ATTACHMENT A

STATEMENT OF WORK
Geophysics, Geodynamics and Space Geodesy Support
(GGSG)

September 2014

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0. INTRODUCTION

0.1 Overview

This 5-year contract supports a wide array of geodynamic, geomagnetic, geophysical, and atmospheric investigations of solar system bodies such as the Earth, Venus, Mars, and Mercury. Among the requirements for these investigations are instrument development; software development and maintenance; data collection, archiving and dissemination; scientific data analysis, modeling and interpretation; reports and presentations of scientific results; public outreach and education; and associated technical and administrative work.

The contractor shall provide support to investigators associated with current programs and projects such as GRACE, the Ocean Surface Topography Mission, the Interdisciplinary Studies in Earth Science, ICESat, and future missions outlined in the roadmap of Earth-science missions defined the National Academy of Science Decadal Survey, such as SWOT, DESDynI, ICESat-2, GRACE Follow-On, and GRACE-2. The contractor shall provide support to investigators involved in analysis of space geodetic data (SLR, DORIS, GNSS), used for geodetic analysis, precision orbit determination, and the determination and maintenance of the terrestrial reference frame. The contractor shall provide support to investigators involved with LAGEOS-1, LAGEOS-2, Starlette, Stella, LARES, Earth Positioning satellites such as GPS, Galileo, and GLONASS; Satellite and satellite constellations that map and determine the Earth's gravity and magnetic fields such as GRACE, GOCE, and SWARM; Earth altimetry satellites such as TOPEX/Poseidon, Jason-1, Jason-2, Jason-3, Envisat, GEOSAT, GEOSAT-Follow-On (GFO-1), ICESat, CryoSat-2, and Sentinel-3; planetary spacecraft such as Mars Global Surveyor, Mars Odyssey, the Lunar Reconnaissance Orbiter, GRAIL, the Mars Reconnaissance Orbiter, MESSENGER, and MAVEN. The contractor shall provide support for data systems such as the CDDIS.

For the purposes of organization, this Statement of Work (SOW) is divided into five main sections. The work is categorized according to whether the main emphasis lies in one of the following five areas: 1.) Geodynamic, Geomagnetic, Earth and Planetary Studies; 2.) Cryospheric science studies; 3.) Atmospheric Studies and Remote Sensing; 4.) Software Development and Maintenance; 5.) Data Center. The Table of Contents shows the further subdivisions of these sections.

Work accomplished on this support services contract shall include support in the areas described above and in the Statement of Work, as defined by the contracting officer, CO, through the Task Ordering Procedure Clause of this Contract. Each order shall include specifications, schedules, deliverables, and performance criteria.

The contractor, in accordance with this SOW, shall provide all necessary resources, including personnel, facilities, equipment, and materials, unless otherwise provided by the

government, in order to fulfill the work requirements. Supporting documentation will be prepared and delivered as specified in the contract.

The contractor shall deliver required documentation in accordance with the terms of the Contract.

0.2 Types of Work

The following types of work are supported by this contract:

SCIENCE

Scientific Instrument Support

Support the design, development, fabrication, testing, integration, and calibration of instruments and readout systems for in-house use or field deployment. Ancillary to this effort are site surveys; field engineering data collection; equipment installation; data analysis; and documentation. For existing instruments, hardware and equipment support is required for design, development, installation, testing, checkout and support for interfacing new optical, mechanical, electrical, and electronic assemblies. Monitoring the status of equipment used in laboratory and field experiments is required. In addition, the contractor will support operation and management of engineering and computing facilities; laboratory and field deployment of hardware and software; field observations and flight support; instrument modification and equipment refurbishment; and personal computer systems including installation of hardware and software, user training and troubleshooting problems involving hardware, software, or networks.

Instrument Modeling and Simulation

The two primary objectives are to:

- Develop and communicate an understanding of the scientific impact of variations in instrument performance with time, as well as the impact of changes in either instrument specifications or spacecraft/aircraft/ground truth requirements.
- Provide spectral, spatial, and radiometric modeling and scene simulation capability, and support algorithm development, testing and analysis. The models will allow for characterization of ground targets, observing conditions, and the observing system. The model results and simulated data sets shall be used in the development and testing of calibration and masking algorithms.

Science Research Support

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Support all phases of geophysical, geodynamic, geodetic, oceanic, atmospheric, and biospheric research from experiment concept and design, through data acquisition and reduction, to data analysis and modeling. This includes geodynamics and geophysics, specifically gravity and magnetism, topography, altimetry, geoid anomalies, planetary rotation, tides, crustal dynamics, and Earth's core fluid motions. One of the objectives is to better understand the spectral, radiometric, and geometric characteristics of image data. This includes research of planetary radiation budgets; radiation transfer through the land, ocean, cryosphere, and atmosphere; soil moisture and forest and plant canopy modeling; land surface heat and water balance modeling; the role of aerosols, trace gases, and pollutants in the photochemistry of planetary atmospheres; thermal structure, dynamics and heat balance of the planetary atmospheres; dynamics and physical and chemical properties of the tropospheric and stratospheric constituents, and thermosphere properties; and global vegetation studies.

Support data analysis operations, which require computer programs encompassing such areas as pattern recognition, simulation of physical systems, parameter estimation, image data analysis, dynamic interaction with graphical displays, mathematical modeling of physical theories and associated numerical and scientific analyses, and data correlation studies using statistical techniques. This requires problem analysis and program implementation for both on-line data processing and on-demand processing via remote terminals. The support also requires development and implementation of data visualization and animation methods in order to provide increased understanding of the prediction capabilities for geophysical processes and parameters.

Support the mathematical analysis and computer implementation of techniques to perform such functions as radiative transfer and optical scattering analysis, image enhancement, noise removal, radiometric corrections, geometric corrections, registration, filtering and other transformations, pattern recognition, multivariate classification, and change detection of Earth resources and meteorological image data. Included will be conducting surveys or literature searches, gathering or generating related data, setting up and conducting tests, analysis of test results, producing reports of the investigation, recommending solutions and development, and implementing techniques to solve particular information extraction problems.

Scientific research support also includes:

- Coordination and support of measurement operations.
- Real-time and near real-time data acquisition and quick look displays.
- Prepare validated data product.
- Analysis, restructuring, modification, and recoding of software and algorithms for efficient use of mainframe computers and the workstation environment, depending on the need.
- Modeling of new measurement data and additional physical phenomena.

- Simulation of processes for studying environmental parameters and performing analysis and validation of physical parameters derived from existing ground, aircraft, and satellite observations.
- Optimization of numerical techniques.
- Extension of parameter estimation capability.
- Development and improvement of program user applications.
- Precision, bias, and error analysis shall accompany the data analysis, with appropriate software development to provide an operational correction capability.

ENGINEERING

Systems Engineering/Development

Support all phases of systems development and systems engineering. This includes all aspects of systems engineering such as requirements definition and analysis; conceptual and detail design; integration; hardware sizing and validation; the development of technical specifications; the development of automatic data processing equipment acquisition plans; configuration management; and the development and control of external interfaces including digital communication networks. Such support may include aspects of mechanical and electrical engineering along with aspects of the computer sciences. In support of the various kinds of scientific research being done, the contractor will provide the expertise to research, design, integrate and enhance technical systems consisting of hardware and software as required.

Engineering Support

Engineering support involves all aspects of the design, development, fabrication and verification of research instrumentation. Included in this support are the basic-engineering designs and analyses of an instrument, the drafting of component sections, the development of electronic components, assembly, field testing, and the evaluation and verification of acceptable performance of systems, subsystems and instrumentation when coupled with computer support. Equipment and instrument installation, maintenance, operation, modification, repair, upgrade, and transport will be required and sustained to assure mission success and maintain effective data collection capabilities. Spare parts will be maintained as required. Documentation of all engineering developments will accompany services. Required completion dates will be established, and milestone schedules will be developed, with sufficient detail to provide a clear understanding to the contractor and to the government of the status of each task, and the estimated hours to complete.

Mission Engineering Support

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Support NASA's mission planning from the conceptual phase to prototype instrumentation to surface/aircraft/spacecraft deployment to data processing systems design, archive, and data distribution. Support is required for mission planning, independent verification and validation of software and hardware, scheduling, instrument control and coordination of activities for data gathering systems. Studies are required for instrument ground support equipment, data systems design, data handling facilities, computing system architecture, networks and communications, mass storage and archiving systems, transformation of observations into physical variables and generation of various data processing scenarios, and data cataloging and distribution systems. Further studies involve estimating data capture volume, Earth coverage, and data delay time for various real-time, near real-time and delayed applications. Included are plans for system design and trade-off considerations for converting raw data to scientifically meaningful products mapped to standard projections. Also included are plans for quality assurance, archiving and distribution of products.

FIELD MEASUREMENTS

The contractor shall aid in conceiving, planning, organizing, and conducting field campaigns to obtain data critical to the data analysis and modeling efforts being conducted. Unexplained or wide variations in the results obtained during different segments of the experiment shall be investigated with software designed to pinpoint and resolve error sources.

COMPUTING

Algorithm Development

Develop and test algorithms, including algorithms for science data products, data and instrument characterization, calibration, utility masking, browsing, and product quality assessment. A theoretical basis for each algorithm shall be provided. The algorithms may be integrated into a single system, implemented in a structured language, and tested to verify scientific utility. Deliverables are the algorithms, software, test datasets and their results, and documentation.

Scientific Data Processing

Support the design of efficient input/output and data packing/unpacking techniques; the application of total orbit/attitude data where necessary; applying the appropriate data reduction algorithms to process the raw initial data into final physical units; and implementing numerical algorithms as required.

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Processing System Development

Design and develop systems for producing scientifically valid data. Known errors will be removed to improve accuracy by conducting appropriate software reviews and prototype tests. Provide programming guidelines that shall enable the users to produce routines, which utilize the services of the processing system. Provide coding guidelines for programmers. An iterative process of modifying software and returning modified code based on processing results shall be used to correct the system. An independent test team will be selected to conduct independent tests of the processing system. They shall develop a test plan, and tests specified in the plan shall test compliance with all system requirements. The test team shall also develop test data sets to exercise the individual software components of the system. Facilitate and run test cases, obtain test data sets as defined by the users, and assess results of test cases. Produce and evaluate quality control products for all aspects of the system. Develop prototypes of any advanced processing systems. The prototypes should allow for the exploration of concepts about the design of the integrated system. The prototypes shall also enable the users to test software in a processing environment. A significant portion of the early effort in this function may be focused on assembling test data sets for development, testing and validation. Software that will support ingesting, storing, browsing, and reading and writing these data sets shall be designed.

ADMINISTRATIVE SUPPORT

The contractor shall provide administrative support for meetings. This support includes the generation of presentations for the meetings and attending the meetings. Provide appropriate staff coverage of the meetings to answer questions and collect requests. Support includes preparing reports and/or position papers for the meetings and documenting the results of the meetings. Analyze and respond to plans, reports, status, etc.

Plan, develop, implement, and test telecommunications systems. Monitor performance, gather statistics, generate reports, evaluate performance, trouble-shoot, analyze and resolve problems in the area of networking systems.

Manage data resources, databases, and computer facilities. Maintain a computer-based formal project management system providing critical path and status information. The project management system should be available via a computer network connection. Develop and maintain a quality assessment program that includes measures of both performance in moving toward agreed upon quantitative goals and in customer satisfaction with products delivered to the user, including citation indices for peer-reviewed papers and trend data of quality assessment parameters of products. This function also includes planning and tracking support, as well as producing, integrating, editing, maintaining and updating electronic and published versions of documents. Attend and make presentations at meetings and

conferences, both within and outside of NASA. All documentation, data, databases, and other pertinent deliverables should be accessible in electronic form.

Plan the agenda, documentation, and computer/software services that will be provided at regional, national, and international workshops, conferences, and symposia; and shall act as executive secretary for the meetings, taking minutes and providing auxiliary technical information as requested and required.

Through the use of appropriate databases, document archives, data products, reliability and quality assurance, configuration control, standard safety procedures, and program and resource analysis tools, provide support for major Laboratory programs. Meetings will be held at specified intervals with the ATRs and COTRs, and reports issued, to assure adequate transfer of information.

0.3 Technical Requirements

This contract complies with the following Section 508 Electronic Information Technology Accessibility Standards: Technical Standard 1194.21, entitled "Software applications and operating systems", which is applicable for any system upgrades or new requirements; Technical Standard 1194.22, entitled "Web-based intranet and internet information and applications", which is applicable for any system upgrades or new requirements.

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0.4 Acronyms

ACMR	Airborne C-Band Microwave Radiometer
AESMIR	Airborne Earth Science Microwave Imaging Radiometer
ALtiKa	Altimeter Ka-band
ALVICE	Atmospheric Lidar for Validation, Interagency Collaboration and Education
ASCII	American Standard Code For Information Exchange
ATLAS	Data receiver associated with ICESat-2
ATBD	Algorithm Theoretical Basis Document
ATM	Airborne Topographic Mapper
ATR	Assistant Technical Representative
BIH Tables	Earth Orientation And Solar And Magnetic Flux Tables
C	Programming language
CD	Compact Disk
CDDIS	Crustal Dynamics Data Information System
CO	Contract Officer
COM	Center of Mass
CNES	Centre Nationale D'Estudes Spatiales
COTR	Contracting Officer's Technical Representative
COTS	Commercial off The Shelf
CRYOSAT	ESA ice radar altimetry mission
DESDynI	Deformation, Ecosystem Structure and Dynamics of Ice mission
DORIS	Doppler ORbitography Integrated by Satellite
DSN	Deep Space Network
Envisat	ESA satellite
ERODYN	Error Analysis Program
ESA	European Space Agency
ESSIC	Earth System Science Interdisciplinary Center
FO	Follow-On
FORTRAN	FORmula TRANslation computer programming language
FPGA	Field Programmable Gate Array
FTP	File Transfer Protocol
GEODYN	Geodynamics Orbit And Geodetic Parameter Estimation System
GEOSAT	Altimeter Satellite
GFO	GEOSAT Follow-On (US Navy altimeter mission)
GGAO	Goddard Geophysical and Astronomical Observatory
GGSG	Geophysics, Geodynamics and Space Geodesy
GLAS	Geoscience Laser Altimeter System
GLONASS	GLObal Navigation Satellite System
GLOW	Goddard Lidar Observatory for Winds
GLTN	Global Laser Tracking Network

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GM	Gravitational constant times mass
GNSS	Global Navigation Satellite System
GOCE	Gravity Ocean Climate Experiment
GPP	GEODYN Pre-Processor/Text Editing Program
GPS	Global Positioning System
GRACE	Gravity Recovery And Climate Experiment
GRAIL	Gravity Recovery and Interior Laboratory
GS	Ground System
GSE	Ground System Engineer
GSFC	Goddard Space Flight Center
HARLIE	Holographic Airborne Rotating Lidar Instrument Experiment
IceBridge	NASA polar ice mission (2009-2015)
ICESat	Ice Cloud and land Elevation Satellite (2003-2009)
ICESat-2	Successor to ICESat (2017)
IDL	Interactive Data Language
IDS	International DORIS Service
IERS	International Earth Rotation Service
IGS	International GNSS Service
ILRS	International Laser Ranging Service
ISF	Instrument Support Facility
ISRO	Indian Space Research Organization
ITOS	Integrated Test and Operations System
ITRF	International Terrestrial Reference Frame
IVS	International VLBI Service for Geodesy and Astrometry
IT	Information Technology
JPL	Jet Propulsion Laboratory
KBRR	K-Band Range-Rate
LAGEOS	Laser Geodynamic Satellite
LARES	Laser Relativity Satellite
LIDAR	Light Detection and Ranging
LRO	Lunar Reconnaissance Orbiter
LLR	Lunar Laser Ranging
LOLA	Lunar Orbiter Laser Altimeter
LRAD	L-band Radiometer
LVIS	Laser Vegetation Imaging Sensor
MABEL	Multiple Altimeter Beam Experimental Lidar
MAVEN	Mars Atmosphere and Volatile Evolution mission
MESSENGER	MErcury Surface, Space ENvironment, GEochemistry, and Ranging
MGS	Mars Global Surveyor
MISR	Multi-angle Imaging SpectroRadiometer
MLA	MESSENGER Laser Altimeter
MOC	Mission Operations Center

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MODIS	Moderate Resolution Imaging Spectroradiometer
MOLA	Mars Global Surveyor Laser Altimeter
MoSST	Modular, Scalable, Self-consistent, and Three-dimensional
MoSST_DAS	Modular, Scalable, Self-consistent, and Three-dimensional Data
MPL	Micro Pulse Lidar
MRO	Mars Reconnaissance Orbiter
NASA	National Aeronautics And Space Administration
NCCS	NASA Center For Computational Sciences
ODYSSEY	Mars spacecraft
OIB	Operation IceBridge
ORAN	Orbit Analysis Program
OSTM	Ocean Surface Topography Mission
POD	Precision Orbit Determination
PPD	Precision Pointing Determination
SAR	Synthetic Aperture Radar
SARAL	Satellite with ARgos and ALtika
SDMS	Scheduling and Data Management System
Sentinel-3	ESA Mission (follow on to Envisat)
SERVIR	Joint Mission NASA/USAID
SGP	Space Geodesy Project
SINEX	Solution INdependent EXchange format
SIPS	Science Investigator-led Processing System
SLR	Satellite Laser Ranging
SOLVE	least squares normal equation solution software
SOW	Statement of Work
STARLETTE	French Laser Retroreflector Satellite
STELLA	French SLR Retroreflector Satellite in orbit since 1994
SWOT	Surface Water Ocean Topography mission
T&C	Telemetry and Command
TOPEX/Poseidon	US/French Ocean Topography Experiment satellite
TRF	Terrestrial reference frame
UAIRP	Upper Air Instrumentation Research Project
UMD	University of Maryland
US, USA	United States, United States of America
USDA	United States Department of Agriculture
UT	University of Texas
VLBI	Very Long Baseline Interferometry

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1. GEODYNAMIC, GEOMAGNETIC, EARTH AND PLANETARY STUDIES

1.1 RESERVED

1.2 Simulation and Analysis of Data from Extraterrestrial Missions

The contractor shall provide analysis support for the Lunar Reconnaissance Orbiter (LRO), Lunar Orbiter Laser Altimeter (LOLA), MESSENGER (including the MESSENGER Laser Altimeter, MLA, and the Gravity Science Experiment), Dawn and support simulation and analysis for new planetary missions that involve laser altimeters.

1.3 Interplanetary Precision Orbit Determination

The purpose of this requirement is to perform precision orbit determination (POD) for Mars Reconnaissance Orbiter, Mars Global Surveyor (MGS), Mars Odyssey and MESSENGER. The Deep Space Network (DSN) tracking data will be used to determine precise spacecraft orbits for the Mars-orbiting spacecraft, using the best possible macro models, and force model parameters. The MRO data (from 2006-2012), the MGS data (1999-2006), the Mars Odyssey data (2002-present) will be processed. A series of Normal equations will be developed with the following adjusted parameters: (1) Low degree harmonics (static); (2) Time-varying harmonic (GRVTIM) components; (3) K2 Love number and GM; A second series of normal equations will be developed to refine the static gravity field of Mars. The joint use of MOLA crossovers and their impact on MGS POD and Time-variable gravity model development will also be assessed.

1.4 SLR and DORIS Data Analysis for the Reference Frame

This requirement supports the analysis of SLR & DORIS tracking data for inclusion in solutions for the International Terrestrial Reference Frame. The latest models (consistent with the processing used in the latest GRACE solutions, and the latest generation of TOPEX and Jason-1 solutions) will be used. The satellite data to be analyzed include current, past and future SLR and DORIS missions. The arcs will be aligned with IERS weeks from 1993 onwards, and made consistent with ILRS/IERS submissions in terms of arc lengths for periods prior to 1993.

Routine SINEX solutions will be developed for the IDS submissions (DORIS-only) – continuing the GSFC series; a cumulative SLR-DORIS reference frame solution will be refined. In preparation for any future ITRF, a new cumulative set of SINEX files will be delivered to the IDS Combination Center. This will be based on updates to the GSFC IDS SINEX series, including updated troposphere refraction correction modeling, updated static and time-variable gravity as a priori, updated ocean tide and ocean loading corrections, application of the ocean pole tide.

This requirement will also support the development of joint SLR+DORIS solutions for the time-variable gravity field of the Earth.

1.5 Mission Planning and Data Reduction

Much of the work in the Planetary Geodynamics Laboratory involves running orbit determination software (GEODYN is the orbit determination software), least squares linear algebra software (SOLVE is the linear algebra software) and other standard analysis software packages. Associated with this is the handling and archiving of the data sets required by and created by these software packages. The purpose of this requirement is to provide assistance to members of the Planetary Geodynamics Laboratory in running analysis software and with handling the data sets needed by and created by these software systems. Typically, those working on this requirement will be contacted by analysts and asked to make series of computer runs associated with the reduction of tracking data. This requirement is also responsible for making the benchmark runs for the GEODYN effort.

1.6 Sea Level and Tides

The objectives of this requirement involve the measurement and analysis of global sea level and oceanic tides. The fundamental measurement types are (a) satellite altimeter data, especially from the TOPEX/Poseidon, Jason-1, Jason-2, and follow-on missions, but also non-NASA missions such as Sentinel-3, SARAL/AltkiKa, and CryoSat, (b) GRACE satellite-to-satellite tracking data, as well as other types of past and future satellite laser ranging data, (c) tide gauge data, and (d) other data as deemed appropriate to the study of sea level and tides. The key role of satellite altimetry requires that considerable effort be devoted to the processing, analysis, calibration and validation of those data and to the merging of data from multiple altimeter missions. Tide gauge data are especially useful for calibrating altimetry; such data are routinely being used to monitor long-term drifts and other errors in Jason data. New satellites with different technology (e.g., Ka-band altimetry) will likely expose new errors and present new challenges for merging multiple missions into consistent data sets.

Sea level is a crucial component of NASA's Science Focus Area of "Climate Variability and Change." Ocean tide models are required for a multitude of applications throughout the geophysical community. In particular, they are needed by NASA and the geodetic community to support the proper interpretation of GRACE and all satellite altimeter measurements. The spatial resolution of these models must be improved to meet requirements for the upcoming SWOT wide-swath altimeter mission.

1.7 Geomagnetic Infrastructure Support

The contractor shall provide geomagnetic infrastructure support in the areas of Earth and planetary magnetic field studies, especially core, crustal, oceanic and external field

modeling, and magnetic field mission support. Work includes extraction of improved crustal magnetic anomaly fields and investigation of the sources of the anomalies, comparison of models for magnetic fields on different planets, mission development and mission support activities. Work involves development, modification and maintenance of algorithms and software for processing, interpreting and modeling magnetic field data especially on regional scales. Work involves travel to working group meetings, presentation of results at national and international scientific conferences, and publication of results.

1.8 Geodynamo and Planetary Dynamos

All planets, except Venus, possess or used to possess a magnetic field of internal origin (the intrinsic field). These planetary magnetic fields are believed to be generated and maintained by convective flow in electrically conducting liquid planetary cores (planetary dynamos). Understanding the dynamics of the planetary dynamos is important for interpreting the planetary magnetic fields measured by past missions, and for providing scientific investigations for future missions. It is also important for understanding the properties of the planetary interiors, planetary evolution history, and magnetic impacts on planetary climate. Investigation of core geodynamics includes numerical simulation, assimilation of data and numerical models, and analysis of various geophysical processes embedded in simulation and assimilation results. The contractor shall maintain and improve the dynamo simulation and assimilation systems, MoSST and MoSST_DAS, the two models used for key geodynamo and planetary dynamo studies. Work includes the development of algorithms and software for the analysis, interpretation, and visualization of simulation and assimilation solutions.

1.9 Space Geodesy SLR Advanced Development

Satellite Laser Ranging is one of the NASA Space Geodesy Project's (SGP) four measurement techniques. SLR data, along with data from the other SGP techniques, are important contributions in the production of the International Terrestrial Reference Frame (ITRF). Advanced development for SLR is part of NASA's Laser Remote Sensing Laboratory. Continued development of advanced concepts and techniques, along with evaluation and demonstration of new instrumentation, is key to the future of SLR. Advanced development involves continued improvement in SLR system accuracy, decrease in operating costs, and development of ways to fill other NASA needs. Included in this work is the support for on-orbit calibration of NASA's Earth-orbiting, Lunar-orbiting and planetary altimetric satellites, experiments with time transfer and laser communication, and potential demonstrations in orbital debris tracking.

The contractor shall provide systems, software, optical, mechanical, and electrical engineering support for the SGP Satellite Laser Ranging (SLR) at the Goddard Geophysical and Astronomical Observatory (GGAO) using NASA's Next Generation Satellite Laser

Ranging System and the 1.2 meter Telescope Facility. This work will also include operation of these SLR systems during engineering testing and experiments.

1.10 Satellite and Airborne Mission Support

This requirement is intended to provide support for the processing and analysis of geodetic satellite and airborne missions. The support includes software development, maintenance and modification as well as data analysis for geodetic research. This support will be provided for existing missions as well as new and proposed missions. Much of the work comprising this requirement is research and development in nature. The work involves support of ICESat-2 POD/PPD mission development and analysis, PGS system development, GRACE, LVIS, ATM, OIB, and GPS data processing and analysis. This work involves cluster computing and software optimization to support these data processing and analysis activities and studies.

1.11 Altimetry of Inland Water Bodies

This project centers on the proven ability of satellite radar altimeters to monitor the variation of surface water height for large inland water bodies. It currently utilizes near-real time altimetric data from the Poseidon-3 instrument on-board the Jason-2 satellite and archived TOPEX/Poseidon, Jason-1, Envisat and GFO data to construct time series of surface water height variations for 75-150 lakes and reservoirs. A semi-automated data ingestion/analysis system delivers time series products directly delivered to a web site for USDA utilization. Currently, 75 lakes are in the operational database but with the inclusion of ISRO SARAL mission data in the next phase, this will expand to several hundred. In addition, several altimeter databases will need to be revised over the forthcoming year, hardware needs to be upgraded, and new lake products will have to be merged with archived products of the same temporal resolution. The requirements of this project are split between NASA/GSFC and UMD/ESSIC. This work includes operational updates of the OSTM and SARAL lake products, updates to the TOPEX, Jason, OSTM, SARAL, and Envisat altimeter parameter databases.

1.12 LVIS Instrument Project and Data Analysis Support

The contractor shall provide mission planning and field operations support, and data processing and analysis of high altitude, airborne lidar data sets from NASA's Land, Vegetation, and Ice Sensor (LVIS) for Solid Earth, Terrestrial Ecology, Cryospheric, and other Earth sciences. This work includes coordination of resources for flight missions, including instrumentation, support infrastructure, instrumentation, ground support and logistics. Provide oversight on project planning, scheduling, and budget planning. Participate in preparation of new proposals and project budgets. Implement and coordinate science workshops and partnering research agreements.

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1.13 Laser Altimetry

The objectives of this requirement are to investigate methods for improved characterization of surface elevations and their change through time (including measurements of land, ice sheet, ice cap, ice shelf and glacier topography, vegetation cover, snow cover and inland surface water) using airborne and satellite remote sensing data sets (principally those acquired by laser or radar altimeters but augmented where appropriate by data from SAR interferometry, passive optical imagers such as MODIS and Landsat, and gravity sensing missions such as GRACE). The work includes management, manipulation and plotting of large spatially-referenced data sets by means of programming in the Interactive Data Language (IDL) and similar data analysis software, statistical analysis, generation of written reports and map products and presentation of results at scientific conferences.

1.14 Earth Science Lidar Instrument Support

This requirement supports the design, development, fabrication, testing, integration, calibration, application and maintenance of lidar, radar and related remote sensing research equipment and instruments. The work includes deployment and operation of remote sensing instruments and equipment in field missions, ground-based as well as airborne, including the GLOW, ALVICE, MPL, MABEL, AESMIR, LRAD, ACMR, Scanning Radar Altimeter and others as necessary. This work includes the data collection, reduction and analysis of the lidar and ancillary measurements.

1.15 System support for SERVIR ad hoc team for hazard assessment

This work entails supporting science activities and research through the SensorWeb System for disaster response. This work will also help provide remotely sensed imagery for landslide hazard assessment and to support the disaster response effort in the Central America region.

1.16 Support for Landsat Cover Science Office

This requirement provides science and programmatic support for the Land Cover Project Science Office at NASA GSFC. The work includes generation of land cover change products from Landsat archive using existing spectral change algorithms, validation of these products, and developing new algorithm improvements for land cover change analysis. This work entails cross-calibration and inter-comparison of Landsat and ESA Sentinel-2 data, including comparing radiometric and geometric quality, calibration, and spectral bandpass characteristics.

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1.17 Hydrospheric and Biospheric Sciences Laboratory Technician

The purpose of this requirement is to provide electronic and mechanical technician support for Hydrospheric and Biospheric Sciences, Code 610HB. The contractor will be responsible for the safe operation, the maintenance of the laboratory instruments and equipment, tools (including the power machine tools) and supplies therein of the HBS laboratory in Building 22 (minor support may be necessary in Building 33 microwave lab).

1.18 SLR Planning and Support

The objective of this requirement is analytical support of the NASA Satellite Laser Ranging (SLR) program in the areas of SLR data analysis, software development, assessment of SLR station performance, development of improved models for atmospheric propagation and interpretation of station calibration techniques, and science coordination and analysis functions for the NASA-led Central Bureau of the International Laser Ranging Service (ILRS). This work includes participation in the ILRS Analysis Working Group and tiger teams established to handle unique analysis problems; maintaining the SLR bibliography and ILRS website; troubleshooting technical and performance problems at the SLR station; contributing to and supporting the publication of NASA SLR and ILRS reports highlighting the results of SLR analysis activity; and providing science-based recommendations and support to the Global Laser Tracking Network (GLTN).

1.19 Space Geodesy Advanced Development

NASA Space Geodesy Project's (SGP's) measurement techniques, Satellite Laser Ranging (SLR), Very Long Baseline Interferometry (VLBI), and the Global Navigational Satellite System (GNSS) receivers, provide a crucial contribution in the production of the International Terrestrial Reference Frame (ITRF). To ensure the most accurate, cost effective and robust data possible, current and future SGP activities include selection of sites to host all of the measurement techniques, advancements in intra-site survey accuracy, automation, and period, and R&D efforts in both SLR and VLBI.

The contractor shall provide systems, software, optical, mechanical, and electrical engineering support for SGP at the Goddard Geophysical and Astronomical Observatory (GGAO) in support of site selection, advancements in survey and VLBI, and general R&D activities related to the Space Geodesy Project at Goddard.

2. CRYOSPHERIC SCIENCE STUDIES

2.1 ICESat-2 Mission Readiness Verification

ATTACHMENT A
STATEMENT OF WORK
Geophysics, Geodynamics and Space Geodesy Support
(GGSG)

The contractor shall develop and successfully implement the ICESat-2 Ground system, which is essential for achieving the ICESat-2 mission goals of collecting elevation measurements of the earth's surface over the mission life. The ground systems, networks, MOC (at OSC/Dulles), SIPS (Science Investigator-led Processing System), ISF (Instrument Support Facility) are all part of the data processing and must correctly process data and flow to the other elements. The scope of this effort is to support the ground system development by providing a mission readiness test manager and a team to plan for and verify the integration of the flight, ground and science elements that will enable the collection and processing of data.

2.2 Ground System Engineering, ICESat-2

The contractor shall provide ICESat-2 Ground System Engineer (GSE) support for the Cryospheric Sciences Branch, Code 615. The GSE has technical responsibility for ICESat-2 Ground System (GS) and is responsible to the GS Manager for ground system success. The GSE has all systems engineering responsibilities, including ensuring that all applicable GSFC engineering practices, procedures and rules are followed on the ICESat-2 GS. This work includes developing the GS level-3 requirements for all GS elements and ensuring the GS meets the mission performance requirements.

2.3 Instrument Support Facility, ICESat-2

The contractor shall develop and maintain the ICESat-2 Instrument Support Facility (ISF) in support of the Cryospheric Sciences Branch, Code 615. The purpose of the ISF is to monitor, maintain, and operate the ATLAS, the primary instrument on the ICESat-2 observatory. This work includes: developing the data system hardware and software for the ISF; supporting ground system and mission readiness testing; providing real-time instrument operations; monitoring the health and status of ICESat-2/ATLAS during on-orbit operations; monitoring the status of the ICESat-2 spacecraft; and performing ICESat-2/ATLAS activity planning.

2.4 ICESat-2 Science Investigator-led Processing System

This requirement provides the ICESat-2 Science Investigator-led Processing System in support of the Cryospheric Sciences Branch, Code 615. The purpose of this system is to produce, archive, and distribute all level 1 through 4 ICESat-2 standard data products through implementation of algorithms supplied in the form of Algorithm Theoretical Basis Documents (ATBDs) by the science team and the ground system team. The SIPS is an automated facility operating 24x7 during mission operations. The SIPS automated processing will be implemented by means of the Scheduling and Data Management System (SDMS). This system, initially developed for ICESat, will be adapted and augmented for ICESat-2. This will require development of a new workflow planning system to plan the science processing and

storage management architecture capable of handling the quantities of data expected from the ATLAS instrument.

2.5 ICESat-2 Project Science Support

The purpose of this requirement is to provide science and analysis services for the ICESat-2 mission in support of the Cryospheric Sciences Laboratory, Code 615.

Among other duties, this includes analysis of ATLAS data and the design of ATLAS and ICESat-2 data products. The performance of this requirement may require discrete studies in areas including, but not limited to: surface-slope/laser-return relationships, laser transmitter/receiver/optics characterizations, atmospheric dynamics, spacecraft attitude estimation, land surface topography, ocean topography, developing and documenting optimal geophysical corrections to precision altimetric data.

This requirement also provides for the analysis of test data collected prior to ICESat-2 launch, specifically that generated by the MABEL instrument, and any simulated data generated by the ATLAS integration and test team. Analysis will guide the optimal processing of ATLAS data in terms of ice sheet elevation, sea ice freeboard, cryospheric surface roughness, surface slope and optical depth of atmosphere to yield optimal elevation change detection strategies. The performance of this requirement will require modeling ICESat-2 performance based on evolving engineering design and test data as it becomes available. These requirements will require statistical analysis of existing and synthetic data and algorithm development to derive elevation and elevation change.

2.6 Cryospheric Sciences Program Support

The purpose of this requirement is to provide technical and programmatic support to the NASA Cryospheric Sciences Program through the Cryospheric Sciences Laboratory, Code 615. This work includes providing technical expertise related to cryospheric science support, mission development, and remote sensing of the cryosphere; representing the Program in conjunction with, or in the absence of, the Program Scientist, at intra- and inter-agency meetings, scientific meetings or conferences, and project meetings; developing and contributing, as needed, inputs for intra- and inter-agency briefings, government reports, and community strategic plans; reviewing and managing budgets for previously awarded grants to Program principal investigators; and establishing and maintaining the Cryosheric Sciences Program website.

2.7 ATLAS Receiver Algorithms Development and Testing

ATTACHMENT A
STATEMENT OF WORK
Geophysics, Geodynamics and Space Geodesy Support
(GGSG)

The contractor shall participate as a member of the Flight Science Algorithm Development Team for ICESat-2/ATLAS. The Flight Algorithms optimize the ATLAS receiver data collection and the selection of what data is down-linked from the ICESat-2 observatory. These algorithms will be implemented partially in the hardware (FPGAs) and partially in the flight software on ATLAS. The activity includes the completion and verification testing of the software simulator, updates as needed prior to launch, and monitoring and optimizing algorithm performance on orbit.

2.8 Cryospheric Mass Balance Research

The purpose of this requirement is to provide support for the processing and analysis of satellite and airborne data for cryosphere mass balance research. Specifically, the work encompasses, but is not limited to, the detailed processing of radar altimetry, GRACE, ICESat, and Operation Ice Bridge (OIB) data for the purposes of measuring cryosphere mass balance at high spatial and temporal resolution. In addition, this requirement will support the integration and analysis of surface mass balance data, dynamics data from SAR, and model data. Furthermore, this requirement will provide data simulation and performance analysis for future missions such as ICESat-2 and GRACE-FO. The requirement may also support processing and integration of Cryosat-2 data. The support includes data analysis and software development, maintenance and modification. Much of the work comprising this requirement is research and development in nature. This work includes develop algorithms and software for the processing of GRACE, ICESat and OIB data, and the analysis of cryosphere mass balance solutions; integration and analysis of surface mass balance data, dynamics, model data, Cryosat and GPS data; future mission data simulation and performance analysis including GRACE-FO, and ICESat-2; and support of cluster computing systems and optimization of software as needed to support the cryospheric studies.

2.9 Cryospheric Science using Satellite Altimetry

The objectives of this requirement are to provide software, processing, and scientific analysis of satellite altimetry over the polar ice sheets, ice shelves and sea ice for the Cryospheric Sciences Laboratory, Code 615. The requirement includes the creation and analysis of polar ice elevation time series and interpretation of the changes in terms of ice dynamics and mass balance. This will require the development of numerical models for analysis and interpretation of observed ice sheet elevation changes, including models of the ice sheet surface mass balance, flow dynamics, and surface energy balance for the Antarctic and Greenland ice sheets. Algorithms for processing and analyzing satellite radar and laser altimeter, and aircraft lidar data will be required to fulfill these requirements.

2.10 Operation IceBridge

ATTACHMENT A
STATEMENT OF WORK
Geophysics, Geodynamics and Space Geodesy Support
(GGSG)

This requirement supports project management for the IceBridge Project Science Office at Goddard directly related to meeting the mission's Level 1 science requirements and mission goals. Provide coordination between the IceBridge units including the instrument teams, university funded campaigns (UAF, ICECAP, U. Colorado), aircraft operators, mission managers, and NSIDC. Lead project documentation and project reports for tracking progress towards meeting the mission's level 1 science requirements.

2.11 Kilometer-scale surface mass balance

This requirement will support investigations into the relationships between surface slope, wind direction, and accumulation rate for East and West Antarctica. The primary deliverables are continental mosaics of grain size and surface roughness derived from MISR (Multi-angle Imaging SpectroRadiometer) image data. The majority of the task work will entail obtaining the needed MISR data, defining and applying cloud masks (existing cloud masks will be used if available), employing the processing scheme, and assembling the results into the final mosaics.

2.12 ICESat-2 Ground System Design and Integration

The purpose of this requirement is to provide Ground System Manager duties; contribution to and review of the ICESat-2 project mission level plans, designs, specifications, requirements, science product analysis and other documents as required; as well as, leading and conducting Ground System Readiness Tests and supporting Ground System reviews. This work includes the delivery and integration of the Instrument Support Facility (ISF) and the Science Investigator Led Processing Facility (SIPS) and the development and delivery of the ITOS T&C system to the MOC and ISF.

3. ATMOSPHERIC STUDIES & REMOTE SENSING

3.1 Atmospheric Studies

The Laboratory for Atmospheres of NASA's Goddard Space Flight Center conducts research on temperature, water vapor, ozone, and wind observations, and development efforts of the Upper Air Instrumentation Research Project (UAIRP). The effort involves support for the operation, data analysis, and data archiving of upper air instruments requiring testing, evaluation, and use, in studies and campaigns, and operation of ground-acquisition equipment.

3.2 Remote Sensing Instrument Development

This requirement provides support within the Mesoscale Atmospheric Process Branch of the Laboratory for Atmospheres to a number of active and passive Remote Sensing Instruments including some existing, under development, and contemplated. These

instruments range from laboratory prototypes, to ground and aircraft field mission deployable instruments, to spaceborne instruments. In particular, the Mesoscale Atmospheric Process Branch has several optics laboratories for the development of lidar and radar remote sensing technologies, including large holographic optics, lidar scanning and imaging, Doppler lidar, Raman lidar, Doppler radars and microwave radiometers. All of these labs and instruments require varying amounts of technical and engineering support. This requirement provides support as well as safety monitoring. This work includes supporting the design, development, fabrication, testing, integration, calibration, application and maintenance of lidar, radar and related remote sensing research equipment and instruments; troubleshooting and repair of lidar, radar and laboratory equipment; deploying and operating remote sensing instruments and equipment in field missions, ground-based as well as airborne; supporting the reduction and analysis of lidar and ancillary measurements from tests and field experiments; developing and documenting test procedures on various optical, microwave, and electrical components like lasers, waveguides, holographic lenses, optical interference filters, photon-counting and analog detectors, analog to digital converters, multi-channel scalars, etc; and supporting deployable remote sensing systems, including the HARLIE, GLOW, ALVICE, MPL, AESMIR, LRAD, ACMR, Scanning Radar Altimeter and others as necessary. This work includes performing the role of safety officer for the associated laboratories and facilities in the Laser Remote Sensing Laboratory, coordinating with the center's safety office to assure these laboratories meet the center's safety standards and documentation

3.3 Microwave Laboratory Support

The purpose of this requirement is to provide electronic and mechanical technician support for the Mesoscale Atmospheric Process Branch of the Laboratory for Atmospheres in the Earth Sciences Division. The contractor will be responsible for the safe operation of the microwave laboratories in Building 33 and Building 22 and maintenance of the laboratory instruments and equipment, tools including the power machine tools and supplies therein. This work includes development, fabrication, testing, integration, calibration, and maintenance of radar, radiometer, and related remote sensing research equipment and instruments; fabrication of microwave waveguide and other mechanical parts, including troubleshooting, repairing and modifying instruments or equipment; and services for experimenters and their instrumentation systems, including packing, shipping of fragile instrumentation systems, and installing and uninstalling of those instruments in the field.

4. SOFTWARE DEVELOPMENT AND MAINTENANCE

4.1 GEODYN Analysis Software Development

Much of the computational effort of the Planetary Geodynamics Laboratory is based on several pieces of software that have been developed within the Lab (or under its

supervision) over a period of years. This includes the GEODYN orbit determination and geodetic parameter estimation program. All programs need professional maintenance (to be kept in good working order through changes in computer operating systems and changes in computing platforms). In addition to that, the GEODYN program shall need continued development to include more capabilities in the areas of orbit dynamics, Earth dynamics and measurement modeling. Some of this type of development may possibly be required for ORAN. ORAN is used for analysis of sensitivity of orbit solutions to various parameters.

The new algorithms developed for and put into GEODYN (and possibly ORAN) shall often be designed starting from a fairly general description of desired capabilities. Many of the capabilities that have proven to be the most useful in GEODYN were conceived of, given a preliminary proof of concept, tested, and final implemented all within a six month period. In some cases a potential capability may not turn out to be useful. Because of this, it is sometimes useful to find quick ways to "patch-in" a limited form of a capability so that testing can be done before further development is approved.

The GEODYN effort requires the use and maintenance of programs that support GEODYN. The first of these programs, the GEODYN Pre-Processor (GPP), is used to prepare GEODYN source code for use on various computing platforms (see Technical Requirements below). The other support programs prepare files for input into GEODYN. The "BIH Tables" program converts ASCII information about Earth orientation, solar and magnetic flux into a compact binary file that GEODYN expects. There are two programs which prepare accelerometry data for input into GEODYN. One program prepares an "external acceleration" file. External accelerations are used instead of accelerations computed by certain force models. The other accelerometry program converts the accelerometry into "tracking data" in the GEODYN II tracking data format. There is also a program that prepares global atmospheric loading information for use at tracking stations in GEODYN runs.

The Planetary Geodynamics Laboratory has used GEODYN on a variety of computing platforms. As new cost effective platforms become available, GEODYN and its support programs will be migrated to work on these platforms. The Planetary Geodynamics Laboratory is currently using Apple multi-processor workstations for most applications as well as some legacy Sun-Blade workstations. For some larger applications, GEODYN is run on parallel processor computers (hundreds of processors linked) at the NASA Center for Computational Sciences (NCCS) at the Goddard Space Flight Center. GEODYN has been optimized to generate large systems of least squares normal equations on this platform.

4.2 SOLVE and ERODYN

The SOLVE and ERODYN programs use normal equations and error covariance matrices created by the GEODYN program. SOLVE combines, manipulates and solves sets of normal equations with the goal of estimating parameters of gravity models, tidal models,

dynamic ocean topography models, Earth orientation parameters, station coordinates, and other parameters such as spacecraft accelerometer parameters, spacecraft macromodel parameters, and GPS antenna phase maps. ERODYN is an error analysis program that performs consider covariance analysis. It computes and propagates the errors associated with both modeled and unmodeled parameters on least squares solutions.

As with GEODYN, the Planetary Geodynamics Laboratory has used SOLVE on a variety of computing platforms. Also as is the case with GEODYN, as new cost effective platforms become available, SOLVE will be migrated to work on these platforms. The Planetary Geodynamics Laboratory is currently using Apple multi-processor workstations for most applications as well as some legacy Sun-Blade workstations. For some larger applications, SOLVE needs to run on parallel processor computers (hundreds of processors linked) at the NASA Center for Computational Sciences (NCCS) at the Goddard Space Flight Center. Optimization of SOLVE on this (and possibly on other parallel platforms) may be necessary.

4.3 GEODYN Analysis Software Operation

Much of the work in the Planetary Geodynamics Laboratory involves running the GEODYN software. Most GEODYN runs require the use of satellite tracking data. These data may be actual data, or in the case of feasibility studies, simulated data. In either case, the data must be prepared for use in GEODYN. In the case of simulated data it is important to create data at realistic observing times with a realistic level of noise. Real data requires preprocessing before use in GEODYN. At the very least, it is necessary to make sure the data is in one of the formats accepted by GEODYN or to convert it into one of those formats. GNSS data requires much effort at the preprocessing stage. GNSS data need to have time tags corrected and cycle slips detected and if possible, repaired. The Planetary Geodynamics Laboratory currently uses the Microcosm GPS preprocessor for this purpose. The preprocessing of data from the Deep Space Network (DSN) also requires a lot of work. Information for a single data point must be gleaned from a number of different files. One set of files may contain information about transmitting frequency (ramping) while another set of files contain information about weather and still other files have the actual observed values. To complicate matters, these files may not be in time order and may contain information, which overlaps with other files. From this, a single file containing all of the information must be created. This file must not contain duplicates and must be in time order.

Many GEODYN runs are production oriented. For example, once a good orbit estimation strategy for a given satellite has been determined, it is often desirable to execute this strategy over a number of orbital arcs. The launching and checking of these runs needs to be automated as much as possible.

After sets of least square normal equations have been generated by GEODYN, the sets are combined and solved by the SOLVE software. Often times it is necessary to try various solutions from the same normal equations by using different data weights or by suppressing certain parameters. In some cases, it may be desirable to use normal equations that have been computed outside of GEODYN. In these cases, it is usually necessary to reformat these normal equations to the GEODYN/SOLVE format.

It is desirable, even necessary, to have GEODYN and SOLVE checked by individuals other than those who have developed and maintained the code. Before new versions of GEODYN and SOLVE are released, they must first be checked independently on a series of standard benchmarks.

5. DATA CENTER

5.1 Crustal Dynamics Data Information System

The contractor shall support the Crustal Dynamics Data Information System (CDDIS), managed by the Solar System Exploration Data Services Office, Code 690.1.

The CDDIS staff is tasked by the geodynamics community to assist investigators with their data requirements. The data services of the CDDIS consist primarily of receiving and archiving geodynamics and geophysics-related data on-line and cataloging these data in the CDDIS data base. The CDDIS is responsible for the dissemination of these data to authorized NASA investigators and scientists participating in other global space geodesy programs.

A majority of the data processing efforts, including data verification, distribution, reformatting, and special requests, will be performed on the CDDIS computing system. These processes include special programs to read received data, summarize their contents, validate data contents, reformat the data if required, and archive the data to the appropriate disk area and backup media. Work includes the development of new applications and tools for data holding visualization and search.

The CDDIS operationally supports many international programs such as the International GNSS Service (IGS) and its pilot projects, the International Laser Ranging Service (ILRS), the International VLBI Service for Geodesy and Astrometry (IVS), the International DORIS Service (IDS), and the International Earth Rotation and Reference Systems Service (IERS). The support of these programs requires timely availability of data holdings, typically within hours, and sometimes minutes, of receipt.