A.39 SCIENCE DEFINITION TEAMS FOR CARBON MONITORING SYSTEM

1. Scope of Program

This announcement offers opportunities for investigators to participate in a newly defined pre-Phase A and pilot initiative for the development of a Carbon Monitoring System (CMS). Under this initiative, NASA will be developing two pilot products and conducting one scoping study. NASA seeks proposals from scientific and technical experts to guide the development and evaluation of the two pilot products as members of a Science Definition Team.

NASA scientists and managers have developed an overall plan for this CMS pilot initiative that covers 18 months. The work to be conducted in this prototyping effort leverages the much larger investment currently made by NASA in satellite observations of carbon-related properties of the Earth, as well as in carbon cycle science and carbon management research. It also takes into account the efforts of other Federal agencies, especially as coordinated through the Carbon Cycle Interagency Working Group of the U.S. Global Change Research Program. It is anticipated that CMS work will continue beyond the initial 18-month period, building upon the lessons learned and further integrating NASA products with the activities of other U.S. agencies and international entities.

2. Background

2.1 NASA Carbon Cycle Science

The goals of the NASA Earth Science Research Program for carbon cycle science are to improve understanding of the global carbon cycle and to quantify changes in atmospheric CO_2 and CH_4 concentrations, as well as terrestrial and aquatic carbon storage in response to fossil fuel combustion, land use and land cover change, and other human activities and natural events. NASA carbon cycle research encompasses multiple temporal and spatial scales and addresses atmospheric, terrestrial, and aquatic carbon reservoirs, their coupling within the global carbon cycle, and interactions with climate and other aspects of the Earth system. A focus on observations from space pervades carbon cycle research by NASA and is a basis for partnerships with other U.S. Government agencies and institutions. NASA carbon cycle research contributes toward the goals of major U.S. Global Change Research Program (USGCRP) activities, including the Carbon Cycle Science Program's U.S. North American Carbon Program (NACP) and the Ocean Carbon and Climate Change Program (OCCC) (http://www.globalchange.gov/ and http://www.carboncyclescience.gov/). NASA carbon cycle research also contributes toward the goals of the U.S. Ocean Action Plan (http://www.whitehouse.gov/assets/documents/09_17_09_Interim_Report_of_Task_Force_FINAL2.pdf

The mission of the NASA Earth Science Applied Sciences Program is to advance the realization of societal and economic benefits from NASA Earth Science by identifying societal needs, conducting applied research and development, and collaborating with application developers and users (http://nasascience.nasa.gov/earth-science/applied-sciences). The program's carbon applications leverage NASA's investments in carbon cycle science to discover and demonstrate applications that inform resource management, policy development, and decision making. Applied sciences carbon research is directed toward enhancing decision making within operational agencies responsible for resource management and policy decisions that affect

carbon emissions, sequestration, and fluxes among terrestrial, aquatic, and atmospheric environments.

2.2 NASA Carbon Monitoring System Pre-Phase A and Pilot Initiative

The Fiscal Year 2010 Congressional Appropriation directed NASA to initiate work towards a Carbon Monitoring System (CMS) and provided specific guidance. Funding was made available for *pre-Phase A and pilot initiatives for the development of a carbon monitoring system.* "Any pilot developed shall replicate state and national carbon and biomass inventory processes that provide statistical precision and accuracy with geospatially explicit associated attribute data for aggregation at the project, county, state and Federal level using a common dataset with complete market transparency, including extraction algorithms and correlation modeling."

The approach NASA has developed in following these directions emphasizes exploitation of the satellite remote sensing resources, scientific knowledge, and end-to-end system expertise that are major strengths of the NASA Earth Science program. The approach takes into account data and expertise that are the domain or other U.S. Government agencies and anticipates close communications and/or partnerships with those agencies and their scientific and technical experts. Additionally, it lays the groundwork for CMS-related applications of future satellite sensors now in development (e.g., OCO-2) or from the Decadal Survey (e.g., Deformation, Ecosystem Structure, and Dynamics of Ice (DESDynI), Active Sensing of CO_2 Emissions Over Nights, Days, and Seasons (ASCENDS), Ice, Cloud, and Land Elevation Satellite-II (ICESat-II)).

2.2.1 *NASA Plan for Carbon Monitoring System Pre-Phase A and Pilot Activities*

NASA's initial Carbon Monitoring System activities will involve two pilot studies and a scoping effort. A brief description of each follows:

- *Biomass and Carbon Storage Pilot Product*: A biomass and carbon storage pilot product (to be hereafter referred to as the Biomass Product) will be developed. The focus will be on quantifying the terrestrial vegetation aboveground carbon stock using consistent approach(es) and performing uncertainty analysis on its magnitude and spatial distribution. The initial emphasis will be on production and evaluation of a U.S. biomass and carbon storage product, but a global product also will be planned.
- *Integrated Emission/Uptake ("Flux") Pilot Product*: A global product for integrated emission/uptake (to be hereafter referred to as the Flux Product) will be developed. This product will be created through a combination of space-based measurements of atmospheric carbon dioxide (from Japan's Greenhouse gases Observing Satellite (GOSAT), NASA's Tropospheric Emission Spectrometer (TES), and other instruments), carbon cycle models and assimilation systems, and observationally-constrained, but model-calculated, information about the processes that couple the surface to the atmosphere.
- *Scoping Study*: The scoping study will map NASA's evolving observational and modeling capability and the ability of the research and applied science community to use this capability to enhance information products to meet policy and decision-making requirements. This effort will focus on streamlining the flow of information

products to decision-makers from future research efforts and planned observation capabilities, allowing NASA to engage the carbon policy and decision-making community.

NASA's CMS pilot activities will be carried out through a mix of directed and competed research. The directed research will be localized at NASA Centers where significant expertise on satellite data analysis and computational infrastructure can be leveraged (i.e., NASA Goddard Space Flight Center (GSFC), the Jet Propulsion Laboratory (JPL), and NASA Ames Research Center (ARC)). The competed research will be selected through two mechanisms: 1) consideration of relevant proposals submitted under NASA's annual disciplinary ROSES solicitations and 2) selection of proposals submitted in response to this dedicated ROSES solicitation for Science Definition Team (SDT) members to participate in the development of the two pilot products. The primary purpose of the SDT for the pilot products is to broaden the product development leadership with respect to scientific direction and product evaluation.

The directed work at the NASA Centers will emphasize the core effort involved in producing the pilot products. It is expected that the center-based efforts will involve defining, producing, evaluating, and, ultimately, archiving, and distributing the pilot products (the latter two efforts may be done through an existing NASA data center and would thus not be the responsibility of the institution(s) developing the products). The Center-based efforts will be complemented by the work of the competed Science Definition Team drawn from the broad science community to support the development and validation of the pilot products.

The scoping study will be led by NASA Headquarters (HQ) using a steering team of HQ and NASA Center personnel, and will be carried out through a series of workshops (involving currently-funded NASA investigators as well as those from NASA's interagency partners) and directed efforts.

Additional information about NASA's plan for the CMS Pre-Phase A and Pilot Initiative can be found in the document entitled *FY 2010 Carbon Monitoring Plan* at http://cce.nasa.gov/cce/.

2.2.2 *CMS Pilot Products*

2.2.2.1 Biomass and Carbon Storage Pilot Product

Carbon storage in terrestrial vegetation represents an important reservoir within the global carbon cycle, and changes in carbon uptake by and storage within terrestrial vegetation and their soils can have significant impact on the global carbon balance. Vegetation biomass density (Mg dry weight per hectare) is used to estimate the amount of carbon stored in vegetation and emitted to the atmosphere when vegetation is disturbed. Emissions from vegetation disturbance and land-use and land-cover change are considered the most uncertain component of the global carbon cycle. The uncertainty is attributed to large errors in the spatial distribution of vegetation biomass, as well as discrepancies in estimates of land cover and land use change. Subsequent uptake of carbon as vegetation recovers from disturbance or is managed for carbon sequestration also requires improved quantification. Apart from their scientific merit in understanding the global carbon cycle, accurate and precise quantification of carbon storage and emissions has become a key issue for policy makers. Recently proposed climate change mitigation actions, including those relating to reducing emissions from deforestation and degradation in developing nations (REDD), will require independent, accurate information for

monitoring, reporting, and verification. This pilot project is designed to address the urgent need for geospatially explicit, consistent carbon and biomass inventory information to inform national and international policy making by addressing two objectives:

- *To develop prototype national and global biomass and carbon storage/change data products based on remotely sensed data (initial focus is on the U.S.)*
- *To demonstrate our readiness to produce a consistent biomass/carbon storage distribution using existing in situ and satellite observations in support of national carbon monitoring needs*

Biomass product development will focus on quantifying carbon stocks in a spatially and globally consistent approach and to perform uncertainty analysis on their magnitude and spatial distribution. The product will enable the estimation of emissions from land cover and land use change by integrating information on the area of change, the corresponding carbon stock of changed land, and the subsequent accumulation of carbon.

The overall approach to the development of this pilot product will take advantage of recent advances in NASA's remote sensing data processing and existing products from a suite of satellite sensors, including the Moderate Resolution Imaging Spectroradiometer (MODIS) on Terra, Landsat, the Geoscience Laser Altimeter System (GLAS) on ICESat, the Phased Array type L-band Synthetic Aperture Radar (PALSAR) on Japan's Advanced Land Observing Satellite (ALOS) satellite, and the Shuttle Radar Topography Mission (SRTM). Currently data from these sensors are available with improved calibration, atmospheric corrections, and/or spatial orthorectification that will allow easy access and data mining for national and global applications. The North American Forest Dynamics (NAFD) and Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) products developed under NASA's research program are particularly relevant examples. Forest inventory data will be used, both in product development and for product evaluation. Newly available infrastructures such as the Terrestrial Observation and Prediction System (TOPS), designed to seamlessly integrate data from such sensors with *in situ* measurements and models to expeditiously produce regional and global products, will be employed.

Analyses at local and regional scales (i.e., project and county level) will be conducted using advanced airborne lidar and multitemporal Landsat data in combination with forest inventory data. The objective will be to demonstrate how well biomass can be quantified with high-quality remotely sensed data taken at fine spatial resolution for selected sites representative of U.S. forest types and conditions. The accuracy of and uncertainties within the national biomass product will be evaluated using these high-resolution products for validation. Additional work to evaluate geospatial aggregation methodologies will be conducted using these data, which offer an opportunity to evaluate how well remote sensing products in grid-cell units can be aggregated into the geopolitical products required for inventory reporting (e.g., counties, states as units).

The biomass product development will:

- Provide a benchmark analysis of the U.S. carbon/biomass stocks and biomass/carbon change at spatially-refined and temporally-constrained resolutions using state-of-the-art remote sensing.

- Assess the accuracy and utility using the Forest Inventory and Analysis (FIA) Program forest inventory plots and address uncertainty in magnitude and spatial scales.
- Develop the best possible forest biomass and biomass change spatial products for the U.S. by combining the forest inventory data and satellite observations. Evaluate the quality of the product and provide uncertainty characterization through a detailed comparison to sites where high-quality forest carbon/biomass data products have been created, especially sites with existing airborne lidar data.
- Compare with other products for the U.S., fully document errors and uncertainties, and evaluate the likely improvements that could be achieved using data from future missions.
- Demonstrate the type and quality of product that can be produced and the accuracies that can be achieved with advanced remote sensing technologies only available currently on airborne platforms.
- Plan for a benchmark analysis of global terrestrial biomass/carbon stocks at spatially refined and temporally-constrained resolutions using the best available state-of-the-art global observations – using the same methodologies as for the U.S., but constrained by the types of remote sensing and supporting data available globally (to be planned within the next 18 months, but product production will follow that of the U.S. product).

Additional information about NASA's plans for the initial CMS biomass product as well as more detail about the data sets to be used and the approach being developed can be found in the White Paper entitled *Carbon Monitoring Pilot Initiative: Biomass and Carbon Storage* at http://cce.nasa.gov/cce/.

2.2.2.2 Integrated Emission/Uptake ("Flux") Pilot Product

There are no direct global-scale observations of carbon fluxes between the land and oceans and the overlying atmosphere. Understanding the carbon cycle requires estimates of these fluxes, which can be computed indirectly using models constrained with global space-based observations that provide information about the physical and biological state of the land, atmosphere or ocean. This pilot study will generate CO_2 flux maps for one year (April 2009-April 2010) using observational constraints in several of NASA's state-of-the-art models. Bottom-up surface flux estimates will be computed using data-constrained land and ocean models; comparison of the different techniques will provide some knowledge of uncertainty in these estimates.

Ensembles of atmospheric carbon distributions will be computed using an atmospheric general circulation model (GEOS-5), with perturbations to the surface fluxes and to transport. Top-down flux estimates will be computed from observed atmospheric CO_2 distributions (GOSAT retrievals) alongside the forward-model fields, in conjunction with an inverse approach based on the CO_2 adjoint of GEOS-Chem. The forward model ensembles will be used to build understanding of relationships among surface flux perturbations, transport uncertainty and atmospheric carbon concentration. This will help construct uncertainty estimates and information on the true spatial resolution of the top-down flux calculations. The agreement of the top-down and bottom-up flux distributions will be documented.

This project will combine NASA's observations and existing modeling tools to generate global maps of land-atmosphere and ocean-atmosphere carbon exchange. Two "bottom-up" flux maps over land will be produced using observationally constrained models of physical and biological

parameters in land biophysical models. Correspondingly, "bottom-up" flux maps over oceans will use observations to constrain the physical state of the ocean surface and, in one case, to constrain ocean biology. Atmospheric carbon will be modeled using such bottom-up fluxes, as well as fossil-fuel emission inventories, as boundary conditions. Ensembles of atmospheric simulations will include a range of uncertainty in surface carbon fluxes and a set of different representations of atmospheric transport. These modeled atmospheric CO_2 concentrations will be compared to space-based observations of partial- and total-column CO_2 to evaluate the consistency between surface flux estimates and atmospheric observations, given the spread in the ensemble. A "topdown" inverse method will be used to derive new surface fluxes that are consistent with the atmospheric observations. This inverse approach will use the adjoint of GEOS-Chem, which is based on the same dynamical core as GEOS-5. An estimate of uncertainty in the fluxes will be determined considering the spread among the bottom-up estimates, the range of values in the ensembles of forward model simulations, and the differences between the bottom-up and top-down flux estimates.

The pilot project will produce carbon flux maps using bottom-up and top-down approaches. Deliverables are:

- Two estimates of ocean-atmosphere carbon fluxes, produced using the ECCO2 and NOBM ocean models constrained with observations. The fluxes and their differences will be documented.
- Two estimates of land-atmosphere carbon fluxes, produced using different versions of the CASA model constrained with satellite observations. The fluxes and their differences will be documented.
- Ensembles of atmospheric CO_2 simulations will be produced using GEOS-5. Half-degree resolution reference runs will be accompanied by ten simulations with perturbed physical parameters. All runs will include fossil fuel emissions and four representations (two ocean combined with two land estimates) of computed fluxes. The ensembles will show how surface flux uncertainty and transport error impact atmospheric CO_2 concentrations.
- Top-down estimates of surface carbon fluxes on a two-degree grid computed using GOSAT CO_2 observations with the adjoint of GEOS-Chem.

Carbon flux estimates will be computed for the period April 2009-April 2010. This is the first full year of GOSAT observations, which are deemed to be the most suitable atmospheric data for this pilot. It is expected that all other space-based observations (e.g., MODIS) will continue to be available in this period. The main caveat about this period is that it is unlikely that *in situ* observations needed for evaluating the realism of the land- and ocean-atmosphere fluxes will be available before the end of the pilot. An alternate approach, of computing the fluxes for earlier years, was deemed to be less suitable because of the importance of total-column CO_2 observations for this project.

Additional information about NASA's plans for the initial CMS flux product, as well as more detail about the data sets and models to be used and the approach being developed, can be found in the White Paper entitled *NASA CMS 2010, Pilot Study: Surface Carbon Fluxes* at http://cce.nasa.gov/cce/.

3. Carbon Monitoring System Science Definition Team (CMS SDT)

The Carbon Monitoring System (CMS) Science Definition Team (SDT) will be the primary mechanism by which NASA engages the broader research community in the development and evaluation of the pilot products as they are prepared over an 18-month period. The SDT will provide insights as to how to choose among multiple approaches and/or approximations that will be required in the process of developing the products. SDT members will provide important perspectives on algorithm implementation and how to quantitatively evaluate the products to be developed. The SDT will assist in making connections to ongoing and newly developing activities with similar and/or complementary objectives being undertaken by other entities, especially other U.S. Federal agencies. The SDT will have two components: one for the Biomass Product and the other for the Flux Product. It is envisioned that most SDT members will work in close association with only one of the two pilot product developments, but that on occasion NASA may request guidance and oversight pertaining to the direction and/or evaluation of both activities.

Meetings of the CMS SDT will be scheduled and led by NASA HQ program scientists in consultation/cooperation with the NASA Center-led core pilot product production teams and SDT members. SDT guidance will be communicated at SDT meetings and teleconference calls and through written documentation of key findings to follow.

3.1 CMS SDT Member Investigations Solicited

NASA requests proposals for SDT membership from scientific and technical experts interested in working closely with the NASA Centers in the production and validation of the two CMS pilot products. The SDT will guide the development and evaluation of the products, providing a perspective independent of that of the directed core pilot product production teams. Specifically, SDT members will:

- Review and provide scientific and technical input regarding the overall development plan for a pilot product (for most proposers this will be either the Biomass or Flux product; for a few, it could be for both);
- Recommend refinements to the product development approach, algorithms, and/or models, recognizing the overall approach has already been selected and that the time and other available resources will be limited;
- Provide guidance for the development of an evaluation plan that includes both validation and characterization of uncertainties associated with a product and participate in product evaluation activities;
- Provide guidance on the nature of the data sets and initial pilot product(s) to be produced and how they may be used for carbon policy and carbon management decisions (e.g., How can they be made most useful? What would make them easy to understand and use? What data products or data product characteristics (e.g. latency, frequency, accuracy, etc.) are missing?);
- Provide liaison with the broader science, applications, and user communities or the related activities of other U.S. Federal agencies;
- In the case of the Biomass Pilot, participate in the development of a plan for a global terrestrial biomass product to follow the regional and national products; and
- Work in close association with NASA HQ and the NASA Center-led teams implementing the development of the pilot products to achieve the CMS goals.

One or two additional SDT members may be selected to provide guidance to both pilot product development activities. These SDT members will:

- Evaluate both the Biomass and the Flux pilot products; and/or
- Provide guidance on future intercomparison or integration of these two pilot products.

3.2 Additional Proposal Requirements

3.2.1 *Science and Technical Plan*

Proposals for SDT membership should include a technical plan no longer than 10 pages describing the proposer's interest in the CMS pilot initiative, the specific expertise the proposer would contribute to the SDT, and the independent research guidance and activities to be offered. The plan should clearly describe the type of scientific and technical guidance that would be offered with respect to the activities listed in section 3.1. Because of the unusual nature of this SDT, proposers should take care to explain in detail how their knowledge and experience will contribute to the success of the pilot studies. The proposers' familiarity and experience with the data sets to be used, the methods and algorithms to be used, carbon measurement and assessment, and/or end uses for carbon monitoring data products should be described. Proposers must identify the specific areas (e.g., which data products, specific aspects of the methodology or algorithm, and/or evaluation approaches) in which they intend to contribute, they should cite their relevant publications, and they should provide a work plan. Proposers should indicate their willingness to work closely with NASA HQ and the NASA Center core teams in the production and validation of a CMS pilot product.

Proposals may have more than one investigator, but only one investigator per proposal will be considered for SDT membership. Proposals with more than one investigator should clearly describe the unique contribution being proposed for each investigator, their qualifications, and the level of effort and budget for each. NASA may only select a subset of the investigators from each of these proposals if only a part of the proposal is deemed meritorious.

Proposals must clearly identify which pilot product will be addressed by the SDT member. While it is permissible to propose to provide guidance for both pilot products, it is expected that most SDT members will focus on one or the other.

3.2.2 *Duration and Cost Plan*

The scientific tasks of the SDT members will be of no more than 18 months duration and proposers may not propose for a longer period of performance.

All proposals must include a budget covering activities to be undertaken as a member of the SDT, including funds for travel of the principle investigator to SDT meetings. Members of the CMS SDT will be required to attend approximately four meetings over the next 12-18 months and provide expert guidance on scientific and technical issues related to CMS pilot product development and evaluation. Between SDT meetings, members will be expected to be available for teleconferences, as needed. For budgeting purposes, proposers should assume two meetings on the U.S. east coast and two meetings on the U.S. west coast.

Total budget requests must not exceed $75,000 over 18 months.

4. Programmatic Information

4.1 Eligibility

This solicitation is open to all organizational sectors.

Scientists employed by other U.S. Federal agencies may submit proposals. No-cost or low cost proposals to provide liaison with related federal programs are especially encouraged.

4.2 Evaluation Criteria

Proposals will be evaluated according to the criteria specified in section C.2 of the *NASA Guidebook for Proposers*. In addition, the evaluation of CMS SDT proposals will emphasize the principal investigator's proven capabilities, as well as his/her experience with the data and approaches that have been selected for use in developing the pilot products (see sections 2.2.2.1 and 2.2.2.2 and the White Papers for the pilot studies at http://cce.nasa.gov/cce/). Therefore, the evaluation of intrinsic merit for a proposal shall consider the knowledge and experience of the principal investigator with respect to the specific data sets to be used, the specific methods and algorithms to be used, carbon measurement and assessment, and/or the end uses of carbon monitoring data products.

5. Summary of Key Information

Expected annual program budget for new awards	~ $1.5M over 18 months
Number of new awards pending adequate proposals of merit	~ 20
Maximum duration of awards	18 months.
Due date for Notice of Intent to propose (NOI)	Not requested.
Due date for proposals	Friday December 17, 2010.
Planning date for start of investigation	4 months after proposal due date.
Page limit for the central Science-Technical-Management section of proposal	10 pp (see section 3.2.1); see also Chapter 2 of the *NASA Guidebook for Proposers*
Relevance to NASA	This program is relevant to the Earth science strategic goals and subgoals in NASA's *Strategic Plan*; see Table 1 and the references therein. Proposals that are relevant to this program are, by definition, relevant to NASA.
General information and overview of this solicitation	See the *ROSES Summary of Solicitation*.

Detailed instructions for the preparation and submission of proposals	See the *NASA Guidebook for Proposers* at http://www.hq.nasa.gov/office/procurement/nraguidebook/.
Submission medium	Electronic proposal submission is required; no hard copy is required or permitted. See Section IV of the *ROSES Summary of Solicitation* and Chapter 3 of the *NASA Guidebook for Proposers*.
Web site for submission of proposal via NSPIRES	http://nspires.nasaprs.com/ (help desk available at nspires-help@nasaprs.com or (202) 479-9376)
Web site for submission of proposal via Grants.gov	http://grants.gov/ (help desk available at support@grants.gov or (800) 518-4726)
Funding opportunity number for downloading an application package from Grants.gov	NNH10ZDA001N-CMS
NASA points of contact concerning this program	Dr. Diane E. Wickland (Biomass/Carbon Pilot) Earth Science Division Science Mission Directorate National Aeronautics and Space Administration Washington, DC 20546-0001 Telephone: (202) 358-0245 E-mail: Diane.E.Wickland@nasa.gov and Dr. Kenneth W. Jucks (CO_2 Flux Pilot) Earth Science Division Science Mission Directorate National Aeronautics and Space Administration Washington, DC 20546-0001 Telephone: (202) 358-0476 E-mail: kenneth.w.jucks@nasa.gov