Global Greenhouse Gas Information System

Interagency Workshop on Needs and Capabilities

20-22 May, 2009
Albuquerque

Contents

Comments and questions on the content of this report, the subject workshop, and the GHGIS effort may be directed to any of the following individuals.

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1. Executive Summary

The second Greenhouse Gas Information System (GHGIS) workshop was held May 20-22, 2009 at the Sandia National Laboratories in Albuquerque, New Mexico. The workshop brought together 74 representatives from 28 organizations including U.S. government agencies, national laboratories, and members of the academic community to address issues related to the understanding, operational monitoring, and tracking of greenhouse gas emissions and carbon offsets.

The workshop presentations and discussions explored scientific and stakeholder requirements for a robust GHGIS, current observation and modeling capabilities that could be brought to bear, and the longer-term information benefits that a GHGIS could provide as an operational system. Discussions pointed to a GHGIS that should continuously integrate new data from sensors in space, air, land, and sea; reconcile, validate and further improve existing GHG inventories, and extend scientific understanding, observational capabilities, and modeling of the carbon cycle and climate system. The primary goal of the workshop was to discuss and report on discussions and recommendations that would be useful in creating such an information system.

Key Findings

I. There is value in continuing this dialogue with the diverse community of contributors and stakeholders – specifically to:
   a. Establish a common lexicon for methods and uncertainties to enable mutual understanding and consensus on issues and facilitate communication with policy-makers and the public
   b. Compile a more comprehensive listing of existing capabilities and programs to improve interagency collaborations and leverage existing efforts.

II. Executing a set of focused coordinated pilot-projects or case studies could help identify user needs and system requirements and ensure relevance of the products.

III. A prototype data/model integration system leveraging existing assets with establishing standard units, metadata, protocols for model and data inter-comparison, etc would offer immediate value to the community.

IV. Coordinated direction and funding is required by the administration/congress to make substantive progress, as grassroots efforts can only take us so far.

V. Information products from a GHGIS must be open and transparent to ensure acceptance by the international community. Future priorities include engaging the related international efforts when appropriate (e.g., the Group on Earth Observations, CarboEurope).

The workshop suggested many technical areas warranting priority for future research including, but not limited to:

1. Consistent and rigorous protocols for data quality control and for the quantification and propagation of uncertainties spanning multiple observing and modeling systems
2. Monitoring non-CO_2 GHGs (e.g., CH_4, N_2O, and various fluorinated gases)
3. Improvements in observations and analysis of isotopes and isotopomers to enable better attribution of emissions
4. Global assessment and sustained monitoring of forest ecosystems (particularly in the tropics) to help establish accurate baselines and track the evolution of international carbon offsets
5. Improved, sustained monitoring of the carbon sequestered in U.S. ecosystems (particularly forests and agricultural soils)
6. Analytical tools to provide actionable diagnostic and prognostic information in support of the design, implementation, and periodic re-assessment of climate mitigation policies
7. Ensuring continuity of existing observing assets to avoid gaps in critical data records
8. An early-warning capability to detect potential abrupt and dangerous CH_4 or CO_2 releases from natural sinks such as arctic permafrost in response to climate change
9. A detailed study of the quantitative assessments of carbon sequestration by 1) land management/use including reforestation and soil carbon replacements and 2) geological means, both with realistic estimates of amounts sequestered by year or decade and as a function of location
10. Accounting for carbon sequestered and released in coastal oceans and general ocean carbon processes
11. Continued refinements in bottom-up analysis techniques and focused regional/local field experiments to evaluate, validate, and improve these accounting methodologies.

2. Background

This workshop was organized by an interagency collaboration among NASA centers, DOE laboratories, and NOAA and was motivated by the perceived need for a global greenhouse gas information system to significantly enhance the ability of the United States, other countries, regional governments, industry, and private citizens to implement effective climate change mitigation policies. Such a system would provide information about greenhouse gas sources and sinks at policy-relevant temporal and spatial scales by continuously and transparently integrating data from a variety of sources, including *in situ* and remote sensing measurements of land, ocean, and atmosphere, economic activity data, and inventories. The system would enable community-wide efforts to reconcile disparate estimates of greenhouse gas sources and sinks produced via different methodologies, validate and further improve existing GHG inventories, and extend scientific understanding of the carbon cycle and climate system.

This meeting continued the work started at the first GHGIS workshop held October 15-16 2008 at the California Institute of Technology in Pasadena, California.[1] The first workshop led to the grassroots interagency collaboration which continued to hold planning and definition meetings over the following months. One of the major recommendations of the first workshop was to hold a second workshop engaging a broader cross-section of the community.

The timing of this second workshop was motivated by related and rapid-moving developments in climate policy including preparations by the U.S. government for the upcoming UN Conference of Parties of the Framework Convention on Climate Change (UNFCCC) in Copenhagen and related legislation moving through Congress this summer. For example, on April 22, 2009, the House Committee on Science and Technology heard related testimony today from representatives of NASA, NOAA, DOE, EPA, USDA, and NIST on "Monitoring, Measurement, and Verification of Greenhouse Gas Emissions II: The Role of Federal and Academic Research and Monitoring Programs" with an one objective being "to identify the key requirements that need to be addressed in developing a scientifically and operationally robust system for verifying compliance with potential climate agreements."

The workshop presentations and discussions explored scientific and stakeholder requirements for a robust GHGIS, current observation and modeling capabilities that could be brought to bear, and the longer-term information benefits that a GHGIS might provide as an operational decision support system. Discussions pointed to a GHGIS that could continuously integrate new data from sensors in space, air, land, and sea; reconcile, validate and further improve existing carbon-cycle models and GHG inventories; and extend scientific understanding, observational capabilities, modeling, and analysis.

3. Meeting Synopsis

The workshop was organized into the following series of plenary presentations, panel discussions, and breakout sessions:

- Day1
    - Welcome and Objectives
    - Plenary 1 – End-user perspective
    - Plenary 2 – Decision Support and Panel: Information Needs
    - Plenary 3 – Requirements

[1] First workshop report - http://climate.nasa.gov/Documents/GHG_workshop_report_final_revA.pdf

- Breakout1 – What do we need to know?
  - Breakout 2 – How well do we need to know it?
  - Plenary 4 – Panel: International considerations
- Day 2
  - Plenary 5 – Breakout summaries and Capabilities I
  - Plenary 6 – Capabilities II
  - Plenary 7 – Capabilities III & Panel: Future Priorities
  - Breakout 3 – What can we do today?
  - Breakout 4 – Where should we focus to improve?
- Day 3
  - Plenary 8 – Breakout summaries and Discussion
  - Plenary 9 – Closing comments and next-steps

The detailed agenda is included as an appendix of this report. Following the workshop, each of the breakout groups generated a summary of its discussions during the breakout sessions. Excerpts from those summaries are incorporated throughout this report, and the summaries are provided in their entirety as an appendix.

Day 1

The workshop began with a welcome from Richard Stuhlen (VP, Sandia National Laboratories) and opening remarks from members of the workshop organizing committee – Paul Dimotakis (Jet Propulsion Laboratory), Jim Butler (NOAA Earth System Research Laboratory), Karl Jonietz (Los Alamos National Laboratory), and Doug Rotman (Lawrence Livermore National Laboratory). Some of the points made in these opening comments include recognizing the challenge of effectively connecting scientific understanding with societal needs, the wide span of technical expertise required to confront this challenge, and the need for transparency in a successful international framework.

The first plenary session began with a presentation by Bill Irving (EPA, Program Integration Branch, Climate Change Division) on GHG needs for climate policy in which he pointed out that such data needs to be tailored for specific policy support – e.g., cap-and-trade, offsets, and international treaties. He highlighted the limitations of cap-and-trade programs, described options for increasing the accuracy of national inventories of other countries through modest investments in process improvements, and suggested focusing on the challenge of quantifying carbon offsets associated with avoided deforestation.

Ko Barrett (NOAA Climate Program Office) then described four potential international drivers for GHG information. First, the United Nations Framework Convention on Climate Change (UNFCCC) calls for “Measurable, Reportable, and Verifiable” data which has implications such as a need to increase the frequency of national inventory reporting by developing countries. Second, the Intergovernmental Panel on Climate Change (IPCC) is planning an upcoming meeting of experts to revise inventory generation methods, including the incorporation of remote-sensing data. Third, the international Group on Earth Observations (GEO) has initiated related efforts to design a Global Carbon Observing and Analysis System (GCOAS) including space- and ground-based observing assets as well as methods for assessing forest carbon storage. Fourth, the G8 forum is considering the coordinated use of space assets to assess climate change including reduced emissions from deforestation and degradation (REDD).

The second plenary session began with Allen Solomon (Co-Chair of the U.S. Carbon Cycle Interagency Working Group, which guides interagency coordination for Carbon Cycle Science under the US Global Change Research Program - USGCRP) who gave an overview of the USGCRP and relative roles between the CCSP, US GEO, and the GHGIS activity. He also summarized the relevant findings of the recent National Academy review of the USGCRP and the need for establishing a climate observing system.

Compton (Jim) Tucker (NASA Goddard Space Flight Center) reported on the status of the US Group on Earth Observations (USGEO) assessment of carbon cycle climate observations. Their "Observing Earth's Vital Signs" report is scheduled for release this summer and Jim offered some excerpts focused on carbon-cycle observations. This included a summary of the different types of ecosystem (terrestrial and oceanic) carbon observations and looming gaps in observational capabilities. Examples of priorities included the need for sustained continuity of ocean-color and land-use change measurements, improved biomass measurements, and the need for a replacement of the Orbiting Carbon Observatory (OCO) mission for atmospheric CO_2 measurements.

Tony King (Oak Ridge National Laboratory), co-lead author of the 2007 State Of the Carbon Cycle Report (SOCCR – published as Synthesis and Assessment Report 2.2 of the USGCRP), offered some perspectives on decision-support. He highlighted the uncertainty about the future of the large North American carbon sink owing to the competing effects of maturing forests (regrowth) versus the ecosystem response to increasing CO_2 levels and climate change. He also shared some comments from reviewers of the SOCCR report who indicated a desire to enumerate the detailed needs for carbon information, but was considered beyond the scope of that effort. The response to the SOCCR report also highlighted tensions between the different drivers: science questions vs. stakeholder interest. Finally, he highlighted a key SOCCR finding and a reminder as to how GHGIS should be approached – the need to engage decision-makers "early and often."

The second plenary session concluded with a panel discussion on Carbon Mitigation Information Needs with Carolyn Olson (USDA Natural Resources Conservation Service), Larry Tieszen (United States Geological Survey), Allen Solomon (USDA Forest Service), and Tony King (ORNL). Larry Tieszen shared the mandate for Department of Interior/USGS from the 2008 Energy Independence and Security Act to develop a methodology for assessing carbon sequestration in ecosystems. He also highlighted an overarching challenge (echoed in much of the discussion which followed) on the need for improved communication between the science community, the public, and policy makers and in particular, infusing detailed scientific information into effective policy. Carolyn

Olson emphasized the need to include private land-owners as stakeholders and pointed out the issues of variability on small (few acre) spatial scales and the need for sustained time-series observations. Tony King expressed a need for wall-to-wall forest inventories, including disturbances of stored carbon. During the discussion period, Bea VanHorne (USGS) raised the need for prognostic forecasting to support policy, not just diagnostic re-analysis. The panelists agreed this was a challenge and a key area for improvement.

Riley Duren (JPL) began the third plenary sessions with an overview of the GHGIS concept and requirements framework. He shared the motivation behind the GHGIS interagency effort and a notional architecture. He also described the relative roles of the "top-down" and "bottom-up" methods of carbon accounting and introduced the different types of uncertainties and their potential magnitudes for different gases and countries. A notional global CO_2 flux monitoring capability for treaty support was presented to illustrate the process of deriving requirements for such a system including spatio-temporal resolution, coverage, and flux uncertainty capabilities.

A plenary discussion was then held on the topic of the GHGIS requirements framework.

John Mitchiner (Sandia) then provided instructions for conducting the breakout discussions. Each workshop participant was assigned to one of five breakout groups, organized according to the following focus areas:

1. Group 1: Reducing Uncertainties in Net Emissions (Inventories)
2. Group 2: Reducing Uncertainties in Attribution
3. Group 3: Reducing Uncertainties in Biophysical Fluxes
4. Group 4: Integration and Uncertainty Quantification
5. Group 5: Decision Support

The same 5 groups would meet for 4 sessions during the workshop with the sessions focused on answering questions in the following sequence:

1. What do we need to know?
2. How well do we need to know it?
3. What can we do today? (current capabilities)
4. Where should we focus to improve? (future priorities)

The membership of each group, including designation of facilitators is listed in the appendix of this report.

Following the first two breakout sessions, the participants reconvened in plenary session for a panel discussion entitled: National versus International Assets and Engaging the Global Community. The panelists for this discussion were Bill Irving (EPA), Paul Bubbosh (Department of Energy), Karl Jonietz (Los Alamos National Lab), and Ko Barrett (NOAA). Karl Jonietz stated that in treaty negotiation, it's important to have as much information as possible and to remain mindful of the communication issue (e.g., executive orders can fail without the proper support by the public and congress). Paul Bubbosh highlighted three areas of relevance for GHG information: long-term prospects for security (climate and natural resources), support for treaty negotiators, and "other environmental conditions" (e.g., the issue of energy poverty). He suggested several priorities for these policies: establishing baselines, meeting targets, and verifying offsets. He pointed out the need for cost/benefit analysis for a GHGIS. Bill Irving described the need to support treaty implementation (not just negotiation) and the challenge of improving other countries' inventories in the presence of missing capacity. Ko Barrett commented that one can't make treaty parties do something against their will (e.g., sovereignty issues). She also pointed out the opportunities that exist for building capacity and ownership in other countries. With regards to bilateral agreements in lieu of treaties, both Irving and Barrett commented that less formal agreements are often more effective than formal treaties.

Day 2

The second day began with summaries from each of the five breakout group meetings from the previous afternoon.

The following series of plenary presentations were then provided on the topic of current capabilities including top-down and bottom-up perspectives.

Bev Law (Oregon State University) presented an overview of the Ameriflux network and its 90 active towers each of which monitor the amounts and variations of carbon storage and terrestrial ecosystem exchanges of CO_2, water, and energy with the atmosphere. Ameriflux is a component of the international FluxNet integrated science program. The importance of maintaining strong links between operational monitoring systems and ongoing science developments was emphasized.

Pieter Tans (NOAA Earth System Research Laboratory) described methods for measuring atmospheric GHGs from surface- and air-based observations, including the four decades of atmospheric greenhouse gas measurements from the NOAA ESRL observation network and the recently introduced CarbonTracker data assimilation system. Some top-down/bottom-up comparisons were offered for selected gases including various fluorocarbons, underscoring both the value of and need for atmospheric tracers as part of this system. The need for (and challenge of) systematic quality control across multiple observing networks was highlighted, as was the need to devise an interagency process for combining the best of the existing measurement and modeling capabilities to help support improvements in GHG inventories.

Chip Miller (Jet Propulsion Laboratory) gave a summary of current capabilities for space-based observations of atmospheric GHGs. He described the existing U.S. and international satellites offering global measurements of CO_2, CO, and CH_4. Examples of current space-based GHG data products were provided as were some simulation results indicating the potential for further improvements from future satellites such as a proposed Orbiting Carbon Observatory (OCO) replacement.

Chris Potter (NASA Ames Research Center) used a case study for the California Air Resources Board (CARB) to illustrate the combined use of satellite land-use data (e.g., MODIS), ecosystem modeling (e.g., CASA-Quest), and carbon inventories to support reconciliation between top-down inversions and bottom-up estimates and between regional/state inventories and national inventories.

Chris Sabine (NOAA Pacific Marine Environmental Laboratory) provided a review of NOAA's global surface ocean carbon monitoring program, a network of approximately 11 ships and 10 open-ocean moored platforms. Such a system already provides large-scale constraints on the global carbon budgets. He also highlighted the need for a coastal observing system in order to provide regional constraints and that such a capability would have synergy with the GHGIS, the North American Carbon Program (NACP), and the U.S. Ocean Acidification Monitoring Program.

Jim Butler (NOAA Earth System Research Laboratory) described a potential timeline for reducing greenhouse gases in the 21st century, along with a map for providing baselines and reduced uncertainties in GHG estimates, and elaborated on the different components of a GHGIS. He also suggested a scheduled for deploying future assets, resulting in an operational system by 2020. The need for robustness (to component failures) in such an operational system was highlighted.

Linda Heath (USDA Forest Service) gave an overview of the role played by the Forest Inventory and Analysis (FIA) system including the scope and methodologies employed. She highlighted that while comprehensive, the FIA is currently not driven by Carbon needs but that is expected to change. Some key challenges noted included: incomplete coverage in some Western States, organic forest soils are currently not recorded, and how to best capitalize on the public's awareness of and use of GIS products.

Ron Follett (USDA Agricultural Research Service) described how soil carbon inventories are currently generated for agriculture including cropped lands, grazing lands, and others. The overview described examples of sectors not included in the national inventories (e.g., urban turfgrass) and measurement challenges.

Ron Prinn (MIT) described the use of GHG measurements, process models, and three-dimensional global circulation models. He emphasized the value of applying control systems theory in the form of optimal estimation to improve parameterizations of the key models and the importance of integrating information provided by a GHGIS with integrated assessment tools (e.g., socio-economic factors) for decision-support. Key needs include improved spatio-temporal resolution, accuracy, and coverage for measurements including isotopomers. Finally, he pointed out the cost of deploying a GHGIS are justified economically (i.e., a small fraction of the total value of an international carbon market, assuming carbon is trading at prices sufficient to achieve the desired reduction in GHG emissions).

Anna Michalak (University of Michigan) described the role of atmospheric constraints on the carbon budget and top-down/bottom-up reconciliation. The impact of prior flux estimates (spanning a range of different assumed models) on ultimate results was highlighted. A series of recommendations were noted including the need for top-down estimation on finer spatio-temporal scales and approaches that don't rely on -up estimates (to avoid bias). The need for flexibility was also described – so the GHGIS can evolve with future changes in modeling and inventory tools.

The final plenary session of Day 2 was capped with a panel discussion of future needs. The panelists included Jim Tucker (NASA Goddard), Steve Running (University of Montana), Linda Heath (USDA Forest Service), Jim Butler (NOAA ESRL), and Chip Miller (JPL). Jim Tucker stated that in the future, multiple copies need to be built of space-based instruments (to provide robustness) and that improvements in ground measurements and numerical simulation are also warranted. Steve Running pointed out that the community currently has all the needed pieces for a prototype system but that we shouldn't underestimate the effort required to integrate those pieces. He cited as an example NASA's Earth Observing System which cost > $100M/year and that it was difficult to see the GHGIS costing less. Jim Butler agreed that we collectively have the capability to implement a GHGIS but not necessarily the capacity – including people and resources. Chip Miller suggested that we try to break down the barriers between observations and models (and between different types of observations) and strive for a single, combined system. He said the community needs a strategy that addresses the trade-space of sustained vs increased vs tapering-off vs new measurements (and the technological implications). Linda Heath highlighted challenges with the FIA including that some states need to be included in the surveys, that re-measurement frequency in the Western U.S. needs to be increased (currently every 10 years), and that land-cover/land-use maps are very important. She also questioned whether the community is up to the task from a "<u>cultural</u>" perspective and there is a challenge of trying to focus on such efforts in the current environment (i.e., competing with other under-funded demands). Discussion followed about the utility of integration and the need for "one system" – with apparent consensus among panelists for both.

The five breakout groups then adjourned for two sessions in the afternoon devoted to defining needed priorities for future capabilities.

Day 3

The majority of the morning of Day 3 was devoted to report-outs from each of the five breakout groups from the previous afternoon. Each report-out included plenary discussions, which allowed identification of cross-cutting needs and themes. Participants indicated there is significant value in continuing this dialogue with the diverse community of contributors and stakeholders to establish mutual understanding and consensus on issues and facilitate communication with policy-makers and the public.

To facilitate this, participants recommended establishing a listing of existing capabilities and programs to improve interagency collaborations and leverage existing efforts to the extent possible. Improved methods to access and intercompare existing data sets through use of standard units, metadata, etc. were also called for.

Plenary discussions amongst participants also highlighted:

- The emerging need to quantify sequestration efforts (e.g., offsets)
- The role of other (non-CO_2) species in providing attribution information
- The need to establish a common lexicon to improve communication across communities using the same words to describe fundamentally different things
- The wide range of temporal and spatial scales of interest
- The challenge of establishing defensible baselines
- The need to integrate measurements and models
- The challenge of quantifying (and defining) uncertainty

More detailed summaries prepared by the breakout groups are included in the appendix.

After breakout group presentations and discussions, the remaining workshop participants (approximately half of the initial 74 participants) were then asked to share their personal impressions and takeaways for the workshop. The meeting closed with a discussion of the proposed process and schedule for generating a workshop report.

Acknowledgement

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Appendix

1. Agenda

Time	**Day 1 (May 20)**	**Speaker**
08:30	Welcome & Objectives	Stulen (SNL), Dimotakis (JPL), Butler (NOAA), Jonietz (LANL), Rotman (LLNL)
09:00	**Plenary 1: End-User Perspectives**	
09:00	Inventories (US and International)	B. Irving (EPA)
09:30	Climate change policy considerations	K. Barrett (NOAA)
10:00	Morning Break	
10:20	**Plenary 2: Decision Support**	
10:20	CCIWG perspective	A. Solomon (CCIWG co-chair)
10:45	USGEO perspective	C.Tucker (USGEO/NASA GSFC)
11:10	SOCCR perspective	A. King (ORNL)
11:25	Panel Discussion: Carbon Mitigation Information Needs	A. King (ORNL) A. Solomon (CCIWG) C. Olson (USDA NRCS) L. Tieszen (USGS)
12:10	Lunch	
13:10	**Plenary 3: Requirements**	
13:10	GHGIS Concept & requirements framework	R. Duren (NASA JPL)
13:40	Plenary discussion of requirements framework	Moderator: E. Sheffner (NASA ARC)
14:00	Instructions to Breakout Groups	J. Mitchiner (SNL)
14:10	**Breakout 1: Requirements (What do we need to know?)**	5 groups
15:10	Afternoon break	
15:30	**Breakout 2: Requirements (How well do we need to know it?)**	same 5 groups
16:45	Evening break	
17:00	**Plenary 4: International Considerations**	
17:00	Panel Discussion: National vs International Assets and Engaging the Global Community	B. Irving (EPA) K. Jonietz (LANL) P. Bubbosh (DOE) K. Barrett (NOAA)
17:45	End of day 1	

Time	Day 2 (May 21)	Speaker
08:00	**Plenary 5: Day 1 Recap & Capabilities I**	
08:00	Summary Day 1 breakout sessions	1 report from each group (10 min each) followed by discussion
09:10	Surface-based bottom-up observations	B. Law (Oregon State Univ)
09:30	Surface-based top-down observations	P. Tans (NOAA ESRL)
09:50	Space-based atmospheric observations	C. Miller (NASA JPL)
10:10	Terrestrial ecosystem observation & modeling	C. Potter (NASA ARC)
10:30	Morning break	
10:45	**Plenary 6: Capabilities II**	
10:45	Ocean carbon observation & modeling	C. Sabine (NOAA PMEL)
11:05	Integrating observations & activities	J. Butler (NOAA ESRL)
11:25	Forest carbon inventories	L. Heath (USDA Forest Service)
11:45	Soil carbon inventories	R. Follett (USDA ARS)
12:05	Lunch	
13:00	**Plenary 7: Capabilities III**	
13:00	Emission Estimation using 3D models	R. Prinn (MIT)
13:20	Data Assimilation & Top-down/Bottom-up Reconciliation	A. Michalak (U. Michigan)
13:40	Panel Discussion: Capabilities & options	J. Butler (NOAA) C. Miller (JPL) S. Running (U. Montana) L. Heath (Forest Service) C. Tucker (USGEO/NASA GSFC)
14:30	Instructions to breakout groups	J. Mitchiner (SNL)
14:40	Afternoon break	
15:00	**Breakout3: Capabilities (what can we do today?)**	Same 5 groups from day 1
16:30	Evening break	
16:45	**Breakout4: Capabilities (where do we need to make improvements?)**	Same 5 groups from day 1
17:45	End of day 2	

Time	Day 3 (May 22)	Speaker
08:00	**Plenary 8: Day 2 Recap & Discussion**	
08:00	Summary and discussion of Day 2 breakout sessions	1 report from each group (20 min each) plus discussion
10:00	Morning Break	
10:20	**Plenary 9: Synthesis & Wrap-up**	
10:20	Synthesis Assessment (Requirements vs Capabilities)	Moderators: R. Duren (JPL), J. Mitchiner (SNL)
11:10	Summary of workshop findings	
11:30	Future Plans	
12:00	Workshop Adjourn	

2. Attendance List and Breakout Group Assignments

*Indicate breakout group facilitators

Group 1 (Emissions)	
Hemming, Brooke	EPA
Wirth, Tom	EPA
Jonietz, Karl*	Los Alamos National Laboratory
Wilson, Cathy	Los Alamos National Laboratory
Guilderson, Tom	Lawrence Livermore National Laboratory
Boland, Stacey*	NASA Jet Propulsion Laboratory
Cox, Bob	NASA Jet Propulsion Laboratory
Gurney, Kevin	Purdue University
Hermina, Wahid	Sandia National Laboratories
Michelsen, Hope	Sandia National Laboratories
Group 2 (Attribution)	
Dreicer, Jared	Los Alamos National Laboratory
Smith, jim	Los Alamos National Laboratory
Jones, Phil	Los Alamos National Laboratory
MacKerrow, Ed	Los Alamos National Laboratory
McDowell, Nathan	Los Alamos National Laboratory
Ringler, Todd	Los Alamos National Laboratory
Scovel, Clint	Los Alamos National Laboratory
Sathaye, Jayant	Lawrence Berkeley National Laboratory
Cameron-Smith, Phillip	Lawrence Livermore National Laboratory
Rotman, Doug*	Lawrence Livermore National Laboratory
Cwik, Tom	NASA Jet Propulsion Laboratory
Friedl, Randy	NASA Jet Propulsion Laboratory
Kaki, Sahid	NASA Jet Propulsion Laboratory
Butler, James*	NOAA Earth System Research Lab & CCIWG
Boslough, Mark B	Sandia National Laboratories
Hunter, Charles	Savannah River National Laboratory

Group 3 (Fluxes)	
Ebinger, Michael*	Los Alamos National Laboratory
Fischer, Mark	Lawrence Berkeley National Laboratory
Potter, Chris	NASA Ames Research Center
Nemani, Rama	NASA Ames Research Center & NACP
Tucker, Compton	NASA Goddard Space Flight Center
Miller, Charles*	NASA Jet Propulsion Laboratory & CCIWG
Tans, Pieter	NOAA Earth System Research Lab & CCSWG
Sabine, Chris	NOAA Pacific Marine Environmental Lab & NACP SSG
Law, Bev	Oregon State Univ & CCSSG
Michalak, Anna	U. Michigan & CCSWG
Running, Dr. Steven	Univ Montana, College of Forestry & Conservation
Follett, Ron	USDA Agriculture Research Service
Heath, Linda	USDA Forest Service
Solomon, Allen	USDA Forest Service & CCIWG
Olson, Carolyn	USDA Natural Resources Conservation Service & CCIWG
Anderson, Dean	USGS
Tieszen, Larry	USGS
Zhu, Zhiliang	USGS
Group 4 (Integration & Uncertainty Quantification)	
Cwik, Tom	NASA Jet Propulsion Laboratory
Higdon, Dave	Los Alamos National Laboratory
Wingate, Beth	Los Alamos National Laboratory
Rake, Doug	Lawrence Livermore National Laboratory
Brown, Molly	NASA Goddard Space Flight Center
Dimotakis, Paul*	NASA Jet Propulsion Laboratory & Caltech
Backus, George A	Sandia National Laboratories
Carr, Marty	Sandia National Laboratories
Jakubczak, Jay	Sandia National Laboratories
Mitchiner, John*	Sandia National Laboratories
Roskovensky, John K	Sandia National Laboratories
Schubert, Kent	Sandia National Laboratories

Group 5 (Decision Support)	
Bubbosh, Paul	DOE
Irving, Bill	EPA
Fred Ambrose	US Government
Erickson, Randy	Los Alamos National Laboratory
Prinn, Ronn	MIT
Sheffner, Ed*	NASA Ames Research Center
Duren, Riley*	NASA Jet Propulsion Laboratory
Barrett, Ko	NOAA Climate Program Office
Cantwell, Elizabeth	Oak Ridge National Laboratory
King, Anthony	Oak Ridge National Laboratory & SOCCR & CCSSG
Geffen, Charlotte	Pacific Northwest National Laboratory
Faith, Kay Sullivan	RAND
Cullen John	USGS
VanHorne, Beatrice	USGS
Moynihan, Mark	US Government

3. Breakout Group Summaries

Group 1: Reducing Uncertainties in Net Emissions (Inventories)

Breakout group one was tasked to discuss the current state of GHG emissions quantification, with an emphasis on national inventories. The group considered existing methodologies, discussed their adequacy to meet near-term policy and regulatory needs, and identified areas needing additional investment and improvement.

Group members were drawn from both the ‘top-down’ and ‘bottoms-up’ communities, providing for a thorough and thoughtful interchange. It was generally recognized that existing national inventory methodologies were accurate for their intended purpose - verifying regulatory compliance within the United States and reporting accurate GHG emissions estimates for certain sectors internationally. However, it was also recognized that connecting such ‘bottoms-up’ data with observed global atmospheric and climate parameters is far from trivial. The latter is currently of primary concern to the research community, is critical for developing a predictive understanding of climate change, and is necessary for verification in some cases, but it requires deconvolution of many poorly-understood interacting natural and anthropogenic processes that influence climate.

The group also considered the importance of quantifying – and understanding – uncertainty in emissions estimates. Differences between communities in the definitions and inherent assumptions associated with uncertainty quantification became readily apparent throughout the discussions and warrant further exploration at future meetings or workshops.

A key goal in emissions quantification is to develop an internationally-accepted set of scientifically-defensible techniques and standard methodologies to provide well-understood emissions factors for building inventories. The group generally agreed that the existing United States national inventory process is the ‘gold standard’ to which other processes are to be compared, as it incorporates well-established processes to quantify emissions from each regulated source category (i.e., combinations of monitoring, emissions factors, and accounting are used and the methodology is delineated in a National Inventory Report in addition to the common reporting format submitted to the United Nations Framework Convention on Climate Change on an annual basis). Significant improvement in global inventories is readily achieved by encouraging other nations to regularly produce emissions inventories that capitalize on existing processes and methods, although some concern was expressed about the accuracy of inventories in those nations or regions where data may be altered or withheld for policy reasons. Existing emissions inventory methodologies would further benefit from improved land use/cover maps - perhaps including information on land use change, forest age, additional land cover types, soil carbon, and crop classification (e.g., perennial vs. annual) – with higher spatial resolution and through injecting new technologies or data to improve individual inventory components. For example, methods for measuring area and fugitive sources (e.g., measuring methane over landfills), which are generally in the research stage should be matured to withstand the test of regulation. Towards this end, the group strongly recommends the compilation (i.e., in list or directory form) of existing efforts to improve situational awareness across agencies, enabling synergistic collaborations and leveraging of existing resources. Along these lines, the group also recommends efforts to improve data access and intercomparison (i.e., through use of standard units, metadata, formats, search tools, etc.) via a prototype information system that builds on existing efforts.

Additional discussion topics included:

- The need for space-based high resolution height-resolved concentrations of CO_2 for both science and emissions verification from a top-down perspective
- The desirability of simultaneous CO information (and possibly aerosols, NOx, SOx, and other trace species) to provide attribution
- The desire for better in situ and ground-based networks to resolve biologic system fluxes, which are poorly constrained by species, location, and time
- The difficulty establishing baselines for various sectors
- The need for improved transport modeling and/or tracer measurement improvements to allow precise attribution
- The need for long-term measurement continuity
- The desire for smaller-scale (spatial & temporal) fuel inventories
- The emerging need to be able to verify sequestration efforts
- The desire for vertical profiles of CO_2, CO, CH_4, and other species and/or an extensive eddy correlation network to determine fluxes
- The possible use of indirect indicators (e.g., night lights data) to provide further constraints for space-time activity allocation when compared with fuel consumption data
- The need for a regional-scale understanding of the global distribution of sources and sinks to constrain models
- The need for methods to openly intercompare different techniques (methods and measurements) to learn how they can jointly further reduce/constrain uncertainty
- The growing need to account for mobile sources
- The need to include communities with aligned interests as appropriate (e.g., water and air quality, national security)

Group 2: Reducing Uncertainties in Attribution

We need to establish accurate baselines - particularly for ecosystem offsets. Our current observations are considered inadequate to establish accurate baselines. The required accuracy for observations depends on:

- Domestic vs foreign
- Size of region
- Detailed desired:
  - net GHG emissions only?
  - Anthropogenic vs natural?
  - Sector detail?
  - Spatially resolved?

Some archetypal requirements include:

- Level 0: global change in GHGs
- Level 1: minimum uncertainty for treaty verification (e.g., 10% for the Top 6 emitters: USA, China, EU, Japan, Russian, India)
- Level 2: separate fossil-fuel from natural contribution
- Level 3: resolve state or small country and attribute to sectors

"We're not going to attribute CO_2 with CO_2 alone": rather, attribution will require:

- Surface flask measurements
  - Currently: qualitative signatures
  - Future: automated and quantitative
- Sample frequency
  - Currently: weekly (and continuous for some)
  - Future: continuous
- Number of sites
  - Currently ~100 globally
  - Future: ~1000 globally

In-situ isotopes and isotopomers:

- in the future, we need to measure these regularly (along with chemicals)
- 14C is particularly useful and specially hard to measure

Validation of offsets is particularly difficult:

- Currently limited to:
  - Satellite visible imaging (e.g., Landsat)
- In the future will likely need:
  - Canopy height (LIDAR)
  - Biomass (SAR)
  - Soil Moisture (satellite)

- Spatially resolved emissions
- Isoprene chemicals (plant stress)
- Carbonyl Sulfide (photosynthesized but not respired)
- Isotopes and isotopmers
- Gravity measurements (satellite)

Conclusions:

- The observations and models needed for a prototype GHGIS are available now:
  - Currently some attribution capability, but incomplete
  - Full system could be done by scaling-up current networks and completion of existing research (doing so may reduce agency “turf wars”)
  - Prototype GHGIS can evaluate the relative value of different observations (support Return on Investment assessments)
- GHIGS will both produce and enable science

Group 3: Reducing Uncertainties in Biophysical Fluxes

Summary

Note that Sessions 1 and 2 had no representation from oceanographers and the discussion focused on terrestrial fluxes only.

Session #1: What do we need to know?

Session #1 focused on the critical question: What do we need to know? This was interpreted by the group to encompass

- Science Drivers
- Policy and Information Drivers
- Spatial and Temporal Scales over which fluxes[2] must be known
- What was the carbon flux for a given country in a given year?

There was vigorous discussion concerning the relevant time scale(s) over which fluxes should be reported and/or reconciled, with an interval of one year seen as a likely minimum between assessments. The time scale on which fluxes are estimated will vary with the data and models used to estimate them, and policies using flux information should evolve as the observations and models become more sophisticated and enable estimates on more detailed spatial and temporal scales.

There was recognition that the knowledge requirements for assessing terrestrial carbon fluxes have been reported in the literature. The Group identified essential references that capture the community consensus on the key carbon and climate variables that must be observed or modeled. Of special note: Chapin *et al.* [2006] defines the concepts, terminology and methodologies used to assess patterns of carbon cycling as well as its controls, particularly the factors that determine whether an ecosystem is a net source or sink of atmospheric carbon dioxide (CO_2). Chapin *et al.* recognized the importance of explicitly identifying the fluxes that comprise all components of the C-cycle to provide a less ambiguous framework for understanding and communicating changes in the global C-cycle.

[2] Use of the term "flux" varied somewhat among different technical communities, reiterating the need for a common lexicon to facilitate community-wide discussions. One consideration is that flux estimates and their corresponding uncertainties typically come from models rather than direct measurements for spatial scales greater than approximately 1 km.

Session #2: What do we know?
In Session #2 the group considered: How well do we need to know what we need to know? It is clear that this will depend on what question is being asked. Treaty monitoring has distinctly different requirements than support for Cap and Trade or carbon market systems. The group thoughts are captured in Table 1.

Table 1. Knowledge requirements for essential flux variables

Essential variable	Dynamic Range (uncertainty)	Spatial Scale	Temporal Scale	Comments/Problems
Atm. CO_2 ($^{14}CO_2$, ^{18}O, CO	340 – 500 ppm (0.1 ppm)	100 – 500 km fetch	30 min, aggregate as needed	Need ~ (tall) 200 towers in continental US; wind turbine towers, cell phone towers; uniform distribution. Need: Satellite CO_2 mapping w <10 km^2 FOV; Challenge: expanding globally;
Flux Towers (FluxNet): NEE; NPP; GPP; Soil Carbon Stocks (live, dead); soil C; soil respiration; LAI (model input for models); FPAR; POC, DOC, DIC all small; Biomass; Albedo; Met Data:	Unc. of 20% (Complex Terrain, local homogeneity)	2-3 km	30 min Aggregate as needed	Need ~150 towers for US; Global: scale up US sampling (~1000 towers) Challenge: fill gaps (Africa) and extend; Remote sensing values; scale-up parameters; high latitude snow depth
Soil Climate Analysis Network (SCAN): soil moisture, temperature, bulk density		4-5 soil depth	Continuous, raw or aggregated	Scope: US at 155 sites
Land Cover: snow cover; glacier cover, lake cover; vegetation associations; fate of harvested products; lateral transport and how products		30 m (LANDSAT)		Spatial driven by microclimate *Detect changes of type over time—history and time since last disturbance; Challenge: Carbon centric land classification; Challenge: Biomass density and class

used; partial/complete disturbances (e.g., combustion eff=pool)				
Vegetation Structure: canopy height; vegetation density	Height distribution ± 3m TBR			
Plant Functional Types	~10 types			
pCO_2 : Marine transport, especially coastal and inland waters. DOC, DIC, POC				Group #3 is under-represented with regard to marine and inland water transport.

An expanded measurement system can be implemented in stages, and we could expect data to start becoming available in 1-3 years from different components of the system. A significant challenge will be translating this new observational data into policy relevant information. This will require commensurate enhancements in various models (e.g., TOPS, Carbon Tracker).

Session #3: What can we do today (in the next 12 months)?

Note: Group added Chris Sabine and Anna Michalak Anna

Question for Session 3: What can be done today (within 12 months) if we integrate available assets? The discussion of this question revolved around the system needed to generate flux estimates and uncertainties (Fig. 1). The components of the system were identified and quantified. Finally, the group identified system components, capabilities, and assessments that could be delivered in the next 12 months with minimal additional resources to support a GHGIS prototype demonstration.

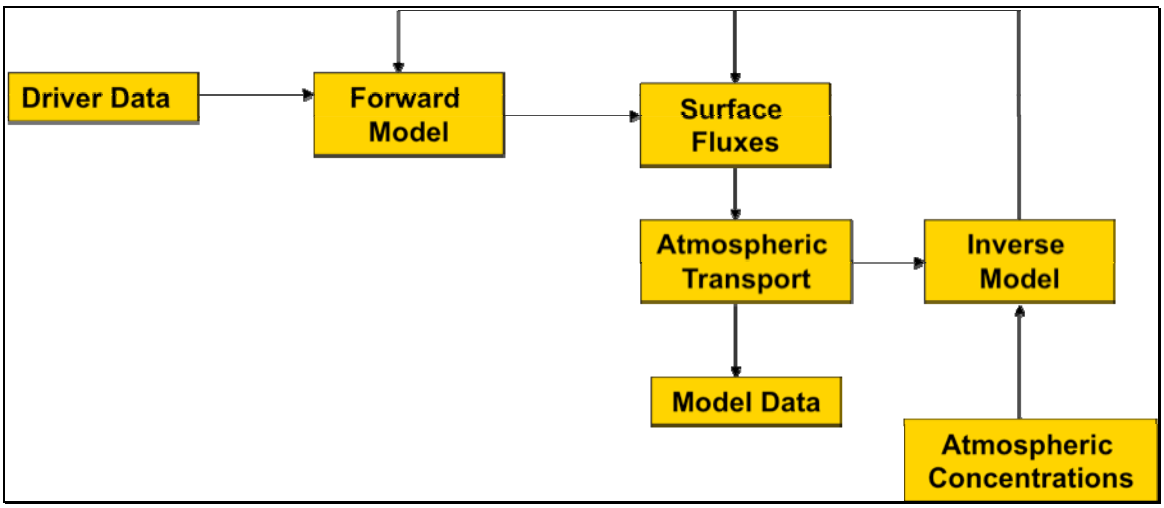


Figure 1. Block diagram of the system required to generate C-cycle flux and flux uncertainty estimates.

Critical Variables:
Consensus opinion was that there were 2 critical carbon flux variables: NEE for land-atmosphere fluxes and pCO_2 for ocean-atmosphere fluxes. All other geophysical variables or observables support the determination of these 2 critical variables.

Databases (part of "Driver Data" in model diagrams)

Ecosystems (Regional Data Sets exist now; Assemble and use in 2-3 years for accurate biopshere modeling)

- Atmospheric CO_2, CH_4, N2O and other atmospheric components
- Surface Imagery (MODIS)
- Landsat
- Ocean Color
- Detailed Land Cover
- Land use change
- Land management

- Historical legacy of land use and management
- Data sets of biomass and soil carbon at various depths
- Fire and disturbances
- Topography
- Site Potential
- Meteorological reanalyses
- Paleo-climate data (for model training)

Oceans

- pCO_2
- Export ratio
- Chlorophyll distributions
- Temperature
- Salinity

Models:

- Forward Models
  - Terrestrial Ecosystem
  - Ocean Biogeochemistry
- Transport Models
  - Atmospheric transport
  - Ocean circulation
- Community Models (lessons learned from prior community model development efforts are important)
- Inverse Modeling framework

Observations (part of "Driver Data" in model diagrams)

- Land surface observations
- Ocean Observations
- Emissions

Near-term deliverables

(1) Statistical analysis of land cover change by ecoregion and the drivers for entire US. (in about 6 months). SE US is Benchmark, data exist with adequate quality (Complete; augment to access impact of climate change or 2050).
(2) pCO_2 of 4 x 5 deg. To 1 x 1 deg in 6-12 months.
(3) Mobile van with multiple fast response GHG gases and isotopics ($^{12}CO_2$, $^{13}CO_2$, $^{14}CO_2$, others)
(4) "Offsets": can look at vegetation change from Pacific west coast to continental divide
(5) Century Model: Cropland at daily time step for N_2O to 2100; C at monthly to 2100.
(6) USGS acquire LIDAR (canopy height, 3D structure, biomass estimates)
(7) Create plug-n-play "ensemble" model system—UMich diff. biosphere models with 1x1 deg outputs

(8) Complete Northern Great Plains (NGP) NEE via AmeriFlux
(9) Great Plains Grasslands ecosystems productivity anomalies and trends @ 250 m
(10) SSURGO soils data base availability; need 1 FTE to convert
(11) In ~3 years, we could get a good estimate of C-stocks (standing wood and soils) for US on 1 km
(12) Biosphere model intercomparison with fixed set of parameters
(13) Carbon-climate model intercomparison (Randerson's proposed C^4MIP; biogeochemistry, dynamic global climate model (DGBM) with information on what climate is doing and response)
(14) Estimates of N_2O CH_4 fluxes urban and rural central California will be available in 6 months

Session #4: What are the long-term (> 12 months) needs to enable flux uncertainty reduction?

During Session #4 the Group assessed observation and modeling needs to reduce flux uncertainties to levels that were thought needed to support future policy and economic mechanisms for event horizons more than 12 months in the future. The capabilities given below can be prioritized based on end user needs and available resources.

Needs:

(1) Increased computing capacity (to meet 200ktC/10,000 km^2 /yr uncertainty objective globally)
   a. Flux models in 1-5 years operating at 1x1 deg for National/global estimates
   b. Native resolution at 10 km^2;
   c. Nested grids to 100 km horizontal scale to aggregate, bundle repetitive errors
(2) Coastal ocean models
(3) New personnel (estimated needs ~ 100 new PhDs over the next 5 years)
(4) Centralized database access point
   a. Data format management format
   b. Centralized benchmark data sets
   c. Ease of data access: better interfaces, more transparency and easily shared (no firewalls) between universities and national labs; training programs; collaborative modeling
(5) Coordinated data assimilation with reliable uncertainty estimates — able to ingest all desired observations
(6) Direct comparison of in situ and remote sensing data
   a. Vertical profiles of atmospheric CO_2, CH_4, N2O, etc.
(7) Improved land surface models
   a. DBMs needed in AR5, but DBMs aren't working well enough to use
   b. DBMs validated against benchmark observation data sets
      i. Current DBMs fail when compared to benchmark data
(8) Improved atmospheric transport models
   a. Boundary Layer/free troposphere transport dynamics
   b. Better vertical transport models

(9) Measuring and Remote Sensing:

a. Higher frequency (~ 4 day) and 30 m spatial resolution for land imaging (Landsat)
b. Complete global C observation system
c. Develop and deploy coastal ocean C-Obs system
d. Urban in situ measurements
e. N_2O at surface and in-situ
f. Tall towers, about 200 in North America; international to about 1000 towers
g. Regular CO_2, CH_4 profiles (Sondes) @ >200 sites worldwide
h. In situ $^{14}CO_2$;
i. In situ measurements on ~10% of all commercial air flights
j. Monitor potential geological sequestration leaks
k. Complete FIA (< 5 yrs, all states, NRI increase C-parameters measurements
l. Subsurface soil T (>1000 sites)
m. Common protocols for soil, Ameriflux
n. Validation of in situ vs. remote sensing (Land surface, ocean, atmosphere)

(10) Multiple species approach for GHG

(11) Space-based remote sensing

a. CO_2, CH_4, CO, N_2O, H_2O, …
b. Profiles for above species with > 3 vertical degrees of freedom (DOF)
c. Global map coverage to about 10 km horizontal resolution

(12) Autonomous ocean C (Argo C)

(13) Total Column Carbon Observing Network (TCCON): At least 50 sites worldwide

(14) Cheap sensors, multisensors with high accuracy

(15) More observations for

a. Young forest sites
b. Tropical forests

Group 4: Integration and Uncertainty Quantification

The task of system integration, quality control and propagation of uncertainties focuses on how the different modeling and observation sources can be integrated into a whole that provides information to decision and policy makers with appropriate estimates of uncertainty. The GHGIS will need to serve a broad, complex and diverse community of users, the task of integrating data and providing its uncertainty is central to the success of the system. The GHGIS will need to provide actionable, clear and transparent information to the public and policy makers as well as to a broad science community. Thus having a clear understanding of the challenges and requirements is critical.

What do we need to know?

The GHGIS will have two fundamental drivers:

- Develop a stronger scientific understanding of the relationship between GHG emissions, climate change and human consequences.
- Climate treaty/policy design and verification of international compliance.

The science driver is more technically challenging because we need to better understand the entire carbon cycle. This includes the natural and anthropogenic sources and sinks of GHGs. We need the complete physical understanding to estimate the effects of mitigation and adaptation policies. This evolving knowledge should inform the policy debate that determines the required reductions in net GHG emissions for each country.

For treaty verification, we can focus on the development of estimates for anthropogenic GHG sources and sinks. These estimates need to be geographically specific for attribution to specific countries.

All possible sources of information need to be used and integrated in to this process. No single source will provide us with all of the necessary information. Onsite data collection is an important source, but we cannot collect everywhere because of cost. Algorithms for optimal placement of sensors will help maximize the information that we get for a given investment. If territory is denied constraints are imposed on the solution. Even without denied territory, we need air, land, and water – based observations as well as remote sensing observations from space. Global data will inevitably be sparse in space and time.

In addition to data, we will need models to estimate the system state between data samples. We need to develop much improved inverse transport models for source-sink analyses and attribution because we have to interpolate time and space between data points. If there are denied territories, this task becomes even more difficult and less accurate. The transport models will need weather models that rely upon local observations to function well. If weather observations are sparse along with sparse GHG data the task becomes more difficult (such as in remote regions of tropical forests and in underdeveloped countries such as those in large areas of Africa). Multiple modeling approaches with differing strengths and weaknesses should be pursued to provide more robust answers.

Some of the challenges include reconciling the data collection with the estimates of anthropogenic sources and sinks from energy production and other human activity, including land use and its impact on climate. For treaty purposes, the international community needs to establish land use baselines and then develop a defensible method to measure variances from the baseline. At the moment, this is beyond our current capabilities since nearly all estimates of the carbon content at local or regional scales are based on very few samples and generalized theoretical knowledge, which is inadequate given the extremely heterogeneous nature of most landscapes. Thus the GHGIS will also need to advance land cover science as it improves other areas of modeling and observation.

Every information source contributing to the GHGIS will have associated errors. Measurement systems can have systematic bias from measurement-calibration errors, and random/statistical errors from a finite signal-to-noise-ratio. With respect to fuel usage and economic activities, there will necessarily be a large element of self-reporting of the quantities of fossil fuels used, the emissions from that usage and proxies for other economic activity. Self-reported data will have unknown sources of error and perhaps even some intentional deception. Such economic activities and their emissions, particularly in regions outside of the US, are simply not known and thus will be hard to capture in the system. Models also have errors deriving from their data sources, inaccuracies in the modeled physics, and numerical error.

After reconciling and integrating all of the information sources, we need to quantify the uncertainty. For the science mission, this requires propagating the uncertainty in the GHG emissions through the data and models to the information about current GHG emissions by country showing the impact of mitigation policies in real time. The system will also provide forecasts of future climatic conditions and identify resulting consequences likely to affect human behavior. Ideally, we want to be able to define treaty requirements to create a safety margin that ensures climatic stability, geopolitical stability and a low level of human suffering. This process requires understanding the tail of the distributions from emissions to climate to human impact to human response.

For treaty purposes, we need to quantify the uncertainty in the attribution of anthropogenic sources and sinks. If we know the uncertainty distribution, we can estimate the probability that a country is in compliance with respect to emissions. We can also calculate the value of reducing the uncertainty.

Both the carbon cycle science mission and carbon attribution treaty mission of the GHGIS must be transparent and communicated in such a way that both policy makers and the public (a large fraction of both will be skeptical) can make informed decisions and understand the potential consequences of those decisions. Information provided through the GHGIS must be clear as to the quality of both the data and the models. The openness and accuracy of information provided by the GHGIS must be above reproach to allow governments and their constituents to develop an appropriate and informed level of confidence in international climate agreements and their ability to reduce climate change to acceptable levels at acceptable cost.

What can we do today, and how well can we do it? (Capability assessment)

The first step is to develop a systematic and comprehensive understanding of the current state of GHG emissions, including our ability to monitor GHG emissions through data and models. Several questions must be answered to develop this understanding. First of all, what is the required input data set for a reasonably comprehensive GHGIS? At what spatial and temporal density do we need such data? Having identified what we need, what are the available data and their uncertainties? In answering this last question it is important to remember that relevant input data is being generated across multiple agencies and projects, and even across international boundaries. Is it really available, and in a form that can be fused with data from other sources? In understanding climate on a global scale, it is a reasonable assumption that we will forever operate in a data starved environment, and therefore we will need to use interpolation models to supplement the measured data. How well do these models work? In situations where we have sufficient data density, can the models match the full data set using interpolations based on spare subsets of the data?

Furthermore, using the data we have (both measured and interpolated), how well can we forecast climate change globally and regionally? In other words, how accurately can we predict climate changes observed already, based on earlier data? .

Eventually, we will want to understand our ability to control climate change to acceptable levels through policy. Realistically, it may be decades before we will begin to have an answer to that question.

What can we start to do in the near term with appropriate funding? (Immediate capability enhancement)

Answers to the questions above will help identify near term actions that should be taken. Even knowing the questions gives us some good hints at fruitful next steps. We must develop a plan to prioritize and systematically fill in the remaining data input gaps. We must define a mathematical framework with embedded uncertainty quantification analysis to fuse and reconcile the data from disparate sources. In parallel we should undertake the parallel development of an operational system concept including hardware, software, data handling and security, system maintenance, etc that is capable of producing actionable, defensible information with associated uncertainties. We could begin to develop and implement government and public information dissemination mechanisms that will promote understandability, transparency, and easy access while still protecting areas of national security importance. We should identify the diverse communities that will provide input data and utilize output information and begin to involve them in the development of the dissemination system.

What should be included in the GHGIS R&D roadmap to improve performance?

We have assumed that many key components of a GHGIS already exist, funded by multiple federal agencies, and implemented in a loose conglomeration of federal and university entities. The first steps toward a rudimentary GHGIS will require new, extensive cooperation among all of these participants. We also believe that while this rudimentary system would be a good start, significant improvements will be required to raise confidence in the information provided. We must develop reasoned mid- and long-term investment strategies to improve our models and our observation networks. These improvements must address not only the recognized shortcomings in the basic science underpinnings, but also in our ability to recognize and anticipate complex, interdependent socio-economic impacts and responses. We must look for deficiencies and define and implement improvements to address those deficiencies. New sources of data, new understanding, and new technologies will necessitate continuous adaptation to maintain the highest possible quality of GHGIS data and uncertainty quantification estimates.

With respect to the scientific basis, there is still much about the workings of nature and atmospheric/oceanic transport models that we simply do not yet understand. Models of ecosystems must be improved to be able to handle all of the interdependencies and interactions. Improved data for such models will require more capable and more numerous observation networks. New instruments will likely be needed where durability, transportability, lowered power requirements, and reasonable cost will all play a crucial role.

Data management will play a crucial role. We will need to fuse data from multiple sources, including bottom-up data (self-reported inventories), and measured, top-down data from space-, air-, ground-, and sea-based systems, as well as outputs from scientific and socio-economic models. On top of all of these more quantitative sources, there will always be a need for expert opinions and judgment. The mathematical/operational data-fusion network will require continuous improvements as new data sources come on line.

We must also develop decision-support tools and the what-if forecasting tools to provide input. These tools do not presently exist. They must be able to handle consequence and cost modeling, adaptation and mitigation strategies, and be adaptable to evolving decision-making requirements.

Finally, we must continually improve and update the system used to provide linkages to the communities who can provide key inputs and who will use the information (policy, science, and government). This is expected to be a permanent need and the system must keep up with communication technology developments.

Group 5: Decision Support

Decision support lies between scientific research and the impact of policy and resource management decisions. Decision support is the primary purpose of the GHGIS. The GHGIS will integrate data about greenhouse gases from various sources – observations from within and above the atmosphere, in situ measurements, model predictions, etc. – into information that those responsible for climate policy and resource management (individuals, state and regional resource managers, federal government officials, etc) can use to base their decisions on the best available science.

The Decision Support Breakout Group defined five topic areas (questions) where decision makers are likely to need improved information to make decisions related to carbon management. The five topic areas are:

1. Emissions – what's emitted, how much and from where?

   Reducing and controlling emissions are key to effective climate change mitigation, but the economic activity data estimates for emissions outside the US and Europe have large uncertainties.

2. What are the fluxes, and variability of fluxes, in "natural" systems?

   Natural greenhouse gas fluxes must be understood before we can gauge the magnitude and impact of anthropogenic emissions.

3. How much carbon can be sequestered – where and for how long?

   Information on the ability of terrestrial and oceanic systems to absorb and sequester carbon is incomplete and too unreliable in current form to base carbon trading.

4. What are the critical uncertainties and limitations in carbon monitoring, reporting and verification (MRV), and what value would accrue from reducing them? Does the cost justify the improvement in resolution (cost-benefit analysis)?

   Reducing uncertainty will likely be of value to most, if not all, users. Uncertainty is partly a problem of the scale/resolution of the data, but more information is needed on the contributions of the elements of the system (in situ observations, model output, etc.) to the uncertainty of the information. User requirements for maximum error and understanding of uncertainty must also be addressed.

5. How do we assess the effectiveness of climate mitigation actions related to the carbon cycle?

   Carbon emission and sequestration protocols will need to be monitored for some time to verify their effectiveness.

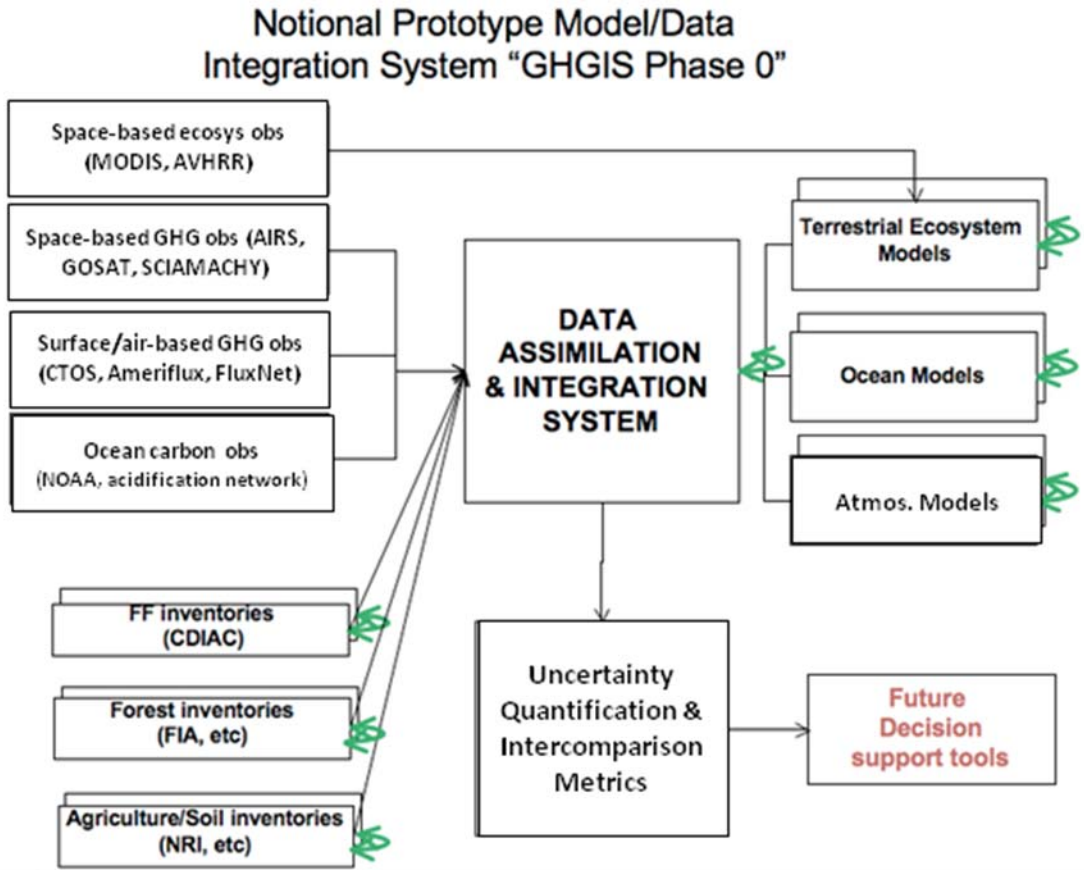
When considering these topics in the context of a GHGIS, numerous other questions arise such as the resolution and timeliness of observations. Designing a GHGIS is difficult until the specific information needs of potential users are understood. Nevertheless, the breakout group compiled recommendations for near term actions that will improve the responsiveness of the GHGIS to user needs (and greatly increase the value of the GHGIS to the science community). These are:

1. Develop a system that supports integration of different models, inventories and data sets, identifies gaps in current capabilities and provides for optimal control of the results (as opposed to reconciling top-down/bottom up approaches). Aspects of such a system already exist, but a more comprehensive system is essential. See figure below. Such a data assimilation system has been recommended by the research community for some years. It will benefit the research and applications communities and it is the logical first step toward building a GHGIS.

2. Complete a systematic design study to expand the existing surface network to meet the global in-situ sampling requirements for a comprehensive data set that can be used to evaluate emissions. Uncertainties will not be reduced without a more comprehensive surface network. Apply this criteria to "denied areas" to determine the minimum collection tools and data needed for confident assessment.

3. Complete case studies of high priority decision support tasks that demonstrate the capabilities and methodologies of the GHGIS, include early and comprehensive input from researchers and end-users and integrate data from field campaigns as appropriate. These case studies will assist in the design and implementation of the GHGIS. Candidate studies include a regional emissions reduction project (e.g. California Air Resources Board (CARB) study of regional emissions and offsets; assessing the relative economics of biofuels versus forest preservation; and determining baseline and tracking credits to avoid deforestation. Although the GHGIS concept emerged in response to needs for treaty support, the selection of case studies should not be constrained to that topic.

Decision support related to the carbon cycle involves the private sector as well as government agencies. Public-private partnerships will be part of the development and implementation of a GHGIS. The GHGIS concept will not succeed without acceptance of the tool by researchers and information users in all elements of the community.



We note that the various models are developed from in situ research as well as remote-sensed information.