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MAGNETIC FIELD BINNING AND DISPLAY OF ION COMPOSITION DATA

Dennis E. Delorey
Paul N. Pruneau
John R. Palys

Boston College
Institute for Space Research
Chestnut Hill, MA 02167

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"This technical report has been reviewed and is approved for publication"

JABIN T. BELL, Lt, USAF
Contract Manager
Space Particlces Env. Branch
Space Physics Division

EDWARD G. MULLEN, Chief
Space Particles Env. Branch
Space Physics Division

WILLIAM SWIDER
Deputy Director
Space Physics Division

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Dennis E. Delorey
Paul N. Pruneau
John R. Palys

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Boston College
Institute for Space Research
Chestnut Hill, MA 02167

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Ion Composition data from a Medium Energy Ion Mass Spectrometer flown aboard the Combined Release and Radiation Effects Satellite (CRRES) has been binned into the magnetic coordinate reference frame of B and L. A personal computer hosted graphics utility has been developed for use in the display of the resultant data.

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1.0 OVERVIEW

Spacecraft sensor data binned into the B and L magnetic reference frame of L-Shell and B/Bo (the ratio of the magnetic field at the point of the measurement to the magnetic field on the same field line at the magnetic equator) has been frequently used by PL/GPS analysts in modeling efforts. Since the use of radiation belt models in satellite mission planning is an essential ingredient to successful spacecraft operation proton and electron models have been extensively used for this purpose. Of particular interest are the Dose Models. As a result, one of the most extensively used data sets for such analysis is Dosimeter data. Data from the Combined Release and Radiation Effects Satellite (CRRES) were added to an extensive data base to permit enhancemented studies of radiation belt model. A number of articles describing the radiation belt studies have been published.

Also of interest is ion composition. The CRRES spacecraft carried a number of ion composition sensors. One such sensor is a Mass Spectrometer which made measurements of H+, He+, O+, and O++ over a wide energy range. The data from this sensor has been converted to flux for the lifetime of the vehicle.

Standardized analysis techniques have been developed for the binning of data sets, generation of data bases, and the visualization of parameters contained in the data bases.

This report details the analysis and data visualization procedures developed and implemented for the Medium Energy Ion Mass Spectrometer Detector.

2.0 DATA FLOW

The down-linked telemetry data was recorded on instrumentation tape. The Phillips Laboratory (PL/GPD) decommutation center input the data from the instrumentation tapes and produced master-frame formatted files of the full telemetry stream. Software packages were used for the generation of master frame formatted telemetry files, magnetic field files, ephemeris files, and attitude coefficient files. These files were generated on an orbit by orbit basis.

Time History Data Bases (THDBs) were generated for the full complement of CRRES sensors. These files contain time tagged parameters necessary for the conversion of raw data into engineering unit parameters. Separate analysis routines were developed for the implementation of appropriate calibration procedures.

After an entire data base is completed, the data is first binned into time tagged L-Shell bins where it can be displayed in spectrogram form. The final phase involves the binning in terms of L-Shell and B/Bo.

The technique which was developed bins the data from the selected sensor into 1/20th L-Shell bins on an orbit by orbit basis. The 1/20th of an L-Shell binned data is subsequently binned by B/Bo by means of an indexing function. PC hosted data visualization routines have been developed for use in viewing the sensor data and for comparative studies with similar sensors. Options have been incorporated into some of these routines to view multiple parameters from the same sensor, or compare parameters from one sensor with those of another sensor. Data visualization is accomplished by the use of color spectrograms, which display the color-coded intensity of the measured parameter flux as a function of B/Bo and L-Shell, or, alternatively, as a function of L-Shell and orbit number.

2.1 ONR-307-8-3 MEDIUM ENERGY ION MASS SPECTROMETER (IMS-HI)

The Medium Energy Ion Mass Spectrometer (IMS-HI) measured both the energetic ion composition energy spectra and pitch angle distributions, and the energetic neutral particle energy spectra and pitch angle distributions, with good mass, temporal, spatial and energy resolution.

The principle of operation of the IMS-HI instrument is based on ion momentum separation in a magnetic field followed by energy and mass defect analysis using an array of cooled silicon solid state sensors. The instrument features a parallel architecture with simultaneous mass and energy analysis at relatively high sensitivity.

Although there were two basic modes of instrument operation; mass lock and mass scan, only the mass scan data was used in the analyses described in this report. Baseline operation of the instrument was a toggle mode between Mass Lock Mode and Mass Scan Mode every 32.768 seconds.

In the Mass Scan Mode each of the solid state sensors is pulse-height analyzed into 256 levels of which 64 intervals are accumulated in memory and read out every eight seconds. This mode is used to scan all mass peaks within the range of the sensor relative to the background continuum.

In this mode, 64 point mass spectra at each of 6 energies plus neutrals are obtained every 8.192 seconds. The data for each of the 7 spectra are simultaneously acquired in the previous 8.192 seconds.

The table below gives the approximate energies for the masses being analyzed in scan mode:

Mass / Energy Table for Mass Spectrometer

Energy (keV)	Mass H+	He+	O+	O++
Det 1	18		-	-
Det 2	58	15	-	-
Det 3	140	37	-	37
Det 4	360	90	22.5	90
Det 5	1200	300	75	-
Det 6	1700	425	106	-

The analysis procedure used to convert to flux involves the summing of counts around selected mass peaks and the subtraction of background counts determined from selected areas of the mass spectrum. When in final calibrated form, the flux data is in units of particles/cm^2/sec/sr/keV.

2.2 ANALYSIS FILE

The analysis file consists of time tagged sums of counts and background corrections for all 4 masses. For He+, O++, and O+ data is not available for all 6 ion detectors. All values are in integer form.

The analysis file has a header record followed by a series of data records. All 32 bit integer data is in big-endian (most significant byte first) form.

If, in the process of generating the file, the sensor flag bits represent a mix of scan and lock mode, the entire 32 seconds was deleted. In addition, if telemetry dropout occurred within a masterframe, the data from that masterframe was deleted.

ANALYSIS FILE HEADER RECORD:

Word Number	Description
1	Analysis File ID (307831)
2	Year
3	Day of Year
4	Orbit Number
5	Start Time of Orbit (UT in milliseconds)
6	End Time of Orbit (UT in milliseconds)
7-32	Vacant (Zero fill)

ANALYSIS FILE DATA RECORDS:

Word Number	Description
1	UT (milliseconds) at center of 8 second interval.
2	H+ summed counts - Detector 1
3	H+ background * 100 - Detector 1

4	H+ summed counts - Detector 2
5	H+ background * 100 - Detector 2
6	H+ summed counts - Detector 3
7	H+ background * 100 - Detector 3
8	H+ summed counts - Detector 4
9	H+ background * 100 - Detector 4
10	H+ summed counts - Detector 5
11	H+ background * 100 - Detector 5
12	H+ summed counts - Detector 6
13	H+ background * 100 - Detector 6
14	H+ summed counts - Detector 7 (neutrals)
15	H+ background * 100 - Detector 7 (neutrals)
16	He+ summed counts - Detector 2
17	He+ background * 100 - Detector 2
18	He+ summed counts - Detector 3
19	He+ background * 100 - Detector 3
20	He+ summed counts - Detector 4
21	He+ background * 100 - Detector 4
22	He+ summed counts - Detector 5
23	He+ background * 100 - Detector 5
24	O++ summed counts - Detector 3
25	O++ background * 100 - Detector 3
26	O++ summed counts - Detector 4
27	O++ background * 100 - Detector 4
28	O+ summed counts - Detector 5
29	O+ background * 100 - Detector 5
30	O+ summed counts - Detector 6
31	O+ background * 100 - Detector 6
32	Vacant

2.3 L-SHELL ANALYSIS

The L-Shell binning effort was split into two phases, the generation of individual files binned in 1/20th of an L-Shell on an orbit by orbit basis and the generation of a single file of binned data for the vehicle's lifetime.

2.3.1 L-SHELL BINNING - Phase I

The first phase of the L-Shell binning process requires, as input, the Analysis File and the Ephemeris File. An interpolation routine was developed to generate an ephemeris file for each orbit that contains a record for every 1/20th of an L-Shell, thus defining the number of records and the beginning and end time for each record that is later used as a look-up table. The fitting technique employs a cubic spline. The analysis consists of converting the counts data into flux for each of the IMS-HI detectors and summing the flux data in the appropriate 1/20th of an L-Shell bin using the look-up table based on the time and data set. Data filtering is performed using a sigma test. The analysis also results in the generation of a data gap file based on the sigma test, the sum of the squares output file and the actual data file based on the 1/20th of an L-Shell binning. The L-Shell value and the value of B/Bo (for future use) were also computed by means of the spline fit interpolation routine. These values were stored in the output data file along with the number of observations in each bin.

The filtering techniques identified and removed 'noise points' in the raw data. These techniques addressed the problem of saturated data and negative values resulting from background counts exceeding summed counts for individual 8 second periods. In the binning process, the averaged outputs were filtered separately for each of the detectors.

The files are sequential and each file contains one orbit of binned data. Each record consists of 26 32-bit words comprised of time, L-Shell, and B/Bo (integers) followed by 15 values (real) of summed flux data based on 1/20th of an L-Shell binning and the associated 15 numbers of observations (integers) in each bin.

PHASE I DATA RECORDS

Word Number	Description
1	Universal time (seconds)
2	L-Shell x 1000
3	B/Bo x 1000
4	H+ summed flux - Detector 1
5	H+ summed flux - Detector 2
6	H+ summed flux - Detector 3
7	H+ summed flux - Detector 4
8	H+ summed flux - Detector 5
9	H+ summed flux - Detector 6
10	H+ summed flux - Detector 7
11	He+ summed flux - Detector 2
12	He+ summed flux - Detector 3
13	He+ summed flux - Detector 4
14	He+ summed flux - Detector 5
15	O++ summed flux - Detector 3
16	O++ summed flux - Detector 4
17	O+ summed flux - Detector 5
18	O+ summed flux - Detector 6
19	Number of observations in L-Shell bin associated with H+ Detector 1 resides in most significant 16 bits of the 32-bit word. Number of observations in L-Shell bin associated with H+ Detector 2 resides in least significant 16 bits of the 32-bit word.
20	As with word 19 for H+ Detectors 3 and 4.
21	" H+ " 5 and 6.

22	"	H+ Detector 7 and He+ Detector 2.
23	"	He+ Detectors 3 and 4.
24	"	He+ Detector 5 and O++ Detector 3
25	"	O++ Detector 4 and O+ Detector 5
26	Number of observations in L-Shell bin associated with O+ Detector 6 resides in most significant 16 bits of the 32-bit word.	

2.3.2 L-SHELL BINNING - Phase II

Phase II of the analysis accesses each 1/20th of an L-Shell file generated in phase I on an orbit by orbit basis and generates one file of binned data covering the lifetime of the vehicle. Each detector is individually averaged for each 1/20th of an L-Shell bin.

The file is sequential and is comprised of a series of fixed length records. Each record of data contains one orbit of binned data. Thus, the total number of records in the file reflects the number of orbits in the period covered. Each record consists of 2404 32-bit words comprised of 4 header words (integer) followed by 15 values of averaged flux data (real) repeated 160 times starting at an L-Shell of 1, incrementing 1/20th of an L-Shell to a value of 8.95. The 4 header words consist of orbit number, year, day of year and multiplicative factor = 1, respectively.

PHASE II DATA RECORDS - SCAN MODE:

Word Number	Description
1	Orbit Number
2	Year
3	Day of year
4	Multiplicative factor = 1
5	H+ averaged flux - Detector 1 (L-Shell = 1)
6	H+ averaged flux - Detector 2 "
7	H+ averaged flux - Detector 3 "
8	H+ averaged flux - Detector 4 "
9	H+ averaged flux - Detector 5 "
10	H+ averaged flux - Detector 6 "
11	H+ averaged flux - Detector 7 "
12	He+ averaged flux - Detector 2 "
13	He+ averaged flux - Detector 3 "
14	He+ averaged flux - Detector 4 "
15	He+ averaged flux - Detector 5 "
16	O++ averaged flux - Detector 3 "
17	O++ averaged flux - Detector 4 "
18	O+ averaged flux - Detector 5 "
19	O+ averaged flux - Detector 6 "

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2404 O+ averaged flux - Detector 6 (L-Shell = 8.95)

Words 5 thru 19 are repeated 159 times starting at an L-Shell of 1.05, incrementing 1/20th of an L-Shell to a value of 8.95.

2.3.3 L-SHELL AND B/Bo BINNING

This effort consists of merging the sensor 1/20th of an L-Shell binned files with those binned by B/Bo. In the binning process, options are available to enter a start and end orbit to define the merging period of interest, i.e., the 'active' period or the 'quiet' period. The technique employed accesses the appropriate 1/20th of an L-Shell binned files generated by phase I and bins the sensor counts data by B/Bo by means of an indexing function. The resulting merged data contains 160 records based on 1/20th of L-Shell bins (binned over values 1 to 9) of sensor data binned over 20 pre-defined B/Bo values (ranging over the values 1.000
to 7.410).

The file is sequential and is comprised of a series of fixed length records. Each record of data contains averaged data for a discrete 1/20th of an L-Shell bin. The file contains 160 records (based on 1/20th of L-Shell bins with a range of 1 to 9) of averaged sensor counts data binned over 20 pre-defined B/Bo values (ranging from 1.000 to 7.410). Each record consists of 601 32-bit words comprised of the record # (integer), 15 values (real) of summed flux data for 20 pre-defined B/Bo intervals (a total of 300 such sums) followed by 300 corresponding numbers of observations (integer) in each B/Bo bin.

DATA RECORDS:

Word Number	Description
1	Record # (1 thru 160)
2	H+ summed flux - Detector 1 for 1.000 < B/Bo < 1.004
3	H+ summed flux - Detector 2 "
4	H+ summed flux - Detector 3 "
5	H+ summed flux - Detector 4 "
6	H+ summed flux - Detector 5 "
7	H+ summed flux - Detector 6 "
8	H+ summed flux - Detector 7 "
9	He+ summed flux - Detector 2 "
10	He+ summed flux - Detector 3 "
11	He+ summed flux - Detector 4 "
12	He+ summed flux - Detector 5 "
13	O++ summed flux - Detector 3 "
14	O++ summed flux - Detector 4 "
15	O+ summed flux - Detector 5 "
16	O+ summed flux - Detector 6 "

17-301	Words 2-16 repeated 19 times for remaining B/Bo intervals ranging from 1.004 to 7.410.
302-316	# of observations for each of 15 summed flux values in bin 1.000 < B/Bo < 1.004
317-601	# of observations for each of 15 summed flux values in remaining B/Bo intervals ranging from 1.004 to 7.410.

2.4 DATA VISUALIZATION

A PC hosted set of display utilities which access the phase III data files was developed to generate a false-color (spectrogram) representation of the IMS-HI averaged flux data as a function of L-Shell and B/Bo, for each of the energies being analyzed. The utility has options for linear or log representation and variable intensity scales based on color coding. These interactive graphics routines proved useful in the analysis of the flight data.

A generalized PC-hosted display utility which accesses the phase II data file was developed to create false-color images of selected CRRES sensor outputs as functions of L-Shell and orbit number. A description of this display utility's capabilities follows.

The CRRES Particle-Flux Display Utility is a PC-hosted code which can provide false-color overviews of particle flux as a function of orbit and L-Shell, over the vehicle lifetime or for a user-specified range of orbits (with the option of excluding selected 'noisy' orbits):

- plots of flux as a function of L-Shell, for arbitrary orbits;
- plots of flux at a specified L-Shell over a range of orbits (with the option of excluding selected 'noisy' orbits).

The Display Utility can be used to view up to five data channels simultaneously, for dataset-to-dataset overviews and channel-to-channel comparisons. The false-color format of these displays facilitates rapid assessment of the gross features of the data, and the ability to display several channels simultaneously allows for rapid correlation of features between data sets.

Once an overview is drawn, profiles of flux versus L-Shell for any orbit, or flux versus orbit for any L-Shell, may be drawn. Data channels may be arbitrarily selected from the existing data files.

The Display Utility supports menu selection of the datasets and channels to display, and permits mouse-driven selection of fixed L-Shells and fixed orbits in the profile displays.

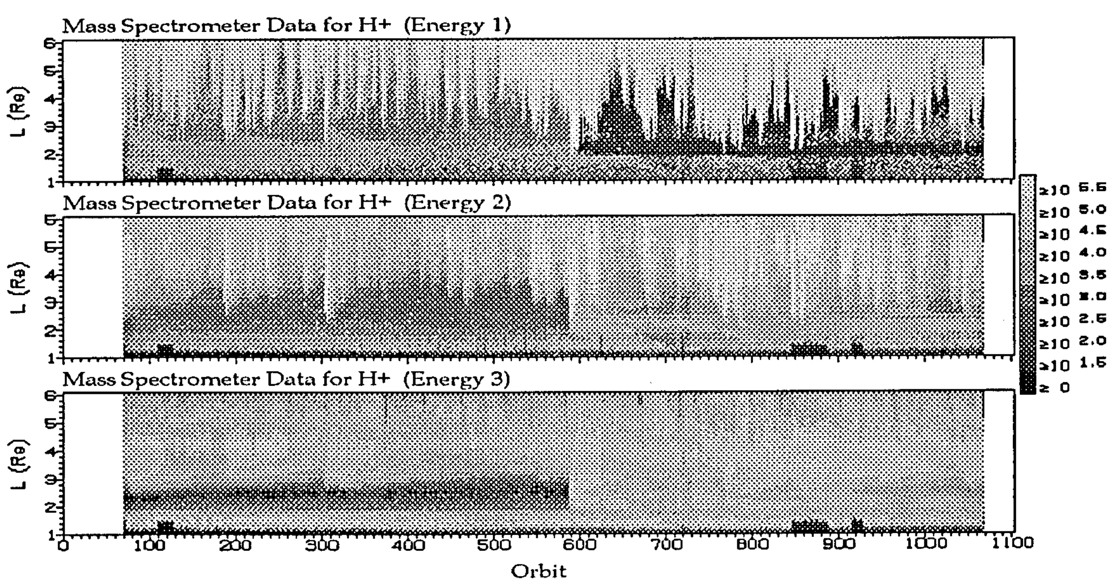
The various data sets the utility can display are defined in an index file containing the data set descriptors, the file names (and, implicitly, their storage locations), the number of data channels per file, and individual channel descriptors. This index file is a text file, and is readily extensible as the numbers and types of data files evolve: thus the capabilities of the display utility are not limited to the currently-defined data sets.

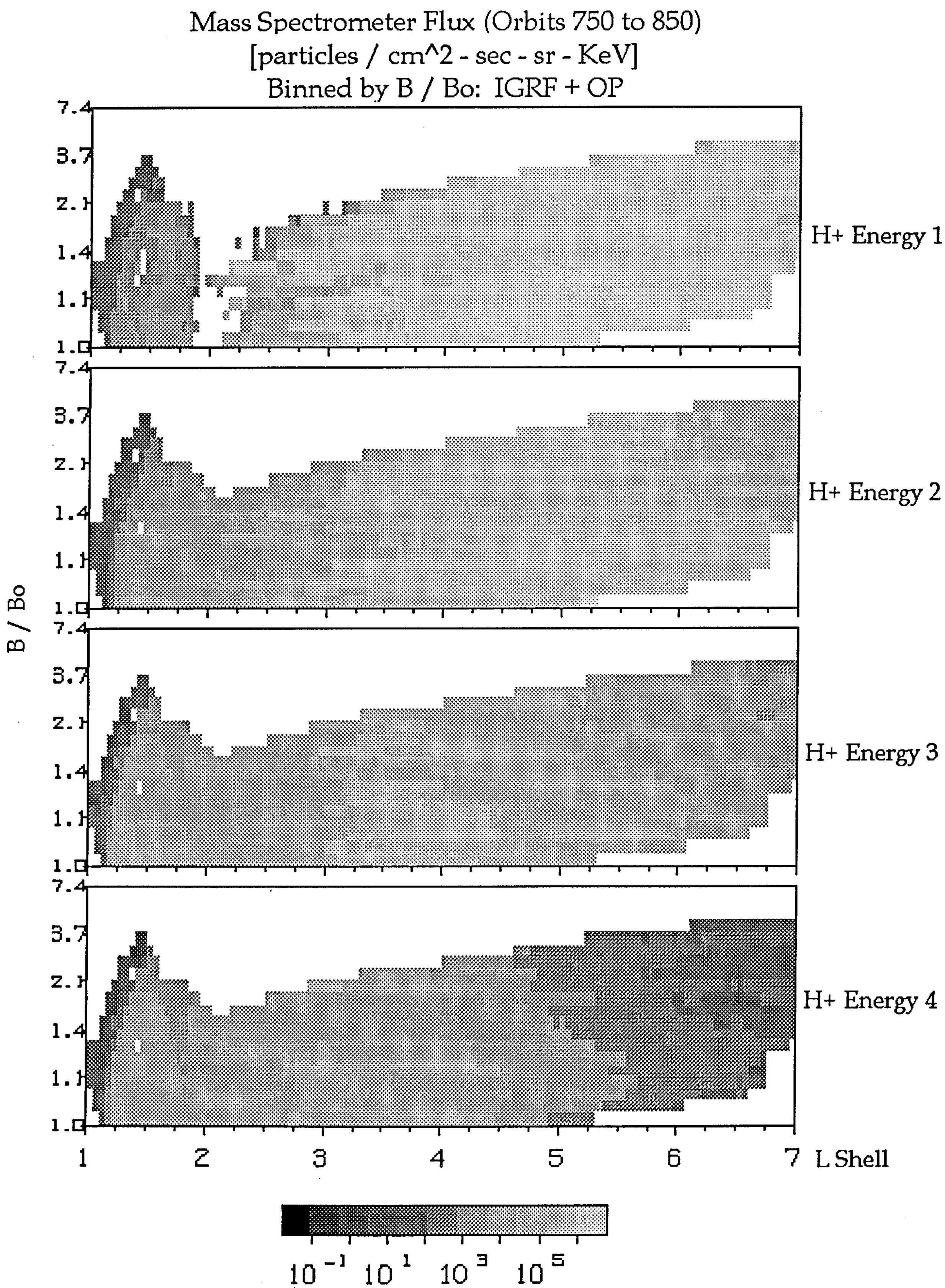
The data files themselves may be stored on the PC, or they may reside on a file server, in which case the Display Utility accesses them through the network at run time. In either case, the usual tradeoffs between local and distributed storage apply: the PC-resident data sets are the more-rapidly accessed, but may be inconvenient to store (potentially consuming many megabytes of disk space), while the access time for the file-server-resident files is greater than that for PC-resident files.

A mixed-mode storage scheme has been found to be practical, in which the data sets are distributed over both platforms in such a way that the more-frequently accessed files reside on the PC, while the remainder are available through the network.

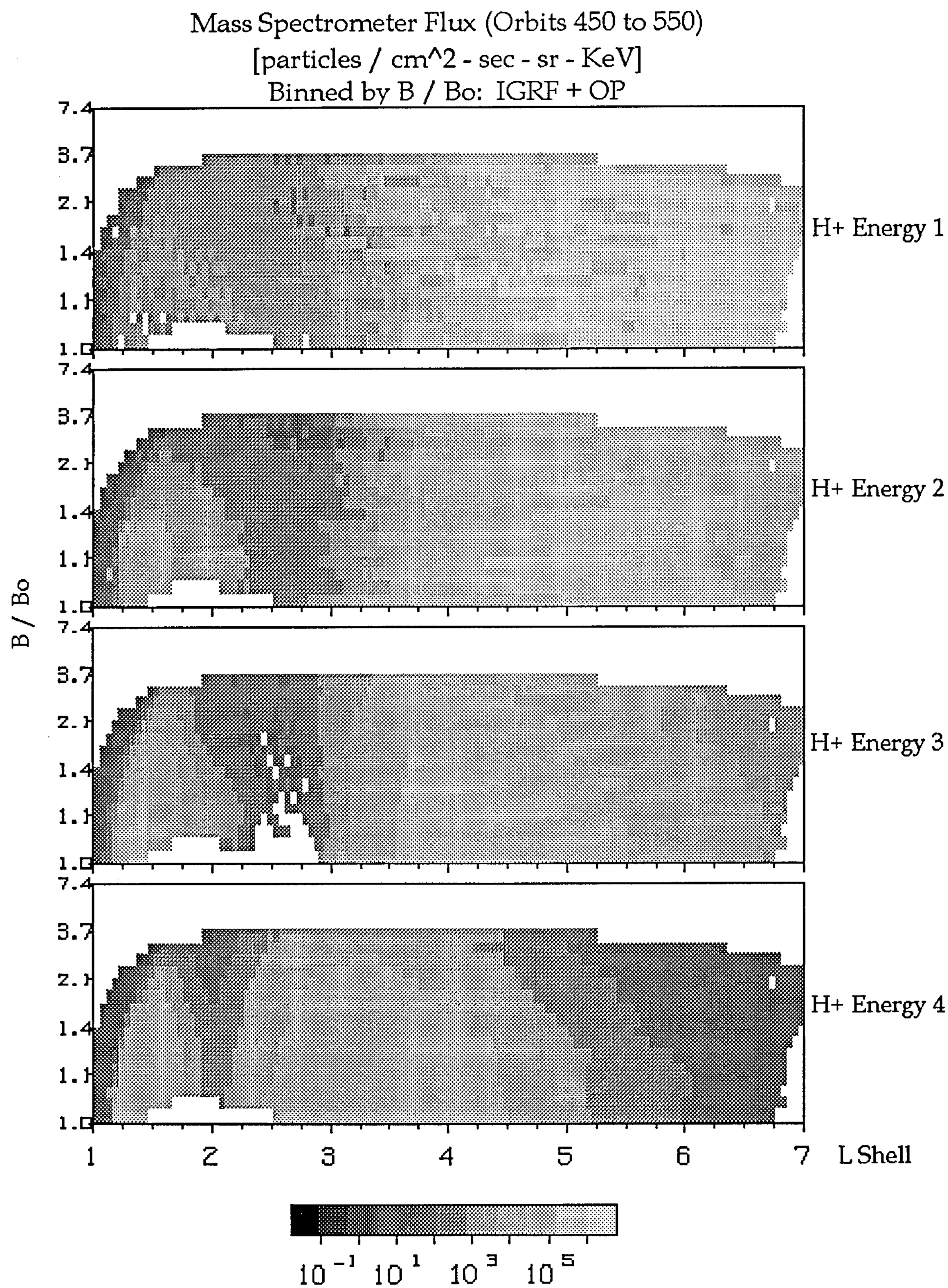
2.4.1 SAMPLE DISPLAYS

The data displayed below is normally output in a false color mode where the color reflects the intensity of the parameter, in this case flux. For the sake of this report, a gray scale display was utilized. The first display reflects flux as a function of L-Shell and orbit number over the lifetime of the vehicle. The final two displays are representative samples of the binned data set in terms of L-Shell and B/Bo.





Mass Spectrometer Flux (Orbits 750 to 850)
[particles / cm^2 - sec - sr - KeV]
Binned by B / Bo: IGRF + OP
B / Bo
7.4
3.7
2.1
1.4
1.1
1.0
H+ Energy 1
H+ Energy 2
H+ Energy 3
H+ Energy 4
1
2
3
4
5
6
7
L Shell
10 -1
10 1
10 3
10 5



Mass Spectrometer Flux (Orbits 450 to 550)
[particles / cm^2 - sec - sr - KeV]
Binned by B / Bo: IGRF + OP
B / Bo
7.4
3.7
2.1
1.4
1.1
1.0
H+ Energy 1
H+ Energy 2
H+ Energy 3
H+ Energy 4
1
2
3
4
5
6
7
L Shell
10^{-1} 10^{1} 10^{3} 10^{5}