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CONCERNING

MONITORING, MEASUREMENT AND VERIFICATION OF GREENHOUSE GAS EMISSIONS II: THE ROLE OF FEDERAL AND ACADEMIC RESEARCH AND MONITORING PROGRAMS

Mr. Chairman and members of the Committee, thank you for inviting me today to discuss monitoring, measuring, and verifying greenhouse gas emissions. I am the Project Leader of the Research Work Unit "Climate, Fire, and Carbon Cycle Sciences" in the Northern Research Station of the U.S. Forest Service. In addition, I currently Chair the Carbon Cycle Science Steering Group. This Steering Group, comprised of about 20 experts involved in carbon cycle research and application from federal, state, university, and non-government organizations, reviews the status of carbon cycle science sponsored by U.S. agencies and departments. I will focus my remarks on the purpose and current status of USDA inventory and monitoring programs, their use in verifying greenhouse gas mitigation activities, and relevant federal interagency activities regarding carbon cycle research and monitoring.

Status of USDA Inventory and Monitoring Programs

Forestry, agriculture, and other land uses may either contribute to or remove greenhouse gases (GHG) from the atmosphere. Land use practices have affected GHG levels in the atmosphere through management of perennial systems and forests, land use changes, cultivation and fertilization of soils, production of ruminant livestock, management of livestock manure, and fuel consumption. Carbon is accumulating in U.S. forests, wood products, croplands, and urban lands, offsetting overall U.S. GHG emissions by about 12%.[1]

USDA conducts critical research, observation, survey, and analysis needed to assess greenhouse gas emissions and carbon storage on U.S. lands. We work closely with our partners in the Environmental Protection Agency and the Department of Energy on national, regional, local, and entity scale greenhouse gas inventories and methods.

[1] http://epa.gov/climatechange/emissions/usinventoryreport.html

USDA also maintains critical observation and data systems that will be needed to monitor and track changes in climate and the implications of climate change. USDA contributions include:

- Providing the greenhouse gas estimates from land use, land use change, and forestry and agricultural statistics to EPA for the Official U.S. Greenhouse Gas Inventory.

- Periodically producing a stand-alone inventory of greenhouse gas sources and sinks from the forestry and agriculture sectors to accompany the Official EPA inventory.

- Preparing project and farm-scale methods for estimating greenhouse gas sources and sinks for the Department of Energy's Voluntary Greenhouse Gas Reporting System.

- Creating user-friendly estimation tools for private landowners and land managers. These tools are designed to provide a "greenhouse gas footprint" of individual forest lands and farms.

These systems include: the U.S. Forest Inventory (FIA), the National Resources Inventory (NRI), the Census of Agriculture, climate and weather observations, Experimental Forests and Ranges, and various surveys of cropping and management practices.

The Forest Inventory and Analysis Program (FIA) of the Forest Service has tracked the condition and changes in vegetation on public and private lands for more than 75 years, and is the longest running forest inventory program if its kind in the U.S. The nationwide network of experimental forests and ranges provides up to 100 years of data on vegetation, climate and hydrology. Scientific support comes from partnerships with universities, federal and state agencies, non-governmental organizations, and the forest industry. Scientists and managers are using this information and working together to develop strategies for managing our changing forests and rangelands.

FIA data has been the basis of the reported changes in carbon stocks of the forestry sector of the U.S. Greenhouse Gas Inventory, as reported annually to the United Nations Framework Convention on Climate Change by the Environmental Protection Agency.[2] This is the national monitoring baseline for carbon in forests and wood products, following international reporting requirements and guidelines, and undergoing annual review by an international panel of experts. Its basis in the existing forest inventory program has advantages because of the extensive sample plot network which confers the ability to attribute observed changes geographically (e.g., by state), by broad ownership category (e.g. public, private) and by other characteristics of the land such as forest type or productivity class. Since the estimates are based on a statistical sampling approach involving remote sensing and direct field observations, the error of the reported estimates

[2] *Id*.

can be statistically described. The extensive FIA data, inventory, and analytical framework has the capacity to answer questions now that will arise as actions are implemented to increase carbon storage.

To improve the data from forest inventories as a basis for monitoring carbon, additional sampling is needed for carbon in soils, dead wood and down woody debris. Areas recently disturbed from events such as hurricanes and large wildfires need additional sampling to assess impacts. If reports are required for areas smaller than states, such as groups of counties or specific national forests, remote sensing augmented with intensified sampling density will be required. Movement of carbon in wood products from specific regions and ownerships are important but are not tracked through the chain of custody. Land-use and land-cover changes are not estimated accurately for small areas, which could be resolved with enhanced use of remote sensing and better coordination between agricultural and forest inventories. Some U.S. regions important to understanding forest carbon dynamics are currently under-sampled, such as Alaskan boreal forests and forested urban areas. Implementing these changes would improve the U.S. greenhouse gas inventory and provide additional capability to report estimates for specific land areas of interest.

The National Resources Inventory (NRI) is a statistically-based, longitudinal survey administered by the USDA Natural Resources Conservation Service (NRCS) that has provided conditions and trends for multiple environmental resources on non-federal US lands since 1956 (known as the Conservation Needs Inventories until 1977). The National Resources Inventory samples more than 800,000 points nationally; each year 210,000 of these are studied remotely and 5,000 to 10,000 field-visited. Much of the sampling relies heavily on information provided by Natural Resources Conservation Service Soil Survey databases. Soil carbon is estimated from biomass production, disturbance (e.g. tillage, grazing or timber harvest) and loss by erosion, decomposition or removal of plant material. Effects of soils, landscape position and climate are factored into the estimates. Scientists from Natural Resources Conservation Service and Agricultural Research Service (ARS) are using National Resources Inventory data to assess the effectiveness of conservation practices in the Conservation Effects Assessment Project (CEAP).

In 2006, USDA prepared the only set of comprehensive landowner-scale greenhouse gas inventory methods available in the U.S. These methods were established by USDA for use the Department of Energy's Voluntary Greenhouse Gas Reporting Registry.[3] Uniform standards and definitions provide consistent assessments of greenhouse gases at the landowner scale. To accompany these methods, the USDA Forest Service and Natural Resources Conservation Service provide decision-support tools. The COLE[4] and COMET-VR[5] models are examples of on-line estimators that support greenhouse gas

[3] Smith, James E.; Heath, Linda S.; Skog, Kenneth E.; Birdsey, Richard A. 2006. Methods for calculating forest ecosystem and harvested carbon with standard estimates for forest types of the United States. Gen. Tech. Rep. NE-343. Newtown Square, PA. USDA NE-343: 216 p.

[4] http://ncasi.uml.edu/COLE/

[5] http://www.cometvr.colostate.edu/

registries and markets. Another example is i-Tree[6], the Forest Service's suite of on-line tools developed to measure urban forestry benefits.

Section 2709 of the 2008 Farm Bill authorized the Secretary of Agriculture to establish technical guidelines for science-based measurement of environmental services benefits derived from conservation and land management activities. The Farm Bill specifically directs the Secretary to give priority to the establishment measurement standards – in consultation with research community and others – for carbon credits in order to facilitate landowner participation. The Secretary has established the Office of Ecosystem Services and Markets as a separate agency and is proceeding to staff the office to accomplish this work.

The Forest Service is an active participant in the U.S. network of flux towers (known as AmeriFlux) along with other sponsoring agencies such as Department of Energy. We have found that locating these intensive measurement systems in areas where other kinds of data collection takes place, such as our network of long-term Experimental Forests, facilitates integration of data across space and time, which improves verification as well as providing critical parameters for models that are used to diagnose the causes of current changes in carbon flux and to project changes under future climate scenarios. Integration of data and models can improve annual estimates and help attribute observed annual changes in carbon stocks to natural causes such as climate variability.

Other Forest Service monitoring and mapping programs are becoming highly relevant for understanding and monitoring changes and impacts on forest carbon stocks. For example, under the National Fire Plan, annual mapping of burned areas and intensity of wildfires provides critical data to estimate the contribution of fire emissions to the overall carbon budget of the nation’s forests. Mapping for the entire U.S. is currently incomplete, and there could be some improvement in linking maps of burned areas with vegetation classifications and better estimates of emissions based on fire intensity.

In addition to the National Resources Inventory, the Soil Survey Division of the Natural Resources Conservation Service routinely samples soils and measures soil organic carbon. This information is available for about 30,000 sites through the U.S. and its territories.[7] Nearly 650 sites are added annually. Land use data is available for many of these sites along with soil landscape attributes.

Characteristics of a Robust Carbon Monitoring System for GHG Mitigation

Project Monitoring

Monitoring needs for GHG mitigation projects are highly dependent on the specific reporting requirements, which are currently inconsistent among emerging GHG registries and markets. Critical determinants of monitoring needs are the definition of the reporting entity, and optional requirements to separate out changes in carbon stocks caused by natural events from those caused by human activities.

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[6] http://www.itreetools.org/

[7] National Soil Survey Center http://ssldata.nrcs.usda.gov/

Reporting entities may be defined as any legally defined entity; examples include individuals, businesses, non-profit organizations, or government entities such as cities or states. Some of the registries and markets allow reporting by one entity on behalf of others. These organizations are known as "aggregators" because their purpose is to work with groups of reporters and thus achieve some efficiency in monitoring and reporting costs. There are 10 million family forest landowners in the U.S.[8] For a small landowner who wishes to participate in a carbon program, the monitoring and reporting cost per acre may be high, or they may lack the technical skills to perform the monitoring. But if the landowner is willing to be grouped with others, aggregators can serve their needs.

At the project or landscape level, we have the technology to measure and monitor changes in carbon stocks using remote sensing and field sampling. Most of the current and proposed markets and registries rely on sampling and measurements, which may be coupled with predictive models, to track or project changes in carbon emissions or sequestration. These approaches are practical and cost effective, and can be independently verified by a third party.

It may be difficult to separate human-induced causes from natural causes of observed changes at the project level. This is because inventory approaches measure the changes in ecosystem carbon that result from all causal factors combined. For example, if tree growth rates increase as a result of both physiological response to increasing atmospheric carbon dioxide and nitrogen fertilization, inventory measurements will not separate the effects of these two causes. Currently, the only ways to separate such causes are to conduct controlled experiments in the ecosystems of interest or to employ ecosystem process models which may or may not be available.

National-scale Monitoring: Capabilities and Gaps[9]

Successful CO_2 management requires robust and sustained carbon cycle observations, yet key elements of a national observation network are lacking or risk displacement on the basis of competing priorities.

Major threats to existing programs involve sustainability of the National Aeronautics and Space Administration (NASA) high accuracy well-calibrated satellite observations of land and oceans, and continuity of land/atmosphere CO_2 flux measurements. Major gaps include an improved spectral range and resolution for satellite measurements of oceans, sustained field observations at sea, insufficient density of atmospheric observations, incomplete geographic coverage of land inventories, lack of soil carbon monitoring, and lack of observations of the terrestrial-ocean interface. Steps could be taken to better integrate monitoring programs, and close current data gaps.

Since 1972, the Landsat series of satellites has provided spatial and temporal representation of land cover/land use change, classification of vegetation, and detection

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[8] NRS-INF-06-08. May 2008. Who owns America's Forests? Family Ownership Patterns and Family Forest Highlights from the National Woodland Owner Survey.

[9] From the U.S. Carbon Cycle Science Steering Group.

of natural disturbances. Landsat enables quantification of land vegetation and soil carbon fluxes to and from the atmosphere by providing spatially continuous and extensive estimates of above-aground biomass and/or land cover type that aid in the extrapolation of in situ measurements over large regions. The critically important Landsat data are expected to continue without a data gap, or if one should develop it is expected to be very brief, until the Landsat Data Continuity Mission (LDCM). The Landsat 5 and Landsat 7 satellites are very resilient. Refined projections of fuel usage computed by the United States Geological Survey (USGS), which operates the NASA-developed Landsat 5 and Landsat 7 satellites, suggest that Landsat 5 and Landsat 7 could have sufficient fuel to operate at least through 2012, exceeding previous expectations. The NASA and USGS LDCM has a launch readiness data of December 2012.

The NASA Moderate Resolution Imaging Spectroradiometer (MODIS) instruments on NASA's Aqua and Terra satellites, which were launched in May 2002 and December 1999, respectively, produce crucial global observations of primary production and vegetation phenology. A continuous record of primary production and phenology started with the National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR) instruments in 1981 and continues with higher accuracy measurements by MODIS. This information is used in combination with ground observations and models to provide regional estimates and maps of carbon stocks and fluxes.

The global network of intercalibrated measurements of atmospheric carbon dioxide (CO_2) and methane (CH_4) concentrations has been central to climate and carbon cycle studies for decades. These properties reflect the net effect of all global carbon sources and sinks to the atmosphere (anthropogenic, terrestrial and aquatic fluxes). The observational system also provides trace gas measurements (e.g. O_2, $^{13}CO_2$, CO, and other species) indicative of carbon sources. Current in situ measurements are made in limited areas from aircraft, towers, and marine, mountaintop and coastal observatories. NASA Aqua and Aura satellites measure global distributions of CO, CO_2, CH_4, and a myriad of greenhouse gases.

Land-based inventories periodically quantify carbon stocks and fluxes for biomass, soil, and fossil fuel emissions, but as already noted, there are some gaps in sampling of carbon pools and some geographic regions are under-sampled. Expanded forest inventories, if deemed necessary, could provide sampling of carbon in soils, dead wood and down woody detritus, especially areas where incidents of natural disturbance have accelerated and where large quantities of soil carbon are vulnerable. Agricultural inventories primarily focus on non-federal lands – federal rangelands are under-sampled. Data on land use management and management history, both of which significantly influence changes in carbon, are lacking. The fate of carbon as it is transported across the landscape and accumulates in other terrestrial or aquatic systems is largely unknown. With a coordinated and consistent suite of core observations, forest and agriculture inventories would be integrated and better positioned to inform emerging policies and actions.

Soil carbon monitoring has large spatial and temporal gaps; this is significant because soil carbon is the largest terrestrial carbon stock and highly vulnerable to loss with warming. If determined to be necessary, a multi-agency supported network of soil carbon observations, with the capacity for performing measurements over decades and associated with other networks of terrestrial observations and inventories, would radically improve estimates of soil and ecosystem carbon dynamics at multiple scales.

Direct observations of CO_2 fluxes over decades are necessary to capture terrestrial carbon and water cycle responses to climate variability and to improve carbon and climate system model simulations. The AmeriFlux network, initiated in 1996, currently has more than 100 sites observing biological properties, meteorology, and carbon, water and energy exchanges between terrestrial ecosystems and the atmosphere. Continuation would provide understanding of long-term trends in response to climate, yet support for AmeriFlux is currently provided on a site-by-site basis, and some long-term, high-quality records are endangered.

Rivers and groundwater at the land-ocean margins play a central role in linking terrestrial and marine cycles of carbon. The magnitude of weathering and erosion processes on land, sediment storage within the river system, and transport, transformation and burial processes in adjacent ocean margins demonstrate that these systems are an important part of the global carbon cycle. Existing research plans stress the importance of examining both the terrestrial and oceanic sinks for organic and inorganic carbon; however, the primary connection between these two environments is not adequately addressed. Despite a long history by the U.S. Geological Survey of gauging U.S. rivers and streams, there has been a gradual loss of long-term discharge monitoring stations and decreased number of annual carbon measurements. These long term measurements provide understanding of anthropogenic changes to the hydrologic cycle.

Observational network design will need to respond in an effective and highly coordinated fashion among agencies, closely integrated with policy, land management, and scientific communities. Long-term global carbon observations can inform climate change mitigation policy and management decisions, and permit steps to be taken to close critical current gaps and avoid future gaps in observation continuity.

Verifying Compliance with Potential Climate Agreements

International climate treaties are likely to require monitoring and verification at the national scale; therefore, the discussion of gaps and threats contained in the previous section is most relevant. However, individual projects and activities that collectively affect national estimates and that may be governed by programs or markets also need monitoring and verification at much more detailed scales. As previously described, at the field plots or small watersheds scale of a project, there are published and practiced methods for sampling and measuring ecosystem carbon pools and how they change over time. At more regional scales such as a state or country, there are ongoing inventories and direct observations of CO_2 flux that form an internationally accepted basis for estimating ecosystem carbon and changes over time.

The difference between detection capabilities of atmospheric measurements and project-level measurements is one of scale. The current level of greenhouse gas mitigation would not produce an effect on the atmosphere that is detectable by direct atmospheric measurements, especially considering that there are other causes of atmospheric CO_2

changes that cannot be easily factored out (e.g., climate variability). Eventually, under a larger global offset program, such changes should be detectable by atmospheric measurements of CO_2 concentrations, and the sum of direct observations of activities on the land would add up to the aggregate observations of effects on the atmosphere.

Federal Interagency Activities Regarding Carbon Cycle Research and Monitoring

The Carbon Cycle Interagency Working Group (CCIWG), currently co-chaired by USDA and NASA, coordinates carbon cycle research under the U.S. Climate Change Science Program (CCSP).[10] This entails coordinating research programs within and across agencies, coordinating the solicitation and review of research proposals (when appropriate), implementing targeted research, providing an interface with the scientific community conducting carbon cycle research, updating needs assessments, working to secure resources for new activities, and reporting results and accomplishments. The CCIWG is comprised of members from 10 participating federal agencies and departments that support and execute U.S. carbon cycle science research.

In order to both improve scientific knowledge and understanding of the carbon cycle and support application of this scientific knowledge to societal needs, a number of strategic research questions are used to guide the efforts of the Carbon Cycle Science Program. These research questions are part of the U.S. Climate Change Science Program strategic plan and indicate the complete scope of the research coordinated by the Carbon Cycle Interagency Working Group.[11]

- What are the magnitudes and distributions of **North American carbon sources and sinks** on seasonal to centennial time scales, and what are the processes controlling their dynamics?

- What are the magnitudes and distributions of **ocean carbon sources and sinks** on seasonal to centennial time scales, and what are the processes controlling their dynamics?

- What are the effects on carbon sources and sinks of past, present, and future **land-use change and resource management practices** at local, regional, and global scales?

- How do **global terrestrial, oceanic, and atmospheric carbon sources and sinks** change on seasonal to centennial time scales, and how can this knowledge be integrated to quantify and explain annual global carbon budgets?

[10] Additional information about U.S. carbon cycle science is available at: http://www.carboncyclescience.gov/programs.php

[11] http://www.climatescience.gov/Library/stratplan2003/final/default.htm

- What will be the **future atmospheric concentrations of carbon dioxide, methane, and other carbon-containing greenhouse gases**, and how will terrestrial and marine carbon sources and sinks change in the future?

- How will the Earth system, and its different components, respond to **various options for managing carbon in the environment**, and what scientific information is needed for evaluating these options?

The Carbon Cycle Science Steering Group reviews the status of carbon cycle science. As mentioned earlier, I currently Chair this Steering Group, comprised of about 20 experts involved in carbon cycle research and application from federal, state, university, and non-government organizations. The function of this group is to provide individual as well as broad scientific and application input to the U.S. Climate Change Science Program about the direction of carbon cycle science and its relevance to the various stakeholder communities, and to identify gaps and potential new areas of emphasis. One of the main recent activities of this group has been to charter a team to update the U.S. Carbon Cycle Science Plan which is now about 10 years old.

One of the principal coordinated interagency activities with a very strong observing component is the North American Carbon Program. The North American Carbon Program is designed to address the strategic research question:

- What are the magnitudes and distributions of **North American carbon sources and sinks** on seasonal to centennial time scales, and what are the processes controlling their dynamics?

Scientists participating in the North American Carbon Program work in a coordinated fashion to assess the status of understanding of the magnitudes and distributions of terrestrial, freshwater, oceanic, and atmospheric carbon sources and sinks for North America and adjacent oceans; enhance understanding of the processes controlling source and sink dynamics; and produce consistent analyses of North America's carbon budget that explain regional and continental contributions and year-to-year variability. This program is committed to reducing uncertainties related to the increase of carbon dioxide and methane in the atmosphere and the amount of carbon, including the fraction of fossil fuel carbon, being taken up by North America's ecosystems and adjacent oceans, including uncertainty regarding the fraction of fossil fuel carbon.

Similarly, the Ocean Carbon and Climate Change (OCCC) program was designed as an ocean component of the U.S. Carbon Cycle Science Program. A strategic plan provides the scientific rationale for coordinated ocean surface and space observations, experimental study, numerical modeling, and data assimilation efforts for the coastal ocean, ocean basins and atmospheric components of the carbon cycle over North America and adjacent coastal ocean and ocean basins.[12] The strategy consists of several coordinated and integrated elements on global ocean carbon observing networks, multidisciplinary process studies, data fusion and integration, synthesis and numerical

[12] http://www.carboncyclescience.gov/documents/occc_is_2004.pdf

modeling, and new technological development. While the program encompasses a wide breadth of ocean biology, chemistry, and physical research, the program promotes linkages and interactions with related ongoing oceanographic, climatic, and carbon cycle programs to address the full range of scientific elements relevant to marine carbon dynamics and climate change.

One of the major products of the Carbon Cycle Science Program is the CCSP *Synthesis and Assessment Product 2.2, The First State of the Carbon Cycle Report (SOCCR): North American Carbon Budget and Implications for the Global Carbon Cycle*.[13] This report involved dozens of scientists from many disciplines interacting with stakeholders to assess knowledge and progress in understanding and managing the carbon cycles. The report highlighted the magnitude and sources of carbon emissions and sinks for North America, how they are changing, and what options are available to reduce emissions or enhance sinks. The future of this North American terrestrial sink is highly uncertain because we lack sufficient predictive capability to know how regrowing forests and other sinks will respond to changes in climate and CO_2 concentration in the atmosphere.

Summary and Conclusions

- USDA plays a leadership role in assessing land based greenhouse gas sources and sinks. U.S. forests currently offset about 12 percent of all U.S. greenhouse gas emissions.

- Forest Inventory and Analysis data has been the basis of the reported changes in carbon stocks of the forestry sector of the U.S. Greenhouse Gas Inventory, as reported annually to the United Nations Framework Convention on Climate Change.

- Improvements are needed in forest inventories for monitoring carbon: additional sampling is needed for some carbon pools and areas recently disturbed from events such as hurricanes and large wildfires; uncertain estimates of land-use and land-cover changes could be resolved; and some critical U.S. regions important to carbon dynamics are currently under-sampled, such as Alaskan boreal forests and forested urban areas.

- National Resources Inventory data estimates soil carbon from biomass production, disturbance and loss. An expansion of efforts to collect agricultural land management data could provide information for modeling carbon dynamics.

- At the smaller scale of a project, there are published and practiced methods for sampling and measuring ecosystem carbon pools and how they change over time.

- USDA has defined the accounting rules and guidelines for forestry and agriculture in a national greenhouse gas registry. This work may inform development of a

[13] http://www.climatescience.gov/Library/sap/sap2-2/final-report/default.htm

federal program under which forestry and agriculture carbon credits could be generated.

- Successful CO_2 management requires robust and sustained carbon cycle observations, yet key elements of a national observation network(s) are lacking or at risk of loss. These gaps and threats limit ability to estimate current carbon budgets or to make projections of baselines.

- Threats to existing monitoring programs involve continuity of satellite observations of land and oceans, and continuity of land/atmosphere CO_2 flux measurements.

- Major gaps in existing carbon cycle monitoring include a need for improved spectral range and resolution for satellite measurements, insufficient density of atmospheric observations, incomplete geographic coverage of land inventories, lack of land use and management histories, lack of long-term soil carbon monitoring, and lack of observations of the terrestrial-ocean interface.

- International climate treaties are likely to require monitoring and verification at the national scale; however, individual projects and activities that collectively affect national estimates and that may be governed by programs or markets also need monitoring and verification at much smaller scales.

- Carbon cycle research under the U.S. Climate Change Science Program is coordinated by the Carbon Cycle Interagency Working Group.

- The Carbon Cycle Science Steering Group is a group of about 20 experts involved in carbon cycle research and application from federal, state, university, and non-government organizations. The function of this group is to provide individual as well as broad scientific and application input to the U.S. Climate Change Science Program.

- One of the principal coordinated interagency activities with a very strong observing component is the North American Carbon Program. The North American Carbon Program is designed to improve monitoring of the magnitudes and distributions of North American carbon sources and sinks on seasonal to centennial time scales, and improve understanding of the processes controlling their dynamics.

- There are globally important carbon sinks in North America in plant material and soil organic matter. The future of this North American terrestrial sink is highly uncertain because we lack sufficient predictive capability to know how regrowing forests and other sinks will respond to changes in climate and CO_2 concentration in the atmosphere.

Thank you for the opportunity to discuss these issues with the Committee. I would be happy to answer any questions that you have.