NASA Earth Science Senior Review 2011

Submitted to:

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Submitted by:

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June 30, 2011

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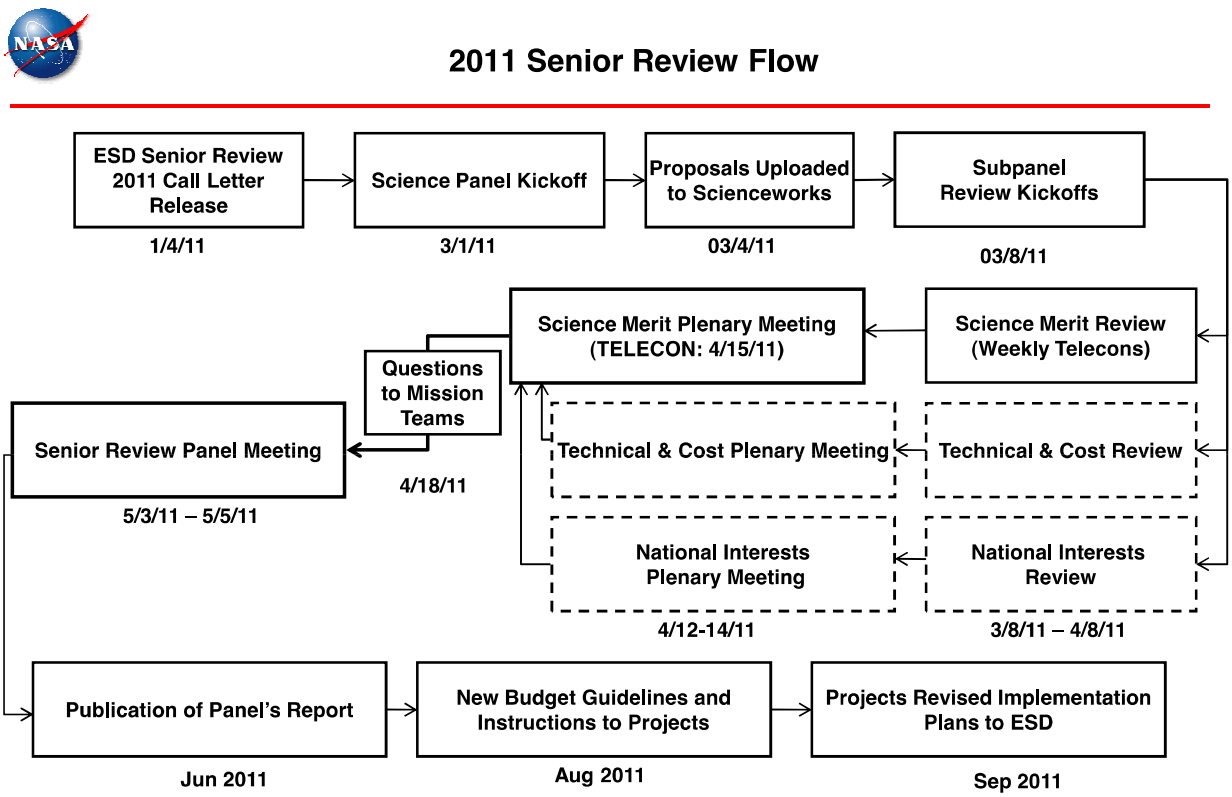
INTRODUCTION

The 2011 Senior Review evaluated 12 NASA satellite missions in extended operations: Aqua, Aura, CALIPS0, CloudSat, EO-1, GRACE, Jason-1, OSTM, QuikSCAT, SORCE, Terra, and TRMM. The Senior Review was tasked with reviewing proposals submitted by each mission team for extended operations and funding for FY12-FY13, and FY14-FY15. The review considered the scientific value, national interest, technical performance, and proposed cost of extending each mission in relation to NASA Earth Science strategic plans. The Science Panel evaluated science in terms of merit, relevance, and product maturity. Subpanels were convened to provide in-depth evaluations of the national interest, technical performance, and costs of extending each mission. The Senior Review's overall findings were categorized as: Baseline, Augment, or Reduce; specific suggestions and justifications were provided for cases of augmentation or reduction.

REVIEW PROCESS

The 2011 Senior Review process (Figure 1) began on January 4, 2011 when the Earth Science Directorate released a call letter inviting NASA missions in extended operation to submit proposals for continuation, due March 4, 2011. Panel Chairs (Science, National Interest, Technical, and Cost) held a teleconference on February 25 to discuss and plan review procedures. The Senior Review Science Panel first convened on March 1 via teleconference to discuss procedures and review assignments. Three reviewers were initially assigned to review each proposal. Over the next month, two teleconferences were held to review status and address any issues. In parallel, subpanels on National Interest, Technical, and Cost were convened and met to review proposals in these areas. These processes led to an all-day plenary meeting teleconference on April 15 in which each mission was discussed, and follow-up questions were identified for each mission. These questions were sent to each mission team on April 18, along with instructions that each mission team should prepare a presentation addressing these questions for the Senior Review Panel Meeting to be held on March 3-5 in Washington DC. Each mission was allotted a 45 minute presentation (90 minute for Aqua, Terra, Aura) focused specifically on panelist's questions. Following these presentations and discussions, the panel developed and documented a collective evaluation of each mission.



GENERAL FINDINGS

The Panel was unanimously impressed that all 12 missions have made unique and important contributions to NASA research objectives. Collectively, these missions constitute an unprecedented Earth observation capability that has transformed our scientific understanding of the Earth system, and provide data for applications of extremely high societal relevance. The Panel was also impressed that these missions all continue to operate beyond their designed lifetime, a fact that is testament to high quality engineering, management, and mission execution. However, the Panel also expressed concern that these missions are aging, and noted that the risk of loss of critical Earth observation capabilities is increasing.

The Panel struggled with providing constructive findings for new products proposed through the medium of the Senior Review. The Panel instead found that the structure and scope of the Senior Review inhibits a fair and effective review of new products: the scope of a proposal which must cover the entire mission limits the amount of the information that can be provided for the proposed new product; and the breadth required for the Senior Review panel limits the panelists who are actually expert enough to provide a quality review of a specific product. An extensive follow-up discussion with the ESD Research Director addressed the priority of established core products for the mission teams, the role

of the research program in developing new products, concerns with continuity of established products developed through the Research Program, and concerns with the potentially valuable products proposed here getting adequately reviewed in other venues. The general findings are (1) this 2011 Senior Review Panel cannot provide specific findings for the new products proposed in this review; these new products should receive additional review by a panel of discipline experts before any decision by NASA to implement them, and (2) clearer direction on the mission team responsibility for core and research products, to both review panels of research program elements and to the mission teams themselves, would be beneficial to future research product development.

All missions received very high marks for Scientific Merit, Scientific Relevance, and Scientific Product Maturity (Table 1). Scientific Merit scores ranged from 4.1-5.0, with 11/12 missions receiving the highest score. Scientific Relevance scores ranged from 4.4-5.0, with 11/12 missions receiving the highest score. Scientific Product Maturity scores ranged from 3.4-5.0, with 9/12 missions receiving the highest score. All missions received a High (9 missions) or Very High (3 missions) Utility Score. Technical Risk was distributed more broadly from Low (1 mission), Medium (8 missions) to High (3 missions). The panel noted the general increase in risk since the 2009 Senior Review, broadly consistent with an aging fleet. The Cost Risk was generally considered Low for missions with a proposed Baseline budget (6), and Medium (5) to High (1) for those with a proposed Augmentation.

Based on these factors, the panel found that the continuation of all 12 missions would make critical contributions to enabling NASA to continue to meet its science objectives. Eleven missions were proposed for Baseline or Augmented support in FY12-13; and four missions have been selected for Augmented support for FY14-15, pending reassessment by the next Senior Review. One mission (Aura) was suggested for Reduced support. Mission specific findings are summarized below.

	Science Scores						Conclusion	
Mission	Merit	Relevance	Product Maturity	Utility Score	Technical Risk	Cost Risk	FY12-13	FY14-15
Aqua	5.0	5.0	5.0	Very High	Medium	Medium	Baseline*	Baseline
Aura	5.0	5.0	5.0	High	Medium-High	Low	Reduce	Reduce
CALIPSO	4.1	5.0	3.8	High	Medium-Low	Low	Baseline	Baseline
CloudSat	5.0	5.0	5.0	High	Medium*	Low	Baseline*	Baseline*
EO-1	4.0	4.4	3.4	High	High*	High	Baseline	Baseline
GRACE	5.0	5.0	4.7	High	Medium-High	Medium	Augment*	Augment*
Jason-1	5.0	5.0	5.0	High	Medium-High	High	Baseline	Augment
OSTM	5.0	5.0	5.0	Very High	Low	Low	Baseline	Baseline
QuikSCAT	5.0	5.0	5.0	High	High*	Medium	Baseline	Augment
SORCE	5.0	5.0	5.0	High	Medium-High	Medium	Augment*	Augment*
Terra	5.0	5.0	5.0	Very High	Medium	Low	Baseline	Baseline
TRMM	5.0	5.0	5.0	High	High*	Low	Baseline	Baseline

*Additional commentary or conditions on the panel's scores and/or conclusions are noted in the mission findings summary below.

MISSION SPECIFIC FINDINGS SUMMARY

AQUA

The Aqua mission has been extremely successful and the data are very widely used by scientists, government agencies and operational groups. The government agencies all gave Aqua the highest ranking of all missions, and scientific citations of Aqua data now exceed 10,000, leaving no doubt that this mission should continue to be funded. The optimal budget proposal is for development of the AIRS CO_2 product, which was felt to be high risk previously. A mid-troposphere AIRS CO_2 product has been successfully validated since then, and it seems reasonable to partially fund this overguide request, as long as it fits within the scope of mission funding. While the panel notes that the AIRS CO_2 product is very important, the development of totally new products was not considered in-scope by the Senior Review Panel (see discussion under 'General Findings'). The Panel conclusion is for Baseline support, with partial Augmentation in FY12-13 for the proven Mid-troposphere CO_2 product if it was not included in the baseline.

AURA

Aura's primary scientific missions are stratospheric chemistry and dynamics related to ozone depletion, tropospheric chemistry, and climate change issues. These missions are central to core NASA research objectives. The scientific output from Aura is impressive (670 refereed journal publications and 351 since the last review). The satellite is in excellent health. The three remaining instruments are showing signs of aging, but are still producing science data of excellent quality, and have an excellent chance of extending beyond the current proposal cycle. There is excellent science justification for continuing the mission. The panel unanimously agreed that the funding for this mission be continued, but that funding for HIRDLS (which has not been operational since March 2008) be gracefully terminated in FY12. For this reason, the Panel conclusion is Reduce.

CALIPSO

The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) satellite carries three instruments. CALIOP is a nadir-viewing two-wavelength laser that detects cloud occurrence, measures cloud optical depth, cloud phase, as well as other cloud properties. The IIR is a three-channel infrared radiometer, whose channels lie in the window region of the infrared spectrum. WFC is a wide-field camera that provides a swath context to CALIOP's nadir-only curtain view of the atmosphere. CALIPSO provides a unique set of data products for the research community that could not be duplicated by any other measurement platform. While some issues (e.g., calibration has been harder than expected due to intra-orbit calibration drifts) have arisen, the instrument team has been making good progress on improving the data products. In particular, the new version 3 algorithm is a tremendous improvement over version 2. The instrument team needs to continue

working to validate the data and to provide validation papers and uncertainty estimates to the user community. In particular, it is important to resolve factor-of-two disagreements in optical depth with MODIS. The instrument team also needs to continue developing level-3 and the near-real-time data products. The technical review panel rated a mission extension as Medium-Low Risk for a two-year extension, because of the excellent shape of the spacecraft, with an increased risk for a four-year extension. The cost review panel rated mission extension as low risk. The national interest panel rated CALIPSO as high utility, and loss of the products would have a measurable negative impact on national agencies and organizations. The Panel conclusion is that the project should be continued at Baseline.

CLOUDSAT

CloudSat flies the Cloud Profiling Radar (CPR), a nadir-viewing , narrow-swath, high-spatial resolution, W-band active sensor that enables detailed mapping of the vertical structure of clouds, hydrometeors and precipitation (rain and snow). Alone and integrated with A-Train data (e.g. MODIS, CALIOP, CERES), CPR observations and retrievals can be used for process-studies to understand the role of cloud systems and precipitation in the Earth Radiation budget, and to characterize the microphysics and morphology of clouds and convection. CloudSat has been operating for about five years, and could continue operating for 1-2 additional years depending on battery condition and power management strategy. Assuming that recovery from the present temporary battery failure to stable operations is successful, the mission will require dedicated hands-on management of the platform function due to the likely need for direct (manual) management of battery recharge cycles and continuous monitoring of overall spacecraft condition. As part of this management strategy, and in order to realize 1-2 additional years of data collection, it may be required that CPR operations be limited to daytime data acquisition only. During this period, it is expected that significant investment of time would be directed toward mission operations while the platform is functional, followed by release of updated CPR and combined constellation data products to the broader community, including error characterization. Because the current battery condition is a determining factor of mission end of life, the panel emphasizes the importance of completing product validation and data distribution, should the mission fail in the next year. The Panel's conclusion is Baseline, but a partial augmentation would be supported by the panel to ensure that a quality data product covering the CloudSat lifetime is produced and distributed.

EO-1

The EO-1 demonstration mission supports two unique instruments that obtain high spatial resolution data for terrestrial monitoring: Advanced Land Imager (ALI) and Hyperion. Launched in 2000, EO-1 has exceeded its original technology demonstration goals: collecting the only civilian high spectral resolution ("hyperspectral") imagery available and demonstrating a prototype sensor to the LDCM/Landsat-8's OLI. Since 2009, EO-1 has expanded its science role in disaster monitoring by taking advantage of its platform pointing ability, SensorWeb network, and ability for user-level tasking. ALI provides NASA

with the capacity to gap-fill between Landsat 7 and LDCM (Landsat 8), gap-fill for ASTER SWIR bands, and provide spaceborne prototyping for HyspIRI. All components are predicted to function through 2015, although the orbit degradation will shift the equatorial crossing-time earlier by one hour. The Technical Review Panel raised concerns about bus ground faults and other trending data. The Senior Review Panel has accepted the Mission Team verbal descriptions of the spacecraft subsystems and has agreed that the Technical Risk Rating may be lower than originally assigned. The National Interests Subpanel review indicated that several agencies find EO-1 data to be of very high utility, especially for disaster management. The Senior Review Panel has three major findings. (1) Multiple reviewers expressed concern and/or confusion with satellite tasking and data acquisition and distribution. We suggest that the team develop a FAQ webpage to guide users on data tasking, acquisition and delivery. This relatively small step could potentially increase EO-1 utility and use in the broader community. (2) Hyperion and ALI use have increased considerably since the last Senior Review because of the distribution of EO-1 data through USGS. The previous Senior Review Panel strongly emphasized the need to more fully develop and distribute the Level 2 data, and we concur that this remains an important need. In particular, Level 2 products need to be finalized with the collaboration-distribution process clearly communicated. The Level 2 data processing stream needs to be clearly documented, with publications and citations to justify the approaches employed. (3) The Senior Review panel concluded that one reason for the delay in delivery of Level 2 data has to do with a lack of resources by the Mission Team. The EO-1 has done an exceptional job in automating acquisition and processing of EO-1 data using limited personnel resources. The Panel conclusion is Baseline. Although there is no augmentation requested for personnel, we feel that successful development of Level 2 data and development of a user community for this data would benefit from additional personnel and resources.

GRACE

For the past nine years, the Gravity Recovery and Climate Experiment (GRACE) mission has provided a synoptic view of large-scale temporal variations of mass distribution within the Earth system, resulting in truly unique constraints on climatically important processes such as mass exchange between ice sheets and the oceans, mass redistribution within the oceans, and large scale variability in precipitation and water availability. The mission is also of operational use, especially through the "aeronomy co-experiment", which is providing radio occultation data for assimilation into atmospheric models, and unique and very valuable data on atmospheric neutral density and thermospheric winds. The panel unanimously supports continuation of the mission, with funding of two of the Augmentation budget items: to support enhanced battery management, and to develop plans for using a single GRACE satellite for lower resolution time-variable gravity solutions. However, continuation of the GRACE mission has to be viewed as high risk—the weakened power system may fail, or result in significantly degradation of data quality within the next two years. GRACE is presently producing data of extremely high value to the scientific community, and the panel has little doubt that the mission should be extended. But this

situation could well change before the next Senior Review, even without a complete "catastrophic" failure, and NASA should be prepared to review the situation and make appropriate adjustments.

JASON-1

Jason-1 is a major contributor to the 19 years of climate data records from satellite radar altimeters. Jason-1 has provided precise measurements of ocean surface topography as a continuity mission to the TOPEX/Poseidon Mission and supported the calibration and validation of the follow-on Ocean Surface Topography Mission (OSTM). Results from these three altimeters has made critical contributions in ocean sciences over the past two decades as evidenced by the over 3000 publications. Jason-1 should be approved for mission extension at Baseline, and Augmentation in FY14-15. That is, Jason-1 should remain in its current interleaved orbit with OSTM until AltiKa data can be validated (presumably mid-2012) and then maneuvered to the proposed 1287 km geodetic orbit. Jason-1 continues to acquire high quality data and the interleaved data of Jason-1 and OSTM are supporting important operational applications and new scientific investigations of mesoscale variability. Additional science contributions will occur when Jason-1 moves to a geodetic orbit to provide estimates of the marine geoid and ocean bottom topography. The panel acknowledges that the mission team responded well to the 2009 Senior Panel recommendations, developing a water vapor product (that will be continued) and a reasonable "conservative decommissioning plan", the geodetic orbit mission. While the panel clearly recognized the scientific value of continuing the Jason-1 mission, there was concern regarding the overall health of the Proteus spacecraft and the mission's ability to respond to future failures; several questions were presented to the mission team and discussed during the mission presentations. The panel thinks that the proposed response scenarios are reasonable and acceptable, but encourage the team to continue to evaluate the scientific gains of obtaining additional data against the potential risks on maintaining Jason-1 in the interleaved orbit.

OSTM

OSTM is the 3rd in a series of satellite-borne altimeters designed to study ocean circulation and its effects on climate. This series has been highly successful meeting all of its goals providing a global high quality time series of global sea surface topography for the past 19 years. Barring an unexpected failure of OSTM, its continuation will extend this important time series for climate change until, at a minimum, the launch of the next altimeter Jason 3 in the series. OSTM altimeter observations are also playing a key role in the analysis of other upper ocean processes in physical oceanography and the science panel supports continuation. In addition, the overall rating for OSTM by the National Interests Panel was Very High, the Technical Review of OSTM ranked the overall risk as Low. The only issue raised by the Cost Panel was the lack of a detailed budget narrative. The team's response to questions about the budget was adequate. The Panel conclusion is for Baseline support.

QuikSCAT

QuikSCAT addresses several NASA science objectives primarily related to ocean winds. The proposed extension is to calibrate Ku-band scatterometer backscatter, from ISRO scatterometers and other future scatterometers, to be consistent with QuikSCAT backscatter; and to produce climate quality winds and ice products that continue the high quality QuikSCAT time series. This approach is viewed as the only way to get science (and climate) quality data from ISRO data, as the ISRO mission is directed at operational quality data, and without appropriate calibration is not useful for climate and cryosphere research. ISRO is cooperating with these goals. Chinese groups launching future scatterometers have also expressed great interest in such collaboration. Intercalibration requires roughly 90 days for each satellite in order to identify and account for drift, which allows several satellites to be intercalibrated each year. QuikSCAT has been extremely stable in its calibration, and the radar instrumentation shows no indication of either calibration drift or deterioration worthy of concern; therefore, long-term stability of the QuikSCAT backscatter is anticipated and makes this instrument ideal for calibration of future Ku-band scatterometers. This approach allows for a common model function to be applied to the intercalibrated backscatter, which is important for long-term consistency. The weak point is the status of the satellite: the technical panel rates the risk of failure as high, but notes that the status for critical elements of the satellite have functioned well for the last two years. The QuikSCAT radar is currently functioning very well, with considerable redundancy. The Baseline proposal includes funding for satellite operations through FY12 and 13, with data analysis support for FY14 and 15. The Augmentation proposal differs only in adding support for satellite operations through FY15. The Panel unanimously supports this augmentation, as a very strong case has been made for the science, and the National Interest Panel found strong support for this mission.

SORCE

SORCE (Solar Radiation and Climate Experiment) launched in January 2003 carrying 4 instruments measuring total solar irradiance (TSI) and spectral solar irradiance (SSI) in different wavelength bands. The primary mission objective is to measure both TSI and SSI with high precision and accuracy. In response to the 2009 Senior Review, the SORCE team evaluated differences in the SORCE TIM and ACRIM TSI measurements. To accomplish this task, a calibration facility was developed and cross-calibrations were performed between various instruments (Glory, PREMOS-1, PREMOS-3, VIRGO-2, and ACRIM-3). The results indicate that SORCE/TIM provides the most accurate measurement. The extended mission has 3 primary objectives: 1) Continue to measure TSI with high precision and provide a contiguous extended climate record of TSI, 2) make daily measurements of the solar spectral irradiance, and 3) to improve understanding of how and why solar irradiance varies, and estimate future and past variations, and investigate the climate response. We find that the objectives of this mission are well aligned with NASA objectives and outcomes are critical to the scientific community. The reviewers unanimously agreed that the scientific merit of SORCE is outstanding and fully support the extension of this mission. The primary concern is the battery health and the impact that it will have on maintaining the

extended climate data record of solar irradiance. An Augmentation budget was presented, which includes an additional FTE for a second battery expert and additional funding to analyze the calibration/degradation of the SIM instrument with respect to the opposing trends discovered in the spectral irradiance. We support the extension of the SORCE mission at the Augmented level to support the additional battery expert. The >$300k budget for 1 FTE effort should be further justified to the budget office when allocating funds. The panel disagreed on the optimal budget for additional SIM analysis. The panel suggests that a more detailed work plan and budget justification is needed before we can fully support this additional task.

TERRA

Terra is a huge success, and continuation of the 11 year record from its five instruments: ASTER, CERES, MISR, MODIS, MOPITT, is critical to a wide array of Earth system science questions. Extending the record will enhance our understanding of long-term atmospheric, terrestrial, and ocean phenomena. It is a workhorse for regional-to-global scale monitoring. Terra data are used in almost every area of earth science, and the science/publication record is outstanding. The demand for Terra data is obvious with 136M files delivered in 2010 alone and 77 core Terra data products. MISR and MODIS provide unique aerosol products, which continue to be needed after the launch failure of Glory. Continuity of CERES data is needed to maintain a continuous record into the NPOESS era. The Terra platform is expected to remain fully functional through 2017 (battery, fuel, subsystems performance). The main failure to date is the SWIR bands on ASTER. But there continues to be significant use of the ASTER data from optical and TIR bands, and from the new global DEM. Delivery of data to the LP-DAAC has increased ASTER data use. The Senior Review panel considered the methane product for MOPITT proposed under the Augmentation proposal to be in the early research and development stage. The MOPITT team is well positioned to conduct this work and a methane total column product would be highly useful to the community, but should be vetted under other competitive science funding opportunities (see the new product discussion under 'General Findings'). The Panel conclusion is Baseline.

TRMM

The Tropical Rainfall Measuring Mission (TRMM) was launched in November 1997 for a 3-5 year mission that has now been flying for 13 years. The spacecraft follows a precessing, low-inclination (35º) orbit initially at 350-km orbit, and was boosted to ~400 km in 2001 to conserve fuel for a longer mission. TRMM products provide a unique database of precipitation amounts and the first global-scale view of the vertical structure of precipitation in the tropics. These data products are very mature, and now extend over a long enough period to robustly characterize annual, seasonal, monthly, and diurnal variability in rainfall across much of the globe. These data have been used for an impressive range of studies from fundamental science to applications of immediate societal value including monitoring of extreme events such as tropical cyclones, floods and

landslides. The extended mission is to expand the dataset another 2-3 years for two main purposes: the first is to extend the current TRMM dataset; and the second is to obtain up to a year of overlap with GPM for cross-calibration so that a continuous climate-quality dataset can be extended into the GPM era. Such a dataset will allow the characterization of interannual to decadal variability and ENSO cycles. It is the opinion of this panel that an additional 2-y of support for this project for FY12-13 should be provided, and that a further 2-y for FY14-15 should also be budgeted, subject to review of the spacecraft health and propellant projections by the 2013 Senior Review Panel. The Panel conclusion is Baseline.

APPENDIX 1. TECHNICAL PANEL REPORT

Results from the Technical Review Subpanel of the Senior Review 2011 and the Mission Extension for the Earth Science operating missions

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Introduction

The Earth Science Division (ESD) of the NASA Science Mission Directorate (SMD) is supporting several Earth observing missions that are, or soon will be, operating beyond their prime mission lifetimes. 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 (MO&DA) funds with the aim of maximizing the missions' contributions to NASA's and the nation's goals. This periodic NASA evaluation process for missions in extended operations is known as the "Senior Review".

The objective of the Senior Review is to identify those missions beyond their prime mission lifetime whose continued operation contributes cost-effectively to both NASA's goals and the nation's operational needs and to identify appropriate funding levels for those missions recommended for extension. While a mission's contribution to NASA's research science objectives is the primary evaluation criterion for mission extension, the Senior Review explicitly acknowledges the importance of long term data sets and overall data continuity for Earth science research and the direct contributions of mission data to national objectives, such as the routine use of near-real-time products from NASA research missions for applied and operational purposes by U.S. public or private organizations.

The 2011 Senior Review invited twelve missions (listed in alphabetical order) to propose: Aqua, Aura, CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations), CloudSat, EO-1 (Earth Observing-1), GRACE (Gravity Recovery And Climate Experiment), Jason-1, OSTM (Ocean Surface Topography Mission), QuikSCAT (Quick Scatterometer), SORCE (SOlar Radiation and Climate Experiment), Terra and TRMM (Tropical Rainfall Measuring Mission). Performance factors were to include quality and demonstrated/anticipated scientific utility of the mission datasets, contributions to national objectives, technical status and budget efficiency.

The 2011 Senior Review comprised of the Senior Review Science Panel with the input of 3 additional subpanels; the National Needs subpanel, the Cost subpanel and the Technical subpanel. The Senior Review Science Panel, which also reviewed the Science Merit, was the primary independent analysis group. They had the sole responsibility to evaluate the scientific merit of the NASA mission based on the applicability of the mission's science to NASA Earth science strategic plans and objectives and considered the results from the National Needs, Cost, and Technical subpanels on their final review findings and ratings.

For the Technical Subpanel review, ESD had requested the NASA Science Office for Mission Assessments (SOMA) to perform a review that parallels the Technical, Management, and Cost (TMC) evaluations that NASA SOMA performs on Pre-Phase A mission concepts. Since the missions were proposing extensions on the Operations and Sustainment phase (extended Phase E), the review emphasized the hardware and consumables status, performance and reliability projections, mission operations plans, and the planned solutions to known and potential technical problems. The technical issues related to cost were examined however it was not be evaluated in detail. The Technical Subpanel was drawn from technical experts in and outside NASA. Figure 1 shows where the Technical Subpanel fits in the 2011 Senior Review flow.

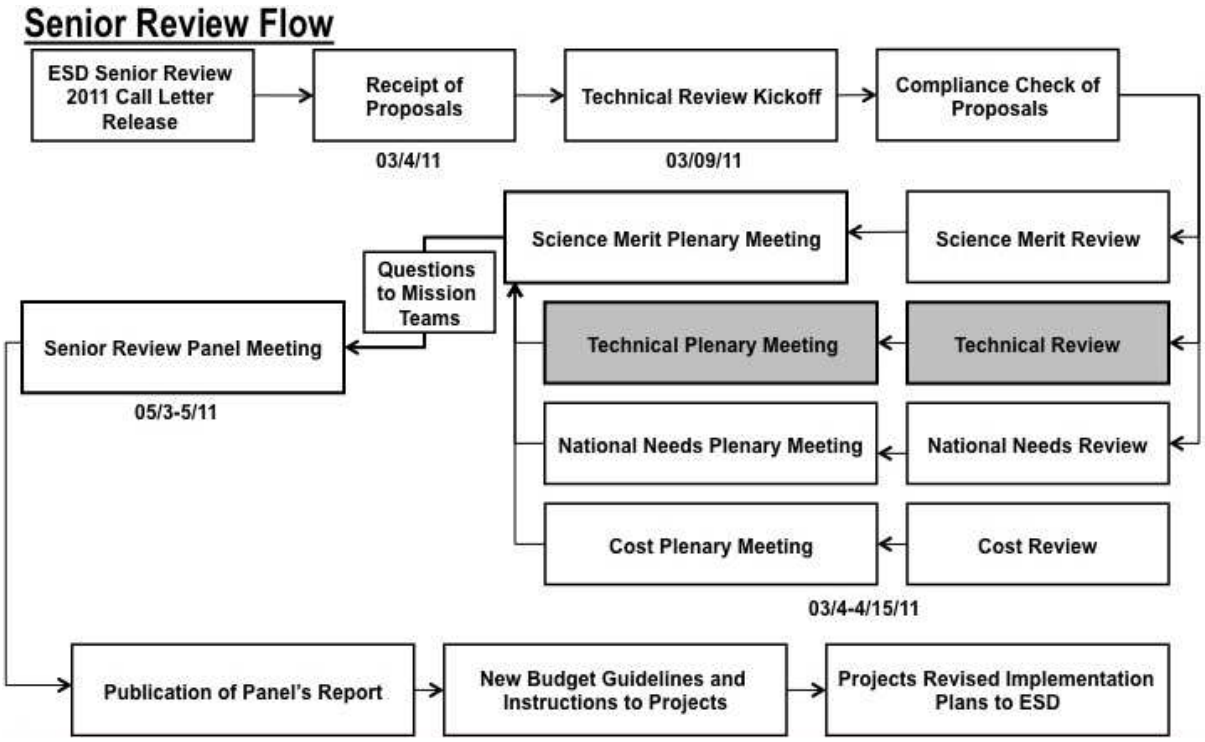

Figure 1. Senior Review Flow showing all Subpanels. The Technical Subpanel review is highlighted.

Proposers were instructed in the "Call for Proposals – Senior Review 2011 and the Mission Extension for the Earth Science operating Missions"; to describe the overall technical status of their mission's major systems that included the spacecraft, instruments, and ground systems; to summarize the status of the spacecraft control center and science center(s); to explain actions taken to improve the effectiveness of the mission operations tasks; to demonstrate that improvements have been accomplished; and to discuss the health of the components and point out limitations as a result of degradation, aging, use of consumables, obsolescence, failures, etc. Proposers were encouraged to provide supporting data in the form of engineering data tables and figures in the optional Appendix E. Proposers were to include an estimate and rationale of mission life expectancy.

Technical Review

Technical Review Criteria

Each proposed mission extension was reviewed in detail for the feasibility of mission implementation as reflected in the perceived risk of accomplishing the extended mission as proposed.

The Technical Subpanel assessed the proposal's performance and reliability projections for the satellite and instrument(s) and the mission operations implementation plan. The evaluation considered factors including the status of consumables and predicted utilization; spacecraft and instrument status, performance degradation, and failure risk; the proposed mission operations approach for the effective and safe management of an aging satellite; and mission and data

management. Strategies to preserve the health of the hardware, to mitigate performance degradation and failures, to manage on-orbit consumables, and to ensure the continued performance and reliability of the ground systems were assessed. The evaluation was reported in a narrative text as well as a risk rating for the feasibility of the extended mission for 2 and 4 years.

Technical Review Principles

The basic assumption is that the mission will be extended unless significant technical weaknesses are evident that would adversely affect the proposed mission extension. The proposer is regarded as the expert on his/her proposal and therefore is given the benefit of the doubt.

On the proposal, the proposer's task is to provide evidence that the mission extension is Low Risk (see definition below). During the review the Technical Review Subpanel's task is to try to validate proposer's assertion of Low Risk.

All Proposals are reviewed to identical standards and they receive same evaluation treatment in all areas and are not compared to other proposals. The Technical Review Subpanel is made up of reviewers that are experts in the areas that they review and they review the investigations using only the review factors that apply to the specific mission.

The proposals are only reviewed on the risks that are under the control of the proposer. Inherent risks from space-based missions, e.g. space environments, are not considered on the review. Programmatic risks of mission extensions, e.g. budgetary uncertainty, are not considered on the review. Risks that the mission team can address, e.g. adequacy of resource management, are considered.

The Technical Review Subpanel develops findings for each proposal that reflect the general agreement of the entire subpanel. The findings can be: "Above expectations" that translates into "Strengths", "Below expectations" that translates into "Weaknesses" and "As expected" that would generate no finding.

Technical Risk Ratings

The Technical Review is to determine, for each proposed mission extension, the level of risk of implementing the mission extension as proposed. An integral part of the Technical Review is the review of available resources to the proposer to handle problems. Resources can be redundant hardware, consumables, reserves, and margins on physical resources such as power and propellant; planned solutions; and personnel.

Technical Risk Ratings are defined as;

- Low Risk: There are no problems evident in the mission that cannot be normally solved with available resources and effective solutions.

- Medium-Low: Problems have been identified, but are considered well within the proposal team's capabilities to correct within available resources with good management and application of effective solutions.
- Medium Risk: Problems have been identified, but are considered within the proposal team's capabilities to correct within available resources with good management and application of effective solutions. Solutions may be complex.
- Medium-High: One or more problems of sufficient magnitude and complexity have been identified that are difficult to be solved within the available resources. Solutions may be complex and resources tight.
- High Risk: One or more problems are of sufficient magnitude and complexity as to be deemed unlikely to be solved within the available resources.

Technical Review: Definitions of Findings

Each finding is identified as a;

- Major Strength: A facet of the response that is judged to be well above expectations and can substantially contribute to the ability to meet the proposed technical objectives and stay within the available resources.
- Major Weakness: A deficiency or set of deficiencies taken together that are judged to adversely affect the ability to meet the proposed technical objectives within the available resources.
- Minor Strength: A strength that is substantial enough to lower the risk of the mission extension.
- Minor Weakness: A weakness that is substantial enough to increase the risk of the mission extension.

For the Senior Review all findings (major and minor) are considered on the Technical Review risk ratings.

Technical Review Process

The Technical Review Subpanel was made up of reviewers who are experts in the areas that they reviewed. These areas included Instruments, Flight Systems, and Mission Operations. The Technical Review Panel was asked to consider technical factors such as; Instruments - status of the instrument(s) and components, redundancies, projected lifetime, and instrument resource management; Spacecraft/Flight Systems – flight systems status and health, redundancies, consumables, margins, and spacecraft resource management; Mission Operations - mission operations approach, ground facilities – new/existing, and telecommunications. The Technical Review Subpanel was lead by a Technical Review Form Lead who was responsible for guiding the discussions and for the Technical Review Form development.

All Technical Review Subpanel members reviewed the proposals and wrote an individual review before discussing findings with other members of the review team. Each individual finding explained the issue in detail and was identified as "Above expectations" that translated into "Strengths", "Below expectations" that translated into "Weaknesses" and "As expected" that

generated no finding. For each proposal, reviewers uploaded individual findings to the NASA SOMA Remote Evaluation System (RES). For each proposal, these individual findings were gathered into a table (referred to as the "Fat Matrix") that was the basis of a subpanel discussion in the Fat Matrix teleconference.

For each proposal, there was a Fat Matrix teleconference where the Technical Review Form Lead guided the discussion of individual findings (on each Fat Matrix) with the entire subpanel. During the discussion individual findings were kept, merged with other similar individual findings, or dismissed when appropriate. An Initial Draft Technical Review Form for each proposal was the outcome of these teleconferences and the basis of the discussion during Initial Draft Technical Review Form review teleconference.

For each proposal, an Initial Draft Technical Review Form review teleconference was held with the purpose of refining the findings before the Plenary Meeting. The Technical Review Form Lead guided the discussion of the Initial Draft Technical Review Form for each proposal. During the discussion findings were refined, merged with other similar findings, or dismissed. A Draft Technical Review Form for each proposal was the outcome of these teleconferences and the basis of the Plenary Meeting discussions.

The Plenary Meeting was held to refine and finalize the forms. The Technical Review Form Lead guided the discussion. During the discussion findings were refined, merged with other similar findings, or dismissed. For each proposal, the Technical Review Form was reviewed 3 times and polling was held to determine the Risk Ratings for each proposed mission extension. Reviewers were only polled on proposals that they have reviewed and only reviewers that participated in the Plenary Meeting were polled on the Ratings.

Technical Review Product

The Technical Review of the 2011 Senior Review results on the Technical Review Form. This form is labeled with the appropriate Mission name and Principal Investigator. It contains the Risk Rating assigned by the Technical Review Subpanel and a rationale paragraph explaining the rating. The form enumerates the Major Strengths, the Major Weaknesses, the Minor Strengths, the Minor Weaknesses, and any questions to be sent to the proposing mission teams. Any comments to the science panel are also included. This form is the product of the Technical Review process described above and for each proposal it is regarded as the report from the Technical Review Subpanel to the Senior Review Panel.

Technical Review Summary Results

Table 1 shows the results of the Risk Ratings assigned by the Technical Review Subpanel to each proposed mission extension. Including the Technical Review Form for each proposal in this report would be very cumbersome therefore only the risk rating and rationale is included for each proposal. If more detail on the results of the Technical Review Subpanel is required, the Technical Review Forms are available from the NASA SOMA archive. The rationales are organized in alphabetical order and the risk ratings and major findings are in bold letters. Addenda to the Technical Review Forms resulted from the mission teams' answers to questions

presented during the 2011 Senior Review Meeting. These addenda have been added to the rationales in this report. Although the Technical Review Subpanel members were not present to participate in the discussion of the new information, the Senior Review panel has agreed to document these addenda as they contain valuable information.

Table 1. Summary results of the Technical Review for the 2011 Senior Review

Mission	Low	Medium-Low	Medium	Medium-High	High	Risk Rating
EO-1					X	High
QuickScat					X	High
TRMM					X	High
GRACE				X		Medium-High
Jason-1				X		Medium-High
SORCE				X		Medium-High
Aura				X		Medium-High
CloudSat			X			Medium
Aqua			X			Medium
Terra		X				Medium-Low
CALIPSO		X				Medium-Low
OSTM	X					Low

Aqua

The Aqua mission extension is rated as **Medium Risk** for a two-year or four-year extension. The Technical Review team has identified 3 Major Strengths, 2 minor strengths, 1 Major Weakness and 2 minor weaknesses that influence the risk determination. **The AIRS instrument is stable and fully operational, and should remain so for the two and four-year planning periods of interest in this review. MODIS is operating well, with full redundancy intact, and no indication of any life-limiting problems that might impact its ability to function well for the next 4 years. Spacecraft systems are in excellent health with all systems performing at nominal levels, or exceeding requirements.** The proposer projects the spacecraft lifetime to last to at least 2018, limited by available fuel. The project team and its supporting infrastructure at GSFC seem to have coped well with the challenge of actively monitoring the spacecraft and payload on a 24/7 basis over the lifetime on orbit. However, **the AMSR-E Antenna Drive Electronics (ADE) is a continuously moving mechanism that has experienced some behavior changes, and could experience further problems at any time through the next four years.** AMSU has lost 3 of its 15 channels at various times, and a fourth channel is nearing an unusable level of operation. Three aspects of the analysis expected for an estimate of extended mission survival were not addressed.

Aura

The Aura mission extension is rated as **Medium-High Risk** for a two-year or four-year extension. The Technical Review team has identified no Major Strengths, 2 minor strengths, 3 Major Weaknesses and 2 minor weaknesses that influence the risk determination. The proposal includes a subsystem-level analysis and anomaly description that provides a complete view of current flight system health and safety. The project team and its supporting infrastructure at GSFC seem to have coped well with the challenge of actively monitoring the spacecraft and payload on a 24/7 basis over the lifetime on orbit. However, **parts degradations in the Microwave Limb Sounder (MLS) instrument have already impacted measurements of OH and HCl, and it is possible that growing problems could impact this instrument's performance in the next 2 or 4-year period. The Ozone Monitoring Instrument (OMI) is experiencing a so-called "row anomaly," serious enough to have some effect on all OMI products, that could worsen during the next two or four year planning periods. The Tropospheric Emission Spectrometer (TES) is showing evidence of component aging in the Interferometer Control Subsystem (ICS) and the Pointing Control Subsystem (PCS), which could result in more downtime or a complete failure at any time during the next two or four year planning periods.** There are two significant anomalies since the 2009 Senior Review that do not have root cause failure resolution: the SADA drift, and the FMU/SSR Side-A random data corruption. Three aspects of the analysis expected for an estimate of extended mission survival were not addressed.

CALIPSO

The CALIPSO mission extension is rated as **Medium-Low Risk** for a two-year extension, with an increased risk for a four-year extension. The Technical Review team has identified 1 Major Strength, 3 minor strengths, no Major Weaknesses and 4 minor weaknesses that influence the risk determination. **The Proteus spacecraft is in excellent health and all subsystems are operating with full redundancy.** The CALIOP laser lifetime should support a 2-year extension, based on number of shots to date. The WFC instrument is working well and there is no indication of any lifetime or performance limiting issues. The telecommunications systems are stable and operating to provide all required support to the mission. However, data from the IIR instrument is negatively impacted by a calibration problem. The Low Voltage Power Supply Converter has shown a history of temperature increase that may impact operation in the next 2-4 years. There is insufficient trending information presented from which to independently assess risk of degradation or failures over the next two and four-year periods. Three aspects of the analysis expected for an estimate of extended mission survival were not addressed.

CloudSat

The CloudSat mission extension is rated as **Medium Risk** for a two-year extension, with an increased risk for a four-year extension. The Technical Review team has identified 2 Major Strengths, 1 minor strength, 1 Major Weakness and 2 minor weaknesses that influence the risk determination. **The Cloud Profiling Radar (CPR) instrument experience to date and the lifetime performance prediction indicate a healthy instrument that should support extended operation. The CloudSat spacecraft is in generally excellent health, retains full as-launched redundancy in all subsystems, and should operate well beyond 2015.** CloudSat is supported by a small, stable mission operations team that

will continue to perform their assigned roles, and that has a 4.5-year record of delivering data products well in excess of the stated requirement. However, **the spacecraft battery history (a one cell soft failure in December 2009) presents an increased possibility of failure during an extended mission, and is not addressed by analysis or trending.** There is insufficient trending information presented from which to independently assess risk of degradation or failures over the next two and four-year periods. Three aspects of the analysis expected for an estimate of extended mission survival were not addressed.

CloudSat addendum: The Technical Review Subpanel of the Earth Science Division (ESD) Senior Review Panel has identified a weakness on the CloudSat Mission Extension that stated "The spacecraft battery history (a one cell soft failure in Dec 2009) presents an increased possibility of failure during an extended mission, and is not addressed by analysis or trending. " On 17/18 of April 2011, at least one additional weak battery cell developed, causing an Under Voltage – Level 3 (UV-3) trip into "Emergency Mode". The transmitter (being powered on/off for contacts) and survival heaters are operational and the spacecraft is rotating about its X-axis with solar arrays canted +/-40 degrees. The mission team is attempting to charge the battery where the spacecraft subsystems can be turn on. The battery is equipped with a spare Common Pressure Vessel (CPV) that can be brought online, however it can result on overvoltage that can risk some of the subsystems; therefore particular care would have to be exercise if the spare CPV is activated. The mission team discussed the mission status as a result of this battery anomaly and the plans address the problem during their presentation at the 2011 Senior Review Meeting. Although the Technical Review Subpanel members were not present to participate in the discussion, the Senior Review panel has agreed that the Technical Risk Rating may be higher than that assigned by the Technical Review Subpanel before the CloudSat mission suffered this recent battery anomaly.

<u>EO-1</u>

The EO-1 mission extension is rated as **High Risk** for a two-year extension. The Technical Review team has identified no Major Strengths, 1 minor strength, 2 Major Weaknesses and 1 minor weakness that influence the risk determination. The automated on-board processing (CASPER) and a ground planner (ASPEN) with web interface now manage user requests for EO-1 images in an automated manner. However, **it is unlikely that the spacecraft will be able to continue normal operation beyond 2 years, and it may not survive beyond its currently approved decommissioning in autumn 2012. There is no description of the current status of the spacecraft, anomaly event history, or trending data to support the assertion that "the spacecraft health is good."** There is no information in the proposal specifically about the current health and status of the cryocooler for the SWIR channels in Hyperion.

EO-1 addendum; The Technical Review Subpanel of the Earth Science Division (ESD) Senior Review Panel has identified a weakness on the EO-1 Mission Extension that stated "Chassis ground current excursions, which could cause a potentially serious failure, have occurred randomly, with no root cause identified". The EO-1 mission team during their presentation at the 2011 Senior Review Meeting showed that the chassis ground current

excursions have diminished and potentially disappeared and explained that they have potentially identified the mechanism causing it.

EO-1 addendum; The Technical Review Subpanel recommended to the ESD Senior Review Panel to request information on the health of spacecraft subsystems of the EO-1 mission. As a result, EO-1 mission team discussed the spacecraft status during their presentation at the 2011 Senior Review Meeting. The Mission Team stated that the spacecraft subsystems are operating nominally and since there has not been significant deviation from expected trends, they did not present trending data. The mission team collects and examines spacecraft subsystems' trending data and explained to the Senior Review Panel that no significant issues have been observed in the subsystems. Although the Technical Review Subpanel members were not present to participate in the discussion, the Senior Review panel has accepted the Mission Team verbal descriptions of the spacecraft subsystems and has agreed that the Technical Risk Rating may be lower than that assigned by the Technical Review Subpanel before the EO-1 mission team's presentation.

GRACE

The GRACE mission extension is rated as **Medium-High Risk** for a two-year extension, with an increased risk for a four-year extension. The Technical Review team has identified no Major Strengths, 2 minor strengths, 1 Major Weakness and 3 minor weaknesses that influence the risk determination. The propulsion systems are expected to last an additional 8.5 years (GRACE-1) and 9.5 years (GRACE-2), with the limiting factor being fuel. The operations team has done a commendable job of working around a series of hardware failures and anomaly conditions to deliver the mission science. However, **the batteries have experienced serious capacity degradations that have already had a major impact on flight operations, and that will probably limit the GRACE mission lifetime to less than two additional years.** Each GRACE spacecraft had several redundant key elements at launch, but there have been failures that have removed some redundancy. There is no discussion of the current health or predicted lifetime of the mass trim mechanism that maintains the accelerometer at the spacecraft center-of-mass. The End-of-Mission plan is inadequate.

Jason-1

The Jason-1 mission extension is rated as **Medium High Risk** for a two-year extension and higher for a four-year extension. The Technical Review team has identified 1 Major Strength, 4 minor strengths, 1 Major Weakness and 1 minor weakness that influence the risk determination. **The primary instruments: Poseidon-2 altimetry radar and Jason Microwave Radiometer (JMR) are both in excellent health, maintain their full as-designed redundancy, and have a strong heritage**. Numerous workarounds and procedures are possible, using different instrument data, to determine satellite position, which is critical to the altimetry dataset. Margins and trends were clearly presented. Batteries, solar arrays and thermal system have been operating nominally with no anomaly history noted over the past 9 years. Operations are managed by a well-organized and integrated team of NASA/JPL and CNES, with each participating organization having clearly defined roles. However, **the PROTEUS spacecraft has suffered several major and minor failures that have eliminated the designed as-launched redundancy, making Jason-1**

effectively a ten-year old, single-string bus that cannot survive a further failure in critical components. The affected systems are the S-band transceiver, processor module and a crippled ACS with little or no redundancy remaining. The proposal notes degraded performance or anomalous behavior in several flight system components: a memory stack, both star trackers, solar array position sensors and, more recently, a gyroscope (April 2010) and a thruster (July 2010).

Jason-1 addendum: The Technical Review Subpanel of the Earth Science Division (ESD) Senior Review Panel has identified a weakness on the Jason-1 Mission Extension that stated "The PROTEUS spacecraft has suffered several major and minor failures that have eliminated the designed as-launched redundancy, making Jason-1 effectively a ten-year old, single-string bus that cannot survive a further failure in critical components.". This raised concern to the Senior Review Panel as Jason's-1 present orbit is a desirable orbit for future generation ocean altimeters. The Jason-1 mission team during their presentation at the 2011 Senior Review Meeting explained that if any of the subsystems identified by the Technical Review Subpanel failed, they could decommission the spacecraft to a different orbit. However, if the S-band transceiver fails decommissioning will be very challenging.

OSTM

The OSTM mission extension is rated as **Low Risk** for a two-year and four-year extension. The Technical Review team has identified 2 Major Strengths, 3 minor strengths and 3 minor weaknesses that influence the risk determination. **All of the OSTM primary instruments have operated without incident for the 3-year primary mission and retain full as-launched redundancy. The spacecraft is in excellent health, remains fully redundant and is expected to survive for several more years.** The DORIS instrument is performing well. The AMR instrument has operated without incident to date and retains full redundancy. Margins and trends are clearly presented. However, The GPS Payload (GPSP) may be subject to the same type of failures encountered on Jason-1. Three aspects of the analysis expected for an estimate of extended mission survival were not addressed. Four agencies participate in operations or operations support for OSTM, and the statement of their respective roles and responsibilities is somewhat unclear.

QuikSCAT

The QuikSCAT mission extension is rated as **High Risk** for a two-year extension. The Technical Review team has identified no Major Strengths, 1 minor strength, 2 Major Weaknesses and 2 minor weaknesses that influence the risk determination. Because the Level-1 requirements were redefined and restricted for QuikSCAT and does not require rotation of the antenna, the instrument performs nominally. However, **the QuikSCAT spacecraft is approaching 12 years in operation (design life was three years), has suffered several faults and degraded components, and seems unlikely to survive the next several years without incurring a mission-ending failure. There is no trending data or component health analysis presented to support the assertion that this 12-year old spacecraft is capable of operating through a 2-year mission extension.** There is a risk that the spacecraft will be unable to achieve the planned decommissioning orbit. Three aspects of the analysis expected for an estimate of extended mission survival were not addressed.

QuikSCAT addendum: The Technical Review Subpanel of the Earth Science Division (ESD) Senior Review Panel has identified a weakness on the QuikSCAT Mission Extension that stated "The QuikSCAT spacecraft is approaching 12 years in operation (design life was three years), has suffered several faults and degraded components, and seems unlikely to survive the next several years without incurring a mission-ending failure." The degraded components have been operating with the same level of performance since the last Senior Review (2009). Although the QuikSCAT spacecraft has suffered several faults and degraded components (other than scatterometer's antenna spin mechanism) and may incur a mission-ending failure, it is also probable that the spacecraft can operated at this level for the next 2 years; therefore the Senior Review panel feels that this is a worthwhile risk.

SORCE

The SORCE mission extension is rated as **Medium-High Risk** for a two-year extension, with increased risk for a four-year extension. The Technical Review team has identified 2 Major Strengths, 1 minor strength, 2 Major Weaknesses and 1 minor weakness that influence the risk determination. **All four instruments are in very good to excellent health with few anomalies noted, and would likely continue to operate nominally for two- and four-year extensions. The SORCE Team is taking exceptionally proactive steps to maximize the life of the mission by mitigating reaction wheel and battery issues.** Most of the flight subsystems have not yet needed to fall back to any of their redundant elements. However, **one of the reaction wheels failed in October 2008, leaving no fallback unit if a second wheel fails. The single battery has degraded sharply in the last two years on orbit and is the likely mission-limiting factor.** Three aspects of the analysis expected for an estimate of extended mission survival were not addressed.

Terra

The Terra mission extension is rated as **Medium-Low Risk** for a two-year or four-year extension. The Technical Review team has identified 1 Major Strength, 6 minor strengths, no Major Weaknesses and two minor weaknesses that influence the risk determination. **The MISR instrument is healthy, and there appears to be every expectation of its continued successful operation for the next 4 years.** The overall payload performance is stable, and there has been no further degradation since the 2009 Senior Review cycle. The VNIR and TIR channels are experiencing a continuing slow loss of sensitivity at acceptable rates. TERRA's history of long-term successful operation of the CERES instruments, together with the team's diagnostic gimbal evaluations showing no significant mechanical degradation of the moving elements, suggest a good probability of continued nominal operation over the next two and four-year periods. The flight system is stable overall. Thorough analysis is presented for the power subsystem. The project team and its supporting infrastructure at GSFC seem to have coped well with the challenge of actively monitoring the spacecraft and payload on a 24/7 basis over the lifetime on orbit. However, MODIS has experienced mechanical anomalies with the door & attenuation screen, and, more recently, angular response changes in the scan mirror and failures of some of the calibration lamps. Three aspects of the analysis expected for an estimate of extended mission survival were not addressed.

TRMM

The TRMM mission extension is rated as **High Risk** for a two-year extension. The Technical Review team has identified no Major Strengths, 1 minor strength, 1 Major Weakness and 3 minor weaknesses that influence the risk determination. TMI has operated well since launch and has heritage in DoD sensors that have exhibited long life and no failures to date. However, **there is insufficient information presented in the TRMM extension proposal to support an assessment by the Technical Review team of the flight system's health and its likelihood of survival over the next two- and four-year periods.** No VIRS trending data are shown to support the descriptive material. The Precipitation Radar experienced an electrical failure in May 2009, and there is very little instrument trending information. Due to fuel depletion, TRMM end of life is nominally predicted for November 2014, but may occur as soon as June 2013.

TRMM addendum; The Technical Review Subpanel recommended to the ESD Senior Review Panel to request information on the health of spacecraft subsystems of the TRMM mission. As a result, the TRMM mission team provided battery data that showed that the battery is operating nominally during their presentation at the 2011 Senior Review Meeting. In addition, the TRMM mission team discussed the spacecraft status. They stated that the spacecraft subsystems are operating nominally and since there has not been significant deviation from expected trends, they did not present trending data. The mission team collects and examines spacecraft subsystems' trending data and explained to the Senior Review Panel that no significant issues have been observed in the subsystems. Although the Technical Review Subpanel members were not present to participate in the discussion, the Senior Review panel has accepted the Mission Team verbal descriptions of the spacecraft subsystems and has agreed that the Technical Risk Rating may be lower than that assigned by the Technical Review Subpanel before the TRMM mission team's presentation.

APPENDIX 2. NATIONAL INTEREST PANEL REPORT

Report of the 2011 National Interests Sub-panel of the NASA Senior Review
Chair: John Haynes, NASA Applied Sciences Program
Co-Chair: Brad Doorn, NASA Applied Sciences Program

The 2011 National Interests Review assessed the contributions of the core data products of the 12 missions under review to national objectives by assigning a utility value to each product or group of products.

Overall, this panel conveyed to the Science Panel the value of the data sets for "applied and operational uses" that serve national interests -- including operational uses, public services, business and economic uses, military operations, government management, policy making, nongovernmental organizations' uses, etc. Essentially, this panel represented all users of the data for primarily non-research purposes.

The following organizations were represented on the panel: the National Oceanic and Atmospheric Administration (NOAA)/National Weather Service (NWS); NOAA/National Environmental Satellite, Data, and Information Service (NESDIS); the Federal Aviation Administration (FAA); the US Department of Agriculture (USDA), the US Air Force Weather Agency (AFWA); the Environmental Protection Agency (EPA); the US Geological Survey (USGS); the Naval Research Laboratory (NRL); Conservation International (CI), the American Society for Photogrammetry and Remote Sensing (ASPRS); the National States Geographic Information Council (NSGIC); and the American Institute of Aeronautics and Astronautics (AIAA).

The panel met April 12-13, 2011, in Arlington, Virginia.

Pre-panel Activities
Each organization represented on the panel pre-assessed three primary factors and one overall rating for each mission during March 2011. The assessed factors included:

1) Value: Overall value of the data products to the range of applied and operational uses within the organization. Value for those times the data is used, independent of frequency of use, latency of receipt, etc. Value was qualitatively assessed as high, medium, or low.

2) Frequency of Use: Frequency the organization currently uses the data products in the range of applied and operational applications. Frequency of use was qualitatively assessed as routine, occasional, rarely, or never.

3) Latency: Current timeliness in which the organization accesses and/or receives delivery of the data products to meet the range of applied and operational uses. Latency was qualitatively assessed as near real time, within one to two days, weekly/monthly, or archival.

4) Overall rating: Utility: Overall *utility* of mission and data products to national interests. Overall utility was qualitatively assessed as very high, high, some, or not applicable.

Panel Activities

Following the pre-assessments, the organization representatives met in a formal panel session over two days in April 2011. During this panel, 45 minutes of discussion time were allocated for each mission; however, 75 minutes were allocated for the flagship missions of Terra, Aqua, and Aura.

At the start of each discussion, an assigned Primary Reviewer introduced the mission and his organization's ratings. The chair also showed a table with all the organizations' pre-panel ratings. A round-table panel discussion then commenced. By the end of each discussion, the panel reached agreement on an overall utility rating for the mission and/or sensor. The panel also determined any questions to forward to mission teams via the Science Panel. These questions were answered by each mission team during the full Science Panel in May 2011.

Following discussions of all the missions, each organization separately ranked each mission quantitatively according to its post-panel view of national interests. Each representative was asked to assign 12 points to the mission of highest priority and one point to the mission of lowest priority.

The Primary Reviewers then prepared panel summaries for each mission.

Panel Overall Summary

The following table summarizes the qualitative utility ratings determined by the panel:

NASA 2011 Earth Science Senior Review *National Interests Panel*		
Rating	**Definition**	**Missions**
Very High Utility	These missions have one or more very relevant and highly valued data products which are routinely used by one or more of the participating organizations for important activities. Loss of the data product(s) would have a significant negative impact on national agencies and organizations.	***Aqua, Jason-2/OSTM, Terra***

High Utility	These missions have one or more data products which are routinely used by one or more of the participating organizations for their activities. Loss of the data product(s) would have a measurable negative impact on national agencies and organizations.	***Aura, CALIPSO, CloudSAT, EO-1, GRACE, Jason-1, QuikSCAT, SORCE, TRMM***
Some Utility	These missions have one or more data products which are used by one or more of the participating organizations. Loss of the data product(s) would have a small but measurable negative impact on national agencies and organizations.	***None***
Not Applicable (Minor/ Negligible)	These missions had no identified or significant applied or operational utility to the participating organizations. Loss of the data product(s) would have no or negligible impact on national agencies and organizations.	***None***

The following chart summarizes the quantitative rank of each mission according to the panel's view of national interests. A higher score indicates greater utility.

Mission	Overall Score	Utility Score
Aqua	***137***	**Very High**
Terra	***135***	**Very High**
TRMM	***99***	**High**
Jason-2/OSTM	***89***	**Very High**
Aura	***83***	**High**
CloudSAT	***65***	**High**
GRACE	***63***	**High**
SORCE	***59***	**High**
CALIPSO	***55***	**High**

Jason-1	***53***	**High**
QuikSCAT	***51***	**High**
EO-1	***47***	**High**

A detailed chart presenting each organizations utility ranking can be found in the chart below:

NASA 2011 Earth Science Senior Review

Overall Utility Rating from National Interests Panel, by Organization & Mission/Sensor

Mission / Sensor	Overall Rating	Civil Agencies						Military / Intelligence Community		State & Locals	Private Sector / NGOs		
		NOAA NWS	NOAA NESDIS	FAA	USDA	USGS	EPA	NRL	DOD/USAF	NSGIC	Conservation Intl.	AIAA	ASPRS
Aqua	Very High Utility	Very High Utility	Very High Utility	Very High Utility	Very High Utility	Very High Utility	Very High Utility	Very High Utility	Very High Utility	Very High Utility	Very High Utility	Very High Utility	Very High Utility
AIRS	Very High Utility	Very High Utility	Very High Utility	Very High Utility	NA	NA	NA	Very High Utility	High Utility	NA	Some Utility	High Utility	Very High Utility
AMSR-E	Very High Utility	Very High Utility	High Utility	Some Utility	High Utility	NA	High Utility	Very High Utility	Very High Utility	NA	NA	High Utility	Very High Utility
CERES	High Utility	Very High Utility	Very High Utility	NA	NA	Some Utility	NA	Some Utility	NA	NA	NA	High Utility	High Utility
MODIS	Very High Utility	Very High Utility	Very High Utility	Very High Utility	Very High Utility	Very High Utility	Very High Utility	Very High Utility	Very High Utility	Very High Utility	Very High Utility	Very High Utility	Very High Utility
Aura	High Utility	High Utility	High Utility	Some Utility	High Utility	NA	High Utility	High Utility	Very High Utility	Some Utility	NA	High Utility	High Utility
HRDLS	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
MLS	Some Utility	Some Utility	High Utility	NA	NA	NA	NA	High Utility	NA	NA	NA	Some Utility	Some Utility
OMI	High Utility	High Utility	Very High Utility	High Utility	High Utility	NA	High Utility	High Utility	Very High Utility	NA	NA	High Utility	High Utility
TES	High Utility	NA	High Utility	NA	NA	NA	Very High Utility	High Utility	Very High Utility	NA	NA	Some Utility	High Utility
CALIPSO	High Utility	Some Utility	Some Utility	Some Utility	High Utility	NA	Very High Utility	Very High Utility	NA	NA	NA	Some Utility	High Utility
CloudSat	High Utility	High Utility	Some Utility	Very High Utility	NA	NA	Some Utility	Very High Utility	Very High Utility	NA	Some Utility	Some Utility	High Utility
EO-1	High Utility	NA	Some Utility	Not Here	High Utility	Very High Utility	Very High Utility	Some Utility	NA	NA	Some Utility	Some Utility	High Utility
GRACE	High Utility	High Utility	Very High Utility	Not Here	NA	NA	NA	High Utility	High Utility	High Utility	NA	High Utility	Very High Utility
Jason-1	High Utility	High Utility	Very High Utility	NA	Very High Utility	NA	Some Utility	Very High Utility	NA	High Utility	High Utility	Some Utility	Very High Utility
Jason-2/OSTM	Very High Utility	High Utility	Very High Utility	NA	Very High Utility	NA	NA	Very High Utility	Some Utility	Very High Utility	High Utility	Very High Utility	Very High Utility
QuikSCAT	High Utility	High Utility	Very High Utility	High Utility	Some Utility	High Utility	High Utility	High Utility	Some Utility	Some Utility	High Utility	Very High Utility	Very High Utility
SORCE	High Utility	High Utility	Very High Utility	Not Here	NA	NA	NA	Very High Utility	High Utility	NA	NA	High Utility	High Utility
Terra	Very High Utility	Very High Utility	Very High Utility	High Utility	Very High Utility	Very High Utility	Very High Utility	Very High Utility	Very High Utility	Very High Utility	Very High Utility	High Utility	Very High Utility
ASTER	High Utility	NA	Some Utility	Some Utility	High Utility	Very High Utility	High Utility	Very High Utility	NA	High Utility	Very High Utility	High Utility	High Utility
CERES	High Utility	Very High Utility	Very High Utility	NA	NA	Some Utility	NA	High Utility	NA	NA	NA	High Utility	Very High Utility
MISR	High Utility	NA	Some Utility	Some Utility	High Utility	High Utility	High Utility	High Utility	NA	NA	NA	Some Utility	High Utility
MODIS	Very High Utility	Very High Utility	Very High Utility	Very High Utility	Very High Utility	Very High Utility	Very High Utility	Very High Utility	Very High Utility	Very High Utility	Very High Utility	Very High Utility	Very High Utility
MOPITT	Some Utility	NA	Some Utility	NA	NA	NA	High Utility	High Utility	NA	NA	Some Utility	Some Utility	High Utility
TRMM	High Utility	High Utility	Very High Utility	Some Utility	High Utility	Some Utility	Some Utility	Very High Utility	Very High Utility	Some Utility	Very High Utility	High Utility	Very High Utility

Color Key	Very High Utility	High Utility	Some Utility	NA	Not Here

Panel Summaries of each Mission

Aqua (Very High Utility)

The panel determined that loss of data from Aqua would have significant negative impact on all organizations in the panel. The widespread use of MODIS alone ensured the highest rating. AMSR-E and AIRS/AMSU were also deemed extremely important, and CERES value was recognized.

Uses included:

1) AMSR-E: Numerical weather prediction (NWP), sea ice, tropical cyclone (TC) location/structure/track; rain estimates for active/global tropical cyclones; operational marine forecasts; wind and wave conditions over open ocean;

2) AIRS/AMSU: Significant importance to aviation community (SO2, volcanic plumes); volcanic ash detection in Rapid Update Cycle Rapid Refresh Model. Profiles assimilated in NOAA NWP suites, and it was considered to be their most critical NASA data set;

3) MODIS: Supports diverse atmospheric, oceanic, and terrestrial applications. MODIS was found to be the most widely and broadly used data set in NOAA.

Terra (Very High Utility)

The panel easily reached a summary rating of very high utility, primarily due to the great practical utility of MODIS for a wide range of applications. The value of other sensors, particularly ASTER, added to the utility rating.

Uses included:

1) ASTER used for numerous applications by state/local governments including: landscape mapping and change, unpermitted construction, disasters, watershed assessment, etc.**;**

2) FAA uses MISR data to produce stereoscopically derived wind values and cloud top height estimates that are useful for volcanic cloud height mitigation;

3) CERES value recognized for general climate applications; global weather forecast models;

4) MODIS: Extraordinary array of applications similar to Aqua/MODIS. While most organizations more broadly utilize Aqua/MODIS, the USDA prefers Terra over Aqua due to the morning pass with less cloud cover. The loss of deep blue aerosol capability on Terra/MODIS was noted by NRL.

TRMM (High Utility)

The panel found a tremendous use for each of TRMM's sensors and data products. The primary benefits of TRMM are with Tropical Cyclones (TC), floods, hazardous weather, fires, hydrology, and forecast modeling. TRMM has widespread use in public health for vector-borne disease risk assessments. TRMM has many synergies with data sets from other satellites to support additional applications. The panel found that the continuation of TRMM data will allow the community to better link the TRMM data sets to that of GPM.

Uses included:

1) TC location and structure at NWS and DOD Joint Typhoon Warning Center, especially when TC circulation center is not visible in geostationary imagery;

2) Rainfall monitoring and impacts of land-falling TCs; precipitation forcing to hydrologic operations; US & overseas modeling agencies assimilate both TMI and VIRS data;

3) LIS lightning helps FAA, NOAA, and the Air Force monitor growth and decay of storms; supports aircraft icing conditions; supports the NCEP Aviation Weather Center; used in investigation of Air France 447 crash;

4) Conservation International indicated that TRMM data is used to determine seasonality of biodiversity measurement stations that are part of Tropical Ecology Assessment and Monitoring (TEAM) network.

Jason-2/OSTM (Very High Utility)

The panel found that Jason-2/OSTM data products are central to the oceanographic and weather communities, but have reduced utility for other communities. The tandem mission with Jason-1 has allowed the community to observe the variability of long term ocean cycles. OSTM and Jason-1 have allowed for the use of cross calibration which enables the overall reduction of variability in either sensor.

Uses included:

1) Only Jason-1 and OSTM observations have sufficient accuracy to detect ocean changes at global and basin scales. Increased spatial resolution of sea surface height data is developed when combined with Jason-1 data;

2) OSTM surface wave height (SWH) data are also used by the National Hurricane Center's (NHC) marine forecasters to provide analyses of the wave field associated with tropical cyclones;

3) Wave-height conditions/forecasts; warnings to mariners;

4) USDA's Foreign Agricultural Service (FAS) uses OSTM as part of its Global Reservoir and Lake Monitor system to estimate reservoir and lake surface altimetry globally;

5) AFWA plans to assimilate OSTM data in their Weather Research and Forecasting (WRF) model during 2012-13.

Aura (High Utility)

The panel found that Aura data are useful for improving our understanding for how various molecular species contribute to changes in the atmosphere and to atmospheric forcing. In recognition of this fact, and the potential benefit from this research, the panel rated the value of this mission as high with OMI observations identified as the most used. However, the current lack of real time data access to many products and limited swath coverage preclude the use of this data more widely in operations.

Uses included:

1) Volcanic activity and ash detection; volcanic plume forecasting (especially in combination with AIRS and MODIS plume detection); information used by Volcanic Ash Advisory Centers. Data was critical during Iceland eruption of 2010;

2) Assimilated in NOAA NWP as an additional source of ozone profiles;

3) Used in monitoring stratospheric ozone; MLS especially valuable in polar regions;

4) NRL and EPA: Aerosols and ozone data fill gaps in information and help support air quality products;

CloudSAT (High Utility)

The overall rating utility was determined as high by the panel, based mostly on atmospheric applications. The panel found that more "operational" and less applied research use of CloudSAT would likely move the overall utility to very high. Near-real-time data needs and utility were very useful where demonstrated, but latency needs to be improved for greater operational utility for other users.

Uses included:

1) A variety of aviation applications including data-gap filling in areas of sparse GOES satellite coverage, verification of icing forecasts, and validation of volcanic ash plume heights and areal coverage;

2) NOAA/Climate Prediction Center (CPC) uses data for cloud structure in climate forecasts;

3) The Air Force uses cloud products to provide reports on cloud coverage, layer thickness, layer type, etc. via their Worldwide Merged Cloud Analysis;

4) NOAA is using data to prepare and educate user community of GOES-R algorithms with similar output;

5) CloudSAT is very important in the data fusion environment. It is tied closely to aerosol data from CALIPSO;

6) NRL is using new, real-time data extensively -- including for validating ground RADAR.

GRACE (High Utility)

The panel determined a high utility rating due to the atmospheric/weather and NSGIC panelists' widespread use of data. However, panelists concerned primarily with land processes did not see as great a value from GRACE – but they noted new research could alter that view.

Uses included:

1) National Geodetic Survey (NGS) is implementing new gravimetric national reference system (geoid vertical datum) by 2017. Datum is updated approximately once each decade and the entire community relies on consistent reference standards. GRACE is extremely important in this effort;

2) States are currently implementing height modernization programs with NGS and are dependent on derivative products produced by NGS. It was stated that next to MODIS, GRACE is of most interest to the States;

3) NOAA: The GRACE accelerometer provides some of the best in situ data on satellite drag and atmospheric neutral density at high altitudes. There are very few other techniques for measuring the actual neutral density of the upper atmosphere and GRACE is one of the few satellites that carries the appropriate sensors for making these observations. These data have been used in numerous research activities to compare with and validate NOAA space weather models. GPS-RO data are operationally assimilated for NWP at NCEP.

SORCE (High Utility)

The panel found that SORCE data are useful for improving our understanding of how solar irradiance contributes to changes in the atmosphere and climate forcings. SORCE has also been invaluable to obtaining and sustaining an historical record of solar measurements across different solar cycles. The continuity of the historical data record, especially with the reduced overlap with other missions/instruments and increasing visibility and concerns surrounding knowledge, understanding, and ability to communicate warnings of solar events that endanger infrastructure, puts this mission into an increasingly high category of importance.

Uses included:

1) Directly used by organizations involved in space weather forecasting, especially near-real-time monitoring of solar flare events, inputs to USAF modeling, value and uses for airlines (arctic routing, personnel/passenger safety);

2) SIM and SOLSTICE ultraviolet spectral irradiance measurements are critical for determining variability of stratospheric temperature and ozone, and climate influences;

3) TIM measurements are fundamental to the TSI record and critical to climate records. Glory failure only magnified the importance of this issue.

CALIPSO (High Utility)

CALIPSO received a high utility rating because it was used by two-thirds of the represented organizations. It rated "high" because of its increased utility in calibration and also improved data access. The panel noted that version 3 reprocessing had significantly improved the data products.

Uses included:

1) EPA has used CALIPSO data to calibrate air quality modeling efforts within the Office of Research and Development;

2) NOAA: Most major operational forecast centers now have mandates to provide forecasts of either air quality or visibility. Representing and forecasting aerosol

distributions are important parts of this requirement, and global aerosol predictions are needed to set boundary conditions on regional air quality models;

3) CALIPSO measurements of volcanic ash plumes from the Iceland 2010 eruption were integrated with data captured from other satellites to help inform Volcanic Ash Advisory Centers of the extent of the aviation hazard. The FAA is in agreement that this instrument has potential high value in the monitoring of ash plumes;

4) NRL used CALIPSO products to examine the Deepwater Horizon spill. This process helped detect volatile organic compounds over the spill in the Spring /Summer of 2010.

Jason-1 (High Utility)

The panel determined that data products from Jason-1 are central to the oceanographic and weather communities, but have reduced utility for other communities. The loss of Jason-1 alone would have a measurable, but not significant negative impact on operations, since OSTM is collecting; however, the loss of Jason-1 and OSTM together would constitute a significant negative impact.

Uses included:

1) Only Jason-1 and OSTM observations have sufficient accuracy to detect ocean changes at global and basin scales. Increased spatial resolution of sea surface height data is developed when combined with OSTM data;

2) Jason-1 SWH data are also used by NHC marine forecasters to provide analyses of the wave field associated with tropical cyclones;

3) Wave-height conditions/forecasts; warnings to mariners;

4) USDA's Foreign Agricultural Service (FAS) uses Jason-1 as part of its Global Reservoir and Lake Monitor system to estimate reservoir and lake surface altimetry globally. This is especially important since many countries are not willing to share their hydrological data for their lakes and reservoirs with USDA.

QuikSCAT (High Utility)

Before the antenna anomaly, QuikSCAT was the gold standard in scatterometry, and the panel found that this value remains intact due to its importance for calibration. QuikSCAT continues to be the only calibration source for other missions, including the Indian mission OSCAT. Ensuring data continuity to cross-calibrate and intercalibrate among missions is absolutely critical.

Uses included:

1) NOAA: Continuing QuikSCAT operations as baseline for OSCAT calibration/validation is critical for all existing users. QuikSCAT measurements at OSCAT measurement angles will be absolutely the best way to help understand how much OSCAT calibration is off due to engineering problems, and what the true

limitations of the OSCAT dataset are. QuikSCAT measurements are crucial for model function development which is heart of any wind vector retrieval algorithm; therefore, it continues to have huge implications for how OSCAT data are used for operations;

2) EPA: Researchers are currently using QuikSCAT data to measure Gulf of Mexico hypoxia ecological processes and responses.

EO-1 (High Utility)

The panel determined that EO-1's applied and operational uses are primarily focused on disaster response for various United States Government Agencies and in supporting National and International Relief Organizations/Agencies. EO-1 also supports scientific applied research as well as calibration and validation for the Landsat/Landsat Data Continuity Mission. While rated as high utility, it quantitatively ranked the lowest of missions under review.

Uses included:

1) Crop residue; post fire-burn severity mapping; forest health; tornado path identification; identification of flooded areas;

2) NOAA/NESDIS uses for special events: fires, volcanic eruptions. Used as a validation point in algorithm development projects**;**

3) USDA uses imagery to monitor Agency administered farm program activity and response to disaster events when higher resolution aerial imagery is not available;

4) EPA compares EO-1/Hyperion data with their airborne hyperspectral sensor for validation and calibration and applied research.

APPENDIX 3. COST PANEL REPORT

Mission Operations and Data Analysis Cost Analysis Team Report

May 2011

The 2011 Senior Review cost analysis team consisted of the following members:

Kathy Shifflett, NASA/Goddard Space Flight Center, Chair
Sheri Platt/NASA/Goddard Space Flight Center
Julie Fowler/NASA HQ
Gwen Leach/NASA/Langley Research Center

The team met via telecom on March 3, 2011, March 9, 2011, March 14, 2011, March 29, 201, March 31, 2011 and April 12, 2011. The initial telecom was to advise the team members of the role we would have in the 2011 Senior Review process. Since this was a new role for all us, we had a lot of discussions on exactly what criteria we would use to evaluate the proposals. Below are the definitions which were settled on for the teams' review:

- Definitions for the rating criteria are as follows:
  - ***Low Risk***: There are no problems evident in the cost portion of the proposal. If minor discrepancies are noted, the discrepancies are not of sufficient magnitude to doubt the Proposer's capability to accomplish the work within the resources.
  - ***Medium Risk***: Minor discrepancies have been identified, but are considered within the proposal's team capabilities to correct within the available resources with good management and application of effective cost management. If an optimal budget is requested for the development of new data products, then the cost proposal was rated a medium risk.
  - ***High Risk***: One or more problems are of sufficient magnitude to be deemed unresolveable within the available resources. If an optimal budget is requested for mission continuation, the team has deemed this a high risk factor.
- The above definitions were developed with the understanding of tight budget constraints within the Earth Science Division (ESD) at NASA HQ. If the Senior Review Panel determines that the new data products and/or the mission continuation are beneficial to NASA and other constituents, then as part of the PPBE 2013 budgetary process Earth Science Division would identify the required funds.

The team developed the rating criteria, which was a team effort and the rating template, which Gwen Leach developed after several of the team's conversations.

Using the 2012 President's budget, Sheri Platt populated the cost format guideline section, which was then provided to each team for use in preparing their proposal. These guidelines were distributed by mission operations and data analysis. Sheri was also instrumental in providing additional budgetary information to Ms. Yuhas as requested. As a team, we looked at the budget details for each of the missions and compared the submission to the guidelines for both dollars and workforce. If the mission's proposal included an optimal budget, the budget details were reviewed and qualified as to mission content, affordability, and applicability to the mission. The Full Time Equivalents (FTEs for civil service support) and the Work Year Equivalents (WYEs for contractor support) for each of the missions was compared to past performance and where an optimal budget was requested, the team reviewed the additional workforce. The team also reviewed past performance as related to uncosted carryover from prior year to the new fiscal year. Each team member was responsible for reading each proposal and completing the rating template for each mission (blank rating template attached). Each team member filled in their ratings on the template with a brief description of comments as well as questions/concerns that they needed to have addressed. When possible, team members were able to depose the questions. These templates were then in turn discussed in detail with the team for each mission and a consensus of opinion for the overall rating was reached by the team. The rating process was iterative among the team members and lively discussions often ensued. There were multiple discussions among the team members to address questions, issues, and concerns before arriving at a final, agreed upon rating for each mission.

Below are the 2011 Senior Review Cost Team findings:

- The ESD operating missions are aging and many are facing technical challenges. The operations teams are keeping the missions operating as efficiently and effectively as possible within existing budgets.
- Optimal budget submissions are requested for the following missions:
  - AQUA, TERRA, SORCE, QUIKScat, EO-1, JASON, GRACE
  - AQUA, GRACE, SORCE and TERRA are requesting optimal budgets to produce additional science products
  - SORCE is requesting an optimal budget in all years to continue the science measurements that were planned for the Glory mission.
  - EO-1 and JASON missions end in 2013 and are requesting an optimal budget to continue operating the missions
    - Requested continuation of funding through 2016 for continued operations
  - QUIKSCAT mission operations are not covered in the inguide budget submission beyond FY 2014. The budget provided is to cover the data analysis portion of the mission. An optimal budget has been submitted in Senior Review to continue mission operations through FY 2016.

- Uncosted Carryover is reasonable from year to year for all missions.

The individual mission evaluations are provided in Table A3-1, below. Summary findings of the budget guidelines vs. mission requests were provided to the Science Panel during its deliberations May 3-5, 2011.

In conclusion, the 2011 Senior Review Panel provided analysis of the mission proposals and evaluations as to the financial standing of each mission.

Table A3-1. Mission Cost Evaluations

Project	In-Guide $ Risk			Optimal $ Request Risk			Comments	In-Guide Total WF Risk			Optimal Request Total WF Risk			Comments	Efficiency/Effectiveness of Prior Yr Funding			Comments	Additional Comments/Questions
	High	Med	Low	High	Med	Low		High	Med	Low	High	Med	Low		High	Med	Low		
Aqua May 2002			X	X			An in-guide and optimal budget are requested. The optimal budget request covers the required effort to complete the algorithms for retrievals in Stratosphere and lower troposphere. ~$600K for each FY12 and FY13 is proposed. Assuming the increase is all labor, the cost per FTE is ~$285K. This is reasonable for senior level support. The in-guide FY budget request is aligned with prior two years' NOA. In-guide rated "Low"; optimal rated "High". AQUA is taking a 433K reduction in FY12, 13, & 14 to help balance the Earth Science 2012 PPBE budget.			X	X			The in-guide budget CS workforce is in range of PPBE2012 request and is the same for optimal budget request. The proposed WYEs reflect an increase of 2.1 for the optimal budget.					X	AQUA has handled their carryover responsibly, and maintains sufficient carryover to proceed with new FY activities.	Spacecraft and instruments are operating nominally with the exception of HSB. Mission life expectancy is beyond the budgeted request period. MO cost sharing strategy for Aura, Aqua, and Terra, and future NPP is good. Need to plan for handling increase cost in the event a mission ends or one does not launch as planned. The In Guide budget increases are based upon inflation only. From a financial point of view, proceed with optimal budget request if mission assessed that there is better science as a result. The Education and Public Outreach (E&PO) Budget meets the Agency metric of 1 to 3 percent.

Project	In-Guide $ Risk			Optimal $ Request Risk			Comments	In-Guide Total WF Risk			Optimal Request Total WF Risk			Comments	Efficiency/Effectiveness of Prior Yr Funding			Comments	Additional Comments/Questions
	High	Med	Low	High	Med	Low		High	Med	Low	High	Med	Low		High	Med	Low		
Aura Jul 2004			X				An in-guide budget is requested. The in-guide reflects planned MO&DA spending that is fairly consistent with the previous two years. Proposed effort is continuation of atmospheric observations and synergies with A-Train and field missions focusing on the troposphere. AURA is taking a 433K reduction in FYs 12, 13, & 14 to help balance the Earth Science PPBE 2012 budget.			X				The in-guide workforce is sufficient to perform the work proposed.					X	AURA has managed to retain enough carryover to maintain operations during new fiscal year start up period.	From financial perspective, there is no evidence to indicate that the mission should not be approved for the next two years covered by the Senior Review 2011 at the in-guide budget level. Spacecraft is performing well and life expectancy is beyond current budget cycle. The payload has experienced some anomalies, appropriate actions are ongoing to minimize the impact on meeting required science performance. No indication of issues with ground operations. The In Guide budget increases are based upon inflation only. The Education and Public Outreach (E&PO) Budget meets the Agency metric of 1 to 3 percent.

Project	In-Guide $ Risk			Optimal $ Request Risk			Comments	In-Guide Total WF Risk			Optimal Request Total WF Risk			Comments	Efficiency/Effectiveness of Prior Yr Funding			Comments	Additional Comments/Questions
	High	Med	Low	High	Med	Low		High	Med	Low	High	Med	Low		High	Med	Low		
CALIPSO			X				Only in-guide budget requested. In-guide reflects planned MO&DA spending that is consistent with previous two years. Proposed effort is continuation of characterization improvements and opportunity for synergies with A-Train and other missions. Note: The in-guide budget reflects an average of 2% annual inflation. (FY11 to FY12 is 1.7%)			X				The in-guide workforce is sufficient to perform the work proposed.					X	CALIPSO maintains enough carryover to adequately cover the next fiscal year's start up costs.	Spacecraft systems are meeting required performance and there is redundancy and/or workarounds for continued operations. The payload has experienced some anomalies(Laser, etc) and again workarounds were implemented for meeting required science performance. No indication of ground systems issues. The Education and Public Outreach (E&PO) Budget meets the Agency metric of 1 to 3 percent.

Project	In-Guide $ Risk			Optimal $ Request Risk			Comments	In-Guide Total WF Risk			Optimal Request Total WF Risk			Comments	Efficiency/Effectiveness of Prior Yr Funding			Comments	Additional Comments/Questions
	High	Med	Low	High	Med	Low		High	Med	Low	High	Med	Low		High	Med	Low		
CloudSat Apr 2006			X				Only in-guide budget requested. In-guide reflects planned MO&DA spending that is fairly consistent with previous two years. Proposed effort is continuation of characterization clouds and percipitation characterization and opportunity for synergies with A-Train.			X				The in-guide workforce is sufficient to perform the work proposed.			X	Cloudsat has worked effectively to clear up past years' high amount of carryover. Currently they are predicted to leave FY11 with approximately 3 months carryover, which is reasonable and sufficient.	The spacecraft's battery is meeting required performance although with a weak cell. Workaround implemented to reduce power load. The payload has experienced some anomalies appropriate actions have been taken to minimize the impact on meeting the required science performance metrics. The Education and Public Outreach (E&PO) Budget exceeds the Agency metric of 1 to 3 percent.

Project	In-Guide $ Risk			Optimal $ Request Risk			Comments	In-Guide Total WF Risk			Optimal Request Total WF Risk			Comments	Efficiency/Effectiveness of Prior Yr Funding			Comments	Additional Comments/Questions
	High	Med	Low	High	Med	Low		High	Med	Low	High	Med	Low		High	Med	Low		
EO-1 Nov 2000			X	X			An in-guide and optimal budget request is proposed. The mission cost is minimum and products present immediate benefit to society. If optimal budget is approved, then additional funds will be required in FY17, which is beyond Senior Review, to passivate and decommission the spacecraft. No E/PO proposed in budget.			X	X			The in guide workforce in FY12 - FY14 appears reasonable to do the work requested. However the workforce in FY15 to conclude the mission is questionable to complete the close out activiites. The workforce increases in FY14 through FY16 to reflect the extension FY14 and beyond in the optimal budget.				EO-1 should have sufficient carry over funds for new fiscal year start up activities.	EO-1 will provide calibration measurements with LDCM and fill the gap until LDCM launches planned for 2012 . Orbital debris waiver granted to stay in an orbit for MLT (Mean local time). Spacecraft and instruments are performing well. From a financial point of view, optimal budget request is small investment for great return provided more explanation can be obtained on their financial management plans.

Project	In-Guide $ Risk			Optimal $ Request Risk			Comments	In-Guide Total WF Risk			Optimal Request Total WF Risk			Comments	Efficiency/Effectiveness of Prior Yr Funding			Comments	Additional Comments/Questions
	High	Med	Low	High	Med	Low		High	Med	Low	High	Med	Low		High	Med	Low		
GRACE Mar 2002			X	X			An in-guide and optimal budget are requested. The in-guide is consistent with the PPBE 2012 request and aligns with prior two years NOA. Proposed effort continues measurements of gravity signals and affects on Earth's climate system and synergies with other missions. The optimal budget request is primarily to address the increased effort for battery control management (36% of Optimal budget) . The batteries are an issue on both satellites; battery life is protected at the expense of short term science data. The proposal discussed the components (high level basis of estimate) of the optimal budget request. Optimal budget reflects increase of 417K over in-guide for FY12. Lack of available funding increases risk for a wider time gap between GRACE and GRACE Follow-on.			X	X			The GSFC in-guide WYEs listed are actualy located at UTCSR/Austin .				Historically GRACE has carried too much uncosted carryover from year to year. Current FY11 analysis indicates that GRACE will end FY11 with excessive uncosted carryover.	From financial perspective, there is no evidence to indicate that the mission should not be approved for the next two years covered by the Senior Review 2011 at the in-guide budget level. As a result of battery issues, increase in cost to cover the implementation of tighter control of battery management is reasonable and includes workaround implemented to reduce power load. The project has terminated plans to refurbish the GRACE Mission Simulator in FY11 to cover increased cost of battery maintenance which will not contribute significantly to the operational life of the two spacecraft. A MOU agreement with German Partner is in place through 2015. The In Guide budget increases are based upon inflation only. The Education and Public Outreach (E&PO) Budget meets the Agency metric of 1 to 3 percent.

Project	In-Guide $ Risk			Optimal $ Request Risk			Comments	In-Guide Total WF Risk			Optimal Request Total WF Risk			Comments	Efficiency/Effectiveness of Prior Yr Funding			Comments	Additional Comments/Questions
	High	Med	Low	High	Med	Low		High	Med	Low	High	Med	Low		High	Med	Low		
JASON-1 Dec 2001			X	X			An in-guide and optimal budget are requested. Proposed effort continues sea surface height observations through 2014. JASON weakness is that if any more reaction wheels fail, the mission will then fail. The optimal budget request allows for the continuation of observations through 2016. (Proposal narrative states 2015) OSTM (JASON 2) is taking measurements and there has been and will be overlap through 2014. Project should have added an alternate Optimal close out budget for FY15 if JASON-1 decommissioning is required by the summer of 2014. Optimal narrative assumes operations through 2015 (p. 26). Why is then there an Optimal 2016 budget? Is it all for decommissioning?			X		X			The in-guide workforce is sufficient to perform the work proposed. The ~6.0 WYEs is consistent with the PPBE2012 budget request. The Optimal budget continues with this level of workforce for 2015-2016. The work at GSFC(approc 85K/year) is contract work for orbit calculation (not CA) for non-routine analysis, it does not include any FTE work. JASON should have added an alternate Optimal close out WYE budget for FY15 if decommissioning is required by the summer of 2014.			X	JASON carryover is reasonable at approximately 3 months.	While the continuation of Jason-1 so that measurements can be taken by three JASON Class instruments at the same time is unprecedented, there are no new science objectives (the JASON-2 is doing well and JASON-3 launches in 2014). If there is an option to and value in receiving the data without daily monitoring and interference with other missions, consideration may be given to the impact of allowing the instrument to stay in orbit. The Education and Public Outreach (E&PO) Budget meets the Agency metric of 1 to 3 percent.

Project	In-Guide $ Risk			Optimal $ Request Risk			Comments	In-Guide Total WF Risk			Optimal Request Total WF Risk			Comments	Efficiency/Effectiveness of Prior Yr Funding			Comments	Additional Comments/Questions
	High	Med	Low	High	Med	Low		High	Med	Low	High	Med	Low		High	Med	Low		
OSTM Jun 2008			X				An in-guide budget is requested only. Project leverages off of JASON-1 and hence shares and optimizes economies of scale. Budget outyears may require augmentation if JASON-1 is decommissioned and economies of scale are lost. Affordablility Rated "Low".			X				The in-guide workforce appears sufficient to perform the work proposed.				As of February 28, 2011 OSTM is predicted to have 10 months of carryover due to large amount of prior year funding given to JPL to obligate late last year. OSTM currently working to reduce the uncosted carryover before the end of this year.	OSTM to ensure successful cross-calibration with JASON-3. Spacecraft and instruments are operating nominally. E/PO is within agency metric. From a financial point of view, small investment and great reward.

Project	In-Guide $ Risk			Optimal $ Request Risk			Comments	In-Guide Total WF Risk			Optimal Request Total WF Risk			Comments	Efficiency/Effectiveness of Prior Yr Funding			Comments	Additional Comments/Questions
	High	Med	Low	High	Med	Low		High	Med	Low	High	Med	Low		High	Med	Low		
QuikSCAT Jun 1999			X	X			An in-guide and optimal budget are requested. The optimal budget request extends spacecraft mission operations in FY15 through FY16 . The optimal request is for continuation of the Ball subcontract (mission operations) in FY15, but FY16 budget is also shown in financial template without supporting narrative. Also, budget template and narrative for FY15 contain differing amounts.			X	X			The in-guide workforce appears sufficient to perform the work proposed.			X	Carryover is reasonable, and is predicted to be about 3 - 4 months at the end of the year, which is sufficient to fund them through new fiscal year start.	

Project	In-Guide $ Risk			Optimal $ Request Risk			Comments	In-Guide Total WF Risk			Optimal Request Total WF Risk			Comments	Efficiency/Effectiveness of Prior Yr Funding			Comments	Additional Comments/Questions
	High	Med	Low	High	Med	Low		High	Med	Low	High	Med	Low		High	Med	Low		
SORCE Jan 2003			X	X			In-guide and Optimal budgets are requested. Due to GLORY launch failure 2/11, SORCE Mission is requesting optimal funding to continue scientific measurements that were planned for GLORY. Optimal budget is reasonable.			X	X			The workforce proposed is identified and the dollars proposed are sufficient to cover the costs.			X	SORCE has maintained adequate carryover to cover new year start up costs. Budget is stable and consistent and increases for inflation only.	The limiting component for SORCE is the battery. There have been anomalies but workarounds are in place. Life expectancy is estimated to continue throught this budget request period. The E/PO budget does not meet Agency metric (less than 1 %) in optimal budget.

Project	In-Guide $ Risk			Optimal $ Request Risk			Comments	In-Guide Total WF Risk			Optimal Request Total WF Risk			Comments	Efficiency/Effectiveness of Prior Yr Funding			Comments	Additional Comments/Questions
	High	Med	Low	High	Med	Low		High	Med	Low	High	Med	Low		High	Med	Low		
Terra Dec 1999			X	X			An in-guide and optimal budget are requested. Proposed effort continues with measurements from 5 instruments observing the Earth Systems. The optimal budget request provides for the algorithm development of NCAR's MOPITT total column methane product for a modest increase of less than $200K per year. TERRA is taking a 433K reduction in FYs 12, 13, & 14 to help balance the Earth Science PPBE 2012 budget.			X				The in-guide workforce appears sufficient to perform the work proposed. There is no change in workforce requirements in the optimal budget request because the optimal funding request is in support of NCAR, therefore no workforce increases.			X	Terra should have sufficient carry over funds for new fiscal year start up activities.	Spacecraft and instrument suite estimated to continue operating through budget period. The In Guide budget increases are based upon inflation only. The Education and Public Outreach (E&PO) Budget meets the Agency metric of 1 to 3 percent.

Project	In-Guide $ Risk			Optimal $ Request Risk			Comments	In-Guide Total WF Risk			Optimal Request Total WF Risk			Comments	Efficiency/Effectiveness of Prior Yr Funding			Comments	Additional Comments/Questions
	High	Med	Low	High	Med	Low		High	Med	Low	High	Med	Low		High	Med	Low		
TRMM Nov 1997			X				An in-guide budget is requested only. Upgrades to mission planning and scheduling is required for extension beyond 2014.			X				The workforce is sufficient to perform the described work.			X	Historically TRMM has had higher than normal carryover, partially due to large number of slower-costing grants (40% in FY09). While carryover has been reduced, the FY11 predicted carryover is still higher than acceptable.	Extending until after GPM launch in 2013 provides opportunity for cross calibration. Mission is fuel limited (est. 2014 to early 2015). Beginning in 2003 TRMM and GPM DA functions were fused into the TRMM (DA) budget by HQ. The need for GPM DA and TRMM/GPM shared activities DA will continue even after TRMM ends. The In Guide budget increases are based upon inflation only. The Education and Public Outreach (E&PO) Budget meets the Agency metric of 1 to 3 percent.

APPENDIX 4. DETAILED SCIENCE PANEL MISSION REVIEWS

AQUA

Finding:

XX Continuation of projects with PARTIAL augmentation to the current baseline

Executive Summary: The Aqua mission has been extremely successful and the data is very widely used by scientists, government agencies and operational groups. The government agencies all gave Aqua the highest ranking of all missions, and scientific citations of Aqua data now exceed 10,000, leaving no doubt that this mission should continue to be funded. The optimal budget proposal is for development of the AIRS CO_2 product, which was felt to be high risk previously. A mid-troposphere AIRS CO_2 product has been successfully validated since then, and it seems reasonable to partially fund this over guide request, as long as it fits within the scope of mission funding. While the panel notes that the AIRS CO_2 product is very important, the development of new products were not considered by the Senior Review panel. Note that the decision to fund the optimal budget was not unanimous among the three reviewers – two reviewers were for and one reviewer was against funding the optimal budget. The entire panel was also split in their votes (6 partial, 5 none, 2 full augmentation votes).

Launched in 2002, Aqua is now 2.5 yrs into its extended mission. Five of six instruments are still operating (all but HSB – there was enough overlap with AIRS/AMSU that HSB failure had no impact on core data). Aqua makes critical measurements of Earth's water and water cycle, radiative energy fluxes, atmospheric temperature and composition, dust and aerosols, cloud properties, land vegetation, organic matter in oceans, surface albedo, temperature, and emissivity. Aqua data is used to study atmosphere, oceans, land, snow, and ice. The data is used to quantify the state of the Earth system, and validate climate models – the mission is crucial to the SMD fundamental question about how earth is changing and its consequences for life. There have been over 850 science publications using Aqua data in the last 2 years, over 10,000 total citations, 89 Gb of data collected per day, and Aqua has a data capture rate > 99.9%. It is expected that the remaining 5 instruments will continue to operate for the duration of FY12-FY15. Publications from Aqua data have been produced in all 6 Earth Science focus areas, and the mission is generating global datasets, which are allowing new discoveries to be made about Earth system processes. Many operational groups use the data including NOAA, USFS, USDA, EPA, FAA, USCG, and DoD. The spacecraft bus and 5 instruments (AIRS, AMSU, AMSR-E, CERES, and MODIS) are all in excellent health, and the satellite has adequate fuel to operate through 2022.

Extension of this mission would add value to climate studies, and produce data covering a wider range of conditions (e.g. major El Nino or volcanic eruption). It would allow overlap with Glory (2011), GCOM-W (2011), OCO-2 (2013), and the NPOESS Preparatory Project

(2011). Substantial overlap is required for confident extension of Aqua climate data with these upcoming missions. Aqua is one of 5 A-train satellites (others: Aura, PARASOL, CALIPSO, CloudSat), and scientists are using these concurrent observations to enhance the value of all products. GCOM-W, Glory, OCO-2 will join A-train between 2011-2013.

The quantity and significance of science contributions using Aqua instrument data by the mission team and investigators worldwide is unquestionable. The impressive list of core science products is very mature and stable. Instruments and spacecraft remain in excellent health. Simply, Aqua is a NASA flagship mission.

This mission is producing a very large number of critical products addressing NASA's Earth Science mission both from the perspective of creating climate data records necessary to evaluate climate change and from the perspective of products needed to better understand fundamental Earth science processes. The instruments (with the exception of HSM) as well as the spacecraft all seem to be in excellent health.

The request for over-guide budget for the AIRS CO_2 product was supported by two of the reviewers for partial support to produce the mid-troposphere product. The AIRS team has shown that the CO_2 product has promise, as the mid-troposphere CO_2 product has now been developed and successfully validated. Over-guide funding is proposed to develop a CO_2 estimate for the lower troposphere and the stratosphere. While the panel acknowledges the very high importance of the AIRS CO_2 product, the Senior Review Panel was specifically directed to not consider funding of any new products. We strongly encourage the investigators to submit a ROSES or unsolicited proposal to fund this work, and urge NASA to fund this critical data product development. Overlap with the upcoming OCO-2 mission is very desirable, since this will provide an additional source of data for comparison. The OCO-2 mission has a much smaller footprint, and is only nadir pointing, therefore will not provide global coverage. In addition, OCO-2 requires reflection of sunlight and is therefore not available during the night. An AIRS CO_2 product would therefore provide greater temporal and spatial coverage than OCO-2, but at a coarser resolution - these two important CO_2 products are complimentary. In addition, ENVISAT is no longer producing a CO_2 product, so this would fill an important gap.

The over-guide was not recommended by one of the main reviewers, due to the difficulty in reviewing this product development without more detailed information, expertise, and since it was declined in a recent ROSES call. This reviewer felt that if this product development was important for OCO-2, then OCO-2 should fund it. It was difficult to evaluate in this proposal as the over-guide request was described in less than one page. It would be much better to evaluate this new product development by experts in a full proposal format.

Any cut in the in-guide budget would have a large negative effect on the mission and would adversely affect the ability of the team to produce quality data products. The National Interest group raised a question with regard to the latency of data. (This was not viewed as a problem by the science panel.) Data latency is mainly limited by the location of ground downlink stations (only in the Arctic). An additional station in Antarctica, which could

possibly be cost-shared with the upcoming SMAP mission, would improve latency by ~45 minutes. Currently 28% of the raw data is available in less than 1 hour, and 89% is available in less than 2 hours. Near real-time algorithms for many of the core products are currently available.

Scientific merits

✠✠ Outstanding ❑ Very Good ❑ Good ❑ Fair ❑ Poor

Science objectives include: to advance understanding of controlling factors of global water and energy cycles; to assess climate forcings, variations, feedbacks; to study of atmosphere-surface interactions; to study diurnal cycles in cloud properties; to produce climate data records for detecting decadal changes in Earth's radiation budget; to improve understanding of soil wetness retrievals; to improve operational weather prediction; to facilitate future science advances, and bridge the gap between past and future spaceborne sensors.

Strengths –

The proposal presents a convincing argument for the need for the data products and for an extended mission. The data is extremely widely used: 850 publications per year have been produced using Aqua data during the last 2 years, over 13,000 total citations to papers using Aqua data have been made to-date, with a rate that is continuing to increase. 1400+ Tb of data was distributed in 2010 alone, and there were 38,000+ users in 2010. Aqua data is used to study atmosphere, oceans, land, snow, ice. The data is used to quantify state of Earth system, and to validate climate models – crucial to the SMD fundamental question about how earth is changing and its consequences for life. Below is a list of some examples of results from Aqua data grouped by subject:
Atmospheric composition: first maps of mid-tropospheric CO2, most detailed daily global observation of CO transport from biomass burning; showed that distribution of mid-tropospheric CO2 strongly influenced by large-scale circulations (e.g. jet stream) + synoptic weather systems; new MODIS aerosol algorithm derives aerosol properties over bright reflecting surfaces (e.g. deserts). Results of CO2 studies using Aqua have led to better understanding of large-scale atmos dynamics on tracer distributions. Other results have provided tests of coupled carbon-climate models.
Weather: Valuable to weather forecasting, but also used for improved understanding of weather processes. Information about Saharan Air Layer from Aqua imrpoves hurricane simulations – SAL also shown to contribute to hurricane formation but suppresses intensification. Signatures of gravity waves in Aqua data found, retrieval algorithms developed, and used to study impact of gravity waves on weather. AMSR-E SST is current gold standard for climate modeling of global SST. Hurricane modeling dramatically improved with MODIS IR data.
Carbon Cycle and Ecosystems: MODIS data used to monitor terrestrial and marine biosphere, quantify global productivity, biomass, and changes in land cover and ocean

color. Particulate inorganic carbon from MODIS is now a data product. MODIS is used as tool to evaluate nutrient stress predictions in ocean ecosystem models. CO2 flux is estimated at air/sea interface using salinity and SST estimates from MODIS, which produces a remote sensing approach to validate carbon cycle models.
Water and Energy Cycle: Aqua instruments are providing information about almost all major components of the water cycle (water vapor, precipitation, liquid water on land and oceans, snow cover, ice on land, in ocean, and in clouds). Heat and moisture fluxes between atmosphere and land or ocean are studied with Aqua data, and it has been shown that heat fluxes from Aqua are more realistic than from re-analyses. Near-surface temperatures have been shown to be much higher correlated with heavy snowfall than re-analyses, suggesting Aqua data may improve forecasts of important precipitation events in the Western U.S. RH remains constant at low temperatures but drops rapidly at high temperature. Latent heat estimates are shown to be accurate when compared with surface measurements. AMSR-E derived precipitation is considered the 'anchor' for satellite precipitation datasets for a range of microwave radiometers. AMSR-E provides the most accurate record of sea ice variability and change. Soil moisture information is produced from AMSR-E (although challenging).
Climate Variability and Change: All operating instruments are being used for climate variability and change studies. Details on atmosphere, cloud and radiation changes provided by Aqua are critical for modeling climate variability and change. Aqua is extending earlier datasets and provides a bridge to new satellite missions. MJO-related correlations have been found with water vapor, temperature and precipitation in 7 years of data. Atmospheric conditions contributing to Arctic sea ice minimum were documented using Aqua data. Anomalously high strength and frequency of temperature inversions in the Arctic during 2007 was found. Decreasing sea ice in Arctic and increasing sea ice in Antarctic was shown with Aqua data. Global average SST from AMSR-E shows large inter-annual variability related to El Nino and La Nina, which is important for feedback studies on the climate system. Greater rainfall under warmer conditions was shown globally during 2002-2011 with Aqua data.
Earth Surface and Interior: Information about the interior comes from estimates of volcanic emissions by AIRS/AMSU and MODIS IR, and ongoing volcanic activity is documented by MODIS thermal data. Land surface temperatures are derived from both AIRS/AMSU and MODIS, along with SST, sea and land ice coverage.

Weaknesses

More explicit coordination with future satellite missions that will replace Aqua sensors, and more coordination with funded ROSES projects would improve the mission.

Core mission data product maturity;
❑ Poor ❑ Fair, ❑ Good, XX Excellent.

AIRS CO_2 mid-troposphere product has been validated using aircraft and ground measurements, with monthly mean accuracy < 3ppmv for retrievals. 10% RMS differences

found when compared to other satellite-based sensors. Ozone retrievals work well when ozone mixing ratios > 200 ppmv from aircraft sensor comparisons.

MODIS ocean color data is now within a few % of SeaWiFS, allowing extension of the record from older SeaWiFS through MODIS record.

As noted in Aqua proposal, the CERES instrument is also on TRMM and Terra; also MODIS is on Terra. Not noted is the overlap of MODIS with LandSat. While MODIS on Terra has much higher temporal resolution than LandSat (daily vs 16 -day), the Aqua MODIS appears to be the same temporal resolution as LandSat, but with lower spatial resolution.

Funding is requested for: monitoring & operation including debris-avoidance; routing of data; instrument maintenance, operation and calibration (except AMSR-E, done by JAXA); maintenance and improvement of core data; data Q/C; science management for 4 Aqua science teams and for Aqua mission. An additional $600k for further development of AIRS CO_2 product in stratosphere and lower troposphere was requested. Funding appears appropriate. The panel supports partial over-guide funding for producing the mature mid-troposphere AIRS CO_2 product. While development of a low troposphere and stratosphere CO_2 product is very important, the Senior Panel was specifically directed not to fund development of new products. The panel strongly encourages the AIRS team to submit this proposed work to ROSES or through an unsolicited proposal.

Relevance to NASA Science Goals:
XX Outstanding ❑ Very Good ❑ Good ❑ Fair ❑ Poor

Strengths

Measurements of Earth's water and water cycle, radiative energy fluxes, atmospheric temp and composition, dust and aerosols, cloud properties, land veg, organic matter in oceans, surface albedo, temp, emissivity. Used to study atmosphere, oceans, land, snow, ice. Used to quantify state of Earth system, validate climate models – crucial to SMD fundamental question about how earth is changing and its consequences for life.

Weaknesses

More coordination of mission team with funded ROSES activities would improve this mission.

Technical and Cost

The Japanese group JAXA operates and maintains AMSR-E on Aqua, therefore this aspect of the mission is dependent on JAXA. CERES is a PI instrument, therefore funds are required to directly support development of higher-level products and investigations.
All other instruments are Facility instruments. The cost sharing between Terra and Aura is viewed to be appropriate.

The panel strongly suggests development of a contingency plan in the event that Japan ceases funding for AMSR-E. Overlap of AMSR-E with AMSR-2 for more than 1 year is highly desirable, and since technical details and training will be required for NASA to operate this instrument, development of a plan for future NASA operation of this instrument is urged and should be a priority.

The Technical Panel gave Aqua a medium risk. The Cost Panel gave Aqua a low risk for the in-guide budget, and a medium risk for the optimal budget.

The reviewers concur with the Technical and Cost reports.

National Needs

Aqua mission addresses numerous national needs, for weather forecasting, air quality, natural disaster monitoring and evaluation, and support of major human activities (agriculture, aviation, commercial fishing, energy management, military operations, oil slick monitoring, and shipping). Direct broadcast capability facilitates many real-time or near real-time applications. ECMWF views AIRS data as one of the most important satellite datasets for weather prediction. Weather forecasting offices throughout the world have found assimilating MODIS estimated polar winds greatly increases forecast accuracy, even in the tropics. The National Interests Panel gave Aqua the highest rating of all missions.

The reviewers concur with the National Interest Panel report.

Other Comments

The proposal was very complete, extremely well written and presented. The optimal budget was only partially supported for funding because the Senior Panel was specifically directed not to fund new product development, and therefore partial funding is suggested to produce the validated mature mid-troposphere AIRS CO_2 product. The Panel strongly suggests the development of a proposal for the low-troposphere and stratosphere CO_2 product to be submitted to ROSES or as an unsolicited proposal.

AURA

Executive Summary:

This is an excellent mission and proposal. Aura's primary scientific missions are stratospheric chemistry and dynamics related to ozone depletion, tropospheric chemistry, and climate change issues. These missions are central to core NASA research objectives. The scientific output from Aura is impressive (670 refereed journal publications and 351 since the last review). The satellite is in excellent health. The three remaining instruments are showing signs of aging, but are still producing science data of excellent quality, and have an excellent chance of extending beyond the current proposal cycle. There is excellent science justification for continuing the mission. The panel unanimously agreed that the funding for this mission be continued, but that funding for HIRDLS (which has not been operational since March 2008) be gracefully terminated in FY12.

Findings:

XX Continuation of projects with reductions to the current baseline : Gracefully terminate HIRDLS science team activities in FY12.

This is an excellent mission and proposal. Aura's primary scientific missions are stratospheric chemistry and dynamics related to ozone depletion, tropospheric chemistry, and climate change issues. These missions are central to core NASA research objectives. The scientific output from Aura is impressive (670 refereed journal publications and 351 since the last review). With regard to tropospheric chemistry and climate, Aura has continued to make great strides since the last review. Particular examples include the TES tropospheric CO_2 product, and new cloud products (e.g., IWC from MLS and from HIRDLS). Also, although Aura is a research mission, the production and use of near-real-time (NRT) products and operational utility has increased markedly since the last review.

Although Aura has completed its core mission, there are strong justifications for continuing the mission. These include: a continuation of the record of measurements of constituents important in ozone photochemistry (e.g., HCl), critical participation in several upcoming field campaigns, validation of NPP OMPS, and increasing NRT operational utility of Aura data.

The Aura s/c is still operating nominally, and appears to have no short-term propellant or battery-life issues. Of the four Aura instruments, HIRDLS is not operational, and two of the others (OMI, and TES) are experiencing significant instrument health issues and signs of aging, but are still producing excellent science products, and have a reasonably high probability of remaining operational through this funding cycle. Of the three remaining operational instruments, MLS appears to be the healthiest, and the scientific value of MLS (with regard to the mission continuation rationale given above) is sufficiently high that it alone would be sufficient justification for continuing to operate the Aura satellite.

The one major issue with regard to this proposal is the continuation of HIRDLS analysis funding. The panel is very impressed with the progress that has been made with regard to the extremely difficult issue of modeling the radiative effects of the HIRDLS FOV obstruction, and the availability of new products that this work has enabled. Of particular note here are the ozone and temperature products. The panel would like to see this work continue so that other important potential HIRDLS products with weaker absorption lines (H_2O, $ClONO_2$, N_2O, CH_4) can be retrieved from the 3 years of available data at the high vertical resolution (1 km) which only HIRDLS among the Aura instruments can deliver. However, the instrument has been in a non-operational state since March 2008, and there appears to be little hope of a return to operation of the sensor. Thus, the panel questions the appropriateness of MODA funding to support this continued analysis work. Perhaps a NASA ROSES proposal would be a more appropriate venue for the HIRDLS team to continue the development of new products.

Thus, the panel finds that the Aura mission be continued at the baseline level except that HIRDLS on-orbit support and science team activities should be gracefully terminated in FY12, and that, thereafter, HIRDLS science team activities no longer be funded under this program.

Scientific merits

❑ XOutstanding ❑ Very Good ❑ Good ❑ Fair ❑ Poor

Science section should describe the science merits of the program and specific contributions of the instruments. It includes current science objectives for the mission and a summary clearly focused on what has been accomplished in the past two years.

Strengths

- ☐ Instrument teams are working well together to generate synergistic products that take advantage of the strengths of each instrument (e.g., MLS/TES ozone product)
- ☐ The mission has been highly successful, and scientifically very fruitful (currently 670 publications in the refereed journal literature, and the number of pubs per year appears to be increasing exponentially).
- ☐ In general, the Aura team appears to have taken the guidance of the 2009 review seriously. We were particularly impressed with the increase in the amount of real time and operational use of the Aura data since the last review.
- ☐ The s/c appears to be healthy with high probability of lasting through the 3-year funding period. The remaining three instruments are all experiencing signs of aging, but are still producing high quality science data with a reasonably high probability of lasting through this funding cycle.

Weaknesses (minor)

- ☐ Although the information is scattered throughout, the proposal lacks a focused discussion of the Aura team's view of the most important problems currently facing the atmospheric science community, and Aura relevance to them, especially with regard to a continuation of the mission. This point was adequately addressed in the Aura presentation.
- ☐ Three of the four instruments appear to be experiencing significant instrument health issues.
- ☐ Since the orbit adjustment in 2008 bringing Aura into closer alignment with the other A-train missions, collaborations are certainly ongoing and increasing, but still appear to be not as extensive as one might have hoped. This issue was addressed in the instrument team presentation, and good progress was reported.

Core mission data product maturity;

❑ Poor ❑ Fair, ❑ Good, X Excellent.

Core mission data products are those developed, refined and validated and have reached a level of maturity that requires algorithm maintenance only. Some missions may have a large amount of products, so reviewer should consider this broadly and not for every product. Suggested rating for consistency:

Strengths

- ☐ The Aura team has done an excellent job of getting mature data products out to the user community in a timely fashion.
- ☐ The team has placed an appropriate emphasis on the validation of data products.
- ☐ The team has gone beyond original plans, and extended the core mission science products. This has greatly enhanced the value of Aura.

Weaknesses

- ☐ The development of several additional products (resulting from combining of radiances from two Aura instruments) was proposed in the 2009 Senior Review Optimal Budget. Most notable among these was the development of a combined TES/OMI tropospheric ozone product, which was given high priority by the 2009 panel. The proposal states that substantial progress was made in that area, but the only references appear to be a simulation study dating back to 2007 (Worden et al). In the presentation to the Senior Review panel, results were presented that show good progress.

Relevance to NASA Science Goals:

X Outstanding ❑ Very Good ❑ Good ❑ Fair ❑ Poor

The science section should explain how the proposed science program contributes to the ESD research objectives and focus areas as stated in the SMD Science Plan.

Strengths

- The mission is designed to address important questions that are at the heart of NASA's Earth Science mission: namely stratospheric chemistry and dynamics related to ozone depletion, tropospheric chemistry, and climate change.

Weaknesses

None

Technical and Cost

Additional comments, or defer/concur with subpanel forms. Include comments on the need for parallel funding sources, such as ROSES, that are required for supporting mission extension proposals.

Technical:

Aura was rated Medium-High Risk by the technical panel. This was largely because of issues with the aging instruments, not because of satellite health issues. These issues were brought up directly in the questions given to the Aura team, and were generally well addressed in their presentation given on 4 May. As a result, it was the general consensus of the panel that instrument health concerns were lessened and there was more optimism that all three remaining instruments would last beyond the current review cycle.

Cost:

The cost panel rated Aura Low Risk.

Strengths:

- The Aura mission (OMI) benefits greatly from support from KNMI (Netherlands), and FMI (Finland)
- The mission has made excellent use of the NASA ROSES proposal calls to augment funding.
- Although I am sure that the information is provided, it was difficult to discern the costs (in terms of FTEs) for the various processing activities (e.g., Level 1, Level 2) associated with the MLS and TES missions.
- 4.5 FTEs of support for Level 0-1 processing in both FY12 and 13 for the HIRDLS mission (which has been non-operational since March 2008) needs to be more extensively justified.

National Needs

Additional comments, or defer/concur with subpanel forms.

Other Comments

For example, was the proposal's quality and completeness sufficient for the review? If not, comment on what was missing and how it impacted the review.

CALIPSO

The CALIPSO satellite carries three instruments. CALIOP is a nadir-viewing two-wavelength laser that detects cloud occurrence, measures cloud optical depth, cloud phase, as well as other cloud properties. The IIR is a three-channel infrared radiometer, whose channels lie in the window region of the infrared spectrum. The wide-field camera provides a swath context to CALIOP'S nadir-only curtain view of the atmosphere.

The reviewers agree that the project should be continued as baselined. CALIPSO provides a unique set of data products for the research community that could not be duplicated by any other measurement platform. While some issues (e.g., calibration has been harder than expected due to intra-orbit calibration drifts) have arisen, the instrument team has been making good progress on improving the data products. In particular, the new version 3 algorithm is a tremendous improvement over version 2.

The instrument team needs to continue working to validate the data and to provide validation papers and uncertainty estimates to the user community. In particular, it is important to resolve factor-of-two disagreements in optical depth with MODIS. The instrument team also needs to continue developing level-3 and the near-real-time data products.

The technical review panel rated a mission extension as Medium-Low Risk for a two-year extension, because of the excellent shape of the spacecraft, with an increased risk for a four-year extension. The cost review panel rated mission extension as low risk. The national interest panel rated Calipso as high utility, and loss of the products would have a measurable negative impact on national agencies and organizations.

Findings:

XX Continuation of projects as currently baselined;

CALIPSO provides a unique set of data products for the research community that could not be duplicated by any other measurement platform. In particular, its ability to measure the locations and properties of thin clouds are unique, and are of particular value to the climate change community. While some previous versions of the products have had issues, the data are improving and the latest V3 release has addressed many of the problems in previous versions. Beyond science, CALIPSO products, particularly the NRT ones, provide wider value to society for things like monitoring volcano plume height. Instrument health is good, and the budget is appropriate for the proposed activities.

Scientific merits

❑ Outstanding **X Very Good** ❑ Good ❑ Fair ❑ Poor

Science section should describe the science merits of the program and specific contributions of the instruments. It includes current science objectives for the mission and a summary clearly focused on what has been accomplished in the past two years.

Strengths: These data are unique and important and have given us an important view of thinner clouds, particularly high-altitude cirrus. There has been considerable high-quality research achieved with these data. In addition, there are important synergies with the rest of the A-train, particularly CloudSat.

Weaknesses: The mission has had limited impact in advancing the main scientific issues the mission was designed to address. These scientific questions include: improved direct radiative forcing by aerosol; improved indirect radiative forcing; improved longwave fluxes at surface and in atmosphere; and improved cloud-radiation feedback.

Core mission data product maturity;

❑ Poor ❑ Fair, ❑ Good **X** **Very Good** ❑ Excellent.

The Version 3 dataset is a robust and scientifically useful data product. But some products remain at lower levels of maturity than would be desired (e.g., ice-water content). In addition, there is no level-3 data. Validation papers for all measurements do not yet exist and this is not only of concern but should be reviewed at the 2013 Senior Panel Review. There are also still important disagreements in the optical depth measurement with other sensors (e.g., MODIS) and this disagreement should be resolved.

For the level 3 data, the panel suggests that the team consider producing not just the mean values, but also higher-order moments. E.g., they could produce histograms of values in every lat/long box, such as was done in the MOD08 product.

Relevance to NASA Science Goals:

X Outstanding ❑ Very Good ❑ Good ❑ Fair ❑ Poor

The science section should explain how the proposed science program contributes to the ESD research objectives and focus areas as stated in the SMD Science Plan.

Strengths: The mission is designed to address important questions that are at the heart of NASA's Earth Science mission including:

1) How is atmospheric composition changing? What trends in atmospheric constituents and solar radiation are driving global climate? How do atmospheric trace constituents respond to and affect global environmental change?

CALIPSO observes the 3D distribution of clouds and aerosols. It has the ability to measure clouds that have not been well observed in the past, such as those in previously inaccessible

regions such as deserts as well as very thin clouds. It also provides a new tool to study the atmospheric distribution of aerosol.

2) How can predictions of climate variability and change be improved?

Cloud multi-layering information from CALIPSO and CloudSat allows the first reliable global estimates of the radiative impact of clouds on our climate. CALIPSO profiles enable more advanced and comprehensive tests of the models used to predict climate, and provide aerosol type information needed to test model speciation.

3) What are the effects of clouds and surface hydrologic processes on Earth's climate?

Cloud multi-layering information from CALIPSO – and in combination with CloudSat – allows improved estimates of the surface radiation budget. Aerosols can affect cloud brightness, cloud water content and precipitation. Aerosol profiles between and above clouds provide a new capability to characterize these effects.

4) How can weather forecast duration and reliability be improved?

Weather forecast models are beginning to incorporate aerosols to improve prediction skill and to forecast air quality. CALIPSO data are being used for model evaluation and the development of lidar assimilation schemes. CALIPSO data are being used to improve the parameterizations of clouds in numerical weather prediction.

Weaknesses: None

Technical and Cost

The CALIPSO mission extension is rated as Medium-low risk by the technical panel. The spacecraft is in excellent health and the CALIOP laser should remain healthy for a minimum 2-y extension.

Cost is also rated excellent and is very reasonable as base-lined.

National Needs

The National Interests panel rated CALIPSO as of high utility.

Other Comments

CLOUDSAT

Findings:

Continuation of project as currently baselined

Executive Summary

CloudSat is a single-instrument ESSP mission that flies the Cloud Profiling Radar (CPR) as part of the A-train constellation with the specific objective of optimizing coordinated sampling among various sensors toward generating combined products. The CPR is a nadir-viewing , narrow-swath, high-spatial resolution, W-band active sensor that enables detailed mapping of the vertical structure of clouds, hydrometeors and precipitation (rain and snow). Alone, CPR observations and retrievals can be used for process-studies to understand the role of cloud systems and precipitation in the Earth Radiation budget, to extract the vertical distributions of ice, liquid, and rain water, to characterize the microphysics of non-precipitating and precipitating clouds, to estimate rain and snowfall rates, and to map the dynamical morphology of convective clouds. CPR rainfall estimates stretched space-based radar rainfall estimates (TRMM PR) to the very light rainfall range, which is dominant in the water budget of high latitudes, mountainous regions and coastal areas. Integrated with A-train data (e.g. MODIS, CALIOP, CERES), CPR observations and retrievals can be used for unraveling multi-layered cloud systems, feedback studies of aerosol-cloud-rainfall interactions, and to elucidate the energy budget from the surface to the TOA. CloudSat data also provides a unique database for the evaluation of existing parameterizations of moist processes in numerical weather prediction models, and mesoscale models generally, over a wide range of conditions, and to draw testable hypothesis leading to improved parameterizations of microphysical processes and convection.

The scientific merits and relevance to NASA goals is outstanding as demonstrated in the proposal. Data products are ambitious and highly synergistic with other A-Train measurements. Advanced data products, however, have been slow to be released and we encourage the development and release of these data to be a focus of the upcoming extended mission, as well as further incorporation of validation results into improving and characterizing algorithms.

CPR sensitivity is expected to remain above nominal mission requirements for a minimum of an additional year, and at very low levels for another year. CloudSat has been operating for about five years, and could continue operating for 1-2 additional years depending on battery condition and power management strategy. At this time, assuming that recovery from the present temporary battery failure to stable operations is successful, the mission will require dedicated hands-on management of the platform function due to the likely need for direct (manual) management of battery recharge cycles and continuous monitoring of overall spacecraft condition. As part of this management strategy, and in order to realize 1-2 additional years of data collection, it may be required that CPR

operations be limited to day-time data acquisition only. Whereas this strategy will reduce sampling, the data collected can still be useful for case-studies, for integration with other day-time data from A-train sensors (e.g. MODIS), and for cross calibration with future sensors. Overall, it is understood that, despite the valiant efforts of the CloudSat team, given current technical challenges and known baseline constraints (e.g. battery life time under ideal conditions), the mission will reach end-of-life sometime in the next two years. During this period, it is expected that significant investment of time would be directed toward mission operations while the platform is functional, followed by release of updated CPR and combined constellation products to the broader community, including error characterization.
The panel's assessment is that the project be continued with baseline funding for the next two years and extended as needed to ensure that currently planned data sets for the integral duration of the mission can be released along with error characterization and uncertainty assessment.

Since the current battery condition is a determining factor of mission end of life, we suggest that, if the mission fails in the next year, resources should be allocated to complete product validation and data distribution. Given the potential large amount of resources that will need to be redirected to keep the satellite functioning in the near term, it is important that data distribution is still completed. The panel expects that an augmentation will be required in order to maintain the operation of the satellite without compromising the data analysis. This should be reevaluated during and at the next Senior Review – if mission operations prevented quality data distribution due to excessive time and resources required for satellite observations due to its current critical state, an augmentation of baseline funding would be supported by the panel to ensure that a quality data product covering the CloudSat lifetime is produced and distributed.

Scientific merits

Outstanding

Strengths

CloudSat has been extremely successful in addressing the very challenging problem of data processing and product validation including the production of consistent multi-sensor products that have already produced (note strong peer-reviewed publication record) and will enable detailed investigation of fundamental cloud and precipitation processes. It appears that a high level of maturity and readiness in terms of data processing and product validation has been achieved, and thus it is expected that scientific investigations and operational uses of the data will further pick up in the years ahead, even after the mission terminates. In particular, the CloudSat team has done an excellent job of not only accurately quantifying uncertainties in their data products, but also has performed detailed analysis to quantify the uncertainties in the errors themselves. This kind of uncertainty quantification is extremely important and valuable, especially in the context of widely used

techniques, such as data assimilation and ensemble modeling, which require quality estimates of uncertainties.

Among the many noteworthy science findings, some especially relevant include:

- a significant change in the estimates of the global average longwave forcing of the land surface which is one order of magnitude larger than the estimated sensitivity to a doubling CO2 scenario, and corresponds to roughly 5-8% of the atmospheric longwave forcing of land-surface processes (200-300 W/m2).
- a first climatology and geography of the structure of convective clouds which for the first time provides strong evidence of the role of tropical convective anvils in cloud-radiation- convection feedbacks.
- a first characterization of microphysical changes and radar reflectivity signatures of the evolution of precipitating cloud systems including the cloud-drizzle-transition;
- an evaluation of cloud and rainfall statistics in numerical models from global to cloud scale which explain well known problems in these models, and which show excessive rainfall in the models along with lack of drizzle, and thus higher intensity, especially for conditions when precipitable water or liquid water path values are modest to moderate. Because of the ubiquitous implications of incorrect representation of precipitation processes both in the atmosphere and for terrestrial hydrology, such validation studies provide clear metrics for the results improved models must demonstrate.
- Combination of CloudSat and CALIPSO observations suggest that aerosol -effects on cloud albedo are of secondary importance vis-à-vis the indirect effect, that is aerosol-cloud-rainfall interactions, as a function liquid cloud water content.

CloudSat focus on light rainfall, snowfall and characterization of ice processes is also a first, which should be of great value in anticipation of GPM. Exploratory operational applications (AFWA, ECMWF-data assimilation, Hawaiian air lines, NRL) are noted. There is no question CloudSat should provide very valuable data in remote regions (e.g. Central Pacific) where no other observations of storm structure, freezing level, etc are available. The visibility and recognition of such efforts is only expected to grow. Their upcoming release of snowfall rates, which have been validated during the StormVEX experiment in Colorado and a second validation experiment in Finland, will provide the first accurate source of snowfall rates. This product will be a major step forward for cold regions research. Overall, the panel commends the Cloudsat team for ongoing efforts concerning uncertainty characterization, and encourages them to incorporate findings from recent validation campaigns (i.e. StormVEX, SPartICus, MACPEX).

Weaknesses

Although it has been nearly five years since launch, some of the more advanced and synergistic data products are not yet available. Making such data available earnestly to a broad segment of the community should be of the highest priority to increase the utility and scientific impact of these data. This also relates to the field-testing and evaluation of uncertainty of mature products, though it is difficult to see how this can be accomplished without a much broader critical mass of scientists looking into the data. Finishing the data

products and releasing them during the extended mission should be a top priority, once the satellite operations are stable.

Value of data record and overall data continuity

The data record has exceptional value for basic research of water cycle processes. In the context of climate science, its full value can only be realized through long-term monitoring in order to address questions of inter-annual variability. Realistically, however, the existing data will be augmented at the most by two years. Besides its value for climate-scale research, data continuity is also very important for inter-sensor calibration and consistency as related missions phase in and out, notably TRMM and GPM.

Core mission data product maturity;

Data maturity is excellent for Level 1 and Level 2 core data products. Strong collaborations and consistency of subset products with TRMM (with linkages to future GPM) and unique synergies with A-train satellites, including innovative combined products of great scientific value [e.g.CALIPSO (CALIOP), and AQUA (MODIS)] are noted.

Maturity is Very Good to Good for level 2 enhanced products. Level 2C- Rain profile and 2C-Snow and 2C will be available in June 2011 to the Science Team and in the fall of 2011 to the community. Physical validation of the more challenging enhanced Level 2C snow and ice products from recently completed field experiments is ongoing.

Care must be taken that new science from recent validation experiments be incorporated into the CloudSat legacy data products. We strongly encourage the incorporation of these findings into product improvement and report updated uncertainties to the users.

Relevance to NASA Science Goals:

Outstanding

Strengths

CloudSat addresses core research objectives of the NASA ES SMD, and is unique in its capacity to address fundamental science questions concerning tropospheric moist processes and a broad range of climate sensitivities to cloud and precipitation processes, and feedbacks ranging from radiative forcing to aerosols to surface soil moisture.

Specifically, there is no question that CloudSat science data address the following objectives:

a- Understand and improve predictive capability for changes in the ozone layer, climate forcing, and air quality associated with changes in atmospheric composition - deep

convection is a major transport mechanism for water vapor and CO to the upper troposphere.

b-Quantify the changing distributions of extreme weather events and enable improved weather prediction – CloudSat data and science contribute already for model evaluation, data assimilation, and subsequent development of new convective and microphysical parameterizations, leading to improved prediction.

c-Quantify the key reservoirs and fluxes in the global water cycle and improve models of water cycle change and freshwater availability- Better understanding of atmospheric radiative heating and moist processes will lead to improved parameterizations of clouds and precipitation processes, better estimates of radiative forcing and pecipitation, and in turn better quantification of the surface energy and water budgets.

d- Understand the roles of oceans, atmosphere, and ice in the climate system and improve predictive capability for future evolution – Cloud feedbacks and convective processes are fundamental mechanisms of land-ocean-atmosphere interaction. Effective predictability hinges on getting them right in models. This is one of the core objectives of the CloudSat mission.

Weaknesses

None

Technical and Cost

The Technical Review Subpanel of the Earth Science Division (ESD) Senior Review Panel has identified a weakness on the CloudSat Mission Extension that stated [3]The spacecraft battery history (a one cell soft failure in Dec 2009) presents an increased possibility of failure during an extended mission, and is not addressed by analysis or trending. [3] On 17/18 of April 2011, at least one additional weak battery cell developed, causing an Under Voltage Level 3 (UV-3) trip into [3]Emergency Mode[2]. The transmitter (being powered on/off for contacts) and survival heaters are operational and the spacecraft is rotating about its X-axis with solar arrays canted +/-40 degrees. The mission team is attempting to charge the battery where the
spacecraft subsystems can be turn on. The battery is equipped with a spare Common Pressure Vessel (CPV) that can be brought online, however it can result on overvoltage that can risk some of the subsystems; therefore particular care would have to be exercise if the spare CPV is activated. The mission team discussed the mission status as a result of this battery anomaly and the plans address the problem during their presentation at the 2011 Senior Review Meeting. Although the Technical Review Subpanel members were not present to participate in the discussion, the Senior Review panel has agreed that the Technical Risk Rating may be higher than that assigned
by the Technical Subpanel before the CloudSat mission suffered this recent battery anomaly.

In summary, battery condition is a determining factor of mission end of life. Given the ongoing changes in mission operations there will likely be a need to adjust the budget to

reflect the need for more direct orbit-to-orbit management of battery recharge cycles. Even if the mission fails in the next year, resources will still be needed to finish product validation and data distribution. Given the potential large amount of resources needed to keep the satellite functioning, it is important that data distribution is still completed before the end of this mission. This should be reevaluated during and at the next Senior Review – if mission operations prevented quality data distribution due to excessive time and resources required for satellite observations due to its current critical state, an augmentation of baseline funding would be supported by the reviewers to ensure that a quality data product covering the CloudSat lifetime is produced and distributed.

National Needs

CloudSat was ranked as high utility by the national needs panel. Besides its specific contribution to the science through improved understanding, one major contribution at the national level is the provision of data sets that can enable the evaluation and further development of parameterizations of cloud, rainfall, and snowfall processes in numerical weather prediction and climate models.

EO-1

Findings:

X Continuation of projects as currently baselined;

The EO-1 demonstration mission supports two unique instruments: ALI and Hyperion that obtain high spatial resolution data for terrestrial monitoring. Launched in 2000, it has exceeded its original technology demonstration goals: collecting the only civilian high spectral resolution ("hyperspectral") imagery available and demonstrating a prototype sensor to the Landsat-8's OLI. At present, EO-1 provides advanced technology to meet continuity data for the LDCM and ASTER SWIR bands and operate as a prototype for the Tier 2 HyspIRI mission. It has expanded its science role in disaster monitoring since 2009 with its platform pointing ability, SensorWeb network, and ability for user-level tasking. Without the optimal 2015 budget, NASA will not be able to gap- fill between Landsat 7 and LDCM (Landsat 8), gap-fill for ASTER SWIR bands, and will lose the ability for spaceborne prototyping for HyspIRI. All components are predicted to function through 2015, although the orbit degradation will shift the crossing-time earlier. Orbit degradation and drift will have minimum impact by 2015 (about 1 hr early equator crossing time and about 200m lower altitude).

The initial evaluation by the Technical Review Subpanel raised concerns about bus ground faults and other trending data. The Senior Review Panel has accepted the Mission Team verbal descriptions of the spacecraft subsystems and has agreed that the Technical Risk Rating may be lower than that assigned by the Technical Subpanel prior to the EO-1 mission team's presentation. The National Interests Subpanel review indicated that several agencies find EO-1 data to be of very high utility, especially for disaster management.

The major concerns of the panel were with clarification and communication to the broader community of how data should be tasked and acquired, and completion/validation of Level 2 products.

The Senior Review Panel has several major suggestions for the mission team.

(1) The major concern among reviewers and users (via the National Interests Subpanel) was with satellite tasking and data acquisition and distribution. We suggest that the team develop a FAQ or Q&A webpage to guide users on data tasking, acquisition and delivery. The Applied Sciences directorate will assist with calling attention to this documentation. This is essential to clearing up confusion in the user community on what the appropriate "paths" are for users to acquire EO-1 data. We feel that this relatively small step could potentially increase EO-1 utility and use in the broader community.

(2) Hyperion and ALI use have increased considerably since the last Senior Review because of the distribution of EO-1 data through USGS. However, the last Senior Review strongly emphasized the need to more fully develop and distribute the Level

2 data. We emphasize that this remains a major need from the EO-1 team. This involves several things:

a. Relative to (1) above, the user community needs better guidance on the acquisition and use of Level 2 data.
b. Most importantly, Level 2 products need to be finalized with the collaboration-distribution process clearly communicated.
c. The Level 2 data processing stream needs to be clearly documented. Publications and citations should be provided to justify the approaches employed. For instance, guidance on atmospheric correction algorithms (of which there are three) needs to be explicit and documented. The EO-1 team should be encouraged to publish results from their Level 2 work.
d. To repeat, there would probably be a larger user community if the process for acquiring Level 2 was more clearly articulated ***and*** there was sufficient science documentation to assist users with use of the data.

(3) The Senior Review panel concluded that one reason for the delay in delivery of Level 2 data has to do with a lack of resources by the Mission Team. We acknowledge that EO-1 has a small team, and has done an exceptional job in automating acquisition and processing of EO-1 data using limited personnel resources. Although there is no augmentation requested for personnel, we feel that successful development of Level 2 data and development of a user community for this data would benefit from additional personnel and resources. We suggest that the EO-1 team seek augmented funding to assist with the continued and timely development of Level 2 products.

Scientific merits

❑ Outstanding X Very Good ❑ Good ❑ Fair ❑ Poor

The Senior Review Panel found that data from EO-1 Hyperion and ALI are of very high science merit. The panel unanimously agreed that EO-1 are of outstanding relevance to NASA science goals.

EO-1 lacks a Science Team and has minimal staffing to support the instruments. This historic consequence of its original status as a technology demonstration has limited the science products delivered by the mission. Since 2009 review, EO-1 data has been transitioned to distribution by USGS. Data are released at no cost by USGS, which has rapidly expanded use of the data. The project office successfully acquired more than 15,000 scene requests in the past two years, and over the course of the mission, has expanded from capturing 1 scene per orbit to its current capacity of 4 scenes. EO-1 has established international leadership in SensorWeb demonstration projects for disaster monitoring, fulfilling U.S. commitments to CEOS and GEOSS. It contributes to calibration/validation for Landsat and lunar irradiance. EO-1 has begun long-term repeat monitoring for 14 CEOS sites, selected for their ecological value (e.g., presence of flux towers), with new sites in Southern Hemisphere. A new science objective is to monitor wildfires and volcanoes for day/night using the SWIR Hyperion bands.

There is no other civilian instrument in space at present that makes measurements at the spectral/spatial resolution of Hyperion. In addition, the performance of ALI remains excellent, providing broadband data of a SNR and spatial resolution that is not currently in NASA's portfolio. For these reasons, the maintenance of EO-1 acquisitions is important to NASA's earth observing capacity. EO-1 data are flexible for many uses.

It is noted that EO-1 Hyperion is an important asset in preparatory activities for HyspIRI, and as such the EO-1 team has adapted its mission to address revised objectives stemming from the Decadal Survey.

Weaknesses – no major scientific weaknesses, although the panel did note some concerns.

Hyperion and ALI use have increased considerably since the last Senior Review because of the distribution of EO-1 data through USGS. However, the last Senior Review strongly emphasized the need to more fully develop and distribute the Level 2 data.
The Level 2 data processing stream needs to be clearly documented. Publications and citations should be provided to justify the approaches employed.

Overall, the project has had limited scientific publications, but that has increased over the past few years as the data became freely available. In general, Hyperion provides a type of imagery unavailable elsewhere, and as such is an important data source for the user community (e.g., disaster response). Hyperion will become more valuable as users become aware of the approach to acquiring the atmospherically corrected data.

Core mission data product maturity;
❑ Poor ❑ Fair, X Good, ❑ Excellent.

Summary: Data product maturity is outstanding for Level 1 data distributed through USGS, but Level 2 data handled by the Goddard team is on average "good," with some panel members indicating "fair" data maturity and others "very good." The general agreement was that clarification on the availability of, distribution of and science underlying Level 2 data would go a long way to receiving a higher rating for data maturity.

Within the scope of the budget, the development of level 1 data products on the LPDAAC site is valuable. The internal GSFC sites are not well advertised or known (GeoBliki site) and this limits the contribution from this instrument. However, it does provide a function as a prototype, which is perhaps all that is possible with their budget. They have a leadership position for international collaboration on disaster response. The mission also has the potential for a leadership position in developing a user-driven and cloud-based acquisition tasking.

We strongly encourage the mission team to develop the information necessary to communicate mission operations to the larger user community. It was noted by the mission team that they had just recently developed a flow diagram showing the various paths by

which EO-1 imagery can be tasked and acquired. This information should be up and front, perhaps provided to users through the EO-1 web page as a Q&A or FAQ, or perhaps as a dichotomous key. It is very important that users understand the levels of data prioritization and delivery.

It is also suggested that the mission team clarify for the user community the approach required for users to access Level 2 data, again possibly through a FAQ (with links to the science behind selection, for example, of an atmospheric correction algorithm). The development a user-driven system to process data to Level 2 is highly appreciated, especially considering the limited resources available to the EO-1 team. More clarity on Level 2 products to the user community is needed.

Relevance to NASA Science Goals:

X Outstanding ❑ Very Good ❑ Good ❑ Fair ❑ Poor

Strengths-

The proposal provides a very good description of the mission relevance to the NASA science questions and Applied Science Program. The data from EO-1 provide an essential earth science data set not met by other missions.

There has been a rapid increase in use of EO-1 data since USGS began distributing it. As such, the number of publications is also increasing.

Imaging spectroscopy data are capable of providing many important measurements for many applications. As such, with EO-1 Hyperion it is difficult to point to "one specific thing" that it is best at! However, its flexibility for measuring multiple environmental and ecological properties must be emphasized and publicized.

Weaknesses

ALI data were not addressed with sufficient depth, but this is an underappreciated and very valuable broadband multi-spectral data source. ALI is an excellent product, especially as a bridging data source for LDCM. The team really should have emphasized the quality of ALI data, in particular the SWIR bands as replacement for the failed ASTER bands.

Greater detail is required on the decision-making process for establishing which data products will be supported, especially the Level 2 on-demand products from GSFC.

The panel commented on how the EO-1 team remains somewhat under-supported, and as such operates much like a PI-driven project. Additional personnel support would help make EO-1 data better available to address a wide range of application and climate-science relevant questions.

Technical and Cost

Summary: Subpanel considered the mission "high risk" but this was offset by the presentation by the mission team. The panel was reassured by the mission team that all systems are performing nominally, and that even with the loss of propellant the instruments on EO-1 can continue collecting useful data, albeit at an earlier equatorial crossing time and from a lower altitude.

The Technical Review Subpanel expressed concerns about instrument performance, anomalies and trending. Their original risk rating was "high." One weakness identified was "Chassis ground current excursions, which could cause a potentially serious failure, have occurred randomly, with no root cause identified." The EO-1 mission team showed at the 2011 Senior Review Meeting that the chassis ground current excursions have diminished and potentially disappeared. They explained that they have identified the likely mechanism causing it (solar array mechanism).

The Subpanel also recommended to the ESD Senior Review Panel to request information on the health of spacecraft subsystems of the EO-1 mission. As a result, EO-1 mission team discussed the spacecraft status during their presentation at the 2011 Senior Review Meeting. The Mission Team stated that the spacecraft subsystems are operating nominally and since there has not been significant deviation from expected trends, they did not present trending data. The mission team collects and examines spacecraft subsystems' trending data and explained to the Senior Review Panel that no significant issues have been observed in the subsystems. Although the Technical Review Subpanel members were not present to participate in the discussion, the Senior Review panel has accepted the Mission Team verbal descriptions of the spacecraft subsystems and has agreed that the Technical Risk Rating may be lower than that assigned by the Technical Subpanel before the EO-1 mission team's presentation.

Optimal Budget

Optimal budget proposes continuation of the data records until 2015 rather than terminating in 2012. This allows bridging between Landsat 7 and LDCM and further prototyping of some HyspIRI data products.

National Needs

Subpanel found some agencies (USDA, USGS) had high demand for EO-1 products while it had limited impact on other agencies. The National Interests Panel emphasized that EO-1's applied and operational uses are primarily focused on disaster response for various United States Government Agencies and supporting National and International Relief Organizations/Agencies. The panel rated EO-1 of high utility, although it ranked the lowest of missions under review. Key applications include mapping of crop residue, post fire-burn severity mapping; forest health; tornado path identification; flooded areas and volcanoes.

GRACE

Findings:

X Continuation of projects with augmentations to the current baseline

Optimal budget component 1: additional operational effort to manage batteries appears to be essential for maximizing mission life and maintaining scientific utility of data.

Optimal budget component 3: Evaluate an approach for a reduced accuracy single satellite mission.

For the past nine years GRACE has provided a synoptic view of large-scale temporal variations of mass distribution within the Earth system, resulting in truly unique constraints on climatically important processes such as mass exchange between ice sheets and the oceans, mass redistribution within the oceans, and large scale variability in precipitation and water availability. The mission is also of operational use, especially through the "aeronomy co-experiment", which is providing radio occultation data for assimilation into atmospheric models, and unique and very valuable data on atmospheric neutral density and thermospheric winds. The panel unanimously supports continuation of the mission, with funding of two of the optimal budget requests, to support enhanced battery management, and to develop plans for using a single GRACE satellite for lower resolution time-variable gravity solutions.

Scientific merits

X Outstanding ❑ Very Good ❑ Good ❑ Fair ❑ Poor

Science section should describe the science merits of the program and specific contributions of the instruments. It includes current science objectives for the mission and a summary clearly focused on what has been accomplished in the past two years.

Strengths

The mission has delivered top quality data products for 9 years, resulting in nearly 800 peer-reviewed publications across an unusually broad range of Earth science sub-disciplines, including; changes in ice sheet volume and their impact on sea level, temporal variability and trends in precipitation and water storage on land, separating steric and volume components of sea level variability, constraining heat storage in the deep ocean, helping to define the time-mean ocean circulation, and improved understanding of mantle viscosity and glacial isostatic adjustment. GRACE provides a unique spatially integrated view of water mass exchange between oceans, land and ice sheets--critical, and otherwise unavailable, information for a range of scientific studies of global climate change. A significant number of the most important scientific results from GRACE have been

published over the past two years, as laid out clearly in the senior review proposal, where roughly two-thirds of the scientific papers were published in 2009-11.

Quick-look gravity fields provided by the mission are also starting to be used in more operational applications, e.g., for assimilation into hydrological models and to support analysis of regional hazards such as floods and drought. Improvements in the static reference gravity field resulting from GRACE were rated to be of high value by a number of operational agencies. In addition, ancillary data obtained as a byproduct of mission operations are being used for operationally. Examples of this include use of GPS occultation data to retrieve profiles of atmospheric temperature and total electron content, which are in turn assimilated into atmospheric models being run by ECMWF and a number of other forecast centers, and estimates of atmospheric neutral density and thermospheric winds, which were cited as a unique and highly valuable data resource by NOAA-NESDIS. Most of these operational applications have been developed over the past two years.

A number of processes studied with GRACE (melting of ice sheets, changes in deep ocean heat storage, depletion of aquifers) exhibit variations at a range of time scales, and understanding these processes will require long, stable, and reasonably continuous records. The increasing operational applications provide additional justification for extension of the GRACE mission.

Weaknesses

The panel did not find significant scientific weaknesses. By far the biggest concern is that batteries have degraded already to the point where a small fraction of data is potentially degraded, although so far apparently only slightly. Conservative approaches to battery management may allow the mission to maintain high data quality most of the time. Further degradation of the batteries, with the possibility of increasingly large gaps in the nominal data stream is of at least some concern. We discuss this further below.

Value of data record and overall data continuity

Continuity of the data record has so far been excellent. The problems with the batteries will result in gaps in the data record (or at the least times of reduced data quality) initially of approximately one month out of every six. Even with these gaps the GRACE *data* will remain of great value for many, if not most applications. Because the battery anomaly is restricted to one of the GRACE platforms, data from the aeronomy co-mission (e.g., radio occultation, atmospheric neutral density) would not actually be interrupted.

Core mission data product maturity;
□ Poor □ Fair, □ Good, x Excellent.

Core mission data products are those developed, refined and validated and have reached a level of maturity that requires algorithm maintenance only. Some missions may have a large amount of products, so reviewer should consider this broadly and not for every product. Suggested rating for consistency:

Other than a number of basic Level 1 products (which require substantial expertise to use for geophysical applications) there are so far only two core mission products: an average reference global gravity field, and time variable deviations (monthly time resolution) from this reference. Both of these products are provided as series of spherical harmonic coefficients. Three slightly different versions of the level 2 products are available, produced by the three institutions involved in GRACE DA (UTCSR, GFZ, JPL). These products are of high maturity, with uncertainties well established, so the majority of the panel rated core mission data product maturity outstanding.

However, a significant minority felt that the rating should be lower (very good) because regional scale mascon solutions, which are potentially of broad scientific use, have not been validated and brought to maturity as a core product. A number of these regional mascon solutions have been produced by ROSES funded investigations (mostly at JPL and GSFC), which have used these for many of the most exciting scientific applications. However, these solutions have not been validated or systematically compared to the global solutions produced by the mission, and are thus not mature enough to be maintained as a core product. The importance of doing such validations was a finding of the 2009 senior review, and the GRACE mission team has begun, but apparently not completed, development of a validation scheme based on inter-comparison of the various solution approaches on a high-fidelity simulated data set. The need to redirect mission resources to battery management appears to have delayed progress on this task. The mission seeks funding through the optimal budget to further develop the validation scheme, and to support users in applying this to regional mascon solutions. The optimal budget also includes funding for further development (into a Level 2 product) for quick-look gravity solutions for operational activities. Most of the infrastructure for production of the quick-look products has already been developed, and at least some tests in operational settings have been reported. However, the quick look products are not yet robust or mature.

The panel felt that further development of these new Level 2 data products was important, but questioned if the Senior Review was the appropriate venue for funding development of new products.

Aeronomy co-mission data used by observational agencies are all obtained from Level 1 products, which are fully mature.

Relevance to NASA Science Goals:

X Outstanding ❑Very Good ❑Good ❑Fair ❑Poor

Strengths

GRACE is making valuable contributions in four ESD research focus areas: (1) Climate Variability and Change; (2) Water and Energy Cycle; (3) Earth Surface and Interior; and (4) Weather. Contributions to the first two are especially significant. With regard to the first, GRACE allows monitoring of mass balance in large continental ice sheets (Greenland and Antarctica) and in glacial systems in mountainous regions, providing spatially resolved data on cryospheric processes, and constraining this critical component of sea level rise.

GRACE also provides information on mass redistribution within the oceans, complimenting altimetry data in studies of ocean processes. In combination with altimetry and drifter data, GRACE also has the potential to help constrain heat storage in the deep ocean. With regard to the second, GRACE provides estimates of variations in water storage in continental areas in response to variations in precipitation, and water use by humans. The information GRACE is providing can only be obtained from the sort of high-precision space geodesy that NASA is capable of.

Weaknesses

No weaknesses with regard to relevance.

Technical and Cost

By far the major concern of both the scientific and technical subpanels is the weakened state of the batteries. The current situation requires very labor-intensive power management strategies; funds to support these activities have been included in the optimal budget. Over the past year, the necessary funding has come from delaying (or eliminating) other planned mission activities (refurbishing the mission simulator). However, at the review the mission team stated that it would not be possible to shift project costs in a similar way in the future. We thus believe that it is essential to fund this component of the proposed optimal budget to minimize risk of premature failure, or serious degradation of future data. The panel also supports element 3 of the optimal budget, to develop and validate strategies for using a single GRACE satellite to maintain time-variable (though significantly lower spatial resolution) gravity solutions.

At least some of optimal budget element 2, which seeks funds for further development of Level 2 data products, would (apparently) have been pursued over the past year if the significant efforts on power management had not been required, and are thus also linked to the battery failure issues. The panel felt that these activities were not crucial to mission extension, and, as with other requests for funds to develop new products, should probably be funded competitively through ROSES.

National Needs

Defer to subpanel forms.

Other Comments

The GRACE mission has to be viewed as somewhat high risk—the weakened power system may fail, or result in significantly degradation of data quality within the next two years. However, GRACE is presently producing data of extremely high value to the scientific community, and the panel has little doubt that the mission should be extended, with enough support to optimize chances for success going forward. This situation could change before the next Senior Review, even without a complete "catastrophic" failure.

NASA should be prepared to review the situation and make appropriate adjustments even over the next two years. Given the value of the data, we would also support funding for years 3-4, with the understanding that future funding might be reconsidered in the next Senior Review, depending on satellite health.

JASON-1

Summary:

Jason-1 should be approved for mission extension at the Optimal Funding Scenario. That is, Jason-1 should remain in its current interleaved orbit with OSTM until AltiKa data can be validated (presumably mid-2012) and then maneuvered to the proposed 1287 km geodetic orbit. Jason-1 continues to acquire high quality data and the interleaved data of Jason-1 and OSTM are supporting important operational applications and new scientific investigations of mesoscale variability. Additional science contributions will occur when Jason-1 moves to a geodetic orbit to provide estimates of the marine geoid and ocean bottom topography.

The panel acknowledges that the mission team responded well to the 2009 Senior Panel findings, developing a water vapor product (that will be continued) and a reasonable "conservative decommissioning plan", the geodetic orbit mission.

While the panel clearly recognized the scientific value of continuing the Jason-1 mission, there was concern regarding the overall health of the Proteus spacecraft and the mission's ability to respond to future failures; several questions were presented to the mission team and discussed during the mission presentations. The panel thinks that the proposed response scenarios are reasonable and acceptable, but encourage the team to continue to evaluate the scientific gains of obtaining additional data against the potential risks on maintaining Jason-1 in the interleaved orbit.

Findings:

X Continuation of projects with augmentations to the current baseline

Since the 2009 Senior Review, Jason-1 has continued to provide high quality data and meet mission objectives. Core science products are mature and support both the science and operational communities. The interleaved orbit of Jason-1 and OSTM has resulted in greater coverage and higher spatial resolution of precise sea surface height measurements. Core data records derived during the interleaved orbit will help improve understanding of mesoscale features. Additional science contributions will occur when Jason-1 moves to a geodetic orbit to provide estimates of the marine geoid and ocean bottom topography. Jason-1 also serves as a science backup mission should OSTM fail. Instruments remain healthy.

Scientific merits

X Outstanding ❑ Very Good ❑ Good ❑ Fair ❑ Poor

Strengths: Jason-1 is a major contributor to the 19 years of climate data records from satellite radar altimeters. Jason-1 has provided precise measurements of ocean surface topography as a continuity mission to the TOPEX/Poseidon Mission and supported the calibration and validation of the follow-on Ocean Surface Topography Mission (OSTM).

Results from these three altimeters has made critical contributions in ocean sciences over the past two decades as evidenced by the over 3000 publications. The combined data of Jason-1 and OSTM in an interleaved orbit provides higher spatial and temporal coverage that has lead to unique scientific achievements/discoveries and new operational support. The proposal documents recent scientific discoveries of ocean features made using multi-altimeter data that will benefit from the proposed continuation of the Jason-1 interleaved mission. These higher resolution data sets are also increasingly being applied to coastal ocean studies, where an important contribution is gaining a better understanding how rising sea levels will impact coastal populations. Continuation of the mission is strongly justified, both to maintain the current spatial resolution and as a scientific backup to OSTM.

The mission was very responsive to previous senior review suggestions, improving use of troposphere water content data from the radiometer in atmospheric applications, and developing an innovative end-of-mission strategy. The plan to move to a long-repeat orbit will result in a substantially improved resolution of the marine geoid. This would result in significant improvements in estimates of deep ocean topography, resolving many presently unknown seamounts and other geologic features on the ocean bottom. This would be a new and important contribution from Jason-1. Improvements in bottom topography will be of value in ocean modeling (e.g., allowing improved representation of topographically induced mixing), in naval operations, and in solid Earth dynamics. Improvements in the geoid would also increase the value of historical altimetry data such as from GEOSAT, and be useful (at least initially) for interpretation of the planned SWOT mission.

Weaknesses – no major scientific weaknesses however several spacecraft system components are "single string."

Value of data record and overall data continuity – Continued operation at the current orbit will increase data continuity for mesoscale studies and investigations / operational use that require high-resolution observations. Data continuity has been excellent. Indeed, a major argument for continuation of Jason-1 is to maintain the robustness and continuity of sea-level and other climate data records.

Core mission data product maturity;

❑ Poor ❑ Fair, ❑ Good, X Excellent.

The main data products used for scientific research (GDR, IGDR) are very mature and stable, and have been thoroughly tested and validated. Jason-1 and OSTM data products are fully integrated and have been cross-calibrated and cross-validated.

Relevance to NASA Science Goals:

X Outstanding ❑ Very Good ❑ Good ❑ Fair ❑ Poor

Strengths- The proposal provides a very good description of the mission relevance to the NASA 4 science questions.

Weaknesses- none

Technical and Cost

Primary technical issue: the transceiver is operating nominally, however is single string. If there is a transceiver failure, the mission team can maneuver in the blind. However this is an undesirable scenario.

The Technical Review Subpanel of the Earth Science Division (ESD) Senior Review Panel has identified a weakness on the Jason-1 Mission Extension that stated "The PROTEUS spacecraft has suffered several major and minor failures that have eliminated the designed as-launched redundancy, making Jason-1 effectively a ten-year old, single-string bus that cannot survive a further failure in critical components". This raised concern to the Senior Review Panel as Jason's-1 present orbit is a desirable orbit for future generation ocean altimeters. The Jason-1 mission team during their presentation at the 2011 Senior Review Meeting explained that if any of the subsystems identified by the Technical Panel failed, they could decommission the spacecraft to a different orbit. However, if the S-band transceiver fails decommissioning will be very challenging.

National Needs

The National Interests Sub-panel ranked Jason-1 data as "High-Utility" and provided the following:

Jason-1 data products are central to oceanographic & weather communities, but reduced utility for other communities. The loss of Jason-1 alone would have a measurable, but not significant negative impact on operations, since OSTM is collecting; however, the loss of Jason-1 and OSTM would constitute a significant negative impact.

Only Jason-1 and OSTM observations have sufficient accuracy to detect ocean changes at global and basin scales. Increased spatial resolution of sea surface height data is developed when combined with OSTM data. Jason-1 SWH data are also used by NHC marine forecasters to provide analyses of the wave field associated with tropical cyclones. USDA's Foreign Agricultural Service (FAS) uses JASON-1 as part of its Global Reservoir and Lake Monitor to estimate reservoir and lake surface altimetry globally. This is especially important since many countries are not willing to share their hydrological data for their lakes and reservoirs with USDA.

Other comments

The reviewers note that the Jason-1 proposal was well written and presented – the team should be commended. Answers to panel questions were well presented and clearly addressed the issues or concerns raised by the questions provided prior to the mission presentation and those posed during the discussion.

OSTM

Findings:

☒ Continuation of projects as currently baselined;

OSTM is the 3rd in a series of satellite-borne altimeters designed to study ocean circulation and its effects on climate. This series has been highly successful meeting all of its goals providing a global high quality time series of global sea surface topography for the past 19 years. Barring an unexpected failure of OSTM, its continuation will extend this important time series for climate change until, at a minimum, the launch of the next altimeter Jason 3 in the series. OSTM altimeter observations are also playing a key role in the analysis of other upper ocean processes in physical oceanography and the science panel supports continuation. In addition, the overall rating for OSTM by the National Interests Panel was Very High, the Technical Review of OSTM ranked the overall risk as Low and the only issue raised by the Cost Panel was the lack of a detailed budget narrative. This issue was raised by others as well which prompted Question 4 to the OSTM team. The response was adequate.

Scientific merits

☒Outstanding ❑ Very Good ❑ Good ❑ Fair ❑ Poor

Strengths The proposal presents a very strong case for the fundamental science related to this mission and what has been accomplished (Sections 1.4.1 and 1.4.2). A number of other interesting applications in oceanography are presented.

Weaknesses The Science Panel felt that the OSTM team would benefit by facilitating access to science-grade higher level terrestrial products (rivers, lakes, estuaries). This includes ease of access – an interface and data formats better adapted to terrestrial users - as well as error and uncertainty characterization. The Panel recognizes that this is not part of the core mission but it is an opportunity that addresses core strategic objectives of NASA ESMD, specifically with regard to the closure of the water budget of large river basins and assessment of water cycle trends from lake level data.

Value of data record and overall data continuity The data record is extremely valuable. Continuity is also crucial given the need to cross calibrate satellites and the need for 20-60 year records to establish global trends in all parts of the ocean.

Core mission data product maturity;

❑ Poor ❑ Fair, ❑ Good, ☒Excellent.

Include comments on:

- Redundant or complementary products not noted by the individual mission proposals
    - Although Jason 1 also measures sea surface topography – the core product for OSTM – it is in an interleaved orbit with OSTM which increases the overall resolution of the generated surface topography fields. This means that although for some applications, such as determination of large scale circulation, one might argue that the products are redundant, for others, such as those related to mesoscale ocean processes, the data are not redundant, but rather complimentary.

- The proposed definition of core data products for each mission, including any suggested changes;
- Justification of the level of science support required to maintain the quality of these core data products.
    - The science is justified.
- Potential collaborations between missions where synergies may exist;
    - There is demonstrated synergy with ocean vector winds, SST, and gravity missions, as well and the ARGO program. NOAA and the Navy use the data operationally, and there is a solid collaboration with EUMETSAT.

Relevance to NASA Science Goals:
☒ Outstanding ❑ Very Good ❑ Good ❑ Fair ❑ Poor

Strengths This program is a tight fit with NASA objectives.

Weaknesses No weaknesses in this regard.

Technical and Cost

National Needs
The impact on ENSO forecasts has a positive impact on the US economy.

Other Comments

There were three sections of the proposal that the panel found to be weak: portions of the science section, the Budget Narrative and the section that dealt with the interaction between JPL, NOAA, CNES and Eumetsat. The panel feels that the latter two issues were addressed adequately in the May review. With regard to the science section, while the panel rates the science capabilities and activities as excellent, we note that the quality of the reporting of the state of the science is mixed. Some of the descriptions are excellent. Some results are presented in a manner that is so incomplete as to strongly suggest alternative interpretations. Other reported results misrepresent the state of the science. For example, the stated cause of the SST connection to the upper troposphere is a controversial (and in this case not well accepted) hypothesis that is presented as truth. The quality of the reporting is spotty for a proposal that is intended to largely support science activities. Since we expect OSTM to be evaluated in the next several Senior Reviews, we encourage more careful statements in future proposals.

Finally, in the May Panel Review, the PI raised a serious concern with regard to the transfer of future altimeter missions from NASA to NOAA. Although he felt comfortable that NOAA would manage these missions well for NOAA's needs, he is concerned that their focus will be on the short term while one of the major values of the altimeter record is in addressing the long term; i.e., climate change. To achieve a record of sufficient quality for this, careful attention must be devoted to continued calibration and validation of the time series. The Panel shares the PI's concern in this regard.

QuikSCAT

Summary: The proposal is to calibrate Ku-band scatterometer backscatter, from ISRO scatterometers and other future scatterometers, to be consistent with QuikSCAT backscatter; and to produce climate quality winds and ice products that continue the high quality QuikSCAT time series. This approach is viewed as the only way to get science (and climate) quality data from ISRO data, as the ISRO mission is directed at operational quality data, and without appropriate calibration is not useful for climate and cryosphere research. ISRO is cooperating with these goals. Chinese groups launching future scatterometers have also expressed great interest in such collaboration. Intercalibration requires roughly 90 days for each satellite in order to identify and account for drift, which allows several satellites to be intercalibrated each year. QuikSCAT has been extremely stable in its calibration, and the radar instrumentation shows no indication of either calibration drift or deterioration worthy of concern; therefore, long-term stability of the QuikSCAT backscatter is anticipated and makes this instrument ideal for calibration of future Ku-band scatterometers. This approach allows for a common model function to be applied to the intercalibrated backscatter, which is important for long-term consistency.
The baseline proposal includes funding for satellite operations through FY12 and 13, with data analysis support for FY14 and 15. The optimal (augmented) funding differs only in adding support for satellite operations through FY15. The science panel unanimously supports the optimal funding, as a very strong case has been made for the science, and the National Interest Panel found strong support for this mission. The weak point is the status of the satellite: the technical panel rates the risk of failure as high, but notes that the status for critical elements of the satellite have functioned well for the last two years. The QuikSCAT radar is currently functioning very well, with considerable redundancy. Given the strong support for the mission science and national interests, and the high quality and stability of the QuikSCAT data, we strongly support the optimal funding, subject to review by the 2013 Senior Review Panel.

Findings:

- **X** Continuation of projects with augmentations to the current baseline; list them
    - The baseline plan is clearly needed for research and climate quality, inter-calibrated, data from other scatterometers. The proposed activities are also needed to produce data of desired quality for a wide range of operational activities as indicated by the National Interests Panel. Continued operation past 2014 is highly desirable, with the goal of intercalibration of the other scatterometers planned to be on line at that time, and to account for calibration drift in the OceanSat-2 (OSCAT) and other scatterometers. The proposed augmentation is for FY14-15 and is necessary for data continuity, and will be of great advantage for science (including climate and cryosphere) and operational applications. We propose that the augmented budget be approved subject to review by the 2013 Senior Review Panel.

Scientific merits

X Outstanding ❑ Very Good ❑ Good ❑ Fair ❑ Poor

Strengths: Science and climate uses of vector wind and backscatter data are strong and clearly identified. The soon to released wind product is much better than the existing product, and should contribute to additional science capabilities, particularly for wind and stress derivative fields (e.g., curl and divergence). In addition, data from QuickSCAT comprises the major source of information about the increase in percentage of first year sea-ice in the polar regions, and is therefore critical to the cryosphere community. The contributions (direct or indirect through intercalibration with other scatterometers) to NASA goals are well identified: a long list of applications is given in the report, and will not be repeated here. A long-term plan to keep the data intercalibrated at a climate quality level of accuracy is sound, and is similar to the EUMETSAT plans for the intercalibration of C-band scatterometers. The intercalibration with OSCAT backscatter and winds is an ongoing effort, and is progressing. Ongoing collaboration with non-NASA groups (e.g., Remote Sensing Systems and Brigham Young University) is leading to improvements in the NASA products and producing additional high quality products, at a reduced cost to NASA. These additional products have a wide range of users.

The proposed signal to noise evaluation will lead to improvements in scatterometer products, and help in the design of future scatterometers. This would not be practical with a fully functional (rotating) SeaWinds instrument.

Weaknesses: there is only one QuikSCAT to be used to intercalibrate multiple missions in the 2013 to 1016 period. The response to the panel explained how roughly 90 days was required for each intercalibration, which would allow for intercalibration with at least 4 instruments per year. Therefore this concern is no longer considered a weakness.

Value of data record and overall data continuity: The technical issues related to the continuity of the data record are clearly given for ocean vector winds, ice and backscatter. The impacts of a lack of continuity in data quality are not well described; however, several studies strongly suggest that the discussed accuracy is indeed required for many applications, including operational activities. In some ways, the plans to obtain mission to mission intercalibration are far better in this plan than in the original planning for the mission. That is particularly impressive, and is critical to obtaining multi-decadal climate-quality data records. The consistency with GCOS principles is also well stated.

Core mission data product maturity;

❑ Poor ❑ Fair, ❑ Good, X Excellent.

Note: The maturity of the QuikSCAT data (backscatter, winds, and ice) is excellent. Since the descriptions for the above ratings are applicable to techniques that are very well planned, and for which preliminary results are excellent, but are still being applied, we

have taken the liberty of assuming these ratings apply to the quality of the plan for producing intercalibrated data from other satellites.

- The QuikSCAT product is truly unique in the ability to be used to intercalibrate current and future Ku band scatterometers. This task is of vital importance to the production of a climate quality record for backscatter (critical for ice and land uses) and for ocean vector winds, which play many roles in understanding ocean/atmospheric coupling and objective in NASA's 2010 Science Mission Directorate Science Plan
- The core products have been modified following the plan of the last senior review, which covered possibility that the antenna would cease to rotate. The original products are now produced indirectly, through climate quality intercalibration with other Ku-band scatterometers, such as India's OceanSat-2 scatterometer (OSCAT). More refined versions of these products are being developed: the data are being better utilized than in the past. However, these improvements are ongoing, and must be periodically reevaluated to account for drift in the other scatterometers (QuikSCAT has been extremely stable, and shows no indication that this stability is degrading). The calibration of OSCAT continues, requiring roughly 45 days for each of the two polarizations. This time might be reduced as the intercalibration techniques become routine.
- The level of science support has been shown to be highly productive in terms of science papers and collaboration with universities, private companies, and other agencies in the US. The National Interests Panel findings demonstrated the desire for these higher quality data produced through the intercalibration process, which in the next few years is only likely to be produced through the NASA/JPL in collaborations with partners. The partnerships with NOAA and ISRO appear to be strong and effective. The cryosphere community uses QuickSCAT for sea ice information more than any other sensor, as reflected in peer-reviewed literature.
- Ocean vector winds (i.e., produced with other scatterometers, in collaboration with other countries, intercalibrated with QuikSCAT) are closely linked to variability in sea surface topography, ocean color, and sea surface temperature, all of which are of interest to NASA. There is also some synergy with gravity missions, in connection with sufficiently long and spatially large perturbations in the curl of the winds. NOAA and other national interests will also make use of these vector wind observations to improve forecasts and improve the safety at the high seas. The proposed tasks also benefit from international collaboration with India and China. The current status of collaboration with India is excellent. Earlier discussion with the two relevant Chinese groups where enthusiastic.

Relevance to NASA Science Goals:

X Outstanding ❑ Very Good ❑ Good ❑ Fair ❑ Poor

Strengths: The redirected QuikSCAT mission directly or indirectly addresses the following Earth Science Objectives in NASA's 2010 Science Mission Directorate Science Plan:

2. *Quantify the changing distributions of extreme weather events and enable improved weather prediction:*

- The intercalibration and reprocessing of OSCAT data will be very important for this task
- The improved accuracy in rain will be a huge improvement

4. *Quantify the key reservoirs and fluxes in the global water cycle and improve models of water cycle change and fresh water availability:*

- Wind speed (relative to the surface, as measured by a scatterometer) is one critical component to determining the evaporation.
- The surface wind convergence can be linked to precipitation
- Surface winds and boundary-layer models have been used to determine transport of water vapor

5. *Understand the roles of oceans, atmosphere, and ice in the climate system and improve predictive capability for future evolution:*

- Vector winds are key to many coupled air/sea interaction processes, and can be linked to the upper troposphere (through wind and SST coupling) and to the deep ocean (through Sverdrup flow).
- The growing sea ice record, including icebergs, is also clearly of importance

7. *Enable the broad use of Earth system science observations and results in mitigating and adapting to a changing environment:*

- The surface wind vector winds are critical to the ocean/atmosphere coupling processes, which are key for understanding how severe weather impacts coastal locations in a changing climate. The changing likelihood of these extremes will have the largest short and medium term impact on coastal and near coastal communities.

Weaknesses:

(1) There is only one QuikSCAT to be used to intercalibrate multiple missions in the 2013 to 1016 period. JPL has shown that roughly 45 days are required for intercalibration of each of the two polarizations, meaning that four intercalibrations could be carried out each year. This assessment does not consider time saved through intercalibrated of other scatterometers with each other; however, it is clear that intercalibration with QuikSCAT is a critical part of the process. Therefore, this is no longer considered a weakness

(2) There is a risk of failure of two critical components assessed at a high level of risk; in other cases, mitigation strategies have been planned; the risk for the radar is low, and. The likelihood of completing another four years of mission is estimated at 50%.

Technical and Cost

- The baseline costs are easily justifiable. Without this activity we will not have a data record of suitable quality for many shorter term science objectives, much less for climate questions.
- The extension of these activities past 2016 is highly desirable, as the planning for OSCAT indicates it will not be available as a transfer, nor is it nearly as stable as QuikSCAT. Therefore, the request for additional support to keep QuikSCAT functional into the period with several more Ku-band scatterometers is quite reasonable on the grounds that it will be needed to preserve the continuity in the fundamental data record and continue the derived ice and vector wind products at the desired quality.
- The Technical Review Subpanel of the Earth Science Division (ESD) Senior Review Panel has identified a weakness on the QuikSCAT Mission Extension that stated [3]The QuikSCAT spacecraft is approaching 12 years in operation (design life was three years), has suffered several faults and degraded components, and seems unlikely to survive the next several years without incurring a mission-ending failure.[2] The degraded components have been operating with the same level of performance since the last Senior Review (2009). Although the QuikSCAT spacecraft has suffered several faults and degraded components (other than scatterometer's antenna spin mechanism) and may incur a mission-ending failure, it is also probable that the spacecraft can operated at this level for the next 2 years; therefore the Senior Review panel feels that this is a worthwhile risk.

National Needs

- The data will be highly useful to several national agencies: several parts of NOAA for forecasting weather, high seas, hurricane centers, and coastal weather offices, as well as the national ice center
    - The results from the National Interests Panel where nine assessments of very high or high utility, and three of some utility. This rating is much better than for most of the other satellites under review.
- The data should also be quite useful for accessing the natural variability and interannual variability in offshore wind power.

Other Comments

The proposal was very well written, and the authors should be commended for the clarity and focus. The proposal would benefit from more support for the need for climate quality data as defined in the document. There are several reports and papers from which this support could be taken. During the panel review process, the panel recognized the need for additional information about the health of the instrument and the satellite. Information on the trends of instrument health would be beneficial (perhaps required) for future reviews. The responses provided at the review were very helpful and greatly appreciated.

SORCE

Executive Summary

SORCE (Solar Radiation and Climate Experiment) launched in January 2003 carrying 4 instruments measuring total solar irradiance (TSI) and spectral solar irradiance (SSI) in different wavelength bands. The primary mission objective is to measure both TSI and SSI with high precision and accuracy. The 2009 Senior Review requested that the SORCE team work out differences in the TSI measured by the SORCE/TIM and ACRIM instruments. In response to this request, and in preparation for the launch of Glory, a calibration facility was developed. An equivalent TIM instrument calibration was performed and compared with several similar instruments calibrated at the same facility (Glory, PREMOS-1, PREMOS-3, VIRGO-2, and ACRIM-3). The results of this comparison indicate that SORCE/TIM provides the most accurate measurement.

The extended mission contains 3 primary objectives: 1) Continue to measure TSI with high precision, connect these data with prior and future measurements, and continue the extended climate record of TSI, 2) make daily measurements of the solar spectral irradiance, and 3) to improve understanding of how and why solar irradiance varies, and estimate future and past variations, and investigate the climate response. Since the last Senior Review, opposing trends in spectral irradiance were identified and reported in peer-reviewed literature. These trends will be explored as part of the extended mission.
We find that the objectives of this mission are well aligned with NASA objectives. Characterization of solar irradiance and its variability is critical to many aspects of the atmospheric dynamics, chemistry, air-sea-land interactions, and radiative forcing in the atmosphere.

The reviewers unanimously agreed that the scientific merit of SORCE is outstanding and fully support the extension of this mission. The primary concern is the battery health and the impact that it will have on maintaining the extended climate data record of solar irradiance. An optimal budget was presented, which includes an additional FTE for a second battery expert and additional funding to analyze the calibration/degradation of the SIM instrument with respect to the opposing trends discovered in the spectral irradiance. We support the extension of the SORCE mission at the optimal level to support the additional battery expert. The >$300k budget for 1 FTE effort should be further justified to the budget office when allocating the funds. There were differing opinions concerning the additional SIM analysis. The panel suggests that a more detailed plan for this analysis is needed, and that further budget justification be provided before we can fully support this additional task.

Recommendation:

X Continuation of projects with augmentations to the current baseline

Benefits to extending the SORCE Mission:

Maintaining the Total Solar Irradiance (TSI) 32-yr data record is critical, particularly due to the launch failure of the Glory mission. A long-term TSI data record is needed to understand the variability of the solar irradiance, the influence of the 11-yr solar sunspot cycle on the TSI climate record and climate change, and to understand the wavelength dependence and offsetting trends/phase of the SSI. This improved understanding will help guide the development of improved models for estimating and predicting future TSI and SSI, and provide reference spectra for climate and atmospheric studies.

Optimal Budget:
We find that the SORCE mission be extended at the optimal level for the additional battery expert. The optimal budget will provide the additional expertise to assist with adjustments related to maintaining the battery. We feel the extra funding is justified because maintaining and extending the life of SORCE/TIM is critical to the TSI record, particularly with the failure of the Glory launch, which would have had an equivalent TIM instrument. There are no other TSI measurements available with the precision of TIM on a U.S. based satellite. The >$300k budget for 1 FTE effort should be further justified to the budget office when allocating the funds.

There were differing opinions concerning the funding of the additional activity under the optimal budget for SIM analysis. While we all agreed that the SIM analysis is important to understanding the long-term trends in solar spectral irradiance, the activity lacked a detailed plan and we felt that it would take at least one complete solar cycle, if not 2 or 3, to really understand the trends. We suggest that the SORCE team submit a more detailed plan concerning this activity in the next Senior Review.

Scientific merits

X Outstanding ❑ Very Good ❑Good ❑ Fair ❑ Poor

Progress since the previous Senior Review:
The 2009 Senior Review requested that the SORCE team work out major differences in the TSI measured by the SORCE/TIM and ACRIM instruments. In response to this request, and in preparation for the launch of Glory, a calibration facility was developed. An equivalent TIM instrument calibration was performed and compared with several similar instruments calibrated at the same facility (Glory, PREMOS-1, PREMOS-3, VIRGO-2, and ACRIM-3). The results of this comparison indicate that SORCE/TIM provides the most accurate measurement.

The additional data recorded over the last several years also helped identify opposing trends in the spectral irradiance record (opposite to that of the solar cycle variability). These trends were explored and published in peer-reviewed literature, but will require more analysis during the extended mission to distinguish physical phenomena from instrument degradation.

A number of peer-reviewed publications released over the past several years describe the implications of the reduced value of the solar constant as measured by TIM. Links to the climate community are well demonstrated through these publications.

Extended mission objectives:
The extended mission contains 3 primary objectives: 1) Continue to measure TSI with high precision, connect these data with prior and future measurements, and continue the extended climate record of TSI, 2) make daily measurements of the solar spectral irradiance, and 3) to improve understanding of how and why solar irradiance varies, and estimate future and past variations, and investigate the climate response. Since the last Senior Review, opposing trends in spectral irradiance were identified and reported in peer-reviewed literature. These trends will be explored as part of the extended mission.

SORCE objectives have broad implications for numerous disciplines. Characterization of solar irradiance and its variability is critical to many aspects of atmospheric dynamics, chemistry, climate variability, and radiative forcing. SIM and SOLSTICE ultraviolet spectral irradiance measurements are critical for determining variability of stratospheric temperature and ozone, and climate influences. Solar irradiance monitoring is clearing important and SORCE instruments provide the measurements with the required accuracy.

Core mission data product maturity;
❑ Poor ❑ Fair, ❑ Good, X Excellent.

Core mission data products from SORCE are basic (daily and 6-hourly irradiances at various wavelengths) but great care has been taken to achieve an accurate calibration for the TIM measurements. The solar spectral irradiance (SSI) measured by SIM has also been analyzed and corrections are starting to be applied to SSI measurements, and will be released in future updates to the data products.

Operational usage of data products:
The National Interests Panel rated SORCE data products as "High Utility". SORCE data products are utilized for space weather forecasting, and near-real-time monitoring of solar flare events, inputs to USAF modeling, has value and uses for airlines (arctic routing, personnel/passenger safety).

Relevance to NASA Science Goals:
X Outstanding ❑ Very Good ❑ Good ❑ Fair ❑ Poor

The proposed science objectives directly apply to numerous NASA science goals related to: 1) understanding how and why Earth's climate and environment are changing, 2) how and why does the Sun vary and affect Earth, and 3) how is the global Earth system changing?

Long-term measurements of solar irradiance are clearly linked to the above-mentioned NASA objectives, and is the fundamental measurement needed to understand inherent natural variability in the Earth-atmosphere system.

Technical and Cost

The Technical Review Panel rates the SORCE spacecraft as Medium-High Risk for a two-year extension, with increased risk for a four-year extension. The Technical Review team has identified 2 Major Strengths, 1 minor strength, 2 Major Weaknesses and 1 minor weakness that influence the risk determination. **All four instruments are in very good to excellent health with few anomalies noted, and would likely continue to operate nominally for two- and four-year extensions. The SORCE Team is taking exceptionally proactive steps to maximize the life of the mission by mitigating reaction wheel and battery issues.** Most of the flight subsystems have not yet needed to fall back to any of their redundant elements. However, **one of the reaction wheels failed in October 2008, leaving no fallback unit if a second wheel fails. The single battery has degraded sharply in the last two years on orbit and is the likely mission-limiting factor.** Three aspects of the analysis expected for an estimate of extended mission survival were not addressed.

A battery anomaly occurred on May 1, bringing even more risk to the extended mission. SORCE has proposed an optimal budget that includes 1 FTE for an additional battery expert who will interface with the current battery contractor and implement their recommendations. Maintaining the battery, particularly in its current state, requires continuous monitoring and adjustments, which warrants the additional funding over the baseline. In addition, the failure of the Glory launch leaves SORCE with the only accurate TSI measurement, further supporting the need to fund the optimal budget and maintain the battery health.

National Needs

TIM is absolutely critical to the operational community. If, due to battery life issues, a choice has to be made between SIM and TIM – the community would highly prefer the TIM only operation.

General Comments

While the proposal at times did not provide sufficient detail or background information, and relied on reviewers to have read all related publications, the SORCE team made an excellent presentation clarifying our concerns.

TERRA

Findings:

X Continuation of projects as currently baselined;

TERRA is a huge success, and continuation of the data collection 11 year TERRA record from the five instruments: ASTER, CERES, MISR, MODIS, MOPITT, is critical to a wide array of earth system science. It is a workhorse for regional-to-global scale monitoring. TERRA data are used in almost every area of earth science, and the science/publication record is outstanding. The demand for Terra data is obvious with 136M files delivered in 2010 alone and 77 core Terra data products.

The benefits for continuing the Terra mission are:

1) Extending the 11-yr data record would enhance our understanding of long-term atmospheric and oceanic phenomena (El Nino, solar cycle effects, etc.) for a wide variety of aerosol/cloud/CO/land properties.
2) Enables the continued development and production of highly synergistic data products.
3) MISR and MODIS will continue to provide unique aerosol products after the failure of the Glory launch.
4) The uniqueness of the MISR instrument provides numerous applications not provided by other datasets (3D morphologies, aerosol/ice shape, vegetation structure etc.).

The uniqueness of the MISR instrument provides numerous applications not provided by other datasets (3D morphologies, aerosol/ice shape, vegetation structure etc.).

The main failure to date is the SWIR bands on ASTER. But there continues to be significant use of the ASTER data from optical and TIR bands, and from the new global DEM. Delivery of data to the LP-DAAC has increased ASTER data use. Platform is expected to remain fully functional through 2017 (battery, fuel, subsystems performance).

The Senior Review panel considered the methane product for MOPITT proposed under the optimal budget to be in the early research and development stage.. The MOPITT team is well positioned to conduct this work and a methane total column product would be highly useful to the community, but should be vetted under science funding (i.e. ROSES) because it is still in the research stage. We encourage the team to seek funds from other sources to conduct the science necessary to develop and validate this product.

Scientific merits

X Outstanding ❑ Very Good ❑ Good ❑ Fair ❑ Poor

Terra's scientific importance is demonstrated by the 1,216 peer-reviewed publications in 2009 and 929 in 2010, with more than 15,000 citations in 2010. Nearly 6000 peer-reviewed papers have been published over the 11 years. The data record continues to grow, algorithms are updated, and new algorithms are added. Examples of scientific accomplishments are shown by the following new instrument products. The depth and breadth of its accomplishments is illustrated by the volume of data provided to the user community and its publication and citation records as described above. ASTER released a new high spatial resolution global DEM, CERES released a 1° x 1° TOA, within atmosphere and surface radiative fluxes at 3 hr and monthly scales. MISR contributed to improved cloud descriptions of top height, motion vectors, aerosol retrievals, and expanded the plume height climatology product beyond North America. MODIS improved its calibration for ocean color and aerosols, and its Rapid Response System for disaster response. MOPITT released its version 4 and completed algorithm development for its version 5 carbon monoxide product. MISR, CERES and MOPITT contribute significantly to climate data. The applications to atmospheric science, climate change effects and modeling, and natural disaster monitoring are exceptional. The data record thus far is extremely valuable to the community. Extending the mission would allow the extension of the climate record, important for examining climate change indicators, and longer temporal oscillations (i.e. El Nino, Pacific Decadal Oscillation etc.).

Extension of the climate record between AVHRR and eventual VIIRS, important for examining climate change indicators, and longer temporal oscillations (i.e. El Nino, Pacific Decadal Oscillation etc.).

Weaknesses – no major scientific weaknesses;

Core mission data product maturity;

❑ Poor ❑ Fair, ❑ Good, X Excellent.

One of the primary reasons for continuing the Terra mission is to continue the long-term data record until it overlaps with NPOESS. Maintaining baseline calibrations and providing quantified uncertainties is well documented and should continue to be a priority. The data products are excellent, and continue to be modified, improved, and updated. MODIS has proven to be an important data source for large-scale monitoring, as has ASTER for filling in ETM+ missing data. The high resolution ASTER DEM is an important contribution.

The link to data from AQUA (especially MODIS) is a real strength of the data. CERES and MODIS on Terra have complementary missions with Aqua. MODIS ocean color is comparable to Aqua and SeaWIFS. Terra has 77 "high quality, calibrated, and validated"core data products for climate and earth science, with 9 new products since the 2009 review (MISR 3, CERES 2, MODIS 1) and refined MOPITT CO product and ASTER DEM. Four products were dropped since 2009.

Terra complements CALIPSO, Cloudsat, RadarSat-2 and ALOS now; in future GLORY2, NPP, Aeolus, Aquarius, and future field programs: Asian monsoon years/AMY 2008-2012 and SEAC4RS.

Relevance to NASA Science Goals:
XX Outstanding ❑ Very Good ❑ Good ❑ Fair ❑ Poor

Strengths-
The proposal demonstrates relevance to all NASA Earth Science objectives. Terra Direct Broadcast contributes to disaster monitoring in the Applications focus area.
TERRA hits a home-run: High science and application value for all 6 areas of NASA earth science.
The Terra mission is directly aligned with NASA's ESD research objectives.

Weaknesses- none

Technical and Cost

Approved budget is $30,617K, $31,345, $31,346, $31,754, $31,808. Includes added administrative cost required by HQ.

Please describe the additional work which will be funded by the Optimal Budget, the benefits of the added work, and justify the additional budget requested

The optimal Terra budget is only to add development of a methane product from MOPITT and a HQ required 1% of the Terra budget for the Project Science Office at GSFC for coordination and management activities (2.8 FTE).Optimal MOPITT budget is about $200k/yr addition. Methane algorithm is not well demonstrated, and Senior Review panel concluded that the effort is still in the research rather than operational phase. This suggests that an alternate funding source should be sought.

The Panel really wants to commend the Terra team on excellent work, also encourage them to pursue the additional MOPITT work. Terra is a workhorse satellite, generating high quality products from multiple instruments. In the context of the overall budget for TERRA ***and other missions***, we did not feel that additional funding would provide enough benefit relative to benefits that might be lost by reducing resources for other missions. This is particularly true because it was clear that operational implementation would not likely occur for two more years. Following from these comments, there seems to be considerable risk that the method would not work as planned. As such, we suggest that the TERRA team seek funding elsewhere for the methane product, perhaps through ROSES. The cost is

relatively low ($200,000/year), but other valuable missions required optimal funding to maintain basic functions, and the Senior Review Panel was not able to support optimal funding for development of new or unproven products.

National Needs
Subpanel finds strong support for Terra instruments from the agencies and organizations.

Other Comments

Difficult to recruit the best matched science team from competitive proposals. Need combination of new science (competitive) and improved algorithms, etc. (staff funding?).

The Terra proposal was well organized and succinct.
Well written and organized. They did a good job highlighting the recent successes of TERRA.

TRMM

Executive Summary:

The Tropical Rainfall Measuring Mission (TRMM) was launched in November 1997 for a 3-5 year mission that has now been flying for 13 years. The spacecraft follows a precessing, low-inclination (35º) orbit initially at 350-km orbit, and was boosted to ~400 km in 2001 to conserve fuel for a longer mission. TRMM products provide a unique database of precipitation amounts and the first global-scale view of the vertical structure of precipitation in the tropics. These data products are very mature, and now extend over a long enough period to robustly characterize annual, seasonal, monthly, and diurnal variability in rainfall across much of the globe. These data have been used for an impressive range of studies from fundamental science to applications of immediate societal value including monitoring of extreme events such as tropical cyclones, floods and landslides. The extended mission is to expand the dataset another 2-3 years for two main purposes: the first is to extend the current TRMM dataset; and the second is to obtain up to a year of overlap with GPM for cross-calibration so that a continuous climate-quality dataset can be extended into the GPM era. Such a dataset will allow the characterization of interannual to decadal variability and ENSO cycles. It is the opinion of this panel that an additional 2-y of support for this project for FY12-13 should be provided, and that a further 2-y for FY14-15 should also be budgeted, subject to review of the spacecraft health and propellant projections by the 2013 Senior Review Panel.

Findings:

X Continuation of projects as currently baselined;

We suggest the budget follow the proposed request. The TRMM budget appears to be minimal for the maintenance tasks required to keep the craft safely operating. Most science-related developments have been transferred to the Precipitation Measurements Mission (PMM) budget to support algorithm development for the forthcoming global precipitation mission (GPM). The potential extension of the current TRMM 13-y dataset through calibration with GPM is extremely important and, in our opinion, more than justifies the current budget request to maintain TRMM as long as possible.

TRMM has met and exceeded its original goal of advancing our understanding of the distribution of tropical rainfall and its relation to the global water and energy cycles. The TRMM suite of measurements has provided an unprecedented 13-y database of precipitation measurements including details of the vertical structure of that precipitation in the tropical and extratropical regions of the world. The precipitation radar (PR) is the only space-borne rain radar (until the GPM launch in 2013) and provides the 3-D structure of rain as well as quantitative information over both land and ocean of rainfall amounts. The TRMM microwave imager (TMI) provides information of rainfall rates and SSTs. The lightning imaging sensor (LIS) detects all lightning within its field of view. An additional strength of the TRMM satellite is the co-location of a visible and infrared scanner (VIRS),

which provides a cloud context for the PR, TMI, and LIS, as well as providing a link to the geostationary operational environmental (GOES) satellites so that retrievals from both systems can be easily compared. Some of the products that are either directly from TRMM, or that TRMM plays an integral part of, include visible and infrared radiances, 3-h almost global (50°N to 50°S) rain-rate retrievals, 3-D structure of rain, hydrometeors and heating profiles, 0.25 degree 13-y lightning flash climatology and actual lightning flashes. The TRMM project has also supported the development and continued production of ground validation observations from surface radar and rain gauges from 4 sites located in the tropics.

TRMM has evolved from an experimental mission focusing on tropical rainfall climatology into the primary satellite in a system of research and operational satellites used for analyzing precipitation characteristics on time scales from 3-hr to seasonal scales and beyond. The science objective of an extended mission is to determine the time- and space-varying characteristics of tropical rainfall and convective systems, and how these characteristics are related to variations in the global water and energy cycles, which is fundamental to NASA's Earth Science strategy and provides answers of key science questions for both the Water and Energy Cycle and Weather focus areas. Examples of operational uses include the use of near-real time images for tropical cyclone intensity estimates and current structure, integrating the TRMM SSTs into standard SST products. These near-real time images are used by forecast centers around the world.

A compelling reason to continue this mission is that there is currently no other platform that can provide the coverage and detail of rainfall observations that TRMM provides until the launch of GPM in 2013. Continued operation until the GPM launch is necessary to ensure a continuing dataset for climate studies. The additional years of data will allow studies of inter-annual and decadal-scale variability of rainfall, and provide a more robust diurnal cycle. Some overlap between the missions would be useful to calibrate and validate the GPM algorithms after GPM launch and allow an ongoing dataset of tropical and extratropical rainfall measurements that begins in 1997 and extends through the GPM mission. In addition, projected overlap with the Megha-Tropiques and GCOM-W satellites in late 2011 and February 2012 respectively will be extremely important to calibrate those passive microwave sensors for additional rain rate information. The May panel presentation provides convincing evidence that there are no platform instrument or subsystem-specific issues that will affect extended mission status. The basic mission extension will continue production of TRMM standard and real-time products and a multi-year extension of TRMM has a very high payoff for science and applications at a relatively low cost to NASA.

Scientific merits

X Outstanding ❑ Very Good ❑ Good ❑ Fair ❑ Poor

Strengths: TRMM's enormous success is related to its two unique attributes that make it ideal for observing tropical rainfall systems: (1) its suite of *complementary observing instruments* and (2) its *orbit characteristics*. TRMM provides a complementary suite of

active and passive sensors flown on a single platform, providing the most complete view of precipitation. The TRMM observing system employs the only precipitation radar in space, the PR, which provides the most direct method of observation of precipitation and its vertical distribution. Efforts to resolve disagreements between precipitation estimates from the PR and the passive microwave radiometer, TMI, have reached the point where TRMM's potential to act as a global rainfall reference standard is being utilized. Without the PR in space, there will be no similar opportunity for calibration with an active sensor until GPM is launched in 2013.

Since its inception, the TRMM science goal has been to advance knowledge of the global energy and water cycles by observing time and space distributions of tropical rainfall, convective systems, and storms, and their associated hydrometeor structure and latent heating distributions. TRMM currently provides a 13-y rainfall dataset that covers the tropics and much of the extratropics. This dataset is now at a stage where the regional impacts of climate change on precipitation patterns – arguably the most important climate variable for societal mitigation – can be assessed. Additional years of data will allow these impacts to be assessed on decadal scales.

NASA Objectives that are directly addressed by TRMM measurements include:

1) *Climate-related research:* TRMM has provided multiple rainfall datasets extending back 13 years for the study of climate-related water questions. These products, of which TRMM PR and TMI are the core components, have allowed robust climatologies of tropical rainfall to be developed on seasonal and monthly timescales, and even allowed the diurnal cycle climatology to be studied. LIS has provided data for detailed global and regional lightning climatologies. Lightning chemistry has also been studied. TRMM data has yielded new insights into the dynamics of tropical waves and oscillations and into theories on the dynamics of convective-climate feedback using the TRMM rainfall, storm height, and SST data. TRMM rainfall and LIS data has yielded information on human impacts on the climate system though the study of the relationship between aerosols, land use change, rainfall, and lightning. SSTs from TRMM help improve SST analyses used for climate studies as well as every day events.

2) *Convective systems and tropical cyclones:* Characteristics of convective systems have been studied using the PR, LIS, VIRS, and TMI. These systems have also been used to study the detailed structure of tropical cyclones, and allowed valuable insight into inner-core processes that were previously not well observed.

3) *Measurement advances:* Comparison between PR and TMI rain rates has lead to improvements in retrievals for passive microwave sensors. The rain rate estimates from TRMM have been used to calibrate rain rates from other satellites resulting in analyses of rain rates at spatial (0.25°) and temporal (3-h) resolutions than would not be possible from one satellite alone.

4) *Data Assimilation:* The TRMM rain rates are being used to develop assimilation techniques for rainfall, SSTs, and soil moisture to improve atmospheric model analyses and forecasts.

5) *Hydrologic research and applications:* TRMM–based multi-satellite analyses are being used by the hydrologic community as inputs to hydrologic models to study variations on surface runoff and improve forecasts of river flow. In addition, this dataset makes it possible to globally monitor crops, and potential for floods and landslides.

6) *Algorithm and model development:* LIS data has been used to help develop the new lightning monitoring strategy for the GOES-R satellite. TRMM rainfall data are used to evaluate the performance of numerical models from cloud-resolving models to global models and GCMs.

7) *Field Campaign Support:* TRMM will be used to support and inter-calibrate observations taken by the NASA Global Hawk during the Hurricane and Severe Storm Sentinel (HS3) field campaign in 2012-2014. In addition, TRMM assets will be used to support the GPM and NOAA Hydrometeorological Testbed field campaign in 2013.

8) *Operational Support:* TRMM provides support to many operational centers globally for various activities including the monitoring of tropical cyclones, rainfall, particularly extreme events with potential for producing floods, numerical weather prediction, and air-traffic control.

Weaknesses: The main weaknesses include: sampling by a single satellite; lack of sampling at higher latitudes; and the limitation of the PR to "see" low precipitation rates, as well as lower consistency of retrieval skill over regions of complex terrain and along coastal areas.

All these problems will be addressed with the launch of the GPM mission in 2013, which will operate at a higher inclination orbit, operate more than one satellite, and fly the dual-channel PR to be launched on the GPM mission in 2013. In addition, there are ongoing efforts to improve radiometer retrievals over land. One other weakness is that although the current rainfall climatology is in excellent condition, it still needs a longer time series to begin to answer questions relating to inter-annual and decadal variability and climate change. A longer mission that overlaps with GPM for intercalibration purposes would go a long way to solve this issue.

Value of data record and overall data continuity: At the request of NASA, the National Academies (NA) completed an assessment of the scientific accomplishments of TRMM and the benefits of extending the TRMM mission (NRC report, 2006). A key conclusion from the Executive Summary of the NA report was: "*Considering the past and expected scientific and operational contributions presented in this report, important benefits would be obtained if TRMM were extended until it runs out of fuel.*" The TRMM data set now extends over 13 years. The value of such an extended dataset is being demonstrated in the use of this dataset to robustly characterize annual, seasonal, monthly, and diurnal variability in rainfall across much of the globe. With another 2-3 years of data including up to a year of overlap with GPM for cross-calibration, a continuous climate-quality dataset can be extended into the GPM era. Such a dataset will allow the characterization of interannual to decadal variability and ENSO cycles. It should be noted that while an overlap with GPM of 3 months to a year is required for inter-calibration, the calibration may be achieved through other means should no overlap occur.

Core mission data product maturity;

❑ Poor ❑ Fair ❑ Good ❑ Very Good ***X Excellent.***

The core mission rainfall data are the standard used to assess other remote-sensed rainfall measurements and are the heart of the current 0.25º latitude/longitude, 3-h merged satellite rainfall product. These measurements are not redundant.

TRMM operations, ground validation sites, and algorithms are being used as the basis for algorithm development for the future GPM mission.

The proposal describes the capabilities of the TRMM instruments used to make the many observations as stable over the mission. Given the long track record it is assumed that the uncertainty in these products is well characterized and documented.

The TRMM data office and the PIs involved in assuring the ready and continuous update of various products including multisensory, higher-level products should be commended for an outstanding service to the broad science community.

Relevance to NASA Science Goals:

X Outstanding ❑ Very Good ❑ Good ❑ Fair ❑ Poor

Strengths: The overall science objective of an extended TRMM mission is *to determine the time and space varying characteristics of tropical rainfall, hydrometeor structure and associated latent heating for convective systems and storms, and how these characteristics are related to variations in the global water and energy cycles*. This TRMM goal is at the heart of NASA's Earth Science strategy and the answering of key science questions, primarily for the Weather and the Water and Energy Cycle focus areas: *"How are global precipitation, evaporation and the water cycle changing?"*; *"How will water and energy cycle dynamics change in the future?"; and "What are the consequences of changes in water availability and weather for human civilization?"* Having an extended record of quasi-global precipitation characteristics is critical to achieving NASA's Earth Science goals. Extension of TRMM for the next two-four years will continue to provide that information to NASA and the world research community. TRMM provides data sets that address a number of SMD recommendations:

1) How are global precipitation, evaporation, and the water cycle changing?

TRMM (and GPM) provide improved climatology of precipitation characteristics such as diurnal variations, vertical structure, extremes, seasonal cycle at finer resolutions, which can be used to investigate inter-decadal change and trend-related processes associated with rainfall.

2) What are the effects of clouds and surface hydrologic processes on Earth's climate?

TRMM provides refined latent heating profiles that help to characterize the effects of clouds. TRMM provides robust climatologies of convective system and lightning characteristics.

3) How do ecosystems, land cover, and biogeochemical cycles respond to and affect global change?

TRMM products make it possible to study human impacts such as land use changes and pollution on rainfall. TRMM rainfall is used as an input to hydrologic models that investigate river flow and land runoff.

4) How do atmospheric trace constituents respond to and affect global environmental change?

TRMM products make it possible to study human impacts such as aerosols on regional rainfall.

5) How are variations in precipitation, and water resources related to global climate variation?

The combination of over 15 years of TRMM rainfall data with follow-on GPM data it will be possible to characterize tropical inter-annual and decadal climate variability as well as the response of convective system climatologies to global climate change.

6) What are the consequences of land-cover and land-use change for human societies and sustainability of ecosystems?

TRMM precipitation can be used to assess human impacts such as land use changes and pollution on rainfall climatologies and precipitation processes.

7) How can weather forecast duration and reliability be improved? How can predictions of climate variability and change be improved?

TRMM products improve analysis and modeling of the global water and energy cycles, which improves weather and climate prediction capability. TRMM data have improved weather forecasting, e.g., monitoring and forecasting the tracks, intensity and associated rainfall of tropical cyclones (NOAA, DoD, WMO RSMC). A continued TRMM data stream will allow continued improvement of weather prediction model initial conditions through ingestion of microwave radiances, precipitation fields, and sea-surface temperatures in cloudy regions.

8) How will water cycle dynamics change in the future?

TRMM provides improved rainfall inputs to hydrologic models used to study water runoff. Continuation of the TRMM data will allow inputs to be used that cover a wide range of current climate conditions (e.g., ENSO extremes).

Weaknesses: TRMM provide these data within a constrained latitude range (50°N to 50°S). The launch of GPM will allow a global dataset to be developed of which TRMM will have provided over 13 years in the tropics and part of the extratropics. In addition, the single channel PR misses the light rain events. This will be fixed with the launch of the dual frequency PR on GPM in 2013.

Technical and Cost

The Technical Review Subpanel recommended to the ESD Senior Review Panel to request information on the health of spacecraft subsystems of the TRMM mission. As a result, the TRMM mission team provided battery data that showed that the battery is

operating nominally during their presentation at the 2011 Senior Review Meeting. In addition, the TRMM mission team discussed the spacecraft status. They stated that the spacecraft subsystems are operating nominally and since there has not been significant deviation from expected trends, they did not present trending data. The mission team collects and examines spacecraft subsystems' trending data and explained to the Senior Review Panel that no significant issues have been observed in the subsystems. Although the Technical Review Subpanel members were not present to participate in the discussion, the Senior Review panel has accepted the Mission Team verbal descriptions of the spacecraft subsystems and has agreed that the Technical Risk Rating may be lower than that assigned by the Technical Subpanel before the TRMM mission team's presentation.

The life–limiting factor is the propellant left on board. This propellant is projected to last until, at the earliest, November 2013, and at the latest, March 2015. After this time, the instruments on board can still be usefully operated for approximately one year until the spacecraft orbit decays below 300 km.

The conclusion of the Cost Subpanel is that the support for this mission is very reasonable for the value-added science and potential for calibration with the future GPM mission. TRMM science is already funded through ROSES. The budget here is to support TRMM maintenance.

National Needs

The conclusion from the National Interests subpanel is that overall, TRMM ranked "very highly" in terms of a quantitative score, with a qualitative label of "high utility" in serving national needs. These data serve national needs by providing unique datasets needed to improve existing models of weather and climate and provide the first part of Climate Data records for horizontal and vertical structure of precipitation, and improved latent heating profiles. In addition, TRMM provides a unique service by providing vital now-casting information on structure, intensity, and track of tropical cyclones that support the operations of the NHC and DoD. TRMM data are also used by the NOAA/NWS to improve hydrologic prediction.

Other Comments

The proposal was extremely well designed and informative and was crucial in convincing us of the high science level of the products being developed and the climate studies being addressed by them. Given that TRMM has been flying for 13 years it is expected that there will be considerable products and science results to be discussed.