

# On the Stratospheric Aerosol and Gas Experiment III on the International Space Station

Gloria Hernandez  
NASA Langley Research Center  
Mail Stop 401B  
Hampton, VA 23681  
757-864-5572  
[gloria.hernandez@nasa.gov](mailto:gloria.hernandez@nasa.gov)

Joseph M. Zawodny  
NASA Langley Research Center  
Mail Stop 475  
Hampton VA 23681  
757-864-2681  
[j.m.zawodny@nasa.gov](mailto:j.m.zawodny@nasa.gov)

Michael S. Cisewski  
NASA Langley Research Center  
Mail Stop 416  
Hampton VA 23681  
757-864-1861  
[m.s.cisewski@nasa.gov](mailto:m.s.cisewski@nasa.gov)

Brooke Thornton  
NASA Langley Research Center  
Mail Stop 416  
Hampton VA 23681  
757 864-4570  
[brooke.thornton@nasa.gov](mailto:brooke.thornton@nasa.gov)

Andrew Panetta  
NASA Langley Research Center  
Mail Stop 432  
Hampton VA 23681  
757 864-1041  
[andrew.d.panetta@nasa.gov](mailto:andrew.d.panetta@nasa.gov)

Marilee M. Roell  
NASA Langley Research Center  
Mail Stop 401B  
Hampton VA 23681  
757 864-3741  
[marilee.m.roell@nasa.gov](mailto:marilee.m.roell@nasa.gov)

Jean Paul Vernier  
Science Systems and Applications, Inc.  
Mail Stop 401B  
Hampton VA 23681  
727 864-9021  
[jeanpaul.vernier@nasa.gov](mailto:jeanpaul.vernier@nasa.gov)

*Abstract*—The Stratospheric Aerosol and Gas Experiment III on International Space Station (SAGE3/ISS) is anticipated to be delivered to Cape Canaveral in the spring of 2015. This is the fourth generation, fifth instrument, of visible/near-IR solar occultation instruments operated by the National Aeronautics and Space Agency (NASA) to investigate the Earth's upper atmosphere. The instrument is a moderate resolution spectrometer covering wavelengths from 290 nm to 1550 nm. The nominal science products include vertical profiles of trace gases, such as ozone, nitrogen dioxide and water vapor, along with multi-wavelength aerosol extinction. The SAGE3/ISS validation program will be based upon internal consistency of the measurements, detailed analysis of the retrieval algorithm, and comparisons with independent correlative measurements. The Instrument Payload (IP), mission architecture, and major challenges are also discussed.

## TABLE OF CONTENTS

1. INTRODUCTION .....	1
2. HISTORY .....	2
3. SAGE III INSTRUMENT .....	2
4. INSTRUMENT ASSEMBLY .....	3
5. MISSION ARCHITECTURE .....	4
6. SAGE III SCIENCE PRODUCTS.....	4
7. VALIDATION APPROACH .....	5
8. CHALLENGES .....	6
9. SUMMARY .....	7
REFERENCES.....	7

## 1. INTRODUCTION

The Stratospheric Aerosol and Gas Experiment III on the International Space Station (SAGE3/ISS) is an important part of the National Aeronautics and Space Administration's (NASA's) earth science program to better understand the effects of natural and human-induced changes on the global environment by focusing on ozone recovery and climate changes.

SAGE3/ISS is the fifth in a series of instruments developed for monitoring aerosols and gaseous constituents in the stratosphere and troposphere. The scientific measurements provided by SAGE3/ISS will form the basis for the analysis of five of the nine critical constituents identified in the U.S. National Plan for Stratospheric Monitoring. These five atmospheric components include the profiles of aerosols, ozone (O<sub>3</sub>), nitrogen dioxide (NO<sub>2</sub>), water vapor (H<sub>2</sub>O), and air density using O<sub>2</sub>.

Solar observations<sup>1</sup> will provide high-resolution vertical profiles of multi-wavelength aerosol extinction coefficient, the molecular density of O<sub>3</sub>, NO<sub>2</sub>, and H<sub>2</sub>O vapor. The inclusion of a repositionable solar attenuator allows lunar occultation<sup>1</sup> observations that will improve geographic coverage and permit measurements of nighttime-only species such as nitrogen trioxide (NO<sub>3</sub>), in addition to O<sub>3</sub> and NO<sub>2</sub>. SAGE III will also provide limb occultation measurements<sup>2</sup> with a flexible instrument design having up to 800 channels, capable of spanning the ultraviolet, visible, and near infrared wavelengths (280-1040 nm). Due to the ISS orbit, SAGE3/ISS will obtain near-global coverage that

will help in understanding processes related to the transport of air from the troposphere to the stratosphere and their impact on the climate.

## 2. HISTORY

Three flight-ready SAGE III instruments were built by Ball Aerospace in the late 1990s and delivered to NASA Langley Research Center (LaRC). One was launched aboard the former Russian Aviation and Space Agency METEOR-3M (M3M) platform in 2001 and continued until the platform lost its power in 2006. Another of those instruments was manifested for the ISS in the 2004 time frame, but was delayed due to budgetary considerations and placed into storage at NASA LaRC. Fortunately, that SAGE3/ISS mission was restarted in 2009 with a major focus upon filling an anticipated gap in the ozone and aerosol observations in the second half of this decade. A new component of this mission is the European Space Agency's contribution of the Hexapod pointing platform, which allows SAGE3/ISS to be in the correct orientation prior to gathering its high precision measurements. The third instrument, originally awaiting a flight of opportunity (FOO) has been used as a spare for both the SAGE3/M3M and the SAGE3/ISS instruments.

The instrument concept originated as a hand-held, single wavelength sun-photometer (Stratospheric Aerosol Measurement or SAM) that was flown onboard an Apollo mission in 1975<sup>3</sup>. SAM II was a single wavelength (1000nm) instrument that operated on Nimbus-7 between 1978 and 1994<sup>4, 5</sup>. The Stratospheric Aerosol and Gas Experiment (SAGE) operated on the Application Explorer Mission 2 (AEM-2) spacecraft between 1979 and 1981. This SAGE instrument made measurements at four wavelengths and measured molecular density profiles of O<sub>3</sub> and NO<sub>2</sub> in addition to aerosol extinction at two wavelengths (450 and 1000nm)<sup>2</sup>. SAGE II operated on the Earth Radiation Budget Satellite (ERBS) from 1984 to 2005 and made measurements at seven wavelengths. In addition to the species measured by SAGE, SAGE II measured the molecular density profile of H<sub>2</sub>O and aerosol extinction at four wavelengths (385, 453, 525 and 1020 nm)<sup>6</sup>. In the case of SAGE III, a charge coupled device (CCD) linear array provides spectral coverage from 280 to 1040nm. In addition, a single photodiode has been added for aerosol extinction measurements at 1550nm<sup>7, 8, 9</sup>. A repositionable solar attenuator will permit both solar and lunar occultation measurements, increasing the geographical coverage and allowing for the detection of NO<sub>3</sub> and chlorine dioxide (OCIO). The incorporation of the CCD array will permit the measurement of gaseous species from multichannel absorption signatures simplifying the retrieval process, and 16-bit digitization improving the precision and altitude range of measurements.

## 3. SAGE III INSTRUMENT

The SAGE3/ISS Instrument Payload (IP) consisting of the instrument, the hexapod positioning system (HPS), the disturbance monitoring package (DMP), the contamination monitoring package (CMP) and the interface adaptor module (IAM) will be mounted externally on the ISS on an Expedite the Processing of Experiments to Space Station (ExPRESS) Pallet Adapter (ExPA) to the Express Logistic Carrier (ELC) 4, site 3.

The SAGE III instrument is a moderate resolution spectrometer (~1nm sampling with 1-2nm spectral resolution) covering wavelengths from 290 nm to 1550 nm. Solar energy, attenuated by the Earth's atmosphere, will be monitored in nine wavelength bands centered at 290, 385, 440, 525, 600, 760, 940, 1020, and 1550 nm. In addition to solar occultation (figure 1), SAGE3/ISS is designed to measure lunar occultation (figure 2) between the first and third quarters of the lunar month. The reflected light from the moon provides a radiant source for making measurements of the key nighttime atmospheric constituents such as NO<sub>3</sub> and OCIO. SAGE3/ISS's measurement capabilities for solar and lunar occultation measurements are listed Table 1. In addition to solar and lunar occultation, SAGE3/ISS will perform Limb Scattering measurements (figure 3), which measures the sunlight as it is scattered by atmospheric gases and particulates (aerosols and clouds) as well as by the Earth's surface.



Figure 1 – Solar Occultation



Figure 2 – Lunar Occultation



**Figure 3 – Limb Scattering**

**Table 1. Measurement Capabilities**

<i>Channel Grouping</i>	<i>Primary Species</i>	<i>Secondary Species+</i>
290 nm (4)	O <sub>3</sub>	
385 nm	Aerosol	NO <sub>2</sub> , O <sub>3</sub>
430-450 nm (20)	NO <sub>2</sub>	O <sub>3</sub>
525 nm	Aerosol	NO <sub>2</sub> , O <sub>3</sub>
560-616 nm (7)	O <sub>3</sub>	NO <sub>2</sub> , H <sub>2</sub> O
670 nm	Aerosol	O <sub>3</sub>
757 nm	Aerosol	O <sub>3</sub>
759-771 nm (14)	O <sub>2</sub> (T/p)	O <sub>3</sub> , H <sub>2</sub> O
872 nm	Aerosol	O <sub>3</sub> , H <sub>2</sub> O
933-960 nm (30)	H <sub>2</sub> O	O <sub>3</sub>
1020 nm (6)	Aerosol	O <sub>3</sub>
1550 nm	Aerosol	

#### 4. INSTRUMENT ASSEMBLY

The SAGE3/ISS Instrument Assembly (figure 4) is comprised of the Sensor Assembly (SA) and the associated Instrument Control Electronics (ICE). The elevation scan mirror on the SA scans through the radiometric center of the sun or the moon from top edge to bottom edge as either rises or descends as seen through the atmosphere, channeling the incoming solar or lunar radiation down the azimuth tube to the Telescope and Spectrometer Assembly. Science requirements dictate the elevation scan range of the instrument to be capable of scanning about the Earth's tangent height of -50 km to 300 km for all the ISS orbital altitudes (with the help of the Hexapod). As a result, the SAGE3/ISS scan mirror is designed to operate over the angular range of 16 degrees. The SAGE III Azimuth System connects the Scan Head to the Telescope and Spectrometer Assembly and provides an azimuth scan capability of > 360°.

*Hexapod Positioning System*—The HPS is used to correct ISS attitude variations in roll and pitch and consists of the Hexapod Mechanical Assembly (HMA) and the Hexapod Electrical Unit (HEU). The HMA consists of a 7 degree wedge and six electro-mechanical linear actuators coupled to an upper and a lower platform to provide ±8° of pitch and roll correction. Yaw corrections are provided by the SAGE III azimuth system.

*Interface Adapter Module*—The Interface Adapter Module (IAM) can be interpreted as an on-orbit “flight director” for the SAGE3/ISS instruments. It interfaces with the SAGE3/ISS Instrument Assembly and has the ability to autonomously command all the SAGE3/ISS instruments. It connects via the Express Payload Adapter (ExPA) to

interface with the ISS. The IAM is capable of communicating using 1553B, UART, and 10Base-T Ethernet protocols. In nominal operation, the IAM operates autonomously in planning the time and direction of the occultation events and in prepositioning the hexapod by monitoring the ISS attitude, but it has the ability to be ground commanded. It has the computing power to plan and execute science events, process and execute commands, provide bi-directional communication, and store up to three days of data using non-volatile solid-state memory. Within the IAM is the Power Distribution Unit (PDU) that regulates, monitors, and distributes 120VDC and 28VDC power to the IAM internal electronics and the SAGE3/ISS instrument electronics.

*Contamination Monitoring Package*—The CMP is used to monitor and characterize the contamination environment around the instrument. It includes eight Thermoelectric Quartz Crystal Microbalances (TQCMs) sensors that monitor the outgassing of materials and other contaminants near the SAGE3/ISS IP. In order to monitor the contamination environment around the entire instrument, two sets of sensors are used. Figure 4 shows the two CMP locations. Each CMP sensor enclosure will detect and quantify gaseous and droplet contaminants that accrete onto the CMP sensors. The sensors combined will have 360 degree plus Nadir view to detect contaminants.

*Disturbance Monitoring Package*—The DMP monitors “jitter” caused by on-orbit vibrations. Scan head vibrations affect the accuracy of the science measurements, because, additional motion in the elevation plane changes the sensor scan rate. The DMP will be used to flag science data that may be affected due to large vibrations. The current science goal is for the DMP to provide angular rate measurements with an accuracy of 0.25 arc-sec/sec.

*Express Payload Adapter*—The ISS Program will provide the SAGE3/ISS project with Government Furnished Equipment (GFE) in order to successfully mount to and communicate with the space station. The ExPA is comprised of the ExPA Plate, connector panels, and cable assemblies (figure 5). The ExPA Plate is the mounting plate for the various ExPA payloads and is attached to the Active Flight Releasable Attachment Mechanism (AFRAM). The ExPA plate provides Square Grid Interface (SGI) capabilities for the payload attachment. The AFRAM system is designed to provide a single generic means for enabling the applicable launch vehicle and the ISS to accommodate a variety of ISS cargo.

*Nadir Viewing Platform*—The Nadir Viewing Platform (NVP) is a passive structural system that enables the IP to be attached to the ELC-4 in a nadir viewing orientation on the ISS (figure 5). The ELC is an unpressurized attached payload platform that provides mechanical mounting surfaces, electrical power, and command and data handling services for science experiments on the ISS. To obtain this nadir viewing capability, the NVP replicates the standard ELC attachment except that it is rotated ninety degrees from

the plane of the ELC-4. The NVP is first attached to the ELC-4, and then the IP is attached to the NVP. Dexterous Extravehicular Robotics will perform both of the attachment operations. The NVP also accommodates pass-through electrical power and data services to the SAGE III IP.

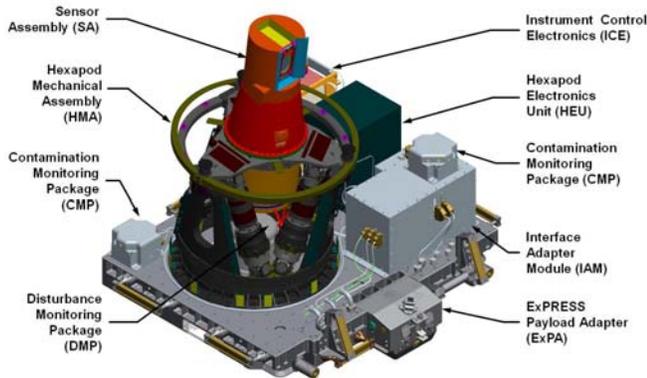


Figure 4 – SAGE3/ISS Instrument Assembly

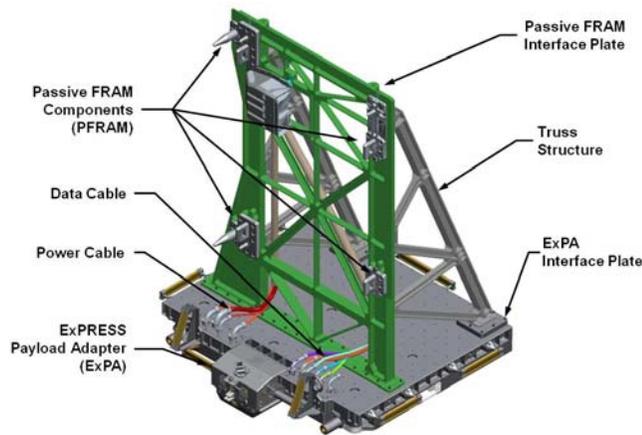


Figure 5 – Nadir Viewing Platform

## 5. MISSION ARCHITECTURE

The SAGE3/ISS mission architecture that integrates the mission segments to ensure successful execution is illustrated in figure 6. The first component of the mission architecture consists of the SAGE III IP and the Nadir Viewing Platform (NVP) Payload, which are externally mounted to the ELC-4, site 3.

The White Sands Complex (WSC) transmits and receives the data to/from the ISS, via the Tracking and Data Relay Satellite System (TDRSS) to the Mission Control Center in Houston (MCC-H) and the Payload Operations Integration Center (POIC). The (MCC-H) at Johnson Space Center (JSC) manages the American Segment of ISS and is responsible for the overall ISS command management including commanding to all the ISS payloads. The POIC manages all the NASA payloads on the ISS and is the direct interface to the ISS for the SAGE III Payload Operations

Center (SPOC). The POIC’s activities include collecting, processing and monitoring the Health and Status (H&S) of the payloads and routing of the payload data to the payload’s control centers. The POIC also routes all the ISS payload commands to the MCC-H for transmission to the ISS.

The SPOC at NASA LaRC will manage and operate the SAGE III IP. This includes mission activity planning and scheduling, monitoring SAGE III’s H&S, developing commands, and processing and trending engineering data. In addition, the SPOC will oversee the engineering effort to resolve any hardware or software anomalies that may occur.

The Science Computing Facility (SCF) located at LaRC will manage the science process. The key SCF functions include science data ingest, science data processing, data quality assessment, distribution of intermediate science products, distribution of production products, science software development and maintenance, data storage, and configuration management.

The Atmospheric Sciences Data Center (ASDC), also located at LaRC, provides the science data distribution and official archiving. The ASDC ingests and archives the data files sent from the SAGE III SCF using the Earth Observing System Data and Information System (EOSDIS) Core System (ECS). The ASDC also archives software, documentation, coefficients, and any other files related to the processing and/or description of the publically released versions of the SAGE III data.

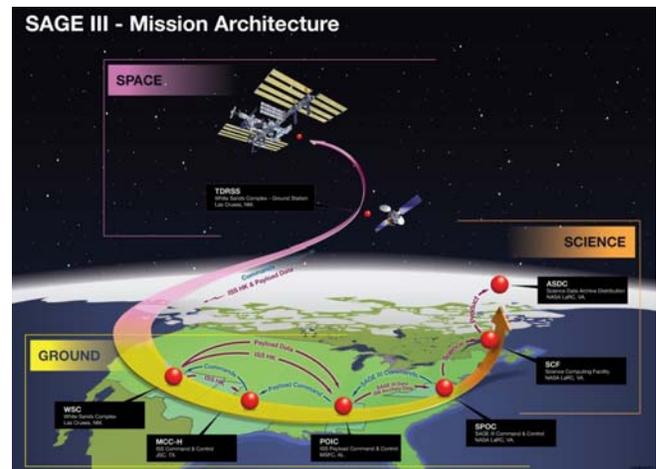


Figure 6 – SAGE3/ISS Mission Architecture

## 6. SAGE III SCIENCE PRODUCTS

The SAGE3/ISS science objectives are to monitor the vertical distribution of aerosols, ozone and other trace gases in the Earth’s stratosphere and troposphere to enhance understanding of ozone recovery and climate change processes in the upper atmosphere.

*Ozone*—Atmospheric ozone is an important greenhouse gas present in both the troposphere and stratosphere. Ozone

research has remained at the forefront of atmospheric science for many years because stratospheric ozone shields the Earth's surface (and its inhabitants) from harmful ultraviolet radiation and also acts as a major oxidizing species that can affect the lifetimes of many chemical species in the atmosphere. Accurate long-term measurements of ozone are crucial.

Ozone also absorbs and emits radiation in several wavelength ranges and plays a prominent role in the radiative balance of the climate system. One of the principal goals of the SAGE3/ISS experiment is to accurately and precisely determine the spatial and temporal distributions of ozone and some of the species (aerosol,  $\text{NO}_2$ , and  $\text{NO}_3$ ) that affect its distribution. The profile measurements by the SAGE3/ISS will provide crucial information on long-term variations and trends, particularly around the tropopause, where radiative forcing is sensitive to changes in ozone level.

It is important to monitor ozone levels in the lower stratosphere and upper troposphere, since the observed trends are the largest and most poorly understood at those altitudes. SAGE III's high vertical resolution and long-term stability make it uniquely well suited to make these measurements. SAGE III will also be able to look at the relationship between aerosol, cloud, and chemical processes affecting ozone by simultaneous measurements of these atmospheric constituents.

*Aerosols*—Aerosols play an essential role in the radiative and chemical processes that govern the Earth's climate. Since stratospheric aerosol loading has varied by a factor of 30 since 1979, long-term monitoring of the tropospheric and stratospheric aerosols is crucial. Thus, SAGE III aerosol measurements will provide important contributions in the area of aerosol research. Occultation technique allows even thick aerosols layers to be probed. The 16-bit digitization improves the quantification of optically thick layers. Even more channels improve the characterization of the aerosol optical and physical properties.

*H<sub>2</sub>O & Clouds*—Clouds play a major role in determining a planet's solar and long wave energy balance and, thus, are important in governing the Earth's climate. SAGE III will provide measurements of mid and high level clouds including thin or "sub-visual" clouds that are not detectable by nadir-viewing passive remote sensors. These observations are important because, while low clouds primarily reflect the incoming solar radiation back into space (acting to cool the planet), mid and high level clouds enhance the "greenhouse" effect by trapping the infrared radiation (acting to warm the planet). Also, the presence of thin cloud near the tropopause may play a significant role in heterogeneous chemical processes that lead to ozone destruction in mid-latitudes.

On a molecule-by-molecule basis,  $\text{H}_2\text{O}$  vapor is the predominant greenhouse gas and plays a crucial role in regulating the global climate system. An improved understanding of the global  $\text{H}_2\text{O}$  vapor distribution can enhance our ability to understand water's role in climate processes. SAGE III  $\text{H}_2\text{O}$  vapor measurements will provide important contributions on the long-term effect of this greenhouse gas.

*Temperature*—SAGE III temperature measurements will provide a unique data set for monitoring and understanding atmospheric temperature changes. In particular, the long-term stability and self-calibration capabilities of SAGE III may permit detection of trends in stratospheric and mesospheric temperatures that would be important for diagnostics of climate change. SAGE III temperature measurements will also allow monitoring of periodic temperature changes, such as those associated with the solar cycle and quasi-biennial oscillation, and the effects of radiative forcing by aerosols.

*Nitrogen dioxide, nitrogen trioxide, and chlorine dioxide*—Nitrogen dioxide ( $\text{NO}_2$ ), nitrogen trioxide ( $\text{NO}_3$ ), and chlorine dioxide ( $\text{OCIO}$ ) play crucial role in stratospheric chemistry and the catalytic cycles that destroy stratospheric ozone. SAGE III  $\text{NO}_2$  measurements are important because the processes that occur in the Antarctic winter and spring seasons and give rise to the ozone hole that effectively convert  $\text{NO}_2$  to nitric acid ( $\text{HNO}_3$ ). Thus  $\text{NO}_2$  is an important diagnostic for the chemistry of formation of ozone hole. Since it is measured during both solar and lunar occultation events, SAGE III observations of  $\text{NO}_2$  will improve our understanding of the strong diurnal (daily) cycles in stratospheric processes. In addition, SAGE III will make complementary measurements of nitrogen trioxide ( $\text{NO}_3$ ). Although short-lived in presence of sunlight,  $\text{NO}_3$  plays an active role in the chemistry of other reactive nitrogen species such as  $\text{NO}_2$  and di-nitrogen pentoxide ( $\text{N}_2\text{O}_5$ ) and, thus, indirectly in ozone chemistry. Since few other measurements of  $\text{NO}_3$  are available, SAGE III measurements, which are made during lunar occultation (nighttime) events, will provide crucial validation for our current understanding of the reactive nitrogen chemistry.

## 7. VALIDATION APPROACH

The SAGE3/ISS validation program will be based upon internal consistency of the measurements, detailed analysis of the retrieval algorithm, and comparisons with independent correlative measurements. The SAGE3/ISS project staff will ensure the validation of each SAGE3/ISS standard science product through internal or independent evaluation. The findings from these validation studies will be reported in the scientific literature.

Estimates of the precision of the SAGE3/ISS measurements will be determined by comparing the observed measurement variance to an independent estimate of the geophysical variance<sup>11</sup>. For SAGE and SAGE II, this technique was employed at low latitudes, where planetary and synoptic

scale wave disturbances are relatively weak and zonal variability in many measured quantities is low. While this was not possible for SAGE III/M3M, we anticipate reviving this method for SAGE3/ISS, since it will make abundant low latitude measurements. Self-consistency analysis will be performed between solar and lunar occultation events, when these events occur at similar latitudes.

The retrieval algorithm analysis will include an evaluation of the soundness of the retrieval process through a comparison of the results from a forward model with those from the inverse retrieval algorithm. Another effort will center upon a self-consistency analysis of different retrieval techniques for the same parameter.

The large range of wavelengths coverage provided by the CCD will permit sensitivity studies of the impact of channel selection on the retrieval of various species. Not only will this activity provide insight into the robustness of the selected retrieval method, it will also provide information on the instrument performance and retrieval error propagation. Internal instrument data (e.g. mirror reflectivity, CCD quantum efficiency, spectrometer temperature) will be closely monitored and the changes will be evaluated for their potential to impact data quality.

External measurement comparisons to SAGE3/ISS will be conducted, with independent correlative measurements of sufficient number and of known quality, to validate the expected accuracy of the SAGE III standard science products. In situ and remote sensors on the ground, aircraft, balloons, and satellites routinely obtain correlative data. The use of correlative measurements requires knowledge of the accuracy and precision of each potential comparative data set. The suitability of any comparative data sets is also dependent on the sampling technique and spatial and temporal characteristics of these measurements. The appropriateness of various comparisons may be a function of location and time of the year. For instance, comparisons made in and around the polar vortices in winter may be subject to much more spatial variability (and thus more difficult to interpret) than the measurements in mid-latitude summer. In a rigorous sense, the validation requires that correlative measurements are traceable to the accepted measurement standards; however, such standards do not exist for many of the SAGE3/ISS measurements, particularly aerosol. For these cases, the validation will be based upon building up confidence through comparisons between different measurement techniques and sources to demonstrate the level of accuracy and precision of the SAGE3/ISS data products. Emphasis will be placed on the ability of each measurement system to replicate structure in the profile shape. (accuracy of the altitude registration).

The correlative measurement activity is intended to leverage low risk, operational (ongoing) measurement activities and field campaigns on a collaborative basis, rather than depend on SAGE3/ISS-specific validation campaigns. Where necessary and as funds are available, routine measurements will be supplemented through in-kind support (e.g.,

providing additional ozonesondes to an existing station to launch when a SAGE3/ISS observation is made near the station) tailored to specific sampling needs. This approach has been successfully employed in the past throughout the SAGE series of missions and is a cost effective way to ensure a continuous validation<sup>12, 13, 14, 15, 16</sup>. Efforts will be made to understand the representativeness of the measurements and minimize the differences in time and space between the SAGE III and correlative measurements.

## 8. CHALLENGES

Two of the biggest challenges SAGE3/ISS has encountered are a slip in the original schedule due to a delay in the hexapod delivery and removal of a patterned variation in the solar science measurements in the SAGE III/M3M data that suggested the presence of an optical etalon.

*Hexapod Electronics Unit*—The HEU was originally designed for delivery to the ISS aboard the Shuttle. During this scenario, the temperature limits of the HEU would be maintained by the use of 28 Volt heaters. The current launch vehicle does not support 28 V power. Since the heaters are located on the interior of the HEU, their replacement required opening the unit. While the unit was opened, it was decided to perform some system enhancements to address the issues encountered on orbit by other payloads with similar circuit boards manufactured by the supplier during the same time frame.

For the first issue (replacing the heaters), a filter was added to an optocoupler circuit to address some resets that were encountered by the European Technology Exposure Facility (EuTEF) and SOLAR. The second issue was to address thermal stress relief of MOSFETs mounted on the power boards. ESA Exchangeable Standard Electronic Module (ESEM) boards were showing signs of cracked solder joints, which could be attributed to the mounting scheme of the MOSFETs. Both of these repairs were considered to be fairly simple. In addition, a procedure was already in place for the MOSFET repair, which had been successfully performed several times.

During the inspection of the power boards, other issues became evident. These included discrepancies such as cracked capacitors, stressed and cracked solder joints, and inadequate thermal stress relief. After further x-ray inspection, it became clear that several of the solder joints contained a significant amount of voids. Since these boards did not meet current ESA workmanship standards this led ESA and NASA to question the integrity of the remaining boards in the HEU which were inspected as well. Experts from industry and the government reviewed the findings and recommendations were made on a board by board basis whether to repair, rebuild, or use as is.

Since the boards were originally manufactured in the late 1990's, locating the replacement parts was difficult. Also,

many of the gerber files used to create the printed circuits boards required updating to conform to current manufacturing processes and standards.

*Etalon*—The SAGE III/M3M replacement instrument, launched in December 2001, was found to have a patterned spectral variation in the solar science measurements that suggested the presence of an optical etalon. This was attributed to the optical attenuator having a possible plane parallel structure, instead of the necessary  $>5$  arc second wedge structure that would have effectively eliminated the possibility of a strong etalon in the optical attenuator. Subsequent measurements confirmed this. It was the decision of the SAGE3/ISS project to replace the known etalon by producing an optical attenuator with a new, wedged structure and a refurbished attenuator mechanism. The refurbished optical attenuator mechanism uses components from the spare SAGE III FOO, and a new optical attenuator that has an 8.2 arc second wedge.

Prior to the removal of the known etalon producing optical attenuator, Optical End-to-End (OE2E) test designed to determine whether an etalon is evident was performed. This test was performed on the Project's Test Occultation Instrument (TOI) with the legacy flight spare attenuator and the new flight spare of the refurbished optical attenuator alternately mounted into a precision rotation stage and placed in front of the TOI aperture. After a successful test that confirmed the technique, the OE2E test was performed on the flight instrument with the legacy attenuator. Similar to the TOI OE2E test results, the post-refurbishment results demonstrated that the pre-refurbishment legacy solar attenuator acts as an optical etalon, while the highly correlated response indicative of a greatly reduced/eliminated etalon effect was seen in the refurbished optical attenuator. Analysis of the post-refurbishment tests shows a reduction of optical etalon signal to better than one-thirtieth of the detected pre-refurbishment etalon signal present with the old attenuator mechanism.

In addition to quantifying the optical etalon reduction, post-refurbishment testing also compared the Charge Coupled Device (CCD) response to the Collimated Source Bench (CSB). The CSB is a source of light producing a uniformly illuminated "solar disk" with an output of  $\sim 1\%$  of the actual sun. Functional Tests were performed using the Project's CSB to establish a pre-refurbishment baseline of the CCD radiometric and instrument functional characteristics and to establish a post-refurbishment baseline for comparison of the CCD radiometric and instrument functional characteristics. The CCD's sensitivity, pre- and post-refurbishment, as determined from these functional tests, showed less than 5% variation, which is well within the radiometric limit of 20% variation for CCD reading.

The post-refurbishment testing also measured the attenuator commanded positions with respect to boresight. A post-refurbishment Theodolite Test was performed to determine the "solar-inserted" position of the new solar attenuator. This test was performed pre- and post- Instrument Assembly

(IA) vibration testing. When commanded to the "solar inserted" position, the new mechanism was measured to place the attenuator  $+0.44$  degrees from the boresight compared to the expected solar position of  $+2$  degrees ( $\pm 1$  degree) from the boresight. Analysis shows that the new solar position of  $+0.44$  degrees is acceptable.

## 9. SUMMARY

SAGE3/ISS is the fifth in a series of instruments developed for monitoring aerosols and gaseous constituents in the stratosphere and troposphere. The scientific measurements provided by SAGE3/ISS will form the basis for analysis of the five of the nine critical constituents identified in the U.S. National Plan for Stratospheric Monitoring. These five atmospheric components include the profiles of aerosols, ozone ( $O_3$ ), nitrogen dioxide ( $NO_2$ ), water vapor ( $H_2O$ ), and air density using  $O_2$ .

The SAGE3/ISS IP will be mounted externally on the ISS. An important component of this exciting mission is the European Space Agency's contribution of the Hexapod Positioning System (HPS) that will be used to correct the ISS attitude variations in roll and pitch.

The primary focus of SAGE3/ISS will be to study aerosols, clouds, water vapor, pressure and temperature, nitrogen dioxide, nitrogen trioxide, and chlorine dioxide.

The SAGE3/ISS validation program will be based upon internal consistency of the measurements, detailed analysis of the retrieval algorithm, and comparisons with independent correlative measurements.

Two of the biggest challenges SAGE3/ISS has encountered are a slip in the original schedule due to the delay in hexapod delivery and the removal of a patterned variation in the solar science measurements in the SAGE III/M3M data that suggested presence of an optical etalon.

## REFERENCES

- [1] William P. Chu and Lemuel E. Mauldin III □ "Overview of the SAGE III experiment", *Proc. SPIE* 3756, Optical Spectroscopic Techniques and Instrumentation for Atmospheric and Space Research III, 102 (October 20, 1999); doi:10.1117/12.366363;
- [2] Didier F. Rault, David Flittner, Robert Loughman, and Richard McPeters, Ozone Retrieval from SAGE III Limb Scattering measurement, Optical Remote Sensing Quebec City, Canada February 3, 2003; ISBN: 1-55752-740-7
- [3] T. J. Pepin, M.P. McCormick, W.P. Chu, J.W. Baer, J. Guy, and A. Ray, Stratospheric Aerosol and Gas Experiment III (SAGE III), *SPIE International Symposium for Optical Engineering*, Orlando, FL, 1993

- [4] McCormick, M.P., P. Hamill, T. J. Pepin, W. P. Chu, T. J. Swissler and L. R. McMaster, Satellite studies of the stratospheric aerosol, *Bull. Amer. Meteor. Soc.*, 60, 1038, 1979
- [5] McCormick, M. P., W. P. Chu, G. W. Grams, P. Hamill, B. M. Herman, L.R. McMaster, T. J. Pepin, P. B Russell, H. M. Steel and T. J. Swissler, High-latitude stratospheric aerosol measured by SAM II satellite system in 1978-1979, *Sciences*, 214, 328, 1981
- [6] M.P. McCormick, et.al., Satellite Studies of the Stratospheric Aerosol, *Bull. Amer. Meteor. Soc.*, 60, 1038, 1979.
- [7] Mauldin, L. E., Stratospheric Aerosol and Gas Experiment II Instrument: A functional description, *Opt. Eng.*, 24, 2, 207-312, 1985
- [8] McCormick *et al.*, Stratospheric Aerosol and Gas Experiment III (SAGE III) Aerosol and trace gas measurements from Earth Observing System (EOS), SPIE Paper No. 1491-16, *SPIE Symposium on Aerospace Sensing*, Orlando Florida, 1991.
- [9] Mauldin, L. E., M. P. McCormick, J. M. Zawodny, L. R. McMaster, W. P. Chu, J. C. Gustafson, and G. L. Maddrea, The Stratospheric Aerosol and Gas Experiment III Instrument proposed for EOS: A conceptual design, *Int. Congress on Opt. Sci. and Eng.* – Paris, France, 1989
- [10] Cunnold, D.M., M.C.Pitts, and C.R.Trepte, 1984: An intercomparison of SAGE and SBUV ozone observations for March and April 1979, *J. Geophys. Res.*, 89, 5249-5262
- [11] Chu, W.P., and M.P. McCormick, 1979: Inversion of stratospheric aerosol and gaseous constituents from spacecraft solar extinction data in the 0.38-1.0 micron wavelength region, *Appl. Opt.*, 18, 1404-1413
- [12] Rind, D., E.-W Chiou, W. Chu., S. Oltmans, J. Lerner, J. Larsen, M.P. McCormick, and L. McMaster, 1993: Overview of the Stratospheric Aerosol and Gas Experiment II water vapor observations: method, validation, and data characteristic, *J. Geophys. Res.*, 98, 4835-4856
- [13] Russell, P.B. et al., 1981b: Satellite and correlative measurements of the stratospheric aerosol, II, comparison of measurements made by SAM II, dustsondes and an airborne lidar, *J. Atmos. Sci.*, 38, 12295-1312
- [14] Russell, P.B., and M.P. McCormick, 1989: SAGE II Aerosol data validation and initial data use: an introduction and overview, *J. Geophys. Res.*, 94, 8335-8338
- [15] Thomason, L. W., and G. Taha, 2003: SAGE III aerosol extinction measurements: Initial results, *Geophys. Res. Lett.*, 30(12), 1631, doi: 10.1029/2003GL017317
- [16] Morris et al., 2000: Trajectory mapping: A tool for validation of trace gas observations, *J. Geophys. Res.*, 105, 17, 875-17, 894



**Gloria Hernandez** received her B.S. in Math from the University of Puerto Rico and an M.S. in Computer Science from The College of William and Mary. She is the Science Manager for the SAGE III/ISS mission. She has been with NASA for over 30 years. Prior to joining the Science Directorate at NASA Langley Research Center, she was the chairperson for Technical, Management and Cost evaluations for various missions selected by NASA for implementation, including the recent MAVEN mission to study the Mars atmosphere.



**Brooke Thornton** has a Bachelor's degree in Physics from Western Washington University and a Master's degree in Mechanical Engineering from George Washington University. She has been with LaRC for more than 11 years, where she has performed Ionized space radiation analysis, mission analyses, thermal analyses, and proposal evaluations. She is currently the mission operations manager and ground systems lead for the Stratospheric Aerosol Gas Experiment (SAGE) III on ISS.