NASA Science Mission Directorate
Research Opportunities in Space and Earth Sciences
NNH17ZDA001N-SAGEIII
A.51 SAGE III/ISS Science Team

NASA's Science Mission Directorate, NASA Headquarters, Washington, DC, has selected proposals for the solicited Stratospheric Aerosol and Gas Experiment III (SAGE III) on the International Space Station (ISS) Science Team program. SAGE III was launched to the ISS on 19 February 2017. The SAGE III instrument's primary objective is to monitor the vertical distribution of aerosols, ozone, and other trace gases in the Earth's stratosphere and troposphere to enhance our understanding of ozone recovery and climate change processes in the stratosphere and upper troposphere. The solicitation sought proposals in 6 topical areas: Independent Validation, Limb scatter retrieval algorithm development or adaptation, Assessing long-term changes in atmospheric composition, Aerosol and cloud studies, Data Analysis and modeling efforts using SAGE datasets, and Multi-sensor data product development. In response to its announcement, NASA received 30 proposals and selected 10, reflecting the foci described above. The total funding for these investigations, over a period of three years, is approximately $5.4 million.

Glen Jaross/Goddard Space Flight Center
Atmospheric Retrievals from SAGE III Limb Scatter Measurements
17-SAGEIII-17-0013

Our team proposes to provide computer software for retrieving vertical profiles of ozone number density and aerosol extinction coefficients from the ISS SAGE III limb scattering measurements as called for under Section 3.2 of the ROSES 2017 Appendix 51. The generation of these products will maximize the value of SAGE III limb measurements, providing more complete geographic coverage than is otherwise available from this instrument.

The proposed software is based largely on existing algorithms developed by our team for the operational retrieval of these same limb scatter products from the Ozone Mapping and Profiler Suite (OMPS) Limb instrument data. The ozone algorithm is suited for use with SAGE III/ISS limb scatter measurements having been previously applied in SAGE III Meteor-3M limb scatter retrievals. It was subsequently adapted for use with OMPS, but has not been substantially altered from its original form. This algorithm is responsible for the current operational OMPS Limb ozone product. The OMPS aerosol algorithm, which we propose for SAGE III/ISS, is new but shares many of its core components with the ozone algorithm.

We will also evaluate the suitability of SAGE III/ISS limb scatter instrument data for use in ozone and aerosol retrievals. Assuming its characteristics are similar to those of its predecessor on Meteor-3M, the instrument data product will require additional corrections for at the least stray light contamination. It may also be necessary to refine the altitude registration of the SAGE III limb scatter products. We propose to provide these additional corrections.

Our validation of the SAGE III ozone and aerosol products will employ correlative data from ozone sondes, ground and satellite LIDARs, Odin/OSIRIS, Aura/MLS, and CALIOP. We are particularly interested in SAGE III occultation scans, which provide both ozone and aerosol profiles. We will document both the limb scatter algorithms and their products.

Eric Jensen/Ames Research Center
Using SAGEIII Measurements and Numerical Models to Investigate Aerosol, Cloud, and Water Vapor Physical Processes in the Upper Troposphere/Lower Stratosphere Region
17-SAGEIII-17-0015

Water vapor concentration and cloud abundance in the upper troposphere/lower stratosphere (UTLS) region have a strong impact on the Earth's radiation budget, climate, and stratospheric chemistry; however, the processes controlling UTLS humidity and cloud formation are not well understood and not well represented in climate models. We propose using measurements of optically thin cirrus and water vapor from SAGE II/III along with complementary measurements of clouds from the CALIOP lidar on the CALIPSO satellite, clouds from OMPS-LP, and water vapor from the Microwave Limb Sounder (MLS) on the Aura satellite to address the UTLS cloud and humidity issues. We propose to adapt SAGE II cloud detection algorithms for SAGE III extinction data, implement SAGE III occultation cloud algorithms, and adapt OMPS-LP limb radiance algorithms for SAGE III limb scan data. We propose to use state-of-the-art transport and microphysical models driven by reanalysis fields to understand the processes controlling clouds and stratospheric water vapor, with a focus on the abundance and the role of optically thin cirrus occurring near the tropical tropopause on the humidity of air entering the stratosphere. The SAGE III solar occultation measurements are particularly well suited for detection of optically thin cirrus. The proposed modeling approaches include (1) computationally efficient ensembles of forward trajectories with simplified cloud microphysics driven by MERRA-2 and ERA- interim meteorological analyses, and (2) one-dimensional cloud simulations with detailed microphysics along back trajectories using temperature fields from the meteorological analyses with high-frequency waves superimposed. The model results will be evaluated and constrained by comparison with measurements of optically thin cirrus by SAGE II/III and OMPS-LP, supplemented by CALIOP cloud measurements and Aura MLS water vapor measurements. Finally, we propose to use SAGE III water vapor measurements along with our existing SAGE II, MLS and HALOE water vapor climatology to test multi-decadal model simulations.

The research will focus on the following specific tasks:

- Development of a SAGE III cloud-detection algorithm. The algorithm will be evaluated by comparison with OMPS-LP, CALIOP, and high-altitude aircraft aerosol and cloud measurements. Cloud products generated with our algorithm will be provided for community use.

- Adaptation of the OMPS-LP cloud algorithms for the SAGE III limb scan measurements.

- Use of the SAGE III cloud product, along with OMPS-LP cloud products, to quantify the occurrence of high-altitude, optically-thin tropical tropopause layer (TTL) cirrus.

- Combination of the SAGE II, HALOE, Aura MLS, and SAGE III data into a unified multi-decadal record of stratospheric water vapor.

- Use of forward and backward trajectory models to analyze the dehydration process in the tropical upper troposphere, and use of the SAGE III, CALIOP and OMPS-LP cloud products as well as SAGE III and MLS water vapor products to constrain simulations of optically thin TTL cirrus and water vapor.

The proposal team has extensive experience in TTL research including algorithm development, modeling, and analysis of cloud, aerosol and trace gas datasets. One of us (MRS) has been on the SAGE III Science Utilization Team for the last 5 years. The proposed modeling tools are mature and ideally suited for addressing the science issues discussed above.

Lars Kalnajs/University Of Colorado, Boulder
Coordinated In Situ Aerosol Size Distribution Measurements for Comparison and Validation of SAGE III/ISS Aerosol Extinction and Surface Area Density
17-SAGEIII-17-0022

The Stratospheric Aerosol and Gas Experiment III on the International Space Station (SAGE III-ISS) continues the long history of SAGE instruments retrieving aerosol extinction profiles from space. A critical element of this long-term data record is the validation of the retrieved aerosol extinction and surface area density profiles against in situ measurements of aerosol properties. The work proposed here will extend and enhance an equally long-term record of in situ measurements of stratospheric aerosol size distribution from balloons and apply these established measurements to the validation of the SAGE III-ISS aerosol extinction and surface area density measurements.

The primary activity of the proposed work is to measure in situ profiles of stratospheric aerosol size distributions using newly developed optical particle and condensation nuclei counters deployed on high altitude balloons, and timed to coincide with SAGE III-ISS overpasses of the two measurement sites, Boulder, Colorado, and San Jose, Costa Rica. This new in situ aerosol instrumentation provides a singular capability to measure stratospheric aerosol size distributions of radius 0.125 - 10 micrometers as well as the total aerosol population with radius > 0.01 micrometers at extremely low non-volcanic particle densities and with a vertical resolution of better than 50m. The measured aerosol size distributions will be used to calculate aerosol extinction at the SAGE III wavelengths and thus provide an independent validation of the SAGE III-ISS aerosol extinction products, in response to the requirements in section 3.1 of the solicitation. The measurements will provide a priori aerosol size distribution information to inform limb scatter algorithm development, providing information to test, validate and refine limb scatter algorithms, addressing requirements in section 3.2 of the solicitation. The in situ measurements will continue a 45-year record of stratospheric aerosol measurements, which spans the history of the SAGE/SAM instruments and can bridge the 12-year gap between SAGE III-Meteor and SAGE III-ISS. Performing aerosol profile measurements at the SHADOZ site in Costa Rica will: increase the latitudinal coverage of in situ aerosol profiles, provide aerosol measurements correlated with measurements of ozone, water vapor and sulfur dioxide, and integrate the aerosol measurements into a long-term tropical record. These measurements can augment SAGE III-ISS aerosol extinction profiles during future volcanic eruptions, when the lower stratosphere may be opaque at SAGE III wavelengths. Tying the SAGE III-ISS measurements into two multi-decadal data sets and insuring the continuity of these data in the case of an abrupt geophysical event addresses section 3.3 of the solicitation. Measurements of stratospheric aerosol size distributions can provide contemporary backscatter-to-extinction ratios and Angstrom exponents necessary to compare SAGE III with lidar and with extinction measurements from other satellite sensors. This facilitates the comparison and synthesis of measurements from multiple sensors, addressing section 3.6 of the solicitation.

Luis Millan Valle/Jet Propulsion Laboratory
SAGE III/ISS Dynamical Diagnostics
17-SAGEIII-17-0018

The upper troposphere/lower stratosphere (UTLS) is a critical region of Earth's atmosphere as it is where substances such as ozone and water vapor have their largest radiative impacts. Strong winds and tropopause dynamics with rapid regional and temporal variations lead to long-range pollution transport and complex stratosphere-troposphere exchange processes. The Stratospheric Aerosol and Gas Experiment III, launched in 2016 and deployed on the International Space Station (SAGE III-ISS), makes daily high-resolution profile measurements of atmospheric composition, temperature, and aerosols from the upper troposphere to the stratosphere that are valuable for studying the complex processes controlling UTLS composition. Measurements from previous SAGE missions have been used in many studies of the ozone layer, the water vapor distribution

in the stratosphere, volcanic eruptions, aerosols, and long-term trends, including studies of the UTLS, among other topics.

We propose to generate an extensive database of dynamical diagnostics (meteorological fields sampled at the measurement locations; diagnostics relating the measurement locations to those of the tropopause(s) and jet streams; and trajectory diagnostics) using existing algorithms developed and proven for the Aura Microwave Limb Sounder (Aura-MLS), Atmospheric Chemistry Experiment (ACE), and other satellite instruments and measurement platforms by this proposal's team. Profiles of dynamical variables that influence composition, such as winds, potential temperature, potential vorticity, equivalent latitude, static stability, temperature gradients, etc., as well as assimilated ozone, will be produced for SAGE III-ISS, sampled at the measurement locations and times. These will be computed within the Jet and Tropopause products for Analysis and Characterization (JETPAC) package. JETPAC will also be used to provide a detailed characterization of UTLS jets and multiple tropopauses. Furthermore, as has been done for MLS by members of this proposal's team, diabatic trajectories will be launched from a cluster of points around each SAGE III-ISS measurement location. All products will be calculated using NASA's state-of-the-art MERRA-2 reanalysis to provide meteorological fields and assimilated ozone.

These dynamical diagnostics facilitate characterization of the atmospheric observations in relation to air mass properties, e.g., with respect to the tropopauses, jet positions, or the stratospheric polar vortex, and will be valuable for research studies including non-coincident validation. These diagnostics will then be used to validate the SAGE III-ISS ozone and water vapor measurements against Aura MLS, ACE, and OSIRIS (Optical Spectrograph and InfraRed Imager System). MLS, ACE, and OSIRIS comparisons with SAGE III-ISS and SAGE II will be used to assess possible biases between SAGE II and SAGE III-ISS and thus aid long-term studies joining those SAGE datasets. The SAGE III-ISS dynamical diagnostics will be made publicly available to expedite studies by the entire community.

The proposed work is responsive to the solicitation since it will contribute to the validation of the accuracy and precision of the SAGE III-ISS standard science products and create products to facilitate the analysis of non-coincident satellite occultation measurements.

William Randel/University Corporation For Atmospheric Research (UCAR)
Assessing Variability and Long-Term Changes in Atmospheric Composition Utilizing SAGE III/ISS data
17-SAGEIII-17-0007

We propose studies of geophysical variability in SAGE III/ISS measurements of H2O, O3 and NO2, focusing on process studies related to seasonal and interannual changes in the upper troposphere/lower stratosphere. We will evaluate and utilize the high vertical

resolution SAGE III/ISS H2O data to study the detailed vertical structure associated with the annual cycle ‘tape recorder’ and behavior of the summer monsoon regions, including links to high resolution temperatures from GPS radio occultation. We will evaluate seasonal and interannual changes in O3 and NO2, and explore using SAGE III/ISS data to construct merged long-term data sets. Our analyses will contribute to evaluating the data quality for SAGE III/ISS measurements and provide novel information on geophysical variability at high vertical resolution.

Karen Rosenlof/Office of Oceanic and Atmospheric Research, Boulder
Validation of SAGE III Water Vapor and Ozone Products to Facilitate their Inclusion in a Long-Term Climate Data Record
17-SAGEIII-17-0006

To assess the success of the Montreal Protocol, a long-term global data set of vertically resolved stratospheric ozone is required. Stratospheric water vapor is another key climate forcing agent that also impacts ozone amounts and requires continuous monitoring. To construct the required data set, combinations of instruments are required, as no single platform covers or will cover the span of ozone depletion and recovery. The longest existing records are from the Stratospheric Aerosol and Gas Experiment II (SAGE II, 1984 - 2005) and the Aura Microwave Limb Sounder (MLS, 2004 -). The International Space Station (ISS) SAGE III (SAGE III-ISS) will continue the water vapor and ozone records into the future. We propose to evaluate and validate the SAGE III-ISS ozone and water vapor observations using a combination of independent satellite and ground-based measurements, and to incorporate SAGE III-ISS into the Stratospheric Water and OzOne Satellite Homogenized (SWOOSH) data set.

We will compare SAGE III-ISS data to both routinely collected ground- and balloon-based measurements, as well as specially collected data timed with SAGE III-ISS occultations. Ground-based data include microwave, lidar, and Dobson Umkehr measurements from stations around the world; data processing and validation for the Dobson stations is managed by one of our team members. We will also compare SAGE III-ISS data with routinely collected ozone and frost point water vapor balloon profile measurements from the Global Climate Observing System (GCOS) Reference Upper-Air Network (GRUAN). In addition to this, we will analyze a special set of balloon-based water vapor and ozone sounding profiles to be taken as part of SAGE III-ISS validation in Colorado and New Zealand by one of our team members. A major goal of using these geographically distributed data sets is to quantify any measurement biases that vary as a function of SAGE III-ISS measurement parameters (e.g., sunrise vs. sunset, beta angle, latitude). We will also carefully assess the differences taking into consideration the different match criteria and disparate vertical resolutions of the different measurement techniques.

Another major component of this work centers around comparing SAGE III-ISS data to the well-validated Aura MLS instrument, as well as vertically-resolved ozone

measurements from the Ozone Mapping and Profiler Suite Limb Profiler (OMPS-Limb) aboard the Suomi National Polar-orbiting Partnership (S-NPP) satellite and planned for the Joint Polar Satellite System (JPSS)-2. We plan to add SAGE III-ISS water vapor and both SAGE III-ISS and OMPS-Limb ozone to SWOOSH. These combined data sets will be useful for analysis done for the World Meteorological Organization (WMO)/United National Environment Programme (UNEP) Scientific Assessments of Ozone Depletion and other global data analysis and modeling studies.

A final component of SAGE III-ISS validation is comparisons with partial column ozone measurements from SBUV/2 and the OMPS Nadir Profiler (OMPS-NP). This comparison allows for a larger sample size for comparison, and will tie the SAGE III-ISS measurements to the 40+ year operational ozone record.

Stanley Sander/Jet Propulsion Laboratory
Validation of SAGE III/ISS Nighttime Measurements of NO3 and NO2
17-SAGEIII-17-0033

The Stratospheric Aerosol and Gas Experiment III on the International Space Station (SAGE III/ISS) is a solar / lunar occultation instrument able to measure aerosol and gaseous constituents of the atmosphere. Compared with SAGE II, SAGE III has wider wavelength coverage and a new capability for nighttime retrievals of O3, NO2, NO3, and OClO using lunar occultation. The specific measurement objectives of SAGE III/ISS are to provide 0.5 km vertical resolution and 1.5 km horizontal resolution profiles of: aerosols and clouds in solar occultation mode from the mid-troposphere into the stratosphere and mesosphere. In addition, lunar occultation mode will provide trace species measurements with 1 km vertical resolution.
To address the requirements of the SAGE III/ISS project for validation of nighttime trace gas retrievals as expressed in the FA, we will deploy a proven method for the measurement of NO3 and NO2. The approach will use a ground-based grating spectrometer operating in lunar occultation mode from JPL's Table Mountain Facility (TMF) near Wrightwood, California. Our previous measurements in support of SAGE III/Meteor-3 demonstrated that this approach could provide the required measurements with sufficient accuracy and precision to provide meaningful comparisons with SAGE III data. In order to address the altitude range of the SAGE III/ISS retrievals (20-55 km) we will employ two complementary methods for separating the total column measurements from TMF into tropospheric and stratospheric partial columns. The first method involves the use of ground-based in situ monitoring of NO2, NO3 and N2O5 using a portable cavity ringdown instrument from NOAA. These measurements will provide an indication of significant tropospheric NOx which would contribute to the measured total columns. Secondly, in combination with a 1-D model, we will compare the temporal profiles of NO3 and NO2 with column measurements. Our previous work showed that significant departures from model behavior also signal significant tropospheric NOx contributions. The combination of these methods will allow us to filter and/or correct the measured TMF columns to accurately represent what SAGE III/ISS is measuring.

All validation data will be processed and archived at frequent intervals for use by the SAGE III/ISS science team.

Ghassan Taha/Goddard Space Flight Center
Validation of SAGE III/ISS Solar and Lunar Products using Backward and Forward Trajectories.
17-SAGEIII-17-0023

We propose to use coincident observations, as well as back-forward trajectories to validate SAGE-III/ISS solar and lunar occultation profiles of aerosols, ozone, Nitrogen dioxide and water vapor against non-coincident observations of these trace species from satellite platforms such as MLS, OSIRIS, CALIPSO and OMPS LP, balloonsonde networks (SHADOZ, WOUDC, and NDACC ozone, aerosol and water vapor) and other available air and ground-based measurement systems. Our approach is a variant of the technique described in Schoeberl et al. [2015] which has been used to validate ATTREX and POSIDON data against MLS retrievals. A chemistry model, which includes diurnal changes in production and loss, will be used to reconcile ozone, NO2 and water vapor measurements taken by SAGE III at sunrise and sunset, and during lunar occultations We will then exploit the ~1 km resolution of the validated SAGE-III observations to characterize of the structure and seasonal variability of ozone, aerosols and water vapor in the upper troposphere and lower-to-middle stratosphere.

JEAN-PAUL VERNIER/Langley Research Center
Studying Properties and Trends in Aerosols and Cirrus Clouds in the Upper Troposphere and Stratosphere using SAGE III/ISS
17-SAGEIII-17-0026

The newly installed Stratospheric Aerosol and Gas Experiment III instrument on the International Space Station (SAGE III/ISS) offers a unique opportunity to improve our understanding of the sources and processes affecting stratospheric aerosol and cirrus cloud variability. We propose to combine the SAGE III dataset with balloon-borne measurements, other satellites (SAGE II and CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations)) observations and use modelling tools to address the following science questions:

I. What are the properties of aerosols and cirrus clouds in the Upper Troposphere and Lower Stratosphere (UTLS) during the Asian Summer Monsoon (ASM)?
II. What are the trends in aerosol and cirrus clouds in the UTLS?
III. What will be the climate impact of the next moderate-to-large volcanic eruption?

The SAGE III/ISS aerosol dataset will be analyzed in light of balloon-borne observations made in India during the Balloon measurement campaigns of the Asian Tropopause

Aerosol Layer (BATAL). SAGE III and balloon data will be compared using trajectory mapping techniques and GEOS-5 assimilated meteorology. Trajectory calculations initialized from the SAGE III observations and the balloon locations will be performed using the Langley trajectory model to match those measurements in space and time. Aerosol simulations from the GEOS-Chem chemical transport model will be performed and compared against SAGE III and BATAL data to shed light on the nature and origin of the ATAL.

The trends in aerosol and cirrus cloud layers in the UTLS will be investigated using SAGE II, the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) and SAGE III observations. The SAGE III aerosol extinction profiles will be compared with CALIOP backscatter profiles on a monthly basis. Lidar ratios will be calculated using monthly-mean collocated measurements between SAGE III and CALIOP, and aerosol optical depth (AOD) time series of SAGE II, CALIOP and SAGE III will be used to study the trends in UTLS aerosols. Trends in cirrus clouds will also be studied using improved aerosol-cloud classification approach developed with the SAGE II dataset. We will use SAGE III data to improve CALIOP calibration and retrieved aerosol extinction and to incorporate it into the Global Space-based Stratospheric Aerosol Climatology (GloSSAC) for climate and chemistry modelling.

Finally, we will study the potential climate impact of the next medium-to-large volcanic eruption by calculating radiative forcings from the SAGE III dataset, which will be compared with that from the Cloud and Earth's Radiant Energy System (CERES). In addition, we will continue exploring ways to fill gaps in the SAGE III dataset using trajectory calculations based upon a method applied during the Post Pinatubo period.

Hsiang-Jui (Ray) Wang/Georgia Institute of Technology
Validation of SAGE III-ISS Ozone Data and Applications of Merged SAGE Datasets for Minimizing Sampling Biases in Trend Analysis and for Model Evaluation
17-SAGEIII-17-0014

The Stratospheric Aerosol and Gas Experiment (SAGE) III is the third generation of SAGE instruments dated back to 1978. Their long-term measurements have provided valuable information for studying ozone change in the stratosphere and its relation to decreasing ozone-depleting substances (ODSs) and increasing greenhouse gases (e.g. Newchurch et al., 2003, Morgenstern et al., 2017). Since the decease of SAGE II instrument, operated between 1984 and 2005, SAGE II observations have been combined with measurements from other satellites (Wang et al., 2013, Froidevaux et al., 2015, Bourassa et al., 2014, Kyrölä et al., 2013) to continue this researches and to support chemistry-climate models validation (CCMVal: SPARC, 2010, Eyring et al., 2016). Those merged ozone datasets, however, have been shown to introduce unintentional errors due to instrument drift in individual satellites, varying merging technique and

sampling biases (different spatial/temporal coverages among satellites) etc. (Hubert et al., 2016, Tummon et al., 2015, Toohey et al., 2013).

This proposal intends to address the following scientific questions:

(1) What is the accuracy and precision of SAGE III-ISS ozone measurements?

We plan to quantify the accuracy and precision of SAGE III ozone data with correlative measurements from satellite (Aura MLS, Odin-OSIRIS) and ground-based (SHADOZ, NDACC) networks, and simulations from the NASA Global Modeling Initiative (GMI) Chemistry Transport Model (CTM).

(2) What is the sampling biases in SAGE (and other satellites) merged ozone datasets?

We will produce/update two merged ozone (GOZCARDS and SAGE-OSIRIS) datasets, and use NASA GMI CTM linked with MERR2 (Modern-Era Retrospective analysis for Research and Applications, Version 2) (Douglas et al., 2017, Strahan et al., 2016) to quantify the sampling biases in merged ozone datasets.

(3) What is the effect of sampling biases in merged ozone datasets on estimated long-term trends, and can we minimize such uncertainty with two-dimension regression technique?

We will apply statistical regression model (e.g. Steinbrecht et al., 2017) to synthetic ozone data (from full GMI CTM model outputs and those subsampled with satellite observed locations and times) to quantify the effect of sampling biases on estimated trends. A two-dimensional regression model (e.g. Bodeker et al., 2013, Damadeo et al., 2014), which tries to account for non-uniform sampling in both time and latitude domains, will be developed and see whether it can be used to minimize the uncertainties of sampling biases in derived ozone trends.

(4) Can we use SAGE (and merged) datasets for model evaluation?

We will use the WACCM6 (Whole Atmosphere Chemistry-Climate Model version 6) as a test model and identify observed features (e.g. QBO driven UTLS processes) in SAGE merged datasets that can used to evaluate chemistry climate models.

Our proposed work is responds to solicited topics in this NRA. The tools (data and models) we plan to use for this analysis are all based on mature techniques and suitable for the proposed studies. Results from this proposal will contribute to SPARC LOTUS (Long-term Ozone Trends and Uncertainties in the Stratosphere) and follow-on activities, providing input to future WMO/UNEP Ozone Assessment, CCMs validation and related studies.