3 Magnetosphere

3-1 Real time data reception of ACE and IMAGE satellites

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A ground station system for receiving and processing satellite telemetry data in real time was built for the ACE real-time solar wind monitor (RTSW) data in 1997. CRL has contributed to the global ACE tracking network by operating the facilities since the start of the RTSW project. A networked real-time data system hosted by NOAA/SEC was set up for exchanging the ACE real-time data, and it has been achieving a very high coverage. In 2000, data reception was extended to that of the IMAGE satellite. This addition incorporated a new antenna-management system for tracking multiple satellites. At CRL we use real-time satellite data for space weather forecasting. As a result of the success with the real-time data from ACE and IMAGE, real-time distribution of satellite data has become an important part of any satellite program dedicated to space science.

Keywords
Satellite observations, Solar wind, Magnetosphere imaging, Aurora, Space weather

1 Introduction

More than thirty years have passed since the birth of the spacecraft, the symbol of the space age. Since then spacecraft have offered revolutionary new research techniques for direct observation of the space environment in solar-terrestrial science. Furthermore, expanded use of spacecraft has shed light on the importance of space weather forecasting, in which changes in the space environment are predicted. Such forecasting is particularly important for stable operation of spacecraft. Today, not only are space environment observations carried out by scientific spacecraft designed primarily for space science research, but operational spacecraft have now begun regular space environment observations. From the viewpoint of space weather forecasting, it is important that spacecraft observation data be available as soon as possible following observation. Previously, it took quite a long time (sometimes longer than a year) for data from spacecraft programs to be made public, rendering use of such data difficult in space weather forecasting. However, recent developments in computing and networking technologies have enabled more rapid data processing. As a result, increasingly spacecraft programs are planned with the aim of offering observation data nearly in real time, in view of the application of such data to space weather forecasting.

At the Communications Research Laboratory (CRL) we perform daily space weather forecasting activities as an important component of our space weather research, and as such we experience first-hand the need for spacecraft observation data on a real-time basis. Moreover, in terms of research, it has become more and more important in recent years to determine which phenomena are important research targets that will help improve our understanding of space weather. In other words, the real-time use of spacecraft observation data is significant not only in space weather forecasting but also space weather research. In 1997 we began to prepare spacecraft reception and processing equipment with an eye to real-time reception of solar wind data from the ACE spacecraft, with operation beginning in 1998. Subsequently, we began real-time reception and processing of data from the IMAGE magnetosphere imaging satellite in 2000.

In this report we present an outline of the use of the real-time data gathered by the two spacecraft and describe the reception system established at CRL.

2 Real-time ACE Spacecraft Solar-Wind Observation Data

2.1 Solar Wind Observation at L1 Point

Interplanetary observations from the late '60s to the early '70s revealed that the solar wind from the Sun and the interplanetary magnetic field (IMF) govern the space environment near the Earth, in particular with respect to magnetospheric activity. For example, it became clear that, when the IMF has a southward component, the energy of the solar wind flows into the magnetosphere more efficiently, causing a strong geomagnetic disturbance[1]. In order to observe the relationship between the solar wind/IMF and disturbances in the space environment more precisely, the ISEE program, in which multiple spacecraft are deployed around the Earth, was initiated in 1978. In this program, the ISEE-1 and ISEE -2 spacecraft were placed in the magnetosphere and the ISEE-3 spacecraft was placed into an orbit that included the L1 point to observe the solar wind and IMF. The L1 point is located between the Sun and the Earth, about 1,500,000 km away from the Earth toward the Sun, and is one of five Lagrange points existing in the Sun-Earth system. The spacecraft placed into an orbit that includes the L1 point travels around the Sun once per year, always maintaining its position between the Earth and the Sun. For this reason, the L1 point is a vantage point for observation of the Sun and the solar wind.

The ISEE program was designed to promote scientific research of the Sun-Earth system. Under the program, as a test of new capabilities in space environment prediction, an experiment was conducted to transmit solar wind observation data in real time to the U. S. National Oceanic and Atmospheric Administration's Space Environment Center (NOAA/SEC), which then carried out space environment forecasting. The experiment continued from 1979 to 1982, and proved that a large-scale geomagnetic disturbance could be predicted within the time required for the solar wind to arrive at the Earth from the L1 point (30 to 40 minutes)[2].

Further, with the WIND spacecraft launched in 1994, real-time transmission of solar wind data was again attempted, although this only took place for approximately three hours per day, providing further confirmation of the importance of real-time solar wind data. However, since data reception from the ISEE-3 and WIND spacecraft required operations by the Deep Space Network (DSN, the NASA ground station network), operation time was significantly limited and it was therefore difficult to receive data for 24 consecutive hours on a regular basis. In recent years, due to an increasing number of deep space missions, the operation schedule of the DSN is quite restricted. Therefore it is necessary to establish a proprietary receiving station network for the purpose of regular 24-hour operations.

In 1989, while NASA was planning the ACE mission to the L1 point, the NOAA proposed the inclusion of the RTSW (Real Time Solar Wind) program to enable real-time transmission of the solar wind observation data from the spacecraft. Initially, the RTSW program envisioned the deployment of an original X-band telemeter transmitter and a ground station network. Later the program developed such that a portion of the data from the ACE spacecraft observation instruments was edited on board and transmitted to the ground in real time using an S-band telemeter [3][4].

2.2 ACE Spacecraft and RTSW

The ACE (Advanced Composition Explorer) spacecraft is a NASA scientific spacecraft whose primary mission is to investigate particle acceleration occurring in celestial bodies, including the solar system, through high-precision observation of plasma particles within a wide energy range, from galactic cosmic rays to low-temperature solar wind plasma[5]. ACE was launched on August 25, 1997, and was placed into an orbit that included the L1 point to permit the start of operations in December of that year. Featuring particle observers for six kinds of particles and a magnetic field instrument, ACE records all observation data in an on-board data recorder and transmits this data via an operation within the DSN once a day.

Additionally, RTSW collects and edits data from various observation instruments in real time and transmits this data on a continuous basis via telemetry. Types of real-time data are shown in Table 1[4]. The RTSW data is transmitted to the ground at a low speed (434 bps) continuously, except during the DSN contact, permitting receipt by ground stations equipped with small-diameter antennas. The RTSW data represents only a portion of the ACE observation data. Thus, while the real-time solar wind parameters and magnetic field/high-energy particle data are intended for use in space weather forecasting and event detection, serious data analysis for research necessarily entails the use of the full set of observation data, which is offered by the ACE Science Team several days after real-time transmission (http://www.srl.caltech.edu/ACE/ASC).

Table 1 *Observation data transmitted in real time by ACE/RTSW* [4].

RTSW parameters

Instrument	Values calculated	Range	Units	Base time resolution	Operational time resolution
MAG	Bx, By, Bz	−200 to 200[1]	nT, in GSM	1 s	1 min ave
SWEPAM	V	200 to 2000[1]	km s^{-1}	64 s	1 min
	n	0 to 200	cm^{-3}	snapshot	snapshot[2]
	T	10^4 to 10^7	K		
EPAM	Electrons	38–53 keV	$(s\ sr\ cm^2\ MeV)^{-1}$	32 s ave	5 min ave
		175–315 keV			
	Ions	47–65 keV			
	(Protons)	112–187 keV			
		310–580 keV			
		1.06–1.91 MeV			
		480–970 keV			
	Anisotropy	0 to 2	Dimensionless		
SIS	Protons	>10 MeV	$(s\ sr\ cm^2\ MeV)^{-1}$	32 s ave	5 min ave
		>30 MeV			
Location[3]	X	0 to 300	R_e (1 = 6378 km)	1 hr	1 hr
	Y, Z	−150 to 150	in GSE		

[1] Range set by RTSW coding; Instrument range larger.
[2] Data placed into nearest 1-min UT value, no averaging or interpolation.
[3] Predict value used, accurate to 0.1 R_e in GSE.

2.3 Ground Station Network

A new element of the ACE/RTSW system lies in the establishment, separately from the spacecraft control stations of the DSN, of a network of ground stations to acquire solar wind data in real-time. Since the ACE spacecraft encircling the L1 point is always positioned near the Sun when viewed from the Earth, multiple (at least three) ground stations, distributed longitudinally around the Earth, are required in order to receive ACE data for 24 hours continuously. To implement the ACE/RTSW program, the NOAA requested that the organizations of several countries, including CRL in Japan, participate in the program. In response to this request, the CRL and the Rutherford Appleton Laboratory (RAL) in the U.K. decided to participate as main ground stations. At present, the NOAA, the CRL, and the RAL are the main tracking stations, and for the times of day that these stations cannot cover, the U.S. Air Force (USAF) and the ISRO in India provide auxiliary reception. In the early phase of the program, a ground station of the French CNES located in South America had participated in the program, but it has now been replaced by an NOAA ground station located at a similar longitude.

Each ground station transfers the ACE/RTSW telemetry data that has been demodulated at the station, in unprocessed form, to a processing computer installed at the NOAA/SEC. Within the NOAA/SEC, a data processing system, which was developed through the cooperation of the teams in charge of the instruments onboard the ACE spacecraft, converts the telemetry data to physical values. After further processing, this data is distributed to user organizations, including the CRL, and also is made available to the public by the NOAA/SEC (http://www.sec.noaa.gov/ace/). The data processing system is designed to require less than five minutes for delivery of the processed data following reception at the antenna. Fig.1 is a chart showing the latest task of each ground station. In reception through the DSN/NASA, telemetry is switched to high-speed mode in order to permit the ACE spacecraft to conduct high-speed play-back of the data recorder. During this time the RTSW data stream continues as a part of the high-speed data stream. The received RTSW data is transmitted to NOAA from NASA.

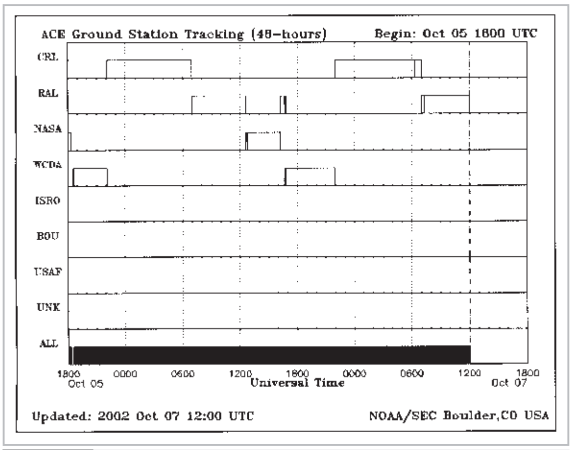

Fig.1 *Task chart of ACE/RTSW ground receiving stations*

The horizontal axis represents time (UT), and the vertical axis represents the receiving states of the following stations, from top to bottom: CRL (Japan), RAL (England), DSN/NASA, WCDA/NOAA (U.S. east coast), ISRO (India), Boulder/NOAA (U.S. mountain), and USAF (United States Air Force). The panel at the bottom shows the overall receiving state of RTSW data. Here it shows the occurrence of a short gap in data some time past 1800 UT on October 5.

The international network designed to accept ACE spacecraft data has received real-time data at a rate exceeding 90 %, from the beginning of operations in 1998 to the present. Since all of the ground stations are located in the Northern Hemisphere, a data gap often occurred in the winter due to reduced reception time at each ground station. However, relying on the NOAA/SEC supervising the entire network of ground stations, gaps in data have now become very uncommon. The ACE spacecraft (including RTSW program) has shown satisfactory performance since 1998, and is highly valued by NASA. The spacecraft is thus scheduled to continue its operations as long as it has sufficient fuel to regulate its orbit.

3 Real-time data of the IMAGE satellite

The IMAGE (Imager for Magnetopause-to-Aurora Global Exploration) satellite was launched as a MIDEX series NASA satellite on March 25, 2000, with the purpose of exploring the magnetosphere[6]. While conventional magnetospheric satellites centered mostly on "in-situ" observation of the magnetic field, the electric field, and plasma, the IMAGE satellite adopts new imaging technologies such as ultraviolet-light imaging and neutral-particle imaging for sensing the magnetosphere remotely, thus enabling a global view and a deeper grasp of magnetospheric activity.

Another feature of the IMAGE satellite is its open data policy. The basic rule governing observation data in conventional scientific satellite projects was that the team responsible for the instrumentation onboard the satellite had priority in the use of the data for a fixed period. On the contrary, for all IMAGE satellite observation data, no period of priority use is set. Instead the immediate release of the observation data has been established as basic policy. Moreover it was envisioned in this project from the beginning that data would be made public in real time for purposes of space weather forecasting and educational use. This data-publication trend is considered extremely important in the context of recent NASA projects, and an element termed "Public Outreach" now forms an essential component of any project. For this purpose, the IMAGE satellite continues to transmit all data, as observed, in real time at 44 kbps. In addition to the real-time transmission, the data is concurrently recorded to the on-board data recorder, and played back in response to an operation within the DSN once per orbital flight. The IMAGE satellite mission operation center (SMOC) conducts primary processing of all data approximately one day following actual observation and then makes the complete set of data available to the public. Also available at the SMOC is a data-analysis software package capable of basic data analysis.

The IMAGE satellite has an orbital inclination of 90 degrees, an orbital period of 13.5 hours, and an apogee of 7 Re (Re: Earth radius). The IMAGE satellite acquires images of the magnetosphere from the neighborhood of the apogee, at which point nearly the entire inner magnetosphere comes into the satellite's field of view. The apogee of the satellite varies in latitude gradually, as shown in Fig.2. In the first two years of the mission period, the apogee was in the high latitudes of the Northern Hemisphere. This period corresponded to the initial period of satellite operation and continued until March 2002. At this point the second period began (and continues to this date), during which the apogee moves in the low latitudes. It has been determined that this period of operations will continue until 2005. For the real-time reception currently conducted by CRL in collaboration with the NOAA, there are three receiving points, as follows: Tokyo (CRL); Fairbanks, Alaska (NOAA); and Berkeley, California (UCB). Unlike the case of the ACE spacecraft, each receiving station receives and processes data according to its own operation schedule. The processed results are then exchanged among the receiving stations. In the first two-year period of the IMAGE operation, when the apogee was located in the higher latitudes, coverage was very high because the Fairbanks station, the receiving point in the polar region, was able to receive over a long period of time. At present, with the apogee in the lower latitudes, overall coverage has decreased, partly because three receiving points are relatively near to one another with respect to longitude. When the apogee moves to the southern hemisphere in the future, the coverage rate will decrease further.

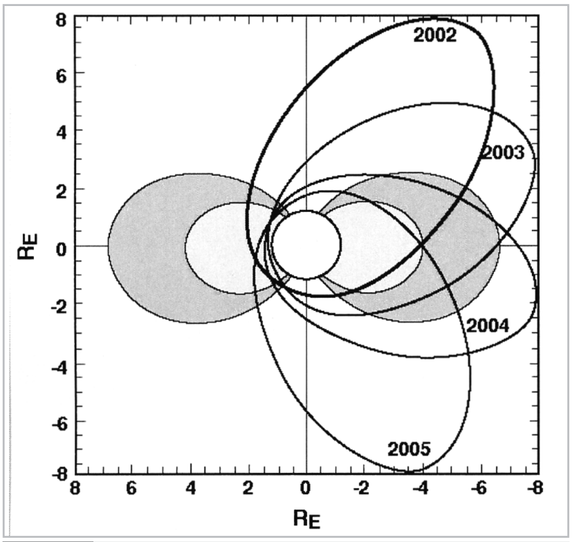

Fig.2 *IMAGE satellite orbital variation after 2002*

The latitude of the apogee moves by approximately 50 degrees per year.

4 ACE/IMAGE spacecraft data reception and processing system

As the ACE receiving system has already been reported on by Maruyama et al.[3], we will provide only an outline here. The receiving system comprises an 11-m parabola antenna as the main apparatus. In the ACE/RTSW program, real-time data transmission is conducted at a low speed so as to permit receipt with an existing 10-m-class antenna in the S-band, which is a common configuration throughout the world. On the other hand, for operations within the DSN, the receiving equipment uses a 34-m-class antenna and receives telemetry data from the data recorder at high speed. The most important characteristic of a continuous operation such as spacecraft data reception is to minimize human involvement. Therefore, this system was designed for unattended operation. As shown in Fig.3, the system consists of a tracking subsystem (composed of an 11-m antenna), an antenna control subsystem, and a scheduling subsystem. There are independent telemetry

(TM) data processing equipments required for each spacecraft. Although the equipment in this system was initially designed exclusively for the ACE spacecraft, in 1999 receiving equipment for the IMAGE satellite was added, and the system was enhanced to allow tracking of multiple spacecraft.

4.1 Multiple spacecraft tracking system

The receiving antenna of this system is an 11-m parabola antenna originally deployed at the Kashima Branch for the "Western Pacific Very Long Baseline Interferometer Program" [7] in fiscal 1987. It was moved to CRL headquarters in 1997. Specifications for this antenna are shown in Table 2. This antenna was designed for spacecraft control and is capable of high-speed spacecraft tracking.

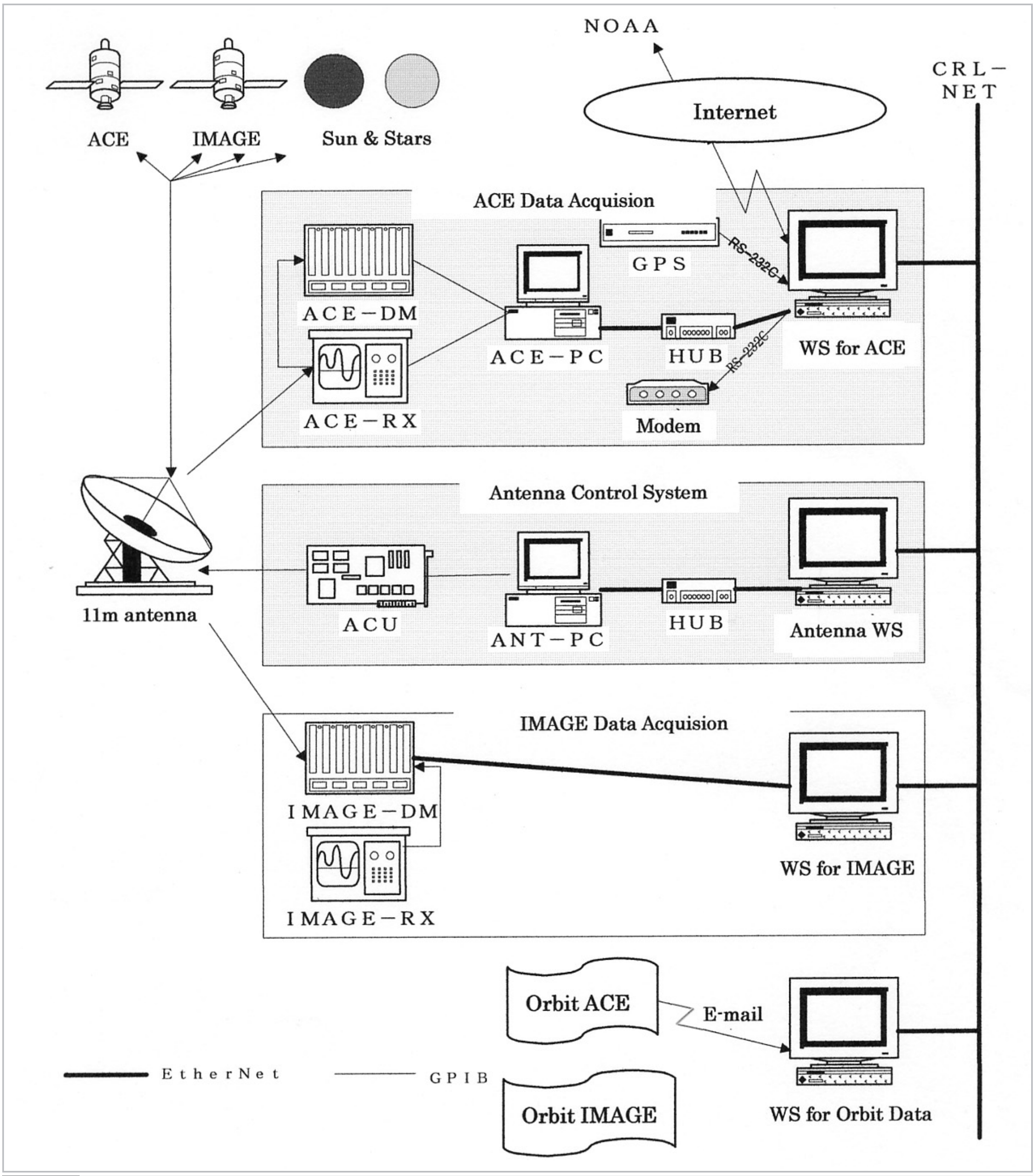

Fig.3 ACE/IMAGE spacecraft reception and processing system configuration

The appearance of the antenna is as shown in Fig.4. The antenna control subsystem reads a daily spacecraft operation schedule from a schedule definition file stored in a controlling WS, and specifies antenna angles while referring to the orbit data of each spacecraft. Operation schedule settings are made through editing of a text file. Since the number of users is limited, there is no interface for the general user. The orbital data and other tracking information are maintained outside of the system. As for the orbital data, NASA/GSFC calculates visible times and antenna angles for CRL antenna each week, and transfers the data via electronic mail. For the IMAGE satellite, the SMOC updates orbital predictions each week. We then acquire this file and calculate applicable angles for CRL antenna. These operations are automatically processed using simple scripts, and are transferred to the WS via a tracking operation system.

Table 2 Specifications of 11-m parabola antenna

Item	Specification
Diameter	11m
Receiving Frequency	S-band 2200 ~ 2320 MHz
Feeding Method	Front Feed
Polarization	R/L Switchable
G/T	S-band: > 24 dB/K
Steering speed	Az 11 deg/sec、El 5 deg/sec
Steering range	Az +/-360 deg、El -2~182 deg

A record of 24-hour spacecraft tracking using the 11-m antenna is shown in Fig.5. From the top, the three panels show the AGC level of the ACE receiver, antenna receiving power, and antenna angles (Az, El). The figure indicates that IMAGE satellite tracking was conducted from 10:30-11:30 UT and from 17:40-22:55 UT, and that ACE spacecraft tracking was conducted from 22:55-07:10 UT. These were automatically operated according to the contents of the schedule definition file. As the spacecraft tracking operation is performed 365 days a year, a monitoring system has been set up separately in order to enable confirmation of operations via the network.

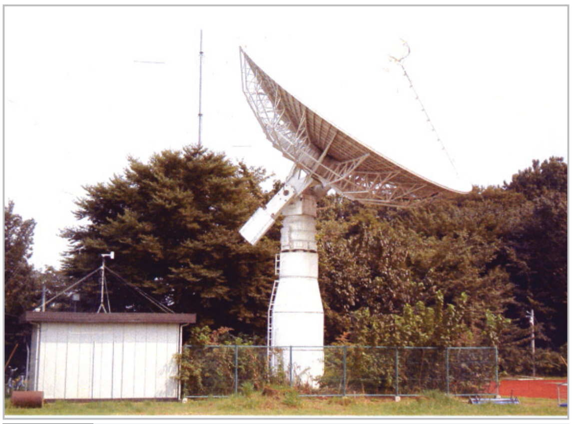

Fig.4 Appearance of 11-m parabola antenna

Moreover, in the event of an operational fault, the monitoring system will provide notification to beepers. This system is characterized by its capability for automatic operation with a minimum of human intervention, due to the automated functions mentioned above.

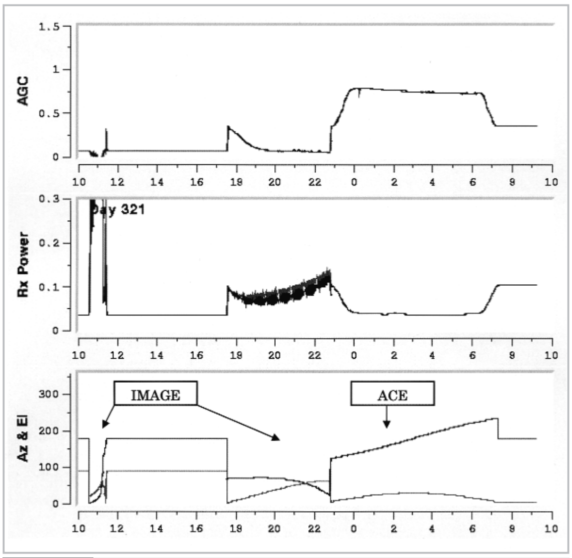

Fig.5 Record of 24-hour spacecraft tracking using the 11-m antenna

From top to bottom, the AGC level of the ACE receiver, the antenna receiving power, and the antenna angle (Az, El) are shown. The figure indicates that tracking of the IMAGE satellite was conducted from 10:30-11:30 UT and from 17:40-22:55 UT, and that tracking of the ACE spacecraft was conducted from 22:55-07:10 UT. All of these tracking operations were automatically implemented according to the schedule described in the file.

This system began operations in January 1998. To date, two long interruptions of operation have occurred due to a mechanical fault of the antenna caused by heavy snowfall. During these periods, CRL requested that the National Space Development Agency of Japan (NASDA) conduct ACE spacecraft tracking. The received data was transferred to the CRL system via telephone line. With the exception of these interruptions, the system has demonstrated favorable operational performance overall.

4.2 ACE Spacecraft Data Processing

The ACE spacecraft's 434-bps telemetry signals received with the 11-m antenna are demodulated to data packets by a demodulator and are sent as they are to NOAA/SEC via the Internet. A system to convert the telemetry signals to physical values is installed at the SEC. Reception data from other stations is also sent to SEC in a similar manner, and the system selects and processes data in the order it is received. The data converted to physical quantities is returned to CRL from the SEC also via the Internet. Thus, 24-hour continuous ACE/RTSW data is ensured (Fig.6).

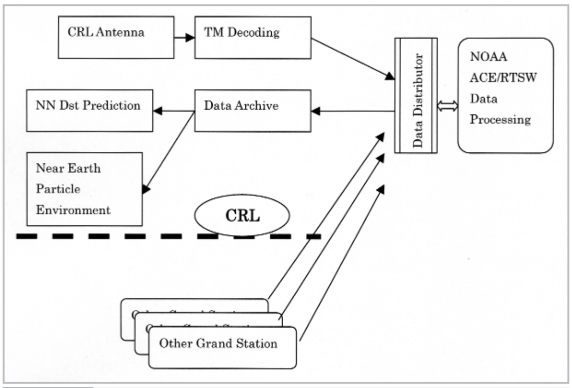

Fig.6 ACE data processing flow

From the processed ACE/RTSW data, which has been transmitted in real time to CRL from the SEC, data plots of the solar wind parameters are generated. These are available to the public on the Web (http://www2.crl.go.jp/dk/c231/ace/1day/). Fig.7 shows an example of a one-day data plot of the solar wind plasma and the IMF. In the figure, in addition to the RTSW data, estimated input power into the magnetosphere is plotted in the bottom panel.

The plot indicates that there is a large influx of energy into the magnetosphere from about 0600 UT onward on this day (November 24, 2001). Similarly, NOAA also provides an ACE data page to the public (http://www.sec.noaa.gov/ace). In addition to the data plot, we have developed additional uses for this ACE data, including a sector structure of the IMF (updated daily), prediction of the Dst index by a neural network (updated hourly)[8][9], and prediction of high-temperature plasma near the geostationary orbit. All of these products are available to the public through the Web.

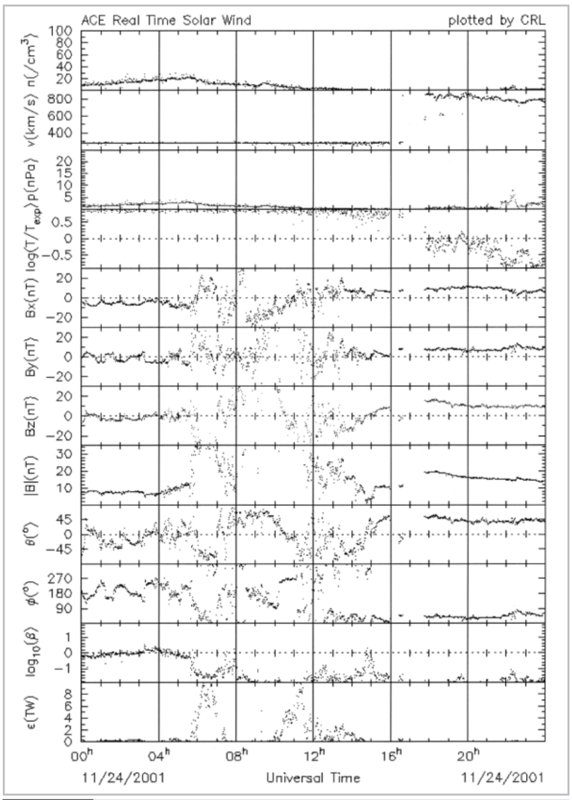

Fig.7 ACE/RTSW data plot of the solar wind plasma and the IMF on November 24, 2001

Solar wind observation at the L1 point enables forecasting about one hour prior to a geomagnetic disturbance by offering information on the solar wind and the IMF approaching the Earth. This represents an extremely significant contribution to space weather forecasting. Moreover, the solar wind data is critical in the interpretation of observations of the magnetosphere and is also indispensable as input data to computer simulations of the Sun-Earth system environment. The ACE spacecraft will continue to play the main role in solar wind observation, as the current prospects for a successor spacecraft of solar wind observation at the L1 point are unclear. However, the operational life of the ACE spacecraft, which began in 1998, depends largely on the quantity of fuel available for orbital maneuvers. Therefore, the ACE spacecraft operation team has decided to conserve fuel by reducing the frequency of such orbital maneuvers. This will enable the spacecraft to continue operations until 2010 or so, although with increasing data gaps. NOAA and NASA are also considering a program (GEOSTORM mission) in which a spacecraft will be positioned at a point closer to the Sun, to increase lead time above the current one hour.

4.3 IMAGE Satellite Data Processing

The IMAGE satellite transmits real-time data at 44 kbps. The telemetry data from the receiver is input into a data processing system after passing through a receiver and a demodulator. We have established an original processing system by modifying the processing software (developed by the teams in charge of on-board instruments) to enable real-time processing. The flow of data processing is shown in Fig.8. The telemetry data from the receiver is converted to UDF format (http://image.msfc.nasa.gov/), which is used as the standard format in the analysis of the IMAGE satellite data. Data exchange with other ground stations is conducted on the basis of this UDF format. In addition, SMOC also offers a UDF data archive of all IMAGE data. Consequently, processing of all data can be performed using common software. The UDF data is then subject to a processing routine specific to each on-board instrument for conversion to images. At present, two kinds of observation data are routinely processed: data from the far ultraviolet aurora imager (FUV) and data from the extreme ultraviolet plasma imager (EUV). Real time images from these two instruments are available to the public at the website (http://www2.crl.go.jp/dk/c231/IMAGE/).

Auroral imaging by ultraviolet light was performed for the first time by the Japanese satellite "Kyokko" in the 1970s[10]. This observation technique has been applied to many satellites, such as the DE-1, Viking, Akebono, Freje, and Polar satellites that followed Kyokko, and has contributed a great deal to auroral research. Since the albedo (reflectance coefficient) of the Earth is low in the ultraviolet wavelength band, imaging can

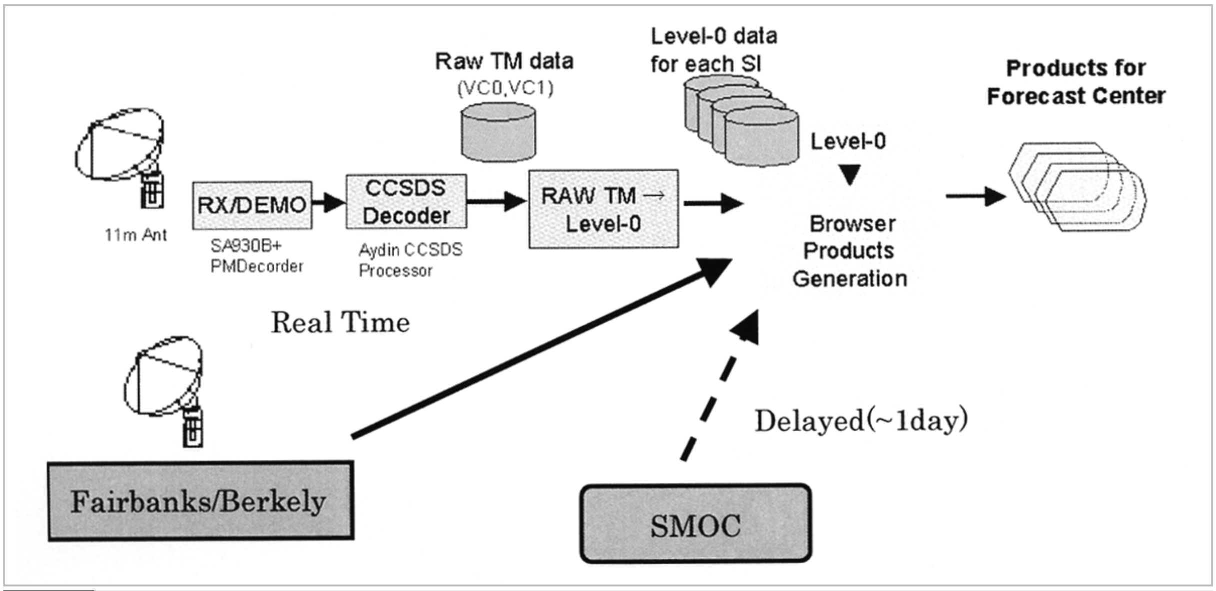

Fig.8 *IMAGE satellite data processing flow*

be performed to some degree even in sunshine. Moreover, this observation technique capitalizes on the simplicity of the luminescence process of auroral ultraviolet light relative to that of visible light, and thus it is easy to obtain information on the particles that cause the emission of auroral light by observing the quantity of such emissions[11]. For these reasons, ultraviolet light is often used in satellite-based observation of the aurora. This method features extensive past results, and allows researchers to predict, prior to satellite launch, the performance of a given data analysis method, in addition to permitting estimation of the sort of data to be obtained. This provides a contrast with the remaining instruments aboard the IMAGE satellite, which consist mostly of new observation instruments with no history of on-board satellite use. Thus implementation of real-time processing was relatively easy for the auroral imaging instrument on board IMAGE, since a method of data analysis using auroral imaging had already been established.

The FUV (Far Ultraviolet Imager) aboard the IMAGE satellite is the latest version of the conventional on-board ultraviolet auroral camera. It is composed of three cameras, each of which has different imaging wavelengths, and each camera takes one image every two minutes[12]. The WIC (Wideband Imaging Camera) observes the atmospheric emission at the N_2 LBH wavelengths (140 nm-180 nm) with high sensitivity. In addition to the WIC, two other cameras capture images of auroras caused both by electrons and by protons at the wavelengths of the oxygen atom (135.6 nm; SI-13) and of Doppler-shifted Lyman-alpha of the hydrogen atom (121.4 nm; SI-12), respectively, with high wavelength resolution. The observation data on November 24, 2001, the same date as for Fig.7, is shown in Fig.9 for purposes of example. The upper panels show the image output from the three cameras and the lower panels show images converted into MLT-MLAT coordinates. The figure shows that auroral activity is activated by the influx of significant amounts of energy from the solar wind shown in Fig.7.

The FUV has unprecedented features as a next-generation auroral imager. For example, it enables imaging of proton auroras for the first time, permitting comparison with electron auroras. Tools are scheduled for development that will enable further processing of FUV data, providing, for example, simultaneous display of the auroral images overlaid with the magnetospheric convection map observed by the HF radar network. Moreover, the use of the FUV renders it possible not only to record the various forms of auroras but also to estimate average energy and flux of the descending particles (electrons and protons) that produce auroras based on data from multiple wavelength channels. We believe that if quantitative evaluation of the descending particles

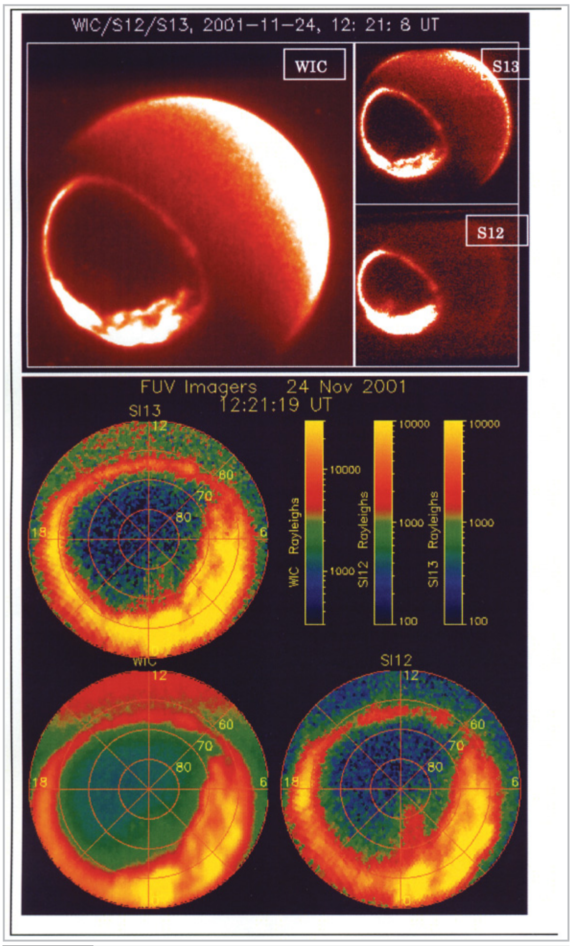

Fig.9 *Auroral image observed by IMAGE/FUV*

The upper panels show original data from the three cameras of FUV. The lower panels are plots in the geomagnetic-coordinate system (MLAT-MLT).

were possible, two-dimensional estimation of electric conductivity in the polar-region ionosphere could then be possible.

The EUV (Extreme Ultraviolet Imager) is an imaging instrument for resonantly scattered He^{+} ion light of 30.4 nm, and is capable of grasping the entire structure of the plasmasphere on a dynamic basis[13]. This method of plasmaspheric imaging using the 30.4-nm band is based on recently developed technology. Although the Japanese Mars explorer "Nozomi" succeeded in the world's first such imaging application[14], the IMAGE satellite is the first to acquire such a large amount of observation data. This observation data is subject to strenuous analysis, allowing us in the process to understand the overall aspects of the plasmasphere. An example of this observation data is shown in Fig.10. In addition to the two imagers mentioned above, the IMAGE satellite carries three energetic neutral atom (ENA) imagers and a radio-wave sounder instrument. To allow for processing of these observational data, additional processing software is scheduled for development in collaboration with the teams in charge of the respective instruments.

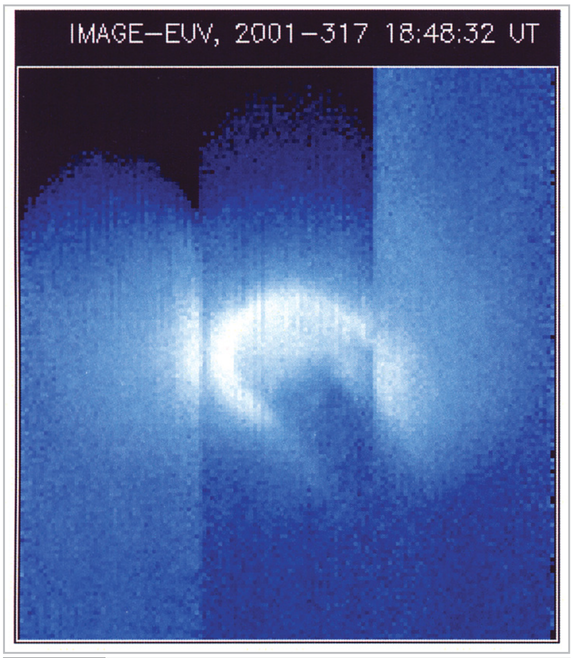

Fig.10 *Earth plasmasphere observed by IMAGE/EUV (November 13, 2001)*

The bright portion in the center is the ionosphere. Since the Sun shines from the upper left of the figure, the upper-left portion in the center is bright. The EUV takes images with three cameras, each designed for one of three divisions of the field of view. Since these images do not compensate for sensitivity differences among the cameras, three bands are recognized.

Real-time IMAGE data also contributes to daily forecasting by helping us to gain an overall grasp of magnetospheric activity, when combined with real-time data from a geomagnetic-field observation network and an HF radar network. Moreover, IMAGE satellite reception is useful because the data processing systems are established locally. As a result both real-time data and observation data may be processed at CRL. The value of such research only continues to grow.

5 Conclusions

We have established and improved a system of reception in real time of ACE spacecraft solar wind data, and have continued data reception nearly without interruption 24 hours a day, 365 days a year. This success is based on international cooperative efforts taking place from 1998 to the present. To use this real-time data most effectively, we have begun to apply it to the prediction of geomagnetic disturbances by using the neural network and similar methods. These results are widely available to the public on the Web. Moreover, in 2000 we began real-time reception of data from the IMAGE magnetospheric observation satellite. This was achieved through improvements to the receiving system, enabling tracking of multiple spacecraft. Auroral images from the IMAGE satellite now contribute to forecasting services and research and provide an indication of the current state of magnetospheric activity.

The establishment of this receiving system and its subsequent extended period of stable operations have paved the way for the real-time utilization of spacecraft data, also laying the groundwork for real-time transmission of data by spacecraft that have yet to be launched.

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