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THE DEVELOPMENT AND OPERATION OF THE INTERNATIONAL SOLAR-TERRESTRIAL PHYSICS CENTRAL DATA HANDLING FACILITY

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ABSTRACT

The National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC) International Solar-Terrestrial Physics (ISTP) Program is committed to the development of a comprehensive, multi-mission ground data system which will support a variety of national and international scientific missions in an effort to study the flow of energy from the sun through the Earth-space environment, known as the geospace.

A major component of the ISTP ground data system is an ISTP-dedicated Central Data Handling Facility (CDHF). Acquisition, development, and operation of the ISTP CDHF were delegated by the ISTP Project Office within the Flight Projects Directorate to the Information Processing Division (IPD) within the Mission Operations and Data Systems Directorate (MO&DSD). The ISTP CDHF supports the receipt, storage, and electronic access of the full complement of ISTP Level-zero science data; serves as the linchpin for the centralized processing and long-term storage of all key parameters generated either by the ISTP CDHF itself or received from external, ISTP Program-approved sources; and provides the required networking and "science-friendly" interfaces for the ISTP investigators. Once connected to the ISTP CDHF, the online catalog of key parameters can be browsed from their remote processing facilities for the immediate electronic receipt of selected key parameters using the NASA Science Internet (NSI), managed by NASA's Ames Research Center.

The purpose of this paper is twofold: (1) to describe how the ISTP CDHF was successfully implemented and operated to support initially the Japanese Geomagnetic Tail (GEOTAIL) mission and correlative

science investigations, and (2) to describe how the ISTP CDHF has been enhanced to support ongoing as well as future ISTP missions. Emphasis will be placed on how various project management approaches were undertaken that proved to be highly effective in delivering an operational ISTP CDHF to the Project on schedule and within budget. Examples to be discussed include: the development of superior teams; the use of Defect Causal Analysis (DCA) concepts to improve the software development process in a pilot Total Quality Management (TQM) initiative; and the implementation of a robust architecture that will be able to support the anticipated growth in the ISTP Program science requirements with only incremental upgrades to the baseline system. Further examples include the use of automated data management software and the implementation of Government and/or industry standards, whenever possible, into the hardware and software development life-cycle. Finally, the paper will also report on several new technologies (for example, the installation of a Fiber Data Distribution Interface network) that were successfully employed.

INTRODUCTION

NASA's spacecraft contribution to the ISTP Program includes the Interplanetary Physics Laboratory (WIND: 11/94 launch) and the Polar Plasma Laboratory (POLAR: 11/95 launch). The international contribution includes the GEOTAIL mission (successfully launched in July 1992) developed by the Japanese Institute for Space and Astronautical Science (ISAS) and the Solar and Heliospheric Observatory (SOHO: 7/95 launch) and Plasma Turbulence Laboratory (CLUSTER: 12/95 launch) being developed by the European Space Agency. In addition, scientific contributions are being provided by several ground-based radar investigations and

on-orbit correlative science missions such as the Los Alamos National Laboratory (LANL) spacecraft and the Geostationary Operational Environmental Satellites (GOES 6/7).

Within the framework of the ISTP Program objectives to combine resources and to promote cooperation in the scientific communities on an international scale, the primary function of the ISTP CDHF became one of computing summary parameter data ("*key parameters*") for every instrument on the GEOTAIL, WIND, and POLAR spacecraft, three instruments on SOHO, and the magnetic field instrument on the Interplanetary Monitoring Platform-8 (IMP-8); and to ingest and catalog key parameters from external sources such as the ground-based radars and other equatorial spacecraft missions that have been made an integral part of the overall ISTP Program. The key parameters provide for a quick, low resolution time series (on the order of one minute) survey of the global geospace. The major advantages of providing key parameters to the science community are their diversity of coverage over the geospace, timeliness and availability. The goal is to generate the key parameters within 6 hours of receipt of the corresponding Level-zero data.

The major functions of the ISTP CDHF are summarized as follows:

- Receive telemetry, orbit, attitude, and command history data from external ground system elements
- Receive and process near real-time data for WIND and POLAR
- Generate key parameter data for all instruments onboard GEOTAIL, WIND, and POLAR, and, selected instruments from the IMP-8 and SOHO spacecraft
- Receive key parameters from ground-based radar investigators and other correlative spacecraft such as LANL, GOES, and CLUSTER
- Store telemetry, orbit, attitude, command history, and key parameter data sets in online storage for user access and transfer to the

IPD's Data Distribution Facility (DDF) for subsequent distribution on Compact-Disk Read Only Memory (CD-ROM) media and to the National Space Science Data Center (NSSDC) for long-term archival purposes

- Manage, track, and account for all data flowing through the CDHF
- Provide interactive user services for catalog access, online data access, and data transfers

The remainder of this paper discusses several key programmatic and technical elements which were employed that directly led to the successful implementation and operation of the ISTP CDHF.

IMPLEMENTATION OF THE ISTP CDHF

Project Management Team

From the beginning of the implementation of the ISTP CDHF, a concerted effort was made to establish a solid project management team. This was accomplished by "matrixing" both technical and management staffs from three GSFC Directorates, namely, the Flight Projects Directorate (Code 400), the Space Sciences Directorate (Code 600), and the Mission Operations & Data Systems Directorate (Code 500). Once the implementation team was in place, several methods for conducting business expeditiously among the three Directorates were established and an excellent partnership evolved as a result.

The following summarizes some of the more important aspects of this partnership and the associated advantages that accrued, particularly from the perspective of the Information Processing Division:

- Requirements documents, Interface Control Documents, and other key documents were negotiated **directly** between the ISTP Project and the IPD which enabled the requirements to be captured in a high-fidelity manner.
- The IPD ISTP CDHF development team was given full responsibility to work directly

with the ISTP Principal Investigator (PI)/Co-Investigator (Co-I) teams both nationally and internationally and Code 600 personnel, when required, with Project oversight.

- The IPD ISTP CDHF development team was an integral part of the Project team and played a major role in the technical decision-making processes. The team was given broad latitude to make technical trade-offs and to suggest solutions, and as a result, a variety of solutions to improve system performance and to reduce on-going ISTP CDHF operations and maintenance costs were provided.

ISTP Science Management Team

The primary guiding force for the evolution of the ISTP CDHF as the key ISTP Program science facility was the ISTP Science Working Group (SWG) chaired by the Project Scientist. The SWG--which included the Project Scientist, Deputy Project Scientists and all of the Instrument Investigators PIs, Co-Is, Ground-Based Investigators, and Theory Investigators--established the ISTP science objectives in coordination with the national and international ISTP science community. The SWG was instrumental in developing a set of "Rules of the Road." This set of rules delineated how the ISTP science community shall "behave" with respect to data generation, data exchange, and data access rights (for example, proprietary data periods).

In order to use effectively the key parameters for collaborative science, several data formatting and exchange standards were jointly prepared by the ISTP science community and the ISTP CDHF development team. By working closely with the various science teams and actively soliciting their inputs, a very useful set of ISTP data standards and conventions was developed: first, the standard header used on all science files cataloged on the ISTP CDHF is the Standard Formatted Data Unit (SFDU). The SFDU standard is defined and operated under the auspices of the Consultative Committee for Space Data Systems. The ISTP Project selected SFDUs as a convenient yet standardized way of structuring, managing,

and tracking the multitude and variety of data products resident on the ISTP CDHF; second, the SWG recommended the adoption of the NSSDC ISTP Common Data Format (CDF) as the common data format protocol for all key parameters generated within the ISTP Program. The adoption of the CDF, the SFDU concept, and other standards and conventions for the key parameters proved to be crucial to supporting multiple-instrument browsing and collaborative science. Also, the selection of the NSSDC's ISTP CDF provided the ISTP Program with the means to influence its future development.

One of the most significant scientific benefits to date of adopting the CDF and related standards has been the ability for the first time to review key parameter data ranging from 35 Earth Radii (Re) in "front" of the Earth to 200 Re "behind" the Earth in conjunction with geosynchronous orbit data at 6.2 Re and ground-based data.

ISTP CDHF Procurement Team

The ISTP Project Office delegated the procurement responsibility of the ISTP CDHF to the IPD. To that end, a Technical Evaluation Panel comprised of senior technical members of the three Directorates and chaired by the IPD Project Manager was formed. This team evaluated the vendor proposals with an emphasis on selecting a robust architecture amenable to the current ISTP requirements, one that could easily be expanded to accommodate future science requirements, and one with the ability to incorporate commercial off-the-shelf (COTS) hardware and software. In July of 1990, Digital Equipment Corporation (DEC) was selected to deliver, integrate, and test the hardware and operating system components of the ISTP CDHF; in September of 1990, this integrated system was turned over to the IPD for development of the ISTP core applications software.

ISTP CDHF Hardware Implementation

The selection of the DEC VMScluster architecture for the ISTP CDHF was significant because it enabled the ISTP CDHF to be configured as a scalable,

integrated system that provided robustness, stability, high availability, and access to a wide variety of computer processors and storage controllers. The initial configuration of the ISTP CDHF consisted of one VAX 6000-410, one VAX 6000-430, two Hierarchical Storage Controllers (HSC70s), twenty-four RA92 disk drives (36 Billion Bytes[GB]), a variety of terminals and workstations, local area and wide area networking interfaces, and the Virtual Memory System (VMS) operating system.

Not long after the initial configuration was installed, new ISTP Program requirements emerged that impacted the hardware baseline. Key among these were additional processing and storage requirements for the key parameters being generated and received at the ISTP CDHF, a requirement to generate three sets of WIND key parameters in near real-time for the Air Force, and expanded user/operator interface requirements. To satisfy the first requirement, a re-conditioned VAX 9000-210 computer and four RA73 disk drives (8 GB) were procured and integrated into the VMScluster; for the second requirement, a VAX 4000 Model 200 was purchased and connected to the existing internal Ethernet network; and, to address the third requirement, an Alpha 4000 Model 300 workstation was acquired. In each case, the VMScluster architecture provided the needed flexibility and ease in accommodating the new hardware elements. Refer to Figure 1 for a depiction of the ISTP CDHF hardware configuration and major external interfaces.

Another salient feature of the DEC architecture that contributed to the success of the ISTP Program was a robust electronic networking infrastructure that provided connectivity for the world-wide ISTP scientific community. Initially, only DECnet support was provided; however, with the rapid proliferation and emerging importance of scientific workstations running Unix, the need to provide connectivity for ISTP users of the Defense Department's Advanced Research Projects Agency Transmission Control Protocol/Internet Protocol (TCP/IP) became apparent. To meet this need, a VMS-based TCP/IP third-party package from TGV, Inc. called Multinet was acquired. The

Multinet software provided a full suite of TCP/IP services (for example, Telnet, File Transfer Protocol, Simple Network Mail Protocol) which enabled the implementation team to establish connectivity to the growing base of Unix-based users. The programmatic mechanism for achieving this overall global connectivity (DECnet and TCP/IP) was to connect the ISTP CDHF to the NSI.

Internal to GSFC, the ISTP community, particularly members of the WIND PI teams, obtained the advantage of high-speed access (1 Mbit/s) to the ISTP CDHF via the GSFC Local Area Communications Network.

Finally, in a proactive response to ISTP Program science requirements for increased bandwidth, reliability, and security, an ISTP-only Local Area Network (LAN) was installed that was based upon the American National Standards Institute-standard Fiber Distributed Data Interface (FDDI) specification. The resultant backbone FDDI LAN (100 Mbit/s) connected the IPD-funded Data Capture Facility (DCF) and DDF to the Project-funded ISTP CDHF, and has proved to be a very reliable platform for the transfer of large volumes of ISTP-only data products among the three facilities. *Note:* the ISTP FDDI network was one of the *first* operational FDDI LANs at the GSFC.

ISTP CDHF Software Implementation

The major software activity undertaken was the development of the ISTP CDHF core system or applications "umbrella." This core system was designated as the ISTP CDHF Software System or ICSS. The ICSS was developed by a combined team of civil servants from the IPD and Computer Sciences Corporation contractor personnel from the MO&DSD Systems, Engineering, and Analysis Support (SEAS) Contract.

The approach taken in developing the ICSS was based upon the SEAS System Development Methodology (SSDM). The SSDM represented a disciplined approach for developing software, consistent with the MO&DSD's System Management Policy. By rigorously applying field-proven software-development techniques, the ISTP

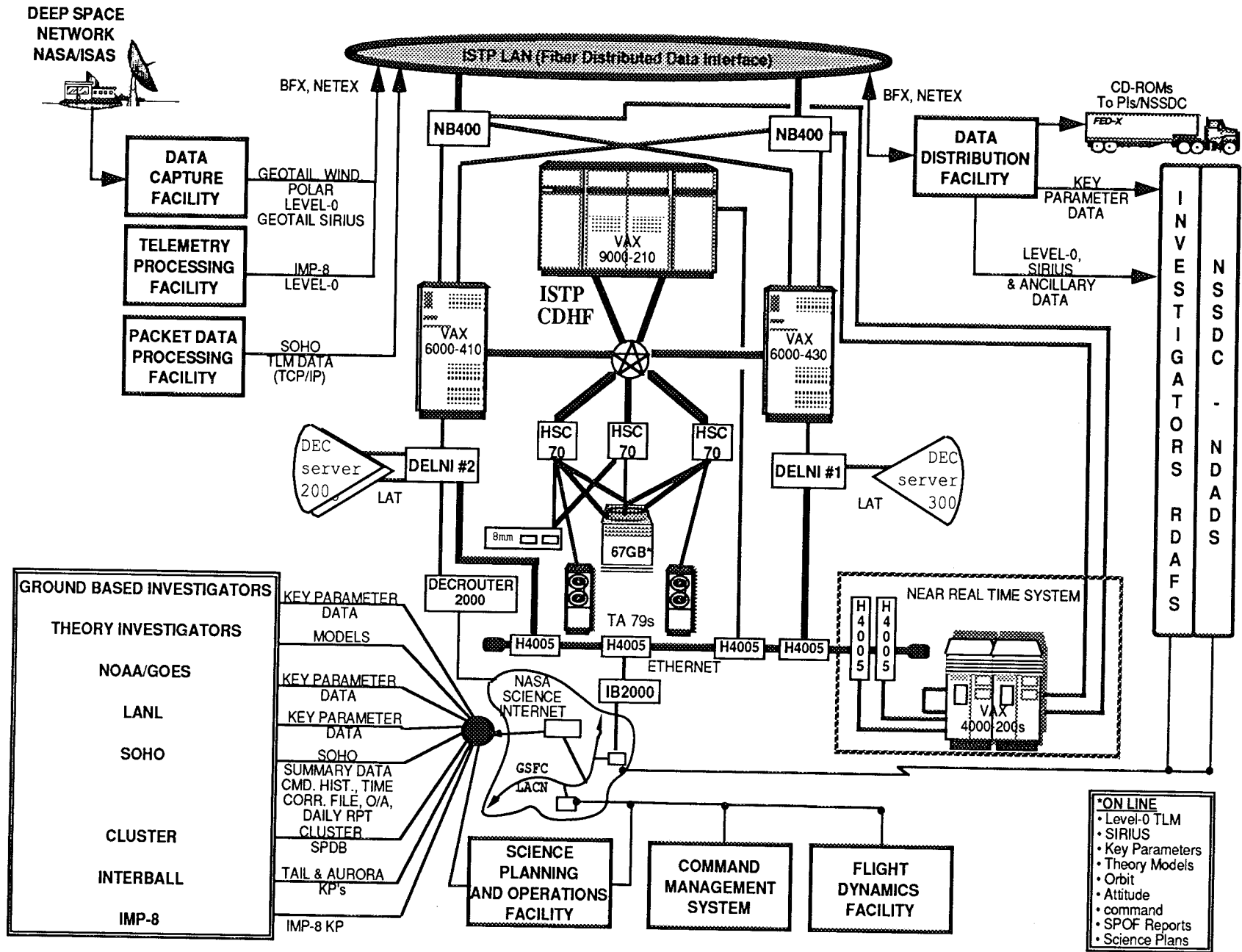


Figure 1: GSFC ISTP Ground Data Handling System

- *ON LINE**
- Level-0 TLM
 - SIRIUS
 - Key Parameters
 - Theory Models
 - Orbit
 - Attitude
 - command
 - SPOF Reports
 - Science Plans

software development team was able to deliver the ICSS on schedule, within budget, and meeting all of the technical and operational requirements.

Another approach that was emphasized and proved invaluable was the use of COTS software to reduce the implementation time. Examples included the MO&DSD Transportable Applications Executive (TAE) software package for the operations interface and the selection of the Oracle relational data base management system (DBMS) to account for all of the ISTP data products. Extensive use of third-party VMS system management and networking software also helped in reducing the amount of new software that had to be developed and tested.

The following lists the major design drivers that were factored into the overall development of the ICSS:

- Must support network access to the ISTP Level-zero and science databases
- Must support multiple missions on different operational timelines
- Must support operations and development activities concurrently and on multiple computers
- Must provide for both manual and automated modes of operation
- Must produce key parameters within 24 hours for each 24 hours of Level-zero data
- Must be able to perform 100% reprocessing of key parameters
- Must process near real-time data within two minutes after receipt (WIND & POLAR only)

In order to implement the core system with these design drivers, the ICSS had to be designed with automation and flexibility in mind. Automation was needed to handle varying processing requirements from multiple missions and to support a variety of external electronic interfaces; flexibility was required so that the ICSS could execute on a variety of VAX computers: from VAX mainframes to Alpha workstations. To accomplish these two objectives, a scheduler concept coupled with the functionality of an Oracle relational DBMS was devised. The general concept was to develop an automated data ingest system which would verify and

catalog all files coming in (mainly unscheduled) from external sources (for example, the DCF, ground-based radar sites, and, ISAS), while at the same time providing the CDHF operations personnel with the means for scheduling, executing and monitoring the key parameter production jobs. This concept proved to be very successful as the ISTP CDHF operation runs "unattended" 75% of the time.

The ICSS was partitioned into two independent software environments: (1) a production environment which supported the daily ingest of Level-zero data, the receipt or generation of the key parameters, and the electronic access from the user community; and, (2) a development and test environment for the PIs' key parameter generation software (KPGS). The latter environment was established to assist the ISTP science teams in the development of their KPGS and was instrumental in the expeditious development, integration, and testing of the ISTP investigator software that executes as part of the ISTP CDHF's production stream. Indeed, one of the biggest challenges was integrating the operating system provided by DEC, the ICSS developed by the IPD, and the KPGS developed remotely at the various science facilities into an ISTP CDHF production environment.

To assist the ISTP science teams, a formal KPGS Integration and Test Team (KITT) was established. The KITT's charter was to work directly with the ISTP science community to provide a smooth transition of a PI's "bench" key parameter program to a full-fledged production version executing on the ISTP CDHF. One of the most important activities of the KITT was to provide "hands-on" training to each of the individual PI science teams. This extensive training, which often required domestic and foreign travel, significantly reduced the KPGS implementation schedule and was very instrumental in fostering an excellent working relationship between the KITT and the various ISTP science teams.

A very successful TQM initiative to emerge from the ICSS development phase was a pilot project to determine if the quality of delivered

software could be improved. This initiative involved applying DCA concepts to the ICSS development process. The basic premise of DCA is that the software developers making the errors have the insight into how those errors/defects were introduced and how to change the process to prevent them in the future. Early results indicated a reduction in error rates between Build 1 and Build 2 and which were also significantly lower than those documented for previous IPD projects.

In summary, to support the scientific objectives of the ISTP Program in general, and the specific objectives of the Japanese GEOTAIL mission, the ICSS implementation team delivered over 75,000 lines of source code on schedule and within budget. This achievement was attributed in large part to the excellent teamwork that was established among the project management teams, the ISTP scientific community (especially our Japanese colleagues at ISAS), and the IPD implementation and test teams.

OPERATIONS OF THE ISTP CDHF

On September 8, 1992, the ISTP CDHF became operational providing support for the GEOTAIL mission, several ground-based radar investigations, and the IMP-8, GOES, and LANL correlative science missions. The ISTP CDHF operations were provided by the MO&DSD Network Mission and Operations Support (NMOS) contract with RMS Technology Incorporated (RMS) responsible for providing daily mission operations and system management functions; AlliedSignal Technical Services Corporation was responsible for all hardware maintenance, sustaining engineering services, and ICSS acceptance testing.

In anticipation of technical and operational questions from the ISTP community, the operations staff was fully trained in all aspects of the ISTP CDHF and were thus able to provide immediate assistance, personally and electronically, to several members of the GEOTAIL science team located at ISAS in Japan, which made communications that much more difficult.

Another important function performed by the operations staff has been the timely re-processing of key parameter data, since it is not uncommon for the science teams to modify or enhance their key parameter science algorithms to reflect better the on-orbit performance of their instrument. The ISTP CDHF operations staff is responsible for accessing the relevant Level-zero data stored on the DDF's optical mass store system. Through a network link to this mass store, the Level-zero data can be expeditiously retrieved and the KPGS re-executed. The updated key parameters are then made available electronically at the ISTP CDHF and on CD-ROMs which are distributed later by the DDF.

In order to keep the ISTP science community informed of events at the ISTP CDHF, the operations staff publishes a bi-annual newsletter containing technical articles submitted from the development staff as well as the science community.

The ISTP CDHF is currently staffed to support a 5 days a week, 8 hours per day operation; because of cross-training of staff personnel, it is anticipated that the current staff will be adequate through the WIND mission, with some increase anticipated to support the SOHO and POLAR missions.

ENHANCEMENTS TO THE ISTP CDHF

In order to provide support for the upcoming WIND, SOHO, POLAR, and CLUSTER missions, additional software enhancements in the form of an ICSS release per mission will be delivered and tested over the upcoming months. In general, because the ICSS was designed from the beginning with multi-mission support in mind, each of these releases contains only minor enhancements. Most of the changes reflect mission-unique requirements and do not impact the existing functionality of the core ICSS. In addition, the KITT will be providing support to those PI teams who will be delivering their KPGS to the ISTP CDHF for integration into the operational environment.

Other noteworthy technical enhancements to be included are: online plotting of orbit data; a "quick-tour" guide for new users; access to Tsyganenko magnetospheric models and Theory Simulation modelling data; extraction of solar activity and magnetic indices from the National Oceanographic and Atmospheric Administration Space Environment Services Center; key parameter plotting using the Interactive Data Language software; generation of key parameters in near real-time during the WIND mission to support an Air Force early warning solar wind experiment; and an upgrade to the I/O subsystem.

CONCLUSIONS

The implementation and operation of the ISTP CDHF was a highly successful program because of several major factors. First and foremost, a strong management team matrixed together and comprised of key individuals from the Flight Projects, Sciences, and Mission Operations and Data Systems Directorates was instituted from the beginning of the Project life-cycle. Decision-making processes were streamlined so that the hardware and software procurement, implementation, and enhancements could proceed smoothly--this was due in large part to the ISTP Program managers' resistance to micro-manage the IPD development effort. In support of this streamlining, appropriate inter-Directorate status reporting and communication methods were devised. Second, by focusing the development of the ISTP CDHF on the science aspects and by working directly with the ISTP science community through the auspices of the SWG, the system that was delivered reflected the way the ISTP science community would operate. Third, the use of existing standards and the decision to adopt a common data format influenced to a large extent by the ISTP science community and to be used by all contributors within the ISTP scientific community have enabled the goal of collaborative science to be attained. And fourth, the development of a robust ISTP CDHF architecture along with the use of standards enabled the ISTP Program to accommodate in a cost-effective manner expanded scientific requirements that have

significantly improved the overall quality of the ISTP science return.

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