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USER'S GUIDE TO THE INTERNATIONAL TOVS PROCESSING PACKAGE

A REPORT from the

Cooperative
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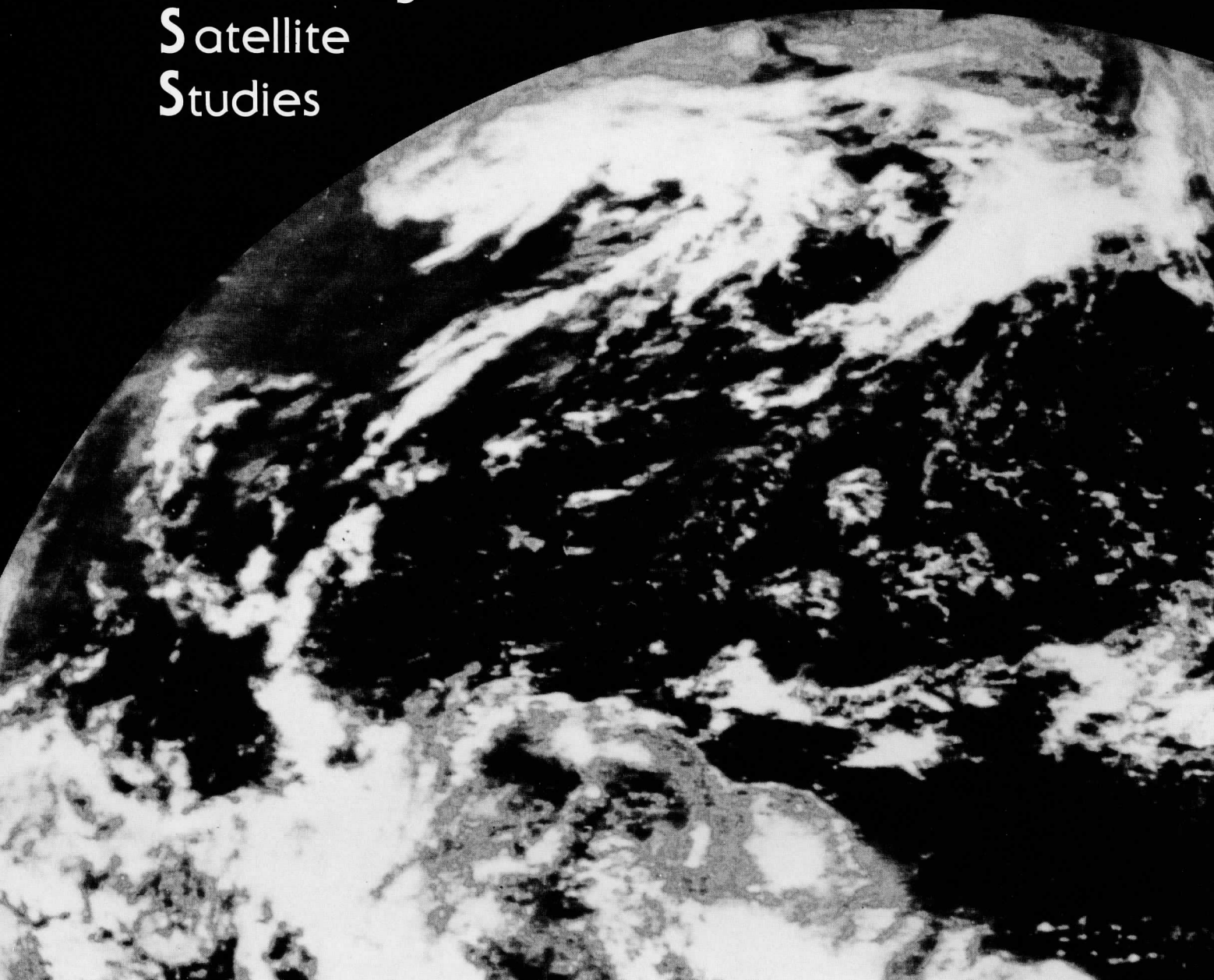

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Thomas Achtor, Harold Woolf, Anthony Schreiner
Cooperative Institute for Meteorological Satellite Studies
University of Wisconsin-Madison

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I. Introduction

This user guide is written for scientific users of the International TOVS Processing Package (ITPP). The guide instructs ITPP users of the key-ins necessary to run the package, from software ingest of radiance data to retrieval product analysis. The content of the guide is designed to follow the sequence of procedures necessary to complete an entire cycle of the ITPP.

The software modules contained in the ITPP are invoked interactively with the key-in format:

$RUN PROGRAMNAME

Program names are enclosed in brackets (e.g., < PROG >). Most programs will then provide a series of prompts, which require the user to enter a value or use the default value. In the examples included below, samples of user input follow an = sign. In section II, the steps to process direct readout (HRPT) data are discussed. Appendix A describes the preprocessing steps for archived 1B data. Section III discusses the temperature and moisture retrieval processing procedure that follows after either of these preprocessing routes.

If facilities exist, the best procedure for processing the NOAA polar orbiter TOVS data, which will obtain the highest quality data sets is given below.

Procedure to obtain TOVS Research/Operational Data Sets:

1) Ingest TOVS radiance data into host computer via direct ingest or 1-B magnetic tape (system dependent)

2) Run the ITPP, including:

   a) PRETIP
   b) PREING
   c) INGTOV
   d) TOVPRE
   e) TOVRET

3) Display an AVHRR or TOVS image for use in quality control

4) Display TOVS retrieval products over the AVHRR (or TOVS) image for several atmospheric levels or layers (e.g.: 850, 700, 500, 300, 200 mb) and use an editing program to delete soundings of questionable or poor quality.

a) Temperature difference between guess and retrieval
b) Absolute temperature
c) Total precipitable water vapor
d1) Geopotential thickness (if no surface data is used)
d2) Geopotential height (if surface data is used)

(Note: an automated editing program <FILRET> is contained in the ITPP. However, experience has shown that a knowledgeable meteorologist performing manual editing provides better quality control than automated techniques.)

5) Compress the TOVRET file after editing, using <COMRET>

6) Generate final meteorological products

II. Data Acquisition

A. Data Format

The ITPP is structured to accept TOVS data in two formats: 1) raw TOVS TIP data embedded within the HRPT data stream, from a direct readout facility, and 2) level 1B archival data from magnetic tape. While the initial steps to prepare the TOVS data for retrieval processing require different software modules, the profile calculation process is the same once the data has been calibrated, navigated and formatted. In this section, the steps to process direct readout data are discussed. Procedures to process archived 1B data are provided in Appendix A. Both processing paths meet at section III, Retrieval Processing, page 5, which discusses the retrieval route that follows after either of these preprocessing paths.

B. Real Time Acquisition

The first requirement in direct readout operations is to make sure the orbital elements are updated (on a weekly basis for TOVS). The orbital elements are contained in a TBUS message, available on the GTS circuit and other means. The TBUS orbital elements are predictive in nature, valid for the next few days in the future. The software program to enter orbital element information into the ITPP is <PUTELE>. The orbital elements may be entered directly by key-in or from an ASCII file containing the elements.

```
$RUN PUTELE
ENTER NOAA-NUMBER (5=TIROS-N)  = 11
ENTER 1 TO INIT. FILE AND STORE DATA, 0 TO ADD ONLY  = 0
ENTER 1 IF READING FROM ASCII FILE, 0 IF USING KBD  = 0
YEAR, MONTH, DAY : = 90 08 12
HOURS, MINUTES, SECONDS : = 19 39 31.77
SEMI-MAJOR AXIS: = 7229.06
ECCENTRICITY:  = .001259
INCLINATION: = 98.984
LONGITUDE OF ASCENDING NODE: = 173.20
ARGUMENT OF PERIGEE:  = 124.03
MEAN ANOMALY:  = 337.879
```

The output for the benchmark data set is:

```
ADDED RECORD  = 105 90 8 12 19 39 31.72
ORBITAL-ELEMENT FILE HAS BEEN UPDATED FOR SATELLITE = 11
FORTRAN STOP
```

With the proper orbital elements, the acquisition of NOAA HRPT satellite data can begin. First, one must know the space and time windows for the desired satellite overpass. A print-out of satellite overpass data can be obtained using the program <ORBITS>.

```
$RUN ORBITS
ENTER NOAA-NUMBER (5=TIROS-N)  = 11
ENTER DATE...YYDDD OR YYMMDD  = 900813
ENTER START TIME ... HHMM  = 1200
ENTER STOP TIME ... HHMM  = 1300
ENTER LOWER-BOUNDARY LATITUDE, DEGREES, +N, -S ...  = 0
ENTER UPPER-BOUNDARY LATITUDE, DEGREES, +N, -S ...  = 70
ENTER LEFT-BOUNDARY LONGITUDE, DEGREES, +E, -W ...  = -20
ENTER RITE-BOUNDARY LONGITUDE, DEGREES, +E, -W ...  = 40
ENTER 0 FOR CRT OUTPUT, 1 FOR PRINTER  = 0
```

The output shows the latitude/longitude of the sub-satellite point at one minute intervals (see below).

```
ORBITAL TRACK(S) FOR NOAA-11 ON DAY 900813 FROM 1200 TO 1300 GMT,
BETWEEN LATITUDES 0 AND 70, LONGITUDES -20 AND 40
...USING ORBITAL ELEMENTS FOR DAY 224

TIME   LATITUDE   LONGITUDE
1212      2.23       28.86
1213      5.71       28.06
...
1231     67.58        1.92
ORBIT ENDED
```

The user then defines the temporal range (start/stop times) of the data request and informs the receiving station personnel. This process is station dependent, given the wide variety of computer and display types used to process the ITPP. Therefore, for the purposes of this user guide, it is assumed the data are then ingested into the resident computer system.

Once the raw radiance data are resident in the computer system, the ITPP processing begins with the software ingest. Certain installations utilize the module <PRETIP> to extract TOVS TIP data from the HRPT data stream.

```
$RUN PRETIP
```

There are no input prompts to <PRETIP>. The process is very I/O intensive and can take 10-15 minutes to execute. Output indicates the number of records processed (see below).

```
DATA TYPE  3  (anything other than a 3 is an error message)
WROTE RECORD    1
WROTE RECORD   11
...
WROTE RECORD  1701
ALL DONE, NRET =   1710
FORTRAN STOP
```

Processing the TOVS TIP data requires a number of tasks; decommutation of raw data, navigation and earth location, and in-flight calibration. The modules <PREING> and <INGTOV> accomplish these tasks.

<PREING> decommutates (reformats) the data, writing the result to output file TOVSTIPO.

```
$RUN PREING
ENTER YEAR = 90
ENTER NOAA NUMBER (DEFAULT = INTERNAL) = 11
ENTER MSU DIAGNOSTIC PRINT FLAG (0=OFF, 1=ON) = 0
ENTER NUMBER OF RECORDS TO SKIP = 0
MSU S/N CHECK WILL BE SKIPPED FOR NOAA-11
ENTER 1 TO FORCE SKIP OF MSU S/N CHECK = 0
ENTER 1 TO BYPASS TIP PARITY CHECK = 0
```

There is a steady stream of output across the CRT, indicating major frame locations, spacecraft time elements, etc. At the end of execution, output should read something like:

```
REACHED END OF HIRS DISK AREA
NO. OF HIRS LINES = 94, NO. OF MSU LINES = 23
TIME COVERAGE (S/C DAY) + MSEC (225) 44367750  TO (225) 44976050
NO. MINOR FRAMES INPUT = 6085 NO. MINOR FRAMES W/ERR = 0
INPUT PARAMETERS FOR INGEST (SAT-ID, YR,MO,DY) = 11 90 8 13
FORTRAN STOP
```

The example shows the number of HIRS and MSU lines for about 10 minutes of data.

<INGTOV>, using file TOVSTIPO, calibrates and earth locates the data, transforming the raw radiance measurements into brightness temperatures and writing them to a system

ıle named TOVSINGO. A "switch" can either process HIRS and MSU data, or if the ı desires, only microwave information, and not process the HIRS.

```
$RUN INGTOV
ENTER DO-HIRS SWITCH (0=YES, 1=NO)  =  0
ENTER HIRS DEBUG FLAG (0=OFF, 1=YES)  =  0
ENTER MSU DEBUG FLAG (0=OFF, 1=YES)  =  0
```

The CRT output from <INGTOV> shows the orbital parameters used, the MSU ingest, the HIRS ingest, the calibration and navigation of the data, and the filling of the TOVSINGO file.

The file TOVSINGO has exactly the same structure whether the TOVS TIP data has come from real time, direct ingest or from level 1B magnetic tape. Appendix A of this user guide discusses how to software ingest TOVS TIP data from the level 1B data tape. To continue retrieval processing, go to section III, immediately below .

III. Retrieval Processing

Regardless of the data source, direct readout HRPT or archive 1B, ITPP software will reach the same point in processing by writing the file TOVSINGO. From this point, the processing steps are identical, regardless of raw data input.

A. Preprocessor

The software module <TOVPRE> transforms the calibrated, earth-located HIRS and MSU brightness temperatures in file TOVSINGO to file structures for image display and retrieval calculation. Additionally, HIRS and/or MSU limb corrections can be applied at this stage. Finally, the MSU radiances are interpolated to the HIRS scan pattern.

Data from TOVSINGO is formatted into file TOVORB(A..Z) for image display and TOVSND(A..Z) for retrievals. TOVORB_ has all the brightness temperatures for a given channel contiguous on disk, to optimize imaging, while TOVSND_ has all the brightness temperatures for a given field of view contiguous on disk, to optimize retrieval processing (where _ indicates file suffix letter A through Z). These two data structures have 26 available files each; that is, one can have 26 pairs of distinct TOVORB_ and TOVSND_ files on the system simultaneously (TOVORBA, TOVSNDA, ... TOVORBB and TOVSNDB, etc). To list out the contents of the TOVORB_ and TOVSND_ files, use the program <TOVDIR>.

```
$RUN TOVDIR
```

The program output is a listing of the file contents with necessary additional supplementary information, including date, start time, end time, number of lines, satellite number, ascending or descending pass, HIRS or MSU limb correction, file status and number of retrievals in TOVRET_.

```
$RUN TOVPRE
ENTER LETTER OF FILE FOR OUTPUT  =  A (see note below)
ENTER HIRS LIMB CORRECTION FLAG (1=ON, 0=OFF)  =  0
ENTER MSU LIMB CORRECTION FLAG (1=ON, 0=OFF)  =  0
```

Note: The letter designated for the TOVORB_ and TOVSND_ files will overwrite any data that has been located there previously. The user should use the <TOVDIR> key-in to list out the contents of TOVORB(A..Z) and TOVSND(A..Z).

The limb correction flag should be turned off for the physical retrieval technique <TOVRET> and turned on for the statistical technique <TOVSTR>. Output from <TOVPRE> indicates the processing steps are completed.

At this point, all steps necessary to prepare the TOVS radiance data for retrieval processing or image display have been completed.

The brightness temperature for a given HIRS or MSU channel, or the latitude/longitude of the spot may be printed using the program <TOVMAP>. The output is a printed map of brightness temperatures (or lat/long) for a specified channel over the range of the pass.

```
$RUN  TOVMAP
ENTER FILE LETTER  = A
ENTER UP TO 7 PARAMETER NOS. IN I3 FORMAT
 ... IF <7, END STRING WITH -1
 1  2  11 -1 (see explanation below)
ENTER STARTING ROW-NUMBER, 0 TO TERMINATE
1
ENTER STARTING ROW-NUMBER, 0 TO TERMINATE
21
ENTER STARTING ROW-NUMBER, 0 TO TERMINATE
0
```

The HIRS or MSU channel parameter numbers requested above are shown in Table 1. Select up to seven channels for display at one time. The program will draw a map of 20 HIRS lines, but prompts you for additional line number input to create a map of greater size. Thus, responding to the prompt for the STARTING ROW NUMBER with the key-ins 1, 21, 41, 61, 81, 0 will create a map of the entire pass. The above input will print out the first 40 lines of brightness temperatures for HIRS channels 1, 2, and 11.

B. Retrieval Algorithms

To summarize ITPP processing to this point: following the hardware and software ingest of the data, calibration and earth location, file formatting and preprocessing, the calculation of vertical temperature and moisture profiles can be accomplished. Additionally, geopotential height, stability parameters and total ozone are determined and written to the output file. Two retrieval algorithms are included in the ITPP, a physical retrieval technique, <TOVRET>, and a statistical method, <TOVSTR>.

TABLE 1. TOVMAP Parameter List

Parameter No.	Quantity	Wavelength	Peak
1	Latitude of HIRS FOV (N+,S-)		
2	Longitude of HIRS FOV (E+,W-)		
3	Solar Zenith Angle (9000 IF NIGHT)		
4	HIRS Ch. 1	15.00 micron	30 mb
5	HIRS Ch. 2	14.70 micron	60 mb
6	HIRS Ch. 3	14.50 micron	100 mb
7	HIRS Ch. 4	14.20 micron	400 mb
8	HIRS Ch. 5	14.00 micron	600 mb
9	HIRS Ch. 6	13.70 micron	800 mb
10	HIRS Ch. 7	13.40 micron	900 mb
11	HIRS Ch. 8	11.10 micron	Surface
12	HIRS Ch. 9	9.70 micron	25 mb
13	HIRS Ch.10	8.30 micron	900 mb
14	HIRS Ch.11	7.30 micron	700 mb
15	HIRS Ch.12	6.70 micron	500 mb
16	HIRS Ch.13	4.57 micron	1000 mb
17	HIRS Ch.14	4.52 micron	950 mb
18	HIRS Ch.15	4.46 micron	700 mb
19	HIRS Ch.16	4.40 micron	400 mb
20	HIRS Ch.17	4.24 micron	5 mb
21	HIRS Ch.18	4.00 micron	Surface
22	HIRS Ch.19	3.70 micron	Surface
23#	MSU Ch. 1A		
24	MSU Ch. 1	50.31GHz	Surface
25	MSU Ch. 2	53.73GHz	700 mb
26	MSU Ch. 3	54.96GHz	300 mb
27	MSU Ch. 4	57.95GHz	90 mb
28	TOTAL OUTGOING LONGWAVE FLUX (Watt/sq.meter x 100)		
29	HIRS Ch. 20	0.70 micron	Visible
30##	BRIGHTNESS TEMPERATURE, HIRS Ch. 18A		

NOTE: ALL TEMPERATURES ARE IN DEGREES x 100

#MSU Ch. 1A: If MSU data are limb-corrected, this is Ch. 1 with surface effects retained; if not limb-corrected, it is indexing information and is not mapable.

##For daytime pass, this is Ch. 18 (4 micron window) with a first-order approximate correction for reflected sunlight.

<TOVRET> contains the most recent improvements to the physical technique (Smith, Hayden, Schreiner, and Woolf, 1986). It obtains solutions for temperature and water vapor in a single step from combined infrared and microwave radiances. Although the most accurate retrieval technique in the ITPP, it is also the most demanding of computer resources. There are many options within <TOVRET> which will be discussed below.

To briefly summarize the <TOVRET> retrieval technique, an initial estimate of the vertical structure is made, using climatology or regression coefficients obtained from a prior source. Surface data may also be used to "anchor" the profiles to known surface conditions. From this point the guess profile or initial estimate is adjusted, using the MSU data and the stratospheric HIRS channels. This is referred to as the "improved guess." Finally, the full HIRS radiances are applied to this improved guess to provide a final vertical retrieval.

```
$RUN TOVRET
ENTER LETTER OF FILE TO PROCESS  =  A
ENTER SFC-DATA FLAG (1=YES, 0=NO)  =  0
ENTER GUESS TYPE (0=REGRESSION, 1=CLIMATOLOGY)  =  0
ENTER START-LINE (DEFAULT=2)  =  3
ENTER START-ELEM (DEFAULT=2)  =  3
TO MAKE SINGLE SOUNDING, LET NUM-LINES AND NUM-ELEMS=1
ENTER NUMBER OF LINES (DEFAULT=98)  =  0
ENTER NUMBER OF ELEMS (DEFAULT=54)  =  0
ENTER LINE-INCREMENT (DEFAULT=3)  =  0
ENTER ELEM-INCREMENT (DEFAULT=3)  =  0
ENTER TOPOGRAPHY FLAG (0=HI-RES, 1=LO-RES)  =  0
MWHS=RTVL USING MSU + HIRS (STRATOSPHERIC) CHANNELS
IF=0, OUTPUT ONLY FULL-HIRS SOUNDINGS
IF=1, OUTPUT MWHS SOUNDING IF FULL-HIRS FAILS
IF=2, OUTPUT ONLY MWHS SOUNDINGS
ENTER VALUE FOR MWHS =0
ENTER DIAGNOSTIC PRINT FLAG (0=NO, 1=YES)  =  0
ENTER RETRIEVAL-FILE INIT FLAG (0=NO,1=YES)  =  1
```

The starting line and element are one FOV in from the edge in this example and cover the full 100 lines of the pass (refer to number of lines and elements). The line and element increment refers to the number of FOVS to be included in one sounding; three provides approximately a 75 km retrieval linear boundary; a 5 x 5 would be around 125 km. High resolution topography is now included globally for the ITPP. The retrieval types in the physical technique are clear (full HIRS), and cloudy (MSU, and HIRS channels peaking above cloud top). Diagnostics are used for debugging or getting detailed information on a very few soundings. Finally, initializing the retrieval file will destroy any retrievals previously made in the file; do not initialize if you wish to add retrieval(s) to the existing file.

The output from <TOVRET> is written to file TOVRET_, where _ is the same letter (A-Z) as TOVORB_ and TOVSND_. The CRT output from <TOVRET> will indicate when a line of retrieval processing is completed, and how many soundings have been made.

```
RETRIEVAL FILE INITIALIZED
FINISHED A LINE, NUMBER OF SOUNDINGS=17
FINISHED A LINE, NUMBER OF SOUNDINGS=35
...
FINISHED A LINE, NUMBER OF SOUNDINGS=550
ALL DONE
FORTRAN STOP
```

A discussion of the post processing procedures follows a summary of the statistical technique <TOVSTR>. The statistical retrieval algorithm <TOVSTR> does a simple regression of TOVS brightness temperatures against a set of coefficients determined from latitudinally segregated radiosonde data. The key-ins for <TOVSTR> are similar to <TOVRET>.

```
$RUN TOVSTR
ENTER LETTER OF FILE TO PROCESS  =  A
ENTER CLEAR FORCE FLAG (1 = YES, 0 = NO)  =  0
MWHS = MICROWAVE + HIRS (STRATOSPHERIC) CHANNELS
ONLY MEANS DO NOT ATTEMPT FULL HIRS RETRIEVAL
KEEP MEANS OUTPUT MWHS IF FULL HIRS RETREIVAL FAILS
ENTER MWHS-ONLY FLAG (1 = YES, 0 = NO)  =  0
ENTER MWHS-KEEP FLAG (1 = YES, 0 = NO)  =  1
ENTER SFC-DATA FLAG (1 = YES, 0 = NO)  =  0
ENTER START-LINE (DEFAULT = 2)  =  3
ENTER START-ELEM (DEFAULT = 2)  =  3
TO MAKE SINGLE SOUNDING, LET NUM-LINES AND NUM-ELEMS = 1
ENTER NUMBER OF LINES (DEFAULT = 98)  =  0
ENTER NUMBER OF ELEMS (DEFAULT = 54)  =  0
ENTER LINE-INCREMENT (DEFAULT = 3)  =  0
ENTER ELEM-INCREMENT (DEFAULT = 3)  =  0
ENTER RETRIEVAL-FILE INIT FLAG (0 = NO, 1 = YES)  =  1
```

The output from <TOVSTR> looks the same as that for <TOVRET>.

The TOVRET file structure contains 112 Integer * 4 words, which include header information, retrieval location, time, temperatures, dewpoints, brightness temperatures, skin temperature, first guess information, cloud properties, and other derived quantities. The exact location and type of information can be found in the Documentation of TOVS Processing Software.

C. Post Processing

An automated quality control algorithm is included in the ITPP. The program, <FILRET>, eliminates soundings of questionable reliability by objective analysis of (1) differences between infrared and microwave retrievals at the same location, (2) the variability in the 1000-500 mb thickness field, and (3) longwave-window brightness temperature comparison to surface temperature.

```
$RUN FILRET
ENTER FILE LETTER  =  A
ENTER SEARCH RADIUS (0 FOR DEFAULT = 3)  =  0
ENTER MAXIMUM SAMPLE (0 FOR DEFAULT = 10)  =  0
ENTER MINIMUM SAMPLE (0 FOR DEFAULT = 5)  =  0
ENTER NO. OF FILTER PARAMETERS (0 FOR DEFAULT = 6)  =  0
ENTER 1 TO AVOID FLAGGING ISOLATED SOUNDINGS  =  1

NO. OF PROFILES FAILED/FILTERED  =  111/538
FORTRAN STOP
```

In this example, the defaults were used and 111 of 538 (21%) retrievals were flagged as failing the quality control tests. This method will eliminate parameter values which deviate significantly from neighboring soundings. While it edits obviously poor quality retrievals, it also may edit meteorological detail.

An alternative method (if facilities exit) would be to manually edit the retrievals, looking at thickness or level temperature fields, total column precipitable water vapor, and perhaps, geopotential height (if surface data is used in the retrieval generation process). At this point, an experienced meteorologist can outperform an automated quality control algorithm.

Once the retrieval file has been edited it must be compressed. The program <COMRET> compresses the TOVRET file by deleting soundings that have been flagged by <FILRET> and moving the remaining soundings to replace the "empty" records.

```
$RUN COMRET
ENTER FILE LETTER = B
```

```
RETRIEVAL FILE COMPRESSED, NUMBER OF SOUNDINGS = 439
```

Following quality control and file compression procedures, geostrophic winds can be calculated using the program <WINRET>. The algorithm does a least squares objective analysis of the geopotential fields for the calculation.

```
$RUNWINRET
ENTER FILE  LETTER = A

WINDS WERE OBTAINED FOR 358 OF 439 SOUNDINGS
FORTRAN STOP
```

Finally, any parameter in the TOVRET_ file can be plotted to a printer using the program <TOVPLTEM>. The program is set up for printer output of level temperatures, but can be modified to print other quantities.

```
$RUN TOVPLTEM
ENTER UP TO SIX PRESSURE LEVELS IN I5 FORMAT  =  850 700 500 300
ENTER FILE LETTER  =  A
ENTER LAT, LON (DEG * 10) AT NW CORNER OF 15 X 15 DEG REGION
...USE 999 999 TO TERMINATE
= 600 -200
=  999 999
FORTRAN STOP
```

Appendix A

Acquisition of TOVS through level 1B data tape

Level 1B TOVS data has already been through preliminary processing by a local receiving station or NESDIS operations. The tapes contain the TOVS radiance measurements, and calibration and earth location information. To inventory the contents of a 1B tape, the software module <INVTAP> has been supplied. The output is a printout of data type, times and locations for each file.

```
$RUN INVTAP
ENTER NUMBER OF FILES=2
```

To produce the system disk file TOVSINGO, discussed in Section II, two software modules are invoked; <TOVTAP>, which does tape to disk transfer, and <TOVING>, which produces the calibrated, earth-located brightness temperature file TOVSINGO.

```
$RUN TOVTAP
ENTER FILE NUMBER FOR HIRS  =  1
ENTER FILE NUMBER FOR MSU  =  2
ENTER STARTING TIME  =  1242
ENTER ENDING TIME  =  1252
```

```
$RUN TOVING
ENTER NOAA-NUMBER (5=TIROS)  =  10
```

The user has now reached the same point discussed in Section II, the completed construction of the file TOVSINGO. From this point on the retrieval processing is identical for direct readout and 1B data. Proceed to section III, Retrieval Processing, page 5, to continue.