Final Version (5/29/98)

Report and Recommendations from EO-1 Advanced Land Imager (ALI) Silicon Carbide Optics Performance Workshop

Please send comments to Nick Speciale (301)286-8704 email: speciale@pop500.gsfc.nasa.gov

The EO-1 Advanced Land Imager (ALI) Silicon Carbide Optics Performance Workshop was held at NASA-Goddard Space Flight Center on May 5th and 6th, 1998. In attendance (see attachment) were members of the EO-1 ALI development contractor, EO-1 Science team, EO-1 Project Management team, Goddard and Industry optics systems experts and New Millenium Program IPDT technologists.

Background:
The workshop was set up to better understand and assess the impacts of stray light on the as built EO-1 Silicon Carbide Mirrors. Based on mirror roughness BRDF measurements performed by SSG and Schmitt, the EO-1 SiC mirrors did not meet the EO-1 adopted Landsat 7 ETM+ specification for scattered light. The relevance and impact of not meeting this specification were not well understood by the project, technology and science teams. Much of the workshop information exchange was directed at better understanding the mirror light scattering problem with respect to overall expected ALI stray light system performance and judge its effect on meeting EO-1 technology and science validation objectives.

The overall goals of the workshop were the following:

1> To determine how well the SiC mirrors on the ALI instrument satisfy EO-1 science and technology validation requirements.

2> To determine the viability of using Silicon Carbide Optics for a future Landsat instrument.

Executive Summary
The recommendation by the workshop team was to move forward with the current set of ALI Silicon Carbide Mirrors to complete the ALI instrument integration and continue towards a baseline launch in May 1999. The full set of NMP technology validation objectives for ALI are realizable with this set of optics. However, the workshop members agreed to study further the impacts due to the ALI stray light performance by modeling response to realistic test scenes to be supplied by the EO-1 Mission Scientist. It was agreed that adopting the ETM+ specification for the ALI stray light is not appropriate for assessing ALI performance. Instead, the stray light performance of the current mirrors will be further assessed for how well they can meet the science validation objectives of the mission through the use of the aforementioned test scenes.

Although there was strong confidence expressed by the workshop team regarding the maturity and viability of SiC technology in meeting future Earth Observing missions needs both for lightweight and athermal optical systems, the workshop team suggested a detailed fabrication program leading to a ground based demonstration and assessment of improved performance mirrors. The group concluded that EO-1 optics performance were limited by programmatic constraints and could have been overcome with better managed fabrication control processes. The workshop team also concluded that over the last year the manufacturing of complex SiC structures are now realizable and show great promise for next generation Earth Observing measurement systems.

Discussion Areas and Recommendations:

A>Purpose of EO-1 Mission
There was reaffirmation that EO-1 is primarily a technology driven mission with priority on validating technologies which have high potential payoff and alleviating any flight worthiness concerns for future Landsat missions. This is in contrast with science driven missions where performance is paramount and obtained using more time proven methods. The end goal of EO-1 is to create a scaleable and reproduceable technology path towards an eventual Landsat 8 mission, but not to be a fully capable Landsat 7 prime or prototype Landsat 8 mission. In this respect programmatic constraints and current technology maturity may have limited performance for the E0-1 mission but lessons learned through flight in concert with further ground technology development should enable a much more capable and lower cost Landsat 8 mission. It was noted that the DS-1 MICAS instrument development team was better integrated with the science team and involved early in instrument performance tradeoffs. As a result of this approach, expectations between science and technology team members were well understood throughout the entire instrument development cycle.

Recommendation:
Future NMP EO missions should bring a full scale science team up to speed much sooner to work closely with the technology (instrument) development team and be more directly involved in performance tradeoff decisions. Closer teaming and cooperation between technologists and scientists should close the gaps between technology and science goals (requirements) and avoid misunderstandings on instrument performance expectations and increase overall understanding of requirement relevance. It should be noted that the NMP EO selection process has been changed to implement this recommendation.

B> ETM+ Light Scatter Specification
Data presented indicated that at least three of the four EO-1 SiC mirrors did not meet the Landsat 7 ETM+ light scattering specifications as adopted by EO-1. However, all parties agreed that the Landsat 7 ETM+ specification was probably not appropriate to use on EO-1 due to significant differences in the two instrument architectures and performance. Furthermore, all parties agreed that the L7 ETM+ light scattering specification did not represent a typical heterogeneous science scene but an extreme worst case scenario which was not useful in assessing impacts for a typical remote sensing application.

Recommendation: Develop a new stray light specification for future Landsat type instruments which have relevance to typical earth science research objectives. (see action item #1 – separate workshop/meeting to develop stray light spec)

C> ALI Stray Light Measurement
Agreement was reached that the “out of spec” BRDF measurements for the as built EO-1 SiC mirrors provided incomplete information needed to make valid judgements regarding overall stray light performance of the EO-1 ALI instrument. Other pieces of the puzzle such as contamination, instrument field of view and baffling could dominate overall instrument stray light performance such that making changes to the ALI optics might not provide any significant increase in performance. Also, a full analysis and measurement of the fully integrated ALI instrument were needed to garner a better understanding of ALI stray light performance and its implications on EO-1 science and technology validation objectives.

Recommendation:
In the short term, additional Lincoln Laboratory analysis on a more typical scene, (to be provided by the EO-1 science team) will be performed by the end of June 1998 to judge its effect on the overall performance of the ALI instrument. Longer term, (August/September timeframe) a more comprehensive set of ALI optical performance parameters will be measured as the ALI is calibrated at Lincoln to assess overall instrument stray light performance (see action item #2) on absolute radiometric accuracy. Lincoln agreed to develop a plan to make the required measurements.

D> Limitations to current EO-1 Optics
The workshop attendees agreed that the SiC mirrors produced by SSG for the ALI were of good quality but constrained by EO-1 programmatic (budget,schedule) in obtaining optimum performance. SSG admitted

that fabrication priorities were to first produce a diffraction limited clear aperture mirror with correct figuring. Mirror finish was lower on the priority list. Better SiC mirrors for EO-1 are realizable but at this stage in the mission development would result in significant cost and schedule delay since the flight telescope has been aligned and delivered to Lincoln Labs for integration. It was noted that if an additional 1-2 months of iterative BRDF and polishing had been available, the EO-1 mirror BRDF may have been significantly better.

Recommendation:
Future missions wishing to utilize SiC mirrors should ensure adequate schedule and budget to sufficient margin to produce mirrors with optimum performance. A balanced fabrication strategy should be employed so that both figuring and mirror finish are considered equally and sufficient backup mirrors created in pipeline fashion to reduce mission risk. A comprehensive ground based witness sampling program leading up to a repeatable fabrication process for full scale mirrors should be undertaken to address shortcomings current fabrication control processes.

E> Contamination Effects
Significant discussion occurred on the topic of contamination and its effects on stray light in an optical system. Data presented indicated that contamination may dominate stray light performance that any attempt at optimizing mirror finish may be unproductive. Therefore attention should be devoted to maintaining tight contamination control of the instrument and optics throughout the mission. EO-1 by virtue of its non-mechanical scan design and smaller size should be much “cleaner” than its ETM+ counterpart, it was agreed to review the level of contamination control being applied to the ALI through integration with the launch vehicle.

Recommendations:

a> The current EO-1 plan has no additional cleaning of the ALI mirrors. It is recommended that careful consideration be given to an additional cleaning that could be conducted before calibration of the instrument.

b> It is recommended that contamination control procedures be discussed and emphasized for ALI throughout its I&T.

c> Significant lessons can be learned by talking to APL about the MSX program which was able to maintain an extremely clean instrument throughout the mission lifecycle.

d> Future instrument and optics design should consider ability to easily clean optics and avoid contamination sources such as black paint. Cleaner materials should be considered to avoid contamination sources.

ACTION ITEMS:

AI1> Conduct separate meeting or workshop to develop a figure of merit based on actual science applications for allowable stray light for future Landsat like land observing systems.

Assigned to : L7 Science Working Group?

AI2 > Develop plan to demonstrate reproducible full performance SiC mirrors with low BRDF

- demonstrate repeatable process through witness sample program
- demonstrate repeatable process through full size mirror fabrication
- include characterizations before and after coating
- address hot pressed vs. casting fabrication process issue and coating issues

Assigned to Dexter Wang/SSG Plan due by 5/26/98 STATUS: completed

NOTE: Draft plan received by Nick Speciale on 5/19/98, copies will be distributed for review to NMP participants ASAP.

AI3> *Develop plans to characterize and calibrate stray light properties of the fully integrated ALI. Plan should include the following elements:*
- Measurements and analyses done at the subsystem level
- Pre launch laboratory measurements and analyses
-On orbit measurements and analyses
- The processing of actual Landsat or equivalent scenes to estimate impact on data quality
- Development of stray light figure of merit for the ALI

Assigned to Lincoln Labs - Don Lencioni, Plan due by 6/1: Analysis due **TBD**

AI4> Provide science validation scenes to support Action Items #2 and #3
- Testable scenes
- Typical scenes

Review lots of scenes, select typical and feed into AI3, could be AVIRIS/L7

Results above fed to LL to support quick turnaround system level evaluation

Select one scene for LL analysis by 5/11 Status: completed
Select four scenes for additional analysis by 6/1 Status:

Assigned to: Steve Ungar see schedule above

AI5> *Determine plan for developing data correction algorithms that are based on information obtained from AI3*

Assigned to LL - Don Lencioni

AI6> *Simulate the effect of stray light on a typical science validation scene provided by the Project Scientist to MIT/LL by 6/1/98 and returned to him by August to support NRA proposers. Objective is to get a quantitative assessment of scatter impact on science data quality based on ALI expected performance and the best available models*

This is needed by Aug 98' to support the NRA selection which will use a substantial portion of the data to assess science objectives. The science objectives will be somewhat determined by the ALI stray light performance.

Assigned to LL – Don Lencioni, Analysis to be conducted in June/July timeframe.

AI7 > *GSFC to conduct independent streamlined ALI straylight/scattered light analysis using modified MODIS PSF model.*

- *Acquire ALI Code V sequence files from LL (6/15/98)*
- *Develop ray trace based Monte-Carlo scatter Pointspread Function model for ALI*
- *Use real scenes to assess effect on scene absolute radiometric correction*

Assigned to GSFC – Steve Ungar analysis to be completed by 8/1/98 to support NRA proposers.

Status: Statement of work generated and in review, study to be started ASAP.

To: **John Loiacono**
From: **Jim Heaney/Swales**
Subject: **Comments from A.L.I. Meeting - 5/5/98**

The following remarks address only optical technology issues.

1. Mirror BRDF

The BRDF data presented by SSG, as well as the Schmidt data, were presented without reference to any 'standard' mirror. It is helpful to display data that represents an 'ideal' mirror case together with test sample data. In that way, one can make an instant comparison of the quality of the test items, such as the SSG mirrors. I will claim that mirror F1 is nearly an ideal case. Therefore its BRDF can serve as a comparative standard for the other mirrors.

In my opinion, subject to challenge, any mirror whose BRDF (at 633 nm) drops by a factor of 10(-4) between 0 deg. and 1 deg. away from the specular peak, is an acceptable mirror for visible wavelength imagery. Therefore, mirrors M1, M2, and F1 are certainly acceptable, and M1 is borderline but may actually be o.k. Acceptable from a BRDF measurement standpoint.

I was able to examine only one mirror, M2, while its BRDF was being measured at Schmidt. The mirror surface had several macroscopic scattering sites that would scatter into an optical system, but were avoided during the BRDF measurement. Therefore, it is possible that mirror scatter is actually worse than indicated by the BRDF measurements.

2. BRDF and Surface Adherents

Mirror scatter will certainly increase as a function of time due to the accumulation of surface adherents, dust, aerosols, etc. Therefore, it would be wise to consider the possibility of cleaning the mirrors after thermal vacuum testing and as close to launch date as feasible. If this cannot be done, then two measures should be implemented. (1) Take careful steps to minimize surface contamination. (2) Model the impact of surface adherents on increased surface scatter, expressed as a BRDF, as indicated by Dexter Wang in his presentation.

3. Lencioni Model

It seems to me that Lencioni has done a credible job of making some sense of a confusing specification. His model can serve to evaluate A.L.I. instrument quality. Efforts should be made to strengthen his model by incorporating the best possible mirror BRDF data. That is key to model credibility.

4. Various Specification Shortcomings

In my opinion, some key steps were omitted when the A.L.I. instrument spec was first written and later translated into an optical mirror specification.

The path usually followed between science and technology usually goes as follows: science hands off to system engineering who hands off to the technologist (SSG in this case). Mirror polishers do not grasp cloud contrast requirements.

Compose a mirror spec that incorporates rms surface roughness. Technologists can easily respond to this and measure it as their work progresses. Measure BRDF as an adjunct to this, but it is not necessary, and may be costly, to burden the polishing vendor with the requirement to meet a BRDF spec.

Be careful when linking surface finish and surface figure requirements. It is the job of the system engineer to decide which is more important - figure vs. surface finish. This should be discussed in detail with the optical polisher before work starts. Continuous polishing to produce lower scatter requires the removal of mirror material that can weaken the mirror and impart internal stresses that may ruin the figure in a space application where launch stresses and temperature cycling must be tolerated. Some happy medium must be agreed upon that is derived from system requirements and material properties.

In the case of SiC, it would be wise to apply surface coatings first to practice samples to test for quality. The usual requirements of reflectance, adherence, and durability are often insufficient to predict long term quality under planned spaceflight usage. The coating specification for the A.L.I. mirrors is not adequate to predict suitability for spaceflight.
For example, mirrors M1 and M2 have coatings that differ significantly in thickness compared to F1 and M3. Yet, all of the coatings meet the stated specification.

4. Future SiC Work

The present A.L.I. are not the best that SSG is capable of making. Their spread in BRDF, as measured by SSG and others, is sufficient to prove that point.

Goddard's Optics Branch measured the surface roughness of one A.L.I. witness sample to be about 32A rms. SiC mirrors for other programs measured by the Optics Branch had roughness values less than 10A. Clearly, there is room for improvement.

Suitable surface coatings for SiC exist, but their value in a spaceflight situation needs to be verified. Very often, reflectance alone is the sole parameter for choosing a coating, e.g. silver, aluminum, or gold with protective overcoats. The choice should be based on a specification translation from science to system engineering to coating specialist, as recommended above for the mirror fabrication.

I hope these thoughts are helpful.

James B. Heaney
Swales Aerospace
5050 Powder Mill Road
Beltsville, MD 20705
Tel: (301)902-4531
jheaney@swales.com

Comments from:

C. M. Stevens, Co-Lead
Instrument Technology and Architectures IPDT
11 May 1998

Status of Silicon Carbide Technology for EO-1

A review of the development status of the SiC mirrors for the Advanced Land Imager (ALI) telescope was conducted at GSFC on May 5-6, 1998. The following comments are my assessment of the current situation and the open issues.

The ALI development team has expended considerable effort in attempting to understand and predict the stray light performance of the ALI flight telescope, both through analysis (Lambda Research) and BRDF testing of the mirrors. The effort was expended in order to determine whether the ALI would meet the ETM+ Specification. The ETM+ Specification was adopted as a requirement in order to tie the performance of the ALI to Landsat. While this appeared to be a expeditious approach to defining the performance of ALI, the specification is both subject to interpretation and likely unrealistically tight, when one considers how Landsat data is used, and what is technically achievable on orbit.

The major shortcoming from an NMP perspective is the absence of a Validation Plan for the EO-1 Mission against which the projected ALI performance can be evaluated. NMP must not continue to proceed with mission implementation without a Technology Validation Plan. Performance of the technologies will likely fall short of some operational specification. Without a validation plan, NMP has no efficient way to determine if the projected performance of the technologies will provide a validated, scalable path to an operational capability.

The radiometric performance model developed for the ALI by MIT/LL should continue to be used as a tool for assessing system performance. The model should be updated with test data on the “as built” condition, as it becomes known. A current, high-fidelity instrument system radiometric performance model should be part of the instrument technology validation.

The Edge Response Function technique discussed by Lencioni should be folded into the validation approach.

NMP needs to define and execute a SiC optics technology fabrication process optimization and control program to be funded by NMP. In addition, a ground demonstration of low surface roughness SiC mirrors should be considered. This need could provide the impetus for NMP to develop a policy as to how technology investigation and further development should be handled within the program.

The ALI telescope mirror surface quality is reasonably good and comparable to other Earth sensing instruments. EO-1 should proceed with integrating the ALI and perform a thorough instrument system calibration.

To: 730/John Loiacono

From: 551/Ritva Keski-Kuha

Subject: Comments on the Advanced Land Imager Workshop on 5/5/98

The two main goals of the workshop were 1) to determine if the scatter from the ALI mirrors is too high to support technology validation, 2) is there an intrinsic problem with SiC that limits the quality of the mirrors that can be produced.

The workshop did not accomplish the first goal, however, steps to be taken to reach that goal were outlined at the workshop and action items assigned as necessary. The key factor in reaching the goal is for the science team to determine what kind of science the instrument needs to do and to what accuracy. Typical scenes need to be convolved with the performance of the as built instrument to determine if it can provide science data that is expected from this type of an instrument. This is essential for demonstrating technology. If the instrument cannot do any of the science expected from this type of an instrument, it is not demonstrating technology and is not worth flying. Therefore it is critical that the science team provides the required information so that the performance of the instrument can be analyzed for realistic situations.

Silicon carbide is a new promising mirror material for earth observing and astronomy applications. Silicon carbide mirrors are being flown on two instruments on SOHO (Solar Heliospheric Observatory) mission. The instruments are SUMER and UVCS. SUMER is an ultraviolet instrument operating in the 50 nm to 160 nm spectral region. To observe features on the sun at these short wavelengths, very low scatter surfaces were required resulting in demanding surface finish requirements for the mirrors. UVCS is a coronagraph operating both in the ultraviolet and visible spectral regions, therefore scatter requirements were very demanding also. Low scatter mirrors were produced for both of these instruments. SiC is hard material and therefore difficult to polish. In some cases silicon cladding is applied on the SiC substrates since Si is easier to polish. In case of SUMER mirrors and some of the UVCS mirrors the optical surface is polished chemically vapor deposited SiC. One of the UVCS mirrors has Si cladding that is polished. In both programs difficulties were encountered during the mirror fabrication, however, low scatter with surface roughness less than 1 nm rms mirrors were achieved. Optics Branch at GSFC was responsible for the development of the SUMER mirrors.

Hot pressed SiC is a different form of SiC, however, it can be polished smooth. Silicon cladded SiC can be polished very smooth also, however, this was not done on ALI mirrors. Therefore the scatter is higher than it should be. The mirror surface finish was not specified properly. In addition to the figure specification, the rms surface roughness should have been specified. The BRDF is a good measure of the scattering properties of an optical material, provided the measurements are done properly. However, the results depend on what kind of instrument is used and skill level of the operator. Figured surfaces in particular are difficult to measure accurately. Therefore it is not a good specification to use during the mirror manufacturing process. The specifications for the mirrors should include figure, mid-frequency surface roughness and microroughness specification. When the mirror surface is characterized at all spacial frequencies its performance can be analyzed even at angles near the specular beam where reliable BRDF measurements cannot be made.

Timo Saha from the Optics Branch has looked at the EO-1 mirror BRDF data. The BRDF measurements made by SSG Inc. and Schmitt Measurements agree fairly well except for M2 which is a convex mirror and therefore the most difficult to measure. On the BRDF data from Schmitt Measurements reflectance on some samples is lower than expected. This may affect the BRDF data. Surface roughness calculated from the BRDF data using the software that came with the data from Schmitt Measurements is high for the F1 mirror compared to what was shown at the meeting by SSG Inc. (about 4.5 nm rms vs. 1.7 nm rms). Surface roughness calculated from the BRDF data is very high for M1 and M3 mirrors (about 10 nm rms). M2 appears to be slightly better, however, this is a convex mirror that is the most difficult to measure. In case of M2 and M3 mirrors the surface roughness calculated from BRDF data at 0.633 nm and 3.39 microns is much higher at 3.39 microns than at 0.633 nm. However, the roughness value can be different since the instrument sees different spatial period range on the surface depending on the wavelength. An rms surface roughness measurement would be required to resolve the differences.

With more effort much better surface finishes and lower scatter could have been accomplished for the EO-1 mirrors. However, the present mirrors may be good enough for technology demonstration. This can be only determined by carefully analyzing the performance of the as built instrument and simulating its response to realistic science scenes.

Comments from meeting with Gerry Gooden/ Steve Ungar/Nick Speciale/Matt Jurotich

Nick's notes from meeting 5/20:

- Mirror light scatter may be more serious problem than anticipated by LL.
- MODIS experienced similar problem and had to replace mirrors to meet science objectives.
- Absolute radiometric accuracy is key to remote sensing applications, rather than just MTF, which is sufficient for astronomical and other military applications.
- ALI has wide field of view, with minimal stops (only M2), every mirror will contribute to the stray light problem. Mirror surface will be dominant factor.
- Contamination control is important but L7 ETM and ALI will be moving through similar contamination control environments.
- Contamination not a factor in previous LANDSAT missions. Need to translate stray light requirements into useful remote sensing applications information such as distance needed to perform precision radiometric analysis away from cloud or snow fields.
- SSG on track to develop better figure and polish process to get fully operational mirrors, need ground based program to mature process whereby it can improve current optics by factor of 10. Should be less expensive than Berylium due to problems in handling (toxic) Be.
- May be able to theoretically correct scenes for stray light but in practice this will be extremely difficult due to following factors (out of view features (clouds) which contribute to scatter), impossible to calibrate out what you can't see, other effects will make correction algorithms in practice unusable.
- DL's model of atmospheric limitation not valid, spectral signature is tied to atmospheric signature.

Recommendation – See Action Item #7

Agenda

The following is the *Revised Agenda* for the EO-1 Advanced Land Imager Silicon Carbide Optics Technology Workshop.

Meeting will be held on Tuesday and Wednesday, May 5th and 6th at NASA - Goddard Space Flight Center, Bldg 16W, Rm 76-80

Please send me any comments, or additions/subtractions, syntax errors to agenda, I will try to clarify any of the listed agenda items. Also, please e-mail back whom you expect to attend from your organization.
My email is Nicholas.J.Speciale.1@gsfc.nasa.gov, phone (301)286-8704

Tentative Agenda for Tuesday May 5th:

10 A.M. to 4:30 P.M.

I Introduction/Goals of Workshop — Bryant Cramer/Dale Schulz

II Background — John Loiacono

III Stray light Performance of EO-1 ALI and impact on mission objectives
- The measurement of mirror and telescope BRDF – **SSG/D. Wang**
  - Compare with L7/EO-1 specifications
  - Unanticipated problems in building EO-1 optics
  - Trade space between figuring, polishing and surface roughness
  - What trades were made on EO-1, how were decisions made?
- ALI system performance analysis and the impact on technology validation – **MIT/LL – D. Lencione**
- ALI system performance impact on science validation – **GSFC/S.Ungar**

LUNCH

IV The Path to a future operational Landsat SiC based optical System –

- Viability of using SiC optics, specifically in duplicating the EO-1 design for a future Landsat instrument
- Strawman plan to produce correct figure, polish and coat on SiC and Si/SiC mirrors for future Landsat instrument - SSG/D.Wang
- Does anything else need to be done with the technology before committing it to an operational instrument.

V SiC mirror technology in general in the New Millenium Program context. **JPL/C.Stevens**
- IPDT Discussion/Experiences/Recommendations
- DS-1 MICAS instrument experience

This concludes information exchange phase of workshop, at this point a smaller technical/management group would be formed to discuss the following:

(Discussion would continue into next day, Wednesday May 6th , if necessary, start time 9:00 A.M., bldg 16W Rm 76-80

A> Revisit and recap specifications for ALI Optical Systems
B> Recovery options for EO-1

- Mirror re-fabrication options/impacts
- Scene selection options/impacts
- Increased Ground data processing/impacts
- Calibration options/impacts

C> Downselection of above options
D> Workshop recommendation for EO-1 recovery with ROM cost/schedule impact
E> Summary/Action Items

ATTENDANCE LIST:

Name	Organization	Phone	E-mail
William Brown	MIT/LL	781-981-7905	Bbrown@ll.mit.edu
Charles Bruce	MIT/LL	781-981-7708	Bruce@ll.mit.edu
Thomas Braake	GSFC/923	301-286-3851	Tbraake@ltpmail.gsfc.nasa.gov
Otis Brooks	GSFC/923	301-286-8210	Obrooks@pop900.gsfc.nasa.gov
John Barker	GSFC/923	301-286-9498	John.l.barker@gsfc.nasa.gov
Gerry Gooden	PAI	703-731-4981	Gooden@ltpmail.gsfc.nasa.gov
Matt Jurotich	GSFC/426	301-286-5919	Matt.jurotich@gsfc.nasa.gov
John Loiacono	GSFC/426	301-286-8562	Loiacono@pop700.gsfc.nasa.gov
Jim Heaney	Swales Aerospace	301-902-4531	Jheaney@swales.com
Don Lencioni	MIT/LL	781-981-7967	Lencioni@ll.mit.edu
Carolyn Merry	Ohio State Univ/GSFC	301-286-7353	Merry@ltpmail.gsfc.nasa.gov
Leslie Moy	GSFC/923-sSAI	301-286-8134	Lmoy@ltpmail.gsfc.nasa.gov
Nicholas Speciale	GSFC/426	301-286-8704	Speciale@pop500.gsfc.nasa.gov
Timo Saha	GSFC/551	301-286-2863	Timo.saha@gsfc.nasa.gov
Pete Spidaliere	NASA/GSFC 426	301-286-4797	Pete.spidaliere@gsfc.nasa.gov
Dale Schulz	NASA/GSFC 426	301-286-8417	Dale.Schulz@gsfc.nasa.gov
Joe Robichaud	SSG Inc	978 694-9991	Jlr@ssginc.com
Chris Stevens	NASA/JPL	818-354-5545	Cstevens@jpl.nasa.gov
David Thomas	NASA/JPL	818-354-0397	David.a.thomas@jpl.nasa.gov
Stephen Ungar	NASA/GSFC/923	301-286-4007	Ungar@gsfc.nasa.gov
Dexter Wang	SSG Inc	978-694-9991	Dexterw@ssginc.com

Wally Wong	SSG Inc.	978-694-9991	Wkwong@ssginc.com
Bryant Cramer	NASA/GSFC 426	301-286-0644	Bcramer@pop400.gsfc.nasa.gov
Ritva Keski-Kuha	NASA/GSFC 551	301-286-6706	rkeski@pop200.gsfc.nasa.gov