FINAL REPORT

Senior Review of the Sun-Earth Connection

Mission Operations and Data Analysis Programs

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Submitted by:

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1. Introduction:

At two-year intervals the Office of Space Sciences (OSS) subjects its programs to technical scrutiny by selected members of the discipline communities. The last Senior Review of the Sun-Earth Connection (SEC) program occurred in June 1997 at a time when all elements of the flagship International Solar Terrestrial Physics (ISTP) missions had either reached or were approaching the end of their primary mission phase. Under prevailing NASA policy, ISTP and supporting satellites should be phased down unless compelling arguments were made for continuing as extended missions. The Senior Review Panel of 1997 argued that the fleet of existing satellites was an irreplaceable resource for radically improving understanding of SEC physics during the approaching period of maximum solar activity. The program recommended by the Senior Review of 1997 was largely accepted and proved so successful that the review scheduled for 1999 was deemed unnecessary.

The situation considered by the Senior Review of 2001 differs from its predecessor in four substantial ways. First, the flights of the new ACE, Cluster, IMAGE and TRACE missions vastly increased the diagnostic powers of the satellite fleet. Second, the Panel reviewed three data facilities as integral components of MO&DA activities. Third, the success of the SEC program led to two new mission lines called Solar-Terrestrial Probes (STP) and Living With A Star (LWS). Fourth, funds projected for the FY02 to FY05 interval of review are significantly less than those requested by the projects. This new environment presented an entirely different challenge to the panel from that experienced previously.

1.1 Space Missions and Data Centers:

The present Senior Review focused on 14 satellite programs and 3 scientific data facilities. In alphabetical order the satellite programs are (1) Advanced Composition Explorer [ACE], (2) Cluster, (3) Fast Auroral Snapshot [FAST] Small Explorer Mission, (4) Geotail, (5) Interplanetary Monitor Platform 8 [IMP-8] (6) Imager for Magnetopause to Aurora Global Explorer [IMAGE], (7) Polar, (8) SAMPEX, (9) Solar and Heliospheric Observatory [SOHO] (10) Transition Region and Coronal Explorer [TRACE], (11) Ulysses, (12) Voyager, (13) Wind, (14) Yohkoh. The data centers are (1) the Central Data Handling Facility [CDHF], (2) the National Space Science Data Center (NSSDC), and (3) the Solar Data Analysis Center [SDAC]. The satellite missions are evaluated in Sections 2 and 3 according to whether they are of prime interest to the solar-heliospheric or the solar-terrestrial interactions communities, respectively. Data centers are evaluated in Section 4.

1.2 Senior Review Panel Responsibilities:

All projects submitted proposals to OSS describing their scientific accomplishments, relevance to NASA programmatic quests and their plans for scientific endeavors in the FY02-05 interval. The proposals were required to include budgets for mission operations and data analysis (MO&DA) at both "bare-bones" and "optimum" scenario levels. Four budget categories were identified: (1) development, (2a) data services, (2b) mission services, (2c) other operations, (3) science center functions, and (4) science data analysis. Costs for each category were presented in terms of full-time equivalent (FTE) manpower and in dollars. For the mature programs under review, requested development costs were expectedly small. Item (2a) concerned mission operations related to data acquisition via the Deep Space Network or the Ground Network. This largely represents a fixed cost, beyond the scope of the Senior Review. Mission services (Items (2b) and (2c)) are subject to the control of program managers and represent the mission operations (MO) element of requested budgets. Data manipulation and analysis and (Items (3) and (4)) were of prime concern to the Senior Review Panel.

A totals of funds requested to support "bare bones" MO&DA programs in FY02-05 were approximately $88M, $89M, $91M, and $88M, respectively. The total requested amount to support DA activities in FY02 was almost $71 M, exceeding allocated funds by ~$17M. Moreover, the gap between requested and available funds increased in FY03-05 to more than ~$30M. Without the addition of significant new funds, decreased levels for program activities are unavoidable. The Senior Review Panel was repeatedly assured that obtaining substantial budgetary relief was unlikely. The central issue of the Senior Review turned on finding ways to promote scientific return while minimizing the long-term impact to NASA's ongoing and future SEC research program.

1.3 Methodology: A Systems Approach:

As the impacts of the restricted fiscal environment were recognized, the Panel realized that simple across the board reductions would inflict senseless damage on all and assured the scientific viability of none. Rather the Panel concluded that the program should be reviewed in the context of two large systems, the Sun-Earth and the Sun-Heliosphere systems. The IMP-8, Wind and ACE spacecraft are elements of both systems. The Panel analyzed the roles of each element, examining how its sensors contribute to system understanding. Evaluations addressed: (1) the health and status of each spacecraft and payload, (2) the scientific strengths of proposed programs, (3) the relevancy to other NASA missions, (4) the accessibility of scientific data products to Principal Investigator (PI) teams and outside investigators, (5) the record for education and public outreach [E&PO], and (6) any weaknesses found in the proposal. From these considerations, the Senior Review Panel developed a scoring system with the greatest weights given to science impact and relevance to ongoing and planned NASA missions. Based on the evaluations the panel developed recommended funding levels for the proposing missions..

In reaching conclusions implicit in the recommended funding profile, the Senior Review Panel adopted two decision rules. First, frequent access to space embodied in the smaller-faster-cheaper concept implies that small/medium missions have limited operational lifetimes. After some reasonable lifetime sufficient to achieve the optimal science per dollar, these missions should be considered for termination. The Senior Review Panel thus recommends that the FAST, SAMPEX, Ulysses and Yohkoh satellite programs be completed during the next one to three years. Second, during extended missions, overall MO&DA costs should be about half those of the prime mission phase. An effective Guest Investigator (GI) program should fund additional scientific investigations. In several instances the Panel requests that managers of older programs seek to increase analysis resources through strict control of MO costs.

Table 1 summarizes grades given to the 14 satellites and the GGS Theory and Modeling effort for their science impacts and relevance to the NASA mission. Scores in the 8 to 10 range represent programs regarded as being "clearly superior." Grades between 4 and 7 were assigned to programs viewed as "very good." Candidates for termination received grades from 0 to 3. The table gives average values and standard deviations of grades assigned by the eight voting panelists. Relatively low standard deviations indicate that after listening to the various presentations the Panel members independently came to similar conclusions. With the exception of SAMPEX there was little difference between the Panel's perceptions of the science impact and relevance.

Satellite Mission	**Science Grade**	**Relevance Grade**
Geospace		
IMAGE	8.25 ± 0.71	8.71 ± 0.95
Cluster	8.00 ± 0.98	8.71 ± 0.95
Polar	6.75 ± 1.39	6.86 ± 1.46
FAST	5.88 ± 1.46	5.75 ± 1.49
Geotail	5.13 ± 1.96	5.50 ± 2.07
GGS Theory	4.38 ± 2.39	4.50 ± 2.67
SAMPEX	4.13 ± 1.25	5.38 ± 1.69
Solar-Heliospheric		
SOHO	8.00 ± 0.93	8.50 ± 0.53
ACE	7.00 ± 1.60	8.75 ± 1.16
Voyager	6.63 ± 1,85	7.38 ± 1.30
Ulysses	6.50 ± 1.77	7.00 ± 1.77
TRACE	6.13 ± 1.13	6.50 ± 1.51
Yohkoh	5.25 ± 1.49	6.13 ± 1.25
Wind	4.38 ± 1.41	4.88 ± 2.10
IMP-8	3.13 ± 0.35	3.63 ± 1.77

Table 1. Grades for science impact and NASA relevance of SEC satellite missions.

The International Solar-Terrestrial Program (ISTP) presented difficult challenges. ISTP is a cooperative venture between NASA, ISAS and ESA embodied in the Cluster, Geotail, Polar, SOHO and Wind satellite programs. The ISTP integration of information from multiple spacecraft, ground facilities and theoretical modeling exemplifies the systems approach employed in this review. Cluster is a constellation of four recently launched satellites that significantly augments ISTP capabilities. NASA views Cluster as a pathfinder for the future Magnetospheric Multiscale mission and is deeply committed to supporting the analysis of its unique scientific data. After examining many alternatives the Senior Review Panel determined that proper funding to support Cluster analysis could only be obtained through a significant redistribution of ISTP (SOHO and GGS) resources. The substantial impact of this recommendation on GGS merits special explanation.

The GGS program consists of five components, the Geotail, Polar and Wind satellites, a Theory and Modeling effort, and the CDHF. In evaluating GGS proposals the Senior Review Panel found that: (1) The precession of the Polar orbit offers opportunities for conducting important scientific investigations of physical processes of interest to SEC. Those investigations will be carried out in coordination with ACE, Cluster, FAST, Geotail, and IMAGE. (2) The GGS proposal failed to show how data from the US instruments on Geotail were critical for these investigations. High-resolution data from Geotail used in scientific papers have been provided by Japanese data centers. (3) Plans to have Wind execute Distant-Prograde and Return-Earth orbits were not compelling in the present budget environment. Placing Wind in an L_1 halo orbit as a backup for ACE would better serve SEC objectives. The Panel strongly urges SEC management to seek out new resources to support campaigns by Wind/ACE to specify solar wind scale sizes and by Wind/SOHO to study coronal mass ejection (CME) propagation dynamics from complementary orbits near L_1. (4) The continuation of an independent GGS theory and modeling program was not justified. Proposals to conduct GGS-related studies should be competed under the GI program. (5) The CDHF requirements and funding to support GGS should be reduced. The Panel recommends that CDHF be placed under the GGS program manager, and that he develop revised plans for FY02 - FY05 operations, using combined GGS/CDHF resources to achieve the best possible scientific output.

1.4 Summary of Major Issues:

Mission operations costs for several spacecraft consume large fractions of their total budgets, thus limiting the science return from the entire constellation. The Panel has identified specific missions for which this is a particular issue, but urges SEC management to address this issue at the Enterprise level. The Panel recommends that program managers be challenged to reduce MO costs by 25% below present target levels. As an incentive, MO savings should be made available for enhancing scientific return.

Factors that drive the high costs of mission operations include demands for very high rates of data return, typically > 95%. Such demands require costly 24 hours a day, 7 days a week operations. The Panel recommends that missions in extended phases should accept a higher science data risk and restrict operations to the normal workweek. Some high MO costs are of historical origin. Older spacecraft were designed to function with nearly continuous contact and commanding. Newer missions with more autonomous operations should mitigate the problem. However, the Senior Review Panel recommends that all missions should be examined closely to identify how operations might be simplified. For example, operating modes of scientific instruments should be well understood and not require frequent changes.

The key to meeting SEC goals of understanding the Sun-Earth and Sun-Heliosphere systems is the integration of data from multiple missions during scientific analysis. This motivates a suggestion to reduce the size of the mission-investigation teams as missions move beyond their primary phase. Most extended-phase scientific analysis should be funded competitively through a substantial GI program to which mission investigators have full access. The Senior Review Panel strongly supports this approach. However, the Panel recognizes that GI funds, "unattached" to specific missions, are often at risk. The Panel urges SEC management to incorporate the GI program as an integral part of MO&DA funding to serve as a bulwark against countervailing fiscal pressures.

From a market perspective, a properly functioning GI program performs a central role in the Senior Review process. Proposals from the science community for further analysis indicate the missions and sensors whose data are most accessible and useful for meeting SEC scientific goals. The Panel also recommends that SEC management track results of the GI selections in order to identify the mission investigations that require higher levels of funding to provide the data processing and services that are most in demand. Funding should be augmented to assist missions subject to strong data demands from the GI.

The Senior Review Panel has worked diligently to help meet budget targets provided by NASA management. The target was substantially below even the minimum requests from the missions. The Panel recommends that SEC management search for new funds to enhance the value of the science returned from the present mission constellation. The Panel strongly recommends that in FY02 SEC management seek out an additional funds for a robust GI program. Any additional funding beyond that level should be used to strengthen missions that did not receive their minimum requests, according to the priority rankings listed in Table 1.

Finally, the Panel notes that many SEC missions have investigative capabilities that apply to space phenomena well beyond the simple Sun-Earth system. The proposals described innovative studies of comets, interplanetary dust, gamma-ray bursts, galactic cosmic rays, and the interstellar medium. The Senior Review Panel recognizes the excitement and value that accompany unique and even historic science. However, there is concern that the Space Science Enterprise fails to receive full credit within NASA, the scientific community, or the public when sponsoring such work. The Panel recommends that more attention be given to insure that these exciting research results are communicated widely.

2. Evaluation of Solar-Heliospheric System Elements

2.1 Advanced Composition Explorer:

ACE was launched in August 1997 and placed in a halo orbit around L_1 in January 1998. Except for the sensor measuring charge-states of energetic ions, the spacecraft and payload are healthy. With proper management ACE can continue to operate for more than a decade. ACE carries the most comprehensive particle composition experiments currently in space. Particle energies cover the range from solar wind through cosmic rays. The solar wind sensors determine both the elemental and charge composition. Unique measurements of charge states of medium energy (0.1-10 Mev/nucleon) particles are taken. The full isotopic composition of cosmic rays is also monitored. ACE will detect important new phenomena during the declining phase of the solar cycle. Large solar flares and a more organized corona, with corotating interaction regions, will mark the period. Composition is an important diagnostic of acceleration processes at the Sun and in the heliosphere. Of particular note is the continuous acceleration of low-energy particles in the solar wind whose cause is unclear. Relevant observations should be made under different solar wind conditions. Also, galactic cosmic ray fluxes intensify, with the likely entry paths to the inner heliosphere along the equatorial current sheet. Similarly, during the return to solar minimum studies of anomalous cosmic rays increase in value.

In addition to comprehensive composition measurements, the principal strength of ACE is its ability to monitor the solar wind and interplanetary magnetic field (IMF). Such measurements are essential for predicting hazardous space weather conditions near Earth for civilian and military purposes and in support of the LWS program. ACE and Ulysses measurements may be used to determine the 3-D behavior of plasma in the inner heliosphere. Combined with Voyager measurements, they can also be used to identify variations between the inner and outer heliosphere.

Assessment and Recommendations:

The Senior Review Panel understands that orbiting the L_1 Lagrangian point, ACE plays a critical role in NASA's quest for increased understanding of the solar corona and its interactions with the heliosphere and the Earth's magnetosphere. Were it not for the maneuverability of Wind, ACE would loom as a single-point failure threat to the LWS and National Space Weather programs. The Panel strongly recommends that it be funded for the full four years of this review, albeit at rates slightly below those requested by the ACE team

2.2 Interplanetary Monitoring Platform-8:

IMP-8 has provided a 27-year baseline for solar wind plasma, energetic particles, and IMF measurements for heliospheric and magnetospheric studies. Data from IMP-8 have contributed to more than 1000 refereed publications. The current rate is about 80 per year. Its plasma measurements have long been *the* solar wind density calibration benchmark among the different spacecraft that have succeeded it, such as the ISEE, Wind, SOHO, and ACE satellites. It has also acted as the L_1 to Earth time-standard. The OMNI data set has been a major community resource for generations of graduate students. IMP-8 has been widely used as a near-Earth solar wind monitor for solar wind-magnetosphere coupling and as the 1 AU baseline for Voyager and Ulysses plasma and energetic particle studies.

The most intense solar energetic particle (SEP) events tend to occur during the waning phase of solar cycles. These events are therefore likely to occur during the period of this review. ACE, Wind, and SOHO also make composition and low-energy measurements, but their high-energy measurements are available only in broad energy bands. IMP-8 provides the highest energy spectral resolution for SEP protons and alphas, needed to model of acceleration processes in the interplanetary medium. Older electronics on IMP-8 are more robust under extreme conditions than those of newer spacecraft.

For unknown reasons the magnetometer on IPM-8 stopped operating in June 2000. A recovery attempt will be made during the next spacecraft eclipse interval. To reduce interference, a replacement for the Wallops VHF telemetry (TM) downlink station in the eastern US is desirable. An alternative to the Redu, Belgium TM station will also be needed after FY02 when ESA support ends. With only the Canberra and eastern US TM sites, data capture will be about 70%. The software used to produce level zero data is 30 years old, poorly documented, and fragile. It runs inefficiently on modern computer operating systems. A re-engineering cost of $500K would take 2.5 years to amortize.

Assessment and Recommendations:

With great regret the Senior Review Panel concluded that the loss of the magnetometer marked *the end* to IMP-8's role as a useful monitor for magnetospheric studies. Sensors on the ACE satellite can act as a 1AU monitor for Ulysses and Voyagers. The Panel feels that IMP-8 energetic particle data are still valuable for heliospheric science. However, in the present budget situation, it also recognizes that adding a few years of data does not increase its statistical significance to a level that justifies continuation of this mission at the expense of others. The Panel recommends that operations cease at the end of FY01.

The Panel also recommends that the long IMP-8 database be further exploited through the GI program. In recognition of reaching the end of an era in space exploration, the Panel urges NASA/HQ to extend well-deserved commendations to the IMP-8 team and the principal investigators.

2.3 Solar and Heliospheric Observatory:

The comprehensive suite of instruments on SOHO is of very high quality. Continuing observations greatly contribute to understanding the solar interior and corona. Science conducted by the teams and the community has evolved over the mission to move beyond the initial descriptions of static structure to new studies of the variability of the 3-D Sun, its interaction with the heliosphere and impacts on the Earth. The scientific case for continuing observations with MDI to build the signal-to-noise required for extraction of the weak but significant signals of interior structure is most compelling. Coordinated experiments with other SEC spacecraft are being actively pursued.

The proposal tends to list observed phenomena rather than address physical problems to be solved. Except using MDI to determine IMF B_Z associated with CMEs, the proposed future focus on geoeffectiveness is vague. The scientific value differs among sensors. *In situ* observations have not lived up to full scientific potential. The Panel believes that UVCS has met many of its basic science objectives but still has an important role in supporting program campaigns, such as the two yearly Ulysses quadratures. Most prime instruments are functional and stable. The LASCO C1 inner coronagraph failed during the SOHO outage in 1998, and SUMER spectrograph degradation limits its use to campaign operations.

The SOHO team is commended for its highly visible and effective public outreach. Movies of halo CMEs, helioseismic maps of sunspots on the far side of the Sun, imaging of global-scale blast waves from flares, and public involvement in discovering comets have helped bring the excitement of SEC science to the forefront of public attention.

Assessment and Recommendations:

SOHO is the flagship mission for solar investigations, and provides fundamental science data for the SEC theme. The Senior Review Panel gave the SOHO satellite the highest rating of any extended-phase mission. SOHO data and science penetrate deeply into the solar-heliospheric science community, resulting in an average of 250 refereed papers per year. The SOHO program has trained future scientists at a rate of 8 PhD theses per year.

Mission operations costs for SOHO are very high and thus limit its mission science. The Panel recommends that direct-downlink hours per day be reduced to a single shift, and to the duration of the annual continuous contact period. These reduced MO costs pose minimal risk of data loss. Some mission teams are larger than required for an extended mission phase and should be decreased. It is safe to conduct operations and analysis with a smaller total FTE count for UVCS and LASCO. However, MDI data processing is complex and requires an appropriately sized team, close to the bare-bones estimate. Scientific research beyond critical items should be funded through the GI program.

2.4 Transition Region and Coronal Explorer:

TRACE carries a single instrument to observe the Sun at uniquely high spatial resolution, over a wide range of temperatures, and with excellent temporal resolution. Observed spatial scales approximate the mean free path of Lyman alpha photons. Thus, what appear as single flux tubes seen at the highest resolution of SOHO and Yohkoh sensors are resolved into multiple loops by TRACE. High-resolution TRACE data seriously constrain models and physical interpretations of SOHO/Yohkoh observations.

Coronal seismology is a major breakthrough achieved with TRACE technology. Other coronal telescopes have tried but failed to observe oscillations and damping times. This is a difficult measurement even for TRACE, and the team is still learning observational techniques. Current observations indicate that oscillations damp very quickly. Damping oscillations combined with theory can be used to deduce field strengths in loops. TRACE's unparalleled high spatial and temporal resolution of the evolution of magnetic loops gives new insights into the evolution of solar electrodynamic processes. Detailed views of the initial conditions on the Sun help to understand events propagating into the heliosphere. TRACE carries the only other high-resolution (spatial and temporal) EUV sensor. In the near future TRACE will provide critical collaboration with HESSI. Solar B is expected to produce observations comparable in quality. However, until Solar B is launched and operating, TRACE operations are of vital importance for advancing solar research. The Panel also notes that a 50% decrease in the sensitivity of the sensor has had no significant impact on the science output, and it is expected to remain fully functional through the period under review. The Panel's only criticism is that the TRACE team tends to focus more on morphology than quantitative physical parameters.

The TRACE team is to be commended for their excellent activities regarding education and public outreach. They initiated space science updates and developed high quality education materials that are widely used.

Assessment and Recommendations:

TRACE is an extremely successful spacecraft and has produced unique science at a modest cost. Its unparalleled spatial resolution has led to new perspectives that constrain theoretical models. TRACE now collaborates closely with SOHO and Yohkoh, and will be of critical importance for the HESSI mission. Given financial constraints on SEC missions the Senior Review Panel believes that it is the necessary to reduce the number of FTEs working on TRACE. The Panel recommends that TRACE decrease the FTE load for pure science and, if necessary, reduce science-planning expenditures. To help reduce MO costs in FY03–05, SEC management should examine the feasibility of passing operational control of TRACE to Bowie State University as it successfully did with the SAMPEX satellite.

2.5 Ulysses:

Ulysses is the critical system element for characterizing the 3-D structure of the solar wind in the heliosphere. The mission has revealed significant differences between solar wind phenomenology at low and high heliospheric latitudes and has spurred progress in understanding the origins of these differences. Moreover, Ulysses demonstrated that latitudinal differences depend on the phase of the solar cycle. This appears to reflect the evolution of the solar magnetic field structure over the solar cycle. The transition from high to low activity solar wind is likely associated with the rotation of the heliospheric current sheet observed as the solar magnetic field polarity reverses. The transition, which may be abrupt, and its variation with heliospheric latitude represent outstanding scientific problems that only Ulysses can resolve as it returns to the ecliptic plane after sampling the Sun's polar region in the fall of 2001. Pursuit of this scientific knowledge provides compelling reasons for Ulysses to continue making solar wind observations until it reaches heliospheric low latitudes.

The energetic particle instruments on Ulysses have produced critical observations for understanding the origin of galactic cosmic rays (GCR) and interstellar pickup ions. The proposal clearly demonstrates that continued measurements would improve the statistics and sharpen the conclusions about these transheliospheric phenomena.

While proposed research on interplanetary dust, planetary radio emissions and energetic particle emissions from Jupiter are interesting, those topics lacked strong justification. There seems to be some duplication of ACE science goals. By 2004 the spacecraft will have completed two high-latitude passes through the heliosphere, at solar minimum and maximum. Further operations would give diminished returns and are not recommended.

Assessment and Recommendations:

The basic science goals of the extended mission are central to SEC objectives, but many secondary goals appear to be tangential. The justification for continuing the mission through the next return to the ecliptic plane to provide the complete pair of latitudinal passes is strong. Beyond that time, the mission utility is questionable. Power and thermal limitations begin to impact the science data return by late in this year.

Considering the total NASA and ESA contributions and the stability of the science instrument modes, the Panel regards the operational costs of this mature mission as too high. The Ulysses Project is challenged to regain or maintain DA money by finding the savings within MO funds.

2.6 Voyager:

The prime mission of the Voyager 1 and 2 (V1, V2) spacecraft is to cross the heliospheric boundary known as the "termination shock" where the solar wind velocity becomes sub-Alfvénic. Although the Voyager will encounter other interesting phenomena in the outer heliosphere, the termination shock is *the* issue. The crossing provides a unique chance to study *in situ* a cosmic ray mediated shock. Results will have astrophysical applications for understanding the physics of supernovae. The Voyager mission directly observes how solar and heliospheric particle fluxes evolve and interact with outer boundaries of the heliosphere. It also provides unique information about interactions of the Sun with the galaxy (interstellar space). In addition, the public recognition factor of the Voyager "interstellar" mission is remarkable and retains a good deal of residual enthusiasm. The project continues to produce refereed publications at a rate of about 55 papers per year.

The Voyager 1 and 2 (V1, V2) spacecraft have sufficient consumables to support mission operations until 2020; after that electrical power will no longer be adequate. Gyros shut down in 2010. V1 is currently at ~80 AU and is moving out at 3.6 AU/year. V2 is 5 yrs behind, moving at 3.3 AU/year. Data are now collected for 7 of the 11 investigations, although only five teams are still active and supported. Since the plasma sensor on V1 no longer returns useful data, qualitative solar wind parameters are estimated by using the Compton-Getting Effect. The magnetometer on V2 experiences spacecraft-generated noise problems, rendering analysis difficult. The entire V2 scan platform has been powered down. The V1 scan platform will be powered down in mid-2002, after UVS finishes an investigation of unexpected radiation coming from the upwind direction.

High-rate data from the plasma wave experiment is the chief means for estimating the locations of the termination shock and heliopause. These data will not be available after 2010 (V1) and 2012 (V2) when telecommunications can no longer support the necessary playback bit rate. Most experiments require real-time telemetry acquisition. Currently, each Voyager requires an average of about 16 hours of DSN coverage per day.

The proposal demonstrates that this mission is expensive to operate. It was recognized that the age of the spacecraft and its technology drive these high operational overhead costs. Still, MO costs appear higher than required. Requiring continuous coverage for V2 does not seem as justified as for V1. The primary role of V2 is to support V1. Although the two spacecraft are at different locations, V2 will act as the internal (this side of the shock) solar wind sampler. V1 is likely to have multiple shock crossings (thereby acting as its own internal/external sampler). However the Voyager Project argued that there are no cost savings achieved either by canceling V2 or decreasing coverage.

Assessment and Recommendations:

Voyager still provides unique and compelling science. The Panel felt that the Project has not done an adequate job recently in maintaining the excitement levels of this mission. It is strongly recommended that the Voyager encounter with the Bastille Day event later this fall, be used to showcase interactions of the Sun with the outer heliosphere and the interaction of radio events with heliospheric boundaries.

Operations should continue for both Voyager spacecraft through FY05, or for one year after shock crossing, whichever comes sooner. This will allow sufficient time for the most likely crossing period of the termination shock and sampling of the subsonic solar wind beyond. However, continued operations, even in the shorter two-year term of this proposal, must become more cost effective. Otherwise, funding for scientific analysis must be reduced to cover the deficit. The Voyager Project is challenged to regain DA money by finding savings within MO funds.

2.7 Wind:

The Wind spacecraft is healthy and has large capability for orbit maneuvers. All of the instruments, except for the SMS SWICS, are operating. Unlike the other GGS satellites, which are mainly devoted to magnetospheric studies, Wind's primary planned activities for the next four years have taken on a heliospheric dimension. It is currently in an elongated orbit (350 R_E) at 90^o to the Sun-Earth line, allowing study of solar wind scale sizes in the vicinity of Earth. However this configuration does not permit Wind to provide measurements of interplanetary inputs into the Earth's magnetosphere. Rather, this function was ceded to ACE and to IMP-8, Geotail, and Cluster when they are in the solar wind. WIND does provide radio and plasma wave measurements that are not present on the other upstream monitors. Wind has great flexibility to maneuver and thus in the event of a failure on ACE could move to an L_1 orbit to serve as the upstream monitor for the LWS program.

The Panel finds that the proposed upcoming Wind activities have substantial weaknesses. The study of solar wind disturbances will address scale sizes that are large relative to the magnetosphere, but small compared to heliospheric dimensions. An orbit of 350 R_E covers only about 0.01 AU, which is of the order of the correlation length for solar wind turbulence. It is doubtful that information about structures of this scale will be useful for comparison with developing models of the evolution of such disturbances as CMEs.

Assessment and Recommendations:

Given the restricted funding available for the operation of ongoing missions, Wind has low priority. The mission does not add significantly to heliospheric studies since its measurements are as effectively provided by ACE. Studies of heliospheric structures with the scale sizes of the proposed elongated Wind orbit are of questionable value.

This assessment does not imply that the Panel regards Wind measurements as being without value. In a positive light, spacecraft operations in the vicinity of L_1 are viewed as having strategic importance for the success of the LWS and National Space Weather programs. The loss of L_1 capabilities represents a glaring single-point failure for both. The Panel considered the possibility of moving Wind to a halo orbit of L_1 to serve as a backup for ACE, the current primary upstream monitor.

Given the fiscal constraints of this review, the panel does not recommend the allocation of any funds to Wind in FY02 to 05. However, the Panel strongly recommends that SEC management determine the cost of moving Wind to L_1 and to seek resources needed to maintain Wind at a near-operational status in a stand-by position near L_1. To facilitate stand-by maintenance, coordinated studies between ACE, Geotail, Cluster and Wind should be conducted. Envisaged campaign mode experiments would use Wind's plasma and magnetic field sensors to study east-west and north-south scale sizes of geoeffective solar-wind/IMF structures. Other campaigns should be conducted using unique wave-detecting capabilities of Wind to specify the characteristics of CMEs and solar-wind shocks approaching the Earth.

2.8 Yohkoh:

Since Yohkoh is a Japanese satellite only the operations of the US-supplied soft x-ray telescope (SXT) were reviewed. Recently increased stray light has been reaching the sensor, but the SXT team has done an excellent job of recalibration. The situation is now stable at a level that is about as bad as it will/can get.

The SXT team does excellent scientific research using data from Yohkoh alone and in collaboration with other spacecraft such as SOHO and TRACE. Critical for solar flare observations, SXT complements EIT on SOHO, covering a higher temperature range. Yohkoh has been operating for many years and provides a long baseline of consistent data to understand how the Sun changes with time. The SXT team also works closely with TRACE, which provides much higher spatial resolution. They contribute to understanding irradiance in the X-ray part of the solar spectrum. The Yohkoh team has done an outstanding job of making their data available within the scientific community and in their outreach to the world beyond.

The SXT provides our only view of medium to large-scale magnetic structures in the hot corona. Future interactions with HESSI are important. The Yohkoh and HESSI teams are already working to coordinate activities. During flares HESSI will observe the nonthermal, impulsive phase, while Yohkoh monitors x-rays generated in the thermal, gradual phase.

Assessment and recommendations:

The Senior Review Panel recommends that the Yohkoh mission be kept operating, but at a reduced level. The SXT team is supporting a very effective theory program that should be subject to open competition in the GI program. While it is laudable to support basic research within the PI teams, the present level goes beyond expectations for the mission-operations budget of an older spacecraft. The team currently sends observers to Japan to support operations. Several others travel to help reformat raw telemetry from all sensors on the satellite and help operate the spacecraft. The archive is mostly a US contribution. A reduction of the US commitment appears prudent. Support for HESSI should take about two years. By then x-ray emissions will decrease as the solar-cycle minimum approaches. The Panel thus recommends that SXT support terminate after two years.

3. Evaluation of Solar-Terrestrial System Elements

3.1 Cluster:

Cluster is a four-satellite mission that is controlled by the European Space Agency, but has deep scientific roots in the US space physics community. Each of the spacecraft flies in tetrahedral formation carrying identical payloads of sensors to measure the geospace environment. The commissioning phase ended in early 2001. The investigator teams are currently working to understand complex cross-calibrations between sensors on the four vehicles. The mission is expected to provide completely new perspectives regarding the 3-D nature of plasma and field structures in the magnetosphere and nearby interplanetary medium such as the bow shock and the magnetopause. Four separated but simultaneous measurements are sufficient to distinguish between spatial and temporal effects. Over the course of the mission different scale sizes will be examined as spacecraft controllers alter the separations between constellation elements. Science objectives of the Cluster mission are central for understanding the space environment of Earth and other planets. The Senior Review Panel viewed Cluster as a pathfinder mission for future multiple-spacecraft NASA programs such as the Magnetospheric Multiscale mission.

US scientists are co-investigators on eight of the Cluster instruments with crucial hardware and data analysis responsibilities on seven of them. The proposal demonstrated that the science potential of Cluster cannot be realized without continued and substantial involvement of US investigators in instrument-performance verification, and data reduction/analysis/interpretation phases of the mission.

Cluster is still in the early stages of the expected mission, and scientific results achieved thus far are more descriptive than quantitative. Data are processed at several centers to provide summary plots for the community. The PIs have been cooperative in opening their data to co-investigator teams selected prior to the attempted launch of Cluster 1.

Assessment and Recommendations:

This is an excellent and exciting mission that will yield fundamentally new perceptions of physical processes in the magnetosphere. It is a new mission and the concept of using four spacecraft to deduce underlying physics will require the development of new techniques for data analysis and display. The Panel expects that Cluster will need significant resources to execute its scientific responsibilities correctly. As Table 1 shows the Panel gave Cluster its highest ranking among the reviewed programs. Thus, it is recommended that significant ISTP resources be diverted from existing missions and used to support the US roles in the Cluster mission.

3.2 Fast Auroral SnapshotT Small Explorer Mission:

The FAST payload contains extremely sophisticated instrumentation to observe *in situ* ion (including composition) and electron distributions with unparalleled resolution in energy from thermal to > 25 keV. Payload sensors also measure electric and magnetic fields at frequencies from DC to above 1 MHz. On-board data acquisition and processing permit great flexibility to address specific science problems at selected portions along the orbit. The FAST instrument complement has been used with remarkable success to explain auroral processes such as electron acceleration, both downward to produce the visible emissions and upward to carry the return field-aligned currents. The prime mission observed and explained processes related to heating and extraction of thermal ions from the ionosphere to populate the magnetosphere. A definitive explanation for AKR generation was demonstrated and correlated with parallel electric fields.

In the proposed extended mission FAST will operate in concert with the IMAGE and Polar satellites to specify the plasma sources for and dynamical behavior of the ring current during magnetic storms. IMAGE has proven capable of determining the large-scale behavior of the ring current ion populations by means of ENA imaging. The Polar orbit has precessed so that its apogee is at low latitude and the satellite will traverse the heart of the ring current ion population over the range L = 2 to 9. FAST will contribute detailed and high cadence observations of ionospheric sources for magnetospheric plasma as well as *in situ* ion populations at all L-values. Combined FAST and Polar will provide IMAGE with *in situ* ring current ion composition and velocity distributions vital for deconvolving ENA observations. Of the constellation, **only** FAST can quantify the ionospheric sources and the underlying processes that give rise to outflows. Science problems addressed during the extended FAST mission regarding the storm-time ring current are of vital importance to NASA/SEC. The coordinated operation of three satellites is an excellent example of the systems approach needed for the LWS program. The FAST team also plans to conduct studies related to seasonal and solar-cycle control of ionospheric ion outflows and to high and low-altitude cusp phenomenology as observed by Cluster and FAST.

Although the TEAMS instrument has suffered degradation and electric field sensitivity was lost at frequencies <1 kHz, the spacecraft and payload are in excellent health. The FAST team's publication record is very good, averaging about 20 papers per year. Many of the papers have had great impacts on the field of auroral physics. The FAST team has an excellent record for making summary data available to the public and developing displays and programs for K-12 teachers.

Assessment and Recommendations:

The IMAGE, Polar and FAST constellation can address and resolve important science questions concerning the plasma sources and dynamic behavior of the storm-time ring current. This warrants continuing the FAST mission for a period of time sufficient to obtain observations during the intense magnetic storms expected to occur early in the declining phase of this solar cycle. The Panel recommends that the FAST mission be funded through FY03 and ended in 2004. The Panel expects that FAST observations will be a rich source of data for scientific proposals through the enhanced GI program.

3.3 Geotail:

Geotail is primarily a Japanese satellite that was launched in July 1992. Although its fuel supply has been used up, it is in a spin-stabilized orbit and can operate indefinitely. In the absence of fuel for active orbital control, Geotail must rely on orbital precession to sample different parts of geospace. Near spring equinoxes of the next four years apogee (~30 R_E) and perigee (~10 R_E) will in the magnetotail and dayside magnetosheath, respectively. The opposite configuration occurs near the autumn equinox. Occasionally this will place Geotail and Polar in close proximity. These orbital characteristics provide the physical basis for proposed collaborations to address four SEC issues: (1) magnetic merging along the dayside magnetopause, (2) the physics of substorm onset, (3) the dynamics of boundary layer plasmas, (4) the evolution of solar wind/IMF structures between L_1 and the vicinity of Earth. With Polar executing skimming orbits along the dayside magnetopause during the spring months, significant progress can be made for understanding merging physics. Geotail provides useful magnetosheath boundary - condition information. Recent analyses from the CRRES and Geotail satellites suggest that substorms have an electrostatic rather than an electromagnetic trigger. With Geotail and Polar operating near 10 R_E in the magnetotail and equipped with electric and magnetic field sensors, this substorm triggering mechanism can be tested. At greater distances Geotail can help improve understanding of mechanisms responsible for the transfer of information from geostationary altitude to locations where near-Earth neutral lines form to release most of the substorm energy. These observational measurements will be critical in validating space weather predictions for the LWS program.

Although Geotail is largely a Japanese contribution to ISTP, it carries two US sensors called EPIC and CPI that measure energetic and plasma sheet /solar wind particles. It was unclear from the proposal that either of the US sensors plays a critical role in meeting the stated scientific goals of this extended-phase Geotail mission. No EPIC paper and only one recent CPI paper are cited in the proposal's list of 168 references.

Assessment and Recommendations:

While scientific studies using Geotail found in the ISTP/GGS proposal are useful, none of them uniquely relies on the US sensors. Required data would come from Japanese sensors. Polar team members interested in the science can obtain access to the required data through Japanese web sites. It is unclear that continued funding of US PI teams for Geotail science represents a useful investment. Rather funds might be better allocated in the context of an enhanced GI program. This appears to be an appropriate vehicle to determine the degree to which new applications of Geotail measurements support SEC mission objectives. The Panel recommends that the data analysis allocation for Geotail be reduced to zero in FY02 and beyond. It will be necessary for the GGS program manager to investigate the cost and utility of CDHF continuing to generate key parameters for Geotail.

3.4 Imager for Magnetopause to Auroral Global Explorer:

The IMAGE satellite provides a totally new view of the magnetosphere, using a new set of remote sensing instruments. IMAGE is still in the primary mission phase. It is the only spacecraft that provides global views of the Earth's magnetosphere, including the dayside magnetopause and the auroral ionosphere. It has even provided information about fluxes of interstellar neutrals crossing the inner heliosphere. If the spacecraft remains healthy, it should proceed into an extended mission to study magnetospheric dynamics during the declining phase of the solar cycle. New remote-sensing techniques employed by the IMAGE team extend traditional single-point measurements to provide 3-D global pictures of the magnetosphere. It thus complements the fine-scale descriptions of geospace plasmas and fields provided by Cluster.

IMAGE already provides very useful input for space weather studies and presents a first step toward the objectives of the future LWS initiative. Data from IMAGE are in the public domain and are accessible from the project's web site or through NSSDC shortly after acquisition. They provide global contexts for interpreting other magnetospheric data. Comparisons with the small-scale measurements from the Cluster satellites should provide critical guidance for organizers of the Magnetospheric Multiscale mission, scheduled for launch late in this decade.

The IMAGE team is very active in education and public outreach, ranking among the best in the SEC. However, further consideration should be given to the degree to which mission resources should be used to finance the development of school textbooks.

The analysis of IMAGE data must become more quantitative. However, this is not easy. New types of measurements require new visualization and modeling techniques to convert raw data into physical units. In the IMAGE team presentation to the Senior Review Panel they gave an impression of providing stand-alone science. Perhaps this perception reflects the early stage of analysis in which the team finds itself. The Panel recommends that the IMAGE team seek to build alliances for cooperative work with other missions. Such cooperation represents the quickest road to effective calibration of their IMAGE measurements and enhancing quantitative output.

Assessment and Recommendations:

The IMAGE mission should continue well beyond its primary phase. Orbital precession will offer new vantages and opportunities for insights into the magnetospheric dynamics. In the present fiscal environment, the Senior Review Panel believes that funding slightly under the requested "bare-bones" level is sufficient. The IMAGE team has demonstrated great skill in reaching scientific goals at about the recommended level. New science opportunities should be exploited though resources available in the enhanced GI Program.

3.5 Polar:

Polar was launched in February 1996 and is in excellent operating condition. With proper maintenance the fuel supply on Polar will allow the satellite to operate nominally until mid 2003. Afterwards Polar will be stabilized, with its spin axis normal to the ecliptic plane. Visible, ultraviolet and X-ray imagers can operate, albeit not optimally. Scientific opportunities arise from the precession of the Polar line of apsides. Near the spring and autumn equinoxes of the next four years, the apogee (~9 R_E) of Polar will be in the magnetotail and near the dayside magnetopause, respectively. Occasionally Geotail and Polar will be in relatively close proximity. These conjunctions provide the physical basis for proposed collaborations to address (1) magnetic merging on the dayside magnetopause, and (2) the physics of substorm onset. During near-equatorial apogee passes the VIS and UVI sensors can simultaneously image emissions from both hemispheres.

Particle and field sensors on Polar and FAST will also provide critical ground-truth information of ring current dynamics critical for quantitative interpretation of ENA fluxes observed by IMAGE. Those observations also provide global contexts for interpreting electrodynamic measurements by the Cluster satellites.

With Polar executing skimming orbits along the dayside magnetopause during the spring months, significant progress can be made for understanding merging physics. Geotail will provide useful boundary condition information as it moves near perigee (~10 R_E) through the dayside magnetosheath. Recent analyses from the CRRES and Geotail satellites suggest that substorms have an electrostatic rather than an electromagnetic trigger. With Geotail and Polar near 10 R_E in the magnetotail and both equipped with electric and magnetic field sensors this can be tested. Particle and field sensors on Polar will be prime detectors for accomplishing both tasks. The proposed new magnetospheric activities address issues related to the transport of mass momentum and energy in geospace. These measurements are useful for validating space weather prediction codes. Electric field and particle data from Polar will be important inputs for modeling and predicting hazardous environments of concern in the LWS program.

Assessment and Recommendations:

Orbital precession and residual fuel supplies allow the Polar satellite to make prolonged observations of magnetic merging along the dayside magnetopause. Definitive measurements are needed to resolve the long-standing controversies between component versus antiparallel models for magnetic merging. Observations taken while apogee is in the magnetotail will help resolve perennial issues concerned with substorm onsets. Polar will contribute information needed to deconvolve ENA images and validate algorithms for remote sensing the location of the storm-time ring current. The Senior Review Panel believes that significant new stand-alone science and support for the IMAGE and Cluster missions will come out of future Polar observations. Thus, it is recommended that substantial funding continue to be given to support continuation of the Polar program.

3.6 SAMPEX:

The SAMPEX spacecraft flies in a polar, low-Earth orbit that provides an ideal vantage for studying penetrating electrons and SEP ions. The spacecraft and its instrumental payload are operational. Some sensor degradation was noted in the last Senior Review. Reentry should not happen before 2009. The Bastille Day magnetic storm offered an opportunity to demonstrate the unique capability of SAMPEX when it discovered a new SEP-related radiation belt. Due to the height of its orbit, Polar does not cross this radiation belt. SAMPEX instruments include the Earth's magnetic field, which acts as a filter to determine charge states of energetic particles from the heliosphere. SAMPEX used this technique to determine that anomalous cosmic rays are predominantly singly charged.

SAMPEX provides an excellent example of LWS science. Measurements of penetrating electrons have basic science and practical utility. The SAMPEX orbit crosses that of the International Space Station and measures all contributions to its radiation dose exposure. The high-energy radiation measurement capabilities of SAMPEX led the Senior Review Panel to give SAMPEX the high NASA relevance grade shown in Table 1.

SAMPEX also supports heliospheric physics. Its measurements are currently being compared with those of ACE to determine the energy dependence of ionic charge states in SEP events. Statistically significant results require more event observations.

The SAMPEX team has achieved considerable savings by moving spacecraft operations to Bowie State University, where students are training to receive FOT certification. Personnel in the Department of Aerospace Engineering at the University of Maryland control flight dynamics. The UMSOC in the Physics Department continues to have responsibility for the management of SAMPEX operations.

Assessment and Recommendations:

SAMPEX has an ideal orbit for making measurements that contribute to system studies of heliospheric linkage to the Earth. SAMPEX will complete a full solar cycle in orbit in just two more years. This would allow further exposure to CIR-induced penetrating electrons. It would also allow sampling of intense solar events typical of the declining solar cycle. SAMPEX should continue operations and data analysis, at reduced DA funding, in FY02. If new funding becomes available, operations should continue, with further reduction, into FY03. After that the Panel recommends that the mission be terminated..

4. Evaluation of Data Center System Elements

4.1 Central Data Handling Facility:

The CDHF came into being in direct response to experience gained by NASA during the course of the ISEE and DE missions. It was planned from the beginning of ISTP to provide the space science communities with maximum access to data generated by the Geotail, Polar, and Wind satellites as well as to support ground data and outputs of the Theory and Modeling groups. To achieve optimum utility from these data, the CDHF recognized that it must also provide access to other related information from external sources such as the SOHO and IMP-8 satellites. After ISTP missions went into full operation, CDHF personnel initiated a reengineering plan to optimize efficiency.

The CDHF ingests ISTP measurements from multiple sources to produce “cleaned-up” and decommutated data (level zero). Calibration algorithms are applied to the level zero data to obtain low-resolution key parameters (KP). CDHF uses NSSDC’s Common Data Format (CDF) to facilitate archiving and utility in scientific analysis. KP files are available on the web or CD-ROMs for researchers to identify interesting geophysical events. Investigators must obtain high-resolution measurements from PI teams. High-resolution event data are then archived at NSSDC where they are available through CDAWeb. ISTP key parameters and science data are being distributed to the ISTP researchers in a timely fashion.

The original CDHF concept was also attractive because of the flexibility achieved through the Science Planning and Operations Facility (SPOF) embedded within CDHF. When an unusual event occurred, such as the Bastille Day magnetic storm, the SPOF could respond quickly by reconfiguring ISTP to obtain the maximum science benefit. Clearly, SPOF planning activities have greatly enhanced the effectiveness of ISTP/GGS event studies.

The proposal expresses concern that the Completion Form/Performance-Based part of its operating contract too closely resembles a financial vehicle appropriate for a factory rather than a scientific research center. This limits CDHF flexibility to exploit opportunities presented by geophysical events. The CDHF Project recommended a Space Operations Directive Agreement (SODA) which would give CDHF managers the authority needed to respond decisively to unusual opportunities. Indeed, CDHF is contending with a basic management problem. Its complement of 41 FTEs is excessive when compared with similar operations of SDAC at GSFC and the FAST data center at the University of California, Berkeley. Also, since CDHF was designed in the early 1990s, its hardware and software have become dated.

Assessment and Recommendation

CDHF is the GGS data system and should continue in the missions for which it was designed. The Senior Review Panel has recommended that GGS missions play reduced roles in future ISTP science. This impacts the demand on CDHF and its required level of funding. To achieve optimal science benefit from remaining resources, the Panel recommends that CDHF be placed under the direct control of the GGS program manager.

The proposal suggests that CDHF be used to provide data services and distribution in the next generation of SEC missions. The Panel does not support this suggestion. It is unclear that the event-oriented approach of ISTP/GGS will be useful in future missions especially since remote sensing and open data policies are becoming more common. Technology used in the CDHF is no longer state of the art. SEC missions such as the LWS program will produce more data and the data processing will require more scientific expertise than before. The Panel believes that a distributed approach will be needed. The centralized approach of CDHF is inappropriate for managing the data of future missions.

4.2 National Space Science Data Center:

The NSSDC serves as the most important archival depository for space environmental data collected by NASA and other space related agencies. As such it enables broad areas of space science and is involved in multiple missions related to the present review. In recent years the NSSDC staff has incorporated value-added services that greatly facilitate accessibility and scientific research. Among these are CDAWeb and SSCWeb. The older OMNI database remains an excellent source for solar wind data. Admittedly, parts of the main NSSDC archive are limited and much is poorly documented. Although NSSDC has not worked out a solution for the problem of archiving raw data and software, the team recognizes the problems and is working on solutions.

Assessment and Recommendation

Over the past several years the NSSDC data archive and services offered to the space physics community have greatly improved. Much of the present emphasis is on serving the heliospheric, magnetospheric and ionospheric communities. The solar physics community uses other services (see the Solar Data Analysis Center discussion). The value-added services such as CDAWeb are widely used by the researchers and have contributed greatly to the success of the ISTP (GGS) mission. Much of the data is available in graphical and digital formats. The graphic displays provide a useful browse function. NSSDC is also active in standards development. They developed the Common Data Format (CDF) that is used by ISTP and other missions. However, much of the SEC community has not yet adopted the CDF approach. NSSDC is working on better ways to accommodate other data formats. Traditionally NSSDC has archived only processed data. Increasingly they are asked to include raw data as well as software in the archive. While team members still have not completed an implementation plan, they are actively working on it. The Panel finds that NSSDC is a cost-effective data resource for the SEC community and recommends that funding continue at the current level.

4.3 Solar Data Analysis Center:

The SDAC enables solar science and supports more than one mission. Although its name indicates that SDAC is a data analysis center, it really serves as an archive and distribution center for a large solar database. It also supports the Solar Soft a software analysis package that is used by many solar physicists. Solar Soft uses proprietary software (IDL). It is possible that the vendor could stop supporting this package. However, the data are well documented and old versions of the software will continue to work for some time so this is not an immediate concern. Part of the solar archive resides at Stanford University. A plan should be developed to assure the long-term availability of data for the broad scientific community. Through informal agreements, SDAC will pass its archive on to the NSSDC when its mission is completed. It would be prudent to formalize this agreement with NSSDC. The Senior Review found that SDAC operations are very cost effective.

Assessment and Recommendation

The SDAC is an excellent example of a small discipline data center. The Center runs on a small budget and provides major services to the solar physics community. The Panel recommends that SDAC receive the full amount requested for data activities. The SDAC team also requested an augmentation in their budget to allow them to carry out data management research. In particular, they requested an augmentation to fund a prototyping study for a virtual solar observatory, modeled after virtual observatories planned for astrophysics. The requested research should be carried out now to facilitate handling of large data volumes expected in the LWS era. The Senior Review Panel recommends that SDAC received the requested funds to initiate a virtual solar observatory.

5. Summary of Conclusions and Recommendations:

The Senior Review Panel has thoroughly examined scientific activities conducted under the aegis of the NASA Solar Maximum Program and proposals for research in the next four years. Material included activities related to fourteen satellites and three supporting data centers. Since the Senior Review of 1997 four spacecraft have joined the SEC fleet. IMAGE and Cluster are still in the primary mission phase. The Panel regarded the quality of scientific research based on measurements from all fourteen satellites to range between very good and excellent. Similar ratings apply to the quality of support from the three data centers to facilitate research within the space physics communities. Unfortunately, even "bare-bones" budgets to cover proposed MO&DA activities in FY02 – FY05 greatly exceed available funds. For this reason it was necessary for the Senior Review Panel to develop a plan for decreasing mission costs and activities. The most significant recommendations are as follows:

1. The SEC Guest Investigator (GI) program should be strengthened. Responses to GI proposals should be used as empirical guides for identifying programs whose data are most available and useful to researchers. Mission scientists are encouraged to propose scientific research projects under the GI program. The Panel urges SEC management to seek new funds to support the enhanced GI program.

2. Through the remainder of the primary mission phase of IMAGE and Cluster, the investigator teams should be funded at least to levels commensurate with "bare-bones" budget requests. After completing the primary mission phase, IMAGE and Cluster, along with the investigator teams for all other programs, should be reduced.

3. The International Solar-Terrestrial Program was augmented by the launch of the four Cluster spacecraft. To support strong US participation in Cluster and IMAGE analysis, the Senior Review Panel recommends that the bulk of the attendant shortfall come from other programs within ISTP. The Panel recommends that in FY02 funding for SOHO and GGS would be reduced. To meet this challenge, the Panel recommends that reductions be accomplished by:
-a- Reducing the number of personnel supporting UVCS and LASCO operations.
-b- Terminating funds for the GGS theory team and US sensors on Geotail.
-c- Moving Wind to an L_1 orbit as a backup for ACE. SEC management should seek new funds to support Wind-ACE and Wind-SOHO campaign operations.

4. Operations of the IMP-8 satellite should terminate at the end of FY01. In the present fiscal environment, the Panel regards the loss of the IMP-8 magnetometer, as having fatally reduced the spacecraft's utility for supporting the Solar-Terrestrial and Solar-Heliospheric system research below the critical level.

5. The Ulysses and Voyager Projects are challenged to increase science funding by reducing the level of personnel needed to support mission operations.

6. Mission support for the FAST, SAMPEX, Ulysses, and Yohkoh satellites should end after FY03, FY02, FY04 and FY03, respectively.

7. The recommended GGS mission profile will greatly reduce demands on CDHF operations after FY01. To maximize output from the remaining mission, the Panel recommends that CDHF be placed under the direct control of the GGS program manager.

8. The SDAC supports solar physics research with great efficiency. Requested funding to establish a Virtual Solar Observatory has great intrinsic merit and the potential for producing significant savings in managing large databases expected during the LWS program. Thus, the Panel recommends that the SDAC proposal be funded near the "optimum scenario" level