MODTRAN4 Version 3 Revision 1 USER'S MANUAL

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1. INTRODUCTION

MODTRAN (Berk *et al.*, 1989; Berk *et al.*, 1998) has served 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 MODTRAN4 Version 3 Revision 1 (Mod4v3r1) is based on HITRAN2K line compilation (Rothman *et al.*, 1992; Rothman *et al.*, 1998) with update through 2001. The MODTRAN 1 cm^{-1} statistical band model was developed collaboratively by Spectral Sciences, Inc. and the USAF Research Laboratory, and it provides a fast alternative (100-fold increase in speed) to the USAF first principles and more accurate line-by-line (LBL) radiative transport models, FASCODE (Clough, 1988) and **FAS**CODE for the **E**nvironment, FASE (Snell *et al.*, 1995). Comparisons between MODTRAN and FASE spectral transmittances and radiances show agreement to within a few percent or better in the thermal IR. MODTRAN4 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 MODTRAN approach are available from a variety of sources. The original MODTRAN 2 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 LOWTRAN 7 (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. For the most up-to-date information about MODTRAN, please email "Gail P. Anderson" <Gail.Anderson@hanscom.af.mil>; "Michael L Hoke Civilian AFRL/VSBT" <Michael.Hoke@hanscom.af.mil> and / or "Alexander Berk" <lex@spectral.com>.

These user instructions for MODTRAN4 Version 3 Revision 1 describe each input in the MODTRAN input files, tape5 or *rootname*.tp5.

2. OVERVIEW OF INPUT DATA FORMAT

A MODTRAN “root name” input file provides the full path for MODTRAN I/O. The rootname file must be located in the executable directory and have the name 'modroot.in' or 'MODROOT.IN'. If 'modroot.in' does not exist, MODTRAN checks for the existence of a 'MODROOT.IN' file. If neither of these files exists, MODTRAN I/O files are traditional ones: 'tape5', 'tape6', 'tape7', 'tape8', etc. If a root name file exists and its very first line contains a non-null string, this string is treated as a prefix. The root name should contain no embedded blanks; leading and trailing blanks are ignored. The 'modroot.in' character string is used as a prefix for the I/O files whose names have mnemonic suffixes. As an example, if the string is **case1**, the MODTRAN I/O files will have these names:

case1.tp5	Primary input file (**tape5**)
case1.tp6	Primary output file (**tape6**)
case1.tp7	Spectral plotting output file (**tape7**)
case1.tp8	Auxiliary spectral data output file (**tape8**)
case1.7sc	‘case1.tp7’ convolved with scanning function (**tape7.scn**)
case1.7sr	Scratch file (**tape7.scr**)
case1.plt	Two column spectral data output file (**pltout**)
case1.psc	‘case1.plt convolved with scanning function (**pltout.scn**)
case1.clr	Spectral cooling rate data output file (**clrates**)
case1.chn	Spectral data convolved with channel response functions (**channels.out**)
case1.flx	Spectral diffuse and direct flux values at each atmospheric level (**specflux**)

MODTRAN is controlled by a single input file, 'tape5' or '*rootname*.tp5', which consists of a sequence of six or more **CARDS** (inputs lines). The input file format is summarized below. Except when specifying file names, character inputs are case insensitive. Also, blanks are read 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 CARDs and Their Format

In the following, optional cards are indented. *Inputs that are new to or have been modified for MODTRAN4 are in Italics.*

CARD 1: MODTRN, SPEED, *MODEL*, ITYPE, IEMSCT, IMULT, M1, M2, M3, M4, M5, M6, MDEF, IM, NOPRNT, TPTEMP, SURREF
FORMAT (2A1, I3, 12I5, F8.3, A7)

CARD 1A: DIS, DISAZM, NSTR, LSUN, ISUN, CO2MX, H2OSTR, O3STR, LSUNFL, LBMNAM, LFLTNM, H2OAER, DATDIR, SOLCON
FORMAT (2L1, I3, L1, I4, F10.5, 2A10, 5(1X, A1), F10.3)

CARD 1A1: SUNFL2
FORMAT (A80) (If LSUNFL = True)

CARD 1A2: BMNAME
FORMAT (A80) (If LBMNAM = True)

CARD 1A3: FILTNM
FORMAT (A80) (If LFLTNM = True)

CARD 1A4: DATDIR
FORMAT (A80) (If LFLTNM = True)

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)

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 (3F8.3) (If ICLD = 18 or 19)

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

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

CARD 2C: ML, IRD1, IRD2, HMODEL, *REE*
FORMAT (3I5, A20, F10.0) (If MODEL = 0, 7 or 8, and IM = 1)

CARDs 2C1, 2C2, 2C2X, and **2C3** (as required) are each repeated ML times.

CARD 2C1: ZM, P, T, WMOL(1), WMOL(2), WMOL(3), (JCHAR(J), J = 1, 14), JCHARX
FORMAT (F10.3, 5E10.3, 14A1, 1X, A1)

CARD 2C2: (WMOL(J), J = 4, 12)
FORMAT (8E10.3, /E10.3) (If IRD1 = 1)

CARD 2C2X: (WMOLX(J), J = 1, 13)
FORMAT (8E10.3, /5E10.3) (If MDEF = 2 & IRD1 = 1)

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

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

CARD 2D1: AWCCON, TITLE
FORMAT (E10.3, 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, 0), CLD(I, 0), CLDICE(I, 0), RR(I, 0), I = 1, NCRALT)
FORMAT ((4F10.5)) (If ICLD = 1 - 10, NCRALT ≥ 3)

CARD 2E2: (WAVLEN(I), EXTC(6, I), ABSC(6, I), ASYM(6, I), EXTC(7, I), ABSC(7, I), ASYM(7, I), I = 1, NCRSPC)
FORMAT ((7F10.5)) (If ICLD = 1 - 10, NCRSPC ≥ 2)

*Alternate **CARD 2E2:** CFILE, CLDTYP, CIRTYP*
FORMAT ((A80)) *(If ICLD = 1 - 10, **NCRSPC = 1**)*

CARD 3: H1, H2, ANGLE, RANGE, BETA, RO, LENN, PHI
FORMAT (6F10.3, I5, 5X, F10.3)

Alternate **CARD 3:** H1, H2, ANGLE, IDAY, RO, ISOURC, ANGLEM
FORMAT (3F10.3, I5, 5X, F10.3, I5, F10.3) (If IEMSCT = 3)

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

CARD 3A2: PARM1, PARM2, PARM3, PARM4, TIME, PSIPO, ANGLEM, G
FORMAT (8F10.3) (If IEMSCT = 2)

CARD 3B1: NANGLS, NWLF
FORMAT (2I5) (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)
FORMAT (8(1X, F9.0)) (If IPH = 1 and NWLF = 0)

CARD 3C1: (ANGF(I), I = 1, NANGLS)
FORMAT (8(1X, F9.0)) (If IPH = 1 and NWLF > 0)

CARD 3C2: (WLF(J), J = 1, NWLF)
FORMAT (8(1X, F9.0)) (If IPH = 1 and NWLF > 0)

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

CARD 3C3: (F(1, I, J), J = 1, NWLF)
FORMAT (8(1X, E9.3)) (If IPH = 1 and NWLF > 0)

CARD 3C4: (F(2, I, J), J = 1, NWLF)
FORMAT (8(1X, E9.3)) (If IPH = 1 and NWLF > 0)

CARD 3C5: (F(3, I, J), J = 1, NWLF)
FORMAT (8(1X, E9.3)) (If IPH = 1 and NWLF > 0)

CARD 3C6: (F(4, I, J), J = 1, NWLF)
FORMAT (8(1X, E9.3)) (If IPH = 1 and NWLF > 0)

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

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

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 (A80) (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

The **CARD 1** format has been modified in MODTRAN4 by the replacement of the logical variable MODTRN with two new CHARACTER*1 variables, MODTRN and *SPEED*, which control the band model choice and the Correlated-*k* options. In addition, the inputs TBOUND and SALB from earlier versions of MODTRAN and LOWTRAN have been replaced by TPTEMP and SURREF to accommodate the updated MODTRAN surface treatment. The new format is fully backward compatible. *Italicized features are exclusive to MODTRAN4.*

CARD 1: MODTRN, SPEED, *MODEL*, ITYPE, IEMSCT, IMULT, M1, M2, M3, M4, M5, M6, MDEF, IM, NOPRNT, TPTEMP, SURREF
FORMAT (2A1, I3, 12I5, F8.3, A7)

MODTRN selects the band model algorithm used for the radiative transport, either the moderate spectral resolution MODTRAN band model or the low spectral resolutionLOWTRAN 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).*

CARD 1 (Required)

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,** 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,** and **2C3** for further details.

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 **IM** on **CARD 1** and for **CARDs 2C, 2C1, 2C2, 2C2X,** and **2C3** for further details.*

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

ITYPE = 1 Horizontal (constant-pressure) path, i.e., single layer, no refraction calculation.

2 Vertical or slant path between two altitudes.

3 Vertical or slant path to space or ground.

IEMSCT determines the mode of execution of the program.

IEMSCT = 0 Program executes in spectral transmittance 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.

IMULT determines inclusion of multiple scattering (MS).

IMULT = 0 Program executes without multiple scattering.

±1 Program executes with multiple scattering.

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

CARD 1 (Required)

1A). If IMULT = 1, the solar geometry at the location of H1 (latitude and longitude) is used in the MS calculation; if IMULT = -1, the MS calculation is instead referenced to H2. The quantity H2 is the final path altitude unless ITYPE = 3 and H2 ≥ 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.) For simulation of sensors on satellite platforms, IMULT should generally be set to -1 since MS will only be significant nearer to H2 (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 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 normal operation of the program using the standard model atmospheres (MODEL 1 to 6), one may set M1 = M2 = M3 = M4 = M5 = M6 = MDEF = 0. MODTRAN then resets M1 through M6 to the value MODEL and MDEF to 1.

If MODEL equals 0 (horizontal path) or 7 (radiosonde data) and if M1 through M6 and MDEF are set to zero or left blank, then the JCHAR parameter on each **CARD 2C1** must be defined to supply the necessary profiles. If M1 through M6 and MDEF are non-zero, then the chosen default profiles will be utilized whenever the 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.
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	=	1	Default CO_2, O_2, NO, SO_2, NO_2, NH_3, and HNO_3 species profiles.

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"; "DATA/CFC99_15.ASC" is the 15 cm^{-1} version of the file. 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 reads user-supplied atmospheric profiles. Set IM = 1 for the first run. To sequentially rerun the same atmosphere (with unchanged molecular *and aerosol* profiles) for a series of cases, set IM to 0 in subsequent runs. MODTRAN will then reuse the previously read data. Changes made to CARD2 are ignored with IM=0 and MODEL = 0, 7 or 8.

IM	=	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.
NOPRNT	=	0	For normal operation of program; controls tape6 output.
	=	1	To minimize printing of transmittance or radiance table and atmospheric profiles in tape6.
	=	-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 or 2).
	=	-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 (15 cm^{-1} results if the 15 cm^{-1} band model data file is used). 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.

CARD 1 (Required)

TPTEMP > 0. Boundary temperature [K] of 'image pixel' (i.e., at H2), used in the radiation mode (if IEMSCT = 1 or 2) 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 H2 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.

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 H2 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 1 summarizes the use of selected **CARD 1** parameters: MODTRN, SPEED, MODEL, ITYPE, IEMSCT, IMULT, MDEF, NOPRNT and SURREF.

CARD 1 (Required)

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

CARD 1 FORMAT (2A1, I3, 12I5, F8.3, A7)		MODTRN, *SPEED*, MODEL, ITYPE, IEMSCT, IMULT, M1, M2, M3, M4, M5, M6, MDEF, IM, NOPRNT, TPTEMP, SURREF						
MODTRN (COL. 1)	*SPEED**	MODEL (COL. 3-5)	ITYPE (COL. 6-10)	IEMSCT (COLA 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 H1 to H2	1 Thermal Radiance	1 Multiple Scattering Based at H1	1 For MODEL = 0,7 Default for Minor Species**	0 tape6 Normal Output	-2 forest
C or K Correlated-K with MODTRAN	*S or M*	2 Mid-Latitude Summer	3 Slant Path to Space	2 Thermal and Solar/Lunar Radiance	-1 Multiple Scattering Based at H2	2 For MODEL = 0,7 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[%]						... *See Sec. 17.6 for list*

M1, M2, M3, M4, M5, M6, MDEF, IM 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 $ClONO_2$, NHO_4, CCl_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, and specification of data files:

CARD 1A: DIS, *DISAZM*, NSTR, LSUN, ISUN, CO2MX, *H2OSTR*, O3STR, LSUNFL, *LBMNAM, LFLTNM, H2OAER*, SOLCON
FORMAT (2L1, I3, L1, I4, F10.5, 2A10, 4(1X, A1), 2X, F10.3)

DIS = *t, s, f or blank* — *Used only if IMULT = ±1 in **CARD 1**. Set DIS to 'T' or 't' to activate the DISORT discrete ordinate multiple scattering algorithm. If DIS is 'F', 'f' or blank, the less accurate but faster Isaac's two-stream algorithm is used. If DIS is set to 'S' or 's', DISORT calculations are performed at a few fixed wavelengths and used to Scale Isaac's results, providing improved accuracy with a minimal time penalty.*

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).

NSTR = 2, 4, 8 or 16 — Number of streams to be used by DISORT. High NSTR values generally provide higher accuracy but slower computation times. NSTR = 8 is recommended with MODTRAN model aerosol and clouds, although more streams are desirable if modeling highly forward peaked scatterers. DISORT has been optimized for NSTR = 4, 8 and 16 only (for further details, see the DISORT documentation: Stamnes *et al.*, 1988 or the DISORT ftp site. ftp://climate.gsfc.nasa.gov/pub/wiscombe/Discr_ord/)

LSUN = t, f or blank — Set to FALSE (F, f or blank) to use the default solar 5 cm^{-1} spectral resolution irradiances (block data routine sunbd.f). Set to TRUE (T or t) to read 1 cm^{-1} binned solar irradiance from a file (see input LSUNFL below) - this requires input of ISUN.

ISUN — The FWHM (Full Width at Half Maximum) of the triangular scanning function used to smooth the TOA solar irradiance (wavenumbers).

CO2MX — CO_2 mixing ratio in ppmv. The default value (used when CO2MX = blank or 0.) is 330 ppmv; the current (1999) recommended value is closer to 365 ppmv (Dutton, 1999).

CARD 1A (Required)

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). H2OSTR should not be used with a constant pressure path, i.e., MODEL = 0 on **CARD 1**. The water density within water clouds (ICLD = 1-10) is not scaled unless CHUMID on CARD2A exceeds 105%. 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 an option to ignore the 100% relative humidity limit. 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. O3STR should not be used with a constant pressure path, i.e., MODEL = 0 on **CARD 1**.

LSUNFL = t, f or blank. If TRUE (T or t), read solar radiance data file name from **CARD 1A1**. The file is only used if LSUN is also TRUE. If LSUNFL is FALSE (F, f or blank) and LSUN is TRUE, the file name 'DATA/newkur.dat' is used. LSUNFL can also be set to 1, 2, 3, or 4; see **CARD 1A1**.

LBMNAM = t, f or blank. If TRUE (T or t), read band model parameter data file name from **CARD 1A2**. Otherwise, the default (1 cm^{-1} bin) band model database ('DATA/B2001_01.BIN') is used.

LFLTNM = 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_2O properties are fixed even though water amount has changed.

LDATDR	=	t, f or blank.	If TRUE (T or t), the directory name of the MODTRAN data files is read in; otherwise, data files are assumed to be in directory DATA/.
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 newkur.dat, 1362.12 W/m^2 for cebchkur.dat, 1359.75 W/m^2 for chkur.dat and 1376.73 W/m^2 for thkur.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'.

5. OPTIONAL CARDS 1A1, 1A2, 1A3, 1A4 (SPECTRAL DATA AND SENSOR RESPONSE FUNCTION FILES)

CARD 1A1: SUNFL2
FORMAT (A80)

CARD 1A1 is used to select the TOA solar irradiance database. It is read only if LSUNFL = T in **CARD 1A**.

SUNFL2	=	1 or blank	The corrected Kurucz database is used (DATA/newkur.dat).
	=	2	The Chance database is used (DATA/chkur.dat).
	=	3	The Cebula plus Chance data are used (DATA/cebchkur.dat).
	=	4	The Thuillier plus corrected Kurucz are used (DATA/thkur.dat)
	=	a file name	A user-defined 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).

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 numbers from newkur.dat so that the data encompasses the range of 50 to 50,000 wavenumbers. *Note that the user-defined file has a form that is different from DATA/cebchkur.dat, DATA/thkur.dat, DATA/newkur.dat, and DATA/chkur.dat.*

CARD 1A2: BMNAME
FORMAT (A80)

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 in* ***CARD 1A****.*

*BMNAME = Name of binary, direct-access version of the band model parameter data file. The default name for the 1 cm^{-1} band model file is 'DATA/B2001_01.BIN'. There are also a 5 cm^{-1} and a 15 cm^{-1} band model file available for faster short-wave calculations: 'DATA/B2001_05.BIN' and 'DATA/B2001_15.BIN'. If the 1 cm^{-1}, 5 cm^{-1} or 15 cm^{-1} band model file is selected, MODTRAN will also open the corresponding 1 cm^{-1}, 5 cm^{-1} or 15 cm^{-1} Correlated-k data file when input variable MODTRN (**CARD 1**) equals 'C' or 'K'. The names of the CK data files are hardwired to 'DATA/CORK01.BIN', 'DATA/CORK05.BIN', and 'DATA/CORK15.BIN'.*

CARD 1A3: FILTNM
FORMAT (A80)

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. Sample AVIRIS and LANDSAT7 filter response functions are supplied with the model ('DATA/aviris.flt' and 'DATA/landsat7.flt').

Whenever this option is used, the included 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	*The maximum number of channels in the response function file.*
MNBIN	*The minimum* ***frequency*** *bin used in the channel function integrations (cm^{-1}).*
MXBIN	*The maximum* ***frequency*** *bin used in the channel function integrations (cm^{-1}).*
MXNCHN	*The 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)
w_{11} r_{11}
w_{12} r_{12}
w_{13} r_{13}
…
HEADER(2)
w_{21} r_{21}
w_{22} r_{22}
w_{23} r_{23}
…
etc.

Here, UNITS_HEADER is a string whose first character is 'N' (for nm), 'W' (for wavenumbers), 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 i^{th} channel.

(w_{ij} r_{ij}) are the j^{th} wavelength and response values for the i^{th} channel.

CARD 1A4: DATDIR
FORMAT (A80)

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.

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, 5F10.5)

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 stratosphere to 100 km. VIS, the meteorological range, when specified, will supersede the default meteorological range in the boundary-layer aerosol profile set by IHAZE. For repeat runs using constant pressure (MODEL = 0) or radiosonde input (MODEL = 7 or 8), and with IM set to 0, updates in the CARD2 inputs are ignored.

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.

APLUS = *Blank Default*

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

CARD 2 (Required)

IHAZE	=	-1	No aerosol attenuation, but the model clouds may be included (i.e., ICLD = 1, 2, …, 10).
	=	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 and 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 FALL-WINTER for MODEL = 3, 5
	=	1	SPRING-SUMMER
	=	2	FALL-WINTER
ARUSS	=	*Blank*	*Default*
	=	*'USS'*	*User-defined aerosol optical properties (instructions in Appendix A)*

The parameter IVULCN (Table 2) 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 STRATOSPHERIC extinction
	=	7	HIGH VOLCANIC profile and BACKGROUND STRATOSPHERIC extinction
	=	8	EXTREME VOLCANIC profile and FRESH VOLCANIC extinction

Table 2. Shows the Value of IVULCN Corresponding to the Different Choices of Extinction Coefficient Model and the Vertical Distribution Profile.

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

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

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.

CARD 2 (Required)

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 (Modeled with cloud 3 and 0.86 mm / hr at 1.0 km).		
	=	7	5.0 mm/hr ground Light rain (Modeled with cloud 5 and 2.6 mm / hr at 0.66 km).		
	=	8	12.5 mm/hr ground Moderate rain (Modeled with cloud 5 and 6.0 mm / hr at 0.66 km).		
	=	9	25.0 mm/hr ground Heavy rain (Modeled with cloud 1 and 0.2 mm / hr at 3.0 km).		
	=	10	75.0 mm/hr ground Extreme rain (Modeled with 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 & 96 μm effective ice particle radius).		
	=	19	Sub-visual Cirrus model (4 μm mode & 6 μm effective ice particle radius).		

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 introduces 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 set to zero, VIS is the default value specified by IHAZE. Visibility is related to surface aerosol extinction at 550 nm (EXT550 in km^{-1}) by the equation

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

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 + Rayleigh 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 Rayleigh limit, MODTRAN will terminate with the error message, "Input aerosol + Rayleigh optical depth too low.".

VIS > 0. User specified surface meteorological range (km).

= 0. Uses the default meteorological range set by IHAZE; (See Table 3).

VIS < 0. Negative of the vertical aerosol plus Rayleigh 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).

Table 3. MODTRAN CARD 2 Input Parameters: IHAZE, ISEASN, IVULCN, and VIS.

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

CARD 2 (Required)

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			

Table 4. Default Wind Speeds for Different Model Atmospheres Used with the Navy Maritime Model (IHAZE = 3).

Model	Model Atmosphere	WSS and WHH Default Wind Speed (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	User-defined	6.9

Table 5. 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

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 4. For the Desert aerosol model (IHAZE = 10), if WSS < 0, the default wind speed is 10 m/s.

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

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.

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

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 6 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 6. 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)

CARD 2A: **CTHIK, CALT, CEXT**
FORMAT (3F8.3) (FORMAT changed in MODTRAN3.5)

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* CTHIK.
	>	0.	User-defined extinction coefficient.

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

CARD 2A: **CTHIK, CALT, CEXT, NCRALT, NCRSPC, CWAVLN, CCOLWD, CCOLIP, CHUMID, ASYMWD, ASYMIP**
FORMAT (3F8.3, 2I4, 6F8.3)

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 7. This will not only scale default clouds but also user-specified cloud profiles (**CARD 2E1**).

Table 7. Properties of the MODTRAN Cumulus and Stratus Type Model Clouds.

ICLD	Cloud Type	Thickness (km)	Base (km)	.55μm Ext. (km^{-1})	Column Amt. (km g / m^3)
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

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.

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

CEXT	>	0.	Cloud water particle vertical extinction [km^{-1}].
	≥	0.	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 7.

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

NCRALT	≥	3	Number of layer boundary altitudes (from **CARD 2E1**) in user-defined cloud/rain profile.
	<	3	Use default cloud profile for ICLD.

The maximum allowed value for NCRALT is 16, parameter NZCLD in; 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	≥	2	Number of spectral grid points for cloud optical data (triggers **CARD 2E2**).
	=	1	Read auxiliary cloud spectral data file (triggers alternate **CARD 2E2**).
	<	1	Use default spectral data for ICLD.

If the cloud spectral data is to be included directly in the <*rootname*>.tp5 input file, NCRSPC must be at least 2 with minimum and maximum wavelengths that do not coincide. With this option, the spectral scattering phase functions are represented as Henyey-Greenstein functions. The maximum number of wavelengths (parameter MXWVLN in PARAMS.h) is set to 788 in the MODTRAN delivery, although this value can be increase at the user discretion. *Tabulated cloud extinction, absorption and phase function data are read from the auxiliary cloud spectral data file if NCRSPC is 1. The format of the auxiliary file is described in Section 12.3, "Alternate CARD 2E2". The Parameter MXWVLN is not used with the auxiliary data file, because the data are read into dynamically allocated arrays.*

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

CWAVLN	≥0.2 & ≤200.0	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	≥	0.	Cloud liquid water droplet vertical column density [km g / m^3].
	<	0.	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 7.

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

CCOLIP	≥	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. & ≤105.	Cloud / rain relative humidity [%].
CHUMID	≤0.	Assume 100% relative humidity at cloud/rain layer boundaries.
CHUMID	>105.	Do not alter H_2O 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 scattering phase function asymmetry factor at all wavelengths.
	≥	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-Greensteinphase function asymmetry factor for scatteringby cloud ice particles:

|ASYMIP|	<	1.	Ice particle Henyey-Greenstein scattering phase function asymmetry factor at all wavelengths.
	≥	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 (required when IVSA = 1 on **CARD 2**).

CARD 2B: ZCVSA, ZTVSA, ZINVSA
FORMAT (3F10.3)

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	>	0.0	sets the known cloud ceiling height;
	=	0.0	height unknown: the program will calculate one for case 2, and default is 1.8 km for case 2'; or
	<	0.0	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	>	0.0	the known value of the cloud thickness;
	=	0.0	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, 2C1, 2C2, 2C2X, 2C3 (USER-DEFINED ATMOSPHERIC PROFILES)

User-supplied profile data are read in when the parameter MODEL is 7 (or 0 for a constant pressure path) and IM 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, *REE* **(MODEL = 0/7/8, IM = 1)**
FORMAT (3I5, A20, F10.0)

ML = Number of atmospheric levels to be inserted (maximum of NLAYER, see PARAMS.h file).

IRD1 Controls reading of WMOL(4-12) as described in Table 8 (**CARD 2C2**)

IRD1 = 0 No read.

IRD1 = 1 Read **CARD 2C2**.

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

IRD2 = 0 No read.

IRD2 = 1 Read **CARD 2C3**.

IRD2 = 2 Read new version of **CARD 2C3**; see Appendix A.

HMODEL = Identification of new model atmosphere.

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

10.2 CARDs 2C1, 2C2, 2C2X

CARD 2C1: ZM, P, T, (WMOL(J), J = 1, 3), (JCHAR(J), J = 1, 14), JCHARX
FORMAT (F10.3, 5E10.3, 14A1, 1X, A1)

CARD 2C2: (WMOL(J), J = 4, 12) (If IRD1 = 1)
FORMAT (8E10.3, /E10.3)

CARD 2C2X: (WMOLX(J), J = 1, 13) (If IRD1 = 1 and MDEF = 2)
FORMAT (8E10.3, /5E10.3)

Z M	=	Altitude of layer boundary (km).
P	=	Pressure of layer boundary.
T	=	Temperature of layer boundary.
WMOL(1-12)	=	Individual molecular species densities (see Table 8 for species).
WMOLX(1-13)	=	Heavy molecular species densities (see Table 9 for species).
JCHAR(1-14)	=	Control variables for selection of units for primary profile inputs (P, T and molecular constituents, see Table 8).
JCHARX	=	Single control variable for selection of units for entire set of CFCs and other heavy molecules. (See Table 9 for order and identification of these species).

By utilizing a choice of values for the JCHAR(J) control variable (where J = 1, 14) the user can designate specific units or accept defaults for the various molecular species and for the temperature and pressure. If JCHAR(J) is left blank the program will default to the values chosen by M1, M2, M3, M4, M5, M6 and MDEF when the given amount is zero. If the amount is non-zero and the JCHAR(J) is blank, the code assumes the first option on units: mb for pressure, K for temperature, and ppmv on constituents. 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 9. These values are required only if MDEF=2.

For JCHAR(1),

A indicates Pressure in (mb)

B indicates Pressure in (atm)

C indicates Pressure in (torr)

1-6 default to specified atmospheric MODEL value

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

Table 8. The Association of the JCHAR(J) Index (J = 1, 14) with the Variables P, T and 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 9. 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 13	CCl_4 N_2O_5		

For JCHAR(2),

A indicates ambient temperature in degrees K

B indicates ambient temperature in degrees C

1-6 will default to specified atmospheric MODEL value

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

For 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 indicates Partial pressure (mb)

F indicates Dew point temperature (TD in T[K]) - H_2O only

G indicates 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).

10.3 CARD 2C3

CARD 2C3: AHAZE, EQLWCZ, RRATZ, IHA1, ICLD1, IVUL1, ISEA1, ICHR
FORMAT (10X, 3F10.3, 5I5)

CARD 2C3 (for user-specified aerosol/cloud/rain models) is read when IRD2 is set to 1 on **CARD 2C**. The following instructions apply to MODTRAN3.5, as well as to more recent versions when IRD2 = 1. Instructions for IRD2 = 2 are given in Appendix A.

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 PARAMETER **ARUSS (CARD 2)** IS NOT SET TO 'USS'. WHEN ARUSS EQUALS 'USS', SEE **APPENDIX A** FOR INSTRUCTIONS.*

11.1 CARD 2D

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

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 boundary altitudes default to 0-2, 3-10, 11-30, 35-100 km but can be overridden with 'IHA1' (**CARD 2C3**) with MODEL = 7 (See Section 7 for a more 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 CARD 2D1

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

CARD 2D1: **AWCCON, TITLE**
FORMAT (E10.3, 18A4)

AWCCON is a conversion factor from extinction coefficient (km^{-1}) to equivalent liquid water content (g/m^3). 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}).

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

11.3 CARD 2D2

CARD 2D2: **(VARSPC(I), EXTC(N, I), ABSC(N, I), ASYM(N, I), I = 1, 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 10 must be entered (actually, the input values are not used and the Table 10 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.

Table 10. VARSPC Array of Fixed (Required) 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: In MODTRAN4, 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 ≥ 3, **CARD 2E2** is read if NCRSPC ≥ 2, and *alternate* **CARD 2E2** is read if NCRSPC = 1 on **CARD 2A**.

12.1 CARD 2E1

CARD 2E1: (ZCLD(I, 0), CLD(I, 0), CLDICE(I, 0), RR(I, 0), I = 1, NCRALT)
FORMAT ((4F10.5)) (If ICLD = 1 - 10, NCRALT ≥ 3)

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 level of layer boundary I for the user-defined cloud/rain profile [KM].

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 must monotonically increase. 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).

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 can not 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 CARD 2E2

CARD 2E2: (WAVLEN(I), EXTC(6, I), ABSC(6, I), ASYM(6, I), EXTC(7, I), ABSC(7, I), ASYM(7, I), I = 1, NCRSPC)
FORMAT (7F10.5) (If ICLD = 1 - 10, NCRSPC ≥ 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 the 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 at wavelength WAVLEN(I) [$km^{-1}\ m^3 / g$]

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) — <u>If positive:</u> liquid water droplet absorption coefficient at wavelength WAVLEN(I) [km^{-1} m^3 / g]

<u>If negative:</u> liquid water droplet scattering albedo minus one (ω_{wat} - 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 the coalbedo, i.e., one minus the liquid water droplet scattering albedo.

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) — <u>If positive:</u> Ice particle absorption coefficient at wavelength WAVLEN(I) [km^{-1} m^3 / g]

<u>If negative:</u> Ice particle scattering albedo minus one (ω_{ice} - 1) at wavelength WAVLEN(I)

If the input value for ABSC(7, I) is less than -1 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 (T) should be used to determine the absorption coefficient. A negative value for ABSC(7, I) not less than -1 is taken to be the negative of the coalbedo, i.e., 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 ((A80)) (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 80 characters).

CLDTYP Water cloud type (maximum 80 characters).

CIRTYP Ice cloud type (maximum 80 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
	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)

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: **H1, H2, ANGLE, RANGE, BETA, RO, LENN, PHI**

FORMAT (6F10.3, I5, 5X, F10.3)

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

H1 = Initial altitude (km)

H2 = 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 or 2) H1, the initial altitude, always defines the position of the observer (or sensor). H1 and H2 cannot be used interchangeably as in the transmittance mode.

ANGLE = Initial zenith angle (0 to 180 degrees) as measured from H1

RANGE = Path length (km)

BETA = Earth center angle subtended by H1 and H2 (0 to 180 degrees)

RO = Radius of the earth (km) at the particular latitude of the calculation

If RO 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 11.

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.

If LENN = 0 (default), path will be "short".

PHI = zenith angle (0 to 180 degrees) as measured from H2 (target or final altitude) towards H1 (sensor or initial altitude).

Table 11. Default Values of the Earth Radius for Different Model Atmospheres.

Model	Model Atmosphere	Earth Radius, RO (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

It is not 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 12).

(1) Horizontal Paths (ITYPE = 1)

(a) specify H1, RANGE

(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 H1, H2, ANGLE, and LENN (LENN only if H2 < H1)

(b) specify H1, ANGLE, and RANGE

(c) specify H1, H2, and RANGE

(d) specify H1, H2, and BETA

(e) specify H2, H1, PHI, and LENN(LENN only if H1 < H2)

(f) specify H2, PHI, and RANGE

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

(a) specify H1 and ANGLE

(b) specify H1 and H2 (for limb-viewing problem where H2 is the tangent height or minimum altitude of the path trajectory).

(c) specify H2 and PHI (here H1 = space)

CARD 3 (Required)

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

```
If (PHI>0 and RANGE>0) THEN
    CASE 2f
ELSE IF (PHI>0) THEN
    CASE 2e
ELSE IF (BETA>0) THEN
    CASE 2d
ELSE IF (RANGE>0 AND ANGLE>0) THEN
    CASE 2b
ELSE IF (RANGE>0) THEN
    CASE 2c
ELSE
    CASE 2a
END IF
```

For ITYPE = 3, a similar scheme is used:

```
IF (PHI>0) THEN
    CASE 3c
ELSE IF (H2 = 0) THEN
    CASE 3a
ELSE
    CASE 3b
END IF
```

Table 12 lists the **CARD 3** options provided to the user for the different types of atmospheric paths.

Table 12. Allowed Combinations of Slant Path Parameters.

Case	H1	H2	Angle	Range	BETA	LENN (Optional)	PHI
2a	*	*	*			(*)	
2b	*		*	*			
2c	*	*		*			
2d	*	*			*		
2e	*	*				(*)	*
2f		*		*			*
3a	*		*				
3b	*	*					
3c	*	*					*

LENN is used only when H1 > H2 and Case 2a, or H2 > H1 and Case 2e. Otherwise, LENN is automatically set in the program.
* Required Inputs.

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:

ALT CARD 3: H1, H2, ANGLE, IDAY, RO, ISOURC, ANGLEM
FORMAT (3F10.3, I5, 5X, F10.3, I5, F10.3)

H1	=	Altitude of the observer.
H2	=	Tangent height of path to sun or moon.
ANGLE	=	Apparent solar or lunar zenith angle at H1.
IDAY	=	Day of the year, used to correct for variation in the earth-to-sun distance.
RO	=	Radius of earth in kilometers (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 H2 or ANGLE should be specified. If both are given as zero, then a vertical path (ANGLE = 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) 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 H1 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 on **CARD 1**) and the selection of the aerosol scattering phase function.

14.1 CARD 3A1

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

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, TIME, PSIPO, ANGLEM, G
FORMAT (8F10.3) (If IEMSCT = 2)

The definitions of PARM1, PARM2, PARM3, PARM4 are determined by the value of IPARM on **CARD 3A1** (see Table 13):

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 (0° to 360° **West** of Greenwich)

PSIPO = true path azimuth from H1 to H2 (degrees East of true North)

For IPARM = 1:

The parametersIDAY (**CARD 3**) and TIME must be specified. This option cannot be used with ISOURC = 1, which refers to the moon as the source.

PARM1 = observer latitude (-90° to +90°)
PARM2 = observer longitude (0°to 360° **West** of Greenwich)
TIME = Greenwich time
PSIPO = true path azimuth from H1 to H2 (degrees East of true North)
PARM3, PARM4 are not required

For IPARM = 2:

PARM1 = relative azimuth angle between the observers 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 H1 (the observer)
PARM3, PARM4 are not required

Note that the calculated apparent solar zenith angle is the zenith angle at H1 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 H2
PARM2 = longitude at H2 (0°to 360° **West** of Greenwich)
PARM3 = source (sun or moon) latitude
PARM4 = source (sun or moon) longitude (0°to 360° **West** of Greenwich)
PSIPO = true path azimuth from H2 to H1 (degrees East of true North)

For IPARM = 11:

PARM1 = latitude at H2
PARM2 = longitude at H2 (0°to 360° **West** of Greenwich)
TIME = Greenwich time
PSIPO = true path azimuth from H2 to H1 (degrees East of true North)

For IPARM = 12:

PARM1 = relative solar azimuth (degrees East of true North) at H2

PARM2 = solar zenith (degrees) at H2

Table 13. CARD 3A2: Input IPARM Options.

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 H2 (-90° to +90°)	Latitude at H2 (-90° to +90°)	Relative Solar Azimuth at H2 (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 H2 (Degrees **West** of Greenwich)	Longitude at H2 (Degrees **West** of Greenwich)	Solar Zenith at H2 (Degrees)
PARM3	Source Latitude	-	-	Source Latitude	-	-
PARM4	Source Longitude	-	-	Source Longitude	-	-
TIME	-	Greenwich Time (Decimal Hours)	-	-	Greenwich Time (Decimal Hours)	-
PSIPO	True Path Azimuth Angle **from H1 to H2** (Degrees East of Due North)	True Path Azimuth Angle **from H1 to H2** (Degrees East of Due North)	-	True Path Azimuth Angle **from H2 to H1** (Degrees East of Due North)	True Path Azimuth Angle **from H2 to H1** (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

The remaining control parameters are:

TIME = 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)

PSIPO = Path azimuth (degrees East of true 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 following instructions apply when the ARUSS (**CARD 2**) is not set to 'USS'. Instructions for the MODTRAN3.7 / MODTRAN4 upgrade (ARUSS = 'USS') are provided in Appendix A.

15.1 CARD 3B1

CARD 3B1: **NANGLS** (If IPH = 1 on **CARD 3A1**)
FORMAT (I5)

NANGLS = number of angles for the user-defined phase functions (maximum of 50).

15.2 CARD 3B2

This card is repeated NANGLS times (1 to NANGLS).

CARD 3B2: **(ANGF(I), F(1, I, 1), F(2, I, 1), F(3, I, 1), F(4, I, 1), I = l, NANGLS)**
FORMAT ((5E10.3))

ANGF(I) = scattering angle in decimal degrees (0.0° to 180.0°)

F(1, I, 1) = Normalized user-defined aerosol scattering phase function at ANGF(I), boundary layer (0 to 2 km default altitude region) [sr^{-1}].

F(2, I, 1) = Normalized user-defined aerosol scattering phase function at ANGF(I), troposphere (2 to 10 km default altitude region) [sr^{-1}].

F(3, I, 1) = Normalized user-defined aerosol scattering phase function at ANGF(I), stratosphere (10 to 30 km default altitude region) [sr^{-1}].

F(4, I, 1) = Normalized user-defined aerosol scattering phase function at ANGF(I), mesosphere (30 to 100 km default altitude region) [sr^{-1}].

The default altitude regions may be overridden by the parameters IHA1, ICLD1 or IVUL1 (**CARD 2C3**). The third index, which is 1 here, is introduced to make scattering phase functions wavelength dependent in MODTRAN3.7/4. There was no wavelength dependence prior to MODTRAN3.7.

15.3 CARDs 3C1-3C6

These cards are used only with the MODTRAN3.7 / MODTRAN4 upgrade; see Appendix A.

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

This card specifies the spectral range, frequency/wavelengthincrements, 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
FORMAT (4F10.0, 2A1, A8, A7, I3)

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, 5 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.

CARD 4 (Required)

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].

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.
	=	M	Spectral units in microns.
	=	N	Spectral units in nanometers.
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 of H	Hamming slit function.
	=	7 of U	User-supplied function.
FLAGS(3:3)	=	blank or A	FWHM is absolute.
	=	R	FWHM is percent relative, i.e., FWHM = 100 dν/ν=100 dλ/λ.
FLAGS(4:4)	=	blank	Degrade only total radiance and transmittance.
	=	A	Degrade all radiance and transmittance components.

CARD 4 (Required)

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.

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:

Triangular

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

Square

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

Gaussian

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

Sinc [Sinc$(x) \equiv \sin(\pi x)/(\pi x)$]

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

Sinc^2

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

Hamming

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

$$s \;=\; \frac{0.88589}{\Delta}$$

17. 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).

17.1 CARD 4A

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

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 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.*

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.

17.2 CARD 4B1

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

Character string *CBRDF* defines the name of 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.*, 2000) are all semi-empirical models. 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 (H1);
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:

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

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

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

Analytically evaluated sinusoidal Walthall reflectance integrals.

CBRDF = '4' or 'Hapke'

$$\rho(\theta_v, \theta_s, \Delta\varphi) =$$

$$\frac{P_1 / 4}{\cos\theta_v + \cos\theta_s} \left\{ \left[1 + \frac{P_4 / P_1}{B(\cos\phi, P_2, P_3)} \right] P_{HG}(\cos\phi, P_2) + H(\cos\theta_v, P_1)\, H(\cos\theta_s, P_1) - 1 \right\}$$

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.

CBRDF = '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 $K_{geo} = \frac{(\pi-\Delta\varphi)\cos\Delta\varphi+\sin\Delta\varphi}{2\pi}\tan\theta_v\tan\theta_s - \frac{\tan\theta_v+\tan\theta_s+G(\theta_v,\theta_s,\Delta\varphi)}{\pi}$

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

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 Ross-Thick volume scattering kernel K_{RT}, so called for its assumption of a dense leaf canopy.

CBRDF = '10' or 'Pinty-Verstraete'

Error! Objects cannot be created from editing field codes.

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

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

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

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, $H(x, \omega)$.

CBRDF = '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

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

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

$$\tan\theta_x' = P_5 \tan\theta_x\ ; \qquad x = v \text{ or } s$$

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 Ross Thick 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).

17.3 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 PARAMS.h 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.*

17.4 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 further 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, …

17.5 CARD 4L1

CARD 4L1: ***SALBFL***
FORMAT (A80) (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.*

17.6 CARD 4L2

CARD 4L2: **C*SALB***
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 46 spectral albedo curves available in the default spectral albedo file 'DATA/spec_alb.dat'. Leading blanks are ignored. The 46 (case-insensitive) CSALB inputs for 'DATA/spec_alb.dat' 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*	*'dead 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%'*
'31'	*or*	*'CCM3 Sea ice' - (Kiehl et al., 1996)*
'32'	*or*	*'conifer' - JHU becknic database, vegetation*
'33'	*or*	*'olive gloss paint' - JHU becknic database, manmade*

'34' or 'deciduous tree' - JHU becknic database, vegetation
'35' or 'sandy loam' - JHU becknic database, soil
'36' or 'granite' - JHU becknic database, igneous rock
'37' or 'galvanized steel' - JHU becknic database, manmade
'38' or 'grass' - JHU becknic database, vegetation
'39' or 'black plastic' - MWIR LWIR
'40' or 'Aluminum' - MWIR LWIR
'41' or 'Evergreen Needle Forest' - Mosart 14, pine forest
'42' or 'Evergreen Broadleaf Forest' - Mosart 18, broadleaf-pine forest
'43' or 'Deciduous Needle Forest' - Mosart 18, broadleaf-pine forest
'44' or 'Deciduous Broadleaf Forest' - Mosart 6, broadleaf forest
'45' or 'Mixed Forest' - Mosart 25, broadleaf 70-pine 30
'46' or 'Closed Shrubs' - Mosart 22, pine-brush
'47' or 'Open/Shrubs' - Mosart 40, broadleaf-brush
'48' or 'Woody Savanna' - Mosart 20, soil-grass-scrub
'49' or 'Savanna' - Mosart 19, grass-scrub
'50' or 'Grassland' - Mosart 13, meadow grass
'51' or 'Wetland' - Mosart 51, wetland
'52' or 'Cropland' - Mosart 45, crop
'53' or 'Urban' - Mosart 21, urban commercial
'54' or 'Crop Mosaic' - Mosart 46, mixed-vegetation
'55' or 'Antarctic Snow' - Mosart 9, old snow 1000 micron radius
'56' or 'Barren/Desert' - Mosart 28, mixture of material (rock & silt-sand)
'57' or 'Ocean Water' - Mosart 1, water
'58' or 'Tundra' - Mosart 16, tundra
'59' or 'Fresh Snow' - Mosart 43, fresh snow (50 micron radius)
'60' or 'Sea Ice' - Mosart 10 sea ice, 3 meters thick

18. CARD 5 (REQUIRED) – REPEAT RUN OPTION

CARD 5: IRPT
FORMAT (I5)

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:

<u>If IRPT = ±3</u>

CARD 5:	IRPT = ±3	
CARD 3:	H1, H2, ANGLE, RANGE, BETA, RO, LENN, PHI	(If IEMSCT < 3)
CARD 3:	H1, H2, ANGLE, IDAY, RO, ISOURC, ANGLEM	(If IEMSCT = 3)
CARD 3A1:	IPARM, IPH, IDAY, ISOURC	(If IEMSCT = 2)
CARD 3A2:	PARM1, PARM2, PARM3, PARM4, TIME, PSIPO, ANGLEM, G	(If IEMSCT = 2)
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

CARD 5 (Required)

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 14 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 14. 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.**

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APPENDIX A: MODTRAN3.7 / MODTRAN4 USER-SUPPLIED AEROSOL UPGRADES

This section contains instructions for the MODTRAN3.7/MODTRAN4 options that provide flexible wavelength-dependent specification of extinction, absorption, and asymmetry parameters and phase functions. 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 10) and different for each aerosol. The scattering phase function can have wavelength dependence in addition to angular dependence. 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 10. This was done using **CARDs 2D, 2D1** and **2D2** with IHAZE = 7 or ICLD = 11.

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

- Now 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 also 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.

Note that 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:

$K_{EXT}(\lambda) = EXT(\lambda) / EXT(0.55\ \mu m)$

$K_{ABS}(\lambda) = ABS(\lambda) / EXT(0.55\ \mu m)$

CARD 2D: IREG(1), IREG(2), IREG(3), IREG(4)

FORMAT (4I5) (If IHAZE = 7 or ICLD = 11 or ARUSS = 'USS')

CARD 2D1: AWCCON, TITLE
FORMAT (E10.3, 18A4) (CARDs 2D1 and 2D2 needed if IREG(1) > 0)

CARD 2D2: (VARSPC(1, I), EXTC(1, I), ABSC(1, I), ASYM(1, I), I = 1, IREG(1) or **47)**
FORMAT (3(F6.2, 2F7.5, F6.4)) (If ARUSS is not set)

CARD 2D1: AWCCON, TITLE
FORMAT (E10.3, 18A4) (If IREG(2) > 0)

CARD 2D2: (VARSPC(2, I), EXTC(2, I), ABSC(2, I), ASYM(2, I), I = 1, IREG(2) or **47)**
FORMAT (3(F6.2, 2F7.5, F6.4)) (If ARUSS is not set)

CARD 2D1: AWCCON, TITLE
FORMAT (E10.3, 18A4) (If IREG(3) > 0)

CARD 2D2: (VARSPC(3, I), EXTC(3, I), ABSC(3, I), ASYM(3, I), I = 1, IREG(3) or **47)**
FORMAT (3(F6.2, 2F7.5, F6.4)) (If ARUSS is not set)

CARD 2D1: AWCCON, TITLE
FORMAT (E10.3, 18A4) (If IREG(4) > 0)

CARD 2D2: (VARSPC(4, I), EXTC(4, I), ABSC(4, I), ASYM(4, I), I = 1, IREG(4) or **47)**
FORMAT (3(F6.2, 2F7.5, F6.4)) (If ARUSS is not set)

CARDs 2D1 and 2D2 are repeated up to four times, one pair for each aerosol. However, the two cards for aerosol i are needed if and only if IREG(N) > 0. The only differences between the present and prior forms are in **CARD 2D** and **CARD 2D2**. Now **CARD 2D** has four integer values denoting 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 is the extinction coefficient, ABSC is the absorption coefficient and ASYM is the asymmetry parameter. Previously the IREG values were all 1 or 0. A value of 1 meant that spectral parameters had to be read using **CARD 2D2** and the number of spectral points were fixed at 47. (Actually the VARSPC array was not used at all because the 47 wavelengths were already fixed in the code at an earlier point.) 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.

The meaning of IREG is summarized and further clarified below:

VALUE OF ARUSS	VALUE AND MEANING OF IREG(N)	
ARUSS = 'USS'	IREG(N) = 0	No user-supplied data.
	IREG(N) = M	User-supplied data for M arbitrary wavelengths.
ARUSS = blank	IREG(N) = 0	No user-supplied spectral data.
	IREG(N) = 1	User-supplied data for the 47 fixed grid points of Table 10; Although VARSPC array is read, they are not used; instead Table 10 wavelengths are used.

A.2 User-Supplied Aerosol Phase Functions (CARDs 3B1, 3B2, 3C1-3C6)

The user-supplied phase function input scheme has also been upgraded. As before, the user-supplied phase functions are read in if IPH (**CARD 3A2**) is set to 1. Now, the user-supplied phase functions can vary with wavelength in addition to angle. This upgrade is actually independent of the A+ and USS upgrades, and it necessitates a "generalized" form of **CARD 3B1**:

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

NWLF is the new variable which can be either 0 or a positive integer; 0 means that the phase function has no wavelength dependence whereas a positive integer means that the phase function will be specified on a wavelength grid with that many points. The phase function array, F, now has three indices: aerosol index, angle index and the wavelength index.

If NWLF = 0 or blank, **CARD 3B2** is used as before:

CARD 3B2: (ANGF(I), F(1, I, 1), F(2, I, 1), F(3, I, 1), F(4, I, 1), I = 1, NANGLS)
FORMAT (5E10.3) (If IPH = 1, NWLF = 0)

If NWLF > 0, **CARD 3B2** is replaced by **CARDs 3C1-3C6:**

CARD 3C1: **(ANGF(I), I = 1, NANGLS)**
FORMAT (8(1X, F9.0)) (Read angles [0° to 180°] if IPH = 1, NWLF > 0)

CARD 3C2: **(WLF(J), J = 1, NWLF)**
FORMAT (8(1X, F9.0)) (Read wavelengths [μm] if IPH = 1, NWLF > 0)

CARD 3C3: **(F(1, I, J), J = 1, NWLF)** (Read phase function for aerosol 1 if IPH = 1
FORMAT (8(1X, E9.3)) and NWLF > 0; repeat NANGLS times)

CARD 3C4: **(F(2, I, J), J = 1, NWLF)**
FORMAT (8(1X, E9.3)) (Read for aerosol 2; repeat NANGLS times)

CARD 3C5: **(F(3, I, J), J = 1, NWLF)**
FORMAT (8(1X, E9.3)) (Read for aerosol 3; repeat NANGLS times)

CARD 3C6: **(F(4, I, J), J = 1, NWLF)**
FORMAT (8(1X, E9.3)) (Read for aerosol 4; repeat NANGLS times)

In this upgrade, 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; the CARDs for the subsequent aerosol then follow.

A.3 User-Supplied Aerosol Profiles (CARD 2C3)

Prior to these upgrades, the user could only input one aerosol profile by using the user-selected profile option, MODEL = 7, IRD2 = 1. Now the user can have up to four user-defined aerosol profiles with MODEL = 7, IRD2 = 2. (MODEL = 0 is not allowed.)

This upgrade cannot be used with the A+ upgrade option; the APLUS option is ignored if MODEL = 7 and IRD2 = 2 or 1. The A+ option allows the built-in aerosols to be shifted around, whereas this upgrade allows the user to input aerosol profiles (up to all four) with greater control. The four profiles can only be input as altitude-dependent aerosol extinction coefficients at 0.55 μm. Previously the single user-defined aerosol profile could be either the altitude-dependent extinction

coefficient or the altitude-dependent liquid water content (in g/m^3). For backward compatibility the previous option for the single aerosol profile is maintained.

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(1), 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 not 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 price of the current upgrade is the elimination of the cloud extinction at an altitude for having the luxury of inputting up to four aerosol extinctions. However, user-specified cloud profiles may be entered using **CARD 2E1**.

As mentioned, in lieu of extinction an aerosol profile could also be given as liquid water content in g/m^3. The conversion factor for converting liquid water content (g/m^3) to extinction coefficient is given by AWCCON. AWCCON can also be user-specified by using **CARD 2D** (IHAZE = 7 or ICLD = 11). However, since in the present upgrade, the aerosol profiles cannot be stated in terms of liquid water content, AWCCON values in **CARD 2D1** are not used.

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 NOVAM Code

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.

Appendix B: NOVAM

The version of NOVAM from NRaD outputs surface layer altitudes, and the net extinction, absorption and asymmetry coefficients by combining 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.

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 2, of the NOVAM manual. These inputs are the same as stated for positions 1 to 7. The revised Table 2 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 4 and Table 5, of the NOVAM manual. Table 4 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 5 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 4 and Table 5. Table 4 is said to be in 'n' format whereas Table 5 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. 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.

```
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
```

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.

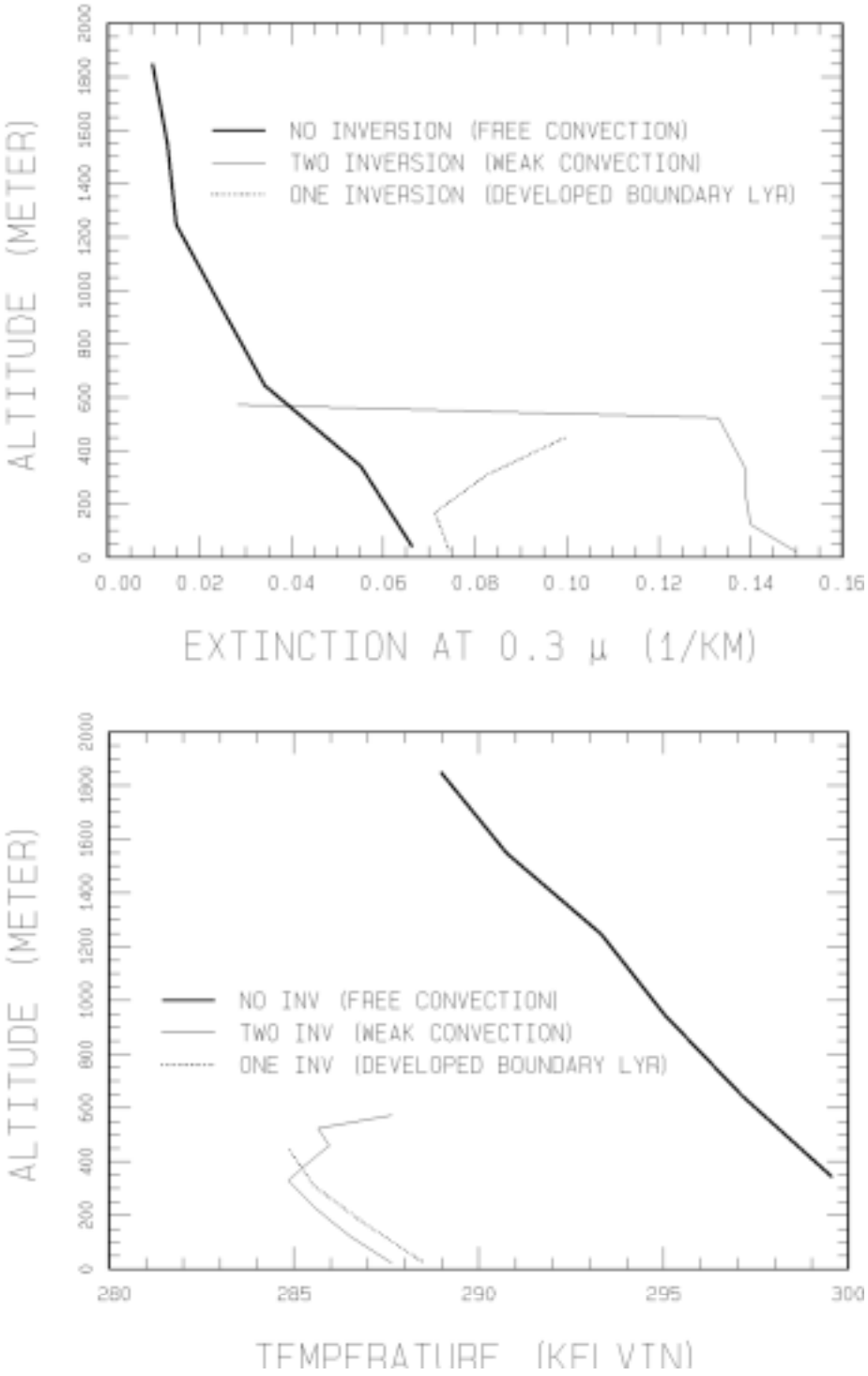

Figure 1a and b. The 3 aerosol and coincident temperature profiles (in extinction at 0.3μm and K, respectively) as a function of altitude. These profiles were chosen to capture the number of temperature inversions used as a parameter in NOVAM, 1 or no inversion, 2 or two inversions, and 3 for 1 inversion. 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.

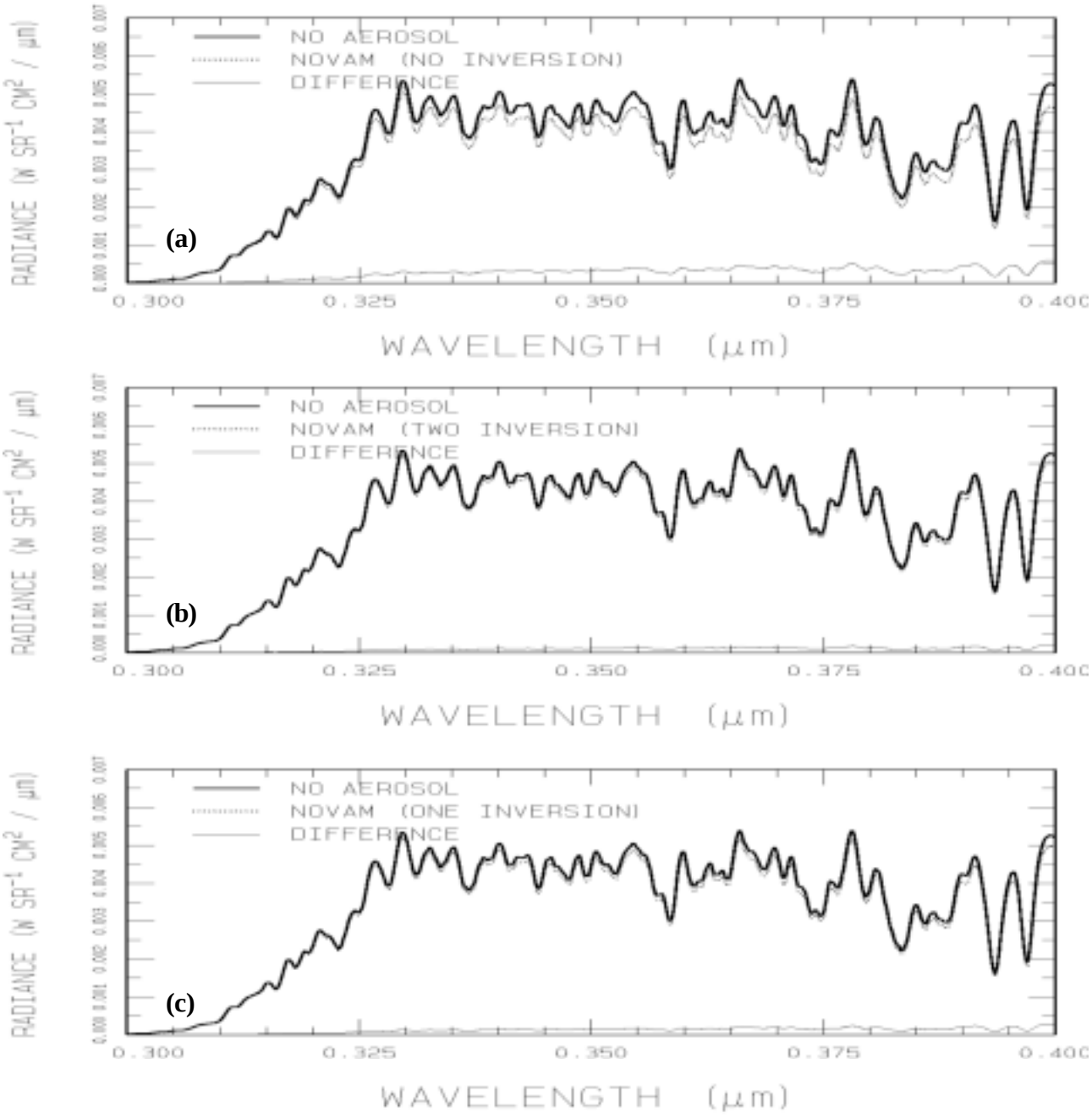

Figure 2a, b, c. As denoted, these represent typical sensitivity to the new NOVAM aerosol profiles shown in Figure 1. The plots are shown linearly to emphasize the impact at the longer wavelengths that 'see' to the surface, and, therefore, would be impacted by boundary-layer variability. At shorter wavelengths, <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.

B.4 NOVAM input and MODTRAN input Files

The NOVAM files were described earlier. So they are not reproduced here. 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

As mentioned 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 **infvile** 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 References

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 AND I/O FILES

This file outlines the steps required to obtain, install and execute MODTRAN on a UNIX system. It also mentions a new input/output (I/O) file structure for MODTRAN. Therefore, this file should be read even if one has already installed the code, or is familiar with the installation process. This file is duplicated as the 'README' file in the MODTRAN distribution tar file.

The top-level directory for MODTRAN is Mod4v3r1. The '4v3r1' refers to MODTRAN4, version 3, and revision 1.

Please contact either “Gail Anderson” <Gail.Anderson@hanscom.af.mil> or “Michael L Hoke Civilian AFRL/VSBT” <Michael.Hoke@hanscom.af.mil> for questions regarding distribution status or installation. Technical questions may be addressed to either Gail Anderson or Alexander Berk <lex@spectral.com>.

C.1 (UNIX) Installation Steps

1) Contact “Gail P. Anderson” <Gail.Anderson@hanscom.af.mil> or “Michael L Hoke Civilian AFRL/VSBT” <Michael.Hoke@hanscom.af.mil> to obtain the code.

2) Unzip the file: 'gunzip Mod4v3r1.tar.gz' will produce the tar file Mod4v3r1.tar. The 'uncompress' command will also work. Then untar the file: 'tar xvf Mod4v3r1.tar'; this will build a MODTRAN directory structure, Mod4v3r1, beneath the directory in which Mod4v3r1.tar is located. The top-level directory Mod4v3r1/ contains these subdirectories:src/, src/_F77only, obj77/, obj90/, DATA/, DOCS/, TEST/, TEST/COMPARE/, mie/, novam/, novam/src/ and novam/test/.

3) Create correlated-*k* binary data files in the DATA/ subdirectory. In DATA/, compile CKBIN.f (e.g., 'f90 CKBIN.f -o CKBIN.exe'). Run CKBIN.exe; you will be prompted for a correlated-*k* ASCII file name. Reply with 'CORK15.ASC', which should be placed in this directory during the untar process. You will be prompted for a binary name; reply with 'CORK15.BIN'. The program should announce a successful write and place the file in the DATA/ directory. Repeat for CORK05.ASC and CORK01.ASC.

4) Create band model parameter files. Compile and run MOLBMP.f. Select a binary-to-ASCII conversion. Although entering names of ASCII files is possible, the files of interest should appear in the menu; select '0' for 'B2001_01.ASC', '1' for 'B2001_05.ASC' or '2' for 'B2001_15.ASC'. Another menu permits choosing output filenames; select the corresponding BIN names. Once the binary files have been created, the ASCII files can be deleted; they can be regenerated from the binary using MOLBMP.f.

5) The command 'make -f Make_F77' will generate the FORTRAN77 executable file Mod4v3r1_F77.exe, while 'make -f Make_F90' will generate the FORTRAN90 executable file

Mod4v3r1_F90.exe. Object files will be placed in the obj77/ and obj90/ directories. You may need to edit the makefile to set the name and compiler parameters needed by your compiler.

6) MODTRAN (version 3.7 and higher) has the ability to use the Navy Oceanic Vertical Aerosol Computer Model (NOVAM). If you need to use this code, NOVAM must be compiled and run before MODTRAN, producing output files for use when needed. The NOVAM files are located in the novam/ subdirectory tree under the top MODTRAN directory. Depending on need, not all users will require NOVAM. MODTRAN is independent of NOVAM. To prepare using NOVAM, go to the novam/ subdirectory. Execute the UNIX script file createnovamexecutable, which will create the NOVAM executable, novam.exe. NOVAM (novam.exe) reads input from novam.in, and writes output to novam.out. Three test case inputs are located in the novam/test/ subdirectory. Copy one into the novam.infile name, or create one, and use 'novam.exe' to create novam.out. Copy that to NOVAM.OUT (upper case) in the topmost MODTRAN directory, which contains mod4v3r1.exe, for use in runs requiring NOVAM data.

7) The TEST/ subdirectory contains a number of input files designed to exercise wide range of MODTRAN capabilities. The input files are named in the pattern *.tp5; copy a *.tp5 file into tape5 in the top-level directory, and then 'mod4v3r1.exe' will run that case. The other way of running MODTRAN and naming I/O files makes use of the file 'modroot.in' or 'MODROOT.IN' as described below. Output files have .tp6, .tp7, .tp8, 7sc, .7sr, .plt, .psc, .clr, flx, and .chn extensions. For a comparison purpose, the *.tp6 output files were created on a PC and included in 'TEST/COMPARE' directory. (Due to the variation in the floating number handling in various versions of compilers there might be minor differences between calculated results and those included in the 'COMPARE' directory, these difference are usually limited to the last significant digit).

8) There is a batch file to run all test cases 'runmt4' the file was tested for Linux system only, and includes "as-is". Alternative is to use file "Batch.full" which also will run all test cases.

C.2 (PC/Windows) Installation Steps

The subdirectory pc/ contains an executable, and binary files, for a PC. If you are using MODTRAN4 on a PC, copy the executable to the mod4v3r1 directory, and move the *.BIN files to the DATA/ directory. You need not compile these files yourself.

There is a simple batch file included with the distribution "Run_all_test.bat". It will run all test cases from TEST directory. It creates a 'log.txt' file which includes time (wall clock) used for calculations of each test case. File "Run_all_test.bat". is a simple text file, if you have a problem running it, check that all paths are correct.