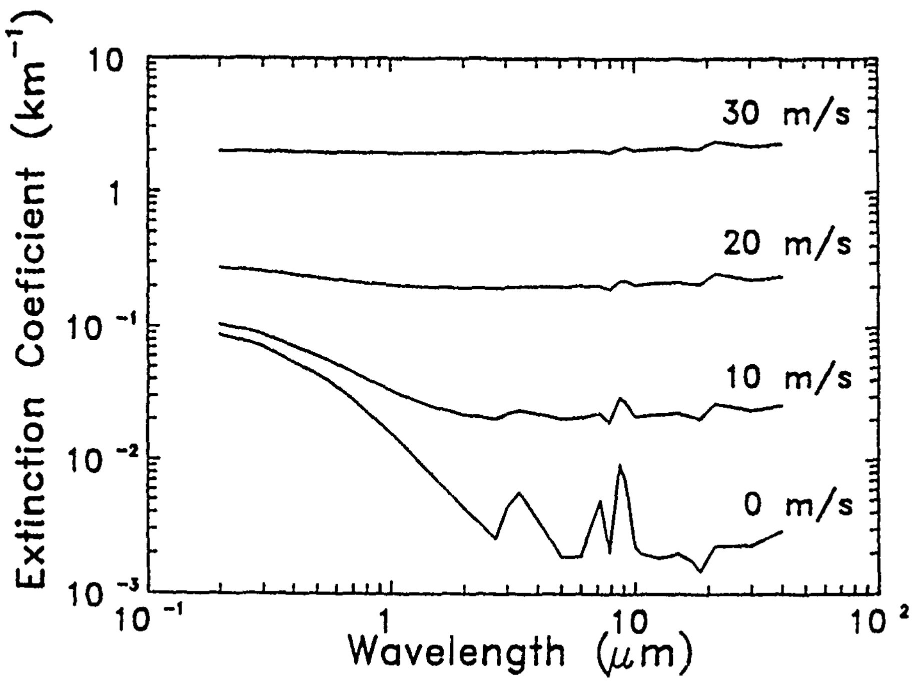

Figure 3. Extinction Coefficients as a Function of Wavelength and Wind Speed for the Desert Aerosol Model[5] in BACKSCAT Version 2.0

Option 1 The user can input the aerosol extinction at the desired lidar wavelength via the BACKSCAT menus.

Option 2 The user can input the surface wind speed and BACKSCAT will determine the aerosol extinction based on the data given in Figure 3. BACKSCAT uses an appropriate interpolation scheme whenever the wind speed does not equal 0, 10, 20 or 30 m/s.

Option 3 The user can input a surface visibility and the extinction will be scaled accordingly. When this option is selected, wavelength scaling factors are based on the surface wind speed in conjunction with the extinction curves in Figure 3.

Section 6 describes how these options are invoked via the BACKSCAT menu system.

2.2.3 User Defined Atmospheric Layer Heights

BACKSCAT Version 2.0 permits users to vary the top of aerosol layers in the boundary layer, troposphere, stratosphere, and upper atmosphere. Although this was an option in the previous version of BACKSCAT, erroneous or undefined values of aerosol extinction often occured during execution.

When the height of an atmospheric layer is changed, BACKSCAT Version 2.0

adapts the extinction coefficient database to match the new layer heights. That is, the database is "stretched" or "squeezed" to conform to the new layer heights rather than extrapolated. The reader is referred to Appendix A for more specifics on how this is accomplished. Figure 4 shows how aerosol extinction profiles change when different boundary layer and troposphere tops are used.

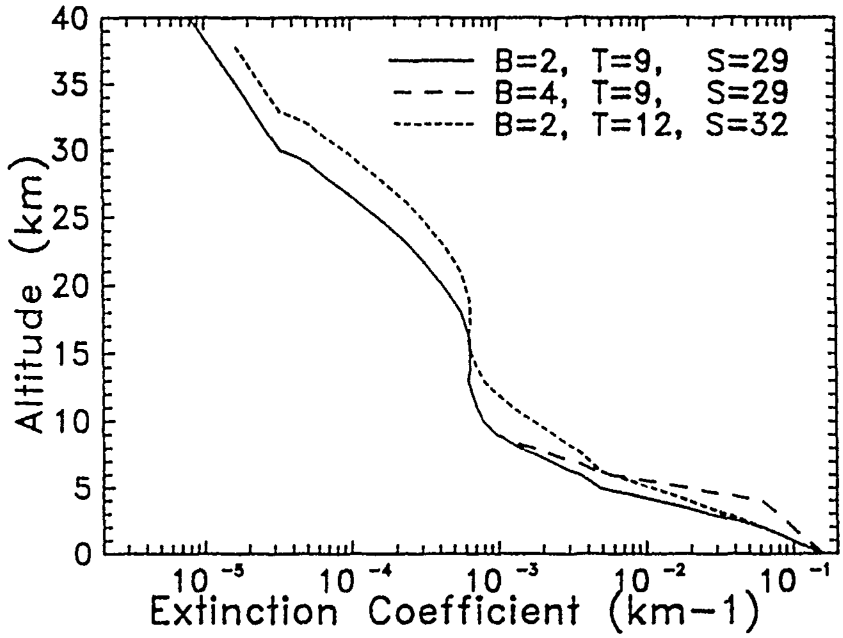

Figure 4. BACKSCAT Aerosol Extinction Profiles For Different Aerosol Layer Tops. In the legend, the values of B, T, S indicate the top of the aerosol layer (in km) for the boundary layer, troposphere and stratosphere respectively. In all examples, the surface visibility is 23 km

2.2.4 Molecular Scattering Profiles for Model Atmospheres

Users can now select from six molecular scattering profiles that correspond to the model atmospheres used in LOWTRAN 7.[4] (BACKSCAT Version 1.0 only used one molecular scattering profile which represented the US Standard Atmosphere.) The six molecular scattering profiles were computed using altitude, pressure, temperature, and humidity data for each model atmosphere, plus equations from Fenn *et al.*[3] The governing equations include effects of water vapor and depolarization. Table 2 shows the six model atmospheres that can now be used to calculate molecular scattering profiles in BACKSCAT Version 2.0.

Table 2. Model Atmospheres Available in BACKSCAT Version 2.0 for use in Calculating Molecular Scattering

MODEL ATMOSPHERE
Tropical
Mid-Latitude Spring/Summer
Mid-Latitude Fall/Winter
Sub-Arctic Spring/Summer
Sub-Arctic Fall/Winter
US Standard (1976)

2.2.5 Molecular Scattering Profiles From Rawinsonde Data

BACKSCAT Version 2.0 allows users to supply rawinsonde data from which molecular scattering is calculated along the BACKSCAT altitude grid. The rawinsonde data can be read from a file or it can be entered manually from a newly developed user interface system (see Section 7). Appendix A describes some computational details involved in calculating the molecular scattering from a radiosonde profile and Appendix B lists a sample radiosonde data file that is included with the package.

2.2.6 Improved Method of Computing Lidar Returns

In BACKSCAT Version 2.0, the standard lidar equation is evaluated using a more accurate numerical integration scheme. Effectively, the standard lidar equation is now evaluated in steps of $ct/2$ (out to the user-specified maximum range) where c is the speed of light and t is the pulse duration. In the previous version of BACKSCAT, by comparison, the lidar equation was only evaluated in steps of the user-specified range resolution. The problem with this earlier approach was that very fine aerosol features would be missed in the backscattering calculations and, consequently, the calculated return would not be representative of a "real" lidar pulse. Given the cirrus cloud option in BACKSCAT Version 2.0, this deficiency would become obvious because cirrus clouds typically have thicknesses less than 1 km. Appendix A contains more details about this revision.

2.2.7 Improvement in Overall Scientific Integrity

While consolidating the atmospheric routines, a few problems were discovered in BACKSCAT Version 1.0. The problems were:

1.) The option to define the boundary layer aerosol extinction as a negative surface visibility did not work
2.) Aerosol attenuation was incorrect when users specified a surface visibility greater than 50 km
3.) Fog models were scaled according to relative humidity (no scaling should be performed)
4.) Wavelength scaling for stratospheric aerosols was used for the upper atmosphere layer (scaling for meteoric dust should be used)

All of the errors have been corrected in BACKSCAT Version 2.0. In addition to correcting the second error, a new scheme for interpolating aerosol attenuation with respect to surface visibility was added. BACKSCAT Version 2.0 now interpolates aerosol attenuation with respect to the reciprocal of visibility. This is a better approach because, by definition, visibility is inversely proportional to aerosol attenuation.

2.2.8 Code Consolidation

An extensive code consolidation and general "cleaning up" of the computer code was performed during this effort. Seeing that BACKSCAT Version 2.0 has an all-new menu interface system, the menu related portions of BACKSCAT Version 1.0 have been eliminated. In addition, many of the original subroutines have been combined with others or eliminated. In general, the resulting code is more compact and efficient than the previous version. Appendix A describes, in greater detail, the code consolidation effort.

3 INSTALLING AND RUNNING BACKSCAT VERSION 2.0

3.1 Overview of Software

The software for BACKSCAT Version 2.0 was written to run on an IBM PC compatible computer. A system with 640 kbytes of memory is recommended. A hard disk is recommended but the code will run without one. The code can be used on either color or monochrome displays, and on systems with or without a floating point processor.

The code is written in C and FORTRAN 77. The menu interface system was written in Microsoft^{TM} C Version 5.1 and utilizes GreenLeaf^{TM} DataWindows software to create the necessary menus for setting up all the simulation conditions and parameters and for performing and analyzing results of a simulation. The menu interface system can be used with or without a mouse. The science portion of the code has been written in Microsoft^{TM} FORTRAN 77 Version 5.0.

Although this version of BACKSCAT Version 2.0 has been designed to run on the IBM PC, the scientific portions of the code are not IBM PC-specific. This portion of the code can be run without the C-based menu interface system. This would allow the science portion of the code to be run on other computer platforms or in batch mode (see Section 8).

3.2 Installing the Program

To install the code, first create a subdirectory to contain the programs and data files. Once this has been completed, insert the diskette containing the executable code and data files into the appropriate disk drive and copy the files into the target subdirectory. The files listed in Table 3 are those required to run the code. The "DEFAULT." files that are also included with the software are a series of data files containing sample data. The "DEFAULT.PFL", "DEFAULT.LOG", "DEFAULT.DAT" are sample output products from the code.

3.3 Starting the Program

To start the program, the user simply types *back* at the main command prompt and hit RETURN. Figure 5 shows the initial screen that is displayed when BACKSCAT Version 2.0 is begun. To proceed to the Main Menu, hit RETURN.*

* The use of RETURN and ENTER will be used interchangeably throughout the report.

Table 3. Files Required to Use BACKSCAT Version 2.0

FILENAME	DESCRIPTION
BACK.EXE	Menu Interface Program
QUIKVIEW.EXE	"Quick View" Graphics Program
RADIO.EXE	Radiosonde Data Entry Program
BACKSCAT.EXE	Backscatter Lidar Solution Program
STANDARD.SCL	Aerosol Profile Data File
MODELS.AER	Aerosol Attenuation Coefficient Data File
MODERN.FON	Font File Required for Graphics

BACKSCAT – LIDAR Backscatter Program
Version 2.0

Developed For:
Phillips Laboratory (AFSC)
Geophysics Directorate
POC: Dr. Robert Beland
(617) 377-4604
By:
SPARTA, Inc., Lexington MA

Press RETURN to continue...

Figure 5. Initial Startup Screen for BACKSCAT Version 2.0

4 MAIN MENU OPTIONS

Figure 6 shows the Main Menu for BACKSCAT Version 2.0. The information shown in Figure 6 represents the default conditions that have been "hard wired" into BACKSCAT Version 2.0. In this and subsequent screen displays, italicized print indicates parameters that can be changed by the user. A line of bold face print indicates the position of the cursor. A bold face letter in a given line of text also represents an "accelerator key." If the bolded letter is typed, the cursor is moved to that line. To execute the command on that line, press the given letter again or RETURN.

BACKSCAT – LIDAR Backscatter Program

FILES TO BE USED:

Configuration Conditions:
Lidar System Parameters:
Atmospheric Model Parameters:
Molecular Absorption Data: *(NONE)*

Propagation Profile: *DEFAULT*
Log Output: *DEFAULT*
Output Data: *DEFAULT*

SIMULATION CONDITIONS:

Propagation Profile from: *BUILT-IN AEROSOL MODELS*
Rayleigh Scattering Based on: *MIDLATITUDE SUMMER* Atmosphere

Change Files to be Used ⇒
Edit Lidar Parameters
Edit Atmospheric Parameters
Change Simulation Conditions
Save Configuration Conditions
Run Calculations
View Results
Exit Program

⇑, ⇓, or Highlighted Letter Match, RETURN to execute.

Figure 6. Main Menu for BACKSCAT Version 2.0

A number of options are available at the Main Menu. These options are listed in the box in the lower center of the Main Menu display. The options are:

- Change Files to be Used
- Edit Lidar Parameters
- Edit Atmospheric Parameters
- Change Simulation Conditions
- Save Configuration Conditions
- Run Calculations
- View Results

- Exit Program

The user selects an option by either using the up and down cursor control keys or a mouse to move the cursor to the desired option and pressing RETURN or by typing the highlighted letter for the desired option and then hitting RETURN once the desired option is highlighted. These options will be discussed in greater detail in the following sections. The discussion on editing the lidar and atmospheric parameters will be found in Sections 5 and 6, respectively.

4.1 Change Files to be Used

BACKSCAT Version 2.0 uses three sets of files during the course of a simulation. One set of files is used to store information about the conditions specified for a lidar simulation. These files can be saved and recalled by the user in subsequent simulations. A second set of files can be optionally used to provide user-supplied data for the calculation. Finally, the third set of files are used for the output generated by BACKSCAT Version 2.0. Appendix B describes the contents of these files. In addition, Appendix B also lists the default files supplied with the code.

To select this option, move the highlighted area (not shown in Figure 6) to the line Change Files to be Used by using the cursor keys or by typing the letter "F" and then press RETURN. A "popup" submenu will appear, as shown in Figure 7, listing the files that can be changed. It is noted that the filenames for the lidar system and atmospheric model parameters are not listed in this submenu. These files can be changed when the "Edit Lidar Parameter" or "Edit Atmospheric Parameters" options are selected (see Sections 5 and 6, respectively.) To change the names of one of the listed files, move the highlighted area to the desired choice and hit RETURN. To exit this option and return to the Main Menu, hit the ESC key. After a change in a file is made, the code returns to the Main Menu.

4.1.1 Change Configuration File

To select this option, the user should move the cursor to the "Change Configuration File" line and press RETURN. The configuration file contains the names of the files with the lidar system and atmospheric model parameters and the information describing the overall simulation conditions, such as the name of the (optional) file with the molecular absorption data, the simulation log output, and the tabular form of the output for the simulation data.

Figure 8 shows the prompt given if the user desires to change the name of the configuration file. The user should type in a name of eight characters or less and then hit RETURN. (The extension in brackets is not typed by the user but is supplied internally by the code.) BACKSCAT Version 2.0 checks to see if the requested file exists and contains data. If the file does not exist, is empty, or

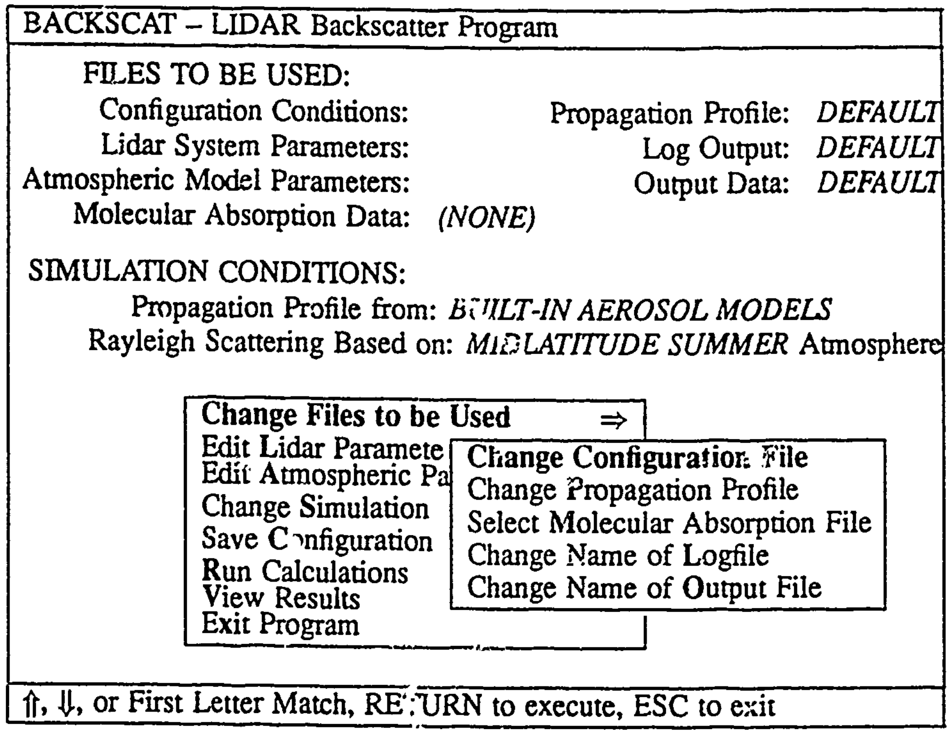

Figure 7. BACKSCAT Submenu for Changing the Names of Files

contains improper values BACKSCAT Version 2.0 alerts the user with an error message as noted in Figure 9. The code will then abort the reading in of the new configuration file and continue with either the default file name or whatever name was last used.

A configuration file is not required to run BACKSCAT Version 2.0. Configuration files are useful if one will be performing a specific type of simulation very often.

4.1.2 Change Propagation Profile

The propagation profile contains the data used by the lidar equation in the calculation of the atmospheric attenuation and backscatter. BACKSCAT Version 2.0 assigns a filename of *DEFAULT* when the program is first started. (On the host computer, this file is listed with an extension of *.pfl.*) If a user-supplied configuration file is being used, the propagation profile name contained in the configuration file will be displayed.

To change the name of the propagation profile, the user should move the cursor to the "Change Propagation Profile" option and press RETURN or type "P". The code will provide a submenu similar to Figure 8 that prompts the user for the name of the Propagation Profile. The user should type in a name of eight characters or less and then hit RETURN. (The extension in brackets is not typed by the user but

BACKSCAT – LIDAR Backscatter Program

FILES TO BE USED:
Configuration Conditions: Propagation Profile: *DEFAULT*
Lidar System Parameters: Log Output: *DEFAULT*
Atmospheric Model Parameters: Output Data: *DEFAULT*
Molecular Absorption Data: *(NONE)*

SIMULATION CONDITIONS:
Propagation Profile from: *BUILT-IN AEROSOL MODELS*
Rayleigh Scattering Based on: *MIDLATITUDE SUMMER* Atmosphere

File Name Entry
Configuration File [.CFG]:

⇑, ⇓, or First Letter Match, RETURN to execute, ESC to exit

Figure 8. BACKSCAT Submenu to Enter the Name of a Desired Configuration File

BACKSCAT – LIDAR Backscatter Program

FILES TO BE USED:
Configuration Conditions: *BADFILE* Propagation Profile: *DEFAULT*
Lidar System Parameters: Log Output: *DEFAULT*
Atmospheric Model Parameters: Output Data: *DEFAULT*
Molecular Absorption Data: *(NONE)*

SIMULATION CONDITIONS:
Propagation Profile from: *BUILT-IN AEROSOL MODELS*
Rayleigh Scattering Based on: *MIDLATITUDE SUMMER* Atmosphere

ERROR Reading Configuration File – No New Values Set
Press ANY Key to continue...

Figure 9. Warning Issued by BACKSCAT Version 2.0 if a Requested Configuration File is Not Found, Empty, or Contains Bad Values

is supplied internally by the code.) Depending on how the simulation conditions are defined (see Section 4.2), the filename specified will either be used to store values calculated internally by BACKSCAT or be used to read the data from a user-supplied file with the specified name. The user should be cautioned that BACKSCAT Version 2.0 **does not** check to see if the name given already exists.

4.1.3 Select Molecular Absorption File

This file is an optional file that contains the molecular absorption data used in the simulation. It is assumed that this file has been created offline by the user and has been prepared in the required format. The format is described in Appendix B.

To select this option, the user should move the cursor to the "Select Molecular Absorption File" line and press RETURN or type the letter "M". The code will provide a submenu similar to Figure 8 that prompts the user for the name of the Molecular Absorption File. The user should type in a name of eight characters or less and then hit RETURN. (The extension in brackets is not typed by the user but is supplied internally by the code.)

4.1.4 Change Name of Logfile

BACKSCAT Version 2.0 keeps a detailed log of the calculations being made and writes this information to this file. The default name of this file is *DEFAULT.* (On the host computer, this file is listed with the extension *.log.*) This file contains a listing of all of the input parameters used for the calculation, a listing of the components of the propagation profile, and the output from the lidar simulation. An example of this file is given in Appendix B.

To change this name, move the cursor to the "Change Name of Logfile" line and press RETURN or type the letter "L". The code will provide a submenu similar to Figure 8 that prompts the user for the name of the Logfile. The user should type in a name of eight characters or less and then hit RETURN. (The extension in brackets is not typed by the user but is supplied internally by the code.) The user is cautioned that BACKSCAT Version 2.0 will not check to see if the name is already in use.

4.1.5 Change Name of Output File

This data file contains the results of the specific BACKSCAT Version 2.0 simulation. Again, BACKSCAT Version 2.0 assigns a default name of *DEFAULT.* It is designed to provide output in a tabular form that can be used with graphics programs. On the host computer, this file is listed with the extension *.dat.* An example of this file is given in Appendix B.

To change the name of the Output File, move the cursor to the "Change Name of Output File" line and press RETURN or type the letter "O." The code will provide a submenu similar to Figure 8 that prompts the user for the name of the Output File. The user should type in a name of eight characters or less and then hit RETURN. (The extension in brackets is not typed by the user but is supplied internally by the code.) Again, BACKSCAT Version 2.0 will not check to see if the name is already in use.

The data in this file consists of seven columns of data:

Column 1: Range (km)

Column 2: Height (km)

Column 3: Optical Depth

Column 4: Lidar Return (W)

Column 5: Normalized Return (Lidar return divided by the transmitted power)

Column 6: Range Compensated Lidar Return (W m^2) (Lidar return multiplied by the square of the range)

Column 7: Normalized Range Compensated Lidar Return (m^2) (Range compensated lidar return divided by the transmitted power)

4.2 Change Simulation Conditions

This option controls two major simulation assumptions required during the calculations. The first assumption is whether the built-in aerosol models will be used to calculate the propagation profile or if the user will supply the propagation profile. The second assumption is if and how Rayleigh scattering is to be accounted for. Figure 10 displays the submenu displayed when this option is invoked. To select a listed option, move the highlighted line to the desired choice or press the highlighted letter. Press the letter again or RETURN.

4.2.1 Change Propagation Profile Source

This option controls whether BACKSCAT Version 2.0 uses the built-in aerosol models to construct the propagation profile or a user-supplied data set. Figure 11 shows the popup menu displayed when this option is selected. Move the highlighted line to the desired choice and press RETURN.

If the choice "User Supplied Data" is selected, BACKSCAT Version 2.0 will read in the propagation profile data from the specified propagation profile file. The user is cautioned that the code does not check, at this point, to see if the specified file exists or is empty. This checking is done at the time of program execution. In other words, it is the user's responsibility to insure that the user supplied propagation profile has been properly created. The reader is referred to Appendix B for instructions on the format of the file containing the propagation profile.

```
BACKSCAT – LIDAR Backscatter Program

  Simulation Conditions
  CURRENT SIMULATION CONDITIONS:
     Propagation Profile Source: BUILT-IN AEROSOL MODELS
     Propagation Profile File [.PFL]: DEFAULT
     Rayleigh Scattering Based on: MIDLATITUDE SUMMER Atmosphere

              Change Propagation Profile Source     ⇒
              Change Propagation Profile File
              Change Rayleigh Scattering Source     ⇒
              Create/Edit Radiosonde File
              EXIT to Main Menu

⇑, ⇓, RETURN to execute/accept, ESC to Previous Menu
```

Figure 10. BACKSCAT Version 2.0 Submenu Used to Change Simulation Conditions

```
BACKSCAT – LIDAR Backscatter Program

  Simulation Conditions
  CURRENT SIMULATION CONDITIONS:
     Propagation Profile Source: BUILT-IN AEROSOL MODELS
     Propagation Profile File [.PFL]: DEFAULT
     Rayleigh Scattering Based on: MIDLATITUDE SUMMER Atmosphere

              Change Propagation Profile Source          ⇒
              Change Propagation Profile   Simulation From:
              Change Rayleigh Scattering   BUILT-IN AEROSOL MODELS
              Create/Edit Radiosonde File  USER SUPPLIED DATA
              EXIT to Main Menu

⇑, ⇓, RETURN to execute/accept, ESC to Previous Menu
```

Figure 11. BACKSCAT Version 2.0 Popup Menu Used to Change the Source of a Propagation Profile

4.2.2 Change Propagation Profile File

This option is used to change the name of the propagation profile. It performs the same operation as the "Change Propagation Profile" option from the Main Menu. If the user chooses to use the built-in aerosol models to construct the propagation data, the file specified is the one into which BACKSCAT *writes* data. If the source of the propagation profile is set as user-supplied data, BACKSCAT will expect to *read* from the specified file. The code will then check to see if the file exists. If it does not, a warning message is given and the operation will be aborted. The user will then have to exit the code altogether and create or load the desired file.

4.2.3 Change Rayleigh Scattering Source

The user may choose to change the source of data for Rayleigh scattering information. Figure 12 displays the popup menu showing the choices. One can choose from a set of six built-in model atmospheres, user-supplied radiosonde data, or having no Rayleigh scattering included in the simulation. The built-in model atmospheres one can choose from are those found in LOWTRAN 7[4] (see Table 2.)

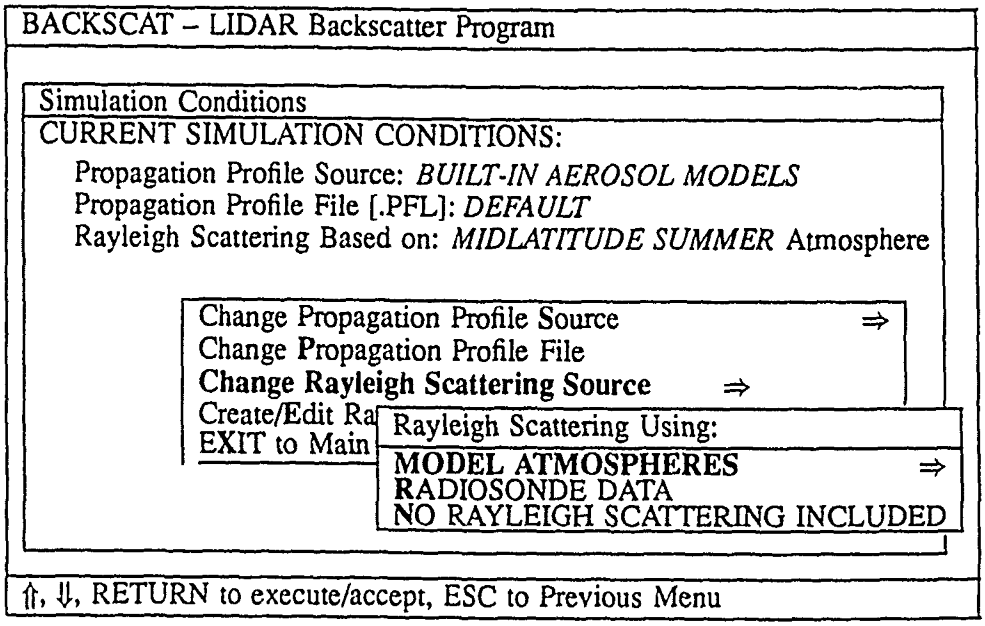

Figure 12. Popup Menu Displaying the Sources of Rayleigh Scattering Data

If the user chooses to use radiosonde data for the Rayleigh scattering, the code will prompt the user for the name of the radiosonde data file. If the file does not exist, the code will give a warning and abort that operation. The user can then create the radiosonde data using the "Create/Edit Radiosonde Data File" option. This option is discussed in greater detail in Section 7.

To return to the Main Menu the user can either highlight the "EXIT to Main Menu" option and hit RETURN, or simply hit the ESC key. In either case, changes made to any of the parameters on this submenu are saved.

4.3 Save Configuration Conditions

This option saves the configuration conditions specified for a particular simulation run. The user is prompted for the name of the file where the configuration values will be stored. BACKSCAT Version 2.0 will display the name of the default or current configuration file name. Either type in a new name and press RETURN or press RETURN to accept the currently listed file name. If the file name already exists, the user will be warned that the file will be overwritten. The user will then be asked to confirm that overwriting the file is acceptable by pressing RETURN or Y and RETURN. To abort the operation, type N and RETURN.

4.4 Run Calculations

When this option is selected, the backscatter simulation is performed. A window is displayed telling the user that the simulation is executing. This portion of the screen will display any errors that occur during the simulation, and will notify the user when the simulation is complete. The user then hits RETURN to return to the Main Menu. A log of the simulation is stored in the Log Output file specified by the user. This log includes a description of the input parameters and any error messages that occurred during the simulation. The data calculated in the simulation are stored in the Output Data file, also specified by the user within the menu interface.

4.5 View Results

The user can choose to view results from the simulation or any previously conducted simulation, by choosing this option from the Main Menu. Figure 13 shows the Quick View Submenu that is displayed.

BACKSCAT – LIDAR Backscatter Program

Quick View Parameters

File to be Plotted [.DAT]: *DEFAULT*
Type of Plot: *ALTITUDE* vs. *BACKSCATTER*

Lowest Altitude/Range: *0.5000*
Highest Altitude/Range: *100.00*

⇑, ⇓, CTRL-ENTER = Plot Results, ESC = Return to Main Menu

Figure 13. BACKSCAT Version 2.0 Submenu for the Quick View Option

The Quick View Submenu will display the name of the currently used output file (see Section 4.1.5). To change the name of the output file to be plotted, type in the new filename.

The user has two choices for the type of plot, the backscatter coefficient as a function of altitude or backscatter coefficient as a function of range. To select from the two options, move the highlighted area to the "Type of Plot" field. A popup menu will appear with the two choices listed, ALTITUDE vs. BACKSCATTER or BACKSCATTER vs. RANGE. Select the desired plot type and press RETURN.

The values given for the lowest and highest altitude/range will be those used in the calculations. However, the user may change these parameters by moving to the given entry and entering new values.

To create the plot, the user should hit the CTRL-ENTER keys. A plot similar to Figure 14 will appear. (The font file *modern.fon* must be located in the current directory or the data will not be plotted and an error message will appear telling the user to move this file to his/her working directory. In addition, the PC computer being used must have graphics capabilities or the data cannot be plotted and an error message indicating that the program cannot set the graphics mode will be printed to the screen.) After viewing the plot, hit RETURN to return to the Quick View Menu. To then return to the Main BACKSCAT Menu, hit the ESC key. The user will be asked to confirm the exit to the Main Menu.

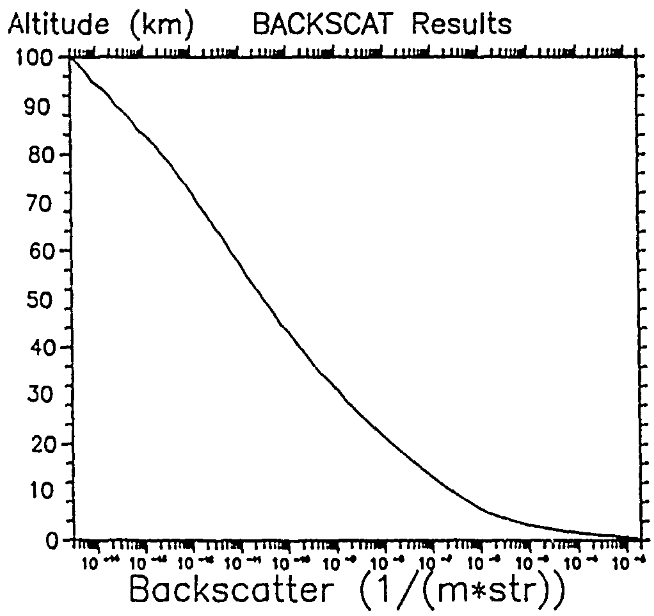

Figure 14. Sample Plot of Backscatter Results as a Function of Altitude Produced by the Quick View Option in BACKSCAT Version 2.0

5 EDIT LIDAR PARAMETERS

This option is selected from the Main Menu by either moving the highlighted area to the "Edit Lidar Parameters" line and pressing RETURN or by pressing the "L" key once or twice. A second menu will appear as shown in Figure 15. The values shown in Figure 15 represent the default values "hardwired" into BACKSCAT Version 2.0. If the user employs a configuration file that includes the name of a file containing specific lidar values, the values in that file will appear instead of those shown in Figure 15 and the name of the file will appear at the top of the menu instead of the name "NONE."

When the Lidar Parameters Submenu first appears, the user will be asked if they want to read in parameters from another file. (This will occur even if a lidar system file was specified in a user-supplied configuration file.) If the answer is "YES" or "Y", the user will be prompted to enter the name of the new file, as shown in Figure 16. BACKSCAT Version 2.0 will check to see that the file exists and if it does not, an error message will be given and the operation aborted. If the file is a valid one, the values in the file will replace those on the Lidar Parameters Submenu. If the user chooses not to read in a new file by responding with a "NO" or "N", the highlighted area will move to the fields with individual laser parameters.

The user can selectively modify any or all lidar parameters by moving the highlighted area to the desired parameter (using the up or down arrow keys), typing in the new values, and hitting RETURN. The program verifies that the new value is within the range limits for that parameter. Table 4 lists the valid ranges for the various parameters. If a given value is not within range, the program will display an error message notifying the user of the range for that particular parameter and prompting them to correct the entry. An example, is shown in Figure 17.

Although the atmosphere through which the laser is propagated is generally limited to a maximum altitude of 100 km, the assumed height of the lidar platform can be above the assumed top of the atmosphere. This feature allows the user to simulate lidars on space platforms. During the calculation of the lidar return, the code stops the propagation at the assumed top of the atmosphere and assumes no further attenuation.

After all changes have been made, the user should hit the CTRL-ENTER keys to exit. The code will ask if you want to write the Lidar Parameters to a file. Answer "Y" or "N." If the answer is "Y," the code will ask the user to enter the name of the file. The name of the current Lidar System File will be listed as the default choice. If this is the file the user wants to use, the code will remind the user that that file already exists and ask for confirmation to overwrite the file. Answer with a "Y" or "N." If the user wishes to save the data to a new file, type in the

BACKSCAT – LIDAR Backscatter Program

Lidar Parameters

Lidar System File: *NONE*

Read parameters from new File? *NO*

Wavelength (microns):	*0.5500*
Pulse Energy (Joules):	*1.0000*
Duration of Pulse (μsec):	*1.0000*
Height of Lidar Sensor (km):	*0.0000*
Elevation Angle (deg):	*90.000*
Azimuth Angle (deg):	*0.000*
Telescope Aperture Diameter (cm):	*100.00*
Obscuring Mirror Diameter (cm):	*2.0000*
Farthest Range (km):	*100.00*
Nearest Range (km):	*0.0000*
Range Resolution (km):	*0.5000*

⇑, ⇓, CTRL-ENTER = Accpt Changes, ESC = Quit

Figure 15. BACKSCAT Lidar System Parameters Submenu

Table 4. Lidar System Parameters Used in BACKSCAT Version 2.0, Default Values Used, and Limits

LIDAR SYSTEM PARAMETER	UNITS	DEFAULT VALUE	LIMITS
Wavelength	microns	0.55	0.2 - 40.0
Pulse Energy	Joules	1.0	> 0
Duration of Pulse	μsec	1.0	>0 & Pulse Duration × 0.1498625 ≤ Range Resolution
Height of Lidar Sensor	km	0.0	≥ 0
Elevation Angle	deg	90.0	-90.0 - 90.0
Azimuth Angle	deg	0.0	0 - 360
Telescope Aperture Diameter	cm	100.0	> 0 and > Obscuring Mirror Diameter
Obscuring Mirror Diameter	cm	2.0	> 0 and < Telescope Aperture Diameter
Farthest Range	km	100.0	> 0 & Nearest Range
Nearest Range	km	0.0	> 0 & < Farthest Range
Range Resolution	km	0.5	> 0 & < Difference Between Farthest and Nearest Range & ≥ Pulse Duration × 0.1498625

BACKSCAT – LIDAR Backscatter Program

Lidar Parameters

Lidar System File: *NONE*

Read parameters from new File? *YES*

Wavelength (microns):	*0.5500*
Pulse Energy (Joules):	*1.0000*
Duration of Pulse (μsec):	*1.0000*
Height of Lidar Sensor (km):	*0.0000*
Elevation Angle (deg):	*90.000*
Azimuth Angle (deg):	*0.000*
Telescope Aperture Diameter (cm):	*100.00*
Obscuring Mirror Diameter (cm):	*2.0000*
Farthest Range (km):	*100.00*

File Entry

Lidar Systems File [.LDR]:

Figure 16. BACKSCAT Lidar System Parameters Submenu Showing the Prompt for the Name of a File Containing the Lidar System Parameters

BACKSCAT – LIDAR Backscatter Program

Lidar Parameters

Lidar System File: *NONE*

Read parameters from new File? *NO*

Wavelength (microns):	*0.5500*
Pulse Energy (Joules):	*1.0000*
Duration of Pulse (μsec):	*1.0000*
Height of Lidar Sensor (km):	*0.0000*
Elevation Angle (deg):	*90.000*
Azimuth Angle (deg):	*0.000*
Telescope Aperture Diameter (cm):	*100.00*
Obscuring Mirror Diameter (cm):	*2.0000*
Farthest Range (km):	*100.00*
Nearest Range (km):	*0.0000*
Range Resolution (km):	*0.5000*

Lidar Wavelength must be in the range 0.2 - 40.0 μm range
Press ANY KEY to continue...

⇑, ⇓, CTRL-ENTER = Accpt Changes, ESC = Quit

Figure 17. Example of an Error Message Given by BACKSCAT Version 2.0 When an Incorrect Value is Entered for a Lidar System Parameter

name of the file and press RETURN. After the data have been saved, the code will return to the Main Menu.

To return to the Main Menu without saving the data, hit the ESC key instead of CTRL-ENTER. The program will ask the user to confirm this operation, since this will not save any changes to the Lidar System file, including any new file read in.

6 EDIT ATMOSPHERIC PARAMETERS

This option is chosen from the Main Menu by either moving the highlighted area to the "Edit Atmospheric Parameters" line and pressing RETURN or by pressing the "A" key twice. The Atmospheric Parameters submenu will then appear as shown in Figure 18. The values shown in Figure 18 represent the default values "hardwired" into BACKSCAT Version 2.0. If the user employs a configuration file that includes the name of a file containing specific atmospheric parameters, the parameters in that file will appear instead of those shown in Figure 18 and the name of the file will appear at the top of the menu instead of the name "NONE."

BACKSCAT – LIDAR Backscatter Program

Atmospheric Parameters

Atmospheric Parameters File: *NONE* **Read in new File?** *N*

Seasonal Distribution: *FALL/WINTER*

Boundary Layer -	Height (km):	*2.00000*
	Type of Aerosols:	*RURAL*
	Relative Humidity (%):	*70.00*
	Visibility at the Surface (km):	*23.0000*
	Wind Speed at 10m (m/s):	*10.0000*
Troposphere -	Height (km):	*9.00000*
	Relative Humidity (%):	*70.00*
Stratosphere -	Height (km):	*29.0000*
	Type of Aerosols:	*STRATOSPHERIC*
	Aerosol Loading:	*BACKGROUND*
Upper Atmosphere -	Height (km):	*100.000*
	Type of Aerosols:	*METEORIC DUST*
	Aerosol Loading:	*NORMAL*
Cirrus Clouds -	Cloud Type:	*NONE*

⇑, ⇓, CTRL-ENTER = Accpt Changes, ESC = Quit

Figure 18. BACKSCAT Atmospheric Parameters Submenu

6.1 Changing Atmospheric Parameters File

When the Atmospheric Parameters Submenu first appears, the user will be asked if they want to read in parameters from another file. (This will occur even if an atmospheric parameters file was specified in a user-supplied configuration file.) If the answer is "YES" or "Y", the user will be prompted to enter the name of the new file, as shown in Figure 19. BACKSCAT Version 2.0 will check to see that the file exists and if it does not, an error message will be given and the operation aborted. If the file is a valid one, the values in the file will replace those in the Atmospheric Parameters Submenu. If the user chooses not to read in a new file type "NO" or "N" or simply move the highlighted area to the fields describing the individual atmospheric components.

BACKSCAT – LIDAR Backscatter Program

Atmospheric Parameters

Atmospheric Parameters File: *NONE* **Read in new File?** *N*

File Name Entry

Atmospheric Parameters File [.ATM]:

	Type of Aerosols:	*RURAL*
	Relative Humidity (%):	*70.00*
	Visibility at the Surface (km):	*23.0000*
	Wind Speed at 10m (m/s):	*10.0000*
Troposphere -	Height (km):	*9.00000*
	Relative Humidity (%):	*70.00*
Stratosphere -	Height (km):	*29.0000*
	Type of Aerosols:	*STRATOSPHERIC*
	Aerosol Loading:	*BACKGROUND*
Upper Atmosphere -	Height (km):	*100.000*
	Type of Aerosols:	*METEORIC DUST*
	Aerosol Loading:	*NORMAL*
Cirrus Clouds -	Cloud Type:	*NONE*

⇑, ⇓, CTRL-ENTER = Accpt Changes, ESC = Quit

Figure 19. BACKSCAT Atmospheric Parameters Submenu Showing the Prompt to Enter the Name of a File Containing the Atmospheric Parameters

6.2 Editing the Atmospheric Parameters

In BACKSCAT Version 2.0, the atmosphere is divided into four layers. From the ground upward, these layers are the boundary layer, the troposphere, the stratosphere, and the upper atmosphere. The layer heights of each layer are user-selectable, unlike in BACKSCAT Version 1.0. The seasonal distribution parameter refers to the seasonal distribution of the aerosols in the boundary layer and troposphere. Table 5 lists the units and ranges for the atmospheric parameters used in BACKSCAT Version 2.0.

The user can now selectively modify any or all of the atmospheric parameters. All numerical values can be changed by simply moving the highlighted area to the desired parameter and typing in a new value. When appropriate, BACKSCAT Version 2.0 will perform error checking on the entered value and warn the user if an incorrect value has been entered.

Text-related atmospheric parameter values have popup submenus that are displayed by hitting the F1 key. The user then chooses from the choices listed in the popup submenus by moving the highlighted area with up and down arrow keys to the desired choice and hitting RETURN to accept it. An alternate method is to type the highlighted letter twice. The Atmospheric Parameters Submenu will then be updated with this new choice.

6.2.1 Boundary Layer Parameters

For the boundary layer, the user is allowed to specify the height of the boundary layer, the type of aerosols, the relative humidity at the surface, and either the visibility at the surface or the extinction coefficient at the surface. When the highlighted area is on the field containing the type of aerosols, one can select from the available choices by hitting the F1 key. A popup menu will appear, as shown in Figure 20. Select the new aerosol type and hit RETURN.

The user can either establish the visibility at the surface or the extinction coefficient. To switch from one to the other, hit the F1 key.

When desert aerosols are chosen for the boundary layer, the wind speed at a height of 10 meters must also be specified. Even though shown on the Atmospheric Parameters Submenu, BACKSCAT Version 2.0 will not allow the user to change the wind speed unless desert aerosols are selected.

6.2.2 Tropospheric Parameters

For the troposphere, the user can vary the height of the troposphere and the relative humidity in the troposphere. To change these values, move the highlighted area to the desired choice and enter a new value. Tropospheric aerosols are assumed to be present throughout the free troposphere.

Table 5. Atmospheric Parameters Used in BACKSCAT Version 2.0, Default Values, and Limits

ATMOSPHERIC PARAMETER	UNITS	DEFAULT VALUE	LIMITS
Seasonal Distribution		Fall/Winter	Fall/Winter, Spring/Summer
Boundary Layer			
Height	km	2.0	> 0 & < Heights of Troposphere Stratosphere, & Top of Atmosphere
Type of Aerosols		Rural	Rural, Maritime, Urban, Tropospheric, Desert, Oceanic Advection Fog, Radiation Fog
Relative Humidity	%	70.0	0 - 100
Visibility at the Surface	km	23.0	0 - 300
Extinction Coefficient at the Surface	1/km	0.158	> 0
Wind Speed at 10 m*	m/s	10.0	0 - 30
Troposphere			
Height	km	9.0	> 0 & > Height of Boundary Layer & < Heights of Stratosphere & Top of Atmosphere
Relative Humidity	%	70.0	0 - 100
Stratosphere			
Height	km	29.0	> 0 & > Heights of Boundary Layer & Troposphere & < Top of Atmosphere
Type of Aerosols		Stratospheric	Stratospheric, Aged Volcanic, Fresh Volcanic
Aerosol Loading		Background	Background, Moderate, High Volcanic, Extreme Volcanic
Upper Atmosphere			
Height	km	100.0	> 0 & > Boundary Layer & > Tropopause & > Stratopause
Type of Aerosols		Meteoric Dust	Meteoric Dust
Aerosol Loading		Normal	Normal or Extreme
Cirrus Clouds		None	None, Standard Cirrus, Subvisual Cirrus
Cloud Base**	km	10.0	≥ 0 & < Top of Atmosphere
Cloud Thickness**	km	1.0	≥ 0 & ≤ 10
Extinction Coefficient**	1/km	0.14	≥ 0†

* Measured above surface. Used only with desert aerosols.

** Used only when cirrus clouds are specified.

† If 0, extinction coefficient given by 0.14 × cloud thickness

```
BACKSCAT – LIDAR Backscatter Program

Atmospheric Parameters
Atmospheric Parameters File: NONE          Read in new File? N
                 Seasonal Distribution: FALL/WINTER

Boundary Layer -      Height (km): 2.00000
              Type of Aerosols: RURAL        Boundary Layer Aerosol Types:
         Relative Humidity (%): 70.00        RURAL
    Visibility at the Surface (km): 23.0000  MARITIME
       Wind Speed at 10m (m/s): 10.0000      URBAN
Troposphere -         Height (km): 9.00000   TROPOSPHERIC
                                             DESERT
         Relative Humidity (%): 70.00        OCEANIC
Stratosphere -        Height (km): 29.0000   ADVECTION FOG
              Type of Aerosols: STRATOSPHE   RADIATION FOG
               Aerosol Loading: BACKGROUND
Upper Atmosphere -    Height (km): 100.000
              Type of Aerosols: METEORIC DUST
               Aerosol Loading: NORMAL

Cirrus Clouds -       Cloud Type: NONE

⇑, ⇓, ENTER = Accpt Aerosol Type for Boundary Layer
```

Figure 20. Popup Menu on the Atmospheric Parameters Submenu Displaying the Choices for Boundary Layer Aerosols

6.2.3 Stratospheric Parameters

For the stratosphere, the user can change the height of the stratosphere, the type of aerosols present, and the degree of aerosol loading. The type of aerosols and aerosol loading choices are contained in popup menus called up by hitting the F1 key when the highlighted area is on the respective fields.

6.2.4 Upper Atmospheric Parameters

For the upper atmosphere, the user can change the height assumed for the top of the atmosphere and the degree of aerosol loading. The choices for aerosol loading are given in a popup menu. Currently, there is only one upper atmosphere aerosol type included in BACKSCAT Version 2.0, meteoric dust.

6.2.5 Cirrus Cloud Parameters

BACKSCAT Version 2.0 offers the option of including cirrus clouds. The user first chooses the type of cirrus cloud by hitting the F1 key to display the available choices as shown in the popup menu displayed in Figure 21. Move the highlighted area to the desired selection and hit RETURN.

If standard cirrus or subvisual cirrus clouds are selected, a second popup menu will appear, as shown in Figure 22. This popup menu is used to enter the cirrus cloud base, thickness, and extinction coefficient. After entries are made, hit the CTRL-ENTER keys to accept the choices and return to the Atmospheric Parameters Submenu. These parameters will then be displayed on the Atmospheric Parameters Menu.

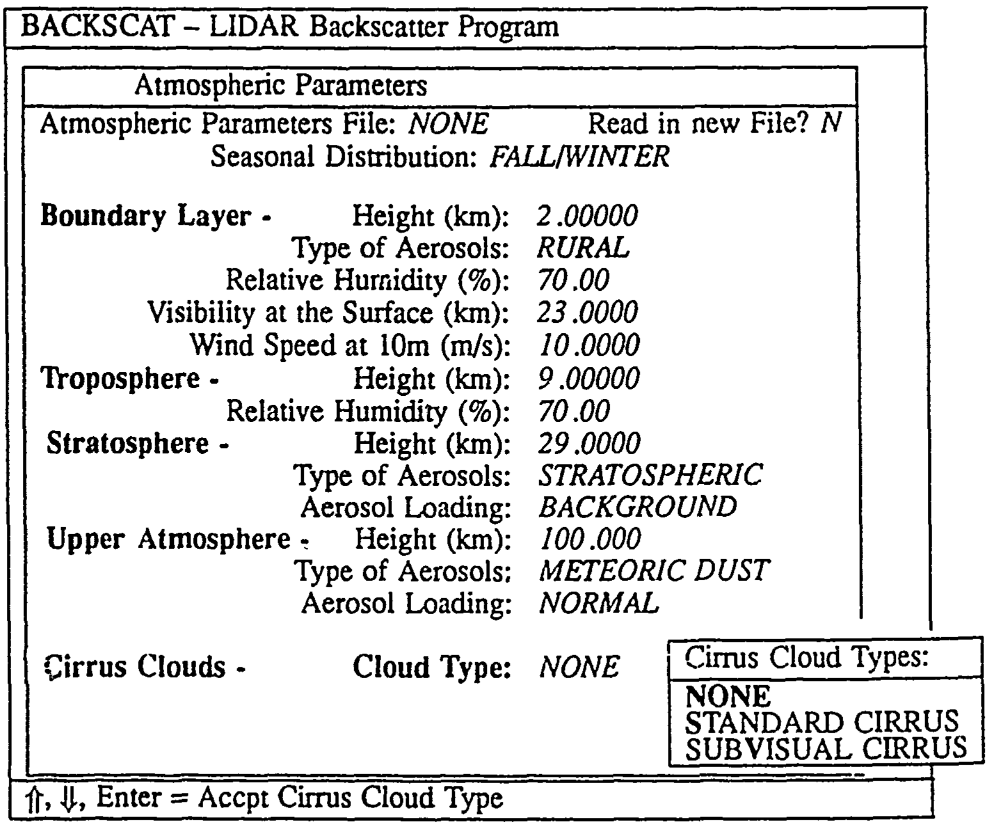

Figure 21. BACKSCAT Cirrus Cloud Type Submenu

```
BACKSCAT – LIDAR Backscatter Program

    Atmospheric Parameters
  Atmospheric Parameters File: NONE          Read in new File? N
              Seasonal Distribution: FALL/WINTER

  Boundary Layer -          Height (km):  2.00000
                      Type of Aerosols:  RURAL
                 Relative Humidity (%):  70.00
          Visibility at the Surface (km):  23.0000
             Wind Speed at 10m (m/s):  10.0000
  Troposphere -             Height (km):  9.00000
                 Relative Humidity (%):  70.00
  Stratosphere -            Height (km):  29.0000
                      Type of Aerosols:  STRATOSPHERIC
                       Aerosol Loading:  BACKGROUND
  Upper Atmosphere -        Height (km):  100.000
                      Type of Aerosols:  METEORIC DUST
                       Aerosol Loading:  NORMAL
      Cirrus Cloud Data
                        Cloud Base (km):  10.0000
                   Cloud Thickness (km):  1.00000
            Extinction Coefficient (1/km):  0.14000

⇑, ⇓, CTRL-ENTER = Accpt Changes, ESC = Quit
```

Figure 22. BACKSCAT Cirrus Cloud Parameters Submenu Used to Specify Cirrus Cloud Data

6.3 Returning to the Main Menu

To accept any changes made to the Atmospheric Parameters and return to the Main Menu, the user should hit the CTRL-ENTER keys. The program will then ask the user if these parameters should be saved to a file. If the answer is "Y", the code will prompt the user for the name of the file. If the name entered is one that already exists, the code will warn the user of this fact and ask for confirmation that overwriting the file is OK. If the user does not want to save the data to a file, type "N" and the code will return to the Main Menu.

To return to the Main Menu without saving any changes in the atmospheric parameters, merely hit the ESC key at anytime during the editing process. The program will ask the user to confirm if this is what they want to do, since this will not save any changes made to the atmospheric parameters, including those read in from a file. (Note that changes made to the cirrus cloud base, thickness and extinction coefficient will be retained if the user hit CTRL-ENTER to exit from the sub-menu for entering these parameters, even if ESC is used to exit from the main Atmospheric Parameters Menu. However, the cirrus cloud type will be reset to its previous value.)

7 RADIOSONDE DATA ENTRY FEATURE

This new feature has been added to BACKSCAT Version 2.0 to aid the user in creating and editing radiosonde data files for use in the calculation of the molecular backscattering. This option can also be used as a standalone program by typing *radio* at the DOS prompt and pressing RETURN. Figure 23 shows the main menu screen for this feature. The options available with this feature are:

- Display Default Units
- Reset to Default Units
- Change Current Units
- Create New Data File
- Edit Data
- Save Data File
- Delete Current Data
- Quit/Restart

RADIONSONDE DATA ENTRY

CURRENT RADIOSONDE UNITS	
Altitude	*m MSL*
Pressure	*mb*
Temperature	*C*
Moisture	*RH(%)*

Display Default Units ⇒
Reset to Default Units
Change Current Units ⇒
Create New Data File
Edit Data ⇒
Save Data File
Delete Current Data
Quit/Restart

Use Cursor or Hit HighLighted Key. ENTER To Select
ESC from MAIN Menu QUITS
ESC from Sub-Menu Retreats 1 Level

Figure 23. Main Menu From BACKSCAT's Radiosonde Data Entry Option

The window at the bottom of the screen contains the instructions for executing the options listed. The user moves the highlighted area to the desired choice with the up or down arrow keys and then hits RETURN or types the highlighted letter to perform that option.

7.1 Setting and Changing the Data Units

The Radiosonde Data Entry feature allows the user to establish the units for the data making up the radiosonde profile. The units being used are displayed in the window at the top of the Main Menu. Table 6 lists the default units, choices of units, and limits on the various radiosonde parameters. The user can also select what data to include in the profile.

Table 6. Radiosonde Parameters Used in the Radiosonde Data Entry Program, Default Units, Units Choices, and Limits on Parameter

RADIOSONDE PARAMETER	DEFAULT UNIT	UNITS CHOICES	LIMITS ON PARAMETER
Altitude	m MSL*	m MSL, m AGL† ft MSL, ft AGL	0 - 100,000 m 0 - 330,000 ft
Pressure	mb	mb, Pa	0.1 - 1100 mb 10 - 110,000 Pa
Temperature	C	C, K, F	-150 C - +150 C 100 K - 450 K -250 F - +250 F
Relative Humidity	%	%	0 - 100
Dew Point Temperature	C	C, K, F	-150 C - +150 C 100 K - 450 K -250 F - +250 F
Station Altitude	m MSL	m, ft	0 - 10,000 m 0 - 30,000 ft

* MSL - Mean Sea Level
† AGL - Above Ground Level

7.1.1 Display Default Units

A set of default units are "hard wired" into the radiosonde data entry option. To display them, select the "Display Default Units" option from the Radiosonde Data Entry Main Menu. A popup window will appear displaying the default units.

7.1.2 Reset to Default Units

To reset the radiosonde units to the default set of units, select the "Reset to Default Units" option. The units being displayed in the top window of the screen will then be reset to the default set.

7.1.3 Change Current Units

The user can also select a set of radiosonde units other than the default values. To change the current units, select the "Change Current Units" option from the Radiosonde Data Entry Main Menu. A popup menu will appear, as shown in Figure 24, listing the radiosonde parameters altitude, pressure, temperature, and moisture for which units are required.

The user chooses which parameter's units to change by again using the up or down arrow keys to highlight the desired choice and hitting RETURN. Another submenu will appear with the available units for that parameter displayed, as shown in Figure 25 for the altitude parameter. The user highlights the units desired and hits return. If the units for altitude are referenced AGL, the user is asked to enter the station altitude in either meters or feet (whichever units are chosen). Once the units have been selected the user is returned to the main menu and the new units are displayed in the top window. The user can retreat one menu level at any time by hitting the ESC key.

7.2 Creating and Editing a Radiosonde Data File

The user can choose to either create a new radiosonde data file or edit an existing file. To create a new file the user chooses the "Create New Data File" option from the main radiosonde menu. The user is then prompted for the filename which is automatically given a ".RSD" extension. Once the user enters the filename, he/she hits F1 to accept the filename or can hit ESC to exit and return to the main menu, as shown in Figure 26. If the file already exists, the user will be told that it exists and the program will display the size of the file and the last time it was modified. The user can still accept the file name by hitting F1 or return to the main menu by hitting ESC.

To edit an existing file the user chooses the "Edit Data" option from the main menu. A submenu appears in which the user chooses to edit an existing file or to edit the currently loaded file displayed in the upper window of the main screen. Similarly to creating a new file, if the user chooses to edit an existing file they are prompted for the filename. If the file exists, the program displays the size of the file and the last time it was modified. The user should hit the F1 key to accept the filename or ESC to return to the main menu. If the file does not exist, the user is given an error message and returned to the main menu.

Once the file name has been accepted, for either the new or existing case, a screen appears for entering the data into the file, as shown in Figure 27. In this figure, the user is editing an existing radiosonde data file. If the user was creating a new file the same screen would appear but the columns of numbers would be empty. To maneuver through the table, the user utilizes the up and down arrow keys and the RETURN key. For example, to move from column to column the

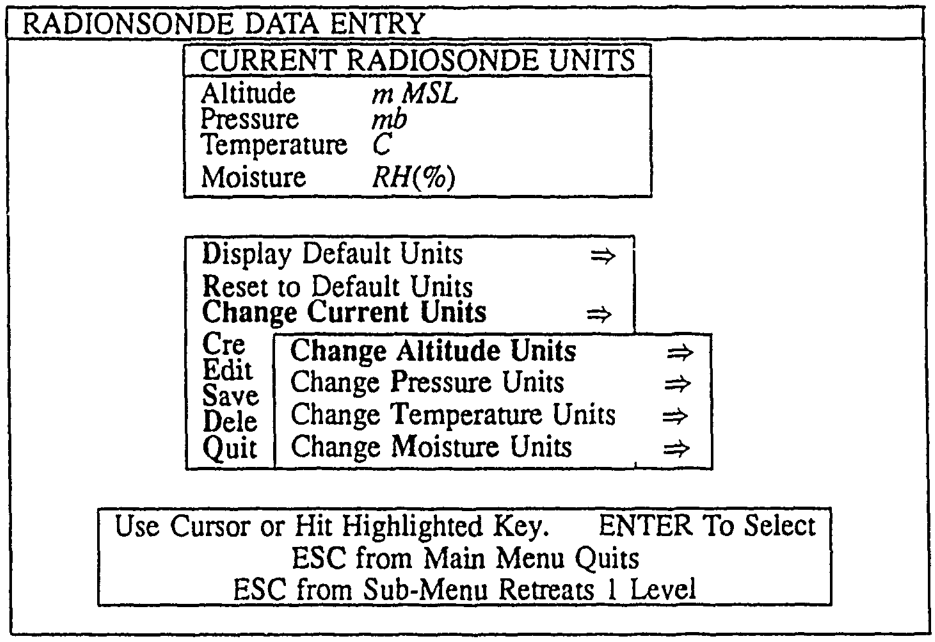

Figure 24. BACKSCAT Version 2.0 Radiosonde Data Entry Submenu to Change the Radiosonde Units

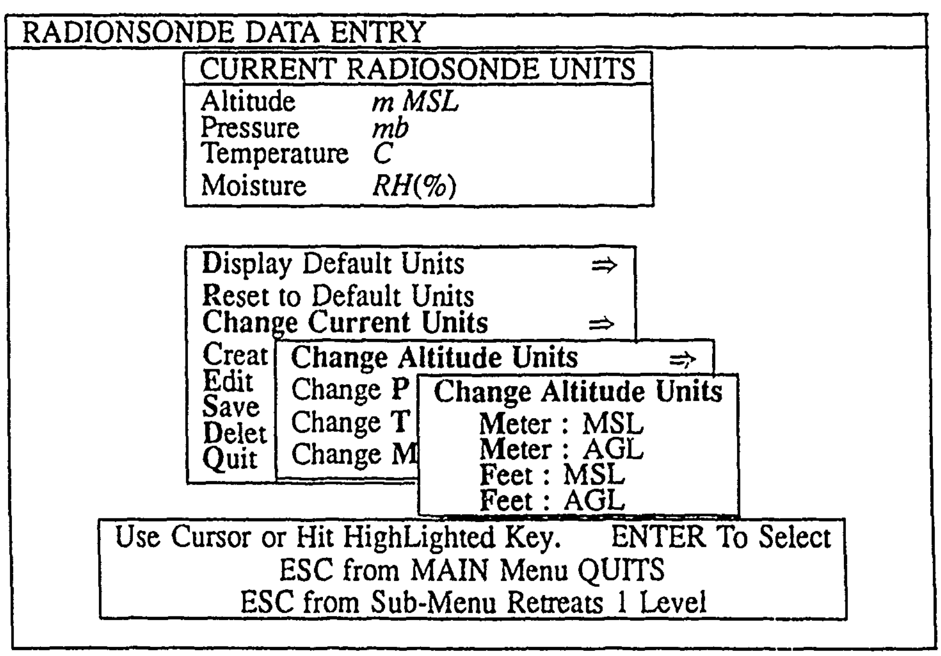

Figure 25. BACKSCAT Version 2.0 Radiosonde Data Entry Submenu to Change Altitude Units

RADIONSONDE DATA ENTRY

CREATE Data File Name

CREATE DATA FILE → *TEST.RSD*

F1 to Accept File Name. ESC to Main Menu

NOTE: New Files of Size 0 Bytes CREATED Here

Figure 26. BACKSCAT Version 2.0 Radiosonde Data Entry Submenu to Create a New Radiosonde Data File

user hits the return key. To move from row to row, the user uses the up and down arrow keys. The current row and column are highlighted and to change a value the user simply types in a value from the keyboard. The user can also scroll down or up by using the "PgDn" and "PgUp" keys, respectively. Once the user has made all of the desired changes, he/she hits CTRL-ENTER to accept the changes. Note that this simply saves the changes within the menu interface - it does **NOT** save the changes in the data file itself. In order to do this the user must select the "Save Data File" from the main menu. If any of the parameters entered are out of range, the user is not allowed to accept the data and error messages indicating which row and column of data are in error are displayed on the screen. If the user chooses to exit to the main menu without saving any of the changes made, they can do so by hitting the ESC key. They are asked to confirm the exit as this will not save any changes made to the data.

The program checks the data to insure that all parameters entered are within their range limits and are entered in sequence. The range limits for each parameter are dependent on the units chosen for each parameter and are as listed in Table 6. If an error is made while entering the data and any of these parameters are out of range, the program will display an error message similar to the one shown in Figure 28. The value of the parameter out of range is given, followed by the applicable range and the row number containing the error. Note that the error message will not be displayed until the user hits CTRL-ENTER to accept the changes made to the data. The error message will remain until the user hits CTRL-ENTER a second time after the data have been corrected. In addition, if there is more than one error in the data, the program only displays the first error it encounters. Subsequent errors will not be found until the user tries to exit again.

In addition to being within range, certain data must be entered in the correct

RADIONSONDE DATA ENTRY

	ALTITUDE (m)	PRESSURE (mb)	TEMPERATURE (C)	MOISTURE (RH(%))
1	79.00	1003.50	23.90	74.00
2	110.00	1000.00	23.60	74.00
3	555.00	950.00	18.60	87.00
4	585.00	946.84	18.30	88.00
5	1017.00	900.00	15.00	96.00
6	1091.00	892.55	14.50	97.00
7	1328.00	867.92	13.50	96.00
8	1498.00	850.68	11.60	74.00
9	1500.00	850.00	11.70	71.00
10	1582.00	842.17	12.60	37.00
11	1717.00	828.93	18.10	11.00

Ctrl-ENTER To ACCEPT DATA
ESC from MAIN Menu
ALTITUDE REFERENCE *MSL*
UNITS: Alt → *m* , P → *mb* , T → *C* , M → *RH(%)*

Figure 27. BACKSCAT Version 2.0 Radiosonde Data Entry Submenu to Enter and Edit Data

RADIONSONDE DATA ENTRY

	ALTITUDE (m)	PRESSURE (mb)	TEMPERATURE (C)	MOISTURE (RH(%))
1	79.00	1003.50	23.90	74.00
2	200000.00	1000.00	23.60	74.00
3	555.00	950.00	18.60	87.00
4	585.00	946.84	18.30	88.00
5	1017.00	900.00	15.00	96.00
6	1091.00	892.55	14.50	97.00
7	1328.00	867.92	13.50	96.00
8	1498.00	850.68	11.60	74.00
9	1500.00	850.00	11.70	71.00
10	1582.00	842.17	12.60	37.00
11	1717.00	828.93	18.10	11.00

DATA ERROR!
Altitude = 200000.0 Out of Range: 0.0 to 100000.0 Row 2

Ctrl-ENTER To ACCEPT DATA
ESC from MAIN Menu
ALTITUDE REFERENCE *MSL*
UNITS: Alt → *m* , P → *mb* , T → *C* , M → *RH(%)*

Figure 28. Sample Warning Message Displayed During the Entry of Radiosonde Data

sequence. Specifically, the altitude data must be entered in increasing order, and the pressure data must be entered in decreasing order. The program will display an error message indicating the row number out of order if the data is not in the correct order. The data must be corrected before the user can save the changes and exit to the main menu. If errors occur and the user wishes to return to the main menu without saving any changes, they can hit the ESC key.

7.3 Save Data File

To save any changes made while either creating a new file or editing an existing file, the user must choose the "Save Data File" option from the main menu. Any changes made in the editing window will **NOT** be saved unless this option is selected. Once the user selects this option, a window appears as shown in Figure 29 indicating the name of the current file, its size and the time it was last modified. The user hits the F1 key to save the data to this file name. If a different file name is desired, the user hits the F2 key and is then prompted for a new file name. If the user decides not to save the data, he/she can hit the ESC key and return to the main menu. Once the user selects F1 to save the data, the data is saved and the user is returned to the main menu.

RADIONSONDE DATA ENTRY

SAVE RADIOSONDE DATA

FILE *TEST.RSD* EXISTS. Size = 1532.
Time Modified : Thu Jan 10 13:32:50 1991
F1 to Accept File Name. F2 to Change Name
ESC for No Action

NOTE: Newly CREATED Files Will Be Size 0 Bytes and EXIST

Figure 29. BACKSCAT Program Save Radiosonde Data File Menu

7.4 Delete Current Data

Once a data file has been loaded (either an existing data file or a newly created data file), that data remains in the editing window. For example, if the user first chooses to edit an existing data file, that file is read in and displayed on the screen. If the user exits from the the editing window (with either CTRL-ENTER or ESC), and then chooses to create a new data file from the main menu, the data from the previously edited file will still show on the screen. Changes can be made to this data and stored in the new file by choosing the "Save Data File" option from the main menu. However, if the user wishes to create a new data file and start with a blank screen in the editing window, he/she must first delete the current data loaded into the program by choosing the "Delete Current Data" option from the main menu. This clears any data stored in the parameter arrays and the user can start editing from scratch. This does **NOT** delete the current data **file**, but only the data that is loaded into the menu interface system. When the user selects the delete option, they are asked to confirm the delete by hitting the F1 key, or hitting ESC to abort the deletion.

7.5 Quit/Restart

This option is chosen from the main menu to either quit the Radiosonde Data Entry program or to restart with all the defaults reset. Figure 30 shows the screen that appears when this option is chosen. The user hits ESC to confirm the quit and exit the Radiosonde Date Entry menus. If the user does not want to quit, they can hit F1 for no action, or F2 to restart the program with all the parameters reset to their default values. The user is again warned, that before quiting they must save all created and changed files by choosing the "Save Data File" option from the main menu if they want these changes to be saved in those files.

```
RADIONSONDE DATA ENTRY

  CONFIRM QUIT
                    ESC to CONFIRM QUIT
                      F1 for No Action
        F2 to RESTART. WARNING : Resets to Default Units.
  ** MAKE SURE YOU SAVED ALL CREATED AND CHANGED FILES! **
```

Figure 30. Quit/Restart Submenu With the Radiosonde Data Entry Option

8 RUNNING BACKSCAT VERSION 2.0 IN BATCH MODE

BACKSCAT Version 2.0 can also be run from outside the menu interface system in batch mode. The user types *backscat* at the main command prompt and the program will prompt the user for the name of the configuration file to use. The program automatically appends the ".CFG" extension on the filename entered by the user. The user must supply a configuration file which contains names of the I/O files to use for the simulation and necessary flags. The contents of a sample configuration file are shown in Appendix B. This file can be created with the menu interface or with a standard text editor. In addition, the input files defined in the configuration file must be created by the user either with the menu interface or with a standard text editor. Note that the filenames contained in the configuration file are entered without extensions; the program automatically appends the appropriate extension to each filename. Both the Lidar System Parameters file and the Atmospheric Parameters file must exist for the program to continue. Examples of the contents of these files are also shown in Appendix B. The propagation profile file must exist if the simulation is using user supplied data for the propagation profile source. If the simulation is using the built-in aerosol models, the propagation profile is generated by the atmospheric model and written to this file.

To plot simulation results from outside the user interface, the user types *quikview* at the main command line prompt. The program will prompt the user for the data file to plot, the type of plot to perform (ALTITUDE vs. BACKSCATTER or BACKSCATTER vs. RANGE), and the range limits for the plot. The data file will then be plotted and the program will exit once the user hits RETURN.

9 COMPILING THE BACKSCAT VERSION 2.0 CODE

The BACKSCAT code is organized into four executable codes. The executable code, *back.exe*, contains the menu interface for BACKSCAT Version 2.0. It is capable of setting up the necessary parameters for a simulation run and executing the code to perform the simulation and to view the results. It is also capable of accessing the program to create/edit radiosonde data files. The GreenLeaf™ DataWindows libraries and MicroSoft™ C Version 5.1 are required to compile the menu interface code. It is then compiled using the make utility and the make file *makemenu*. The user types *make makemenu* at the main command line prompt and the necessary code is compiled and *back.exe* is created. The second executable code, *radio.exe* contains the menus for creating and/or editing radiosonde data files. It also requires the GreenLeaf™ DataWindows libraries and MicroSoft™ C Version 5.1. It is compiled separately from the main menu interface so that it can also be accessed from outside the main BACKSCAT menus. It is compiled by typing *make makerads* at the main command line prompt. This creates the executable file *radio.exe*. The last two executable codes, *backscat.exe* and *quikview.exe* are written in Fortran and contain the code for performing the simulation and for plotting the results, respectively. Both of these codes are compiled with MicroSoft™ Fortran Version 5.0. They can be compiled by the user by typing *make makeback* at the main command line prompt.

10 SUMMARY AND RECOMMENDATIONS FOR FUTURE WORK

10.1 Summary

Backscatter from atmospheric aerosols can produce significant returns in monostatic laser radar (lidar) systems. To aid in the design and use of such systems, SPARTA has developed a simulation program, BACKSCAT, that calculates the backscatter return for various lidar systems, viewing aspects, and atmospheric conditions. This study described the features of a new version of the code, BACKSCAT Version 2.0.

BACKSCAT Version 2.0 has been totally redesigned. The redesign effort has included the addition of several new features as well as improvements to the code. As with Version 1.0, BACKSCAT Version 2.0 is modular in fashion. This allows for further expansion and growth in the code.

Wind dependent desert aerosols and cirrus clouds have been added. Both the desert aerosols and cirrus clouds are based on the formulations used in LOWTRAN 7.[4] The cirrus cloud models include standard cirrus clouds as well as subvisual clouds.

An all new User Interface System has also been developed. The new interface is designed to be easy to use while providing the operator with maximum flexibility. The User Interface System includes a built-in graphics package that permits the user to display the results from a simulation. The User Interface System also permits the user to include molecular scattering profiles based on a library of built-in model atmospheres or a user-supplied radiosonde profile.

10.2 Recommendations for Future Work

BACKSCAT is an evolutionary code. While Version 2.0 offers many new features that increases the usefulness of the code over Version 1.0, the code's growth is not complete.

10.2.1 Adding User-Defined Aerosol Layers

The aerosol models currently used in BACKSCAT Version 2.0 are based on static formulations of atmospheric aerosols. These formulations assume that the aerosol size distributions are fixed temporally as well as spatially.

It is recommended that the ability to add, via the User Interface System, aerosol layers at specific altitudes be added to BACKSCAT. Currently, the user can do this by creating a propagation profile offline and including it as an input file. The addition of user-defined aerosol layers could be accomplished in two different ways. The first would be to give the user the opportunity to selectively change the type of aerosol found at a given altitude. The second way would be to allow the user to "create their own" aerosol layer by specifying a size distribution and aerosol type.

This information would be used with a library of pre-calculated Mie parameters to calculate the attenuation coefficients required to describe an aerosol layer.

10.2.2 Expand to Other Lidar Systems

BACKSCAT Version 2.0 is designed to simulate a backscatter lidar system. However, the Phillips Laboratory is involved in atmospheric studies utilizing other lidar techniques, such as Doppler and Raman systems. The atmospheric simulation concepts adopted with BACKSCAT Version 2.0 can be extended to create a general purpose lidar simulation system that could be used with backscatter, Doppler, and/or Raman lidar systems. The basic atmospheric characterization portion of BACKSCAT Version 2.0 would be used with specific physics modules to enable a user to simulate different lidar systems under various atmospheric conditions.

References

1. Guivens, Jr., N.R., Rafuse, S.E., Hummel, J.R., and Cheifetz, M.G. (1988) "BACKSCAT Lidar Backscatter Simulation User's Manual for Version 1.0," Air Force Geophysics Laboratory, Hanscom AFB, Massachusetts, AFGL-TR-88-0331, 27 December,ADA 219487.
2. Klett, J.D. (1981) Stable Analytical Inversion Solution for Processing Lidar Returns, *Applied Optics*, **20**:211.
3. Fenn, R.W., Clough, S.A., Gallery, W.O., Good, R.E., Kneizys, F.X, Mill, J.D., Rothman, L.S., Shettle, E.P., Volz, F.E. (1985) "Optical and Infrared Properties of the Atmosphere," Chapter 18 in *Handbook of Geophysics and the Space Environment*, A.S. Jursa Scientific Editor, Air Force Geophysics Laboratory, Hanscom AFB, Massachusetts, AFGL-TR-85-0315, ADA167000.
4. Kneizys, F.X, Shettle, E.P., Abreu, L.W., Anderson, G.P., Chetwynd, J.H., Gallery, W.O., Selby, J.E.A., and Clough, S.A. (1983) "Users Guide to LOWTRAN 7," Air Force Geophysics Laboratory, Hanscom AFB, MA, AFGL-TR-88-0177, ADA206773.
5. Longtin, D.R., Shettle, E.P., Hummel, J.R., Pryce, J.D. (1988) "A Wind Dependent Desert Aerosol Model: Radiative Properties," Air Force Geophysics Laboratory, Hanscom AFB, MA, AFGL-TR-0112, ADA206164.

Appendix A

Notes About the Computer Code

A-1. Code Consolidation

A number of small subroutines and logical functions have been eliminated in BACKSCAT Version 2.0. Basically, these routines were combined into existing routines without adding confusion. Also, the program flow in the atmospheric routines has been simplified. Table A-1 lists the routines that were modified in this effort. A fair amount of time has been spent validating these modified routines against those in BACKSCAT Version 1.0.

A-2. Including Cirrus Clouds

BACKSCAT Version 2.0 implements the cirrus cloud model in the routine *cirrus*. When the user opts for a cirrus cloud, the code adds values of cirrus extinction and backscattering to the values of aerosol extinction and backscattering for all height references between the base and top of the cirrus cloud. Additional levels representing the base and top of the cloud are inserted also. Also extra coding in BACKSCAT Version 2.0 insures that the lidar equation is properly evaluated at the boundaries of the cirrus cloud layer.

A-3. Relocating Atmospheric Layer Heights

To relocate the tops of aerosol layers, the routine *newscl* first reads the file *standard.scl* which contains the standard AFGL vertical aerosol extinction profiles. (In these profiles, the tops of the boundary layer, troposphere, stratosphere and upper atmosphere are 2, 9, 29 and 100 km, respectively.) The routine then alters the standard altitude grid so it is consistent with the layer tops defined by the user. For example, when a user defines the top of the boundary layer as 4 km, the altitude grid in the boundary layer is changed from 0, 1, 1.5, 2 km to 0, 2, 3, 4 km. Note that the values of aerosol extinction are not modified in any way. Instead the profiles are stretched or squeezed to conform with the user-defined layer tops. Since no extrapolation is performed in this approach, there is no chance for extreme discontinuities between layers.

A-4. Revision of Aerosol Attenuation Database

A-4-1. Wavelength Scaling Factors

The database containing the wavelength scaling factors used to determine the aerosol attenuation factors has been revised. The data for all aerosol types are now contained in the single file *models.aer*. Previously in BACKSCAT Version 1.0, they were contained in individual files *mod01.aer*, *mod02.aer*, ... Wavelength scaling factors for desert aerosol extinction are stored as models 27, 28, 29 and

Table A-1. Routines Eliminated From, Modified and Added to BACKSCAT Version 2.0

ROUTINES ELIMINATED	ROUTINES MODIFIED	ROUTINES ADDED
visint	*atmpfl*	*wrtatm*
extint	*phget*	*rawin*
rhint		*getmod*
fbscat		*newscl*
wavint		*ldrclt*
lidar		*cirrus*
prsatm		

30. The scaling factors for cirrus extinction are stored as models 31 and 32. The routine *getmod* has been appropriately modified to extract the necessary scaling factors from *models.aer*.

A-4-2. Addition of Model Atmospheres

Users can now select from six molecular scattering profiles that correspond to the GL model atmospheres. The molecular scattering profiles are read into BACKSCAT from the routine *newscl* where a flag determines what model is to be used for BACKSCAT simulations. Table A-2 shows the six molecular scattering profiles that are included in the file *standard.scl*.

Table A-2. Molecular Scattering Profiles Contained in the File *standard.scl*. The profiles represent the molecular scattering at 0.55 μm

COLUMN NO.	MODEL ATMOSPHERE
9	Tropical
10	Mid-Latitude Spring/Summer
11	Mid-Latitude Fall/Winter
12	Sub-Arctic Spring/Summer
13	Sub-Arctic Fall/Winter
14	US Standard (1976)

A-5. Molecular Scattering Profiles From Rawinsonde Data

BACKSCAT Version 2.0 allows users to supply rawinsonde data from which molecular scattering is calculated along the BACKSCAT altitude grid. The rawinsonde data can be read from a file or it can be entered manually from a newly developed user interface system (see Section 7). A file containing rawinsonde data must have a *.rsd* extension. To calculate molecular scattering, each record of rawinsonde data must consist of: altitude, pressure, temperature, relative humidity, or dew point temperature.

When the relative humidity is unavailable, it should be set to 999.0. Additionally, BACKSCAT Version 2.0 permits users to specify rawinsonde data with physical units of their choosing. Because of this, the first record of a rawinsonde file must be a sequence of flags that specify the physical units of the rawinsonde data. The units flags, which are read as (5X,5I3), are shown in Table A-3. An example of a rawinsonde file is shown in Figure A-1.

Table A.3 Description of Units Flags Making Up the First Record of a Rawinsonde File

FLAG NO.	MEANING	POSSIBLE VALUES
1	Reference altitude	0 = Mean sea level 1 = Station altitude
2	Altitude units	0 = Meters 1 = Feet
3	Pressure units	0 = Millibars 1 = Pascals
4	Temperature units	0 = Celsius 1 = Kelvin 2 = Farenheit
5	Moisture units	0 = Relative humidity (%) 1 = Dew point (Celsius) 2 = Dew point (Kelvin) 3 = Dew point (Farenheit)

The routine *rawin* in BACKSCAT Version 2.0 calculates profiles of molecular scattering from rawinsonde data. The routine is called from *newscl*. After reading rawinsonde data and writing it to the BACKSCAT log file, *rawin* first calculates molecular scattering at 0.55 μm for each level of rawinsonde data. Here equations from Fenn *et al.*[3] are used, including the effects of water vapor and depolarization. After applying appropriate wavelength scaling factors, molecular scattering data

0	0	0	0	0
79	1003.50	23.9	74	
110	1000.00	23.6	74	
555	950.00	18.6	87	
585	946.84	18.3	88	
1017	900.00	15.0	96	
1091	892.55	14.5	97	
1328	867.92	13.5	96	
1498	850.68	11.6	74	
1500	850.00	11.7	71	
1582	842.17	12.6	37	
1717	828.93	18.1	11	
2014	800.00	16.6	13	
2560	750.00	13.3	21	
2834	726.55	11.5	33	
2915	719.56	11.4	16	
3117	702.40	10.2	33	
3136	700.00	10.1	32	
3362	682.06	8.9	16	
3747	650.00	6.5	13	
4399	600.00	3.3	12	
4414	599.96	3.3	12	
4950	561.33	-1.8	14	
5096	550.00	-1.4	11	
5205	543.72	-1.3	9	
5851	500.00	-4.3	10	

Figure A-1. Example of File Containing Rawinsonde Data Used To Calculate Molecular Scattering. (Only part of the file is shown for brevity)

are then interpolated on to the BACKSCAT altitude grid according to

$$log(\sigma) = mz + b$$

where σ is the molecular scattering, z is altitude and m and b are linear fit parameters. An extrapolation is used to obtain molecular scattering for any BACKSCAT altitudes below the lowest level of radiosonde data. Above the highest level of radiosonde data, an interpolation is performed using the molecular scattering at highest level of radiosonde data and a value representative of 100 km.

A-6. Improved Method of Computing Lidar Returns

In BACKSCAT Version 2.0, the standard lidar equation is evaluated using a more accurate numerical integration scheme. Effectively, the standard lidar equation is now evaluated in steps of $ct/2$ (out to the user-specified maximum range) where c is the speed of light and t is the pulse duration. In the previous version of BACKSCAT, by comparison, the lidar equation was only evaluated in steps of the user-specified range resolution. The problem with this earlier approach was that very fine aerosol features would be missed in the backscattering calculations and, consequently, the calculated return would not be representative of a "real" lidar pulse. Given the cirrus cloud option in BACKSCAT Version 2.0, this deficiency would become obvious because cirrus clouds typically have thicknesses less than 1 km.

The routine *ldrclt* first calculates lidar returns in increments of $ct/2$ and the results are written to a scratch file. Along the way, lidar returns are also calculated for the following ranges (where applicable):

1.) Range to top of each aerosol layer in the atmosphere

2.) Range to cirrus cloud base/top

3.) Range if path hits the ground

When computing lidar returns, integrated optical depths are computed using the trapezoid rule. At cirrus bases and tops, where sharp discontinuities in attenuation are expected, additional coding has been included to insure that the integrated optical depths accurately represent the path geometry. The results from the scratch file are then used to obtain lidar returns between the user-specified minimum and maximum ranges. Here a linear interpolation is used to obtain lidar returns at the user-specified range resolution.

Appendix B

Sample and Description of Input and Output Files for BACKSCAT Version 2.0

B-1. Configuration, Lidar, and Atmospheric Files

The configuration, lidar, and atmospheric files contain the information required to perform a simulation and can be used to save data from one run to another. Figure B-1 shows the sample configuration file that is included with the BACKSCAT Version 2.0 package. Table B-1 describes the information contained in a configuration file. Figure B-2 shows the sample lidar systems parameters file and Figure B-3 the atmospheric parameters file included with BACKSCAT Version 2.0. The user is referred to Tables 4 and 5, respectively, in the main body of the report for an explanation of the parameters and units for the lidar and atmospheric parameters.

B-2. Propagation Profile

The propagation profile file contains the attenuation data used by BACK-SCAT Version 2.0 to simulate the backscatter return. The file is given with a filename that has the extension *.pfl*. As discussed in the text, the user can either let the code create this file or one can supply one that has been generated externally. Figure B-4 lists a sample of a propagation profile.

The propagation profile consists of a table of seven columns. The entries in the table are:

Column 1: Height (km)
Column 2: Extinction Coefficient (km^{-1})
Column 3: Scattering Coefficient (km^{-1})
Column 4: Absorption Coefficient (km^{-1})
Column 5: Backscatter Coefficient (m^{-1} str^{-1})
Column 6: Molecular Extinction Coefficient (km^{-1})
Column 7: Molecular Backscatter Coefficient(m^{-1} str^{-1})

If the user generates the propagation profile externally to BACKSCAT Version 2.0, the data must be in the order given above with altitudes in increasing order. The current version of the code limits the number of altitudes to one hundred.

B-3. Radiosonde Data

Figure B-5 lists a sample of a radiosonde data file. The first line in the file is a series of flags the set the units being used. The reader is referred to Appendix A for an explanation of the units that are available.

```
    DEFAULT          Lidar System File
    DEFAULT          Atmospheric Parameters File
    DEFAULT          Propagation Profile File
     (NONE)          Molecular Absorption File
    DEFAULT          Simulation Log File
    DEFAULT          Simulation Output File
T T 1 DEFAULT          Flags, Model Atm #, Rawinsonde File
```

Figure B-1. Sample Configuration File (DEFAULT.CFG)

Table B-1. Parameters Contained in the Configuration Conditions File

RECORD	FORMAT	DESCRIPTION
1	(4X,A8)	Lidar System Parameters File
2	(4X,A8)	Atmospheric Parameters File
3	(4X,A8)	Propagation Profile File
4	(4X,A8)	Moiecular Absorption File
5	(4X,A8)	Simulation Log Output File
6	(4X,A8)	Simulation Output Data File
7	(L2,L2,I2,A8)	Logical Flag Indicating Propagation Profile Source T = BUILT-IN AEROSOL MODELS F = USER SUPPLIED DATA Logical Flag Indicating Rayleigh Scattering T = Rayleigh Scattering Included F = Rayleigh Scattering Not Included Model Atmosphere Number 1 = TROPICAL ATMOSPHERE 2 = MIDLATITUDE SUMMER 3 = MIDLATITUDE WINTER 4 = SUBARCTIC SUMMER 5 = SUBARCTIC WINTER 6 = U.S. STANDARD >6 = RAWINSONDE PROFILE (using Radiosonde Data File) Radiosonde Data File

0.550	Wavelength (microns)
1.000	Pulse Energy (J)
1.000	Pulse Duration (usec)
100.000	Aperture Diameter (cm)
2.000	Obscuration Diameter (cm)
0.000	Nearest Range (km)
100.000	Farthest Range (km)
0.500	Range Resolution (km)
0.000	Sensor Height (km)
10.000	Viewing Azimuth Angle (deg)
90.000	Viewing Elevation Angle (deg)

Figure B-2. Sample Lidar System Parameters File (DEFAULT.LDR)

1	Season: 1 = F/W 2 = S/S
2.00	Boundary Layer Height (km)
1	Type of Aerosol
70.00	Relative Humidity (%c)
23.00	Surface Visibility (km)
10.00	Wind Speed at 10 m (m/s)
9.00	Tropopause Height (km)
13	Type of Aerosol
70.00	Relative Humidity (%c)
29.00	Stratopause Height (km)
23	Type of Aerosol
1	Aerosol Loading
100.00	Top of Atmosphere (km)
26	Type of Aerosol
1	Aerosol Loading
1	0=no cirrus, 1=stnd, 2=sub
1.00	Cirrus cloud thickness (km)
10.00	Cirrus cloud base (km)
0.14	Cirrus extinction at 0.55

Figure B-3. Sample Atmospheric Parameters File (DEFAULT.ATM)

.00	1.580E-01	1.494E-01	8.560E-03	3.466E-06	1.120E-02	1.318E-06
1.00	9.910E-02	9.373E-02	5.369E-03	2.174E-06	1.010E-02	1.189E-06
1.50	7.920E-02	7.491E-02	4.291E-03	1.737E-06	9.630E-03	1.134E-06
2.00	6.210E-02	5.874E-02	3.364E-03	1.362E-06	9.160E-03	1.078E-06
3.00	2.720E-02	2.621E-02	9.928E-04	5.918E-07	8.280E-03	9.747E-07
4.00	1.200E-02	1.156E-02	4.380E-04	2.611E-07	7.490E-03	8.817E-07
5.00	4.850E-03	4.673E-03	1.770E-04	1.055E-07	6.750E-03	7.946E-07
6.00	3.540E-03	3.411E-03	1.292E-04	7.702E-08	6.070E-03	7.146E-07
7.00	2.300E-03	2.216E-03	8.395E-05	5.004E-08	5.450E-03	6.416E-07
8.00	1.410E-03	1.359E-03	5.147E-05	3.068E-08	4.880E-03	5.745E-07
9.00	9.800E-04	9.442E-04	3.577E-05	2.132E-08	4.370E-03	5.144E-07
10.00	1.408E-01	1.408E-01	8.266E-07	6.698E-07	3.890E-03	4.579E-07
11.00	1.407E-01	1.407E-01	8.266E-07	6.687E-07	3.460E-03	4.073E-07
12.00	6.630E-04	6.630E-04	3.924E-11	9.468E-09	3.070E-03	3.614E-07
13.00	6.220E-04	6.220E-04	3.682E-11	8.882E-09	2.710E-03	3.190E-07
14.00	6.450E-04	6.450E-04	3.818E-11	9.211E-09	2.320E-03	2.731E-07
15.00	6.430E-04	6.430E-04	3.806E-11	9.182E-09	1.970E-03	2.319E-07
16.00	6.410E-04	6.410E-04	3.794E-11	9.153E-09	1.680E-03	1.978E-07
17.00	6.010E-04	6.010E-04	3.557E-11	8.582E-09	1.440E-03	1.695E-07
18.00	5.630E-04	5.630E-04	3.332E-11	8.040E-09	1.220E-03	1.436E-07
19.00	4.920E-04	4.920E-04	2.912E-11	7.026E-09	1.040E-03	1.224E-07
20.00	4.230E-04	4.230E-04	2.504E-11	6.040E-09	8.860E-04	1.043E-07
21.00	3.520E-04	3.520E-04	2.084E-11	5.027E-09	7.550E-04	8.888E-08
22.00	2.960E-04	2.960E-04	1.752E-11	4.227E-09	6.440E-04	7.581E-08
23.00	2.420E-04	2.420E-04	1.432E-11	3.456E-09	5.510E-04	6.486E-08
24.00	1.900E-04	1.900E-04	1.125E-11	2.713E-09	4.700E-04	5.533E-08
25.00	1.500E-04	1.500E-04	8.879E-12	2.142E-09	3.970E-04	4.674E-08
26.00	1.150E-04	1.150E-04	6.807E-12	1.642E-09	3.390E-04	3.991E-08
27.00	8.950E-05	8.950E-05	5.298E-12	1.278E-09	2.890E-04	3.402E-08
28.00	6.700E-05	6.700E-05	3.966E-12	9.568E-10	2.460E-04	2.896E-08
29.00	5.200E-05	5.200E-05	3.078E-12	7.426E-10	2.090E-04	2.460E-08
30.00	3.320E-05	3.303E-05	1.680E-07	2.029E-09	1.770E-04	2.084E-08
35.00	1.650E-05	1.642E-05	8.348E-08	1.008E-09	7.670E-05	9.029E-09
40.00	8.000E-06	7.959E-06	4.047E-08	4.889E-10	4.220E-05	4.968E-09
45.00	4.020E-06	4.000E-06	2.034E-08	2.457E-10	2.130E-05	2.507E-09
50.00	2.100E-06	2.089E-06	1.062E-08	1.283E-10	1.130E-05	1.330E-09
55.00	1.090E-06	1.084E-06	5.514E-09	6.661E-11	6.240E-06	7.346E-10
60.00	5.780E-07	5.751E-07	2.924E-09	3.532E-11	3.450E-06	4.061E-10
65.00	3.050E-07	3.034E-07	1.543E-09	1.864E-11	1.890E-06	2.225E-10
70.00	1.600E-07	1.592E-07	8.095E-10	9.777E-12	1.000E-06	1.177E-10
75.00	6.950E-08	6.915E-08	3.516E-10	4.247E-12	4.990E-07	5.874E-11
80.00	2.900E-08	2.885E-08	1.467E-10	1.772E-12	2.250E-07	2.649E-11
85.00	1.200E-08	1.194E-08	6.071E-11	7.333E-13	8.860E-08	1.043E-11
90.00	5.100E-09	5.074E-09	2.580E-11	3.116E-13	3.240E-08	3.814E-12
95.00	2.150E-09	2.139E-09	1.088E-11	1.314E-13	1.140E-08	1.342E-12
100.00	9.300E-10	9.253E-10	4.705E-12	5.683E-14	4.420E-09	5.203E-13

Figure B-4. Sample Propagation Profile File (DEFAULT.PFL)

B-4. Molecular Absorption Data

The user can include a file containing a set of molecular absorption coefficients as a function of data. It is assumed that this data file has been created off-line by the user and is for the laser wavelength being used in the simulation. The user is cautioned to note that BACKSCAT Version 2.0, in its current form, has no way to check for what wavelength the absorption file has been produced.

```
        0    0    0     0     0
  79 1003.50 23.9   74
 110 1000.00 23.6   74
 555  950.00 18.6   87
 585  946.84 18.3   88
1017  900.00 15.0   96
1091  892.55 14.5   97
1328  867.92 13.5   96
1498  850.68 11.6   74
1500  850.00 11.7   71
1582  842.17 12.6   37
1717  828.93 18.1   11
2014  800.00 16.6   13
2560  750.00 13.3   21
2834  726.55 11.5   33
2915  719.56 11.4   16
3117  702.40 10.2   33
3136  700.00 10.1   32
3362  682.06  8.9   16
3747  650.00  6.5   13
4399  600.00  3.3   12
4414  599.96  3.3   12
4950  561.33 -1.8   14
5096  550.00 -1.4   11
5205  543.72 -1.3    9
5851  500.00 -4.3   10
```

Figure B-5. Sample Radiosonde Data Input File (RAWIN.RSD). (*Shortened for brevity*)

The name of the file is any valid eight character name. No file extension is assumed. The file containing the molecular absorption must consist of two columns of data. The first column is the altitude in kilometers and the second column is the absorption coefficient in km^{-1}. The data must be arranged with the altitudes in increasing order.

B-5. BACKSCAT Version 2.0 Output Products

BACKSCAT Version 2.0 produces two output products, a log output file and a data output file. The log output file contains a summary of all of the simulation assumptions, a listing of the propagation data used, and the results for the lidar simulation. Figure B-6 lists a sample output from a log output file.

The data output file is a data file that is produced to provide input for graphics programs. The data in this file is the same as the "Lidar Backscatter" section in the log output file. Figure B-7 lists a sample output from a data output file.

```
*****************************************
*                                       *
*     LIDAR Backscatter Simulation      *
*            (Version 2.0)              *
*                                       *
*            Simulation Log             *
*                                       *
*****************************************


            ***** LIDAR SYSTEM *****

Transmitter Parameters:
          Wavelength (um)                      .5500
          Pulse Energy (J)                      1.00
          Pulse Duration (us)                  1.000

Receiver Parameters:
          Aperture Diameter (cm)               100.0
          Obscuration Diameter (cm)              2.0

Viewing Geometry:
          Sensor Height (km)                     .00
          Viewing Azimuth Angle (Deg)           10.0
          Viewing Elevation Angle (Deg)         90.0

Range of the Lidar Calculation:
          Nearest (Minimum) Range (km)            .0
          Farthest (Maximum) Range (km)        100.0
          Range Resolution (km)                   .5


          ***** ATMOSPHERIC MODEL *****

Boundary Layer:
          Aerosol                              RURAL
          Surface Visibility (km)               23.0
          Relative Humidity (Percent)            70.
          Wind Speed (m/s) at 10 m              10.0

Troposphere:
          Relative Humidity (Percent)            70.

Stratosphere:
          Aerosol Composition          STRATOSPHERIC
          Aerosol Profile                 BACKGROUND

Upper Atmosphere:
          Aerosol Profile                     NORMAL

Season:                                  FALL/WINTER
```

Figure B-6. Sample Log Output File (DEFAULT.LOG) (*Cont'd on next page*)

```
Layer Heights:
        Boundary Layer (km)                         2.0
        Troposphere (km)                            9.0
        Stratosphere (km)                          29.0
        Top of Atmosphere (km)                    100.0

Standard Cirrus Cloud Model:
        Cloud Base and Thickness (km)            10.0  1.0
        Cirrus Extinction at 0.55 um (1/km)       .1400
Propagation profile written to file DEFAULT.pfl
```

***** PROPAGATION PROFILE *****

Height (km)	Extinct (1/km)	Scatter (1/km)	Absorp (1/km)	B'scatter (1/m-sr)	Mol Ext (1/km)	Mol B'scat (1/m-sr)
.00	1.580E-01	1.494E-01	8.560E-03	3.466E-06	1.120E-02	1.318E-06
1.00	9.910E-02	9.373E-02	5.369E-03	2.174E-06	1.010E-02	1.189E-06
1.50	7.920E-02	7.491E-02	4.291E-03	1.737E-06	9.630E-03	1.134E-06
2.00	6.210E-02	5.874E-02	3.364E-03	1.362E-06	9.160E-03	1.078E-06
3.00	2.720E-02	2.621E-02	9.928E-04	5.918E-07	8.280E-03	9.747E-07
4.00	1.200E-02	1.156E-02	4.380E-04	2.611E-07	7.490E-03	8.817E-07
5.00	4.850E-03	4.673E-03	1.770E-04	1.055E-07	6.750E-03	7.946E-07
6.00	3.540E-03	3.411E-03	1.292E-04	7.702E-08	6.070E-03	7.146E-07
7.00	2.300E-03	2.216E-03	8.395E-05	5.004E-08	5.450E-03	6.416E-07
8.00	1.410E-03	1.359E-03	5.147E-05	3.068E-08	4.880E-03	5.745E-07
9.00	9.800E-04	9.442E-04	3.577E-05	2.132E-08	4.370E-03	5.144E-07
10.00	1.408E-01	1.408E-01	8.266E-07	6.698E-07	3.890E-03	4.579E-07
11.00	1.407E-01	1.407E-01	8.266E-07	6.687E-07	3.460E-03	4.073E-07
12.00	6.630E-04	6.630E-04	3.924E-11	9.468E-09	3.070E-03	3.614E-07
13.00	6.220E-04	6.220E-04	3.682E-11	8.882E-09	2.710E-03	3.190E-07
14.00	6.450E-04	6.450E-04	3.818E-11	9.211E-09	2.320E-03	2.731E-07
15.00	6.430E-04	6.430E-04	3.806E-11	9.182E-09	1.970E-03	2.319E-07
16.00	6.410E-04	6.410E-04	3.794E-11	9.153E-09	1.680E-03	1.978E-07
17.00	6.010E-04	6.010E-04	3.557E-11	8.582E-09	1.440E-03	1.695E-07
18.00	5.630E-04	5.630E-04	3.332E-11	8.040E-09	1.220E-03	1.436E-07
19.00	4.920E-04	4.920E-04	2.912E-11	7.026E-09	1.040E-03	1.224E-07
20.00	4.230E-04	4.230E-04	2.504E-11	6.040E-09	8.860E-04	1.043E-07
21.00	3.520E-04	3.520E-04	2.084E-11	5.027E-09	7.550E-04	8.888E-08
22.00	2.960E-04	2.960E-04	1.752E-11	4.227E-09	6.440E-04	7.581E-08
23.00	2.420E-04	2.420E-04	1.432E-11	3.456E-09	5.510E-04	6.486E-08
24.00	1.900E-04	1.900E-04	1.125E-11	2.713E-09	4.700E-04	5.533E-08
25.00	1.500E-04	1.500E-04	8.879E-12	2.142E-09	3.970E-04	4.674E-08
26.00	1.150E-04	1.150E-04	6.807E-12	1.642E-09	3.390E-04	3.991E-08
27.00	8.950E-05	8.950E-05	5.298E-12	1.278E-09	2.890E-04	3.402E-08
28.00	6.700E-05	6.700E-05	3.966E-12	9.568E-10	2.460E-04	2.896E-08

Figure B-6. Sample Log Output File (DEFAULT.LOG) (*Cont'd on next page*)

29.00	5.200E-05	5.200E-05	3.078E-12	7.426E-10	2.090E-04	2.460E-08
30.00	3.320E-05	3.303E-05	1.680E-07	2.029E-09	1.770E-04	2.084E-08
35.00	1.650E-05	1.642E-05	8.348E-08	1.008E-09	7.670E-05	9.029E-09
40.00	8.000E-06	7.959E-06	4.047E-08	4.889E-10	4.220E-05	4.968E-09
45.00	4.020E-06	4.000E-06	2.034E-08	2.457E-10	2.130E-05	2.507E-09
50.00	2.100E-06	2.089E-06	1.062E-08	1.283E-10	1.130E-05	1.330E-09
55.00	1.090E-06	1.084E-06	5.514E-09	6.661E-11	6.240E-06	7.346E-10
60.00	5.780E-07	5.751E-07	2.924E-09	3.532E-11	3.460E-06	4.061E-10
65.00	3.050E-07	3.034E-07	1.543E-09	1.864E-11	1.890E-06	2.225E-10
70.00	1.600E-07	1.592E-07	8.095E-10	9.777E-12	1.000E-06	1.177E-10
75.00	6.950E-08	6.915E-08	3.516E-10	4.247E-12	4.990E-07	5.874E-11
80.00	2.900E-08	2.885E-08	1.467E-10	1.772E-12	2.250E-07	2.649E-11
85.00	1.200E-08	1.194E-08	6.071E-11	7.333E-13	8.860E-08	1.043E-11
90.00	5.100E-09	5.074E-09	2.580E-11	3.116E-13	3.240E-08	3.814E-12
95.00	2.150E-09	2.139E-09	1.088E-11	1.314E-13	1.140E-08	1.342E-12
100.00	9.300E-10	9.253E-10	4.705E-12	5.683E-14	4.420E-09	5.203E-13

Molecular scattering model is ON.

No absorption from molecular resonances.

Simulation output written to DEFAULT.dat

***** LIDAR BACKSCATTER *****

Range (Km)	Height (Km)	Optical Depth (-)	Lidar Return (W)	Normalized Return (-)	Rng. Ind. Lidar (W-sq m)	Normalized Return (sq m)
5.000E-01	5.000E-01	7.695E-02	1.645E-03	1.645E-09	4.113E+02	4.113E-04
1.000E+00	1.000E+00	1.391E-01	3.011E-04	3.011E-10	3.011E+02	3.011E-04
1.500E+00	1.500E+00	1.888E-01	1.029E-04	1.029E-10	2.316E+02	2.316E-04
2.000E+00	2.000E+00	2.288E-01	4.544E-05	4.544E-11	1.817E+02	1.817E-04
2.500E+00	2.500E+00	2.598E-01	2.244E-05	2.244E-11	1.402E+02	1.402E-04
3.000E+00	3.000E+00	2.821E-01	1.166E-05	1.166E-11	1.049E+02	1.049E-04
3.500E+00	3.500E+00	2.979E-01	7.173E-06	7.173E-12	8.787E+01	8.787E-05
4.000E+00	4.000E+00	3.096E-01	4.549E-06	4.549E-12	7.278E+01	7.278E-05
4.500E+00	4.500E+00	3.184E-01	3.140E-06	3.140E-12	6.359E+01	6.359E-05
5.000E+00	5.000E+00	3.252E-01	2.223E-06	2.223E-12	5.556E+01	5.556E-05
5.500E+00	5.500E+00	3.308E-01	1.698E-06	1.698E-12	5.137E+01	5.137E-05
6.000E+00	6.000E+00	3.358E-01	1.322E-06	1.322E-12	4.759E+01	4.759E-05
6.500E+00	6.500E+00	3.404E-01	1.046E-06	1.046E-12	4.418E+01	4.418E-05
7.000E+00	7.000E+00	3.445E-01	8.345E-07	8.345E-13	4.089E+01	4.089E-05
7.500E+00	7.500E+00	3.482E-01	6.761E-07	6.761E-13	3.803E+01	3.803E-05
8.000E+00	8.000E+00	3.515E-01	5.514E-07	5.514E-13	3.529E+01	3.529E-05
8.500E+00	8.500E+00	3.545E-01	4.572E-07	4.572E-13	3.304E+01	3.304E-05
9.000E+00	9.000E+00	3.573E-01	3.809E-07	3.809E-13	3.085E+01	3.085E-05
9.500E+00	9.500E+00	3.600E-01	3.400E-07	3.400E-13	3.069E+01	3.069E-05
1.000E+01	1.000E+01	3.627E-01	3.052E-07	3.052E-13	3.052E+01	3.052E-05

Figure B-6. Sample Log Output File (DEFAULT.LOG) (*Shortened for brevity*)

5.000E-01	5.000E-01	7.695E-02	1.645E-03	1.645E-09	4.112E+02	4.112E-04
1.000E+00	1.000E+00	1.391E-01	3.011E-04	3.011E-10	3.011E+02	3.011E-04
1.500E+00	1.500E+00	1.888E-01	1.029E-04	1.029E-10	2.316E+02	2.316E-04
2.000E+00	2.000E+00	2.288E-01	4.544E-05	4.544E-11	1.817E+02	1.817E-04
2.500E+00	2.500E+00	2.598E-01	2.244E-05	2.244E-11	1.402E+02	1.402E-04
3.000E+00	3.000E+00	2.821E-01	1.166E-05	1.166E-11	1.049E+02	1.049E-04
3.500E+00	3.500E+00	2.979E-01	7.173E-06	7.173E-12	8.787E+01	8.787E-05
4.000E+00	4.000E+00	3.096E-01	4.549E-06	4.549E-12	7.278E+01	7.278E-05
4.500E+00	4.500E+00	3.184E-01	3.140E-06	3.140E-12	6.359E+01	6.359E-05
5.000E+00	5.000E+00	3.252E-01	2.223E-06	2.223E-12	5.556E+01	5.556E-05
5.500E+00	5.500E+00	3.308E-01	1.698E-06	1.698E-12	5.137E+01	5.137E-05
6.000E+00	6.000E+00	3.358E-01	1.322E-06	1.322E-12	4.759E+01	4.759E-05
6.500E+00	6.500E+00	3.404E-01	1.046E-06	1.046E-12	4.418E+01	4.418E-05
7.000E+00	7.000E+00	3.445E-01	8.345E-07	8.345E-13	4.089E+01	4.089E-05
7.500E+00	7.500E+00	3.482E-01	6.761E-07	6.761E-13	3.803E+01	3.803E-05
8.000E+00	8.000E+00	3.515E-01	5.514E-07	5.514E-13	3.529E+01	3.529E-05
8.500E+00	8.500E+00	3.545E-01	4.572E-07	4.572E-13	3.304E+01	3.304E-05
9.000E+00	9.000E+00	3.573E-01	3.809E-07	3.809E-13	3.085E+01	3.085E-05
9.500E+00	9.500E+00	3.599E-01	3.190E-07	3.190E-13	2.879E+01	2.879E-05
1.000E+01	1.000E+01	3.624E-01	2.678E-07	2.678E-13	2.678E+01	2.678E-05
1.050E+01	1.050E+01	3.646E-01	2.282E-07	2.282E-13	2.516E+01	2.516E-05
1.100E+01	1.100E+01	3.668E-01	1.951E-07	1.951E-13	2.360E+01	2.360E-05
1.150E+01	1.150E+01	3.688E-01	1.678E-07	1.678E-13	2.219E+01	2.219E-05
1.200E+01	1.200E+01	3.707E-01	1.444E-07	1.444E-13	2.079E+01	2.079E-05
1.250E+01	1.250E+01	3.726E-01	1.249E-07	1.249E-13	1.952E+01	1.952E-05
1.300E+01	1.300E+01	3.743E-01	1.080E-07	1.080E-13	1.825E+01	1.825E-05
1.350E+01	1.350E+01	3.759E-01	9.290E-08	9.290E-14	1.693E+01	1.693E-05
1.400E+01	1.400E+01	3.774E-01	7.973E-08	7.973E-14	1.563E+01	1.563E-05
1.450E+01	1.450E+01	3.789E-01	6.866E-08	6.866E-14	1.444E+01	1.444E-05
1.500E+01	1.500E+01	3.802E-01	5.896E-08	5.896E-14	1.327E+01	1.327E-05
1.550E+01	1.550E+01	3.815E-01	5.116E-08	5.116E-14	1.229E+01	1.229E-05
1.600E+01	1.600E+01	3.827E-01	4.428E-08	4.428E-14	1.134E+01	1.134E-05
1.650E+01	1.650E+01	3.838E-01	3.862E-08	3.862E-14	1.051E+01	1.051E-05
1.700E+01	1.700E+01	3.849E-01	3.361E-08	3.361E-14	9.712E+00	9.712E-06
1.750E+01	1.750E+01	3.858E-01	2.929E-08	2.929E-14	8.969E+00	8.969E-06
1.800E+01	1.800E+01	3.868E-01	2.542E-08	2.542E-14	8.237E+00	8.237E-06
1.850E+01	1.850E+01	3.876E-01	2.226E-08	2.226E-14	7.619E+00	7.619E-06
1.900E+01	1.900E+01	3.884E-01	1.942E-08	1.942E-14	7.010E+00	7.010E-06
1.950E+01	1.950E+01	3.892E-01	1.704E-08	1.704E-14	6.479E+00	6.479E-06
2.000E+01	2.000E+01	3.898E-01	1.490E-08	1.490E-14	5.960E+00	5.960E-06
2.050E+01	2.050E+01	3.905E-01	1.310E-08	1.310E-14	5.504E+00	5.504E-06
2.100E+01	2.100E+01	3.911E-01	1.147E-08	1.147E-14	5.057E+00	5.057E-06
2.150E+01	2.150E+01	3.916E-01	1.012E-08	1.012E-14	4.677E+00	4.677E-06
2.200E+01	2.200E+01	3.921E-01	8.891E-09	8.891E-15	4.303E+00	4.303E-06
2.250E+01	2.250E+01	3.925E-01	7.865E-09	7.865E-15	3.982E+00	3.982E-06
2.300E+01	2.300E+01	3.929E-01	6.932E-09	6.932E-15	3.667E+00	3.667E-06
2.350E+01	2.350E+01	3.933E-01	6.131E-09	6.131E-15	3.386E+00	3.386E-06
2.400E+01	2.400E+01	3.937E-01	5.398E-09	5.398E-15	3.109E+00	3.109E-06
2.450E+01	2.450E+01	3.940E-01	4.766E-09	4.766E-15	2.861E+00	2.861E-06
2.500E+01	2.500E+01	3.943E-01	4.187E-09	4.187E-15	2.617E+00	2.617E-06

Figure B-7. Sample Output Data File (DEFAULT.DAT) (*Shortened for brevity*)