MODTRAN®5.3.2 USER'S MANUAL

(*www.modtran5.com*)

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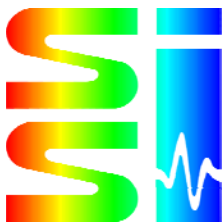
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1. INTRODUCTION

1.1 <u>Changes from Mod5.2.0 to Mod5.2.1</u>

Most changes in this revision are minor, such as correcting comments or removing unused source code. The more important changes are listed below:

- Corrected error in calculation of spherical albedo term in <rootname>.acd file;

- Corrected error in <rootname>.7sc brightness temperatures for nanometer based response functions;

- Eliminated geometry problem most prevalent for line-of-sight paths that terminate near a tangent point;

- Introduced the 2009 series of band model parameter data based on HITRAN2008 with 2009 updates.

- Added the <rootname>.wrn output file which contains a duplicate listing of all warning and error messages written to the <rootname>.tp6 and <rootname>.tp8 files;

- Modified source for compatibility to GNU compilers and FORTRAN77; and

- Eliminated DISORT scaling of thermal radiance contributions.

1.2 <u>Changes from Mod5.2.1 to Mod5.2.2</u>

The number of changes in this revision is small. They are delineated below:

- Mod5.2.1 had an error in its treatment of the boundary term for down-looking radiance calculations which used DISORT multiple scattering; the sensor-to-ground attenuation was being modeled using the true transmittance when the delta-M transmittance should have been used. For particular wavelength bins, spectral radiances could be in error by as much as a few percent.

- MODTRAN *.tp6 output file lists the vertical and line-of-sight total path **550nm** extinction optical depths for molecular scattering, the aerosol components and cirrus clouds. For calculations in the thermal infrared (TIR), for example, the visible wavelength optical depths are not particularly helpful. MODTRAN *.tp6 output file now also lists the vertical and line-of-sight total path extinction optical depths at the **central frequency of the input spectral range** for molecular scattering, the aerosol components and cirrus clouds.

- The MODTRAN headed, which previously was only written to the *.tp6 file, is now included in the standard output and in the *.wrn file. The header has been modified to remind users who obtain MODTRAN via a Government Purpose Use license that their copy of the model is only to be used for Government Purposes as described in the license. Finally, the header is now only written once to each file.

- MODTRAN now includes a frequently asked questions (FAQ) document. It is listed as Appendix G of this document.

1.3 <u>Original Introduction</u>

MODTRAN [Berk *et al.*, 1989; Berk *et al.*, 1998; Berk *et al.*, 2000] serves as the U.S. Air Force (USAF) standard moderate spectral resolution radiative transport model for wavelengths extending from the thermal Infrared (IR) through the visible and into the ultraviolet (0.2 to 10,000.0 μm). The spectroscopy of MODTRAN5.2.0.0 (Mod5.2.0.0) is based on the HITRAN2004 line compilation [Rothman *et al.*, 1992; Rothman *et al.*, 1998] with updates through January, 2007. The original MODTRAN 1 cm^{-1} statistical band model was developed collaboratively by Spectral Sciences, Inc. and the USAF Research Laboratory to provide a fast alternative to the first principles, high accuracy line-by-line (LBL) radiative transport approach. For comparisons between MODTRAN and LBL, see Clough and Kneizys, 1979; Clough *et al.*, 1981; and Snell *et al.*, 1995. Comparisons between MODTRAN and the LBL model FASE (FASCODE for the Environment) [Clough *et al.*, 1992; Clough and. Iacono, 1995; Clough *et al.*, 2005] spectral transmittances and radiances show agreement to within a few percent or better in

the thermal IR. FASE shares its LBL line shape fitting algorithms with LBLRTM, which evolved from FASCODE; see, for instance, Clough *et al.*, 1992; Clough and Iacono, 1995; Clough *et al.*, 2005]. The MODTRAN model includes flux and atmosphere-scattered solar calculations, essential components in analysis of near-IR and visible spectral region data that are not readily generated by LBL models.

Technical descriptions of the MODTRAN5 approach are available from a variety of sources. The original MODTRAN2 code and many of the MODTRAN3 upgrades are described in the 1996 report "MODTRAN 2/3 Report and LOWTRAN 7 Model" [Abreu and Anderson, 1996]. The current documentation incorporates material from that report, from Section 3 of the 1988 Users Guide to LOWTRAN7 [Kneizys *et al.*, 1988], from the 1989 Air Force Research Laboratory (AFRL) report on the MODTRAN band model [Berk *et al.*, 1989], and from the 1996 Spectral Sciences, Inc. report on the cloud and rain model upgrades [Berk and Anderson, 1995]. Articles [Bernstein *et al.*, 1995; Berk *et al.*, 1998] discuss improvements to the band model.

MODTRAN5 upgrades and improvements take the utility and science of the code to a new level, which includes, among other features, a much finer spectroscopy – spectral resolution can now be as fine as 0.1 cm^{-1} – and the ability to handle new species not already included in the built-in profile and molecular parameter files. A summary of new features include:

- Reformulating the band model parameters and radiation transport formalism to increase the resolution of MODTRAN spectral calculations to 0.1 cm^{-1};

- Increasing the TOA solar database resolution to 0.1 cm^{-1};

- Incorporating code interface changes between MODTRAN and DISORT to increase its speed and accuracy of multiple scattering calculations;

- Upgrading MODTRAN to perform spectral radiance computations for auxiliary molecules (by including their concentrations and spectral parameters) that are not part of the traditional MODTRAN database; Band models are provided for all HITRAN molecular species;

- Incorporating effect of a thin layer of water, which can either simply wet the ground or accumulate on it, on radiance computations;

- Capability to model a boundary layer aerosol whose extinction coefficient obeys the Angstrom law or to modify the extinction of a model aerosol with an Angstrom law perturbation;

- Capability to determine the spherical albedo and reflectance of the atmosphere and diffuse transmittance from a single MODTRAN run;

- Ability to include only the solar contribution to multiple scattering and ignore the thermal component where it is not significant;

- Option to write spectral output in binary, and a utility to convert the binary output to ASCII;

- Capability to process several tape5 input files by a single execution of MODTRAN;

- Upgrade to the MODTRAN-DISORT interface so that only a single parameter (MXCMU in routine PARAMS.h) needs to be modified to change the maximum number of streams available for DISORT runs.

- Added dithering of the solar angle in cases where the DISORT particular solution to the solar problem was unstable.

- Introduced Fontenla top-of-atmosphere (TOA) solar irradiance data files, changing the MODTRAN default to "SUNp1med2irradwnNormt.dat".

- Added option to save and re-use DISORT scattering data.

- Added <rootname>.wrn files, and modified comments, warnings, and errors to have a common format.

- Added separate flux and atmospheric correction data (*.acd) binary output files.

- Added option to model line center data via 2 pairs of absorption coefficient and line spacing band model parameters.

- Introduced a much improved algorithm for computing the finite bin Voigt transmittance.

- Added option to use distinct temperature grid data for each auxiliary (Y) species.

- Added atmospheric correction data to the *.chn output files.

- Added path geometry output files with the extension *._pth (these can be used as path geometry input files by renaming the files without the underscore).

- Added thermal scatter as a DISORT run spectral output.

- Replaced the spherical refractive geometry package with a iterative circular arc algorithm for improve accuracy.

- Added H2-CH4 and CH4-CH4 absorption features for modeling extra-terrestrial planet atmospheres.

These user instructions for MODTRAN5 Version 3 describe each input in the MODTRAN input files, tape5 or *rootname*.tp5.

2. OVERVIEW OF INPUT DATA FORMAT

MODTRAN5 makes it easy for the users to keep track of input and output (I/O) files. A MODTRAN input file named either '**mod5root.in**' or '**MOD5ROOT.IN**' contains a list of file root names. If 'mod5root.in' does not exist, MODTRAN checks for the existence of a 'MOD5ROOT.IN' file. If neither of these files exists, MODTRAN I/O files are the traditional ones: 'tape5', 'tape6', 'tape7', 'tape8', etc. If a root name file exists and its very first line contains a non-null string (maximum length is 80 characters), this string is treated as a prefix. If the string consists of all blanks or is a null string, the traditional I/O file names are assumed. The root name should contain no embedded blanks; leading and trailing blanks are properly ignored. If the rootname file has the extension ".tp5", this extension is also ignored. The character string is used as a prefix for the I/O files whose names have mnemonic suffixes. As an example, if the string is **Denver**, the MODTRAN I/O files will have these names:

Denver.tp5	(corresponding to **tape5**)	**Denver.pth**	(corresponding to **rfracpth.dat**)
Denver.sap	(corresponding to **SpecAerProf.dat**)	**Denver.tp6**	(corresponding to **tape6**)
Denver.tp7	(corresponding to **tape7**)	**Denverb.tp7**	(corresponding to **tape7b**)
Denver.tp8	(corresponding to **tape8**)	**Denverb.tp8**	(corresponding to **tape8b**)
Denver.7sc	(corresponding to **tape7.scn**)	**Denver.7sr**	(corresponding to **tape7.scr**)
Denver.plt	(corresponding to **pltout**)	**Denverb.plt**	(corresponding to **pltoutb**)
Denver.psc	(corresponding to **pltout.scn**)	**Denver.clr**	(corresponding to **clrates**)
Denver.chn	(corresponding to **channels.out**)	**Denver.flx**	(corresponding to **specflux**)
Denver.acd	(corresponding to **atmcor.dat**)	**Denver.t_k**	(corresponding to **t_kdis.dat**)
Denver.r_k	(corresponding to **r_kdis.dat**)	**Denverb.t_k**	(corresponding to **t_kdis.bin**)
Denverb.r_k	(corresponding to **r_kdis.bin**)	**Denver.wrn**	(corresponding to **warnings.txt**)
Denver._pth	(corresponding to **rfractpth.dat**)		

A useful feature of MODTRAN5 is the ability to process several input files in a single execution of MODTRAN. To accomplish this, list the *rootname* of each input file as consecutive lines (without intervening blank lines) in '**mod5root.in**' or '**MOD5ROOT.IN**'. When the user executes MODTRAN, each input '.tp5' file, whose *rootname* is listed in '**mod5root.in**' or '**MOD5ROOT.IN**', is processed until the first blank line is encountered. Any '.tp5' file whose *rootname* is encountered after the first blank line is not processed.

As noted above, MODTRAN is controlled by a input file, 'tape5' or '*rootname*.tp5', which consists of a sequence of six or more formatted **CARDS** (inputs lines). The input file format is summarized below. With the exception of file names, character inputs are case insensitive. Also, blanks are read in as zeroes for numerical inputs, and as default values otherwise. Detailed descriptions of the card formats and parameters are given in the following sections.

2.1 Listing of MODTRAN5 CARDs and Their Format

In the following, optional cards are indented. The mandatory input CARDS are **CARD 1**, **CARD 1A**, **CARD 2**, **CARD 3**, **CARD 4** and **CARD 5**. Newer inputs are in *Italics*. Note that all floating point inputs are entered using a 'Fn.0' format; this format will properly read any floating point entry, e.g. '1.234', **AND** will also properly read integers as floating point real variables, (either 1234. or 1234 with no decimal).

CARD 1: MODTRN, *SPEED*, *BINARY*, *LYMOLC*, MODEL, T_BEST, *ITYPE*, IEMSCT, IMULT, M1, M2, M3, M4, M5, M6, MDEF, I_RD2C, CKPRNT, NOPRNT, *TPTEMP, SURREF*
FORMAT (4A1, I1, A1, I4, 10I5, A1, I4, F8.0, A7)

CARD 1A: DIS, *DISAZM, DISALB,* NSTR, SFWHM, CO2MX, H2OSTR, O3STR, C_PROF, LSUNFL, LBMNAM, LFLTNM, H2OAER, CDTDIR, SLEVEL, SOLCON, CDASTM, ASTMC, ASTMX, ASTMO, AERRH, NSSALB
FORMAT (3A1, I3, F4.0, F10.0, 2A10, 2A1, 4(1X, A1), 2(A1, F9.0), 3F10.0, I10)

CARD 1A1: USRSUN
FORMAT (A256)   (If LSUNFL = 'T')

CARD 1A2: *BMNAME*

FORMAT (A256)   (If *LBMNAM* = 'T', 't', '4' or '2')

CARD 1A3:   *FILTNM*
FORMAT (A256)   (If *LFLTNM* = 'T')

CARD 1A4:   *DATDIR*
FORMAT (A256)   (If CDTDIR = 'T')

CARD 1A5:   (S_UMIX(IMOL), IMOL = 4, 12)
FORMAT (9F5.0)   (If C_PROF = 1, 3, 5 or 7)

CARD 1A6:   (S_XSEC(IMOL), IMOL = 1, 13)
FORMAT (13F5.0)   (If C_PROF = 2, 3, 6 or 7)

CARD 1A7:   (S_TRAC(IMOL), IMOL = 1, 16)
FORMAT (16F5.0)   (If C_PROF = 4, 5, 6 or 7)

CARD 1B: (*AWAVLN(ISSALB), ASSALB(ISSALB), ISSALB=1, NSSALB*)
FORMAT ((8F10.0))   (If NSSALB > 0)

      ACOALB, RHASYM
FORMAT (2F10.0)   (If NSSALB < 0)

CARD 2:   APLUS, IHAZE, CNOVAM, ISEASN, *ARUSS*, IVULCN, ICSTL, ICLD, IVSA, VIS, WSS, WHH, RAINRT, GNDALT
FORMAT (A2, I3, A1, I4, A3, I2, 3I5, 5F10.0)

CARD 2A+:   ZAER11, ZAER12, SCALE1, ZAER21, ZAER22, SCALE2, ZAER31, ZAER32, SCALE3, ZAER41, ZAER42, SCALE4
FORMAT ((3(1X, F9.0), 20X, 3(1X, F9.0)))   (If APLUS = 'A+')

CARD 2A: CTHIK, CALT, CEXT
FORMAT (3F8.0)   (If ICLD = 18 or 19)

Alternate **CARD 2A:**   CTHIK, CALT, CEXT, NCRALT, NCRSPC, CWAVLN, CCOLWD, CCOLIP, CHUMID, ASYMWD, ASYMIP
FORMAT (3F8.0, 2I4, 6F8.0)   (If ICLD = 1-10)

CARD 2B: ZCVSA, ZTVSA, ZINVSA
FORMAT (3F10.0)   (If IVSA = 1)

CARD 2C: ML, IRD1, IRD2, HMODEL, REARTH, AYRANG, NMOLYC, E_MASS, AIRMWT
FORMAT (3I5, A20, F10.0, A1, I4, 2F10.0)   (If MODEL = 0, 7 or 8; and I_RD2C = 1)

CARD 2CY: (*YNAME*(I), I=1, NMOLYC)
FORMAT ((8A10))   (If NMOLYC > 0)

<u>**CARDs 2C1, 2C2, 2C2X, *2C2Y*** and **2C3** (as required) are each repeated ML times.</u>

CARD 2C1:   ZM, P, T, WMOL(1), WMOL(2), WMOL(3), (JCHAR(J), J = 1, 14), JCHARX, JCHARY
FORMAT (6F10.0, 14A1, 1X, 2A1)

CARD 2C2:   (WMOL(J), J = 4, 12)
FORMAT (8F10.0, /F10.0)   (If IRD1 = 1)

CARD 2C2X: (WMOLX(J), J = 1, 13)
FORMAT (8F10.0, /5F10.0)   (If MDEF = 2 & IRD1 = 1)

CARD 2C2Y: (*WMOLY*(J), J = 1, NMOLYC)
FORMAT ((8F10.0))   (If NMOLYC > 0 & IRD1 = 1)

CARD 2C3*:*   AHAZE, EQLWCZ, RRATZ, IHA1, ICLD1, IVUL1, ISEA1, ICHR
FORMAT (10X, 3F10.0, 5I5)   (If IRD2 = 1)

CARD 2C3:   AHAZE(1), RRATZ, AHAZE(2), AHAZE(3), AHAZE(4)

      FORMAT(10X, F10.0, 10X, 4F10.0)   (If IRD2 = 2)

CARD 2D: IREG(1), IREG(2), IREG(3), IREG(4)
FORMAT (4I5)   (If IHAZE = 7 or ICLD = 11 or ARUSS = 'USS')

CARDs 2D1 and 2D2 pairs are repeated for each N (1 to 4) for which IREG(N) > 0 when ARUSS='USS' or IREG(N) ≠ 0 when IHAZE=7 or ICLD=11.

CARD 2D1:   AWCCON, AERNAM
FORMAT (F10.0, A70)

CARD 2D2:   (VARSPC(N, I), EXTC(N, I), ABSC(N, I), ASYM(N, I), I = l, 2, ..., I_{max})
If ARUSS = 'USS' and IREG(N) > 1, then I_{max} = IREG(N); Else I_{max} = 47
FORMAT ((3(F6.2, 2F7.5, F6.4)))

CARD 2E1:   (ZCLD(I), CLD(I), CLDICE(I), RR(I), I = 1, NCRALT)
FORMAT ((4F10.0))   (If ICLD = 1 - 10, NCRALT ≥ 2, MODEL < 8)

Alternate **CARD 2E1:**   (PCLD(I), CLD(I), CLDICE(I), RR(I), I = 1, NCRALT)
FORMAT ((4F10.0))   (If ICLD = 1 - 10, NCRALT ≥ 2, MODEL = 8)

CARD 2E2:   (WAVLEN(I), EXTC6(I), ABSC6(I), ASYM6(I), EXTC7(I), ABSC7(I), ASYM7(I),
                                        I = 1, NCRSPC)
FORMAT ((7F10.5))   (If ICLD = 1 - 10, NCRSPC ≥ 2)

Alternate **CARD 2E2:**   *CFILE, CLDTYP, CIRTYP*
            FORMAT ((A256))   *(If ICLD = 1 - 10, NCRSPC = 1)*

CARD 3:   H1ALT, H2ALT, OBSZEN, HRANGE, BETA, RAD_E, LENN, BCKZEN, **CKRANG**
FORMAT (6F10.0, I5, 5X, 2F10.0)

Alternate **CARD 3:**   H1ALT, H2ALT, OBSZEN, IDAY, RAD_E, ISOURC, ANGLEM
           FORMAT (3F10.0, I5, 5X, F10.0, I5, F10.0)   (If IEMSCT = 3)

CARD 3A1:   IPARM, IPH, IDAY, ISOURC
FORMAT (4I5)   (If IEMSCT = 2 or 4)

CARD 3A2:   PARM1, PARM2, PARM3, PARM4, GMTIME, TRUEAZ, ANGLEM, G
FORMAT (8F10.0)   (If IEMSCT = 2 or 4)

CARD 3B1:   NANGLS, NWLF
FORMAT (2I5)   (If IEMSCT = 2 or 4; IPH = 1)

CARD 3B2:   (ANGF(IANG), F(1, IANG), F(2, IANG), F(3, IANG), F(4, IANG), IANG = l, NANGLS)
FORMAT ((5F10.0))   (If IEMSCT = 2 or 4; IPH = 1; NWLF = 0)

CARD 3C1:   (ANGF(IANG), IANG = 1, NANGLS)
FORMAT ((8F10.0))   (If IEMSCT = 2 or 4; IPH = 1; NWLF > 0)

CARD 3C2:   (WLF(IWAV), IWAV = 1, NWLF)
FORMAT ((8F10.0))   (If IEMSCT = 2 or 4; IPH = 1; NWLF > 0)

In **CARDs 3C3-3C6**, 'IANG' is angle index as in **CARD 3C1** and 'JWAV' is the wavelength index as in **CARD 3C2**.

CARD 3C3:   (F(1, IANG, IWAV), IWAV = 1, NWLF)
FORMAT (8F10.0)   (If IEMSCT = 2 or 4; IPH = 1; NWLF > 0)

CARD 3C4:   (F(2, IANG, IWAV), IWAV = 1, NWLF)
FORMAT (8F10.0)   (If IEMSCT = 2 or 4; IPH = 1; NWLF > 0)

CARD 3C5:   (F(3, IANG, IWAV), IWAV = 1, NWLF)
FORMAT (8F10.0)   (If IEMSCT = 2 or 4; IPH = 1; NWLF > 0)

CARD 3C6:   (F(4, IANG, IWAV), IWAV = 1, NWLF)

FORMAT (8F10.0)   (If IEMSCT = 2 or 4; IPH = 1; NWLF > 0)

CARD 3D: **(**H1ALT, H2ALT, OBSZEN, HRANGE, BETA, AZ_INP, LENN,
                                                                                    BCKZEN**, CKRANG**, ILOS = 2, |ITYPE|**)**
                FORMAT (6F10.0, I5, 5X, 2F10.0)   (If ITYPE ≤ −2, IMULT = ±1, DIS(1:1) = 'T')

CARD 4:   V1, V2, DV, FWHM, YFLAG, XFLAG, DLIMIT, FLAGS, *MLFLX, VRFRAC*
                FORMAT (4F10.0, 2A1, A8, A7, I3, F10.0)

CARD 4A: NSURF, AATEMP, DH2O, MLTRFL
                FORMAT (I1, 2F9.0, A1)   (If *SURREF* = 'BRDF' or 'LAMBER')

The set of **CARD 4B1**, **4B2**, and **4B3** inputs or set of **CARD 4L1** and **4L2** are only entered once unless ITYPE is less than zero and NSURF=2. In that case, these sets of inputs are repeated for all |ITYPE| lines-of-sight.

The set of **CARD 4B1**, **4B2**, and **4B3** inputs is repeated *NSURF* times.

CARD 4B1:   *CBRDF*
                FORMAT (A80)   (If *SURREF* = 'BRDF')
CARD 4B2:   *NWVSRF, SURFZN, SURFAZ*
                FORMAT (*)   (If *SURREF* = 'BRDF')
CARD 4B3 is repeated *NWVSRF* times.

CARD 4B3:   *WVSURF, (PARAMS(I), I = 1, NPARAM)*
                FORMAT (*)   (If *SURREF* = 'BRDF')
CARD 4L1:   *SALBFL*
                FORMAT (A256)   (If *SURREF* = 'LAMBER')
CARD 4L2 is repeated *NSURF* times.

CARD 4L2:   *CSALB*
                FORMAT (A80)   (If *SURREF* = 'LAMBER')
CARD 5:   IRPT
                FORMAT (I5)

3. CARD 1 (REQUIRED) – MAIN RADIATION TRANSPORT DRIVER

Although **CARD 1** format has been modified over the years, the format is backward compatible if inputs are right justified.

CARD 1:   **MODTRN**, *SPEED*, *BINARY*, *LYMOLC*, **MODEL**, T_BEST, *ITYPE*, **IEMSCT, IMULT, M1, M2, M3, M4, M5, M6, MDEF, I_RD2C,** CKPRNT, **NOPRNT,** *TPTEMP, SURREF*
                   FORMAT (4A1, I1, A1, I4, 10I5, A1, I4, F8.0, A7)

MODTRN selects the band model algorithm used for the radiative transport, either the moderate spectral resolution MODTRAN band model or the low spectral resolution LOWTRAN band model. **LOWTRAN spectroscopy is obsolete** and is retained only for backward compatibility. The MODTRAN band model may be selected either with or without the Correlated-*k* treatment.

MODTRN   =   'T', 'M' or blank   MODTRAN band model.

          =   *'C' or 'K'*   *MODTRAN correlated-k option (IEMSCT radiance modes only; most accurate but slower run time).*

          =   'F' or 'L'   20 cm^{-1} LOWTRAN band model (not recommended except for quick historic comparisons).

SPEED   =   *'S' or blank*   *'slow' speed Correlated-k option using 33 absorption coefficients (k values) per spectral bin (1 cm^{-1} or 15 cm^{-1}). This option is recommended for upper altitude (> 40 km) cooling-rate and weighting-function calculations only.*

          =   *'M'*   *'medium' speed Correlated-k option (17 k values).*

BINARY   =   *'F' or blank*   *All outputs are in ASCII (normal situation).*

          =   *'T'*   *tape7, tape8 and plot files are generated by MODTRAN in binary format. ASCII equivalents are generated by executing auxiliary program(s): m5binrestore and m5binrestore_k. See Appendix E for details.*

LYMOLC   =   *'+'*   *Include 16 auxiliary trace species when either a model atmosphere is selected* (MODEL = 1 *to* 6) *or a user-defined atmosphere is selected* (MODEL = 0, 7 *or* 8) *AND input NMOLYC* (CARD 2C) *is zero. In the latter case, NMOLYC is reset to 16 requiring that both JCHARY* (CARD 2C1) *and CARDs 2C2Y be read in. The 16 auxiliary trace species are referred to as "Y" species within the source code. The specific 16 species, in order, are* OH, HF, HCl, HBr, HI, ClO, OCS, H$_2$CO, HOCl, N$_2$, HCN, CH$_3$Cl, H$_2$O$_2$, C$_2$H$_2$, C$_2$H$_6$, PH$_3$.

          =   *blank*   *Do not include auxiliary species with model atmosphere.*

MODEL selects one of the six geographical-seasonal model atmospheres or specifies that user-defined meteorological or radiosonde data are to be used.

MODEL   =   0   If single-altitude meteorological data are specified (constant pressure, horizontal path only; see instructions for **CARDs 2C, 2C1, 2C2, 2C2X, 2C2Y** and **2C3**).

                1   Tropical Atmosphere (15° North Latitude).

                2   Mid-Latitude Summer (45° North Latitude).

                3   Mid-Latitude Winter (45° North Latitude).

                4   Sub-Arctic Summer (60° North Latitude).

                5   Sub-Arctic Winter (60° North Latitude).

                6   1976 US Standard Atmosphere.

                7   If a user-specified model atmosphere (e.g. radiosonde data) is to be read in; see instructions for **CARDs 2C, 2C1, 2C2, 2C2X, 2C2Y** and **2C3**.

                8   *Pressure-dependent atmospheric profiles. A user-specified model atmosphere (e.g. radiosonde data) is to be read in with altitudes determined from the pressure profile by*

> *solving the hydrostatic equation. See instructions for **I_RD2C** on **CARD 1** and for **CARDs** **2C, 2C1, 2C2, 2C2X, 2C2Y** and **2C3** for further details.*

T_BEST provides an painstakingly slow debugging option to benchmark the Voigt line transmittance calculations. This option should only be selected if the user suspects that there is a problem with MODTRAN's standard Voigt line transmittance calculation. Transmittance differences of significance (> 0.0001) should be reported to modtran@spectral.com for further investigation.

T_BEST	=	*'T' or 't'*	*Use benchmark Voigt line transmittance algorithm*
	=	*otherwise*	*Use default Voigt line transmittance expansion*

ITYPE indicates a geometric type for the atmospheric line-of-sight (LOS) path.

ITYPE	=	1	Horizontal (constant-pressure) path, i.e., flat Earth constant altitude path.
		2	Vertical or slant path between two altitudes.
		3	Vertical or slant path to space or ground.
		4	*User-defined line-of-sight.*
	<	0	|ITYPE| is the number of slant paths between two altitudes using a single multiple scattering calculation. See CARD 3D.

The ITYPE=4 option was introduced as part of the Mod5.3 release to enable modeling of refractive paths resulting from large index of refraction vertical gradients. When this option is used, all inputs on the standard CARD 3 are ignored other than the Earth radius *RAD_E* and the *k*-distribution dependent output path range parameter *CKRANG*. Path parameters are read from an auxiliary ASCII input file named either "rfracpth.dat" or "<rootname>.pth"; the latter name is used if a root name is read from mod5root.in or MOD5ROOT.IN. A sample <rootname>.pth file is included in Table 1.

Specification of a user-defined path requires that some stringent rules be followed. Four columns of data are required. As illustrated in Table 1, these columns contain the *cumulative* (spherical) Earth surface distance in meters, the altitude in meters, the path zenith angle in degrees, and the *incremental* path segment length in meters. All lines beginning with an exclamation are ignored and all line entries following an exclamation (in-line comments) are also ignored. The 4 columns of data must be separated by spaces or commas, but no tabs. Leading or trailing blanks are ignored. The first non-blank character in each data line must be a plus sign, a minus sign, a decimal or a digit, 0 through 9. Any line not beginning with one of these characters or with an exclamation is interpreted as a delimiter between defined paths. In the example of Table 1, the word "NEXT" is used as the delimiter. Every atmospheric profile level between the beginning of the path (H1ALT) and the end of the path (H2ALT) must be explicitly included in the user-defined path file. In addition, if the line-of-sight passes through a tangent point, the altitude of the tangent point and the altitude of the minimum of H1ALT and H2ALT must be included in the path definition. In Table I, the minimum altitude is listed at 0.16075426526368 meters, and the final altitude (25.821244410585 m) is listed as the third entry in the downward leg. If a non-zero ground altitude or a cloud were to be added to the MODTRAN atmosphere, it would be necessary to run MODTRAN first without a user-defined path to determine the model relayering. Note that it is not necessary that "mirrored" path segments within a common atmospheric layer have identical path lengths or angles; thus, one could use the user-defined path option to model bent paths such as a sensor to ground to sun path. All these requirements does make the use of the user-defined path rather complex, but, as stated above, this option is necessary for modeling strong index of refraction gradients such as those observed in the marine boundary layer.

CARD 1 (Required)

Table 1. User-Defined Path Parameter File from Test Case User Path.

!###			
!#Atmospheric file: TDP00sub.txt			
!#Full refraction (Mirage ray)			
!#Curved earth representation (R = 6371230.0 m)			
!###			
!			
!Earth surface	Altitude	Zenith Angle	Segment Lengths
!distance (m)	(m)	(deg)	(m)
!			
0.0000000000000	29.900000000000	90.189000000000	0.0000000000000
1041.9012954644	26.538244292473	90.180733953598	1041.9113336288
1270.3560625281	25.821244410585	90.178908112818	228.45683147277
2038.7644494551	23.463065803670	90.172762325063	768.41497742361
2964.7678300263	20.731295125158	90.165288500462	926.01062164312
3824.1902900742	18.304583613239	90.158276863904	859.42851892983
4621.1260668439	16.148865050039	90.151693040154	796.94084715816
5359.4938828508	14.233877421347	90.145503806883	738.37205984105
6043.0445474172	12.532738097948	90.139677023359	683.55421721182
6675.3673650761	11.021566456806	90.134181491957	632.32579225008
7259.8955694608	9.6791486444739	90.128986871664	584.53069546048
7799.9109567221	8.4866397766488	90.124063541044	540.01747381047
8298.5481454158	7.4272993933662	90.119382401136	498.63893670373
8758.7986010627	6.4862564561342	90.114914739278	460.25192023864
9183.5148066126	5.6503005880400	90.110631911152	424.71743276353
9575.4155575907	4.9076966262520	90.106504727038	391.90177926706
9937.0915791127	4.2480198836023	90.102503543286	361.67688300182
10271.013265885	3.6620098066495	90.098596673395	333.92240826494
10579.540504055	3.1414399758701	90.094750408679	308.52784207464
10864.936400155	2.6790026230402	90.090926277237	285.39640111885
11129.386251322	2.2682060446596	90.087080169216	264.45027291130
11375.024382517	1.9032834713067	90.083158113572	245.63848268456
11603.982028179	1.5791121136302	90.079087071713	228.95793773649
11818.455868850	1.2911412485443	90.074773233897	214.47408232363
12020.841683321	1.0353283360997	90.070068860443	202.38601311481
12214.001067940	.80808227023856	90.064744519726	193.15954626868
12401.895848521	.60621296678608	90.058369650734	187.89490992932
12591.541884888	.42688658099378	90.049986342712	189.64613663414
12802.014760646	.26758572597844	90.036744693052	210.47294785778
13135.178041776	.16075426526368	90.000000000000	333.16331427414
13468.341309379	.26758572597844	89.963255306948	333.16330074681
13678.814177420	.42688658099378	89.950013657288	210.47294014061
13868.460213787	.60621296678608	89.941630349266	189.64613663414
14056.354994368	.80808227023856	89.935255480274	187.89490992932
14249.514378987	1.0353283360997	89.929931139557	193.15954626868
14451.900193458	1.2911412485443	89.925226766103	202.38601311481
14666.374034128	1.5791121136302	89.920912928287	214.47408232363
14895.331679791	1.9032834713067	89.916841886428	228.95793773649
15140.969810986	2.2682060446596	89.912919830784	245.63848268456
15405.419662153	2.6790026230402	89.909073722763	264.45027291130
15690.815558253	3.1414399758701	89.905249591321	285.39640111885
15999.342796423	3.6620098066495	89.901403326605	308.52784207464
16333.264483195	4.2480198836023	89.897496456714	333.92240826494

CARD 1 *(Required)*

16694.940504717	4.9076966262520	89.893495272962	361.67688300182
17086.841255695	5.6503005880400	89.889368088848	391.90177926706
17511.557461466	6.4862564561342	89.885085260722	424.71743298422
17971.807917113	7.4272993933662	89.880617598864	460.25192023864
18470.445105806	8.4866397766488	89.875936458956	498.63893670373
19010.460493068	9.6791486444739	89.871013128336	540.01747381047
19594.988697452	11.021566456806	89.865818508043	584.53069546048
20227.311515111	12.532738097948	89.860322976641	632.32579225008
20910.862179678	14.233877421347	89.854496193117	683.55421721182
21649.229995685	16.148865050039	89.848306959846	738.37205984105
22446.165772454	18.304583613239	89.841723136096	796.94084715816
23305.588232502	20.731295125158	89.834711499538	859.42851892984
24231.591613073	23.463065803670	89.827237674937	926.01062164312
25000.000000000	25.821244410585	89.821091887182	768.41497742361
NEXT			
!###			
!#Atmospheric file: TDP00super.txt			
!#Full refraction			
!#Curved earth representation (R = 6371230.0 m)			
!###			
!			
!Earth surface	Altitude	Zenith Angle	Segment Lengths
!distance (m)	(m)	(deg)	(m)
!			
0.0000000000000	29.900000000000	90.138700000000	0.0000000000000
1432.0520333674	26.538234947326	90.130304016400	1432.0623223780
2826.6801095559	23.463048381598	90.122371724184	1394.6369394816
4144.7661531722	20.731270727672	90.115122098766	1318.0934462897
5388.1113540536	18.304553196561	90.108532821564	1243.3513783152
6558.2193216778	16.148829443811	90.102581801495	1170.1131174709
7656.3676975820	14.233837344980	90.097246629860	1098.1526642895
8683.6955503978	12.532694174894	90.092504019028	1027.3314195118
9641.3029977289	11.021519227019	90.088329456568	957.61041006051
10530.357400979	9.6790985752820	90.084696796382	889.05686125431
11352.198107782	8.4865872722433	90.081578095204	821.84274379247
12108.428824130	7.4272448030740	90.078943688842	756.23240292916

IEMSCT determines the radiation transport mode of execution of the program.

IEMSCT	=	0	Program executes in spectral transmittance only mode.
	=	1	Program executes in spectral thermal radiance (no sun / moon) mode.
	=	2	Program executes in spectral thermal plus solar / lunar radiance mode (if IMULT = 0, only single scatter solar radiance is included).
	=	3	Program calculates directly transmitted spectral solar / lunar irradiance.
	=	4	Program executes in spectral solar / lunar radiance mode with *no thermal scatter*. Thermal path and surface emission is included.

IMULT determines inclusion of multiple scattering (MS).

IMULT	=	0	Program executes without multiple scattering.
	=	±1	Program executes with multiple scattering.

IEMSCT must equal 1, 2 or 4 to execute with multiple scattering. MS contributions are calculated using plane parallel geometry (the solar illumination impingent upon each atmospheric level (altitude) is determined with spherical refractive geometry, important for low sun angles, when the ISAACS MS model is selected on **CARD 1A**

but not with DISORT MS). If IMULT = 1, the solar geometry at the location of H1ALT (latitude and longitude) is used in the MS calculation; if IMULT = -1, the MS calculation is instead referenced to H2ALT. The quantity H2ALT is the final path altitude unless ITYPE = 3 and H2ALT ≥ 0; in that case, the MS plane parallel atmosphere is defined *near* the tangent point of the limb path. (The path zenith of 90° *at* the tangent point is a forbidden input to the plane-parallel MS models because it leads to a mathematical singularity.) If multiple lines-of-sight are defined (ITYPE < 0), then the reference point is based on the H1ALT (H2ALT if IMULT = -1) of the first line-of-sight. For simulation of sensors on satellite platforms, IMULT should generally be set to -1 since MS will only be significant nearer to H2ALT (the surface or tangent height).

M1, M2, M3, M4, M5, M6, and MDEF are used to modify or supplement user-specified altitude profiles for temperature, pressure, and default molecular gases: H_2O, O_3, CH_4, N_2O, CO, CO_2, O_2, NO, SO_2, NO_2, NH_3, HNO_3, and 13 "heavy molecules." For operation of the program using the standard model atmospheres (MODEL 1 to 6), *the* those CARD1 profile inputs (M1, M2, M3, M4, M5, M6 and /or MDEF *values*) that are read in as non-zero (i.e., 1 to 6) are each set internally*; input values from CARD 1 are ignored* to that specified profile, replacing the MODEL profile.

If MODEL equals 0 (horizontal path) or equals 7 or 8 (radiosonde data) and if M1 through M6 are set to zero or left blank and *MDEF is set to -1*, then the JCHAR parameter on each **CARD 2C1** must be defined to supply the necessary profiles. If M1 through M6 are non-zero and *MDEF not equal to -1*, then the chosen default profiles will be utilized *only if* a specific JCHAR input is blank:

M1	=	1 to 6	Default temperature and pressure to specified model atmosphere.
M2	=	1 to 6	Default H_2O to specified model atmosphere volume mixing ratio.
	=	−1 to −6	Default H_2O to specified model (= |M2|) atmosphere relative humidity.
M3	=	1 to 6	Default O_3 to specified model atmosphere.
M4	=	1 to 6	Default CH_4 to specified model atmosphere.
M5	=	1 to 6	Default N_2O to specified model atmosphere.
M6	=	1 to 6	Default CO to specified model atmosphere.
MDEF	=	0 or 1	Default CO_2, O_2, NO, SO_2, NO_2, NH_3, and HNO_3 species profiles.

Note that for H_2O there are 2 options. With a positive value of M2, the H_2O concentration is only a function of altitude and model profile. When a negative value of M2 is selected, the model atmosphere relative humidity is held constant. Thus, with this latter option, a change in the temperature profile will result in a change in the water concentration. The positive M2 option is preferred when one desires a H_2O profile that is independent of the temperature profile; the negative M2 option can be used to insure that over saturation (RH > 100%) is avoided.

If MDEF = 1, default heavy species profiles are used. If MDEF = 2, the user must input the profiles for the heavy species, which include nine chlorofluorocarbons (CFCs) plus $ClONO_2$, HNO_4, CCl_4, and N_2O_5. The 1 cm^{-1} absorption cross-sections are stored in "DATA/CFC99_01.ASC"; the 15 cm^{-1} version of the file is named "DATA/CFC99_15.ASC". The specification of user-defined profiles is modeled after the MODEL = 7 option in LOWTRAN, but only one unit definition (see JCHARX definition in **CARD 2C1**) can be used for the whole set of heavy species. The "default" profiles for these species are stored in BLOCK DATA /XMLATM/ and are based on 1990 photochemical predictions (after M. Allen, JPL). Since some of the CFCs have increased by as much as 8% per year, the user might well wish to redefine these values. Note that both CFC11 and CFC12 are now as much as 80% larger than the default profiles.

If MODEL = 0, 7 or 8, MODTRAN expects to read user-supplied atmospheric profiles. Set I_RD2C = 1 for the first run. To sequentially rerun the same atmosphere for a series of cases, set I_RD2C to 0 in subsequent runs; MODTRAN will then reuse the previously read data.

I_RD2C	=	0	For normal operation of program or when calculations are to be run with the atmosphere MODEL last read in.
	=	1	When user input data are to be read.

CARD 1 (Required)

CKPRNT = *'T'*   Write *k*-distribution dependent cumulative path transmittance (output file "t_kdis.dat" or "<rootname>.t_k" if a root name is provided) and radiance (output file "r_kdis.dat" or "<rootname>.r_k") data. If input *CKRANG* on CARD 3 is non-zero, the *k*-dependent data is output as a function of slant range; see CARD 3 input instructions for further details. The correlated-*k* option (input *MODTRN* on CARD 1) must be selected. If the binary output option is also selected (input *BINARY* on CARD 1), the data is written to files "t_kdis.bin" and "r_kdis.bin" (or "<rootname>b.t_k" and "<rootname>b.r_k"). The binary data can be translated to ASCII by running the utility "m5binrestore_k.f" from the MOD5v3r4/ directory.

           = *'F' or blank*   Do not write out *k*-distribution dependent range data.

     Sample output for the CKPRNT option is generated from the "CKoutput.tp5" test case. The number of *k* intervals is a function of wavelength, varying among 17 (33, if SPEED='S' in column 2 of CARD 1), 4 and 1 *k*'s per interval depending upon the presence or absence of molecular line center and line tail absorption. In the ASCII *k*-distribution output files, the first 4 columns contain the spectral frequency (no convolution or filter function), the number of *k*'s, the line-of-sight altitudes, and the line-of-sight path ranges. The next column contains the transmittance (or radiance) summed over the all the *k* intervals. The remaining columns contain the value for the individual *k* intervals.

NOPRNT = 0   Normal writing to tape6 and tape7.
            = 1   Create a tape6 with no writing out of model atmosphere profiles.
            = 2   Create a tape6 with no spectral data or writing of model atmosphere profiles.
            = 3   Delete tape6 at end of processing if run is successful.
            = -1   Create additional tape8 output, including either weighting functions in transmission mode (IEMSCT = 0) or fluxes in radiation modes with multiple scattering on (IMULT = ±1 and IEMSCT = 1, 2 or 4).
            = -2   Generates spectral cooling rate data in addition to the tape8 output; spectral cooling rates are written to the 'clrates' or '*rootname*.clr' file.

     If NOPRNT is set to -1 for multiple scattering calculations, spectral diffuse and total flux values along the lines of sight will be written to tape8. These values are 1 cm^{-1} spectral resolution results (0.1, 5 or 15 cm^{-1} results if the 0.1, 5 or 15 cm^{-1} band model data file is used, respectively). Spectral flux values convolved with the instrument slit function are output to the 'specflux' or '*rootname*.flx' file if FLAGS(7:7) is not left blank (**CARD 4**). Be warned that setting NOPRNT to -1 for long paths (e.g., ground to space) over a large spectral range (e.g., 0.4 to 0.7 μm) will generate large tape8 files.

TPTEMP > 0.   *Boundary temperature [K] of 'image pixel' (i.e., at H2ALT), used in the radiation mode (if IEMSCT = 1, 2 or 4) for slant paths that intersect the earth OR terminate at a gray boundary (for example, cloud, target). If the 'area-average' temperature (AATEMP, CARD 4A) is not entered and the line-of-sight intersects the earth, TPTEMP is also used as the lower boundary temperature in the multiple scattering models.*

            ≤ 0.   *No surface emission if H2ALT is above ground. If the path intersects the Earth and TPTEMP is either not positive or left blank, MODTRAN uses the temperature of the first atmospheric level as the boundary temperature. If the 'area-average' temperature (AATEMP, CARD 4A) is not entered and the line-of-sight intersects the earth, the temperature of the first atmospheric level is also used as the lower boundary temperature in the multiple scattering models.*

CARD 1 (Required)

SURREF = *'BRDF'*   (or the first non-blank character is 'B' or 'b') Surface spectral BRDFs (Bidirectional Reflectance Distribution Functions) are specified by **CARD 4A, 4B1, 4B2** and **4B3** inputs.

= *'LAMBER'*   (or the first non-blank character is 'L' or 'l') Spectral Lambertian surface(s) is (are) specified by **CARD 4A, 4L1** and **4L2** inputs.

≥ 0. or blank   Albedo of the earth (and at H2ALT if TPTEMP > 0), equal to one minus the surface emissivity and spectrally independent (constant). If the value exceeds one, the albedo is set to 1; if SURREF is blank, the albedo is set to 0.

< 0   Negative integer values allow the user to access pre-stored spectrally variable surface albedos from the 'DATA/spec_alb.dat' file.

The file 'DATA/spec_alb.dat' is a replacement for the 'DATA/refbkg' file used in MODTRAN3.7 and earlier versions of the model. The current version contains 46 surfaces. A complete list is provided in Sec. 17.6. These are only meant to be representative of the types of options available; the user is encouraged to add to the set or replace the existing ones. Instructions for adding surfaces to the 'spec_alb.dat' file are provided directly within the file. It is recommended that the wavelength limits on the surface properties match or exceed the spectral range specified for the MODTRAN run. MODTRAN will use the endpoint values at any wavelength outside this range (no extrapolations). Table 2 summarizes the use of selected **CARD 1** parameters: MODTRN, SPEED, MODEL, ITYPE, IEMSCT, IMULT, MDEF, NOPRNT and SURREF.

Table 2. Columns List Allowed Values of MODTRAN **CARD 1** Input Parameters MODTRN, *SPEED*, MODEL ITYPE, IEMSCT, IMULT, MDEF, NOPRNT and *SURREF*.

CARD 1 FORMAT(4A1, I1, A1, I4, 10I5, A1, I4, F8.0, A7)							MODTRN, *SPEED*, *BINARY*, *LYMOLC*, MODEL, T_BEST, *ITYPE*, IEMSCT, IMULT, M1, M2, M3, M4, M5, M6, MDEF, I_RD2C, CKPRNT, NOPRNT, *TPTEMP*, *SURREF*		
MODTRN (COL. 1)	S P E E D *	MODEL (COL. 5)	ITYPE (COL. 7-10)	IEMSCT (COL 11-15)	IMULT (COL. 16-20)	MDEF (COL. 51-55)	NOPRNT (COL. 61-65)	SURREF (COL. 74-80)	
T or M MODTRAN Run		0 User-Defined %	1 Horizontal Path	0 Transmittance	0 No Multiple Scattering	0 For MODEL = 1-6. Default for Minor Species**	- 1 tape Short Output	- 1 snow	
F, L or blank LOWTRAN Run		1 Tropical	2 Slant Path H1ALT to H2ALT	1 Thermal Radiance	1 Multiple Scattering Based at H1ALT	1 For MODEL = 0, 7 or 8. Default for Minor Species**	0 tape6 Normal Output	- 2 forest	
C or K Correlated-*k* with MODTRAN	S o r M	2 Mid-Latitude Summer	3 Slant Path to Space	2 Thermal and Solar/Lunar Radiance	- 1 Multiple Scattering Based at H2ALT	2 For MODEL = 0, 7 or 8. User Control of Heavy Molecules $	- 1 tape8 Output	- 3 farm	
		3 Mid-Latitude Winter		3 Transmitted Solar/Lunar Irradiance			- 2 tape8 plus Spectral Cooling Rates	- 4 desert	
		4 Sub-Arctic Summer						- 5 ocean	
		5 Sub-Arctic Winter						- 6 cloud deck	
		6 1976 U.S. Standard						- 7 old grass	
		7 User-Defined %						.. …	

M1, M2, M3, M4, M5, M6, MDEF, IM_RD2C TPTEMP, and SURREF are left blank for standard cases.
% Options for non-standard models.
**CO_2, O_2, NO, SO_2, NO_2, NH_3, HNO_3
$ CFC's plus $CIONO_2$, NHO_4, CCI_4, and N_2O_5.
* *S stands for slow and M stands for medium speed of execution of the code.*

4. CARD 1A (REQUIRED) – RADIATIVE TRANSPORT DRIVER CONT'D

CARD 1A inputs enable selection of scattering options, scaling of molecular profiles, customizing of the top-of-atmosphere (TOA) solar irradiance, specification of data files, and Angstrom Law perturbations of aerosol optical properties:

CARD 1A: DIS, *DISAZM, DISALB,* **NSTR, SFWHM, CO2MX, H2OSTR, O3STR, C_PROF, LSUNFL, LBMNAM, LFLTNM, H2OAER, CDTDIR, SLEVEL, SOLCON, CDASTM, ASTMC, ASTMX, ASTMO, AERRH, NSSALB**
FORMAT (3A1, I3, F4.0, F10.0, 2A10, 2A1, 4(1X, A1), 2(A1, F9.0), 3F10.0, I10)

DIS	= f, F or blank	The very approximate but fast Isaac's two-stream multiple scattering algorithm is used if IMULT = ±1 on **CARD 1**.
	= s or S	If IMULT = ±1 on **CARD 1,** DISORT discrete ordinate multiple scattering calculations are performed at selected spectral points in atmospheric window regions. These handfuls of DISORT radiances are then used to scale Isaac's two-stream multiple scattering values for the entire wavelength region.
	= t or T	The first-principles, plane parallel atmosphere DISORT discrete ordinate multiple scattering algorithm is used if IMULT = ±1 on **CARD 1**.
	= w or W	The first-principles, plane parallel atmosphere DISORT discrete ordinate multiple scattering algorithm is used if IMULT = ±1 on **CARD 1**. The DISORT solution to the radiation transport equation at each spectral point is *W*ritten to a formatted (ASCII) data file "msdata.asc" or "<rootname>.ms" for subsequent MODTRAN runs. The output file can be very large. (Note: the ASCII output option is primarily provided for testing; generally, this option is not recommended because reading the ASCII data is often slower than rerunning DISORT. The following binary option should be used). See test case DISORTsavASC.
	= b or B	The first-principles, plane parallel atmosphere DISORT discrete ordinate multiple scattering algorithm is used if IMULT = ±1 on **CARD 1**. The DISORT solution to the radiation transport equation at each spectral point is written to an unformatted (*B*inary) data file "msdata.bin" or "<rootname>.msB" for subsequent MODTRAN runs. The output file can be very large. See test case DISORTsavBIN.
	= r or R	The first-principles, plane parallel atmosphere DISORT discrete ordinate multiple scattering algorithm is used if IMULT = ±1 on **CARD 1**. The previously generated DISORT solution to the radiation transport equation at each spectral point is read in. MODTRAN first checks for the existence of an unformatted (binary) data file. "msdata.bin" or "<rootname>.msB". The ASCII data file ("msdata.asc" or "<rootname>.ms") is only used the binary does not exist. The band model data files (CARD 1A2) and the spectral inputs (CARD 4) must *exactly* match those used to generate the DISORT data file. Also, the solar zenith angle should equal (or, at least, be very close to) the value used in the original DISORT calculation. Diffuse transmittances are currently not generated with this option (DISALB is set to FALSE). The DISORT data can be used with any viewing geometry and relative solar azimuth angle. See test cases DISORTuseDNLOOK and DISORTuseUPLOOK.
DISAZM	= t, f or blank	*Azimuth dependence flag used with DISORT. Set DISAZM to TRUE (T or t) to include azimuth dependence in the line-of-sight multiple scatter solar. Since this option increases computation time, DISAZM should be set to FALSE (F, f or blank) if only vertical fluxes are needed, if solar or viewing zenith angle is near vertical, or if solar multiple scattering is a small radiance component (e.g. for LWIR calculations).*
DISALB	= t, f or blank	*If DISALB is set to TRUE (T or t) with DISORT multiple scattering **AND** solar scatter is on (IEMSCT=2 or IEMSCT=4), MODTRAN will calculate the spectral spherical albedo of the atmosphere and diffuse transmittance for the line-of-sight and sun-to-ground paths, as described in Appendix F.*

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CARD 1A (Required)

NSTR	= 2, 4, 8, 16, 32, 64, 128, 256, 512	Number of streams to be used by DISORT. Using high NSTR values generally improves accuracy but slows computation. NSTR = 8 is recommended for most applications, although more streams may be desirable if modeling highly forward peaked scatterers. Currently MODTRAN is delivered with the maximum allowed number of streams (MXCMU in file PARAMS.h) set to 32. MXCMU must be increased and the source recompiled to use more than this value (for further details, see ftp://climate.gsfc.nasa.gov/pub/wiscombe/Discr_ord/).
SFWHM		The FWHM (Full Width at Half Maximum) of the triangular scanning function used to smooth Top-Of-Atmosphere (TOA) solar irradiance data [wavenumbers].
	= 0.	Use the default TOA solar data. The "DATA/SUNp1rawkur.bin" data is default for the 0.1 cm^{-1} band model; all other band models use "DATA/SUN01newkur.dat" data degraded to 5 cm^{-1} spectral resolution.
	> 0.	Spectral resolution in wavenumbers used to degrade data from a TOA solar irradiance data file utilizing a triangular slit spectral response function.
	< 0.	Spectral resolution set to |SFWHM| with spectrally convolved data output to a local data file. The data file is given the name "s0_xxxx.dat" where xxxx is int(|SFWHM|) unless a 0.1 cm^{-1} band model calculation is performed; in that case, xxxx is int(|10×SFWHM|). If repeat runs are performed with the same value of |SFWHM|, only the last output file is saved.
CO2MX		CO$_2$ mixing ratio in ppmv. The default value (used when CO2MX = blank or 0.) is 330 ppmv; the current (2012) recommended value is closer to 390 ppmv.
H2OSTR		Vertical water vapor column character string. If blank or 0., the default water vapor column is used. If the first non-blank character is 'g', the water vapor column in g / cm^2 follows 'g' (e.g., g 2.0). If the first non-blank character is an 'a', the water column in ATM-cm follows 'a' (e.g., a 3000.). Otherwise, a positive value is interpreted as a scaling factor for the water column (e.g., 2.0 doubles the default water vapor column). If H2OSTR is used with a constant pressure path, i.e., MODEL = 0 (**CARD 1**), the scaling will be applied to the water density; if an absolute water column amount is input, then the scaling factor is defined relative to the model atmosphere specified by M2 (assuming it is not 0). The water density within water clouds (ICLD = 1-10) is not scaled. Also, the water number density at each profile altitude will not be increased above 100% RH (relative humidity) or by more than 5 times the original value. When the 100% RH limit is reached, the water is distributed to other levels to the extent possible to achieve the input water column. There is a new H2OSTR option to ignore the 100% relative humidity limit; however, there is still a restriction that the H$_2$O densities not exceed 5 times the nominal value. This option is invoked by setting the first non-blank character in H2OSTR to "+", a plus sign. Thus, if one wants to set the water column to 3.0 g / cm^2 without the 100% RH limit, set H2OSTR to '+g3.0'.
O3STR		Vertical ozone column character string. If blank or 0., the default ozone column is used. If the first non-blank character is 'g', the ozone column in g / cm^2 follows 'g' (e.g., g 0.0001). If the first non-blank character is an 'a' the ozone column in ATM-cm follows 'a' (e.g., a 0.2). Otherwise, a positive value is interpreted as a scaling factor for the ozone column (e.g. 2.0 doubles the default ozone column). One Dobson unit equals 10^{-3} ATM-cm at 273.15 K. If O3STR is used with a constant pressure path, i.e., MODEL = 0 (**CARD 1**), the scaling will be applied to the ozone density; if an absolute ozone column amount is input, then the scaling factor is defined relative to the model atmosphere specified by M3 (assuming it is not 0).

CARD 1A (Required)

C_PROF	= 0 or blank	Do not scale default profiles.
	= 1	Default profile scale factors are read in on CARD 1A5 for 10 uniformly mixed molecular species.
	= 2	Default profile scale factors are read in on CARD 1A6 for 13 cross-section molecular species.
	= 3	Default profile scale factors are read in on CARDs 1A5 and 1A6 for 10 uniformly mixed and 13 cross-section molecular species.
	= 4	Default profile scale factors are read in on CARD 1A7 for 16 trace molecular species.
	= 5	Default profile scale factors are read in on CARDs 1A5 and 1A7 for 10 uniformly mixed and 16 trace molecular species.
	= 6	Default profile scale factors are read in on CARDs 1A6 and 1A7 for 13 cross-section and 16 trace molecular species.
	= 7	Default profile scale factors are read in on CARDs 1A5, 1A6 and 1A7 for 10 uniformly mixed, 13 cross-section and 16 trace molecular species.

Six top-of-atmosphere (TOA) solar irradiance data files generated by Fontenla, *et al.* [2011] were added to MODTRAN in 2012 [LSUNFL = '8', '9', 'A', 'B', 'C' and 'D']. The differences between these files are described in the Fontenla reference.

LSUNFL	= T or t	Read a user-specified Top-Of-Atmosphere (TOA) solar irradiance data file name [USRSUN] from **CARD 1A1**.
	= F, f or blank	The solar irradiance data to be used depends on the spectral resolution of the MODTRAN band model:

> "DATA/SUN15med2irradwnNormt.dat" solar irradiances are used with the 15.0 cm^{-1} band model (S15BD block data).
>
> "DATA/SUN05med2irradwnNormt.dat" solar irradiances are used with the 5.0 cm^{-1} band model (S05BD block data).
>
> "DATA/SUN01med2irradwnNormt.dat" solar irradiances are used with the 1.0 cm^{-1} band model (S01BD block data).
>
> "DATA/SUNp1med2irradwnNormt.bin" solar irradiances are used with the 0.1 cm^{-1} band model.

If |SFWHM| is a multiple of the band model resolution, the block data is degraded to |SFWHM| cm^{-1} using a triangular slit.

	= 1	Use "DATA/SUN01kuruzc2005.dat", the 2005 Kurucz 1.0 cm^{-1} TOA solar irradiance data file with the 1, 5 and 15 cm^{-1} band models. Use "DATA/SUNp1kuruzc2005.bin", the 2005 Kurucz 0.1 cm^{-1} TOA solar irradiance binary data file with the 0.1 cm^{-1} band model.
	= 2	Use "DATA/SUN01chkur.dat", the Chance plus 1997 Kurucz 1.0 cm^{-1} TOA solar irradiance data file with the 1, 5 and 15 cm^{-1} band models. Use "DATA/SUNp1kurucz1997.dat" with the 0.1 cm^{-1} band model.
	= 3	Use "DATA/SUN01cebchkur.dat", the Cebula, the Chance, and the 1997 Kurucz 1.0 cm^{-1} TOA solar irradiance data file with the 1, 5 and 15 cm^{-1} band models. Use "DATA/SUNp1kurucz1997.dat" with the 0.1 cm^{-1} band model.
	= 4	Use "DATA/SUN01thkur.dat", the Thuillier plus 1997 Kurucz 1.0 cm^{-1} TOA solar irradiance data file with the 1, 5 and 15 cm^{-1} band models. Use "DATA/SUNp1rawkur.dat" with the 0.1 cm^{-1} band model.
	= 5	Use "DATA/SUN01fontenla.asc", the Fontenla 1.0 cm^{-1} TOA solar irradiance data file with the 1, 5 and 15 cm^{-1} band models. Use "DATA/SUNp1fontenla.bin", the binary Fontenla 0.1 cm^{-1} TOA solar irradiance data file with the 0.1 cm^{-1} band model.

	= 6	Use "DATA/SUN01kuruzc1997.dat", the spectral sub-region renormalized Kurucz 1.0 cm^{-1} TOA solar irradiance data file with the 1, 5 and 15 cm^{-1} band models. With the 0.1 cm^{-1} band model, use "DATA/SUNp1kuruzc1995.bin", the 0.1 cm^{-1} 1995 Kurucz TOA solar irradiance binary data file.
	= 7	Use "DATA/SUN01kuruzc1995.dat", the 1995 Kurucz 1.0 cm^{-1} TOA solar irradiance data file with the 1, 5 and 15 cm^{-1} band models. Use "DATA/SUNp1kuruzc1995.bin", the 0.1 cm^{-1} 1995 Kurucz TOA solar irradiance binary data file with the 0.1 cm^{-1} band model.
	= 8	Use "DATA/SUN01lowirradwnNormt.dat" with the 1, 5 and 15 cm^{-1} band models, and "DATA/SUNp1lowirradwnNormt.bin" with the 0.1 cm^{-1} band model.
	= 9	Use "DATA/SUN01med1irradwnNormt.dat" with the 1, 5 and 15 cm^{-1} band models, and "DATA/SUNp1med1irradwnNormt.bin" with the 0.1 cm^{-1} band model.
	= A	Use "DATA/SUN01med2irradwnNormt.dat" with the 1, 5 and 15 cm^{-1} band models, and "DATA/SUNp1med2irradwnNormt.bin" with the 0.1 cm^{-1} band model.
	= B	Use "DATA/SUN01high1irradwnNormt.dat" with the 1, 5 and 15 cm^{-1} band models, and "DATA/SUNp1high1irradwnNormt.bin" with the 0.1 cm^{-1} band model.
	= C	Use "DATA/SUN01high2irradwnNormt.dat" with the 1, 5 and 15 cm^{-1} band models, and "DATA/SUNp1high2irradwnNormt.bin" with the 0.1 cm^{-1} band model.
	= D	Use "DATA/SUN01peakirradwnNormt.dat" with the 1, 5 and 15 cm^{-1} band models, and "DATA/SUNp1peakirradwnNormt.bin" with the 0.1 cm^{-1} band model.
LBMNAM	= F, f or blank	The default (1 cm^{-1} bin) band model database files ('DATA/p1_2008c.bn4' and 'DATA/p1_2008t.bin') are to be used.
	= 4, T or t	Read the root name of the band model parameter data file from **CARD 1A2**. The root names for the 0.1, 1.0, 5.0 and 15.0 band models are 'p1_2008', '01_2008', '05_2008', and '15_2008'. The actual files read have the suffix 'c.**bn4**' or 't.bin' added to the root name; the first suffix is for the **4-parameter** line center and the second is for the line tail parameter file.
	= 2	Read the root name of the band model parameter data file from **CARD 1A2**. The root names for the 0.1, 1.0, 5.0 and 15.0 band models are 'p1_2008', '01_2008', '05_2008', and '15_2008'. The actual files read have the suffix 'c.**bin**' or 't.bin' added to the root name; the first suffix is for the **2-parameter** line center and the second is for the line tail parameter file.
LLFLTNM	= t, f or blank.	If TRUE (T or t), read file name for user-defined instrument filter function from **CARD 1A3**.
H2OAER	= t, f or blank	If t, aerosol optical properties are modified to reflect the changes from the original relative humidity profile arising from the scaling of the water column (see H2OSTR on this CARD). Otherwise, the H$_2$O properties are fixed even though water amount has changed.
CDTDIR	= t, f or blank.	If TRUE (T or t), the directory name of the MODTRAN data files is read in on **CARD 1A4**. Alternatively, the data directory name can be included as a second string on the first line of the "mod5root.in" file; if this option is to be used, the input root file name must explicitly include the .tp5 string as a suffix. If neither of these options are invoked, data files are assumed to be in directory DATA/.
SLEVEL	= t, f or blank.	If TRUE (T or t), atmospheric level multiple scattering source function data is retrieved from DISORT, and used to compute segment radiances. Otherwise, DISORT segment radiances are scaled to correct differences between the DISORT plane parallel atmosphere geometry and the MODTRAN spherical refractive atmosphere geometry. It is recommended that SLEVEL be set to true for limb paths, i.e. paths that pass through a tangent height.
SOLCON	< 0.	The absolute value of SOLCON, likely close to +1, is used as a scale factor for the TOA (Top-Of-Atmosphere) solar irradiance. The built-in data files (in the DATA/

directory) integrate to 1368.00 W/m^2 for SUN01newkur.dat, 1362.12 W/m^2 for SUN01cebchkur.dat, 1359.75 W/m^2 for SUN01chkur.dat and 1376.73 W/m^2 for SUN01thkur.dat. An additional scaling of the solar irradiance value to account for earth-to-sun distance (based on day of year, **CARD 3A1**) is applied within MODTRAN, and this earth-to-sun correction factor is written to 'tape6' or '*rootname*.tp6'.

	= 0. or blank.	Do not scale the TOA solar irradiance.
	> 0.	The solar constant is assigned the input value [W/m^2]. As with SOLCON < 0., an additional scaling of the solar irradiance value to account for earth-to-sun distance (based on day of year, **CARD 3A1**) is applied within MODTRAN, and this earth-to-sun correction factor is written to 'tape6' or '*rootname*.tp6'.

The aerosol Angstrom Law inputs, CDASTM, ASTMC, ASTMX and ASTMO, are ignored and the reference spectral aerosol extinction, Ext$_{ref,\lambda}$, used unless ASTMX input is non-zero. Two Angstrom Law options are provided:

(1) Define boundary layer and tropospheric aerosol spectral extinction by the equation Ext(λ) / Ext(550nm) = [ASTMO + ASTMC (550nm/λ)^{ASTMX}] / [ASTMO + ASTMC], or

(2) Perturb the reference spectral extinction using the equation: Ext(λ) = Ext$_{ref,\lambda}$ (0.55/λ)**ASTMX.

With both methods, the visibility defines the 0.55μm extinction. In the perturbation approach, the reference spectral extinction curve is specified by IHAZE. The atmospheric scattering albedo is maintained unless NSSALB is non-zero.

CDASTM	= t, T, d or D	Perturb both the boundary layer and tropospheric aerosol reference spectral extinction data (see ASTMX input for details).
	= b or B	Perturb the boundary layer aerosol reference spectral extinction.
	= otherwise	If Angstrom Law input ASTMX is non-zero, use Angstrom Law description of boundary layer and tropospheric aerosol extinction data.
ASTMC		The Angstrom Law coefficient for both the boundary layer and tropospheric aerosols. ASTMC and ASTMO should sum to unity. This input is not used with the perturbation method.
ASTMX	= blank or 0.	Angstrom Law parameters are not used.
	≠ 0.	The Angstrom Law exponent for the boundary layer aerosol and for the tropospheric aerosol unless CDASTM equals ′B′ or ′b′.
ASTMO		The Angstrom Law offset for both the boundary layer and tropospheric aerosols. ASTMC and ASTMO should sum to unity. This input is not used with the perturbation method.
AERRH	> 0.	Relative humidity for the boundary layer aerosol.
	≤ 0.	The relative humidity value determined from the input atmosphere boundary layer is used for the boundary layer aerosol.

The NSSALB input allows the user to tailor the value of the aerosol spectral single scattering albedo. The tailor is applied to either the boundary layer (BL) region or both the BL and tropospheric aerosol regions depending upon the value of input CDASTM. A spectral grid of single scattering albedo values are read in if the integer input NSSALB exceeds zero, and a co-albedo scaling factor is used if NSSALB is less than zero. The former (spectral grid) option is only available with MODTRAN model aerosols, but the co-albedo scaling can also be applied to user-specified aerosol input data.

NSSALB	> 0	Number of CARD 1B aerosol single scattering albedo spectral grid points.
	= 0	Use reference aerosol spectral single scattering albedo values.
	< 0	Aerosol single scattering co-albedo (one minus the albedo) is read in on CARD 1B along with the relative humidity used to define the asymmetry factor

5. OPTIONAL CARDS 1A1, 1A2, 1A3, 1A4, 1A5, 1A6, 1A7, 1B

(SPECTRAL DATA, SENSOR RESPONSE FUNCTION FILES, AND PROFILE SCALING FACTORS)

CARDs 1A1, **1A2**, **1A3** and **1A4** all read in a character string. By default, this string has a maximum length of 256 characters. Occasionally, a user will need to accommodate and even longer name due to a complex directory structure. The length of the input character string can be increased by resetting parameter NAMLEN in included file PARAMS.h to the desired value. Note, that some compilers do have a maximum string length restriction.

CARD 1A1:   USRSUN
            FORMAT (A256)

CARD 1A1 is used to select the TOA solar irradiance data file. It is only read in if LSUNFL equals ′T′ or ′t′ in **CARD 1A**.

USRSUN = 1   Use "DATA/SUN01kuruzc2005.dat", the 2005 Kurucz 1.0 cm^{-1} TOA solar irradiance data file with the 1, 5 and 15 cm^{-1} band models. Use "DATA/SUNp1kuruzc2005.bin", the 2005 Kurucz 0.1 cm^{-1} TOA solar irradiance binary data file with the 0.1 cm^{-1} band model.

        = 2   Use "DATA/SUN01chkur.dat", the Chance plus 1997 Kurucz 1.0 cm^{-1} TOA solar irradiance data file with the 1, 5 and 15 cm^{-1} band models. Use "DATA/SUNp1kurucz1997.dat" with the 0.1 cm^{-1} band model.

        = 3   Use "DATA/SUN01cebchkur.dat", the Cebula, the Chance, and the 1997 Kurucz 1.0 cm^{-1} TOA solar irradiance data file with the 1, 5 and 15 cm^{-1} band models. Use "DATA/SUNp1kurucz1997.dat" with the 0.1 cm^{-1} band model.

        = 4   Use "DATA/SUN01thkur.dat", the Thuillier plus 1997 Kurucz 1.0 cm^{-1} TOA solar irradiance data file with the 1, 5 and 15 cm^{-1} band models. Use "DATA/SUNp1rawkur.dat" with the 0.1 cm^{-1} band model.

        = 5   Use "DATA/SUN01 Fontenla, *et al.* [2011].asc", the Fontenla 1.0 cm^{-1} TOA solar irradiance data file with the 1, 5 and 15 cm^{-1} band models. Use "DATA/SUNp1fontenla.bin", the binary Fontenla 0.1 cm^{-1} TOA solar irradiance data file with the 0.1 cm^{-1} band model.

        = 6   Use "DATA/SUN01kuruzc1997.dat", the spectral sub-region renormalized Kurucz 1.0 cm^{-1} TOA solar irradiance data file with the 1, 5 and 15 cm^{-1} band models. With the 0.1 cm^{-1} band model, use "DATA/SUNp1kuruzc1995.bin", the 0.1 cm^{-1} 1995 Kurucz TOA solar irradiance binary data file.

        = 7   Use "DATA/SUN01kuruzc1995.dat", the 1995 Kurucz 1.0 cm^{-1} TOA solar irradiance data file with the 1, 5 and 15 cm^{-1} band models. Use "DATA/SUNp1kuruzc1995.bin", the 0.1 cm^{-1} 1995 Kurucz TOA solar irradiance binary data file with the 0.1 cm^{-1} band model.

        = 8   Use "DATA/SUN01lowirradwnNormt.dat" with the 1, 5 and 15 cm^{-1} band models, and "DATA/SUNp1lowirradwnNormt.bin" with the 0.1 cm^{-1} band model.

        = 9   Use "DATA/SUN01med1irradwnNormt.dat" with the 1, 5 and 15 cm^{-1} band models, and "DATA/SUNp1med1irradwnNormt.bin" with the 0.1 cm^{-1} band model.

        = A   Use "DATA/SUN01med2irradwnNormt.dat" with the 1, 5 and 15 cm^{-1} band models, and "DATA/SUNp1med2irradwnNormt.bin" with the 0.1 cm^{-1} band model.

        = B   Use "DATA/SUN01high1irradwnNormt.dat" with the 1, 5 and 15 cm^{-1} band models, and "DATA/SUNp1high1irradwnNormt.bin" with the 0.1 cm^{-1} band model.

        = C   Use "DATA/SUN01high2irradwnNormt.dat" with the 1, 5 and 15 cm^{-1} band models, and "DATA/SUNp1high2irradwnNormt.bin" with the 0.1 cm^{-1} band model.

        = D   Use "DATA/SUN01peakirradwnNormt.dat" with the 1, 5 and 15 cm^{-1} band models, and "DATA/SUNp1peakirradwnNormt.bin" with the 0.1 cm^{-1} band model.

        = a file name   A user-defined top-of-atmosphere solar irradiance database residing in the file.

The solar databases are obtained from various sources (Anderson and Hall, 1989; Cebula *et al.*, 1996; Chance and Spurr, 1997; Kurucz, 1993; Kurucz, 1995; McElroy, 1995; McElroy *et al.*, 1995; Thuillier *et al.*, 1997; Thuillier *et al.*, 1998; Woods *et al.*, 1996; Fontenla, *et al.,* 2011).

The user-defined file must be in a special form. The first line must contain a pair of integers. The first integer designates the spectral unit [1 for frequency in wavenumbers (cm^{-1}); 2 for wavelength in nanometers (nm); and 3 for wavelength in microns (μm). The second integer denotes the irradiance unit [1 for Watts cm^{-2}/ cm^{-1}; 2 for photons sec^{-1} cm^{-2}/ nm; and 3 for Watts m^{-2}/ μm or equivalently milli-watts m^{-2}/ nm]. The subsequent lines contain one pair of frequency and irradiance entry per line. There is no restriction on frequency or wavelength increments. However, data beyond 50,000 wavenumbers are ignored. If needed, data in the user-supplied file are padded with irradiances from SUN01newkur.dat (SUNp1rawkur.dat for the 0.1 cm^{-1} band model) so that the data encompasses the range of 0 to 50,000 wavenumbers. *The user-defined file has a form that is different from that used in the solar irradiance data files delivered MODTRAN.*

CARD 1A2: *BMNAME*
FORMAT (A256)   **(If *LBMNAM* = ' T ', ' t ', ' 4 ' or ' 2 ')**

CARD 1A2 is used to select the name of the binary, direct-access version of the band model parameter data file. It is read only if LBMNAM = 'T', 't', '4' or '2' in CARD **1A**.

BMNAME = Root name for the binary, direct-access band model parameter data files. The default root names for the 0.1, 1.0, 5.0 and 15.0 cm^{-1} band model data files are 'DATA/p1_2008', 'DATA/01_2008', 'DATA/05_2008', and 'DATA/15_2008', respectively. The root name will be appended with 'c.bn4' for the 4-parameter line center band model data file, with 'c.bin' for the 2-parameter line center band model data file and with 't.bin' for the line tail band model data file. The Correlated-*k* data file with matching spectral resolution will also be opened when input variable MODTRN (**CARD 1**) equals 'C' or 'K'. The name of the Correlated-*k* data files are 'DATA/CORKp1.BIN', 'DATA/CORK01.BIN', 'DATA/CORK05.BIN', and 'DATA/CORK15.BIN'.

CARD 1A3: *FILTNM*
FORMAT (A256)   **(If *LFLTNM* = ' T ')**

CARD 1A3 is used to select a user-supplied instrument filter (channel) response function file. It is read only if LFLTNM = T in **CARD 1A**.

FILTNM   = User-supplied instrument filter response function file name. A **sample** AVIRIS filter response function is supplied with the model ('DATA/aviris.flt').

Whenever this option is used, the include file CHANNELS.h should be reviewed to insure consistency between the CHANNELS.h PARAMETERS and the input response function file. CHANNELS.h defines 4 parameters:

MXCHAN   Maximum number of channels in the response function file.

MNBIN   Minimum **frequency** bin in the channel function integrations (cm^{-1}).

MXBIN   Maximum **frequency** bin in the channel function integrations (cm^{-1}).

MXNCHN   Maximum number of channels to which a single band model spectral bin will contribute.

The CHANNELS.h MNBIN and MXBIN parameters must be defined in frequency (cm^{-1}) units even though the filter function file data may be entered in frequency or wavelength (nm or microns) units.

If the filter function file is used, it must be in the following form:

```
UNITS_HEADER
HEADER (1)
w₁₁        r₁₁
w₁₂        r₁₂
w₁₃        r₁₃
…
HEADER (2)
w₂₁        r₂₁
w₂₂        r₂₂
w₂₃        r₂₃
```

> **...**
> etc.

Here,

- UNITS_HEADER is a string whose first character is 'N' (for nm), 'W' (for wavenumber), or 'M' (for microns), denoting the wavelength or frequency unit;
- HEADER (i) is a string, whose first character is non-numeric and not a decimal point, denotes the start of a list of (wavelength, response) pairs for the ith channel; and
- (w_{ij} r_{ij}) are the jth wavelength and response values for the ith channel.

CARD 1A4:   *DATDIR*
          FORMAT (A256)   **(If CDTDIR = ' T ')**

CARD 1A4 contains DATDIR, the path name for the MODTRAN data files. If a molecular band model data file name is explicitly entered, DATDIR/ is used for that file.

DATDIR   =   Path name for the directory containing MODTRAN data files.

Scale factors for the default profiles are entered using **CARD**s **1A5**, **1A6** and **1A7**.

CARD 1A5:   **(S_UMIX(IMOL), IMOL = 4, 12)**
          FORMAT (9F5.0)   **(If C_PROF = 1, 3, 5 or 7)**

CARD 1A6:   **(S_XSEC(IMOL), IMOL = 1, 13)**
          FORMAT (13F5.0)   **(If C_PROF = 2, 3, 6 or 7)**

CARD 1A7:   **(S_TRAC(IMOL), IMOL = 1, 16)**
          FORMAT (16F5.0)   **(If C_PROF = 4, 5, 6 or 7)**

CARD 1A5 contains scale factors for the default vertical profiles of 9 uniformly mixed molecular species: N_2O, CO, CH_4, O_2, NO, SO_2, NO_2, NH_3, HNO_3, *and* N_2. **CARD 1A6** contains scale factors for the default vertical profiles of 13 cross-section molecular species: CFC−11, CFC−12, CFC−13, CFC−14, CFC−22, CFC−113, CFC−114, CFC−115, $ClONO_2$, HNO_4, $CHCl_2F$, CCl_4, and N_2O_5. **CARD 1A7** contains scale factors for the default vertical profiles of 16 trace molecular species: OH, HF, HCl, HBr, HI, ClO, OCS, H_2CO, HOCl, N_2, HCN, CH_3Cl, H_2O_2, C_2H_2, C_2H_6, and PH_3.

CARD 1B: (*AWAVLN(ISSALB), ASSALB(ISSALB), ISSALB=1, NSSALB*)
          FORMAT ((8F10.0))   **(If NSSALB > 0)**

          ACOALB, RHASYM
          FORMAT (2F10.0)   **(If NSSALB < 0)**

AWAVLN   Wavelength grid for boundary layer (and tropospheric) aerosol single scattering albedo in monotonically increasing order [μm].

ASSALB   Boundary layer (and tropospheric) aerosol spectral single scattering albedo values.

ACOALB   Aerosol single scattering co-albedo (one minus the albedo) scaling factor. The scaling factor may exceed one, but the spectral co-albedo at each grid point is restricted to not exceed one.

RHASYM   Relative humidity used to define the aerosol asymmetry factor [%]

6. CARD 2 (REQUIRED) – MAIN AEROSOL AND CLOUD OPTIONS

CARD 2: **APLUS, IHAZE, CNOVAM, ISEASN, *ARUSS*, IVULCN, ICSTL, ICLD, IVSA, VIS, WSS, WHH, RAINRT, GNDALT**
FORMAT (A2, I3, A1, I4, A3, I2, 3I5, 5F10.0)

IHAZE, ISEASN, IVULCN, and VIS select the altitude and seasonal-dependent aerosol profiles and aerosol extinction coefficients. IHAZE specifies the aerosol model used for the boundary-layer (0 to 2 km) and a default, surface-meteorological range. The relative humidity dependence of the boundary-layer aerosol extinction coefficients is based on the water vapor content of the model atmosphere selected by MODEL. ISEASN selects the seasonal dependence of the profiles for both the tropospheric (2 to 10 km) and stratospheric (10 to 30 km) aerosols. IVULCN is used to select both the profile and extinction type for the stratospheric aerosols and to determine transition profiles through the stratopause to 100 km. VIS, the meteorological range, when specified, will supersede the default meteorological range in the boundary-layer aerosol profile set by IHAZE.

IHAZE selects the type of extinction and a default meteorological range for the boundary-layer aerosol models only. If VIS is also specified, it will override the default IHAZE value. Interpolation of the extinction coefficients based on relative humidity is performed only for the RURAL, MARITIME, URBAN, and TROPOSPHERIC coefficients used in the boundary layer (0 to 2 km altitude).

The character string inputs APLUS, CNOVAM, and ARUSS (for AeRosol User Supplied Spectra) were introduced in MODTRAN3.7 to give greater flexibility in defining aerosols. APLUS was introduced to modify aerosol profiles, NOVAM introduced to allow selection of NOVAM, and ARUSS introduced to give greater flexibility in defining aerosol optical properties. MODTRAN5.3 introduces even greater flexibility in defining aerosol by setting the ARUSS string to 'SAP', Spectral Aerosol Profiles.

APLUS   = Blank Default
         = 'A+'   Use "Aerosol Plus" option (triggers reading of **CARD 2A+**) to characterize user-defined aerosols optical profiles.

IHAZE   = −1   No aerosol attenuation, but a model clouds is included (i.e., ICLD = 1, 2… 10, 18 and 19).
         = 0   No aerosol or cloud attenuation included in the calculation.
         = 1   RURAL extinction, default VIS = 23 km.
         = 2   RURAL extinction, default VIS = 5 km.
         = 3   NAVY MARITIME extinction (sets VIS based on wind speed & relative humidity).
         = 4   MARITIME extinction, default VIS = 23 km (LOWTRAN model).
         = 5   URBAN extinction, default VIS = 5 km.
         = 6   TROPOSPHERIC extinction, default VIS = 50 km.
         = 7   User-defined aerosol extinction coefficients. Triggers reading **CARDs 2D, 2Dl** and **2D2** for up to 4 altitude regions of user-defined extinction, absorption and asymmetry parameters. (This option is kept for backward compatibility; the ARUSS = 'USS' option affords greater flexibility in specifying user-defined aerosols).
         = 8   FOG1 (Advective Fog) extinction, 0.2 km VIS.
         = 9   FOG2 (Radiative Fog) extinction, 0.5 km VIS.
         = 10   DESERT extinction, sets visibility from wind speed (WSS).

CNOVAM = Blank Default
         = 'N'   Navy Oceanic Vertical Aerosol Model (NOVAM) (Appendix B).

ISEASN selects the appropriate seasonal aerosol profile for the tropospheric and stratospheric aerosols. Only the tropospheric aerosol extinction coefficients are used with the 2 to 10 km profiles.

ISEASN   = 0   Season determined by the value of MODEL;
                  SPRING-SUMMER for MODEL = 0, 1, 2, 4, 6, 7, 8
                  FALL-WINTER for MODEL = 3, 5
         = 1   SPRING-SUMMER
         = 2   FALL-WINTER

CARD 2 (Required)

ARUSS = Blank Default

= 'USS' User-defined aerosol optical properties (instructions in Appendix A)

= 'SAP' Spectral Aerosol Profiles. This option allows vertical profiles of aerosol spectral extinction, spectral absorption and spectral phase functions to be read in. MODEL (CARD 1) must be 7 or 8 so SAP cannot be used with the model atmospheres.

The SAP option reads in spectral aerosol profile data from an ASCII "<rootname>.sap" or "SpecAerProf.dat" file; the later name is used if no rootname is provided from the mod5root.in file. A sample input file is shown in Table 3. Each line of the SpecAerProf.dat files is read in using a free format, so values must be separated by spaces and/or a comma – no tabs. The first line contains 3 integers, NWVSAP (the number of spectral grid points), NLGSAP (the number of scattering phase function Legendre moments) and NANSAP (the number of scattering phase function angular points). Header information can follow these numbers on this line, but it is not 764read in. The second line contains the scattering phase function angular grid. Angles are in degrees. The angular grid must begin with 0., be monotonically increasing and end with 180.

Table 3. Sample Spectral Aerosol Profiles (SAP) Input Data File.

40 64 181	wave	Bext(1/km)	Bsca(1/km)	Pmom0	Pmom1	...	Pmom64	Phase Function vs Angle (°)			
								0.0000	1.0000	...	180.0000
.0003653	.2000	.9173681	.9158943	1.0000	.7966921	...	.1319957	208.9782	193.6871	...	.7423355
.0003653	.3000	.8726480	.8726359	1.0000	.8118536	...	.1070675	208.8804	194.0608	...	.3700137
.0003653	.3371	.8525812	.8525700	1.0000	.8112088	...	.1012243	207.9938	193.4231	...	.3866308
.	. . . .										
.0003653	30.00	.2369326	.0895308	1.0000	.7221835	...	.0000000	29.82364	29.57460	...	.1475345
.0003653	40.00	.2156776	.0699561	1.0000	.6948593	...	.0000000	21.41463	21.30646	...	.1690632
.1260741	.2000	.3358318	.3343440	1.0000	.7796006	...	.0807715	172.1363	160.5204	...	.6840323
.1260741	.3000	.3008995	.3008881	1.0000	.7767678	...	.0675285	161.2990	150.9579	...	.6125076
.1260741	.3371	.2897007	.2896896	1.0000	.7733779	...	.0646587	157.8538	147.8797	...	.6019086
.	. . . .										
.1260741	30.00	.0562292	.0217360	1.0000	.6611843	...	.0000000	14.18904	14.14785	...	.1608776
.1260741	40.00	.0584414	.0161276	1.0000	.5706048	...	.0000000	10.02048	10.00178	...	.2772588
.	. . . .										
1993.880	.2000	.2613175	.2602409	1.0000	.7697431	...	.0518847	152.5157	142.7655	...	.6152996
1993.880	.3000	.2297381	.2297099	1.0000	.7593464	...	.0413473	136.5168	128.3560	...	.5908967
1993.880	.3371	.2196234	.2196121	1.0000	.7543240	...	.0390868	131.9052	124.1712	...	.5874675
.	. . . .										
1993.880	30.00	.0271156	.0099214	1.0000	.6250932	...	.0000000	11.57627	11.55026	...	.1904991
1993.880	40.00	.0317162	.0074431	1.0000	.5096798	...	.0000000	8.037910	8.026117	...	.3562035
2237.286	.2000	.0000000	.0000000	0.0000	.0000000	...	.0000000	0.000000	0.000000	...	.0000000
2237.286	.3000	.0000000	.0000000	0.0000	.0000000	...	.0000000	0.000000	0.000000	...	.0000000
2237.286	.3371	.0000000	.0000000	0.0000	.0000000	...	.0000000	0.000000	0.000000	...	.0000000
.	. . . .										
2237.286	30.00	.0000000	.0000000	0.0000	.0000000	...	.0000000	0.000000	0.000000	...	.0000000
2237.286	40.00	.0000000	.0000000	0.0000	.0000000	...	.0000000	0.000000	0.000000	...	.0000000
40 64 18	wave	Bext(1/km)	Bsca(1/km)	Pmom1	Pmom2	...	Pmom64	Phase Function vs Angle (°)			
								0.0000	1.0000	...	180.0000
.0003653	.2000	.9173681	.9158943	1.0000	.7966921	...	.1319957	208.9782	193.6871	...	.7423355
.0003653	.3000	.8726480	.8726359	1.0000	.8118536	...	.1070675	208.8804	194.0608	...	.3700137
.0003653	.3371	.8525812	.8525700	1.0000	.8112088	...	.1012243	207.9938	193.4231	...	.3866308
.	. . . .										

CARD 2 (Required)

The next NWVSAP lines contain the aerosol data for the first (i.e. ground) MODTRAN altitude. The altitude, which is entered in meters, is the first entry in each line and it must agree with the first altitude from CARD 2C1 (on CARD 2C1, the altitude is entered in km). The second entry on each line is the wavelength in microns. Wavelengths must be monotonically increasing. The 3rd and 4th entry on each line are the extinction and scattering coefficients in units of km^{-1}. The remainder of each line contains phase function data. The NLGSAP Legendre moments are listed first (with the Nth term divided by 2N+1 so that Σ (2N+1) P_{mom}(N) equals the forward peak of the phase function). The Legendre moments should be normalized so that P_{mom}(1) always equals 1. Phase function values at each of the angular grid points are listed after the Legendre moments, on the same line. Within MODTRAN, the tabulated phase function is renormalized to 1 (not 4π sr) assuming exponential variation between the <u>cosine of scattering angle</u> values.

Data for the second CARD 2C1 altitude, again with NWVSAP lines, follows the data from the first altitude. The spectral grid is re-entered as the second entry on each line, but it must fully correspond to the spectral grid from the first altitude.

The SAP input altitude grid is terminated by entering NWVSAP lines containing the terminating altitude (2.237286km for Table 3). These lines must also contain the spectral wavelengths and **zeros for all other entries**. (MODTRAN keys in on the zero value for P_{mom}(1).

For the terminating altitude and all altitudes above it, aerosol properties are determined by the CARD 2 inputs IHAZE, ISEASN, IVULCN, ICSTL, ICLD, VIS, WSS, WHH, GNDALT. However, these "background" aerosol are set to zero at all altitude levels below the SAP termination altitude.

If a repeat run is performed with IRPT=1 or IRPT=-1, and with ARUSS again set to SAP, the next set of spectral aerosol profile data must follow the first set. See the MODTRAN test cases UserPath.tp5, UserPathBinary.tp5 and UserPathDisort.tp5 for examples.

The parameter IVULCN controls both the selection of the aerosol profile as well as the type of extinction for the stratospheric aerosols. It also selects appropriate transition profiles above the stratosphere to 100 km. Meteoric dust extinction coefficients are always used for altitudes from 30 to 100 km.

IVULCN	=	0,1	BACKGROUND STRATOSPHERIC profile and extinction
	=	2	MODERATE VOLCANIC profile and AGED VOLCANIC extinction
	=	3	HIGH VOLCANIC profile and FRESH VOLCANIC extinction
	=	4	HIGH VOLCANIC profile and AGED VOLCANIC extinction
	=	5	MODERATE VOLCANIC profile and FRESH VOLCANIC extinction
	=	6	MODERATE VOLCANIC profile and BACKGROUND STRATO-SPHERIC extinction
	=	7	HIGH VOLCANIC profile and BACKGROUND STRATOSPHERIC extinction
	=	8	EXTREME VOLCANIC profile and FRESH VOLCANIC extinction

ICSTL is the air mass character (1 to 10), used with the precursor to NOVAM, i.e., the Navy-maritime Aerosol Model NAM (**IHAZE = 3**). Default value is 3. ICSTL is not used with NOVAM.

ICSTL	=	1	Open ocean
		.	
		.	
		.	
		10	Strong continental influence

CARD 2 (Required)

Table 4. Shows the Value of IVULCN Corresponding to the Different Choices of Extinction Coefficient Model and the Vertical Distribution Profile.

	VERTICAL DISTRIBUTION			
EXTINCTION MODEL	BACKGROUND STRATOSPHERIC	MODERATE VOLCANIC	HIGH VOLCANIC	EXTREME VOLCANIC
BACKGROUND STRATOSPHERIC	0,1	6	7	-
AGED VOLCANIC	-	2	4	-
FRESH VOLCANIC	-	5	3	8

ICLD specifies the cloud and rain models used. The rain profiles decrease linearly from the ground to the top of the associated cloud model. The program cuts off the rain at the cloud top.

ICLD	=	0	No clouds or rain.
	=	1	Cumulus cloud layer: base 0.66 km, top 3.0 km.
	=	2	Altostratus cloud layer: base 2.4 km, top 3.0 km.
	=	3	Stratus cloud layer: base 0.33 km, top 1.0 km.
	=	4	Stratus/stratocumulus layer: base 0.66 km, top 2.0 km.
	=	5	Nimbostratus cloud layer: base 0.16 km, top 0.66 km.
	=	6	2.0 mm/hr ground Drizzle (Cloud 3 and 0.86 mm / hr at 1.0 km).
	=	7	5.0 mm/hr ground Light rain (Cloud 5 and 2.6 mm / hr at 0.66 km).
	=	8	12.5 mm/hr ground Moderate rain (Cloud 5 and 6.0 mm / hr at 0.66 km).
	=	9	25.0 mm/hr ground Heavy rain (Cloud 1 and to 0.2 mm / hr at 3.0 km).
	=	10	75.0 mm/hr ground Extreme rain (Cloud 1 and 1.0 mm / hr at 3.0 km).
	=	11	Read in user defined cloud extinction and absorption. Triggers reading **CARDs 2D, 2D1** and **2D2** for up to 4 altitude regions of user defined extinction, absorption, and asymmetry parameters (This option is kept for backward compatibility; **CARD 2A** inputs afford greater flexibility in specifying user-defined clouds).
	=	18	Standard Cirrus model (64 μm mode radius for ice particles).
	=	19	Sub-visual Cirrus model (4 μm mode radius for ice particles).

IVSA selects the use of the Army Vertical Structure Algorithm (VSA) for aerosols in the boundary layer.

IVSA	=	0	Not used.
	=	1	Vertical Structure Algorithm.

MODTRAN4 introduced a new option for input VIS. Traditionally, VIS specifies the surface meteorological range (km) overriding the default value associated with the boundary layer chosen by IHAZE. If VIS is set to zero, a default value based on IHAZE is used. Visibility is related to surface aerosol extinction at 550 nm (EXT550 in km^{-1}) by the equation

$$VIS\,[km] \quad = \quad \frac{\ln(50)}{EXT550\,[km^{-1}] + 0.01159\,km^{-1}}$$

where 0.01159 km^{-1} is the surface Rayleigh scattering coefficient at 550nm. The new option for the VIS input allows one to define the 550nm aerosol vertical optical depth (OD). The NEGATIVE of the OD is entered. A new MODTRAN routine GETVIS combines the OD with ground altitude, season ('Summer/Spring' or 'Winter/Fall'), and volcanic aerosol model inputs to determine the appropriate surface meteorological range. Note, if the input OD is too small, i.e., less than the contribution from the higher altitude aerosols, MODTRAN will terminate with the error message, "GETVIS Error: Input aerosol optical depth is too low."

CARD 2 (Required)

Table 5. MODTRAN CARD 2 Input Parameters: IHAZE, ISEASN, IVULCN, VIS.

CARD 2	APLUS, IHAZE, CNOVAM, ISEASN, ARUSS, IVULCN, ICSTL, ICLD, IVSA, VIS, WSS, WHH, RAINRT, GNDALT FORMAT (A2, I3, A1, I4, A3, I2, 3I5, 5F10.5)								
IHAZE			ISEASN		IVULCN				
In COL. 3-5	VIS* (KM)	EXTINCTION	In COL. 7-10	SEASON	In COL. 14-15	SEASON	PROFILE	EXTINCTION	PROFILE/ EXTINCTION
0	No Aerosols								
1	23	RURAL	0	Set by model		Set by model			Meteoric dust extinction
2	5		1	Spring-Summer		Spring-Summer			
3	**	Navy maritime	2	Fall-Winter		Fall-Winter			
4	23	LOWTRAN maritime	Tropospheric profile/ tropospheric extinction		0 1		Background stratospheric	Background stratospheric	Normal atmospheric profile
5	5	URBAN			2		Moderate volcanic	Aged volcanic	Transition profiles - volcanic to normal
6	50	Tropospheric			3		High volcanic	Fresh volcanic	
7	23	User-defined			4		High volcanic	Aged volcanic	
8	0.2	Fog 1			5		Moderate volcanic	Fresh volcanic	
9	0.5	Fog 2			6		Moderate volcanic	Background stratospheric	
10	**	Desert			7		High volcanic	Background stratospheric	
					8		Extreme volcanic	Fresh volcanic	
0 to 2 km			2 to 10 km		10 to 30 km				30 to 100 km
* Default VIS, can be overridden by VIS > 0 on CARD 2 ** Sets own default VIS									

It should be recognized that Meteorological Range as defined by the above equation is **not the same as the Visibility.** Visibility is a subjective quantity depending on the ability of an observer to see and identify a prominent dark object against the horizon sky or at night a light source. (See *Glossary of Meteorology,* T.S. Glickman, Managing Editor, American Meteorological Society, Boston, MA, 2000). Point Visibility Meters, or other instruments that measure "visibility" are generally calibrated to match the sensitivity of a typical observer, and replace the threshold contrast "ε=0.02" in the visual range formula by "ε=0.05". More generally Meteorological Range, VIS, can be estimated from reported values of visibility by:

$$\text{Meteorological Range} = \text{VIS} = (1.3 \pm 0.3) \times \text{Visibility}$$

VIS	>	0.	User specified surface meteorological range (km).
	=	0.	Uses the default meteorological range set by IHAZE; (See Table 5).
	<	0.	Negative of the 550 nm vertical aerosol optical depth.

WSS specifies the current wind speed for use with the Navy maritime and desert aerosol models.

WSS   =   Current wind speed (m/s). Used with the Navy Aerosol Maritime (NAM) model (IHAZE = 3) or the DESERT model (IHAZE = 10).

WHH specifies the 24-hour average wind speed for use with the Navy maritime model.

WHH   =   24-hour average wind speed (m/s). Used with the Navy Aerosol Maritime (NAM) model (IHAZE = 3)

For the Navy Aerosol Maritime model, if WSS = WHH = 0, default wind speeds are set according to the value of MODEL, Table 6. For the Desert aerosol model (IHAZE = 10), if WSS < 0, the default wind speed is 10 m/s.

CARD 2 (Required)

Table 6. Default Wind Speeds for Different Model Atmospheres Used with the Navy Maritime Model (IHAZE = 3).

Model	Model Atmosphere	WSS & WHH Default Wind Speeds (m/s)
0	User-defined (Horizontal Path)	6.9
1	Tropical	4.1
2	Mid-latitude summer	4.1
3	Mid-latitude winter	10.29
4	Sub-arctic summer	6.69
5	Sub-arctic winter	12.35
6	U.S. Standard	7.2
7,8	User-defined	6.9

RAINRT specifies the rain rate and GNDALT specifies the altitude of the surface:

RAINRT   =   Rain rate (mm/hr). The default value is zero for no rain. Used to top of cloud when cloud is present; when no clouds, rain rate used to 6km.

GNDALT   =   Altitude of surface relative to sea level (km). GNDALT may be negative but may not exceed 6 km. The baseline 0 to 6-km aerosol profiles are compressed (or stretched) based on input GNDALT. *GNDALT is set to the first profile altitude when radiosonde data is used (model = 7).*

Table 5 summarizes the use of the input control parameters IHAZE, ISEASN, IVULCN, and VIS on **CARD 2**. Table 7 summarizes the use of the parameter ICLD.

Table 7. MODTRAN CARD 2 Input Parameter: ICLD.

ICLD	Cloud and/or Rain Option		
0	NO CLOUDS OR RAIN		
1	CUMULUS CLOUD		
2	ALTOSTRATUS CLOUD		
3	STRATUS CLOUD		
4	STRATUS / STRATOCUMULUS		
5	NIMBOSTRATUS CLOUD		
6	2.0 MM/HR	DRIZZLE	(MODELED WITH CLOUD 3)
7	2.0 MM/HR	LIGHT RAIN	(MODELED WITH CLOUD 5)
8	12.5 MM/HR	MODERATE RAIN	(MODELED WITH CLOUD 5)
9	25.0 MM/HR	HEAVY RAIN	(MODELED WITH CLOUD 1)
10	75.0 MM/HR	EXTREME RAIN	(MODELED WITH CLOUD 1)
11	USER DEFINED CLOUD EXTINCTION AND ABSORPTION		
18	STANDARD CIRRUS MODEL		
19	SUB VISUAL CIRRUS MODEL		

7. OPTIONAL CARD 2A+ (FLEXIBLE AEROSOL MODEL)

CARD 2A+, which is read if APLUS = 'A+' in **CARD 2**, allows the user to move MODTRAN's built-in aerosols from their original positions to arbitrary altitude regions (which may overlap) and to compress and stretch them using only two input lines. If the **CARD 2** input GNDALT is non-zero, the aerosol densities below 6 km will undergo an additional compression or stretching, as described in Section 6. An important benefit is the ability to move the tropopause height. The **CARD 2A+** options cannot be used in conjunction with NOVAM. Furthermore, *if A+ is used with MODEL=7* (from **CARD 1**), the atmospheric profile must contain atmospheric levels precisely at GNDALT, GNDALT + (6 – GNDALT) / 3, GNDALT + (6 – GNDALT) / 2, 10.000, 11.000, 30.000, 35.000 and 100.000 km; there are no added restriction on the **CARD 2A+** inputs:

> **CARD 2A+:** **ZAER11, ZAER12, SCALE1, ZAER21, ZAER22, SCALE2, ZAER31, ZAER32, SCALE3, ZAER41, ZAER42, SCALE4**
> **FORMAT ((3(1X, F9.0), 20X, 3(1X, F9.0)))** **(If APLUS = 'A+')**

There are 12 variables in the two lines of **CARD 2A+** as enumerated above. The first set of three is for aerosol number 1; the second set of three, for aerosol 2; the third set, for aerosol 3 and the fourth set, for aerosol 4. The meanings of the numerical values for ZAERi1, ZAERi2 and SCALEi, i = 1, 2, 3 and 4, are as follows:

ZAERi1		The base/bottom of aerosol i
ZAERi2 >	ZAERi1	The top of aerosol i
<	ZAERi1	Translate original profile to new base, ZAERi1
=	ZAERi1	Set values to default, ignore SCALEi (Also set to default when both ZAERi1 and ZAERi2 are blank)
SCALEi >	0.0	Multiply vertical profile by SCALEi
=	0 or blank	Multiply vertical profile by 1.0 (i.e., preserves column density)

The aerosols are linearly mapped into the new region and the column densities are preserved if SCALEi is unity. Note that since the cards are read using fixed formats, blanks are interpreted as zeros. By default, SCALEi is set to unity if blanks or 0.0 are input. Note that if the APLUS option is used, the two lines of **CARD 2A+** must be present even if any of these lines are intended to consist of all blanks.

The MODTRAN/LOWTRAN definition of an aerosol region leads to some confusion. Possibly a preferred definition of the aerosol region would be the contiguous altitudes over which the aerosol concentration is positive. By this definition, the region of aerosol 1, for example, is from 0 to 3 km; the profile linearly decreases from a positive value at 2 km to zero at 3 km. Instead, in previous MODTRAN documentation this region is said to be from 0-2 km. In the MODTRAN upgrade, the ZAERi1 and ZAERi2 values refer to the bounding altitudes, which sandwich the entire region where the aerosol concentration is positive. Table 8 lists the default values of these bounding altitudes along with the commonly referred to region boundaries for each aerosol.

One caveat with regard to the **CARD 2+** inputs should be noted. For the Tropospheric aerosol model (**IHAZE = 6**), MODTRAN combines the boundary layer (Aerosol 1) and tropospheric (Aerosol 2) regions; therefore, these region may not be scaled independently. Thus, the parameters used to scale the tropospheric aerosol model are min (ZAER11, ZAER21), max (ZAER12, ZAER22) and max (SCALE1, SCALE2).

Table 8. Default Aerosol Region Boundaries.

Aerosol	Common Region Definition	Actual ZAERi1	Actual ZAERi2
1	0-2 km	0 km	3 km
2	2-10	2	11
3	10-30	10	35
4	30-100	30	100

8. OPTIONAL CARD 2A (CLOUD MODELS)

CARD 2A is required for all cloud models (ICLD > 0) except ICLD = 11.   Note that the original MODTRAN3.0 format has been changed.   To run a default cloud case with ICLD = 1-10, the alternative **CARD 2A** should read:

```
 -9.000   -9.000   -9.000   -9   -9   -9.000   -9.000   -9.000   -9.000   -9.000   -9.000
```

The standard and alternate forms are discussed in Subsections 8.1 and 8.2, respectively.

8.1 CARD 2A Standard Form (CIRRUS CLOUD MODELS, ICLD = 18 or 19

The standard cirrus option should not be used in conjunction with user-defined layering (MODEL = 7 or 8); instead, the alternate form (Section 8.2) should be invoked with user specified profiles.

> **CARD 2A: CTHIK, CALT, CEXT**
> **FORMAT (3F8.0)**   **(If ICLD = 18 or 19)**

CTHIK is the cirrus thickness (km):

CTHIK   ≤ 0.   Use thickness statistics.
        > 0.   User-defined thickness.

CALT is the cirrus base altitude (km):

CALT   ≤ 0.   Use calculated value.
      > 0.   User-defined base altitude.

CEXT is the extinction coefficient (km^{-1}) at 0.55 micron:

CEXT   ≤ 0.   Use (0.14 km^{-2}) * CTHIK.
      > 0.   User-defined extinction coefficient.

8.2 CARD 2A Alternate Form (WATER/ICE CLOUD MODELS, ICLD = 1 - 10)

> Alternate **CARD 2A: CTHIK, CALT, CEXT, NCRALT, NCRSPC, CWAVLN, CCOLWD, CCOLIP,**
> **CHUMID, ASYMWD, ASYMIP**
> **FORMAT (3F8.0, 2I4, 6F8.0)**   **(If ICLD = 1-10)**

This form of **CARD 2A** is for modifying parameters for clouds other than cirrus. Use of this CARD triggers the reading of **CARDs 2E1** and **2E2,** described below in their respective sections. See Berk and Anderson, SSI-TR-267, for a more extensive discussion.

Default values can be assigned to any of the **CARD 2A** variables by setting them equal to negative nine. An actual computer card image is shown below (2 leading spaces and two spaces between each number). All **CARD 2A** variables are set to their default value with this input line:

```
 -9.000   -9.000   -9.000   -9   -9   -9.000   -9.000   -9.000   -9.000   -9.000   -9.000
```

A blank line will not generate the default values. In fact, setting all **CARD 2A** inputs to zero would produce an isotropic scattering ground-level cloud.

CTHIK is the cloud vertical thickness:

CTHIK   > 0.   Cloud vertical thickness [km].
      ≤ 0.   Use default cloud thickness.

The cloud vertical thickness is defined as the altitude difference between the highest and lowest cloud profile boundary altitude for which either water droplet or ice particle density is positive. The ten MODTRAN cloud/rain models are derived from five distinct clouds. The default thicknesses for these clouds are listed in Table 9. This will not only scale default clouds but also user-specified cloud profiles (**CARD 2E1**).

CALT is the cloud base altitude relative to ground level:

CALT   ≥ 0.   Cloud base altitude relative to ground level [km].
      < 0.   Use default cloud base altitude.

This differs from the meaning of CALT in the cirrus cloud models (ICLD = 18 or 19) which define base altitude relative to sea level. Note that a value of zero translates the cloud down to the ground; the user must enter a negative altitude to have the cloud automatically placed at the default altitude. If there is a non-constant rain profile below a cloud, that profile is stretched or compressed depending upon whether the base altitude is increased or decreased.

Table 9. Properties of the MODTRAN Cumulus and Stratus Type Model Clouds.

ICLD	Cloud Type	Thickness (km)	Base (km)	0.55µm Ext. (km⁻¹)	Column Amt. (km g / m³)
1	Cumulus	2.34	0.66	92.6	1.6640
2	Altostratus	0.60	2.40	128.1	0.3450
3	Stratus	0.67	0.33	56.9	0.2010
4	Stratus/Stratocumulus	1.34	0.66	38.7	0.2165
5	Nimbostratus	0.50	0.16	92.0	0.3460

CEXT is the cloud liquid water droplet and ice particle vertical extinction:

CEXT $\quad > \quad 0.$ $\quad$ Cloud water particle vertical extinction [km⁻¹].

$\qquad \leq \quad 0.$ $\quad$ Do not scale extinction coefficients.

CEXT is defined for wavelength CWAVLN (see below). Within the code, CEXT is used to scale the extinction (and absorption) coefficient curves. The ratio of the input optical depth (CEXT * CTHIK) to the calculated optical depth (the product of column density and extinction coefficient at CWAVLN, summed for both liquid water droplets and ice particles) is determined. The extinction and absorption coefficients at all frequencies are multiplied by this ratio. The default cloud extinction at 0.55 µm for each of the five MODTRAN liquid water droplet model clouds is listed in Table 8.

NCRALT is the number of layer boundary altitudes if a user-defined cloud/rain profile is being input:

NCRALT $\geq$ 3 $\qquad$ Number of layer boundary altitudes (from **CARD 2E1**) in user-defined cloud/rain profile.

$\qquad <$ 3 $\qquad$ Use default cloud profile for ICLD.

The maximum allowed value for NCRALT is 16, parameter NZCLD in PARAMS.h; this value can be increased, but this change requires some modification of block data /MDTA/. NCRALT must be at least 3 to define the cloud base, the cloud top, and the highest boundary altitude for which the water droplet and ice particle densities must be zero. It is generally recommended that the altitude below which cloud densities are zero also be included in the cloud profile. If this altitude is not entered, MODTRAN assumes that the cloud densities drop to zero 1 meter below the cloud base.

NCRSPC is the number of wavelength entries:

NCRSPC $\quad \geq$ 2 $\qquad$ Number of cloud spectral data wavelengths to be input (on **CARD 2E2**).

$\qquad =$ 1 $\qquad$ Read *alternate* **CARD 2E2**.

$\qquad \leq$ 0 $\qquad$ Use default spectral data for ICLD.

NCRSPC must be at least 2 so the minimum and maximum wavelengths do not coincide. A maximum of 788 wavelengths (parameter MXWVLN in PARAMS.h) may be input.

CWAVLN is the reference wavelength used in defining cloud vertical extinction:

CWAVLN $\geq$ 0.2 & $\leq$ 200.0 $\quad$ Reference wavelength for defining cloud vertical extinction [µm]

CWAVLN outside this range specifies the default, 0.55 µm. The variable CWAVLN is only used if a user-selected value for CEXT is input. Furthermore, if CWAVLN is outside the spectral range of user-defined cloud spectral data (**CARD 2E2**), a fatal error message is logged and execution terminated.

CCOLWD is the water droplet (WD) cloud vertical column density:

CCOLWD $\geq$ 0. $\qquad$ Cloud liquid water droplet vertical column density [km g / m³].

$\qquad <$ 0. $\qquad$ Do not scale the water droplet densities.

MODTRAN determines the ratio of this input water droplet vertical column density to the column density calculated from the input cloud base, thickness, and the default water droplet densities. Then all the water droplet densities are scaled by this ratio so that the desired column amount results.

It should be noted that if the cloud being modeled only has liquid water and a positive cloud vertical extinction, CEXT, is input, MODTRAN will change spectral extinction and absorption coefficients so that predicted path transmittances and radiances are independent of CCOLWD. However, if the spectral data are not being scaled to give a particular vertical extinction, increasing column density will increase extinction. Furthermore, if the cloud consists of both liquid water droplets and ice particles, CCOLWD can be used to customize the relative contribution from the two particle types. The default cloud water droplet column densities for the five MODTRAN liquid water clouds are listed in Table 8.

CCOLIP is the ice particle (IP) cloud vertical column density:

CCOLIP $\geq$ 0.   Cloud ice particle vertical column density or amount [km g / m^3].
            < 0.   Do not scale the ice particle densities.

Generally, CCOLIP is used to scale ice particle density the same way CCOLWD is used to scale water droplet density. However, two points should be noted: (1) The MODTRAN cumulus and stratus type clouds (ICLD = 1 - 10) treated by this alternate **CARD 2A** do not contain ice particles. Thus, only user-defined cloud profiles (see **CARD 2E1** below) can be scaled using CCOLIP; (2) If both CCOLWD and CCOLIP are zero, scaling is turned off for both; it does not make sense to define a cloud with no liquid water droplets or ice particles.

CHUMID is the relative humidity at all layer boundaries with either a positive rain rate or a positive cloud density:

CHUMID   > 0. & $\leq$ 105.   Cloud / rain relative humidity [%].
            $\leq$ 0.   Assume 100% relative humidity at cloud/rain layer boundaries.
            > 105.   Do not alter H$_2$O profile within the cloud.

As much as 5% super saturation is permitted, and clouds with 0% relative humidity throughout the entire cloud region are forbidden.

ASYMWD is the Henyey-Greenstein phase function asymmetry factor for scattering by cloud liquid water droplets:

|ASYMWD| < 1.   Water droplet Henyey-Greenstein wavelength-independent scattering phase function asymmetry factor.
            $\geq$ 1.   Use user-defined or model spectral asymmetry factors for scattering by cloud liquid water droplets.

Even if the spectral asymmetry factors are input using **CARDs 2E2**, MODTRAN uses the ASYMWD value if its absolute value is less than one.

ASYMIP is the Henyey-Greenstein phase function asymmetry factor for scattering by cloud ice particles:

|ASYMIP| < 1.   Ice particle Henyey-Greenstein wavelength-independent scattering phase function asymmetry factor.
            $\geq$ 1.   Use user-defined or model (standard cirrus) spectral asymmetry factors for scattering by cloud ice particles.

9. OPTIONAL CARD 2B (ARMY VERTICAL STRUCTURE ALGORITHM)

CARD 2B is the input card for the Army VSA (Vertical Structure Algorithm) subroutine. This option is initiated by setting IVSA to 1 on **CARD 2**.

>**CARD 2B:**   **ZCVSA, ZTVSA, ZINVSA**
>   **FORMAT (3F10.0)**   **(If IVSA = 1)**

The case is determined by the parameters VIS, ZCVSA, ZTVSA, and ZINVSA.

CASE 1:   cloud/fog at the surface; increasing extinction with height from cloud/fog base to cloud/fog top. Selected by VIS ≤ 0.5 km and ZCVSA ≥ 0.

Use case 2 or 2' below the cloud and case 1 inside it.

CASE 2:   hazy/light fog; increasing extinction with height up to the cloud base. Selected by 0.5 < VIS ≤ 10 km, ZCVSA ≥ 0.

CASE 2':   clear/hazy; increasing extinction with height, but less so than case 2, up to the cloud base. Selected by VIS > 10 km, ZCVSA ≥ 0.

CASE 3:   no cloud ceiling but a radiation fog or an inversion or boundary layer present; decreasing extinction with height up to the height of the fog or layer. Selected by ZCVSA < 0 ZINVSA ≥ 0.

CASE 4:   no cloud ceiling or inversion layer; constant extinction with height. Selected by ZCVSA < 0 and ZINVSA < 0.

ZCVSA is the cloud ceiling height [km]:

ZCVSA   > 0.   Sets the known cloud ceiling height;
         = 0.   Height unknown: the program will calculate one for case 2, and default is 1.8 km for case 2'; or
         < 0.   No cloud ceiling (cases 3 and 4).

ZTVSA is the thickness of the cloud (case 2) or the thickness of the fog at the surface   (case 1) [km]:

ZTVSA   > 0.   The known value of the cloud thickness;
         = 0.   Thickness unknown; default is 0.2 km.

ZINVSA is the height of the inversion or boundary layer [km]:

ZINVSA > 0.0   the known height of the inversion layer;
        = 0.0   height unknown: default is 2 km, 0.2 km for fog;
        < 0.0   no inversion layer (case 4, if ZCVSA < 0.0 also).

10. OPTIONAL CARDS 2C, 2CY, 2C1, 2C2, 2C2X, 2C2Y, 2C3

(USER-DEFINED SPECIES AND ATMOSPHERIC PROFILES)

User-supplied profile data are read in when the parameter MODEL is 7 (or 0 for a constant pressure path) and I_RD2C is 1 on **CARD 1**. In this case**, CARDs 2C** and **2C1** are required.

Using **CARDs 2C, 2C1,** and **2C2**, the user has the choice of entering gas concentration data in any of several different sets of units or defaulting to a model atmosphere concentration at the specified altitude. The concentrations are entered on **CARDs 2C1** and **2C2** in the units specified by JCHAR on **CARD 2C1**. If MDEF (**CARD 1**) is set to 2, concentrations of the heavy molecular gases are read from **CARD 2C2X** in the units specified by JCHARX on **CARD 2C1**.

Aerosol vertical distributions, cloud liquid water contents, and rain rates can be input at specified altitudes using **CARD 2C3**. The default altitudes for the four aerosol regions may be modified using the parameters IHA1, ICLD1 or IVUL1.

CARDs 2C1 through **2C3** are repeated ML times, where ML (in **CARD 2C**) is the number of atmospheric levels (ML = 1 for a horizontal path).

10.1 *CARD 2C*

CARD 2C: ML, IRD1, IRD2, HMODEL, REARTH, AYRANG, NMOLYC, E_MASS, AIRMWT
        FORMAT (3I5, A20, F10.0, A1, I4, 2F10.0)   (If MODEL = 0, 7 or 8; and I_RD2C = 1)

ML   =   Number of atmospheric levels to be inserted (maximum of LAYDIM in PARAMS.h file).

IRD1 controls reading of WMOL(4-12) as described in Table 10 (**CARD 2C2**)

IRD1   = 0   No read.
        = 1   Read **CARD 2C2**.

IRD2 controls reading AHAZE, EQLWCZ, ... (**CARD 2C3**)

IRD2   = 0   No read.
        = 1   Read **CARD 2C3**.
        = 2   Read new version of **CARD 2C3**; see Appendix A.

HMODEL =   Identification of new model atmosphere.

REARTH   =   Earth radius in kilometers (default according to MODEL). This input is only read in when MODEL = 8. It is redundant with RAD_E on CARD 3, but the Earth radius is required before CARD 3 is read when the hydrostatic equation is being solved. The RAD_E input from CARD 3 is ignored when MODEL = 8.

AYRANG = ′F′ or blank   No range profile data will be read in from a <rootname>.rng input file (or the "Yrange.asc" input file if no rootname is provided).

AYRANG = ′T′   This option is disabled. AYRANG should not be set to ′T′.

NMOLYC =   Number of user-defined species with specified names and concentrations.

E_MASS   =   Planetary mass in Earth masses. If a value of zero is input, E_MASS is set to 1. Used in the hydrostatic equation when MODEL=8.

AIRMWT =   The molecular weight of air at the surface in g/mol. If a value of zero is input, AIRMWT is set to parameter AIR_MW = 28.964 g/mol.

> *CARD 2CY*: (*YNAME*(I), I=1, NMOLYC)
> FORMAT ((8A10))   (If NMOLYC > 0)

YNAME   =   Array of names of user-defined species. A name may have a minus sign (-) preceding it for excluding the species from being included in radiance/transmittance calculations. A placeholder for a molecule's concentration profile must be included in CARD 2C2Y even if it is not being used (e.g. if there are NMOLYC = 3 auxiliary species, but the name for the second of the three has either a minus sign (-) or a tilde (~) as its first non-blank character, MODTRAN will read 3 density values on each CARD 2C2Y line).

One of two possible types of band model parameters must be supplied for each species. The first type of parameters is the cross-section parameters similar to those for the CFCs. A file of this type must have the name: *species-name*. The other type of parameters is similar to that for the molecular band model species, say, for example, CO_2. If such a band model parameter set is to be used for a species, its name must have an asterisk at the end. The band model parameters must be separated into line center and tail components, each with its own file: *species-name*.tBM (for tail parameters) and *species-name*.cBM (for center parameters). The contents of these files are described in Appendix D.

10.2 *CARDs 2C1, 2C2, 2C2X, 2C2Y*

> CARD 2C1:   ZM, P, T, WMOL(1), WMOL(2), WMOL(3), (JCHAR(J), J = 1, 14), JCHARX, JCHARY
> FORMAT (6F10.0, 14A1, 1X, 2A1)
>
> CARD 2C2:   (WMOL(J), J = 4, 12)
> FORMAT (8F10.0, /F10.0)   (If IRD1 = 1)
>
> CARD 2C2X: (WMOLX(J), J = 1, 13)
> FORMAT (8F10.0, /5F10.0)   (If MDEF = 2 & IRD1 = 1)
>
> *CARD 2C2Y*: (*WMOLY*(J), J = 1, NMOLYC)
> FORMAT ((8F10.0))   (If NMOLYC > 0 & IRD1 = 1)

ZM   = Altitude of layer boundary (km).

P   = Pressure of layer boundary.

T   = Temperature of layer boundary.

WMOL(1-12)   = Individual molecular species densities (see Table 10 for species).

WMOLX(1-13)   = Heavy molecular species densities (see Table 11 for species).

WMOLY(1-NMOLYC) = User-defined species densities.

JCHAR(1-14)   = Control variables for selection of units for primary profile inputs (P, T and molecular constituents, see Table 9).

JCHARX   = Single control variable for selection of units for entire set of CFCs and other heavy molecules. (See Table 11 for order and identification of these species).

JCHARY   = Similar to JCHARX but for user-defined species in **MODTRAN5.**

By utilizing a choice of values for the JCHAR(J) control variables (where J = 1, 14), the user can designate specific units or accept defaults for the pressure, temperature and molecular densities are each level. If JCHAR(J) is left blank, the values default to the model atmosphere values using the model atmosphere defined by inputs M1, M2, M3, M4, M5, M6 and MDEF. The single unit option, JCHARX, follows the same rules, and for each altitude specified on **CARD 2C1**, the code will expect to find a full set (2 card images) containing values for the 13 species in the order specified by Table 10. These values are required only if MDEF=2.

JCHAR(1) = ′A′   indicates Pressure in (mb)
           = ′B′   indicates Pressure in (Atm)
           = ′1-6′   will default to specified atmospheric MODEL value
           = blank   will default to M1 (**CARD 1**) model atmosphere value

JCHAR(2) = ′A′   indicates ambient temperature [Kelvin]
              ′B′   indicates ambient temperature [degrees Celsius]

'C'   indicates temperature difference from M1 profile [Kelvin]. For example, the mid-latitude summer surface temperature is 294.2K; if M1 on CARD 1 is set to 2 (for mid-latitude summer) and CARD 2C1 inputs JCHAR(2) and T are set to 'C' and -10.0K, respectively, at 0km altitude, then the profile temperature will be set to 294.2K - 10.0K = 284.2K at that altitude.

'1-6'   will default to specified atmospheric MODEL value

blank   will default to M1 (**CARD 1**) model atmosphere value

JCHAR(3-14) = 'A'   indicates Volume mixing ratio (ppmv)

= 'B'   indicates Number density (molecules/cm^3)

= 'C'   indicates Mass mixing ratio (g/kg)

= 'D'   indicates Mass density (g/m^3)

= 'E'   Partial pressure (mb)

= 'F'   indicates Dew point temperature (TD in T[K]) - H_2O only

= 'G'   Dew point temperature (TD in T[C]) - H_2O only

= 'H'   indicates Relative humidity (RH in percent) - H_2O only

= '1-6'   will default to specified model atmosphere

= blank   default to **CARD 1** model atmosphere values (M2 for H_2O; M3 for O_3; M4 for CH_4; M5 for N_2O; M6 for CO; otherwise, MDEF).

Table 10. Association of the JCHAR(J) Index (J = 1, 14) with the Variables P, T & WMOL.

J	Variable	Species
1	P	pressure
2	T	temperature
3	WMOL(1)	water vapor (H_2O)
4	WMOL(2)	carbon dioxide (CO_2)
5	WMOL(3)	ozone (O_3)
6	WMOL(4)	nitrous oxide (N_2O)
7	WMOL(5)	carbon monoxide (CO)
8	WMOL(6)	methane (CH_4)
9	WMOL(7)	oxygen (O_2)
10	WMOL(8)	nitric oxide (NO)
11	WMOL(9)	sulfur dioxide (SO_2)
12	WMOL(10)	nitrogen dioxide(NO_2)
13	WMOL(11)	ammonia (NH_3)
14	WMOL(12)	nitric acid (HNO_3)

Table 11. Various Names for the Heavy Molecular Gases, (WMOLX(J), J = 1, 13).

1	$CC1_3F$	F11	CFC-11
2	CCl_2F_2	F12	CFC-12
3	$CClF_3$	F13	CFC-13
4	CF_4	F14	CFC-14
5	$CHClF_2$	F22	CFC-22
6	$C_2Cl_3F_3$	F113	CFC-113
7	$C_2Cl_2F_4$	F114	CFC-114
8	C_2ClF_5	F115	CFC-115
9	$ClONO_2$		
10	HNO_4		
11	$CHCl_2F$		
12	CCl_4		
13	N_2O_5		

10.3 <u>CARD 2C3</u>

CARD 2C3 (for user-specified aerosol/cloud/rain models) is read when IRD2 is set to 1 on **CARD 2C**. See Appendix A for instructions when IRD2 is set to 2.

> **CARD 2C3***:*   AHAZE, EQLWCZ, RRATZ, IHA1, ICLD1, IVUL1, ISEA1, ICHR
> FORMAT (10X, 3F10.0, 5I5)   (If IRD2 = 1)

If AHAZE is positive, EQLWCZ is ignored.

AHAZE   Aerosol or cloud scaling factor (equal to the visible [wavelength of 0.55 μm] extinction coefficient [km^{-1}] at altitude ZM)

EQLWCZ   Equivalent liquid water content (G / m^3) at altitude ZM for the aerosol, cloud or fog models

RRATZ   Rain rate (mm / hr) at altitude ZM

Only one of IHA1, ICLD1 or IVUL1 is allowed:

IHA1   Aerosol model extinction and meteorological range control for the altitude, ZM. See IHAZE (**CARD 2**) for options.

ICLD1   Cloud extinction control for the altitude, ZM; see ICLD (**CARD 2**) for options. When using ICLD1 it is necessary to set ICLD to the same value as the initial input of ICLD1.

IVUL1   Stratospheric aerosol profile and extinction control for the altitude ZM; see IVULCN (**CARD 2**) for options.

The precedent order of these parameters (IHA1, ICLD1 and IVUL1) is as follows:

> If (IHA1 > 0) then others ignored
> If (IHA1 = 0) and (ICLD1 > 0) then use ICLD1
> If (IHA1 = 0) and (ICLD1 = 0) then use IVUL1

If AHAZE and EQLWCZ are both zero, the default profile is loaded from IHA1, ICLD1, IVUL1.

ISEA1   Aerosol season control for the altitude, ZM, see ISEASN (**CARD 2**) for options.

ICHR   Used to indicate a boundary change between 2 or more adjacent user defined aerosol or cloud regions at altitude ZM (required for IHAZE = 7 or ICLD = 11).

ICHR =   0   no boundary change in user defined aerosol or cloud regions (regions are not adjacent).

       =   1   signifies the boundary change in adjacent user defined aerosol or cloud regions.

NOTE: ICHR internally defaults to 0 if (IHA1 ≠ 7) or (ICLD1 ≠ 11).

11. OPTIONAL CARDS 2D, 2D1, 2D2

(USER-DEFINED AEROSOL AND CLOUD PARAMETERS)

These cards allow the user to specify the aerosol and cloud parameters (extinction and absorption coefficients and asymmetry parameter) for any or all four of the aerosol altitude regions. They are only read if IHAZE = 7 or ICLD = 11 are specified on **CARD 2**.

*THE FOLLOWING INSTRUCTIONS ONLY APPLY WHEN INPUT **ARUSS** (**CARD 2**) IS NOT SET TO 'USS'. WHEN ARUSS EQUALS 'USS', SEE **APPENDIX A** FOR INSTRUCTIONS.*

11.1 <u>CARD 2D</u>

> **CARD 2D:**   (IREG(N), N = 1, 2, 3, 4)
>   **FORMAT (4I5)**   **(If IHAZE = 7 or ICLD = 11)**

IREG specifies in which of the four altitude regions a user-defined aerosol or cloud model is used (IHAZE = 7 / ICLD = 11). It controls the number of pairs of **CARDs 2D1** and **2D2** read in (1 pair for each region for which IREG(N) = 1). The region default level altitudes are 0-2, 3-10, 11-30, 35-100 km but can be overridden using 'IHA1' (**CARD 2C3**) with MODEL=7 (See Section 7 for a complete description of the default aerosol regions).

IREG(N) = 0   Use default values for the region N, N = 1, 2, 3 and 4.
            = 1   Read extinction, absorption, and asymmetry parameter for the region.

11.2 <u>CARD 2D1</u>

CARD 2D1 and **CARD 2D2** are read sequentially once for each of the four aerosol regions for which IREG(N) = 1.

> **CARD 2D1:**   AWCCON, AERNAM
>   **FORMAT (F10.0, A70)**

AWCCON   A conversion factor from extinction coefficient (km^{-1}) to equivalent liquid water content (g/m^3), ONLY USED FOR MICROWAVE ($\lambda > 287.9\mu m$, $\nu < 37.4$ cm^{-1}) FOG EXTINCTION! It is numerically equal to the equivalent liquid water content corresponding to an extinction coefficient of 1.0 km^{-1}, at a wavelength of 0.55 μm. AWCCON has units of (km g / m^3).

AERNAM   name for an aerosol or cloud region (up to 72 characters)

11.3 <u>CARD 2D2</u>

> **CARD 2D2:**   (VARSPC(N, I), EXTC(N, I), ABSC(N, I), ASYM(N, I), I = l, 2, ..., I_{max})
>   **If ARUSS = 'USS' and IREG(N) > 1, then I_{max} = IREG(N); Else I_{max} = 47**
>   **FORMAT ((3(F6.2, 2F7.5, F6.4)))**

CARD 2D2 consists of 47 sets of 4 numbers (3 sets or 12 numbers per line) in each aerosol region N for which IREG(N) is 1 (See Appendix A for the meaning of IREG(N) > 1. There are no corresponding **CARDs 2D1** and **2D2** if IREG(N) = 0. This card is for input of user-defined aerosol or cloud extinction and absorption coefficients when IHAZE = 7 or ICLD = 11.

VARSPC(I)   Wavelengths for the aerosol or cloud coefficients. If IREG(N) is 1, the wavelengths from Table 12 must be entered (actually, the input values are not used and the Table 12 entries are assumed). For IREG(N) > 1, see Appendix A.

EXTC(N, I)   Aerosol or cloud extinction coefficients, normalized so that EXTC for a wavelength of 0.55 μm is 1.0 km^{-1}.

ABSC(N, I)   Aerosol or cloud absorption coefficient, normalized so that EXTC for a wavelength of 0.55 μm is 1.0 km^{-1}.

ASYM(N, I)   Aerosol or cloud asymmetry parameter. If CARD 3A1 is to be read in, IPH must be set to 2 to insure that the asymmetry factor will not be overwritten.

Table 12. VARSPC Array of Fixed Wavelengths for the Multiply Read CARD 2D2.

Index	Wavelength (μm)	Index	Wavelength (μm)	Index	Wavelength (μm)
1	0.2000	17	5.5000	33	15.0000
2	0.3000	18	6.0000	34	16.4000
3	0.3371	19	6.2000	35	17.2000
4	0.5500	20	6.5000	36	18.5000
5	0.6943	21	7.2000	37	21.3000
6	1.0600	22	7.9000	38	25.0000
7	1.5360	23	8.2000	39	30.0000
8	2.0000	24	8.7000	40	40.0000
9	2.2500	25	9.0000	41	50.0000
10	2.5000	26	9.2000	42	60.0000
11	2.7000	27	10.0000	43	80.0000
12	3.0000	28	10.5910	44	100.0000
13	3.3923	29	11.0000	45	150.0000
14	3.7500	30	11.5000	46	200.0000
15	4.5000	31	12.5000	47	300.0000
16	5.0000	32	14.8000		

Note: This array contains the wavelengths at which the spectral data are read in when IREG(N) = 1. The spectral grid of built-in cloud data is now much finer with 788 points. The aerosol optical properties are also tabulated at the 788 grid points, but the data is simply an interpolation of the lower resolution data. This array is retained for backward compatibility with earlier tape5's.

12. OPTIONAL CARDS 2E1 AND 2E2

(USER-DEFINED CLOUD PARAMETERS)

The following inputs, used with the alternate **CARD 2A**, permit the user to control profile and spectral (optical) parameters for cloud models 1 through 10. These cards cannot be used with the ICLD=18 and ICLD=19 cirrus cloud models. **CARD 2E1** is read if NCRALT $\geq$ 2, and **CARD 2E2** is read if NCRSPC $\geq$ 2 on **CARD 2A**.

12.1 <u>CARD 2E1</u>

CARD 2E1:   **(ZCLD(I), CLD(I), CLDICE(I), RR(I), I = 1, NCRALT)**
        FORMAT ((4F10.0))   **(If ICLD = 1 - 10, NCRALT $\geq$ 2, MODEL < 8)**

Alternate **CARD 2E1:**   **(PCLD(I), CLD(I), CLDICE(I), RR(I), I = 1, NCRALT)**
        FORMAT ((4F10.0))   **(If ICLD = 1 - 10, NCRALT $\geq$ 2, MODEL = 8)**

A series of these **CARD 2E1** inputs is used to set up user-defined cloud/rain profiles, one card per layer boundary. The profile parameters being set are all arrays. If the alternate **CARD 2A** inputs CTHIK, CALT, CCOLWD and CCOLIP are all assigned negative values, MODTRAN calculations are performed using the user-defined cloud/rain profiles exactly as input. However, the **CARD 2A** variables can be used to study the effect of changing the input cloud's thickness, altitude or column amounts.

ZCLD(I, 0)   Altitude above ground of level I for the user-defined cloud/rain profile [KM]

PCLD(I, 0)   Pressure above ground of level I for the user-defined cloud/rain profile [mbar]

ZCLD(1, 0) can be 0., and this is necessary if it is raining on the ground. The model also allows the cloud to actually sit on the ground. The ZCLD input values must monotonically increase and the PCLD input values must monotonically decrease. Also, a fatal error will result if the highest cloud altitude, ZCLD(NCRALT, 0), is above the top of the MODTRAN atmosphere (100 km above sea level for the model atmospheres). Similarly, the top pressure profile input must not be below the top-of-atmosphere pressure.

CLD(I, 0)   Liquid water droplet density at altitude ZCLD(I, 0) [g/m^3]

The liquid water droplet densities cannot be negative. MODTRAN models the densities as varying linearly between altitudes. The entire CLD array is scaled if the **CARD 2A** variable CCOLWD is assigned a non-negative value.

CLDICE(I,0) Ice particle density at altitude ZCLD(I, 0) [g/m^3]

The ice particle densities cannot be negative. MODTRAN models the densities as varying linearly between altitudes. The entire CLDICE array is scaled if the **CARD 2A** variable CCOLIP is assigned a non-negative value.

RR(I, 0)   Rain rate at altitude ZCLD(I, 0) [mm/hr]

The rain rates cannot be negative. If a rain rate is entered through **CARD 2** (variable RAINRT), that constant rain rate supersedes this parameter. Thus, if a user-defined rain rate profile is desired, variable RAINRT must not be positive.

12.2 <u>CARD 2E2</u>

CARD 2E2:   **(WAVLEN(I), EXTC6(I), ABSC6(I), ASYM6(I), EXTC7(I), ABSC7(I), ASYM7(I),**
                                                      I = 1, NCRSPC)
        FORMAT ((7F10.5))   **(If ICLD = 1 - 10, NCRSPC $\geq$ 2)**

The **CARD 2E2** variables are used to input user-defined cloud spectral data arrays. If the **CARD 2A** inputs CEXT, ASYMWD and ASYMIP all specify the use of defaults, MODTRAN uses these spectral data exactly as input. However, if a positive vertical cloud extinction, CEXT, is input, the extinction and absorption coefficients curves are scaled. Similarly, if the **CARD 2A** asymmetry factors ASYMWD and ASYMIP have magnitude less than one, they supersede the ASYM(6, I) and ASYM(7, I) values, respectively.

WAVLEN(I)   Wavelength [µm] I in the spectral grid

The first wavelength, WAVLEN(1), can be as low as 0.0 μm, and wavelengths must be entered in increasing order. If a positive vertical cloud extinction (CEXT) is input on **CARD 2A**, the reference wavelength (CWAVLN or 0.55 μm) must be between WAVLEN(1) and WAVLEN(NCRSPC) inclusive, or else MODTRAN execution will be terminated with an error message.

EXTC(6, I)   Liquid water droplet extinction coefficient [km^{-1} m^3 / g] at wavelength WAVLEN(I)

If a negative value is input, EXTC(6, I) is assigned the wavelength-interpolated extinction coefficient from the default data for cloud model ICLD.

ABSC(6, I)   If positive: liquid water droplet absorption coefficient [km^{-1} m^3 / g] at wavelength WAVLEN(I)
                          If negative: liquid water droplet scattering albedo, minus 1, at wavelength WAVLEN(I)

If the input value for ABSC(6, I) is less than -1 or if it exceeds the extinction coefficient at WAVLEN(I), ABSC(6, I) is calculated by first determining the default absorption to extinction ratio for cloud model ICLD, and then multiplying EXTC(6, I) by this ratio. This is equivalent to assuming that the liquid water model cloud single scatter albedo (T) should be used to determine the absorption coefficient. A negative value for ABSC(6, I) not less than -1 is taken to be the negative of one minus the liquid water droplet scattering albedo, -(1-T).

ASYM(6, I)   Liquid water droplet Henyey-Greenstein scattering phase function asymmetry factor at wavelength
                          WAVLEN(I)

These inputs are ignored if the magnitude of the **CARD 2A** input ASYMWD is less than one. If ASYM(6, I) is also not between -1. and 1., ASYM(6, I) is assigned the wavelength interpolated value from cloud model ICLD.

EXTC(7, I)   Ice particle extinction coefficient at WAVLEN(I) [km^{-1}m^3 / g]

If a negative value is input, EXTC(7, I) is assigned the wavelength interpolated extinction coefficient from the standard cirrus cloud model (ICLD = 18).

ABSC(7, I)   If positive: Ice particle absorption coefficient [km^{-1} m^3 / g] at wavelength WAVLEN(I)
                          If negative: Ice particle scattering albedo minus 1 at WAVLEN(I)

If the input value for ABSC(7, I) is less than minus one or if it exceeds the extinction coefficient at WAVLEN(I), ABSC(7, I) is calculated by first determining the default absorption to extinction ratio for the standard cirrus cloud model (ICLD = 18), and then multiplying EXTC(7, I) by this ratio. This is equivalent to assuming that the standard cirrus cloud model single scatter albedo should be used to determine the absorption coefficient. A negative value for ABSC(7, I) not less than not less than minus one is taken to be the negative of one minus the ice particle scattering albedo.

ASYM(7, I)   Ice particle Henyey-Greenstein scattering phase function asymmetry factor at wavelength
                          WAVLEN(I)

These inputs are ignored if the magnitude of the **CARD 2A** input ASYMIP is less than one. If ASYM(7, I) is also not between -1. and 1., ASYM(7, I) is assigned the wavelength interpolated value from the standard cirrus cloud model (ICLD = 18).

12.3 Alternate *CARD 2E2*

> *Alternate* **CARD 2E2:**   **CFILE, CLDTYP, CIRTYP**
>   **FORMAT ((A256))**   *(If ICLD = 1 - 10, NCRSPC = 1)*

Alternate **CARD 2E2** contains 3 lines and is used to enter the name of auxiliary cloud spectral data file and a pair of cloud types. Nominally, the first cloud is a water cloud and the second is a cirrus cloud; however, one can assign any cloud type each of the pair.

CFILE   Cloud spectral data full path file name (maximum 256 characters).

CLDTYP   Water cloud type (maximum 256 characters).

CIRTYP   Ice cloud type (maximum 256 characters).

'DATA/Macke.dat' (Macke, 2001), a sample cloud spectral data file, is included in the MODTRAN delivery. (The Macke data is supplied provided strictly as a sample file; its spectral resolution is more coarse than MODTRAN internal cloud data.) The cloud spectral data files can contain data for any number of cloud types. The format for each cloud type is as follows:

Input 1 [FORMAT (A80)]: CLDNAM
                                 Water or cirrus cloud type name
Input 2 [FORMAT (*)]: NCLDAN, NCLDLG, NCLDWV
                                 Number of angular grid points, number of Legendre expansion coefficients minus one, and number of spectral points
Input 3 [FORMAT (A80)]: INPSTR
                                 Angular grid header (not used)
Input 4 [FORMAT (*)]: (CLDANG(ICLDAN), ICLDAN = 1, NCLDAN)
                                 Scattering angles, from 0° to 180°

LOOP OVER "NCLDWV" *INCREASING* SPECTRAL WAVELENGTHS

Input 5 [FORMAT (*)]: CLDWAV, CLDEXT, CLDABS
                                 Spectral wavelength (μm), spectral extinction cross-section over average particle mass at CLDWAV ($km^{-1} \ m^3 / g$), and spectral absorption cross-section over average particle mass at CLDWAV ($km^{-1} \ m^3 / g$)
Input 6 [FORMAT (A80)]: INPSTR
                                 Phase function header (not used)
Input 7 [FORMAT (*)]: (CLDPF(ICLDAN), ICLDAN = 1, NCLDAN)
                                 Scattering phase function as a function of angle at CLDWAV (sr^{-1})
Input 8 [FORMAT (A80)]: INPSTR
                                 Legendre expansion coefficients header (not used)
Input 9 [FORMAT (*)]: (CLDLEG(ICLDLG), ICLDLG = 0, NCLDLG)
                                 Legendre expansion coefficients over (2 ICLDLG + 1)

END LOOP OVER "NCLDWV" SPECTRAL WAVELENGTHS

The Alternative CARD 2E2 inputs CLDTYP and CIRTYP must each match a cloud type name, CLDNAM, from the CFILE data file. The comparison *is* case-sensitive, but leading blanks are ignored. Extensive checking is performed on the input data. The spectral scattering phase functions are assumed to be normalized to unity, and they are renormalized (and a warning is generated) if the normalization condition is not satisfied. The Legendre expansion coefficients (over 2N+1) are normalized such that the leading order coefficient is 1.

13. CARD 3 (REQUIRED) – LINE-OF-SIGHT GEOMETRY

13.1 Standard CARD 3

CARD 3:   **H1ALT, H2ALT, OBSZEN, HRANGE, BETA, RAD_E, LENN, BCKZEN, CKRANG**
            FORMAT (6F10.0, I5, 5X, 2F10.0)

CARD 3 is used to define the geometrical path parameters for a given problem.

H1ALT	=	Initial altitude (km)	
H2ALT	=	Final altitude (km)	(for ITYPE = 2)
	=	Tangent height (km)	(for ITYPE = 3)

It is important to emphasize here that in the radiance mode of program execution (IEMSCT = 1, 2 or 4) H1ALT, the initial altitude, always defines the position of the observer (or sensor). H1ALT and H2ALT cannot be used interchangeably as in the transmittance mode.

OBSZEN	=	Initial zenith angle (degrees) as measured from H1ALT
HRANGE	=	Path length (km)
BETA	=	Earth center angle subtended by H1ALT and H2ALT (degrees)
RAD_E	=	Radius of the earth (km) at the particular latitude that the calculation is to be performed

If RAD_E is left blank, the program will use the mid-latitude value of 6371.23 km if MODEL is set equal to 7. Otherwise, the earth radius for the appropriate standard model atmosphere (specified by MODEL) will be used as shown in Table 13.

Table 13. Default Values of the Earth Radius for Different Model Atmospheres.

Model	Model Atmosphere	Earth Radius, RAD_E (km)
0	User-defined (Horizontal Path)	Not used
1	Tropical	6378.39
2	Mid-latitude summer	6371.23
3	Mid-latitude winter	6371.23
4	Sub-arctic summer	6356.91
5	Sub-arctic winter	6356.91
6	U. S. Standard	6371.23
7	User-defined	6371.23

LENN   =   Switch to determine short and long paths for cases 2a and 2e as described below.

If LENN = 1, path will be "long", extending through the tangent height; otherwise, if LENN = 0 (default), path will be "short".

BCKZEN   =   Zenith angle at H2ALT (target/final altitude) towards H1ALT (sensor or initial altitude)

CKRANG   Slant range (km) for *k*-distribution output (if CKPRNT = ′T′ on CARD 1)

> 0.   Data is output at all path boundary intersections up to the first one exceeding CKRANG (in km) and for the total path.
= 0.   Data is only output for the full slant range (minimum output).
< 0.   Data is output at all path boundary intersections (maximum output).

CARD 3 (Required)

It is <u>not</u> necessary to specify every variable on **CARD 3**; only those that adequately describe the problem according to the parameter ITYPE, as described below (also see Table 14).

    (1) Horizontal Paths (ITYPE = 1)

        (a) specify H1ALT, HRANGE

        (b) If non-standard meteorological data are to be used, that is, if MODEL = 0 on **CARD 1,** then refer to the instructions for **CARD 2C** for a detailed explanation.

    (2) Slant Paths Between Two Arbitrary Altitudes (ITYPE = 2)

        (a) specify H1ALT, H2ALT, OBSZEN & LENN (LENN only if H2ALT < H1ALT)

        (b) specify H1ALT, OBSZEN & HRANGE

        (c) specify H1ALT, H2ALT & HRANGE

        (d) specify H1ALT, H2ALT & BETA

        (e) specify H2ALT, H1ALT, BCKZEN & LENN (LENN only if H1ALT < H2ALT)

        (f) specify H2ALT, BCKZEN & HRANGE

    (3) Slant Paths to Space (ITYPE = 3)

        (a) specify H1ALT & OBSZEN

        (b) specify H1ALT & H2ALT (for limb-viewing problem where H2ALT is the tangent height or minimum altitude of the path trajectory).

        (c) specify H2ALT & BCKZEN (here H1ALT = space)

Table 14. Allowed Combinations of Slant Path Parameters.

Case	H1ALT	H2ALT	OBSZEN	HRANGE	BETA	LENN (Optional)	BCKZEN
2a	*	*	*			(*)	
2b	*		*	*			
2c	*	*		*			
2d	*	*			*		
2e	*	*				(*)	*
2f		*		*			*
3a	*		*				
3b	*	*					
3c	*	*					*
LENN is used only when H1ALT > H2ALT and Case 2a, or H2ALT > H1ALT and Case 2e. Otherwise, LENN is automatically set in the program.
* Required Inputs.

For ITYPE = 2, the following scheme is used to classify geometry inputs:

     If (BCKZEN>0 and HRANGE>0) THEN
        CASE 2f
     ELSE IF (BCKZEN>0) THEN
        CASE 2e
     ELSE IF (BETA>0) THEN
        CASE 2d
     ELSE IF (HRANGE>0 AND OBSZEN>0) THEN
        CASE 2b
     ELSE IF (HRANGE>0) THEN
        CASE 2c
     ELSE
        CASE 2a
     END IF

CARD 3 (Required)

For ITYPE = 3, a similar scheme is used:

    IF (BCKZEN>0) THEN

        CASE 3c

    ELSE IF (H2ALT = 0) THEN

        CASE 3a

    ELSE

        CASE 3b

    END IF

Table 14 lists the **CARD 3** options provided to the user for the different types of atmospheric paths.

13.2 **Alternate CARD 3 (TRANSMITTED SOLAR/LUNAR IRRADIANCE, IEMSCT = 3)**

For calculating directly transmitted solar or lunar irradiance, an ITYPE = 3 path is assumed and **CARD 3** has the following form:

Alternate **CARD 3:**   **H1ALT, H2ALT, OBSZEN, IDAY, RAD_E, ISOURC, ANGLEM**
                    FORMAT (3F10.0, I5, 5X, F10.0, I5, F10.0)   **(If IEMSCT = 3)**

H1ALT	=		Altitude of the observer.
H2ALT	=		Tangent height of path to sun or moon.
OBSZEN	=		Apparent solar or lunar zenith angle at H1ALT.
IDAY	=		Day of the year, used to correct for variation in the earth-to-sun distance.
RAD_E	=		Radius of earth (default according to MODEL).
ISOURC	=	0	Extra-terrestrial source is the sun.
	=	1	Extra-terrestrial source is the moon.
ANGLEM	=		Phase angle of the moon in degrees, defined here as the moon centered angle between the sun and the earth (required only if ISOURC = 1). Enter 0º for a full moon, 90º for a half-moon, and 180º for no moon.

Either H2ALT or OBSZEN should be specified. If both are given as zero, then a vertical path (OBSZEN = 0) is assumed. If both are greater than zero, the scheme for ITYPE = 3 is invoked. If IDAY is not specified, then the mean earth to sun distance is assumed.

If the apparent solar zenith angle is not known for a particular case, then the solar scattering option (IEMSCT = 2 or IEMSCT = 4) may be used along with, for instance, the observer's location, day of the year and time of day to determine the solar zenith angle (see instructions for **CARDs 3A1** and **3A2**). Note that the apparent solar zenith angle is zenith angle at H1ALT of the refracted path to the sun and is less than the astronomical solar zenith angle. The difference between the two angles is small for angles less than 80°.

14. OPTIONAL CARDS 3A1 AND 3A2

(SOLAR / LUNAR SCATTERING GEOMETRY)

These optional input cards control the specification of the solar/lunar scattering geometry (when IEMSCT = 2 or IEMSCT = 4 on **CARD 1**) and specification of the selection of the aerosol scattering phase function.

14.1 CARD 3A1

CARD 3A1:   IPARM, IPH, IDAY, ISOURC
FORMAT (4I5)   **(If IEMSCT = 2 or 4)**

IPARM	= 0, 1, 2, 10, 11, 12	Controls the method of specifying the solar/lunar geometry on **CARD 3A2**.
IPH	= 0	Selects spectrally independent Henyey-Greenstein aerosol phase function (see **CARD 3A2**).
	= 1	Selects user-supplied aerosol phase function (see **CARD 3B**).
	= 2	Selects Mie-generated internal database of aerosol phase functions for the MODTRAN models.
IDAY	=	Day of the year from 1 to 365 used to specify the earth to sun distance and (if IPARM = 1) to specify the sun's location in the sky. (Default value is the mean earth to sun distance, IDAY = 93).
ISOURC	= 0	Extraterrestrial source is the sun.
	= 1	Extraterrestrial source is the moon.

14.2 CARD 3A2

CARD 3A2:   PARM1, PARM2, PARM3, PARM4, GMTIME, TRUEAZ, ANGLEM, G
FORMAT (8F10.0)   **(If IEMSCT = 2 or 4)**

The definitions of PARM1, PARM2, PARM3, and PARM4 are determined by the value of IPARM on **CARD 3A1** (see Table 15):

> For IPARM = 0:
>
> | | | |
> |---|---|---|
> | PARM1 | = | observer latitude (-90° to +90°) |
> | PARM2 | = | observer longitude (0°to 360° west of Greenwich) |
> | PARM3 | = | source (sun or moon) latitude |
> | PARM4 | = | source (sun or moon) longitude |
> | TRUEAZ | = | true path azimuth from H1ALT to H2ALT |
>
> For IPARM = 1 (not available with lunar source, CARD 3A1 in ISOURC equal 1):
>
> | | | |
> |---|---|---|
> | PARM1 | = | observer latitude (-90° to +90°) |
> | PARM2 | = | observer longitude (0° to 360°, west of Greenwich) |
> | PARM3, PARM4 are not required | | |
>
> For IPARM = 2:
>
> | | | |
> |---|---|---|
> | PARM1 | = | azimuth angle between the observer's line-of-sight and the observer-to-sun path, measured from the line of sight, positive east of north, between -180° and 180° |
> | PARM2 | = | the solar zenith angle at H1ALT (the observer) |
> | PARM3, PARM4 are not required | | |

Note that the calculated apparent solar zenith angle is the zenith angle at H1ALT of the refracted path to the sun and is less than the astronomical solar zenith angle. The difference between the two angles is negligible for angles less than 80 degrees.

For IPARM = 10:

PARM1	=	latitude at H2ALT
PARM2	=	longitude at H2ALT
PARM3	=	source (sun or moon) latitude
PARM4	=	source (sun or moon) longitude
TRUEAZ	=	true path azimuth from H2ALT to H1ALT

For IPARM = 11:

PARM1	=	latitude at H2ALT
PARM2	=	longitude at H2ALT
GMTIME	=	Greenwich time in decimal hours (also uses CARD 3 input IDAY).
TRUEAZ	=	true path azimuth from H2ALT to H1ALT

For IPARM = 12:

PARM1	=	relative solar azimuth (degrees East of North) at H2ALT
PARM2	=	solar zenith (degrees) at H2ALT

Table 15. CARD 3A2: Options for Different Choices of IPARM.

IPARM	0	1	2	10	11	12
PARM1	Observer Latitude (-90° to +90°)	Observer Latitude (-90° to +90°)	Azimuth Angle Between Observer LOS & Observer to Sun Path	Latitude at H2ALT (-90° to +90°)	Latitude at H2ALT (-90° to +90°)	Relative Solar Azimuth at H2ALT (Degrees East of North)
PARM2	Observer Longitude (0° to 360° **West** of Greenwich)	Observer Longitude (0° to 360° **West** of Greenwich)	Solar Zenith Angle	Longitude at H2ALT (Degrees **West** of Greenwich)	Longitude at H2ALT (Degrees **West** of Greenwich)	Solar Zenith at H2ALT (Degrees)
PARM3	Source Latitude	-	-	Source Latitude	-	-
PARM4	Source Longitude	-	-	Source Longitude	-	-
GMTIME	-	Greenwich Time (Decimal Hours)	-	-	Greenwich Time (Decimal Hours)	-
TRUEAZ	True Path Azimuth Angle **from H1ALT to H2ALT** (Degrees East of Due North)	True Path Azimuth Angle **from H1ALT to H2ALT** (Degrees East of Due North)	-	True Path Azimuth Angle **from H2ALT to H1ALT** (Degrees East of Due North)	True Path Azimuth Angle **from H2ALT to H1ALT** (Degrees East of Due North)	-
ANGLEM (only if ISOURC = 1)	Lunar Phase Angle	-	Lunar Phase Angle	Lunar Phase Angle	-	Lunar Phase Angle
G (only if IPH = 0)	Asymmetry Parameter (-1 to +1) for use with Henyey-Greenstein Phase Function	Asymmetry Parameter (-1 to +1) for use with Henyey-Greenstein Phase Function	Asymmetry Parameter (-1 to +1) for use with Henyey-Greenstein Phase Function	Asymmetry Parameter (-1 to +1) for use with Henyey-Greenstein Phase Function	Asymmetry Parameter (-1 to +1) for use with Henyey-Greenstein Phase Function	Asymmetry Parameter (-1 to +1) for use with Henyey-Greenstein Phase Function

Optional CARDs 3A1 and 3A2

The remaining control parameters are:

GMTIME = Greenwich time in decimal hours, that is, 8:45 a.m. is 8.75, 5:20 p.m. is 17.33 etc. (used with IPARM = 1 or 11)

TRUEAZ = Path azimuth (degrees east of north, that is, due north is 0.0° due east is 90.0° etc. (used with IPARM = 0, 1, 10, or 11)

ANGLEM = Phase angle of the moon in degrees, defined here as the moon centered angle between the sun and the earth (required only if ISOURC = 1). Enter 0º for a full moon, 90º for a half-moon, and 180º for no moon.

G   = Asymmetry factor for use with Henyey-Greenstein phase function (only used with IPH = 0); +1 for complete forward scattering, 0 for isotropic or symmetric scattering, and -1 for complete back scattering.

15. OPTIONAL CARDS 3B1, 3B2, 3C1-3C6

(USER-DEFINED SCATTERING PHASE FUNCTIONS)

These input cards are for entering user-defined phase functions when IPH = 1 (**CARD 3A1**). The input NWLF should be set to 0 if the phase function is to be modeled with no wavelength dependence. If positive, NWLF defines the number of wavelength grid points.

15.1 CARD 3B1

CARD 3B1:   NANGLS, NWLF
FORMAT (2I5)   (**If IEMSCT = 2 or 4; IPH = 1**)

NANGLS =   Number of angles for the user-defined phase functions (maximum MANGLS is set to 94 in parameters file PARAMS.h).

NWLF   = 0   Aerosol scattering phase functions will be modeled as spectrally independent using CARD 3B2 inputs.

> 0   Number of wavelength grid points for aerosol scattering phase functions, defined using CARDS 3C1-3C6

15.2 CARD 3B2

This card is repeated NANGLS times (for IANG equals 1 to NANGLS). The angles must monotonically increase from 0° to 180°.

CARD 3B2:   (ANGF(IANG), F(1, IANG), F(2, IANG), F(3, IANG), F(4, IANG), IANG = l, NANGLS)
FORMAT ((5F10.0))   (**If IEMSCT = 2 or 4; IPH = 1; NWLF = 0**)

ANGF(IANG) =   Scattering angle in decimal degrees (0.0° to 180.0°)

F(1, IANG)   =   Unit-normalized user-defined scattering phase function at angle ANGF(IANG) for aerosol no. 1, nominally the boundary layer aerosol between 0 to 2 km altitude [sr^{-1}].

F(2, IANG)   =   Unit-normalized user-defined scattering phase function at angle ANGF(IANG) for aerosol no. 2, nominally the troposphere aerosol between 2 to 10 km altitude [sr^{-1}].

F(3, IANG)   =   Unit-normalized user-defined scattering phase function at angle ANGF(IANG) for aerosol no. 3, nominally the stratosphere aerosol between 10 to 30 km altitude [sr^{-1}].

F(4, IANG)   =   Unit-normalized user-defined scattering phase function at angle ANGF(IANG) for aerosol no. 4, nominally the mesosphere aerosol between 30 to 100 km altitude [sr^{-1}].

The default altitude regions may be overridden by the parameters IHA1, ICLD1 or IVUL1 (**CARD 2C3**).

15.3 CARDs 3C1-3C6

The angular grid must monotonically increase from 0° to 180°. The wavelength grid must also monotonically increase. If the computational spectral range extends beyond the range of scattering phase function spectral grid, end point values (IWAV = 1 and IWAV = NWLF) are used.

CARD 3C1:   (ANGF(IANG), IANG = 1, NANGLS)
FORMAT ((8F10.0))   (**If IEMSCT = 2 or 4; IPH = 1; NWLF > 0**)

ANGF(IANG) =   Scattering angle in decimal degrees (0.0° to 180.0°)

CARD 3C2:   (WLF(IWAV), IWAV = 1, NWLF)
FORMAT ((8F10.0))   (**If IEMSCT = 2 or 4; IPH = 1; NWLF > 0**)

WLF(IWAV)   =   Wavelength grid point (microns)

CARD 3C3:   (F(1, IANG, IWAV), IWAV = 1, NWLF)
FORMAT (8F10.0)   (**If IEMSCT = 2 or 4; IPH = 1; NWLF > 0**)

F(1, IANG, IWAV) =   Unit-normalized user-defined scattering phase function at angle ANGF(IANG) and wavelength WLF(IWAV) for aerosol no. 1, nominally the boundary layer aerosol between 0 to 2 km altitude [sr^{-1}].

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CARD 3C4:   **(F(2, IANG, IWAV), IWAV = 1, NWLF)**
          FORMAT (8F10.0)   **(If IEMSCT = 2 or 4; IPH = 1; NWLF > 0)**

    F(2, IANG, IWAV) =   Unit-normalized user-defined scattering phase function at angle ANGF(IANG) and wavelength WLF(IWAV) for aerosol no. 2, nominally the troposphere aerosol between 2 to 10 km altitude $[\text{sr}^{-1}]$.

CARD 3C5:   **(F(3, IANG, IWAV), IWAV = 1, NWLF)**
          FORMAT (8F10.0)   **(If IEMSCT = 2 or 4; IPH = 1; NWLF > 0)**

    F(3, IANG, IWAV) =   Unit-normalized user-defined scattering phase function at angle ANGF(IANG) and wavelength WLF(IWAV) for aerosol no. 3, nominally the stratosphere aerosol between 10 to 30 km altitude $[\text{sr}^{-1}]$.

CARD 3C6:   **(F(4, IANG, IWAV), IWAV = 1, NWLF)**
          FORMAT (8F10.0)   **(If IEMSCT = 2 or 4; IPH = 1; NWLF > 0)**

    F(4, IANG, IWAV) =   Unit-normalized user-defined scattering phase function at angle ANGF(IANG) and wavelength WLF(IWAV) for aerosol no. 4, nominally the mesosphere aerosol between 30 to 100 km altitude $[\text{sr}^{-1}]$.

The wavelength grid and the angle grid is the same for each of the four aerosols. Furthermore, the phase function must be supplied either for all aerosols or no aerosol. For each, all **CARDs 3C3** are supplied first, then all **CARDs 3C4,** all **3C5,** and finally all **3C6**.

16. CARD 3D (OPTIONAL) - MULTIPLE LINE-OF-SIGHT / LOOK-UP TABLE OPTION

CARD 3D is designed to enable the user to model multiple lines-of-sight (MLOS) with each call to DISORT. Since the DISORT multiple scattering routines are the most computationally intensive in MODTRAN, major time savings are realized when this option is utilized.

The MLOS option does require all paths to have the same solar zenith angle at either the sensor (H1ALT) if IMULT equals +1 or at the final point (H2ALT) if IMULT equals −1. This is the only restriction on the slant path geometry of the MLOS. The |ITYPE − 1| CARD 3D input lines, which immediately proceed CARD 4, are each completely analogous to the CARD 3 input line except that the Earth radius input (RAD_E) is replaced by AZ_INP, an input used to define the relative solar azimuth angle:

CARD 3D: **(H1ALT, H2ALT, OBSZEN, HRANGE, BETA, AZ_INP, LENN,**
                                            BCKZEN, CKRANG, ILOS = 2, |ITYPE|)
          FORMAT (6F10.0, I5, 5X, 2F10.0)   **(If ITYPE ≤ −2, IMULT = ±1, DIS(1:1) = 'T')**

The interpretation of AZ_INP depends on the value of IPARM:

>   For IPARM = 0 or 1:
>
>   AZ_INP   =   True path azimuth angle **from H1ALT to H2ALT** [Degrees East of Due North (−90º to +90º)]
>
>   For IPARM = 2:
>
>   AZ_INP   =   Relative azimuth angle between the line-of-sight **from H1ALT to H2ALT** and the **H1ALT-to-sun** path [Degrees (0º and 180º)]
>
>   For IPARM = 10 or 11:
>
>   AZ_INP   =   True path azimuth angle **from H2ALT to H1ALT** [Degrees East of Due North (−90º to +90º)]
>
>   For IPARM = 12:
>
>   AZ_INP   =   Relative azimuth angle between the line-of-sight **from H2ALT to H1ALT** and the **H2ALT-to-sun** path [Degrees (0º and 180º)]

Care is required in specifying AZ_INP using a true path azimuth angle under some conditions. If IMULT is +1, so that the sensor (H1ALT) latitude and longitude are fixed for all the lines-of-sight, and if IPARM is 10 or 11, so that the true azimuth angle is defined at H2ALT, then there may be 0, 1 or 2 possible pairs of values for the latitude and longitude at H2ALT. Consider, for example, the case where fixed sensor (H1ALT) is located at 70º N and 0º W of Greenwich, and the earth center angle of the line-of-sight, BETA, is 30º. If the true path azimuth at H2ALT is entered as south (180º East of North), there are no possible values for the latitude and longitude at H2ALT − you cannot go 30º south and end up at 70º N. On the other hand, if the true path azimuth at H2ALT is entered as north (0º East of North), there are 2 acceptable pairs of values for the latitude and longitude at H2ALT: (40º N, 0º W) and (80º N, 180º W). The analogous problem occurs if IMULT is −1 so that the final (H2ALT) latitude and longitude are fixed for all the lines-of-sight, and if IPARM is 0 or 1, so that the true azimuth angle is defined at H1ALT. If it is determined that a solar azimuth input has no solution or more than one solution, than MODTRAN will log a geometry error and terminate the current MODTRAN run.

17. CARD 4 (REQUIRED) - SPECTRAL RANGE AND RESOLUTION

This card specifies the spectral range, frequency/wavelength increments, and spectral degradation of the outputs using a slit function. The default slit function, which is used when FLAGS(1:2) is blank, is triangular and defined on a discrete wavenumber grid. Setting FLAGS(1:4) accesses a set of alternate, continuous slit functions, which may be defined in various frequency or wavelength units. The outputs from the alternate slit functions are written to the files 'tape7.scn' [*rootname*.7sc] and 'pltout.scn' [*rootname*.psc]. When an optional slit function is selected [i.e., FLAGS(1:2) is not blank], tape6 [*rootname*.tp6], tape7 [*rootname*.tp7], tape8 [*rootname*.tp8] and pltout [*rootname*.plt] files are all generated using the finest spectral resolution parameters [e.g., DV = 1 cm^{-1} and FWHM = 1 cm^{-1} if the 1 cm^{-1} band model is selected].

CARD 4: **V1, V2, DV, FWHM, YFLAG, XFLAG, DLIMIT, FLAGS, *MLFLX, VRFRAC***
FORMAT (4F10.0, 2A1, A8, A7, I3, F10.0)

V1 Initial frequency in wavenumber [cm^{-1}] or, alternatively, wavelength in units defined via FLAGS(1:1)

V2 Final frequency (or wavelength)

DV Frequency (or wavelength) increment used for spectral outputs. DV applies to all output files when using the default slit function, i.e., FLAGS(1:4) is blank. Otherwise, DV is applied to tape7.scn and pltout.scn, and the frequency increment for the other files (tape6, tape7, tape8 and pltout) is set to the calculation bin size. **Unless only bandpass information is required, DV should not exceed FWHM for MODTRAN runs to avoid under sampling in the output spectra.** The recommended value for DV is FWHM / 2.

FWHM Slit function Full Width at Half Maximum. FLAGS(1:1) is the unit specifier. For the MODTRAN band model, the maximum FWHM value is 50 times calculation bin size (1 cm^{-1} or 15 cm^{-1}). The type of slit function is defined in FLAGS. A minimum of twice the bin size (2 cm^{-1} for the standard 1 cm^{-1} bin size) will insure proper sampling. No convolution is performed if FWHM equals the bin size and the default slit function is selected.

YFLAG = T Transmittances are output in pltout [*rootname*.plt] and pltout.scn [*rootname*.psc].

= R Radiances (instead of transmittances) are output in pltout [*rootname*.plt] and pltout.scn [*rootname*.psc]. If IEMSCT on CARD 1 is 3, the output is irradiance.

XFLAG controls the units for output files pltout and pltout.scn:

XFLAG = W Spectral frequency in wavenumbers; line-of-sight radiances in W/sr/cm^2/cm^{-1} or solar/lunar irradiances (IEMSCT=3) in W/cm^2/cm^{-1}.

= M Spectral wavelength in microns; line-of-sight radiances in W/sr/cm^2/μm or solar/lunar irradiances (IEMSCT=3) in W/cm^2/μm.

= N Spectral wavelength in nanometers; line-of-sight radiances in μW/sr/cm^2/nm or solar/lunar irradiances (IEMSCT=3) in μW/cm^2/nm.

DLIMIT Character string, up to 8 characters long. Used in pltout [*rootname*.plt] and pltout.scn [*rootname*.psc] to separate output from repeat (sequential) MODTRAN runs.

FLAGS: A string of seven characters, each defined below. If FLAGS(1:2) (the first two characters) are both blank, the default slit function is used and FLAGS(3:7) are ignored. Otherwise, an alternative slit function is used and the results are written to pltout.scn [*rootname*.psc] and tape7.scn [*rootname*.7sc].

FLAGS(1:1) defines the spectral units for input parameters V1, V2, DV and FWHM and output files pltout.scn [*rootname*.psc] and tape7.scn [*rootname*.7sc].

FLAGS(1:1) = blank Default spectral units in wavenumbers.

= W Spectral units in wavenumbers (radiance in W sr^{-1} cm^{-2}/cm^{-1}).

= M Spectral units in microns (radiance in W sr^{-1} cm^{-2}/μm).

= N Spectral units in nanometers (radiance in μW sr^{-1} cm^{-2}/nm).

CARD 4 (Required)

FLAGS(2:2)	=	blank	Default slit function (triangular).
	=	1 or T	Triangular slit function.
	=	2 or R	Rectangular slit function.
	=	3 or G	Gaussian slit function.
	=	4 or S	Sinc slit function.
	=	5 or C	Sinc^2 slit function.
	=	6 or H	Hamming slit function.
	=	7 or U	User-supplied function.

FLAGS(3:3)	=	blank or A	FWHM is absolute.
	=	R	FWHM is percent relative, i.e., FWHM = $100\ d\nu/\nu = 100\ d\lambda/\lambda$.

FLAGS(4:4)	=	blank	Degrade only total radiance and transmittance.
	=	A	Degrade all radiance and transmittance components.

FLAGS(5:5)	=	s or S	Save non-degraded results for degrading later.
	=	blank	Do not save current results.

FLAGS(6:6)	=	r or R	Use saved results for degrading with the current slit function.
	=	blank	Do not use saved results.

FLAGS(7:7) = t or T Write a "specflux" (or *rootname*.flx) file. Use no more than 80 characters per line in spectral flux table (i.e., include line feeds for each spectral point). These files can be quite large unless input MLFLX (see below) is used to limit the number of atmospheric levels (altitudes). The output data is spectrally gridded based on the input DV (CARD 4) value. This option is unavailable with the LOWTRAN band model (MODEL = 'L' or 'F' on CARD 1).

= f or F Write a "specflux" (or *rootname*.flx) file. For each spectral point, all flux values are on a single line (i.e., there are no line feeds). [A warning is warranted here: Some FORTRAN compilers limit the number of characters per line and setting FLAGS(7:7) to FALSE can cause this limit to be exceeded.] This option is not available with the LOWTRAN band model (MODEL = 'L' or 'F' on CARD 1).

= blank Do not write a spectral flux table.

MLFLX = Number of atmospheric levels for which spectral fluxes [FLAGS(7:7) = 'T' or 'F'] are output, starting from the ground. The Top-Of-Atmosphere value is also output. If MLFLX is left blank or set to 0, spectral flux values are output at all atmospheric levels.

VRFRAC = blank Index of refraction profile for spherical refraction performed at central spectral frequency value for input bandpass.

> 0. Spectral frequency [cm^{-1}] at which index of refraction profile is calculated for spherical refraction.

The scanning / slit functions as chosen by FLAGS(2:2) are defined below. All built-in scanning functions are symmetrical about the central spectral wavelength ($\delta_o = \lambda_o$) or frequency ($\delta_o = \nu_o$) [the unit is specified by FLAGS (1:1)]. Let Δ be the FWHM along the frequency-axis:

CARD 4 (Required)

Triangular

$$F_{\delta_o,\Delta}(\delta) \;=\; \frac{1}{\Delta}\left(1-\frac{|\delta-\delta_o|}{\Delta}\right) \;\;;\;\;\;\; |\delta-\delta_o| \;<\; \Delta \;\;\;\; (=0 \;\; elsewhere)$$

Rectangular

$$F_{\delta_o,\Delta}(\delta) \;=\; \frac{1}{\Delta} \;\;;\;\;\;\; |\delta-\delta_o| \;<\; \frac{\Delta}{2} \;\;\;\; (=0 \;\; elsewhere)$$

Gaussian

$$F_{\delta_o,\Delta}(\delta) \;=\; \frac{s}{\sqrt{\pi}}\, e^{-s^2(\delta-\delta_o)^2} \;\;;\;\;\;\; s \;=\; \frac{2\sqrt{\ln 2}}{\Delta}$$

Sinc [Sinc(x) ≡ sin (πx) / (πx)]

$$F_{\delta_o,\Delta}(\delta) \;=\; s\,Sinc\big[s\,(\delta-\delta_o)\big] \;\;;\;\;\;\; s \;=\; \frac{1.2067}{\Delta}$$

Sinc²

$$F_{\delta_o,\Delta}(\delta) \;=\; s\,Sinc^2\big[s\,(\delta-\delta_o)\big] \;\;;\;\;\;\; s \;=\; \frac{0.88589}{\Delta}$$

Hamming

$$F_{\delta_o,\Delta}(\delta) \;=\; 0.230822\,s\,\big\{2.33235\,Sinc\big[s\,(\delta-\delta_o)\big]+ Sinc\big[s\,(\delta-\delta_o)-1\big]+ Sinc\big[s\,(\delta-\delta_o)+1\big]\big\} \;\;;$$

$$s \;=\; \frac{1.8218}{\Delta}$$

18. OPTIONAL CARDS 4A, 4B1, 4B2, 4B3, 4L1 AND 4L2 - GROUND SURFACE CHARACTERIZATION

These optional input cards control the specification of the ground surface reflectance and emittance when the first non-blank character in *SURREF* (**CARD 1**) is 'B' or 'L' (case insensitive).

18.1 CARD 4A

CARD 4A: **NSURF, AATEMP, DH2O, MLTRFL**
                 FORMAT (I1, 2F9.0, A1)   (If *SURREF* = 'BRDF' or 'LAMBER')

CARD 4A inputs permit the modeling of adjacency effects by providing an option to decouple reflectance properties of the image-pixel (H2) surface and the ground surface used in the multiple scattering models. As an example, this option allows one to model observations of a ground calibration tarp placed within a uniform background.

NSURF   = 1   Use the reflectance properties of the image pixel for the 'area-averaged' ground surface in the multiple scattering models. If the line-of-sight intersects the earth, the area-averaged surface temperature is set to TPTEMP (**CARD 1**); otherwise, this temperature is determined from the atmospheric temperature profile.

          = 2   Define reflectance properties for the area-averaged ground surface that are independent of those of the image pixel. Also specify an area-averaged ground surface temperature.

AATEMP > 0. Area-averaged ground surface temperature [K] if NSURF = 2 (not used if NSURF = 1).

        ≤ 0. Set the area-averaged ground surface temperature to TPTEMP (**CARD 1**) if the line-of-sight intersects the earth; otherwise, determine it from the atmospheric temperature profile.

DH2O   ≥ 0. Liquid water option, water layer thickness input [mm].

MLTRFL = F   Embedded surface moisture attenuation model.

         T   *Surface water layer model.*

CARDs 4B1, 4B2 and **4B3** (*SURREF* = 'BRDF') or **CARD 4L2** (*SURREF* = 'LAMBER') are included for the image-pixel surface first and then repeated for the area-averaged ground surface if *NSURF* equals 2.

18.2 CARD 4B1

CARD 4B1: *CBRDF*
               FORMAT (A80)   (If *SURREF* = 'BRDF')

Character string *CBRDF* defines the name or number associated with a BRDF parameterization. Model names are case insensitive and leading blanks are ignored. Currently, there are 7 BRDF model options. The symmetric Walthall [Walthall, 1985] and symmetric Sinusoidal-Walthall are empirical models; the Hapke [Hapke, 1981; Hapke 1986], Rahman [Rahman *et al.*, 1993], Roujean [Roujean *et al.*, 1992], and Ross-Li [Wanner *et al.*, 1995; Wanner *et al.*, 1997; Lucht *et al.*, 1999) are all semi-empirical models; and the Pinty-Verstraete [Pinty and Verstraete, 1991] is a physical model. Generally, the BRDFs are numerically integrated to define surface albedo, directional (hemispheric) reflectivities and emissivities, and azimuth moments (required for interfacing to the DISORT multiple scattering routines); negative values of the BRDF (which can result from angular extrapolation of the measurement-based parameterizations) are replaced by 0. For the simple empirical models, an option to use analytic representations of the reflectance quantities is also provided.

The model descriptions below are primarily intended just to define the BRDF parameters expected by MODTRAN; the user should consult the original references for further details.

   CBRDF = '2' or 'Walthall'

$$\rho(\theta_v, \theta_s, \Delta\varphi) \;=\; P_1 \;+\; P_2\, \theta_v\, \theta_s\, \cos(\Delta\varphi) \;+\; P_3\, \theta_v^2\, \theta_s^2 \;+\; P_4\, (\theta_v^2 + \theta_s^2)$$

   where θ_v is the view zenith angle from the surface to the sensor (H1ALT);
              θ_s is the source zenith angle at the surface; and
              $\Delta\varphi$ is the view-to-source relative azimuth angle from the surface.

CBRDF = '51' or 'Walthall(a)'

    Analytically evaluated Walthall reflectance integrals.

CBRDF = '11' or 'Sine-Walthall'

$$\rho(\theta_v, \theta_s, \Delta\varphi) \;=\; P_1' \;+\; P_2' \sin\theta_v \, \sin\theta_s \, \cos(\Delta\varphi)$$
$$+\; P_3' \sin^2\theta_v \, \sin^2\theta_s \;+\; P_4' \, (\sin^2\theta_v + \sin^2\theta_s)$$

    The sinusoidal Walthall form was introduced to facilitate Monte-Carlo sampling of photon trajectories. The sinusoidal Walthall parameters can be approximated from the Walthall parameters by equating zenith integrations, term-by-term. This lead to the following relationships:

$$P_1' \;=\; P_1 \qquad\qquad\qquad P_2' \;=\; 9\,\pi^2 P_2/64$$

$$P_3' \;=\; (\pi^2/4 - 1)^2 \, P_3 \qquad\qquad P_4' \;=\; (\pi^2/4 - 1)\, P_4$$

CBRDF = '52' or 'Sine-Walthall(a)'

    Analytically evaluated sinusoidal Walthall reflectance integrals.

CBRDF = '4' or 'Hapke'

$$\rho(\theta_v, \theta_s, \Delta\varphi) = \frac{\left(P_1 + \dfrac{P_4}{B(\cos\phi, P_2, P_3)}\right) P_{HG}(\cos\phi, P_2) + H(\cos\theta_v, P_1)\, H(\cos\theta_s, P_1)\, P_1 - P_1}{4\left(\cos\theta_v + \cos\theta_s\right)}$$

    where $\cos\phi \;=\; \cos\theta_v \, \cos\theta_s \;+\; \sin\theta_v \, \sin\theta_s \, \cos\Delta\varphi$

$$P_{HG}(\cos\phi, g) \;=\; \frac{1 - g^2}{(1 + g^2 + 2\,g\,\cos\phi)^{3/2}}$$

$$B(\cos\phi, g, h) \;=\; \frac{1 - g}{(1 + g)^2}\left[1 + \frac{\sqrt{(1 + \cos\phi)/(1 - \cos\phi)}}{h}\right]$$

$$H(x, \omega) \;=\; \frac{1 + 2\,x}{1 + 2\,x\,\sqrt{1 - \omega}}$$

    Parameter $P_1 = \omega$ is the average single scattering albedo of the particles making up the surface; parameter $P_2 = g$ is the Henyey-Greenstein asymmetry factor ranging from -1 (backward scattering) to $+1$ (forward scattering); parameter $P_3 = h$ controls the width of the opposition effect (hot spot); and parameter $P_4 = S_H$ controls the magnitude of the opposition effect. [Note that the atmospheric radiative transport convention for the Henyey-Greenstein variables has been adopted in these equations. The BRDF community generally represents the asymmetry factor with the symbol Θ (instead of g) and represents the scattering angle with the symbol g (instead of ϕ) – a confusing state of affairs to say the least.]

CBRDF = '5' or 'Rahman'

$$\rho(\theta_v, \theta_s, \Delta\varphi) \;=\; P_1 \,[\cos\theta_v \, \cos\theta_s \, (\cos\theta_v + \cos\theta_s)]^{P_3 - 1} \, P_{HG}(\cos\phi, P_2)\,[1 + \frac{1 - P_1}{1 + G(\theta_v, \theta_s, \Delta\varphi)}]$$

    where $G(\theta_v, \theta_s, \Delta\varphi) \;=\; \sqrt{\tan^2\theta_v + \tan^2\theta_s - 2\,\tan\theta_v \, \tan\theta_s \, \cos\Delta\varphi}$

    Parameter $P_1 = \rho_o \geq 0$ characterizes the reflectance of the surface cover; parameter $P_2 = g$ is the Henyey-Greenstein asymmetry factor ranging from -1 (backward scattering) to $+1$ (forward scattering); and parameter $P_3 = k$ indicates the level of anisotropy of the surface.

<u>*CBRDF*</u>   =   '6' or 'Roujean'

$$\rho(\theta_v,\theta_s,\Delta\varphi) \;=\; P_1 + P_2\,K_{geo}(\theta_v,\theta_s,\Delta\varphi) + \frac{4}{3\pi}\,P_3\,K_{RT}(\theta_v,\theta_s,\Delta\varphi)$$

where $K_{geo} \;=\; \dfrac{(\pi-\Delta\varphi)\cos\Delta\varphi+\sin\Delta\varphi}{2\,\pi}\tan\theta_v\,\tan\theta_s - \dfrac{\tan\theta_v+\tan\theta_s+G(\theta_v,\theta_s,\Delta\varphi)}{\pi}$

$$K_{RT} \;=\; \frac{(\pi/2-\phi)\cos\phi+\sin\phi}{\cos\theta_v+\cos\theta_s} - \frac{\pi}{4}$$

Parameter $P_1 = k_{\text{Lamb}}$ is the Lambertian scattering component and equal to the bidirectional reflectance for $\theta_v = 0$ and $\theta_s = 0$. Parameter $P_2 = k_{\text{geo}}$ is the coefficient of the geometric scattering kernel K_{geo}, and parameter $P_3 = k_{\text{vol}}$ is the coefficient for the RossThick volume scattering kernel K_{RT}, so called for its assumption of a dense leaf canopy.

<u>*CBRDF*</u>   =   '10' or 'Pinty-Verstraete'

$$\rho(\theta_v,\theta_s,\Delta\varphi) \;=\; \frac{P_1/4}{\cos\theta_v + \kappa_v(P_3)\left(\dfrac{\cos\theta_s}{\kappa_s(P_3)}\right)} \quad *$$

$$\left\{ T(\theta_v,\theta_x,\Delta\varphi,P_3,P_4)\,P_{HG}(\cos\phi,P_2) + H\!\left[\left(\frac{\cos\theta_v}{\kappa_v(P_3)}\right),P_1\right] H\!\left[\left(\frac{\cos\theta_s}{\kappa_s(P_3)}\right),P_1\right] - 1 \right\}$$

where $T(\theta_v,\theta_s,\Delta\varphi,\chi_l,r\Lambda) \;=\; 1 \;+\; \dfrac{1}{1+\left(4-\dfrac{16}{3\pi}\right)\left(\dfrac{\cos\theta_v}{\kappa_v(\chi_l)}\right)\left(\dfrac{G(\theta_v,\theta_s,\Delta\varphi)}{r\Lambda}\right)}$

$$\kappa_x(\chi_l) \;=\; 1-\Psi(\chi_l)+1.754\,\Psi(\chi_l)\cos\theta_x$$

$$\Psi(\chi_l) \;=\; (1.2666+0.66\,\chi_l)\,\chi_l\,; \qquad x \;=\; v \ or \ s$$

Parameter $P_1 = \omega$ is the average single scattering albedo of the particles making up the surface; parameter $P_2 = g$ is the Henyey-Greenstein asymmetry factor ranging from -1 (backward scattering) to $+1$ (forward scattering); parameter $P_3 = \chi_l$ is most negative (-0.4) for an erectophile canopy (mostly vertical scatterers), 0. for a canopy with a uniform distribution (equal probability for all scatterer orientations), and most positive (0.6) for a planophile canopy (mostly horizontal scatterers); and parameter $P_4 = r\Lambda$ is the product of r, the radius of the Sun flecks on the inclined scatterers, and Λ, the scatterer area density of the canopy (expressed as the scatterer surface per unit bulk area). Note that the functions describing the orientation distribution of the scatterers for the illumination and viewing angles, κ_v and κ_s, are defined here as twice their normal value to be consistent with the definition of multiple scattering functions, $H(x, \omega)$.

<u>*CBRDF*</u>   =   '12' or 'Ross-Li'

$$\rho(\theta_v,\theta_s,\Delta\varphi) \;=\; P_1 + P_2\,K_{LSR}(\theta_v,\theta_s,\Delta\varphi,P_4,P_5) + P_3\,K_{RT}(\theta_v,\theta_s,\Delta\varphi)$$

where

$$K_{LSR} \;=\; \frac{1+\sec\theta_v'\,\sec\theta_s'+\tan\theta_v'\,\tan\theta_s'\cos\Delta\varphi}{2} \;+\; \left(\frac{t-\sin t\cos t}{\pi}-1\right)(\sec\theta_v'+\sec\theta_s')$$

$$\cos^2 t \;=\; \min\left\{\left(\frac{P_4}{\sec\theta'_v + \sec\theta'_s}\right)^2 \left[G(\theta'_v,\theta'_s,\Delta\varphi)^2 + \left(\tan\theta'_v\,\tan\theta'_s\,\sin\Delta\varphi\right)^2\right],\; 1\right\}$$

$$\tan\theta'_x \;=\; P_5\,\tan\theta_x\,; \qquad x \;=\; v \ \ or \ \ s$$

Parameter $P_1 = k_{\text{Lamb}}$ is the Lambertian scattering component and equal to the bidirectional reflectance for $\theta_v = 0$ and $\theta_s = 0$. Parameter $P_2 = k_{\text{geo}}$ is the coefficient of the LiSparse-Reciprocal geometric scattering kernel K_{LSR}, derived for a sparse ensemble of surface objects casting shadows on a Lambertian background. Parameter $P_3 = k_{\text{vol}}$ is the coefficient for the RossThick volume scattering kernel K_{RT}, so called for its assumption of a dense leaf canopy. The two constants, dimensionless crown relative height ($P_4 = h / b$) and shape ($P_5 = b / r$) parameters have been empirically obtained and should not be interpreted too literally. **The LiSparse-Reciprocal kernel has only been validated for h / b = 2 and b / r =1. These are the recommended constant input values for parameters P_4 and P_5**, and the values that will be used to invert the angular radiance data from NASA's Moderate Resolution Imaging Spectroradiometer - MODIS [Justice *et al.*, 1998].

> *CBRDF* = '13' or 'Ross-Sea'

The Ross-Sea model computes the specular component of the BRDF of the sea surface according to Ross, et al. (2005) with an empirical correction of slope statistics due to shadowing near the horizon as described in Ross and Dion (2007). This is a 7 parameter model. The parameters are

1. Real part of complex refractive index
2. Imaginary part of complex refractive index
3. Upwind slope root-mean-square (RMS), negative value for horizon correction
4. Crosswind slope RMS, negative value for horizon correction
5. Azimuth angle between surface-receiver vector and wind vector
6. Whitecap coverage fraction
7. Whitecap hemispherical albedo

Two test case examples are provided with Modtran5.3: seaBRDFnoGLINT and seaBRDF_GLINT.

18.3 CARD 4B2

CARD 4B2: *NWVSRF, SURFZN, SURFAZ*
  FORMAT (*)   **(If *SURREF* = 'BRDF')**

CARD 4B2 defines the number of BRDF spectral grid points and the direction of the surface normal. Currently, the surface normal is required to point upward; the surface normal inputs are included in anticipation of a future upgrade allowing modeling of a graded ground surface and/or arbitrarily oriented image facets.

NWVSRF   *Number of BRDF spectral grid points. If NWVSRF is set to 1, the BRDF will be spectrally independent. The maximum allowed value for NWVSRF is defined by the parameter MWVSRF in the PARAM.LST file. If necessary, the user can increase MWVSRF and then recompile MODTRAN. Upon delivery of MODTRAN, MWVSRF is set to 50.*

SURFZN   The zenith angle [degrees] of the surface normal. Currently, only a value of 0. is supported.

SURFAZ   The true azimuth angle of the image pixel surface normal [0 for North, 90 for East, 180 for South, and 270 for East. This value is currently not used.

18.4 CARD 4B3

CARD 4B3: *WVSURF, (PARAMS(I), I = 1, NPARAM)*
  FORMAT (*)   **(If *SURREF* = 'BRDF')**

CARD 4B3 defines the BRDF parameters on the input spectral grid and is repeated *NWVSRF* times.

WVSURF   *BRDF spectral wavelength [μm]. The wavelength grid must be input in increasing wavelength order.*

PARAMS(I)   BRDF parameters at wavelength WVSURF. The Rahman and Roujean BRDF models are 3-parameter models. Ross-Li is also a 3 parameter model, although an additional two constants [PARAMS(4) = 2. and PARAMS(5) = 1.] are required as inputs (See Section 17.2 for details). All other current BRDF models require 4 parameters. The parameters must be entered in the order specified by the model equations of Section 17.2, i.e., P_1, P_2, …

18.5 CARD 4L1

CARD 4L1:   *SALBFL*
                FORMAT (A256)   **(If *SURREF* = 'LAMBER')**

CARD 4L1 defines the name of the input data file being used to define the spectral albedo. Leading blanks are ignored.

SALBFL   *Name of the spectral albedo data file. The default spectral albedo file, 'DATA/spec_alb.dat' may be used or a user-supplied file. If a user-supplied file is specified, it must conform to the format described in the default file.*

18.6 CARD 4L2

CARD 4L2:   *CSALB*
                FORMAT (A80)   **(If *SURREF* = 'LAMBER')**

CARD 4L2 defines the number or name associated with a spectral albedo curve from the *SALBFL* file. As noted above, input of **CARD 4L2** is repeated *NSURF* times.

CSALB   Number **or** name of a spectral albedo curve in the SALBFL file. There are currently 49 spectral albedo curves available in the default spectral albedo file 'DATA/spec_alb.dat'. Leading blanks are ignored. The 49 'DATA/spec_alb.dat' case-insensitive CSALB spectral curves are:

'1'	or	'snow cover'	'2'	or	'forest'
'3'	or	'farm'	'4'	or	'desert'
'5'	or	'ocean'	'6'	or	'cloud deck'
'7'	or	'old grass'	'8'	or	'decayed grass'
'9'	or	'maple leaf'	'10'	or	'burnt grass'
'20'	or	'constant, 0%'	'21'	or	'constant, 5%'
'22'	or	'constant, 50%'	'23'	or	'constant, 80%'
'24'	or	'constant, 30%'	'25'	or	'constant, 10%"
'26'	or	'constant, 100%'	'31'	or	'CCM3 Sea ice'
'32'	or	'conifer'	'33'	or	'olive gloss paint'
'34'	or	'deciduous tree'	'35'	or	'sandy loam'
'36'	or	'granite'	'37'	or	'galvanized steel'
'38'	or	'grass'	'39'	or	'black plastic'
'40'	or	'Aluminum'	'41'	or	'Evergreen Needle Forest'
'42'	or	'Evergreen Broadleaf Forest'	'43'	or	'Deciduous Needle Forest'
'44'	or	'Deciduous Broadleaf Forest'	'45'	or	'Mixed Forest'
'46'	or	'Closed Shrubs'	'47'	or	'Open/Shrubs'
'48'	or	'Woody Savanna'	'49'	or	'Savanna'
'50'	or	'Grassland'	'51'	or	'Wetland'
'52'	or	'Cropland'	'53'	or	'Urban'
'54'	or	'Crop Mosaic'	'55'	or	'Antarctic Snow'
'56'	or	'Barren/Desert'	'57'	or	'Ocean Water'
'58'	or	'Tundra'	'59'	or	'Fresh Snow'
'60'	or	'Sea Ice'	'80'	or	'Spectralon'
'81'	or	'dry sand'			

19. CARD 5 (REQUIRED) – REPEAT RUN OPTION

CARD 5:   **IRPT,** *AMOD3D, NFACMN, SCALMN, NFACMX, SCALMX*
                FORMAT (I5, 50X, A1, 2(I3, F9.0))
    Non-zero values of the control parameter IRPT cause MODTRAN to repeat program execution, so that a series of problems can be run with a single submission of tape5. *A message is written to standard output indicating a repeat run is beginning if a negative value of IRPT is input*.

IRPT   =   0 or blank   STOP program.
        =   ±1   Read full set of new data cards followed by an additional **CARD 5**.
        =   ±3   Read new line-of-sight (and solar / lunar) geometry (**CARD 3, CARD 3A, …**) and surface (**CARD 4A, …**) inputs followed by an additional **CARD 5**.
        =   ±4   Read new spectral and surface (**CARD 4, …**) inputs followed by an additional **CARD 5**.

    The previous calculation atmospheric profiles are reused when the IRPT = ±3 or IRPT = ±4 options are selected. In these cases, the specific sequences of CARD inputs are as follows:

    If IRPT = ±3

CARD 5:	IRPT = ±3	
CARD 3:	H1ALT, H2ALT, OBSZEN, HRANGE, BETA, RAD_E, LENN, BCKZEN	(If IEMSCT < 3)
CARD 3:	H1ALT, H2ALT, OBSZEN, IDAY, RAD_E, ISOURC, ANGLEM	(If IEMSCT = 3)
CARD 3A1:	IPARM, IPH, IDAY, ISOURC	(If IEMSCT = 2 or 4)
CARD 3A2:	PARM1, PARM2, PARM3, PARM4, TIME, TRUEAZ, ANGLEM, G	(If IEMSCT = 2 or 4)
CARD 3B1:	NANGLS, NWLF	(If IPH = 1)
CARD 3B2:	(ANGF(I), F(1, I, 1), F(2, I, 1), F(3, I, 1), F(4, I, 1), I = l, NANGLS),	(If IPH = 1 and NWLF = 0)
CARD 3C1:	(ANGF(I), I = 1, NANGLS)	(If IPH = 1 and NWLF > 0)
CARD 3C2:	(WLF(J), J = 1, NWLF)	(If IPH = 1 and NWLF > 0)
CARD 3C3:	(F(1, I, J), J = 1, NWLF)	(If IPH = 1 and NWLF > 0)
CARD 3C4:	(F(2, I, J), J = 1, NWLF)	(If IPH = 1 and NWLF > 0)
CARD 3C5:	(F(3, I, J), J = 1, NWLF)	(If IPH = 1 and NWLF > 0)
CARD 3C6:	(F(4, I, J), J = 1, NWLF)	(If IPH = 1 and NWLF > 0)
CARD 4A:	*NSURF, AATEMP*	(If *SURREF* = 'BRDF' or 'LAMBER')
CARD 4B1:	*CBRDF*	(If *SURREF* = 'BRDF')
CARD 4B2:	*NWVSRF, SURFZN, SURFAZ*	(If *SURREF* = 'BRDF')
CARD 4B3:	*WVSURF, (PARAMS(I), I = 1, NPARAM)*	(If *SURREF* = 'BRDF')
CARD 4L1:	*SALBFL*	(If *SURREF* = 'LAMBER')
CARD 4L2:	*CSALB*	(If *SURREF* = 'LAMBER')
CARD 5	IRPT = 0	

    If IRPT = ±4

CARD 5:	IRPT = ±4	
CARD 4	V1, V2, DV, FWHM, YFLAG, XFLAG, DLIMIT, FLAGS	
CARD 4A:	*NSURF, AATEMP*	(If *SURREF* = 'BRDF' or 'LAMBER')
CARD 4B1:	*CBRDF*	(If *SURREF* = 'BRDF')
CARD 4B2:	*NWVSRF, SURFZN, SURFAZ*	(If *SURREF* = 'BRDF')
CARD 4B3:	*WVSURF, (PARAMS(I), I=1, NPARAM)*	(If *SURREF* = 'BRDF')
CARD 4L1:	*SALBFL*	(If *SURREF* = 'LAMBER')
CARD 4L2:	*CSALB*	(If *SURREF* = 'LAMBER')
CARD 5	IRPT = 0	

    The final IRPT card should always be blank or contain a value of zero. Table 16 summarizes the user-control parameters on **CARD 5**. IRPT can be -1, -3, or -4, which are same as 1, 3, or 4, respectively, with the exception that a message is printed to the screen each time a repeat run begins. The user is thus able more easily to follow the progress of an extensive series of calculations.

Table 16. MODTRAN CARD 5 Input Parameter: IRPT.

CARD 5	IRPT
COLUMNS 1-5	**Format (I5)**
0	End of program.
±1	Read full set of new **CARDs**.
±2	Not used (same as 0).
±3	Read new **CARDs 3 and 5** plus optional **CARDs**.
±4	Read new **CARDs 4 and 5** plus optional **CARDs.**

AMOD3D	= 'T' or 't'	Create MOD3D database (outdated option)
	= 'C' or 'c'	Create MCScene continuum transmittance database
	= 'M' or 'm'	Create MCScene molecular transmittance database
	= otherwise	No additional data files generated
NFACMN		Number of column scaling factors less than one to be used in the MCScene molecular transmittance database; must be a positive integer.
SCALMN		Minimum column scaling factor in the MCScene molecular transmittance database; generally SCALMN is set to 0., but any non-negative value less than one is acceptable.
NFACMX		Number of column scaling factors greater than one to be used in the MCScene molecular transmittance database; must be a positive integer.
SCALMX		Maximum column scaling factor in the MCScene molecular transmittance database; generally SCALMN is set to 1000., but any value greater than one is acceptable.

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APPENDIX A: MODTRAN USER-SUPPLIED AEROSOL UPGRADES

This section contains instructions for the MODTRAN options that provide flexible wavelength-dependent specification of extinction, absorption, and asymmetry parameters. These upgrades, used in conjunction with a stand-alone Mie code, allow aerosols to be modeled more realistically. The spectral grid can be arbitrary (i.e., not limited to the default 47 fixed spectral points of Table 12) and different for each aerosol. There can be up to four user-defined aerosol profiles. In addition, utility programs are provided which allow MODTRAN to be run with the Navy Oceanic Vertical Aerosol Model (NOVAM).

A.1 User-Supplied Aerosol Spectral Parameters (ARUSS Option)

Previous to this upgrade, the user could provide extinction, absorption and asymmetry parameters only for user-supplied aerosol profiles (IHAZE = 7 or ICLD = 11) which are in fact the extinction values at 0.55 µm. Furthermore, the spectral parameters were limited to the 47 wavelengths of Table 12. This was done using **CARDs 2D, 2D1** and **2D2** with IHAZE = 7 or ICLD = 11.

There have been two generalizations to the original user-supplied aerosol spectral data:

- The user can supply spectral data on an arbitrary grid for IHAZE = 7 or ICLD = 11. For this ARUSS (in **CARD 2**) needs to be set to the three-character string 'USS'. Additionally, the meaning of the IREG(N), N = 1, 2, 3 and 4, variables in **CARD 2D** has been generalized; when > 1, they now specify the number of wavelengths at which data is supplied.

- The user can supply spectral data for the default aerosol profiles, as selected by IHAZE, ISEASN and IVULCN (IHAZE≠7 and ICLD≠11), instead of relying on the sparse built-in databases of MODTRAN. Setting ARUSS to the character string 'USS' also does this. The USS option can also be used in conjunction with the APLUS option.

The relevant CARDs for these upgrades are **CARD 2D, 2D1** and **2D2** as described below. The extinction and absorption coefficients in MODTRAN are dimensionless because they are defined by dividing the actual values by the extinction at 0.55 µm:

$$K_{EXT}(\lambda) = EXT(\lambda) / EXT(0.55 \text{ µm}) \qquad K_{ABS}(\lambda) = ABS(\lambda) / EXT(0.55 \text{ µm})$$

CARD 2D:	**IREG(1), IREG(2), IREG(3), IREG(4)**
	FORMAT (4I5) **(If IHAZE = 7 or ICLD = 11 or ARUSS = 'USS')**
CARD 2D1:	**AWCCON, AERNAM**
	FORMAT (F10.0, A70) **(IREG(1) > 0)**
CARD 2D2:	**(VARSPC(1, I), EXTC(1, I), ABSC(1, I), ASYM(1, I), I = l, I$_{max}$)**
	I$_{max}$ = IREG(1) if ARUSS = 'USS' and IREG(1) > 1; otherwise I$_{max}$ = 47
	FORMAT ((3(F6.2, 2F7.5, F6.4)))
CARD 2D1:	**AWCCON, AERNAM**
	FORMAT (F10.0, A70) **(IREG(2) > 0)**
CARD 2D2:	**(VARSPC(2, I), EXTC(2, I), ABSC(2, I), ASYM(2, I), I = l, I$_{max}$)**
	I$_{max}$ = IREG(2) if ARUSS = 'USS' and IREG(2) > 1; otherwise I$_{max}$ = 47
	FORMAT ((3(F6.2, 2F7.5, F6.4)))
CARD 2D1:	**AWCCON, AERNAM**
	FORMAT (F10.0, A70) **(IREG(3) > 0)**
CARD 2D2:	**(VARSPC(3, I), EXTC(3, I), ABSC(3, I), ASYM(3, I), I = l, I$_{max}$)**
	I$_{max}$ = IREG(3) if ARUSS = 'USS' and IREG(3) > 1; otherwise I$_{max}$ = 47
	FORMAT ((3(F6.2, 2F7.5, F6.4)))
CARD 2D1:	**AWCCON, AERNAM**
	FORMAT (F10.0, A70) **(IREG(4) > 0)**

CARD 2D2: **(VARSPC(4, I), EXTC(4, I), ABSC(4, I), ASYM(4, I), I = l, I$_{max}$)**
                                     I$_{max}$ = IREG(4) if ARUSS = 'USS' and IREG(4) > 1; otherwise I$_{max}$ = 47
              FORMAT ((3(F6.2, 2F7.5, F6.4)))

CARDs 2D1 and 2D2 are repeated up to four times, one pair for each of 4 aerosol regions. However, the two cards for aerosol N are needed if and only if IREG(N) > 0. The only differences between the original and upgraded inputs are in **CARD 2D** and **CARD 2D2**. Now **CARD 2D** denotes the number of spectral grid points for each of the four aerosols; IREG(N) = number of spectral grid points for aerosol N. **CARD 2D2** is the list of the spectral parameters: VARSPC is the wavelength in microns, EXTC and ABSC are the 0.55 μm normalized spectral extinction and absorption coefficients, respectively, and ASYM is the spectral asymmetry parameter. Previously the IREG values were all 0 (no **CARDs 2D1** and **2D2**) or 1 (read **CARDs 2D1** and **2D2**). Although the VARSPC array read in, it was not used because the 47 wavelengths were fixed. Now, VARSPC is a 2D-array; the first dimension identifies the aerosol and the second is the wavelength index. The user must input VARSPC values in microns and in increasing order; that is, the first VARSPC must be the lowest wavelength. The VARSPC array may differ for each aerosol.

> AWCCON   A conversion factor from extinction coefficient (km^{-1}) to equivalent liquid water content (g/m^3), designed for use in the microwave (λ > 287.9μm, ν < 37.4 cm^{-1}) with the fog extinction model. It is numerically equal to the equivalent liquid water content corresponding to an extinction coefficient of 1.0 km^{-1} at a wavelength of 0.55 μm. AWCCON has units of (km g / m^3).

A.2 User-Supplied Aerosol Profiles (CARD 2C3)

In the original MODTRAN model, the user could only input a single aerosol profile using the user-selected profile option: MODEL = 7 and IRD2 = 1. This upgrade allows the user to define up to four user-defined aerosol profiles with MODEL = 7 and IRD2 = 2.

This upgrade cannot be used with the A+ upgrade option; the APLUS option is turned off if MODEL = 7 and IRD2 = 1 or 2. The A+ option allows the built-in aerosols to be stretched, compressed or translated, whereas this upgrade allows the user to input aerosol profiles (up to all four) with greater control. For backward compatibility, the original MODTRAN option for the single aerosol profile is retained.

This upgrade is achieved by a generalization of **CARD 2C3**. For this purpose AHAZE was changed from a scalar variable to an array, AHAZE(4). The two versions of **CARD 2C3** are shown below:

CARD 2C3*:*   **AHAZE, EQLWCZ, RRATZ, IHA1, ICLD1, IVUL1, ISEA1, ICHR**
                  FORMAT (10X, 3F10.0, 5I5)   **(If IRD2 = 1)**

CARD 2C3:   **AHAZE(1), RRATZ, AHAZE(2), AHAZE(3), AHAZE(4)**
                  FORMAT (10X, F10.0, 10X, 4F10.0)   **(If IRD2 = 2)**

The variables missing in the newer version of **CARD 2C3** (IRD2 = 2) are no longer needed for specifying aerosols. However, ICLD1 (IRD2 = 1) allows the user to specify cloud profiles in addition to aerosol profiles with the restriction that a cloud extinction and an aerosol extinction cannot be specified at the same altitude using **CARD 2C3**. The user-specified cloud profiles may be entered using **CARD 2E1**.

A.4 Example tape5 File

Here is an example of a tape5 that has both the A+ and ARUSS aerosol options. Notice the **CARD 2A+** following **CARD 2** (which contains 'A+' as its first two characters). Also note that user-supplied spectral data are used for a built-in aerosol profile.

```
M    4    3    0    1    0    0    0    0    0    0    1    0   -1          .0500
F    0F   0
A+   1    1USS 0    0    0    0     0.000     0.000     0.000     0.000
        0.0        4.0        1.0  (CARD 2A+)
(This blank line must be here or this line should have zeros)  (CARD 2A+)
   40    0    0    0  (CARD 2D)
 0.000e+00region #1 desert summer aerosol
   .20 1.0167 .43495 .8797    .30 1.0167 .43495 .8797    .34 1.0194 .44735 .8857
   .55 1.0000 .21935 .7980    .69 1.0370 .16743 .7666   1.06 1.1149 .03721 .7143
  1.54 1.2084 .04348 .7689   2.00 1.0471 .04212 .8557   2.25 .90502 .03577 .8936
  2.50 .77022 .05025 .9116   2.70 .66704 .08621 .9281   3.00 .62886 .11468 .9247
  3.39 .81244 .12218 .8623   3.75 .78888 .10013 .8493   4.50 .67765 .10404 .8524
  5.00 .60842 .10488 .8551   5.50 .51168 .11551 .8706   6.00 .36239 .15033 .9038
  6.20 .33716 .15081 .9065   6.50 .31172 .15288 .9079   7.20 .67035 .20663 .7748
  7.90 .28524 .12992 .8881   8.20 .30108 .18832 .8855   8.70 .60029 .25834 .7717
  9.00 .82965 .33903 .6736   9.20 .83153 .34675 .6684  10.00 .80838 .34487 .6558
 10.59 .69210 .27596 .6814  11.00 .66931 .25000 .6748  11.50 .62531 .23290 .6805
 12.50 .52648 .20100 .7023  14.80 .49395 .19037 .6708  15.00 .48791 .18807 .6700
 16.40 .46622 .17702 .6539  17.20 .46122 .17202 .6408  18.50 .44203 .18161 .6366
 21.30 .48520 .26897 .5959  25.00 .45705 .22352 .5460  30.00 .40179 .25847 .5494
 40.00 .36801 .23947 .4688
  4.90000           180.00000
     2500        2600          25           5
     0
```

APPENDIX B: NOVAM IN MODTRAN

The most recent compilation of the NOVAM (Navy Oceanic Vertical Aerosol Model) profiles offers a new set of aerosol descriptions, providing both optical and size distributions appropriate from the shipboard surface to 6 km, covering the spectral range from 0.2 micron to 40 microns at relatively sparse spectral resolution. Since the ozone retrievals currently implemented in the UV encompass an accounting of the aerosol background, the addition of NOVAM profiles to MODTRAN was deemed critically important.

B.1 <u>NOVAM Code</u>

Spectral Sciences, Incorporated (SSI) obtained the NOVAM code from NRaD through S. Gathman (Gathman and Davidson, 1993). R.A. Paulis released this code under the authority of J. H. Richter, Oceanic and Atmospheric Sciences Division, Naval Command, Control and Ocean Surveillance Center, San Diego. The NOVAM code is an upgrade to NAM (Navy Aerosol Model) which is already in MODTRAN. NOVAM is based on extensive direct shipboard measurements carried out by several different agencies specializing in the marine environment. The inputs to the NOVAM code are radiosonde data consisting of altitude, temperature, pressure and relative humidity (RH), and other surface observation parameters such as optical visibility, wind speeds and surface IR extinction (1/km) at 10.6 microns; not all the inputs are required for implementation.

NOVAM recognizes three types of meteorological profiles characterized by existence or non-existence of temperature inversions. The cases are denoted numerically: 1 for no inversion; 2 for two inversions; and 3 for one inversion. The wavelength spectrum ranges from 0.2 to 40 microns. The actual spectral grid (in microns) is: 0.2, 0.3, 0.3371, 0.55, 0.6943, 1.06, 1.536, 2.0, 2.25, 2.5, 2.7, 3.0, 3.3923, 3.75, 4.5, 5.0, 5.5, 6.0, 6.2, 6.5, 7.2, 7.9, 8.2, 8.7, 9.0, 9.2, 10.0, 10.591, 11.0, 11.5, 12.5, 14.8, 15.0, 16.4, 17.2, 18.5, 21.3, 25.0, 30.0, 40.0. The model contains four classes of marine aerosols with three mode radii of 0.03, 0.24 and 2.0 microns, where the mode radius is the "size" of the most populous part (i.e., the peak) of the distribution at the RH of 80%. The 0.03-micron aerosol consists of two classes: soluble and insoluble. The other two sizes consist of soluble aerosols only.

The version of NOVAM from NRaD outputs surface layer altitudes and the net extinction, absorption and asymmetry coefficients by <u>combining</u> the effect of all four aerosols. The output of NOVAM consists of aerosol size distribution parameters and total extinction, absorption and asymmetry values as a function of wavelength. In this study, NOVAM was modified to output this information as a function of wavelength for a series of altitude values beginning at the lowest "significant" radiosonde altitude (usually a few meters), extending into the lower troposphere. The NOVAM model is claimed to be valid up to 6 km. However, in consultation with Gathman (private communication), we have restricted the NOVAM aerosol profiles to reach no higher than 2 km.

The set of NOVAM routines consists of about 6000 lines of FORTRAN code written in non-standard FORTRAN 77. NOVAM, however, needs only minimal modification so as to be acceptable to most FORTRAN compilers. Extensive modification of the code was ruled out in order to maintain an easily discernible correspondence between the modified and original versions.

The user should familiarize herself / himself with the NOVAM input files of which there are three: (i) the **Surface Observation Data File**, (ii) the **Radiosonde Profile File**, and (iii) a file called **novam.in**. For purposes of familiarizing with NOVAM, it is highly recommended that the user consult the above referenced NOVAM manual. In this report only a very brief description of the inputs and output are given. Questions regarding the use of NOVAM within MODTRAN should be directed to the authors of this report.

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Note that the NOVAM code supplied with this delivery has 13 inputs in the **Surface Observation File** as opposed to 9 as stated on page 9, Table 4, of the NOVAM manual. These inputs are the same as stated for positions 1 to 7. The revised Table 4 is described below. Values outside the stated range make the code use built-in default values. It is suggested that the user employ the default values when any of the specific data items are not available.

1   Sea Surface Temperature (°C)
2   Air Temperature (°C)
3   Relative Humidity (%)
4   Optical Visibility (km)
5   Current Real Wind Speed (m / s)
6   Averaged Wind Speed (24 hours, m / s)
7   Air Mass Parameter (1 to 30)
8   Cloud Cover Fraction (0 to 1)
9   Cloud Type (0 to 9)
10   Surface IR Extinction at 10.6 micron (1/km, 0.001 to 100.0)
11   Weather (0 to 11)
12   Height of Lowest Cloud (meters, negative value uses default)
13   Zonal/Seasonal Category (1 to 6)

The **Radiosonde Profile Data File** is in either of the formats described on page 15, Table 6 and Table 7, of the NOVAM manual. Table 6 contains data, each line of which consists of an altitude (m), potential temperature (°C) and aerosol mixing ratio (g/kg). The relationship between the potential temperature (Θ) and the usual air temperature (T) is given by the formula:

$$\Theta = T \, (P_0/P)^{\kappa}; \quad \kappa = (C_p - C_v) / C_p \approx 0.288$$

where the C's are heat capacities at constant pressure and constant volume, $P_0 = 1013.25$ mb and both temperatures are in Kelvin. [Potential temperature is the temperature attained by air at pressure P and temperature T where it is brought adiabatically (i.e., at constant entropy) to a standard pressure P_o (Houghton, 1986).] Table 7 contains data, each line of which consists of a line number (an integer), log (base 10) of pressure in millibars multiplied by 10^4, the air temperature in °C, RH in percent and pressure in millibars multiplied by 10. As stated above, one needs the profile data either in the format of Table 6 and Table 7. Table 6 is said to be in 'n' format whereas Table 7 is said to be in 'r' format, presuming that 'n' denotes 'number' defined by mixing ratio, while 'r' denotes 'relative humidity.'

In addition to these files, NOVAM needs another file called **novam.in**. An example of **novam.in** is reproduced below:

    1905sops
    1905prof.txt
    n

Here, **1905sops** is the **Surface Observation File** and **1905prof.txt** is the **Profile File** in the 'n' format as indicated by the last line. This file then specifies for the program where the necessary data files can be found.

The output of NOVAM, **novam.out**, now in a form suitable for MODTRAN, typically looks as follows:

```
  40      (number of wavelengths and wavelengths in microns)
      .2000     .3000     .3371     .5500     .6943    1.0600    1.5360    2.0000
     2.2500    2.5000    2.7000    3.0000    3.3923    3.7500    4.5000    5.0000
     5.5000    6.0000    6.2000    6.5000    7.2000    7.9000    8.2000    8.7000
     9.0000    9.2000   10.0000   10.5910   11.0000   11.5000   12.5000   14.8000
    15.0000   16.4000   17.2000   18.5000   21.3000   25.0000   30.0000   40.0000
  10     (number of altitudes and altitudes in m )
   20.9  123.6  226.3  329.1  393.8  458.6  523.4  572.0  620.7  669.3
  (temperature in K)
 287.65    286.49    285.57    284.85    285.37    285.95  285.65 287.65 288.91  288.45
  (pressures in mb)
 1010.70   999.40   988.10   976.80   969.66   962.55   955.50   949.60   943.73   937.90
  (RH)
   88.80    91.41    95.39    95.60    81.88    66.69    65.60    50.08    37.44    35.80
  (spectral data for 0.2 microns)
   .156E+00    .146E+00    .145E+00    .145E+00    .144E+00    .142E+00    .140E+00
   .377E-01    .377E-01    .377E-01   (extinction)
   .224E-03    .140E-03    .133E-03    .132E-03    .130E-03    .128E-03    .125E-03
   .635E-06    .635E-06    .635E-06   (absorption)
   .801E+00    .798E+00    .797E+00    .797E+00    .797E+00    .797E+00    .797E+00
   .758E+00    .758E+00    .758E+00   (asymmetry)
  (spectral data for 0.3 microns)
   .150E+00    .140E+00    .139E+00    .139E+00    .137E+00    .135E+00    .133E+00
   .283E-01    .283E-01    .283E-01
   .377E-05    .255E-05    .245E-05    .243E-05    .240E-05    .236E-05    .233E-05
   .488E-06    .488E-06    .488E-06
   .804E+00    .800E+00    .799E+00    .799E+00    .799E+00    .799E+00    .799E+00
   .777E+00    .777E+00    .777E+00
```

The *italicized* text will not appear in the output. The first number is 40, which is the number of wavelengths (in microns) which are then individually listed. The number 10 is the number of altitudes (in meters) which are then individually listed. Then the temperatures (in K) for each altitude are listed, followed by the pressures (in MB) and relative humidity (RH in %). Then for the first wavelength (0.2 micron), the extinction coefficients (in 1/km) for each altitude are listed. The absorption coefficients (in 1/km) for each altitude are followed by the asymmetry parameters for each altitude. Then the same set of information of the second wavelength (.3 micron) is listed. This pattern continues.

B.2 Incorporation into MODTRAN

First all structure variables were eliminated and all non-standard system routines (such as **gettim**) were also eliminated from NOVAM. Several non-standard (i.e., non-FORTRAN 77) features were left intact. These include the DO ... ENDDO structure, longer than six character variable names and the use of the INCLUDE statement as these are acceptable by almost all modern compilers. The goal was to minimize changes to NOVAM and to use it almost "as is". The changes to the NOVAM code are briefly stated later.

Extensive changes were made to the MODTRAN code to accommodate the way NOVAM treats its four aerosols. The reason changes were extensive is that, unlike MODTRAN's current requirement, NOVAM does not output an aerosol profile (varying with altitude) and spectral extinction and absorption coefficients (varying with wavelength but not with altitude). Instead NOVAM outputs both altitude and spectrally varying quantities which are products of profile and spectral parameters. Changes to NOVAM code itself, however, were kept to a minimum. This meant that in order to use NOVAM in MODTRAN the user must supply the required radiosonde input data to NOVAM, separate from the MODTRAN inputs. NOVAM is executed off-line and creates a file called **novam.out** (lower case in UNIX) which is used as input to MODTRAN (uppercase filename in UNIX). Note that NOVAM input files are currently separate and in addition to MODTRAN's usual input file (which is named **tape5**). If the altitudes in **tape5** overlap with those in the NOVAM output file, the meteorological parameters, such as humidity, pressure and temperature, used by MODTRAN will be those provided by NOVAM.

In a future upgrade, the requirement for NOVAM to have a separate input file can be eliminated; both MODTRAN and NOVAM will then use the information contained in the MODTRAN input file, **tape5**. This process will be facilitated by the prior development of a radiosonde compression scheme. SSI and PL/GPO have collaborated to write a program, called **SNDTP5**, which can compress radiosonde measurements, consisting of hundreds of altitude layers (such as those used by NOVAM), into a form more suitable for the finite layering appropriate (and generally just as accurate for transmittance and radiance calculations) for a MODTRAN **tape5**.

As mentioned, NOVAM actually can model altitudes as high as 6000 meters. However, in consultation with E.P. Shettle (Naval Research Laboratory, private communication) and S. G. Gathman (NOSC, private communication), the maximum NOVAM altitude relevant for MODTRAN was determined to be 2 km. In reality, for most applications it will be less than 2 km. NOVAM distinguishes between three different temperature inversion cases. The code was modified to output these inversion layers explicitly which are then used in MODTRAN. This enables MODTRAN to use only a few layers and still accurately model the temperature effects. If the aerosol does not contain inversion layers, currently MODTRAN will introduce layers, which are at most 100 m apart. Although adequate, this scheme may be improved so those layers are more closely spaced nearer to the surface (where the scale height is smaller/steeper) and are farther apart towards the top of the boundary layer (where the scale height is generally larger). This may allow using fewer layers without loss of accuracy.

In summary, NOVAM is simply used to generate a database of marine aerosol profiles and spectral information for MODTRAN. NOVAM does not at present generate angular phase functions. Instead, it has a database of asymmetry parameters from which Henyey-Greenstein phase functions can be computed. In principle, a Mie code can be used to generate the phase functions for NOVAM.

B.3 Some Results

Three typical (as provided in the NOVAM package) profiles of aerosol extinction and coincident temperature are shown if Figures 1a and 1b. Figure 2a, b, and c shows the simulated backscattered UV signatures associated with these profiles, as might be measured by a potential ozone monitor staring down from a space platform. These calculations use all three types of temperature inversions modeled in NOVAM. The calculation with no aerosol includes only the Rayleigh scattering component and is used as the measure of change imparted to the backscattered signature by low-lying aerosols. No attempt was made to smoothly incorporate these profiles into a total profile. Rather, the "default" US Standard temperature, pressure, and constituent (primarily ozone) profiles and background rural (23 km visibility) aerosols were employed above 0 - 2 km, the acceptable vertical range for the NOVAM input. The spectral range presented is only that reaching the surface and near-surface, as wavelengths short of 300 nm will be absorbed (in general) at higher altitudes. MODTRAN will accommodate simulations from 200 nm to the far-IR, including the aerosol impact, so the short spectral range depicted in these calculations is not a restriction.
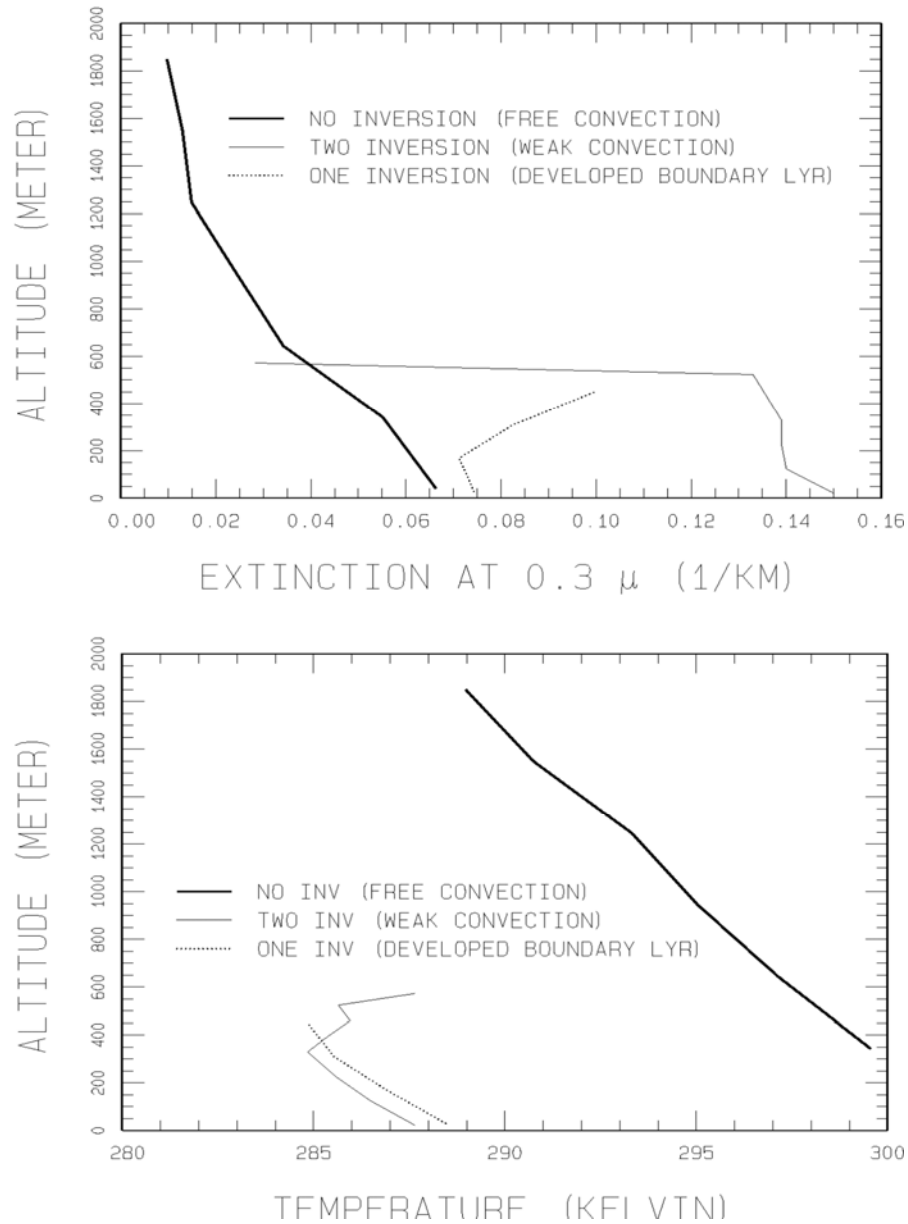
Figure 1a and b. The 3 aerosol and coincident temperature profiles (in extinction at 0.3μm and K, respectively) as a function of altitude. These profiles were chosen to capture the number of temperature inversions used as a parameter in NOVAM, 1 or no inversion, 2 or two inversions, and 3 for 1 inversion. There was not attempt to find the most perturbing case, so these can be considered typical. Note the MODTRAN merges these profiles into those describing the rest of the atmospheric profile from whatever source has been specified, 'default' or 'user-defined'. This can lead to very coarse discontinuities whose impact might need to be further explored.

Figure 2a, b and c. As denoted, these represent typical sensitivity to the new NOVAM aerosol profiles shown in Figure 1. The plots are shown linearly to emphasize the impact at the longer wavelengths that 'see' to the surface, and, therefore, would be impacted by boundary-layer variability. At shorter wavelengths, <0.3 μm), the stratospheric aerosol component might be important under extremes of volcanic loading. That sensitivity requires a logarithmic plot and has not been explored in this study.

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B.4 NOVAM Input and MODTRAN Input Files

NOVAM files were described earlier. In the delivered code, there are several **novam.in**, **Surface Observation** and **Radiosonde Profile** files. The **tape5** used to run MODTRAN with NOVAM aerosols for the calculations in this report is shown below. The 'N' in the third line invokes the NOVAM aerosol option in MODTRAN.

```
T    6    2    2    1    0    0    0    0    0    0    1    0    1         .0500
F   0F    0
     1N    0    0    0    0    0      0.000      .000      .000      .000
 0050.0000  .10        180.00000
     2    2    0    0
       45.  60.
        .3         .4      .0001      .0010 $         M1
     0
```

First NOVAM is executed to produce the **novam.out** file. This file then should be copied to the directory containing the MODTRAN executable as **NOVAM.OUT**; MODTRAN requires this file with the uppercase name.

B.5 Future Upgrades to NOVAM Implementation

There are at least six general areas in which the aerosol product in MODTRAN can be improved:

1. The first is to enable NOVAM to run from MODTRAN's input file, **tape5**. This task will enable MODTRAN to use radiosonde data consisting of several hundred altitude layers several of which can even be redundant. This will alleviate the need for NOVAM to have its own input file as is required in the current input scheme. Note that there still may be a need for the NOVAM input file, for example, to input surface observations.

2. MODTRAN does not now have phase functions for several aerosols (e.g., the desert aerosols) and for none of the cloud models. In the future this can be rectified by generation of the phase functions using the Mie code and incorporating them in MODTRAN.

3. The phase functions for NOVAM are also not available. In consultation with S. Gathman, they can be generated for the NOVAM aerosols and incorporated in MODTRAN.

4. The output of the Mie code can be put in a format so that user can include them in the MODTRAN input file without extensive editing.

5. Based on the El Chichon and Mt. Pinatubo eruptions, the content, size, type, and H_2SO_4 component of fresh and aging volcanic aerosols need to be altered from the default profiles now available within MODTRAN (E.P. Shettle, private communication).

6. MODTRAN currently merges NOVAM-generated profiles (e.g., extinction and temperature) into those describing the rest of the atmospheric profile from whatever source has been specified, 'default' or 'user-defined'. This could lead to very coarse discontinuities whose impact might need to be explored. General validation against real radiosonde data will provide additional confidence in the procedure.

B.6 Modifications to NOVAM to Code

NOVAM modifications were kept to a bare minimum. Here is a list of types of coding changes to NOVAM.

1. All structure variables were replaced using this scheme:

    structure.member was replaced by **structure_member**

This of course meant that numerous corresponding changes to subroutine arguments had to be made.

2. The **driver3.f** routine was substantially changed to output the **novam.out** file described earlier.

3. The assym1 routine in the file **optics2.f** was substantially rewritten to fix an interpolation problem with the asymmetry parameters.

4. The calls to **gettim** were eliminated as it is not available on all machines.

5. **potential_temperature** was replaced by **potential_temp** as this variable and routine name is too long.

6. The file **drivesub2.f** was renamed **drivesb2.f** so that the new prefix has no more than eight characters which is the maximum for the PC environment.

7. As before the **sigfile** is created by calling it with **repeatflag** equal to .false.. In the same call, a new file called **invfile** is created with inversion and other extra layers to be used as MODTRAN layers. This file also contains pressure, air temperature (not potential temperature) and RH. It is created by modifying the routine **make_rdataary**. Later the driver (with **repeatflag** = .true.) reads the **invfile** and creates the **novam.out** file at these altitudes.

8. The driver checks to see that all altitudes in the **invfile** that are greater than 2 km are discarded. Also discarded is the set of all top altitudes if the first altitude in the set has a relative humidity, which is below 50%. That is because the NOVAM aerosols appear to be restricted to be in an environment of 50% humidity or higher.

B.7 <u>References</u>

Gathman, S.G. and Davidson, K.L., "The Navy Oceanic Vertical Aerosol Model," TR-1634, Naval Command Control and Ocean Surveillance Center, RDT&E Division, San Diego CA (1993).

Houghton, J.T., "The Physics of Atmospheres," Cambridge University Press (1986).

APPENDIX C: MODTRAN INSTALLATION

MODTRAN5.3.2 is delivered as a single DVD. The DVD contains a PC distribution with both 32-bit and 64-bit machine installation files, Mac distribution installation file, and a Linux distribution as a gzip'ped tar file.

Installation instructions for PC, Mac and Linux systems are provided below. For additional installation or technical questions, please email either Spectral Sciences, Inc. (SSI) at modtran@spectral.com or AFRL at Gail.Anderson@hanscom.af.mil.

C.1 **MODTRAN5.3.2 PC Installation Steps**

The PC version of MODTRAN is delivered ready to run. Enter the Mod5.3.2 sub-directory appropriate for your machine [pc_32bit/ or pc_64bit/ and double click the installation file modtran5.3.2.msi or modtran5.3.2(x64).msi, respectively]. Icons will be set-up for MODTRAN executables, Mod5.3.2qwin.exe or Mod5.3.2cons.exe. The only difference between these is that the QuickWin executable retains the standard output window upon completion of the MODTRAN run(s), while the Console executable closes the window. This will run all the test cases. On most modern PC's, all the test cases should run in ~30 minutes. The newly generated output (located in the TEST/ directory) can be compared to the files in TEST/COMPARE/ sub-directory.

C.2 **MODTRAN5.3.2 MAC Installation Steps**

This Mac version of MODTRAN delivers executables and binary data files for Mac systems based on the i386 architecture. The executables were built with gfortran and use dynamic gfortran libraries that are also provided here. The terms of the gfortran license can be found in the file Licenses.txt that comes with this media.

If you are unsure of what Mac hardware you have, type

   uname -m

on the command line. We do not support PPC-based Macs at this point.

You can build MODTRAN yourself on such systems by following the instructions for Linux installation.

To install,

1. Copy the disk image (.dmg) file to your desktop, and then double-click. This will mount the Volume called Mod5.3.2.

2. Open a console. Navigate to the directory where you want Mod5.3.2 installed. Then uncompress and unpack MODTRAN. The following commands show how this is done (Note: In the following lines, "$" denotes the command prompt, and "<>" is used to indicate user-defined input):

       $ cd <some directory>

       $ tar xvzf /Volumes/Mod5.3.2/Mod.5.3.2.tgz

    The second command will unpack everything to a directory "Mod5.3.2/"

3. Change directory to Mod5.3.2/. All the appropriate executables and data files are contained there. On most current systems, all the test cases should run in ~30 minutes. The newly generated output (located in the TEST/ directory) can be compared to the files in COMPARE/ sub-directory.

C.3 <u>MODTRAN5.3.2 Linux Installations</u>

 With the introduction of MODTRAN5.3, a new Linux installation approach based on Autotools has been implemented. The users must have Autotools on their Linux system. The Linux distribution comes as a single gzip'ped tar file. To install MODTRAN5.3, follow these steps:

 (1) *Place Mod5.3.2.0.tar.z in your desired directory*:

   cp Mod5.3.2.0.tar.z /home/my_name/Mod53/

 (2) *Extract the gzip'ped tar file*: (~14 minutes)

   tar xvzf Mod5.3.1.2.tar.z

 (3) *Edit the* configure.in *file to define your favorite FORTRAN executable. In the middle of the* configure.in *file, you should find the following line*

   AC_PROG_FG([ifort pgf90 g77 gfortran])

 *This line dictates that the Intel FORTRAN compiler **ifort** should be used if found. If **ifort** is not found, the Portland-Group FORTRAN90 compile **pgf90** should be used if found. If **ifort** is not found, the GNU77 compiler **g77** should be used if found. If **g77** is not found, the GNU FORTRAN compiles **gfortran** should be used. If you do not like this hierarchy or you wish to use another compiler, edit this line appropriately.*

 (4) *Run bootstrap*:

   ./bootstrap

 (5) *Run configure*:

   ./configure

 (6) *Run makefiles*: (~2 minutes)

   make

 (7) *Install executables*:

   make install prefix=$HOME

 (8) *Create the full set of binary databases*: (~30 minutes)

   make databases

 (9) *Run the full set of 83 test cases*: (~30 minutes)

   mod53

 The test cases output files that you just generated will be located in subdirectory TEST/ and these output files can be compared to the delivered output files in TEST/COMPARE/.

C.4 I/O Files

MODTRAN5 makes it easy for the users to keep track of input and output (I/O) files. A MODTRAN input file named either '**mod5root.in**' or '**MOD5ROOT.IN**' contains a list of file root names. If 'mod5root.in' does not exist, MODTRAN checks for the existence of a 'MOD5ROOT.IN' file. If neither of these files exists, MODTRAN I/O files are the original ones: 'tape5', 'tape6', 'tape7', 'tape8', etc. If a root name file exists and its very first line contains a non-null string (maximum length is 80 characters), this string is treated as a prefix. If the string consists of all blanks or is a null string, the traditional I/O file names are assumed. The root name should contain no embedded blanks; leading and trailing blanks are properly ignored. If the rootname file has the extension ".tp5", this extension is ignored. The character string is used as a prefix for the I/O files whose names have mnemonic suffixes. As an example, if the string is '**Denver**', the MODTRAN I/O files will have these names:

Denver.tp5	(corresponding to **tape5**)	**Denver.pth**	(corresponding to **rfracpth.dat**)
Denver.sap	(corresponding to **SpecAerProf.dat**)	**Denver.tp6**	(corresponding to **tape6**)
Denver.tp7	(corresponding to **tape7**)	**Denverb.tp7**	(corresponding to **tape7b**)
Denver.tp8	(corresponding to **tape8**)	**Denverb.tp8**	(corresponding to **tape8b**)
Denver.7sc	(corresponding to **tape7.scn**)	**Denver.7sr**	(corresponding to **tape7.scr**)
Denver.plt	(corresponding to **pltout**)	**Denverb.plt**	(corresponding to **pltoutb**)
Denver.psc	(corresponding to **pltout.scn**)	**Denver.clr**	(corresponding to **clrates**)
Denver.chn	(corresponding to **channels.out**)	**Denver.flx**	(corresponding to **specflux**)
Denver.acd	(corresponding to **atmcor.dat**)	**Denver.t_k**	(corresponding to **t_kdis.dat**)
Denver.r_k	(corresponding to **r_kdis.dat**)	**Denverb.t_k**	(corresponding to **t_kdis.bin**)
Denverb.r_k	(corresponding to **r_kdis.bin**)	**Denver.wrn**	(corresponding to **warnings.txt**)
Denver._pth	(corresponding to **rfractpth.dat**)		

A useful feature of MODTRAN5 is the ability to process several input files in a single execution of MODTRAN. To accomplish this, list the *rootname* of each input file as consecutive lines (without intervening blank lines) in '**mod5root.in**' or '**MOD5ROOT.IN**'. When the user executes MODTRAN, each input '.tp5' file, whose *rootname* is listed in '**mod5root.in**' or '**MOD5ROOT.IN**', is processed until the first blank line is encountered. Any '.tp5' file whose *rootname* is encountered after the first blank line is not processed.

A new Frequently Asked Questions (FAQ) document provides detailed information on the actual data written to each of the MODTRAN output files. See Appendix F for a copy of the FAQ.

APPENDIX D: BAND MODEL FILES FOR USER-DEFINED SEPCIES

Each user-defined species require one of two types of band model parameters. The first type is similar to the CFC cross-section parameters used in MODTRAN, except for the units used. The CFC cross-sections are in units of cm^{-1} / atm at 273.15K while the user-defined cross-sections should be entered in cm^2 / mol. A cross-section file name must be of the form

species-name.BM

An example of the contents follows:

```
   0        0       0.        0        0        0.  153.8235 CCL4
 7860    1.290E-19 1.290E-19 1.290E-19 1.290E-19 1.290E-19 1.290E-19
 7861    9.177E-20 9.177E-20 9.177E-20 9.177E-20 9.177E-20 9.177E-20
 7862    1.885E-19 1.885E-19 1.885E-19 1.885E-19 1.885E-19 1.885E-19
 ...
 8060    4.216E-20 4.216E-20 4.216E-20 4.216E-20 4.216E-20 4.216E-20
```

The molecular weight of the species is on the first line. Here 153.8235 is the molecular weight of the species, which is CCl_4 (carbon tetrachloride). The file contains cross-section parameters from 786.00 cm^{-1} to 806.00 cm^{-1} in increments of 0.1 cm^{-1}. No frequency between the first and the last value can be omitted; however, a zero value of cross-section for any frequency is a valid entry. The next six entries on a line following the frequency are cross-sections for these six temperatures: 180, 205, 230, 255, 280 and 305 K. The unit for cross-section is molecule/cm^2.

In general, cross-section will be interpolated over available temperatures. It is suggested that extrapolation be avoided above and below available temperature extremes. Instead, the end point values should be used for temperatures beyond the end points.

APPENDIX E: BINARY OUTPUT OPTION

MODTRAN calculations often produce very large formatted ASCII output files, creating a significant load on the CPU and resulting in excessive use of the disk space. A new binary-out option has been added to MODTRAN 5. Activation of this option causes the program to produce binary outputs for the spectral data in tapes 7, 8, plot, fluxes, and spherical albedo files. The speedup from the use of this option can be very significant. In the case of Isaacs multiple scattering option, it is up to 50% faster. In addition, binary files can be easily imported by post processing programs without any lost of precision.

The binary-out option is activated by the placing the flag "t" (one character in the third position of the Card 1 as shown below.

```
mmt  2    3    2   -1    0    0    0    0    0    0    0    0   -1    .000 0.300
tt 4f   1    360.000    1.00000    1.00000 F F F
    2    0    0    0    0    0    0.000    0.000    0.000    0.000    0.000
    20.000    0.000   180.000    .000    .000    .000    0    0.00000
    2    2    0    0
    45.0000   40.0000
    19900.0 20000.0    1.    1.rn
  0
```

A new tool **M5binrestore.exe** (which must be compiled from its source file **M5binrestore.f** and is also included with this distribution) converts existing MODTRAN binary output files to their standard ASCII form.

If the file "mod5root.in" is present, **m5binrestore.exe** uses it to find the binary files for conversion; otherwise the program prompts for user input of the binary file names.

E.1 Naming Convention

MODTRAN appends an additional suffix "b" to the name of the each binary output file. For example, MODTRAN run using an input tape5 named test.tp5 will produce text files test.tp6, test7.tp7, test.7sc, test.tp8, etc. If the binary-out option is on, MODTRAN creates additional binary files: testb.tp7, testb.tp8 and testb.plt. The text file test.tp7 contains headers necessary for restoring other files. Upon executing the binary-to-ASCII conversion is done, the suffix "b" is changed to the suffix "a" (i.e. testa.tp7, testa.tp8, testa.plt are created). Files created by this conversion are identical to the text files that MODTRAN would create if binary option had not been used. Note that tape8 is present only if the extended print is requested. However, binary tape8 is also created if any of the flux output or the spherical albedo output is requested.

E.2 Binary File Structures

While implementing the binary-out option we were constrained by the requirement that the text files restored from the binary counterparts must be exactly the same as the ASCII outputs without binary-out option.

The FORTRAN standard requires that binary read operator be supplied with the length of the record. MODTRAN generates records of various lengths, creating complications for reading binary files. Additional complication arises from the fact that the single tape5 can request several MODTRAN runs that append output to the same file.

When the binary-out option is requested, the tape7 is split into two pieces: the text and the binary counterparts. For each binary run the text part contains only the header, while the actual data are placed in the binary part. As before, a separator between different runs from the same tape5 takes the form of a single text line containing a number -9999. only.

The structure of the binary tape7 depends on the type of the MODTRAN radiance/irradiance/transmittance run (i.e. whether multiple scattering is on, what kind of path is considered, etc.) The restoring program reads the header from the ASCII portion of the tape7 and makes the branching decision based on the information in this header.

The binary tape8 also includes spectral output described elsewhere in this manual. It is created as a single stream of information. There is a unique tag assigned to the each MODTRAN write statement that goes to tape8 (that includes fluxes and spherical albedo/transmittances.) Each record in the binary file consists of this tag followed by the size of the record and by the actual data. Hence it is easy to read and search for specific data. For example, subroutine loop.f has three different write statements to tape8. If the binary option is invoked this three statements have tags 7, 9, and 13. While two writes from the file flxsum.f have tags 1000 and 1001. The actual writing to the binary tape8 is done through several subroutines collected in the binwrite.f file.

E.3 Description of the File Restoring Program

The program searches for the file mod5root.in or MOD5ROOT.IN to locate binary output files. If neither exists, the program prompts user to input the filename. Then the program opens both counterparts, ASCII and binary tape7, for input. If the binary plot file (*.plt) and/or tape8 file exist, the program also operates on them.

APPENDIX F: SPECIAL DISORT OPTION FOR ATMOSPHERIC CORRECTION

MODTRAN can now be used to determine atmospheric correction parameters, which in turn can be used in atmospheric correction models such as FLAASH [See M. W. Matthew, S. M. Adler-Golden, A. Berk, S. C. Richtsmeier, R. Y. Levine, L. S. Bernstein, P. K. Acharya, G. P. Anderson, G. W. Felde, M. P. Hoke, A. Ratkowski, H.-H. Burke, R. D. Kaiser and D. P. Miller, "Status of atmospheric correction using a MODTRAN4-based algorithm," *SPIE Proceeding, Algorithms for Multispectral, Hyperspectral, and Ultraspectral Imagery VI*, Volume 4049 (2000); S. Adler-Golden, M.W. Matthew, L.S. Bernstein, R.Y. Levine, A. Berk, S.C. Richtsmeier, P.K. Acharya, G.P. Anderson, G. Felde, J. Gardner, M. Hoke, L.S. Jeong, B. Pukall, A. Ratkowski and H.-H Burke, "Atmospheric Correction for Short-wave Spectral Imagery Based on MODTRAN4," Proc. of SPIE, Optical Spectroscopy Techniques and Instrumentation for Atmospheric and Space Research**, 3753** (July 1999)].

Atmospheric correction is the process of mapping of down-looking sensor radiance images into surface reflectance maps via the retrieval of atmospheric state. In the solar dominated short-wave region, it is convenient to introduce the dimensionless pixel *apparent* reflectance, ρ, defined as the reflectance that would be retrieved given an observed pixel radiances, *R,* no atmosphere and a flat Lambertian surface:

$$\rho = \frac{\pi R}{\mu I_0} \qquad (1)$$

Here I_0 is the top-of-atmosphere solar irradiance, μ is the cosine of the solar zenith angle and the π steradians results from the angular integration of the Lambertian surface. The observed down-looking apparent reflectance ρ in the absence of adjacency correction equals:

$$\rho = \rho_0 + \frac{TA}{1 - AS} \qquad (2)$$

where ρ_0 is the portion of the solar scattered apparent reflectance coming directly from the atmosphere, *T* is total (diffused plus direct) transmittance for the Sun-Ground-Observer path, *A* is the surface albedo, and *S* is spherical albedo (the portion of the radiation that comes back to the ground as a result of isotropic illumination from the ground).

In 3-albedo method, parameters T, ρ_0, and S are found by solving the algebraic equations that result of three independent MODTRAN calculations with different surface albedo values, typically 0, ½ and 1.

Alternatively, one can calculate the three parameters directly from a single A=0 DISORT calculations by exploiting the reciprocity principle of radiation transport theory [Chandrasekhar, 1950; Stamnes, *et al.*. 1982]. MODTRAN and DISORT been modified to include an implementation of this approach. DISORT already had a routine for computing the total transmittance (and spherical albedo) for the entire atmosphere; the modifications to DISORT allow the total transmittance to be computed for a line-of-sight path initiated at any altitude within the atmosphere. In a single MODTRAN run, parameters *T* and *S* are found from a special call to DISORT (much faster than a radiance calculation) and ρ_0 is determined from a standard DISORT call with ground albedo equal to zero. This new option is triggered by a single switch in the MODTRAN input file.

Figure 3 a-b.
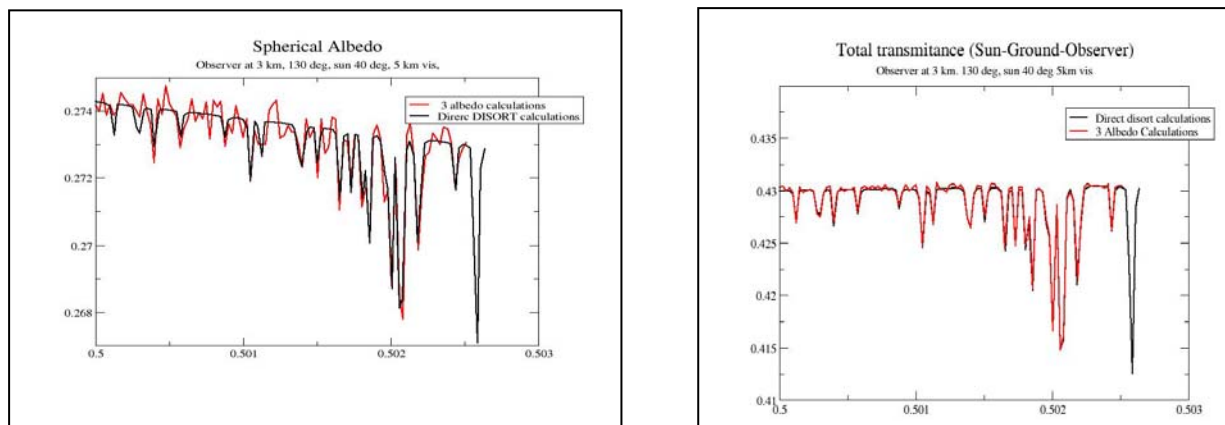
Figure 3a-b illustrate a comparison between the 3-albedo and the A = 0 DISORT approaches for computing spherical albedo and total (direct + diffuse) transmission with 4 streams. These comparisons focus on a short spectral range within the visible near 0.5 μm. Ground meteorological range (visibility) was set very low (5 km) to accentuate the diffuse transmittance contribution. The airborne sensor is modeled as viewing 50º off-nadir from 3 km with a 40º sun. The vertical scales are very much expanded in these figures, so the residuals are small and, most likely, the result of round-off errors arising from the 3-albedo approach.

For these calculations, the A = 0 DISORT method required 3.0 CPU seconds while the 3-albedo calculations required 7.5 CPU seconds, a savings of a factor of 2.5. In order to invoke albedo calculations user has to add the "t" flag in the 1A card in the 3rd position.

Figure 4a-b is for a nadir-viewing sensor at 20 km with a 40º sun.

Figure 4 a-b.
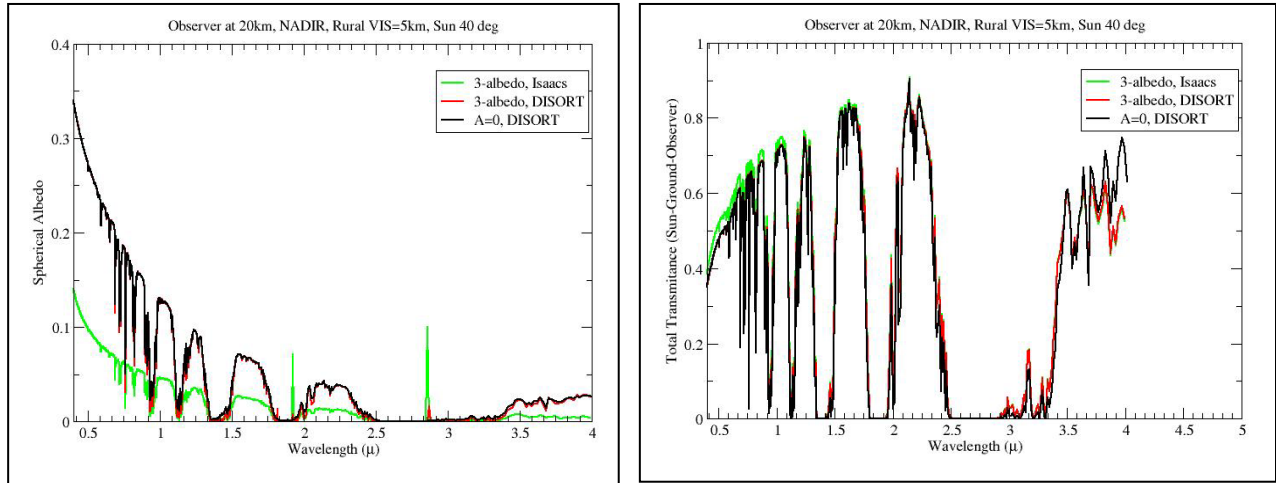
APPENDIX G MODTRAN FREQUENTLY ASKED QUESTIONS (FAQ)

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WHAT IS MODTRAN?

MODTRAN is radiative transfer software designed to predict how light passes through the Earth's atmosphere. The fundamental radiative transfer equation is solved using a "narrow band model" approach. The atmosphere is modeled as stratified (horizontally homogeneous), and its constituent vertical profiles, both molecular and particulate, may be defined either using built-in models or by user-specified vertical profiles. Spectral coverage extends from the UV through the far-infrared ($0 - 50,000$ cm^{-1}), providing resolution as fine a 0.2 cm^{-1}. MODTRAN solves the radiative transfer equation including the effects of molecular and particulate absorption/emission and scattering, surface reflections and emission, solar/lunar illumination, and spherical refraction. Outputs include narrow spectral band direct and diffuse transmittances, path component and total radiances, transmitted and top-of-atmosphere solar/lunar irradiances, horizontal fluxes, cooling rates, and more. With over a 30 year heritage, MODTRAN has been extensively validated, and it serves as the community standard atmospheric band model radiative transfer algorithm. See the users' manual for more information [Berk *et al*., 2011].

1.1 Who developed MODTRAN?

LOWTRAN was a low spectral resolution (20 cm^{-1}) band model radiative transfer algorithm developed by the Air Force Geophysics Laboratories, now the Air Force Research Laboratories (AFRL). Spectral Sciences, Inc. (SSI) integrated a 1.0 cm^{-1} band model into LOWTRAN as part of an Air Force sponsored effort, creating MODTRAN in the late 1980's. SSI has continued development of MODTRAN over the past 2+ decades with support and validation from AFRL. MODTRAN5.3 was released in May of 2013.

1.2 How do I get a copy of MODTRAN5?

To purchase MODTRAN5, go to www.modtran5.com, click the "Order MODTRAN5 Now" button and select your options from the price list, then email orders@spectral.com.

1.3 How much does MODTRAN5 cost?

The baseline price of MODTRAN5 for all commercial and non US government agencies with 1 year maintenance is $1,200.00. Reduced prices are offered to educational institutions and to U.S. government agencies and their contractors. Long-term maintenance agreements are also available. For a full listing of prices, please go to http://modtran5.com/purchase/index.html.

1.4 How accurate is MODTRAN5?

The accuracy of MODTRAN depends on the scenario of one's calculation and the output quantities. A good rule of thumb is that transmittances are absolute accuracy is generally better than ±0.005, thermal brightness temperature are generally accurate to better to 1K, and radiances accuracy is approximately ±2%.

1.5 What reference(s) should be used for MODTRAN5?

The "MODTRAN5: 2006 Update" SPIE paper [Berk *et al*., 2006] and U.S. Patents [Berk *et al*., 2008; Anderson *et al*., 2009] are the best general references for MODTRAN5. A reference is also provided for the MODTRAN5.2 user's manual [Berk *et al*., 2011].

1.6 What is the MODTRAN version number convention?

Currently (June, 2011), the public release version of MODTRAN is MODTRAN5.2.1. The leading number is only incremented when a major change to the model is developed. For example, MODTRAN4 introduced a statistical correlated-*k* algorithm into MODTRAN, and MODTRAN5 increased the spectral resolution of the software with a 0.1 cm^{-1} band model. The second number is incremented when new features are added to the model. When MODTRAN5.3 is released, it will include an upgraded aerosol capability, an improved interface to the DISORT scattering algorithm, and an ocean bidirectional reflection distribution function (BRDF). The last number is incremented when a new release is made available, with corrections and minor code changes.

2.   Installation and Trouble Shooting

2.1   How do I install the MODTRAN5 software package?

Installation instructions are included in both the MODTRAN5 README file and the Users' manual.   These instructions are duplicated here for your convenience.

MODTRAN(R)5.2.1 is delivered as a single DVD. The DVD contains a PC distribution containing both 32-bit and 64-bit machine installation files, a Mac distribution installation file, and a Linux distribution as a gzipped tar file.

Installation instructions for the PC, Mac and Linux systems are provided below.   For additional installation or technical questions, please email either Spectral Sciences, Inc. (SSI) at <u>modtran@spectral.com</u> or AFRL at Jeannette.VanDenBosch@kirtland.af.mil.

2.1.1   *MODTRAN5.2.1 PC Installation Steps*

The PC version of MODTRAN is delivered ready to run. Enter the Mod5.3.2 sub-directory appropriate for your machine [pc_32bit/ or pc_64bit/ and double click the installation file modtran5.3.2.msi or modtran5.3.2(x64).msi, respectively]. Icons will be set-up for MODTRAN executables, Mod5.3.2qwin.exe or Mod5.3.2cons.exe. The only difference between these is that the QuickWin executable retains the standard output window upon completion of the MODTRAN run(s), while the Console executable closes the window. This will run all the test cases. On most modern PC's, all the test cases should run in ~30 minutes. The newly generated output (located in the TEST/ directory) can be compared to the files in TEST/COMPARE/ sub-directory.

2.1.2   *MODTRAN5.2.1 MAC Installation Steps*

This Mac version of MODTRAN delivers executables and binary data files for Mac systems based on the i386 architecture. The executables were built with gfortran and use dynamic gfortran libraries that are also provided here. The terms of the gfortran license can be found in the file Licenses.txt that comes with this media.

If you are unsure of what Mac hardware you have, type

uname -m

on the command line. We do not support PPC-based Macs at this point.

You can build MODTRAN yourself on such systems by following the instructions for Linux installation.

To install,

1.   Copy the disk image (.dmg) file to your desktop, and then double-click. This will mount the Volume called Mod5.3.2.

2.   Open a console. Navigate to the directory where you want Mod5.3.2 installed. Then uncompress and unpack MODTRAN. The following commands show how this is done (Note: In the following lines, "$" denotes the command prompt, and "<>" is used to indicate user-defined input):

    $ cd <some directory>

    $ tar xvzf /Volumes/Mod5.3.2/Mod.5.3.2.tgz

    The second command will unpack everything to a directory "Mod5.3.2/"

3.   Change directory to Mod5.3.2/. All the appropriate executables and data files are contained there. On most current systems, all the test cases should run in ~30 minutes. The newly generated output (located in the TEST/ directory) can be compared to the files in COMPARE/ sub-directory.

2.1.3   *MODTRAN5.2.1 Linux (UNIX) Installation Steps*

With the introduction of MODTRAN5.3, a new Linux installation approach based on Autotools has been implemented. The users must have Autotools on their Linux system. The Linux distribution comes as a single gzip'ped tar file. To install MODTRAN5.3, follow these steps:

(1) *Place Mod5.3.2.0.tar.z in your desired directory*:

cp Mod5.3.2.0.tar.z /home/my_name/Mod53/

(2) *Extract the gzip'ped tar file*: (~14 minutes)

tar xvzf Mod5.3.1.2.tar.z

(3) *Edit the* configure.in *file to define your favorite FORTRAN executable. In the middle of the* configure.in *file, you should find the following line*

AC_PROG_FG([ifort pgf90 g77 gfortran])

*This line dictates that the Intel FORTRAN compiler **ifort** should be used if found. If **ifort** is not found, the Portland-Group FORTRAN90 compile **pgf90** should be used if found. If **ifort** is not found, the GNU77 compiler **g77** should be used if found. If **g77** is not found, the GNU FORTRAN compiles **gfortran** should be used. If you do not like this hierarchy or you wish to use another compiler, edit this line appropriately.*

(4) *Run bootstrap*:

./bootstrap

(5) *Run configure*:

./configure

(6) *Run makefiles*: (~2 minutes)

make

(7) *Install executables*:

make install prefix=$HOME

(8) *Create the full set of binary databases*: (~30 minutes)

make databases

(9) *Run the full set of 83 test cases*: (~30 minutes)

mod53

The test cases output files that you just generated will be located in subdirectory TEST/ and these output files can be compared to the delivered output files in TEST/COMPARE/.

2.2   *Who do I contact if I have problems with the software?*

For installation or technical questions, please email either Spectral Sciences, Inc. (SSI) at modtran@spectral.com or AFRL at Gail.Anderson@hanscom.af.mil. If your maintenance contract is up-to-date, you will generally receive an email response within one business day.

2.3   *Are there 64-bit distributions of MODTRAN5?*

The MODTRAN distribution supports PC, Mac and Linux platforms. For the PC, both 32-bit and 64-bit executables are provided. With the Linux distribution, the installers must provide their own FORTRAN compiler. The source code has been tested with multiple compilers (e.g. ifort, g77, gfortran, pgf77, pgf90), and it has been shown to be compatible with both 32-bit and 64-bit machines.

2.4   *What is the difference between the Mod5.2.1cons.exe and Mod5.2.1qwin.exe executables on my pc?*

When MODTRAN is run, warning and error messages are written to standard output (this information is also stored in a *<rootname>*.wrn file). The difference between the Mod5.2.1cons.exe and Mod5.2.1qwin.exe executables is that the standard output window is automatically closed when a Mod5.2.1cons.exe run is finished and it is left open when a Mod5.2.1qwin.exe run is finished. If one is running a single MODTRAN run, using the Mod5.2.1qwin.exe executable is preferable because warning and error messages are easily reviewed. With production runs, generating large numbers of open windows is problematic; in this case, it is preferable to run the Mod5.2.1cons.exe executable.

3. <u>Input</u>

3.1 General

3.1.1 *How does one set up an input file or which test case should I use as a template?*

MODTRAN is delivered with ~60 test cases. The input files are located in sub-directory TEST/. The best way to set up an input is to use one of these as your template. It can be difficult to determine which test case to use. It is probably best to classify the type of case you wish to run and peruse the test cases to find a match. For example, suppose you wanted to input temperature, H_2O and O_3 profile data but use default profiles for all other species. With a quick look at the test case *<rootname>*.tp7 files, one can see that only the test cases AuxilSpecies, AuxSpecRad, AuxSpecTrn, CD2c3_USS, CF4_CCL4, CorrelatedK, Denver, HClRadiance, HClTransm, HIS104b1, HIS104b2, HIS104t1, Lambertian, SO2_CF4_CCL4 and TraceSpecies use a user-defined atmosphere (CARD 1 input MODEL = 7). Of these, only the CorrelatedK, Denver, HIS104b1, HIS104b2, HIS104t1, and Lambertian test cases use default profiles for all species other than H_2O, CO_2 and O_3 (CARD 2C inputs IRD1 and IRD2 both equal to 0). The Denver test case computes transmittance only (CARD 1 input IEMSCT = 0), the CorrelatedK, HIS104b1, HIS104b2 and HIS104t1 test cases compute thermal radiance (IEMSCT = 1), and the Lambertian test case computes thermal plus solar radiance (IEMSCT = 2). Based on this type of information, the user can choose an appropriate test case for his or her application.

3.1.2 *Why does MODTRAN use a Fn.0 format (e.g. F10.0) to read in floating point inputs?*

In FORTRAN, a format of the form *'Fn.m'* ($n > m$) is used to write a floating point number with *m* digits after the decimal. However, the value of *m* does not affect how a floating point number is read in. For example, the floating point number –1.2345 is correctly read in with an *'F7.0'* format. The advantage of setting *m* to 0 in a FORTRAN READ statement is that a floating point input that is specified using an integer is properly interpreted. Consider the frequency inputs V1 and V2 on CARD 4. Both of these inputs are read in with an *'F10.0'* format. If one selects the 0.1 cm^{-1} band model and sets V1 to 200.3 (cm^{-1}) and V2 to 210 (cm^{-1}), both the floating point number 200.3 and the integer 210 will be interpreted correctly. That is not be the case if an *'F10.1'* format is used; the integer would be misread.

3.2 Atmosphere: Altitude, Pressure, Temperature and Molecular Profiles

3.2.1 *How does one convert radiosonde data into MODTRAN5 vertical profiles?*

The MODTRAN5.2 distribution sets the maximum number of atmospheric level (Parameter LAYDIM in /src/PARAMS.h) to 126. Radiosonde data often defines hundreds of atmospheric levels. One must either increase parameter LAYDIM and recompile MODTRAN or down sample the radiosonde data to incorporate them into MODTRAN run. Down sampling is the preferred approach because the raw radiosonde data often includes undesired statistical noise. The radiosonde data can be plotted to determine which altitude levels should be retained. Alternatively, Spectral Sciences, Inc. has a tool which reads in the radiosonde data and automatically generates reasonable MODTRAN outputs; this tool is available upon request via the modtran@spectral.com email.

3.2.2 *How do the model atmospheres differ?*

The 6 model atmospheres in MODTRAN differ most significantly in their temperature, H_2O and O_3 profiles. The temperature profiles are illustrated in Figure 3.2A. Not surprisingly, the Sub-Arctic Winter Atmosphere has the coolest surface temperature; the Mid-Latitude Winter Atmosphere has the next coolest surface temperature. The Tropical and Mid-Latitude Summer Atmospheres have the warmest surface temperatures. At the tropopause, the temperature of the Tropical Atmosphere is the coolest and the temperature of the Sub-Arctic Summer Atmosphere is the warmest. For all 6 atmospheres, a secondary temperature peak occurs near 50 km; here the Sub-Arctic Summer temperature is the warmest, essentially equal to that of the Mid-Latitude
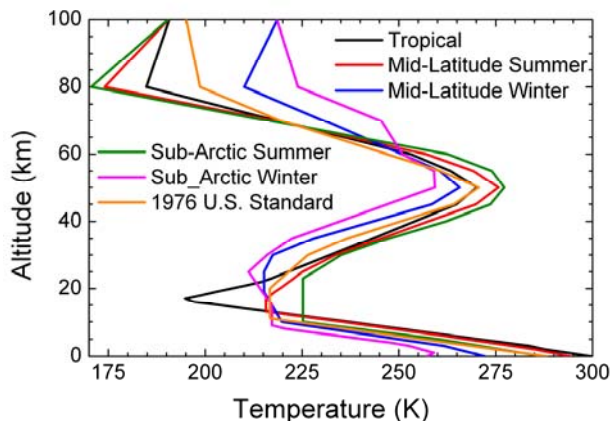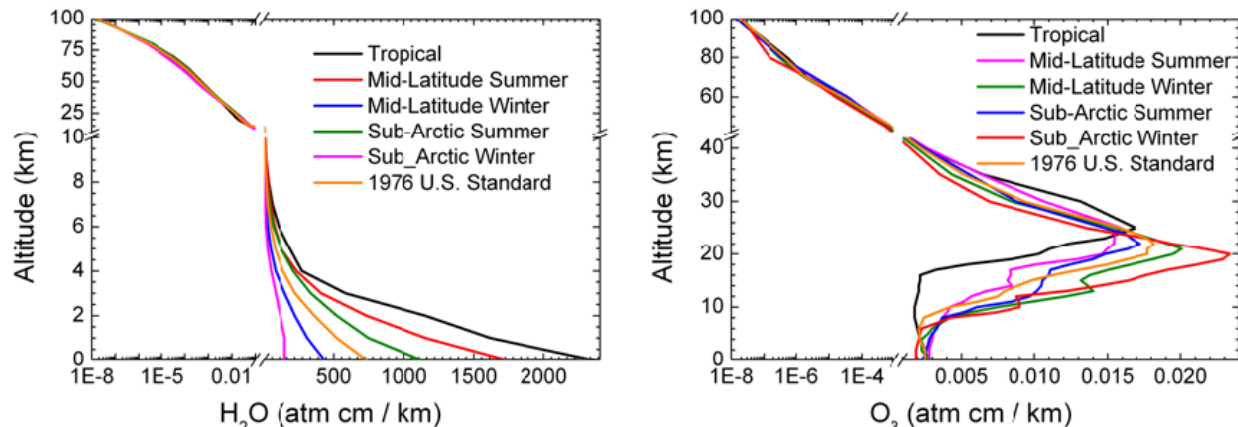

Figure 3.2A. Temperature Profiles of the MODTRAN Model Atmospheres.

Summer. The Sub-Arctic Winter temperature is the coolest at this altitude. The 1976 U.S. Standard Atmosphere temperature profile provides an effective median for the set of profiles.

Figure 3.2B. MODTRAN Model Atmosphere Profiles for H_2O and O_3. Note there is a break in the altitude vertical scales, at 10 km for H_2O and 42 km for O_3.

Figure 3.2B contains the density profiles for H_2O and O_3. Total vertical column amounts for the 12 ambient band model species are listed in Table 3.2; the CO_2 mixing ratio used in creating this table was 380 ppmV. It is interesting to note that the 6 atmospheres provide a nice spread of boundary layer and lower tropospheric water densities.

Table 3.2. MODTRAN Model Atmosphere Vertical Column Amounts in atm-cm. For CO_2, the mixing ratio was set to 380 ppmV.

Mol\Atm	Tropical	Mid Lat Summer	Mid Lat Winter	Sub Arc Summer	Sub Arc Winter	US Standard
H_2O	5119.4	3635.9	1059.7	2589.4	517.73	1762.3
O_3	0.27727	0.33176	0.37681	0.34492	0.37550	0.34356
CO_2	305.87	305.13	305.99	303.47	304.21	304.48
CO	0.087663	0.087740	0.090032	0.088048	0.090924	0.088742
CH_4	1.3243	1.2684	1.2806	1.2556	1.2719	1.3203
N_2O	0.24649	0.23743	0.24037	0.21920	0.23993	0.24593
O_2	168230	167820	168290	166910	167320	167460
NH_3	0.00016986	0.00017121	0.00018032	0.00017393	0.00018409	0.00017517
NO	0.00031691	0.00032271	0.00030953	0.00032243	0.00030233	0.00031390
NO_2	0.00021091	0.00021814	0.00019842	0.00021543	0.00018654	0.00020418
SO_2	0.00010799	0.00010838	0.00011245	0.00010928	0.00011391	0.00010997
HNO_3	0.00037983	0.00038298	0.00035617	0.00037403	0.00033808	0.00036287

3.2.3 *What chemical species are included in MODTRAN5?*

The MODTRAN standard atmospheres include 12 band model molecules (H_2O, O_3, CO_2, CO, CH_4, N_2O, O_2, NH_3, NO, NO_2, SO_2, HNO_3) and 13 cross-section species (CFC11, CFC12, CFC13, CFC14, CFC22, CFC113, CFC114, CFC115, $ClONO_2$, HNO_4, $CHCL_2F$, CCl_4 and N_2O_5). An additional 16 molecules (OH, HF, HCl, HBr, HI, ClO, OCS, H_2CO, HOCl, N_2, HCN, CH_3Cl, H_2O_2, C_2H_2, C_2H_6, PH_3) are included by setting CARD 1 input LYMOLC to '+'.

3.2.4 *How can the MODTRAN default altitude or pressure grids most easily be modified?*

When a model atmosphere is selected (CARD 1 input MODEL set to 1 for Tropical, 2 for Mid-Latitude Summer, 3 for Mid-Latitude Winter, 4 for Sub-Arctic Summer, 5 for Sub-Arctic Winter or 6 for U.S. Standard), MODTRAN uses 1 km gridding up to 25 km altitude, 5 km gridding between 25 and 60 km, and additional altitude levels at 70, 80 and 100km for a total of 36 altitude levels or 35 atmospheric layers. The model atmosphere data is actually stored internally (routine src/mlatmb.f) up to 120 km and with a somewhat finer vertical spacing (1 km gridding to 25 km, 2.5 km gridding between 25 and 50 km, and 5 km gridding between 50 and 120 km).

The MODTRAN atmospheric layering can be tailored while still using model atmosphere data. For example, to model the atmosphere with Mid-Latitude Summer data but including finer layering near the ground (altitude levels at 0.1, 0.3 and 0.6 km), set CARD 1 input MODEL to 7, CARD 1 inputs M1 through M6 each to 2 (for Mid-Latitude Summer), and CARD 1 inputs MDEF and I_RD2C both to 1:

```
Spacing:    123456789 123456789 123456789 123456789 123456789 123456789 123456789 123456789
CARD 1:     CMF 7    2    2   -1    2    2    2    2    2    2    1    1    0   0.000  0.100
```

The number of levels, 39 (36 + 3), is set on CARD 2C and each CARD 2C1 only requires an altitude level:

```
CARD 2C:      39    0    0 Added Alt Levels
CARD 2C1:      0.000
CARD 2C1:      0.100
CARD 2C1:      0.300
CARD 2C1:      0.600
CARD 2C1:      1.000
CARD 2C1:      2.000
CARD 2C1:      3.000
CARD 2C1:      4.000
CARD 2C1:      5.000
CARD 2C1:      6.000
CARD 2C1:      7.000
CARD 2C1:      8.000
CARD 2C1:      9.000
CARD 2C1:     10.000
CARD 2C1:     11.000
CARD 2C1:     12.000
CARD 2C1:     13.000
CARD 2C1:     14.000
CARD 2C1:     15.000
CARD 2C1:     16.000
CARD 2C1:     17.000
CARD 2C1:     18.000
CARD 2C1:     19.000
CARD 2C1:     20.000
CARD 2C1:     21.000
CARD 2C1:     22.000
CARD 2C1:     23.000
CARD 2C1:     24.000
CARD 2C1:     25.000
CARD 2C1:     30.000
CARD 2C1:     35.000
CARD 2C1:     40.000
CARD 2C1:     45.000
CARD 2C1:     50.000
CARD 2C1:     55.000
CARD 2C1:     60.000
CARD 2C1:     70.000
CARD 2C1:     80.000
CARD 2C1:    100.000
```

One can also define the atmospheric layering by entering a pressure grid and ground altitude. With CARD 1 input MODEL set to 8, MODTRAN solves the hydrostatic equation to determine the above ground altitude levels. The ground altitude is set via CARD 2 input GNDALT. With a ground altitude of 0.22 km and 50 mbar spacing from 1,013.25 to 13.25 mbar, the inputs are as follows:

```
Spacing:    123456789 123456789 123456789 123456789 123456789 123456789 123456789 123456789
CARD 1:     CMF 8    2    2   -1    2    2    2    2    2    2    1    1    0   0.000  0.100
…
CARD 2        1    0    0    0    0    0  0.00000   0.00000   0.00000   0.00000   0.22000
CARD 2C:     21    0    0 Added Alt Levels
CARD 2C1:         1013.25000
CARD 2C1:          963.25000
CARD 2C1:          913.25000
CARD 2C1:          863.25000
CARD 2C1:          813.25000
CARD 2C1:          763.25000
CARD 2C1:          713.25000
CARD 2C1:          663.25000
CARD 2C1:          613.25000
CARD 2C1:          563.25000
CARD 2C1:          513.25000
CARD 2C1:          463.25000
CARD 2C1:          413.25000
CARD 2C1:          363.25000
CARD 2C1:          313.25000
CARD 2C1:          263.25000
CARD 2C1:          213.25000
CARD 2C1:          163.25000
CARD 2C1:          113.25000
CARD 2C1:           63.25000
CARD 2C1:           13.25000
```

3.2.5 *Is there an easy way to offset MODTRAN5 profile temperatures?*

MODTRAN5 has an option to set JCHAR(2) on CARD 2C1 to ′C′. When this option is used, the CARD 2C1 temperature input, T, is interpreted as a temperature perturbation. For example, one can DECREASE the temperature of the mid-latitude summer profile by 3K at each altitude, while making no other change to the atmospheric profiles. After setting MODEL to ′7′ on CARD 1, M1 through M6 each to 2 (for Mid-Latitude Summer), and CARD 1 inputs MDEF and I_RD2C both to 1, CARDs 2C and 2C1 should be defined as follows:

```
Spacing:    123456789 123456789 123456789 123456789 123456789 123456789 123456789 1234567
CARD 2C:       36    0     0 -3K_T_offset
CARD 2C1:        0.000                    -3.000                                        C
CARD 2C1:        1.000                    -3.000                                        C
CARD 2C1:        2.000                    -3.000                                        C
CARD 2C1:        3.000                    -3.000                                        C
CARD 2C1:        4.000                    -3.000                                        C
CARD 2C1:        5.000                    -3.000                                        C
CARD 2C1:        6.000                    -3.000                                        C
CARD 2C1:        7.000                    -3.000                                        C
CARD 2C1:        8.000                    -3.000                                        C
CARD 2C1:        9.000                    -3.000                                        C
CARD 2C1:       10.000                    -3.000                                        C
CARD 2C1:       11.000                    -3.000                                        C
CARD 2C1:       12.000                    -3.000                                        C
CARD 2C1:       13.000                    -3.000                                        C
CARD 2C1:       14.000                    -3.000                                        C
CARD 2C1:       15.000                    -3.000                                        C
CARD 2C1:       16.000                    -3.000                                        C
CARD 2C1:       17.000                    -3.000                                        C
CARD 2C1:       18.000                    -3.000                                        C
CARD 2C1:       19.000                    -3.000                                        C
CARD 2C1:       20.000                    -3.000                                        C
CARD 2C1:       21.000                    -3.000                                        C
CARD 2C1:       22.000                    -3.000                                        C
CARD 2C1:       23.000                    -3.000                                        C
CARD 2C1:       24.000                    -3.000                                        C
CARD 2C1:       25.000                    -3.000                                        C
CARD 2C1:       30.000                    -3.000                                        C
CARD 2C1:       35.000                    -3.000                                        C
CARD 2C1:       40.000                    -3.000                                        C
CARD 2C1:       45.000                    -3.000                                        C
CARD 2C1:       50.000                    -3.000                                        C
CARD 2C1:       55.000                    -3.000                                        C
CARD 2C1:       60.000                    -3.000                                        C
CARD 2C1:       70.000                    -3.000                                        C
CARD 2C1:       80.000                    -3.000                                        C
CARD 2C1:      100.000                    -3.000                                        C
```

3.3 Aerosols and Clouds

3.3.1 *How does one input aerosol extinction profiles into MODTRAN5?*

Only one MODTRAN5.2 test case reads in user-defined aerosol profiles, namely CD2c3_USS. This same test case reads in aerosol optical data. To read in aerosol extinction profile data, a user-defined atmosphere must be entered by setting CARD 1 input MODEL to ′7′ (altitude-dependent profiles) or to ′8′ (pressure-dependent profiles) and by setting CARD 1 input I_RD2C to 1. The CARD 1 input of test case CD2c3_USS is

```
Spacing:    123456789 123456789 123456789 123456789 123456789 123456789 123456789 123456789
CARD 1:     M 7    3    0    0    2    2    2    2    2    2    1    1   -1            .0500
```

Note that CARD 1 inputs M1 through M6 are all set to ′2′ and input MDEF is set to ′1′ indicating that the mid-latitude summer molecular profiles are the defaults.

APPENDIX G

On CARD 2 of the CD2c3_USS test case, IHAZE is set to 1 (Rural extinction with 23 km visibility):

```
Spacing:    123456789 123456789 123456789 123456789 123456789 123456789 123456789 123456789
CARD 2:        1    1USS 0    0    0    0    0.000    0.000    0.000    0.000
```

Since the aerosol profile and optical data is being over-written it does not really matter which aerosol model is selected as long as IHAZE is not set to ′-1′ or ′0′. Either of these values would force no aerosol attenuation. CARD 2 also sets input string ARUSS to ′USS′, which initiates reading of user-defined aerosol optical properties.

To indicate that a user-defined atmosphere is to include the reading in of aerosol profile data, CARD 2C input IRD2 must be set to either ′1′ (original aerosol profile inputs) or ′2′ (updated aerosol profile inputs). The preferred option, which is used in test case CD2c3_USS, is to set IRD2 to ′2′:

```
Spacing:    123456789 123456789 123456789 123456789 123456789 123456789 123456789 123456789
CARD 2C:        36    0    2 aer_profs
```

This particular CARD 2C also sets the number of atmospheric levels (input ML) to 36 and sets input IRD1 to 0 indicating that profiles for the ambient band model species (other than H_2O, CO_2 and O_3) are not to be read in.

The aerosol profile data is listed on CARD 2C3. The ML = 36 couplets of CARD 2C1 and CARD 2C3 inputs for test case CD2c3_USS follow:

```
Spacing:    123456789 123456789 123456789 123456789 123456789 123456789 123456789 123456789
CARD 2C1:      0.000
CARD 2C3:            4.309E-02                    2.731E-02 0.000E+00 0.000E+00
CARD 2C1:      1.000
CARD 2C3:            3.794E-02                    2.316E-02 0.000E+00 0.000E+00
CARD 2C1:      2.000
CARD 2C3:            3.341E-02                    1.901E-02 0.000E+00 0.000E+00
CARD 2C1:      3.000
CARD 2C3:            2.942E-02                    1.108E-02 0.000E+00 0.000E+00
CARD 2C1:      4.000
CARD 2C3:            2.590E-02                    7.235E-03 0.000E+00 0.000E+00
CARD 2C1:      5.000
CARD 2C3:            2.280E-02                    6.187E-03 0.000E+00 0.000E+00
CARD 2C1:      6.000
CARD 2C3:            2.007E-02                    5.197E-03 0.000E+00 0.000E+00
CARD 2C1:      7.000
CARD 2C3:            1.767E-02                    3.260E-03 0.000E+00 0.000E+00
CARD 2C1:      8.000
CARD 2C3:            1.386E-02                    1.970E-03 0.000E+00 0.000E+00
CARD 2C1:      9.000
CARD 2C3:            9.238E-03                    1.256E-03 0.000E+00 0.000E+00
CARD 2C1:     10.000
CARD 2C3:            4.619E-03                    7.631E-04 0.000E+00 0.000E+00
CARD 2C1:     11.000
CARD 2C3:            0.000E+00                    0.000E+00 7.990E-04 0.000E+00
CARD 2C1:     12.000
CARD 2C3:            0.000E+00                    0.000E+00 6.410E-04 0.000E+00
CARD 2C1:     13.000
CARD 2C3:            0.000E+00                    0.000E+00 5.170E-04 0.000E+00
CARD 2C1:     14.000
CARD 2C3:            0.000E+00                    0.000E+00 4.420E-04 0.000E+00
CARD 2C1:     15.000
CARD 2C3:            0.000E+00                    0.000E+00 3.950E-04 0.000E+00
CARD 2C1:     16.000
CARD 2C3:            0.000E+00                    0.000E+00 3.820E-04 0.000E+00
CARD 2C1:     17.000
CARD 2C3:            0.000E+00                    0.000E+00 4.250E-04 0.000E+00
CARD 2C1:     18.000
CARD 2C3:            0.000E+00                    0.000E+00 5.200E-04 0.000E+00
CARD 2C1:     19.000
CARD 2C3:            0.000E+00                    0.000E+00 5.810E-04 0.000E+00
CARD 2C1:     20.000
CARD 2C3:            0.000E+00                    0.000E+00 5.890E-04 0.000E+00
```

```
CARD 2C1:        21.000
CARD 2C3:              0.000E+00                    0.000E+00 5.020E-04 0.000E+00
CARD 2C1:        22.000
CARD 2C3:              0.000E+00                    0.000E+00 4.200E-04 0.000E+00
CARD 2C1:        23.000
CARD 2C3:              0.000E+00                    0.000E+00 3.000E-04 0.000E+00
CARD 2C1:        24.000
CARD 2C3:              0.000E+00                    0.000E+00 1.980E-04 0.000E+00
CARD 2C1:        25.000
CARD 2C3:              0.000E+00                    0.000E+00 1.310E-04 0.000E+00
CARD 2C1:        26.000
CARD 2C3:              0.000E+00                    0.000E+00 3.320E-05 0.000E+00
CARD 2C1:        27.000
CARD 2C3:              0.000E+00                    0.000E+00 0.000E+00 4.300E-06
CARD 2C1:        28.000
CARD 2C3:              0.000E+00                    0.000E+00 0.000E+00 1.670E-06
CARD 2C1:        29.000
CARD 2C3:              0.000E+00                    0.000E+00 0.000E+00 8.000E-07
CARD 2C1:        30.000
CARD 2C3:              0.000E+00                    0.000E+00 0.000E+00 4.200E-07
CARD 2C1:        35.000
CARD 2C3:              0.000E+00                    0.000E+00 0.000E+00 2.207E-07
CARD 2C1:        40.000
CARD 2C3:              0.000E+00                    0.000E+00 0.000E+00 1.159E-07
CARD 2C1:        50.000
CARD 2C3:              0.000E+00                    0.000E+00 0.000E+00 3.200E-08
CARD 2C1:        70.000
CARD 2C3:              0.000E+00                    0.000E+00 0.000E+00 5.795E-09
CARD 2C1:       100.000
CARD 2C3:              0.000E+00                    0.000E+00 0.000E+00 1.900E-10
```

The only input listed on the CARD 2C1 lines is the altitude in km. Since the JCHAR CARD 2C1 inputs are all blank, CARD 1 inputs M1 through M6 and MDEF define the pressure, temperature and molecular profiles. For test case CD2c3_USS, these CARD 1 inputs are set to default to the mid-latitude summer profiles, as noted above. With CARD 2C input IRD2 set to 2, the CARD 2C3 inputs are AHAZE(1), RRATZ, AHAZE(2), AHAZE(3), AHAZE(4) and are read in using a ′(10X, F10.0, 10X, 4F10.0)′ FORTRAN format. The rain rate input RRATZ is blank (zero), but 4 aerosol profiles are listed. The profile data is in units of km^{-1} at 550 nm.

The remainder of the CD2c3_USS.tp5 file contains the aerosol optical data (CARDs 2D, 2D1 and 2D2), the path geometry definition (CARD 3), the spectral range inputs (CARD 4), and the termination input (CARD 5).

3.3.2 *Does MODTRAN have an aerosol Angstrom exponent input option?*

MODTRAN5.2 does include the capability to model the boundary layer (nominally, 0-3 km) and tropospheric (nominally, 2-11km) aerosol extinction coefficients using the Angstrom law parameterization or to modify the baseline extinction of a model aerosol with an Angstrom law perturbation. The use of Angstrom Law parameters is turned on by setting CARD 1A input ASTMX to a non-zero value. There are 3 options depending upon the value of case-insensitive CARD 1A character*1 input CDASTM

$CDASTM$ = t, T, d or D   Perturb both the boundary layer and tropospheric aerosol reference spectral extinction data.

= b or B   Perturb the boundary layer aerosol reference spectral extinction.

= otherwise   If Angstrom Law input ASTMX is non-zero, use Angstrom Law description for the boundary layer and tropospheric aerosol spectral extinction coefficients.

In general, MODTRAN normalizes all its aerosol spectral extinction coefficients to one at 550 nm, and the extinction at 550 nm is entered as a separate parameter. For the boundary layer aerosol, the visibility (CARD 2 input VIS) sets the 550 nm extinction at the ground.

If one of the two perturbation options is selected, then the 550 nm normalized, model aerosol extinction data, Ext_{ref} (λ), is modified according to the equation

$$Ext(\lambda) = Ext_{ref}(\lambda)\left(\frac{0.55\mu m}{\lambda}\right)^{ASTMX} \quad .$$

Two additional CARD 1A inputs, ASTMC and ASTMO, are used if the Angstrom Law description is used directly; however, there is only one independent variable since these two parameters are required to sum to one (If they sum to a positive number other than one, MODTRAN renormalizes them; if they do not have a positive sum, then the Angstrom Law option is turned off completely and warning messages are generated). The 550 nm normalized extinction for the boundary layer and tropospheric aerosols are defined as follows:

$$Ext(\lambda) = \frac{ASTMO + ASTMC\left(\frac{0.55\mu m}{\lambda}\right)^{ASTMX}}{ASTMO + ASTMC} \quad .$$

The model aerosol spectral single scattering albedo curves, $\omega(\lambda)$, are assumed to be unchanged. Thus, the scattering, $Sct(\lambda)$, and absorption, $Abs(\lambda)$, coefficient curves are modified accordingly:

$$\omega(\lambda) = \frac{Ext_{ref}(\lambda) - Abs_{ref}(\lambda)}{Ext_{ref}(\lambda)}$$

$$Sct(\lambda) = \omega(\lambda)\, Ext(\lambda) \quad and \quad Abs(\lambda) = Ext(\lambda) - Sct(\lambda)$$

3.3.3 *Can aerosol and/or clouds be defined with sharp boundaries?*

MODTRAN has four aerosol regions, nominally defined with the following vertical profiles (The notation (*a*, *b*] implies altitude *z* exceeds altitude *a* and is less than or equal to altitude *b*.):

1. Boundary Layer Aerosol: [0, 2] km
2. Tropospheric Aerosol: (2, 10] km
3. Stratospheric Aerosol: (10, 30] km
4. Meteoric Dust / Volcanic Aerosols: (30, 120] km

With MODTRAN model atmospheres, the aerosol extinction profiles have the general structure illustrated in Table 3.3. Between 2 and 3 km altitude, the boundary layer aerosol extinction decreases linearly with altitude to zero and the tropospheric aerosol extinction increases linearly from zero. A similar transition occurs from 10 to 11 km for the tropospheric and stratospheric aerosols. The transition region for the stratospheric and meteoric dust / volcanic aerosols is even larger, extending from 30 to 35 km. These profiles, including the transition regions, are illustrated on the left in Figure 3.3A.

Naturally occurring atmospheric aerosols can have sharper vertical boundaries than those illustrated in Figure 3.3A. For MODTRAN built-in aerosols, sharp boundaries can be defined by inserting altitude levels just above the bottom of the tropospheric, stratospheric and meteoric dust / volcanic aerosol layers, e.g. 2.001, 10.001 and 30.001 km. The resulting aerosol profiles are illustrated on the right in

Z(KM)	AEROSOL 1	AEROSOL 2	AEROSOL 3	AEROSOL 4
0.	6.670E-02	0.000E+00	0.000E+00	0.000E+00
1.	4.150E-02	0.000E+00	0.000E+00	0.000E+00
2.	2.600E-02	0.000E+00	0.000E+00	0.000E+00
3.	0.000E+00	1.460E-02	0.000E+00	0.000E+00
4.	0.000E+00	1.020E-02	0.000E+00	0.000E+00
…	0.000E+00	…	0.000E+00	0.000E+00
9.	0.000E+00	1.820E-03	0.000E+00	0.000E+00
10.	0.000E+00	1.140E-03	0.000E+00	0.000E+00
11.	0.000E+00	0.000E+00	7.990E-04	0.000E+00
12.	0.000E+00	0.000E+00	6.410E-04	0.000E+00
…	0.000E+00	0.000E+00	…	0.000E+00
25.	0.000E+00	0.000E+00	1.310E-04	0.000E+00
30.	0.000E+00	0.000E+00	3.320E-05	0.000E+00
35.	0.000E+00	0.000E+00	0.000E+00	4.300E-06
40.	0.000E+00	0.000E+00	0.000E+00	1.670E-06
…	0.000E+00	0.000E+00	0.000E+00	…

Table 3.3. MODTRAN Aerosol Extinction (km^{-1} at 550 nm) Profile Transition Regions. Profiles were defined with the 50 km Visibility Rural Boundary Layer, Spring / Summer Tropospheric, and Background Stratospheric Aerosols.
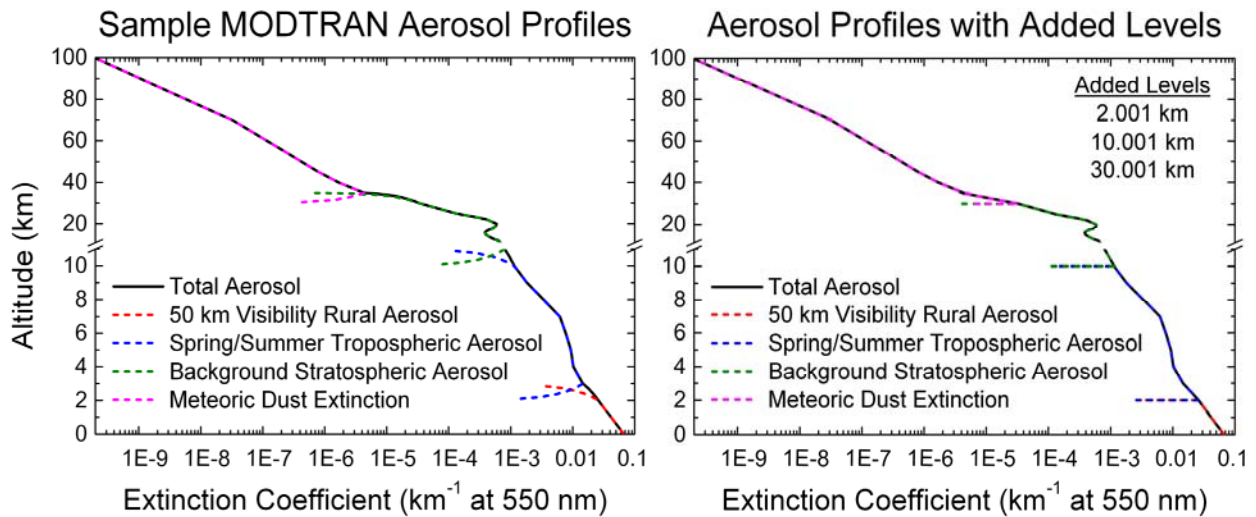
Figure 3.3A.

Figure 3.3A: MODTRAN Aerosol Extinction (km^{-1} at 550 nm) Profile defined with the 50 km Visibility Rural Boundary Layer, Spring / Summer Tropospheric, and Background Stratospheric Aerosols. On the right-hand side, altitude levels at 2.001, 10.001 and 30.001 km have been added to create sharp transitions between aerosol regions. Note there is a break in the vertical scale at 11 km altitude.

One can also define sharp aerosol boundaries by explicitly entering the aerosol extinction profiles using CARD 2C3 inputs. The A+ option allows one to translate, stretch or compress, and scale baseline aerosol profiles such as those of Table 3.3. Unfortunately, this option cannot be used to create sharp boundaries. If, for example, Aerosol 1 from Table 3.3 is stretched to 6 km by setting CARD 2A+ inputs ZAER11, ZAER12 and SCALE1 to 0.0 km, 6.0 km and 1.0, respectively, then the extinction drops from 0.026 to 0.000 between 4 and 6 km rather than between 2 and 3 km.

Figure 3.3B illustrates the MODTRAN built-in cloud profiles. These profiles, similar to those of the aerosol models, do not have particularly sharp boundaries. User-defined cloud profiles are defined via the CARD 2E1 inputs, and this option is required if sharp cloud boundaries are to be modeled.

One subtle precaution must be noted. When fine vertical layering is introduced into MODTRAN, it is critical that one not create a large temperature or relative humidity (RH) gradient. The refractive index profile is defined as a function of temperature and RH. The MODTRAN spherical refractive geometry package fails when large vertical gradients in the refractivity profile are present. These failures sometimes produce warning or error messages, but not always. Unrealistic bending of the refractive path can occur and produce erroneous results.
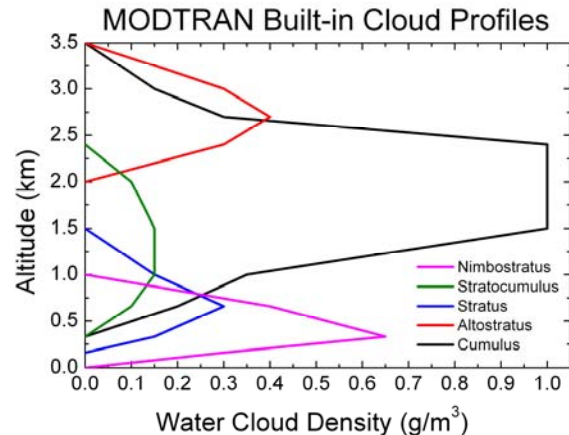

Figure 3.3B: MODTRAN Built-in Cloud Profiles.

3.3.4 *When the 550 nm vertical optical depth is an input to the <rootname>.tp5 file (a negative entry for CARD 4 input VIS), should the 550 nm Rayleigh molecular scattering contribution to the optical depth be included?*

If a negative value is entered for the CARD 4 input VIS, that value is interpreted as the negative of the 550 nm aerosol optical depth – no Rayleigh molecular scattering contribution should be included in the input. If the vertical optical depth at 550 nm is obtained from a measurement, the user must subtract the Rayleigh contribution. For vertical paths from sea-level (GNDALT = 0.0km), the model atmosphere values for the Rayleigh vertical optical depth are

0.097547	Tropical	0.097310	Mid-Latitude Summer	0.097583	Mid-Latitude Winter
0.096780	Sub-Arctic Summer	0.097018	Sub-Arctic Winter	0.097102	U.S. Standard Atmosphere

A baseline MODTRAN multiple scattering run can be run to determine the 550 nm scattering optical depth for a given scenario if an independent measurement of the Rayleigh optical depth is not available.

3.3.5 *If aerosol optical data is entered over a spectral range that does not include 550nm, how should one set the 550 nm total vertical aerosol optical depth (or equivalently, the visibility)?*

Whenever user-defined aerosol spectral data is entered, MODTRAN models spectral regions beyond the input spectral range with end-point values; spectral extrapolation is never used. The spectral extinction values closest to 550 nm are used within MODTRAN to calculate the 550 nm total vertical optical depth. If a 550nm total vertical aerosol optical depth (a negative entry for CARD 2 input VIS) is specified, it will be used to scale the input aerosol optical data.

3.3.6 *What is the appropriate "default value" for the IPH input on CARD 3A1?*

Unless the user is explicitly entering aerosol scattering phase function data (CARD 3A1 input IPH = 1), IPH should be set to 2, not 0. The input IPH = 0 was an initial option provided prior to integrating Mie scattering function data for the aerosol models into LOWTRAN, the pre-cursor of MODTRAN. These phase functions are used to compute single-scatter solar radiance. Unfortunately, the Henyey-Greenstein approximation is still used for multiple scattering calculations. With the introduction of MODTRAN5.3, a new option is being provided that correctly couples the aerosol scattering phase function within the DISORT multiple scattering algorithm.

3.4 The Ground Surface

3.4.1 *How does one enter surface altitude, pressure, air temperature and relative humidity into a MODTRAN input file?*

There is no special option for entering surface values of altitude, pressure, air temperature and relative humidity into a MODTRAN <rootname>.tp5 input file. If user-defined profiles are already being defined, one simply inserts the desired surface values into the first profile level. The real question is how to input these surface values when one of the model atmospheres, such as Mid-Latitude Summer (CARD 1 input MODEL = 2), is being used. It is best to demonstrate with an example. Suppose one desires to alter test case SolarScaledCK in order to set the ground altitude to 0.2km, the surface pressure to 980 mbar, the surface air temperature to 280 K, and the surface relative humidity to 60%. The SolarScaledCK test case CARD 1 input is

```
CM 2   3   2   1   0   0   0   0   0   0   0   0   0   0.000 0.1000
```

To enter the surface values, the user-defined atmosphere option must be selected. Thus, MODEL is reset to 7 (User-Defined Atmosphere), CARD 1 inputs M1, M2, M3, M4, M5 and M6 are all set to 2 (Mid-Latitude Summer default profiles) to match the original value of MODEL, CARD 1 input MDEF is set to 1 (default profiles), and I_RD2C is set to 1 (Read in profile data):

```
CM 7   3   2   1   2   2   2   2   2   2   1   1   0   0.000 0.1000
```

CARDs 2C and 2C1 now must be read. Keeping the number of altitude levels at the default value of 36, these input lines can simply be written as

```
     36    0    0 Surface Inputs
     0.20000 980.00000    280.00    60.000                        AAH
      1.00000
      2.00000
      3.00000
      4.00000
      5.00000
      6.00000
      7.00000
      8.00000
      9.00000
     10.00000
     11.00000
     12.00000
     13.00000
     14.00000
     15.00000
     16.00000
     17.00000
     18.00000
     19.00000
     20.00000
     21.00000
     22.00000
     23.00000
     24.00000
     25.00000
     30.00000
     35.00000
     40.00000
     50.00000
     70.00000
    100.00000
```

The single CARD 2C input line sets the number of levels. The first CARD 2C1 line sets the surface values with "AAH" in columns 61-63 defining the pressure, temperature and water vapor concentration units (mbar, K, and % humidity, respectively). For the remaining 35 levels, only the altitude is needed because profiles are set by M1, M2, M3, M4, M5, M6 and MDEF. The one caveat on this example is that MODTRAN does require monotonically decreasing pressures. Thus, if the surface pressure were less than the model atmosphere pressure at 1km altitude, the default altitudes would have to start at a higher level.

3.4.2 *Does MODTRAN support input of tabulated or user-defined surface BRDFs?*

MODTRAN Bi-directional Reflectance Distribution Function (BRDF) option supports a host of parameterized terrain models. The option was originally designed to allow tabulated surface BRDFs, but that option has never been implemented. Therefore, to introduce a user-defined BRDF, one must edit routine RDBRDF within the rflect.f module to add source code for the desired reflectance function.

3.5 Input Variable Choices

3.5.1 *When is it appropriate to use the ISAACS scaled to DISORT scattering option?*

MODTRAN5 provides 3 scattering model options. Running the DISORT scattering model is preferable if one can afford the computational costs. Quick approximate results are available from the Isaacs 2-stream model. However, instances arise in which the accuracy of the 2-stream approach is insufficient but the computation time of DISORT processing is too long. MODTRAN provides an alternative for the solar dominated spectral regime ($< 4 \mu m$) – the Isaacs 2-stream scaled to DISORT option (Card 1A case-insensitive input DIS set to ′S′). DISORT scattering calculations are performed for a small fixed set of spectral points in atmospheric window regions. The ratio of DISORT to Isaacs multiple scatter solar path radiances is calculated at each spectral grid point, creating a spectral

correction curve. This curve is use to adjust the Isaacs multiple scatter solar path radiances at each spectral point. An analogous correction is made to the ground reflected downward diffuse flux for lines-of-sight that intersect the ground.

The Isaacs scaled to DISORT option should really only be used for the shortwave (< 4 μm). Moreover, one should compare the scaled results to a full DISORT calculation for a subset of runs to verify that the accuracy of the approximation is sufficient for the application.

3.5.2   *Can MODTRAN5 be run with older band model data files*?

MODTRAN5 includes an upgraded the band model formulation, required for the finer spectral resolution 0.1 cm^{-1} band model. In the new formulation, line tails are modeled using Padé approximant spectral fits. Since MODTRAN4 band model data files do not include the Padé approximant coefficients, MODTRAN5 is incompatible with the MODTRAN4 band model data files.

The initial beta-test versions of MODTRAN5 were released prior to the year 2000. Band model files from these early releases are compatible with the current release of MODTRAN5. However, the 4-parameter band model (CARD 1A input LBMNAM = ′4′, ′T′ or ′t′) was only introduced in 2008. If you choose to use band model data dated prior to 2008, the input LBMNAM must be set to ′2′.

3.5.3   *What is the difference between CARD4 spectral inputs DV and FWHM*?

DV is the increment or step size at which output is generated while the Full Width at Half Maximum (FWHM) is the resolution of the slit function. Nyquist sampling would suggest that DV be set to FWHM / 2.

4.   <u>Output</u>

4.1   General

4.1.1   *Is there documentation describing MODTRAN output*?

Currently, there is no MODTRAN output file manual. However, answers to many questions regarding MODTRAN output are provided here. If additional help is required, please email your questions to modtran@spectral.com. Responses to email are generally sent within one business day, assuming the user's maintenance agreement is current.

4.1.2   *What are atm-cm and atm-cm/km units used in MODTRAN*?

Band model absorption coefficient data were traditionally measured in units of cm^{-1}/atm. A gas would be placed in a 1 cm long cell at standard pressure and temperature, and the spectral bin extinction measured. With this set up, column densities were recorded in units of atm-cm at standard temperature and pressure (STP) and absorption coefficients defined in cm^{-1}/atm at STP. Since column density is a path integral over molecular concentration, mol/cm^2 is a more natural unit from the molecular perspective. To convert mol/cm^2 to atm-cm, multiply by the ideal gas standard volume [22,413.83 cm^3 atm / mole] and divide by Avogadro's constant [6.022045E+23 mol/mole]. Alternatively, divide by Loschmidt number at STP [2.686754E+19 mol cm^{-3} / atm], defined as Avogadro's number over the ideal gas standard volume.

4.1.3   *Can the scattering phase functions used by MODTRAN5 be written to a file*?

In the early 1980's, when aerosol models were integrated into LOWTRAN, the precursor of MODTRAN, memory was at a premium. Storing the aerosol Mie theory spectral scattering phase functions in block data was not an option. To circumvent this problem, a compact master list of scattering phase functions was defined along with a function that mapped each aerosol type and spectral grid point to the entry in the master list that most closely matched original phase function. This heritage remains in MODTRAN, and, as a result, it is cumbersome to try to extract aerosol phase function data from the model.

There is one hidden option that is available. If a solar radiance calculation is run (CARD 1 input IEMSCT equal to 2 or 4) without invoking the correlated-*k* options (CARD 1 input MODTRN = ′M′), one can (a) edit routine ssrad.f changing logical LWRITE from .FALSE. to .TRUE., (b) recompile MODTRAN, and (c) run the code. This will generate a table, written to unit 69 (e.g. output file "fort69") that contains the scattering phase function values at the solar scattering angle for each level along the line-of-sight.

If additional scattering phase function information is required, please email your questions to modtran@spectral.com. Responses to email are generally sent within one business day, assuming the user's maintenance agreement is current.

4.1.4 *Why is the "therml_sct" column empty in my <rootname>.tp7 output file?*

MODTRAN contains two scattering models: the rapid but lower fidelity 2-stream Isaacs algorithm and the first-principles DISORT discrete ordinate approach. Since the Isaacs model computes the thermal emission and scatter component separately, MODTRAN output includes both the total thermal path radiance and its scattering component, column "therml_sct" in *<rootname>*.tp7. DISORT does not partition the components, so the "therml_sct" column is left blank when DISORT is run with MODTRAN5.2.

In MODTRAN5.3, which is anticipated to be released in 2011, a distinct path thermal emission calculation is performed outside of DISORT. The thermal scattered radiance, calculated as the difference between the DISORT total thermal radiance and the path thermal emission, is, therefore, included in the *<rootname>*.tp7 output.

4.1.5 *The MODTRAN up-look thermal radiances seem too large. Why?*

For a line-of-sight that intersects the Earth, CARD 1 input TPTEMP is the ground surface temperature in degrees Kelvin (if TPTEMP is ≤ 0., then the ground surface temperature is set to the surface air temperature). It is not uncommon for a user to set TPTEMP to the desired ground temperature for up-look scenarios or down-look scenarios that do not terminate at the ground. In these cases, MODTRAN interprets TPTEMP as the temperature of a grey body target at the end of the line-of-sight. Unless one is actually modeling a grey body target, TPTEMP should be set to zero for lines-of-sight not terminating at the ground. Otherwise, the target thermal emission will be included in the total radiance, making it too large.

One may still wish to set a surface ground temperature, distinct from the surface air temperature, for lines-of-sight not terminating at the ground. This value will indirectly affect the thermal multiple scattering radiance component. To define the ground surface temperature in these cases, set CARD 1 input SURREF to either ′LAMBER′ or ′BRDF′. This initiates reading of CARD 4A. On CARD 4A, set input NSURF to 2 and set input AATEMP to the desired surface ground temperature in degrees Kelvin.

4.1.6 *Why is the product of molecular and particulate component transmittances generally not equal to the combined transmittance in the <rootname>.tp7 and <rootname>.7sc files?*

One of the MODTRAN statistical approximations is that the absorption from distinct species is randomly correlated. This implies that combined transmittance is simply the product of the individual species transmittances. Within MODTRAN, this assumption is applied at the resolution of the chosen band model, 0.1, 1.0, 5.0 or 15.0 cm^{-1}. Unless, the output spectral resolution (CARD 4 input FWHM) equals the band model resolution, the transmittances in the *<rootname>*.tp7 when MODTRAN is run in transmittance-only mode (CARD 1 input IEMSCT = 0) are at a coarser resolution. The *<rootname>*.7sc transmittances are essentially always at a coarser resolution. For the spectrally convolved transmittance components, the product relationship does not strictly hold.

4.1.7 *Why is the <rootname>.tp7 output GRND_RFLT zero for up-look geometry calculations?*

It may seem confusing that the GRND_RFLT radiance column is always zero for lines-of-sight that do not intersect the ground. Radiation scattered off the ground can scatter into the line-of-sight, but that component is included in the SOL_SCAT and THRML_SCT path radiance terms. The GRND_RFLT radiance only includes ground reflected radiance that directly transmits to the sensor.

4.1.8 *Are vertical aerosol optical depths included in MODTRAN output?*

The *<rootname>*.tp6 file always includes a section beginning with the phrase "TOTAL COLUMN ABSORBER AMOUNTS FOR THE LINE–OF–SIGHT PATH:". This section includes the line-of-sight column amounts for MODTRAN's four aerosol regions. Whenever multiple scattering is included in a MODTRAN run (CARD 1 input IMULT = ±1), there is a separate section in the *<rootname>*.tp6 file that begins with the phrase "TOTAL COLUMN ABSORBER AMOUNTS FOR A VERTICAL PATH FROM GROUND TO SPACE:". The aerosol amounts in this second section sum to the total vertical aerosol optical depth (AOD) at 550nm. To determine the total vertical AOD

without running a multiple scattering calculation, simply set up a ground-to-space (H1ALT = 0, H2ALT = 100 and BCKZEN = 180) transmittance only calculation (CARD 1 input IEMSCT = 0) and sum the aerosol line-of-sight column absorber amounts.

4.1.9   *Why did the total thermal radiance decrease when thermal scattering was turned on?*

In thermal radiance mode (CARD 1 input IEMSCT = 1), the total thermal radiance will generally decrease when multiple scattering is enabled (CARD 1 input IMULT changed from 0 to ±1). At first this is perplexing; the thermal emission cannot exceed the thermal emission plus scatter. The reason this happens is that MODTRAN uses the conservative scattering approximation when no multiple scattering algorithm is used. With the conservative scattering approximation, the radiance scattered out of the line-of-sight is assumed to be equal to the radiance scattering back into the line-of-sight. The approximation is implemented by setting the single scattering albedo to zero. Generally, the result is an over estimate of the thermal scatter. For this reason, if one cannot afford the computational cost of running DISORT, it is recommended that at least the Isaacs 2-stream model be used. The Isaacs model adds minimal processing time.
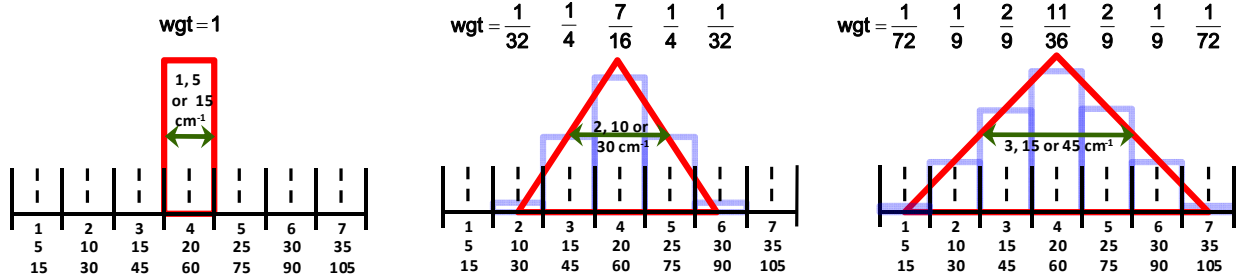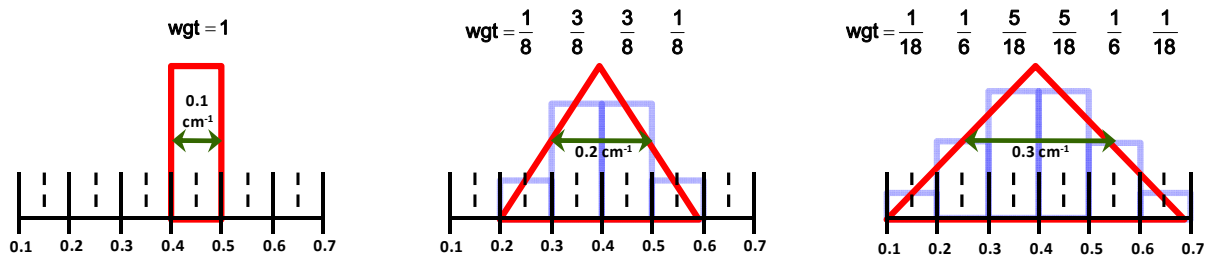
4.2   The *<rootname>*.tp7 (or tape7) spectral table file

4.2.1   *What is a <rootname>.tp7 file?*

A *<rootname>*.tp7 file is the primary MODTRAN spectral output file containing transmittance, radiance and/or irradiance data.

4.2.2   *What is the definition of the <rootname>.tp7 spectral outputs?*

The *<rootname>*.tp7 file contains MODTRAN's primary spectral output whenever the character string FLAGS(1:4) on CARD 4 is blank, i.e., if the default slit function option is used. In this case, the first 4 inputs on CARD 4 define the initial spectral frequency (V1), the final spectral frequency (V2), the frequency output step size or increment (DV), and the spectral resolution in terms of the Full Width at Half-Maximum (FWHM) of the slit function. All these inputs are in units of cm^{-1}. The FWHM can either be equal to or a multiple of the band model resolution. When the FWHM and the MODTRAN band model spectral resolution are equal, then a rectangular slit function is used to generate output at the resolution of the band model without any spectral degradation. If, on the other hand, the input FWHM is a multiple of the band model resolution, then a discretized triangular slit function is defined. In Figure 4.2, the procedure for weighting the spectral bin contributions is illustrated. Note that an odd number of spectral bins contribute to the triangular slit function when the 1, 5 or 15 cm^{-1} band model is used, but an even number of bins contribute when the 0.1 cm^{-1} band model is used. This difference arises because the 1, 5 and 15 cm^{-1} spectral bins are centered on multiples of 1, 5, and 15 cm^{-1}, while the edges of the 0.1 cm^{-1} bins are multiples of 0.1 cm^{-1}.

Coarser Spectral Resolution (1, 5 and 15 cm^{-1}) MODTRAN Band Models

$$wgt = 1$$

1, 5
or 15
cm^{-1}

1	2	3	4	5	6	7
5	10	15	20	25	30	35
15	30	45	60	75	90	105

$$wgt = \frac{1}{32} \quad \frac{1}{4} \quad \frac{7}{16} \quad \frac{1}{4} \quad \frac{1}{32}$$

2, 10 or
30 cm^{-1}

1	2	3	4	5	6	7
5	10	15	20	25	30	35
15	30	45	60	75	90	105

$$wgt = \frac{1}{72} \quad \frac{1}{9} \quad \frac{2}{9} \quad \frac{11}{36} \quad \frac{2}{9} \quad \frac{1}{9} \quad \frac{1}{72}$$

3, 15 or 45 cm^{-1}

1	2	3	4	5	6	7
5	10	15	20	25	30	35
15	30	45	60	75	90	105

Finest Spectral Resolution (0.1 cm^{-1}) MODTRAN Band Model

$$wgt = 1$$

0.1
cm^{-1}

0.1 0.2 0.3 0.4 0.5 0.6 0.7

$$wgt = \frac{1}{8} \quad \frac{3}{8} \quad \frac{3}{8} \quad \frac{1}{8}$$

0.2 cm^{-1}

0.1 0.2 0.3 0.4 0.5 0.6 0.7

$$wgt = \frac{1}{18} \quad \frac{1}{6} \quad \frac{5}{18} \quad \frac{5}{18} \quad \frac{1}{6} \quad \frac{1}{18}$$

0.3 cm^{-1}

0.1 0.2 0.3 0.4 0.5 0.6 0.7

Figure 4.2. Illustration of *<rootname>*.tp7 slit functions. The green double-arrowed lines display the FWHM. The normalized spectral bin weights listed above the bins equal the fraction of total slit function area within each bin. MODTRAN models the (red) triangular slit functions with the discretized (purple) rectangular representation.

If the character string FLAGS(1:4) on CARD 4 is used to define a scanning (filter) function, then the *<rootname>*.tp7 file will contain spectral data at the resolution of the band model, again with no spectral degradation. The spectral region will also be padded to contain the spectral coverage required to define the scanning function. In this case the primary spectral output is not the *<rootname>*.tp7 file, but instead the *<rootname>*.7sc file.

A number of MODTRAN inputs influence exactly what spectral data is written to the *<rootname>*.tp7 file. Of particular importance is input IEMSCT on CARD 1. The descriptions below consider the following 3 cases: IEMSCT=0 (transmittance only mode), IEMSCT = 1, 2 or 4 (radiance modes) and IEMSCT = 3 (solar/lunar irradiance mode). For each case, the output columns are described.

IEMSCT = 0 (transmittance only mode)

FREQ CM-1:	Slit function central frequency in cm^{-1}
COMBIN TRANS:	Slit function direct transmittance for the line-of-sight (LOS) path including all sources of molecular and particulate extinction
H2O TRANS:	Slit function water vapor transmittance for the LOS path EXCLUDING water continuum contributions
UMIX TRANS:	Slit function uniformly mixed gases transmittance for the LOS path. The uniformly mixed gases are defined here to include CO_2, CO, CH_4, N_2O and O_2.
O3 TRANS:	Slit function ozone transmittance for the LOS path
TRACE TRANS:	Slit function trace gas transmittance for the LOS path. The trace gases are defined here to include NH_3, NO, NO_2, SO_2 and HNO_3. Water vapor, the uniformly mixed gases, ozone and the trace gases together constitute the 12 MODTRAN default band model species.
N2 CONT:	Slit function nitrogen continuum transmittance for the LOS path
H2O CONT:	Slit function water vapor continuum transmittance for the LOS path
MOLEC SCAT:	Slit function molecular scattering (Rayleigh) transmittance for the LOS path

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AER+CLD TRANS:	Slit function aerosols plus clouds transmittance for the LOS path
HNO3 TRANS:	Slit function nitric acid transmittance for the LOS path
AER+CLD abTRNS:	Slit function transmittance for the LOS path resulting from aerosol and cloud absorption. This term excludes the extinction from aerosol and cloud scattering.
–LOG COMBIN:	The negative natural logarithm of the slit function direct transmittance for the LOS path. If the band model transmittances (H2O TRANS, UMIX TRANS, O3 TRANS and TRACE TRANS) are all equal to one, then this quantity is equal to the LOS optical depth. However, band model transmittances do not obey Beer's Law and the negative natural logarithm of the transmittance should not be associated with an optical depth when a spectral bin has significant spectral structure.
CO2 TRANS:	Slit function carbon dioxide transmittance for the LOS path
CO TRANS:	Slit function carbon monoxide transmittance for the LOS path
CH4 TRANS:	Slit function methane transmittance for the LOS path
N2O TRANS:	Slit function nitrous oxide transmittance for the LOS path
O2 TRANS:	Slit function oxygen gas transmittance for the LOS path
NH3 TRANS:	Slit function ammonia transmittance for the LOS path
NO TRANS:	Slit function nitric oxide transmittance for the LOS path
NO2 TRANS:	Slit function nitrogen dioxide transmittance for the LOS path
SO2 TRANS:	Slit function sulfur dioxide transmittance for the LOS path
CLOUD TRANS:	Slit function cirrus plus water cloud transmittance for the LOS path
CFC11 TRANS:	Slit function trichlorofluoromethane transmittance for the LOS path
CFC12 TRANS:	Slit function dichlorodifluoromethane transmittance for the LOS path
CFC13 TRANS:	Slit function chlorotrifluoromethane transmittance for the LOS path
CFC14 TRANS:	Slit function carbon tetrafluoride transmittance for the LOS path
CFC22 TRANS:	Slit function chlorodifluoromethane transmittance for the LOS path
CFC113 TRANS:	Slit function 1,1,2-trichlorotrifluoroethane transmittance for the LOS path
CFC114 TRANS:	Slit function 1,2-dichlorotetrafluoroethane transmittance for the LOS path
CFC115 TRANS:	Slit function chloropentafluoroethane transmittance for the LOS path
CLONO2 TRANS:	Slit function chlorine nitrate transmittance for the LOS path
HNO4 TRANS:	Slit function hydroxyl nitrate transmittance for the LOS path
CHCL2F TRANS:	Slit function dichlorofluoromethane transmittance for the LOS path
CCL4 TRANS:	Slit function carbon tetrachloride transmittance for the LOS path
N2O5 TRANS:	Slit function dinitrogen pentoxide transmittance for the LOS path
H2–H2 TRANS:	Slit function transmittance arising from H_2–H_2 collision induced absorption (CIA) for the LOS path (*available in MODTRAN5.3 and subsequent versions of MODTRAN*)
H2–HE TRANS:	Slit function transmittance arising from H_2–He CIA for the LOS path (*available in MODTRAN5.3 and subsequent versions of MODTRAN*)
H2–CH4 TRANS:	Slit function transmittance arising from H_2–CH_4 CIA for the LOS path (*available in MODTRAN5.3 and subsequent versions of MODTRAN*)
CH4–CH4 TRANS:	Slit function transmittance arising from CH_4–CH_4 CIA for the LOS path (*available in MODTRAN5.3 and subsequent versions of MODTRAN*)
Aux Species TRANS:	Slit function transmittance arising from input set of auxiliary species for the LOS path

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<u>IEMSCT = 1, 2 or 4 (radiance modes)</u>

FREQ:	Slit function central frequency in cm^{-1}
TOT_TRANS:	Slit function direct transmittance for the LOS path including all sources of molecular and particulate extinction
PTH_THRML:	Slit function path thermal radiation in units of W cm^{-2} sr^{-1} / cm^{-1}, including both the path thermal emission and the thermal radiation scattered by the atmosphere directly into the LOS and transmitted to the sensor. It does not include surface emission or reflected downward surface flux transmitted directly to the sensor along the LOS.
THRML_SCT:	The atmospherically scattered component of PTH_THRML in units of W cm^{-2} sr^{-1} / cm^{-1}. That is, the slit function thermal radiation scattered by the atmosphere directly into the LOS and transmitted to the sensor.
SURF_EMIS:	The slit function surface emission directly transmitted to the sensor in units of W cm^{-2} sr^{-1} / cm^{-1}. If the LOS terminates at the ground, this term is computed as the product of the Planck surface emission, the directional emissivity and the path transmittance. If the LOS does not terminate at the ground BUT a positive temperature is specified for CARD 1 input TPTEMP, SURF_EMIS will contain the transmitted surface emission of a target object. If the LOS does not terminate at the ground AND input TPTEMP is zero, then SURF_EMIS is zero.
SOL_SCAT:	Slit function solar/lunar radiation in units of W cm^{-2} sr^{-1} / cm^{-1} scattered by the atmosphere and directly transmitted to the sensor. This includes the single scatter component (SING_SCAT).
SING_SCAT:	The single scatter contribution to SOL_SCAT in units of W cm^{-2} sr^{-1} / cm^{-1}.
GRND_RFLT:	Slit function ground reflected radiation directly transmitted to the sensor in units of W cm^{-2} sr^{-1} / cm^{-1}. It includes reflection of three downward flux components – the direct solar, the diffuse solar and the diffuse thermal.
DRCT_RFLT:	The direct solar component of GRND_RFLT. That is, the slit function radiance in units of W cm^{-2} sr^{-1} / cm^{-1} arising from solar photons that travel along the sun to ground to sensor path without being scattered or absorbed by the atmosphere.
TOTAL_RAD:	The total slit function radiance observed by a sensor in units of W cm^{-2} sr^{-1} / cm^{-1}. This is computed as the sum of PTH_THRML, SURF_EMIS, SOL_SCAT and GRND_REFL.
REF_SOL:	The product of the sensor-to-final_altitude-to-sun transmittance (final_altitude is either the ground or CARD 3 input H2ALT) and the slit function TOA (top-of-atmosphere) solar irradiance in units of W cm^{-2} / cm^{-1}. It does not include the surface reflectance. This is included in the output for target insertion applications.
SOL@OBS:	Slit function solar irradiance transmitted to the observer, calculated as the product of the TOA spectral solar irradiance in units of W cm^{-2} / cm^{-1} and the sun to sensor or observer (CARD 1 input H1ALT) spectral transmittance.
DEPTH:	The negative natural logarithm of the slit function direct transmittance for the LOS path. Since band model transmittances do not obey Beer's Law, the negative natural logarithm of the transmittance should not be associated with an optical depth when a spectral bin has significant spectral structure.
DIR_EM:	Slit function directional emissivity at the ground toward the sensor (between 0 and 1 inclusive).
TOA_SUN:	Slit function top-of-atmosphere (TOA) solar irradiance in units of W cm^{-2} / cm^{-1}.
BBODY_T[K]:	Slit function brightness temperature in Kelvin, defined as the temperature a blackbody would need to have to emit the TOTAL_RAD slit function radiance. The calculation method, is described by Berk [2008].

IEMSCT = 3 (solar/lunar irradiance mode)

FREQ:	Slit function central frequency in cm^{-1}
TRANS:	Slit function direct transmittance for the solar path including all sources of molecular and particulate extinction
SOL TR:	Product of the slit function direct transmittance (TRANS) and the slit function top-of-atmosphere (TOA) solar irradiance (SOLAR) in units of W cm^{-2} / cm^{-1}
SOLAR:	Slit function top-of-atmosphere (TOA) solar irradiance in units of W cm^{-2} / cm^{-1}
Unlabeled:	The negative natural logarithm of the slit function direct transmittance for the solar path. Since band model transmittances do not obey Beer's Law, the negative natural logarithm of the transmittance should not be associated with an optical depth when a spectral bin has significant spectral structure.

4.2.3 *How do inputs affect which <rootname>.tp7 outputs are generated?*

For transmittance-only runs (CARD 1 input IEMSCT = 0), the first 35 columns (through N_2O_5) [*39 columns (through CH4–CH4 TRANS) for MODTRAN5.3*] of the <rootname>.tp7 file are always the same. If auxiliary species are included in the transmittance run (CARD 2C input NMOLYC > 0), then an additional column is added for each active auxiliary species.

For thermal radiance runs (CARD 1 input IEMSCT = 1), there are 3 output scenarios for the <rootname>.tp7 file:

- If DISORT multiple scattering is selected (CARD 1 input IMULT = ±1 and CARD 1A input DIS = ′T′), then the output columns include FREQ, TOT_TRANS, PTH_THRML, SURF_EMIS, GRND_RFLT, TOTAL_RAD, DEPTH, DIR_EM and BBODY_T[K];

- If ISAACS 2-stream multiple scattering is selected, the additional output column THRML_SCT (between PTH_THRML and SURF_EMIS) is written to the <rootname>.tp7 file; and

- If no scattering model is used (CARD 1 input IMULT = 0), then the output columns are identical to those used with ISAACS 2-stream but the THRML_SCT and GRDN_RFLT columns are set to zero. Furthermore, MODTRAN invokes the conservative scattering approximation (the thermal radiance scattered out of the LOS equals the thermal radiance scattering into the LOS). The PTH_THERML column contains the path emission and the conservative scattering contributions.

For thermal plus solar / lunar radiance runs (CARD 1 input IEMSCT = 2), the thermal radiance outputs follow the thermal only (IEMSCT = 1) rules. The <rootname>.tp7 file additionally contains the SOL_SCAT, SING_SCAT, DRCT_RFLT, REF_SOL, SOL@OBS and TOA_SUN columns. If multiple scattering is not selected (CARD 1 input IMULT = 0), then the SOL_SCAT and GRND_RFLT columns simply equal the SING_SCAT and DRCT_RFLT columns, respectively.

For solar / lunar irradiance runs (CARD 1 input IEMSCT = 3) the <rootname>.tp7 file output is independent of any additional input value.

For solar scatter radiance plus thermal emission but no thermal scatter (CARD 1 input IEMSCT = 4), the output columns are identical to those used with the thermal plus solar / lunar radiance runs (IEMSCT = 2) but all thermal scatter contributions are zero.

4.3 The *<rootname>*.7sc (or tape7.scn) spectral table file

4.3.1 *What is a <rootname>.7sc file?*

A *<rootname>*.7sc file is a MODTRAN output file containing spectral transmittance, radiance and/or irradiance data that has been scanned using a user-specified filter function.

4.3.2 *When is th*e *<rootname>.***7sc** *file generated*?

A *<rootname>*.7sc file is generated whenever the CARD 4 input 4-character string FLAGS(1:4) is not blank. The individual characters determine

- input and output units [FLAGS(1:1)];
- the type of slit (or scanning) function [FLAGS(2:2)];
- the type of spectral resolution, absolute or relative [FLAGS(3:3)]; and
- which *<rootname>*.tp7 outputs should be scanned [FLAGS(4:4)].

If FLAGS(4:4) is set to ′A′, then scanned results are generated for ALL of the *<rootname>*.tp7 outputs. Only the total (ir)radiance and the direct path transmittance is output if FLAGS(4:4) is not set to ′A′.

4.3.3 *What is the definition of the <rootname>.***7sc** *spectral outputs*?

The meaning of the *<rootname>*.7sc outputs is the same as their complement in the *<rootname>*.tp7 file. However, if a wavelength (rather than frequency) unit is requested, then output radiances and irradiances units change. The output radiances and irradiances are in units of W cm^{-2} sr^{-1} / μm and W cm^{-2} / μm, respectively, if CARD 4 input FLAGS(1:1) equals ′M′ (microns), and they are in units of μW cm^{-2} sr^{-1} / nm and μW cm^{-2} / nm, respectively, if FLAGS(1:1) equals ′N′ (nanometers).

4.3.4 *How do inputs affect which <rootname>.***7sc** *outputs are generated*?

The same rules which dictate how MODTRAN *<rootname>*.tp5 inputs affect which *<rootname>*.tp7 outputs are generated apply to the *<rootname>*.7sc file.

4.4 The *<rootname>***.tp8 (or tape8) path segment dependent spectral data file**

4.4.1 *What is a <rootname>.***tp8** *file*?

A *<rootname>*.tp8 file is an auxiliary MODTRAN spectral output file containing spectral data for each path segment along the observer (sensor) lines-of-sight.

4.4.2 *When is th*e *<rootname>.***tp8** *file generated*?

A *<rootname>*.tp8 file is generated when the MODTRAN integer print flag (CARD 1 input NOPRNT) is negative and a line-of-sight radiance calculation is performed (CARD 1 input IEMSCT equals 1, 2 or 4).

4.4.3 *What is the definition of the <rootname>.tp8 file path segment dependent spectral outputs?*

The *<rootname>*.tp8 file output changes depending upon whether multiple scattering is on (CARD 1 input IMULT = ±1) or off (IMULT = 0). In either case, the *<rootname>*.tp8 file provides information about incremental transmittances and radiances. Descriptions of the spectral outputs follow:

IMULT = 0 (Conservative Scattering)

FREQ (CM-1):	Band model spectral bin central frequency in cm^{-1}
BEGINNING ALTITUDE (KM):	Altitude at beginning of current line-of-sight path segment
ENDING ALTITUDE (KM):	Altitude at end of current line-of-sight path segment
INT:	Not used and always left blank
LAYER B(V,T) (W SR^{-1} CM^{-2}/CM^{-1}):	Planck function at current frequency and segment averaged temperature
BOUNDARY B(V,T) (W SR^{-1} CM^{-2}/CM^{-1}):	Planck function at current frequency and segment front-end temperature
TRANSMISSION TO BEGIN:	Cumulative band model resolution spectral transmittance from beginning of line-of-sight through current segment
TRANSMISSION IN LAYER:	Incremental band model resolution spectral transmittance for current path segment
LAYER RADIANCE (W SR^{-1} CM^{-2}/CM^{-1}):	Incremental band model resolution spectral radiance, equal to the product of the segment source radiance and the foreground (sensor to segment) band model transmittance
TOTAL RADIANCE (W SR^{-1} CM^{-2}/CM^{-1}):	Cumulative band model resolution spectral radiance from the sensor through the current path segment

IMULT = ±1 (DISORT or ISAACS 2-Stream Scattering)

FREQ (CM-1):	Band model spectral bin central frequency in cm^{-1}
ALT (KM):	Altitude at end of current segment
TOTAL TRANS:	Cumulative band model resolution spectral transmittance from beginning of line-of-sight through current segment
DELTA TRANS:	Incremental band model resolution spectral transmittance for current path segment
UP–DN–DIR (W CM^{-2}/CM^{-1}):	Band model resolution net upward horizontal spectral flux at ALT
THRML_UP (W CM^{-2}/CM^{-1}):	Band model resolution thermal upward spectral flux at ALT
THRML_DN (W CM^{-2}/CM^{-1}):	Band model resolution thermal downward spectral flux at ALT
THRML_SRC (W CM^{-2}/CM^{-1}):	Band model resolution segment thermal source function
THRML_SUM (W CM^{-2}/CM^{-1}):	Cumulative band model resolution spectral thermal radiance from beginning of line-of-sight through current segment
SOLAR_UP (W CM^{-2}/CM^{-1}):	Band model resolution solar upward spectral flux at ALT
SOLAR_DN (W CM^{-2}/CM^{-1}):	Band model resolution solar downward spectral flux at ALT
SOLAR_SRC (W CM^{-2}/CM^{-1}):	Band model resolution segment solar source function
SOLAR_SUM (W CM^{-2}/CM^{-1}):	Cumulative band model resolution spectral solar radiance from beginning of line-of-sight through current segment

4.5 The *<rootname>*.plt (or pltout) plot data file

4.5.1 *What is a <rootname>.plt file?*

A *<rootname>*.plt file is a MODTRAN spectral output file containing just two columns of data, with a spectral grid in the first column and either transmittance, radiance or irradiance in the second column.

4.5.2   *When is the <rootname>*.plt *file generated*?

A *<rootname>*.plt file is generated when the case-insensitive CARD 4 input YFLAG (column 41) equals ′T′ (transmittance) or ′R′ (radiance or irradiance). The unit of the spectral grid (the abscissa) is determined by the case-insensitive CARD 4 input XFLAG (column 42) – ′M′ for wavelength in microns, ′N′ for wavelength in nanometers, and frequency in cm^{-1}, otherwise. When YFLAG equals ′R′, irradiance is output if CARD 1 input IEMSCT equals 3; radiance is output if CARD 1 input IEMSCT equals 1, 2 or 4.

4.5.3   *What is the definition of the <rootname>*.plt *file spectral output*?

The abscissa of the *<rootname>*.plt output is a monotonic spectral grid, either a wavelength (microns if CARD 4 input XFLAG = ′M′ or nanometers if XFLAG = ′N′) or a frequency (cm^{-1} if XFLAG does not equal ′M′ or ′N′). The location of the abscissa is the central frequency of a frequency-based slit function, either a discretized triangular or rectangular (Figure 4.2) response function. A rectangular slit function of width equal to the band model resolution (0.1, 1.0, 5.0 or 15.0 cm^{-1}) is used if the CARD 4 input string FLAGS(1:4) is not blank or if the CARD 4 input of the FWHM is less than twice the band model resolution; the band model resolution is defined by the root name of the band model file name (the CARD 1A2 input). Otherwise, the slit function is a discretized triangular response function with full width at half maximum defined by the FWHM input.

In transmittance mode (CARD 4 input YFLAG = ′T′), the plot file ordinate is the *<rootname>*.tp7 ′TOT_TRANS′ output, the slit function direct transmittance for the LOS path including all sources of molecular and particulate extinction.

In radiance mode (YFLAG = ′R′, CARD 1 input IEMSCT ≠ 3), the plot file ordinate is the *<rootname>*.tp7 ′TOTAL_RAD′ output, the slit function total radiance observed by a sensor in units of μW cm^{-2} sr^{-1} / μm if CARD 4 input XFLAG equals ′M′, in units of W cm^{-2} sr^{-1} / nm if XFLAG equals ′N′, and in units of W cm^{-2} sr^{-1} / cm^{-1} otherwise.

In irradiance mode (YFLAG = ′R′, IEMSCT = 3), the plot file ordinate is the *<rootname>*.tp7 ′SOL TR′ output, the product of the slit function direct transmittance (′TRANS′ in *<rootname>*.tp7) and the slit function top-of-atmosphere solar irradiance (′SOLAR′ in *<rootname>*.tp7) in units of μW cm^{-2} / μm if XFLAG equals ′M′, in units of W cm^{-2} / nm if XFLAG equals ′N′ and, otherwise, in units of W cm^{-2} / cm^{-1}.

4.6   The *<rootname>*.psc (or pltout.scn) plot data file

4.6.1   *What is a <rootname>*.psc *file*?

A *<rootname>*.psc file is a MODTRAN spectral output file containing just two columns of data, with a spectral grid in the first column and either transmittance, radiance or irradiance in the second column. The second column of data has been scanned using a user-defined filter function.

4.6.2   *When is the <rootname>*.psc *file generated*?

A *<rootname>*.psc file is generated when (a) the case-insensitive CARD 4 input YFLAG (column 41) equals ′T′ (transmittance) or ′R′ (radiance or irradiance) and (b) the CARD 4 input string FLAGS(1:4) is not blank. The unit of the spectral grid (the abscissa) is determined by the case-insensitive CARD 4 input XFLAG (column 42) – ′M′ for wavelength in microns, ′N′ for wavelength in nanometers, and frequency in cm^{-1}, otherwise. When YFLAG equals ′R′, irradiance is output if CARD 1 input IEMSCT equals 3; radiance is output if IEMSCT equals 1, 2 or 4.

4.6.3   *What is the definition of the <rootname>*.psc *file spectral outputs*?

The *<rootname>*.psc file has two columns of data; the first containing a monotonic spectral grid and the second containing spectrally scanned plot file output of transmittances, radiances or irradiances. The slit function type (triangular, rectangular, Gaussian, Sinc, Sinc-squared or Hamming) is defined by CARD 4 input FLAGS(2:2). The slit function can either be wavelength-based [microns if case-insensitive CARD 4 input FLAGS(1:1) = ′M′ or nanometers if FLAGS(1:1) = ′N′] or frequency-based [cm^{-1} if FLAGS(1:1) does not equal ′M′ or ′N′]. The full-width half maximum of the slit function is defined by CARD 4 input FWHM. The abscissa of the *<rootname>*.psc output is the central spectral point of the response function.

In transmittance mode (CARD 4 input YFLAG = ′T′), the plot file ordinate is the *<rootname>*.7sc ′TOT_TRANS′ output, the slit function direct transmittance for the LOS path including all sources of molecular and particulate extinction.

In radiance mode (YFLAG = ′R′, CARD 1 input IEMSCT ≠ 3), the plot file ordinate is the *<rootname>*.7sc ′TOTAL_RAD′ output, the slit function total radiance observed by a sensor in units of μW cm^{-2} sr^{-1} / μm if CARD 4 input XFLAG equals ′M′, in units of W cm^{-2} sr^{-1} / nm if XFLAG equals ′N′, and in units of W cm^{-2} sr^{-1} / cm^{-1} otherwise.

In irradiance mode (YFLAG = ′R′, IEMSCT = 3), the plot file ordinate is the *<rootname>*.7sc ′SOL TR′ output, the product of the slit function direct transmittance (′TRANS′ in *<rootname>*.7sc) and the slit function top-of-atmosphere solar irradiance (′SOLAR′ in *<rootname>*.7sc) in units of μW cm^{-2} / μm if XFLAG equals ′M′, in units of W cm^{-2} / nm if XFLAG equals ′N′ and, otherwise, in units of W cm^{-2} / cm^{-1}.

4.7   The *<rootname>*.acd (or atmcor.dat) atmospheric correction data file

4.7.1   *What is a <rootname>*.acd *file*?

A *<rootname>*.acd file is a MODTRAN spectral output file containing data used to atmospherically correct down-looking spectral imagery data.

4.7.2   *When is the <rootname>*.acd *file generated*?

A *<rootname>*.acd file is generated when a solar radiance calculation is performed (CARD 1 input IEMSCT equals 2 or 4) with DISORT multiple scattering (CARD 1 input IMULT = ±1 and CARD 1A input DIS = ′T′), with a line-of-sight that terminates at the ground, and with the input flag DISALB (CARD 1A) set to ′T′.

4.7.3   *How do inputs affect which <rootname>*.acd *outputs are generated*?

The *<rootname>*.acd file output changes depending upon whether or not the Correlated-k (Ck) algorithm is selected (CARD 1 input MODTRN). When Ck is used, spherical albedo and both the direct and diffuse transmittances are output for each band model bin k sub-interval. Sun-to-ground and ground-to-sensor direct transmittances are included in the table. When Ck is not used, band model resolution spherical albedo and both the direct and diffuse transmittances are output. In addition, the sun-to-ground direct transmittance is replaced by the sun-to-ground-to-sensor transmittance. This is necessary because the L-shaped path transmittance averaged over the band model spectral bin does not equal the product of the sun-to-ground and ground-to-sensor band averaged transmittances.

4.7.4   *What is the definition of the <rootname>*.acd *file spectral outputs*?

The *<rootname>*.acd file contains 8 columns of spectral data including diffuse transmittances and spherical albedo from the ground, Figure 4.7. The data are spectrally unconvolved, generated at the resolution of the chosen band model (0.1, 1.0, 5.0 or 15.0 cm^{-1}). If the correlated-k algorithm is selected, the spectral outputs are defined for each k sub-interval; otherwise, the band model resolution outputs are defined for individual band model spectral bins. The columns are described below.

Diffuse Transmittance Definition   Diffuse Transmittance from Reciprocity   Atmosphere Embedded Diffuse Transmittance   Spherical Albedo from Ground
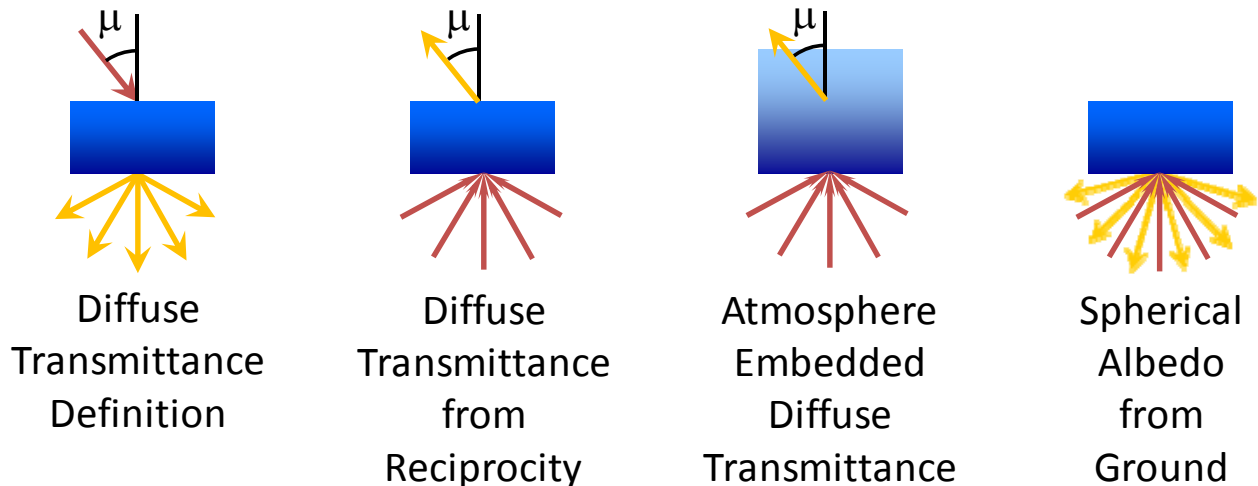
Figure 4.7 Illustration of Diffuse Transmittance and Spherical Albedo. In these images, the brown rays represent illumination impingent on the atmosphere and yellow rays represent outgoing radiation.

SPECTRAL FREQUENCY [CM-1]:	Central frequency of the current band model spectral bin in cm^{-1}.
K INT:	Integer label of a *k*-distribution interval. If the band model option is used, the *k* interval is the entire band model spectral bin and the label is always 1. With the Correlated-*k* algorithm turned on, there are up to 17 intervals if CARD 1 input SPEED = ′M′ (for moderate speed) or up to 33 intervals if SPEED = ′S′ (for slow speed). However, some band model spectral bins may have fewer than the maximum number of *k* sub-intervals. If there are no molecular transitions centered in the band model spectral bin, then only 4 *k* sub-intervals are used to model molecular line tail contribution. If there are no molecular transitions or line tails, then a single *k* value is used.
k WEIGHT:	The weight of the *k* sub-interval. The sum of the weight of all *k* sub-intervals in a band model spectral bin is one.
SUN->GND DIFFUSE TRANSM:	The sun to ground diffuse transmittance of the atmosphere at solar zenith angle, θ. For a horizontally homogeneous semi-infinite medium illuminated on side A by a collimated source at incident angle θ, the diffuse transmittance is defined as the fraction of that source that passes through the medium (to side B) after being scattered at least once, Figure 4.7. For vertically inhomogeneous media, the diffuse transmittance for angle θ varies depending upon which side of the medium is illuminated. It has been proved via the law of reciprocity that the diffuse transmittance is also equal to the density of scattered radiation exiting side A in direction θ resulting from homogeneous illumination of side B [Stamnes *et al.*, 1982].
SUN->GND DIRECT TRANSM *or* SUN->GND->OBS DIRECT TRANSM:	The sun to ground direct transmittance if the MODTRAN correlated-*k* algorithm is used; otherwise, the sun to ground to observer (or sensor) direct transmittance.
OBS->GND EMBEDDED DIF TRANSM:	The observer to ground embedded diffuse transmittance, Figure 4.7. As noted above, the diffuse transmittance equals the density of radiation exiting a medium in direction θ when isotropically illuminated from the other side. MODTRAN introduces the concept of an embedded diffuse transmittance. That is the density of radiation headed in direction θ at a location within a medium when isotropically illuminated.
OBS->GND DIRECT TRANSM:	The observer (or sensor) to ground direct transmittance.
SPHERICAL ALBEDO FROM GND:	The spherical albedo from the ground, Figure 4.7. For a horizontally homogeneous semi-infinite medium illuminated on side A by a homogeneous source, the spherical albedo is the fraction of that source that scatters back to side A. Like the diffuse transmittance, the spherical albedo depends on which side is being illuminated if the medium is not vertically homogenous. Here, the spherical albedo is explicitly defined from the perspective of the ground.

4.7.5 *How can the <rootname>.acd data be used in atmospheric correction?*

Atmospheric correction is the process of mapping of down-looking sensor radiance images into surface reflectance maps by first retrieving the atmospheric state and then utilizing the retrieved atmosphere to determine the radiance to reflectance map. In the solar dominated short-wave region, it is convenient to introduce the dimensionless pixel *apparent* reflectance, ρ_a, defined as the reflectance that would be retrieved given observed pixel radiance, *R*, no atmosphere and a flat Lambertian surface:

$$\rho_a = \frac{\pi R}{\mu I_0} \tag{1}$$

Here I_0 is the top-of-atmosphere (TOA) solar irradiance, μ is the cosine of the solar zenith angle and the π steradians results from the Lambertian surface reflectance normalization.

Since the goal of atmospheric correction is retrieval of surface reflectances, the solar apparent reflectance is partitioned into the following three components:

- Photons that never interact with the ground,
- Photons that reflect off the imaged pixel and are directly transmitted to the sensor, and
- Photons leaving the ground surface that subsequently scatter into the line-of-sight.

The first term provides no information about the surface, the second term provides information about the imaged pixel, and the final term provides information about the effective average reflectance of the extended surface neighboring the imaged pixel. This partitioning of the total radiance is very different from that in the <rootname>.tp7 output files where the path scattered radiance terms include surface contributions, emitted and reflected, that scatter into the line-of-sight. The monochromatic apparent reflectance can be written as follows:

$$\rho_a = \rho_0 + \frac{(T_s + t_s)T\rho}{1 - \bar{\rho}\,\sigma} + \frac{(T_s + t_s)t\,\bar{\rho}}{1 - \bar{\rho}\,\sigma} \quad, \tag{2}$$

where

- ρ_0 is the path reflectance resulting from photons that never interact with the surface,
- T is the observer-to-ground direct transmittance,
- T_s is the sun-to-ground direct transmittance,
- t is the (TOA or atmosphere-embedded) observer-to-ground diffuse transmittance,
- t_s is the sun-to-ground diffuse transmittance,
- σ is the spherical albedo from the ground,
- ρ is the imaged-pixel ground reflectance, and
- $\bar{\rho}$ is the area-averaged ground reflectance.

Each of these quantities varies spectrally, but the spectral index has been suppressed for notational simplicity. The sum $T_s + t_s$ is the total downward transmittance of the solar flux, $T\rho$ is the pixel reflectance of that flux transmitted directly to the sensor, and $t\,\bar{\rho}$ is the diffusely transmitted reflected flux. The denominator accounts for the upward surface flux that is reflected by the atmosphere (σ) back to the ground and then reflected by the ground ($\bar{\rho}$) upward. Since this can occur multiple times, Eq. (2) follows from the geometric sum:

$$(T_s + t_s)(T\rho + t\,\bar{\rho})\left[1 + \bar{\rho}\,\sigma + (\bar{\rho}\,\sigma)^2 + \cdots\right] = \frac{(T_s + t_s)T\rho}{1 - \bar{\rho}\,\sigma} + \frac{(T_s + t_s)t\bar{\rho}}{1 - \bar{\rho}\,\sigma} \quad. \tag{3}$$

MODTRAN can generate band model resolution values for all the Eq. (2) atmospheric terms, namely ρ_0, T, T_s, t, t_s, and σ, in a single run. The path reflectance ρ_0 is obtained from MODTRAN by setting the surface albedo (CARD 1 input SURREF) to zero and the surface temperature to near zero (CARD 1 input TPTEMP = 1.0 K). This eliminates any surface contributions to the down-looking radiance so that the apparent reflectance and path reflectance are equal. Thus, Eq. (1) defines the path reflectance, and both the total spectral radiance, R, and the TOA solar irradiance, I_0, are <rootname>.tp7 outputs. The remaining atmospheric terms are either included in or available from the <rootname>.acd output file. If the band model option is run (CARD 1 input MODTRN = ′M′ or ′T′), then the sun-to-ground direct transmittance T_s is computed as the quotient of the sun-to-ground-to-observer direct

transmittance and the observer-to-ground direct transmittance T^l. If the correlated-k option is run (MODTRN = 'C' or 'K'), then Eq. (2) can be rewritten in its k-distribution form:

$$\rho_a = \rho_0 + \sum_i \Delta g_i \left(\frac{(t_{s,i} + T_{s,i}) T_i \rho}{1 - \overline{\rho}\, \sigma_i} + \frac{(t_{s,i} + T_{s,i_s}) t_i \overline{\rho}}{1 - \overline{\rho}\, \sigma_i} \right) \quad . \tag{4}$$

The sum is over the k sub-intervals i, and the Δg_i's are the interval weights, which are included in the *<rootname>*.acd output file.

It is important to note that Eq. (2) is only valid for monochromatic radiation. Consider what happens when the apparent reflectance is integrated over a spectral channel or band:

$$\langle \rho_a \rangle_f = \langle \rho_0 \rangle_f + \left\langle \frac{(T_s + t_s) T \rho}{1 - \overline{\rho}\, \sigma} \right\rangle_f + \left\langle \frac{(T_s + t_s) t \overline{\rho}}{1 - \overline{\rho}\, \sigma} \right\rangle_f \quad ; \quad \langle x \rangle_f \equiv \int_\nu x(\nu) f(\nu)\, d\nu \quad ,$$

$$\approx \langle \rho_0 \rangle_f + \left\langle \frac{(T_s + t_s) T}{1 - \overline{\rho}\, \sigma} \right\rangle_f \rho_f + \left\langle \frac{(T_s + t_s) t}{1 - \overline{\rho}\, \sigma} \right\rangle_f \overline{\rho}_f \tag{5}$$

where ν is spectral frequency and $f(\nu)$ is a unit normalized spectral response function. In the second line, the assumption is made that spectral variation of the (condensed-matter) surface reflectance terms is modest, and effective, channel-averaged values, ρ_f and $\overline{\rho}_f$, can be factored out of the spectral integration. The problem remains that two of the spectral convolutions in Eq. (5) couple surface and atmospheric terms. Standard atmospheric correction algorithms require that atmospheric terms be independent of the unknown surface reflectance. To accomplish this, the geometric series are reintroduced into Eq. (5)

$$\langle \rho_a \rangle_f \approx \langle \rho_0 \rangle_f + \left\langle (T_s + t_s) T \left[1 + \overline{\rho}\, \sigma + (\overline{\rho}\, \sigma)^2 + \cdots \right] \right\rangle_f \rho_f$$

$$+ \left\langle (T_s + t_s) t \left[1 + \overline{\rho}\, \sigma + (\overline{\rho}\, \sigma)^2 + \cdots \right] \right\rangle_f \overline{\rho}_f \tag{6}$$

If $\overline{\rho}\,\sigma$ is small, higher order terms can be ignored to give:

$$\langle \rho_a \rangle_f \approx \langle \rho_0 \rangle_f + \left\{ \langle (T_s + t_s) T \rangle_f + \langle (T_s + t_s) T\, \sigma \rangle_f \overline{\rho}_f \right\} \rho_f + \left\{ \langle (T_s + t_s) t \rangle_f + \langle (T_s + t_s) t\, \sigma \rangle_f \overline{\rho}_f \right\} \overline{\rho}_f \tag{7a}$$

$$\approx \langle \rho_0 \rangle_f + \frac{\langle (T_s + t_s) T \rangle_f}{1 - \sigma_1 \overline{\rho}_f} \rho_f + \frac{\langle (T_s + t_s) t \rangle_f}{1 - \sigma_2 \overline{\rho}_f} \overline{\rho}_f \quad , \tag{7b}$$

where

$$\sigma_1 \equiv \frac{\langle (T_s + t_s) T\, \sigma \rangle_f}{\langle (T_s + t_s) T \rangle_f} \quad and \quad \sigma_2 \equiv \frac{\langle (T_s + t_s) t\, \sigma \rangle_f}{\langle (T_s + t_s) t \rangle_f} \quad . \tag{8}$$

This derivation suggests that distinct spectral channel spherical albedos be defined for the two denominators in the apparent reflections equation.

In practice, the difference between the two spectral channel spherical albedos will be very small. It is desirable to define a single spectral channel spherical albedo $\overline{\sigma}$ to replace σ_1 and σ_2 since existing atmospheric correction algorithms do use a single value. To derive an expression for $\overline{\sigma}$, consider the constant surface reflectance case, i.e.,

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[1] This quotient is not well defined if the observer-to-ground transmittance T is zero. In this case, T_s is generally just set to zero. This is a good working approximation because it is essentially impossible to retrieve the ground pixel reflectance, ρ, if no photons reach the sensor along the direct sensor-to-ground path.

$\rho_f = \overline{\rho}_f$. With a derivation analogous to that from the previous paragraph, the following equation for the spectral channel apparent reflectance is obtained:

$$\langle \rho_a \rangle_f \approx \langle \rho_0 \rangle_f + \frac{\langle (T_s + t_s)(T + t) \rangle_f}{1 - \overline{\sigma}\,\overline{\rho}_f}\,\overline{\rho}_f \quad , \tag{9}$$

where

$$\overline{\sigma} \equiv \frac{\langle (T_s + t_s)(T + t)\,\sigma \rangle_f}{\langle (T_s + t_s)(T + t) \rangle_f} \quad . \tag{10}$$

Using this value for the spherical albedo, the spectral channel observed radiance, $\langle R \rangle_f$ is given by

$$\langle R \rangle_f \approx \langle R_0 \rangle_f + \frac{A_f \rho_f + B_f \overline{\rho}_f}{1 - \overline{\sigma}\,\overline{\rho}_f} \quad , \tag{11}$$

where

$\langle R_0 \rangle_f = \mu I_0 \langle \rho_0 \rangle_f / \pi$ is the spectral channel observed radiance for a non-reflecting and zero emission surface,

$A_f = \mu I_0 \langle (T_s + t_s)T \rangle_f / \pi$ is the product of the total transmitted solar irradiance and the sensor-to-ground direct transmittance convolved with the channel spectral response function,

$B_f = \mu I_0 \langle (T_s + t_s)t \rangle_f / \pi$ is the product of the total transmitted solar irradiance and the sensor-to-ground diffuse transmittance convolved with the channel spectral response function, and

$\overline{\sigma}$ is the spectral channel spherical albedo.

In MODTRAN5.3, these four outputs are included in the <rootname>.chn file for all the channels in the user-selected sensor spectral response function file. With MODTRAN5.2, the onus is placed on the user to perform the spectral convolutions.

4.8 The *<rootname>*.chn (or channels.out) spectral flux data file

4.8.1 *What is a <rootname>.chn file?*

A *<rootname>*.chn file is a MODTRAN output file containing data that has been spectrally convolved with user-supplied sensor response function data.

When is the *<rootname>*.chn *file generated?*

A spectral channel output file, *<rootname>*.chn, is generated whenever CARD 1A input LFLTNM is set to true. Setting LFLTNM to true triggers reading of the CARD 1A3 input FILTNM, which is the full path file name of a sensor filter file. These 2 column files contain sensor channel or band spectral response function values. The MODTRAN5.2 distribution includes filter files for a number of sensors in its DATA directory including ′airs.flt′, ′ASTER_swir.flt′, ′ASTER_tir.flt′, ′ASTER_vnir.flt′, ′aviris.flt′, ′GOES12ir.flt′, ′HyspIRI_TIR.flt′, ′landsat7.flt′, ′modis399_2176nm.flt′, and ′modis3p615_14p532.flt′. The format of these files is described in the MODTRAN user's manual for those who wish to create their own sensor filter file.

4.8.2 *How do inputs affect <rootname>.chn outputs?*

Many inputs affect the output of the *<rootname>*.chn files. In particular, CARD 1 input IEMSCT defines the type of radiation transport calculation, with IEMSCT = ′0′ for transmittance only mode, IEMSCT = ′1′ for thermal emission with or without scattering, IEMSCT = ′2′ for thermal plus solar radiance calculations, IEMSCT = ′3′ for transmitted solar/lunar irradiance, and IEMSCT = ′4′ for thermal emission plus solar radiance (no thermal scatter). The *<rootname>*.chn output columns for IEMSCT = ′2′ and = ′4′ are the same, but they differ for all other values of IEMSCT. Test case CirrusProfile uses the MODTRAN repeat run option to demonstrate all 4 *<rootname>*.chn output formats.

A more subtle input affecting the *<rootname>*.chn is first character on the first line of the selected sensor filter file. If that first character is ′M′ (for microns) or ′N′ (for nanometers), then the spectral response function f_λ for each

channel is defined on a wavelength (λ) grid and the corresponding channel output is computed as spectral integrals over wavelength with f_λ interpolated linearly in wavelength between spectral grid points. Similarly, if, the first character in the selected sensor filter file is 'W' (for wavenumbers), then the spectral response function f_ν for each channel is defined on a frequency (ν) grid and the corresponding channel output is computed as spectral integrals over frequency with f_ν interpolated linearly in frequency between spectral grid points.

If IEMSCT equals '1', '2' or '4' and if DISORT scattering is used, the path thermal radiance is not partitioned into its emission and scattering components. As a result, the DISORT thermal scatter column is not included in the output; there is only a total thermal path radiance column.

Finally, the *<rootname>*.chn file output is affected by CARD 1 input NOPRNT in concert with the CARD 4 spectral range inputs. If NOPRNT $\leq$ –1, then output is written for each sensor channel whether or not the calculation spectral range overlaps at all with the channel's spectral response function. If NOPRNT = 0, then output is written for any spectral channel for which there is at least some overlap with the spectral range. If NOPRNT $\geq$ 1, then output is written only for the spectral channels for which the calculation spectral range completely covers the channels response function spectral range.

4.8.3 *What is the definition of the <rootname>.chn outputs?*

There is a one-to-one correspondence between most of the *<rootname>*.chn and *<rootname>*.tp7 output, but the names of the columns are expanded upon in the *<rootname>*.chn header lines. The *<rootname>*.chn file for transmittance-only runs (CARD 1 input IEMSCT = 0) does not include columns for the collision induced absorption (CIA) species when MODTRAN5.2 is run; this output is only available with MODTRAN5.3. Each output column from the *<rootname>*.chn files is described below, and the corresponding *<rootname>*.tp7 column header is noted. Test case CirrusProfile uses the MODTRAN repeat run option to demonstrate the 4 distinct *<rootname>*.chn output formats that result from different input options. The *<rootname>*.chn files generally contain molecular absorbances (1 – molecular transmittances), while *<rootname>*.tp7 files contain transmittances. The general equations used to compute *<rootname>*.chn channel outputs are

Full Channel Equivalent Width in cm^{-1}: $\quad \int_\nu f_\nu \, d\nu \quad or \quad \int_\lambda f_\lambda \frac{C}{\lambda^2} \, d\lambda$

Full Channel Equivalent Width in μm or nm: $\quad \int_\lambda f_\lambda \, d\lambda \quad or \quad \int_\nu f_\nu \frac{C}{\nu^2} \, d\nu$

First Spectral Moment: $\quad \int_x x f_x \, dx \Big/ \int_x f_x \, dx$

Absorbance or Extinction: $\quad \int_x (1 - T_x) f_x \, dx \Big/ \int_x f_x \, dx$

Transmittance: $\quad 1 - \left[\int_x (1 - T_x) f_x \, dx \Big/ \int_x f_x \, dx \right]$

Channel Radiance (W sr^{-1} cm^{-2}) or Irradiance (W cm^{-2}): $\quad \int_x R_x f_x \, dx$

Channel Spectral Radiance or Irradiance: $\quad \int_x R_x f_x \, dx \Big/ \int_x f_x \, dx \quad or \quad \int_x R_x f_x \, dx \Big/ \int_y f_y \frac{C}{y^2} \, dy$

In these equations, f_ν is a channel spectral response function defined on a frequency, ν, grid (cm^{-1}) and f_λ is the channel spectral response function defined on a wavelength, λ, grid (μm or nm). The constant C is a conversion factor equal to either 10^4 μm / cm or 10^7 nm / cm. Variable x is frequency ν if the response function is defined on a frequency grid and x is wavelength λ if the response function is defined on a wavelength grid; $y = \lambda$ if $x = \nu$, and $y = \nu$ if $x = \lambda$. T_x represents an arbitrary spectral transmittance and R_x represents an arbitrary spectral radiance or irradiance. The term absorbance is used when scattering attenuation is excluded from the extinction, and the term extinction is used when both scattering and absorption attenuation is included.

APPENDIX G

<u>COLUMNS COMMON TO ALL <*rootname*>.chn OUTPUT FILES</u>

1ST SPECTRAL MOMENT:	Defined using the equations above, with its units (cm⁻¹, μm or nm) chosen to be the spectral grid unit of the spectral response function. This value does not depend on the spectral range of the MODTRAN calculation, only on the spectral response function itself. The 1st spectral moment is used as the channel reference frequency or wavelength, not the spectral point at which the response function is maximum.
CHANNEL NO.	Spectral channels are numbered, starting from one, based on the order they are listed in the spectral response function file. A negative value is output if the spectral range of the MODTRAN calculation did not completely cover the spectral range of the response function.
FULL CHANNEL EQUIVALENT WIDTH	Two output columns, defined using the equations above. The first column is in units of cm⁻¹, and the second column is in units of μm unless the spectral grid of the response function is in nm units.
SPECTRAL MINIMUM	The spectral minimum of the response function. This value does not depend on the spectral range of the MODTRAN calculation, only on the spectral response function itself.
SPECTRAL MAXIMUM	The spectral maximum of the response function. This value does not depend on the spectral range of the MODTRAN calculation, only on the spectral response function itself.
CHANNEL DESCRIPTION	This column contains the header line for the current channel from the spectral response function (filter) file.

<u>IEMSCT = 0 (transmittance only mode)</u>

AVERAGE EXTINCTION (1-TRANSM):	Absorbance plus scattering attenuation computed from the band model resolution <*rootname*>.tp7 "COMBIN TRANS", i.e. the direct transmittance for the line-of-sight (LOS) path including all sources of molecular and particulate extinction
CHANNEL EXTINCTION (CM-1):	Product of AVERAGE EXTINCTION and FULL CHANNEL EQUIVALENT WIDTH (CM-1)
H2O (NO CONT) ABSORBANCE:	Absorbance computed from the band model resolution <*rootname*>.tp7 "H2O TRANS" output, i.e. the water vapor transmittance for the LOS path *excluding* water continuum contributions
UNIFORMLY MIX GASES ABSORBANCE:	Absorbance computed from the band model resolution <*rootname*>.tp7 "UMIX TRANS" output, i.e. the uniformly mixed gases transmittance for the LOS path. The uniformly mixed gases are defined here to include CO_2, CO, CH_4, N_2O and O_2.
O3 ABSORBANCE:	Absorbance computed from the band model resolution <*rootname*>.tp7 "O3 TRANS" output, i.e. the LOS path ozone transmittance
TRACE GASES ABSORBANCE:	Absorbance computed from the band model resolution <*rootname*>.tp7 "TRACE TRANS" output, i.e. the trace gas transmittance for the LOS path. The trace gases are defined here to include NH_3, NO, NO_2, SO_2 and HNO_3. Water vapor, the uniformly mixed gases, ozone and the trace gases together constitute the 12 MODTRAN default band model species.

N2 CONTINUUM ABSORBANCE:	Absorbance computed from the band model resolution *<rootname>*.tp7 "N2 CONT" output, i.e. the LOS path nitrogen continuum transmittance
H2O CONTINUUM ABSORBANCE:	Absorbance computed from the band model resolution *<rootname>*.tp7 "H2O CONT" output, i.e. the LOS path water vapor continuum transmittance
MOLECULAR (RAYLEIGH) SCATTERING:	Extinction computed from the band model resolution *<rootname>*.tp7 "MOLEC SCAT" output, i.e. the LOS path molecular scattering (Rayleigh) transmittance
AEROSOL PLUS CLOUD EXTINCTION:	Absorbance plus scattering attenuation computed from the band model resolution *<rootname>*.tp7 "AER+CLD TRANS" output, i.e. the LOS path aerosols plus clouds transmittance
HNO3 ABSORBANCE:	Absorbance computed from the band model resolution *<rootname>*.tp7 "HNO3 TRANS" output, i.e. the LOS path nitric acid transmittance
AEROSOL PLUS CLOUD ABSORBANCE:	Absorbance computed from the band model resolution *<rootname>*.tp7 "AER+CLD abTRNS" output, i.e. the LOS path attenuation arising from aerosol and cloud absorption. This term excludes the attenuation from aerosol and cloud scattering.
CO2 ABSORBANCE:	Absorbance computed from the band model resolution *<rootname>*.tp7 "CO2 TRANS" output, i.e. the LOS path carbon dioxide transmittance
CO ABSORBANCE:	Absorbance computed from the band model resolution *<rootname>*.tp7 "CO TRANS" output, i.e. the LOS path carbon monoxide transmittance
CH4 ABSORBANCE:	Absorbance computed from the band model resolution *<rootname>*.tp7 "CH4 TRANS" output, i.e. the LOS path methane transmittance
N2O ABSORBANCE:	Absorbance computed from the band model resolution *<rootname>*.tp7 "N2O TRANS" output, i.e. the LOS path nitrous oxide transmittance
O2 ABSORBANCE:	Absorbance computed from the band model resolution *<rootname>*.tp7 "O2 TRANS" output, i.e. the LOS path oxygen gas transmittance
NH3 ABSORBANCE:	Absorbance computed from the band model resolution *<rootname>*.tp7 "NH3 TRANS" output, i.e. the LOS path ammonia transmittance
NO ABSORBANCE:	Absorbance computed from the band model resolution *<rootname>*.tp7 "NO TRANS" output, i.e. the LOS path nitric oxide transmittance
NO2 ABSORBANCE:	Absorbance computed from the band model resolution *<rootname>*.tp7 "NO2 TRANS" output, i.e. the LOS path nitrogen dioxide transmittance
SO2 ABSORBANCE:	Absorbance computed from the band model resolution *<rootname>*.tp7 "SO2 TRANS" output, i.e. the LOS path sulfur dioxide transmittance
CLOUD EXTINCTION:	Absorbance plus scattering attenuation computed from the band model resolution *<rootname>*.tp7 "CLOUD TRANS" output, i.e. the LOS path cirrus plus water cloud transmittance
CFC11 ABSORBANCE:	Absorbance computed from the band model resolution *<rootname>*.tp7 "CFC11 TRANS" output, i.e. the LOS path trichlorofluoromethane transmittance

CFC12 ABSORBANCE:	Absorbance computed from the band model resolution *<rootname>*.tp7 "CFC12 TRANS" output, i.e. the LOS path dichlorodifluoromethane transmittance
CFC13 ABSORBANCE:	Absorbance computed from the band model resolution *<rootname>*.tp7 "CFC13 TRANS" output, i.e. the LOS path chloro-trifluoromethane transmittance
CFC14 ABSORBANCE:	Absorbance computed from the band model resolution *<rootname>*.tp7 "CFC14 TRANS" output, i.e. the LOS path carbon tetrafluoride transmittance
CFC22 ABSORBANCE:	Absorbance computed from the band model resolution *<rootname>*.tp7 "CFC22 TRANS" output, i.e. the LOS path chlorodifluoromethane transmittance
CFC113 ABSORBANCE:	Absorbance computed from the band model resolution *<rootname>*.tp7 "CFC113 TRANS" output, i.e. the LOS path 1,1,2-trichlorotrifluoroethane transmittance
CFC114 ABSORBANCE:	Absorbance computed from the band model resolution *<rootname>*.tp7 "CFC114 TRANS" output, i.e. the LOS path 1,2-dichlorotetrafluoroethane transmittance
CFC115 ABSORBANCE:	Absorbance computed from the band model resolution *<rootname>*.tp7 "CFC115 TRANS" output, i.e. the LOS path chloropentafluoroethane transmittance
CLONO2 ABSORBANCE:	Absorbance computed from the band model resolution *<rootname>*.tp7 "CLONO2 TRANS" output, i.e. the LOS path chlorine nitrate transmittance
HNO4 ABSORBANCE:	Absorbance computed from the band model resolution *<rootname>*.tp7 "HNO4 TRANS" output, i.e. the LOS path hydroxyl nitrate transmittance
CHCL2F ABSORBANCE:	Absorbance computed from the band model resolution *<rootname>*.tp7 "CHCL2F TRANS" output, i.e. the LOS path dichlorofluoromethane transmittance
CCL4 ABSORBANCE:	Absorbance computed from the band model resolution *<rootname>*.tp7 "CCL4 TRANS" output, i.e. the LOS path carbon tetrachloride transmittance
N2O5 ABSORBANCE:	Absorbance computed from the band model resolution *<rootname>*.tp7 "N2O5 TRANS" output, i.e. the LOS path dinitrogen pentoxide transmittance
Aux Species ABSORBANCE:	Absorbance computed from the band model resolution *<rootname>*.tp7 "Aux Species TRANS" output, i.e. the LOS path transmittance arising from input set of auxiliary species

IEMSCT = 1, 2 or 4 (radiance modes)

SPECTRAL RADIANCE:	Two output columns, defined using the equations above and computed from the band model resolution *<rootname>*.tp7 "TOTAL_RAD" output, i.e. the total radiance observed by a sensor. The first column is in W sr^{-1} cm^{-2} / cm^{-1} units. The second column is in W sr^{-1} cm^{-2} / μm units unless the spectral grid of the response function is in nm units. In that case, output is in W sr^{-1} cm^{-2} / nm units.
BRIGHTNESS TEMP:	Brightness temperature in Kelvin, defined as the temperature a blackbody would need to have to emit the CHANNEL RADIANCE (described next).

CHANNEL RADIANCE:	Defined using the equations above and computed from the band model resolution <*rootname*>.tp7 "TOTAL_RAD" output, i.e. the total radiance observed by a sensor. The output has units of W sr^{-1} cm^{-2}. This is computed as the sum of the following terms described below: PATH + SCAT EMISSION, TRANSM GROUND EMISSION, PATH TOTAL SCAT SOLAR and TOTAL TRANSM GRND REFLECT.
PATH + SCAT EMISSION:	Channel radiance computed from the band model resolution <*rootname*>.tp7 "PTH_THRML" output, i.e. the path thermal radiation, including both the path thermal emission and the thermal radiation scattered by the atmosphere directly into the LOS and transmitted to the sensor. The output is in W sr^{-1} cm^{-2} units.
SCATTERED EMISSION:	Channel radiance computed from the band model resolution <*rootname*>.tp7 "THRML_SCT" output, i.e. the atmospherically scattered component of PTH_THRML equal to the thermal radiation scattered by the atmosphere directly into the LOS and transmitted to the sensor. The output is in W sr^{-1} cm^{-2} units.
TRANSM GROUND EMISSION:	Channel radiance computed from the band model resolution <*rootname*>.tp7 "SURF_EMIS" output, i.e. the surface emission directly transmitted to the sensor. The output is in W sr^{-1} cm^{-2} units. If the LOS terminates at the ground, this term is computed as the product of the Planck surface emission, the directional emissivity and the path transmittance. If the LOS does not terminate at the ground BUT a positive temperature is specified for CARD 1 input TPTEMP, SURF_EMIS will contain the transmitted surface emission of a target object. If the LOS does not terminate at the ground AND input TPTEMP is zero, then SURF_EMIS is zero.
PATH TOTAL SCAT SOLAR:	Channel radiance computed from the band model resolution <*rootname*>.tp7 "SOL_SCAT" output, i.e. the solar/lunar radiation scattered by the atmosphere and directly transmitted to the sensor. The output is in W sr^{-1} cm^{-2} units. This includes the PATH SINGLE SCAT SOLAR component.
PATH SINGLE SCAT SOLAR:	Channel radiance computed from the band model resolution <*rootname*>.tp7 "SING_SCAT" output, i.e. the solar/lunar radiation single scattered by the atmosphere and directly transmitted to the sensor. The output has units of W sr^{-1} cm^{-2}.
TOTAL TRANSM GRND REFLECT:	Channel radiance computed from the band model resolution <*rootname*>.tp7 "GRND_RFLT" output, i.e. the ground reflected radiation directly transmitted to the sensor. The output has units of W sr^{-1} cm^{-2}. This column includes reflection of three downward flux components – direct solar, diffuse solar and diffuse thermal.
DIRECT TRANSM GRND REFLECT:	Channel radiance computed from the band model resolution <*rootname*>.tp7 "DRCT_RFLT" output, i.e. the ground reflected radiation arising from solar photons that travel along the sun to ground to sensor path without being scattered or absorbed by the atmosphere. The output has units of W sr^{-1} cm^{-2}.
TRANSM SOLAR LOS+SUN PATH:	Channel irradiance computed from the band model resolution <*rootname*>.tp7 "REF_SOL" output, i.e. the product of the sensor-to-final_altitude-to-sun transmittance (final_altitude is either the ground or CARD 3 input H2ALT) and the TOA (top-of-atmosphere) solar irradiance. The output has units of W cm^{-2}. It does not include the surface reflectance.

TRANSM SOLAR TO SENSOR:	Channel irradiance computed from the band model resolution *<rootname>*.tp7 "SOL@OBS" output, i.e. the TOA solar irradiance transmitted to the sensor or observer (CARD 1 input H1ALT). The output is in W cm^{-2} units and the surface reflectance is excluded.
SENSOR PATH TRANSM:	Transmittance computed from the band model resolution *<rootname>*.tp7 "TOT_TRANS" output, i.e. the direct transmittance for the line-of-sight path including all sources of molecular and particulate extinction.
SURFACE DIRECTIONAL EMISSIVITY:	Directional emissivity at the ground toward the sensor (between 0 and 1 inclusive) computed from the band model resolution *<rootname>*.tp7 "DIR_EM" output.

IEMSCT = 3 (solar/lunar irradiance mode)

TRANSMITTED SPECTRAL SOLAR IRRADIANCE:	Two channel spectral irradiance columns defined using the equations above and computed from the band model resolution *<rootname>*.tp7 "SOL TR" output, i.e. the product of the band model resolution direct transmittance and the top-of-atmosphere solar irradiance. The first column has units of W cm^{-2} / cm^{-1}. The second column is in W cm^{-2} / μm units unless the spectral grid of the response function is in nm. In that case, the output is in W cm^{-2} / nm units.
TRANSMITTED SOLAR IRRADIANCE:	Channel irradiance computed from the band model resolution *<rootname>*.tp7 "SOL TR" output, i.e. the product of the band model resolution direct transmittance and the top-of-atmosphere solar irradiance. The output is in W cm^{-2} units.
TOP OF ATMOS SOLAR IRRAD.:	Channel irradiance computed from the band model resolution *<rootname>*.tp7 "SOLAR" output, i.e. the band model resolution top-of-atmosphere solar irradiance. The output is in W cm^{-2} units.
SOLAR PATH TRANSM:	Transmittance computed from the band model resolution *<rootname>*.tp7 "TRANS" output, i.e. the band model resolution top-of-atmosphere solar irradiance. The output is in W cm^{-2} units.

4.9   The *<rootname>*.flx (or specflux) spectral flux data file

4.9.1   *What is a <rootname>.flx file?*

A *<rootname>*.flx file is a MODTRAN output file containing spectral flux data at multiple altitude levels.

4.9.2   *When is the <rootname>.flx file generated?*

MODTRAN generates spectral flux data whenever a multiple scattering line-of-sight radiance calculation is performed (IEMSCT = ′1′, ′2′ or ′4′ and IMULT = ′-1′ or ′1′, both on CARD 1).

The spectral flux data is written to a *<rootname>*.flx (or specflux) output file whenever it is generated and the case insensitive input FLAGS(7:7) on CARD 4 equals either ′T′ or ′F′ [the *<rootname>*.flx file is not created when FLAGS(7:7) is left blank]. The ′T′ or ′F′ distinguishes a line feed option. If FLAGS(7:7) is set to ′T′, then the table in the *<rootname>*.flx file is only 80 characters wide and contains spectral flux data for at most 2 altitudes per line. If, on the other hand, FLAGS(7:7) is set to ′F′, then each line of the *<rootname>*.flx file table contains a spectral grid point (wavelength or frequency) and spectral flux data for ALL selected altitude levels. The FLAGS(7:7) equals ′F′ option is preferred for plotting or importing the data into a spread sheet, while the FLAGS(7:7) equals ′T′ option is preferred for simple editing and viewing of the spectral flux data.

4.9.3 *How do MODTRAN inputs affect <rootname>.flx output?*

The *<rootname>*.flx (or specflux) output files can be quite large. By default, they contain spectral flux data for each spectral grid point and at each atmospheric altitude level. For many applications, the totality of information is not required. MODTRAN provides the MLFLX input on CARD 4 to limit the number of output altitude levels. If MLFLX is a positive integer less than the total number of atmospheric levels, then spectral flux information is only written for the first MLFLX atmospheric levels and for the top-of-atmosphere (TOA). For example, if MLFLX is set to ′1′, then the *<rootname>*.flx table will only contain ground and TOA spectral flux data.

If input FLAGS(1:1) on CARD 4 equals blank or ′W′, then the spectral flux data is generated on a cm^{-1} grid from V1 to V2 cm^{-1} with a DV cm^{-1} step size (V1, V2 and DV are all CARD 4 inputs). Spectral flux values are in units of W cm^{-2}/cm^{-1}. The spectral resolution of the flux output is FWHM cm^{-1}, where FWHM is a CARD 4 input equal to the full width at half maximum of the scanning or filter function. If FLAGS(2:2) is blank, then a rectangular slit function is used if the FWHM is less than twice the band model resolution and a triangular slit function is used otherwise. If FLAGS(2:2) is not blank, then its value determines the type of slit function (′1′ or ′T′ for triangular, ′2′ or ′R′ for rectangular, ′3′ or ′G′ for Gaussian, ′4′ or ′S′ for Sinc, ′5′ or ′C′ for Sinc-squared, and ′6′ or ′H′ for Hamming).

If input FLAGS(1:1) on CARD 4 is ′M′ for microns [′N′ for nanometers], then the spectral flux data is generated on a μm [nm] grid from V1 to V2 μm [nm] with a DV μm [nm] step size, respectively. Spectral flux values are in units on W cm^{-2}/μm [W cm^{-2}/nm]. The spectral resolution of the flux output is FWHM μm [nm]. The value of FLAGS(2:2) determines the type of slit function.

4.9.4 *What is the definition of the <rootname>.flx outputs?*

There are three primary spectral flux outputs in the *<rootname>*.flx (or specflux) output files: upward diffuse flux F^+, downward diffuse flux F^- and direct solar flux. The direct solar flux is computed as the product of 3 terms, the top-of-atmosphere (TOA) solar irradiance, the solar path direct transmittance from the TOA to the current atmospheric altitude level, and the cosine of the solar zenith angle at that level. The spectral diffuse flux terms are calculated from the MODTRAN plane-parallel multiple scattering modules, either the 2-stream Isaacs [Isaacs *et al*., 1987; Meador and Weaver, 1980] or the discrete ordinate DISORT [Stamnes *et al*., 1988; Stamnes *et al*., 2000]. The basic equation is

$$F^\pm(z) = 2\pi \int_0^1 \mu\, I^0(z,\pm\mu)\, d\mu \quad,$$

where z is the altitude level, μ is the positive cosine of the hemisphere view angle, and $I^0(z,\pm\mu)$ is the zero order coefficient of the azimuth angle ϕ Fourier cosine series for the line-of-sight diffuse radiation intensity $I(z,\mu,\phi)$:

$$I(z,\mu,\phi) = \sum_{m=0}^{2M-1} I^m(z,\mu)\cos m(\phi-\phi_0) \quad.$$

In this equation, ϕ_0 is the solar azimuth angle and $2M$ is the number of azimuth moments included in the calculation.

In the 2-stream model, the flux values are proportional to the 60° intensities and equal to $\pi I^0(z,\pm\frac{1}{2})$. DISORT computes the upward and downward fluxes of Eq. (1) with a Gaussian quadrature integral, and only requires solving the radiative transfer equations for the first (m=0) azimuth moment.

MODTRAN scattered radiance calculations can be run in a thermal radiance only mode (CARD 1 input IEMSCT equal to ′1′), in a thermal plus solar radiance mode (IEMSCT equal to ′2′), or in a thermal emission plus solar radiance model (IEMSCT equal to ′4′). In the thermal radiance only mode (IEMSCT=′1′), the diffuse flux terms only include thermal contributions and the direct solar flux is zero. In the thermal plus solar radiance mode (IEMSCT=′2′), the diffuse flux terms include both the solar and thermal contributions. In the thermal emission plus solar radiance mode (IEMSCT=′4′), the diffuse flux terms only include solar contributions.

The end of the *<rootname>*.flx table contains the sum of the spectral flux terms multiplied by the spectral step size, CARD 4 input DV. The unit of the band pass flux values is W / cm^2.

4.9.5 *Can the <rootname>.flx data be used to model the flux impingent on a surface?*

For a flat ground, the sum of the downward diffuse and the direct solar flux values at the ground level is the flux impingent on the ground. The question has arisen as to whether data from the flux file can be used to compute the spectral flux impingent on an arbitrarily oriented facet within the atmosphere. The correct method for calculating this flux requires integrating the impingent radiance over the hemisphere normal to the facet. If thousands of facets are being considered, the full set of calculations soon become unmanageable.

In the 2-stream approximation, the assumption is made that downward and upward diffuse radiances are each isotropic. Obviously, this is not an optimal assumption, but it may suffice for some applications. Using the 2-stream approach, the diffuse spectral flux impingent on a facet, with normal zenith angle θ (θ equals 0° for an upward facing facet and equals 180° for a downward facing facet) is given by

$$F(z, \theta) = F^-(z)\cos^2(\theta/2) + F^+(z)\sin^2(\theta/2) \quad,$$

where F^+ is the upward diffuse flux and F^- is the downward diffuse flux.

The direct solar flux is zero unless the facet faces the sun, i.e., the dot product of the facet normal, $\hat{r}_f$, and the solar direction unit vector, $\hat{r}_s$, is positive (note that the z-component of $\hat{r}_f$ equals the cosine of θ). Since the MODTRAN direct solar flux, $F^{dir}(z)$, includes the cosine solar zenith angle factor, the direct solar flux impingent on a facet is computed as follows:

$$F^{dir}(z, \hat{r}_f, \hat{r}_s) = \begin{cases} F^{dir}(z)\,\hat{r}_f \bullet \hat{r}_s / \mu_0 & for \quad \hat{r}_f \bullet \hat{r}_s > 0 \\ 0 & otherwise \end{cases}$$

Here, μ_0 is the cosine of the solar zenith angle, equal to the z-component of $\hat{r}_s$.

4.10 The *<rootname>*.clr (or clrates) spectral flux data file

4.10.1 *What is a <rootname>.clr file?*

A *<rootname>*.clr file is a MODTRAN output file containing spectral cooling rate data.

4.10.2 *When is the <rootname>.clr file generated?*

MODTRAN generates a *<rootname>*.clr (or clrates) file containing spectral cooling rates as a function of altitude if a multiple scattering radiance calculation is run (IEMSCT = ′1′, ′2′ or ′4′ and IMULT = ′-1′ or ′1′, both on CARD 1) and the CARD 1 input NOPRNT is set to -2.

4.10.3 *How do MODTRAN inputs affect <rootname>.clr output?*

There is no spectral convolution of spectral cooling rates. The spectral resolution of the cooling rates is the band model resolution. The selection of the band model file root name (CARD 1A2 input BMNAME) determines whether a 0.1, 1.0, 5.0 or 15.0 cm⁻¹ band model is being used; if BMNAME is not entered, then the 1.0 cm⁻¹ band model is used. The spectral cooling rate table contains data for every band model spectral bin processed. This will generally include spectral padding beyond the V1 to V2 (CARD 4 inputs) spectral range to enable processing of spectral filters and interpolation of spectral data internal to MODTRAN.

Data is generated at each atmospheric level. MODTRAN requires that the atmosphere be defined with at least 4 altitude levels.

4.10.4 *What is the definition of the <rootname>.*clr *outputs*?

The *<rootname>*.clr file contains 4 header lines as shown:

```
P(MB): 1012.99854 901.995728 802.001099 709.996399 628.000000

   FREQ   SPECTRAL COOLING RATES
   CM-1   K DAY-1 / CM-1
```

This example is taken from test case SO2_CF4_CCl4, which contains 2 MODTRAN runs, the second of which generates cooling rate data. Note that this test case defines the atmosphere with only 4 layers (5 altitude levels). The first line of the header lists the pressure (mb) of each atmospheric altitude level from ground to top-of-atmosphere. The next 3 lines are always the same, and indicate that the first column is the band model center frequency in cm^{-1}, and the spectral cooling rate data is defined in units of (K/day) / cm^{-1}.

The spectral cooling rates are defined as the change in temperature, *T*, with time, *t*, and they are calculate from the equation

$$\frac{dT}{dt} = \frac{g}{C_p} \frac{dF}{dP} = \frac{g}{C_p} \frac{1}{P} \frac{dF}{d\left[\ln\left(P/P_0\right)\right]}$$

Here *g* is the planet's (Earth's) gravitational constant [9.80665 m/s^2], C_p is the specific heat of air at constant pressure [~1.006 kJ/kg-K], *P* is the atmospheric pressure [mb] at each altitude level, P_0 is standard pressure [1013.25 mb], and *F* is the net downward flux at altitude *P*. MODTRAN approximates g / C_p as a constant equal to 84220 mb (K / day) / (W / cm^2), and the derivatives are calculated by fitting the flux versus logarithm-pressure curves to a 5-point spline fit.

4.11 Binary output

This section discusses the structure of unformatted (binary) MODTRAN output files. The user is reminded that these unformatted FORTRAN files contain record-length information that must be properly accounted for when these files are read by code written in a different language. That problem will not arise if a common platform and FORTRAN compiler is used to generate and read these files.

How does one translate MODTRAN5 binary output files to ASCII files?

The MODTRAN5.2 root directory includes the M5_bn2as program. M5_bn2as reads in the first line (and only the first line) of the mod5root.in file, which must be located in the current local directory when M5_bn2as is run. The mod5root.in file should contain the full or local path *<rootname>* of the MODTRAN binary output run. M5_bn2as will then read in the *<rootname>*_b.*ext* binary output files (the allowed extensions *ext* are ′tp7′, ′tp8′, ′acd′, ′flx′ and ′plt′) and convert them to ASCII *<rootname>*_a.*ext* files.

MODTRAN5.2 includes the ′BINwrite′ test case that generates binary output files. The mod5root.in file, delivered with MODTRAN5.2, contains all the test case root names, and intentionally lists the ′BINwrite′ test case first. After running through the MODTRAN test cases, one can run M5_bn2as without having to edit mod5root.in since ′BINwrite′ is first. Running M5_bn2as generates the ′BINwrite_a.tp7′, ′BINwrite_a.tp8′, ′BINwrite_a.acd′, ′BINwrite_a.flx′ and ′BINwrite_a.plt′ files. Each of these output files can be compared to test case ASCIIwrite output file with the same extension. The paired files should be essentially identical except for header lines that contain the CARD 1 input variable BINARY.

4.11.1 *How does one read a MODTRAN5 <rootname>_b.acd binary output file?*

The MODTRAN5 *<rootname>*_b.acd files are unformatted and sequentially accessed FORTRAN files. The format of the *<rootname>*_b.acd files is described here. Subroutine WT_ACD in the M5_bn2as program, which reads *<rootname>*_b.acd files for conversion to ASCII, can serve as a template.

Each line of a *<rootname>*_b.acd file is read using the following FORTRAN read statement:

`READ(UNIT=I1,IOSTAT=I2)R1,I3,R2,R3,R4,R5,R6,R7`

where the I*n* variables are of type integer*4 and the R*n* variables are of type real*4. The integer I1 is the file unit number. If integer I2 is non-zero, the end of file has been reached. If real R1 is less than zero, then output from a repeat run will begin on the next line. Otherwise, the variables map into the following *<rootname>*.acd outputs:

- R1 = SPECTRAL FREQUENCY [CM-1]
- I3 = K INT
- R2 = k WEIGHT
- R3 = SUN→GND DIFFUSE TRANSM
- R4 = SUN→GND DIRECT TRANSM *or* SUN→GND→OBS DIRECT TRANSM
- R5 = OBS->GND EMBEDDED DIF TRANSM
- R6 = OBS->GND DIRECT TRANSM
- R7 = SPHERICAL ALBEDO FROM GND

4.11.2 *How does one read a MODTRAN5 <rootname>_b.flx binary output file?*

The MODTRAN5 *<rootname>*_b.flx files are unformatted and sequentially accessed FORTRAN files. The format of the *<rootname>*_b.flx files is described here. Subroutine FLUXIO in the M5_bn2as program, which reads *<rootname>*_b.flx files for conversion to ASCII, can serve as a template.

The spectral flux table begins with a header line that is read in as follows:

`READ(UNIT=I1,IOSTAT=I2)C1,C2,C3,I3,R1,R2,R3,R4,(R5(I4),I4=0,I3)`

where the I*n* variables are of type integer*4, the R*n* variables are of type real*4 and the C*n* variables are of type character*1. The integer I1 is the file unit number. Integer I4 is a dummy loop index. If integer I2 is non-zero or C1 is blank (=' '), the end of file has been reached. Otherwise, the header variables have the following values:

- C1 = CARD 4 input FLAGS(1:1) [Defines the spectral grid and spectral flux units with 'W' for frequency in wavenumbers (cm^{-1}) and flux in W cm^{-2} / cm^{-1}, with 'M' for wavelength in microns (μm) and flux in W cm^{-2} / μm, and with 'N' for wavelength in nanometers (nm) and flux in W cm^{-2} / nm]
- C2 = CARD 4 input FLAGS(3:3) [Defines the spectral resolution either as 'A' for absolute full-width at half maximum (FWHM) or as 'R' for relative percent (FWHM = 100 dν/ν = 100 dλ/λ)]
- C3 = CARD 4 input FLAGS(7:7)
- I3 = CARD 4 input MLFLX [Spectral flux values are output at MLFLX + 1 altitude levels]
- R1 = CARD 4 input V1 [First spectral grid point]
- R2 = The spectral resolution of the band model [0.1, 1.0, 5.0 or 15.0 cm^{-1}]
- R3 = FWHM of scanning function in units defined by C1 ONLY IF R3 > 0.
- R4 = FWHM [cm^{-1}] of triangular slit function if R3 ≤ 0.
- R5 = Array of output altitude levels [km].

Each line of the spectral flux table contains $3 \times$ MLFLX + 4 values and is read in as follows:

```
READ(UNIT=I1)(D1(I4),I4=0,3*I3+3)
```

where the D1 array is of type real*8. The D1 array contains altitude dependent flux data for either a single spectral grid point or the in-band values. If D1(0) is non-negative [D1(0) $\geq$ 0.], then the D1 array contains the following:

- D1(0)   = Spectral grid point in units defined by C1
- D1(1), D1(4), … D1(3 I3 + 1) = Upward diffuse *spectral* flux in units dictated by C1 for R5 altitude levels 0, 1, …, MLFLX
- D1(2), D1(5), … D1(3 I3 + 2) = Downward diffuse *spectral* flux in units dictated by C1 for R5 altitude levels 0, 1, …, MLFLX
- D1(3), D1(6), … D1(3 I3 + 3) = Direct solar *spectral* flux in units dictated by C1 for R5 altitude levels 0, 1, …, MLFLX

The last line of the table has a negative entry for D1(0), and the remaining D1 array elements contain in-band flux values in units of W / cm^2:

- D1(1), D1(4), … D1(3 I3 + 1) = Upward diffuse *in-band* flux (W / cm^2) for R5 altitude levels 0, 1, …, MLFLX
- D1(2), D1(5), … D1(3 I3 + 2) = Downward diffuse *in-band* flux (W / cm^2) for R5 altitude levels 0, 1, …, MLFLX
- D1(3), D1(6), … D1(3 I3 + 3) = Direct solar *in-band* flux (W / cm^2) for R5 altitude levels 0, 1, …, MLFLX

After reading the last line of the flux table, another header line should be read to see if there is repeat run data remaining.

4.11.3 *How does one read a MODTRAN5 <rootname>_b.plt binary output file?*

The MODTRAN5 *<rootname>*_b.plt files are unformatted and sequentially accessed FORTRAN files. The format of the *<rootname>*_b.plt files is described here.

The data in a *<rootname>*_b.plt file is read using the following FORTRAN read statement:

```
READ(UNIT=I1, IOSTAT=I2)R1,R2
```

where the I*n* variables are of type integer*4 and the R*n* variables are of type real*4. The integer I1 is the file unit number. If I2 is non-zero, the *<rootname>*_b.plt file has no more data. Real R1 is negative when all the (*x*, *y*) data from a given run has been read in. Otherwise, R1 and R2 are defined as follows:

- R1 = Spectral grid point in either frequency (cm^{-1}) or wavelength (μm or nm); the spectral grid unit is determined from CARD 4 input XFLAG.
- R2 = Either spectral transmittance, radiance or irradiance. If CARD 1 input IEMSCT is 0 or CARD 4 input YFLAG is 'T', then R2 is a spectral transmittance; otherwise, R2 is a spectral radiance (IEMSCT = 1, 2, or 4) or spectral irradiance (IEMSCT = 3).

After a negative R1 value has been read in, a character string of maximum length 128 (c128) is read:

```
READ(UNIT=I1, IOSTAT=I2)c128
```

This string will either be blank (if CARD 4 input DLIMIT is blank) or it will contain the DLIMIT string and information about the location and magnitude of the maximum R2 value.

One should attempt to read addition (*x*, *y*) data to see if there is a repeat run. Terminate if I2 is not zero.

4.11.4 *How does one read a MODTRAN5 <rootname>_b.tp7 binary output file?*

The MODTRAN5 *<rootname>*_b.tp7 files are unformatted and sequentially accessed FORTRAN files. The format of the *<rootname>*_b.tp7 files is described here. The *<rootname>*_b.tp7 spectral output file begins with a header line containing a single character string of length 57, `c57`:

```
READ(UNIT=I1)c57
```

The integer `I1` is the *<rootname>*_b.tp7 file unit number. The `c57` character string contains MODTRAN version number and date information.

Whenever a *<rootname>*_b.tp7 file is generated, a short ASCII header is written in an accompanying *<rootname>*.tp7 file (if the *<rootname>*_b.tp7 file is converted to ASCII using the M5_bn2as program, the ASCII version is given the name *<rootname>*_a.tp7, so there is no conflict with *<rootname>*.tp7). In order to read a *<rootname>*_b.tp7 file, one must know the number of output spectral grid points for each MODTRAN run (the CARD 5 input IRPT can be used to run MODTRAN multiple times with a single input stream). To determine the number of output spectral grid points, read the first 10 characters of each line in the *<rootname>*.tp7 file until the `'TO RESTORE'` string is found:

```
10 CONTINUE
   READ(UNIT=J1, '(A)')c10
   IF(c10.NE.'TO RESTORE')GO TO 10
```

The integer*4 variable `J1` is the *<rootname>*.tp7 file unit number. The next line of the *<rootname>*.tp7 file contains the number of spectral grid points that are output:

```
   READ(UNIT=J1, '(46X, I8)')J2
```

The number of spectral grid points, `J2`, is a variable of type integer*4.

In addition to the `c57` header line, which only occurs once for the entire *<rootname>*_b.tp7 file, there is a header line for each binary output run:

```
READ(UNIT=I1, IOSTAT=I2)I3,I4,I5,I6,I7,L1,L2,C1
```

Here the `In` variables are of type integer*4, the `Ln` variables are of type logical and the `C1` variable is of type character*1. If integer `I2` is non-zero and/or `I3` is not equal to –9998, the end of file has been reached. Otherwise, the remaining header variables have the following values:

- `I4 =` CARD 4 input IEMSCT
- `I5 =` Number of MODTRAN default cross-section species, equal to parameter NMOLX in the src/PARAMS.h file
- `I6 =` Number of auxiliary (Y) species included in the MODTRAN calculation
- `I7 =` CARD 4 input IMULT
- `L1 =` CARD 1A input DIS
- `L2 =` CARD 1A input DISAZM
- `C1 =` CARD 4 input XFLAG

Spectral table format depends on four header values, `I4` (input IEMSCT), `I6` (number of auxiliary species), and `L1` (input DIS). Each case is described below. In the FORTRAN `READ` statements, the `Rn` variables are of type real*4. Once a table has been read in, one should try reading an additional MODTRAN run header from the *<rootname>*_b.tp7 file to see if it contains another table from a repeat run. If it does contain additional data, one should return to reading the *<rootname>*.tp7 file to determine the number of output spectral grid points, `J2`, for the next table.

Transmittance Only Mode, I4 = 0 (IEMSCT = 0)

```
 DO I8 = 1, J2
     READ(UNIT=I1, IOSTAT=I9)R1,R2,R3,R4,R5,R6,R7,R8,                    &
&      R9,R10,R11,R12,R13,R14,R15,R16,R17,R18,R19,                       &
&      R20,R21,R22,R23,R24,R25,R26,R27,R28,R29,R30,                      &
&      R31,R32,R33,R34,R35,R36,(R37(I10),I10=1,I6)
 ENDDO
```

The mapping of inputs to <*rootname*>.tp7 file columns is as follows:

R1	FREQ CM-1	R2	COMBIN TRANS	R3	H2O TRANS	R4	UMIX TRANS
R5	O3 TRANS	R6	TRACE TRANS	R7	N2 CONT	R8	H2O CONT
R9	MOLEC SCAT	R10	AER+CLD TRANS	R11	HNO3 TRANS	R12	AER+CLD abTRNS
R13	–LOG COMBIN	R14	CO2 TRANS	R15	CO TRANS	R16	CH4 TRANS
R17	N2O TRANS	R18	O2 TRANS	R19	NH3 TRANS	R20	NO TRANS
R21	NO2 TRANS	R22	SO2 TRANS	R23	CLOUD TRANS	R24	CFC11 TRANS
R25	CFC12 TRANS	R26	CFC13 TRANS	R27	CFC14 TRANS	R28	CFC22 TRANS
R29	CFC113 TRANS	R30	CFC114 TRANS	R31	CFC115 TRANS	R32	CLONO2 TRANS
R33	HNO4 TRANS	R34	CHCL2F TRANS	R35	CCL4 TRANS	R36	N2O5 TRANS
R37	Aux Species TRANS						

Thermal Radiance Mode with DISORT Scattering, I4 = 1 (IEMSCT = 1) and L1 = ′T′ (DIS = ′T′)

```
 DO I8 = 1, J2
     READ(UNIT=I1, IOSTAT=I9)R40,R41,R42,R43,R44,R45,R46,R47,R48
 ENDDO
```

The mapping of inputs to <*rootname*>.tp7 file columns is as follows:

R40	FREQ	R41	TOT_TRANS	R42	PTH_THRML	R43	SURF_EMIS
R44	GRND_RFLT	R45	TOTAL_RAD	R46	DEPTH	R47	DIR_EM
R48	BBODY_T[K]						

Thermal Radiance Mode with ISAACS' or Conservative Scattering, I4 = 1 (IEMSCT = 1) and L1 = ′F′ (DIS = ′F′)

```
 DO I8 = 1, J2
     READ(UNIT=I1, IOSTAT=I9)R50,R51,R52,R53,R54,R55,R56,R57,R58,R59
 ENDDO
```

The mapping of inputs to <*rootname*>.tp7 file columns is as follows:

R50	FREQ	R51	TOT_TRANS	R52	PTH_THRML	R53	THRML_SCT
R54	SURF_EMIS	R55	GRND_RFLT	R56	TOTAL_RAD	R57	DEPTH
R58	DIR_EM	R59	BBODY_T[K]					

Solar (+*Thermal*) *Radiance Mode with DISORT Scattering,* I4 = 2 or 4 (IEMSCT = 2 or 4) and L1 = ′T′ (DIS = ′T′)

```
 DO I8 = 1, J2
     READ(UNIT=I1, IOSTAT=I9)R60,R61,R62,R63,R64,                       &
&      R65,R66,R67,R68,R69,R70,R71,R72,R73,R74
 ENDDO
```

The mapping of inputs to <*rootname*>.tp7 file columns is as follows:

R60	FREQ	R61	TOT_TRANS	R62	PTH_THRML	R63	SURF_EMIS
R64	SOL_SCAT	R65	SING_SCAT	R66	GRND_RFLT	R67	DRCT_RFLT
R68	TOTAL_RAD	R69	REF_SOL	R70	SOL@OBS	R71	DEPTH
R72	DIR_EM	R73	TOA_SUN	R74	BBODY_T[K]			

Solar (+ Thermal) Radiance Mode with ISAACS' or Conservative Scattering, `I4` = 2 or 4 (IEMSCT = 2 or 4) and `L1` = ′F′ (DIS = ′F′)

```
 DO I8 = 1, J2
     READ(UNIT=I1, IOSTAT=I9)R80,R81,R82,R83,R84,                       &
 &      R85,R86,R87,R88,R89,R90,R91,R92,R93,R94,R95
 ENDDO
```

The mapping of inputs to *<rootname>*.tp7 file columns is as follows:

R80	FREQ	R81	TOT_TRANS	R82	PTH_THRML	R83	THRML_SCT
R84	SURF_EMIS	R85	SOL_SCAT	R86	SING_SCAT	R87	GRND_RFLT
R88	DRCT_RFLT	R89	TOTAL_RAD	R90	REF_SOL	R91	SOL@OBS
R92	DEPTH	R93	DIR_EM	R94	TOA_SUN	R95	BBODY_T[K]

Solar/Lunar Irradiance Mode with DISORT Scattering `I4` = 2 or 4 (IEMSCT = 2 or 4) and `L1` = ′T′ (DIS = ′T′)

```
 DO I8 = 1, J2
     READ(UNIT=I1, IOSTAT=I9)R100,R101,R102,R103,R104
 ENDDO
```

The mapping of inputs to *<rootname>*.tp7 file columns is as follows:

R100	FREQ	R101	TRANS	R102	SOL TR	R103	SOLAR
R104	Unlabeled						

4.11.5 *How does one read a MODTRAN5 <rootname>_b.tp8 binary output file?*

The structure of the *<rootname>*_b.tp8 binary output files is quite complicated. For these binary files, unlike all the others, it is recommended that one run M5_bn2as to convert the file to ASCII first, and then read the data from the ASCII file. If it is truly necessary to read the binary *<rootname>*_b.tp8 file directly, it is recommended that the user modify the M5_bn2as.f file for this purpose. Any questions regarding details of the M5_bn2as.f source code can be sent to modtran@spectral.com.

5. Geometry

5.1 *Are there figures illustrating the MODTRAN geometry inputs?*

MODTRAN geometry inputs are illustrated in Figures 5.1A and 5.1B. Figure 5.1A contains the CARD3 line-of-sight (LOS) inputs. These inputs all lie within a plane defined by 3 points: the center of the Earth, the sensor (observer), and the final altitude. Two LOS's, with a common observer location and view angle, and with the same final altitude (**H2ALT** = **H2ALT′**) are illustrated; primes (′) are appended to the longer path variable names. Generally, 4 geometry inputs (one being **RAD_E**, the Earth radius) define a slant path (CARD 1 input ITYPE = 2), although only specific combinations are allowed. The full set of MODTRAN line-of-sight inputs are
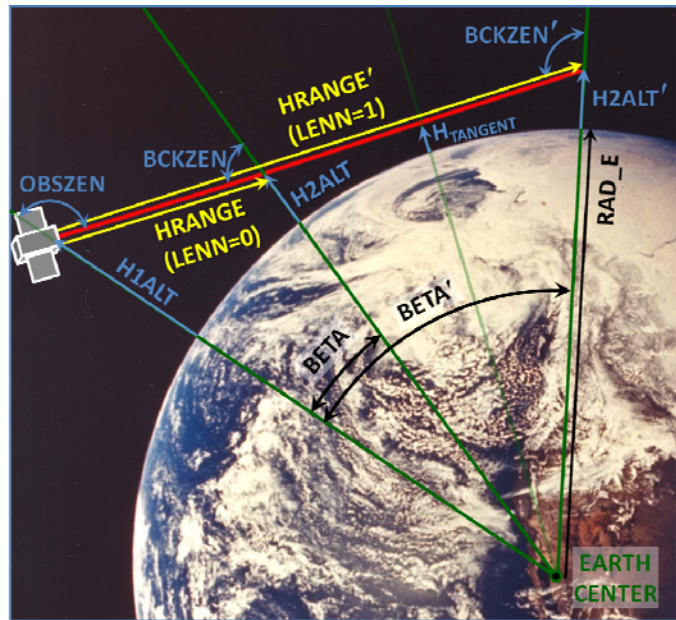
H1ALT	Observer altitude above sea level (km),
H2ALT	Path final altitude above sea level (km),
OBSZEN	Observer path zenith angle (deg),
HRANGE	Refracted path slant range (km),
BETA	Earth center angle (deg),
LENN	Short (0) vs. long (1) path range switch,
RAD_E	Earth radius (km), and
BCKZEN	**H2ALT** to **H1ALT** zenith angle (deg).

As Figure 5.1A illustrates, ambiguity arises when the observer zenith angle (**OBSZEN**) exceeds 90°, the observer altitude (**H1ALT**) exceeds the final altitude (**H2ALT**) and the LOS does not intersect the Earth; these inputs are consistent with both a short and long path – the long path passes through the tangent height (H$_{TANGENT}$). The input **LENN** selects which of these 2 paths should be used. Note that the same ambiguity arises for the slant path is defined by the input set (**BCKZEN**, **H2ALT**, **H1ALT**) when **BCKZEN** > 90° and **H2ALT** > **H1ALT**; this case also requires specification of input **LENN**.
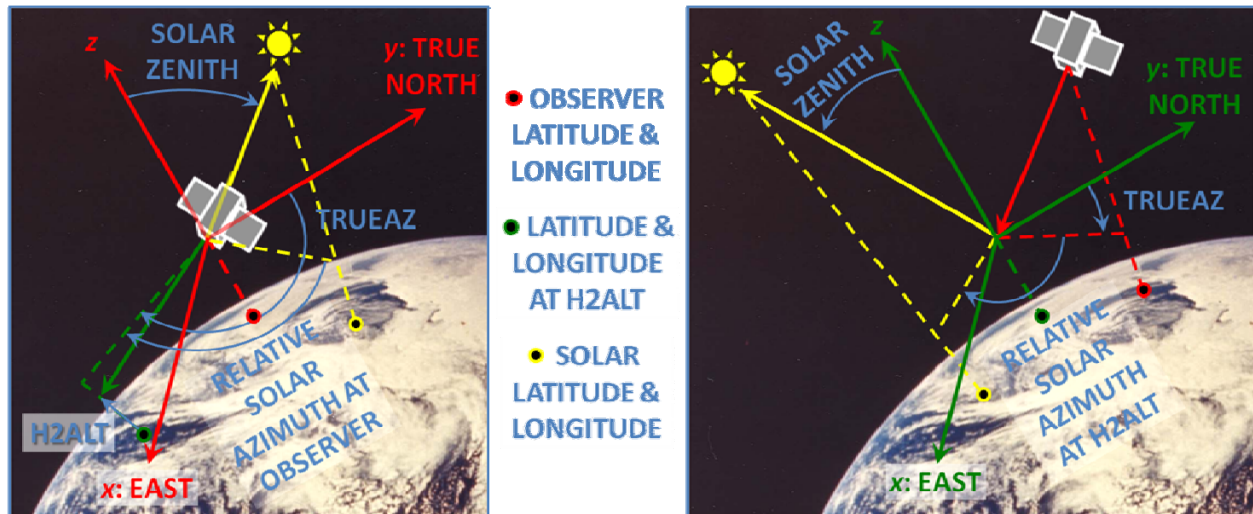
MODTRAN also includes an option to have the line-of-sight specified as a path to space or ground (CARD 1 input ITYPE = 3). For these paths, there are only 3 input options: (**H1ALT**, **OBSZEN**), (**H1ALT**, **H2ALT**) and (**H2ALT**, **BCKZEN**). It is important to remember that when the (**H1ALT**, **H2ALT**) option is used, the input **H2ALT** defines tangent height (H$_{TANGENT}$), not a final path altitude, and that **H1ALT** must exceed **H2ALT**. Also, note that input **RAD_E** is used if provided; otherwise, a default value is selected based on the chosen model atmosphere (CARD 1 input MODEL).

A second set of MODTRAN geometry inputs (CARDs 3A1 and 3A2) defines the solar (or lunar)

Figure 5.1A. MODTRAN (CARD 3) line-of-sight geometry inputs. When the observer (sensor) zenith angle exceeds 90°, the observer altitude (**H1ALT**) exceeds the final altitude (**H2ALT** = **H2ALT′**), and the path does not intersect the Earth, both a shorter (**LENN** = 0) and a longer (**LENN**=1) path are possible. Input **LENN** distinguishes these two possibilities.

geometry as illustrated in Figure 5.1B. The direction of incident radiation is specified from the perspective of either the sensor (CARD 3A1 input IPARM equal 0, 1, or 2) or the path end point (IPARM equal 10, 11 or 12). Whichever frame of reference is used, the solar direction is ultimately defined in terms of solar zenith and relative solar azimuth angles. The solar zenith angle is the angle between the vertical at the reference point and the refracted path solar direction (yellow ray) at that point. The relative azimuth is the angle between two vertical planes at the reference point, one containing the line-of-sight (green ray in left image; red ray in right image) and the second containing the solar path.

If the two solar angles are not entered directly via IPARM equal 2 or 12, the required inputs are the latitude and longitude of the reference point along with **TRUEAZ**, the true path azimuth (degrees East of North) at the reference point. In addition, the absolute angular location of the sun from the Earth's perspective must be determined either by directly entering the solar latitude and longitude (IPARM equal 0 or 10) or from temporal data by specifying the day of year (CARD 3A1 input IDAY) and Greenwich Mean Time (CARD 3A2 input GMTIME). For all cases, the Earth to Sun distance is determined from the day of year (IDAY).

Figure 5.1B. Illustration of Observer (left) and Final Altitude (right) Based MODTRAN Solar Geometry Inputs.

5.2 *What are the limitations of MODTRAN5's atmospheric refraction algorithm?*

MODTRAN lines-of-sight are defined based on a spherical refractive geometry model. The refractive geometry calculations are performed at a single spectral frequency. More precisely, a single frequency is used to define the index of refraction profile which is input to the refractive geometry model. By default, this frequency is chosen to be the mid-point wavenumber value of the spectral range defined by CARD 4 inputs V1 and V2. However, the user can override the default frequency used to define the refractive index profile by setting CARD 4 input VRFRAC. For most scenarios, the refractive geometry model works well. However, if a user-defined atmosphere is specified which has an excessively large temperature or relative humidity vertical gradient, then an upward directed path can be predicted to bend downward, a phenomenon known as super refraction. MODTRAN is unable to handle this type of refraction, and if it occurs MODTRAN will terminate with an appropriate error message.

6. Specialized Applications

6.1 *Can MODTRAN5 be used for modeling laser wavelength transmittances?*

Generally, the answer to this question is no. At its finest spectral resolution, MODTRAN can generate 0.1 cm^{-1} spectral bin transmittances. For laser applications, the transmittance at a specific spectral frequency is required. For ground to ground scenarios, it has been argued that MODTRAN's spectral resolution should be sufficient because of the line pressure broadening at the surface. A typical Lorentz line width at 1 Atm pressure (Half-Width at Half Maximum) is ~0.06 cm^{-1}. Thus, the optical depth of a single, off-centered line in a 0.1 cm^{-1} interval will drop by more than half from its peak value. Using a spectral bin averaged transmittance is quite inaccurate. However, if your interval extinction is dominated by continuum sources, such as aerosol extinction, then the MODTRAN bin averaged values may be sufficiently accurate.

6.2 *Does MODTRAN5 atmospherically correct hyperspectral and/or multispectral imagery?*

If DISORT solar multiple scattering is used (CARD 1 input IEMSCT = 1, 2 or 4; CARD 1 input IMULT = ±1 and CARD 1A input DIS = ′T′) with a downward viewing line-of-sight, and if CARD 1A input DISALB is set to ′T′, MODTRAN will generate an atmospheric correction data (<*rootname*>.acd) output file. This file contains the spectral spherical albedo and both solar and line-of-sight path diffuse and direct transmittance data required for mapping observed radiances into ground reflectances. However, MODTRAN itself does not process radiance imagery to generate surface reflectance maps. A number of software products are available for atmospherically correcting hyperspectral and/or multispectral imagery, most of which rely on MODTRAN radiative transfer to perform the radiance to reflectance mapping. In particular, we recommend the atmospheric correction code FLAASH, developed by Spectral Sciences, Inc. and distributed as an add-on to the ITT ENVI Geospatial Software. For more information, see http://www.ittvis.com/portals/0/pdfs/envi/Flaash_Module.pdf.

6.3   *Does MODTRAN5 compute polarization radiance vectors*?

There is a version of MODTRAN4 that computes polarization radiance vectors using the vectorized version of DISORT, VDISORT [Schulz *et al*., 1999]. This capability has yet to be integrated in MODTRAN5. For more information, contact Dr. Michael Hoke at Michael.Hoke@hanscom.af.mil.

6.4   *Is the extra-terrestrial planetary version of MODTRAN5 generally available*?

A MODTRAN derivative model known as MOD-ET is being developed by Spectral Sciences, Inc. to model extra-terrestrial (ET) planetary atmospheres [Bernstein *et al*., 2007; Berk *et al*., 2008; Fox *et al*., 2009]. MOD-ET uses the MODTRAN band model, however, it includes absorption sources that are insignificant for the terrestrial atmosphere but that are critical to ET atmospheres such as H_2-H_2, H_2-He, H_2-CH_4 and CH_4-CH_4 collision induced absorption (CIA). MOD-ET also incorporates a broader temperature range of band model data, a generalized treatment of Rayleigh scattering, and input of planetary mass and air molecular weight for solving the hydrostatic equation. Atmospheric and aerosol models have been defined for Neptune, Saturn and Jupiter. MOD-ET has been validated against measurement data for the entire microwave through UV spectral range.

At present, the code has yet to be released. For more information, please contact Dr. Alexander (Lex) Berk at lex@spectral.com.

6.5   *Can MODTRAN5 be used to model sky radiance*?

For a stratified atmosphere, defined by molecular and particulate vertical profiles, MODTRAN can be used to model the downward surface spectral flux and/or the angular variation of the spectral radiance impingent on the ground.

To generate the surface flux data, case-insensitive CARD 4 input FLAGS(7:7) should be set to ′T′ or ′F′ and CARD 4 input MLFLX set to 1. This will generate a <*rootname*>.flx file.

The angular radiance data is defined by placing the observer (CARD 3 input H1ALT) at the ground, setting the desired sensor zenith angle (CARD 3 input OBSZEN), and setting the relative solar/lunar azimuth angle (CARD 3A1 and 3A2 inputs) if the sun/moon is being included in the simulation.

Often times, sky radiance measurements are associated with modeling of partial cloud cover scenes. Because of its assumption of horizontal homogeneity, MODTRAN is not specifically designed to model broken cloud scenes. Many users have successfully pieced together cloud-free and semi-infinite cloud results to model the partial clouds, but the onus for those studies resides with the user.

6.6   *Does MODTRAN5 model airglow and other non local thermodynamic equilibrium (NLTE) affects*?

MODTRAN is strictly a local thermodynamic equilibrium (LTE) model, meaning that the population of electronic, vibrational and rotational excitation states is determine solely on the basis of the local temperature. The LTE assumption is valid as long as the frequency of molecular collisions exceeds relaxation times. For the terrestrial atmosphere, this is essentially always true for altitudes below ~30km. At higher altitudes, the LTE assumption is still valid in many spectral regions. However, for limb paths above 30km, a radiative transfer model that treats NLTE phenomena such as SAMM2 [Dothe *et al*., 2004] is preferred over MODTRAN.

6.7   *Can MODTRAN5 be used to model solar terminator affects* [*Alternatively, does MODTRAN5 model twilight (low sun) conditions*]?

MODTRAN calculates the refractive path to the sun for each altitude level along the sensor line-of-sight (LOS). If the hard Earth, which MODTRAN models as a sphere, intersects with the solar illumination path, then the LOS altitude level is labeled as being in shadow and the solar single scatter radiance at that point is set to zero. If, on the other hand, the LOS altitude level is solar illuminated, MODTRAN does calculate the single scatter solar for the refracted path.

MODTRAN does not model the atmospheric chemistry that occurs across the terminator. Also, the scattering algorithms in MODTRAN do not accurately model the solar multiple scatter for low sun conditions. Thus, MODTRAN can only be used to model solar terminator affects if the chemical changes in the atmosphere are inconsequential for one's applications and multiple scatter is not the dominant source of radiation ($> \sim 3\ \mu m$).

6.8 *Can the MODTRAN atmosphere be varied to match ground measurements of the direct and hemispherical solar flux?*

MODTRAN is a forward rather than inversion model. There is no option to input spectral radiance data and automatically retrieve atmospheric conditions. However, MODTRAN does provide input options which can be used to help retrieve atmospheric conditions. Suppose, for example, that you have made ground measurements of spectral channel direct and hemispherical solar flux values and you wish to retrieve the atmosphere. Given a baseline atmosphere definition, possibly based on local radiosonde data, one can use the aerosol Angstrom Law inputs (CDASTM, ASTMC, ASTMX and ASTMO on CARD 1A) to perturb the aerosol spectral extinction until the direct solar flux predictions match the data. In a second step, one could perturb the darkness of the aerosols by adjusting the spectral dependence of the aerosol single scattering albedo using CARD 1A input NSSALB and CARD 1B inputs AWAVLN and ASSALB.

6.9 *Can MODTRAN5 segment transmittances be multiplied together to get the total path transmittance?*

MODTRAN is a statistical band model radiative transfer algorithm. As such, MODTRAN does not solve the radiative transfer equation monochromatically. Instead, narrow spectral band transmittances are calculated. Beer's Law states that monochromatic segment transmittances are multiplicative:

$$T_v^{AB} = T_v^A \times T_v^B \quad .$$

Here, T_v^A is the spectral transmittance through segment A at spectral frequency v, T_v^B is the spectral transmittance through segment B, and T_v^{AB} is the spectral transmittance through combined segment AB. Unfortunately, transmittances integrated over a spectral band, Δv, are not multiplicative:

$$\int_{\Delta v} T_v^{AB} dv = \int_{\Delta v} T_v^A \times T_v^B dv \neq \int_{\Delta v} T_v^A dv \times \int_{\Delta v} T_v^B dv \quad .$$

MODTRAN does include a statistical *k*-distribution and correlated-*k* algorithm. With the *k*-distribution method, the band model transmittance is represented as a weighted sum of monochromatic transmittances:

$$\int_{\Delta v} T_v^A dv = \sum_i \Delta g_i T_i^A \quad .$$

The correlated-*k* ansatz states that each interval satisfies Beer's Law so that

$$\int_{\Delta v} T_v^{AB} dv = \sum_i \Delta g_i T_i^{AB} = \sum_i \Delta g_i T_i^A T_i^B \quad .$$

Thus, if the *k*-distributions are known for segments *A* and *B*, then one can calculate the total *A+B* path transmittance, but it still does not equal the product of the segment spectral band transmittances.

6.10 *Can MODTRAN be used in the microwave through terahertz spectral region?*

The MODTRAN band model data begins at 0 cm^{-1}. In principle, MODTRAN can provide as fine as 0.1 cm^{-1} spectral resolution results in the microwave through terahertz spectral region. For some planetary atmosphere applications, this capability has been validated against measured data in regions where collision induced absorption (CIA) dominates. However, finer spectral resolution is generally required in the microwave through terahertz spectral region, and line-by-line calculations are generally preferred.

7. Internal and External Data

7.1 *What version of HITRAN is MODTRAN5 based upon?*

The 2009 series of MODTRAN5 band model data files are based on HITRAN2008 with updates through September 2009. The 2008 series of MODTRAN5 band model data files are based on HITRAN2004 with updates through 2007.

7.2   *What water vapor continuum is used in MODTRAN5?*

MODTRAN5 uses Version 2.4 of the Clough-Kneizys Water Continuum Data from the AER Inc. Line-By-Line Radiation Transport Model (24 March 2000).

7.3   *What surface spectral albedo curves are included in the MODTRAN5.2 distribution?*

The MODTRAN5.2 distribution includes the ′spec_alb.dat′ surface spectral albedo file in its DATA/ directory. This file contains 51 sample surface albedo curves listed in a (x, y) format. Figure 7.3 illustrates all 51 spectral curves along with their numerical label and name. Note that many of the curves do not cover the entire 0.2 to 16 μm region (a few extend beyond 16 μm but that region is not shown). If one of these reflectance curves is selected for use by MODTRAN (CARD 1 input SURREF set to an integer equal to the negative of the spectral albedo curve's numerical label) and the spectral range of the MODTRAN calculation extends beyond the limits of the spectral albedo curve, then end point values are used for the spectral regions outside of the spectral data domain.

Most of the spectral albedo curves in Figure 7.3 are either constant values or data obtained from the Johns Hopkins University becknic database [Korb *et al*., 1996; Salisbury *et al*., 1991a; Salisbury *et al*., 1994; Salisbury *et al*., 1991b] or from the MOSART radiative transfer model [Cornette *et al*., 1994].
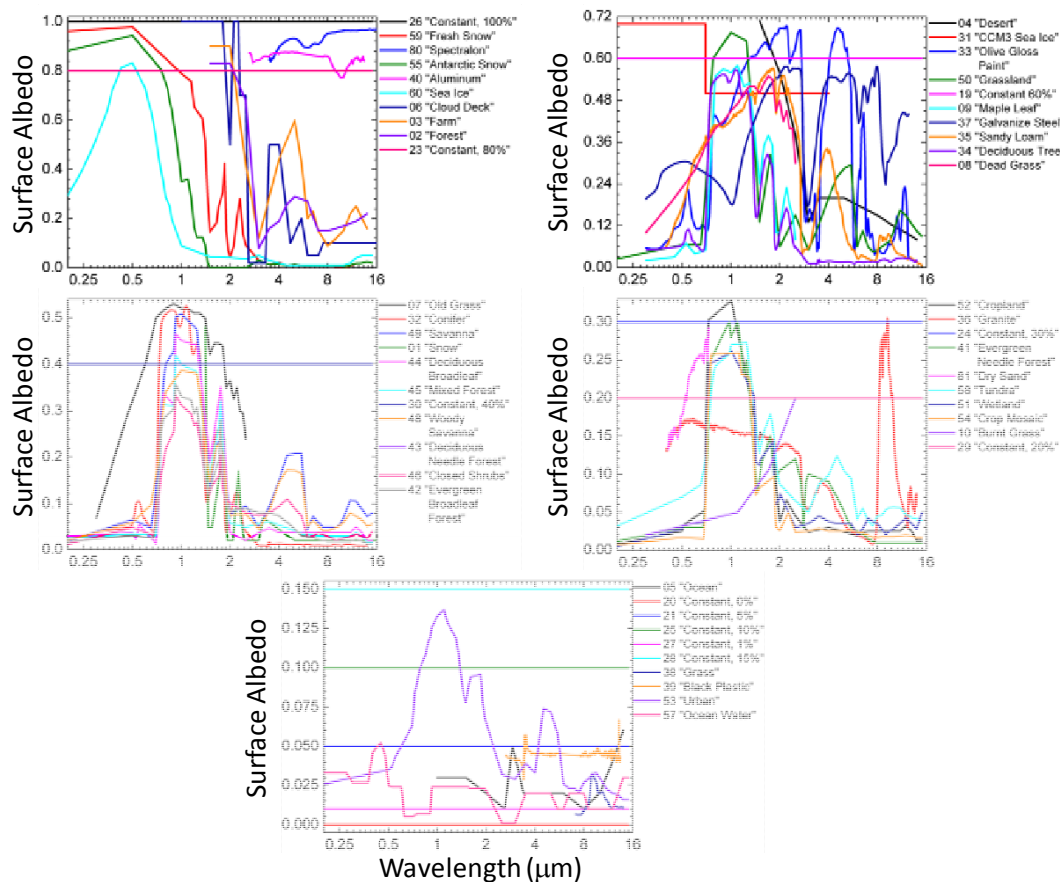
Figure 7.3. Curves of surface spectral reflectance data from the MODTRAN file ′DATA/spec_alb.dat′ Note that the maximum value of the surface albedo scale differs on each graph.

7.4 *What top-of-atmosphere solar irradiance data are the defaults within MODTRAN5*?

MODTRAN5 uses the Kurucz 1995 top-of-atmosphere (TOA) solar irradiance data as default when the 0.1 cm⁻¹ band model is selected, and the Kurucz 1997 TOA solar irradiance data as default when one of the coarser spectral resolution (1.0, 5.0 or 15.0 cm⁻¹) band models is selected. Newer solar irradiance files are distributed with MODTRAN5.2, in particular, the Kurucz 2005 and the Fontenla data sets. However, these were found to have some small sub-regions where the values are in question. The Fontenla data has recently [June 2011] been updated, and these data will be included in future deliveries of MODTRAN.

7.5 *How do the MODTRAN5 model aerosols differ*?

The aerosol models in MODTRAN originate from LOWTRAN. The models are described in a pair of manuscripts by Shettle and Fenn [Shettle and Fenn, 1976; Shettle and Fenn, 1979]. The implementation of aerosol phase functions in LOWTRAN is described in Appendix D of the LOWTRAN 6 manual [Kneizys *et al*., 1983]. Scanned electronic copies of all three of these documents are available upon request from modtran@spectral.com. An alternate and less complete source of information on the aerosol models is Chapter 18 of the AFGL handbook [Jursa, A.S., 1985].

8. Model Features

8.1 *Does MODTRAN use the DISORT BRDF option*?

DISORT Version 2 includes an upgrade for treatment of the lower boundary condition using an Legendre expansion of the surface Bi-directional Reflectance Distribution Functions (BRDFs). Unfortunately, DISORT was integrated into MODTRAN before this upgrade was ready for distribution. Although MODTRAN5.2 models surface BRDFs, the DISORT multiple scattering calculation within MODTRAN5.2 assumes the surface is a Lambertian reflector. Recently, MODTRAN5.3 was upgraded to interface the DISORT BRDF capability, but that upgrade has not been ported to MODTRAN5.2. MODTRAN5.3 will be available for distribution by late 2011.

8.2 *Does MODTRAN5.2 include an ocean surface model*?

MODTRAN5.2 does not have an ocean surface model. However, the "Ross-Sea" ocean surface model [Ross *et al*., 2005] has been integrated into MODTRAN5.3 as BRDF (Bidirectional Reflectance Distribution Function) number 13. The option is activated by setting CARD 4B1 input CBRDF to ′13′ or ′Ross-Sea′ with CARD 1 input SURREF set equal to 'BRDF'. The Ross-Sea BRDF serves as the lower boundary condition for DISORT multiple scattering.

8.3 *Does MODTRAN5 model mixed phase (water and ice) clouds*?

MODTRAN does model mixed phase (water and ice) clouds. Whenever a water cloud model is selected (CARD 2 input ICLD equal 1-10), "Alternate CARD 2A" is read in. Setting "Alternate CARD 2A" input NCRALT to 3 or greater initiates reading of CARD 2E1 cloud profile data. CARD 2E1 reads in distinct profiles for water and ice clouds. These profiles can be chosen to be overlapping, creating mixed phase clouds.

8.4 *Can MODTRAN5 model multiple cloud layers*?

MODTRAN5 can model multiple cloud layers, but with a few caveats. The MODTRAN cloud option allows a user to define cloud profiles via CARD 2E1 inputs. The cloud profiles are read in whenever a water cloud is selected on CARD 2 (ICLD equals 1 through 10) and the number of cloud altitude levels (NCRALT on CARD 2A) exceeds 2. One can define cloud profiles to contain multiple layers by simply setting the cloud density to zero between layers. However, this creates multiple cloud layers with common optical properties.

For the two cloud layer scenario, each layer can be defined with distinct optical properties. CARD 2E1 nominally reads in both a water and ice cloud profile. If default cloud optical properties are used, then indeed the input CLD on CARD 2E1 will contain the profile of a cloud defined with water droplet optical data and the input CLDICE, also on CARD 2E1, will contain the profile of a cloud defined with ice particle optical data. However, CARD 2E2 can be used (by setting CARD 2A input NCRSPC > 1) to define the optical data for both CLD and CLDICE. Using this option, CLD and CLDICE can contain whatever type of cloud one wishes.

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