Chapter 8

The ISEE data base and radiation belt model

This chapter reviews the results presented in Technical Note 1: it contains a brief overview of the ISEE 1 and ISEE 2 missions, of the KED and WIM instruments which have been used to measure electron fluxes, and a description of the ISEE data base which has been used to produce a new model for the trapped electron radiation belt.

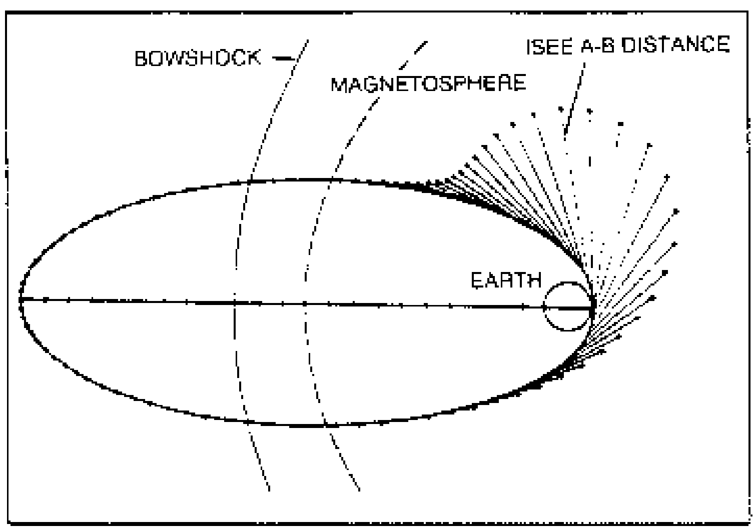

Figure 8.1. Plot of the ISEE orbits. Distances between ISEE-A and ISEE-B are represented by straight lines tangential to the leading orbit position of ISEE-A. Distance between both is represented by the length of the tangent.

8.1 The ISEE mission and instruments

The ISEE program consisted of three satellites, ISEE 1, ISEE 2, and ISEE 3. ISEE 3 Was anchored at the libration point L_1 in front of the Earth. ISEE 1 and 2 were launched into a highly eccentric orbit with an apogee of 23 R_E and a perigee height of several hundred km. Both were launched into the same orbit, but ISEE 1 had the capability to change its distance along the orbit relative to ISEE 2 from a few hundred km up to several R_E, as illustrated in Fig. 8.1. During the time span when ISEE 3 was anchored at the libration point, additional information on the solar wind speed and density, and thus on the solar wind ram pressure exerted on the magnetosphere, and the interplanetary magnetic field were available, all of which are important input parameters for the magnetosphere, including particle fluxes in the outer magnetosphere.

The WIM and the KED instruments on ISEE 1 and ISEE 2 were part of a joint proposal between D. Williams, NOAA Boulder, and E. Keppler, MPAE Lindau and their teams. Both instruments rely on the Wide Angle Particle Spectrometer (WAPS), a magnetic spectrometer based on a design already flown on the Helios space probes. On ISEE 1 this sensor was mounted on a sweeping platform, which rotated in a plane including the spacecraft spin axis by $180°$ in 32 minutes. Due to the spacecraft spin rotation (spin period 3 seconds) sectorisation was possible so that with this instrument a detailed pitch angle distribution could be measured. Energy spectra were measured in 128 channels.

On ISEE 2 the WAPS sensor was mounted in a fixed position almost normal to the spin axis (which was for both spacecraft normal to the ecliptic plane). It was, however, accompanied by four Narrow Angle Particle Spectrometers (NAPSs), which were mounted under different angles relative to the spin axis.

Figure 8.2 shows cross sections of the two sensor types. All sensors were able to measure ion and electron fluxes and to determine their angular distribution and energy spectra by utilizing 16 or 32 sectors, depending on low or high available bit rate, respectively (Williams et al. 1978).

The sensors used inhomogeneous (WAPS) or homogenous (NAPS) magnetic fields in order to separate electrons from ions. Ions and neutral particles could, however, not be distinguished, but neutral particle fluxes were very low as has been shown in a study by Roelof et al. (1976), which was based on ISEE 2 data. All sensors used silicon surface barrier semiconductor detectors. For ions the energy threshold was 25 keV, for electrons 18 keV. The maximum energy for electrons was 1 MeV for WAPS and 300 keV for NAPS. For ions it was 3 MeV in both sensors. Determination of particles of much higher energies was possible by the back detectors, which were shielded by massive tantalum cans up to 35 MeV in the case of protons.

The orbital plane of the ISEE spacecraft rotated about the Earth once per year (see Fig. 8.3) so that the measurements scanned through all parts of the magnetosphere. The active life time for ISEE 2 was almost 10 years from launch in 1977 until 1987, when the spacecraft entered the Earth's atmosphere. The WIM instrument on ISEE 1 ceased operation due to a power failure in 1980. The instruments were designed for measurements in the outer radiation zones. In the presence of energetic particles the interpretation of the data is not straightforward but needs to take into account the energy losses of these penetrating particles. Therefore, the analysis of data should be restricted to those parts of the orbit when the spacecraft was in regions with high L

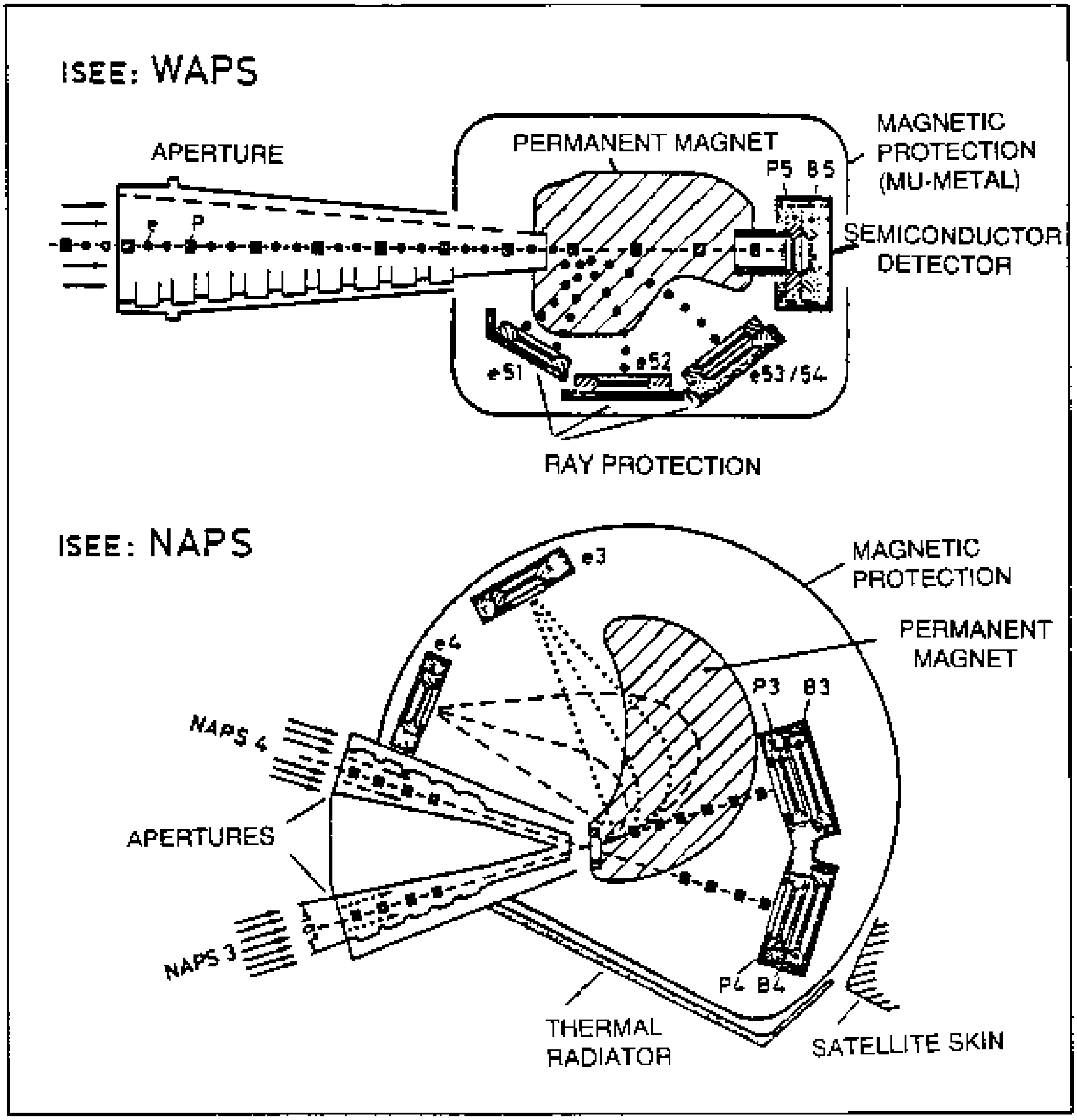

Figure 8.2. Cross section through the WAPS and the NAPS magnetic spectrometers. WAPS uses an inhomogeneous magnetic field to deflect electrons, NAPS a homogeneous magnetic field. Ions above the threshold energy of the instruments pass through the fields practically unaffected.

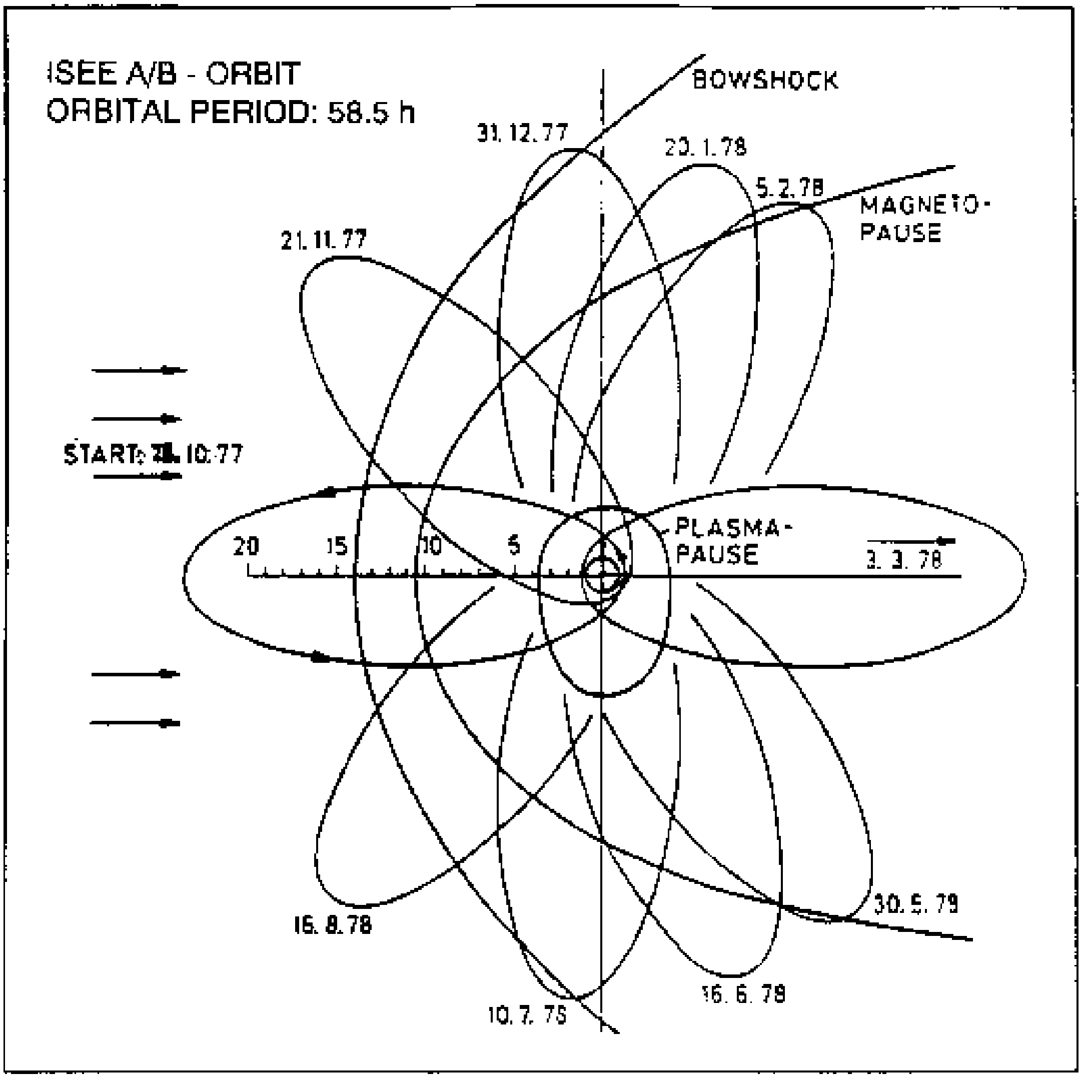

Figure 8.3. ISEE orbits during one year. Orbital period was 58.5 h. Apogee was 21 R_E, perigee 400 km.

values ($L > 4$). This can be easily accomplished by inspecting the back detector count rates, which were transmitted along with each data frame.

The data of the WIM instrument and most of the KED instrument data were processed on tapes containing the orbit data, the altitude data, and the magnetic field data (courtesy C.T. Russell). However, after the prime mission was terminated the KED data which were transmitted were no longer processed, but only stored as raw data. In order to make them available for this study, a significant effort had been started in order to convert the raw data (stored on 1000 tapes) to accessible data in the same format as the data which had been processed in the previous period (see Sect. 8.2). Figures 8.4 and 8.5 show examples of time vs. intensity plots of ISEE particle and magnetic field data. The data files contain a set of housekeeping data, sta-

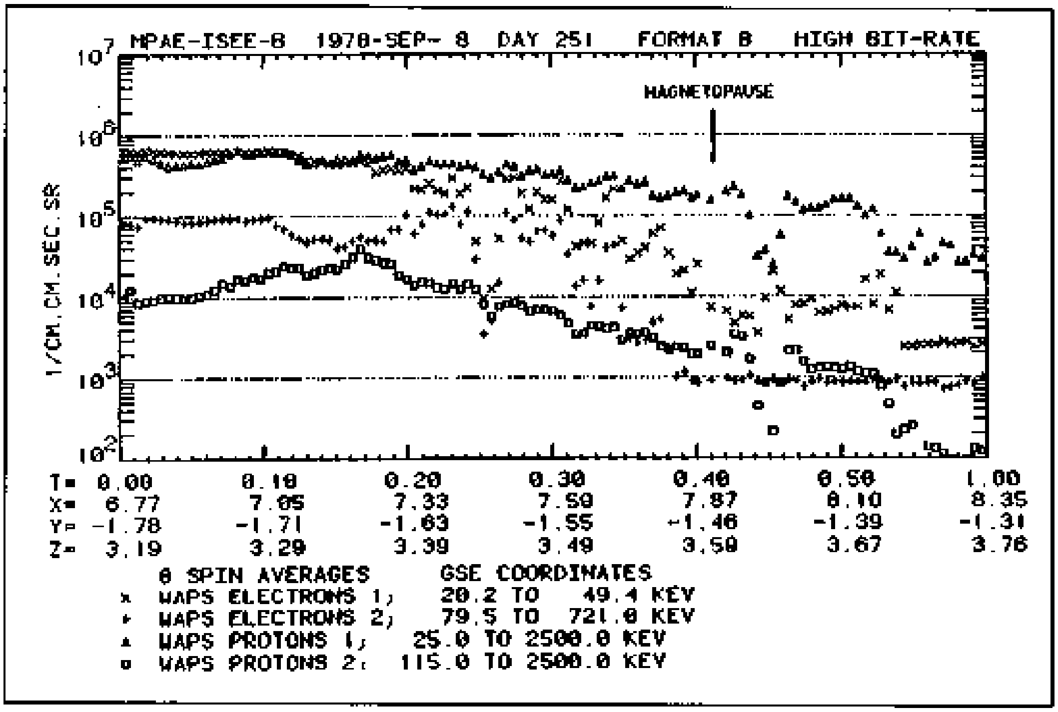

Figure 8.4. ISEE Ion and electron fluxes vs. time on day 251/1978. One hour of data is shown.

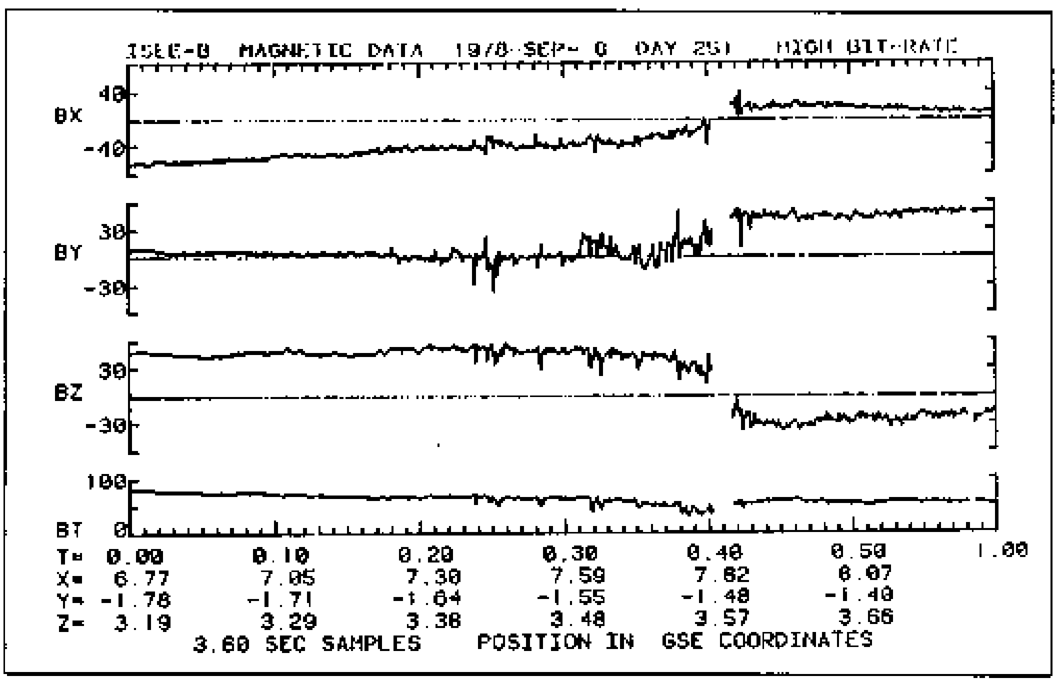

Figure 8.5. Total magnetic field B_T and components B_X, B_Y, B_Z vs. time on day 251/1978. One hour of data is plotted.

tus information and the science data. Orbital data are contained in headers in front of the data blocks. The status data must be inspected in order to recognise the operational mode of the instruments. The science data are generated from 8 bit words which contain the information quasi logarithmically compressed (GSFC 623C counters were used).

The raw data tapes are cleaned for redundancies and errors and contain the fully evaluated magnetometer data, but otherwise contain the original data. Four data analysis programs have been developed that started from these tapes. The programs include all necessary steps to convert the data from technical numbers into physical parameters ($cm^{-2}s^{-1}sr^{-1}$). The programs also contain plotting routines for intensity vs. time plots, angular distribution plots, and energy spectra.

8.1.1 The ISEE-1/WIM instrument

The WIM instrument consists of a Wide Angle Particle Spectrometer (WAPS), a Heavy lon Telescope (HIT), a motor-driven scan platform, and the associated instrument electronics.

8.1.1.1 WAPS

The WAPS has evolved from similar units flown on HELIOS 1 and 2 (Keppler et al. 1978), Explorer 45 (Williams et al. 1968), ATS-6 (Fritz & Cessna 1975), and IMP 7 and IMP 8 (Williams 1977). It consists of an analysing magnet and six surface barrier solid state detectors. The pole pieces produce an inhomogeneous magnetic field having a $\sim$800 Gauss peak field generated by permanent SmCoS magnets. The field deflects electrons up to 1.5 MeV onto three electron detector positions E51, E52, and the pair (E53,E54) while protons (ions) proceed undisturbed to the two-element telescope P5/B5. To reduce radiation damage effects, detector P5 is positioned with its $\sim 15\,\mu\mathrm{g\,cm^{-2}}$ Al contact toward the entrance aperture. All detectors are shielded by material composed of Al, Cu, Au, and Pt positioned to reduce energetic electron and bremsstrahlung background. Electrons with energy > 1.5 MeV may reach the ion telescope, but these will be eliminated from being counted through the coincidence veto signal of detector B5 with almost 100% efficiency.

To reduce system noise, pre-amplifiers are mounted just above the detector mounting bracket. Four pre-amplifiers are used with the responses of the higher energy electron detectors, E52, E53, and E54, being summed into a single pre-amplifier. The entire assembly is surrounded by a magnetic shielding can which reduces the stray field to less than 26 γ at 50 cm. The instrument has a geometric factor of 8.6$\times 10^3 \mathrm{cm^2 sr}$ for ions.

8.1.1.2 Scan platform

The WAPS sensor is mounted on a scanning platform which permits the sensor collimator, $\hat{f}$, to scan from a position approximately antiparallel to approximately parallel to the spacecraft spin axis, $\hat{s}$, through the radial ($\hat{f} \times \hat{s} = 0$) direction. The platform is rotated by a brushless, direct drive, DC torquing motor which has a history of high reliability. The stall torque of the motor is 720 g cm. A torque of 145 g cm is required to overcome the centrifugal force of the spinning spacecraft and drive or hold the platform in any location. The controlling electronics are mounted in their own separate housing which interfaces to the spacecraft and command system through the main instrument electronics. The rotation system has two modes of operations: fixed and scanning.

In scanning mode, the platform is driven continuously, completing a 160° rotation cycle from $\cos^{-1}(\hat{f} \times \hat{s}) = 170^\circ$ to $\cos^{-1}(\hat{f} \times \hat{s}) = 10^\circ$ in 12 spins (~ 36.5 s). The platform is driven spin synchronously using the 1024/spin clock line from the spacecraft. Data collection is also synchronized with the scanning cycle. The position of the platform is controlled actively in an analog feedback loop using a Rotary Variable Differential Transformer (RVDT) for position sensing. The RVDT position voltage is monitored routinely once every 8 seconds and on command can be monitored 16 times per second in flight. The scanning mode has been the standard in-flight mode since Oct 31, '77, and operation of the platform has been normal. System linearity is good to within $\pm 1^\circ$.

In the manual mode the platform can be commanded into 15 positions by ground command. In the fifteenth position the WAPS "looks" back into the spacecraft and views a radioactive source rod. This rod is rotated by 90° by a mechanical ratchet each time the platform is commanded into position 15. The rod contains radioactive isotopes of Americium (241) and Barium (133) (200 microcuries each) in two positions and blanks in the remaining two positions. These sources can be used to calibrate the WAPS energy channels and pulse height analyzers with α, electron, and γ ray lines.

A total of fourteen electrical lines are brought across the rotating interface by means of a Poly-twist cable. The Poly-twist feed-through consists of two Kapton film flexible circuits counter-wound on a single axis. 42 Circuit paths are provided and most are used for providing shielding for four pre-amp outputs. Normal life expectancy for these devices is 5 to 20 million cycles, permitting a minimum operational lifetime on ISEE 1 in excess of 6 years.

8.1.2 The ISEE-2/KED instrument

The KED instrument consists of five sensor systems mounted at various angular positions with respect to the spacecraft spin axis. All sensor systems are mounted on a common platform and protrude slightly through the spacecraft skin. Two different types of systems are used: the WAPS (described earlier) and the Narrow Angle Particle Spectrometer (NAPS), described below. The whole sensor system is contained within a Mu-metal can to provide for magnetic shielding. In addition to the sensor housing, the instrument consists mechanically of two other boxes housing the analog electronics and the digital electronics. Each of the detectors is connected by a short coaxial cable to the analog box. Signals between the analog and digital boxes are digital. The digital electronics provide all electrical interfaces to the spacecraft.

8.1.2.1 WAPS

The ISEE-2 WAPS is identical to that described for ISEE-1 in all operational and scientific aspects. For ISEE-2 the external shape of the collimator is slightly different from that presented in Fig. 8.2 and the pre-amps are located in the analog electronics instead of being colocated with the detectors. The dimensions of all detectors and apertures are identical in the two versions of the WAPS.

8.1.2.2 NAPS

A homogeneous magnetic field is used to separate electrons and ions. The ions traverse the field unaffected and are detected with a semiconductor detector telescope arrangement similar to that used in WAPS. All electrons < 300 keV entering the aperture are focused on a semiconductor detector. Two detectors are used in one magnetic system defining two directions ($4 \times 10°$), as shown in Fig. 8.2. A mechanical collimator limits the opening angle. The geometrical factor for each electron detector is $10^{-5}\mathrm{cm}^2\mathrm{sr}$, and $2.5 \times 10^{-4}\mathrm{cm}^2\mathrm{sr}$ for ions. Permanent magnets are used to generate the magnetic field. Two such systems are used giving ion ($E > 25$ keV in case of protons) and electron (18 keV$< E < 300$ keV) measurements from four different directions.

8.1.2.3 Temperature control and detector noise

In order to provide for low operating temperatures, a $100\,\mathrm{cm}^2$ surface covered with second surface mirrors is mounted in good thermal contact with the detector system. Calculations indicated that by this means the detector temperature should remain below a few degrees centigrade. Actual flight data have shown the temperature to be slightly higher ($\sim 10°$C).

8.1.2.4 Instrument electronics

The electronics can be divided into three sections: the pulse analog section, the digital data processing section, and the command/housekeeping section.

In the pulse analog section each detector is followed by a charge sensitive preamplifier. Preamplifier pulses are differentiated with pole zero cancellation, amplified by linear amplifiers with passive filters and DC restored by an active low level baseline restorer to produce unipolar semi-gaussian-shaped pulses ($0.9\,\mu$s width at 10% level) with very rapid recovery even after overload. Amplitude discriminators are differential comparators with DC-hysteresis. In order to save weight and power, low level multiplexers have been introduced between the charge sensitive amplifiers and the pulse shaping amplifier which feed the PHA. However, to provide permanent rate information each detector output is fed into a simple, fast amplifier (integral rates, I data), which is directly connected to it.

Rate channels are digitized by discriminators. For more detailed energy information, a pulse height analyzer, built from 13 discrete discriminators, is used. Whenever a pulse is identified ($0.6\,\mu$s after it arrived), its pulse height will be stored in a D-flip-flop for readout. However, the analyzer is prepared to accept the next pulse for identification. The conversion dead time is less than $0.2\ \mu s$, but due to pulse pileup separate pulses are obtained only for $1.2\ \mu s$ separation which should be considered as the resolution time. It has been shown that the analyzer will provide true spectra without significant pileup deterioration up to statistical pulse rates of $10^5 s^{-1}$.

In the digital data processing section, pulses from 12 rate channels and from the PHA (13 channels) are counted in 27 623C microprocessors, being quasilog compressed to provide 8 bit words (4 bit exponent, 4 bit mantissa, suppression of leading “1”). All data words are sequentially extracted and temporarily stored in a 2 kB buffer memory (two redundant memories are used). Data words are routed from the memory to the telemetry system through two data lines in an alternating sequence. Measurements are performed on a spin synchronous basis using the sun pulse generated by the spacecraft. Four sectors of data per spin (~ 3 s) are generated at low bit rate.

The buffer memory has a capacity which is only three quarters of an Experiment Data Frame (EDF). The memories are organized to form a ring and a writing marker identifying the memory cell to be used. This is followed by a read marker. Provision is made to exclude the possibility that both markers meet for nominal spin rates. For non-nominal spin rates an “empty” quarter frame is transmitted (containing “0”).

In the command/housekeeping section, the instrument is controlled via four serial commands of 16 bits each. For safety reasons, 8 bits are used to identify commands, each command being identically repeated in the subsequent 8 bits. Each command has to be identified by the instrument twice, prior to execution. Fifty eight different commands may be executed by the instrument. Four multiplexers (4 positions each) may be commanded to either remain in any given position or to scan continuously, all detectors may be turned on and off, and in-flight calibration may be initiated and stopped. A pulse command is used to turn the instrument on and off. Nine different housekeeping measurements (temperatures, currents, voltages) are transmitted and four data words per EDF are used to transmit command status information.

For in-flight calibration (IFC) a pulse train (30 kHz pulse frequency) of 2^{10} pulses is applied on command to each channel of the test input of charge sensitive pre-amps. The amplitude of the pulse is increased in 128 steps, 1 keV per step. This provides for a determination of discriminator thresholds, channel noise, performance of the counters logic and memory. The data obtained during IFC are organised in the same manner as during measurements. To test one channel, 8 EDFs of data are required, while 88 EDFs are required for a complete instrument test (about 29 minutes). It is planned to have one channel tested per orbit, initiated preferentially while the spacecraft is close to apogee.

8.1.2.5 Operational modes

ISEE-2 may be operated at two bit rates (2 or 8 kB s^{-1}) whilst maintaining the same data format. The KED instrument portion is maintained by accelerating the operational speed by a factor of 4. In addition, in order to properly adapt the information rate to the varying situations along the orbit, the instrument has two basic commandable operational modes (A and B).

8.1.2.5.1 Mode A All the sensor systems viewing the five directions relative to the spin axis contribute equal fractions to the data stream. Additional options are to give the full rate to electrons only, or to ions only, or to electrons and ions from one direction only. With decreasing number of detectors thus involved, the time resolution (and spatial resolution) is increased. Identification data for each detector are established and inserted into the appropriate data stream to the spacecraft. Angular resolution is four sectors in LBR and sixteen in HBR.

8.1.2.5.2 Mode B Most of the data stream is devoted to the WAPS system, which scans in the ecliptic plane. This mode is of particular interest in situations where the magnetic field subtends large angles with respect to the spin axis and particle fluxes are low (no significant contribution from the NAPS system). The four NAPS systems are monitored and their spin averaged rates transmitted. Again, instead of sharing the data between ions and electrons, either ions only or electrons only may be measured. The NAPS sensors provide spin averaged integral rates in LBR, but these rates are sectored four per spin in HBR. The WAPS PHA data are obtained for 4 and 16 sectors, respectively, in LBR and HBR, whereas the integral rates above 20 keV and above 100 keV for both electrons and ions are obtained in 8 and 32 sectors for LBR and HBR, respectively. The instrument is described in full detail in Williams et al. (1978).

8.2 The ISEE raw data base

The ISEE-B satellite delivered telemetry raw data (experiment data, orbit data, magnetic field data) from 1977 day 307 up to 1987 day 61. The WIM instrument on ISEE-A stopped operation in 1980 after a power supply failure, so only a limited data set is available for ISEE-A. Both sets of electron data will be included in the final data base.

Experiment data tapes have been generated by GSFC. Raw data processing was performed at NOAA, Boulder. Here the experiment data were merged with magnetic field, orbit and attitude data. These data products have been termed Master Sciences Files (MSFs). All programs generated for further data analysis were designed in such a way that they started the calculations from the data contained in these tapes. Data processing in Boulder stopped in 1982. As a result, only the data from 1977 day 305 up to 1982 day 51 existed at the beginning of this study in MSF format. Later data from 1982 day 52 up to 1987 day 61 existed as raw data only, stored on 10” magnetic tapes. To convert this data into a useable format, the MSF production had to be reactivated because all existing analysis programs use the MSF format. At this point, we encountered a major difficulty. The existing raw data programs were written in an old Fortran code for a computer which no longer existed. For this reason, these programs had to be re-established in order to make the data accessible on a modern computer. With the help of still available personnel who had participated in the original ISEE program this was finally achieved. The cooperation and help of L. Matheson and J. Stevenson at NOAA, Boulder, USA have been of great help in resurrecting the original ISEE-B processing chain. After considerable effort, the restoration of the full data set of ISEE-B until its end of life has been accomplished.

8.2.1 Telemetry raw data

Original ISEE-2 telemetry raw data tapes have been obtained courtesy of T. Fritz, Boston University, USA. Experiment-Magnetic and Orbit-Attitude data beyond 1982 day 51 existed on old magnetic tapes (9 track, 1600 bytes per inch), but format, word, and record structure of the tapes were unknown. Likewise, there was no information on the interpretation of the obvious words. It was, therefore, first attempted to interpret the bit pattern with conventional formats knowing only a few characteristics of the original processing computer. The production of the MSFs was originally done on a Cyber machine at NOAA in Boulder. With significant effort some of the manuals for the Cyber and some information on the data format descriptions were recovered in Boulder. Some descriptions were wrong because data formats had been changed several times. So all the different formats had to be tested in order to find the correct one. Finally, the right interpretation of the bit pattern was reconstructed, and the program was run on all available data tapes. However, it was then realised that the tapes containing the magnetic field data did not contain the calibration data. As offsets are critical in interpreting these data, C.T. Russell, UCLA, was asked to assist with the calibration factors. These factors had to be inserted from time to time in order to readjust for drifts in the instrument. It turned out that the required calibration data were not easily accessible at UCLA. After many approaches, data files supported to contain the calibration factors were delivered only in April 96, from which the required calibration data were extracted. With these data it was possible to process the remaining raw data and make the full data set accessible.

8.2.2 Master Science File production

There were originally two kinds of raw data tapes: DECOM tapes, containing the experiment data, and MCE tapes, containing the orbit and attitude data. The DECOM tapes contain additionally the magnetic field data from C. Russell, UCLA. In order to use this data, some additional offset data and coupling matrices were needed. These data are necessary in order to calculate pitch angles, and were delivered by UCLA. The raw data were then copied from the old 10” magnetic tapes onto DAT. About 1000 old tapes have been copied. They fit on only 7 DATs. Next, the copied raw data were cleaned from bad data and time overlap. Unreadable tapes (the tapes were 10 to 15 years old) caused some minor gaps: approximately 6% of the available data volume could not be recovered and is therefore lost.

The cleaned raw data were used as input to the converted MSF production programs. While the original raw data processing had been performed on a Cyber computer with a word length of 60 bit, the old MSF production programs were written in non ANSI Fortran II and IV for Cyber and some essential subroutines were written in Assembler for Cyber. There were a number of bit operations in these programs based on specific Cyber structure. The programs therefore had to be rewritten in modern Fortran and in C for modern machines. This task turned out to be the bulk of the work and, as such, required several months (it was not expected when this contract started).

The MSF consists of four data blocks, one header data block, one magnetic data block,

Experiment data

merge with ↘

Orbit-Attitude data ⟶ **MSF**

merge with ↗

Magnetic field data

coupling matrices

offset values from C.T. Russell

Figure 8.6. ISEE Master Science File production scheme

one experiment data block, and one housekeeping data block. For detailed description see the "Description Document for Users of the Master Science File", delivered with the MSFs. MSFs are delivered on DATs. The production scheme is illustrated in Fig. 8.6.

8.3 The ISEE final data base

8.3.1 Final data processing

With the existing Fortran programs NAPS pitch angle data, orbit and attitude data, time and measured magnetic field have been extracted from the MSFs.

The pitch angle data do not contain spectral information. The NAPS data contain the spectral information only once per spin. Energy spectra do not vary significantly over one spin period. Therefore, spin averaged spectra may be readily applied. For evaluation of the data the following procedure was applied. Spectral information was derived from the four NAPSs and spin averaged rates were used. Where spectra changed, interpolated spectral slopes have been used (power laws in kinetic energy were always assumed). These normalized spin averaged energy spectra for 12 energy channels have been merged into the final data files. A comparison of original and averaged spectral data is shown in Fig. 8.7.

Mirror point magnetic field intensities for 9 pitch angles and the corresponding L values have been calculated with BLXTRA and were added to the final data base. The magnetic field was calculated with the Olson & Pfitzer (1977) quiet model, in addition to the IGRF internal field model.

The geomagnetic activity index K_{p}, the number density n and velocity V of the solar wind, and the geomagnetic activity index D_{st} have been merged from the OMNI data base.

A quality flag for the magnetic field data and energy spectra, the local time and the invariant

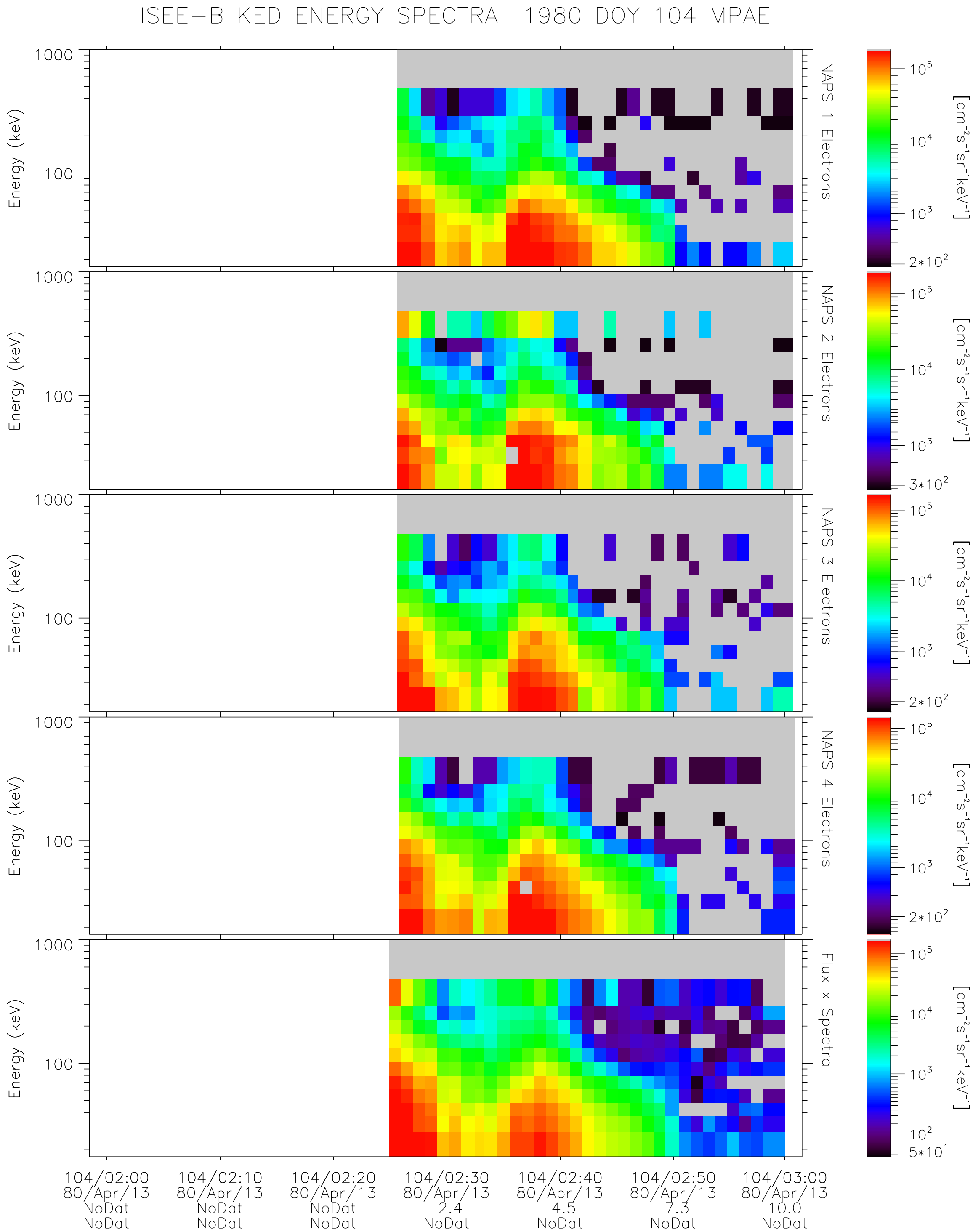

Figure 8.7. ISEE Example of four original dynamic energy spectra and the averaged spectrum. The first four plots show the data from the four NAPS sensors, the fifth plot shows the averaged spectrum adjusted to the total flux.

geomagnetic latitude have been calculated and also added.

Only times for which L values could be calculated are included (i.e. inside the magnetopause). Therefore, there are days without data and the length of the existing files varies. On average, the final daily files (in ASCII format) have a size of about 200 kB. The time resolution of the final data is about one minute.

8.3.2 Format of the final data base

8.3.2.1 Data base frame for ISEE-1

The full set of ISEE-1 data files are stored as a set of ASCII files, one file per day. The whole data set is about 21 Gb. The files are named `ISEE1_YEAR_DAY.DAT`, where `YEAR` is the year expressed as four digits, and `DAY` is the day of year (three digits).

There are two kinds of files, depending on the bit rate (low or high). On average, a low bit rate file is about 2500 kB, and a high bit rate file is about 7500 kB. Each file contains an integer header, a floating header, magnetic data, pitch angles, and electron flux data. The format of the integer and floating headers is given in Table 8.1, and that of the flux data for low and high bit rates in Table 8.2.

8.3.2.2 Data base frame for ISEE-2

The full set of final ISEE-2 data files are stored as ASCII files, one file per day. The average file size is about 200 kB, the whole data set is about 280 Mb. The files are named `ISEE2_YEAR_DAY.FINAL`, where `YEAR` is the year expressed as four digits, and `DAY` is the day of year (four digits). The record structure of the data files is listed in Table 8.3. The values of the one byte quality flag `qf` are given in Table 8.4.

8.3.2.3 Magnetic field model for ISEE-2 data

Since the electron flux data will be ordered by some pre-selected variables such as L and α_0, the choice of the magnetic field model used to calculate these data is of paramount importance.

On ISEE-2 we have the magnetic field data available: this can be used to provide some checks on the model calculations. Typically, the only input in a static model is the satellite position and time, for which the model returns model magnetic field values. The L values can be computed using the model to trace field lines. Some models take input parameters such as K_p or D_st, and the L value is a function of particle pitch angle α.

In the past, a large volume of data was averaged into one single flux map to provide a statistical model as a function of some of these parameters, without any pre-sorting of the data according to quality or applicability. In this way, data can be systematically assigned to the wrong averaging bins if the model used was not applicable or inaccurate for the data point in question. This can frequently happen in the inner magnetosphere which is inherently dynamic, and where, for example, model L values can be out by several R_E, or L values can be assigned

Table 8.1. Contents of the ISEE-1 file headers

Header No.	Description
	Integer headers
1	Year
2	Day
3	Hour
4	Minute
5	Second
6	Bit rate (0: low, 1: high)
7	Physical regime (0: trapping region, 1: tail, 2: magnetosheath, 3: interplanetary)
8	Scan direction (0: up, 1: down)
	Floating headers
1	L Value
2	B/B_0
3	Geocentric distance
4	GSE X Coordinate
5	GSE Y Coordinate
6	GSE Z Coordinate
7	Geographic latitude
8	Geographic longitude
9	Magnetic vector, GSE latitude
10	Magnetic vector, GSE longitude
11	GSM Latitude
12	GSM Longitude
13	ρ
14	GSM X Coordinate
15	GSM Y Coordinate
16	GSM Z Coordinate
17	Subsolar latitude, GSM
18	Subsolar longitude, GSM
19	Sun-Earth-satellite angle
20	SAO Spin axis, GSE latitude
21	SAO Spin axis, GSE longitude
22	Spin period
23	GSE To GSM transformation
24	GSE To GEI transformation (λ)
25	GSE To GEI transformation (E)
26	Satellite orbit number

Table 8.2. Electron flux channels in the ISEE-1 data frames (in keV)

Channel No.	Channel width
Low bit rate files	
1	22.5–39.0
2	39.0–75.0
3	75.0–120
4	120–189
5	189–302
6	302–477
7	477–756
8	756–1200
High bit rate files	
1 odd	22.5–30.5
1 even	30.5–39.0
2 odd	39.0–60.0
2 even	60.0–75.0
3 odd	75.0–94.5
3 even	94.5–120
4 odd	120–150
4 even	150–189
5 odd	189–238
5 even	238–302
6 odd	302–380
6 even	380–447
7 odd	447–602
7 even	602-756
8 odd	756–952
8 even	952–1200

to data which are obviously already beyond the magnetopause or in the lobes on open field lines (where the concept of an L value becomes meaningless).

Using the available magnetic field data on ISEE-2 and also checking on the data values to distinguish between open and closed field lines allows us to choose for incorporation into the flux maps only those data for which the used magnetic field models are valid.

Several external models were tested against the ISEE-2 magnetic field data to determine the quality of the model in terms of a long term statistical difference between measured and model field, expressed as a mean offset and a standard deviation. In general, the static models are only good for a certain range of L values, with around 70% of all data points being reproduced by the

Table 8.3. Record structure of the ISEE-2 final data base frames

Variable	Description
	Header Records
`iy`	Year
`id`	Day of year
`model`	Number of internal magnetic field model (from `BLXTRA NAMELIST`)
`mmoflg`	Flag for B value at Earth surface (from `BLXTRA NAMELIST`) 0: $M = 0.311653$ 1: $M = M(\text{epoch})$
`outer`	Number of external magnetic field model (from `BLXTRA NAMELIST`)
	Data Records
`ih`	Hours
`im`	Minutes
`sec`	Seconds
`dlonm`	Longitude (deg)
`dlatm`	Latitude (deg)
`radim`	Radius (R_E)
`bm`	Measured magnetic field strength (nT)
`flux`	Flux for 18 pitch angles ($0°$–$10°$, $10°$–$20°$, $\ldots$, $170°$–$180°$)
`spec`	normalized spin-averaged energy spectra for 12 energy ranges (keV): 17.5–28.0, 28.0–37.6, 47.6–61.5, 61.5–79.5, 79.5–103.5, 103.5–133.1, 133.1–172.5, 172.5–223.3, 223.3–289.5, 289.5–480.5, 480.4–801.0, 801.0–1000.0
`iokp`	Fitted K_p
`value_kp`	K_p (from OMNI data base)
`oni`	Density of solar wind (from OMNI data base)
`ofs`	Velocity of solar wind (from OMNI data base)
`iodst`	D_st
`b`	Model magnetic field strength (from `BLXTRA`)
`ly`	Local time, year
`ldy`	Local time, day of year
`lh`	Local time, hours
`lm`	Local time, minutes
`ls`	Local time, seconds

Table 8.3. (Continued)

Variable	Description
`bmir`	$B_{\rm m}$ For 9 pitch angles (from `BLXTRA`): 0°–10°, 10°–20°, . . . , 70°–80°, 80°–90°
`lval`	L Values for 9 pitch angles (from `BLXTRA`): 0°–10°, 10°–20°, . . . , 70°–80°, 80°–90°
`inlat`	Invariant latitude (deg)
`qf`	Quality flag (see Table 8.4)
`wb`	WAPS Back detector flux
`wk`	WAPS Coincidence flux

Table 8.4. Values of the one-byte quality flag in the ISEE-2 data files

Bit number	Meaning
no bit set	Valid data point, no problems
bit 0	Local magnetic field measurement differs from model by more than 5%
bit 1	Local magnetic field measurement differs from model by more than 10%
bit 2	Local magnetic field measurement differs from model by more than 20%
bit 3	Local magnetic field measurement differs from model by more than 50%
bit 4	Local magnetic field measurement differs from model by more than 100%
bit 5	Flux below magnetospheric threshold (on open field lines): spin averaged flux $< 1.2 \times 10^5 {\rm cm}^{-2}{\rm s}^{-1}{\rm sr}^{-1}{\rm keV}^{-1}$
bit 6	No spectral data, integral flux only

model to within 5% of the measured data. Using the Tsyganenko 1989 model with the $K_{\rm p}$ value adjusted to the published value for the period in question raises the percentage to 76%, while the best results were achieved using the Tsyganenko 1989 with a self-adjusting $K_{\rm p}$ (iteratively chosen to minimize the error). This pseudo $K_{\rm p}$ has a much more dynamic behaviour than the real $K_{\rm p}$, although the general trend of the real $K_{\rm p}$ is followed. This is due to the local nature of the measurement which is scaled using a global parameter.

For the TREND-3 project, the choice of magnetic field model is the Olson & Pfitzer (1977) quiet time model which has no input parameters besides position and time. Using this model, the ISEE-2 data base of energetic electron data was extended by a one byte parameter which serves as a quality flag (see Table 8.4). A comparison of the measured and calculated magnetic field is given in Technical Note 1.

8.4 Flux maps

The flux data have been binned in an (E, L, α_0) grid with the same grid spacings in L and α_0 as were used for the CRRES/MEA flux maps. The energy bin limits are (in keV): 17.5–28.0, 28.0–37.6, 47.6–61.5, 61.5–79.5, 79.5–103.5, 103.5–133.1, 133.1–172.5, 172.5–223.3, 223.3–289.5, 289.5–480.5, 480.4–801.0, 801.0–1000.0. The corresponding central energies are (in keV): 22.75, 32.8, 54.55, 70.5, 91.5, 118.3, 152.8, 197.9, 256.4, 385.0, 640.7, 900.5.

The flux maps constitute a new electron belt model, called EIM97. Five versions of the model were created, one each for the K_p ranges 0 to 1^+, 2 to 3^+, 4 to 5^+, and 6 to 7^+, and one for all K_p values combined. The corresponding flux maps have been converted to the format described in Sect. 2.1.6 and added to TREP.

Figures 8.8–8.11 show some examples of the final ISEE flux maps. The programs used to produce these plots are described in Technical Note 1. The left hand panel in each plot shows the number of data points in each bin, and the right hand panel shows the average flux in the bins. The plots show the inner and outer radiation belts and some significant fluxes at higher L values. These plots are only a preliminary result.

Figure 8.8 shows a flux map binned with all available data from 1977 day 307 up to 1987 day 61, over the total energy range. Figure 8.9 is similar to Fig. 8.8, but the flux map only contains data with spectral information and with a good agreement between measured magnetic field data and model magnetic data. Figures 8.10 and 8.11 show the same flux maps for energy bins 1 and 2, respectively.

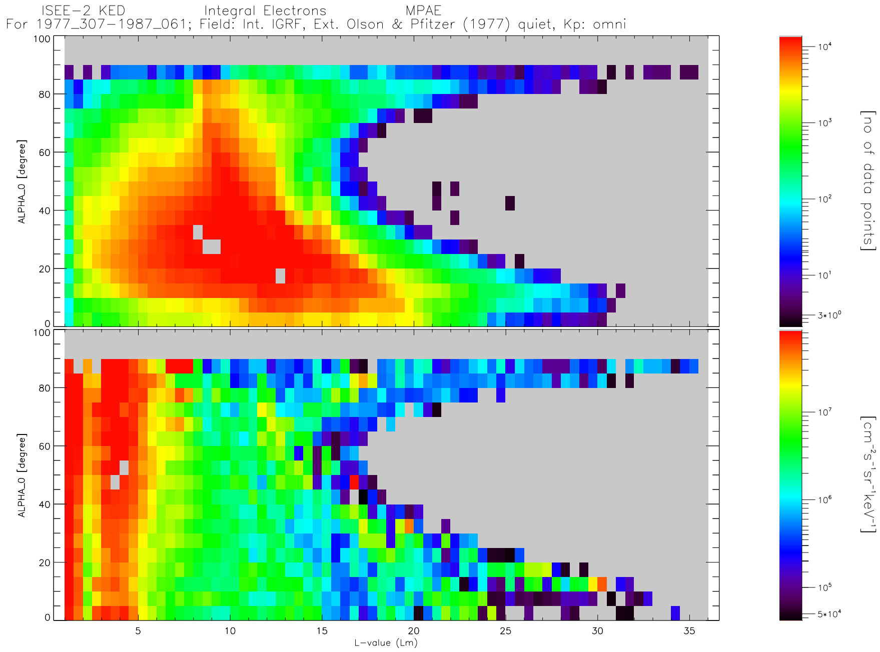

Figure 8.8. ISEE Electron flux map for all energies obtained with all data from 1977 day 307 up to 1987 day 61

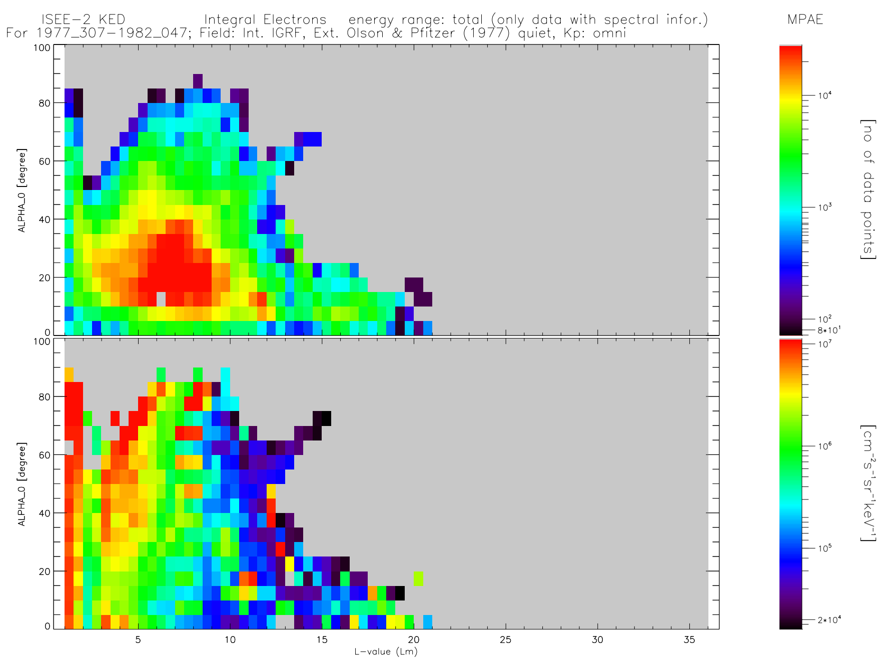

Figure 8.9. ISEE Electron flux map for all energies obtained with the data from 1977 day 307 up to 1982 day 47 that contain spectrum information

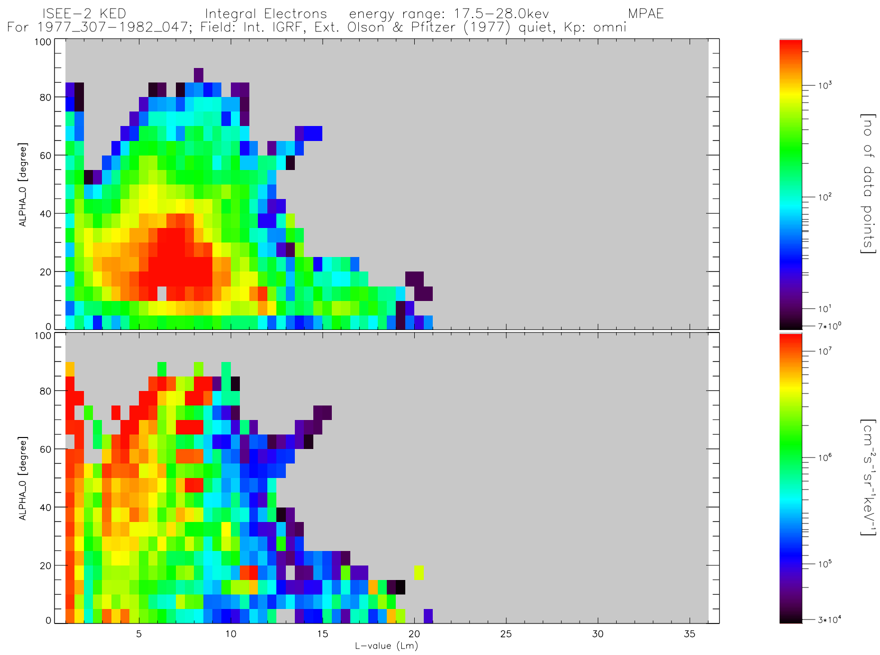

Figure 8.10. ISEE Electron flux map for energy range 17.5–28.0 keV obtained with the data from 1977 day 307 up to 1982 day 47 that contain spectrum information

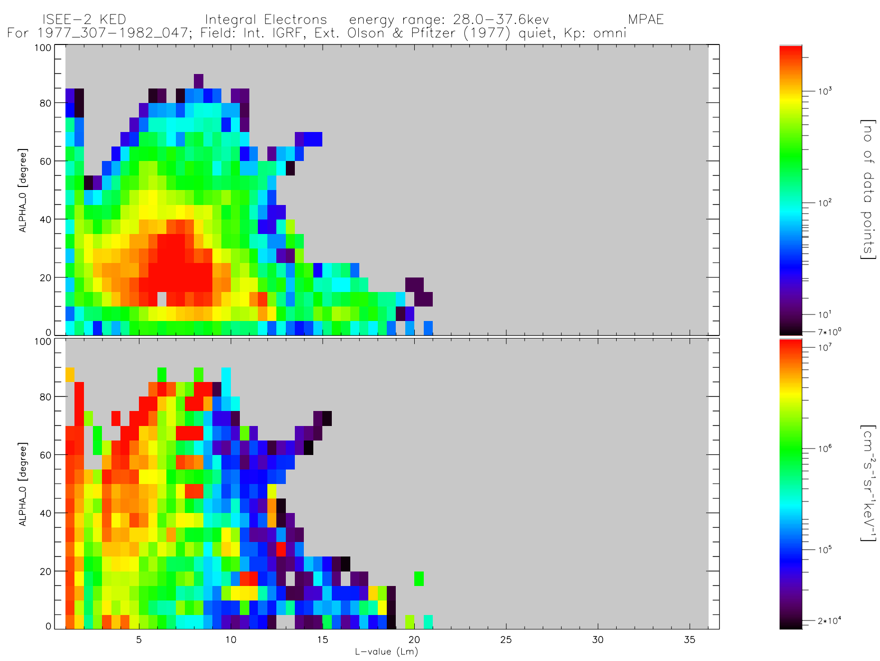

Figure 8.11. ISEE Electron flux map for energy range 28.0–37.6 keV obtained with the data from 1977 day 307 up to 1982 day 47 that contain spectrum information