NASA EARTH SCIENCE
SENIOR REVIEW

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Submitted to:

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INTRODUCTION

The Senior Review Committee met from April 25-27, 2007 to evaluate 11 ongoing NASA satellite missions: ACRIMSAT, Aqua, CloudSat, Earth Observing-1, GRACE, ICESat, Jason, QuikSCAT, SORCE, Terra and TRMM. Eight of the missions are currently operating beyond their prime mission periods, while Aqua, CloudSat, and SORCE will transition into extended mission mode sometime between FY2008 and FY2009. The Committee was tasked with reviewing proposals submitted by each mission science team for extended funding support through FY2011. The Committee focused on the scientific performance of each mission and the continued relevance of each mission to the NASA Science Strategic Plan. In addition, the Committee assessed the importance of a mission extension at the proposed basic funding level and, when applicable, requests for enhanced funding. When proposals included requests for enhanced funding, the Committee assessed the scientific importance of the proposed enhanced mission products, along with their relevance to NASA science objectives. The Committee did not review the Education and Public Outreach (E/PO) aspects of the missions, as E/PO performance was reviewed by a separate panel.

REVIEW PROCESS

Each mission team was asked to submit a proposal for mission extension through FY2011. The request for proposals centered on the continuation of "core" mission data products as well as solicited "enhanced" mission data products. Specific direction for core mission funding requests was provided to mission teams as follows:

"The core mission data product discussion should describe how the mission will continue to produce the core data products during the extension, including discussion of any performance degradation in the instrument(s) or spacecraft that affect the quality of those products. The core data products include those valuable higher levels (typically but not restricted to level 1 and level 2) data products that are produced on a routine basis and that are typically tied to the mission level-1 requirements. If products have developed since launch and are now considered core, they should have clear and mature algorithms supporting their production, and should show a clear traceability to NASA science or national operational objectives. The products considered core may also include high value, mature, operational data products not directly connected to ESD science research objectives. Resources required to provide routine calibration, validation, and algorithm maintenance to maintain the quality of these data products should be included.

The Basic Continuation section should be considered the minimum viable funding level for your project to the Senior Review and to NASA. By identifying the minimum acceptable funding level, you are indicating that any lower funding level is untenable, and that the project should be terminated rather than funded at a sub-minimal level. If the current budget guideline for your project for any of the fiscal years is zero, then this section will constitute your minimum mission."

Every proposal was examined by each member of the Senior Review Committee. Representatives from each mission were provided the opportunity to present their proposal for mission extension, to provide additional information not included in their proposals, and to field questions asked by the Committee. In addition, each mission extension proposal was assigned to 2-3 Committee members,

who drafted mission-specific comments and recommendations included in this report. The review draft was then discussed by the entire Committee prior to the formulation of the final assessment of the mission. The Committee members organized their inputs into general and detailed comments based on the following steps:

(1) In the context of the science goals, objectives and research focus areas described in the NASA Science Strategic Plan, the Committee evaluated the scientific merits of the proposed returns from each mission during FY2008 and FY2009. Include consideration of the value of and need for continuation of high value, high quality long-term data records and overall data continuity.

(2) The Committee evaluated the proposed "basic continuation" and "enhanced science" data products.

(3) The Committee evaluated the overall portfolio of data products for all missions under review, identifying possibly redundant or complementary products not noted by the individual mission proposals, and searching for synergies not yet realized.

(4) The Committee evaluated cost efficiency, technology development and dissemination, data collection, archive and distribution, and education/outreach as secondary criteria, after science merit of the proposed research and data product development and delivery.

(5) The Committee provided science-based findings for an implementation strategy for the NASA Earth Science Division extended missions for FY2008 and FY2009, including specifically:
– Validation of the proposed definition of core data products for each mission or recommending changes to same
– Authorization of the core and selections of the enhanced data products and research objectives
– Directed additional collaborations between missions where complementarities may exist
– Possible limitation of the mission to mission operations and core data products only

(6) The Committee provided preliminary assessments and findings for all above-listed areas for FY2010 and FY2011.

GENERAL FINDINGS

(1) The Committee concluded that the 11 missions continue to provide a portfolio of observations critical to meeting the NASA Science Strategic Plan. These missions, along with several others not included in this review, provide an unprecedented combination of scientific observations for Earth science, and the current constellation of instruments is likely to be unmatched in the coming decade. However, the Committee also concluded that the current set of missions and their observations will not meet their full scientific potential until the measurements, taken from multiple satellite platforms, are utilized collectively. While a few missions or instrument teams, namely TRMM, CloudSat, and Terra, have undertaken valuable steps to integrating data streams and products, far more could be done to utilize the satellite constellation in a data fusion mode. **An overarching finding of the 2007 Senior Review is that NASA could be more proactive in facilitating the integrated use of the measurement constellation via competed research proposals [e.g. NASA Research and Analysis (R&A) Program].** The Committee also recognized the central role that the mission teams play in bringing diverse satellite data streams together to foster data fusion and analysis efforts of NASA R&A investigators across scientific disciplines. A more comprehensive framework for integrating the missions and R&A investigators into cross-platform and cross-measurement fusion activities could be undertaken at NASA Headquarters.

(2) **The Committee unanimously agreed that basic continuation is critically important for all missions through FY2008-2009 to best enable NASA to continue to meet its stated science objectives.** For FY2010-2011, continuation of ACRIMSAT may be unnecessary if it remains redundant with and/or less accurate than measurements from SORCE-TIM, Glory or PICARD.

(3) The mission teams were instructed to provide a minimum core mission science budget with justification (see review process instructions), and a detailed breakdown of their enhanced mission budgets, but this instruction was not followed, which ultimately precluded a detailed analysis of the cost effectiveness of all core and most enhanced mission data products. This resulted in apparently high and/or unjustified mission science budgets in most mission extension proposals. With the exception of TRMM, mission science budget requests were nearly flat for their basic extended mission phase, and the justification for nearly level funding during what should be routine data production for most missions was neither presented nor justified to the Committee. **The Committee observed that a detailed analysis of the basic mission science budgets could be led by NASA HQ to verify the cost-effectiveness of current core mission activities, and to seek ways that mission budgets could be decreased while maintaining the production of routine data streams.**

(4) **Nearly all proposed enhanced mission products were viewed as being more appropriate for core mission or for open competition (NASA R&A) rather than as products that could be uniquely derived by mission teams.** Exceptions include the enhanced mission proposals for CloudSat and Terra/MOPPIT. The panel found these proposals to be of high merit.

MISSION-SPECIFIC FINDINGS

(1) **ACRIMSAT:** The Committee recognizes the fundamental importance of total solar irradiance (TSI) measurements for climate studies within the NASA Science Strategic Plan. However, the scientific need for sufficient temporal overlap with newer SORCE mission TSI observations has now been met, and thus there is no truly compelling reason to maintain redundant measurements. The current temporal overlap between ACRIMSAT and SORCE TSI measurements should be sufficient to resolve the substantial discrepancy between them. No enhanced data products were proposed by this mission. *The Committee finds the core science mission merits funding through FY2009, during which time a discrepancy between ACRIM/TSI and SORCE/TSI measurements should be resolved to conclusion.*

(2) **AQUA:** The Committee recognizes the central relevancy of the Aqua mission to the NASA Science Strategic Plan and global Earth science needs. The platform serves a vital role in the provision of data products as part of the A-Train constellation. Current data products are in various stages of validation, but the AIRS products, being new and complex in nature, are lagging behind the development and dissemination of other Aqua measurements. The AIRS core data products ought to be brought to maturity prior to the end of the Prime mission in September 2008. The proposed enhanced mission data products were deemed to be better suited for incorporation into ongoing core mission efforts or for competition via the NASA R&A program. The Committee was concerned about the nearly level funding request for basic science mission continuation (FY2009-2011); there should be ways to decrease the budget over time, especially for instruments common to the Aqua and Terra missions such as MODIS and CERES. The Committee also questioned the redundancy of certain Aqua/Terra data products, for example, AIRS and MOPITT for O_3, AIRS and TES for CO. These redundancies ought to be clearly justified scientifically, with appropriate changes in funding possible based on this evaluation. *The Committee finds the core science mission merits funding through FY2009, but with a cost reduction plan that reflects the routine nature of data production following Prime mission. Extension though FY2011 at reduced cost is also warranted, depending upon spacecraft/instrument health and redundancy with other mission products.*

(3) **CLOUDSAT:** This mission is still in Prime mode, but with only 11 months remaining before extended mission status is needed. Early results from CloudSat show great promise in advancing the science of cloud dynamics deemed critical for meeting NASA Earth science objectives. The relevance of this mission to the NASA Science Strategic Plan continues to be high, and the derived core data products are already showing signs of maturity and applicability to a wide range of studies. The proposed enhanced mission data products were clearly defined and compelling additions to the core mission. *The Committee finds the core science mission merits funding through FY2009, with potential extension though FY2011 depending upon spacecraft/instrument health and redundancy with other mission products. The Committee also finds that funding support is warranted for the enhanced mission proposed by the CloudSat team.*

(4) **EO-1:** The Committee finds EO-1 to be unique among current NASA missions. Originally designed as a technology demonstration, the mission continues to serve this purpose by way of a flexible and largely autonomous spacecraft, a unique hyperspectral imager, and an innovative data collection approach. The Committee also finds this asset to be underutilized by the NASA science

community due to weak financial and programmatic support leading to insufficient data availability. Increased NASA programmatic support could transition the EO-1 mission from a small technology demonstration to a broad science and applications test bed. This would allow for an expansive use of the EO-1 ALI and Hyperion data across science disciplines, and at the same time, advance the methods for autonomous (cost-effective) spacecraft, instrument and tasking operations already initiated by the PI. *The Committee finds the core mission merits funding through FY2009, with potential extension through FY2011, but with increased funding from NASA Headquarters to facilitate an increased use of EO-1 data throughout the Earth science community.*

(5) **GRACE:** The Committee views GRACE as highly relevant to NASA objectives and the Science Strategic Plan in the areas of ice sheet mass change and water storage. GRACE provides a highly unique measurement that should be continued for the purposes of building a long-term climate data record, and for incorporation into multi-sensor analyses with Jason, ICESat, and other systems. The proposed enhanced data products were, however, deemed to be more appropriate for core mission activities or for competition via the NASA R&A program. *The Committee finds the core science mission merits funding through FY2009, with potential extension though FY2011 depending upon spacecraft/instrument health and redundancy with the forthcoming GOCE mission.*

(6) **ICESAT:** The Committee considers ICESat a unique mission that provides observations critical to cryospheric studies. Despite problems with laser longevity, the ICESat team has made exemplary progress toward their prime objective of measuring ice-sheet mass balance. The cost of the continuing mission seems justified by the complexities of the limited laser operations and the analyses required to maintain the altimeter accuracy. However, the core science budget appears high relative to other missions of similar scope and complexity. The decision to change the data acquisition plan from three to two periods per year seemed necessary but caused concern among some Committee members. The Committee strongly feels that the proposed two-period acquisition plan is the minimum acceptable approach, and should be maintained through FY2009. At the end of this time, however, the Committee felt that NASA could review and consider whether its cryospheric objectives would be better served by using the laser's remaining capability to complete a continuous 90-day cycle to improve Antarctic and Greenland DEMs. No specific enhanced mission data products were proposed, but several improvements within the core mission funding were discussed and deemed useful by the Committee. *The Committee finds the core science mission merits funding through FY2009, with potential extension though FY2011 depending upon spacecraft/instrument health.*

(7) **JASON:** The Committee considers the Jason experiment highly relevant to NASA Science Strategic Plan, especially in the area of sea-level dynamics in response to climate change. The core science data products continue to be highly relevant, extending the previous TOPEX/POSEIDON mission measurements, and bringing the ongoing time-series to the upcoming OSTM (Jason-2) launch in 2008. No enhanced products were proposed, but the expressed Jason team philosophy is to incorporate incremental enhancements into their core budget, which was well received by the Committee. *The Committee finds the core mission merits funding through FY2009, with potential extension through FY2011 depending upon spacecraft/instrument health and redundancy with the follow-on OSTM mission.*

(8) **QuikSCAT:** The Committee recognizes QuikSCAT as the best U.S. source for ocean vector winds, and thus it was given a high ranking for scientific merit and relevance to the NASA Science Strategic Plan. The Committee views the proposed core science mission budget as high and level during what should be a time of routine data processing and dissemination. There were four proposed enhanced data products, two of which were considered more appropriate for incorporation into core mission funding (coastal winds and high winds), while the remaining two were deemed appropriate for open competition in the NASA R&A program. *The Committee finds the core science mission merits funding through FY2009 but ought to include the proposed coastal and high winds data products, with potential extension through FY2011 depending upon spacecraft/instrument health and redundancy with the SeaWinds and ASCAT missions.*

(9) **SORCE:** The Committee views the SORCE mission measurements of total solar irradiance and spectral properties as critical to the NASA Science Strategic Plan. The Committee acknowledges the complex suite of measurements being taken by SORCE instruments, and the ongoing effort to resolve the discrepancy between SORCE/TSI and ACRIM/TSI measurements. The Committee also recognizes the unique spectral irradiance measurement provided by SIM instrument onboard SORCE; this measurement should be extended as long as possible to provide a spectrally-resolved record over at least a complete solar cycle. The proposed enhanced science data products were not scientifically compelling, could be provided under core mission funding, or could be competed in the NASA R&A program. *The Committee finds the core mission merits funding through FY2009, during which time the discrepancy between ACRIM/TSI and SORCE/TSI measurements ought to be resolved to conclusion. Core funding through FY2011 is also warranted, contingent upon spacecraft/instrument health.*

(10) **TERRA:** The Committee considers Terra critically important to meeting the objectives of the NASA Science Strategic Plan. The overall review of the Terra proposal was positive, and core mission continuation is considered a high priority. Nearly all instruments and core data products were considered highly relevant and should be continued. However, questions about the accessibility of ASTER data (by tasking) were raised by the Committee and could not be answered via the proposals or presentations. Overall, the proposed enhanced mission data products were deemed to be better suited for incorporation into ongoing core mission efforts or for competition via the NASA R&A program. The exception was the proposed enhanced MOPITT CO product, which the Committee believes to warrant support through the mission line. Regarding the basic science mission continuation budget, the Committee expected significant cost reductions in a late mission stage at which products are mature and routinely produced. There was no clear justification for the nearly level funding request of routine data production, especially for highly mature data products from MODIS and CERES, and the lack is a weakness of the Terra mission proposal. The Committee believes that NASA Headquarters could consider a review of the science budget plan for these instrument teams before approving the basic mission science continuation. *The Committee finds that the core science mission merits funding through FY2009, but there could be an opportunity for appreciable cost reductions reflecting the routine nature of data production during an extended mission. Extension though FY2011 is also warranted, depending upon spacecraft/instrument health and redundancy with other mission products.*

(11) **TRMM:** The Committee views TRMM as a mission of central relevancy to the NASA Science Strategic Plan and Earth science objectives. Although the mission is aging (~10 yrs), the

spacecraft and instruments are in good condition, and the core data product suite is mature and widely disseminated. The Committee recognizes the importance of continued core mission funding. However, the Committee was not given sufficient information regarding TRMM/LIS operations and budgeting, both of which were not discussed in the mission extension proposal. The proposed enhanced data products are useful, but they could be provided under core mission funding or could be competed through NASA's R&A program. *The Committee finds the core mission merits funding through FY2009, and warrants extension though FY2011, depending upon spacecraft/instrument health.*

APPENDIX: DETAILED MISSION REVIEWS

ACRIMSAT

Instrument(s): ACRIM
Research Activities: Monitoring long-term variations of total solar irradiance
Data Product Names: Total Solar Irradiance
Science Strengths/Weaknesses: Extending longest record of high-quality measurements of a primary forcing of climate change; Overlap with SORCE TIM measurements
Relevance to NASA Science Goals: **HIGH**
Maturity of Data Products: **HIGH**

General Comments

Primary merit is high (relative) accuracy monitoring of solar irradiance with simple, low cost mission; continuing the mission would continue a key climate dataset. Other positive features are re-examination and re-processing of older parts of record by experts with this type of instrument (no enhanced products proposed). High science value is obtained from continuing investigations to explain observed variations by looking for relations to measurements of other solar characteristics and their variations (transit studies not entirely germane). Strong overlap with SORCE/TIM has provided the needed alternative measurements for accuracy studies; however, given that several years of overlap now exist, the value of continued measurement is reduced and the difference in absolute calibration of the two instruments should be resolved. There is no plan/justification given for how/why continued measurements by both instruments would resolve this discrepancy. One year overlap has been achieved, so there should be enough observations to resolve difference without additional measurements.

Detailed Comments

(1) Scientific merit is very high as this mission continues the monitoring record of the primary climate forcing, without which interpretation of observed climate variations is not possible. Proposed work to improve understanding of the whole record and to seek explanations for observed solar variability are key science contributions. Nevertheless, this measurement is redundant with the SORCE/TIM measurement, and NASA has no requirement or precedent for funding redundant observations beyond appropriate overlap for calibration and reference. Overlapping records required to obtain needed long-term accuracy has been achieved. It is not clear that SORCE/ACRIM redundancy is required.

(2) No enhanced products proposed. The main proposed task is to extend the record and to re-examine and re-process the whole record to produce the best measure of solar variability over 30 years, improving the existing product. An extension of the mission by two years should establish the third solar minimum value to determine the slower variation of the sun. Data product processing is part of the science budget, which is appropriate for the maturity of the dataset.

(3) The proposal notes that the alternate measurement technologies of ACRIMSAT/ACRIM and TIM/SORCE are crucial to current efforts to resolve reasons for absolute discrepancies, as referred to by the 2005 Senior Review. ACRIM-type instruments provide the bulk of the long-term record, but the synergy of ACRIMSAT and SORCE is key to understanding the observations.

Nevertheless, the difference between the TSI measurements must now be resolved.

(4) The science cost efficiency of the proposal is very high, covering adequate efforts in all needed areas, including data collection, processing and dissemination, as well as education/outreach. The science team support is too low to provide the needed investment in developing the next generation expertise required to continue this long-term monitoring activity. The mission operations costs seem very high for such a simple satellite (similar to SORCE costs which has 4 instruments); apparently driven by a decision to operate "24/7" even though this is not obviously required. This part of the budget could probably now be reduced significantly by increasing the risk as there are already several years of overlap with SORCE/TIM that can be used to investigate the differences in the measurements.

(5) TSI is key to the NASA contribution to climate research, and ACRIM3 provides a low cost, long-term monitoring capability. No changes or enhancements are needed, but the proposed investigations to increase understanding of the whole record, as well as seeking explanations of the observed solar variations, are important contributions. A key common goal of ACRIMSAT and SORCE ought to be to understand the absolute differences of solar irradiance measurements and the overlap between observations has been achieved to accomplish this goal. The Committee found that continuation of ACRIMSAT ought to be contingent upon the resolution of this issue.

(6) The current overlap with SORCE and with the launch of GLORY, the scientific utility of an overlap of TSI observations will have been achieved.

AQUA

Instrument(s): AIRS/AMSU/HSB, MODIS, CERES, AMSR-E
Research Activities: EOS platform #2 in the A-train
Data Product Names: numerous
Science Strengths/Weaknesses: (below)
Relevance to NASA Science Goals: **HIGH**
Maturity of Data Products: **LOW to HIGH**

Detailed Comments

(1) Aqua's core data products are highly relevant to NASA's Scientific Strategic Plan. There is strong scientific merit for continuing the high-value, high-quality data products being produced by Aqua. This includes both NASA Earth science objectives as well the enhancement of weather prediction. The science merit for maintaining the whole A-train complement for several more years is even higher because this may be the "best-case" observing system for the next decade or more, and synthesis of A-train data is just beginning.

(2) Few product changes were proposed for the Enhanced Science extended mission as compared to the Basic Continuation extended mission. Most of these were AIRS-only activities that would not lead to any new data products during the extended mission (out to FY2011). CERES proposed a synthesis product using AMSR-E to produce ice-water and liquid-water paths for clouds. The Committee felt this effort could be competed through the ROSES R&A process.

The proposal included other enhanced activities (e.g., an overall unification of Aqua products through re-gridding, support teams) that were enabling but did not include scientific synthesis. The proposal said that the mission would convene "science teams" to decide on gridding issues and combined products, but this selection of science investigations also could be done in the R&A process.

The ability of any user to acquire the Aqua products on a number of standard grids should be a core deliverable within the Prime mission and can likely be achieved simply by providing software tools to the research and user communities, rather than remapping and merging all Aqua data sets.

Another enhancement, direct broadcast, is not needed as that capability is already available in a variety of locations and data is freely shared. Most of the cost of delivering near real-time data appears to be covered by the users, and no additional costs for NRT data should be incurred in the extended mission.

Justification for enhanced science in the proposal is not strongly argued and the Committee felt it could be better competed under R&A type activities. Nevertheless, should proposals for enhanced data products be funded under R&A, there is no reason the instrument teams could not implement the enhancements during the extended mission.

Overall, is the Committee found there was no compelling reason given to support the enhanced mission activities.

(3) Most of the data products have proven scientifically useful and complementary to other Earth observations. There is clear recognition within NASA of the synergy of the A-train instruments, but this has been primarily recognized by the newer A-train missions rather that Aqua. Support for synthesis products involving other Aqua instruments was proposed at a very low level (standard gridded products, support services), but synthesis across the A-train including Aura was not proposed. This is disturbing given the apparent redundancy of some of the chemical composition measurements (see below).

There are some obvious redundancies between the new AIRS products and MOPITT (CO) and TES (CO, O3) with no clear plan for producing either a single combined product or at least two, rationalized, non-conflicting data products. While the AIRS measurements have different vertical averaging kernels, there is so much overlap that inconsistencies will become apparent once these products are used by the community.

In terms of obvious duplication of instruments, MODIS and CERES are on both Aqua and Terra. While there is some obvious redundancy, much critical data comes from the diurnal offset of the two platforms, including different access to land-surface data because of changing cloudiness. The Aqua instruments are unique for synthesized A-train science, but this is currently being used only in CloudSat products.

(4) The information presented to the Senior Review was insufficient to determine what was needed to maintain calibration and quality assurance as Aqua moves from Prime to Extended Mission. Opportunities for cost savings or continued product improvement during this transition were not presented, yet the costs should decrease as data products mature and become routine, especially for MODIS and CERES that have been operating much longer on Terra. No indication was given to show when and how mission maturity would lead to decreased science mission costs. This was considered a critical shortfall of the proposal.

Despite the missing budget justification, the calibration of all instruments is considered essential to current and future data products. It is crucial to maintain instrument science and calibration teams at a level to maintain current quality as well as to address unforeseen problems with the instrument, but level funding over the next four years is not credible as described in the proposal.

(5) Continued production of currently established and well validated data is a high priority.

AIRS algorithms and products are "newer" than the products from other Aqua instruments. Many products are currently experimental (beta, provisional, or validation-1) with uncertain overall accuracy and uncertain scientific usefulness. All of the Aqua data products, and those of AIRS in particular, need to be reviewed in terms of data quality and scientific utility at the end of Prime mission in FY2008.

In terms of new products, none of the enhanced mission efforts or products was deemed worth supporting in the extended mission; however, some of the ideas and research involved have merit and could be competed through NASA R&A where the products would be better defined in terms of science questions and better reviewed. The Committee felt that some of the enhanced activities,

such as data availability and data reprocessing, are essential to continued production of the established data and ought to included within the regular extended-mission requirements.

In general, justification as to why the basic extended missions should be continued at FY2008 funding levels was not adequate.

(6) Continued production of established data products through FY2010 and FY2011 has high merit, but the budget/personnel needed to achieve should be justified for the next Senior Review.

CLOUDSAT

Instrument(s): Cloud Profiling Radar (CPR)
Research Activities: Global vertical structure of cloud properties
Data Product Names: Cloud profiles, cloud optical depth, cloud liquid water content
Science Strengths/Weaknesses: Cloud profiles, low rain rate retrievals, extratropical rain rates/limited validation plan
Relevance to NASA Science Goals: **HIGH**
Maturity of Data Products: **MEDIUM**

General Comments

CloudSat is delivering on its stated goal to provide the first global survey of cloud profiles and cloud physical properties based on 94 GHz radar retrievals. Comparison with NWP and climate models has begun. A CloudSat simulator is being developed to assist in this regard. CloudSat is a good example of the synergy to be gained from the A-Train mission formation concept. Given the recent problems with climate sensors on NPOESS, CloudSat is demonstrating what may prove to be a new paradigm for climate monitoring from space, where multiple satellite measurements are integrated on the ground. Scientific merit is high for extended mission and proposed enhanced products. For example, the proposed rain rate product has the potential to measure light rain rates that TRMM cannot observe. Given that the CloudSat rain retrieval saturates at 10mm/h, it was not clear to the panel the level at which quantitative retrievals cut off. The flight system is healthy, well within calibration budget, with a life expectancy of an additional five years. Within the past year, 1TB of data have been accessed by the scientific community, well in advance of the funded science team. The panel thought the validation plan for CloudSat could be strengthened, but aspects of this may come from the recent R&A (ROSES) solicitation.

Given the novelty of the measurement being made, there is no question that this modest-costing mission warrants continuation. The team has already been more successful than most in transitioning its algorithm developments to near-routine (they even have a plan for episodic re-processing). Moreover, the approach of this team has been multi-instrument, multi-satellite from the beginning. Despite the brevity of CloudSat operations to date, this team already has a specific plan for transitioning its products to "routine" activities. To exploit the novelty more fully, the Committee felt that the modest enhanced mission has high scientific and technical merit and could provide more systematic products; the two proposed enhancements are critically valuable extensions of available observations. Note that, unlike for other missions, more of the "standard products" are multi-instrument, multi-platform in character (more would have been done if funding had been approved) and that all of the enhanced products are of this character. Hence, this team is in a leadership position (along with CERES) with respect to developing and implementing multi-instrument analyses.

Detailed Comments

(1) Scientific merit is high. The mission is providing the first global survey of the vertical structure of cloud systems and measurements of the profiles of cloud liquid water and ice water content. The products are new, but of high value, and there is interest throughout the science community in these

products. NASA ROSES is funding additional science activities, $3M a year – and so new products and uses are likely to come in the future.

(2) Enhanced products are proposed for quantitative surface rain rate estimates, snow profiles, profiles of ice-water characteristics, CloudSat-TRMM match-ups, and AMSR radiances mapped to the CloudSat ground track. The algorithms are already in development, so moving to enhanced mode will likely be straight forward. The science team has been selected and will meet in June 2007. The CloudSat simulator is a useful tool for model comparison. The precipitation product has unique value in the extratropics, beyond the TRMM orbit, in preparation for GPM. Within the tropics, CloudSat is seeing more warm rain than TRMM. Where possible, the CloudSat project looks to TRMM as partners for validation. Recently, a four month experiment in Canada was conducted for snow validation, and the project is also collaborating with a GPM group in Finland.

(3) The synergy with existing missions such as MODIS, CERES, TRMM and CALIPSO is well documented and discussed. Six of the core products depend on other observations from the A-Train. A good example of this is the LiDAR/RADAR combination of cloud profile from the CloudSat/Calipso combination. The group is pushing and succeeding at multi-instrument data products.

(4) The project has an effective and efficient data system. One terabyte of data was been served to users this past year, well in advance of the funding of a science team. The project is gearing up to reprocess the first year of data.

(5) Given the high merit and success to date, the Committee felt the CloudSat mission readily warrants funds for the extended and enhanced mission. The panel felt that the CloudSat validation plan could be strengthened, but it is anticipated that some of the recently selected science team PIs will propose validation activities.

(6) Based on 1-5 above a strong case can be made for extension well into FY2010-2011.

EO-1

Instrument(s): ALI and Hyperion
Research Activities: Technology demonstration for highly automated data collection, Sensor webs for volcanic activities, Ecosystem characterization
Data Product Names: Multispectral and hyperspectral images
Science Strengths/Weaknesses: Strength is agility / flexibility to collect data in response to events such as hurricanes, volcanic eruptions, floods, forest fires, etc.
Relevance to NASA Science Goals: **HIGH**
Maturity of Data Products: **HIGH**

General Comments

EO-1 is the first and only Earth Science New Millennium Program (NMP) mission to make it into orbit. As a technology demonstration, it has successfully pioneered a number of new techniques (e.g., formation flying, shared launch with SAC-C, automated spacecraft tasking, onboard processing, and spectroscopy). Launched in November 2000 with a nominal expected lifetime of one year, and a second year for data analysis, the prime mission ended in 2002. This mission has thus been in extended mode since January 2003. Currently, the satellite acquires approximately 100 scenes total per week from the ALI and Hyperion instruments. "Collects" are scheduled based on a variety of purposes (events such as storms or volcanic eruptions, requests from NASA HQ, DoD, and "paying customers," on-orbit calibration, and "filler" scenes collected for historical value).

EO-1 began as a NMP demonstration of flight technology, but has recently morphed into a facility instrument that provides a unique demonstration two satellite capabilities: (1) high-resolution (30 m) hyperspectral (10 nm) remote sensing at prescribed look angles; and (2) a rapid-response high-resolution imager that can retrieve scene data within a few hours to one day. These satellite capabilities are unique in the civilian sector and provide data that are relevant to NASA's mission.

This is the first time it has been considered by a Senior Review, whereas earlier efforts to justify continued mission operations have been based on a variety of criteria. The mission operation, data acquisition and archiving were transferred to the USGS EROS Data Center (EDC) after the prime mission with the intent to support mission operations by selling data. The cost of a tasking request and scene delivery was initially about $5K but is now reduced to $750 for tasking and $500 or less per image for distribution for acquisitions requested by the general public, and scenes in the archive can be ordered for the cost of reproducing data. There are efforts underway by the GSFC management team to facilitate free and open access to data by NASA-sponsored investigators. This is a critically important step since the previously stated costs for EO-1 data have likely precluded their widespread use by the scientific community.

Detailed Comments

(1) With the possible exception of data collected over coral reefs, atolls, and islands (see below), there has been no effort made to collect long-term systematic data records. The collection of scenes is ad hoc. One (possible) exception is the collection of coral reef, atoll and island scenes in

support of the ESD mid-decadal study, an effort that was undertaken in the wake of the Landsat-7 anomaly. This collection focused on a time frame of 2004-2006, and will be repeated again in 2009-2011 if the mission is extended.

There are numerous projects that utilize EO-1 data to address science goals consistent with NASA's Science Strategic Plan, but these are not explicitly included as part of the continued or enhanced mission. These could have been included as 'in kind.' It would be a stronger proposal if they had identified a couple of key facilitating tasks directly funded as part of the project that ensure some of the key developments continue (e.g., sensor web and highly automated collection).

(2) The proposal makes no distinction between "basic continuation" and "enhanced science." The ad hoc nature of data collection allows for the use of EO-1 data collection in response to natural and anthropogenic hazards/disasters, and the development of new technologies (e.g., sensor webs that alert observing systems of volcanic activity) allow experimental use of the sensors. This flexibility (agility) has merit because use of EO-1 to collect 'event/rapid response' data or experiment with new techniques does not interrupt data streams from the systematic global missions.

(3) EO-1 was initially flying in formation with Landsat 7, Terra, and SAC-C as part of the morning constellation. The redundancy of collecting visible/NIR data for the same scene with different spatial and spectral resolution was deliberate, and has led to improved algorithms for future mission (e.g., LDCM, HyspIRI). This purpose does not justify continued operation of the mission because the algorithm development efforts can be carried out with data in hand (over 30,000 scenes).

A complementary application of EO-1 data is for cross-calibration of other visible/NIR sensors. This purpose could justify continued operation, but the proposal lacks detail about the calibration / characterization of the ALI and Hyperion sensors. Use of one or both of these instruments as a "transfer radiometer" to cross-calibrate other sensors requires that their own calibration be well characterized.

ASTER on Terra lists an enhanced mission goal of expanding the volcano sensor web initiated by EO-1 to alert ASTER to collect data.

(4) There is no E/PO plan in the proposal, but in many respects, the ability to collect images in response to disasters serves an E/PO purpose. These "secondary criteria" are actually the primary reasons for continuing the mission. That is, the mission is continuing to be used for technology development (e.g., sensor webs, Open Geospatial Consortium demo, ESTO AIST funded projects, Nabster, etc.). The cost is very low.

The proposal is only to continue mission operations at a minimum level to schedule, collect and distribute data to serve science and technology development efforts funded by other means.

(5) The flight demonstration of the hyperspectral images HYPERION is complete, and now HYPERION is being used to support specific, individual field investigations or data gathering (e.g., coral reefs) and to develop new satellite missions. The ability to gather HYPERION data at different look angles provides an observational simulation system that can test the necessary spectral/spatial needs for new instruments. Such data cannot be acquired from aircraft instruments.

The spacecraft has been re-programmed to act as an autonomous scheduling and data acquisition platform with a response time to high priorities within one orbit. The scheduling algorithm merges with Air Force weather data to determine if the target is cloud-free for that orbital pass. It works with a 'web' of other sensors (in situ, satellite) that creates autonomously a 'request' and 'location' and 'time' for the EO-1 acquisition. Such capability is expected for national technical means but unheard of in the civilian sector. The commercial very-high-resolution satellites (QuickBird, Ikonos) can be targeted, but the response time for data acquisition and distribution is generally far too slow (10 days) for observing transient science or responding to geohazards.

(6) The proposal is to continue the mission throughout the four year proposal window, or as long as the satellite and sensors continue to operate. Continuation of the mission and the many 'in kind' uses of the data has largely depended on the continued lead evangelism of one or two individuals and the contributed time of others who built the hardware and have a personal interest in its continuation. It appears to be operating outside of the realm of the other earth science missions at the GSFC. It would be worthwhile to develop a strategy for succession of this 'management team' in the event of personnel changes.

A problem with the effective utilization of the EO-1 satellite lies in the very limited use of this facility by NASA to define future missions. EO-1 is being used as a gap-filler for some projects (e.g., coral reefs, other field studies), but there is no clear plan for proposals to use EO-1 as an observing simulator. There also appear to be a large set of "in-kind" users for individual science projects. The 'sensor web' project is being highlighted for individual geo-hazards and possibly outreach, but the capability of rapid acquisition of transient geophysical events has potential application beyond volcanic plumes (e.g., landslides, major air pollution events, dangerous chemical releases, etc). Use of the autonomous schedule/acquisition for volcanic plumes is included in Terra's enhanced mission.

The Committee observes that by improving the organizational structure via HQ support and some additional project level support to the EO-1 team could significantly enhance the value of EO-1 to Earth science. The project needs to develop a plan for how the data will be used (e.g., for simulating future missions, for demonstrating sensor web technology, and for cross-calibration of orbiting sensors). It could be valuable as a facility, but currently is it "below the radar" and too dependent on the energy of an individual investigator.

GRACE

Instrument(s): GRACE
Research Activities: Measurement of static and time variable gravity field; Radio occultation measurements of atmospheric refractivity profiles
Data Product Names: Level 2; GSM (time variable gravity coefficients); GCM (time averaged gravity field coefficients).
Science Strengths/Weaknesses: Unique data products for time variable gravity field variations. Broad areas of applications to ice sheet mass changes, deep ocean currents, large post-seismic earthquake deformations and hydrology changes.
Relevance to NASA Science Goals: **HIGH**
Maturity of Data Products: **HIGH**

General Comments

GRACE is a joint NASA/DLR (German) mission with the day-to-day mission operations executed by the DLR. The rationale for continuation of this mission, especially in combination with ICESat and GOCE, is powerful. Given the changes in polar conditions that we are already seeing in these data, we must see more to improve the interpretation and reconciliation of the difference gravity estimates (e.g., masscon vs. spherical harmonics). Beyond the ice-sheet mass-balance problem, the other applications of these measurements, particularly to elucidating the deep ocean circulation and thermal and mass contributions to sea-level change and to determining water storage over land, are novel and crucial inputs to understanding these aspects of climate variation. These measurements will be made much more valuable by extending the length of record. Solid earth applications for post-seismic deformation after large earthquakes and evaluation of glacial isostatic adjustment also are possible.

Radio occultation (RO) measurements of atmospheric refractivity are being started but only briefly discussed in the proposal. The ultra-stable oscillator on GRACE makes these measurements somewhat different to other RO systems (e.g., CHAMP and COSMIC), although the quantitative impact of this difference is not discussed in the proposal. GRACE contribution of RO measurements to atmospheric studies is not clear now that COSMIC is operating.

Detailed Comments

(1) The GRACE measurement of relatively high-spatial-resolution gravity-field changes is unique and applicable to broad areas of NASA Earth science. GRACE measurements, when coupled with other missions provide, new insights. Examples include:

(a) JASON altimeter measurements of mean sea level (MSL) change, which reflect both mass and temperature effects. The addition of GRACE measurements allows decomposition of sea-surface height change into thermosteric and eustatic components. Currently, there is a difference between the steric effects from ocean buoys and ARGO floats and the JASON/GRACE results, which is thought to be due to systematic differences between the older ocean buoys and the newer ARGO floats. The differences, however, could also have implications related to thermal changes below 750m depth in the ocean.

(b) ICESat ice volume changes compared to GRACE mass changes allow the separation of secular effects from GIA and current ice mass changes to be separated.

Most of the rapid gravity changes are due to water movements, and GRACE provides direct hydrological measurement on spatial scales of ~500-600km and monthly temporal scales. There is also a contribution from atmospheric mass changes, but these are removed in a calibration step using ECMWF atmospheric fields. In Antarctica there could be sizable leakage of atmospheric effects into the ice mass changes. Assimilation of COSMIC radio occultation profiles into meteorological models could considerably improve the atmospheric models.

The static gravity from GRACE has application to surveying (difference between ellipsoidal height from GPS and conventional, potential based, orthometric heights), in oceanography for computing ocean currents from altimetry derived dynamic ocean topography, and in spacecraft orbit reconstruction.

(2) The panel felt that the products listed as enhanced did not fit the definition of enhanced products. The products, in general, were considered worthwhile efforts, but that they could be included in the core budget i.e., they reflected refinements of existing products rather than new products. The re-processing of GRACE data with the latest models and calibrations with improved modeling of spacecraft effects could also be included in the core activities. Combination of GRACE and GOCE (high-resolution gravity gradiometer measurements) is important but could be incorporated into GOCE processing. Near-real-time gravity products (for assimilation into hydrologic models) are an enhanced product and reasonably priced (<100K per year), but their application is not clearly demonstrated. Investigation of this product is an appropriate R&A (e.g. ROSES) activity. Aeronomy results at 360-400 km altitude are interesting but are applicable to space science products rather Earth science. Annual data user workshops are also proposed but are not a new product. At a cost 146-149K each year, they are expensive and not appropriate as an enhanced product.

The combination of GOCE and GRACE will provide an important high-resolution static gravity-field product. In this case, GOCE benefits from the addition of longer wavelength GRACE data (not well measured with gradients) and GRACE will benefit from better-determined short-wavelength gravity field.

(3) The gravity field results are unique and complement products from other missions. The RO measurements (only briefly discussed in the proposal) are not unique except for the impact of the GRACE ultra-stable oscillator.

(4) Costs for basic mission seem reasonable. The costs of some of the enhanced products (workshops and possibly the reprocessing) are high. The other enhanced mission activities seem reasonable.

(5) Gravity field products generated by GRACE are unique and no changes or enhancements are needed.

(6) Given unique nature mission, the above comments apply equally well to the 2010-2011 time frame.

ICESAT

Instrument(s): GLAS
Research Activities: Determining ice sheet mass balance (primary) with other focus areas.
Data Product Names: Surface elevation, backscatter, boundary layer and cloud heights, canopy heights
Science Strengths/Weaknesses: Repeat track change detection across major ice sheets in unique; twice per year sampling is problematic in missing variations throughout the seasonal cycle. Sea-ice applications are unique. Some proof-of-concept demonstration of vegetation applications
Relevance to NASA Science Goals: **HIGH**
Maturity of Data Products: **HIGH**

General Comments

Despite problems with laser longevity, the ICESat team has made exemplary progress toward their prime objective of measuring ice-sheet mass balance. The core team and their ROSES collaborators have also extended the instruments utility to include pan-Arctic estimates of sea-ice thickness change/volume, which complement observations from other sensors that are limited to measuring ice extent. The shift to a limited set of observation periods, however, has limited the GLAS instrument applicability to vegetation studies. In addition, the snow-depth and water-level measurements are too sparse in time to be directly useful, but they do provide an important proof-of-concept and validation of other measurements activities. The cost of the continuing mission seems justified by the complexities of the limited-laser operations and the analysis required to maintain the altimeter accuracy. However, the core science budget appears high relative to other missions of similar scope and complexity.

Detailed Comments

(1) With the progress toward ice-sheet and sea-ice thickness and mass balance, the scientific merit of continuing the operations in high. Accurate ice sheet mass balance that resolves long-term trends rather than natural short-term variability requires a long time series of observations. ICESat begins this record and a non-overlapping subsequent mission has been recommended by the Decadal Survey. In addition to ice-sheet mass balance, the instrument also is providing important data for understanding ice-sheet change. For example, observations recently published in *Science* reveal the sub-glacial movement of water beneath the ice sheet, which one of the most poorly understood controls on ice sheet motion. The ice sheet results are particularly timely, given the recent IPCC acknowledgement that of the importance of sea level rise as ice sheet volume and mass changes.

(2) Basic mission includes continued production of the core products. While no enhanced products were formally proposed, several products are proposed as part of the basic mission that actually belong in the enhanced proposal, including time series of dH/dt and new sea-ice freeboard products. Significant project resources have gone into the development of the firn-compaction model. It is imperative that the compaction corrections or the model itself should be distributed to the broader community, well in advance of the next Senior Review. Considerable effort is still

needed to calibrate the pointing for each of the laser campaigns and, due to thermal effects, even within one laser type.

There was no discussion in the proposal about atmospheric forward-scattering, which is difficult to correct due to the significant degradation of the (sensitive) green channel. The possibility of systematic cloud coverage changes associated with climate change could alias into apparent ice sheet height changes.

(3) The standard set of core products is well utilized, and there is significant merit in production of the proposed additional products. NASA R&A is funding 23 Science Team members who, along with other investigators, are actively using the product. Some products, such as sea ice thickness, are insensitive to pointing and absolute calibration of the range data. There is strong synergy with GRACE, and the Committee observed that ROSES funding opportunities could encourage studies to produce joint ICESat and GRACE ice-sheet mass balance estimates. The cloud products are superseded by CALIPSO. Some products such as the vegetation products are probably best targeted as demonstration products.

(4) High costs have partially been driven by calibration/correction issues to compensate for known instrument deficiencies prior to launch and additional on-orbit problems. The team has done a commendable job in making a successful mission out of what otherwise might have been a complete failure. Dissemination of data by NSIDC is very good. As a result, GLAS cloud observations have been used for validation of passive instruments, but now with the launch of CALIPSO and CloudSat, there will be less use of GLAS due to limited data sets and degradation of GLAS atmospheric products. Given that many of the difficulties have been overcome and the processing is now fairly mature, the $6.3M for science/data processing seems high relative to similar missions.

(5) The proposed products and validation efforts are key to meeting NASA's cryospheric objectives and the Committee felt they warrant continuation. Joint efforts in determining ice-sheet mass balance with GRACE might also produce valuable scientific insight. Validation efforts and complementary ice-sheet elevation measurements made the NASA/Wallops Airborne Topographic Mapper (ATM) could also be considered an important effort by NASA for determining ice sheet mass balance. In this time frame, it makes sense to maintain the ice sheet elevation change strategy with at least two acquisitions per year.

(6) An accurate ice-sheet DEM is an important constraint for ice sheet modeling efforts, and there is strong merit in producing such a product. ICESat has already produced a DEM, but the resolution is limited by the 33-day orbit sub-cycle. As the laser quality degrades to the point where dH/dT measurements are marginal, the accuracy of the degraded observations would still be highly useful for DEM production and the mission could be directed to acquire surface elevation for the unobserved sub-cycles. In 2009, when the GLAS instrument laser is expected to be nearing its end, the Committee feels that it would be highly useful if NASA should convene an independent review board to consider this issue, and to consider the best strategy for observations in 2010 and beyond.

JASON

Instrument(s): CNES/Alcatel dual frequency radar altimeter at Ku-band (13.6 GHz) and C-band (5.3 GHz)
Research Activities: radar altimetry measurement of ocean surface topography
Product Names: ocean surface height, wave height, wind speed, tropospheric water vapor, and satellite orbit height
Science Strengths/Weaknesses: continue the radar altimetry measurement of the TOPEX/ POSEIDON mission to provide 14-year (1993-2007) high-quality record of a key ocean variable; No major weaknesses noted
Relevance to NASA Science Goals: **HIGH**
Maturity of Data Products: **HIGH**

General Comments

Jason-1 is a joint NASA/CNES (French) satellite mission to continue the radar altimetry measurement of the global ocean surface topography as a follow-on mission to TOPEX/POSEIDON (T/P). The combined data record now extends more than a decade in length (1993-present). A follow-on mission to Jason-1, the Ocean Surface Topography Mission (OSTM), will be launched in 2008 to further extend the T/P and Jason-1 data record to the next decade.

Jason-1 and T/P together provide the first and only global ocean surface topography data record for more than a decade (1993 – present) at 2 cm accuracy over a 1 deg by 4 deg box on monthly time scales. Jason can measure sea-level change and the contributions from ice melting versus ocean heating/salinity through its synergy with the GRACE data. The further separation of the contribution of ocean heating versus salinity to the sea level change can be augmented by the launch of SMOS and Aquarius. Sea-level rise is recognized by the 2007 IPCC Report as one of the most important consequences and indicators of global climate change. Extension of the Jason-1 mission will provide its overlap with the follow-on OSTM mission for cross-calibration. A tandem mission between Jason and OSTM will be able to measure ocean eddies and coastal tides. Enhanced data will be provided by ROSES-funded projects and hence were not proposed.

Detailed Comments

(1) Jason and T/P together provide the first and only global ocean surface topography data record for more than a decade (1993 – present) at 2 cm accuracy with 1 x 4 degree spatial resolution on monthly time scales. Jason-1 measurements are relevant to five of the 24 specific NASA Earth Science questions. The synergistic use of Jason and other altimetry data makes it possible to resolve ocean eddies (which are the oceanic analog of the storms in the atmosphere, carrying around 90% of the kinetic energy of ocean circulation) on the order of 100 km. The synergistic use of Jason and GRACE makes it possible to measure sea-level change and the contributions from ice melting versus ocean heating/salinity. The value and need of Jason-1 is also reflected by the fact that its follow-on mission, OSTM (or Jason-2), has been approved by NASA for launch in 2008. A tandem mission between Jason and OSTM will further improve the measurement of ocean eddies and coastal tides.

(2) No enhanced products were proposed, because they will be provided by ROSES-funded projects. The proposed main task is to extend the sea level height record, but also to emphasize the synergy with other missions for the measurement of eddies and coastal tides and for an improved understanding of sea level rise since 1993. Data product processing is part of the science budget, which is appropriate for the maturity of the dataset.

(3) Jason provides the sea level height data that are not available from any other existing NASA missions. Altimetry measurements are available from ESA's ENVISAT. While the synergy with GRACE and ENVISAT is emphasized by the Jason proposal, its synergy with other NASA missions, particularly QuikSCAT, was not mentioned.

(4) The Jason payload contains one main instrument with four support/correction instruments, and provides two products (one for geophysical data record, others for quick-look investigation and operational applications). Data processing and distribution are shared by JPL and CNES. The mission operation FTEs and costs appear high. Mission operation costs include data processing at JPL, and are partly driven by near-real-time requirement from operational users, not the science. Other costs are reasonable. Altimetry measurement technology is mature and will continue to be used in the follow-on OSTM mission. The mission science budget covers data quality assurance and calibration/validation, but there is also $5.6M/yr of ROSES science team support.

(5) Sea level rise is recognized by the 2007 IPCC report as one of the most important consequences and indicators of global climate change, and the proposed core data products directly address this issue and other NASA science questions. The scientific return justifies the mission extension for FY08 and FY09 as proposed, but the mission team needs to provide additional details to justify the mission operation FTEs and costs. Collaborations with other ocean measurement missions (e.g., QuikSCAT, Aqua, Terra) were not proposed but could be pursued, or clarified if such collaborations already exist.

(6) The same comments can be made for items (1) though (5) concerning mission continuation for FY2010 and FY2011. While the one-year overlap with the OSTM mission is needed for cross-validation, the potential value of a tandem mission and related higher-resolution product is high. The Committee feels a new proposal for mission operations, including a new funding profile, could be proposed after approximately one year of overlapping observations with OSTM

QUIKSCAT

Instrument(s): QuikSCAT
Research Activities: Weather Research, Air-Sea Interaction Studies
Data Product Names: Ocean Vector Winds
Science Strengths/Weaknesses: Only US source of active sounding of ocean vector winds; No major weaknesses noted
Relevance to NASA Science Goals: **HIGH**
Maturity of Data Products: **HIGH**

General Comments

QuikSCAT's observations of high spatial resolution vector winds over the oceans are valuable for research into storms over the ocean, air-sea interactions, and driving of ocean currents by wind stress. The data are also used operationally for weather forecasting. In addition to its key role in diagnosing ocean-atmosphere exchanges much more thoroughly and completely than ever before possible (a key climate contribution), the series of scatterometer surface wind data products has allowed for a noticeable improvement in long range weather forecasts by providing an unprecedented density (in space and time) of surface wind information.

Detailed Comments

(1) Scientific merit is very high, as this mission provides a unique data set. It is the only US mission to actively sense surface vector winds, and produces near global coverage daily at 25 km resolution. These data are valuable for several of NASA science themes, including weather research, climate variability and change research, and water and energy cycle research. Surface vector winds are also useful in understanding the exchange of gases at the ocean surface. The scientific value of the data set increases with its length and continuity, as this provides information about climate variability mechanisms. In addition, the data products, or the primary measurement of backscattered radiation, are used operationally by the weather forecasting community (NOAA).

(2) The basic data product is a continuation of the global ocean backscatter and vector winds data products to a distance of 30 km from land areas. Four enhanced products are proposed. As a general comment, the proposal expended much more text on the general scientific utility of the proposed enhanced products, and much less text on describing the specific algorithms and their maturity, and the specifics of the data products that would be produced.

The four enhanced products are:

a) Coastal Winds Data Set: Extend vector wind retrievals inside of 30 km from land. It is possible to extend the retrieval to a limit of about 5 km of coasts under certain conditions, when the larger dimension of the instrument foot print is parallel to the shore. It is not clear from the proposal how near to the coast the retrieval would be possible on average, and how much area globally this would represent. The answer to these questions seems to depend upon the alignment and complexity of the coastline and the orbit of the QuikSCAT platform. It is proposed to select the best elements of two coastal retrieval schemes into the operational wind

retrieval software, and to make it part of the standard product. This seems like a potentially valuable product that is best produced within the core science data production stream. Wind stress nearer to sea ice boundaries could also be proposed, but was not specifically mentioned in the proposal. One justification for resolving winds close to the coast is to observe the wind-driven upwelling zones. This offers a potential application to fisheries and NASA's carbon ecosystem focus area. High winds near the coast are also of concern in the context of forecasting storm surge and inundation. This is a potentially important enhancement that the Committee feels could be pursued as a part of the basic vector wind data set, but question why it could not be produced with the current core mission funding.

b) High Wind Data Set: It is proposed to use *a priori* information from models or other data to improve the estimation of wind speed and direction under conditions of high wind speed. This is important for getting better real-time observations of wind strength and storm structure for mid-latitude and tropical storms. The effort involves an algorithm selection, evaluation in collaboration with the storm forecasting community, and a reprocessing activity. This seems like an important activity that would best be incorporated within the operational data processing scheme. This is a potentially important enhancement that Committee feels could be pursued as a part of the basic vector wind data set, but question why it could not be produced with the current project science budget.

c) Sea Ice Data Set: Active scanning of sea ice with QuikSCAT has the capability to add information not available with passive microwave scanning. It is not as clear, as in the previous two enhanced data products, that the sea ice data product should be processed by the operational data stream. It could be equally well produced outside the data stream for the standard wind products. The Committee feels this data product could be competed via ROSES or a similar mechanism.

d) Multi-Sensor Wind Products. It is proposed to do research into combining vector wind measurements from QuikSCAT, WindSat, and ASCAT to produce an enhanced wind data product. This seems like a research project that is not ready for operational use. If available in real time, these scatterometry measurements could be incorporated operationally within a weather forecasting data assimilation system. This appears to be a proposal to use an offline regridding and optimal combination of these data inputs as a combined product. The Committee feels this data product could be competed via ROSES or a similar mechanism.

(3) As previously mentioned, QuikSCAT is the sole US source of actively sensed vector winds over the ocean. Other sources of vector wind data are or will be available from ASCAT on the European Metop-2 satellite and from WindSat on a DoD satellite. ASCAT has a narrower swath width than QuikSCAT, and WindSat is a passive wind measurement.

(4) The mission operations cost seems reasonable compared to some other missions, in part because of the decision not to use a 24/7 staffing model. In addition, the data are disseminated in near-real-time to operational weather forecasting agencies and are also moving promptly to research data archives. The routine science data processing is about $2.7 M/yr, and about $4.5M/yr is expected from in-kind support. These allocations appear high and level in a time of routine data processing. The science mission budget justification for continued near-level funding was not

provided.

(5) The basic ocean vector winds data provided by QuikSCAT are the core requirement and warrant continuation for the FY2008 – FY2009 period. A comparison to other data sets such as SeaWinds and ASCAT could be conducted to demonstrate the added utility of the QuikSCAT data. The core data product of the vector winds is very valuable.

At least three of the four enhanced products are considered worthwhile. The first two are best produced by the project within the core science data production stream. The second two might better be produced outside the operational data processing, possibly by an investigator selected competitively through NASA R&A.

(6) It is likely that, if QuikSCAT maintains its core capabilities, it will be a very good investment to continue the core mission through the FY2010-11 period. There is little likelihood that an equivalent data stream will become available in the FY10-11 time frame, so the data will remain unique and valuable, and the technical justification for continuation will remain.

SORCE

Instrument(s): Spectral Irradiance Monitor (SIM), Solar Stellar Irradiance Comparison Experiment (SOLSTICE), Total Irradiance Monitor (TIM), and the XUV Photometer System (XPS)
Research Activities: Monitoring long-term variations of total solar irradiance
Data Product Names: Total Solar Irradiance, Solar Spectral Irradiance
Science Strengths/Weaknesses: High-quality measurements of a climate variable
Relevance to NASA Science Goals: **HIGH**
Maturity of Data Products: **HIGH**

General Comments

SORCE carries four instruments including the SORCE Total Irradiance Monitor (TIM) which measures the Total Solar Irradiance (TSI). The SORCE Solar Spectral Irradiance (SSI) composite data product is constructed using measurements from the SOLSTICE, SIM, and XPS instruments, which are combined into merged daily solar spectra over the spectral intervals. These observations are important for addressing discrepancies in solar flux observed between the TIM and other instruments. These are mature data projects, but the proposal did not provide sufficient justification for the funding requested.

The TSI appears to be up to 5 Wm^{-2} lower than previous measurements. The TIM overlaps with ACRIM3 measurements; however, given the temporal overlap between the two missions, the difference in absolute calibration of the two instruments needs to be resolved. SORCE will also provide the overlap with its follow-on mission, GLORY, for cross-validation. Funding for mature science products may be too high in comparison with other missions. The enhanced science budget is very modest but could be covered in a (possibly reduced) core science budget.

Detailed Comments

(1) SORCE measures solar irradiance, the planet's primary natural forcing, knowledge of which is needed to quantify climate dynamics and change. Climate trends need long-term measurements of incoming solar radiation at high accuracy. Solar flux changes on the Earth are more accurately determined with spectral information; measurements provide optimum observations when made over at least one full solar cycle to look for any regime dependence. SORCE carries four instruments: Spectral Irradiance Monitor (SIM), Solar Stellar Irradiance Comparison Experiment (SOLSTICE), Total Irradiance Monitor (TIM), and the XUV Photometer System (XPS). Thus, continuation of SORCE is intrinsically of very high value. It will also provide the overlap with its follow-on mission, GLORY, for cross-validation.

The Committee found that the continued absolute calibration differences between SORCE and ACRIM data set need to be corrected, and observed that SORCE/ACRIM3 teams must be encouraged to work together to resolve the differences and to define an observation strategy for future solar measurements. Essentially the same finding was reported in the 2005 Senior Review.

(2) While the Basic Continuation mission warrants support, there is no strong justification for funding any of the five enhanced data products proposed as part of the SORCE mission. Although the budget is comparatively small for the enhanced products, the panel feels that these new products could be incorporated into the core mission. Indeed, one can argue that the proposed enhancements for long-term solar irradiance records and data quality and access are essentially a part of the core mission, while the enhancement for atmospheric heating rate is more appropriate for ROSES proposals. The proposed lunar and stellar observation, with an annual budget of $79K, could be incorporated into the basic budget. While the proposed enhancement for atmospheric density is an interesting retrieval method, a user base outside of the SORCE science team needs to be demonstrated. If the SORCE team deems it very important, this enhancement, with an annual budget of $53K, could be covered by the basic budget as well.

Long-term solar records from the combination of SORCE irradiance measurements with earlier measurements: SORCE observations play a key role in extending the irradiance measurements but this could be considered part of the core mission and covered by the proposed core mission budget. The SORCE team provides the expertise to address this issue but it must also be done in collaboration with other appropriate solar missions, not as a stand-alone SORCE activity.

Solar heating rates in the atmosphere: In addition to accurate measurements this activity will also requires an accurate radiative transfer model for the atmosphere. This activity is thought to be more appropriately funded in a ROSES-type mechanism under peer review of data and radiative transfer models.

Improved data access via the innovative LASP Interactive Solar Irradiance Datacenter (LISIRD): Easy access to data should be a core part of any mission. SORCE delivers data well and should continue to find new ways to improve the distribution – but under the currently proposed core budget.

Lunar and stellar irradiances for calibrating other Earth Science satellite instruments: SOLSTICE measures the ratio of solar to stellar irradiance and this technique, can measure the ratio of solar to lunar irradiance, and thereby determine the reflectance properties of the moon in the ultraviolet and thereby extend the use of the moon as calibration target to the ultraviolet. This seems like an interesting product, but potential users were identified. The proposed core mission budget is relatively large in comparison to other missions and largely supports science team activities, including science data processing. This product could be incorporated into current budget or shared with potential collaborators who need the data set.

Atmospheric densities from the SOLSTICE stellar occultation measurements: To quote the proposal: "This dataset of SOLSTICE stellar occultation profiles has yet to be analyzed in detail, and promises new insight into nighttime oxygen and ozone density variations. As an enhanced science objective, modest funding for Dr. Jerry Lumpe (CPI) is requested during the extended mission to help produce a new SOLSTICE data product of densities derived from stellar occultation observations. Once these products are generated, we assume others will seek NASA ROSES as well as NSF funding to perform more detailed analysis and atmospheric modeling to interpret these data." The assumption that others will seek funding indicates that

there is not currently a broad user community need for this product. Thus, while an interesting retrieval method, a user base outside of the SORCE science team should first be demonstrated.

(3) SORCE provides the SSI that is not available from other NASA missions, but there is redundancy with ACRIM3 in the TSI measurement. It is still not clear that NASA needs to provide redundancy in this measurement by these two instruments. This redundancy needs to be directly addressed and dealt with by NASA. Because of the spectral information and its newer technology, SORCE is an important mission for resolving these absolute discrepancies among other solar TSI measurements.

(4) The overall mission costs are reasonable. Part of the reason for a relatively expensive science budget is that competitive type-funded projects (e.g. ROSES) have not been pursued (no in-kind funding). The combined SSI and TSI measurements of SORCE represent a new technology, and will continue to be used in the follow-on GLORY mission. SORCE data are primarily distributed through the SORCE portal at CU-Boulder LASP, and the level-3 products are archived at GES DISC.

(5) SORCE provides both SSI and TSI that are crucial climate variables, and these critical measurements warrant continuation. This extension also provides the necessary overlap with the GLORY mission for cross validation. Additional support for enhanced data product development is not justified by the proposal.

(6) Differences in SORCE/TSI and previous TSI measurements ought to be resolved or understood prior to FY2010 to determine if redundancy of this particular observation is needed. The SORCE spectral irradiance measurement will continue to be unique amongst current and planned missions, so the scientific justification for continuing the SORCE observations through FY2011 is high, as long as spacecraft and instrument health permits.

TERRA

Instruments: ASTER, CERES, MISR, MODIS, MOPITT
Data Products: Many
Maturity of Data Products: High (except for a few MISR core products)
Relevance to NASA Science Goals: **HIGH**
Maturity of Data Products: **HIGH**

Detailed Comments

(1) Data products from Terra are of high value and are widely used by the scientific community. The proposal lists many applications of data products that cover the five major science categories listed by NASA. In addition, data products from Terra are used by other agencies for forecasting, air quality monitoring, climate modeling, etc. The proposal does an excellent job of highlighting NASA science questions and the role that Terra products have played and will be playing in addressing these questions. Thus, there is no doubt that continuation of Terra data products will advance science in many important areas of interest to NASA and the scientific community at large. However, the return of science or its value from the five instruments is not evenly balanced. Based on the citation record (given in the proposal) to journal articles using Terra data, MODIS and CERES have made a substantial impact in advancing science. The proposal lists a total of 18,000 citations to papers using Terra data products. Over 80% of this citation comes from MODIS (11511) and CERES (3056), followed by MISR, MOPITT and ASTER.

ASTER data have been used in relatively fewer scientific publications than the other four instruments onboard Terra. We assessed that this has to do mostly with difficulties in accessing the ASTER data products by the user community. Better science management of ASTER could make the data products more accessible and user-friendly.

Overall the record is strong in showing that all instruments are performing well in terms of providing high quality data for use in scientific investigations. We find that the continuation of all basic core data products listed in Table 3.1 of the proposal through FY2009 is warranted.

(2) All core products merit continuation. MISR core products are less mature than those from ASTER, MODIS, CERES and MOPITT. However, this was not surprising, given the novelty of the MISR measurement. The value of the MISR products would increase if the MISR group focused on developing the maturity of the core data products rather than inventing new products. With the current size of the MISR team, it seems feasible to reach data maturity without adding additional FTEs. Between instruments, CERES and MOPITT use MODIS data products, and ASTER uses both MODIS and MISR data products.

Most of the activities listed under enhanced products deal with merging (or fusion) of data from various sensors. The proposal does an excellent job of highlighting science questions for justifying the need for developing new data products, but few individual "new" products are specifically spelled out in the proposal except for MOPITT. However, many details of what variables are going to be merged for each new product and the time/FTE commitments to accomplish the proposed enhanced tasks are not clearly defined in the proposal. Also, in almost all cases, the proposed activities seem to fall under the category of either core or in-kind activity. If a data product is

better suited for in-kind activity (specialized research topic), then the user community for this new product may be quite limited to warrant classification of a "new" product and large-scale processing of data.

ASTER is proposing one new product and two new service products in the enhanced mission. We assessed that almost all enhanced activities are more suited for NASA R&A competition. CERES has one new enhanced product proposed, involving better angle dependence in polar regions and improving polar cloud products. This data product is obtained by merging or fusing core products (these are not defined in the proposal) from MISR, MODIS and CERES. We assessed that this activity, although very innovative and potentially important, could seek funding through the NASA R&A program. Other enhanced tasks listed for CERES are in-kind activities, and the Committee found the in-kind mechanisms for funding were more appropriate. MISR science team activities could be focused on developing core data maturity and enhanced MISR activities could be proposed via the R&A program. MODIS enhanced merging of data activities could also be proposed via the R&A program. Enhanced activities to merge Aqua and Terra MODIS data could be a part of basic core activities. MOPITT is proposing one new data product to improve the vertical resolution of CO retrieval. This new activity warrants support and it produces a better vertical resolution data set for CO (the core product is only a column measurement). The MOPITT team has a relatively small budget, and this new task merits support. We assess that this new data product will be useful for scientific investigations of air quality and transport and will attract multiple users.

(3) There are two MODIS and two CERES instruments used to explore diurnal variations in products. MODIS data products are also used in MOPITT, CERES and ASTER core data products. Little mention is made of merged Terra-Aqua products in the proposal. Specialized subsets of merged data sets and common grid products are not compelling approaches. Instead, tools for merging the two data sets could be developed and made available to the community at large. There could be more synergy between MODIS and CERES data sets onboard Terra and Aqua than what was described in the proposals and presented to the review committee.

(4) Calibration of all instruments is clearly essential to current and future data production; it is crucial to maintain instrument calibration teams at a level to maintain current quality as well as to address unforeseen problems that may arise. The proposed cost of Terra extension is slighter higher than Aqua for both basic and enhanced activities. Almost all enhanced activities are closer to core basic and R&A.

After seven years of operation, product generation becomes nearly a routine task. It seems unjustified that the operations/science cost for MODIS and CERES is nearly identical given the more intense calibration/validation requirements for the MODIS instrument. The cost for CERES calibration/validation, and the science team cost in general, seems to be too high when compared against MODIS. Why? There does not appear to be a credible justification for continuing the very large science teams at current sizes for all five instruments. Instead of adding $3 M/yr for funding "enhanced" science, the team's resources might be better spent supporting activities from the EOS re-compete process under NASA R&A.

For all instruments, the extended mission would have ideally continued the routine calibration/validation activities for "modest" data quality improvements while reducing the overall

cost. For enhanced activities, the plan is to add two FTEs to work across the five instrument teams for data fusion. In addition, each instrument is proposing to add an additional FTE for their team to work on enhanced activities. In all, seven new FTEs are proposed to carry on enhanced activities, but the specific justification for these FTEs was weakly supported and thus not compelling.

(5) Basic core data products for all instruments are scientifically valuable and warrant continuation. The Committee assessed that the proposed MOPITT enhanced CO product was the only compelling enhanced mission data product.

(6) Same as above, mainly continuation of basic activities. The proposal did not provide sufficient justification for the large science budget (14 $M/yr), and the Committee felt the next extension proposal should do a better job. The Committee also found the proposals for "new" or "enhanced" products to be described in general rather than specific terms, resulting in a weak proposal. What core variables will be merged? When the products become available?

TRMM

Instrument(s): Precipitation Radar/Microwave Imager/Visible-InfraRed Scanner/Lightning Imaging Sensor
Research Activities: tropical precipitation rate retrievals
Data Product Names: rainfall
Science Strengths/Weaknesses: extending long-record tropical satellite-measured rainfall
Relevance to NASA Science Goals: **HIGH**
Maturity of Data Products: **HIGH**

General Comments

The Tropical Rainfall Measuring Mission (TRMM) is the first joint NASA/JAXA venture to use passive and active microwave instruments in measuring tropical rainfall. Since the TRMM was launched in November 1997, its instruments have remained in excellent working condition. The fuel on board is sufficient to maintain its operation until 2012-2013. The extension of TRMM will allow for not only continuation of rainfall measurements, but also aid in preparation for the Global Precipitation Measurement (GPM) mission to be launched in 2013. Overlap between the TRMM and GPM would extend the satellite-measured rainfall record, which can be used to enhance our understanding in numerous aspects of precipitation science. The TRMM precipitation products are widely used by the research community and operational centers. Extension/continuation of the TRMM mission will definitely help this need. In addition, the full constellation of other measurements, particularly CloudSat, that will be available in the next few years, may aid in measurements of light rain and snow.

Detailed Comments

(1) TRMM started as an experimental measurement, but now precipitation products are widely used for science, climate study, and operational purposes. TRMM has already produced an excellent climatology and case study data sets of precipitation, and will continue to do so. It is the TRMM datasets, with their higher spatial resolution, that finally showed that the statistics of precipitation, particularly extreme events, are such that very long data records (or very high space-time density, or both) are required for stable statistics. Moreover, to sub-divide the data by type of system, season, geographic location, etc., requires more data. Thus, the argument for mission continuation is already strong. It is even stronger when the full constellation of other measurements become available, particularly CloudSat. The excellent condition of TRMM instruments will warrant the continuity of the high-quality TRMM measurements of precipitation and lightning. Thus, the Committee gives a strong endorsement for the continuation of the TRMM mission.

(2) Basic data products are well developed. In addition to the basic continuation of data products, the following proposed product enhancements are important: Identification of characteristics of precipitation features, production of the wide-swath primary precipitation product, A-Train subset of TRMM data are produced by matching TRMM data with crossovers of A-Train within various time offsets, and generation of maps detailing rain accumulation from tropical cyclones are generated. This proposed modification to product generation costs $1.1M (FY08) to $0.4M (FY11) in addition to the basic mission extension budget.

(3) The data products offered in the proposed enhanced mission are considered useful and could be pursued. However, it appears that these enhancements could be readily provided under core mission funding or could be competed through NASA's R&A program.

(4) Despite reductions (reported in the proposal presentation) in its original mission budget, the budget of the basic continuation mission remains high (66.7 FTE in FY07 to 49.3 FTE in FY11). Although the science budget at GSFC is reduced, the mission operation budget is slightly increased. The science budget required by MSFC is maintained almost at the same level for FY07-11. For the science budget, GSFC proposes to answer 19 science questions, but MSFC proposes nothing, except the budget. The funding for routine processing of LIS data is constant over the extended mission and seems too large (there is no science justification given), although other portions of the mission are reducing their costs significantly over the four year period. NOAA is providing some funding to some scientists to do TRMM work. Currently, the TRMM portion of funding is decreasing and the GMP portion is increasing.

(5) The proposed core data products are vital to NASA contribution to research of the global/regional hydrological cycle. The proposed science investigations with a longer record of TRMM rainfall are important contributions. TRMM loses sensitivity at light rain rates, thus the collaboration between TRMM and CloudSat is seen as having potentially high scientific value. The mission warrants continuation through the period in question; although the Committee feels some reduction in mission science team costs are possible.

(6) The review comments made for Items (1)-(5) should be applied to mission continuation for FY2010 and FY2011.