



TOVPIX: Software for Extraction and Calibration of TOVS Data from the High Resolution Picture Transmission from TIROS-N Satellites

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DIVISION OF ATMOSPHERIC RESEARCH TECHNICAL PAPER No. 10
COMMONWEALTH SCIENTIFIC AND INDUSTRIAL
RESEARCH ORGANIZATION, AUSTRALIA 1985

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ABSTRACT

This report describes software which accepts the HRPT service of the NOAA series of polar orbiting meteorological satellites, and extracts the data pertaining to the HIRS and MSU instruments of the TOVS package. The output from the program is an image containing the calibrated data for the 20 HIRS channels and 4 MSU channels, with the latter linearly interpolated to the HIRS spots. The output image is cast in the format for the SLIP image processing software, developed by CSIRONET. Earth location of points on the image is accomplished by the satellite navigation package which has been integrated with SLIP in the CSIDA system developed at DAR. The software is designed for routine application, with manual intervention only required whenever a new satellite is launched or whenever NOAA update the calibration parameters of the operational satellites.

ACRONYMS

AVHRR : advanced very high resolution radiometer.
FOV : field of view.
HIRS : high resolution infrared radiation sounder.
HRPT : high resolution picture transmission.
MSU : microwave sounding unit.
TIROS : television and infrared observation satellite.
TIP : TIROS information processor.
TOVS : TIROS operational vertical sounder.
DISIMP : device independent software for image processing.
SLIP : software for satellite image processing.
CSIDA : CSIRO system for interactive data analysis.
DAR : CSIRO division of atmospheric research.

1. INTRODUCTION

The CSIRO division of atmospheric research (DAR) has developed a system for interactive data analysis, called CSIDA. The hardware consists of two dishes for receiving telemetry from the geostationary and polar orbiting meteorological satellites, together with computing power which permits the satellite images to be displayed in real time. The software of the CSIDA system is based upon the general image processing package SLIP/DISIMP, developed by CSIRONET (formerly the CSIRO Division of Computing Research).

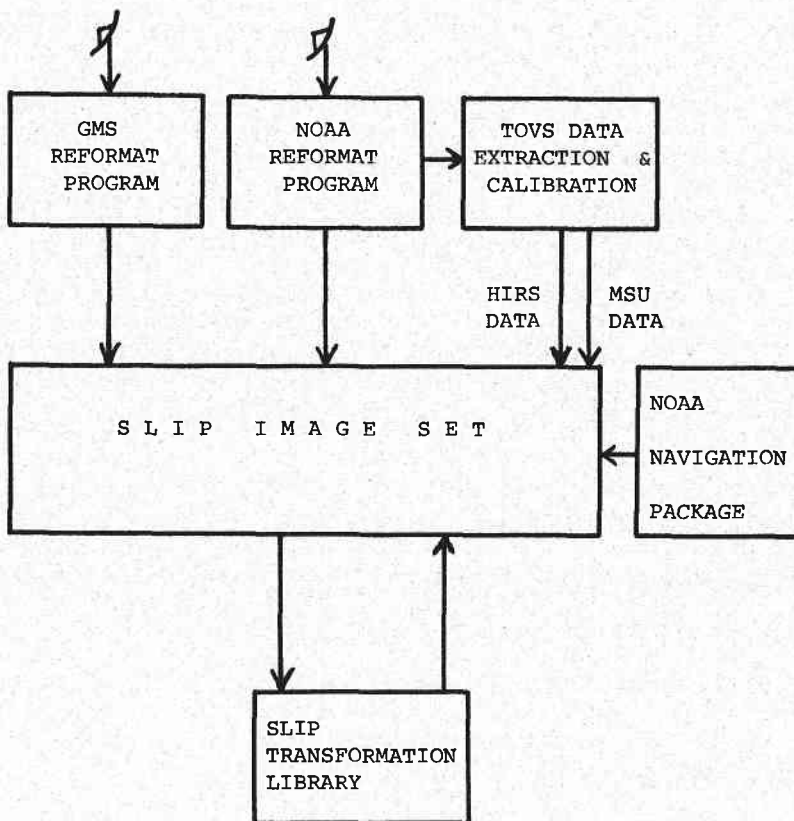


Figure 1. Schematic of the CSIDA system.

The SLIP software establishes a standard format for images and provides a large library of image transformations, each of which maps images from the SLIP image set back into the image set. Thus, complex image transformations can be constructed quickly from elementary transformations drawn from the SLIP library. The SLIP software is both well structured and well documented. In addition, the device dependent parts of the code are clearly identified, so that the software can be transferred from one host to another with only minor revision of the code. This permits image processing systems based upon SLIP to take advantage of new developments in computing hardware.

Before SLIP can be called to process an image, the data must be cast in the standard SLIP format. The CSIDA system contains software which reformats the data stream from the radiometers on the geostationary meteorological satellites and also from the advanced very high resolution radiometer (AVHRR) on the NOAA polar orbiting meteorological satellites.

Embedded in the high resolution picture transmission (HRPT) from the NOAA polar orbiters is the data from the TIROS observational vertical sounder package (TOVS), which consists of three instruments:

- (1) the high resolution infrared scanner (HIRS), which samples nineteen infrared channels, with wavenumbers from 669 cm^{-1} to 2660 cm^{-1} , and one visible channel with wavenumber 14500 cm^{-1} ;
- (2) the microwave sounding unit (MSU), which samples four channels with wavenumbers 1.68 cm^{-1} , 1.79 cm^{-1} , 1.83 cm^{-1} , 1.93 cm^{-1} ;
- (3) the stratospheric sounding unit (SSU), which employs a selective absorption technique to make measurements in three infrared channels, whose spectral characteristics are determined by the pressure in a carbon dioxide gas cell in the optical path.

These instruments are designed for temperature and humidity soundings of the atmosphere, and are used routinely by meteorological forecasters. Software to extract the temperature and humidity profiles from TOVS data will be added to the CSIDA system in the near future.

This technical report describes software which accepts the HRPT service of the NOAA series of polar orbiting meteorological satellites, and extracts the data pertaining to the HIRS and MSU instruments of the TOVS package. The output from the program is an image containing the calibrated data for the 20 HIRS channels and 4 MSU channels, with the latter linearly interpolated to the HIRS spots. The output image is cast in the format for the SLIP image processing software. Earth location of points on the image is accomplished by the satellite navigation package which has been integrated with SLIP in the CSIDA system developed at DAR.

Although the task may be simply stated, as in the last paragraph, the code is quite complicated for the following reasons.

- (1) The HRPT data stream is organized into frames for the AVHRR instrument. Embedded in each AVHRR frame is a sequence of five TIP (TIROS information processor) frames, which contain the data for the instruments in the TOVS package. The five TIP

frames are updated every three AVHRR frames, so the TIP frames are not received in sequence. Because transmission errors or loss of synchronisation between transmitter and receiver can corrupt the data stream, it is important to retain the least corrupted copy of each TIP frame. This requires that the words in each TIP frame must be subjected to synchronisation, parity and consistency checks.

- (2) Each AVHRR frame contains data for a full scan of the AVHRR instrument, and the format of the data within the frame is straight forward. In contrast, each TIP frame contains multiplexed data for all three TOVS instruments, each of which has its own sampling rate and scan period. The data for a single HIRS field of view is contained in a single TIP frame, and 64 consecutive frames contain the data for a complete HIRS scan. However, the data for a single MSU field of view is contained in either 4 or 5 TIP frames and 256 consecutive frames contain the data for a complete MSU scan, although the MSU words in most of the 256 frames are zero filled.
- (3) TIP frames which contain non-zero MSU data do not contain labels to identify the MSU scan and pixel number; indeed, these must be determined by the position of the MSU data in the sequence. While this arrangement is satisfactory for high quality data, there obviously will be problems when the data is corrupted and synchronisation of the data sequence is lost.
- (4) The TOVS radiometric data consists of either 13 or 12 bit words, packed into successive 8 bit words, with two check bits added to make the 10 bit words of the HRPT data stream. Furthermore, the CSIDA front end reformatter embeds the 10 bit words in 16 bit computer words.

Although every effort has been made to emphasise the structure of the code and to document it extensively, the complexities mentioned above warrant additional explanation which (hopefully!) is provided by this report.

The sections of the report are listed in the index on page 4.

The technical data concerning the satellite data stream is described in detail by Lauritson, Nelson and Porto in 'Data extraction and calibration of TIROS-N/NOAA radiometers', NOAA technical memorandum NESS 107. Throughout this report, the above authors and their document will be referred to simply as 'NOAA'.

2. TOVS DATA

2.1 FORMAT OF THE HRPT DATA

The HRPT data stream from the satellite consists of a sequence of frames for the AVHRR instrument. Each AVHRR frame contains 5 TIP frames, which are repeated in 3 successive AVHRR frames before being updated. Because data may be corrupted during transmission, the software described here adopts the following strategy.

- (1) A fictitious channel 0 is added to both the HIRS and MSU data. Its purpose is to hold information concerning the quality of the data received in each TIP frame. Ultimately, this data may be viewed on the display device in order to obtain a clear assessment of the quality of the data.
- (2) Initially, channel 0 is set to zero.
- (3) Each frame is subjected to a number of checks:
 - (a) two synchronisation word checks;
 - (b) two parity checks per word;
 - (c) equipment status checks.

A score is assigned to the frame according to the number of parity checks passed.

- (4) If the frame is a repetition of an earlier frame, then its score is compared with the value in channel 0, and, if it is higher, both the channel 0 value and the frame data are updated.

This strategy recovers as much usable data as possible from the data stream.

2.2 HIRS DATA

Each HIRS line consists of 64 fovs (fields of view), with the data corresponding to one fov completely contained in one TIP frame. Here fov is used in a general sense, as only 56 of the fovs actually contain radiometric data for earth views, while the other 8 fovs contain calibration target temperatures and house-keeping data.

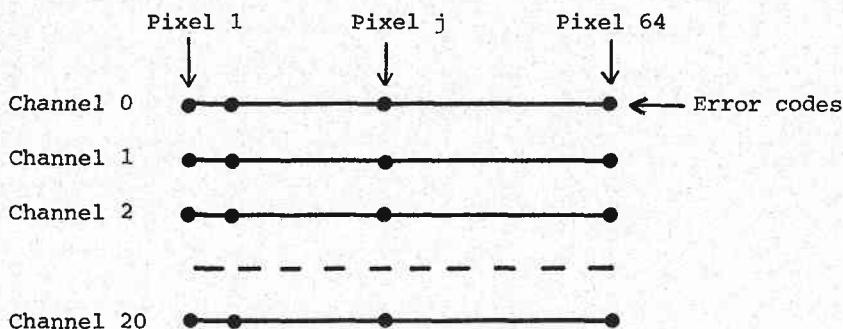


Figure 2. Format of a HIRS line.

The data for a HIRS line is contained in 64 successive TIP frames, and can be arranged into a 64 x 21 array as shown in figure 2. The first row of the array contains the channel 0 data for the TIP frames comprising the line, and the remaining 20 rows contain radiometric/house-keeping data for the 20 HIRS channels.

2.3 MSU DATA

Each MSU line consists of 14 fovs, each of which contains 16 TIP words, from which 8 words of radiometric/house-keeping data are to be extracted. The TIP frames which contain the non-zero data for an MSU scan are not consecutive; rather, they are spread over a 256 frame period, with the MSU words in the unused frames zero filled.

Associated with each MSU word is a quality code equal to the number of checks passed by the TIP frame which contained the word. The quality words and the MSU data are packed into a 16 x 14 matrix in which the upper 8 rows contain the quality words and the lower 8 rows contain the MSU data, as shown on page 34 of the NOAA document. Thus, the (i,j) entry of the matrix is the quality code for the MSU data word $(8+i,j)$, where $i=1,2,\dots,8$. The score can take values from 1 through 5. The contents of the lower 8 x 14 submatrix are displayed in figure 3.

COLUMN	1	2	3	4	5	6	7	8	9	10	11	12	13	14
ROW														
9	INST SCR LO	E CAL LO	E CAL HI	XTAL 1+	XTAL 1-	XTAL 2+	XTAL 2-	XTAL 3+	XTAL 3-	XTAL 4+	XTAL 4-	-15 VOLTS	5 VOLTS	E ZERO
10	TA CAL LO	TA CAL HI	OTH 1 TEMP	L.O. 1 TEMP	L.O. 3 TEMP	DICKE LOAD 1 TEMP	DICKE LOAD 3 TEMP	PRT 1A	PRT 2A	ANT.1 BEARING TEMP	MOTOR TEMP	RF CHASSIS	PROG TEMP	PROG TEMP
11	TB CAL LO	TB CAL HI	OTH 2 TEMP	L.O. 2 TEMP	L.O. 4 TEMP	DICKE LOAD 2 TEMP	DICKE LOAD 4 TEMP	PRT 1B	PRT 2B	ANT.2 BEARING TEMP	MOTOR TEMP	RF CHASSIS	PROG TEMP	PROG TEMP
12	CHANNEL 1 DATA	●											→	CHANNEL 1 REF
13	CHANNEL 2 DATA	●											→	CHANNEL 2 REF
14	CHANNEL 3 DATA	●											→	CHANNEL 3 REF
15	CHANNEL 4 DATA	●											→	CHANNEL 4 REF
16	SCAN POS 0 SCAN COUNT	SCAN POS 1 SCAN COUNT	●									→	→	SCAN POS X SCAN COUNT

Figure 3. Format of a MSU line.

3. TIMING AND FRAME IDENTIFICATION

TIP frames are organised into major frames and super frames. There are MINMAJ minor frames in every major frame, and MAJSUP major frames in every super frame;

$$\text{MINMAJ} = 320,$$

$$\text{MAJSUP} = 8.$$

Thus, the number of minor frames in every super frame is

$$\begin{aligned} \text{MINSUP} &= \text{MINMAJ} * \text{MAJSUP} \\ (2560 &= 320 * 8). \end{aligned}$$

Each TIP frame is labelled by a minor frame counter (TIPMIN) and a major frame counter (TIPMAJ), which take the values

$$\text{TIPMIN} = 0, 1, \dots, \text{MINMAJ}-1,$$

$$\text{TIPMAJ} = 0, 1, \dots, \text{MAJSUP}-1.$$

We define a sequence number for each frame by

$$\text{TIPSEQ} = \text{TIPMIN} + \text{TIPMAJ} * \text{MINMAJ},$$

which takes the values

$$\text{TIPSEQ} = 0, 1, \dots, \text{MINSUP}-1,$$

and uniquely labels the TIP frame within the super frame.

The data for a HIRS scan begins in TIP frames whose sequence numbers have the form

$$\text{TIPSEQ} = \text{HIRBEG} + n * \text{HIRMIN},$$

where n is any integer,

$$\text{HIRBEG} = 1,$$

$$\text{HIRMIN} = 64.$$

HIRMIN is the number of TIP frames per HIRS scan. We define a sequence number (HIRSEQ), a scan number (HIRSCN) and a pixel number (HIRPIX) for the HIRS data in TIP frame number TIPSEQ by

$$\text{HIRSEQ} = \text{ADDMOD}(\text{TIPSEQ} - \text{HIRBEG}, \text{MINSUP}),$$

$$\text{HIRSCN} = \text{HIRSEQ} / \text{HIRMIN},$$

$$\text{HIRPIX} = \text{MOD}(\text{HIRSEQ}, \text{HIRMIN}).$$

Here ADDMOD is the function

$$\text{ADDMOD}(i,j) = \begin{cases} i, & \text{if } i \leq 0, \\ i+j, & \text{otherwise.} \end{cases}$$

The relation between TIPSEQ and HIRSEQ is shown below.

TIPSEQ	2558, 2559, 0, 1, 2, ...
HIRSEQ	2557, 2558, 2559, 0, 1, ...

Thus, the cyclic sequence of TIPSEQ values is shifted one place to the left.

Similarly, the data for an MSU scan begins in TIP frames whose sequence numbers have the form

$$\text{TIPSEQ} = \text{MSUBEG} + n * \text{MSUMIN},$$

where n is any integer,

$$\text{MSUBEG} = 19,$$

$$\text{MSUMIN} = 256.$$

MSUMIN is the number of TIP frames per MSU scan. We define a sequence number (MSUSEQ), a scan number (MSUSCN) and a pixel number (MSUPIX) for the MSU data in TIP frame TIPSEQ by

$$\text{MSUSEQ} = \text{ADDMOD}(\text{TIPSEQ} - \text{MSUBEG}, \text{MINSUP}),$$

$$\text{MSUSCN} = \text{MSUSEQ} / \text{MSUMIN},$$

$$\text{MSUPIX} = \text{MOD}(\text{MSUSEQ}, \text{MSUMIN}).$$

The relation between TIPSEQ and MSUSEQ is shown below.

TIPSEQ	0, 1, ... , 18, 19, 20, 21, ...
MSUSEQ	2542, 2543, ... , 2559, 0, 1, 2, ...

Thus, the cyclic sequence of TIPSEQ values is shifted 19 places to the left.

4. CALIBRATION OF THE HIRS AND MSU INSTRUMENTS

4.1 HIRS CALIBRATION

The HIRS instrument has a 40 line calibration sequence. During this period, the instrument continually monitors the temperature of the internal warm and cold targets, and this data is transmitted in HIRS fovy 59 and 60 of every HIRS line. The target temperatures are averaged over the 40 line sequence for the calibration. In addition, the first 3 lines of data are directed to space, the cold target and the warm target, respectively. The remaining 37 lines of data are earth view lines.

The calibration of the instrument with this data is described in detail by NOAA, pages 51-52.

4.2 MSU CALIBRATION

The MSU instrument has two internal targets, each of which is used to calibrate two channels. The radiances and temperatures of the targets are sampled every scan. The temperatures are averaged over a 25 line sequence, centred on the current line, and the average value is used to compute calibration coefficients for the current line.

Again, the procedure is described in detail by NOAA, pages 47-49.

5. PROGRAMMING CONVENTIONS AND PORTABILITY

5.1 BITS AND WORD LENGTHS

It will be assumed in this report that computer words have 16 bits, which are ordered

bit(15), . . . , bit(1), bit(0),

with bit(15) the most significant and bit(0) the least significant.

The data in the HRPT data stream has only 10 significant bits. We assume that the receiver embeds the 10 bits in positions 0 through 9 of a 16 bit word. It is this data that the TOVPIX software processes.

Furthermore, the TIP data embedded in the HRPT data stream has only 8 significant bits, which are stored in bit positions 2 through 9. Bit(1) is an even parity check over bits 2 through 9. Bit(0) is the complement of bit(9). Before any data is accepted, both bits 0 and 1 are checked by subroutine PARITY.

5.2 STORAGE CONVENTIONS

In most of the program, storage has been allocated for different purposes by placing partitions in an integer array `STRING` and a real array `VECTOR`. For example, if an output buffer is needed for HIRS data, then a pointer will be set to the last used location of array `STRING`, and data will be written into locations beyond the pointer. An end of array marker is then advanced to the end of the buffer.

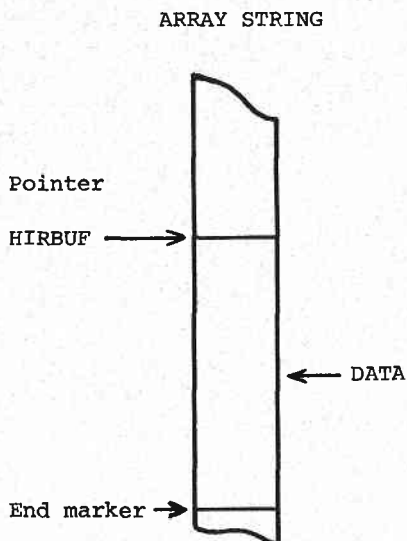


Figure 4. Pointer to an array.

Thus, instead of writing statements such as

```
HIRBUF(I)=.....
```

where HIRBUF denotes an output array, we write instead

```
STRING(HIRBUF+I)=.....
```

where HIRBUF now denotes the pointer.

When the buffer is no longer needed, the pointer is removed and the end of string marker is pushed down to recover the storage.

A second convention used in the code is the systematic use of variable names for parameters of the TOVS instruments. For example, the HIRS instrument has 20 channels and the number of earth views in a scan is 56, but in the code these quantities are referred to as HIRCHA and HIRGEO, and values are set for these variables in a block data program. The reason for this convention is that 20 has many meanings (for example 5 x 4), whereas HIRCHA describes what the quantity is.

5.3 PORTABILITY

The code is written in FORTRAN 77 with only two extensions of the standard. The first of these is the use of block DO and DO WHILE loops. The second is the use of a bit move routine called MVBITS,

```
CALL MVBITS(A,B,C,D,E),
```

which moves C bits from positions B through B+C-1 of argument A to positions E through E+C-1 of argument D. Both of these extensions conform to MIL-STD-1753.

One more non-standard feature is needed to implement the code on the HP-1000 series computers at DAR. It is a call to system subroutine LGBUF, which establishes an input/output buffer of suitable length. There is only one call to LGBUF, and it appears in subroutine TOVPIX.

6. INTERPOLATION OF THE MSU DATA

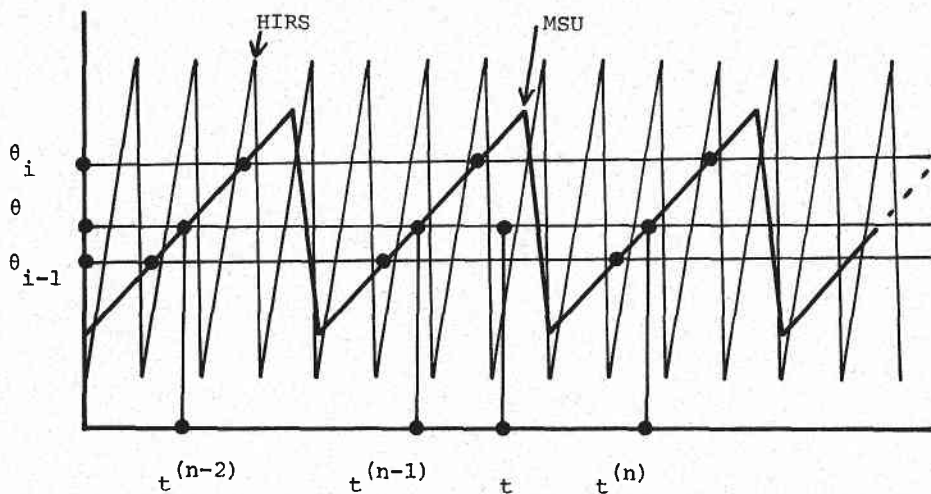


Figure 5. Timing of HIRS and MSU scans.

Let $\theta_1, \theta_2, \dots, \theta_{11}$,

denote the scan angles of the MSU instrument, let

$$t_1^{(n)} = np + t_1, t_2^{(n)} = np + t_2, \dots, t_{11}^{(n)} = np + t_{11},$$

denote the times of observation for scan number n , and let

$$f_1^{(n)}, f_2^{(n)}, \dots, f_{11}^{(n)},$$

denote the observed MSU radiances. Here p is the period of the MSU scan. We require an approximation to the MSU radiance at a point (t, θ) corresponding to the time and angle of a HIRS observation. The procedure used is as follows.

(1) Interpolate linearly between the MSU scan angles. If

$$\theta_{i-1} \leq \theta \leq \theta_i,$$

then define

$$\alpha = \frac{\theta - \theta_{i-1}}{\theta_i - \theta_{i-1}}$$

and

$$f^{(n)}(\theta) = (1-\alpha) f_{i-1}^{(n)} + \alpha f_i^{(n)} .$$

If

$$\theta \leq \theta_1 \quad \text{or} \quad \theta \geq \theta_{11} ,$$

then define

$$f^{(n)}(\theta) = f_1^{(n)} \quad \text{or} \quad f^{(n)}(\theta) = f_{11}^{(n)} ,$$

respectively. This interpolation is performed by subroutine GAPANG.

(2) Interpolate in time between successive scans. Calculate the time t where the line through θ parallel to the time axis cuts MSU scan n . If

$$t^{(n-1)} \leq t \leq t^{(n)} ,$$

then define

$$\beta = \frac{t - t^{(n-1)}}{t^{(n)} - t^{(n-1)}} ,$$

and

$$f(t, \theta) = (1-\beta) f^{(n-1)}(\theta) + \beta f^{(n)}(\theta) .$$

If

$$t \leq t^{(1)} \quad \text{or} \quad t \geq t^{(k)} ,$$

where k is the label of the last scan, then define

$$f(t, \theta) = f^{(1)}(\theta) \quad \text{or} \quad f(t, \theta) = f^{(k)}(\theta) ,$$

respectively. Subroutine GAPTIM performs this interpolation.

7. EARTH LOCATION

Software for earth location of satellite images has been integrated into the SLIP software in the CSIDA system. The communication between the navigation package and the image file is via one of the user data records associated with the image file. The contents of the user data record are:

- (1) orbital details of the satellite;
- (2) time of acquisition of the first pixel of the image;
- (3) time increments between pixels and lines;
- (4) angular range of the scanning radiometer.

In the file NOAFIL, which contains the HRPT received during a satellite overpass, these parameters are set for the AVHRR radiometer. In subroutine TOVPIX, the user data records are recovered from NOAFIL and subroutine ORBMOD is called to modify the records for the HIRS and MSU instruments.

8. PROGRAM OUTLINE

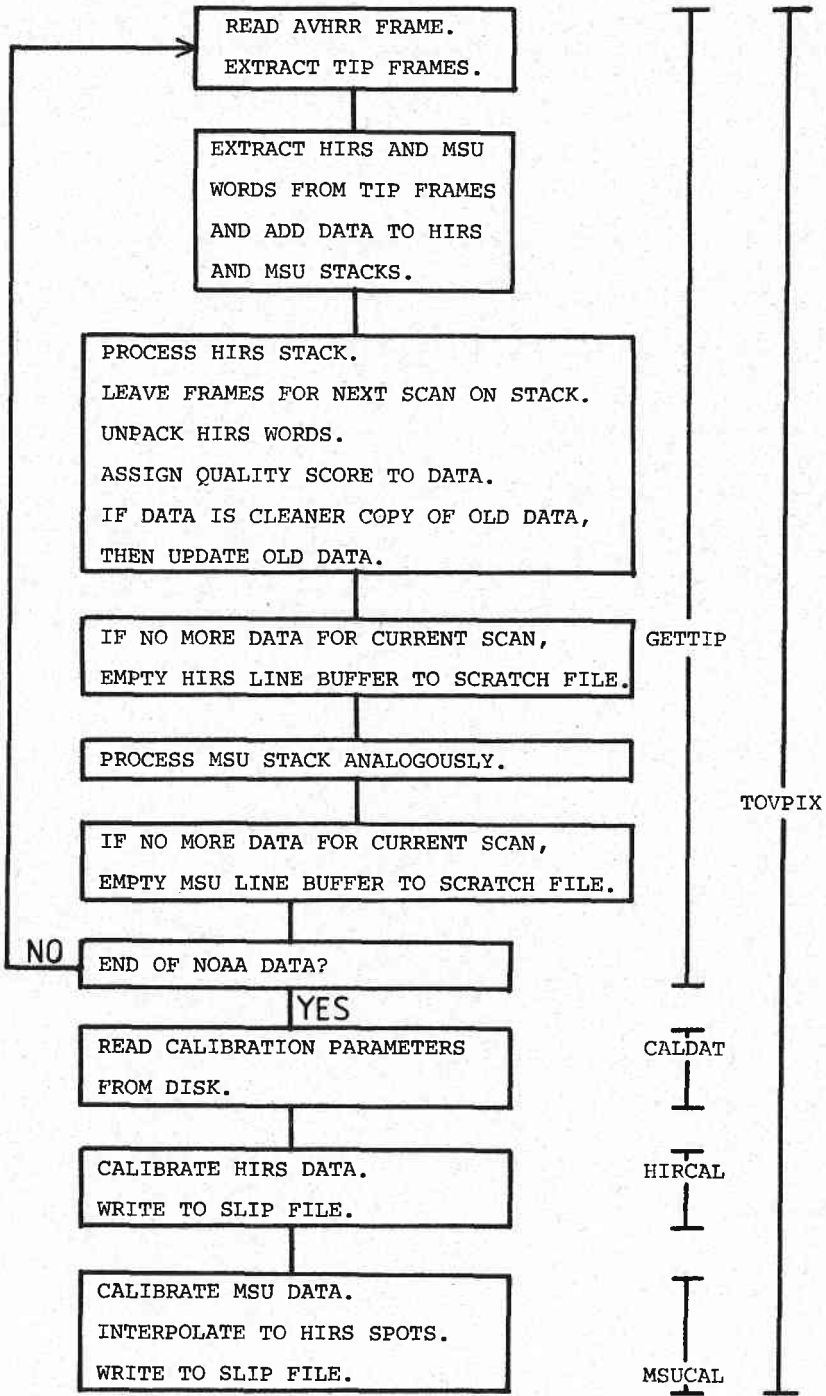


Figure 6. Flow chart.

Subroutine TOVPIX supervises the data extraction and calibration. In addition TOVPIX updates the SLIP header and user data records for the output files.

In subroutine GETTIP, the HIRS and MSU data are separated and written to scratch files. The 21 x 64 array of HIRS data for each scan is written by rows to a direct access file whose record length is 64 words. Similarly, the 16 x 14 array of MSU data for each scan is written by rows to a direct access file whose record length is 14 words.

Subroutine CALDAT reads a sequential access file which contains the calibration parameters for the current NOAA satellites.

Subroutine HIRCAL reads the HIRS scratch file, calculates gains and intercepts to calibrate the infrared channels, and writes the calibrated data to the file HIRFIL.

Subroutine MSUCAL performs the same task for the MSU data, with the extra step of interpolation of the MSU data to the angles and times of the HIRS observations.

9. SUBROUTINE TOVPIX

The call statement for subroutine TOVPIX is

```
CALL TOVPIX(NOAFIL,HIRFIL,MSUFIL,CALFIL,
1          NOALOG,HIRLOG,MSULOG,CALOG,
2          HIRSCR,MSUSCR)
```

Here NOAFIL, HIRFIL, MSUFIL, CALFIL are CHARACTER variables which contain file names, and NOALOG, HIRLOG, MSULOG, CALOG are INTEGER*2 variables which contain the associated logical unit numbers.

NOAFIL is the name of the file containing the HRPT received during a satellite overpass. The format assumed for NOAFIL is described in the section entitled SUBROUTINE GETTIP.

HIRFIL is the name of the file for calibrated HIRS data. This file has the following format.

```
SLIP header          (256 words).
*****
Scan 1, channel 0 (112 words).
Scan 1, channel 1 (112 words).
.....
Scan 1, channel 20 (112 words).
*****
*****
Scan n, channel 0 (112 words).
Scan n, channel 1 (112 words).
.....
Scan n, channel 20 (112 words).
*****
*****
User data records   (256 words).
```


The reason for the number 112 is that there are 56 earth views per HIRS scan and each calibrated radiometric value requires 2 words of storage. The information is packed into blocks of length 128 and written to a direct access file with record length 128.

Pixel *i* of channel 0 contains an error code equal to the number of parity checks passed by the HIRS words in the TIP frame corresponding to pixel *i*. The maximum value is 36. Thus, by displaying channel 0, one can immediately assess the quality of the data.

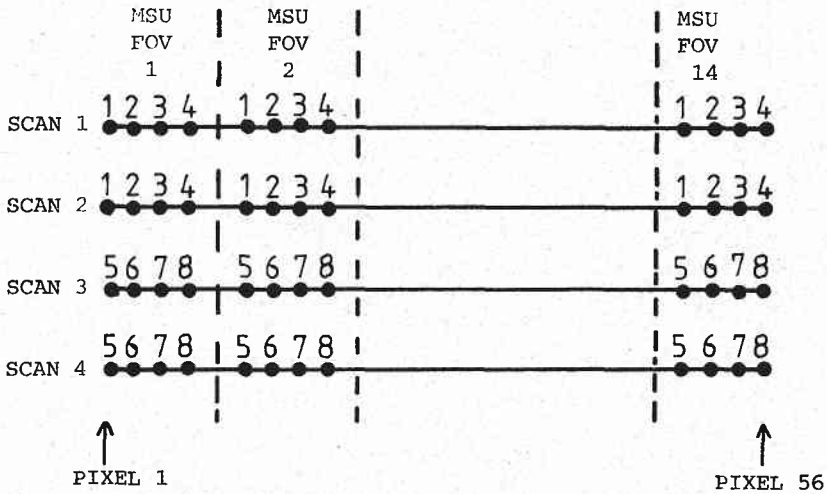
MSUFIL is the name of the output file for calibrated and interpolated MSU data. This file has the following format.

```

SLIP header          (256 words).
*****
Scan 1, channel  0 (112 words).
Scan 1, channel  1 (112 words).
.....
Scan 1, channel  4 (112 words).
*****
*****
Scan n, channel  0 (112 words).
Scan n, channel  1 (112 words).
.....
Scan n, channel  4 (112 words).
*****
User data records  (256 words).

```

The information in MSU channel 0 requires a little explanation. The MSU instrument has 14 fovs in a scan, of which only 11 are earth views. At each fov, 8 words of radiometric/house-keeping data are transmitted, with either 1 or 2 words per TIP frame. Each TIP frame is assigned a score equal to the number of MSU words in the frame which passed parity checks. If this score is PASSES, then each MSU word extracted from the TIP frame is assigned a score PASSES+1 if further checks on the scanner status are passed, and a score 1 otherwise. Thus, there are $8 \times 14 = 112$ words of quality code associated with every MSU scan. Since the period of the MSU scan (25.6 seconds) is four times that of the HIRS scan (6.4 seconds), the 112 quality codes must be packed into 4 lines of 56 pixels. How this has been done is illustrated below in figure 7.



THE NUMBERS SHOWN AGAINST THE PIXELS ARE THE LABELS OF THE ROWS IN THE 16x14 MSU MATRIX.

Figure 7. Packing the MSU error codes.

The 8 error codes from MSU fov 1 are written to pixels 1, 2, 3, 4 of scans 1 and 3. Similarly, the 8 error codes for MSU fov 2 are written to pixels 5, 6, 7, 8 of scans 1 and 3, and so on. Scans 2 and 4 are then copies of scans 1 and 3. Thus, the error codes for the MSU scan have been packed, with some padding, into the standard format for channel 0.

CALFIL is the name of a sequential access file which contains the calibration parameters for the operational NOAA satellites. The format assumed for CALFIL is described in the section entitled SUBROUTINE CALDAT.

HIRSCR and MSUSCR are CHARACTER variables which contain names for scratch files for HIRS and MSU data. These files are deleted by TOVPIX at the end of the run.

Subroutine TOVPIX opens and closes the various files, and supervises the four main subroutines, GETTIP, CALDAT, HIRCAL, MSUCAL.

- (1) GETTIP reads the NOAA data file NOALOG and extracts the HIRS and MSU data, which is written to scratch files with formats suited to the HIRS and MSU instruments, respectively.
- (2) CALDAT reads the calibration parameters for the appropriate NOAA satellite.
- (3) HIRCAL reads the HIRS scratch file, calibrates the HIRS data, and writes the file HIRFIL.
- (4) MSUCAL reads the MSU scratch file, calibrates the MSU data, interpolates the data to the times and angles of the HIRS scans, and writes the file MSUFIL.

10. SUBROUTINE GETTIP

Subroutine GETTIP extracts the HIRS and MSU data from the HRPT data stream and writes it to two scratch files.

There are three levels of processing carried out by routine GETTIP:

- (1) acquisition of AVHRR frames;
- (2) transfer of TIP data from each AVHRR frame to the HIRS and MSU stacks;
- (3) processing of the HIRS/MSU data from each TIP frame.

10.1 AVHRR FRAME ACQUISITION

The HRPT data is assumed to be supplied in a data file accessible to logical unit number NOALOG. Furthermore, it is assumed that the HRPT data has been written in blocks of 128 words which are organised as shown below.

Block	Contents
1	header 1
2	header 2
3- 18	line 1, channel 1 AVHRR (2048 words).
19- 34	line 1, channel 2 AVHRR (2048 words).
35- 50	line 1, channel 3 AVHRR (2048 words).
51- 66	line 1, channel 4 AVHRR (2048 words).
67- 82	line 1, channel 5 AVHRR (2048 words).
83- 98	line 1, HRPT header (103 words), TIP data (520 words).
99-114	line 2, channel 1 AVHRR (2048 words).
.....	
3+96n	2 user data records (64 words each).
4+96n	2 user data records (64 words each).

Thus, the first TIP data set occurs at block 83 of NOAFIL, and subsequent data sets occur at intervals of 96 blocks. In routine GETTIP, these quantities are stored in NOABEG and NOADEL;

NOABEG = 83,

NOADEL = 96.

In fact, subroutine GETTIP never looks at the AVHRR data. All that is required is that the TIP data commence at records

NOABEG + n NOADEL,

where $n = 0, 1, 2, \dots$. Thus, subroutine GETTIP will still function correctly if the AVHRR data has been stored in line interleaved mode rather than channel interleaved mode.

10.2 EXTRACTION OF HIRS/MSU DATA FROM TIP FRAMES

Array STRING is now partitioned as shown in figure 8. The purposes of the various sections will become clear later.

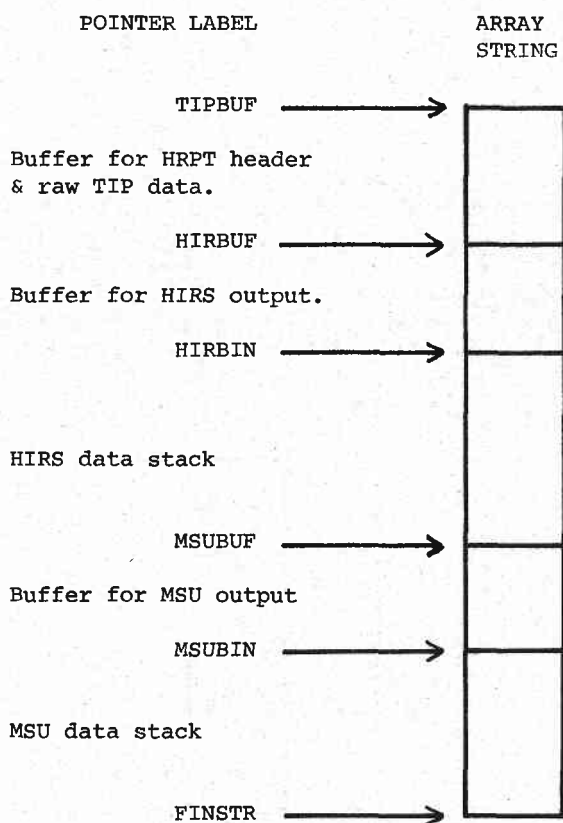


Figure 8. Partitions placed in array STRING by routine GETTIP.

(1) The number of words in a TIP frame is TIPWRD, and the number of TIP frames in an AVHRR frame is TIPAVH:

$$\text{TIPWRD} = 104,$$

$$\text{TIPAVH} = 5.$$

The HRPT header contains 103 words. The header and TIPAVH frames are read into the TIP buffer which begins at address TIPDOT. Then the pointer TIPDOT is advanced to the beginning of the last TIP frame in the TIP buffer.

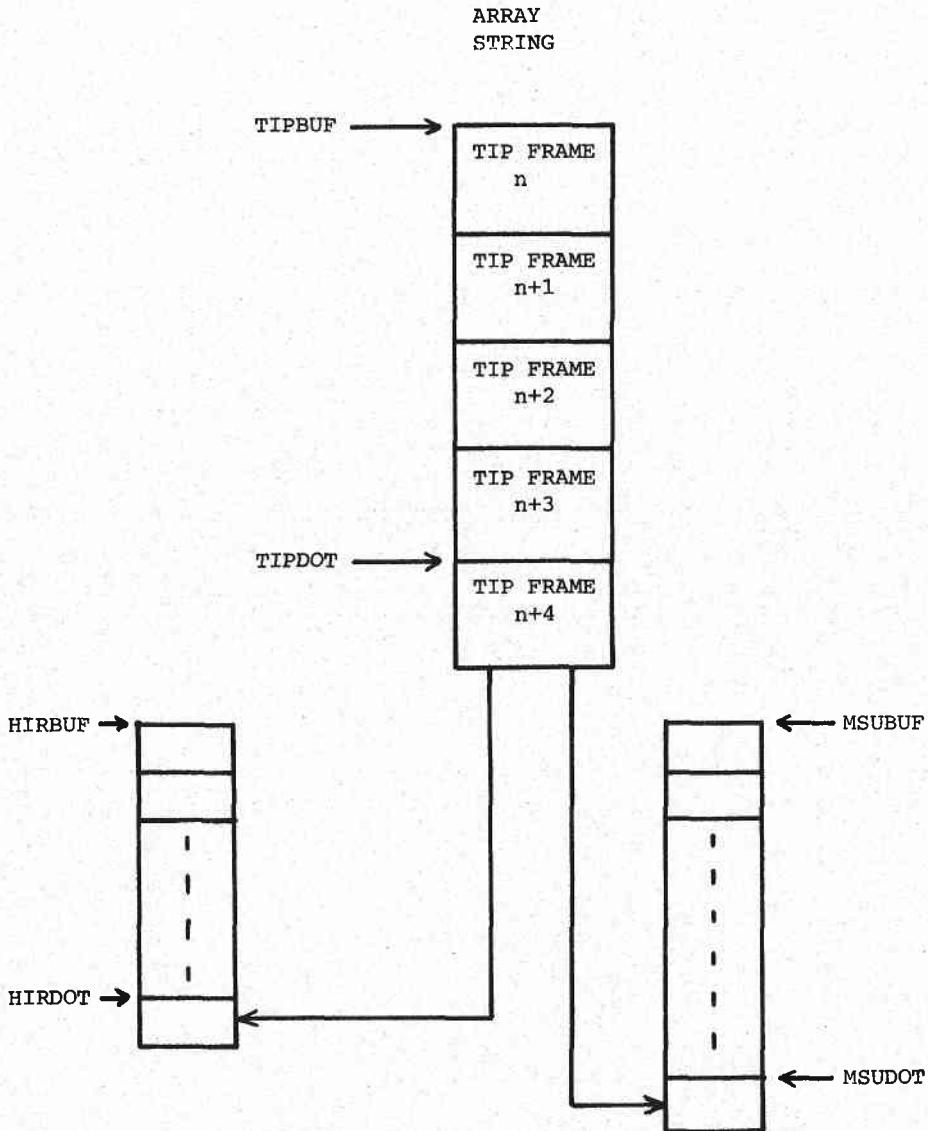


Figure 9. Pointers to the TIP buffer.

(2) Check the status of the TIP frame at TIPDOT. This is done by routine TIPTIM, which:

- (a) checks the two synchronisation words at the beginning of the TIP frame;
- (b) checks the parity bits 0 and 1 of the first 6 words in the frame which contain the timing data;
- (c) recovers:

the satellite identification code (SATLAB);

the TIP minor frame counter (TIPMIN);

the TIP major frame counter (TIPMAJ);

the TIP status word (TIPSTA), which is 0 if all checks are passed and 1 otherwise.

(3) If the frame fails any of these checks, it is discarded. Otherwise, the following steps are taken.

- (a) Sequence, scan and pixel numbers (HIRSEQ, HIRSCN, HIRPIX and MSUSEQ, MSUSCN, MSUPIX) are calculated.
- (b) The TIP frame contains HIRWRD words of HIRS data and MSUWRD words of MSU data;

$\text{HIRWRD} = 36,$

$\text{MSUWRD} = 4.$

The location of these words within the frame are stored in indices HIRIND and MSUIND. The data words are copied from the TIP frame to the HIRS and MSU stacks at addresses HIRDOT and MSUDOT. The scan and pixel numbers are appended in the next two locations of each stack, and the stack pointers are advanced by HIRDEL and MSUDEL, where

$\text{HIRDEL} = \text{HIRWRD} + 2,$

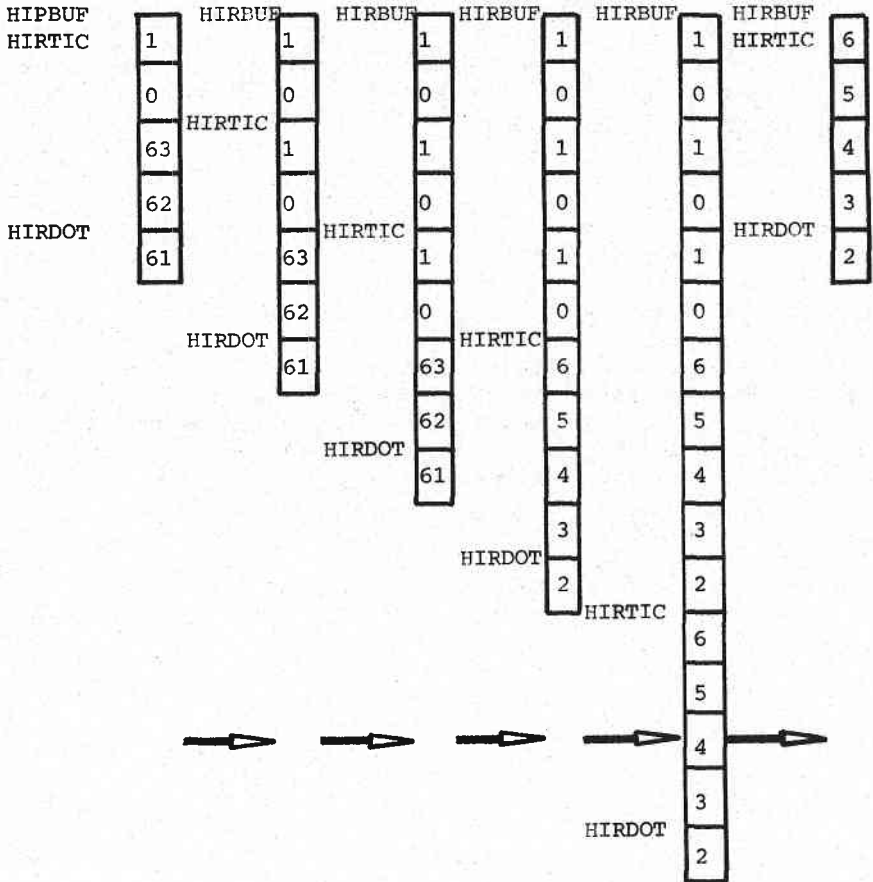
$\text{MSUDEL} = \text{MSUWRD} + 2.$

10.3 PROCESSING OF THE HIRS/MSU STACKS

Because each TIP frame is repeated three times in successive AVHRR frames, the appearance of the HIRS data for a new scan does not necessarily signal the end of data for the current scan. It may happen that data for the current line is corrupted, but subsequent copies of that data are uncorrupted. Consequently, data for the next scan must be held on the stacks until the end of all data for the current line.

10.3.1 PROCESSING THE HIRS STACK

The evolution of the HIRS stack is illustrated in figure 10 below. The initial stack has five TIP frames on the stack, of which three, with pixel numbers 61,62,63, belong to the current HIRS scan, and two, with pixel number 0,1, belong to the next scan. As extra AVHRR frames are read, the TIP frames for the next scan accumulate on the stack, and the pointer HIRTIC is advanced. Finally, when all of the TIP frames for the current scan have been processed, the pointer HIRTIC is pulled back to recover storage and the stack is again left with only five TIP frames.



The entries in the stack are the HIRS pixel numbers, which range from 0 to 63 in a full HIRS scan.

Figure 10. Evolution of the HIRS stack.

Two pointers are maintained in the HIRS stack, HIRTIC and HIRDOT, and in each pass through the stack, the TIP frames between HIRTIC and HIRDOT are processed. At the commencement of the pass, the scan number of the current line is held in HIROLD. As each frame is processed, its scan number HIRSCN is compared with HIROLD. If HIRSCN is not equal to HIROLD, then the frame belongs to a subsequent scan, so the pointer HIRTIC is advanced to the end of the stack and processing of the stack ceases. Otherwise, the frame is processed and HIRDOT is moved back to the beginning of the preceding frame in the stack. Processing of frames continues as long as HIRDOT is at least equal to HIRTIC.

The processing steps are as follows:

- (1) The HIRS words in the TIP frame are subjected to parity checks, and a score is assigned to the TIP frame. Its value is

$$\text{PASSES} = k \text{ if } k \text{ words passed parity checks,}$$

$$k=1, 2, \dots, 36.$$

- (2) The 36 HIRS words of the TIP frame contain 8 bits each, giving a bit stream of length 288 bits. The radiometric data consists of 20 words of 13 bits each, packed into bits 27-286 of the bit stream. Subroutine UNPACK recovers the 20 radiometric words from the bit stream, and writes them into array STRING at address HIRDOT.
- (3) The order of the radiometric data in the bit stream is not the natural order of increasing wavenumber. Subroutine TANGLE permutes the words into the correct order.
- (4) The last data acquired is overwritten if the new error code PASSES is higher than the old value, stored in pixel HIRPIX for channel 0 in the output buffer at address HIRBUF.
- (5) If the last pass through the HIRS stack did not find any more data for the current line, signalled by HIRGAP not equal to zero, then:
 - (a) write out the current line by rows of length HIRFOV into the scratch file;
 - (b) blank fill any missing lines;
 - (c) reset the pointer HIRTIC to the beginning of the HIRS stack and update the line counter HIROLD.

10.3.2 PROCESSING THE MSU STACK

The general strategy, of holding data for a new scan on the stack until the old scan is complete, is the same for the MSU data as for the HIRS data. The only differences concern the processing of the frames and the reformatting of the output buffer before the scan is written to the scratch file. These differences are detailed below:

- (1) The MSU words in the TIP frame are subjected to parity checks and a score is assigned to the TIP frame. Its value is

PASSES = k if k words passed parity checks,

k=1,2,3,4.

- (2) Subroutine MSUDEC extracts radiometric/house-keeping data from the MSUWRD words of MSU data in the TIP frame. Its output has the following form:

word 1 - quality code for output word 2;

word 2 - radiometric/house-keeping data extracted from input words 1 and 2;

word 3 - quality code for output word 3;

word 4 - radiometric/house-keeping data extracted from input words 3 and 4.

The quality word is:

zero if the data is zero;

positive if the data word is not the end of the fov;

negative if the data word is the end of the fov.

The absolute value of the quality code is $1 + \text{PASSES}$, where PASSES is the number of MSU words in the TIP frame which passed the parity checks. However, if the MSU scanner status checks fail (signalled by the Z and S bits of NOAA, page 35), then the absolute value of the quality code is set to 1.

- (3) The MSU output buffer, which starts at address MSUBUF, has length sufficient for MSUMIN frames with the following data per frame:

channel 0 - quality code for the TIP frame;

channel 1 - quality word for channel 2;

channel 2 - radiometric/house-keeping data;

channel 3 - quality word for channel 4;

channel 4 - radiometric/house-keeping data.

11. SUBROUTINE CALDAT

Subroutine CALDAT reads a sequential access disk file which contains the calibration data for the HIRS and MSU instruments for the different NOAA satellites. The notation used here for the calibration parameters is that of NOAA, pages B-6 through B-11.

The data for each satellite must be organised as follows. Note that the order of the lines is important, but the format within any line is free.

Data	Number of lines	Contents of lines
header	3	descriptive blurb
number of satellites	1	
index of satellites	1	Entry i is the id of satellite i.
header	3	descriptive blurb
HIRS counts/temperature conversion coefficients	1 per sensor	$a(0), \dots, a(4)$
header	3	descriptive blurb
HIRS normalised response functions, channels 1-19	8 per channel	v_1 Δv $\hat{\phi}_1, \dots, \hat{\phi}_5$ $\hat{\phi}_6, \dots, \hat{\phi}_{10}$ ----- $\hat{\phi}_{26}, \dots, \hat{\phi}_{30}$
header	3	descriptive blurb
HIRS visible channel gain and intercept	2	G I
header	3	descriptive blurb
MSU nonlinearity correction, channels 1-4	1 per channel	$d(0), d(1), d(2)$
header	3	descriptive blurb
MSU PRT counts/resistance conversion coefficients	2	$k(0)$ $k(1)$
header	3	descriptive blurb
MSU PRT resistance/temp conversion coefficients	1 per PRT	$e(0), e(1), e(2)$
header	3	descriptive blurb
MSU normalised response functions, channels 1-4	1 per channel	
header	3	descriptive blurb
Radiance of space for MSU channels 1-4	1 per channel	$N(\text{space})$

12. SUBROUTINE HIRCAL

Subroutine HIRCAL recovers the HIRS data from the HIRS scratch file and calibrates it as follows:

- (1) The number of lines in the HIRS calibration sequence is CALSEQ = 40. A pointer (HIRREC) is set to the first record of the HIRS scratch file at which both a HIRS scan and a MSU scan start simultaneously. Similarly, a pointer (HIRMAX) is set to the last record of the HIRS scratch file at which a HIRS scan and a MSU scan end simultaneously. Subroutine HIRCAL scans through CALSEQ lines, or until record HIRMAX, and extracts from these lines:
 - (a) the counts for the four platinum resistance thermometers embedded in the internal warm target;
 - (b) the line of space views, signalled by scan (HIRSCN) equal to 0;
 - (c) the line of target views, signalled by scan (HIRSCN) equal to 2.

The target temperature and the channel gains and intercepts are then calculated according to the prescription given by NOAA, pages 51-52. A pointer (NEXREC) is set to the first record beyond the lines read from the scratch file.

- (2) The records between HIRREC and NEXREC are reread and the earth view data is calibrated according to the formula

$$N = G X + I ,$$

where N is the calibrated radiance, X is the radiometer count, and G and I are the channel gain and intercept.

- (3) The pointer HIRREC is advanced to NEXREC and the process is repeated until the whole file is calibrated.
- (4) The calibrated data is packed into blocks of length 128 words by subroutine PAKLIN.

If the satellite overpass lasts for fewer than 40 lines, then it might not contain the space and internal target views necessary to calculate the gains and intercepts. In this case the infrared channels are not calibrated. Similarly, the last group of lines in the scratch file to be processed might not contain the space and internal target views needed for calibration. In this case, the last calculated set of gains and intercepts are used for the calibration.

12.1 SUBROUTINES CALLED BY HIRCAL

Utilities

NULDBL, POLNOM

GETLIN, PAKLIN

13. SUBROUTINE MSUCAL

Subroutine MSUCAL recovers the data from the MSU scratch file, calibrates and interpolates the data, and writes the file MSUFIL. The routine operates as follows:

- (1) The number of lines in the MSU calibration sequence is CALSEQ = 25. Buffers (called count stacks) of length 25 are established for the platinum thermometer counts, space view counts, and internal target view counts. The first 13 lines of the MSU scratch file are read, and the calibration data is extracted and stored in the last 13 locations in the count stacks. The remaining locations are zero filled. Pointers are set midway down the count stacks.
- (2) Routine MSUCAL now begins to loop over the lines in the MSU scratch file. The non-zero elements of the count stacks are averaged, and used to calculate gains and intercepts for the different channels, according to the prescription in NOAA, pages 47-49. The MSU channels are then calibrated.
- (3) Subroutine GAPANG is called to interpolate from the MSU scan angles to the HIRS scan angles. The interpolated values are stored in buffer (called the line stack) of sufficient length to hold three MSU scans.
- (4) Every time a new line is read from the scratch file, the values for the platinum resistance thermometer counts, space view counts and target view counts are shuffled down the count stacks, the oldest values are dropped from the end, and new values, extracted from the new line are added at the beginning. (Equivalently, a pointer directs the storage to the oldest entries in the count stacks, which are then overwritten). This means that the gains and intercepts are calculated from averages taken over a window of CALSEQ lines, centred on the current line.
- (5) Similarly, as each new line is interpolated to HIRS angles, the lines are shuffled down the line stack, the oldest is dropped from the end, and the new line is added at the beginning. Consequently, at any time, the line stack holds three lines.
- (6) Subroutine GAPTIM interpolates in time between the three lines held in the MSU line stack in order to obtain data at the same sample times as the HIRS data. The output from subroutine GAPTIM is a set of four scans, corresponding to the four HIRS scans which occur during every MSU scan.
- (7) The data is packed into blocks of 128 words by subroutine PAKLIN and written to file MSUFIL.

SUBROUTINE MSUTEM(parameter list)

Subroutine MSUTEM extracts from the 16 x 14 array of data acquired in an MSU scan:

- (1) target temperature counts;
- (2) space view counts;
- (3) target view counts.

The target temperature counts are converted to resistance and thence to temperature. The space and target radiometric counts are corrected for non-linearity of the MSU instrument.

SUBROUTINE MSUACC(STRING,MSUFOV,ERRBUF)

Subroutine MSUACC packs the error codes in words 1 through 8 of columns 1 through 14 of the 16 x 14 array into rows of length 56 stored in ERRBUF. Because each MSU scan corresponds to 4 HIRS scans, the $8 \times 14 = 112$ MSU error codes are duplicated and packed into 4 HIRS scans of 56 pixels each.

SUBROUTINE GAPANG(parameter list)

Subroutine GAPANG interpolates linearly between the MSU dwell angles of a single scan in order to estimate the MSU data at HIRS dwell angles.

SUBROUTINE GAPTIM(parameter list)

Subroutine GAPTIM interpolates linearly in time between successive MSU scans in order to estimate the MSU data at the HIRS scan times.

SUBROUTINE ORBMOD(parameter list)

The image identification record associated with the CSIDA satellite images contains:

- (1) the time of reception of the first element of the image;
- (2) orbital parameters;
- (3) the angular increments between pixels and lines;
- (4) the time increments between pixels and lines.

Initially, these parameters are set for the AVHRR image. Subroutine ORBMOD updates the image identification record with the new time and the appropriate increments between pixels and lines for the HIRS instrument.

SUBROUTINE USRMOD(parameter list)

Subroutine USRMOD updates the image description record, the image history record, the channel names record for the output files, HIRFIL and MSUFIL, which contain the calibrated HIRS and MSU data.

SUBROUTINE HEDMOD(parameter list)

Subroutine HEDMOD updates the SLIP header record for the HIRS and MSU output files.

FUNCTION ADDMOD(I,J)

Function ADDMOD is equal to I if I is non-negative, and equal to I+J otherwise. This function arises when counting the number of places between two integers M and N, both modulo J.

FUNCTION POLNOM(DEGREE,ARGMNT,COEFFS)

Function POLNOM evaluates a polynomial of degree DEGREE, coefficients COEFFS and argument ARGMNT. The coefficient of ARGMNT**I is stored in COEFFS(I+1), I=0, 1, ... , DEGREE.

SUBROUTINE NULSGL(STRING,OFFSET,LENGTH)

Subroutine NULSGL zeros LENGTH locations in array STRING at addresses after OFFSET. Array STRING is assumed to be INTEGER*2.

SUBROUTINE NULDBL(VECTOR,OFFSET,LENGTH)

Subroutine NULDBL zeros LENGTH locations in array VECTOR at addresses after OFFSET. Array VECTOR is assumed to be REAL*4.

SUBROUTINE GETLIN(String,OFFSET,LENGTH,RECORD,DEVICE,NEXREC)

Subroutine GETLIN reads RECORD records from a direct access file, beginning at record NEXREC. The logical unit number of the device is DEVICE. Each record has length LENGTH. The data is read into array STRING at addresses after OFFSET.

SUBROUTINE OUTLIN(String,OFFSET,LENGTH,RECORD,DEVICE,NEXREC)

Subroutine OUTLIN writes, whereas GETLIN reads.

SUBROUTINE PAKLIN(VECTOR,OFFSET,LENGTH,RECLLEN,DEVICE,NEXREC)

Subroutine PAKLIN writes as many records of length RECLLEN as possible from the data in array VECTOR at addresses 1 through OFFSET+LENGTH. The data is written to logical unit DEVICE, beginning at record NEXREC. Any data which cannot be parcelled into a record of length RECLLEN is shifted to address 1, and OFFSET is set to the last occupied location in VECTOR.

SUBROUTINE ENDLIN(String,USRDAT,VECTOR,OUTOFF,NOALEN,OUTLOG,OUTREC)

Subroutine ENDLIN appends the user data records, stored in array STRING at address USRDAT, to the last of the intensity data, stored in array VECTOR at address ENDVEC in common block LOCATE. The combined data is parcelled into records of length NOALEN and written to logical unit number OUTLOG, beginning at record OUTREC. The number of intensity words is OUTOFF.

SUBROUTINE MOVBAR(VECTOR,LENGTH,OFFSET,LENDEL,AVERAG)

Subroutine MOVBAR computes the average of non-zero elements at addresses

POINTR, POINTR+LENDEL, ... , POINTR+LENDEL*(LENGTH-1),

in array VECTOR, where

POINTR=OFFSET+I, I=1, ... ,LENDEL.

The average value is stored at address $\text{POINTR} + \text{LENDEL} * \text{AVERAG}$. This routine is used to compute a sliding average of length LENGTH of a sequence stored in VECTOR .

FUNCTION PLANCK(WAVNUM, BBTEMP)

Function PLANCK computes the radiance at wavenumber WAVNUM (cm^{-1}) of a black body with temperature BBTEMP .

SUBROUTINE AVHTIM(HEADER, DAYNUM, MILSEC, AVHMIN, AVHSEQ)

Subroutine AVHTIM extracts from the HRPT header, stored in array HEADER :

- (1) the day of the year (DAYNUM);
- (2) the milli-second of the day (MILSEC);
- (3) the HRPT minor frame number (AVHMIN);
- (4) the AVHRR scan number (AVHSEQ).

SUBROUTINE SATTIM(STRING, MILSEC, TIMSTA)

Subroutine SATTIM extracts the satellite clock time from a TIP frame stored in array STRING . MILSEC is the milli-second of the day. TIMSTA is set to 0 if the extraction is successful, and set to 1 otherwise. Note that only those TIP frames with minor frame counter equal to zero contain the time code. Subroutine SATTIM checks the parity of the relevant TIP words.

SUBROUTINE TIPTIM(STRING, SATLAB, TIPSTA, TIPMIN, TIPMAJ)

Subroutine TIPTIM extracts from the TIP minor frame stored in array STRING :

- (1) the satellite id code (SATLAB);
- (2) the TIP status word (TIPSTA);
- (3) the TIP minor frame number (TIPMIN);
- (4) the TIP major frame number (TIPMAJ).

Before extracting these quantities, subroutine TIPTIM checks the parity of the relevant TIP words and the minor frame synchronisation words. The synchronisation words are words 1 and 2 of the TIP frame. Their contents should be

11101101 and 11100010.

SUBROUTINE HIRTIM(String,HIRSTA,HIRENC,HIRELE,HIRLIN)

Subroutine HIRTIM extracts from the HIRS bit stream stored in array STRING the encoder position, element number and line number for the HIRS instrument.

- (1) the HIRS data is contained in words 15, 16, 23, 24, 27, ... of each TIP frame. These words have been copied into locations 1, 2, 3, 4, 5, ... , 36 of array STRING.
- (2) Bits 9 through 2 of each of these words form a continuous bit stream of HIRS data, which the NOAA document labels as bits 1 through 288.
- (3) The encoder position, element number and line number are stored in the following bit positions:
 - (a) bits 1 - 8, HIRS encoder position (HIRENC);
 - (b) bits 20 - 25, HIRS element number (HIRELE);
 - (c) bits 27 - 39, HIRS scan line count (HIRLIN), when HIRELE=63.
- (4) Before extracting the data, subroutine HIRTIM checks the parity of the relevant TIP words. If the parity checks are passed, the HIRS status word (HIRSTA) is set to 0; otherwise, HIRSTA is set to 1.

SUBROUTINE PARITY(String,LENGTH,PASSES)

Subroutine PARITY checks the parity of 10 bit words in locations STRING(1), ... ,STRING(LENGTH).

- (1) The bits are arranged in the order

bit(9), bit(8), ... , bit(1), bit(0),

 where the most significant bit is in position 9 and the least significant in position 0.
- (2) TIP data is contained in bits 9 through 2.
- (3) Bit 1 is an even parity check over bits 9 through 2.
- (4) Bit 0 is the complement of bit 9.

- (5) Subroutine PARITY returns PASSES, the number of words in STRING which passed the parity checks.

SUBROUTINE UNPACK(STRING)

Radiometric TIP data consists of a bit stream of 260 bits which must be separated into 20 words of 13 bits each. On input to UNPACK, array STRING contains the bit stream in bit positions 9 through 2 of words 4 through 36, with the last bit in position 4 in STRING(36). On output from UNPACK, array STRING contains the 20 words of 13 bits stored in locations 1 through 20. Bit 13 is the sign bit: if the bit is zero, then the word is negative.

SUBROUTINE TANGLE(STRING)

Subroutine TANGLE permutes the HIRS radiometric data, stored in array STRING, into order of increasing wavenumber.

SUBROUTINE BITLIS(STRING,DEVICE)

Subroutine BITLIS is a diagnostic routine which lists on logical unit DEVICE the bits of the word STRING in the order

bit(15), bit(14), ... , bit(1), bit(0).