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AUTHOR(S): Bruce T. Tsurutani and D. N. Baker

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los alamos scientific laboratory
of the University of California
LOS ALAMOS, NEW MEXICO 87545

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A REAL-TIME ISEE DATA SYSTEM

Bruce T. Tsurutani
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California 91103

Daniel N. Baker
University of California
Los Alamos Scientific Laboratory
Los Alamos, New Mexico 87545

Prediction of geomagnetic substorms and storms would be of great scientific and commercial interest. A real-time ISEE data system directed toward this purpose is discussed in detail. Such a system may allow up to 60+ minutes advance warning of magnetospheric substorms and up to 30 minute warnings of geomagnetic storms (and other disturbances) induced by high speed streams and solar flares. The proposed system utilizes existing capabilities of several agencies (NASA, NOAA, USAF), thereby minimizing costs. This same concept may be applicable to data from other spacecraft, and other NASA centers, thus allowing each individual experimenter to receive "quick-look" data in real time at his or her base institution.

INTRODUCTION

It would be of great potential benefit for scientific, commercial and national defense purposes to be able to predict the onset of a magnetospheric substorm or a geomagnetic storm. The Solar Terrestrial Predictions Workshop has shown that if the solar wind plasma and fields which are about to impinge upon the Earth's magnetosphere are known, it may be possible to predict the intensity, duration, and other features of such geomagnetic activity.

At the present time there exists a very good opportunity to implement a real-time interplanetary (IP) monitoring system to make such geomagnetic predictions. The heart of this system is the third International Sun-Earth Explorer spacecraft (ISEE-3) which is located some 240 R_E (1 R_E = 6375 km) upstream from the earth in a halo orbit (Figure 1) about the sun-earth libration point, L_1.(1) The ISEE-3 spacecraft has 12 onboard instruments which continuously measure the interplanetary medium.(2) In particular, ISEE-3 carries a sensitive magnetometer (provided by the Jet Propulsion Laboratory)(3) and a solar wind plasma instrument (provided by the Los Alamos Scientific Laboratory).(4) These instruments can, respectively, provide interplanetary magnetic field (IMF) and solar wind data that are indicative of interplanetary conditions well upstream of the earth.

For a quiet solar wind, with typical bulk flow speeds of the order of 300-400 km/sec, the interplanetary features measured at ISEE-3 will reach the earth's vicinity in about one hour's time. Any associated growth phase of

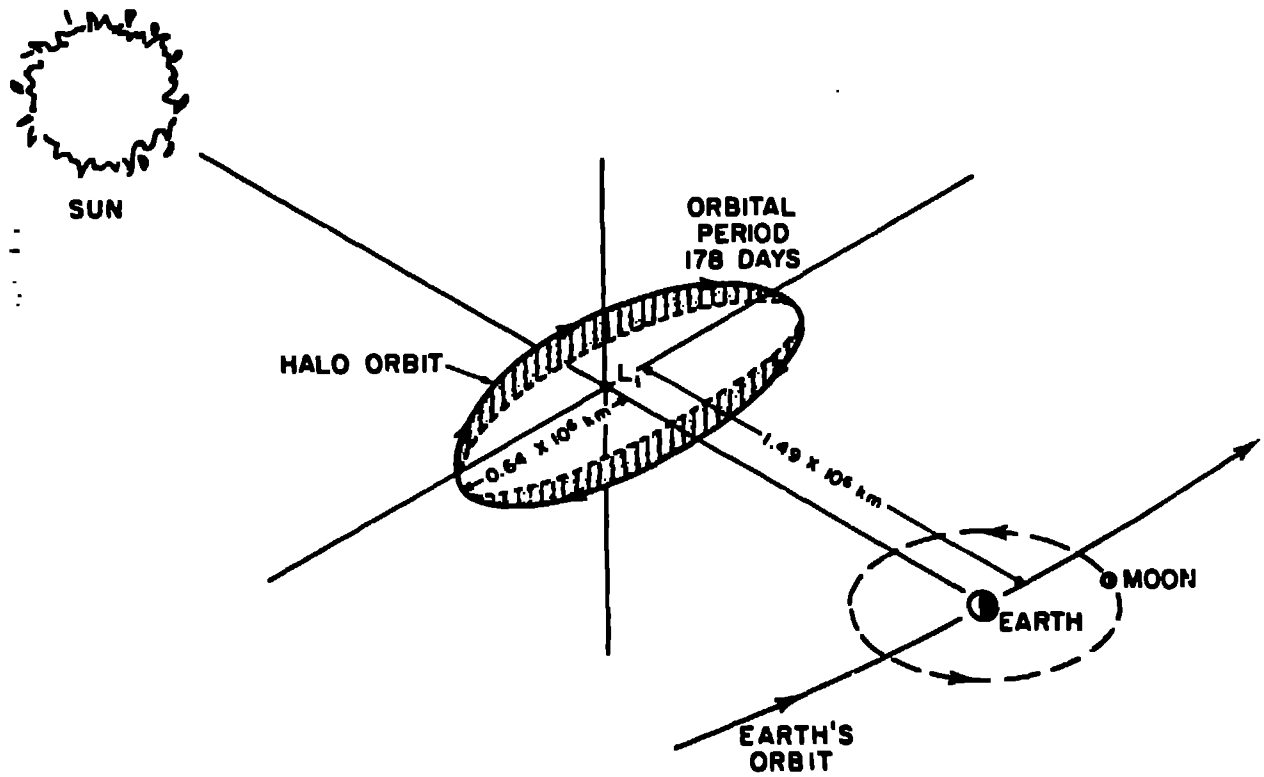

Figure 1. The International Sun Earth Explorer-3 orbit about the sun-earth libration point, L_1.

substorms[5] will give a further predictive lead time for such cases. However, velocities of 600 km/sec, or even greater, occur in high speed corotating streams[6] associated with coronal holes, implying a lead time of only ~30 minutes for recurrent events. Geomagnetic storm-time warnings might be even shorter owing to the higher solar wind streaming velocities which occur in association with the solar flares that cause storms. A real-time data system employing data from a satellite closer to the sun used in conjunction with either magnetohydrodynamic numerical modeling[7] or field-line tracing [8] may provide additional warning times in such cases. Furthermore, if the ISEE-3 solar x-ray instrument is also monitored[9], longer times would be available for events in these latter categories.

Our discussion of predictions in this paper will center around substorm predictive capabilities. Various workers have shown that a host of parameters in the solar wind are (or may be) important indicators of magnetospheric substorm response. Among these interplanetary parameters are: V_{sw} , the interplanetary magnetic field z-component (B_z), and combinations of V_{sw} and the interplanetary magnetic field such as $V_{sw}B_z$, $V_{sw}B_y$, etc.[10] At present, no one has had available a continuous, long-term, real-time set of interplanetary data in order to truly evaluate _a priori_ the predictive character of these parameters. All analyses to date have been done with archival data evaluated _a posteriori_. Now, with the advent of ISEE-3 and a strong interest in solar-terrestrial predictions, a true magnetospheric predictive capability can be developed.

Four agencies, viz., NASA, NOAA, the U.S. Air Force, and NSF, have expressed interest in using (and possibly funding) real-time ISEE data to make predictions. It is expected that predictions made under such a system would also be made available to the general scientific community.

We envisage that the International Magnetospheric Study (IMS) and related scientific activities could benefit from a real-time substorm prediction capability. For example, rocket and balloon launches could be keyed to the output of such a predictive program. Moreover, satellite experiment mode changes, spacecraft pointing changes, etc., could be implemented so as to optimize scientific payoff. Air Force workers could make use of ISEE data to analyze the propagation of high-energy solar flare particles and could use the substorm predictive capabilities to prepare for ionospheric disturbances which might affect high frequency communications or various radar systems. Finally, commercial interest in magnetospheric phenomena should not be overlooked. Exploratory activities of oil companies using magnetometer techniques are adversely affected by geomagnetic storms and substorms. Also, civilian communication, both ground-based and via satellite, can be affected by magnetospheric disturbances. Because of possible exposure of passengers and crews, even airlines flying over the polar regions of the earth have an interest in solar and magnetospheric radiation conditions.

POSSIBLE REAL-TIME SYSTEMS

In Figure 2 we show a different sketch of the relationship between the sun, the earth, and the ISEE-3 spacecraft. The halo orbit about L_1 is roughly elliptical with a semimajor axis of 0.64×10^6 km. The orbit is such that

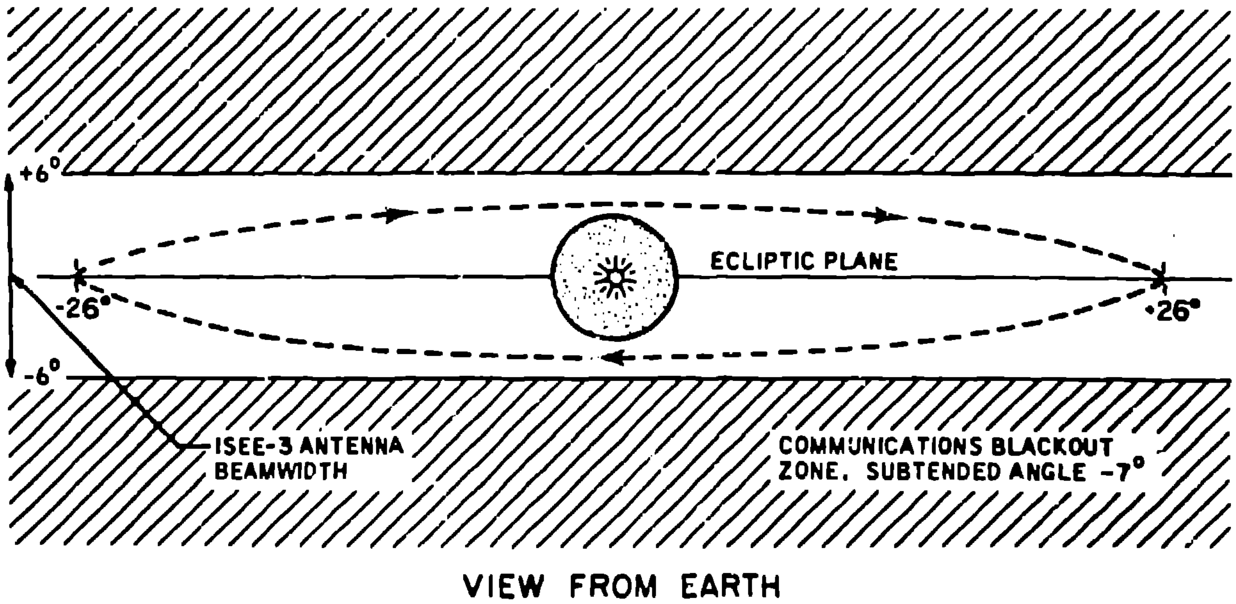

Figure 2. The ISEE-3 orbit as viewed from the Earth. The orbit avoids the region of strong solar radio interference, within about 3.5° of the sun, shown in the center of the figure. The ISEE spin axis is oriented perpendicular to the ecliptic plane. The full width transmission beam width is 12°, thus the ISEE orbit is constrained to within 6° of the ecliptic plane.(1)

when viewed from the earth, the spacecraft never moves across the face of the sun. If it did so, radio communication with ISEE-3 would be lost due to solar interference.(1) The ISEE orbital period is 178 days and at its maximum distance from the earth, the one-way light time is ~ 5.5 seconds.

We remark here that it is possible that the substorm predictive capabilities of ISEE-3 may be degraded somewhat by the highly elliptical orbit. The scale length of both the field and plasma in the y- and z- direction must be calculated (perhaps by a correlative study of ISEE-1 and -3 data) to determine the correctness of the assumption that the characteristics of the solar wind as detected by ISEE-3 are the same as those impinging upon the magnetosphere. If the assumption is found to be incorrect, an assessment of the degradation of the predictability of substorms must be made.

Figure 3 illustrates additional elements in the ISEE-3 system as they exist or are presently conceived. ISEE data are telemetered to ground receiving stations on an S-band communications link. Computers at the ground stations send the received data to the Goddard Space Flight Center (GSFC) via the NASA communications (NASCOM) system in real time. The data received at a

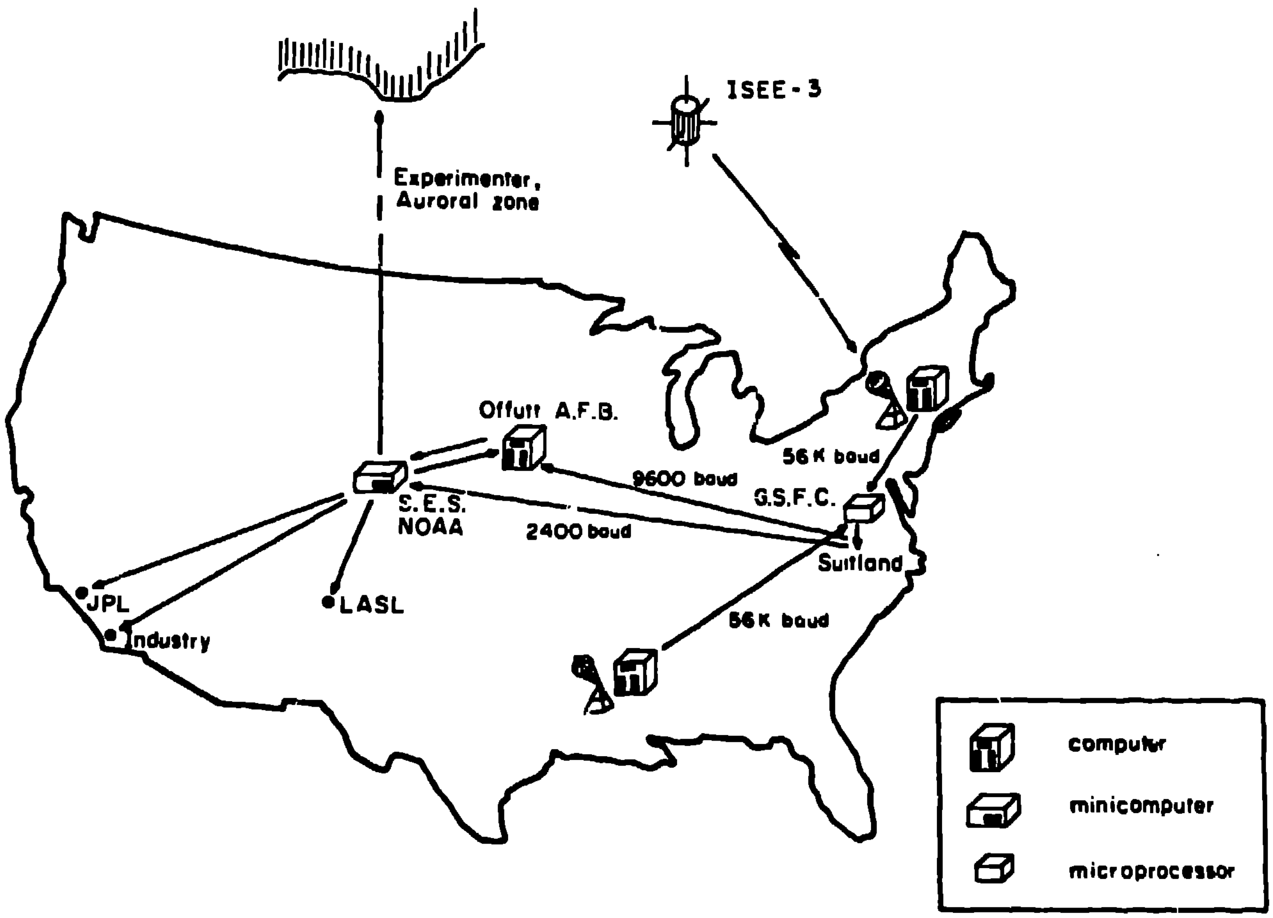

Figure 3. The ISEE real-time data link as it is presently envisioned. The encoded data are deconvolved at the ground station, then sent to G.S.F.C. via high data rate lines. The data are intercepted as they come into G.S.F.C. and are routed through Suitland, Maryland to the Space Environment Services Center, N.O.A.A. where the data reduction and index calculations are performed. Index dissemination will take place from the S.E.S.C. at Boulder, Colorado.

given ground station from the ISEE spacecraft are also recorded on tape. However, these tapes are never sent to GSFC. If NASCOM data transmission was not of adequate quality on the first transmission, the recorded data from the ground station are simply played back and sent to GSFC again by way of the NASCOM link.

NASCOM handles data from many satellite systems beside ISEE-3. This system also handles ISEE-1 and -2 data, for example. Hence, the NASCOM link is a 56 kbps (kbps = 10^3 bits per second) line capable of carrying many transmissions to Goddard from a variety of spacecraft being tracked by the ground station.

At Goddard, the data being carried by NASCOM can go to one of two locations. The first is the Multi-Satellite Operations Control Center (MSOCC) where the spacecraft location and operational status are monitored and commands are originated. The second location at Goddard is the Information Processing Division (IPD). The IPD has the responsibility for receiving the scientific data, reformatting it, and eventually sending data tapes to experimenters. A basic part of the IPD is a large mass storage capability called TELOPS. TELOPS has the potential to store all data from all NASCOM-linked spacecraft for 6 months. It also has an extensive editing capability which facilitates the production of final, "cleaned-up" data tapes for experimenters.

Because of the vast quantities of data entering the TELOPS system, the necessity of editing the final ISEE data output, and the precise ranging and timing requirements of the gamma-ray burst experiment on ISEE-3, it takes a substantial period of time (i.e., several weeks) for experimenter data tapes to finally be generated from TELOPS. Thus, for purposes of a real-time system, it is most practical to intercept the ISEE-3 data as it comes into GSFC on the NASCOM link and before it goes into TELOPS (T. Von Rosenvinge, personal communication). Hence, it is presently proposed that a suitable microprocessor-based computer be interposed into the system at Goddard and this microprocessor will be designed to recognize ISEE data, strip out and read the solar wind plasma and magnetometer data, and then transmit these relevant 700-800 bps to a data reduction site. The basic cost for such a microprocessor system to read and divert ISEE data in the NASCOM stream is ~$50K, with NASA providing the necessary funds.

Having, by means of the GSFC microprocessor system, isolated and diverted the ISEE-3 data stream necessary for magnetospheric predictions, there comes the problem of further processing the raw data to make it useful in physical terms. In the case of the LASL solar wind plasma data, the basic instrumental counting rates must be converted into moments of the distribution function such as density, velocity, etc. In the case of the JPL magnetometer, the data must be "despun" to get interplanetary magnetic fields in terms of the usual solar magnetospheric cartesian components. Even for relatively rough cuts at these reduced parameters, fairly complicated algorithms are required and substantial computer processing capability is necessary. We presently see three possible locations for such processing: (1) at GSFC; (2) at Offutt A.F.B., Nebraska; and (3) at NOAA in Boulder, Colorado.

The GSFC-processing option looks very desirable in many ways. The diverted ISEE data stream is immediately available at Goddard and this facility has a long history of handling such data, overseeing preliminary data reduction, and protecting the interests of the principal investigators (PIs). However, GSFC at present does not have a minicomputer in place to do the processing being discussed and it does not have the available manpower to take care of these tasks around the clock. Thus, with the Goddard-processing option, we are talking about the requirement for new hardware (a minicomputer: ~ $20K) and new personnel. Given these requirements, the GSFC option looks expensive and less desirable.

The second option involves data processing at the U.S. Air Force Air Weather Service (AWS) facility at Global Weather Central, Offutt A.F.B. in Omaha, Nebraska. This option obviously has an immediate drawback, namely, the distance between GSFC and Omaha. The 700-800 bps stripped out by the microprocessor at Goddard must be shipped continually to AWS for this to be a workable real-time approach. Fortuitously, and as illustrated by Figure 3, there presently exists a high-speed (9600 baud) line most of the way between Goddard and Offutt. This line extends between Suitland (the NOAA National Environmental Satellite Center) in Maryland and Offutt Field. Thus with a relatively modest cost (~ $0.30 per mile) of establishing a high-speed line from GSFC to Suitland, the Offutt-processing option would be possible.

The Air Weather Service has had considerable experience in handling, reducing, and utilizing real-time data from satellite systems, as well as protecting the interests of investigators. This experience includes many years of receiving LASL solar wind plasma data from the Vela series of spacecraft. The AWS also has in place computers which are manned at all times. However, the AWS computers are presently operating near their capacity and AWS is only marginally staffed to accomplish its present space environmental monitoring services. Current Air Force funding precludes adding more AWS hardware capability now or in the near future and additional staffing must await a requirement directive from the Air Force. Thus with the AWS-option, as with the GSFC-option, hardware and personnel costs detract from the present use of this avenue for a real-time ISEE-3 prediction system.

This brings us to the third option, which involves sending the raw ISEE-3 data to the Space Environment Services Center (SESC), operated by NOAA in Boulder, Colorado. This is a desirable approach since the SESC group has had long experience in the collection and dissemination of data from space systems. This option again requires the emplacement of a high-speed line from GSFC to Suitland, as was required for option (2) above. There presently exists a 2400 baud line between Suitland and SESC, as is shown in Figure 3. Thus, transmission of ISEE data to Boulder presents no major obstacle and, furthermore, the SESC personnel have expressed a desire and capability, as described below, to handle ISEE data in a fashion directed toward real-time alert usage.[11]

The essential features of the NOAA Space Environment Laboratory data system (SELDADS) are illustrated in Figure 4. The system is composed of two Data General NOVA and one Data General ECLIPSE minicomputers with 58K Megabyte storage capability for each NOVA and smaller storage on the ECLIPSE. At present, data from x-ray, particle, and magnetometer sensors on two GEOS satellites, the TIRCS-N spacecraft, from ground-based IMS magnetometers, and from various teletype networks are already being collected by this system. The ISEE-3 data would be an additional load on the SELDADS system and the computer processing and programming resources available to SELDADS would be the prinicpal limitation to handling ISEE data. As illustrated in Figure 4, ISEE data would be received by the NOVA minicomputers and the data would be recorded on a disk storage device. Subsequent processing of the data (as described below) would then provide reduced interplanetary data (or indices) to public users and SESC forecasters via the ECLIPSE computer.

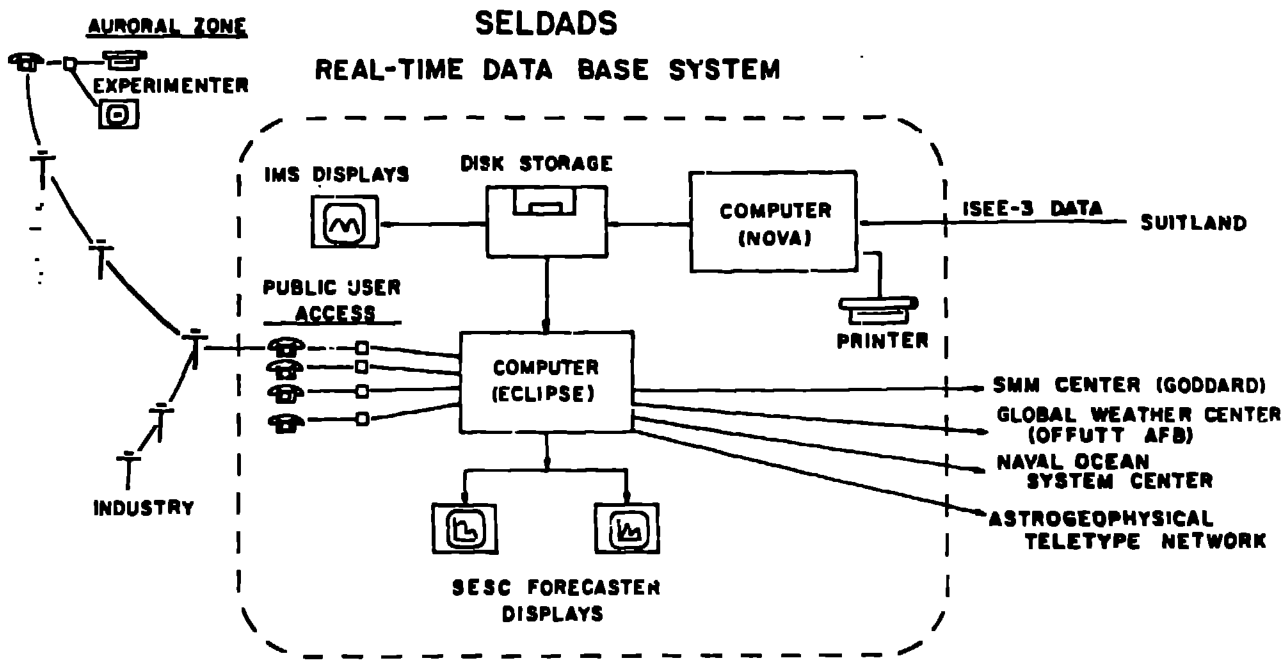

Figure 4. The NOAA Space Environment Laboratory Data Acquisition and Display System (SELDADS) which will be used to reduce the data, form the substorm and storm predictive indices, and disseminate this information.

Because SELDADS is presently taxed in terms of both hardware capability and programmer support, SESC personnel have suggested a phased approach to implementing the ISEE real-time system:

Phase I — Data would be handled by minimal programs that would extract a data point every one minute or five minutes (depending on complexity of the next step), compute the 3-dimensional magnetic field parameters and bulk plasma parameters and output these on a printer. These would be monitored visually by a forecaster for configurations of interest that would initiate an alert and that would be relayed verbally to GWC (Global Weather Central). Phase I could be implemented as soon as the microprocessor system is installed at Goddard, the Goddard-Suitland link is provided, and some programming is done at Boulder.

Phase II — As some programming time and space become available at Boulder, the data from Phase I would be added to the data stream flowing to GWC on the 2400 baud data line. At the same time, it would be put in a file in the SELDADS for driving some simple CRT displays in the SESC. This could take from 6 months to a year after Phase I is completed.

Phase III — During this phase an implementation of more sophisticated displays and algorithms that produce indices yet to be determined could occur. Phase III would come at some undefined time following Phase II.

Table 1. The ISEE-3 real-time data flow as it is presently envisioned. See Figure 3.

FLOW DIAGRAM

Facility	Location	Hardware	Data Processing	Transmission Link
ISEE-3	Earth-Sun Liberation Point, L_1. Halo Orbit 0.01 AU from Earth	VHM Magnetometer Plasma Analyzer		
				S-band
Ground Station		Computer	Deconvolve Data	
				56 K Baud Line
NASCOM	Goddard S. F. C. Greenbelt, MD	Heetderks/Mozer Black Box (microprocessor)	Strip off ISEE-3 Magnetometer, Plasma Data	
				Dedicated Phone Line
N.O.A.A.	Suitland, MD		None	
				Dedicated Phone Line
Space Environment Services Center, N.O.A.A.	Boulder, CO	Minicomputer Data Displays	Despin Data to Inertial Coordinates. Remove Spacecraft Offsets. Calculate Velocity. Calculate Substorm. Prediction Indices	
				Two-Wire Telephone (to Experimenter, Industry) Computer-Computer Link (to Offutt)
Experimenter Industry		Modem		
Offutt A.F.B.	Omaha, NE			

Figure 3 and Table 1 illustrate the essential features of the flow of ISEE-3 data in the proposed real-time system. Beginning at the spacecraft, the data from all instruments are telemetered to a particular ground station. After initial deconvolution, the data are sent to Goddard SFC via the NASCOM 56K baud line. At Goddard a microprocessor system strips off the ISEE-3 solar wind and IMF data and these data are then sent via Suitland to the SESC facility illustrated in Figure 4 above. Finally, after processing at Boulder, substorm alerts and predictive indices (yet to be chosen) are sent out and provided to IMS experimenters, to industrial users, and to the military.

CONCLUSIONS

We conclude from our own investigations, and from the generous input of many other knowledgeable persons, that it is readily within present technical capabilities to implement a real-time prediction system using upstream interplanetary data input. As outlined above, a crude system (Phase I) could be established within a matter of a few months. A more sophisticated system involving the generation of CRT displays and well-conceived predictive parameters will probably take on the order of one to two years to implement. As presently envisaged, the real-time ISEE-3 system being proposed here can be implemented at a modest cost of perhaps \$50-100K.

As described in the Introduction, many benefits can accrue from the presently proposed real-time system. Scientific, commercial, and military activities will all be enhanced, possibly in many unforeseen ways, by knowing more about the near-earth space environment, and knowing this in advance. Thus, we may expect to benefit scientifically and socially from the modest investment required in order to implement a real-time alert system.

We have stressed an ISEE-3 real-time substorm prediction system in our present discussions, but obvious extensions of these ideas spring to mind. First of all, we can envision providing all ISEE-3 experimenters with their data on a real-time basis. As illustrated by Figure 5, if one once again had the proper microprocessor system located at Goddard to tap into the NASCOM system, one could easily send the ISEE-3 data stream of interest to JPL, LASL, or wherever needed. A phone link, appropriate modems, and a minicomputer to process the data would together provide a much improved "quick-look" data system. Something of this sort could be done at present even if a substorm prediction system were not implemented.

Obviously, the above quick-look system need not be restricted to ISEE-3. The same basic approach could be used for ISEE-1 and -2, or any other NASA spacecraft data which are being sent via the NASCOM link. The same approach

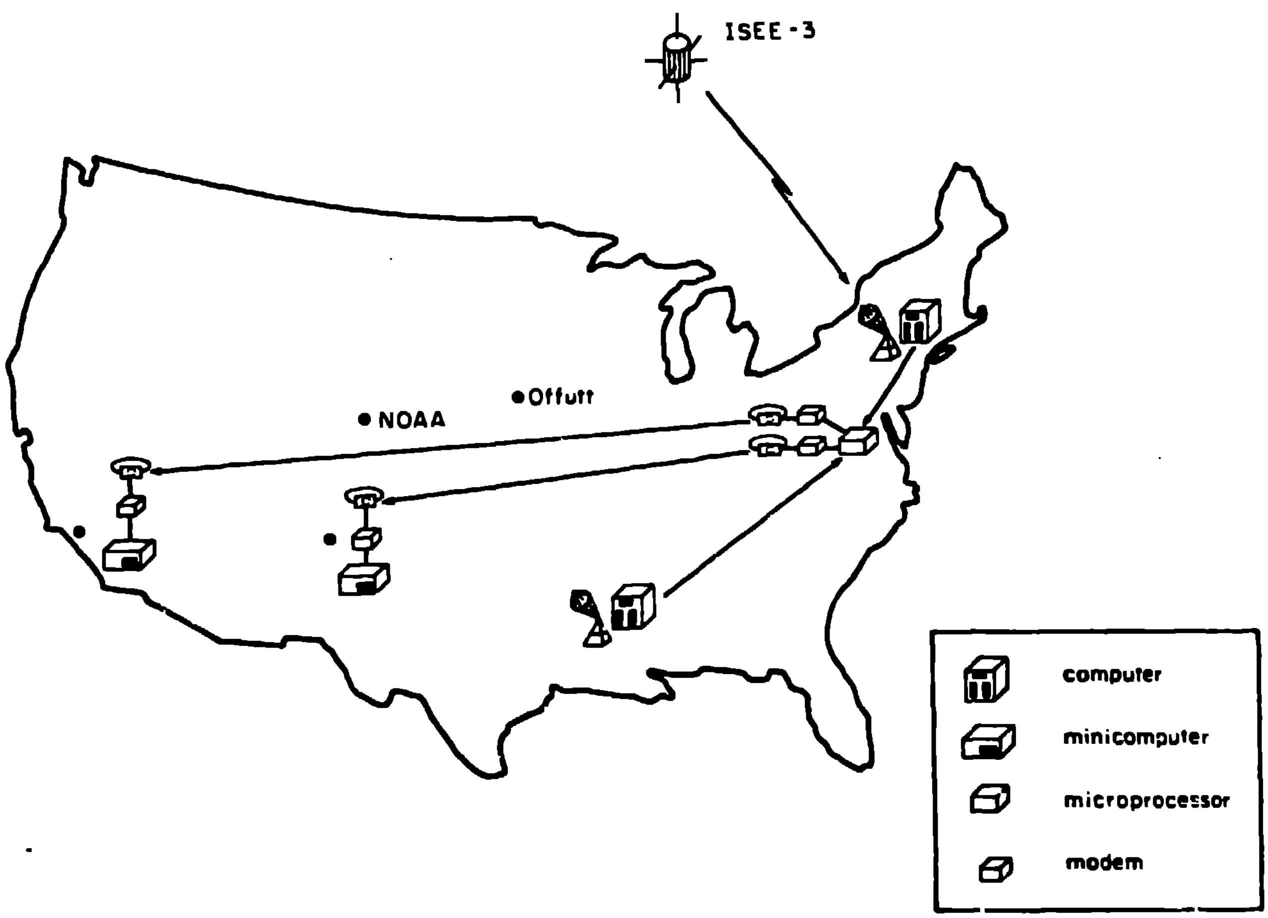

Figure 5. An ISEE real-time "quick look" data system. This same approach could be used to send "quick look" data from all NASA satellites to individual experimenters.

could also easily be extended to other NASA centers because the difficult, initial data deconvolution is done by computers at the ground stations. Thus the ideas being explored here may represent the wave of the future as to how NASA and various satellite experimenters exchange information and preliminary data.

ACKNOWLEDGMENTS

The ideas and information presented in this paper are the result of the efforts of many people. Figure 6 shows a list of key personnel at various institutions who have and, hopefully, will continue to play instrumental roles in the real-time ISEE-3 system. We are particularly indebted to Sam Bame and Ed Smith who are, respectively, the principal investigators on the ISEE-3 plasma analyzer and Vector Helium magnetometer experiments. We also thank Tycho Von Rosenvinge, the ISEE-3 project scientist, for patient descriptions of the ISEE data system and we thank Mike Wiskerchen and Erwin Schmerling for pursuing the details of the data system, and most importantly for obtaining NASA funds to make this possible. We sincerely thank Gary Heckman and Don Williams of the SESC in Boulder for providing us with detailed information about the SELDADS system and we acknowledge many useful conversations with Dick Thompson and Vern Patterson of the Air Weather Service regarding the Air Force role in the utilization of ISEE data. Finally, we thank Dick Donnelly and the chairmen of the International Solar-Terrestrial Predictions working groups (Syun Akasofu, George Paulikas, and Chris Russell) for providing the forum in which to discuss the ideas presented in this paper.

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KEY PERSONNEL

National Aeronautics and Space Administration Headquarters

H. Glaser

E. Schmerling

M. Wiskerchen

Air Force

Major V. Patterson

Lt. Col. L. Snyder

Lt. Col. R. Thompson

National Science Foundation/International Magnetospheric Survey

R. Manka

National Oceanic and Atmospheric Administration

G. Heckman

C. Hornback

D. Williams

Goddard Space Flight Center

R. Farquhar

D. Muhonen

T. Von Rosenvinge

ISEE-3 Experimenters

D. Baker

S. Bame

E. Smith

B. Tsurutani

Solar Terrestrial Physics Working Group

S. Akasofu

R. Donnelly

G. Paulikas

C. Russell

Figure 6. Some of the key people involved in constructing the ISEE-3 real-time data system.