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USER GUIDE TO TOVSRAD: A PROGRAM FOR CALCULATING SYNTHETIC HIRS-2 AND MSU EQUIVALENT BLACK-BODY TEMPERATURES

by

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USER GUIDE TO TOVSRAD:

a program for calculating synthetic HIRS-2 and MSU equivalent black-body temperatures.

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1. INTRODUCTION

TOVSRAD is a program which calculates, through numerical integration of the radiative transfer equation, the equivalent black body temperatures which should be measured by the instruments HIRS-2 and MSU on the TIROS-N series of satellites for atmospheric profiles, surface conditons and scan angles chosen by the user. TOVSRAD was developed from the programs RAOBHIRS and RAOBMSU included in the Madison TOVS Export Package; the two programs have been combined with some minor modifications, and more flexible means for input and output of data have been included.

Section 2 provides a description of the main elements of TOVSRAD and gives references to the science which underlies it. An understanding of the program at the level given in this section is required in order to make informed decisions on the options available which are described in section 3. Section 4 lists diagnostic information on the "STOP messages" which may be obtained when the program terminates incorrectly. Section 5 gives a brief description of the function of each subroutine.

2. DESCRIPTION

The broad outline of the program is illustrated in figure 1. The major elements are described below.

2.1 INITIALISATION.

This includes:

- reading flags controlling input and output of data,
- reading satellite identifier, instrument flags, number of profiles to be processed, number of scan angles to be processed,
- reading the list of scan angles,
- reading the list of HIRS channels to be processed,
- reading parameters which specify the statistical relation to be assumed between the air temperature at the surface and the physical surface temperature (to be used in the absence of specific data for each profile),
- reading the cloud parameters used for MSU transmittance calculations.

2.2 THE ATMOSPHERIC PROFILE.

Using different input modes (see section 3.1.3.1) the program can read pressure/temperature/humidity profiles at either:

- arbitrary pressure levels (e.g. the special levels of a radiosonde report), or
- 40 standard levels (the NESS standard levels from 0.1 to 1000 mb).

Data given at arbitrary levels are interpolated to the 40 standard levels within the program using linear interpolation in temperature against log(pressure) and in log(mixing ratio) against log(pressure). The uppermost level must have a pressure of 50 mb or less, otherwise the profile is rejected. Valid temperatures must exist for all levels given, and above the top level a reasonable temperature profile is extrapolated up to 0.1 mb using a regression relation based on the interpolated temperatures at 700, 500, 300, 200, 100 and 50 mb. The humidity profile must be specified at least for those levels with a pressure of 600 mb or greater. Humidities above the uppermost level at which the profile is specified are extrapolated to give a constant relative humidity in the troposphere and a constant mixing ratio (0.003 g/Kg) in the stratosphere. If profile data are given at the standard pressure levels in the standard format, no interpolation is necessary and no checking is performed.

For data given at arbitrary levels, 2 input data formats are allowed: one is suited to radiosonde-only data, the other applies to radiance-radiosonde collocation data used on Met.O.19's HERMES system. In the latter case the physical surface temperature is taken from the cloud-cleared brightness temperature of HIRS channel 8. In other input modes, if the temperature of the physical surface has not been specified it is set equal to:

surface air temperature + offset + random Gaussian "noise",

where the offset and the standard deviation of the Gaussian noise are specified by the user.

The total ozone amount, required for transmittance calculations in some of the HIRS channels, is currently set constant at 347 Dobson Units. The program could easily be modified to make ozone amount a function of season, latitude and/or temperature profile.

The program is written in such a way as to allow the inclusion of additional profile input modes, if required.

2.3 CLOUD PARAMETERS.

HIRS transmittances are always calculated assuming cloud-free profiles. However it is possible to simulate the radiances measured above opaque cloud by specifying a pressure and temperature appropriate to the cloud-top as the first level in the atmospheric profile. MSU transmittances can be calculated assuming either no cloud or a single cloud layer by specifying a base pressure, a top pressure and a total liquid water content.

2.4 SCAN ANGLE PARAMETERS.

Instrument scan angles (relative to nadir) are required as input parameters. The program converts these to zenith angles at the surface, air mass factor, etc., using the following data:

height of satellite 1 (e.g. TIROS-N, NOAA-7) = 870 km,
height of satellite 2 (e.g. NOAA-6, NOAA-8) = 833 km.

2.5 HIRS TRANSMITTANCE CALCULATIONS.

The methods used are described by Weinreb et al., 1981. HIRS transmittances are calculated as a product of the separate transmittances of the different contributions to the total absorption. These are caused by:

- carbon dioxide (or, more correctly, carbon dioxide plus other uniformly mixed species such as dinitrogen oxide): see McMillin and Fleming, 1976, and Fleming and McMillin, 1977;
- ozone: see Weinreb et al., 1981;
- water vapour spectral lines: see Weinreb and Neuendorffer, 1973;
- continuum absorption (water vapour and pressure-induced nitrogen absorption): see Weinreb and Hill, 1980.

The calculated transmittances, τ, are empirically corrected to give τ^{γ}. The γ-values have been calculated at Madison and attempt to minimise the r.m.s. difference between synthetic and measured radiances using a representative set of radiance-radiosonde collocations.

2.6 HIRS RADIANCES AND BRIGHTNESS TEMPERATURES.

Using the transmittances from 40 standard levels to space in all channels then the transmittances from the surface (at the pressure of the first level of the specified profile) to space are calculated by interpolation or extrapolation. The radiative transfer equation is then integrated numerically as follows to give the radiance in the ith channel:

$$R_i = B_i(T_s)\tau_i(s) + \tfrac{1}{2}\{B_i(T_{as}) + B_{ij'}\}\{\tau_{ij'} - \tau_i(s)\} + \sum_{j=1}^{j'} \tfrac{1}{2}\{B_{ij} + B_{i(j+1)}\}\{\tau_{ij} - \tau_{i(j+1)}\} + B_{i1}(1 - \tau_{i1}), \qquad \ldots 1$$

where j is the index of a standard level (j=1 being the uppermost),
B_{ij} is the effective Planck function for the ith channel at the temperature T_j of the jth level,
τ_{ij} is the mean transmittance for the ith channel from level j to space,
j' is the first standard level above the surface,
$\tau_i(s)$ is the mean transmittance for the ith channel from the surface to space,
T_s is the temperature of the physical surface,
T_{as} is the air temperature at the surface,
and $B_i(T)$ is the effective Planck function for the ith channel at temperature T.

$B_i(T)$ is given by:

$$B_i(T) = \frac{c_1 \nu_i^3}{\exp\{c_2 \nu_i / T_i^*\} - 1}, \qquad \ldots 2$$

where $c_1 = 1.1911 \times 10^{-8}$ $W.m^{-2}.sr^{-1}.(cm^{-1})^{-4}$,
$c_2 = 1.4388$ $K.(cm^{-1})^{-1}$,
is the central wavenumber of the ith channel,
and T_i^* is the effective temperature in K given by

$$T_i^* = a_i + b_i T.$$

a_i and b_i are the "band correction coefficients" for the ith channel which allow an expression in the form of the monochromatic Planck function to be used for a channel of finite spectral width.

The equivalent black body temperatures (brightness temperatures) corresponding to the computed radiances are calculated using the inverse of equation 2.

The program also makes provision for the addition of empirical offsets (delta corrections) to the calculated brightness temperatures. The δ-values are all currently set to zero. If δ is non-zero, then the brightness temperature is corrected and the corresponding radiance re-calculated.

2.7 MSU TRANSMITTANCE CALCULATIONS.

The methods used are described by Weinreb et al., 1981. MSU transmittances are calculated for all 4 channels as the product of transmittance contributions from oxygen, water vapour and (optionally) cloud liquid water. The calculated transmittances are empirically corrected using γ-factors in the same way as for HIRS channels. MSU transmittances may be calculated in one of 2 modes: for an infinitely narrow field-of-view, or for a field-of-view corresponding to the real antenna gain pattern to give a weighted-average transmittance. These

2 modes will then yield "brightness temperatures" and "antenna temperatures" respectively, but they are both referred to as brightness temperatures below.

2.8 MSU BRIGHTNESS TEMPERATURES.

These are calculated for all channels from the transmittances by numerical integration of the radiative transfer equation in a similar manner to HIRS. The main differences are:

- in the microwave region the radiance is proportional to the brightness temperature, and so the Planck function is not required,
- the variation of surface emissivity must be taken into account (for HIRS it is always fairly high in reality, and in TOVSRAD it is currently set equal to 1.0).

There are 3 program modes for prescribing surface emissivity; it may be set equal to 1.0 (to allow comparison with brightness temperatures which have been corrected for surface emissivity), or it may be set to a typical value for land surfaces (= 0.95 at present), or it may be calculated for a typical sea surface as a function of frequency, surface temperature and scan angle with an assumption about the percentage foam coverage (currently set at 5%).

The radiative transfer equation is integrated numerically using the equation:

$$T_i = T_i(s) + T_i(dir) + T_i(ref),$$

which contains three components of brightness temperature: emission from the surface, direct emission from the atmosphere, and downward emission from the atmosphere reflected back by the surface. These components are given by:

$$\left.\begin{aligned}
T_i(s) &= T_s\, \epsilon_s\, \tau_i(s), \\
T_i(dir) &= \tfrac{1}{2}\{T_{as} + T_{j'}\}\{\tau_{ij'} - \tau_i(s)\} \\
&\quad + \sum_{j=1}^{j'} \tfrac{1}{2}\{T_j + T_{j+1}\}\{\tau_{ij} - \tau_{i(j+1)}\} + T_1(1 - \tau_{i1}), \\
T_i(ref) &= (1-\epsilon_s)\Big[\tfrac{1}{2}\{T_{as} + T_{j'}\}\{\tau_{ij'} - \tau_i(s)\} \\
&\quad + \sum_{j=1}^{j'} \tfrac{1}{2}\{T_j + T_{j+1}\}\left\{\frac{\tau_i(s)}{\tau_{i(j+1)}} - \frac{\tau_i(s)}{\tau_{ij}}\right\} + T_1\left\{\frac{\tau_i(s)}{\tau_{i1}} - \tau_i(s)\right\}\Big]
\end{aligned}\right\} \quad \ldots 3$$

where ϵ_s is the surface emissivity and other symbols are as defined in section 2.6.

The program also makes provision for the addition of empirical offsets (delta corrections) to the calculated brightness temperatures. The δ-values are all currently set to zero.

2.9 OUTPUT

Standard output modes are available to transfer to disk (and also to terminal or printer, if required) the calculated brightness temperatures for HIRS and MSU along with the profiles (specified at 40 standard levels) from which the brightness temperatures were generated. If the input data set contains collocated data (i.e. radiosonde profiles plus measured brightness temperatures and retrieved quantities) a corresponding output mode is available which also outputs the measured brightness temperatures and retrieved quantities.

3. RUNNING TOVSRAD

On HERMES the executable program resides in file [EYRE.TOVSRAD]TOVSRAD.EXE. It is run using a command procedure similar to one of the examples given in figure 2. Example 1 is the structure to be used when the atmospheric profile data are contained in a separate file (FOR007). In example 2 the atmospheric profile data follow the initialisation data in the command procedure.

3.1 INPUT DATA SETS.

3.1.1 FOR013: HIRS transmittance coefficients currently refer to NOAA-7 and NOAA-8 and are held in [EYRE.TOVSRAD]HIRTAU78.DAT.

3.1.2 FOR014: MSU transmittance coefficients currently refer to NOAA-7 and NOAA-8 and are held in [EYRE.TOVSRAD]MSUTAU78.DAT.

3.1.3 FOR005: Initialisation data: records following the RUN command in the command procedure. They are all read as list-directed I/O.

3.1.3.1 Record 1: MDEIN, MDEOUT, ICHPRF
Program control parameters.

MDEIN: input mode selector. This parameter controls the way in which the program interprets subsequent input records. Values allowed at present are: 1, 2 and 11.

MDEIN=1: Reads initialisation data as explained below. Then reads in atmospheric profiles at ARBITRARY pressure levels in the format given in section 3.1.4.1 and interpolates to standard levels.

MDEIN=2: As MDEIN=1, except reads in atmospheric profiles as radiosonde/radiance collocation data in the format given in section 3.1.4.2.

MDEIN=11: Reads in initialisation data as explained below. Then reads in atmospheric profiles at STANDARD pressure levels in the format given in section 3.1.4.3.

The program has been written so that other input modes controlled by different values of MDEIN could quite easily be included in the program if required.

MDEOUT: output mode selector. This parameter controls the way in which the program outputs data. Values allowed at present are: 1, 2, 11 and 12.

MDEOUT=1: The normal output mode for use with most formats of input data (see sections 3.2.1.1 and 3.2.2). Output to I/O unit 6 is suppressed except for header data and error messages.

MDEOUT=2: The output mode suitable for processing collocated radiosonde/radiance data (see sections 3.2.1.1 and 3.2.3). Output to I/O unit 6 is suppressed except for header data and error messages.

MDEOUT=11: As MDEOUT=1, except all output written to I/O unit 6 as well as to I/O unit 10.

MDEOUT=12: As MDEOUT=2, except all output written to I/O unit 6 as well as to I/O unit 12.

ICHPRF: I/O unit for input of atmospheric profile data.
ICHPRF=5: Atmospheric profile data must follow initialisation data in command procedure file in the format given in section 3.1.4.
ICHPRF=7: Atmospheric profile data are on separate file, I/O unit 7. See section 3.1.4.

3.1.3.2 Record 2: ISAT, INSTR, ILOBES, KPROF, JANG

ISAT: satellite number
ISAT=1: satellite 1 (currently NOAA-7)
ISAT=2: satellite 2 (currently NOAA-8)

INSTR: instrument selector
INSTR=1: HIRS only
INSTR=2: MSU only
INSTR=3: HIRS + MSU

ILOBES: MSU "side-lobe calculation" switch
ILOBES=1: calculation including effect of antenna gain pattern
ILOBES=2: calculation for infinitely narrow field-of-view

KPROF: number of profiles to be processed
KPROF>0: process the first KPROF profiles in the data set
KPROF≤0: no limit: process all profiles to the end of the data set. (If KPROF≤0, it is changed inside the program to KPROF=9999.)

JANG: number of angles of view to be processed for each profile. 1 ≤ JANG ≤ 100.

3.1.3.3 Next records: SATANG(J),J=1,JANG
JANG values of satellite viewing angle in degrees from nadir.

3.1.3.4 Next record: JCHAN(I),I=1,19: (for INSTR=1 or INSTR=3).
19 integers indicating HIRS channels to be processed.
Channel numbers may be given in any order but the list must have 19 members: channels not required should be set to 0 in this list.
HIRS channel 9 calculations can be performed but are of no use; all transmittances are calculated as 1.0, and so the brightness temperature calculated is always that of the surface.
If INSTR=2, this record MUST BE OMITTED.

3.1.3.5 Next record: TGOFF, TGSD

Surface temperature information.
This record must be included, but the information is only used if an explicit physical surface temperature is missing from the profile data.

TGOFF: offset of physical surface (land or sea) temperature from surface air temperature in degrees.

TGSD: standard deviation in degrees of random difference between physical surface temperature and surface air temperature.

i.e. T(surf) - T(air) = TGOFF + ϵ(TGSD),
where ϵ(TGSD) is a random number chosen from a Gaussian distribution of zero mean and standard deviation, TGSD, and is constrained so that $\epsilon \leq$ 2xTGSD.

3.1.3.6 Next record: LST, LCLDIN, PTOP, PBOT, WLIQIN: (for INSTR=2 and INSTR=3).

Parameters for MSU calculations.
If INSTR=1, this record MUST BE OMITTED.

LST: surface emissivity indicator for MSU calculations
- LST=1: surface emissivity = 1.0
- LST=2: surface emissivity calculated for typical land surface
- LST=3: surface emissivity set for typical land surface
- N.B. Applies only to MSU; for HIRS, emissivity = 1.0.

LCLDIN: cloud flag
- LCLDIN=0: no cloud; subsequent parameters in this record are ignored (but must be given some value).
- LCLDIN$\neq$0: one layer of cloud present.

PTOP: pressure at cloud top in mb.

PBOT: pressure at cloud base in mb.

WLIQIN: cloud liquid water content in mm of water.

3.1.3.7 Subsequent records:

If ICHPRF=7, this is the end of the data.

If ICHPRF=5, the subsequent records contain atmospheric profile data, and their format is described in section 3.1.4.

3.1.4 I/O unit ICHPRF (= 5 or 7): Atmospheric profile data

3.1.4.1 MDEIN=1. Profiles specified at arbitrary pressure levels.

1st record: INBUF(I),I=1,13:
format for ICHPRF=5 is * (list-directed I/O),
format for ICHPRF=7 is unformatted integer*2 array.

ATMOSPHERIC PROFILE HEADER.
INBUF(1): WMO block number for sonde station
INBUF(2): sonde station code number
INBUF(3): latitude in degrees N x 10
INBUF(4): longitude in degrees E x 10
INBUF(5): year x 100 + month, e.g. 8201
INBUF(6): day x 100 + hour, e.g. 3112
INBUF(7): NLEV, number of levels of profile data to follow: 2≤NLEV≤45
INBUF(8-12): reserved for cloud parameters (currently unused)
INBUF(13): physical surface temperature in deg.C x 10
Missing elements must be set to -32768. INBUF(7) must always be present.

Next NLEV records: IPROF(I),I=1,3:
format for ICHPRF=5 is * (list-directed I/O),
format for ICHPRF=7 is unformatted integer*2 array.

ATMOSPHERIC PROFILE DATA at NLEV pressure levels.
IPROF(1): pressure in mb x 10
IPROF(2): temperature in deg.C x 10
IPROF(3): dew point in deg.C x 10

Notes:
(a) Elements 1 and 2 must always be present; if element 3 is missing it must be set to -32768.
(b) Records must be in descending pressure order.
(c) Dew point must be present at pressures ≥ 600 mb.
(d) The last level must have a pressure ≤ 50 mb.
(e) The profile is interpolated/extrapolated internally to the 40 standard levels given in section 3.1.4.3.

Subsequent records: More atmospheric profiles, each in the form header record followed by profile records, as described above.

3.1.4.2 MDEIN=2. Profiles in radiosonde/retrieval collocation format.
Each record: (XSONDE(I),I=1,190),(XRET(I),I=1,112)
Format (190A2,112A4)

Radiosonde profile:

XSONDE(1): WMO block number (=99 for weather ships)
XSONDE(2): station number (for weather ships = "letter number", e.g. L=12)
XSONDE(3): station latitude in degrees N x 10
XSONDE(4): station longitude in degrees E x 10
XSONDE(5): year x 100 + month
XSONDE(6): day x 100 + hour
XSONDE(7): (no. of collocated retrievals) not relevant here
XSONDE(8-9): not used
XSONDE(10): number of special levels given below (in array elements 56-190)
XSONDE(11): geopotential height of 1000 mb level in metres
XSONDE(12): temperature in deg.C x 100 at 1000 mb
XSONDE(13): dew point in deg.C x 10 at 1000 mb
XSONDE(14-55): as (11-13) for other standard levels: 850, 700, 500, 400, 300, 250, 200, 150, 100, 70, 50, 30, 20 and 10 mb
XSONDE(56): pressure in mb x 10 of 1st special level
XSONDE(57): temperature in deg.C x 10 of 1st special level
XSONDE(58): dew point in deg.C x 10 of 1st special level
XSONDE(59-190): as (56-58) for other special levels up to maximum of 45 levels in all. XSONDE(10) indicates number of special levels.

Retrieval:

XRET(1): Latitude in degrees N x 100
XRET(2): Longitude in degrees E x 100
XRET(3): Time of this sounding: hour x 100 + minute
XRET(4): Surface elevation in metres
XRET(5-19): 15 retrieved thicknesses, in metres, for 15 layers: 1000-1000, 1000-850, 1000-700, 1000-500, 1000-400, 1000-300, 1000-250, 1000-200, 1000-150, 1000-100, 1000-70, 1000-50, 1000-30, 1000-20 and 1000-10 mb
XRET(20-34): 15 retrieved temperatures, in K x 100, for 15 levels: 1000, 850, 700, 500, 400, 300, 250, 200, 150, 100, 70, 50, 30, 20, 10 mb
XRET(35-40): 6 retrieved dew point temperatures, in K x 100, for 6 levels: 1000, 850, 700, 500, 400, 300 mb
XRET(41-59): 19 equivalent black body temperatures for HIRS channels, in K x 100, HIRS channels 1 to 19. (These data have been corrected for limb effects, cloud effects, etc.)
XRET(60-63): 4 equivalent black body temperatures for MSU channels, in K x 100, MSU channels 1 to 4. (These data have been corrected for limb effects, surface effects, etc., and interpolated to HIRS sounding locations.)
XRET(64): Not used at present: reserved for mean sea-level pressure in mb
XRET(65): HIRS line number
XRET(66): HIRS element number
XRET(67): Not used at present: reserved for surface pressure in mb
XRET(68-82): 15 retrieved temperatures in K x 100, for 15 layers (same layers as words 20-34). These values are calculated from MSU-only soundings. They are then corrected for biases (relative to HIRS soundings) and the results written to words 20-34.
XRET(83-96): Not used
XRET(97): Node (1 = northbound, 2 = southbound)
XRET(98): Satellite ID (currently, 1 = NOAA-7, 2 = NOAA-8)
XRET(99): (position of sonde station in collocated sonde list) not relevant here
XRET(100): Separation of retrieval and sonde in km
XRET(101): Sonde station number collocated with this retrieval
XRET(102): Retrieval type: 10 = clear, 20 = partly cloudy, 30 = MSU-only
XRET(103): Solar zenith angle, in degrees x 100
XRET(104-112): 9 thermal winds, in metres/second, calculated geostrophically from the local gradient of the thickness field, for 9 layers: 1000-850, 1000-700, 1000-500, 1000-400, 1000-300, 1000-250, 1000-200, 1000-150, 1000-100 mb

3.1.4.3 MDEIN=11. Data in NESS standard profile format.

Each profile is stored in 4 records each of 80 bytes: IZONE, ISAMP, (IDENT(I),I=1,5), (ITEMP(I),I=1,40), (IMR(I),I=1,20), format: (I2,6I3,12I5/16I5/16I5/16I5).

IZONE: latitude zone
- IZONE=1: 60°-90°
- IZONE=2: 30°-60°
- IZONE=3: 0°-30°

ISAMP: sequential number of profile in data set
IDENT(1): station number (special code)
IDENT(2): year
IDENT(3): month
IDENT(4): day
IDENT(5): hour
ITEMP(1-40): temperature in K x 100 at standard levels (0.1 mb to 1000 mb)
IMR(1-20): humidity mass mixing ratio in g/Kg at standard levels (115 mb to 1000 mb)

The 40 standard levels are (in mb):

0.1	0.2	0.5	1	1.5	2	3	4	5	7
10	15	20	25	30	50	60	70	85	100
115	135	150	200	250	300	350	400	430	475
500	570	620	670	700	780	850	920	950	1000

3.2 OUTPUT DATA SETS.

3.2.1 FOR006: diagnostic output

Listing of input parameters used:

* satellite number
* instruments to be processed
* MSU with or without correct antenna gain pattern
* viewing angles to be processed
* HIRS channels to be processed
* surface temperature parameters

Error messages and diagnostics are also printed.

For MDEOUT=1 and MDEOUT=2, results of calculations are suppressed.

For MDEOUT=11, the input parameters given above are followed by a listing of results (profiles interpolated to 40 standard levels and brightness temperature calculations) as described in 3.2.2.

For MDEOUT=12, the input parameters given above are followed by a listing of results (profiles interpolated to 40 standard levels and brightness temperature calculations and associated collocated retrieval data) as described in 3.2.3.

3.2.2 FOR010: Normal disk data set for results
(with MDEOUT=1 or MDEOUT=11).
All records formatted (124A4).

Record 1: ISAT, INSTR, ILOBES, KPROF, JANG
Output header record.
These parameters are defined in section 3.1.3.2

Subsequent records: (IOUT(I),I=1,12), (XOUT(I),I=1,112)
Processed data, with 1 record for each profile.
IOUT is an integer*4 array, XOUT is a real*4 array.

IOUT(1): WMO block number
IOUT(2): station number
IOUT(3): latitude in degrees N x 10
IOUT(4): longitude in degrees E x 10
IOUT(5): year x 100 + month
IOUT(6): day x 100 + hour
IOUT(7): MSU surface emissivity indicator
(see section 3.1.3.6: LST)
IOUT(8): cloud flag (see section 3.1.3.6: LCLDIN)
IOUT(9-11): spare
IOUT(12): profile sequential number

XOUT(1-40): temps. at standard levels in K
XOUT(41-80): humidity mass mixing ratios in g/Kg
XOUT(81-99): HIRS br.temps. in K (channels 1-19)
XOUT(100-103): MSU br.temps. in K (channels 1-4)
XOUT(104): total ozone amount (Dobson units)
XOUT(105): surface pressure in mb (at earth surface)
XOUT(106): air temp. at surface in K
XOUT(107): temp. of surface (land/sea) in K
XOUT(108): nadir angle of view at satellite in deg
XOUT(109): zenith angle of view at surface in deg
XOUT(110): cloud top pressure in mb
XOUT(111): cloud base pressure in mb
XOUT(112): cloud liquid water content in mm of water

Missing data values:
IOUT(1-6): -32768
IOUT(7-12): 0
XOUT(1-80): always present
XOUT(81-99): 0.0
XOUT(104-109): always present
XOUT(110-112): 0.0

3.2.3 FOR012: Special disk data set for results (with MDEOUT = 2 or 12).

Contains sets of LASS cloud-cleared brightness temperatures and corresponding retrieved profiles and collocated radiosonde profiles and equivalent TOVSRAD-computed brightness temperatures.

The data set has variable length records which are written as 3 records for each profile with the format (190A2/112A4/124A4).

Each set of 3 records: (XSONDE(I),I=1,190),(XRET(I),I=1,112), (IOUT(I),I=1,12),(XOUT(I),I=1,112)

XSONDE(1-190): radiosonde profile at special levels in standard Met.O.19 collocation data format (see section 3.1.4.2).
XRET(1-112): collocated LASS retrieval in standard Met.O.19 F024 format (see section 3.1.4.2).
IOUT(1-12): see section 3.2.2.
XOUT(1-112): see section 3.2.2.

4. STOP MESSAGES

To minimize problems from errors in program development, program extension and input data, several FORTRAN statements of the form, STOP nnn, have been included. This section explains their meaning and is intended for use in error detection. The message "STOP nnn" appears when the program terminates incorrectly. If the source of the error cannot be traced to incorrect specification of input data, the problem should be reported to the program owner.

nnn	sub-prog	meaning
901	MAIN	variable IFAIL out of range on return from GETPRF
902	MAIN	variable IFAIL out of range on return from GETPRS
911	INIT	variable INSTR is out of range
912	INIT	variable ISAT is out of range
913	INIT	variable JANG is out of range
914	INIT	variable MDEIN has a value which is not allowed
915	INIT	incorrect end of data found
920	GETPRF	variable MDEIN has a value which is not allowed
925	INTPRF	variable NREF $\neq$ 40
930	GETPRS	variable MDEIN has a value which is not allowed
935	SETCLD	LTOP > LBOT; this is not allowed
940	ANGLES	satellite viewing angle does not intersect earth
945	TAUGAM	transmittance < 0.0
946	TAUGAM	transmittance > 1.0
950	SFCTAU	variable NN is out of range
951	SFCTAU	transmittance < 0.0
955	HIRRAD	N > NREF; this is not allowed
960	MSSTAU	variable ILOBES is out of range
965	MSUTEM	variable LST is out of range
966	MSUTEM	NN > NREF; this is not allowed
970	TBBOUT	variable MDEOUT has a value which is not allowed

5. DESCRIPTION OF SUBROUTINES

Figure 3 gives a tree-diagram of the subroutine structure. The routines have the following functions:

TOVSRAD Main program. Controls the program flow as shown by figures 1 and 3.

INIT Performs initialisation functions (see section 2.1) and sets up standard pressure levels.

GETPRF Reads in atmospheric profiles at arbitrary pressure levels, checks, converts units and stores (see section 2.2).

ANOISE Generates pseudo-random Gaussian noise of given mean and standard deviation.

OZONE Sets total ozone amount (see section 2.2).

INTPRF Interpolates atmospheric profile specified at arbitrary levels to the standard levels (see section 2.2).

EXTEMP Extrapolates temperature profile from highest level given to 0.1 mb using regression on some standard levels in the lower atmosphere (see section 2.2).

GETPRS Reads in atmospheric profile at standard levels in standard format (see section 2.2).

SETCLD Sets cloud parameters which affect MSU transmittance calculations (see section 2.3).

ANGLES Performs the path geometry calculations for a satellite viewing the earth at a given nadir angle (see section 2.4).

TAUHIR Controls the calculation of transmittances from each of 40 standard levels to space for a given HIRS channel (see section 2.5).

PFCOEF Reads in and stores Planck function coefficients (see section 2.6), γ-corrections (see section 2.5) and δ-corrections (see section 2.6) for HIRS channels.

PREHIR Initialisation for transmittance calculations for a new HIRS channel. Reads HIRS transmittance coefficients and stores them. Also (first call only) sets up mean atmospheric profile parameters.

PREATM Calculates atmospheric profile parameters needed for HIRS transmittance calculations with a new profile.

CO2TAU Calculates transmittances for carbon dioxide (and other uniformly mixed gases) from all standard levels to space for a HIRS channel (see section 2.5).

H2OTAU Calculates transmittances for water vapour from all standard levels to space for a HIRS channel (see section 2.5).

CONTAU Calculates transmittances for continuum absorption from all standard levels to space for a HIRS channel (see section 2.5).

O3TAU Calculates transmittances for ozone from all standard levels to space for a HIRS channel (see section 2.5).

TAUGAM Corrects HIRS and MSU transmittances using empirical γ-corrections (see sections 2.5 and 2.7).

SFCTAU Takes transmittances from standard levels to space and interpolates/extrapolates to calculate the transmittance from the surface pressure level to space for any channel (see section 2.6).

HIRRAD Performs numerical integration of the radiative transfer equation to calculate, from the transmittances, the radiance measured by a HIRS channel. Converts the radiance to brightness temperature and adds empirical brightness temperature correction (see section 2.6).

PLANCK Calculates the Planck function appropriate to a HIRS channel at a given temperature (see section 2.6).

BRIGHT Inverse of Planck: calculates the equivalent black body temperature for a radiance measured by a HIRS channel (see section 2.6).

TAUMSU Controls the calculation of MSU transmittances (see section 2.7).

PREMSU Initialisation routine for MSU transmittance calculation. Reads in the absorption coefficients for MSU channels.

CLDGAM Calculates MSU cloud absorption parameters (see section 2.7).

MSUABS Calculates the absorption coefficients for layers between standard pressure levels due to oxygen, water vapour and clouds for the 4 MSU channels (see section 2.7).

MSSTAU Calculates MSU transmittances for either an infinitely narrow field-of-view or the true MSU antenna gain pattern (see section 2.7).

ANGAIN Stores the MSU antenna gain pattern.

MSUTEM Calculates the brightness temperatures measured by the 4 MSU channels by numerical integration of the radiative transfer equation and adds empirical brightness temperature corrections (see section 2.8).

EMISS Calculates sea surface emissivity in the microwave region as a function of frequency, surface temperature, scan angle and foam amount (see section 2.8).

TBBOUT Routine to output profile data and corresponding brightness temperatures from HIRS and MSU channels (see section 2.9).

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Calculation of atmospheric radiances and brightness temperatures in infra-red window channels of satellite radiometers.

Figure 1 TOVSRAD: Program Structure

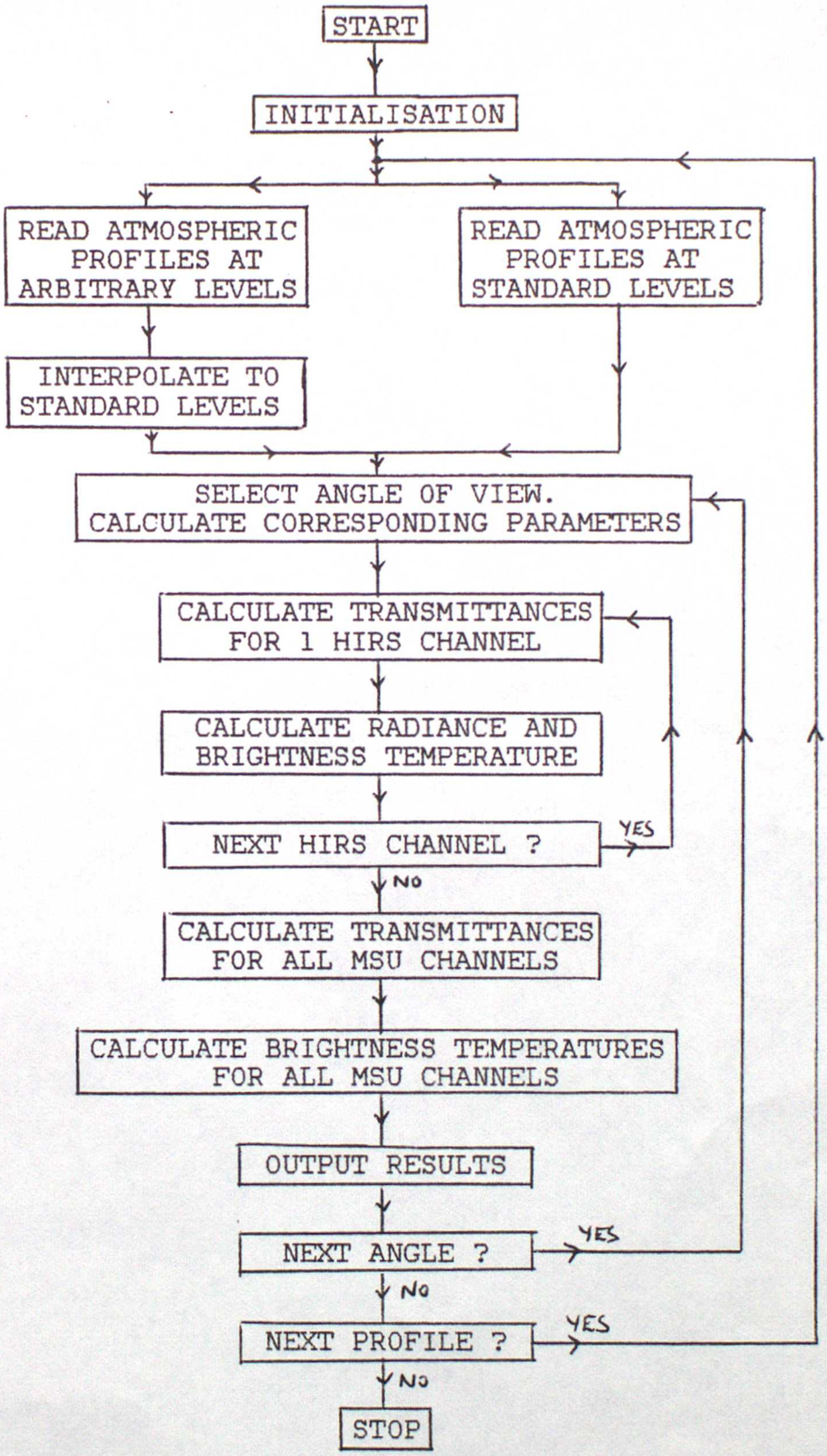

Figure 2 Examples of Command Procedure Files

Example 1 Atmospheric profile data in separate file

```
$ASSIGN [EYRE.TOVSRAD]HIRTAU78.DAT FOR013
$ASSIGN [EYRE.TOVSRAD]MSUTAU78.DAT FOR014
$ASSIGN MIDLAT.DAT FOR007
$ASSIGN OUTPUT.DAT FOR010
$RUN [EYRE.TOVSRAD]TOVSRAD
1 11 7                                               : MDEIN,MDEOUT,ICHPRF
1 3 2 1 100                                          : ISAT,INSTR,ILOBES,KPROF,JANG
0.                                                   : SATANG
1 2 3 4 5 6 7 8 0 10 11 12 13 14 15 16 17 18 19      : JANG
0. 3.                                                : TGOFF,TGSD
1 0 0 0 0                                            : LST,LCLDIN,PTOP,PBOT,WLIQIN
```

Example 2 Atmospheric profile data in command procedure file

```
$ASSIGN [EYRE.TOVSRAD]HIRTAU78.DAT FOR013
$ASSIGN [EYRE.TOVSRAD]MSUTAU78.DAT FOR014
$ASSIGN OUTPUT.DAT FOR010
$RUN [EYRE.TOVSRAD]TOVSRAD
1 11 5                                               : as above
1 3 2 1 1                                            :
0.                                                   :
1 2 3 4 5 6 7 8 0 10 11 12 13 14 15 16 17 18 19      :
0. 3.                                                :
1 0 0 0 0                                            :
0 0 500 0 8201 3112 5 0 0 0 0 0 -32768               : INBUF
10000 200 150                                        : IPROF
5000 -200 -300                                       : IPROF
2000 -600 -32768                                     : IPROF
500 -500 -32768                                      : IPROF
50 -200 -32768                                       : IPROF
```

Figure 3 TOVSRAD subroutine structure

- Main program (TOVSRAD)
  - INIT
  - GETPRF
    - ANOISE
    - OZONE
  - INTPRF
    - EXTEMP
  - GETPRS
    - OZONE
  - SETCLD
  - ANGLES
  - TAUHIR
    - PFCOEF
    - PREHIR
    - PREATM
    - CO2TAU
    - H2OTAU
    - CONTAU
    - O3TAU
    - TAUGAM
  - SFCTAU
  - HIRRAD
    - PLANCK
    - BRIGHT
  - TAUMSU
    - PREMSU
    - CLDGAM
    - MSUABS
    - MSSTAU
      - ANGAIN
    - TAUGAM
  - MSUTEM
    - EMISS
    - SFCTAU
  - TBBOUT