Ecoinformatics for Biospheric Carbon Sequestration

Introduction

The first Canada-California Strategic Innovation Partnership (CCSIP) calls for collaborative Canadian-Californian proposals to develop transformative science-based partnerships leading to new industry opportunities and socio-economic benefit. In an era where human activities are profoundly changing the ecology of the Earth, causing unpredictable responses with economic impacts, it is necessary to understand these changes and anticipate their long-term consequences. Recent science reports indicate that climate change and biological responses are occurring far faster than originally predicted, with large socioeconomic implications. As scientific understanding has been improved, the prognosis has become more serious and urgent (NRC 2009). Climate change is already having measurable impacts on both Canadian and Californian ecosystems, threatening the sustainability of large industries (e.g. fisheries, forestry, agriculture). These effects, which are likely to increase in the coming decades present significant challenges, as well as untapped opportunities, which this proposed initiative seeks to address.

Carbon is central to the discussion of climate change because carbon emissions through fossil fuel emissions and land use and land cover change is the largest contributor to the current warming trend (IPCC 2007). There is a general consensus that net carbon emissions must be reduced, but we lack agreement on how best to do this. Regarding this "carbon problem," the pervading paradigm emerging in both U.S. and Canada is that industry will be able to use engineering solutions to capture carbon and sequester it (Carbon Capture and Sequestration, CCS). We argue that a comprehensive CCS program must also consider the *biospheric* potential for carbon loss and gain, since biosphere-atmosphere carbon exchange (photosynthesis and respiration by terrestrial ecosystems) represent the largest global fluxes of carbon (several times larger than anthropogenic releases). Furthermore this carbon released from biospheric sources cannot be captured through engineering "fixes", but requires proper monitoring and management of terrestrial ecosystems. These biological exchanges of carbon ("biospheric carbon") represent "biological feedbacks" that have the potential to either slow down or speed up atmospheric carbon increases and climate change, and could easily undermine or support a successful CCS program.

To illustrate this point, "natural disturbances" (e.g. interannual variability in weather, fire regimes, or insect outbreaks) readily turn Canadian forests from carbon sinks to carbon sources (Kurz et al. 2008). Similarly, drought in Canada and the Western US has triggered widespread forest decline, outbreaks of forest pathogens, increased fire frequency, and consequent carbon release (Breshears et al. 2005, Hogg et al. 2005). Currently, these dynamic biological feedbacks to the atmospheric carbon and climate are not adequately considered in the emerging global carbon markets. These markets generally view forests in static terms (X hectares of forest = Y tons of carbon = Z dollars), and generally ignore disturbance effects or the large carbon storage potential of soils and other non-forest ecosystems. Effective carbon markets require better tools for monitoring biospheric carbon losses and gains. A certifiable system of monitoring biospheric carbon would have significant impacts on the evolving carbon markets, would assist industry and resource managers in buffering the economic impacts of bad years, and could have a profound impact on the market for emerging monitoring technologies.

Objectives of the Bilateral Initiative

We propose the development of an efficient, cost-effective "ecoinformatics" network to monitor biospheric carbon and inform carbon markets, with several potential economic benefits. A central objective of this initiative will be the development of a unified Biospheric Carbon Index (BCI) that captures the dynamics of biological carbon exchange. This objective requires the development of cyberinfrastructural and informatics technologies (e.g. networked hardware and software tools) to integrate data from multiple sources and translate these data into usable information that can be readily incorporated into emerging carbon markets. The development of accessible informatics tools will also enhance the growing market for existing and emerging monitoring tools by clarifying data and communication standards needed for integrating the existing variety of often proprietary data formats. This initiative will clarify targets for commercialization of these monitoring technologies, and will spur the training of highly qualified personnel in the use and integration of these new technologies. Finally, by facilitating the incorporation of a certifiable biospheric component into the carbon markets, this effort will assist in the development of long-range economic forecasts linked to climate change.

To implement this initiative, we will first form a "working group" of key stakeholders from both Canada and California representing industry, academia, government, and non-governmental organizations (NGOs, which play a large role in the current carbon markets). Through meetings and web conferences, we will identify mechanisms for translating carbon exchange into an index of biospheric exchange (the Biospheric Carbon Index, BCI). Note that these technologies exist, but often in proprietary formats that do not facilitate data integration or transparent evaluation of the results needed for certification. Furthermore, there are critical issues of provenance (documenting data sources and ownership) that must be resolved. Essential to this effort will be the cyberinfrastructure and informatics tools that will capture and integrate carbon exchange data into a near-real-time index (the BCI). Thus, developing our "business plan" will entail working with stakeholders to address the potential markets and sources of capital for investing in this informatics effort. To produce this business plan, we will hire a team of experts from academia or industry (to be selected from several possibilities, including TecEdmonton). The ultimate goal of this effort will be a business plan that outlines the strategy for ecoinformatics, the benefits to the monitoring market, and the larger impacts on the carbon markets and carbon policy. This plan will also outline key steps that Canadian and Californian governments and industry can take to foster the development of further research and commercialization in this area.

Novelty and Quality of the Proposed Idea or Concept for a Bilateral Initiative

We propose a fundamentally new strategy to incorporate ongoing scientific data on biospheric carbon stocks and fluxes into the evolving carbon market, with the additional benefit of spurring innovative, high-tech green industries involved in biospheric carbon monitoring. While carbon markets now exist, the focus of these markets is on emissions and offsets, and these markets largely fail to account for the biospheric carbon exchanges (fluxes), which dominate the global carbon exchange. Slight imbalances in these biospheric fluxes (due to climate change, variability, or periodic disturbance) have a large cumulative impact on the global carbon cycle and standing carbon stocks (e.g. forest biomass and soil carbon), and, after fossil fuel combustion, are the second major contribution to global warming (IPCC 2007). This dynamic, biospheric carbon must be part of a comprehensive carbon market. Currently, the scientific and monitoring tools to enable the incorporation of biospheric carbon into the market exist in the form of flux networks (e.g. FLUXNET), satellites (e.g. MODIS and the recently launched GOSAT satellite), and field sampling networks (e.g. SpecNet). The full development of the biospheric carbon market is currently hindered by several barriers to data integration and access, which include proprietary software and hardware issues, data provenance challenges, lack of appropriate eco-informatics tools, and a history of unclear economic and science policy signals from the US and Canadian governments. We argue that a clear demonstration and subsequent implementation of transparent ecoinformatics tools for biospheric carbon can advance innovation and economic opportunities in the market for monitoring technologies while simultaneously clarifying evolving carbon policy goals.

The situation is perhaps analogous to the biotechnology field two to three decades ago. Prior to the 1980s, the basic concepts and rudimentary tools of gene and protein sequencing were in place, but the emerging data could not be readily integrated or used. Beginning in the early 1980s, a policy of steady US government investment in medical research stimulated a several-fold expansion of private-sector investment, which stimulated the rapid emergence of the bioinformatics industry (Friedman 2008). We argue that the ecoinformatics industry is now poised for a similar transformation.

In the US, several states (including California) have taken the lead in carbon policy in recent years due to the lack of a clear federal policy, despite urgings from science and industry for stable and consistent federal signals. With the current Obama administration, it is likely that federal climate policy will advance to include some form of mandatory carbon accounting, and that federal policy and state policy will begin to align to support common policy goals. This alignment, along with a recent call for expanded federal funding for science research, makes the timing of our initiative particularly propitious.

In Canada, a signatory to the Kyoto accords, there has been a failure to meet the terms of Kyoto agreement. While there are several reasons for this, one explanation has been the realization that potential biospheric carbon losses from Canada's boreal and arctic ecosystems in a changing climate pose a significant economic risk for a country bound to the accords. A consequence of abandoning this agreement is that Canadian carbon emissions have continued to increase unabated; Canadian carbon emissions have increased 25% between 1990 and 2005, including the period of Kyoto Protocol implementation (http://www.statcan.ca/Daily/English/080422/d080422a.htm). Failure to meet the Kyoto accords has, if anything, provided additional pressure to readdress carbon policy, making our initiative to assemble and integrate biospheric carbon data particularly timely. As of this writing, the upcoming Copenhagen talks will revisit the Kyoto Accord and consider modifications in light of new science and economic findings. It is likely that the policy and market signals will evolve to favour the rapid development of the ecoinformatics and monitoring industry along with other "green industries." As we enter a post-Kyoto world, the emergence of an effective ecoinformatics industry could transform how we measure and value carbon, and could develop entire new "green technology" markets. We envision a world where rural communities can participate in a growing carbon market, can set up a local monitoring station, and gain carbon credits for certified biospheric carbon sequestration via proper management of forests, rangeland or farmlands. Our "products" will include the network tools to encourage the delivery of information (on biospheric carbon sequestration) to market (the carbon market).

Scope of the Proposed Initiative

We view this initiative as a three-layered strategy (figure 1). Tools for monitoring biospheric carbon exchange that provide the essential data lie at the core. As mentioned above these tools largely exist, but integrating and validating the emerging data remain a key challenge, in part due to the lack of a coherent informatics strategy. Consequently, the central target of this initiative will be to define the informatics strategy needed to effectively integrate data from a diverse set of disciplines and monitoring tools. While the ultimate goal of this will be to address biospheric carbon at a global scale, our initial focus will be on Canada and western North America (including California), two regions that are particularly prone to disturbance, interannual variability, and climate change impacts (Breshears et al. 2005, Hogg et al. 2005, Kurz et al. 2008).

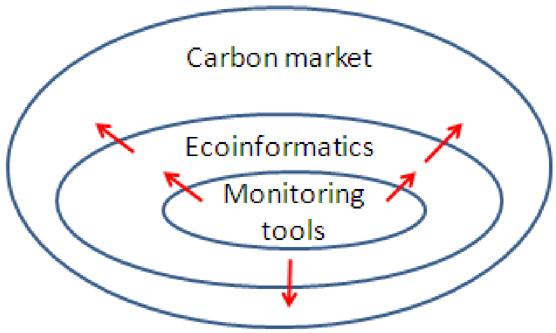

Figure 1

The three layers to be considered by this initiative, consisting of monitoring tools, nested within an ecoinformatics and cyberinfrastructural framework, located within an evolving carbon market. Information flows outwards (arrows) from the monitoring tools to the carbon market, which, in turn, stimulates on the monitoring industry.

Defining an effective informatics strategy will have several benefits for the monitoring industries. By evaluating the barriers to utilization and integration of these technologies, including proprietary data and communications formats, limited networking or real-time reporting capabilities, issues of data provenance and intellectual property (IP), limited networking or real-time reporting capabilities, and pricing structures (e.g. economics of scale), we will identify pathways to improving the utility and availability of these monitoring tools. These paths might include the recommendation for standards for better integration, or might involve moving towards open-source software. We anticipate that this phase will lead to new products and improvement of existing products over the next few months to years.

Because the ecoinformatics and cyberinfrastructural tools are located within a carbon market (figure 1) that currently considers biospheric carbon in a static way, this initiative will also have transformational benefits to the emerging carbon markets and evolving carbon policy. By using ecoinformatics tools to incorporate real-time data on dynamic biospheric carbon exchange into the carbon markets, this initiative will enable a more complete carbon accounting that will send more realistic price signals into the larger economy. Thus the longer term (years) goal of this project will be to stimulate a more realistic accounting of biospheric carbon that should have long-term economic benefits (decades).

Because full realization of this initiative requires interdisciplinary skills not adequately represented in the current workforce, our plan will also address the needs for highly qualified personnel (HQP). We will review existing academic and industry training programs and develop specific recommendations for improving the training of a new generation of skilled workers needed for this effort. For example, in addition to the technical skills required for carbon monitoring instrumentation, we will evaluate the biological, earth science, economic, computer science, and quantitative (e.g. modeling and GIS) skills needed to create an integrated Biospheric Carbon Index.

Technology Transfer and Delivery to Market

This initiative will develop a web-based network for the translation of scientific data (biospheric carbon monitoring) into a transparent metric of carbon exchange (the BCI). Our goal is to make this information freely available, with the goal of stimulating the growing market for the monitoring tools and with the expectation of influencing scientific and economic policy (e.g. via the carbon market). While the underlying software tools may need to be proprietary, the approach to information distribution is intended to be transparent, and differs from many traditional business models that emphasize proprietary approaches to intellectual property. Our example resembles the approach used by Google when developing Google Earth; while the underlying software remains proprietary, software tools are freely available, and the information is built by a cooperating community of contributors, supported through web-based advertising revenues. Thus, our technology transfer and market delivery will emphasize a Google-style model for technology development and information delivery, with the content contributed from a variety of sources (primarily the scientific and biospheric carbon monitoring community). It is likely that the business model will involve the formation of a non-profit corporation, and revenues will come through web based advertising.

Here, we briefly consider likely barriers to the development of this network. A major hindrance to wider adoption of monitoring tools is the lack of a coherent ecoinformatics framework for data access and integration. The lack of hardware and software standards, along with the proprietary nature of many existing monitoring tools, serve as a disincentive to the spread of information, and discourages wider use of the monitoring tools. This keeps production low and prices high for many of the carbon monitoring instruments. While we will explore this issue, it is unlikely that industries will readily drop proprietary formats or adopt external standards quickly or easily. Consequently, the main focus will be on the development of the necessary ecoinformatics framework (e.g. network-based software tools) needed to spur the development and integration of new and existing monitoring tools, with the expectation that industry will adjust existing designs or develop new designs to be compatible with these new informatics tools as they become available.

Again, a review of the history of bioinformatics is instructive. The development of public databases (e.g. Genbank, a database of publicly available DNA sequences), along with the requirement that researchers use these databases as a condition of funding, allowed the ready integration and transmission of new data (DNA sequences in this case). Similar web-based databases now exist for proteins. Simultaneously, in part because of these new biological databases, the market for the actual data generating tools (e.g. PCR machines and gene sequencers) expanded dramatically yet still remained proprietary as the instrument makers scrambled to meet the growing market for sequencing tools. We expect that a similar transformation will occur with ecoinformatics. Thus a key focus will be to identify the necessary cyberinfrastructural and informatics tools for integrating large volumes of monitoring data and for translating these data into a common standard. To do this, we will examine several analogous efforts now underway in the US and Canada, including the NEON program (US National Science Foundation), the NCEAS Ecoinformatics effort (UC Santa Barbara), and the Geochronos effort (U. Calgary and U. of Alberta).   Our Action Plan will focus on informatics, but will also include recommendations for industry to meet emerging ecoinformatics standards, and will develop recommendations for government funding sources to support the use of these informatics tools (e.g. via the requirement for data delivery for any publicly funded data, once provenance issues are addressed).

Benefits of the Proposed Bilateral Initiative for both Canada and California

Both Canada and California have strong resource-based economies that are threatened by climate change and that would benefit from a more balanced, integrated, and less confrontational approach to sound environmental management. Additionally, both California and Canada have forest and rangeland resources threatened by wildfires and insect pest outbreaks, and in both regions, the frequency, size and intensity of these disturbances are being aggravated by climate change. (Luers et al. 2006, Kurz et al. 2008). In California, agricultural industries compete with fisheries for water, logging activities affect runoff and soil erosion causing conflicts with agriculture and fisheries, and each of these industries are threatened by climate change (Luers et al. 2006). Although manifestations of climate change in Canada will be different, the large changes in climate that are predicted for northern regions will have significant major detrimental impacts on Canada's existing ecosystems, which evolved in response to historic conditions. In Canada, conflicts between economic sectors over water also exist, and several resource industries (agriculture, forestry) have uncertain futures. Both Canada and California have public support for green technologies and support programs that encourage environmental sustainability. In fact, public opinion on resource management and now on climate change supports environmental conservation and green technologies well beyond current policy mandates.

This initiative addresses these challenges by providing a web-accessible index (the BCI) that will provide a summary metric of ecosystem condition regarding carbon and will help evaluate policy successes or identify areas needing improvement. A direct benefit of this initiative will be the further development of environmental monitoring industries in Canada and California. Key among these are many innovative start-ups and small high-technology companies, including companies in the instrumentation, digital media and geomatics fields. A key focus will be the training of highly qualified personnel in the skills needed to use the data from these monitoring tools in an informatics context.

Proposed Approach to the Development and Delivery of the Business Plan

An initial task will be to identify key "stakeholders" – leaders from industry, academia, government, and NGOs who have a direct stake in monitoring technologies and carbon policy, but who have also shown an interest and willingness to find innovative solutions. The industry representatives will include manufacturers and distributors of monitoring technologies both in Canada and California, as well as trade associations and government agencies representing forestry and agricultural industries. This includes well-established industries as well as emerging start-ups. Also included in the industry list will be insurance companies that have a strategic financial interest in intelligent carbon policy. NGOs will include key representatives from the non-profit communities that participate in the carbon offset markets or develop carbon policy recommendations. Academic representatives will come from several universities and disciplines (e.g. biology, atmospheric science, computer science, and business), and will be particularly helpful in identifying pathways for training HQP.

We plan to hire consultants for key components of our business plan. For the economic aspects, potential sources will include the Business Schools of the PIs Universities, or university-government partnerships (e.g. TecEdmonton) designed to spur innovation and technology transfer. To address issues of provenance (analogous to IP issues), we will consult with experts in computer science who specialize in addressing this aspect of data management within a network. Expertise in biospheric carbon will come from the PIs and their colleagues in the scientific community (primarily from Californian and Canadian universities) involved in biospheric carbon monitoring.

Management of the business plan development will be handled by the PIs through the Centre for Earth Observation Sciences (CEOS, University of Alberta) and the Center for Spatial Technologies and Remote Sensing (CSTARS, University of California, Davis), who have experience using interdisciplinary, Earth monitoring tools and managing collaborative projects.

Expertise of the Applicants and Partners Involved

The PIs, Dr. John Gamon and Dr. Susan Ustin collectively have several decades of experience in carbon monitoring technologies (carbon flux measurements, field spectroscopy and remote sensing), and are acknowledged experts in this area, with numerous publications on the topic of Earth monitoring and biospheric carbon flux. More recently, they have focused on novel approaches to information extraction and networks for sharing this information. For example, Dr. Gamon founded "SpecNet" (Spectral Network – http://specnet.info), a collaboration of investigators and sites where remote sensing is integrated with biospheric carbon monitoring. Dr. Ustin has served on several scientific panels involved in planning future observations, including scientific review teams sponsored by the National Center for Ecological Analysis and Synthesis (NCEAS), the National Ecological Obervatories Network (NEON), and the National Research Council (NRC). Currently, they both serve on the science planning team for HyspIRI, a planned NASA satellite instrument with new capabilities for biospheric monitoring. Both Dr. Ustin and Dr. Gamon have extensive experience working closely with industry, particularly with manufacturers of monitoring technologies.

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