

**NASA EARTH SCIENCE  
2007 SENIOR REVIEW**

**CORE MISSION REVIEW PANEL  
(CoMRP)**

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**Panel Report from the  
Core Mission Review Panel  
In support of NASA's 2007 Earth Science Senior Review**

**Overview**

The NASA Earth Science Division (ESD) of the Science Mission Directorate (SMD) is supporting 11 Earth observing missions that are, or soon will be, operating beyond their prime mission lifetimes<sup>1</sup>. Each of these missions has made unique contributions to NASA research objectives, and in many cases mission extensions have great potential for advancing the ESD science goals. Additionally, data from several of these *research* missions are being used routinely by U.S. and international operational agencies in support of important Earth system prediction and monitoring tasks. Extended operations and associated data production activities require a significant fraction of the ESD annual budget. NASA and the ESD thus periodically evaluate the allocation of mission operation and data analysis funds with the aim of maximizing the missions' contributions to NASA's and the nation's goals.

In the Call for Proposals for the 2007 Earth Science Senior review the ESD directed the mission teams to prepare two separate mission extension proposals: one was for the continuation of the basic or core mission and the other was for an enhanced mission. The core mission includes complete mission operations activities and established data product deliveries, without embellishment or additional research, while the enhanced mission provides for development of new and improved science data products. The evaluation of the core mission explicitly includes the utility of the mission data products to both NASA and operational partner agency applications and to the greater National interest. For the enhanced mission, where additional NASA research funding is being considered, only the applicability of the proposed activities to NASA science objectives is to be considered.

NASA convened a Senior Science Review panel to evaluate the overall mission proposals for their continued relevance to the NASA science objectives. A second panel was chartered to focus on the basic mission proposals. Specifically from the Call for Proposals that was sent to the mission teams:

*The ESD will ask a second panel, the Core Mission Review Panel (CoMRP) to conduct an assessment of the health and viability of the operating satellites, and to evaluate the data products routinely provided by the missions, taking into account national operational objectives as well as NASA science goals. The CoMRP will include the necessary external representation to complete this assessment. The output from this panel will be a hardware risk assessment of each mission, a critique of the mission and data management and operational implementation approach, and an evaluation of the operational utility of the core data products.<sup>2</sup>*

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<sup>1</sup> The missions that are or will be under consideration for mission extension beyond Fiscal Year FY2007 are, ACRIMSAT, Aqua, CloudSat, EO-1, GRACE, ICESat, Jason-1, QuickSCAT, SORCE, Terra, and TRMM.

<sup>2</sup> "Call for Proposals – Senior Review 2007 and the Mission Extension for Earth Science operating missions", letter from Michael Freilich to mission teams, January 12, 2007, page 3.

The CoMRP consisted on two separate subpanels, one that focused on the utility of the core mission data products to operational organizations with predictive or forecast responsibilities, and a second that focused on the satellite and instrument current and projected health and performance.

The two subpanels were provided with the complete mission proposals in advance. For the case of the mission data products review, the panelists were encouraged to discuss the applicability of the data products with others within their organizations, to provide a wider range of input into the panel deliberations. The panelists brought these other inputs in person, and in some cases we received their comments and observations in writing.

The subpanels met on separate days in Washington DC for panel sessions to discuss the proposals and the panelists’ observations. The mission rankings, whether referring to operational utility for the data products panel or mission risk for the technical panel, were arrived at by consensus within the panel. Minority opinions are included where applicable in this report.

The CoMRP summary assessments were presented to the Senior Review Science panel presentation on April 26, prior to the mission team presentations to the Science review panel.

**Part 1: Mission Data Product Review**

Because the CoMRP was to take into account national operational objectives, the product review panel was comprised of representatives from those agencies. The panel included representatives from NOAA, the USGS, and the Air Force and the Navy from the Department of Defense. The CoMRP reviewed all 11 missions under consideration for mission extension, evaluated the data products they produced, and developed an overall assessment for each mission. The missions were placed in one of four categories depending on the criticality of the data products to the operational agencies. The categories defined the panel’s assessment of the operational utility or criticality of the overall mission to their agency’s mission, and included **Very High Utility**, **High Utility**, **Some Utility**, and **Not Applicable**. The definitions and the panel’s assessments are shown in Table 1, and the details by instrument and agency assessment follow.

Ranking	Definition	Missions
<b>Very High Utility</b>	These missions have one or more very relevant and highly valued data products which are routinely used by one or more of the participating agencies, for near real time operational or important analytical activities. One or more of the products may be unique. The loss of the data product or products would have a significant negative impact on elements of one or more of the partner agency charters.	<b>Aqua, Jason, QuikSCAT, Terra, TRMM</b>
<b>High Utility</b>	These missions have one or more standard data products which are routinely used by one or more of the participating agencies. Loss of the data product or products would have a measurable negative impact on elements of one or more of the partner agency charters.	<b>GRACE, SORCE, CloudSat</b>
<b>Some Utility</b>	These missions have one or more standard data products which are used by one or more of the participating agencies. Loss of the data product or products would have a small but measurable negative impact on elements of one or more of the partner agency charters.	<b>ICESat, EO-1</b>
<b>Not Applicable</b>	These missions had no identified operational value to the operational agency. In principle it could apply to missions whose measurements are not applicable to any of the operational agencies included on the panel, or to missions that once had value but have lost it through performance degradation or other causes. For this review it was only applied to the first category: missions whose science focus did not overlap with the operational agencies.	<b>ACRIMSAT</b>

Table 1: Operational Agency Consensus Utility Ranking

### ***Mission and Instrument Product Review Details***

For some missions there is only one instrument or measurement, such as for ICESat, CloudSat and QuikSCAT. For the large Earth Observing System satellites as Aqua and Terra there are multiple instruments making different observations and delivering highly variable data products. The panel considered individual instruments as well as the overall satellite observatory in their assessments. The more detailed data product utility assessment summary is shown in Table 2, followed by the mission by mission assessments.

	CoMRP Ranking	NOAA	USGS	Navy	Other DOD
<b>Aqua</b>	<b>Very High</b>	Very High	Very High	Very High	Very High
MODIS	Very High	Very High	Very High	Very High	Very High
AIRS	Very High	Very High	NA	Very High	Very High
AMSR-E	Very High	High	NA	Very High	Very High
CERES	NA	NA	NA	NA	NA
<b>Terra</b>	<b>Very High</b>	Very High	Very High	Very High	Very High
MODIS	Very High	High	Very High	Very High	Very High
ASTER	High	NA	High	NA	High
CERES	NA	NA	NA	NA	NA
MISR	NA	NA	NA	NA	NA
MOPITT	NA	NA	NA	NA	NA
<b>TRMM</b>	<b>Very High</b>	High	Some Utility	Very High	Very High
<b>QuikSCAT</b>	<b>Very High</b>	Very High	NA	Very High	Very High
<b>Jason</b>	<b>Very High</b>	Very High	NA	Very High	High
<b>CloudSat</b>	<b>High</b>	Some Utility	NA	High	Very High
<b>SORCE</b>	<b>High</b>	High	NA	NA	High
<b>GRACE</b>	<b>High</b>	NA	NA	NA	High
<b>ICESat</b>	<b>Some Utility</b>	NA	Some Utility	NA	High
<b>EO-1</b>	<b>Some Utility</b>	NA	NA	NA	Very High
<b>ACRIMSAT</b>	<b>NA</b>	NA	NA	NA	NA

Table 2: Detailed Mission and Product Assessment Breakout

### **Very High Utility: Aqua, Jason, QuikSCAT, Terra, TRMM**

#### **Aqua**

This mission received very high evaluations from all panelists due to the wealth of operational near real-time products created by the multiple sensors used by both NOAA and multiple DoD partners. NOAA makes routine use of several AIRS sounding products in its weather forecasts and the Navy will be adding this data set to its NWP suite shortly. AMSU data has been a standard operational NWP data set for years and the microwave soundings have proven to have significant positive impact at all modeling forecast centers. The MODIS sensor is particularly valuable due to its diverse spectral channel suite and large swath, especially for its ability to observe aerosols (including dust), cloud properties, atmospheric temperature and humidity soundings, and ocean surface properties. The AMSR-E sensors are also very important to operational Navy NWP due to its superb spatial resolution and SST, sea ice and rain rate measuring capabilities. In general, Aqua, in conjunction with Terra, provides a very powerful and useful system for earth observing that is relied upon every day in support of naval operations.

**MODIS** was rated very high overall and very important to national operational programs. **AIRS** was rated as very high for the aid it provides to the weather forecasting. The *AIRS Atmospheric Minor Constituents* products, however, were not rated high by any panelists. **AMSR** was rated as high value overall specifically by the Navy and also by others within the DoD operational organizations and medium to high by NOAA for the *Sea Surface Temperature, Sea Surface Wind Speed, and Sea Ice Concentration* products. **CERES** was mentioned as providing data of interest, but not enough to sustain the high ranking for Aqua.

### **Jason**

This mission has very high value to the Navy's Naval Oceanographic Office (NAVO) and the Fleet Numerical Meteorological and Oceanography Center (FNMOC) and the Navy's R&D Naval Research Laboratory (oceanography – Stennis) and to NOAA ocean analyses and fisheries organizations. Jason data are absolutely crucial for operational Navy and NOAA ocean-modeling capabilities. The NOAA fisheries service uses the Geophysical Data Record to support their fisheries assessments and forecasts. This includes both the sea surface height data and significant wave height data provided by Jason.

The Navy noted that altimeter data are of paramount importance for ocean front and eddy analysis and ocean model thermal initialization and they are interested in near-real-time application of the data for synoptic applications, rather than for longer time-scale application for climate studies and would prefer to see the interim geophysical data records released in hours instead of days.

### **QuikSCAT**

This mission received uniformly high marks from NOAA and the DoD. All of the near-real time wind products at all stated resolutions are being utilized daily by the partners and their continued production is very important to civilian and military forecasting efforts. The applications range from marine forecasting to worldwide tropical cyclone warnings. QuikSCAT is, and should remain, a key part of the very limited scatterometer constellation.

While not a part of the basic mission continuation proposal, the Panel identified the proposed improvements in coastal winds and high winds data products as potentially very valuable and highly desirable. In addition, proposed efforts to improve observations of surface winds by combining QuikSCAT, WindSat and ASCAT data, particularly in coastal regions, are strongly endorsed.

### **Terra**

The primary value from the Terra mission for the partners comes from MODIS, with ASTER as an important secondary element. The MODIS sensor is valuable for its ability to observe aerosols, cloud properties, atmospheric temperature and humidity soundings, and ocean surface properties. The data from MODIS are used to great advantage in support of Navy operational missions, fire threat detection and fire mapping, tropical cyclone analysis, and many other applications. In general, Terra, in conjunction with Aqua, provides a very powerful and useful system for earth observing that is relied upon every day in support of naval operations.

**MODIS** was rated very highly overall, with extensive use of virtually all MODIS products endorsed. A significant part of the Terra MODIS rating comes from its complementary operation with the Aqua MODIS instrument. In some key areas the Terra MODIS performance is significantly below the Aqua MODIS, and the Terra products are generally not used as a result. Specifically the *Sub-surface Chlorophyll Concentration* and the *K490 Diffuse Attenuation* products from Terra are not used.

**ASTER** was mentioned as possible gap-filler role for land imaging. The LandSat Data Gap Study team has considered this possible application.

**CERES** was mentioned as providing data of interest, but not enough to sustain the high ranking for Terra.

**MISR** was not listed by any partner agency as a ranked priority instrument.

**MOPITT** was not listed by any partner agency as a ranked priority instrument.

## **TRMM**

Due to its unique ability to accurately monitor rainfall, observe tropical cyclone positions and structure and map SSTs and atmospheric moisture throughout the daily cycle and complement other constellation members TRMM has very high value to the Air Force and the Navy and high value to NOAA. TRMM's unique tropical inclination ensures it will fill temporal gaps created by the operational sun synchronous satellites, thus magnifying its importance. The panel specifically identified the value of the real time data products such as the VIRS Radiances, TMI Brightness Temperatures, LIS Flashes and PR 20 level profiles to their data forecasting efforts. Some individual data products (such as level 3 standard products 3A11, 3A25, and 3B31) received very high importance ratings and the TRMM rainfall products are routinely noted as the most accurate versions available globally and are critical to our analysis and forecasting of the hydrological cycle, and on the whole the mission received a strong recommendation for continuation. The TRMM products are fused with other data by DoD and NOAA and used in direct support of Navy, NOAA and Air Force tropical cyclone forecasting requirements at both the National Hurricane Center (Miami, FL), the Central Pacific Hurricane Center (CPHC) and the Joint Typhoon Warning Center (Pearl Harbor, HI). The USAID, working through the USGS, uses the 3B42RT Multi-Satellite Precipitation Analysis for drought monitoring and crop water balance modeling in Mexico and Central America. Furthermore, TRMM provides the USGS with a back-up data source for near real time daily precipitation estimates over Africa, Afghanistan, and Southeast Asia, for whenever NOAA satellite estimates are unavailable.

## **High Utility: CloudSat, GRACE, SORCE**

### **CloudSat**

The consensus view was that the CloudSat mission has shown very early promise in its deliverable products, and is already being utilized in near real time by the DoD in its global weather products. Even at this early stage, CloudSat quick look products are being used by the Navy and the Air Force in several venues with great success. The panel agreed the rating for this mission would probably have been much higher if the mission had more operating time. NOAA recognizes the great potential for CloudSat products but has not yet been able to integrate them into their operational systems. The CoMRP consensus is that the promise of CloudSat is very high, and the panelists indicated their agencies would continue to integrate CloudSat products

into their analysis and modeling efforts as they become available. Proposed new science objectives, such as light rain fall, snow fall, and satellite inter-comparisons, are potentially of value. As with other missions, the Navy indicated that less latency in the delivery of CloudSat products would increase Navy's usage of and interest in this mission.

### **GRACE**

The panelists identified the primary value the GRACE mission brings to the operational community is through the refinement and improvement of the knowledge of the earth's geoid. Improvement in the geoid leads to improved altimetry accuracy overall, and in particular was noted to be of value to oceans research and land altimetry. Also noted is the value of the GPS radio occultation atmospheric soundings GRACE provides in near-real-time. These soundings have proved useful in support of Numerical Weather Prediction (NWP) models.

### **SORCE**

The SORCE mission was strongly endorsed exclusively on its value to the space environmental measurements, which were identified as being of use to NOAA. The MgII product is used by the SOLAR2000 EUV model that in turn is used by the Air Force.

### **Some Utility: ICESat and EO-1**

#### **ICESat**

This mission has medium value based both on its ice mapping (thickness and extent) and land and canopy elevation mapping data products. However the very limited temporal coverage and the complete lack of near real time data distribution severely limits the operational utility of the mission. Based on its altimetry measurements alone the Panel felt the mission warranted continuation.

#### **EO-1**

The panel concluded that the EO-1 mission was very difficult to assess, for a number of reasons. The value of a hyperspectral imager such as Hyperion should have great utility and applicability, but the mission does not have real data products in the same manner as the other NASA missions. Hyperspectral Imaging (HSI) is considered a new research capability recognized for National applications for coastal /land applications and targeting by both DoD and NOAA. EO-1 can be considered a pathfinder to HSI applications, however present restrictions were identified as reasons data are not used routinely in operations. These include: one, timeliness of data to support near real-time applications, two, restricted coverage and limited capability for data acquisition, and three, the lack of any specific established data products to share with the partners. Combined with the data buy approach for images EO-1's value has not been realized by the partner agencies. The one exception was identified by the DoD that gave Hyperion's hyperspectral imagery a very high utility rating due to its unique capabilities and its capability to produce operational products in the coastal zone. NOAA rated the *potential* use as very high, for coastal studies as an example, but could not identify a mechanism to collect or distribute the imagery.

### **Not Applicable / Not Reviewed: ACRIMSAT**

**ACRIMSAT**

This mission was not identified by any of the panelists as having any operational utility. It was not evaluated for any other purpose.



## Part 2: Mission Health and Technical Status Review

The Earth Science mission teams were directed to present in their proposals for an extended mission their assessment of the health of their satellites, and the projected ability of the satellites to deliver the measurements with the quality necessary to accomplish the science proposed. The CoMRP Technical evaluation subpanel was chartered to evaluate the current and projected health of the missions under review, and to provide an assessment of the expected future reliability of the spacecraft and instruments based on these assessments.

### Overview

The missions, although aging, with an average age of about 6½ years for the eleven missions under review, continue to perform remarkably well. The spacecraft and instruments, with a few exceptions, continue to perform meeting specifications and providing high quality data. On some missions redundancy has been lost, and performance degradation has been corrected for by operational workarounds, but again with some exceptions full mission functionality has been maintained

While selected key performance trends were included in the mission extension proposals, in general the proposals lacked sufficient detail necessary for the panel to conduct an independent assessment of the overall mission health. Where the technical background data were not presented to support the mission teams' assertions of current health and predicted performance the panel accepted the proposal's claim. The panel did, however, suggest specific technical questions for the ESD to pursue with the missions to get a clearer picture of the instrument or mission health.

For the purposes of our assessment we defined **failure** to be a significant, non-recoverable loss of instrument measurement capability sufficient to compromise the research and/or operational value of the instrument. The performance loss can be driven by either a spacecraft or an instrument failure. This definition allows for operational workarounds to compensate for a loss of capability and to recover from potential mission failure. For example, if ground processing of on orbit position can substitute for the loss of an on-board GPS than what might have been a mission ending failure is mitigated. For multiple instrument missions the loss of a single instrument may not signify failure of the entire mission, but without a priori knowledge of the criticality of the individual instruments to the overall mission science the panel had to conclude that the loss of a single instrument signified mission failure.

The panel assigned a risk level or probability of mission failure in qualitative terms: **Low**, **Medium**, or **High**, with the associated probabilities shown at right. The accuracy of the projections was limited by several factors. First, in most cases anticipation of an instrument or mission ending failure is extremely difficult for one-of-a-kind instruments. Spacecraft do share many common elements, and the panel did use relevant heritage in their estimations of possible spacecraft failures. However many of these satellites are well past their expected operating age, where we have limited data for comparison. Second, as mentioned above the proposals generally

Rating	Probability of Failure
Low	$P_F < 30\%$
Medium	$30\% < P_F < 50\%$
High	$50\% < P_F$

provided insufficient information to enable an independent assessment of the instrument and spacecraft health. On a mission-by-mission basis the panel posed follow-up questions regarding specific issues with the mission assessment that could improve the analysis.

### Summary

Based on these analyses the technical panel developed a projection of the expected health of the missions for two two-year windows of FY08 – FY09 and of FY10 – FY11. The panel conclusions are shown below in Table 3.

	Risk of failure within 2 years	Risk of failure within 4 years	Primary Risk Factor	Age (years) in 2011
<b>TRMM</b>	Low	Low	Age	15
<b>ACRIMSAT</b>	Low	Low	Age	13
<b>QuikSCAT</b>	Medium	High	Spacecraft	13
<b>Terra</b>	Low	Medium	SSR	13
<b>EO-1</b>	Medium	High	Spacecraft	11
<b>GRACE</b>	Low	Low	Age	10
<b>Jason</b>	Medium	High	Spacecraft	10
<b>Aqua</b>	Low	Medium	Spacecraft	9
<b>ICESat</b>	Medium	High	Laser	8
<b>SORCE</b>	Low	Medium	XPS/SOLSTICE	8
<b>CloudSat</b>	Low	Medium	Klystron	5

Table 3: Technical Panel estimation of the risk of significant mission failure over the period of FY08 – FY11.

For three of the satellites the panel identified “age” as the primary risk factor. This was the panel’s acknowledgement that not many NASA satellites built to typical mission standards survive much past 10+ years on orbit. However, we could not indicate specific likely failure mechanisms, and we did not find preliminary evidence of significant aging. Details on a mission-by-mission basis follow.

Extensive reliability analyses are routinely done as part of the pre-flight certification for all satellites, but systematic updates for missions after launch are typically not done. The Panel felt that some level of routine updated reliability assessment would enable a more accurate projection of mission health. Furthermore, comparisons across missions could possibly show common failure modes or lead to a better understanding of expected future performance. For example, a review of all of the current missions might find that transmitter failures account for a significant fraction of total mission losses. This knowledge could lead to some directed research to improve the reliability of satellites pre-launch, either through a better transmitter or through an alternate approach to redundancy such as selective cross strapping.

### ACRIMSAT

ACRIMSAT was launched in December 1999, into a 740 km, 98 degree sun synchronous circular orbit. The instruments and satellite are relatively simple, with no fuel required for station keeping and only one mechanism (a shutter) on the instrument complement. The

spacecraft is a one-of-a-kind design, built by a company that was acquired by Orbital Sciences Corporation (OSC) while the mission was in development. Consequently there is only limited technical expertise at OSC in the event of a spacecraft anomaly. No such anomaly has occurred to date.

The ground station and operations are also very simple, and are run largely by the original ACRIMSAT instrument team. The team maintains its own receiving station near JPL, and are connected by a pager system in the event of any telemetry or communications anomalies.

The panel felt the on orbit assets had a low probability of failure during the four year window. The ground network is also simple, but the team has been downsized to what is probably an irreducible minimum, and is dependent upon the singular experience of the current staff. The mission is well supported by this current staff and should be able to maintain adequate coverage with low risk to mission success with the level of support currently supplied, and with the current staff still attached.

### **Aqua**

Aqua was launched in March 2002, into 705 km sun synchronous orbit with a 1:30 PM equator crossing time. It is the lead satellite in the Afternoon or “A-Train” constellation (along with CloudSat, CALIPSO, PARASOL, and Aura). Aqua is one of the Earth Observing Systems (EOS) flagship missions, along with Terra and Aura, and hosts a complement of six instruments, AIRS, AMSU, AMSR-E, CERES, HSB, and MODIS.

Since launch there has been some degradation in the performance of some of the instruments. The HSB failed outright approximately 8 months after launch and is no longer powered. The sounding science algorithms have been corrected to use only AIRS and AMSU data. AMSR-E has lost one 89 GHz channel, but its algorithms too have been adjusted to compensate for the loss. One of two of the CERES instruments lost the shortwave (SW) channel, but normal science data collection continues without it. The MODIS instrument initially had some accelerated loss on the calibration lamps, but operations have since been modified and the instrument is providing good quality data.

There was insufficient data provided in the proposal to quantify the net effect of these individual instrument problems, or to project future instrument performance.

The spacecraft was built by TRW (now NGST), and shares a common design with the Aura spacecraft. There is sufficient fuel on board for all anticipated operations, including required station-keeping within the A-Train, beyond the proposal window of 2011 (in fact it is good through ~2014 according to the proposal). Maneuvering in general is difficult for the satellite due to many operational constraints, including exhaust impingement on the instruments, thermal limitations, and the size of the thrusters. Consequently orbit adjust maneuvers required to maintain the A-Train constellation are complex and require extensive coordination.

There was insufficient data provided in the proposal to project the expected life of the spacecraft. The proposal quotes a spacecraft reliability prediction of 63% without any information to support it. This alone would indicate the system has a medium risk of failure within the four-year

window. Taking into consideration the complexity of the maneuvering required, the number of instrument systems on board, and the lack of countervailing information, the panel concluded that the satellite has a low risk for failure in the FY08 – FY09 period but a medium risk for failure in the FY10 – FY11 period.

NASA allocates considerable resources to maintaining the health and status of the Aqua satellite, Considering the investment, the panel felt that a systematic review of the spacecraft and instrument reliability is warranted.

Follow-up Questions. The proposal quotes a reliability estimate of 63% for the spacecraft and the CERES instruments. It would be helpful to know what that estimate is based on.

### **CloudSat**

CloudSat was launched in April 2006 into the same 705 km, sun synchronous, 1:30 PM crossing time orbit as Aqua, and is now a part of the A-Train constellation. It flies in formation with the CALIPSO satellite, following behind Aqua in the constellation. It includes a single instrument, the Cloud Profiling Radar (CPR) operating in a very simple nadir-pointing mode.

CloudSat is the youngest satellite under consideration for the Senior Review. The CPR has operated very smoothly since turn-on, and is showing no appreciable degradation. However, it is a first of its kind for orbiting operation, and is single string in many areas. The CPR does have a redundant klystron and high voltage power supply, two elements of the instrument considered the most exploratory. The unique character of the CPR makes it difficult to assess the long term reliability of the instrument.

The CloudSat spacecraft is the Ball Aerospace BCP-2000 commercial bus. The same bus supports QuikSCAT and ICESat and so has significant on orbit heritage and an experienced engineering team available in the event of any spacecraft anomaly. All operating parameters for the spacecraft are within expected limits.

Based exclusively on the uncertain long term performance of the protoflight CPR and its klystron, the panel concluded that the satellite has a low risk for failure in the FY08 – FY09 period but a medium risk for failure in the FY10 – FY11 period.

Follow-up questions. The proposal indicates some spacecraft components will exceed the qualified life before five years on orbit, before the end of FY2011. This statement should be checked as part of an updated reliability assessment for the satellite.

### **EO-1**

EO-1 was launch in November 2000 into a 705 km, sun-synchronous, 10:30 AM equator crossing time orbit, 1 minute behind Landsat 7. Starting in late 2005 the satellite orbit was lowered to take it out of constellation flying with Landsat 7. EO-1 includes two primary instruments, the Advanced Land Imager (ALI), a prototype for a Landsat-7 replacement instrument, and the Hyperion Imaging Spectrometer, a high spatial resolution imaging spectrometer.

EO-1 was built as a technology demonstration mission, consequently numerous elements of the spacecraft and instruments are protoflight or experimental, and many are also single string. The spacecraft was a one-of-a-kind build done in-house at GSFC with support from Swales engineering, meaning the mission can draw on the experienced engineers from GSFC for troubleshooting. The C&DH has sustained a failure limiting the access to satellite engineering data. This error may be correctable, but the mission operations approach has been to leave it alone rather than try a direct fix.

Due to its protoflight approach and developmental nature, the panel concluded that the satellite has a medium risk for failure in the FY08 – FY09 period but a high risk for failure in the FY10 – FY11 period.

### **GRACE**

The two GRACE satellites were launched in March 2002 to formation fly in a 498 km, near circular polar orbit. The orbit has since decayed to 460 km. GRACE maps the earth gravitational geoid through monitoring the relative time dependent separation of the two satellites as they orbit the Earth.

The satellites are relying on redundant subsystem elements in several areas. The operations team has worked through numerous little problems as the spacecraft have matured. It is expected that more idiosyncrasies will occur and the system will have to be further adapted. The mission operations team is forced to track satellite performance very closely to maintain the science data quality, and has been very successful in that activity

The panel felt that based on the ability of the team to correct for problems encountered to date, and the types of problems overcome, the mission was at low risk for mission failure over the proposal window, from FY08 – FY11.

It would be helpful to know how the operating hours for the many spacecraft subsystems match against pre-flight predictions. This could be used to provide a better prediction for on orbit lifetime.

### **ICESat**

ICESat was launched in January 2003 into a 600 km, 94 degree inclination orbit. The satellite has one instrument, the Geoscience Laser Altimeter System (GLAS). Launched with three redundant lasers, only one laser now remains functional and is operating with a fraction of the initial laser pulse output.

To preserve laser life, the instrument is limited to two 33 day periods each year, once in the spring and once in the fall. The mission team estimates there is sufficient laser power for up to 8 more 33-day campaigns, but they provide no details on the laser power loss rate to support that conclusion. These eight campaigns would carry the instrument operations into the first half of 2011.

The spacecraft is the BATC BCP-2000 bus, common with QuikSCAT and CloudSat. The spacecraft appears to be functioning well, within its design parameters, and should meet the four year mission extension period.

Based on the observed performance and the history of problems with the laser system, the panel concluded that the satellite has a medium risk for failure in the FY08 – FY09 period but a high risk for failure in the FY10 – FY11 period.

### **Jason**

Jason was launched in December 2001 into a 1334 km, 66 degree inclination orbit, the same orbit at the TOPEX/Poseidon satellite to which is was a sequel. Jason is a NASA-CNES collaboration. The satellite includes the POSEIDON-2, a dual frequency radar, DORIS, for Doppler Orbitography and Radiopositioning Integrated by Satellite, and the JMR, Jason Microwave Radiometer, a three frequency microwave radiometer.

The instruments have degraded since launch, but the operations and data analysis teams have been able to work around the problems. Part of the GPS system, the Turbo Rogue Space Receiver (TRSR) is at risk of failure, but the operations team has developed a workaround for that potential failure as well.

The Jason spacecraft is the Alcatel-Alenia Proteus bus. The same bus is flying on CALIPSO, COROT and will be flown on OSTM, so there is significant investment by CNES and Alcatel on the bus. The spacecraft has A side / B side redundancy, but is now flying on the redundant side for several subsystems, including the transceiver and the C&DH. Furthermore, it has lost one reaction wheel entirely, and now has no redundancy in the RW. The solar array drive is also exhibiting degraded performance, with reduced range of motion.

Due primarily to the advanced age of the spacecraft and the loss of redundancy in several critical areas, the panel concluded that the satellite has a medium risk for failure in the FY08 – FY09 period but a high risk for failure in the FY10 – FY11 period.

### **QuikSCAT**

QuikSCAT was launched in June 1999 into an 803 km, sun synchronous orbit. The satellite includes one instrument, SeaWinds scatterometer used to measure vector winds over the ocean.

The instrument appears to be aging gracefully, with expected slow degradation in some of the bearings. The spacecraft is the BATC BCP-2000 and is doing well. It is operating on the redundant GPS, but the operations team has a back-up approach to continue operations and science data product delivery without any GPS. However, it is also operating on the redundant transmitter with no additional back-up available.

Based primarily on the expected life of the transmitter the panel concluded that the satellite has a medium risk for failure in the FY08 – FY09 period but a high risk for failure in the FY10 – FY11 period.

Little data were presented on the remaining life expected from many critical spacecraft and instrument subsystems. A systematic assessment of the overall satellite is needed.

## **SORCE**

SORCE was launched in January 2003 into a 640 km, 40 degree inclination orbit. The satellite instrument complement includes the Total Irradiance Monitor (four TIM radiometers), two Spectral Irradiance Monitors (SIM A & B), two Solar Stellar Irradiance Comparison Experiments (SOLSTICE A & B), and the XUV Photometer System (XPS).

The XPS and SOLSTICE instruments have both experienced mechanism failures. Back-ups are available and in operation, but it is not clear how much lifetime there is remaining in these back-ups. Also, the SIM and TIM are the primary instruments but it is not clear how critical the XPS and SOLSTICE are to the overall SORCE mission.

The spacecraft was manufactured by OSC, which retains significant engineering knowledge in the event of a spacecraft anomaly. The bus has full redundancy, and is still operating on the primary side of all subsystems. There are no consumables required, so the spacecraft has a low probability of failure during the four year proposal window.

Based on the possible failure of the XPS and/or SOLSTICE instruments, and the uncertainty in their criticality to the overall SORCE mission science, the panel concluded that the satellite has a low risk for failure in the FY08 – FY09 period but a medium risk for failure in the FY10 – FY11 period. If only the TIM and SIM instruments are needed, or if they can continue to meet requirements with significantly degraded XPS or SOLSTICE performance then the panel concluded the mission is at low risk of failure throughout the four year period.

Follow-up questions to the mission team could help assess the risk. The SORCE team may know the answers, but they were not provided in the proposal. Is the root cause for SOLSTICE A aperture mechanism anomaly understood? What is the probability the SOLSTICE B aperture mechanism would exhibit similar behavior and what would the impact be? Does SOLSTICE and/or XPS performance drive SIM & TIM data products or accuracy? The XPS filter wheel anomaly was said to be caused by debris. What data do they have to support the debris theory? Was a probable source identified and what is the probability that this will recur?

## **Terra**

Terra was launched in December 1999 into a 700 km sun synchronous orbit with a 10:30 AM equator crossing time orbit, in constellation with Landsat and SAC-C. Terra is another of the EOS flagship missions (along with Aqua and Aura) and hosts five instruments: MODIS, CERES, MOPITT, ASTER and MISR.

Each of the instruments is showing signs of wear, some more serious than others. The MODIS solar diffuser screen mechanism failed in 2003, and now the diffuser is left open. The MODIS ocean color bands are not productive. The ASTER cryocooler is performing poorly, and may lead to the loss of the SWIR channel in 2007. Four of eight MOPITT channels failed early due to a cooler failure, but the algorithms were modified to compensate and the other four channels appear to be working well, operating on a second cooler. Loss of the second cryocooler will lead

to the complete loss of the MOPITT instrument. MISR is working well with little age-related performance degradation.

The Terra spacecraft was provided by Lockheed Martin Aerospace, in a custom designed build. Hence LMA is available for consultation in the event of an anomaly, but as the mission ages the engineering continuity degrades. The system Solid State Recorder (SSR) has lost several of the memory modules over time, and the mission memory management approach has required updating. There is sufficient fuel on-board to cover operations through 2013 at least.

Overall, the mission is aging but gracefully. It will be 13 years old in 2011, and the instruments and spacecraft are sufficiently complex that the panel thought there was a medium probability that at least one of the instruments or spacecraft subsystems will suffer a significant failure in the second half of the proposal window. The solar diffuser screen on MODIS may be of a type that suffers long term UV degradation. It would be useful to find that out. As with other satellites, a systematic update of the instrument and spacecraft reliability assessment would be warranted for Terra.

### **TRMM**

TRMM was launched in November 1997 into a 400 km, 35 degree inclination orbit. TRMM is a JAXA-NASA collaboration, and carries five instruments in its complement: a Precipitation Radar (PR), the TRMM Microwave Imager (TMI), the Visible Infrared Scanner (VIRS), the Lightning Imaging Sensor (LIS), and a version of the CERES instrument (which failed after 8 months on orbit).

The TRMM instruments, with the exception of CERES, continue to provide reliable data with no evidence of significant degradation. The instruments either have no moving parts or are based on highly reliable proven scanner technology with much longer demonstrated on orbit lifetimes. The panel feels the risk of failure of the TRMM instrument complement is low for the entire four year window of the proposal.

The spacecraft was a GSFC in house build and continues to perform very well. Spacecraft engineering expertise is available in the event of a spacecraft anomaly. The proposal references a GSFC internal reliability study but does not provide details from it. The fuel reserves on the spacecraft are sufficient to support operations beyond the proposal window of 2011.

Based on the demonstrated performance and the high reliability of the instrument types onboard the panel felt that, despite its advanced age of 15 years in 2011, has a low probability of a mission ending failure during the four year proposal window.