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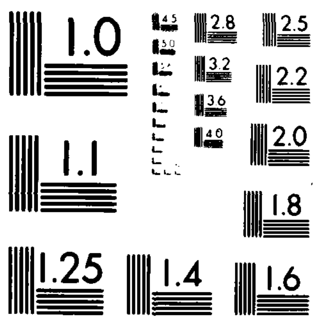

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HFNET - A COMPUTER PROGRAM TO CALCULATE NUCLEAR EFFECTS ON HF/VHF COMMUNICATIONS SYSTEMS

Volume II – User's Guide

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The HFNET computer code is a simulation for estimating the performance of HF communications systems in a nuclear weapon-disturbed environment. This document provides the user with all of the basic information required to utilize the code. Primary emphasis is placed on the details of the input and output, model documentation is to be found in a companion report, Volume I.

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SECTION 1
INTRODUCTION

The HFNET computer code is a simulation tool for estimating nuclear effects on HF communications systems. The code has been developed under Defense Nuclear Agency (DNA) sponsorship for the purpose of rapid analysis of nuclear effects on multiple HF to VHF radio links in a multiple nuclear burst environment. The basic philosophy behind HFNET has been to include all effects believed to be important to HF/VHF communications, but to do so in a manner which gives adequate (not necessarily the best) accuracy while avoiding long running times or large memory requirements.

In most cases the goal of producing a fast running code has resulted in simplified models. For example, the nuclear environment models in HFNET are much less elaborate than those found in detailed, state-of-the-art numerical simulations such as MICE or MELT (Reference 1). The HFNET phenomenology models use orders of magnitude less computer resources while still providing a time-dependent specification of nuclear debris parameters which is adequate for HF propagation effects calculations.

On the other hand, the goal of being able to handle large numbers of links and bursts has forced a fairly elaborate simulation structure and sophisticated data management techniques to be incorporated in the code. These features, along with the fast running models, enable HFNET to handle problems much too large for other nuclear environment HF communications codes.

This report describes the September 1979 version of HFNET and is primarily oriented towards the user of the program. As such, the most detailed information concerns the input and output. No attempt has been made here to fully explain the various physical and mathematical models incorporated in the code. Any discussion of these models is made in the context of explaining some facet of the input or output. Full descriptions of the models in HFNET are contained in a companion report (Reference 2).

Sections 2 and 3 to follow describe the input requirements and output options available. The input section gives details on the format, units, defaults and restrictions of the various input quantities as well as examples of their use. The output section "walks through" the output from an elaborate sample problem and explains in detail the quantities displayed in the various output formats.

The information contained in the three appendices is oriented more towards the implementor of the code than the general user. Appendix A gives information on the simulation structure used by HFNET. Anyone not familiar with event-structured simulation techniques should read this appendix to get a feel for how the program works. Appendix B contains alphabetical lists of the routines and common blocks in HFNET with short summaries of how each is utilized by the code. Finally, Appendix C contains a short discussion of the implementation of the code from a computer programmer's perspective.

SECTION 2
HFNET INPUT

2.1 GENERAL

Input to HFNET comes from two major sources: a user-supplied input file containing problem specification and program control information, and several binary data files containing fixed databases required by the program. The user-supplied input file is the subject of this section while the binary data files are discussed in Appendix C.

The input file consists of a sequence of standard (up to 80 character) input records, or lines. These input lines are organized into groups, depending on the type of information they contain, with each group identified by a special alphanumeric identifier called a "keyword". Following the keyword line are one or more data lines whose content and format vary from keyword to keyword. In addition to keyword and data lines the input file may also contain any number of comment lines.

HFNET problem specification and simulation control information are read at the beginning of each run by the input module. The input module does more than "just read input", it translates the external problem specification, contained in the input file, into an internal specification, ready for execution by the simulation. During this translation process the input module performs several tasks:

1) reads input lines and saves them for later echoing on the output,

2) recognizes keyword lines and checks for keyword errors,

3) interprets data lines depending on the keyword, supplies default values when needed, and checks for data errors,

4) skips comment lines,

5) stores events in the event list,

6) stores data in dynamic storage and common blocks, and

7) causes the program to abort if input errors are detected.

As can be seen above, many checks are made by the input module to insure that the input is "reasonable". This results in many runs being aborted before they even get started, usually due to some trivial error in the input. The desirability of this program "feature" is, hopefully, self evident.

Keyword lines are used to inform the input module what kind of data line(s) follow. A keyword line contains one of the input keywords listed in Table 1. A few simple rules govern the use of keywords:

1) keywords must be left justified on the keyword line,

2) except for $RUN, no keyword is required,

3) except for $RUN, keywords may appear in any order,

4) the $RUN keyword is required and must be last,

5) no keyword may appear more than once.

If any of these rules are violated the run will be aborted with an error message explaining the problem.

Following each keyword are one or more data lines. Data lines may contain either numeric or alphanumeric data. Data lines containing numeric data are read using FORTRAN list-directed ("*") format into floating-point (REAL) variables. In practice what this means is that numeric data items may be expressed in any "natural" format (with or without decimal points or E's) and they may appear anywhere on the input line, separated by any number of spaces or tabs and/or a single comma. Alphanumeric data lines are read using FORTRAN "A" format and must be left justified on the input line. The quantities contained on data lines and the order in which data lines must appear are explained below in the subsections devoted to the individual keywords.

Table 1. HFNET keywords.

Keyword	Description
$IDENT	Problem identification lines
$AMBIENT	Ambient problem conditions
$BURSTS	Nuclear bursts
$CLDOUT	Cloud list output
$NODES	Define nodes (transmitters/receivers)
$LINKS	Define links
$HFCALC	HF propagation calculations
$PLCALC	Plume mode propagation calculations
$DEBUG	Debug output
$RUN	Simulation start/stop

Any input line which is either totally blank or begins with a semicolon is treated as a comment line. Comment lines are echoed on the output but are otherwise ignored by the input module. There are no restrictions on the use of comment lines; any number of comment lines may appear anywhere in the input file. The user would be well advised to take full advantage of the power of comment lines to document exactly what problem is being run (and, perhaps, why the problem is being run). Comment lines are also extremely useful as labels for input quantities as shown in the examples given below.

HFNET keeps track of time, simulation time, in units of "seconds from midnight (GMT) on day zero". Day zero is the date (year, month, day) specified on the $AMBIENT data line. In these units, noon on day zero is t_{sim} = 43,200 seconds and 19:00 on day three is t_{sim} = 327,600 seconds. Needless to say, this method of timekeeping is fine for computers but not for people. In an attempt to make time easier to express, HFNET allows the user to input time in a special seven digit format, "DHHMM.SS", called DHMS format. In this format noon on day zero is t_{DHMS} = 01200.00 = 1200, and 19:00 on day 3 is t_{DHMS} = 31900.00 = 31900. Both absolute (GMT) time and time intervals are expressed in DHMS format. For example, a time interval of 45 minutes is dt_{DHMS} = 00045.00 = 45. The components (D, HH, MM and SS) of DHMS format are restricted as follows: $0 \leq D \leq 9$, $0 \leq HH \leq 24$, $0 \leq MM \leq 60$ and $0 \leq SS \leq 60$. If these restrictions are violated the program will abort. An example of bad DHMS format is dt_{DHMS} = 90 (used, presumably, to indicate 90 minutes). The "correct" way to specify 90 minutes is dt_{DHMS} = 130.

The following ten subsections contain discussions of the individual keywords, their use and their data requirements. In addition, Tables 2 through 11 give a "quick look" summary of each keyword including examples of their use. These tables contain a few notational oddities used to indicate the range of acceptable values a given data item may take on. The notation [a,b] is used to indicate that the associated data item, say X, must satisfy the inequality: $a \leq X \leq b$. A "U" is used to denote the set theoretic union of two or more such intervals. For example, [0]U[2,30] should be translated as $X = 0$ OR $2 \leq X \leq 30$, and [0,+] translates into $X \geq 0$. The input module checks all input data against the specified limits and aborts the program if any data item is found to be out of range.

2.2 $IDENT KEYWORD

The $IDENT keyword is used to input arbitrary problem identification information that will be echoed on the summary output as a means of easily identifying the problem being run. Any number of problem identification lines may appear, each containing up to 80 arbitrary characters.

2.3 $AMBIENT KEYWORD

The ambient "weather" conditions for a problem are specified using the $AMBIENT keyword. The quantities associated with the $AMBIENT keyword are the date (year, month, day), the sunspot number, the magnetic storm index, the solar disturbance index, the east and north wind velocities and a wind model selector. These quantities are all expressed on a single data line which follows the $AMBIENT keyword line. If $AMBIENT data are not specified the defaults shown at the bottom of Table 3 are used.

The values specified on the $AMBIENT data line are used by the different ambient environment models in various ways. The current version of the code does not use the year parameter at all. The month, day and sunspot number are used by all three ionospheric models and by other models such as the ambient D-region model. The magnetic storm index is used by the RADC (polar) ionospheric model exclusively. Likewise, the ambient D-region absorption model is the only model which uses the solar disturbance index. Finally, the three wind parameters are used to select one of three wind models (constant winds, median winds or diurnal winds) which affect the behavior of late time nuclear debris clouds.

Table 2. $IDENT keyword.

Keyword line: $IDENT

Data line: HIDENT

Data name	Description
HIDENT	Problem identification line (80 characters)

Example

```
;---------------------------------------------------------------------------
: $IDENT EXAMPLE
; --------------
: PROBLEM IDENTIFICATION LINES FOR AN EXAMPLE HFNET PROBLEM.
;---------------------------------------------------------------------------
$IDENT
;-----
:HIDENT
;------

        ==========================================
        EXAMPLE HFNET PROBLEM FOR THE USER'S MANUAL
        ==========================================

 THE PROBLEM CONSISTS OF 3 BURSTS, 4 NODES, 3 LINKS, CALCULATIONS  EVERY 1/2
 HOUR FOR 2 HOURS AND EVERY HOUR THEREAFTER FOR 1 DAY, STARTING AT 19:00 (GMT).
```

Notes: (1) Any number of $IDENT data lines may appear.

(2) Problem identification lines are echoed on the first page of the summary output.

Table 3. $AMBIENT keyword.

Keyword line: $AMBIENT

Data line: YEAR, MONTH, DAY, SSN, KP, SOLAR, VEWIND, VNWIND, WINDS

Data name	Description
YEAR	Year [1900, 2000]
MONTH	Month [1,12]
DAY	Day of the month [1, 31]
SSN	Zurich smoothed sunspot number [10, 200]
KP	Magnetic storm index [0, 9]
SOLAR	Solar disturbance coefficient [0, 2] 0 = quiet 1 = disturbed 2 = highly disturbed
VEWIND	East wind velocity, wind model 0 (m/s) [-100, 100]
VNWIND	North wind velocity, wind model 0 (m/s) [-100, 100]
WINDS	Wind model selector [0, 2] 0 = constant winds (VEWIND/VNWIND) 1 = median winds 2 = full diurnal winds

Example

```
;---------------------------------------------------------------------------
; $AMBIENT EXAMPLE
; ----------------
; DATE = 1 APRIL 1984  --  SUNSPOT NUMBER = 113  --  KP INDEX = 4
; SOLAR = QUIET  --  WIND MODEL = MEDIAN WINDS
;---------------------------------------------------------------------------
$AMBIENT
;-------
;YEAR   MONTH   DAY    SSN    KP    SOLAR   VEWIND  VNWIND  WINDS
;----   -----   ---    ---    --    -----   ------  ------  -----
1984    4       1      113    4     0       0       0       1
```

Notes: (1) At most one $AMBIENT data line may appear.

(2) Defaults for $AMBIENT data are: YEAR = 1979; MONTH = 1; DAY = 1; SSN = 100; KP = 2; SOLAR = VEWIND = VNWIND = WINDS = 0. These values are used when no $AMBIENT data are supplied in the input file.

2.4 $BURSTS KEYWORD

Nuclear bursts are specified using the $BURSTS keyword. Any number of bursts may be specified with almost any combination of the following burst parameters: time, latitude, longitude, altitude, yield, fission yield, X-ray yield, late-time radial spread rate, conjugate burst flag and output flag. However, due partly to uncertainties in phenomenology and partly to modeling inadequacies there are a few arbitrary restrictions on the location and yield of bursts. These restrictions include:

- the location of a burst (lat, lon) cannot be nearer than one degree from any pole (geographic or geomagnetic),
- the burst altitude must be in the range 0 to 1000 kilometers (no underground, underwater or outer space bursts allowed),
- the total yield must be at least 1 kt (.001 MT) and no more than $10^{(2- \text{alt}/400)}$MT. This odd restriction translates into maximum yields of 100, 56, 10, 1 and .32 megatons at altitudes of 0, 100, 400, 800 and 1000 kilometers (respectively).

As usual, the program will abort if any burst is specified with parameters which violate these restrictions.

Late time wind dispersal of subsiding nuclear debris clouds can be simulated in two ways within HFNET. The most straightforward way is to select one of the internal wind models (using the $AMBIENT keyword) and let the wind blow the debris where it may. The other way is to use the late time radial spread rate parameter on the $BURSTS data line to force the debris to expand at a constant rate with no associated movement of the center of mass. The two approaches can also be combined, with the effects simply added together.

To more realistically model a very high altitude explosion, the debris and energy is split into two components. One component moves down

Table 4. $BURSTS keyword.

Keyword line: $BURSTS

Data line: TIME, LAT, LON, ALT, Y, FY, XY, SPREAD, CBFLAG, PBFLAG

Data name	Description
TIME	Burst time (DHMS) [0, +]
LAT	Burst latitude (°N) [-89, 89]
LON	Burst longitude (°E) [-360, 360]
ALT	Burst altitude (km) [0, 1000]
Y	Yield (MT) [.001, $10^{(2-\text{ ALT}/400)}$]
FY	Fission yield (MT) [0, Y] 0 = use $FY = \begin{cases} Y & \text{if } Y < .01 \\ Y/2 & \text{if } Y \geq .01 \end{cases}$
XY	X-ray yield (MT) [-1] U [0, Y] 0 = use XY = 3/4 Y -1 = use XY = 0
SPREAD	Late time radial spread rate (m/s) [0, 1000]
CBFLAG	Conjugate burst flag [0, 1] 0 = suppress conjugate bursts 1 = allow conjugate bursts
PBFLAG	Print/binary output flag (packed, PB) [00, 21] P: 0 = off 1 = on, output at cloud creation and splits 2 = on, output at cloud creation, splits and updates B: 0 = off 1 = on, binary output at cloud creation and updates

Table 4. (cont.)

Example

```
;-----------------------------------------------------------------------------
: $BURSTS EXAMPLE
; ---------------
; SETUP THREE BURSTS: (1)  1 MT, 200 KM, 40 DEG N,  90 DEG W, 18:06 GMT
:                     (2) 20 MT,   1 KM, 40 DEG N, 110 DEG W, 18:14 GMT
;                     (3)  5 MT,  10 KM, 40 DEG N,  70 DEG W, 18:31 GMT
;-----------------------------------------------------------------------------
$BURSTS
;------
:TIME   LAT    LON    ALT    Y      FY     XY     SPREAD  CBFLAG  PBFLAG
;----   ---    ---    ---    -      --     --     ------  ------  ------
01806   40     -90    200    1      .5     .75    0       0       10
01814   40     -110   1      20     10     15     0       0       00
01831   40     -70    10     5      2.5    3.75   0       0       00
```

Notes: (1) Any number of $BURSTS data lines may appear

(2) Notice the restrictions on burst location and yield; the yield/altitude restrictions result in the following table:

Altitude (km)	Max. yield (MT)
0	100
100	56
400	10
800	1
1000	.32

(3) The output flag only affects the single burst being set up; output for the entire cloud list can be independently specified using the $CLDOUT keyword.

the local magnetic field line until it encounters enough air to contain it, then acts as if an explosion with appropriately reduced yield occurred at the displaced position. The other, usually much smaller, component moves to the magnetic conjugate region and acts as if it were an additional explosion there. The conjugate (pseudo) explosion occurs with a delay time appropriate to a debris velocity of 10^8 cm/sec to the conjugate region. The conjugate burst flag allows the user to suppress the formation of this conjugate burst. Turning off conjugate bursts is advisable when the effects of debris in the magnetic conjugate region would be negligable.

The print/binary output flag controls the outputting of cloud parameters to the printed output file and to an auxiliary binary data file used to generate plots. Three levels of printed output are available: (1) none, (2) at cloud creation and split times, and (3) at cloud creation split and update times. The user should be warned that the amount of printed output generated at cloud update times (level 3 output) can be excessive. The binary (plot) output is primarily intended for debugging the nuclear phenomenology models and requires an additional program to process the data into plots.

2.5 $CLDOUT KEYWORD

Output from the nuclear phenomenology models can be requested in two different ways. As explained in the previous section the output flag on the $BURSTS data line can be used to request output describing <u>individual</u> clouds at cloud creation, split and update event times. Independently the $CLDOUT keyword can be used to request that data describing <u>every</u> cloud in the cloud list be output at simulation times specified by the user. In most cases the $CLDOUT keyword method is preferable since it can provide "snapshots" of the nuclear environment at precisely the same times that HF propagation and/or plume mode calculations are made. This can be very useful when the results of these calculations are later analyzed.

Table 5. $CLDOUT keyword.

Keyword line: $CLDOUT

Data line: T1, T2, DT, PBFLAG

Data name	Description
T1	First event time (DHMS) [0, +]
T2	Last event time (DHMS) [0, +]
DT	Event rescheduling interval (DHMS) [0, +]
PBFLAG	Print/binary flag (packed, PB) [00, 11] P: 0 = off 1 = on, printed cloud list output B: 0 = off 1 = on, binary cloud list output

Example

```
;-----------------------------------------------------------------------------
; $CLDOUT EXAMPLE
; ---------------
; CLOUD OUTPUT EVERY HALF HOUR FROM 19:00 TO 21:00 (GMT)
; AND EVERY HOUR FROM 21:00 TO 19:00 (THE NEXT DAY).
;-----------------------------------------------------------------------------
$CLDOUT
;------
;T1      T2      DT      PBFLAG
;--      --      --      ------
01900   02100   0030    10
02200   11900   0100    10
```

Notes: (1) Any number of $CLDOUT data lines may appear.

(2) Cloud list binary output goes to an auxiliary output file

The $CLDOUT keyword is used to set up cloud list output events. The $CLDOUT keyword line can be followed by any number of data lines each containing four quantities: first event time, last event time, event rescheduling interval, and print/binary output flag. The printed and binary output are independently controllable using the output flag and each contains detailed information describing every cloud in the cloud list at the time of the event. The printed output is written to the standard output file and the binary output to an auxiliary output file.

In addition to the detailed printed and binary output described above, cloud list summary output is also generated at each cloud list output time. This output is not controlled by the print/binary output flag. Examples of cloud list output are given in Section 3.

2.6 $NODES KEYWORD

In the HFNET code a node can be a transmitter or a receiver or both. Nodes are created using the $NODES keyword and then connected into links (transmitter/ionosphere/receiver triplets) using the $LINKS keyword. A single node can be shared by any number of links, being the transmitter for some and the receiver for others.

The $NODES keyword line can be followed by any number of data line pairs which specify the location (latitude, longitude, altitude) and attributes of each node. Besides its location, a node has a name, a number and four other parameters: transmitter power, receiver noise temperature, receiver man-made noise class, and receiver bandwidth. If a node is used as the transmitter for a given link then the receiver parameters are ignored (and vice-versa).

About the only restriction concerning the location of nodes is that they must not be too near (one degree) to a pole. This is to keep

Table 6. $NODES keyword.

Keyword line: $NODES

Data Lines: (A) NODE, LAT, LON, ALT, TPOWER, RNTEMP, RMMNCL, RBANDW
(B) HNODE

Data name	Description
NODE	Node number [1, 1000]
LAT	Node latitude (°N) [-89, 89]
LON	Node longitude (°E) [-360, 360]
ALT	Node altitude (km) [0, 20]
TPOWER	Transmitter power (kw) [0, 1000] 0 = use TPOWER = 1 kw
RNTEMP	Receiver noise temperature (°K) [0, 1000] 0 = use RNTEMP = 288 °K
RMMNCL	Receiver man-made noise class [0, 4] 0 = use RMMNCL = 2 (rural) 1 = remote 2 = rural 3 = residential 4 = industrial
RBANDW	Receiver bandwidth (kHz) [0, 1000] 0 = use RBANDW = 1 kHz
HNODE	Node name (24 characters, 6A4)

Table 6. (cont.)

Example

```
;---------------------------------------------------------------------------
; $NODES EXAMPLE
; --------------
; SETUP 4 NODES: SANTA BARBARA. BIG FORK, CAMBRIDGE BAY, AND WASHINGTON.
;---------------------------------------------------------------------------
$NODES
;-----
:NODE   LAT     LON     ALT     TPOWER  RNTEMP  RMMNCL  RBANDW  / HNODE
;----   ---     ---     ---     ------  ------  ------  ------    -----
1       34.25   -119.41 0       1       288     2       1
SANTA BARBARA, CALIF.
2       48      -114    0       1       288     2       1
BIGFORK, MONTANA
3       69      -105    0       1       288     1       1
CAMBRIDGE BAY, CANADA
4       38.55   -77     0       1       288     3       1
WASHINGTON, D.C.
```

Notes:
(1) $NODES data lines A and B are paired
(2) Any number of A/B data line pairs may appear
(3) Node numbers must be unique
(4) Nodes must be at least 1 degree from any pole

certain geometric approximations from blowing up. It is also somewhat dangerous to define a link which crosses directly over a pole, although the code does not check for this occurrence.

2.7 $LINKS KEYWORD

The $LINKS keyword is used to specify the attributes of any number of links. Each link is described on a single data line containing six parameters: link number, transmitter node number, receiver node number, ionospheric model selector, surface type, and output flag.

Obviously the link number must be unique and the transmitter and receiver nodes must be defined elsewhere in the input using the $NODES keyword. The ionospheric model selected is up to the users' preference. Pros and cons on the different models [Aerospace, RADC (polar), and ITS] are given in a companion report (Reference 2). The surface type (land or sea) is used to compute ground reflection losses on multihop paths. It should be set according to the characteristics at the midpoint of the link. The settings provided give reasonable results in the absence of a world map of surface characteristics. Finally, the print flag controls whether the entire ionospheric data table (around 3 pages worth) is printed or not.

2.8 $HFCALC KEYWORD

The major calculation performed by HFNET is the HF propagation calculation. The standard HF calculation event consists of several related calculations which can be expressed in pseudo-code as follows:

- loop over links;
  - initialize for this link;
  - loop over hops;
    - compute N-hop MUF and decile frequencies;
    - compute propagation geometry, losses, signal strength, noise and S/N for MUF;

Table 7. $LINKS keyword.

Keyword line: $LINKS

Data line: LINK, TXNODE, RXNODE, IMODEL, SURTYP, PFLAG

Data name	Description
LINK	Link number [1, 1000]
TXNODE	Transmitter node number [1, 1000]
RXNODE	Receiver node number [1, 1000]
IMODEL	Ionospheric model [0, 3] 0 = use IMODEL = 1 (Aerospace) 1 = Aerospace 2 = RADC (POLAR) 3 = ITS
SURTYP	Surface type [0, 2] 0 = use SURTYP = 1 (land) 1 = land 2 = sea
PFLAG	Print flag [0, 1] 0 = off 1 = on, print full ionospheric data table

Table 7. (cont.)

Example

```
;-------------------------------------------------------------------------------
; $LINKS EXAMPLE
; --------------
; SETUP 3 LINKS: (1) SANTA BARBARA TO   BIG FORK.  AEROSPACE
;                (2) WASHINGTON TO CAMBRIDGE BAY.  RADC (POLAR)
;                (3) SANTA BARBARA TO WASHINGTON.  ITS
;-------------------------------------------------------------------------------
$LINKS
;-----
;LINK    TXNODE  RXNODE  IMODEL  SURTYP  PFLAG
;----    ------  ------  ------  ------  -----
1        1       2       1       1       0
2        4       3       2       1       0
3        1       4       3       1       0
```

Notes: (1) Any number of $LINKS data lines may appear

(2) Link numbers must be unique

(3) Transmitter and receiver node numbers must correspond to nodes set up using the $NODES keyword

Table 8. $HFCALC keyword.

Keyword line: $HFCALC

Data line: T1, T2, DT, LINK, FREQ, HOPS, EFLAG, PFLAG

Data name	Description
T1	First event time (DHMS) [0, +]
T2	Last event time (DHMS) [0, +]
DT	Event rescheduling interval (DHMS) [0, +]
LINK	Link number [0, 1000] 0 = use all links
FREQ	Frequency (MHz) [-30, -2] U [0] U [2, 30] - = use ABS (FREQ) only 0 = use MUF only + = use MUF and FREQ
HOPS	Number of hops (packed, H_1 H_2) [00, 66] 00 = use internally computed defaults (see notes) H_1 H_2 = use H_1 to H_2 hops ($H_1 \leq H_2$)
EFLAG	Event flag [0, 1] 0 = normal 1 = multimode
PFLAG	Print flag [0, 1] 0 = off 1 = on, print detailed output

Table 8. (cont.)

Example

```
:-----------------------------------------------------------------------------
: $HFCALC EXAMPLE
: ---------------
: HF PROPAGATION CALCULATIONS EVERY HALF HOUR FROM 19:00 TO 21:00 (GMT)
: AND EVERY HOUR FROM 21:00 TO 19:00 (THE NEXT DAY).
: ALL LINKS  --  FREQ = MUF, 10, 20 MHZ  --  DEFAULT HOPS
: DETAILED PRINTOUT FOR 20 MHZ ONLY.
:-----------------------------------------------------------------------------
$HFCALC
:------
:T1     T2     DT     LINK   FREQ   HOPS   EFLAG  PFLAG
:--     --     --     ----   ----   ----   -----  -----
01900   02100  0030   0      10     00     0      0
01900   02100  0030   0      -20    00     0      1
02200   11900  0100   0      10     00     0      0
02200   11900  0100   0      -20    00     0      1
```

Notes:

(1) Any number of $HFCALC data lines may appear

(2) Unless zero, the link number must correspond to a link set up using the $LINKS keyword

(3) The defaults for hops are: 1 hop per 3000 km (minimum) and 1 hop per 1000 km (maximum), rounded to nearest hop; this results in the following table:

Kilometers	Min. hops	Max. hops
1000	1	1
2000	1	2
3000	1	3
4000	1	4
5000	2	5
6000	2	6
9000	3	6
12000	4	6
15000	5	6
18000	6	6

        - compute the probability of mode occurrence for specified frequency, f;
        - compute propagation geometry, losses, signal strength, noise and S/N for f;
    - next hops;
- next link;

The $HFCALC keyword is used to set up any number of HF calculation events. Each $HFCALC data line contains eight parameters: first event time, last event time, event rescheduling interval, link number, frequency, minimum and maximum number of hops, event flag and print flag.

The "usual" setting for the link number is zero. This causes the calculation to be performed for all links simultaneously. This feature is very convenient when there are many links in the problem. However, the flexibility to set up HF propagation calculations with different times, frequencies and hops for each link is available if required.

The frequency parameter is interpreted in a slightly complicated fashion. Since the MUF is a very important parameter in most HF communications studies, the calculation of the MUF is included as part of the "normal" HF calculation event unless explicitly suppressed. The MUF calculation is made whenever the specified frequency is positive or zero. A negative frequency suppresses the MUF calculation (the absolute value of the frequency is then used), while a zero frequency causes the MUF alone to be used. If the MUF and several fixed frequencies are desired then these frequencies should be specified on separate $HFCALC data lines with the first one positive and the rest negative (to suppress the MUF; see example in Table 8.)

The number of hops parameter is somewhat of a nuisance. The recommended value is zero, which lets the code decide how many hops are feasible depending on the length of the link. However, if only 1 hop paths are of interest then this parameter allows the user the option of suppressing multiple hop mode calculations. The factors used to internally compute the number of hops to try are: 1 hop per 3000 km (minimum) and 1 hop per 1000 km (maximum), rounded to the nearest hop. These factors result in the table shown at the bottom of Table 8. Note that the hops parameter is a two digit packed number. For example, HOPS = 36 is interpreted as "try 3 to 6 hops".

The event flag is used to select between the "normal" and the "multimode" HF propagation calculation. Basically the multimode calculation is a more detailed calculation which attempts to study the possibility of multipath propagation by 1) using several frequencies (in place of a single MUF) chosen for their likelihood of producing multipath and 2) using a modified propagation algorithm which allows more than one ray to propagate at a given frequency. Except for these differences the multimode variation is very similar to the normal HF calculation. Use of the multimode option is recommended only for single links and for no more than 3 hops.

The print flag is used to control the amount of detailed output from the propagation calculations. When the print flag is turned "on" fairly elaborate output is generated for each successful mode and an explanation is offered for each unsuccessful mode. Turning the print flag "off" still leaves the summary output which is adequate for many applications. See Section 3 for examples of both the detailed and summary outputs.

2.9 $PLCALC KEYWORD

In addition to conventional ionospheric skywave propagation, HFNET is capable of computing nuclear induced "plume mode" propagation. This type of anomalous propagation involves bouncing HF/VHF rays off of

Table 9. $PLCALC keyword.

Keyword line: $PLCALC

Data line: T1, T2, DT, LINK, FREQ, PFLAG

Data name	Description
T1	First event time (DHMS) [0, +]
T2	Last event time (DHMS) [0, +]
DT	Event rescheduling interval (DHMS) [0, +]
LINK	Link number [0, 1000] 0 = use all links
FREQ	Frequency (MHz) [0] U [20, 100] 0 = use "MUF" only + = use FREQ only
PFLAG	Print flag [0, 1] 0 = off 1 = on, print detailed output

Example

```
;-----------------------------------------------------------------------------
: $PLCALC EXAMPLE
; ---------------
: PLUME MODE CALCULATIONS EVERY HALF HOUR FROM 19:00 TO 21:00 (GMT)
; AND EVERY HOUR FROM 21:00 TO 19:00 (THE NEXT DAY).
: ALL LINKS  --  FREQ = "MUF"  --  DETAILED PRINTOUT
;-----------------------------------------------------------------------------
$PLCALC
;------
:T1     T2     DT     LINK   FREQ   PFLAG
;--     --     --     ----   ----   -----
01900   02100  0030   0      0      1
02200   11900  0100   0      0      1
```

Notes: (1) Any number of $PLCALC data lines may appear

(2) Unless zero, the link number must correspond to a link set up using the $LINKS keyword

regions of enhanced electron density created by nuclear explosions. Three types of plume modes are computed:

- specular reflection off of the side of a plume
- isotropic reflection off of fireballs and plume bases
- forward scatter off of plume bases.

Because plume mode propagation is not as well understood as normal ionospheric propagation and because it is highly coupled to the nuclear phenomenology models, the results of plume mode calculations need to be analyzed closely. The models should be considered as preliminary versions which, while useful when used wisely, are not the final word in plume mode modeling.

Plume mode calculations are organized and set up very much like HF propagation calculations. The $PLCALC keyword is used to specify any number of plume mode calculation events. Each $PLCALC data line contains the following parameters: first event time, last event time, event rescheduling interval, link number, frequency and print flag. Most of these parameters act just like the corresponding parameters on the $HFCALC data line.

The frequency parameter is, however, interpreted in a slightly different way than the $HFCALC frequency. Since plume modes are primarily a VHF phenomena the frequency must be zero or between 20 and 100 megahertz; negative frequencies are not allowed. If entered as zero the code will compute the "best" frequency to use depending on the type of mode, the electron density in the cloud, the available scattering cross section and the mode geometry. If the frequency is positive then that frequency alone will be used.

2.10 $DEBUG KEYWORD

HFNET, like any large computer code, may contain bugs. Be they incorrect physical models, inappropriate computational algorithms or plain

Table 10. $DEBUG keyword.

Keyword line: $DEBUG

Data line: HDEBUG

Data name	Description
HDEBUG	Names of up to 10 subroutines (8 characters each, 10A8)

Example

```
;---------------------------------------------------------------------------
; $DEBUG EXAMPLE
; --------------
; DEBUG OUTPUT FROM MOD10 AND PLMODE (PLUME MODE SUBROUTINES).
;---------------------------------------------------------------------------
$DEBUG
;------
:HDEBUG
;------
MOD10...PLMODE..
```

Notes: (1) At most one $DEBUG data line may appear

(2) Subroutine names must be left justified in fields of 8 characters and right filled with periods

coding errors the result is the same: the code may not work correctly for some combinations of input data. Since the task of totally eradicating all bugs in any large code is clearly impractical, the real problem is to make it less likely for a bug to go undetected and, once detected, to make it easy to locate the exact nature of the bug.

The detection of bugs, especially subtle bugs, is a difficult problem. The code itself trys to locate possible bugs by making consistency checks on the data it uses. These checks are of the grossest nature but do occasionally find bugs which would probably have gone unnoticed otherwise. However, the best line of defense against bugs (and the incorrect results they foster) is a skeptical user of the code. The user should never rely on the results of any computer code without first checking to see if the results are reasonable, and if they are not, finding out why not.

Once a bug has made its presence known by causing the program to abort or by giving unreasonable results, the problem still remains to locate and fix the bug. The traditional method of debugging a large FORTRAN code is to scatter diagnostic print statements throughout those parts of the code where the bug is thought to reside. Once the bug has been eradicated these print statements are then removed, only to reappear again in the future when some new bug crops up.

HFNET extends this traditional debugging method by 1) incorporating debug print statements <u>before</u> the occurrence of a bug and 2) leaving them in the code in such a way that they can be turned on or off easily (without recompiling or relinking the program). Because of this, HFNET debug output can be used not only to find bugs but also to provide <u>very</u> detailed output which the regular output cannot provide.

The $DEBUG keyword is used to request that detailed debug output be produced. This output is turned "on" or "off" on a subroutine by subroutine basis, with up to 10 subroutines turned "on" at the same time. For the most part this output is only useful to someone reasonably familiar with the code and normally requires a source listing for proper interpretation. Table 10 shows the format required to request debug output. One warning: debug output can be quite lengthy, so it should be used with caution.

2.11 $RUN KEYWORD

The $RUN keyword is the last of the input keywords. It is the only keyword that is required and it must be the last keyword appearing in the input file. The $RUN keyword has two functions: 1) it signals the end of the input phase and the beginning of the simulation phase and 2) it allows the user to specify when the simulation should stop. After the $RUN keyword has been processed the input module returns to the simulation manager. If no errors were detected in the input, the simulation manager will then proceed to execute events until the stop simulation event is encountered.

The $RUN data line contains two parameters: the simulation stop time and an output flag. The output flag is used to control printouts of the event list and dynamic storage at the beginning and end of the simulation.

Table 11. $RUN keyword.

Keyword line: $RUN

Data line: TSTOP, PFLAG

Data name	Description
TSTOP	Simulation stop time (DHMS) [0, +]
PFLAG	Print flag [0, 1] 0 = off 1 = on, print event list and dynamic storage maps

Example

```
;-----------------------------------------------------------------------
; $RUN EXAMPLE
; -----------
; STOP SIMULATION AT 19:01 (GMT) THE NEXT DAY; PRINT EVENT LIST AND D.S. MAPS.
;-----------------------------------------------------------------------
$RUN
;---
:TSTOP          PFLAG
;-----          -----
11901           1
```

Notes: (1) The $RUN keyword must appear and be the last keyword in the input file

(2) Exactly one $RUN data line must appear

SECTION 3
HFNET OUTPUT

3.1 GENERAL

Printed output from HFNET can be divided into two categories: 1) detailed simulation-time-ordered output, and 2) summary post-processed output. This section describes these two types of printed output in detail.

There are three basic differences between the detailed output and the summary output. The most obvious difference is that the summary output contains much less information than the detailed output. For example, detailed output describing a single HF skywave mode includes printouts of raypath geometry, propagation losses, noise sources and signal/noise. All this can easily amount to an entire page of output depending on the number of hops. In contrast, the same mode is described on a single line in the summary output.

The second difference is the "time" at which the outputs are created. Simulation-time output is generated "on the fly" during the course of the simulation. Due to the fact that events are executed in a strictly time ordered sequence, printouts from many different events can be interleaved. Consequently, a good deal of "page flipping" through the output to find the printout of interest is commonplace. On the other hand, post-processed output is generated by a separate program, HFPOST, after the main program, HFNET, has finished execution. This enables the summary output to be sorted and reformatted in a way that is convenient for the user to read instead of just convenient for the program to generate.

The third difference is that, for the most part, the detailed simulation-time output can be suppressed using the various print flags described in Section 2. The summary output, on the other hand, is automatically generated. (Of course the user can elect not to run the post-processor program and thereby suppress all summary output.) The output from a "typical" HFNET run consists of some user selected detailed output in addition to the summary output.

As a means of conveniently discussing HFNET printed output, examples will be taken from a test problem that shows most of the major types of output as well as exercises a large part of the code. A listing of the input file for the test problem is shown in Table 12. Except for $DEBUG, all of the keywords discussed in Section 2 are used in this input file.

The test problem is a calculation of nuclear effects on three specific links shortly after the detonation of two nuclear devices. The two nuclear bursts are a high altitude megaton class burst over the western United States followed closely in time by a low altitude, large yield burst over the eastern part of the country. The links in the problem are 1) Santa Barbara, California to Big Fork, Montana, 2) Washington, D.C. to Cambridge Bay, Canada and 3) Santa Barbara to Washington. The test problem includes both HF propagation and plume mode calculations made approximately 30 and 90 minutes after the burst. Figure 1 shows the problem geometry including the location of each of the two bursts, three links and four nodes. A prospective user should at this point study Table 1 carefully (reviewing Section 2 if needed) until he or she fully understands how each keyword, data and comment line is being used.

Table 12. Test problem input file.

```
;***************
;* USERMAN.DAT *
;***************

;----------------------------------------------------------------------------
$IDENT
;-----
;PROBLEM IDENTIFICATION
;------- --------------

       EXAMPLE PROBLEM FOR HFNET USER'S MANUAL

;----------------------------------------------------------------------------
$AMBIENT
;-------
;YEAR   MONTH   DAY     SSN     KP      SOLAR   VEWIND  VNWIND  WINDS
;----   -----   ---     ---     --      -----   ------  ------  -----
1984    4       1       113     4       0       0       0       1

;----------------------------------------------------------------------------
$BURSTS
;------
;TIME   LAT     LON     ALT     Y       FY      XY      SPREAD  CBFLAG  PBFLAG
;----   ---     ---     ---     -       --      --      ------  ------  ------
01831   40      -120    200     1       0       0       0       0       10
01832   40      -80     1       20      0       0       0       0       80

;----------------------------------------------------------------------------
$CLDOUT
;------
;T1     T2      DT      PBFLAG
;--     --      --      ------
01900   11900   0100    10

;----------------------------------------------------------------------------
$NODES
;-----
;NODE   LAT     LON     ALT     TPOWER  RNTEMP  PMMNCL  RBANDW  / NODE NAME
;----   ---     ---     ---     ------  ------  ------  ------    ---- ----
1       34.25   -119.41 0       1       283     3       1
SANTA BARBARA, CALIF.
2       48      -114    0       1       288     2       1
BIGFORK, MONTANA
3       69      -105    0       1       268     1       1
CAMBRIDGE BAY, CANADA
4       38.55   -77     0       1       289     4       1
WASHINGTON, D.C.

;----------------------------------------------------------------------------
$LINKS
;-----
;LINK   TXNODE  RXNODE  IMODEL  SURTYP  PFLAG
;----   ------  ------  ------  ------  -----
1       1       2       1       1       0
2       4       3       2       1       1
3       1       4       3       1       0

;----------------------------------------------------------------------------
$HFCALC
;------
;T1     T2      DT      LINK    FREQ    HOPS    EFLAG   PFLAG
;--     --      --      ----    ----    ----    -----   -----
01900   11900   0100    0       10      00      0       0
01900   11900   0100    0       -20     00      0       1

;----------------------------------------------------------------------------
$PLCALC
;------
;T1     T2      DT      LINK    FREQ    PFLAG
;--     --      --      ----    ----    -----
01900   11900   0100    0       0       1

;----------------------------------------------------------------------------
$RUN
;---
;TSTOP          PFLAG
;-----          -----
02001           1
```

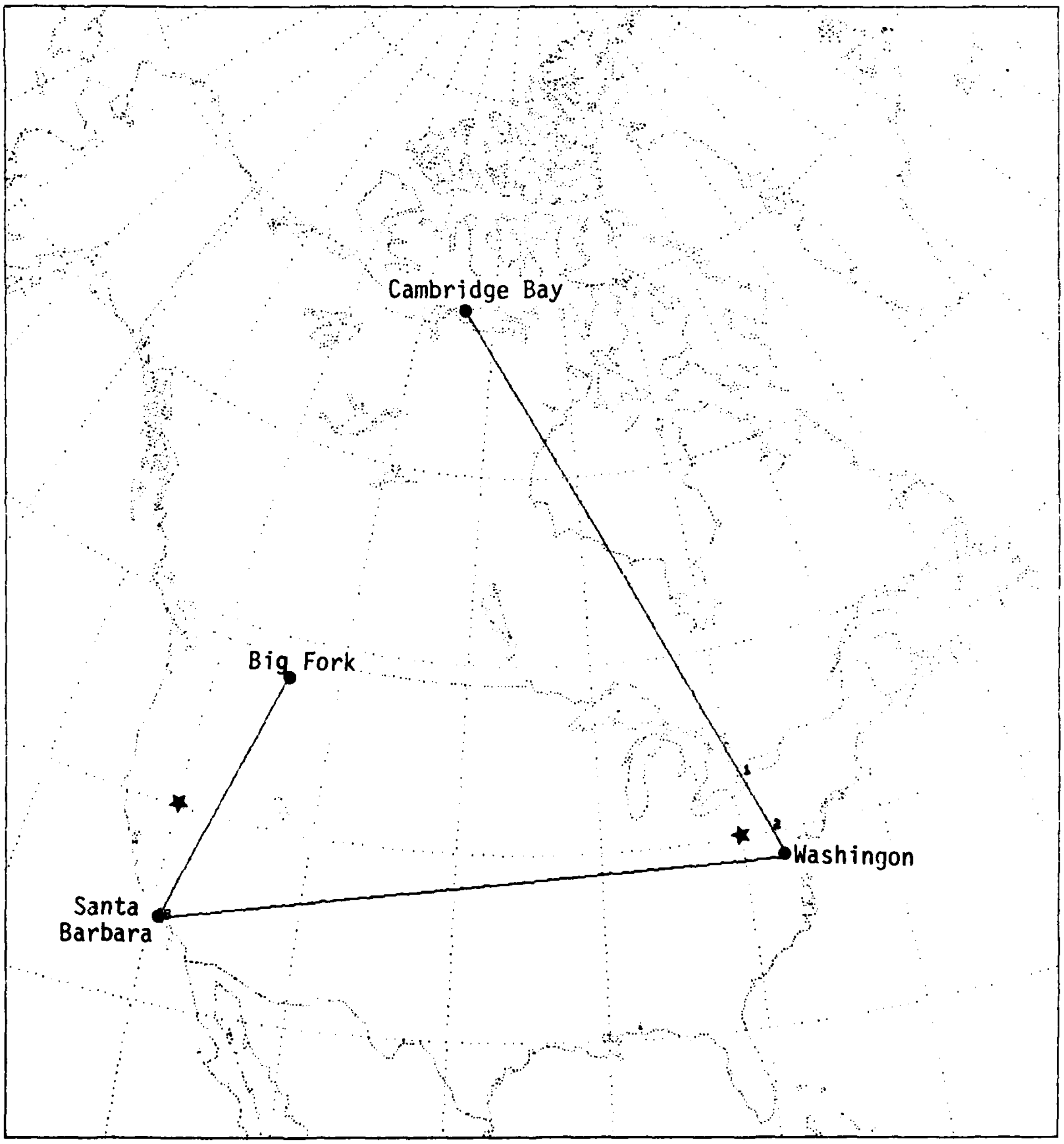

Figure 1. Test problem geometry.

3.2 SIMULATION START OUTPUT

The initial output from the HFNET code is shown in Table 13. This output begins with a short header containing the version of the code being used, the name of the input file and the date and time of the run. Following this is a listing of the entire input file enclosed in a box of asterisks. If any input errors were detected then error messages would also appear interspersed with the echoed input. Finally, printouts showing the $AMBIENT and $DEBUG data being used during this run follow the echoed input.

Table 14 shows the event list and dynamic storage printouts at the beginning of the run (after all input has been read and stored but before any further events have been executed). These printouts are optional and appear here because the print flag on the $RUN data line was turned "on". The headings for the event list printout are:

EVENT - event sequence number
TIME - event simulation time (GMT in DHMS format)
TYPE - event type number (see Appendix A)
NAME - event descriptive name
EVENT DATA - 16 words of event data for each event

Notice that the first four events all have a simulation time of -0.01 (-1 second). These events are initialization events, they read in the wind model database and compute ionospheric data tables for the three links in the problem. Following the initialization events are seven events which were explicitly set up using the $BURSTS, $CLDOUT, $HFCALC, $PLCALC and $RUN keywords in the input file.

Table 13. Simulation start output.

```
**************************************************
* HFNET * VERSION 5 (VAX) * SEPTEMBER 1979 *
**************************************************

SIMULATION INPUT FILE:  DATA:USERMAN.DAT

DATE AND TIME OF RUN:  31-OCT-79      17:10:26

*****************************************************************************************************
*                                                                                                   *
* ;***************                                                                                  *
* :* USERMAN.DAT *                                                                                  *
* ;***************                                                                                  *
*                                                                                                   *
* ;------------------------------------------------------------------------------------------------ *
* $IDENT                                                                                            *
* ;-----                                                                                            *
* :PROBLEM IDENTIFICATION                                                                           *
* ;------- --------------                                                                           *
*                                                                                                   *
*                                                                                                   *
*          EXAMPLE PROBLEM FOR HFNET USER'S MANUAL                                                  *
*                                                                                                   *
*                                                                                                   *
* ;------------------------------------------------------------------------------------------------ *
* $AMBIENT                                                                                          *
* ;-------                                                                                          *
* :YEAR    MONTH    DAY     SSN     KP        SOLAR   VEWIND  VNWIND  WINDS                         *
* ;----    -----    ---     ---     --        -----   ------  ------  -----                         *
* 1984     4        1       113     4         0       0       0       1                             *
*                                                                                                   *
* ;------------------------------------------------------------------------------------------------ *
* $BURSTS                                                                                           *
* ;------                                                                                           *
* :TIME    LAT      LON     ALT     Y         FY      YY      SPREAD  CBFLAG  PBFLAG                *
* ;----    ---      ---     ---     -         --      --      ------  ------  ------                *
* 01831    40       -120    200     1         0       0       0       0       10                    *
* 01832    40       -90     1       20        0       0       0       0       00                    *
*                                                                                                   *
* ;------------------------------------------------------------------------------------------------ *
* $CLDOUT                                                                                           *
* ;------                                                                                           *
* :T1      T2       DT      PBFLAG                                                                  *
* ;--      --       --      ------                                                                  *
* 01900    11900    0100    10                                                                      *
*                                                                                                   *
```

Table 13. (cont.)

```
* :------------------------------------------------------------------------- *
* $NODES                                                                     *
* :-----                                                                     *
* :NODE   LAT     LON     ALT     TPOWER  PNTEMP  PMMNCL  RBANDW  / NODE NAME *
* :----   ---     ---     ---     ------  ------  ------  ------    ---- ---- *
* 1       34.25   -119.41 0       1       288     3       1                  *
* SANTA BARBARA, CALIF.                                                      *
* 2       48      -114    0       1       288     2       1                  *
* BIGFORK, MONTANA                                                           *
* 3       69      -105    0       1       288     1       1                  *
* CAMBRIDGE BAY, CANADA                                                      *
* 4       38.55   -77     0       1       288     4       1                  *
* WASHINGTON, D.C.                                                           *
*                                                                            *
* :------------------------------------------------------------------------- *
* $LINKS                                                                     *
* :-----                                                                     *
* :LINK   TXNODE  RXNODE  IMODEL  SUPTYP  PFLAG                              *
* :----   ------  ------  ------  ------  -----                              *
* 1       1       2       1       1       0                                  *
* 2       4       3       2       1       1                                  *
* 3       1       4       3       1       0                                  *
*                                                                            *
* :------------------------------------------------------------------------- *
* $HFCALC                                                                    *
* :------                                                                    *
* :T1     T2      DT      LINK    FREQ    HOPS    EFLAG   PFLAG              *
* :--     --      --      ----    ----    ----    -----   -----              *
* 01900   11900   0100    0       10      00      0       0                  *
* 01900   11900   0100    0       -20     00      0       1                  *
*                                                                            *
* :------------------------------------------------------------------------- *
* $PLCALC                                                                    *
* :------                                                                    *
* :T1     T2      DT      LINK    FREQ    PFLAG                              *
* :--     --      --      ----    ----    -----                              *
* 01900   11900   0100    0       0       1                                  *
*                                                                            *
* :------------------------------------------------------------------------- *
* $RUN                                                                       *
* :---                                                                       *
* :TSTOP          PFLAG                                                      *
* :-----          -----                                                      *
* 02001           1                                                          *
*                                                                            *
******************************************************************************

**  AMBIENT WEATHER CONDITIONS  **

       YEAR     MONTH      DAY      SSN      KP    SOLAR    VEWIND    VNWIND    WINDS
      1984.       4.        1.      113.     4.      0.      0.00      0.00       1.

**  DEBUG OUTPUT HAS BEEN REQUESTED FROM THE FOLLOWING SUBROUTINES  **

     NONE....
```

Table 14. Event list and dynamic storage printouts.

* HFNET EVENT LIST CONTAINS 11 EVENTS * THE FIRST 11 EVENTS ARE LISTED BELOW *

EVENT	TIME	TYPE	NAME	EVENT DATA							
(1)	-0.01	15	READWIND	-1.000E+00	1.500E+01	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
				0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
(2)	-0.01	7	IONOSPHR	-1.000E+00	7.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
				0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
(3)	-0.01	7	IONOSPHR	-1.000E+00	7.000E+00	2.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
				0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
(4)	-0.01	7	IONOSPHR	-1.000E+00	7.000E+00	3.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
				0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
(5)	1031.00	3	BURST...	6.660E+04	3.000E+00	1.000E+00	5.000E-01	4.000E+01	-1.200E+02	2.000E+02	1.000E+01
				7.500E-01	0.000E+00	-2.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
(6)	1032.00	3	BURST...	6.672E+04	3.000E+00	2.000E+01	1.000E+01	4.000E+01	-8.000E+01	1.000E+00	0.000E+00
				1.500E+01	0.000E+00	-2.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
(7)	1900.00	21	CLDOUT..	6.840E+04	2.100E+01	1.000E+01	1.540E+05	3.600E+03	0.000E+00	0.000E+00	0.000E+00
				0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
(8)	1900.00	4	HECALC..	6.840E+04	4.000E+00	1.540E+05	3.600E+03	0.000E+00	1.000E+07	0.000E+00	0.000E+00
				0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
(9)	1900.00	4	HECALC..	6.840E+04	4.000E+00	1.540E+05	3.600E+03	0.000E+00	-2.000E+07	0.000E+00	0.000E+00
				0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
(10)	1900.00	10	PLCALC..	6.840E+04	1.000E+01	1.540E+05	3.600E+03	0.000E+00	0.000E+00	1.000E+00	0.000E+00
				0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
(11)	2001.00	2	STOP....	7.200E+04	2.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
				0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00

***** DYNAMIC LIST STORAGE MEMORY MAP ***** TOTAL CALLS = 32 TOTAL CPU TIME = 0.56

LIST STORAGE PARAMETER VALUES

MAXSCM	MAXREC	NUMREC	MRECIN	LOCMIN	LOCMAX	LOCTOP	IAVAIL	IAROVE	NWPOVE	NOVRHD	MAXDIF	NWLOST	NSWAPS	MAXNAM	NUMNAM	LST
50000	1	0	1	1	50000	341	0	0	0	3	10	0	0	20	3	1

LIST NAMES AND LIST POINTERS

LIST NUMBER	LIST NAME	LIST POINTERS END	ACCESS	NXTSET
1	EVNT	322	322	322
2	NODE	146	146	0
3	LINK	233	233	0

STORAGE MAP OF DATA LISTS

LIST NUMBER	LIST NAME	RECORD NUMBER	DATASET NUMBER	ABSOLUTE ADDRESS	RELATIVE ADDRESS	DATASET HEADER NEXT	LIST	NWDS	TOTAL SETS	WORDS
1	EVNT	1	1	1	1	182	EVNT	16		
1	EVNT	1	2	182	182	214	EVNT	16		
1	EVNT	1	3	214	214	246	EVNT	16		
1	EVNT	1	4	246	246	20	EVNT	16		
1	EVNT	1	5	20	20	39	EVNT	16		
1	EVNT	1	6	39	39	58	EVNT	16		
1	EVNT	1	7	58	58	265	EVNT	16		
1	EVNT	1	8	265	265	284	EVNT	16		
1	EVNT	1	9	284	284	303	EVNT	16		
1	EVNT	1	10	303	303	322	EVNT	16		
									11	176
2	NODE	1	1	77	77	100	NODE	20		
2	NODE	1	2	100	100	123	NODE	20		
2	NODE	1	3	123	123	146	NODE	20		
2	NODE	1	4	146	146	77	NODE	20		
									4	80
3	LINK	1	1	169	169	201	LINK	10		
3	LINK	1	2	201	201	233	LINK	10		
3	LINK	1	3	233	233	169	LINK	10		
									3	30

In the dynamic storage memory map only three data lists are shown: the EVNT list containing 11 events,* the NODE list with datasets for 4 nodes, and the LINK list containing 3 link datasets. The "TOTAL CALLS" and "CPU TIME" printouts show how many calls have been made up to this point to dynamic storage routines and how much CPU time (in seconds) it took to execute those calls. These numbers are very useful in evaluating the amount of overhead the dynamic storage system entails. If this overhead is too great then some alteration of the dynamic storage parameters is probably needed.

3.3 IONOSPHERIC MODEL OUTPUT

The complete ionospheric data table computed for the Washington to Cambridge Bay link using the RADC (polar) model is shown in Table 15. The headings in the top portion of this table are self explanatory. The body of the table shows ionospheric parameters above seven equally spaced points on the great circle path from the transmitter to the receiver. At each of these points data are given for three ionospheric layers (E, F1 and F2) and for 25 times during the day. The headings for this table are:

- PLACE - place number (1-7); latitude (°N) and longitude (°E) of this place (place 1 is the transmitter; place 7 the receiver)
- TIME - local time (hours)
- ELECTRONS - layer peak electron density (cm^{-3})
- C-FREQ - layer critical frequency (MHz)
- ALT - layer altitude (km)
- 1/2 THICK - layer semi-thickness (km)

Ionospheric data tables like the one shown in Table 15 are computed and stored for every link set up using the $LINKS keyword. The printing of the table is optional and controlled by the $LINKS print flag.

* To save space, only the first 10 datasets in any dynamic storage list are shown.

Table 15. Ionospheric data table output.

* IONOSPHERIC DATA TABLE CREATED FOR LINK 2.

NODE	LOCATION	LAT (DEG)	LON (DEG)	ALT (KM)	AZIMUTH (DEG)	RANGE (KM)	MODEL
4.	WASHINGTON, D.C.	38.55	-77.00	0.00	342.49	3778.15	RADC (POLAR)
3.	CAMBRIDGE BAY, CANADA	69.00	-105.00	0.00	138.93		

POWER (KW)	TEMP (DEG K)	BANDWIDTH (HZ)	MAN-MADE NOISE	SURFACE TYPE
1.00	290.00	1000.00	REMOTE	LAND

PLACE (LAT,LON)	TIME (HR)	***** E LAYER ELECTRONS (CM-3)	C-FREQ (MHZ)	***** ALT (KM)	1/2 THICK (KM)	***** F1 LAYER ELECTRONS (CM-3)	C-FREQ (MHZ)	***** ALT (KM)	1/2 THICK (KM)	***** F2 LAYER ELECTRONS (CM-3)	C-FREQ (MHZ)	***** ALT (KM)	1/2 THICK (KM)
1	0.00	2.790E+04	1.50	115.31	20.00	1.000E+02	0.09	100.00	40.00	4.015E+05	5.59	367.85	98.13
38.55	1.00	2.790E+04	1.50	115.31	20.00	1.000E+02	0.09	100.00	40.00	3.622E+05	5.40	376.37	95.62
-77.00	2.00	2.790E+04	1.50	115.31	20.00	1.000E+02	0.09	100.00	40.00	3.379E+05	5.22	376.37	97.82
	3.00	2.790E+04	1.50	115.31	20.00	1.000E+02	0.09	100.00	40.00	3.031E+05	4.94	376.37	97.80
	4.00	2.790E+04	1.50	115.31	20.00	1.000E+02	0.09	100.00	40.00	2.516E+05	4.50	376.37	97.32
	5.00	2.790E+04	1.50	115.31	20.00	1.000E+02	0.09	100.00	40.00	2.381E+05	4.38	365.86	96.25
	6.00	3.791E+04	1.75	126.39	20.00	1.000E+02	0.09	100.00	40.00	3.244E+05	5.11	259.72	64.51
	7.00	1.799E+05	3.81	114.68	20.00	1.000E+02	0.09	100.00	40.00	5.241E+05	6.50	236.22	58.43
	8.00	1.763E+05	3.79	113.37	20.00	1.000E+02	0.09	100.00	40.00	7.535E+05	7.79	243.97	61.13
	9.00	1.654E+05	3.65	113.73	20.00	2.547E+05	4.53	197.96	40.00	9.194E+05	8.61	251.71	63.32
	10.00	1.693E+05	3.63	114.06	20.00	2.765E+05	4.72	188.63	40.00	1.045E+06	9.18	259.45	66.64
	11.00	1.771E+05	3.78	114.32	20.00	2.913E+05	4.85	183.36	40.00	1.176E+06	9.74	267.19	69.34
	12.00	1.820E+05	3.83	114.52	20.00	2.998E+05	4.92	181.31	40.00	1.292E+06	10.17	274.94	71.95
	13.00	1.820E+05	3.83	114.53	20.00	3.023E+05	4.94	182.13	40.00	1.313E+06	10.29	282.68	74.33
	14.00	1.773E+05	3.73	114.50	20.00	2.996E+05	4.91	186.11	40.00	1.288E+06	10.19	290.42	76.51
	15.00	1.702E+05	3.70	114.30	20.00	2.973E+05	4.82	193.65	40.00	1.257E+06	10.07	298.17	78.57
	16.00	1.656E+05	3.65	114.08	20.00	2.587E+05	4.65	206.31	40.00	1.229E+06	9.96	305.91	80.14
	17.00	1.615E+05	3.61	114.26	20.00	2.753E+04	1.49	228.20	40.00	1.179E+06	9.75	313.65	91.38
	18.00	1.320E+05	3.26	116.15	20.00	1.000E+02	0.09	100.00	40.00	1.071E+06	9.29	321.39	100.86
	19.00	2.790E+04	1.50	115.31	20.00	1.000E+02	0.09	100.00	40.00	8.955E+05	8.50	329.14	114.14
	20.00	2.790E+04	1.50	115.31	20.00	1.000E+02	0.09	100.00	40.00	7.006E+05	7.51	336.88	109.79
	21.00	2.790E+04	1.50	115.31	20.00	1.000E+02	0.09	100.00	40.00	5.564E+05	6.71	344.62	104.40
	22.00	2.790E+04	1.50	115.31	20.00	1.000E+02	0.09	100.00	40.00	4.971E+05	6.27	352.37	101.65
	23.00	2.790E+04	1.50	115.31	20.00	1.000E+02	0.09	100.00	40.00	4.463E+05	6.00	360.11	100.63
	24.00	2.790E+04	1.50	115.31	20.00	1.000E+02	0.09	100.00	40.00	4.015E+05	5.69	367.65	98.13
2	0.00	2.790E+04	1.50	115.31	20.00	1.000E+02	0.09	100.00	40.00	3.315E+05	5.17	369.51	97.44
43.93	1.00	2.790E+04	1.50	115.31	20.00	1.000E+02	0.09	100.00	40.00	2.879E+05	4.82	453.10	99.76
-79.76	2.00	2.790E+04	1.50	115.31	20.00	1.000E+02	0.09	100.00	40.00	2.559E+05	4.54	453.10	99.61
	3.00	2.790E+04	1.50	115.31	20.00	1.000E+02	0.09	100.00	40.00	2.166E+05	4.20	453.10	99.58
	4.00	2.790E+04	1.50	115.31	20.00	1.000E+02	0.09	100.00	40.00	1.783E+05	3.79	453.10	99.60
	5.00	2.790E+04	1.50	115.31	20.00	1.000E+02	0.09	100.00	40.00	1.722E+05	3.73	453.10	99.71
	6.00	2.790E+04	1.50	115.31	20.00	1.000E+02	0.09	100.00	40.00	2.522E+05	4.51	275.07	68.49
	7.00	1.472E+05	3.44	115.35	20.00	1.000E+02	0.09	100.00	40.00	3.958E+05	5.65	239.46	59.40
	8.00	1.617E+05	3.61	113.93	20.00	1.000E+02	0.09	100.00	40.00	5.748E+05	6.81	245.62	61.59
	9.00	1.730E+05	3.57	114.17	20.00	2.415E+05	4.41	202.74	40.00	7.254E+05	7.65	253.36	64.33
	10.00	1.626E+05	3.62	114.39	20.00	2.641E+05	4.61	192.79	40.00	8.463E+05	8.26	261.11	66.99
	11.00	1.691E+05	3.69	114.56	20.00	2.796E+05	4.75	187.05	40.00	8.613E+05	9.30	268.85	69.65
	12.00	1.735E+05	3.74	114.65	20.00	2.889E+05	4.83	184.55	40.00	1.057E+06	9.23	276.59	72.23
	13.00	1.743E+05	3.75	114.65	20.00	2.923E+05	4.85	184.96	40.00	1.108E+06	9.45	284.34	74.66
	14.00	1.713E+05	3.72	114.55	20.00	2.895E+05	4.83	188.33	40.00	1.121E+06	9.51	292.08	76.99
	15.00	1.666E+05	3.66	114.30	20.00	2.901E+05	4.75	195.13	40.00	1.115E+06	9.48	299.82	78.35
	16.00	1.656E+05	3.65	114.00	20.00	2.627E+05	4.60	206.59	40.00	1.096E+06	9.40	307.57	80.49
	17.00	1.704E+05	3.71	114.06	20.00	5.281E+04	2.06	225.95	40.00	1.056E+06	9.23	315.31	81.77
	18.00	1.536E+05	3.49	115.77	20.00	1.000E+02	0.09	100.00	40.00	9.730E+05	8.86	323.05	98.13
	19.00	2.790E+04	1.50	115.31	20.00	1.000E+02	0.09	100.00	40.00	9.323E+05	8.19	330.79	112.69
	20.00	2.790E+04	1.50	115.31	20.00	1.000E+02	0.09	100.00	40.00	6.644E+05	7.32	338.54	108.50
	21.00	2.790E+04	1.50	115.31	20.00	1.000E+02	0.09	100.00	40.00	5.276E+05	6.52	346.28	102.66
	22.00	2.790E+04	1.50	115.31	20.00	1.000E+02	0.09	100.00	40.00	4.426E+05	5.87	354.02	97.72
	23.00	2.790E+04	1.50	115.31	20.00	1.000E+02	0.09	100.00	40.00	3.847E+05	5.57	361.77	95.56
	24.00	2.790E+04	1.50	115.31	20.00	1.000E+02	0.09	100.00	40.00	3.315E+05	5.17	369.51	97.44

Table 15. (cont.)

3	0.00	2.135E+05	4.15	115.49	20.00	1.000E+02	0.09	100.00	40.00	4.556E+05	6.06	370.86	88.02
49.25	1.00	2.202E+05	4.21	115.21	20.00	1.000E+02	0.09	100.00	40.00	4.195E+05	5.82	433.98	97.41
-82.20	2.00	2.173E+05	4.19	115.27	20.00	1.000E+02	0.09	100.00	40.00	3.872E+05	5.59	433.98	97.24
	3.00	2.790E+04	1.50	115.31	20.00	1.000E+02	0.09	100.00	40.00	3.347E+05	5.19	433.98	97.20
	4.00	2.790E+04	1.50	115.31	20.00	1.000E+02	0.09	100.00	40.00	2.556E+05	4.54	433.98	97.21
	5.00	2.790E+04	1.50	115.31	20.00	1.000E+02	0.09	100.00	40.00	1.918E+05	3.93	433.98	97.29
	6.00	2.790E+04	1.50	115.31	20.00	1.000E+02	0.09	100.00	40.00	2.012E+05	4.03	290.20	72.23
	7.00	1.546E+05	3.53	115.60	20.00	1.000E+02	0.09	100.00	40.00	3.002E+05	4.32	242.36	60.41
	8.00	1.593E+05	3.58	114.22	20.00	1.000E+02	0.09	100.00	40.00	4.334E+05	5.91	246.97	61.97
	9.00	1.565E+05	3.55	114.12	20.00	1.000E+02	0.09	100.00	40.00	5.617E+05	6.73	254.72	64.65
	10.00	1.576E+05	3.56	114.32	20.00	2.439E+05	4.49	197.88	40.00	6.722E+05	7.36	262.46	67.26
	11.00	1.613E+05	3.61	114.49	20.00	2.662E+05	4.63	191.55	40.00	7.707E+05	7.88	270.20	69.87
	12.00	1.636E+05	3.65	114.54	20.00	2.764E+05	4.72	188.53	40.00	8.551E+05	8.30	277.95	72.41
	13.00	1.669E+05	3.67	114.52	20.00	2.807E+05	4.76	188.39	40.00	9.201E+05	8.61	285.69	74.82
	14.00	1.657E+05	3.65	114.42	20.00	2.791E+05	4.74	191.13	40.00	9.620E+05	8.81	293.43	77.04
	15.00	1.640E+05	3.64	114.18	20.00	2.712E+05	4.68	197.12	40.00	9.750E+05	8.87	301.18	79.03
	16.00	1.567E+05	3.67	113.88	20.00	2.558E+05	4.54	207.32	40.00	9.603E+05	8.80	308.92	80.75
	17.00	1.753E+05	3.79	113.79	20.00	7.415E+04	2.44	224.23	40.00	9.267E+05	8.64	316.66	82.08
	18.00	1.655E+05	3.65	115.39	20.00	1.000E+02	0.09	100.00	40.00	8.666E+05	8.36	324.40	94.31
	19.00	2.790E+04	1.50	115.31	20.00	1.000E+02	0.09	100.00	40.00	7.616E+05	7.84	332.15	110.41
	20.00	2.790E+04	1.50	115.31	20.00	1.000E+02	0.09	100.00	40.00	6.245E+05	7.09	339.89	106.32
	21.00	2.790E+04	1.50	115.31	20.00	1.000E+02	0.09	100.00	40.00	5.037E+05	6.37	347.63	101.17
	22.00	2.790E+04	1.50	115.31	20.00	1.000E+02	0.09	100.00	40.00	4.515E+05	6.03	355.38	99.26
	23.00	1.938E+05	3.99	115.39	20.00	1.000E+02	0.09	100.00	40.00	4.772E+05	6.20	363.12	105.21
	24.00	2.135E+05	4.15	115.49	20.00	1.000E+02	0.09	100.00	40.00	4.556E+05	6.06	370.86	88.02
4	0.00	2.209E+05	4.22	115.17	20.00	1.000E+02	0.09	100.00	40.00	3.364E+05	5.21	371.71	88.56
54.48	1.00	2.288E+05	4.30	114.86	20.00	1.000E+02	0.09	100.00	40.00	2.940E+05	4.87	381.20	89.83
-95.71	2.00	2.310E+05	4.32	114.31	20.00	1.000E+02	0.09	100.00	40.00	2.668E+05	4.64	381.20	89.67
	3.00	2.229E+05	4.24	115.33	20.00	1.000E+02	0.09	100.00	40.00	2.339E+05	4.34	381.20	89.62
	4.00	2.056E+05	4.07	116.15	20.00	1.000E+02	0.09	100.00	40.00	1.953E+05	3.97	381.20	89.62
	5.00	1.865E+05	3.88	115.97	20.00	1.000E+02	0.09	100.00	40.00	1.803E+05	3.81	381.20	89.66
	6.00	2.790E+04	1.50	115.31	20.00	1.000E+02	0.09	100.00	40.00	2.212E+05	4.22	304.85	75.65
	7.00	6.232E+04	2.35	120.50	20.00	1.000E+02	0.09	100.00	40.00	3.341E+05	5.19	246.33	61.45
	8.00	1.902E+05	4.00	114.10	20.00	1.000E+02	0.09	100.00	40.00	4.784E+05	6.21	247.82	62.22
	9.00	1.819E+05	3.93	113.29	20.00	1.000E+02	0.09	100.00	40.00	5.514E+05	6.67	255.57	64.33
	10.00	1.639E+05	3.63	113.67	20.00	2.336E+05	4.34	204.11	40.00	5.307E+05	6.54	263.31	67.03
	11.00	1.593E+05	3.58	113.99	20.00	2.508E+05	4.50	197.05	40.00	6.132E+05	7.03	271.05	69.83
	12.00	1.603E+05	3.59	114.15	20.00	2.619E+05	4.60	193.37	40.00	6.875E+05	7.44	278.80	72.43
	13.00	1.610E+05	3.61	114.14	20.00	2.674E+05	4.64	192.59	40.00	7.587E+05	7.82	286.54	74.82
	14.00	1.623E+05	3.62	114.05	20.00	2.672E+05	4.64	194.68	40.00	8.166E+05	8.11	294.28	77.04
	15.00	1.641E+05	3.64	113.88	20.00	2.610E+05	4.59	199.66	40.00	8.401E+05	8.23	302.03	79.05
	16.00	1.705E+05	3.71	113.65	20.00	2.480E+05	4.47	208.51	40.00	8.277E+05	8.17	309.77	80.83
	17.00	1.861E+05	3.87	113.53	20.00	8.642E+04	2.64	223.00	40.00	7.999E+05	8.03	317.51	82.27
	18.00	1.853E+05	3.87	114.94	20.00	1.000E+02	0.09	100.00	40.00	7.592E+05	7.82	325.25	99.27
	19.00	4.737E+04	1.97	125.93	20.00	1.000E+02	0.09	100.00	40.00	8.263E+05	8.16	333.00	99.17
	20.00	2.790E+04	1.50	115.31	20.00	1.000E+02	0.09	100.00	40.00	8.249E+05	8.15	340.74	117.54
	21.00	1.651E+05	3.65	116.73	20.00	1.000E+02	0.09	100.00	40.00	6.751E+05	7.38	348.48	114.03
	22.00	1.872E+05	3.88	116.23	20.00	1.000E+02	0.09	100.00	40.00	5.162E+05	6.45	356.23	86.82
	23.00	2.055E+05	4.08	115.66	20.00	1.000E+02	0.09	100.00	40.00	4.066E+05	5.73	363.97	87.66
	24.00	2.209E+05	4.22	115.17	20.00	1.000E+02	0.09	100.00	40.00	3.364E+05	5.21	371.71	88.56
5	0.00	1.808E+05	3.82	116.33	20.00	1.000E+02	0.09	100.00	40.00	2.784E+05	4.74	379.58	89.39
59.58	1.00	1.791E+05	3.80	116.76	20.00	1.000E+02	0.09	100.00	40.00	2.536E+05	4.52	379.74	89.85
-90.24	2.00	1.751E+05	3.76	116.43	20.00	1.000E+02	0.09	100.00	40.00	2.210E+05	4.22	379.74	89.78
	3.00	1.735E+05	3.74	116.57	20.00	1.000E+02	0.09	100.00	40.00	1.820E+05	3.83	379.74	89.76
	4.00	1.703E+05	3.71	116.95	20.00	1.000E+02	0.09	100.00	40.00	1.585E+05	3.57	379.74	89.79
	5.00	1.696E+05	3.70	117.35	20.00	1.000E+02	0.09	100.00	40.00	1.676E+05	3.68	318.78	73.35
	6.00	2.244E+05	4.25	116.03	20.00	1.000E+02	0.09	100.00	40.00	2.114E+05	4.13	253.47	63.51
	7.00	2.164E+05	4.18	114.60	20.00	1.000E+02	0.09	100.00	40.00	2.843E+05	4.79	249.32	62.33
	8.00	2.059E+05	4.07	113.22	20.00	1.000E+02	0.09	100.00	40.00	3.849E+05	5.57	255.63	64.83
	9.00	1.816E+05	3.83	113.18	20.00	1.000E+02	0.09	100.00	40.00	5.217E+05	6.49	263.43	67.31
	10.00	1.561E+05	3.56	113.50	20.00	2.331E+05	4.33	203.31	40.00	6.831E+05	7.42	271.18	69.79
	11.00	1.607E+05	3.60	113.76	20.00	2.454E+05	4.45	199.30	40.00	8.037E+05	8.05	278.92	72.24
	12.00	1.608E+05	3.60	113.81	20.00	2.522E+05	4.51	197.70	40.00	8.729E+05	8.39	286.66	74.61
	13.00	1.622E+05	3.62	113.79	20.00	2.537E+05	4.52	198.83	40.00	9.263E+05	8.64	294.40	76.83
	14.00	1.654E+05	3.65	113.70	20.00	2.495E+05	4.49	202.32	40.00	9.640E+05	8.82	302.15	78.87
	15.00	1.727E+05	3.73	113.56	20.00	2.392E+05	4.39	210.19	40.00	9.850E+05	8.91	309.89	80.69
	16.00	1.857E+05	3.87	113.48	20.00	8.709E+04	2.65	222.23	40.00	9.849E+05	8.91	317.65	82.30
	17.00	1.808E+05	3.82	114.72	20.00	1.000E+02	0.09	100.00	40.00	9.217E+05	8.62	325.38	93.53
	18.00	1.812E+05	3.82	116.00	20.00	1.000E+02	0.09	100.00	40.00	7.746E+05	7.90	333.12	84.59
	19.00	1.771E+05	3.78	115.95	20.00	1.000E+02	0.09	100.00	40.00	6.056E+05	6.99	340.86	106.05
	20.00	1.535E+05	3.52	116.37	20.00	1.000E+02	0.09	100.00	40.00	4.821E+05	6.23	348.61	86.27
	21.00	1.650E+05	3.65	116.67	20.00	1.000E+02	0.09	100.00	40.00	4.070E+05	5.73	356.35	87.17
	22.00	1.733E+05	3.74	116.46	20.00	1.000E+02	0.09	100.00	40.00	3.538E+05	5.34	364.09	88.06
	23.00	1.784E+05	3.80	116.35	20.00	1.000E+02	0.09	100.00	40.00	3.100E+05	5.00	371.83	88.99
	24.00	1.808E+05	3.82	116.33	20.00	1.000E+02	0.09	100.00	40.00	2.784E+05	4.74	379.58	89.39

Table 15. (cont.)

6	0.00	1.519E+05	3.50	113.04	20.00	1.000E+02	0.09	100.00	40.00	2.887E+05	4.82	378.49	90.26
64.47	1.00	1.519E+05	3.50	113.04	20.00	1.000E+02	0.09	100.00	40.00	2.633E+05	4.51	381.77	90.51
-96.55	2.00	1.519E+05	3.50	113.04	20.00	1.000E+02	0.09	100.00	40.00	2.313E+05	4.32	381.77	90.52
	3.00	1.519E+05	3.50	113.04	20.00	1.000E+02	0.09	100.00	40.00	1.949E+05	3.96	381.77	90.50
	4.00	1.519E+05	3.50	113.04	20.00	1.000E+02	0.09	100.00	40.00	1.726E+05	3.73	381.77	90.51
	5.00	1.519E+05	3.50	113.04	20.00	1.000E+02	0.09	100.00	40.00	1.768E+05	3.77	331.52	81.69
	6.00	1.884E+05	3.90	123.86	20.00	1.000E+02	0.09	100.00	40.00	2.050E+05	4.06	277.74	69.96
	7.00	1.987E+05	4.00	121.68	20.00	1.000E+02	0.09	100.00	40.00	2.486E+05	4.48	253.58	63.39
	8.00	1.940E+05	3.95	114.25	20.00	1.000E+02	0.09	100.00	40.00	3.012E+05	4.93	254.60	64.50
	9.00	1.932E+05	3.95	113.13	20.00	1.000E+02	0.09	100.00	40.00	3.577E+05	5.37	262.35	66.90
	10.00	1.764E+05	3.77	113.35	20.00	1.000E+02	0.09	100.00	40.00	4.172E+05	5.80	270.09	69.31
	11.00	1.672E+05	3.67	113.57	20.00	2.264E+05	4.27	206.64	40.00	4.919E+05	6.30	277.83	71.73
	12.00	1.633E+05	3.63	113.64	20.00	2.349E+05	4.35	203.39	40.00	5.895E+05	6.89	285.58	74.09
	13.00	1.644E+05	3.64	113.65	20.00	2.353E+05	4.38	203.39	40.00	6.625E+05	7.42	293.32	76.29
	14.00	1.674E+05	3.67	113.62	20.00	2.366E+05	4.37	206.65	40.00	7.280E+05	7.86	301.06	78.36
	15.00	1.738E+05	3.74	113.54	20.00	2.294E+05	4.30	212.39	40.00	7.163E+05	7.60	308.80	80.25
	16.00	1.640E+05	3.65	113.48	20.00	7.677E+04	2.48	221.30	40.00	6.738E+05	7.37	315.55	81.94
	17.00	1.730E+05	3.80	114.49	20.00	1.000E+02	0.09	100.00	40.00	6.199E+05	7.07	324.29	83.40
	18.00	1.704E+05	3.71	115.63	20.00	1.000E+02	0.09	100.00	40.00	5.585E+05	6.71	332.03	84.55
	19.00	1.590E+05	3.58	116.75	20.00	1.000E+02	0.09	100.00	40.00	4.964E+05	6.33	339.78	85.56
	20.00	2.187E+05	4.20	112.25	20.00	1.000E+02	0.09	100.00	40.00	4.455E+05	5.99	347.52	86.45
	21.00	2.187E+05	4.20	112.25	20.00	1.000E+02	0.09	100.00	40.00	4.043E+05	5.71	355.26	87.30
	22.00	1.519E+05	3.50	113.04	20.00	1.000E+02	0.09	100.00	40.00	3.623E+05	5.40	363.01	88.25
	23.00	1.519E+05	3.50	113.04	20.00	1.000E+02	0.09	100.00	40.00	3.206E+05	5.08	370.75	89.23
	24.00	1.519E+05	3.50	113.04	20.00	1.000E+02	0.09	100.00	40.00	2.887E+05	4.82	379.49	90.26
7	0.00	1.519E+05	3.50	113.04	20.00	1.000E+02	0.09	100.00	40.00	2.764E+05	4.72	383.15	91.29
69.00	1.00	1.519E+05	3.50	113.04	20.00	1.000E+02	0.09	100.00	40.00	2.456E+05	4.45	383.15	91.16
-105.00	2.00	1.519E+05	3.50	113.04	20.00	1.000E+02	0.09	100.00	40.00	2.131E+05	4.14	383.15	91.12
	3.00	1.519E+05	3.50	113.04	20.00	1.000E+02	0.09	100.00	40.00	1.942E+05	3.96	383.15	91.11
	4.00	1.519E+05	3.50	113.04	20.00	1.000E+02	0.09	100.00	40.00	1.981E+05	4.09	342.32	84.07
	5.00	1.519E+05	3.50	113.04	20.00	1.000E+02	0.09	100.00	40.00	2.189E+05	4.20	300.06	75.44
	6.00	1.938E+05	3.95	123.52	20.00	1.000E+02	0.09	100.00	40.00	2.467E+05	4.46	257.79	65.10
	7.00	2.016E+05	4.07	120.96	20.00	1.000E+02	0.09	100.00	40.00	2.792E+05	4.74	257.23	65.21
	8.00	2.063E+05	4.10	118.61	20.00	1.000E+02	0.09	100.00	40.00	3.179E+05	5.06	259.27	65.97
	9.00	2.136E+05	4.15	116.88	20.00	1.000E+02	0.09	100.00	40.00	3.618E+05	5.40	267.01	68.32
	10.00	2.180E+05	4.19	115.64	20.00	1.320E+05	3.35	215.96	40.00	4.099E+05	5.75	274.75	70.67
	11.00	2.209E+05	4.22	114.90	20.00	2.150E+05	4.16	211.79	40.00	4.613E+05	6.10	282.49	72.99
	12.00	2.227E+05	4.23	114.63	20.00	2.209E+05	4.22	210.33	40.00	5.065E+05	6.39	290.24	75.22
	13.00	2.222E+05	4.23	114.84	20.00	2.221E+05	4.23	211.42	40.00	5.312E+05	6.54	297.98	77.34
	14.00	2.204E+05	4.21	115.55	20.00	2.185E+05	4.20	215.17	40.00	5.336E+05	6.56	305.72	79.30
	15.00	2.170E+05	4.18	116.75	20.00	5.662E+04	2.14	222.02	40.00	5.238E+05	6.50	313.47	81.09
	16.00	2.119E+05	4.13	118.51	20.00	1.000E+02	0.09	100.00	40.00	5.068E+05	6.39	321.21	82.70
	17.00	2.019E+05	4.03	120.56	20.00	1.000E+02	0.09	100.00	40.00	4.821E+05	6.23	328.95	84.14
	18.00	1.946E+05	3.96	123.26	20.00	1.000E+02	0.09	100.00	40.00	4.560E+05	6.06	336.69	85.23
	19.00	1.519E+05	3.50	113.04	20.00	1.000E+02	0.09	100.00	40.00	4.356E+05	5.93	344.44	86.29
	20.00	2.187E+05	4.20	112.25	20.00	1.000E+02	0.09	100.00	40.00	4.139E+05	5.78	352.18	87.22
	21.00	2.187E+05	4.20	112.25	20.00	1.000E+02	0.09	100.00	40.00	3.792E+05	5.57	359.92	88.10
	22.00	1.519E+05	3.50	113.04	20.00	1.000E+02	0.09	100.00	40.00	3.373E+05	5.21	367.67	89.14
	23.00	1.519E+05	3.50	113.04	20.00	1.000E+02	0.09	100.00	40.00	3.030E+05	4.94	375.41	90.15
	24.00	1.519E+05	3.50	113.04	20.00	1.000E+02	0.09	100.00	40.00	2.764E+05	4.72	383.15	91.29

3.4 BURST AND CLOUD OUTPUT

There are several different ways to obtain printed output of cloud (fireball, debris cloud or plume) parameters. Tables 16 through 19 show four different types of cloud output: 1) cloud creation and split output controlled by the $BURSTS print flag (Table 16); 2) burst summary output provided automatically (Table 17); 3) detailed cloud list output controlled by the $CLDOUT output flag (Table 18); and 4) cloud list summary output controlled by the $CLDOUT keyword (Table 19).

The detailed cloud output shown in Tables 16 and 18 share a common format. The labels for this format are:

CLOUD	- cloud number (assigned internally by the code)
BURST	- burst number (assigned internally by the code)
TYPE	- type of cloud (mixed (ion/neutral) fireball, ionized fireball, neutral fireball, late plume or subsiding debris)
TIME	- time that data is valid (GMT in modified DHMS format)
LAT	- latitude of cloud center (deg N)
LON	- longitude of cloud center (deg E)
ALT	- altitude of cloud center (km)
RMAJ	- major horizontal radius (km)
RMIN	- minor horizontal radius (km)
RVERT	- vertical radius (km)
WXRAY	- X-ray yield in cloud (MT)
WFISS	- Fission yield in cloud (MT)
MASS	- mass of cloud (kg)
VN	- north velocity (m/s) of center of mass
VE	- east velocity (m/s) of center of mass
VUP	- upward velocity (m/s) of center of mass
VXMAJ	- major axis expansion velocity (m/s)

Table 16. Cloud creation and split outout.

```
******************************************************************************************************
* BURST EVENT -- TIME = 0:18:31:00 GMT -- LAT = 40.00 DEG N -- LON = -120.00 DEG E -- ALT = 200.00 KM -- Y = 1.00 MT     *

CLOUD CREATED

  ** CLOUD:    1 -- BURST:    1 -- TYPE: MIXED  FIREBALL  -- TIME: 0:18:31:00  GMT **

     LAT(DEG)    LON(DEG)     ALT(KM)    RMAJ(KM)    RMIN(KM)   RVERT(KM)   WGRAY(MT)   WFISS(MT)    MASS(KG)
       40.027    -119.994     193.358     144.625     141.625     100.000       0.750       0.414   2.821E+06
      VN(M/S)     VE(M/S)    VUP(M/S)  VMAJ(M/S)   VMIN(M/S)   VVUP(M/S)       ALIGN       FRACV   MASSC(KG)
        0.000       0.000   -1573.407       0.000       0.000       0.000       0.000       0.848   0.000E+00
      DTBURST  TBURST(GMT)  TIMELS(GMT) LATELS(DEG) LONELS(DEG)  ALTELS(KM) DENELS(G/CC)   DEC(DEG)
   0:00:00:00  0:18:31:00  0:18:31:00      40.000    -120.000     200.000   3.219E-13      12.783

CLOUD    1 SPLIT - NEW CLOUDS FOLLOW.

  ** CLOUD:    3 -- BURST:    1 -- TYPE: IONIZED FIREBALL -- TIME: 0:18:32:59  GMT **

     LAT(DEG)    LON(DEG)     ALT(KM)    RMAJ(KM)    RMIN(KM)   RVERT(KM)   WGRAY(MT)   WFISS(MT)    MASS(KG)
       40.021    -119.995     671.154     184.170     166.560     343.542       0.750       0.414   2.392E+06
      VN(M/S)     VE(M/S)    VUP(M/S)  VMAJ(M/S)   VMIN(M/S)   VVUP(M/S)       ALIGN       FRACV   MASSC(KG)
      -15.408      -3.406    3389.400    1336.568       0.000     905.298       0.744       1.000   0.000E+00
      DTBURST  TBURST(GMT)  TIMELS(GMT) LATELS(DEG) LONELS(DEG)  ALTELS(KM) DENELS(G/CC)   DEC(DEG)
   0:00:01:59  0:18:31:00  0:18:31:00      40.000    -120.000     200.000   3.219E-13      12.782

  ** CLOUD:    4 -- BURST:    1 -- TYPE: NEUTRAL FIREBALL -- TIME: 0:18:32:59  GMT **

     LAT(DEG)    LON(DEG)     ALT(KM)    RMAJ(KM)    RMIN(KM)   RVERT(KM)   WGRAY(MT)   WFISS(MT)    MASS(KG)
       40.021    -119.995     671.154     184.170     166.560     343.542       0.000       0.000   4.291E+05
      VN(M/S)     VE(M/S)    VUP(M/S)  VMAJ(M/S)   VMIN(M/S)   VVUP(M/S)       ALIGN       FRACV   MASSC(KG)
      -15.408      -3.406    3389.400    1336.568       0.000     905.298       0.000       0.000   0.000E+00
      DTBURST  TBURST(GMT)  TIMELS(GMT) LATELS(DEG) LONELS(DEG)  ALTELS(KM) DENELS(G/CC)   DEC(DEG)
   0:00:01:59  0:18:31:00  0:18:31:00      40.000    -120.000     200.000   3.219E-13      12.782

CLOUD    3 SPLIT - NEW CLOUDS FOLLOW.

  ** CLOUD:    5 -- BURST:    1 -- TYPE: LATE   PLUME     -- TIME: 0:18:44:25  GMT **

     LAT(DEG)    LON(DEG)     ALT(KM)    RMAJ(KM)    RMIN(KM)   RVERT(KM)   WGRAY(MT)   WFISS(MT)    MASS(KG)
       41.088    -119.675     770.680     233.107     212.221     507.120       0.000       0.000   2.393E+06
      VN(M/S)     VE(M/S)    VUP(M/S)  VMAJ(M/S)   VMIN(M/S)   VVUP(M/S)       ALIGN       FRACV   MASSC(KG)
    -1013.609    -140.705    2350.650       0.000       0.000    2358.650       0.979       1.000   0.000E+00
      DTBURST  TBURST(GMT)  TIMELS(GMT) LATELS(DEG) LONELS(DEG)  ALTELS(KM) DENELS(G/CC)   DEC(DEG)
   0:00:13:25  0:18:31:00  0:18:31:00      40.000    -120.000     200.000   3.219E-13      12.997

  ** CLOUD:    6 -- BURST:    1 -- TYPE: SUBSIDING DEBRIS -- TIME: 0:18:44:25  GMT **

     LAT(DEG)    LON(DEG)     ALT(KM)    RMAJ(KM)    RMIN(KM)   RVERT(KM)   WGRAY(MT)   WFISS(MT)    MASS(KG)
       41.088    -119.675     770.680     233.107     212.221     507.120       0.750       0.414   9.065E+00
      VN(M/S)     VE(M/S)    VUP(M/S)  VMAJ(M/S)   VMIN(M/S)   VVUP(M/S)       ALIGN       FRACV   MASSC(KG)
     1254.464     280.805   -2590.463       0.000       0.000       0.000       0.979       1.000   0.000E+00
      DTBURST  TBURST(GMT)  TIMELS(GMT) LATELS(DEG) LONELS(DEG)  ALTELS(KM) DENELS(G/CC)   DEC(DEG)
   0:00:13:25  0:18:31:00  0:18:31:00      40.000    -120.000     200.000   3.219E-13      12.991
```

Table 17. Burst summary output.

** BURST SUMMARY **

BURST	TIME (GMT)	NORTH LATITUDE (DEG)	EAST LONGITUDE (DEG)	ALTITUDE (KM)	YIELD (MT)	FISSION YIELD (MT)	X-RAY YIELD (MT)
1	0:18:31:00	40.00	-120.00	200.00	1.00	0.50	0.75
2	0:18:32:00	40.00	-80.00	1.00	20.00	10.00	15.00

Table 18. Detailed cloud list output.

```
*******************************************************************************************************************
* CLOUD OUTPUT EVENT AT 0:20:00:00 GMT -- TOTAL BURSTS:    2 -- TOTAL CLOUDS:    4 -- REFLAG: 10.              *

** CLOUD:    2 -- BURST:    2 -- TYPE: SUBSIDING DEBRIS -- TIME: 0:20:00:00 GMT **

   LAT(DEG)    LON(DEG)     ALT(KM)    RMAJ(KM)    RMIN(KM)   RVERT(KM)   WXRAY(MT)   WFISS(MT)    MASS(KG)
     40.044     -79.851      28.348      17.501      16.236       5.585      15.000      10.000   2.371E+11
     N(M/S)      E(M/S)    ALF(M/S)  VRMAJ(M/S)  VRMIN(M/S)    VUP(M/S)       ALIGN        FRAC   MASSC(KG)
      0.365       2.493       0.000       0.000       0.000       0.000       0.000       0.000   0.000E+00
    DTBURST  TBURST GMT  TIMFLS GMT  LATFLS(DEG) LONFLS(DEG) ALTFLS(KM) DENFLS(G/CC)   DEC(DEG)
 0:01:28:00  0:18:32:00  0:18:32:00      40.000     -80.000       1.000   1.111E-03       3.301

** CLOUD:    4 -- BURST:    1 -- TYPE: SUBSIDING DEBRIS -- TIME: 0:20:00:00 GMT **

   LAT(DEG)    LON(DEG)     ALT(KM)    RMAJ(KM)    RMIN(KM)   RVERT(KM)   WXRAY(MT)   WFISS(MT)    MASS(KG)
     39.499    -119.961     158.789     500.100     452.132      26.290       0.000       0.000   4.293E+05
     N(M/S)      E(M/S)    ALF(M/S)  VRMAJ(M/S)  VRMIN(M/S)    VUP(M/S)       ALIGN        FRAC   MASSC(KG)
    -17.332       1.415      -6.203       0.000       0.000      -3.052       0.000       0.000   0.000E+00
    DTBURST  TBURST GMT  TIMFLS GMT  LATFLS(DEG) LONFLS(DEG) ALTFLS(KM) DENFLS(G/CC)   DEC(DEG)
 0:01:29:00  0:18:31:00  0:18:31:00      40.000    -120.000     200.000   3.219E-13      12.778

** CLOUD:    5 -- BURST:    1 -- TYPE: LATE  PLUME    -- TIME: 0:20:00:00 GMT **

   LAT(DEG)    LON(DEG)     ALT(KM)    RMAJ(KM)    RMIN(KM)   RVERT(KM)   WXRAY(MT)   WFISS(MT)    MASS(KG)
     39.225    -120.234    1061.336     233.107     212.221     821.691       0.000       0.000   1.287E+06
     N(M/S)      E(M/S)    ALF(M/S)  VRMAJ(M/S)  VRMIN(M/S)    VUP(M/S)       ALIGN        FRAC   MASSC(KG)
    -45.379     -11.021      -7.073       0.000       0.000       0.000       1.000       1.000   1.405E+22
    DTBURST  TBURST GMT  TIMFLS GMT  LATFLS(DEG) LONFLS(DEG) ALTFLS(KM) DENFLS(G/CC)   DEC(DEG)
 0:01:29:00  0:18:31:00  0:18:31:00      40.000    -120.000     200.000   3.219E-13      12.675

** CLOUD:    6 -- BURST:    1 -- TYPE: SUBSIDING DEBRIS -- TIME: 0:20:00:00 GMT **

   LAT(DEG)    LON(DEG)     ALT(KM)    RMAJ(KM)    RMIN(KM)   RVERT(KM)   WXRAY(MT)   WFISS(MT)    MASS(KG)
     42.605    -118.717     159.403     243.335     218.946      26.272       0.750       0.414   9.065E+00
     N(M/S)      E(M/S)    ALF(M/S)  VRMAJ(M/S)  VRMIN(M/S)    VUP(M/S)       ALIGN        FRAC   MASSC(KG)
    -16.333       3.963      -6.198       0.000       0.000      -2.624       0.000       0.000   0.000E+00
    DTBURST  TBURST GMT  TIMFLS GMT  LATFLS(DEG) LONFLS(DEG) ALTFLS(KM) DENFLS(G/CC)   DEC(DEG)
 0:01:29:00  0:18:31:00  0:18:31:00      40.000    -120.000     200.000   3.219E-13      13.026
```

Table 19. Summary cloud list output.

** CLOUD SUMMARY AT 0:20:00:00 GMT ** TOTAL BURSTS = 2 ** TOTAL CLOUDS = 4 **

BURST	CLOUD	TYPE	N.LAT (DEG)	E.LON (DEG)	ALT (KM)	RMAJOR (KM)	RMINOR (KM)	RVERT (KM)	WXRAY (MT)	WFISS (MT)	DT BURST
1	4	S.D.	39.50	-119.95	158.79	501.35	453.31	34.92	0.00	0.00	0:01:29:00
1	5	L.P.	39.23	-120.23	1061.34	233.11	212.22	821.69	0.00	0.00	0:01:29:00
1	6	S.D.	42.60	-118.30	159.41	244.39	219.89	30.93	0.75	0.41	0:01:29:00
2	2	S.D.	40.04	-79.85	28.35	17.50	16.24	5.58	15.00	10.00	0:01:28:00

VXMIN	- minor axis expansion velocity (m/s)
VXUP	- upward expansion velocity (m/s)
ALIGN	- fraction of ions aligned with geomagnetic field
FRACV	- fraction of debris that is ionized
MASSC	- mass in conjugate region (kg) (for plumes only)
DTBURST	- time since burst (GMT in modified DHMS format)
TBURST	- time of burst (GMT in modified DHMS format)
TIMFLS	- X-ray emission time (GMT in modified DHMS format)
LATFLS	- X-ray emission latitude (deg N)
LONFLS	- X-ray emission longitude (deg E)
ALTFLS	- X-ray emission altitude (km)
DENFLS	- atmospheric density (g/cc) at X-ray emission point
DEC	- declination angle (deg) of major horizontal axis

The labels for the burst and cloud list summary outputs shown in Tables 17 and 19 are very similar to the above labels and need no further explanation.

The development of the clouds created by the high altitude burst (burst 1 in the test problem) can be seen in Table 16. The burst initially creates a mixed (ion/neutral) fireball (cloud 1). Approximately 2 minutes later, after rising and expanding appreciably, this cloud splits into an ionized fireball (cloud 3) and a neutral fireball (cloud 4). The ionized fireball in turn splits into a late plume (cloud 5) and a subsidence cloud (cloud 6). This second split happens over 13 minutes after the burst, well after the cloud has reached apogee and started falling. Without splitting or changing number, the neutral fireball (cloud 4) turns into a subsidence cloud as can be seen in Tables 18 and 19. This illustrates that a single high altitude burst can create many clouds. In this problem the high altitude burst gave rise to 5 different clouds during its evolution and ended up forming 3 different clouds (two subsiding debris clouds and a late plume) at late times. This behavior is typical of most high altitude bursts.

Low altitude bursts, on the other hand, usually display less complicated life cycles. The typical low altitude burst creates a single neutral fireball which rises to apogee and then turns into a subsidence cloud on the way back down. This behavior of clouds formed by low altitude bursts is demonstrated by the second burst in the test problem. The subsiding debris cloud created by burst number 2 (cloud 2) is seen in Tables 18 and 19.

3.5 HF PROPAGATION OUTPUT

Like most HFNET output the output from HF propagation calculations is available at two levels of detail. The more detailed output is generated during the execution of the simulation proper and is optionally produced depending on the setting of the $HFCALC print flag. An example of detailed simulation-time HF propagation output is shown in Table 20. The less detailed propagation summary output is produced by the post-processor program after the simulation has completed execution. An example of post-processed propagation summary output is shown in Table 21.

Table 20 shows the detailed HF propagation output for the Washington to Cambridge Bay link at 20:00 GMT. (Detailed output for the other two links at this time was also produced during this run but is not shown.) The first few lines announce the event as an "HF CALCULATION EVENT" and show the values of the $HFCALC parameters being used. Of particular interest are the frequency of -20 Megahertz and the print flag of 1. The negative frequency caused the MUF propagation calculation to be suppressed and the print flag caused the detailed propagation output seen here to be generated.

Below the event header are the transmitter and receiver node names enclosed in a box of asterisks. Because the hops parameter on the $HFCALC data line was specified as zero, the code computed how many hops were

Table 20. Detailed HF propagation output.

```
* HF CALCULATION EVENT -- TIME =  2000.00 GMT -- LINK =    2. -- FREQ =  -20.00 MHZ -- EFLAG =    0. -- PFLAG =    1.

 * WASHINGTON, D.C.            * CAMBRIDGE BAY, CANADA     *

           **********

MODE GEOMETRY  -- ALINK   2.  --  TIME   2000.00 GMT  --  FREQ   20.00 MHZ  --  1 HOPS

  F90     F50     F10    FREQ    PROB
 19.62   27.12   32.01   20.00   0.30

LAUNCH  ELEVATION      1.71 DEG      RECEIVE ELEVATION      1.42 DEG      TIME DELAY     13.29 MS
        AZIMUTH        0.03 DEG              AZIMUTH       -0.03 DEG      RAY PATH      3985.22 KM

INTERMEDIATE RESULTS
         EQUAL SPACING         SINGLE HOP V.H.           EQUAL ANGLES              ALONG G.C.              ACROSS G.C.
 POINT    LAT      LON     F2-STEP  F1-STEP  E-STEP    LAT      LON        TILT    DISPL     V.H.      TILT    DISPL
   1     38.55   -77.00     0.00     0.00     0.00    38.55   -77.00      0.00     0.00     0.00      0.00     0.00
   2     54.48   -95.71   258.54   316.72   354.22    54.40   -95.71      0.17   -14.47   354.12     -0.47     2.97
   3     69.00  -105.00     0.00     0.00     0.00    69.00  -105.00      0.00     0.00     0.00      0.00    -0.03

FINAL AMBIENT BREAKPOINTS
  POINT    LAT      LON       V.H.     LAYER
   1      38.55   -77.00     0.00
   2      54.35   -95.58   354.10       F2
   3      69.00  -105.00     0.00

PROPAGATION LOSSES  --  LINK   2.  --  TIME   2000.00 GMT  --  FREQ   20.00 MHZ  --  1 HOPS

  FREE    AMBIENT   NUCLEAR     OTHER     TOTAL
 130.46     3.33      0.00       3.00    137.30

HOP POINT D-PASS(DB)     LAT       LON     SECANT     XOGAM  CLD    XOBET  CLD    XOAME     NE (O)     NE (XR)  CLD      ALT

 1   2       0.00      43.25    -73.01     3.33     0.000   2     0.000   0    1.000   1.51E+04   0.00E+00   0     90.00
             1.73      46.17    -90.43     5.82

 1   3       0.00      64.35    -96.32     3.48     0.000   0     0.000   0    1.000   2.35E+03   0.00E+00   0     90.00
             3.03      63.32    -93.25     5.34

SIGNAL / NOISE CALCULATION  --  LINK   2  --  TIME  0:20:00:00  GMT  --  FREQ   20.00 MHZ  --  1 HOPS

              NOISE SOURCES(DBW)                    TOTAL       TRANS     RECEIVER
 THERMAL    GALACTIC    MAN-MADE  ATMOSPHERIC       NOISE       POWER      POWER        S/N
 -174.35    -152.26     -155.76     -149.43        -146.93      30.00     -107.30      39.63

           **********
```

Table 20. (cont.)

MODE GEOMETRY -- ALINK 2. -- TIME 2000.00 GMT -- FREQ 20.00 MHZ -- 2 HOPS

** USING ENHANCED IONOSPHERE ***** NOTICE ***** THIS FREQUENCY IS ABOVE THE MUF **

F90	F50	F10	FREQ	PROB
13.75	19.30	25.30	20.00	0.50

LAUNCH ELEVATION 11.51 DEG RECEIVE ELEVATION 10.71 DEG TIME DELAY 13.38 MS
AZIMUTH 0.35 DEG AZIMUTH -0.30 DEG RAY PATH 4014.37 KM

INTERMEDIATE RESULTS

	EQUAL SPACING		SINGLE HOP V.H.			EQUAL ANGLES		ALONG G.C.			ACROSS G.C.	
POINT	LAT	LON	F2-STEP	F1-STEP	E-STEP	LAT	LON	TILT	DISPL	V.H.	TILT	DISPL
1	38.55	-77.00	0.00	0.00	0.00	38.55	-77.00	0.00	0.00	0.00	0.00	0.00
2	46.60	-90.71	242.54	253.40	265.90	46.52	-90.67	0.17	-17.92	263.84	-0.39	4.02
3	54.43	-95.71	0.00	0.00	0.00	54.34	-95.60	0.00	-18.81	0.00	0.00	4.52
4	62.06	-98.05	254.12	264.79	269.96	61.99	-92.97	0.21	-20.57	269.64	-0.59	5.02
5	69.00	-105.00	0.00	0.00	0.00	69.00	-105.00	0.00	0.00	0.00	0.00	-0.07

FINAL AMBIENT BREAKPOINTS

POINT	LAT	LON	V.H.	LAYER
1	38.55	-77.00	0.00	
2	46.59	-90.55	263.81	F2
3	54.32	-95.44	0.00	
4	61.87	-92.73	269.79	F2
5	69.00	-105.00	0.00	

PROPAGATION LOSSES -- LINK 2. -- TIME 2000.00 GMT -- FREQ 20.00 MHZ -- 2 HOPS

FREE	AMBIENT	NUCLEAR	OTHER	TOTAL
130.53	4.86	15.55	12.79	163.73

HOP	POINT	D-LOSS DB.	LAT	LON	SECANT	XOGAM	CLD	XOSET	CLD	XOAMB	NE (O)	NE (XR)	CLD	ALT
1	2	15.55	40.13	-77.64	4.38	1.000	2	0.000	0	0.000	2.17E+03	0.00E+00	0	60.00
		1.09	41.84	-78.37	3.96									
1	3	0.00	52.65	-84.30	4.48	0.000	0	0.000	0	1.000	1.45E+04	0.00E+00	0	90.00
		1.10	50.96	-83.13	3.37									
2	4	0.00	55.77	-86.64	4.49	0.000	0	0.000	0	1.000	1.43E+04	0.00E+00	0	90.00
		1.05	57.43	-88.06	3.37									
2	5	0.00	67.66	-101.30	4.59	0.000	0	0.000	0	1.000	2.35E+03	0.00E+00	0	60.00
		1.30	66.17	-99.02	4.00									

SIGNAL / NOISE CALCULATION -- LINK 2 -- TIME 0:20:00:00 GMT -- FREQ 20.00 MHZ -- 2 HOPS

	NOISE SOURCES(DBW)			TOTAL	TRANS	RECEIVER	
THERMAL	GALACTIC	MAN-MADE	ATMOSPHERIC	NOISE	POWER	POWER	S/N
-174.00	-152.26	-155.76	-149.43	-145.98	30.00	-133.73	12.25

****

MODE GEOMETRY -- ALINK 2. -- TIME 2000.00 GMT -- FREQ 20.00 MHZ -- 3 HOPS

** USING ENHANCED IONOSPHERE ***** NOTICE ***** THIS FREQUENCY IS ABOVE THE MUF **

F90	F50	F10	FREQ	PROB
7.60	13.92	19.09	20.00	0.03

FAILED TO FIND F2 REFLECTION POINT

****

MODE GEOMETRY -- ALINK 2. -- TIME 2000.00 GMT -- FREQ 20.00 MHZ -- 4 HOPS

** USING ENHANCED IONOSPHERE ***** NOTICE ***** THIS FREQUENCY IS ABOVE THE MUF **

F90	F50	F10	FREQ	PROB
7.43	11.08	15.74	20.00	0.01

RAY PENETRATED F2 LAYER.

Table 21. Summary HF propagation output.

** PROPAGATION SUMMARY FOR LINK 2 AT 0:20:00:00 GMT **

	NODE #	NODE NAME	LATITUDE (DEG N)	LONGITUDE (DEG E)	ALTITUDE (KM)	AZIMUTH (DEG)	RANGE (KM)
TRANSMITTER	4.	WASHINGTON, D.C.	38.55	-77.00	0.00	342.48	3773.15
RECEIVER	7.	CAMBRIDGE BAY, CANADA	69.00	-105.00	0.00	138.93	

YEAR	MONTH	DAY	TIME(GMT)	SSN	KP	SOLAR	WINDS
1984.	4.	1.	0:20:00:00	117.	4.	0.	1.

TRANSMITTER POWER (KW)	1.00	IONOSPHERIC MODEL	RADC (POLAR)
NOISE TEMP (DEG KELVIN)	288.00	MAN-MADE NOISE CLASS	REMOTE
RECEIVER BANDWIDTH (HZ)	1000.00	SURFACE TYPE	LAND

DECILE FREQUENCIES

HOPS	F(90%) (MHZ)	F(50%) (MHZ)	F(10%) (MHZ)
1	19.3	27.1	32.0
2	13.7	19.9	25.3
3	9.6	13.9	18.1
4	7.4	11.1	15.7

FREQ (MHZ)	PROB	MODE	DELAY (MS)	LAUNCH ELEV (DEG)	LAUNCH DAZM (DEG)	RECEIVED ELEV (DEG)	RECEIVED DAZM (DEG)	LOSSES FREE (DB)	LOSSES D-AMB (DB)	LOSSES D-NUC (DB)	LOSSES OTHER (DB)	POWER SIGNAL (DBW)	POWER NOISE (DBW)	S/N (DB)
10.00 F	0.99	1-												
10.00	0.99	2-EE	12.3	1.6	0.0	1.7	0.0	124.1	26.1	0.0	12.3	-132.5	-143.8	11.3
10.00	0.99	3-EEE	12.9	6.1	0.0	6.2	0.0	124.2	32.7	11.6	20.4	-158.9	-143.8	-15.1
10.00	0.63	4-*FFF	14.5	26.4	1.2	23.7	-1.5	125.2	17.9	16.9	33.9	-163.3	-143.3	-20.0
11.03 M	0.50	4-FFFF	14.8	29.7	1.2	24.1	-2.1	126.3	14.2	11.9	34.0	-156.5	-144.7	-11.8
13.92 M	0.50	3-FFF	14.1	21.9	0.7	19.2	-0.8	127.8	9.0	14.7	23.3	-145.3	-146.0	0.7
19.92 M	0.50	2-FF	13.6	14.7	0.5	10.5	-0.6	130.6	4.4	14.4	13.1	-132.6	-147.0	14.4
20.00	0.90	1-F	13.3	1.7	0.1	1.4	-0.1	130.5	3.8	0.0	3.0	-107.3	-147.0	39.7
20.00 E	0.50	2-FF	13.4	11.5	0.3	10.7	-0.3	130.5	4.3	15.5	12.8	-133.7	-147.0	13.2
20.00 F	0.03	3-												
20.00 F	0.01	4-												
27.12 M	0.50	1-F	12.4	1.6	0.0	3.1	0.0	133.2	2.1	0.0	3.0	-108.3	-151.6	43.3

(SYM: * = MULTIMODE, M = MUF, E = ENHANCED IONOSPHERE, F = MODE FAILED) appropriate for this link using the great circle distance from the transmitter to the receiver. In this case the G.C. distance is 3778 km which translates into a minimum of 1 hop and a maximum of 4 hops. Printouts from the 1, 2, 3, and 4 hop propagation calculations are shown in Table 20, separated by lines of equal signs. The printouts for the successful 1 and 2 hop modes are further subdivided into three subsections labeled "MODE GEOMETRY", "PROPAGATION LOSSES" and "SIGNAL/NOISE CALCULATION".

Within the mode geometry section the first printout has the following labels:

F90 - upper decile frequency (MHz)

F50 - median frequency (MHz)

F10 - lower decile frequency (MHz)

FREQ - frequency being used (MHz)

PROB - probability that the given frequency will propagate

These quantities give an indication of the variability one can expect over time in the ambient ionosphere's ability to support the given mode. The F90, F50, and F10 frequencies should propagate 90%, 50%, and 10% of the time with the F50 frequency being the N-hop MUF during median ionospheric conditions. The probability that the given frequency will propagate is computed from the three decile frequencies assuming a chi-squared distribution.

In some cases the frequency used is above the F50 frequency (or MUF). Since frequencies above the MUF have a reduced chance of propagating during median ionospheric conditions, the ionosphere is artifically "enhanced" to its lower decile level in order to obtain useful information about this frequency that otherwise would be lost. Whenever this happens the message "** USING ENHANCED IONOSPHERE **..." is printed. The 2, 3, and 4 hop printouts in Table 20 all display this message. In the 2-hop case the frequency (20 MHz) is slightly above the 2-hop MUF and well below the 2-hop lower decile frequency, so propagation is possible with the ionosphere "enhanced" to the 10% level. However, both the 3 and 4 hop lower decile frequencies are below 20 MHz so the 3 and 4 hop modes fail, even with the enhancement.

Moving along to the second printout in the mode geometry section the following labels are seen:

ELEVATION	-	transmitted and received elevation angles (deg)
AZIMUTH	-	transmitted and received azimuth angles (deg) (measured relative to G.C. azimuth angle, positive clockwise)
TIME DELAY	-	group time delay (ms)
RAY PATH	-	ray path distance (km)

Under the title "INTERMEDIATE RESULTS" are several quantities which show the intermediate steps in the mode geometry calculation. The headings are:

POINT	-	breakpoint along the raypath (point 1 is the transmitter; point 2 is the first ionospheric virtual reflection point; point 3 is the receiver for 1 hop modes or the first ground reflection point for multihop modes; etc.)
EQUAL SPACING	-	latitude and longitude (deg N, E) of equally spaced points along the great circle path from transmitter to receiver
SINGLE HOP V.H.	-	virtual reflection heights (km) after sequentially accounting for the effects of the F2, F1 and E layers at each hop
EQUAL ANGLES	-	latitude and longitude (deg N, E) of breakpoints after adjusting for equal angles of incidence and reflection

ALONG G.C. - tilt (deg), displacement (km) and new virtual height (km) after accounting for ionospheric gradients parallel to the great circle path

ACROSS G.C. - tilt (deg) and displacement (km) due to ionospheric gradients perpendicular to the great circle path

The last printout in the mode geometry section shows the final mode geometry. Under the title "FINAL AMBIENT BREAKPOINTS" are the headings "POINT", "LAT", "LON", "V.H." and "LAYER" which need no further explanation except that the latitude and longitude are in degrees (north and east) and the virtual height in kilometers.

Immediately after the "PROPAGATION LOSSES..." heading, losses in signal power are shown broken down into four categories depending on the mechanism which caused the loss. The labels are:

FREE - free space loss (dB)

AMBIENT - losses due to ambient D-region absorption (dB)

NUCLEAR - excess nuclear induced absorption in the D-region (dB)

OTHER - losses due to various other mechanisms: ground reflection and scattering losses, deviative losses, etc. (dB)

TOTAL - total losses (dB) (sum of the four component losses)

The next printout in Table 20 shows details from the ambient and nuclear D-region absorption calculations. This printout is complicated but also very useful in the interpretation of results. The labels are as follows:

HOP - hop number

POINT - index of endpoint for this pass (point 2 indicates the upward pass on the first hop; point 3 downward pass on the first hop; etc.)

D-PASS (DB)	-	D-region absorption (dB) during this pass (the top number is the excess nuclear absorption; the bottom number is the ambient absorption)
LAT	-	latitude (deg N) of ray path D-region entry and exit points for this pass (the top number is for the intersection with the <u>bottom</u> of the D-region and the bottom number is for the intersection with the <u>top</u> of the D-region)
LON	-	longitude (deg E) of ray path D-region entry and exit points
SECANT	-	secant factor at the ray path D-region entry and exit points
%QGAM CLD	-	percentage of total Q (ion production rate) at altitude ALT due to the largest single gamma source; cloud number of that gamma source
%QBET CLD	-	percentage of total Q at altitude ALT due to the largest single beta source; cloud number of that beta source
%QAMB	-	percentage of total Q due to ambient conditions at altitude ALT
NE (Q)	-	electron density (cm^{-3}) due to Q at altitude ALT
NE (XR) CLD	-	electron density (cm^{-3}) at altitude ALT due to the largest single X-ray source; cloud number of that X-ray source
ALT	-	altitude (km) of the largest single contribution to the total absorption on this pass

As an example of the utility of this printout in interpreting results refer to the 1-hop and 2-hop printouts shown in Table 20. The 1-hop mode shows an ambient D-region absorption loss (AMBIENT) of 3.82 dB and an excess nuclear D-region absorption loss (NUCLEAR) of 0.00 dB. In contrast the 2-hop mode shows an ambient loss of 4.86 dB and an excess nuclear loss of 15.55 dB. Why are the losses so much higher in the 2-hop case?

The difference in the ambient absorption is easily explained by the fact that the 2-hop path has 4 D-region crossings while the 1-hop path has only 2. Thus the total absorption is greater for 2-hops than for 1-hop even though each pass in the two hop case has less dB due to different secant factors. (1.09, 1.20, 1.25 and 1.32 dB for the 2-hop path versus 1.79 and 2.03 for the 1-hop path.)

The difference in the excess nuclear absorption between the 1-hop and 2-hop modes can be explained by two observations. The first is that the only source of nuclear absorption shown in the printout is cloud 2, seen under the "%QGAM CLD" heading for both modes. (Cloud 2 is a subsiding debris cloud located at 40.044°N, -79.852°E and 28.348 km, according to the printout in Table 18.) The second observation is that the geometry for a 1-hop mode is quite different from that of a 2-hop mode, especially in the location of the D-region crossings. The D-region crossings of interest in this case are the ones closest to Washington. As shown in Table 20, the 1-hop path enters the D-region at 43.25°N, and -79.01°E (approximately 360 km from the cloud) while the steeper 2-hop path enters at 40.13°N and -77.64°E approximately 190 km from the cloud). Referring back to Figure 1, the cloud is approximately in the same location as the burst, marked by an asterisk, and the 1-hop and 2-hop D-region entry points are marked with a 1 and a 2, respectively. Now it is easy to see how this difference in excess nuclear absorption came about, and also how mode geometry can sometimes play a crucial role in nuclear effects calculations.

Moving on to the signal and noise calculation printouts (in Table 20 again) we find the following labels under the "*NOISE SOURCES (DBW)*" title:

THERMAL	-	receiver thermal noise (dBW)
GALACTIC	-	attenuated galactic noise (dBW)
MAN-MADE	-	man-made (local) noise (dBW)
ATMOSPHERIC	-	attenuated atmospheric (thunderstorm) noise (dBW)
TOTAL NOISE	-	total noise power (dBW) at receiver

These noise values reflect the effective transmitted power of the different noise sources as well as propagation losses (for galactic and atmospheric noise) and the bandwidth of the receiver. To the right of the noise printout are the following quantities:

TRANS POWER	-	transmitted signal power (dBW)
RECEIVED POWER	-	received signal power (dBW) (= transmitted power - propagation losses)
S/N	-	signal to noise ratio (dB) (= received power - total noise)

In many applications the signal to noise ratio is the "bottom line", but as seen above many of the quantities provided in the detailed output are needed for the proper interpretation of results.

The summary HF propagation output in Table 21 contains much of the same information as the detailed output in Table 20. One thing that should be noticed however, is that <u>all</u> modes calculated for this link at this time are included in the summary output, even though they may have been calculated during separate HF calculation events. In this case the modes for 10 MHz and the various MUFs are shown in Table 21 in addition to the 20 MHz modes. The summary output has two headings that require some explanation:

SYM - symbol explaining something about this mode:

* = computed during a "multimode" calculation

M = this is the N-hop MUF

E = computed using "enhanced" ionosphere

F = mode failed to propagate

MODE - number of hops and the reflecting layer for each hop

E = E-layer reflection

* = F1-layer reflection

F = F2-layer reflection

3.6 PLUME MODE PROPAGATION OUTPUT

Output from the plume mode calculation is also available at two levels of detail. Table 22 shows the detailed plume mode output generated during the plume mode calculation at 20:00 GMT. This output can be turned on or off using the $PLCALC print flag. Summary plume mode output, on the other hand, is produced automatically during any plume mode calculation event. An example of plume mode summary output is shown in Table 23 for the Santa Barbara to Big Fork link at 20:00 GMT.

Referring to Table 22, the plume mode calculation event notice line is followed by printouts of the plume modes for each link. In this case two plume modes were found for the Santa Barbara to Big Fork link and none were found for the other two links. The following quantities appear on the first line of output for each successful plume mode:

CLOUD - number of cloud supporting plume mode

TYPE - type of plume mode; three types are defined:

SIDE - side mode off of field aligned plasma

BASE - forward scatter off of plume base

ISOT - isotropic scatter off of plume base

LAT - latitude (deg N) of reflection point

Table 22. Detailed plume mode output.

```
****************************************************************************************************************************
* PLUME MODE CALCULATION EVENT AT TIME =  1000.00 GMT -- LINK =     0. -- FREQ =     0.00 MHZ -- NCLOUDS =     4           *

  **********************************************************
  * SANTA BARBARA, CALIF.     * BIGFORK, MONTANA          *
  **********************************************************

  2 POSSIBLE PLUME MODES FOUND FOR THIS LINK.

                  **********

CLOUD     TYPE      LAT      LON      ALT     V.H.     FREQ    CFREQ    SIGMA     DELAY     ELT      AZT      ELR      AZR
   3.     BASE    41.15  -116.93   233.54   233.64   100.00   340.30 3.30E+05     5.64    12.93     0.00    12.93     0.00

                  FPLAT    FPLON   FPRMIN   FPRMAJ      GRT
                  50.22  -113.21   424.44   466.21   452.13

    FREE  AMBIENT  NUCLEAR     OTHER     TOTAL
  140.59     0.14     0.47     10.00    151.19

PASS   PASS DB      LAT       LON    SECANT      %OGAM  CLD     %OBET  CLD     %OAMB      NE (O)     NE (XR)  CLD       ALT

  1       0.13    35.70   -119.94      4.04      0.373    6     0.016    4     0.011    6.33E+02    2.63E+01    6     50.00
          0.07    37.30   -119.40      3.63

  2       0.21    46.57   -114.69      4.04      0.395    6     0.000    0     0.005    8.64E+02    2.63E+01    6     50.00
          0.07    44.93   -115.41      3.63

                 NOISE SOURCES                           TOTAL TRANSMITTED    RECEIVED
  THERMAL    GALACTIC    MAN-MADE ATMOSPHERIC            NOISE       POWER       POWER       S/N
  -174.00     -167.27     -300.00     -300.00          -166.93       50.00     -121.18     45.74

                  **********

CLOUD     TYPE      LAT      LON      ALT     V.H.     FREQ    CFREQ    SIGMA     DELAY     ELT      AZT      ELR      AZR
   5.     ROOT    42.03  -119.72   233.64   233.64   100.00   331.73 1.00E+01     5.34    10.31   -14.30    13.62    16.65

    FREE  AMBIENT  NUCLEAR     OTHER     TOTAL
  131.07     0.15     0.49      0.00    131.71

PASS   PASS DB      LAT       LON    SECANT      %OGAM  CLD     %OBET  CLD     %OAMB      NE (O)     NE (XR)  CLD       ALT

  1       0.23    36.01   -119.39      4.55      0.376    5     0.014    4     0.010    6.72E+02    2.63E+01    6     60.00
          0.08    37.58   -119.77      4.01

  2       0.27    46.33   -115.20      3.85      0.395    5     0.000    0     0.005    8.62E-02    2.63E+01    6     60.00
          0.30    45.52   -116.46      3.49

                 NOISE SOURCES                           TOTAL TRANSMITTED    RECEIVED
  THERMAL    GALACTIC    MAN-MADE ATMOSPHERIC            NOISE       POWER       POWER       S/N
  -174.00     -157.37     -300.00     -300.00          -166.93       30.00     -131.71      5.21

  **********************************************************
  * WASHINGTON, D.C.          * CAMBRIDGE BAY, CANADA     *
  **********************************************************

  0 POSSIBLE PLUME MODES FOUND FOR THIS LINK.

  **********************************************************
  * SANTA BARBARA, CALIF.     * WASHINGTON, D.C.          *
  **********************************************************

  0 POSSIBLE PLUME MODES FOUND FOR THIS LINK.
```

Table 23. Summary plume mode output.

** PLUME MODE PROPAGATION SUMMARY FOR LINK 1 AT 0:20:00:00 GMT **

	NODE (#)	NODE NAME	LATITUDE (DEG N)	LONGITUDE (DEG E)	ALTITUDE (KM)	AZIMUTH (DEG)	RANGE (KM)
TRANSMITTER	1.	SANTA BARBARA, CALIF.	34.25	-119.41	0.00	14.77	1593.68
RECEIVER	2.	BIGFORK, MONTANA	46.00	-114.00	0.00	198.35	

YEAR	MONTH	DAY	TIME(GMT)	SSN	KP	SOLAR	WINDS
1984.	4.	1.	0:20:00:00	113.	4.	0.	1.

TRANSMITTER POWER (KW)	1.00	IONOSPHERIC MODEL	AEROSPACE
NOISE TEMP (DEG KELVIN)	288.00	MAN-MADE NOISE CLASS	RURAL
RECEIVER BANDWIDTH (HZ)	1000.00	SURFACE TYPE	LAND

				REFLECTION POINT			LAUNCH		RECEIVED		LOSSES		POWER		
FREQ (MHZ)	MODE	DELAY (MS)	CLD	N.LAT (DEG)	E.LON (DEG)	ALT (KM)	ELEV (DEG)	DAZM (DEG)	ELEV (DEG)	DAZM (DEG)	D-NUC (DB)	TOTAL (DB)	SIGNAL (DBW)	NOISE (DBW)	S/N (DB)
100.00	BASE	5.6	5	41.2	-117.0	239.6	12.3	0.0	12.3	0.0	0.5	151.2	-121.2	-166.9	45.7
100.00	ISOT	5.8	5	42.2	-119.3	239.6	10.8	-14.3	13.6	16.6	0.5	191.7	-161.7	-166.9	5.2

LON - longitude (deg E) of reflection point

ALT - actual altitude (km) of reflection point

V.H. - virtual height (km) of reflection point

FREQ - frequency (MHz)

CFREQ - critical frequency (MHz) - maximum frequency that would reflect*

SIGMA - reflecting cross section (km^2)*

DELAY - group time delay (ms)

ELT - elevation angle (deg) at transmitter

AZT - azimuth angle (deg) at transmitter (measured relative to G.C. path, positive clockwise)

ELR - elevation angle (deg) at receiver

AZR - azimuth angle (deg) at receiver (measured relative to G.C. path, positive clockwise)

These quantities describe the basic geometry of the plume mode.

For forward scatter base modes a second line of printout is also provided which describes the "footprint" region:

FPLAT - latitude (deg N) of footprint center

FPLON - longitude (deg E) of footprint center

FPRMIN - minor radius (km) of footprint

FPRMAJ - major radius (km) of footprint

GRT - ground range (km) from footprint center to receiver

The "footprint" is an elliptical region on the surface of the earth illuminated by rays propagating from the transmitter and bouncing off of the base of the plume (assumed to act like a mirror). If the receiver is in or very near this region then these forward scatter plume base modes are predicted.

---

* See Reference 2 for explanations of these quantities.

The remainder of the plume mode detailed output consists of the propagation loss printout, the detailed D-region absorption printout and the noise, signal and S/N printout. These printouts have exactly the same format and meaning as their counterparts in the HF propagation output explained above.

As can be seen by comparing Tables 22 and 23, the plume mode summary output contains a subset of what the detailed output contains, presented in a more concise format. Also provided in the summary output are link, node and ambient environment parameters, included to reduce the amount of "page flipping" required on the part of the reader.

3.7 SIMULATION STOP OUTPUT

At the end of the simulation HFNET reports the status of the event list and dynamic storage in the same format as at the beginning. It is interesting to compare the situation at the end of the test problem run (shown in Table 24) with that at the start (shown in Table 14). Note that the event list at the end of the run still contains events to be executed: 4 cloud updates, a cloud list output event, 2 HF calculation events and a plume mode calculation event. Also note that dynamic storage has a great deal more structure than it did at the beginning and that well over 30,000 calls were made to dynamic storage routines during the run. These observations reveal two important aspects of HFNET's simulation structure. One is that the simulation would continue executing events (mostly cloud updates) forever if it weren't for the stop event. The second is that dynamic storage is truly the heart of the simulation structure from which the rest of the program obtains its sustenance (events and data).

One additional printout is provided at the end of a run. This is the event/module runtime statistics table seen at the bottom of Table 24. In addition to displaying the total number of events executed and

Table 24. Simulation stop output.

```
* HFNET EVENT LIST CONTAINS    8 EVENTS * THE FIRST    8 EVENTS ARE LISTED BELOW *

EVENT     TIME     TYPE    NAME                              EVENT DATA

  1      2001.32     6    UPDATE..     7.206E+04  6.000E+00  4.000E+00  5.000E+00  0.000E+00  0.000E+00  0.000E+00  1.000E+01
                                       0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
  2      2002.02     6    UPDATE..     7.212E+04  6.000E+00  5.000E+00  4.000E+00  0.000E+00  0.000E+00  0.000E+00  1.000E+01
                                       0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
  3      2001.17     6    UPDATE..     7.214E+04  6.000E+00  6.000E+00  5.000E+00  0.000E+00  0.000E+00  0.000E+00  1.000E+01
                                       0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
  4      2036.31     6    UPDATE..     7.419E+04  6.000E+00  2.000E+00  5.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
                                       0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
  5      2100.00    21    CLDOUT..     7.560E+04  2.100E+01  1.000E+01  1.548E+05  3.600E+03  0.000E+00  0.000E+00  0.000E+00
                                       0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
  6      2100.00     4    HFCALC..     7.560E+04  4.000E+00  1.548E+05  3.600E+03  0.000E+00  1.000E-07  0.000E+00  0.000E+00
                                       0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
  7      2100.00     4    HFCALC..     7.560E+04  4.000E+00  1.548E+05  3.600E+03  0.000E+00 -1.000E+07  0.000E+00  0.000E+00
                                       0.000E+00  1.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
  8      2100.00    10    FLCALC..     7.560E+04  1.000E+01  1.548E+05  3.600E-03  0.000E+00  0.000E+00  1.000E+00  0.000E+00
                                       0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00


***** DYNAMIC LIST STORAGE MEMORY MAP *****      TOTAL CALLS =     33363    TOTAL CPU TIME =     30.31

      LIST STORAGE PARAMETER VALUES
 MAXSOM NAPREC NUMREC NRECIN LOCMIN LOCMAX LOCTOP IAVAIL IABOVE NUBOVE NOVPHD MAXDIF NULOST NSWAPS MAXNAM NUMNAM LST
  50000     1      0      1      1  50000  21560    322  17931     36      3     10      7      0     20     10   1

      LIST NAMES AND LIST POINTERS
  LIST    LIST          LIST POINTERS
 NUMBER   NAME      END    ACCESS   NXTSET

    1     EVNT     17970    17970    17970
    2     NODE       146      146        0
    3     LINK       233      233      233
    4     WDML      2222     1625        0
    5     WDTH      2933     1537        0
    6     [illegible] 13931  13931        0
    7     [illegible]    0        0        0
    8     [illegible] 18167  18167    18167
    9     [illegible] 17989  18095        0
   10     FLUM         0        0        0

      STORAGE MAP OF DATA LISTS
  LIST    LIST   RECORD  DATASET ABSOLUTE RELATIVE        DATASET HEADER            TOTAL
 NUMBER   NAME   NUMBER   NUMBER  ADDRESS  ADDRESS      NEXT     LIST     NWDS    SETS    WORDS

    1     EVNT      1        1    18221    18221        20     EVNT      16
    1     EVNT      1        2       20       20     18148     EVNT      16
    1     EVNT      1        3    18148    18148        39     EVNT      16
    1     EVNT      1        4       39       39        58     EVNT      16
    1     EVNT      1        5       58       58       265     EVNT      16
    1     EVNT      1        6      265      265       234     EVNT      16
    1     EVNT      1        7      234      234     17970     EVNT      16
    1     EVNT      1        8    17970    17970     18221     EVNT      16
                                                                                     8      128
    2     NODE      1        1       77       77       100     NODE      20
    2     NODE      1        2      100      100       123     NODE      20
    2     NODE      1        3      123      123       146     NODE      20
    2     NODE      1        4      146      146        77     NODE      20
                                                                                     4       80
    3     LINK      1        1      169      169       201     LINK      10
    3     LINK      1        2      201      201       233     LINK      10
    3     LINK      1        3      233      233       169     LINK      10
                                                                                     3       30
    4     WDML      1        1        1        1       377     WDML       9
    4     WDML      1        2      377      377       389     WDML       9
    4     WDML      1        3      389      389       401     WDML       9
    4     WDML      1        4      401      401       413     WDML       9
    4     WDML      1        5      413      413       425     WDML       9
    4     WDML      1        6      425      425       437     WDML       9
    4     WDML      1        7      437      437       449     WDML       9
    4     WDML      1        8      449      449       461     WDML       9
    4     WDML      1        9      461      461       473     WDML       9
    4     WDML      1       10      473      473       485     WDML       9
                                                                                   216     1944
```

Table 24. (cont.)

5	WDMH	1	1	341	341	665	WDMH	33		
5	WDMH	1	2	665	665	989	WDMH	33		
5	WDMH	1	3	989	989	1313	WDMH	33		
5	WDMH	1	4	1313	1313	1637	WDMH	33		
5	WDMH	1	5	1637	1637	1961	WDMH	33		
5	WDMH	1	6	1961	1961	2285	WDMH	33		
5	WDMH	1	7	2285	2285	2609	WDMH	33		
5	WDMH	1	8	2609	2609	2933	WDMH	33		
5	WDMH	1	9	2933	2933	341	WDMH	33		
									9	297
6	IONO	1	1	3245	3245	18402	IONO	1576		
6	IONO	1	2	18402	18402	19981	IONO	1576		
6	IONO	1	3	19981	19981	3245	IONO	1576		
									3	4728
8	CLOD	1	1	18294	18294	18240	CLOD	51		
8	CLOD	1	2	18240	18240	18348	CLOD	51		
8	CLOD	1	3	18348	18348	18167	CLOD	51		
8	CLOD	1	4	18167	18167	18294	CLOD	51		
									4	204
9	NOIS	1	1	18095	18095	18042	NOIS	50		
9	NOIS	1	2	18042	18042	17989	NOIS	50		
9	NOIS	1	3	17989	17989	18095	NOIS	50		
									3	150

STORAGE MAP OF AVAIL LIST

RECORD NUMBER	NODE NUMBER	ABSOLUTE ADDRESS	RELATIVE ADDRESS	NEXT	NODE HEADER LIST	NWDS	ISON	TOTAL SETS	WORDS
1	1	322	322	17931	EVNT	16	0		
1	2	17931	17931	17873	PLUM	36	322		
1	3	17873	17873	303	PLUM	55	17931		
1	4	303	303	4824	EVNT	16	17873		
1	5	4824	4824	214	[illegible]	13046	303		
1	6	214	214	246	EVNT	16	4824		
1	7	246	246	182	EVNT	16	214		
1	8	182	182	0	EVNT	16	246		
								8	13217

* HENET RUNTIME STATISTICS - 593 EVENTS EXECUTED, 199.390 CP SECONDS *

EVENT	TIMES	CP SEC	MEAN	MIN	MAX
1	1	4.140	4.140	4.140	4.140
3	2	0.550	0.275	0.060	0.490
4	4	131.600	32.900	11.770	55.010
6	575	17.040	0.030	0.010	0.100
7	3	26.380	8.793	2.010	19.940
8	2	0.290	0.145	0.130	0.160
10	2	4.570	2.285	1.770	2.800
13	1	0.080	0.080	0.080	0.080
15	1	1.140	1.140	1.140	1.140
21	2	0.570	0.285	0.250	0.320

MODULE	CALLS	CP SEC	MEAN	MIN	MAX
1	1	2.140	2.140	2.140	2.140
2	2	2.430	1.215	0.440	1.990
3	2	0.390	0.195	0.060	0.330
4	4	131.570	32.893	11.750	55.900
5	579	0.640	0.001	0.000	0.140
6	575	15.930	0.028	0.010	0.100
7	3	24.590	8.197	1.900	18.390
8	2	0.060	0.030	0.010	0.050
10	2	4.570	2.285	1.770	2.800
12	1	0.030	0.030	0.030	0.030
13	1	0.080	0.080	0.080	0.080
15	1	1.140	1.140	1.140	1.140
17	3	1.770	0.590	0.110	1.540
20	577	0.210	0.000	0.000	0.010
21	2	0.570	0.285	0.250	0.320

the amount of CPU time they took to execute (593 events and 188.380 seconds in this case) the following quantities are shown:

- EVENT - event number (see Appendix A)
- TIMES - number of times this event was executed
- MODULE - module number (see Appendix A)
- CALLS - number of times this module was called
- CP SEC - total CPU time (sec) used by this event or module
- MEAN - mean CPU time (sec) used by this event or module
- MIN - minimum CPU time (sec) used by this event or module
- MAX - maximum CPU time (sec) used by this event or module

This printout can be extremely useful in understanding the workings of the simulation and also in locating where the code spends most of its time. In this case the majority of the time (131.600 seconds) was spent executing HF propagation calculation events (event 4's). As can be seen by comparing this table with the tables of events and modules in Appendix A, almost all of the defined events and modules in the program were exercised during this test problem.

3.8 DEBUG OUTPUT

Debug output is optionally produced by most major HFNET modules and subroutines. This type of output is only produced when requested by the user on the $DEBUG data line. The quantities, units, and labels are peculiar to the routine producing the output. An effort has been made to provide ample debug print statements with clear labels for routines where such output might be found useful in the location and extermination of bugs. However, since the authors of the code suffer from human limitations in the prediction of their own errors, inadequacies in debug output can be anticipated. A fairly deep understanding of the workings of the HFNET code and a listing of the FORTRAN are prerequisites to the successful interpretation of debug output. Naturally the creators of the code would appreciate hearing about any bugs found and/or fixed by users.

3.9 TROUBLE OUTPUT

Many subroutines in the HFNET code make tests for the reasonableness, consistency and existence of data on which they are instructed to operate. Should such a test fail, an error message is normally printed and the program aborted by a call to subroutine ABORT. This routine then prints a message telling which subroutine requested the abortion and the line number in that routine where the trouble was detected. ABORT will also attempt to provide additional information which may prove useful in locating the source of the problem.

In addition to the program stopping due to errors that are discovered and reported by the code itself, it is also possible that the program execution may be interrupted due to errors caught by the hardware, the operating system or the FORTRAN run-time system. Problems of this sort are usually the result of programming errors, but sometimes are due to bad input data. The normal course of events when this happens is that some sort of cryptic error message is supplied by the system, a core dump and/or a subroutine call traceback is provided, and the job is terminated. Of course, in theory, if the computer is working properly, the input is reasonable, and no bugs reside in the code, no such problems will occur.

REFERENCES

1. Fajen, F. E., MICE: An Implicit Difference Scheme for MHD Calculations, DNA 2877I, MRC-R-12, Mission Research Corporation, March 1972 (U).

2. Schlueter, W. A., and Sowle, D. H., HFNET: A Computer Program to Calculate Nuclear Effects on HF/VHF Communications Systems, Volume 1: Description of Physical Models, MRC-R-515, November 1979 (U).

3. Bogusch, R. L., A Flexible Data Storage and Retrieval System, MRC-N-239, Mission Research Corporation, March 1976 (U).

APPENDIX A

SIMULATION STRUCTURE

HFNET is a forward-running event-sequenced simulation that employs a flexible, modular logical structure. In a very real sense, HFNET consists of several independent simulations which operate under the control of an overall simulation "manager", as depicted conceptually in Figure A.1. In this chart, the ambient environment simulation contains descriptions of the location and characteristics of all transmitters and receivers as well as models of various "ambient" phenomena such as RF noise, atmospheric winds and natural ionospheric conditions. The nuclear environment simulation includes time-dependent specification of the location and properties of debris regions formed by nuclear bursts. In other words, the ambient and nuclear environment simulations together model the "real world" in which the propagation simulation must operate. Finally, the propagation simulation computes what effects this modeled environment may have on signals propagating through it.

The basic HFNET simulation control structure is illustrated in Figure A.2. As shown, the simulation consists of a number of distinct modules that are interconnected by the simulation manager. A module is a subroutine (or collection of subroutines) which is a self-contained simulation of a specific part of the overall simulation. Modules are only called by the simulation manager, never by any other module, and have no calling arguments. All necessary inputs are obtained from the event data list and from appropriate dynamic storage lists or labeled common blocks. The modules contained in the current version of HFNET are listed in Table A.1. Modules can readily be added or deleted to meet the requirements of each application.

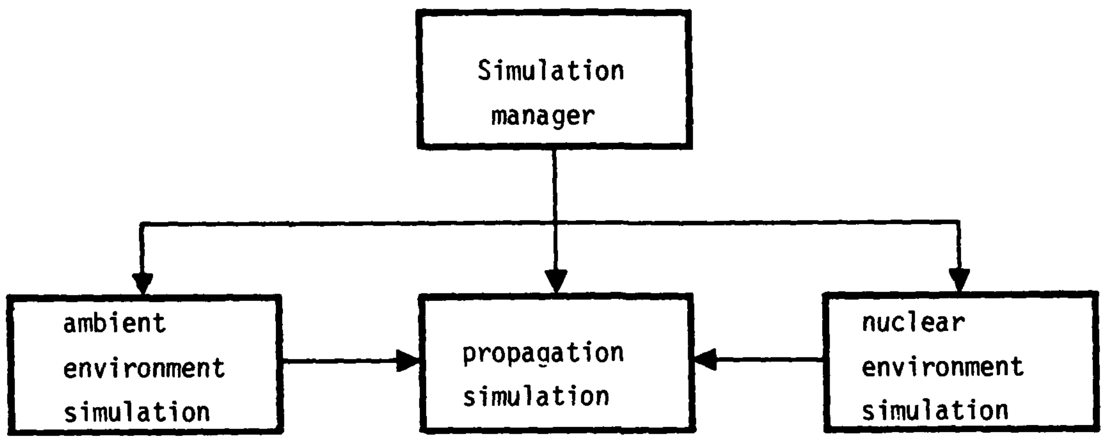

Figure A.1. HFNET conceptual block diagram.

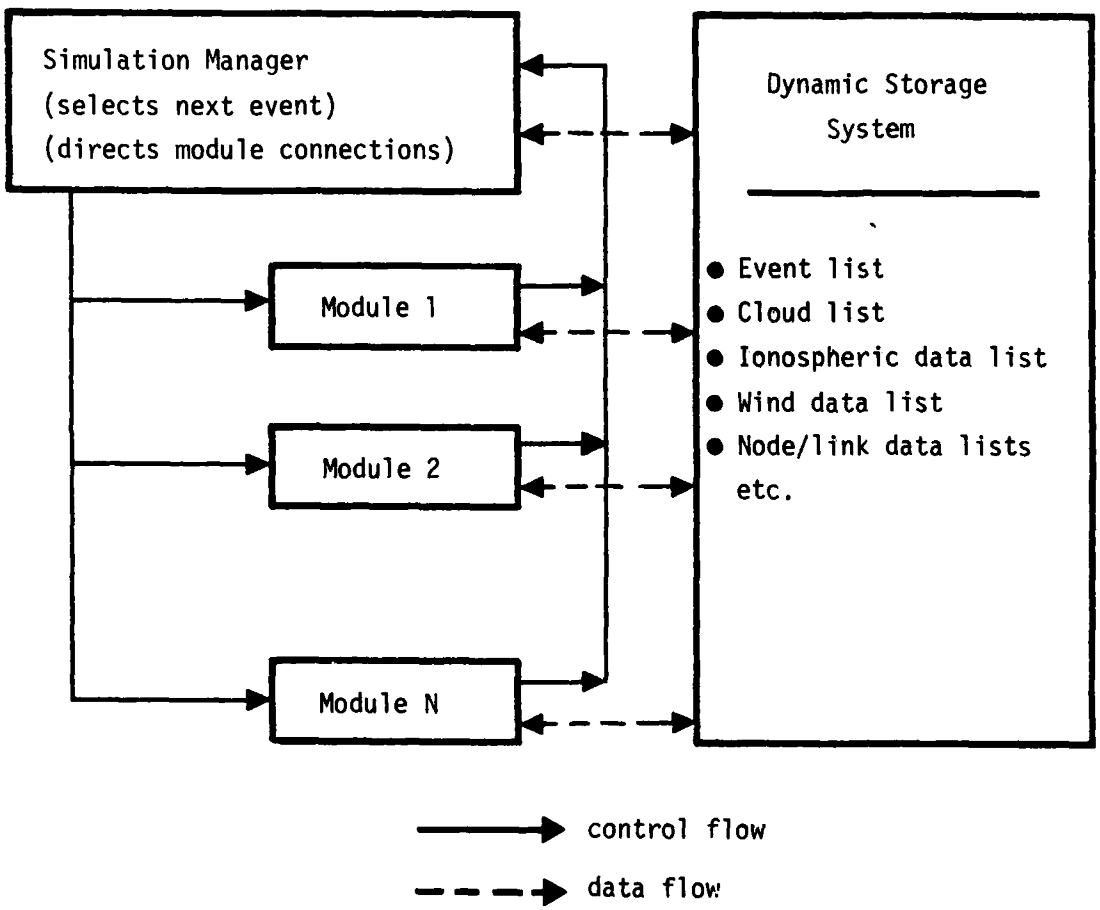

Figure A.2. HFNET simulation structure.

Table A.1. HFNET modules.

Module #	Module Description	Event(s)
1	data input	1
2	simulation start/stop output	1, 2
3	nuclear burst (cloud creation)	3
4	HF propagation calculation	4
5	output for cloud creation/update/split events	3, 6, 8
6	cloud update	6
7	compute ionospheric data tables	7
8	cloud split	8
10	HF/VHF plume mode propagation	10
12	end of run housekeeping	2
13	start of run housekeeping	13
15	read wind model database	15
17	output for ionospheric data tables	7
20	output cloud data for plotting	3, 6
21	cloud list output	21
22	output contour plot data	22
23	cloud list input	23

(Modules 9, 11, 14, 16, 18, 19, 24, and 25 are available for future use.)

The simulation is time-ordered and advances by means of "events" which are user input or generated internally. A HFNET simulation event is defined to be any occurrence that requires a particular sequence of calculations to be performed at a specified simulation time. For example, a sequence of calculations which constitute the event "HF propagation calculation" might include: 1) calculation of the maximum useable frequency (MUF); 2) calculation of the upper and lower decile frequencies; 3) computation of the probability of mode occurrence; 4) determination of the ray path geometry; 5) calculation of propagation losses, noise power, received signal strength and signal-to-noise ratio; and 6) printing the results. For structural purposes these calculations are considered to occur simultaneously even though, strictly speaking, some small amount of "real" time does pass due to propagation delays.

Events may be generated in any time order by any module and are stored in the event list which is processed by the simulation manager. Each event has an event dataset associated with it which contains the required information to process the event. The event dataset structure is, in general, defined differently for each type of event. However, the first two words of every event dataset specify the event time and the event type. Table A.2 shows the event types defined in the current version of HFNET.

HFNET modules and HFNET events are interconnected by means of an "event transfer list". The event transfer list is operationally a part of the simulation manager and specifies, for each event, the sequence in which modules are to be called to execute the event. This module transfer list is set in a data statement and can readily be altered to redefine an event or to add new events as applications dictate. The last column in both Tables A.1 and A.2 show these event/module interconnections and are, in fact, representations of the module transfer list.

Table A.2. HFNET events.

Event #	Event Description	Module(s)
1	start simulation/read input	1, 2
2	stop simulation	2, 12
3	nuclear burst/cloud creation	3, 5, 20
4	HF propagation calculation	4
6	cloud update	6, 5, 20
7	initialize ionospheric model	7, 17
8	cloud split	8, 5, 20
10	HF/VHF plume mode propagation calculation	10
13	dynamic storage cleanup	13
15	initialize wind model	15
21	cloud list output	21
22	contour plots	22
23	cloud list input	23

(Events 5, 9, 11, 12, 14, 16-20, 24 and 25 are available for future use.)

The HFNET simulation structure is set up to allow individual modules to perform calculations on a time scale which is consistent with the requirements of the objects or processes being simulated. Interpolation procedures are used to provide this flexibility. Data computed and stored by a module at time intervals determined by it's own accuracy requirements can then be accessed and interpolated by other modules operating at higher (or lower) simulation rates. The primary example of this in HFNET is the interaction between the nuclear environment simulation and the propagation simulation.

The user can specify the location, time, yield, etc., of any number of nuclear bursts. Once the burst event has been executed and the nuclear debris cloud (fireball) created, the model itself decides the rate at which the cloud data need to be updated. Cloud data are computed and stored in the cloud list at two simulation times which always bracket the current simulation time. Two different clouds, or the same cloud at different points in its development, are generally updated at different rates. For example, low altitude bursts usually require less updating than high altitude ones and cloud phenomenology at late times can normally be updated at a slower rate than at early times.

However, the propagation simulation does not know (or care) about these details in the nuclear environment simulation. What the propagation model needs to know is the location and parameters of all existing nuclear debris regions at the time of an HF skywave or plume mode calculation. An interpolation subroutine (INTERP) is provided to supply this information. This enables the propagation model to work independently of the nuclear environment model and greatly reduces the impact on one model of modifications to the other.

Most of the data in the HFNET simulation, either input data or internally generated data, is stored in a flexible dynamic storage allocation system. This permits large data arrays to be handled efficiently, and avoids the necessity of dimensioning data arrays for the largest number of allowed quantities. The dynamic storage allocation system was developed at MRC and is fully documented in Reference 3. It provides a versatile and easy-to-use capability for data storage and retrieval of dynamically varying data lists and list structures. The dynamic storage data lists used by the current version of HFNET are shown in Table A.3 below.

Table A.3. HFNET dynamic storage data lists.

LIST NAME	DATASET SIZE	DESCRIPTION
EVNT	16	event list
NODE	20	node list
LINK	10	link list
IONO	1576	link ionospheric data tables
CLOD	51	cloud list
NOIS	50	noise calculation scratch storage
PLUM	55	plume mode calculation scratch storage
F77X	183	geomagnetic data temporary storage
WDML	9	median wind model low altitude database
WDMH	33	median wind model high altitude database
WDDI	87	diurnal wind model data base

APPENDIX B
ROUTINES AND COMMON BLOCKS

The HFNET computer code consists of a main program, a block data routine, 195 subroutines and functions, and 40 common blocks. The following sections contain alphabetical lists of these program components along with a brief explanation of each.

B.1 LIST OF HFNET ROUTINES

ROUTINE	DESCRIPTION
ABORT	Provides a subroutine traceback and stops the program whenever a fatal error is detected by any HFNET routine.
ABSORB	Computes incremental D-region absorption given the frequency, electron density and collision frequency.
ACLRX	Clears an array. Alternate entry points: ACLRR and ACLRI.
ADDCLD	Adds a newly created cloud of any type to the cloud list.
AMOVX	Moves an array. Alternate entry points: AMOVR and AMOVI.
ASETX	Sets an array to a specified constant value. Alternate entry points: ASETR and ASETI.
ASWICH	Keeps track of several logical switches relating to the mass entrainment parameter of a rising, expanding fireball.

ATMOSU	Provides mean atmospheric quantities as a function of altitude in an undisturbed atmosphere.
AVWIND	Finds the average wind velocity at the center altitude of a debris cloud by averaging over the vertical thickness of the cloud.
BDRAG	Decelerates the velocity component of a cloud perpendicular to the geomagnetic field line.
BEND	Calculates the amount of deflection a ray suffers while passing through an ionized layer.
BLACK	Black body deposition function.
BLKDAT	Block data routine used to perform compile-time initialization of HFNET common blocks.
BOUNCL	Computes ground reflection and scattering losses as a function of takeoff angle, frequency, and surface type (land or sea).
BSCATR	Geometry routine for plume side scatter modes.
CHI	Computes solar zenith angle as a function of position, time and season.
CHISQ	Calculates cumulative chi-square probability function. Used to compute mode probability as a function of the MUF and upper and lower decile frequencies.
CLIP	1-D clipping function (real).
CLIPM	Generalized modulus function. Finds X modulo I where I = [A, B] is any interval.
CM2KM	Convert centimeters to kilometers.
COLUMN	Computes integrated column density. Used in calculation of X-ray flash electron density and gamma ionization rate (QGAM).

COMB	Used to compute all possible modes for multipath propagation calculation.
COMPUT	Used by the ITS and RADC (polar) models to compute F2 layer critical frequencies from the ITS annual and solar cycle coefficients. Alternate entry: COMPT.
CPATCH	Computes parameters for the creation of a pseudo-fireball in the opposite hemisphere (the conjugate region) to simulate the debris energy patch in that region.
CPUSEC	Returns CPU time used. This routine is specific to the VAX/VMS operating system.
CR2D	Convert co-radians to degrees.
CREATF	Computes initial conditions for a mixed, neutral or ionized fireball given burst location and yield.
CROSPT	Subroutine used to find D-region crossing points and secant factors.
CUBIC	Solves cubic equations. Used by the RADC (polar) model in fitting electron density profiles.
D2CR	onvert degrees to co-radians.
D2R	Converts degrees to radians.
DAMBNT	Determines ambient D-region electron density as a function of altitude, position, solar zenith angle and E-layer critical frequency.
DATAPT	The major interface between the nuclear environment section and the propagation section. Computes electron density and collision frequency at D-region crossing points.

DCROSS	Locates all D-region crossing points for a ray-path.
DEBUG	Tells whether or not debug print has been requested from a given routine.
DELCLD	Deletes a specified cloud from the cloud list.
DELIST	Dynamic storage routine to delete an entire D.S. list.
DELSET	Dynamic storage routine to delete a specified D.S. dataset.
DENS	A function used in RADC model of altitude of maximum electron density in the F2 layer.
DHMS2H	Converts from real DHMS format to hollerith DHMS format.
DHMS2S	Converts real DHMS format to time in seconds.
DISCAT	Calculates distances in the special geomagnetic XYZ coordinate system used in the plume side mode geometry calculation.
DISPLC	Computes displacements due to ionospheric tilts (both parallel and perpendicular to the great circle path.)
DISTNC	A function used by DISCAT.
DPROB	Computes probability of mode occurrence using the MUF and the upper and lower decile frequencies.
ECOMB	Determines E-layer parameters from solar E and sporadic E. Part of the RADC (polar) ionospheric model.
EINT1	Exponential integral of the first kind. Used in D-region electron density calculation.
ELCOL	Computes the location of point 2 given the location of point 1 and the azimuth angle and great circle distance of point 2 from point 1.

ELLIPS	Computes new ellipse radii for an ellipse being perturbed by wind gradients. Part of the late time subsiding debris model.
EQUATR	Subroutine to compute the great circle distance to the equator from any point on the earth given the location of the point and an azimuth angle. Part of the atmospheric noise model.
EXOT	A function called by SCALHT. Used in determining the F2 layer altitude for the RADC (polar) model.
EXPND	Computes the radial expansion of a mixed, ionized, or neutral fireball during a single time step.
F2DIS	Computes upper and lower decile frequencies given the MUF, sunspot number, location of point and time. This routine uses data from the DECILE.BIN data file.
FEX	Computes a function used in determination of the radial expansion of a fireball.
FGENRL	A function used in obtaining auroral region E layer critical frequencies; called by QCHAT.
FLASHC	Computes X-ray flash electron density given initial value of electron density and rate constants.
FOEFUN	Computes E layer critical frequency as a simple analytic function of sunspot number and solar zenith angle.
GEOPT	Converts from geomagnetic (dipole field) to geographic coordinates. This is the inverse routine of subroutine MAGNET.
GETSET	Dynamic storage routine to retrieve a specified D.S. dataset.

GTRANS	Computes atmospheric gamma energy transmission fraction given the column density. Used in calculation of gamma ionization rate (QGAM).
HEAVIS	Interpolates ionospheric parameters (layer critical frequency, altitude and semithickness) for three ionospheric layers (E, F1 and F2) from precomputed ionospheric data tables. Used by the propagation models.
HEIGHT	Computes virtual height of rays reflected by parabolic ionospheric layers.
HFABSB	Computes absorption and other propagation losses on an HF skywave ray path.
HFMODE	Computes ray path geometry for HF skywave modes.
HFNET	Main program.
HFPOST	Writes propagation data to post processor output file.
HFS2NR	Subroutine to calculate and print noise power, signal strength and signal-to-noise ratio for an HF skywave ray path.
HZ2MHZ	Converts hertz to megahertz.
ICLIP	1-D clipping function (integer).
ICLIPM	Generalized modulus function (integer). Finds X modulo I where I = [A, B] is any interval.
INPERR	Reports input errors found by the input module (MODI).
INTERP	Computes interpolated cloud data for a specific cloud at a specific time. Interpolated cloud data is stored in common block NOWDTA.
INTWND	Computes wind dataset index given the altitude.
IONFIT	Computes best fit parabolic parameters for Aerospace ionospheric model.

IONUP	Returns ionospheric data at any of seven points between transmitter and receiver interpolated to a specified local time.
ITSION	Computes ionospheric parameters for 24 hours above a specified point using ITS ionospheric model.
ITSPAR	Calculates ionospheric data tables for ITS ionospheric model.
KM2CM	Converts kilometers to centimeters.
LAYER	Routine used to compute atmospheric tilts.
LISDAT	Dynamic storage routine to initialize constants and variables in LISTOR common.
LOSPRP	Checks for line-of-sight propagation using a 4/3 earth's radius to account for atmospheric refraction.
LSWICH	Keeps track of the mass entrainment parameter of a rising, expanding fireball relative to several logical switches.
LTRAN1	Converts cloud radii from a coordinate system aligned with the geomagnetic field lines to one aligned with the local vertical.
LTRNV1	Transforms cloud radial (expansion) velocities from a coordinate system aligned with the geomagnetic field lines to one aligned with the local vertical.
LTRNV2	Transforms cloud radial (expansion) velocities from a coordinate system aligned with the local vertical to one aligned with the geomagnetic field lines.
MAGFIN	Computes magnetic field components using normalized magnetic field coefficients. Used by the ITS ionospheric model.

MAGNET	Computes magnetic field components using an earth centered dipole field. Used by most models in the code requiring magnetic field data.
MAPOUT	Dynamic storage routine to print D.S. maps.
MAPSET	Initializes map projection data in MAPCOM common.
MEMLOC	Dynamic storage routine to compute relative address in D.S. buffer given absolute address. Also performs buffer swapping to secondary storage if necessary.
MHZ2HZ	Converts megahertz to hertz.
MOD1	Input module.
MOD10	Module to control plume mode calculations.
MOD12	Module to write "end of simulation" data to post processor data file.
MOD13	Module to delete F77X data list to free dynamic storage space.
MOD15	Module to initialize wind model data lists.
MOD17	Module to print ionospheric data tables.
MOD2	Module to print simulation start/stop output.
MOD20	Module to write debris model binary (plot) output.
MOD21	Module to generate cloud list print and binary output.
MOD22	Module to write data file for contour plots.
MOD22X	Used in conjunction with MOD22 to compute data for "special" contour plots.
MOD23	Cloud list input module. Reads in precomputed cloud data.

MOD3	Cloud creation (burst) module. Controls the creation and storing of initial fireball parameters. Also stores an update event for newly created cloud.
MOD4	Module to control HF calculation events.
MOD5	Output module for cloud creation, split and updates.
MOD6	Cloud update module. Controls the updating of all five types of clouds.
MOD7	Ionospheric initialization module. Controls the computation of link ionospheric data tables using the three ionospheric models.
MOD8	Cloud split module.
MUFS	Computes the N-hop maximum useable frequency (MUF).
MULMOD	Computes propagation mode geometry for "multimode" calculation.
MULMUF	Computes frequencies to use during "multimode" calculations.
MULTPH	Adjusts ray-path geometry for differing reflection heights and ionospheric tilts during "multimode" calculation.
NINT	Nearest integer function. Supplied for systems that lack this routine. Not used in VAX version.
NOISE1	Used by the noise model to precompute quantities used in the atmospheric noise calculation for a specific receiver at a specific time. This information is saved in the NOIS data list for subsequent use.
NOISE2	Computes thermal, galactic, man-made, and atmospheric noise power for a specified receiver, time and frequency.

NXEVNT	Searches the event list for the event with the smallest time.
NXTCRD	Routine to skip comment lines in the input file.
NXTSET	Dynamic storage routine used to cycle through a D.S. data list.
OB	Logical function to test for out of bounds variables.
OPENFILES	Routine to open data files for readonly access. Allows sharing of these input files in the VAX version.
PARABI	Computes ionospheric parameters for the Aerospace ionospheric model.
PATCH	Moves the burst point down the magnetic field line to a point where the energy trapped in the local conjugate is a certain proportion of the total yield. Most of the energy and debris will be deposited near this point.
PATHW	Routine used by the propagation routines to locate data in an ionospheric data table. Also computes spatial interpolation weights.
PLABSB	Computes propagation losses for a plume mode ray path.
PLMODE	Calculates plume modes for a single link and cloud.
PLS2NR	Computes noise, signal and signal-to-noise ratio for a plume mode ray path.
POLAR	Function used by the Aerospace ionospheric model.
POLPAR	Computes ionospheric parameters for the RADC (polar) ionospheric model.
PRABSB	Generates detailed printout of propagation losses on an HF skywave ray path.

PREPAR	Initializes for the RADC (polar) ionosphere. Reads and stores data from the ITS yearly data file (YEAR.BIN) and the geomagnetic data file (GEOMAG.BIN).
PRMODE	Prints HF skywave mode geometry.
PRMULT	Prints "multimode" output.
PRNCLD	Prints cloud parameters for a specified cloud at a specified time.
PRNEVN	Generates a printout of the event list.
PROF3	Computes a function used by PROFIL.
PROFIL	Computes vertical electron density profiles for the RADC (polar) model.
PRPLUM	Prints plume mode geometry, losses, signal and noise data. Also writes plume mode data to the postprocessor data file.
PSTATS	Prints event/module runtime statistics at end of run.
QAMBNT	Computes ambient D-region ion production rate (Q).
QCHAT	Computes ionospheric parameters derived from the Chatanika electron density profiles. Part of the RADC (polar) model.
QEPHEM	Computes solar declination and ascension.
QF2FH	Calculates F2 layer critical frequency for RADC (polar) model.
QFETCH	Fetches geomagnetic data stored in the F77X data list for use in computing corrected geomagnetic coordinates. See ZCGMCS. Part of the RADC (polar) model.
QFOEF1	Computes E and F1 layer critical frequencies for the RADC (polar) model.

QHTF2	Computes the height of the F2 layer for the RADC (polar) model.
QMAGFI	Computes magnetic field components for the RADC (polar) model. Same as MAGFIN.
QOLION	Computes ionospheric parameters using the RADC (polar) ionospheric model.
QUADR	Solves quadratic equations using the quadratic formula. Used by the RADC (polar) model.
QUASIC	Computes the electron density and collision frequency at a D-region point given the pressure, air density, ion-production rate (Q) and the attachment/detachment rates.
R2D	Converts radians to degrees.
RAB	Computes the ground range and azimuth angle from point 1 to point 2 given the locations (latitude, longitude) of the two points.
RATES	Computes D-region attachment and detachment rates.
RCLCLD	Recalls cloud data for a specified cloud from the cloud list.
REFLC	Computes the maximum frequency that will reflect off a plume/fireball and the effective reflecting cross section.
REMTABS	Removes tab characters (replacing them with the appropriate number of blanks) from 80 character card images. Used in the VAX version of HFNET to make echoed input lines print correctly.
RINTRP	Two dimensional (4 point) interpolation routine used by the wind models to compute wind velocities at the location of the cloud center.

RISE	Calculates the buoyant rise and entrainment of ambient air by a rising, expanding fireball.
S2DHMS	Converts time in seconds to DHMS format.
SCALHT	Subroutine used by the RADC (polar) ionospheric model to obtain altitude of maximum electron density in F2 layer.
SCAT	Subroutine used by the plume mode geometry model.
SETKP	Computes K (corrected Kp index) as a function of Kp index, corrected geomagnetic time and latitude. Part of the RADC (polar) ionospheric model.
SETLNK	Initializes for a specified link in preparation for an HF propagation calculation.
SETPAR	Subroutine to initialize constants and read in data for the ITS ionospheric model. Data is read from the ITS yearly and monthly data files (YEAR.BIN and MONTH.BIN).
SIMMGR	*Simulation manager.* Manages the execution of all events in the simulation and collects data on event/module activity.
SMOOTH	Function with smooth derivatives. $\text{Smooth}(X) = \begin{cases} 2X^2 & 0 \leq X \leq .5 \\ 1-2(1-X)^2 & .5 < X \leq 1 \end{cases}$
SPACE	Function used by the wind interpolation routine (AVWIND) to compute the vertical spacing between data points in the wind database.
SPLIT1	Handles the splitting of a mixed fireball into a neutral fireball and an ionized fireball.

SPLIT2	Splits a mixed (or ionized) fireball into a late plume and a subsiding debris cloud.
STEVNT	Routine to store events in the event list.
STOCLD	Routine to store cloud data in the cloud list.
STOSET	Dynamic storage routine to store a D.S. dataset.
TATR	A function used in RADC model of height of maximum electron density in the F2 layer.
TILT	Used by the propagation model to compute the ionospheric tilts due to gradients in the ionospheric electron density.
TIMERR	Logical function used by the input module to check for correct DHMS format.
TIMEW	Computes the location in the ionospheric data table and the interpolation weights for a given local time.
TIMSTP	Determines the appropriate time step for updating mixed, ionized or neutral fireballs.
TRITRP	Interpolation routine used by the RADC model to obtain K (corrected Kp) as a function of Kp and local geomagnetic coordinates; called by SETKP.
TSTCLD	Tests to see if a particular cloud is currently active.
TVARF2	Function used by the Aerospace ionospheric model.
TVEF1	Function used by the Aerospace ionospheric model.
UFUNC	Function used by the propagation models. UFUNC = $\tan^{-1}(u)/u-1$.
UPDAT1	Handles the updating of mixed fireballs (cloud type 1).
UPDAT2	Handles the updating of ionized fireballs (cloud type 2).

UPDAT3	Handles the updating of neutral fireballs (cloud type 3).
UPDAT4	Handles the updating of late plumes (cloud type 4).
UPDAT5	Handles the updating of subsiding debris clouds (cloud type 5).
VERSY	Evaluates series expansions for world maps of various ITS ionospheric parameters.
VIRTUL	Used by the propagation model to compute virtual reflection heights.
W	Function used in the Aerospace ionospheric model.
WIND	Computes wind velocities for use by the late-time subsiding debris model. Uses constant winds or wind database values averaged over the vertical thickness of the cloud and interpolated to the latitude and longitude of the cloud center.
XYMAP	Converts latitude and longitude to map X-Y coordinates using the polyconic, gnomic or "flat earth" projection equations.
XYMAPI	Converts map X-Y coordinates to latitude and longitude using the polyconic, gnomic or "flat earth" inverse projection equations.
YONII	Function used by the Aerospace ionospheric model.
ZCGMCS	Used by the RADC (polar) ionospheric model to convert from geographic to (corrected) geomagnetic coordinates.
ZEUS	Computes atmospheric noise power transmitted at a given frequency from a point source on the equator.
ZFIX	Adjusts HF ray path break points for variations in the virtual reflection heights at each hop.

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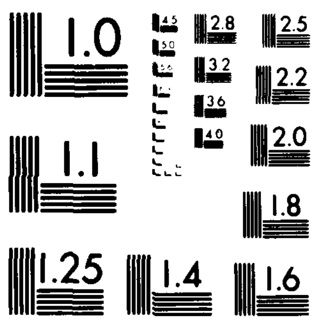

MICROCOPY RESOLUTION TEST CHART

B.2 LIST OF HFNET COMMON BLOCKS

COMMON	DESCRIPTION (SIZE)
AMBINT	Holds ambient atmospheric and magnetic properties at the location of a cloud before it is updated. Set by MOD6 and used by all of the cloud update routines during a cloud update event. (11)
BNOISE	Buffer for noise calculation dynamic storage datasets. Used by the propagation models in computing noise power and signal-to-noise ratio. (50)
CHEM	Holds various chemistry constants and rate coefficients. Set by block data routine BLKDAT and used by the D-region absorption models. (36)
CLOUD	Holds cloud list bookkeeping parameters and the cloud list dynamic storage dataset buffer. Partially set by block data routine BLKDAT. (59)
CON	Holds various constants. Set by subroutine SETPAR and used by the ITS ionospheric model subroutines. (9)
CONST	Holds various constants. Set by block data routine BLKDAT and used by many subroutines. (8)
DATA1	Holds world map data, interpolated for sunspot number, used to generate F2 layer parameters in RADC ionosphere model. (1019)
DEBRIS	Holds various debris model parameters used in the creation and updating of clouds. Set by block data routine BLKDAT. (31)
ELAYER	Holds data used by the RADC (polar) ionospheric model. (9)

EVENT	Holds event bookkeeping parameters and 3 event list dataset buffers. Partially set by block data routine BLKDAT and used by the simulation manager and the various modules. (52)
F2DCOM	Holds data used to calculate upper and lower decile frequencies. The data is read from file DECILE.BIN by subroutine DPROB and is used by subroutine F2DIS. (576)
FILES	Holds logical unit numbers for all input, output and scratch files. Set by block data routine BLKDAT and used throughout the code. (15)
GEOPAR	Holds various geographic and geomagnetic parameters used by the RADC (polar) ionospheric model. (9)
HDEBUG	Holds the names of subroutines from which debug output has been requested. Initially set by block data routine BLKDAT and possibly modified by input (using the $DEBUG keyword). (20)
HFLOSS	Holds data used in the propagation loss calculation for HF skywave or plume modes. (587)
HFPATH	Holds data used in the propagation geometry calculation for HF skywave modes. Partially initialized by block data routine BLKDAT. (369)
IONBUF	Used to buffer link ionospheric data tables for the propagation models. Partially initialized by block data routine BLKDAT. (1591)
ITSCOM	Holds data used by the ITS ionospheric model. (3514)
KEYALT	Holds data used in the integration of incremental D-region absorption. Set by block data routine BLKDAT and used in various absorption calculations (HF skywave, plume modes, noise absorption). (13)

LINK	Holds link list dataset buffer. Partially set in block data routine BLKDAT. (11)
LISTOR	Holds dynamic storage bookkeeping data and the main dynamic storage buffer. Partially initialized by subroutine LISTOR and used by all of the dynamic storage subroutines. (50099)
MAPCOM	Holds map projection information used by the mapping routines. (7)
MODTRN	Holds the module transfer list. Set by block data routine BLKDAT and used by the simulation manager (SIMMGR). (203)
MPATH	Holds data used by the multimode propagation routines. (100)
NEWCLD	Used to temporarily hold time variant cloud data for a cloud that is being created, updated or split. (20)
NEWFIX	Used to temporarily hold time invariant cloud data for a cloud that is being created, updated or split. (10)
NODE	Holds node list dataset buffer. Partially set by block data routine BLKDAT. (41)
NOWDTA	Holds interpolated cloud data for a particular cloud at a particular time. Set by subroutine INTERP. (31)
OLDCLD	Used to temporarily hold time variant data for a cloud that is being updated or split. (20)
OLDFIX	Used to temporarily hold time invariant data for a cloud that is being updated or split. (10)
PLTGRD	Holds contour plot grid data. Set and used by MOD22 during contour plot events. (5104)

PLUME	Holds plume parameters. Set by block data routine BLKDAT and used by UPDAT4 during late plume update events. (14)
PLUMOD	Holds data used in plume mode propagation calculations. Partially set by block data routine BLKDAT and used as a buffer for plume list datasets. (117)
POSTER	Holds data used to generate a file for input to the post processor program, HFPOST. Partially set in block data routine BLKDAT. (49)
RUNTIM	Holds event and module run-time statistics. Initialized by block data routine BLKDAT, updated by the simulation manager, and printed by subroutine PSTATS. (202)
SUBSID	Holds constants used while updating subsiding debris clouds. Set by block data routine BLKDAT and used by subroutine UPDAT5. (6)
TABLIN	Used as an input buffer for data read from file GEOMAG.BIN and also as a dynamic storage dataset buffer for the F77X data list. This data is used by the RADC (polar) ionospheric model (subroutines PREPAR and QFETCH). (258)
WEATHR	Used to hold ambient "weather" conditions. Initialized by block data routine BLKDAT but usually reset by input (using the $AMBIENT keyword). Used throughout the code. (10)
WHEN	Holds date and time information for RADC (polar) ionospheric model routines. Set by subroutine QOLION. (8)
WHERE	Holds locational information for RADC (polar) ionospheric model routines. Set by subroutine QOLION. (7)

APPENDIX C
IMPLEMENTATION NOTES

HFNET is written in VAX-11 FORTRAN IV PLUS and runs on a DEC VAX-11/780 minicomputer using the VAX/VMS operating system. Previous versions of HFNET have been implemented on the following computer systems:

DEC PDP 11/45 using RSX-11D,
DECSYSTEM 10 using TOPS-10,
CDC 6600 using NOS/BE, and
CDC CYBER/176 using NOS/BE.

While most of the code is written in ANSI standard FORTRAN IV some conversion would be required to implement HFNET on another computer system. Conversion to another VAX, a DECSYSTEM 10 or 20, or a large CDC system should be a straightforward task, conversion to a computer system significantly different from these could prove to be a non-trivial task.

Some of the known pitfalls to watch out for while implementing HFNET are:

- VAX machine-dependent routines: CPUSEC, REMTABS, OPENFILES, etc. These routines can either be removed or replaced with equivalent routines.
- FORTRAN 77 extensions:
  - List-directed input format
  - "ERR=" and "END=" error condition branching
  - CHARACTER variables and constants
  - CHARACTER constants in FORMAT statements

For the most part the uses of these extensions are either isolated or easily "fixed" using a good text editor.

- Some routines make the assumption that arguments to subroutines are passed "by reference" (and not "by value" or some other way). This is particularly true of calls to the array manipulation routines (AMOVX, ASETX and ACLRX).

- INTEGER and REAL variables must occupy the same amount of storage. This assumption is made throughout the code in conjunction with EQUIVALENCE statements.

- Both INTEGER and REAL variables are used to hold Hollerith data. The code assumes that 4 characters can fit in a word and 8 into a double precision word.

- The dynamic storage (D.S.) buffer is dimensioned to 50,000 words with no secondary storage backup. The D.S. routine MEMLOC can easily be altered to allow for secondary storage (disk, large core or whatever is available). This allows the in-core D.S. buffer to be reduced in size without restricting the total D.S. space available.

- HFNET is not small - it uses over 500,000 bytes (including the 200KB D.S. buffer) on the VAX. If this is too large then here are 3 suggestions:
  1. Change the D.S. buffersize (see above),
  2. Delete unwanted modules or models, or
  3. Use an overlay scheme.

- HFNET and HFPOST together require 19 external files as shown in Table C.1. How files are implemented is very operating system dependent. In order to get an idea of how they might be handled, the VAX implementation's command procedure for running the code is shown in Table C.2.

Table C.1. HFNET/HFPOST external files.

Logical Name*	Internal Name	External Name*	File Type**	File Description
				HFNET
FOR001	LUNDAT	*.DAT	C/I	Simulation input
FOR002	LUNOUT	*.OUT	P/O	Detailed output
FOR002	LUNBUG	*.OUT	P/O	Debug output
FOR010	LUNSCN	*.SCN	C/I	Scenario Input
FOR012	LUNF77	GEOMAG.BIN	B/I	RADC geomagnetic data
FOR014	LUNYR	YEAR.BIN	B/I	ITS yearly ionospheric data
FOR016	LUNMON	MONTH.BIN	B/I	ITS monthly ionospheric data
FOR020	LUN20	*.020	B/O	Cloud plot data
FOR021	LUN21	*.021	B/O	Cloud list binary output
FOR022	LUN22	*.022	B/O	Contour plot data
FOR023	LUN23	*.023	B/I	Cloud list binary input
FOR050	LUNPST	*.PST	B/O	Post-processor data
FOR060	LUN1	*.060	B/S	Input module scratch file
FOR070	LUNPRB	DECILE.BIN	B/I	ITS decile frequency data
FOR080	LUNWND	WIND.BIN	B/I	Wind data base
				HFPOST
FOR010	LUNOUT	SYS$OUTPUT	P/O	HFPOST error messages
FOR010	LUNBUG	SYS$OUTPUT	P/O	HFPOST debug output
FOR020	LUNPST	*.PST	B/I	Post-processor data
FOR030	LUNSUM	*.SUM	P/O	Summary output

* Logical and external file names are for the VAX implementation of HFNET.
** File types: C = card image, P = print, B = binary
I = input, O = output, S = scratch.

Table C.2. Command procedure for running HFNET.

```
$
$ ! HFNETX.COM
$
$ ! VAX/VMS COMMAND PROCEDURE TO RUN HFNET AND HFPOST
$
$ ! THE JOB NAME IS PASSED TO THIS PROCEDURE AS PARAMETER 1 (P1)
$
$ SET WORKING←SET /LIMIT=200
$
$ JOB←NAME := 'P1'
$
$ ASSIGN  'JOB←NAME'.DAT  FOR001  ! SIMULATION INPUT
$ ASSIGN  'JOB←NAME'.OUT  FOR002  ! DETAILED OUTPUT
$ ASSIGN  'JOB←NAME'.SCN  FOR010  ! SCENARIO INPUT
$ ASSIGN      GEOMAG.BIN  FOR012  ! RADC GEOMAGNETIC DATA
$ ASSIGN        YEAR.BIN  FOR014  ! ITS YEARLY DATA
$ ASSIGN       MONTH.BIN  FOR016  ! ITS MONTHLY DATA
$ ASSIGN  'JOB←NAME'.020  FOR020  ! CLOUD PLOT OUTPUT
$ ASSIGN  'JOB←NAME'.021  FOR021  ! CLOUD LIST OUTPUT
$ ASSIGN  'JOB←NAME'.022  FOR022  ! CONTOUR PLOT OUTPUT
$ ASSIGN  'JOB←NAME'.023  FOR023  ! CLOUD LIST INPUT
$ ASSIGN  'JOB←NAME'.PST  FOR050  ! POST PROCESSOR DATA FILE
$ ASSIGN  'JOB←NAME'.060  FOR060  ! INPUT MODULE SCRATCH FILE
$ ASSIGN      DECILE.BIN  FOR070  ! ITS DECILE DATA
$ ASSIGN        WIND.BIN  FOR080  ! WIND DATA
$
$ RUN HFNET
$
$ ASSIGN      SYS$OUTPUT  FOR010  ! TROUBLE / DEBUG OUTPUT
$ ASSIGN  'JOB←NAME'.PST  FOR020  ! POST PROCESSOR DATA FILE
$ ASSIGN  'JOB←NAME'.SUM  FOR030  ! SUMMARY OUTPUT
$
$ RUN HFPOST
$
$ DELETE 'JOB←NAME'.060;*
$ DELETE 'JOB←NAME'.PST;*
$
$ PRINT 'JOB←NAME'.OUT,'JOB←NAME'.SUM
$
$ SHOW PROCESS /ACCOUNTING
$
```

The code comes on a standard 9-track, unlabeled, 800 BPI, ASCII magnetic tape. This tape contains the following 11 files:

1. HFNET program
2. HFPOST program
3. A program (CONVERT) to convert the ASCII data files (files 4-7) to binary format for use by HFNET
4. ITS monthly data file
5. ITS yearly data file
6. RADC geomagnetic data file
7. Wind data file
8. VAX/VMS command procedure for setting up the program
9. VAX/VMS command procedure for running the program
10. Test case data file
11. Test case output file

The files on the tape are all in FIXED RECORD SIZE/BLOCKED format with the record and block sizes (in bytes) as shown in Table C.3 below.

Table C.3. HFNET tape file attributes.

File #	File Name	Record Size	Block Size	# Records	# Blocks	File Type
1	HFNET.FOR	88	4400	26583	532	source
2	HFPOST.FOR	88	4400	2443	49	"
3	CONVERT.FOR	80	4000	138	3	"
4	MONTH.DAT	80	4000	24660	494	data
5	YEAR.DAT	120	3600	4006	134	"
6	GEOMAG.DAT	80	4000	1314	27	"
7	WIND.DAT	80	4000	7884	158	"
8	SETUP.COM	80	4000	18	1	command
9	HFNETX.COM	80	4000	41	1	"
10	TEST.DAT	80	4000	72	2	data
11	TEST.LIS	133	2660	1056	53	print

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