

Scientific Mission of the IPEI Payload Onboard ROCSAT-1

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ABSTRACT

The Ionospheric Plasma and Electrodynamics Instrument (IPEI) onboard ROCSAT -1 is designed to measure the ion composition, density, temperature and drift velocity at the 600 km altitude along the ROCSAT-1 orbit within the latitude band of $\pm 35^\circ$. The unique features of the 100% duty cycle together with the 1 kHz sampling rate capability of the IPEI payload will enable us to make a significant contribution to the study the dynamic behavior of low-latitude ionospheric phenomena such as the bottom-side sinusoids, the equatorial spread F and the latitude effect of space weather phenomena during the active phase of Solar Cycle 23.

(Key words: ROCSAT-1, Ionospheric Plasma and Electrodynamics Instrument (IPEI))

1. INTRODUCTION

The Ionospheric Plasma and Electrodynamics Instrument (IPEI) onboard ROCSAT-1 is designed to take in-situ measurements of ion density, temperature, composition and drift velocity, over a large dynamic range with high accuracy. It consists of an Ion Trap (IT), a pair of Ion Drift Meters (+YDM and -YDM) and a Retarding Potential Analyzer (RPA). A detailed description of the payload instruments is given in Chang et al., [1, this issue]. IPEI will normally be operated with a 100% duty cycle and is capable of a sampling data at 1 kHz in selected regions. With these features, the IPEI data are suitable for investigating not only large scale electrodynamics but also small scale plasma structures in the top-side ionosphere at middle and low latitudes. Moreover, due to the 35° inclination orbital motion, ROCSAT-1 will have good spatial coverage in local time and longitude. In addition, the ROCSAT-1 mission will take place during the active phase of Solar Cycle 23 when space weather phenomena will be most variable. Under these favorable conditions, a wealth of new scientific data can be expected from the ROCSAT-1 IPEI project. Outputs of particular significant expected from the IPEI experiment are several global-scale models for solar maximum condi-

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tions, namely, the NCU/ROCSAT electric field model, the plasma structure model (including ion temperature) and the spectral model of low-latitude ionospheric irregularities.

The current report is extracted from "The Characteristics of the IPEI Payload On Board ROCSAT-1" by H. C. Yeh [2] which contains further topics related to the IPEI performance characteristics and operation procedure. Many instruments specifications can further be found in from the reports [4-11] have been quoted in the current report.

2. SCIENTIFIC OBJECTIVES

Taking advantage of the ROCSAT - IPEI unique features, we expect to apply the IPEI payload to achieve the following scientific goals.

- To conduct a systematic examination of the latitudinal, longitudinal and seasonal variations of ionospheric plasma and electrodynamics at low and middle latitudes.

The statistical data will be parameterized to produce global scale electric field and plasma structure models. These models should be the useful inputs to study the thermosphere-ionosphere-mesosphere electrodynamics couplings, and are important to the space-weather specifications.

- To investigate the morphology and processes of plasma irregularities in the low-latitude ionosphere using high resolution IPEI data.

The spectral model of low-latitude plasma irregularities will be formulated to help identifying the processes that trigger the plasma instabilities. This is necessary because small scale variations related to instabilities in the ionosphere plasma can affect the scintillation of radio signals, thus place constraints on the communications links. In addition, improved understanding of the onset and evolution of the low latitude plasma irregularities is essential to the space-weather forecast.

- To identify the mechanisms driving the coupling of the high-latitude and low-latitude phenomena in the ionosphere-magnetosphere system.

During magnetic storms/substorms, high latitude magnetospheric and ionospheric disturbances, such as electric field variations and plasma heating, can penetrate and/or propagate to the lower latitudes and modify the low latitude ionospheric structures. ROCSAT/IPEI data taken at medium inclination are particularly suitable to study the coupling phenomena prevalent in the middle latitudes.

- To complement the observations of the International Solar Terrestrial Program (ISTP) satellites and the ground-based instruments to study the electrodynamics and space weather features of the solar terrestrial systems.

In order to achieve these goals, we will not only perform detailed analyses of the IPEI data, but also collaborate with ground-based instruments as well as other scientific satellites experiments. Theoretical simulations will also be pursued to help interpretation of the IPEI observations and the underlying processes.

2.1 IPEI Geophysical Measurement Requirements

To investigate the ionospheric phenomena on the scale sizes of greater than 10 km (i.e., global scale) and on the scale size of a few meters (i.e., local scale), IPEI should be able to

take measurements that fulfill the following requirements listed in Table 1 and Table 2.

Table 1. Measurement Requirements for Global Scale (> 10 km).

Parameter	Dynamic Range	Accuracy
Ion Velocity Vector	± 2 km/s	± 10 m/s
Total Ion Concentration	50 to 5×10^6 cm ⁻³	10%
Ion Temperature	500 to 10,000 °K	10%

For the global scale phenomena, it is sufficient to have each of the above parameters sampled at about 1 Hz rate. With the ROCSAT-1 orbital configuration, the observations will be over all local times and longitudes in less than 4 months. The latitude coverage is up to $\pm 35^\circ$ geographic latitudes.

Table 2. Measurement Requirements for Local Scale (> a few meters).

Parameter	Dynamic Range	Sensitivity
Transverse Velocity Vector Deviations (ΔV_H and ΔV_V)	± 500 m/s	± 2 m/s
Total Ion Concentration Deviations ($\Delta N/N$)	1% to 500%	1%

Local scale observations will be emphasized in local time region from 1700 hrs to 0700 hrs SLT (Solar Local Time). The scale sizes will be greater than a few meters. The latitudinal coverage will be up to $\pm 45^\circ$ dipole latitudes. Again the observations over all longitudes will be obtained in less than 4 months. Each of these parameters will be measured at 1 kHz sample rate in relative intervals.

2.2 Instrument Specification Summary

Table 3 provides a quick-look of the major features of the IPEI payload. Some details of this summary are discussed elsewhere in this report.

Table 3. IPEI Specification Summary.

Instrument	RPA	IDM	IT
Measurement	Ion Temperatures, and Ram Velocity	Transverse Ion Velocity Components	Total Ion Concentration
Heritage	AE, DE,	DMSP, Viking,	and San Marco.
Detector	Linear Electrometer, 8 ranges	Log Electrometers with Linear Diffe. Amplifier, 2 ranges	Log Electrometer
Range	$V_x = \pm 2$ km/s $T_i = 500 \sim 10^4$ K	$V^{\wedge} = \pm 2$ km/s	$N_i = 50 \sim 5 \times 10^6$ cm ⁻³
Accuracy	$\Delta V = \pm 10$ m/s $\Delta T_i = \pm 10$ %	$\Delta V^{\wedge} = \pm 10$ m/s	$\Delta N_i / N_i = \pm 10$ % $\Delta N_i / N_i = \pm 1$ %
Sampling Rate	32 Hz (Normal) 64 Hz (Fast)	32 Hz (Normal) 1024 Hz (Fast)	32 Hz (Normal) 1024 Hz (Fast)
Mass	< 14 kg (total weight)		
Envelope Dimension (cm)	SEP: 17 x 37 x 36 ;	MEP: 7 x 21 x 27	
Power (W)	10 W		
DC Power Bus (V)	Minimum: 22 V,	Nominal: 28 V,	Maximum: 34 V
Pointing Direction	Ram		
FOV (full angle)	45° x 45°,	Conical	
Temperature	- 20°C ~	+ 50°C	
Data Rates	Normal Mode : 2.224 kbps,	Fast Mode: 53.376 kbps	
Duty Cycle	Normal Mode: 83 %	Fast Mode: 17 %	

2.3 COLLABORATIVE SCIENCES

To maximize the usage of IPEI data, we expect significant opportunities to collaborate with ground-based observations, theoretical modeling and other space-borne experiments.

2.3.1 Coordination with Ground-based Instruments

The planned corrective studies with ground-based instruments are described in Table 4. Briefly, observations with incoherent scatter radars (ISRs), VHF coherent scatter radar (CSR), HF radar heater, image intensified all sky camera, Fabry-Perot interferometer and spaced antenna scintillation system at the middle and low latitude observatories are all of interest to the ROCSAT-IPEI mission. Table 5 contains a list of the geographic locations as well as the existing instruments of several possible sites for pursuing the coordinated ground-based experiments.

The incoherent scatter radars are particularly valuable because ISR measurements can provide fairly detailed altitude distributions of the ion temperature and drift velocity, and are directly comparable to the IPEI measurements. In addition, ISR is frequently used as a coherent scatter radar to probe the small scale plasma irregularities. Important information regarding the fine structure and evolution of plasma irregularities (and their driving instabilities) can often be derived by combining the high resolution data from IPEI with the echo power spectra from CSR experiments. Comparison of the IPEI measurements with data from the Altair, Arecibo, Jicamarca, Millstone, and MU radars will be conducted on a statistical basis and during scheduled overflights of these observing stations.

Table 4. ROCSAT-IPEI and Ground-based Coordination Studies.

Ground-Based Instrumentation	Parameter	Science
Incoherent Scatter Radar (ISR)	Plasma density, Temperature, and Drifts	In-flight data verification, 2D ionospheric structure, and electrodynamics
VHF Coherent Scatter Radar (CSR)	Non-thermal Structures	Plasma irregularities
HF Radar Heater	Non-thermal Structures	Artificial field-aligned plasma irregularities
Image Intensified	Airglow	Imaging equatorial anomaly and bubbles
Fabry-Perot Interferometer (FPI)	Thermal wind, Temperature	Thermosphere - Ionosphere coupling
Spaced Antenna Scintillation System	Scintillation Ion drift	Plasma irregularities zonal drifts

Table 5. Ground-Based Experiment Sites.

Observatory	Instrumentation	Geographic	
		Latitude	Longitude
Jicamarca, Peru	ISR, VHF CSR	11.90° S	76.00° W
Millstone Hill, MA	ISR, All-Sky Imager, FPI	42.60° N	71.50° W
Arecibo, Puerto Rico	ISR, HF Heater All-Sky Imager	18.30° N	66.75° W
Altair, Kwajalein	ISR, All-Sky Imager	8.80° N	167.5° E
MU, Japan	ISR, VHF CSR	34.85° N	136.1° E
Chung-Li, Taiwan	VHF CSR	25.00° N	121.0° E
Ancon, Peru	Scintillation System	11.79° S	77.18° W

2.3.2 Coordination with TIME-GCM Model and TIMED-TIDI Payload to Study Ion-neutral Coupling

The IPEI in-situ measurements of ion drifts at 600 km can be used to derive the large scale electrostatic potential models under various geophysical conditions. By means of electric field mapping along magnetic field lines, these models can then be applied to map the ion drift patterns of the dynamo region at lower altitudes. Thus IPEI ion drift data can contribute important inputs to the NCAR thermosphere-ionosphere-mesosphere-electrodynamics general circulation model (TIME-GCM).

Thermosphere-Ionosphere-Mesosphere Energetic and Dynamics (TIMED) satellite is the first science mission in the Solar Connections Program of the US-NASA. TIMED is scheduled to launch in the first quarter of 2000 into a 600 km circular orbit with 74.4° inclination. Onboard TIMED are four payloads, namely Solar EUV Experiment (SEE); TIMED Doppler Interferometer (TIDI); Global Ultraviolet Imager (GUVI); Sounding of the Atmosphere using Broad band Emission Radiometry (SABER), to remotely explore the Earth's mesosphere and lower thermosphere (60-180 km). Possibility exists that ROCSAT-1 and TIMED would be making simultaneous measurements at nearby regions coincident near simultaneously. With proper electric field and conjugate magnetic field mappings, we will be able to combine the in-situ measurements of ion drifts by IPEI with the remote sensing data of neutral winds by TIDI

to study the ion-neutral couplings in the dynamo region during the ROCSAT-1 and TIMED coincidences.

2.3.3 Global Campaigns Participation and Space Weather Study

IPEI data can be useful to many of the existing research programs which involve global collaborators and multiple instruments experiments. Among the programs, CEDAR, GEM, STEP and World's Day are the global campaigns most relevant to the IPEI project. These campaigns are expected to be active through the ROCSAT-1 era and beyond. Specifically, the CEDAR program focuses on studying the coupling, energetics, and dynamics of atmospheric regions. GEM emphasizes the geospace environment modeling. The principal goal of STEP is to advance the quantitative understanding of the coupling mechanisms that are responsible for the transfer of energy and mass from one region of the solar-terrestrial system to another. The World's Day program, on the other hand, designates several periods of each year to run coordinated experiments utilizing the ground-based facilities (in particular radars) around the world to study specific events such as magnetic storm, substorm or other large-scale coupling phenomena. In spite of differences in the emphasis, one of the common goals among the programs is to make contribution to the space weather research.

IPEI data and the derived empirical models can provide much information regarding the low-latitude ionospheric irregularities, the ionization anomaly and other ionospheric responses to solar and magnetospheric disturbances, which are part of important space weather features at low-latitude ionosphere. With IPEI data we therefore can make significant contributions to the space weather research.

3. MISSION OPERATION

The communication between the ground and the IPEI is a two way link. The instrument receives operation commands from the ground and sends back science as well as instrument status data. The IPEI-to-Ground communication is conducted by the NSPO ROCSAT Ground Segment (RGS) and the NCU IPEI Science Data Distribution Center (SDDC) at the National Central University. RGS is composed of the Mission Operations Center (MOC), Tracking, Telemetry and Command (TT&C) stations, Flight Dynamics Facility (FDF), Mission Control Center (MCC), Science Control Center (SCC), and the Ground Communications Network (GCN). The role of IPEI SDDC, IPEI instrument commands and constraints, data telemetry and monitoring, routine mode operations, and finally the ground-based coordination of experiments during the ROCSAT-1 mission operation phase is described in the following.

3.1 IPEI Science Data Distribution Center (SDDC)

The functional architecture of the IPEI SDDC is shown in Figure 1. The SDDC major functions include science operation support and IPEI-science data management. The role of SDDC in supporting the IPEI operations is discussed first, and the discussion of science data management will be deferred to Section 6.

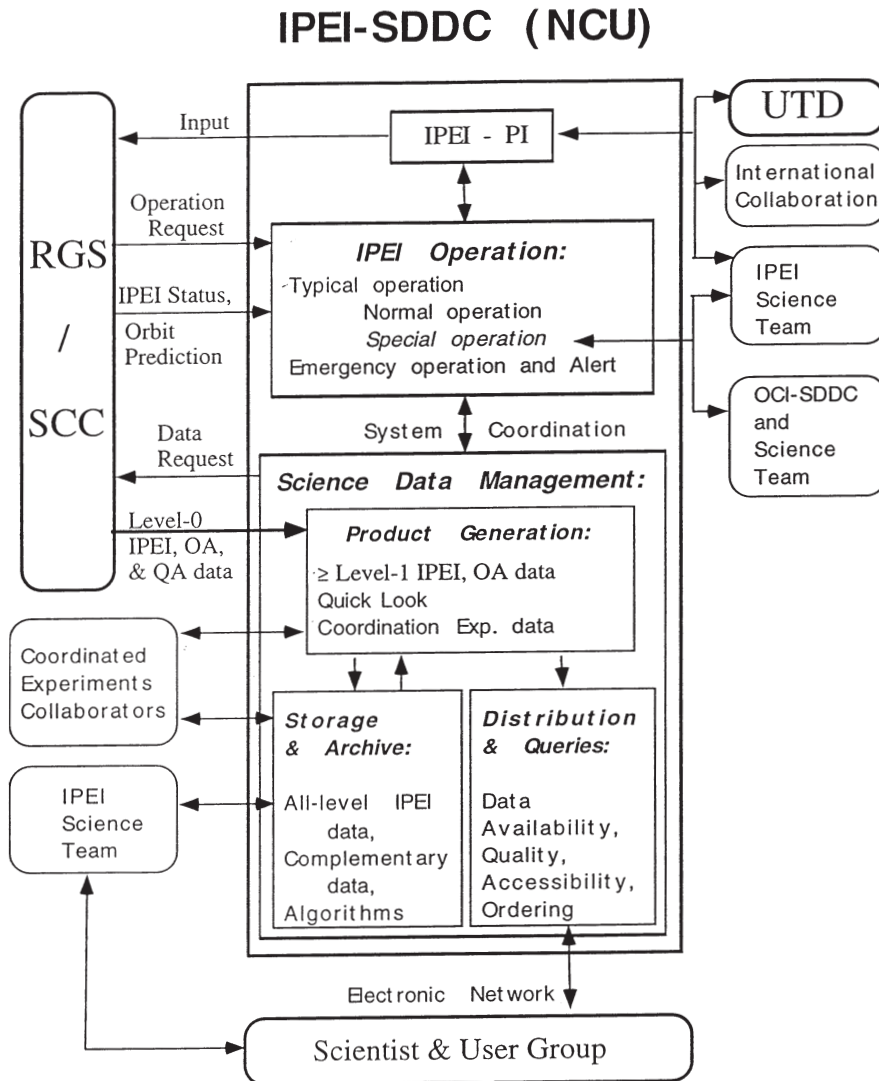


Fig. 1. The functional architecture of the IPEI SDDC.

In the ROCSAT-1 pre-launch phase, the SDDC is responsible for organizing the IPEI science team, domestic user groups, and the international collaborations. During the mission operation phase, the IPEI SDDC will interact with NSPO/SCC, UTD, the IPEI science team, and the OCI SDDC to plan the IPEI operation activities. Furthermore, the SDDC will provide RGS/MOC the necessary inputs to command the requested operations. Upon receiving the SDDC Level_0 data sets from the SCC via the electronic network, the SDDC will perform data decoding and further processing to generate the Quick-look data plots of the IPEI science data. By inspecting the IPEI status of health (SOH) telemetry and the Quick-look data plots,

the IPEI team will be able to monitor the instrument performance during the flights.

3.2 Science Operations and Commands

Figure 2 delineates the route of commanding the IPEI operations. The IPEI SDDC plans the operation activities and routinely places the commands request to the RGS-SCC. The SCC retrieves the SDDC inputs (requests) and interfaces with other RGS subsystems (FDF, MCC, MOC) to schedule the SDDC requested activities. The relevant subsystems will generate the required commands, perform constraint checks and upload the commands to the spacecraft Transponder Interface Electronics (TIE) and On Board Computer (OBC), which are parts of the Command and Data Handling subsystem (C&DH). The spacecraft C&DH subsystem processes these uplink commands and transmit them to IPEI over an 1553B bus to activate the appropriate IPEI actions. However, the ON/OFF commands for IPEI instrument will be executed by the spacecraft OBC. Reversibly, the IPEI health and status data will be routed back through the 1553B interface to the spacecraft (TIE-OBC) down link telemetry system and are transmitted to the RGS and then to the IPEI SDDC. The IPEI instrument representatives will continuously monitor the status of health of the instrument in order to control the IPEI operations.

3.2.1 IPEI Operation Modes

The IPEI instrument is operated in four modes: (1) OFF Mode; (2) NORMAL Mode; (3) FAST Mode; and (4) AUTO Mode. The descriptions of these modes are presented in Table 6. When ROCSAT-1 is in the science mode phase, the major operating modes of IPEI are NOR-

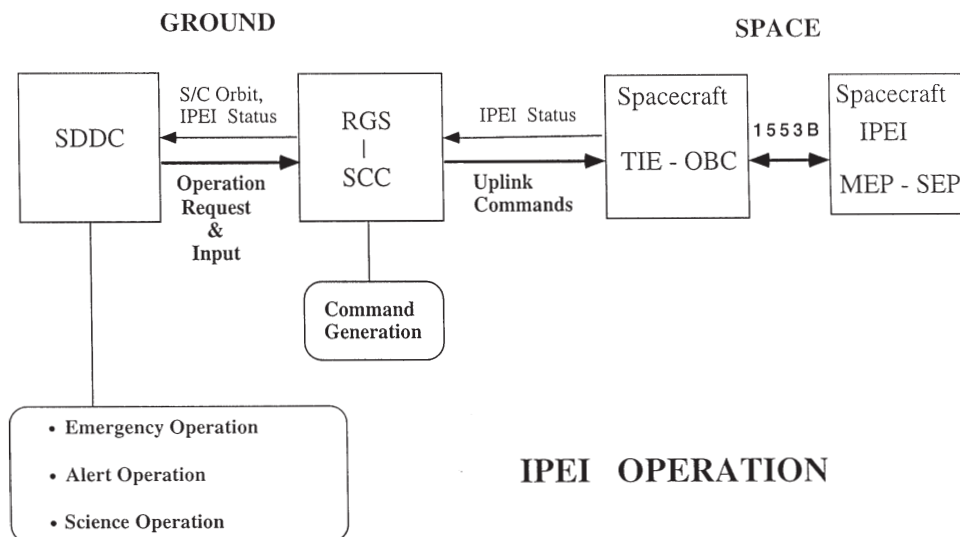


Fig. 2. The route of commanding the IPEI operations.

Table 6. IPEI Instrument Modes.

Instrument Mode	Description	S/C Mode
OFF Mode	The IPEI instrument is unpowered.	Launch Mode Sun Mode Safe-Hold Mode Maneuver Mode
NORMAL Mode	The IPEI NORMAL Mode is the primary measurement mode for the science mission. In the NORMAL mode, each of the 4 sensors is sampled at 32 samples/sec.	Science Mode
FAST Mode	The IPEI FAST Mode is activated from the ground. In the FAST mode, IT, +YDM, and -YDM are sampled at 1024 samples/sec rate, and RPA is sampled at 64 samples/sec.	Science Mode
AUTO Mode	In the AUTO mode, IPEI operates in the NORMAL mode until the FAST mode is initiated by a trigger controlled by an IPEI DPU algorithm.	Science Mode

MAL, FAST and AUTO, with Normal mode as the default after the IPEI power on. The combination of NORMAL mode and FAST/AUTO mode will be operated at 100% duty cycle. However, the maximum duty cycle of FAST mode and/or AUTO mode operation is subject to the limitation of the allocated Solid State Recorder (SSR) space (66.97 Mb per orbit) for IPEI. Typically, the IPEI instrument will operate at NORMAL mode with a FAST or AUTO mode on the night side every orbit. The duty cycle of the IPEI operation is limited to ~17% FAST mode rate and ~83% NORMAL mode rate data collection. In the AUTO mode, the IPEI operates in NORMAL mode until FAST mode is initiated by a trigger controlled by a MEP DPU algorithm. The AUTO mode operation can be reactivated after each SSR dump. Whether the satellite is on the day side or on the night side, IPEI will only operate at NORMAL mode when the OCI instrument is in FULL BAND imaging mode. However, it is understood between the IPEI team and the OCI team that OCI Full Band imaging mode shall occur only once a month at most, and will not be operated when IPEI is conducting the coordinated observations between the spacecraft and ground-based radar. Furthermore, the IPEI submode operations can be activated by time tagged commands to improve the instrument in-flight performance and data quality.

4. DATA MANAGEMENT

The most important function of the IPEI SDDC is to manage the science data generated by IPEI. The data flow chart is shown in Figure 3. Starting from the pre-launch phase of ROCSAT-1, SDDC is responsible to develop the software required for processing and analyzing the IPEI data. Soon after receiving the reconstructed IPEI telemetry data (SDDC Level-0) sets and the satellite orbit and attitude (OA) information from the Science Control Center, the SDDC data processing program will decode the Level-0 IPEI data packets and combine with the synchronized OA data to generate the Level-1 geophysical data files and the WWW-accessible Quick-Look plots. Moreover, the SDDC will compile the higher levels IPEI data according to various geophysical parameters of interest. Throughout and after the mission operation phase, the IPEI SDDC is responsible for storing, archiving and distributing the IPEI data and algorithms. Furthermore, the IPEI SDDC will actively communicate with the local and international research and education communities to promote the maximum usage of IPEI data.

To discuss the generation of high level IPEI data files, it is useful to briefly summarize again the geophysical parameters measured by the IPEI sensors. These include the total ion concentration $[N_i]$ by the Ion Trap (IT), the transverse horizontal $[V_y]$ and vertical $[V_z]$ velocity components by the paired Drift Meters (DM), and the data set of ion temperature $[T_i]$, ram velocity component $[V_x]$, sensor potential $[f_{sen}]$ with respect to ambient plasma and the relative ion compositions $[N_i/N_{O+}]$ by the Retarding Potential Analyzer (RPA). The vectors measurements, V_x , V_y , and V_z are referred to the instrument coordinate axes, and will be transformed in reference to the spacecraft coordinate axes for data presentation. The detailed methods of

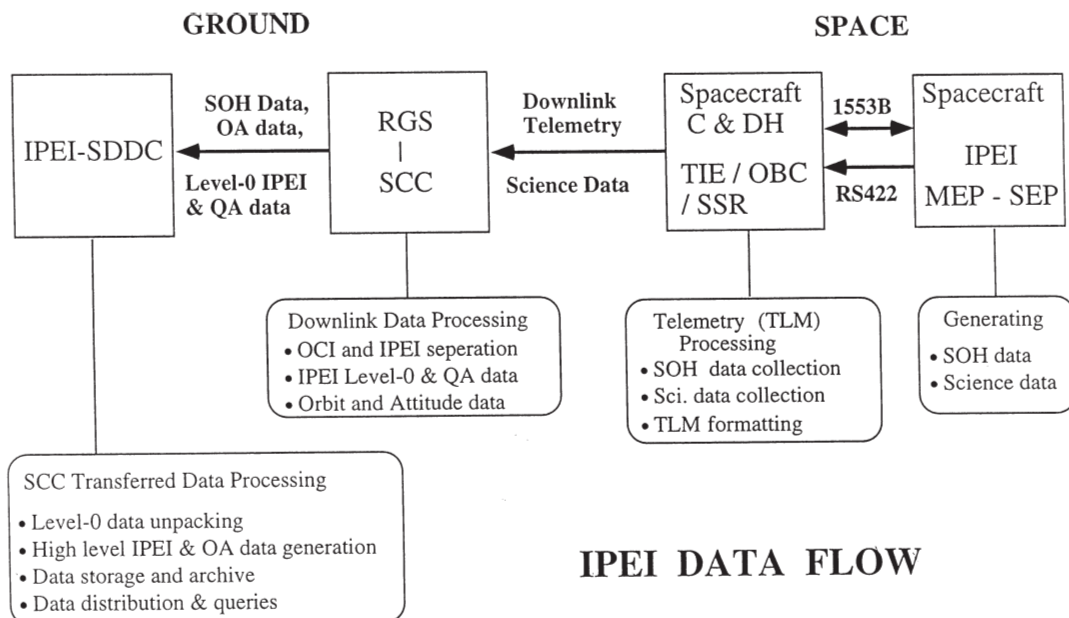


Fig. 3. The IPEI data flow chart.

deriving these geophysical parameters from telemetry data have been discussed in Chapter 4 for each of the sensors.

Figure 4 is a flow chart, delineating the different levels of IPEI data that will be derived from the Level_0 data set files. Four levels of IPEI data are defined. The definitions of the IPEI high level data sets ($> \text{Level}_0$) are in part based on the UTD recommendation that each level of the IPEI data should stand alone and Level_0 returning to the lower levels to re-derive the higher level data is unwarranted to respond to the request of scientists and users. The contents of the four levels are discussed as follows.

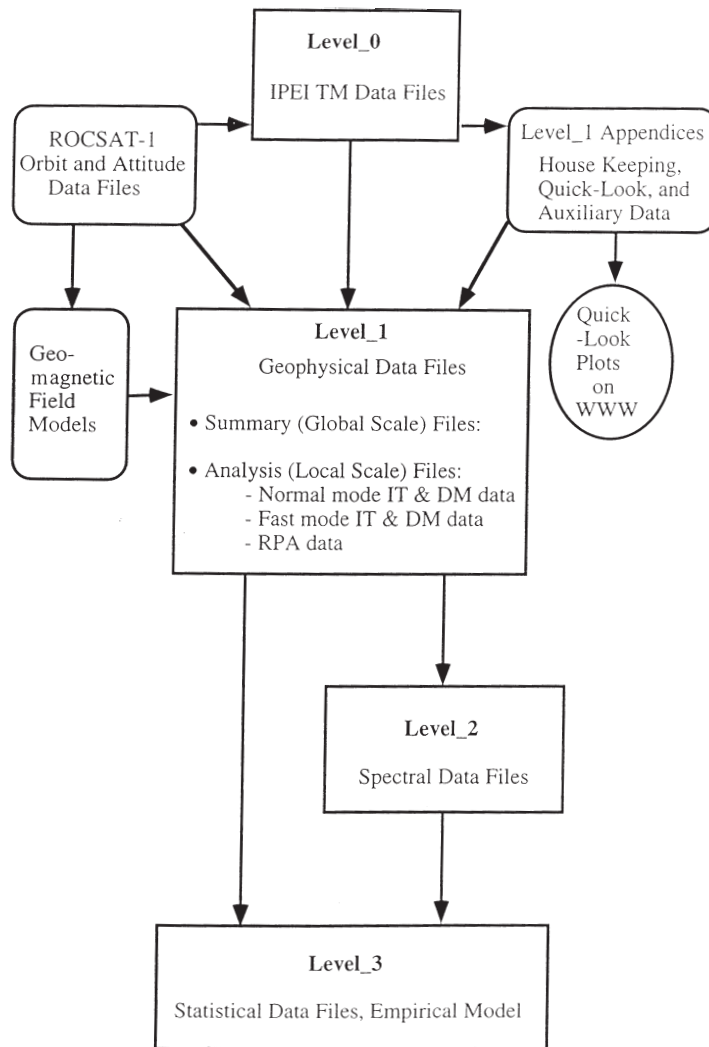


Fig. 4. The different levels of IPEI data files.

4.1 Data from Other Sources

From previous discussions, it is clear that reduction of the IPEI data to geophysical parameters and subsequent interpretation of the data require additional parameters not directly derivable from the IPEI output. Most importantly, the spacecraft orbit as well as attitude data and the geomagnetic field models should be available for this purpose.

4.1.1 ROCSAT-1 Orbit and Attitude Data

In order to put the IPEI data into a geophysical content, the satellite orbit and inertial attitude must be known. The RGS-SCC will provide SDDC three different file types of the ROCSAT-1 orbit and attitude data. These are the definitive OA data, the predictive Cartesian data and the predictive Keplerian data. The content of each file type is described in the RGS/SDDC Interface Control Document [8]. The two predictive data files will be used as references for implementing the IPEI operation requests (e.g., to time tag the stored commands), and for planning the coordination experiments (e.g., to optimize the ground experiment configuration) during the mission operation phase. Only the definitive OA data will be used with IPEI output to compile the higher levels data files.

Each definitive data file from the RGS-SCC corresponds to the OA data received from all of the down links in a single day. Therefore, any one definitive orbit and attitude data file may cover a time interval from 18 to 30 hours. Each record of a definitive OA file consists of the spacecraft position, velocity and attitude information at a 4-second interval. Spline-fit technique (or other methods) will be applied to these definitive OA data to derive the analytical time functions of OA for interpolating the data at a finer time interval (say, at 1-second interval). Moreover, it will be possible from these data to resolve the spacecraft velocity along the spacecraft coordinate axes and to construct a rotation matrix that allows any vector (such as V_x, V_y, V_z) in the spacecraft reference frame to be transformed into the geocentric inertial frame (ECI). The vectors in ECI can further be transformed into any other reference frame of geophysical interest.

4.1.2 Geomagnetic Field Data and Models

To study the ionospheric electrodynamics, it will be frequently desirable to resolve the observed ion drifts into their components parallel and perpendicular to the magnetic field. This will require specification of a model geomagnetic field in the spacecraft reference frame. Because the ROCSAT-1 orbits will be in low altitude and low latitude regions, the updated International Geomagnetic Reference Field (IGRF95) model will be used for this purpose. Meanwhile, the low resolution in-situ measurements of magnetic field will also be available from the RGS FDF. These data can provide an additional verification of the model magnetic fields.

Furthermore, for the purpose of quantitatively analyzing geophysical phenomena, the corrected geomagnetic coordinate (CGM) system [12] will be applied to the position tagging of high level IPEI data. The corrected geomagnetic coordinates are calculated from the IGRF model. Computer code (e.g., GEO_CGM program) has been developed for coordinate trans-

form among the geographic coordinate system, the CGM system, and the dipole magnetic coordinate system. The GEO_CGM computer program is available from the National Space Science Data Center (NSSDC) of USA on request.

4.2 Level_0 Data File (File name: eYYDDDDHHMMSSXX.zsi , defined at SCC)

Downlink telemetry data from the spacecraft are processed and separated among the subsystems by the RGS Science Control Center. The SCC constructs the payload status and the Level_0 with Quality Assurance (QA) data files for IPEI and then makes these file sets available to the IPEI SDDC via the electronics network. An IPEI Level_0 data file consists of the time tagged telemetry data sets for each downlink (about 2 ~ 3 orbits' worth of data). The data sets are the reconstructed packets generated by the IPEI instrument, except for the unrecoverable errors which occur in the downlink and are flagged in the associated QA files.

The science data are expressed as a "count" occupying 12 bits. These digital data are packaged into packets with a fixed packet length of 278 bytes. The data rate is 1 packet per second when the IPEI operation is in NORMAL mode and 24 packets per second when IPEI is in FAST mode. The format of packets varies with the operation modes. There are 4 primary packet formats, one for NORMAL mode, three for FAST mode. Byte by byte details of each packet content can be found in the ROCSAT/IPEI System Specification Document [4] provided by UTD. Moreover, the RGS-SCC will add a header record packet (also 278-byte long) at the beginning of the above instrument data packets for every IPEI Level-0 data set file. This record describes the file name, start/stop time of the first/last data point, number of records in the file and number of QA records, of an IPEI Level-0 file. Thus, only one such header record is allowed per file.

The data packets are described in separate reports [3,4]. Here we briefly restated in following.

4.2.1 Header Record

Though the arrangements for every IPEI packet are different in each corresponding mode, every IPEI Level-0 data set file has only one header record at the beginning. It records information such as file name, start and stop time of an instrument measurement, the length of the referring downlink file and the number of records in the corresponding QA data file.

Here are the data descriptions for the header record below. The first row represents the bytes count; the second row is the field name; and the third row gives the data size and type.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
e	Y	Y	D	D	D	H	H	M	M	S	S	X	X	.	z	s	i	X
18 bytes / ascii																		blank
20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
Start Time										X	Stop Time							
10 bytes / ascii										blank	10 bytes / ascii							

39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	
		X	Length								X	The Number of Records in The Corresponding QA file							
		blank	8 bytes / ascii								blank	8 bytes / ascii							

58	59-278																	
	Reserved for Future Use																	
	220 bytes / ascii																	

4.2.2 NORMAL Mode

The IPEI instruments produce one packet every second in the NORMAL mode as shown below.

Second count	Sec 1	sec 2	sec 3...
normal mode	Pkt1	pkt2	pkt3...

All IPEI packet information is written in binary code. It provides packet header, secondary header, internal counter, command status, housekeeping (HK1 & HK2) information, and the sequential analog data which are sampled alternately at 32 samples/sec by four IPEI sensors. The following table depicts the contents of IPEI packets collected in NORMAL mode. The first row represents the byte count and the second row shows the corresponding field name. For details of field description, see the RGS/SDDC Interface Control Document for the ROCSAT Ground Segment.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Packet Header						Secondary Header (Year, Julian day, Hour, Min, Sec)									Internal Counter	Command Status		

20	21	22	23 ~ 278															
HK2	HK1		Sequential Analog Data (32 samples / sec)															

4.2.3 FAST Mode

Second count	sec 1			sec 2			sec 3...
Fast mode	pkt1	pkt2-23	pkt24	pkt25	pkt26-47	pkt48	pkt49..

In FAST mode, IPEI produce 24 packets per second as shown above. All of them are written in binary code. Of the 24 packets produced in FAST mode, the first, the second through to the twenty-third, and the twenty-fourth packet all have different data constructions, in which packet header, process time, command status, DPU status, secondary header, and sequential analog data are provided in the following table. In the FAST mode, four sensors sample at rates different from NORMAL mode: +YDM, -YDM, and IT devices sample at a rate of 1024 Hz, and RPA device samples at a rate of 64 Hz.

Byte Series	1~6	7	8	9	10	11	12	13	14	15	16	17	18	19 ~ 278	
1 st packet	Packet Header	Hr	Min	Command Status		DPU status	Spare		Sequential Analog Data						
2 nd ~ 23 rd packet	Packet Header	Time		Sequential Analog Data											
24 th packet	Packet Header	Secondary Header (Year, Julian day, Hr, Min, Sec)									Internal Counter	Time	Sequential Analog Data		

4.2.4 AUTO Mode

In AUTO mode, the IPEI operates in NORMAL mode until FAST mode is initiated by a trigger controlled by a DPU algorithm. Therefore the DPU status field of the first packet in FAST mode serves as notice of what collected mode will be coming.

4.3 Level_1 Data File

A Level_1 file consists of time and position tagged geophysical parameter data which are derived from the Level_0 with OA data and the magnetic field models. The contents of Level_1 data files vary with the spatial/temporal scales of interest in the scientific studies. Two types of Level_1 data file are defined. The first type is the "Summary File" which should be satisfactory for studying the large scale ($10 \geq$ km) phenomena, such as global scale electrodynamic. The second type is the "Analysis File" which is most useful for investigating the local scale features of ionospheric plasma. Depending on the data rates of the sensors, the Analysis File includes three subtypes. These are: Normal_IT&DM at a rate of 32 Hz rate; Fast_IT&DM at a rate of 1024 Hz; and RPA at a 2 to 16 Hz data rate which varies with both the operation mode and the selected RPA RV block. The parameters included in each type of the Level_1 files are described below. A brief summary of the principal procedures involved in deriving these parameters is also presented.

4.3.1 Summary File (or Global Scale File)

Remarks:

- Define one file from minimum latitude to minimum latitude

(One file contains about one orbit worth of data.)

- Round start time to previous minute
 - Round stop time to following minute
 - Ensures two equatorial crossings in one file
- Temporal resolution: 1 Hz (resulting from averaging)
- Vector components with reference to spacecraft coordinate system
(Assuming that the instrument coordinate system perfectly matches the spacecraft coordinate system)

Parameters included in the file:

- 1) UT in Hr:Min:Sec
- 2) Geographic Latitude in degrees
- 3) Geographic Longitude in degrees
- 4) Solar Local Time in Hr:Min:Sec
- 5) Dip Latitude in degrees
- 6) Altitude in km
- 7) Transverse Horizontal component of **B**
- 8) Transverse Vertical component of **B**
- 9) In-Track Horizontal component of **B**
- 10) Spacecraft (Instrument) to Inertial Rotation Matrix
- 11) Transverse Horizontal Ion Drift from DM
- 12) Transverse Vertical Ion Drift from DM
- 13) In-Tack Horizontal Ion Drift (Ram) from RPA
- 14) • rms fit error
- 15) Ion Temperature from RPA
- 16) • rms fit error
- 17) Constituent Ion Concentrations (relative to O+) from RPA
- 18) • rms fit error
- 19) Sensor Potential from RPA
- 20) • rms fit error
- 21) Total Ion Concentration from Ion Trap

Principal steps to processing the data for the Summary File parameters (items 11-21) which are directly derivable from IPEI digital output are as follows.

- (1) Unpack the Level_0 data packets, separate the digital data by operation modes (i.e., NORMAL or FAST) and further separate data according to sensors (i.e., RPA, IDM, and IT).
- (2) Calculate electrometer voltage outputs from sensor digital outputs (counts) using the formula $V_{\text{out}} = 0.0025 * (\text{Count} - 2048)$.
- (3) Apply the laboratory calibration results, including the sensitivity level coefficients (G) and other characteristic constants of the sensors, to the electrometer voltage outputs to recover

from them the inputs of ion current (or arrival angle in the case of DM) to the sensors. This is the step for converting engineering measurements to first-order geophysical measurements. Detailed mathematical formulas, geometry and characteristic constants of the instruments required for this step are described elsewhere [2].

(4) Analyze the products resulting from the above step and implement the necessary corrections to the output from each of the different sensors.

- The data reduction procedures described in section 4.6.4 should be applied to fit the observed RPA I- R_v curves with a theoretical I- R_v characteristic curve for a multiple-species, single temperature Maxwellian distributed plasma. The least squares fit solutions with their corresponding fit errors for the four parameters (ion temperature, ram velocity (\mathbf{V}_x), sensor potential and the relative density of constituents) are included in the Summary File (i.e., items 13-20).
- To improve the DM data analysis, offset values of the arrival angle measurements at each log-amplifier polarity change will be determined and corrected. Satellite attitude contributions to the arrival angle measurements will be removed. The transverse, horizontal and vertical velocity components can then be derived from the corrected arrival angle measurement.
- The corrected ion ram velocity ($\mathbf{V}_r = \mathbf{V}_{sc,r} + \mathbf{V}_x$) must be used to calculate the total ion concentration (N_i) from the Ion Trap.

It is worth noting that the data value included in the Summary File for each of the above parameters is the one-second average regardless of the operation mode and the RPA RV block selection.

Data for those Summary File parameters not related to IPEI output (i.e., items 2-10) are derived through the following procedures.

- (1) As the UT time, altitude, geographic latitude and geographic longitude are the parts of a Definitive Orbit and Attitude data file provided by SCC, the time duration of interest will be identified (i.e., the timings when ROCSAT-1 travels from a minimum latitude to the next minimum latitude) from the Definitive OA data file. The spline fit technique to the OA data is applied within the time duration of interest to obtain the values of geographic latitude, geographic longitude and altitude at one-second interval.
- (2) Similarly, spacecraft attitude and velocity data included in the definitive OA file are used to calculate the spacecraft to inertial rotation matrix at one-second interval. If the instrument coordinate axes are not parallel to the corresponding axes of the spacecraft coordinate frame, the instrument to inertial rotation matrix must be derived instead.
- (3) Using the satellite position data (namely, geographic latitude and longitude and altitude) as the input to run the GEO_CGM program, the solar local time, the IGRF magnetic field components at the point, and the dipole latitude can then be calculated. However, the magnetic field vectors from the GEO_CGM output are referenced to the local E_N_U coordinate axes and should be transformed into those in reference to the spacecraft (or instrument) coordinate frame to be included in the Summary File (i.e., items 7-9).

4.3.2 Analysis Files (Local Scale Files)

4.3.2.1 Normal_IT&DM Data File

Remarks:

- Define one file from minimum latitude to minimum latitude
(One file contains about one orbit worth of data.)
- Round start time to previous minute
 - Round stop time to following minute
 - Ensures two equatorial crossings in one file
- Data rate at 32 Hz
 - Write data in 1 minute blocks
- Time and position tags at 1 minute intervals
- Vector components in reference to spacecraft coordinate system
(Assuming that the instrument coordinate system perfectly matches the spacecraft coordinate system)

Data included in the file:

- 1) UT in Hr:Min:Sec
- 2) Geographic Latitude in degrees
- 3) Geographic Longitude in degrees
- 4) Solar Local Time in Hr:Min:Sec
- 5) Dip Latitude in Degrees
- 6) Altitude in km
- 7) Transverse Horizontal component of **B**
- 8) Transverse Vertical component of **B**
- 9) In-Track Horizontal component of **B**
- 10) Block of Horizontal Velocity (\mathbf{V}_y)
(60*32 samples)
- 11) Block of Vertical Velocity (\mathbf{V}_z)
(60*32 samples)
- 12) Block of Total Ion Concentration (N_i)
(60*32 samples)

The steps to process IPEI data for the parameters \mathbf{V}_y , \mathbf{V}_z and N_i to be included in a Normal_IT&DM file are the same as those for a Summary File. No averaging is involved in the process. The data at the first second of each one-minute block will be included in the file for those parameters indicating the satellite position, dip latitude and magnetic field components.

4.3.2.2 Fast_IT&DM Data File

Remark:

- Define one file for each FAST mode (and/or AUTO mode) event
(In general, one file contains about 15 minute worth of data.)
- Data rate at 1024 Hz
 - Write data in 10 second blocks
- Time and position tags at 10 second intervals
- Vector components in reference to spacecraft coordinate system
(Assuming that the instrument coordinate system perfectly matches the spacecraft coordinate system)

Data included in the file:

- 1) UT in Hr:Min:Sec
- 2) Geographic Latitude in degrees
- 3) Geographic Longitude in degrees
- 4) Solar Local Time in Hr:Min:Sec
- 5) Dip Latitude in Degrees
- 6) Altitude in km
- 7) Transverse Horizontal component of **B**
- 8) Transverse Vertical component of **B**
- 9) In-Track Horizontal component of **B**
- 10) Block of Horizontal Velocity (V_y)
(10*1024 samples)
- 11) Block of Vertical Velocity (V_z)
(10*1024 samples)
- 12) Block of Total Ion Concentration (N_i)
(10*1024 samples)

Again, the steps to process IPEI data for the parameters V_y , V_z and N_i to be included in a Fast_IT&DM file are the same as those for a Summary File, but no averaging is involved in the process. The data at the first second of each ten-second block will be adopted for inclusion in the file for the parameters of satellite position, dip latitude and magnetic field components.

4.3.2.3 RPA Data File

Remark:

- Define one file from minimum latitude to minimum latitude
(One file contains about one orbit worth of data.)
- Round start time to previous minute
 - Round stop time to following minute
 - Ensures two equatorial crossings in one file

- Data rate at 2 Hz (Normal mode) to 16 Hz (Fast mode and Block 5)
 - Write data in 1 minute blocks
- Time and position tags at 1 minute intervals
- Vector components with respect to spacecraft coordinate axes
(Assuming that the instrument coordinate system perfectly matches the spacecraft coordinate system)

Data included in the file:

- 1) UT in Hr:Min:Sec
- 2) Geographic Latitude in degrees
- 3) Geographic Longitude in degrees
- 4) Solar Local Time in Hr:Min:Sec
- 5) Dip Latitude in Degrees
- 6) Altitude in km
- 7) Transverse Horizontal component of **B**
- 8) Transverse Vertical component of **B**
- 9) In-Track Horizontal component of **B**
- 10) Block of In-Track Horizontal Ion Drift (Ram, or V_x)
and σ rms fit error from RPA
(minimum $60 \times 2 \times 2$ samples); (maximum $60 \times 16 \times 2$ samples)
- 11) Block of Ion Temperature and Σ rms fit error from RPA
(minimum $60 \times 2 \times 2$ samples); (maximum $60 \times 16 \times 2$ samples)
- 12) Block of Constituent Ion Concentrations
and σ rms fit error from RPA
(minimum $60 \times 2 \times 2$ samples); (maximum $60 \times 16 \times 2$ samples)
- 13) Block of Sensor Potential and Σ rms fit error from RPA
(minimum $60 \times 2 \times 2$ samples); (maximum $60 \times 16 \times 2$ samples)

It is worth reminding that each RPA RV sweeping cycle consists of two I- R_v curves to be fitted. Depending on the sweep rate of a selected RV Block and on the mode of operation (Normal or Fast), the data rate for the parameters (items 10-13) derived from observed I- R_v curves can be from 2 Hz to 16 Hz. Again, the data at the first second of each one-minute block will be adopted for inclusion in the file for those annotation parameters including satellite position, dip latitude and magnetic field components.

This file keeps track of variations in the offset value between two measurements made near simultaneously by the DM with opposite polarities. The offset values shall be close to a constant when the ambient environment remains quiet for a long period. This data file should be used to correct the DM outputs to account for the inherited system bias.

4.4 Level_2 Data File

Level_2 data processing is to reduce the Level_1 IT and DM analysis files data to the

refined analysis parameters, such as spectral index and background trend, through spectral analysis techniques. These data files will be used to study the small scale structures and dynamics of the low-latitude ionosphere. Two types of Level_2 data file are proposed, which may be generated by the investigators themselves. The principal characteristics of these files are the followings.

(A) Spectral analysis of local scale file:

- 4 second (128 samples) segments for total ion concentration and transverse ion drifts.
- Detrended background (zero frequency) parameters.
- 5 or 6 point k-spectrum of $\text{Log}(N_i)$ (to cover the dynamic range of N_i measurements).
- Power and spectral slope.
- Time and position tagged every 4 seconds.

(B) Spectral analysis of Fast mode event file:

- 4 second (4096 samples) segments for total ion concentration and transverse ion drifts.
- Detrended background (zero frequency) parameters.
- 15 or 16 point spectrum (to study the spectral shape of DN_i).
- Power and spectral slope.
- Time and position tagged every 4 seconds.

4.5 Level_3 Data File

Level_3 data processing is to generate the global scale diagnostic data files to study the statistical behaviors of large scale ionospheric structures and dynamics. The following data files may be considered as the Level_3 data.

- Cumulative averages of geophysical parameters
- Data binned according to latitude, longitude and local time
- Monthly data files
- Mean and variance from each contribution by pass
- Empirical electrostatic potential models by yearly data

4.6 Data Archive and Access

The IPEI data of all levels will be stored in the SDDC data base. Commercial software packages such as Oracle, DB2, or others will be applied to manipulate the data base.

The SDDC will create the world wide web accessible Quick-Look plots for the uncalibrated Level_1 summary data. This should make a representative sampling of the IPEI data more immediately accessible to the scientific community and to the general public. The users shall be able to identify the specific time intervals associated with the data of interest from survey-

ing Quick-Look plots and place the requests to the IPEI SDDC. The requested data (> Level_0), will generally be repackaged into the Hierarchical Data Format (HDF) which is the data format most popular to the ionosphere scientists. The HDF data files will be put on CD-ROMs to be passed to the requesters. In general, only the Level_1 summary data files will be released. However, the data level of access for the external users will be determined by the PI or the authorized personal at SDDC after reviewing their data usage proposals.

5. DISCUSSION AND CONCLUSION

Although the IPEI data are obtained at the 600km altitude, they can be mapped along the geomagnetic field lines to study the global ionospheric phenomena in the low latitude regions. Together with the coordinated ground ISR radar observations, we can extend the study of ionospheric plasma and electrodynamics of the coupling regions into three dimensional form. The current report provides a brief description of the hardware capabilities of the IPEI payload onboard ROCSAT-1 as well as the data processing procedures of the IPEI data. It is hoped that the report will generate some interests for persons who are interested in using IPEI data for collaborated studies. Furthermore, we have other report by Yeh [13] detailing the study of the global coupling phenomena with the ROCSAT- IPEI.

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