BCN
California Action Framework

Developed by: UC Davis

January, 2011

Table of Contents

Executive Summary

Recently, California has adopted a cap-and-trade framework to reduce carbon emissions. The result is an emerging carbon market whose investors will need a reliable, science-based system for measuring carbon stocks and for the actual carbon content of carbon assets and liabilities. Such products will allow investors to assign value to carbon assets, thus creating an efficient carbon marketplace. Indeed, California's carbon market is predicted to be one of the largest in the world and will transform California's economy. Currently, carbon offsets are the most cost-effective way to reduce carbon emissions under California's new cap-and trade framework, and it is anticipated that demand for carbon offsets will be high. The greatest demand will be in the forestry sector, with much of the supply coming from within California itself. However, the agriculture sector-the most important sector to California's economy and one of the dominant land cover types in the state-has great potential to supply carbon offsets while still functioning in its current economic capacity, but more research is needed. BCN products will allow carbon investors to assign value to carbon assets and liabilities; it will provide several products to be released in two phases. The first phase will respond to the immediate market need in California by assessing and monitoring existing carbon stocks, which could be marketed to both buyers and sellers of carbon offsets. The second phase, in partnership with University of Alberta, we will develop and release more sophisticated products, developed from a larger suite of scientific data, that will provide measures of carbon uptake and release from different land areas. These measures will drive investors toward market valuation of carbon, and drive the carbon market toward greater efficiency.

California BCN Overview

The BCN is the next generation of carbon monitoring and verification tools for the carbon market being proposed for development and implementation in Alberta and California. Both Alberta and California plans share a common framework and many elements yet each plan emphasizes aspects unique to the ecological conditions of their region and their emerging carbon credit policies. Using a framework of ecological informatics and cyberinfrastructure, the BCNs will provide standardized regional metrics of biospheric carbon stocks and fluxes that after testing and demonstration have potential for global application. These metrics will be based on consistent, transparent science-based methodologies that integrate many already available scientific datasets, including information from airborne and satellite remote sensing imagery, flux towers, inventory data, and field observations. BCN is a tool for measuring carbon stocks and fluxes to quantify and verify carbon assets that will provide market confidence and promote an effective carbon market.

Value Proposition

There is a growing expectation that land based systems, such as forests, will have an increasingly important role to play in climate change mitigation by serving as carbon-offsets. For instance large corporate buyers of carbon offsets, such as Starbucks and Silicon Valley Power, are actively pursuing forest-based carbon offsets. Programs like Google Earth, Amazon web services, and Cisco Alerts plan for aspects of the necessary cyberinfrastructure and ability to provide data to carbon market. Other third party programs are developing tools and abilities to value carbon assets for the voluntary market. All land (not just forested land) can be represented as a carbon asset or liability. The goal of this initiative is to stimulate biologically based protocols and initiatives that encourage carbon sequestration by recognizing that sequestered carbon has market value. Lack of investor confidence in the valuation of carbon assets has significantly reduced their value. We propose that there is a need for a comprehensive cyberinfrastructure (defined here as the system from carbon relevant data collection to delivery of information to the carbon market) that will provide transparent, accurate information for market entities to properly value carbon credits. With this need in mind we propose that a Biospheric Carbon Network (BCN;Figure 1) can be developed from today's data sources, ranging from field data like flux towers to global weather satellites. We envision production of a BCN product that will provide accurate, reliable metrics of actual land-based, or "biospheric" carbon assets (stocks) and liabilities (fluxes), a necessity for assigning value in a carbon marketplace. The development of such an entity will aid the rapid development of a growing carbon market.

Product Description

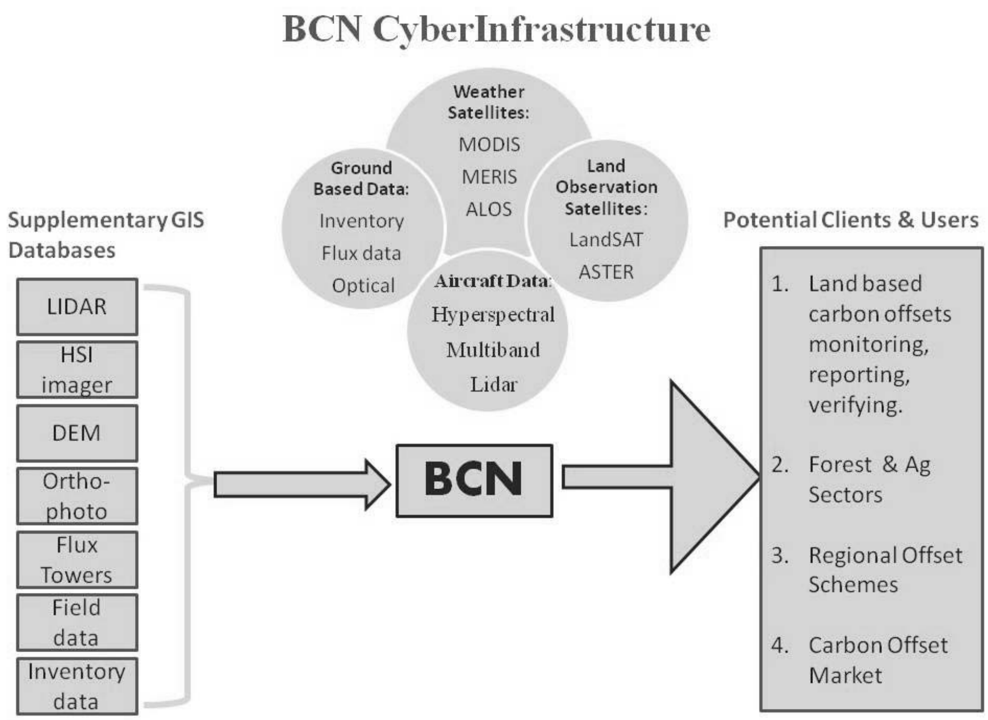

Figure 1. Conceptual overview of BCN. Both Canadian and California plans share a similar framework for estimating stocks and fluxes. Differences are principally in terms of the data elements that are emphasized, which are based on the most relevant models that meet the needs of each region.

Under California's new cap and trade system, carbon-offsets are anticipated to be in high demand as they provide the lowest-cost solution to legislated emissions reductions (see Target Market Overview, below). Thus, we envision a need to create standardized metrics of existing carbon stocks, at scales relevant to the emerging California market (i.e. individual tree canopies and forests stands for which the methodology may be applied anywhere in the world), and verification and monitoring of such stocks, is in immediate demand. Current methods that are applied at the national scale are unsuitable for the significantly smaller size of carbon credit projects. To downscale programs to the appropriate scale that will correctly estimate specific credits, requires higher spatial resolution data and new models that capture the relevant processes at the scales of several hectars to a few kilometers. California has opened its international market for carbon credit agreements with more than 20 countries and regional entities, the first being Chiapas, Mexico and Acre, Brazil.

In response to the emerging California carbon market, and anticipated demand for carbon asset verification, the University of California in partnership with the University of Alberta, will develop a BCN as an approach for integrating disparate measurements of biospheric stocks and fluxes into a verifiable measurement of carbon sequestration. These BCNs will offer accurate estimates of carbon assets that will assist the carbon credit market by providing carbon investors with the ability to verify a potential carbon stock exists and monitor its status as an asset. Because of the powerful informatics and cyberinfrastructure framework, the BCNs will provide efficient and cost-effective metrics , thus making these tools useful to the developing market and improving market confidence.

Phase 1: Carbon stock verification and monitoring

Currently, the California carbon market only exists as a carbon sequestration market, particularly forestry-based carbon offset purchases. Thus, the initial products offered by the California BCN will be assessment and monitoring of land cover type and carbon stocks. These products have heritage in the national assessments, such as the Australian Carbon Accounting Office program described by Gary Richards (http://www.ieabioenergy-task38.org/workshops/canberra01/cansession1.pdf). Appears to be the model for other national level forest carbon assessments (http://www.clintonfoundation.org/what-we-do/clinton-climate-initiative/our-approach/forests/). What we propose is to develop an observation network and cyberinfrastructure that can operate at the scales relevant for the carbon market in forests and agriculture. Using BCN, investors will be able to verify potential purchases, and monitor those assets to ensure they exist and have not been altered (due to land management practices, disturbance, etc.) Such data is required to establish market value and promote market confidence. To this end, BCN will use its cyber-infrastructure to develop an automated carbon stock mapping procedure based on routine, inexpensive remote sensing informatics. Development of an ability to monitor soil sequestration in agriculture focuses on tillage practices, another facet of carbon sequestration quantifiable using remote sensing data.

Phase 2: Quantifying carbon assets and liabilities

As the California carbon market evolves, additional information will be needed by carbon markets to assess both carbon assets and liabilities. Through the California BCN cyberinfrastucture, we envision an expansion of the suite of products for assessing and monitoring existing carbon stocks that can be offered in the second phase of development to include flux (changing stocks) metrics and other carbon relevant information, derived from a full suite of BCN informatics, such as data from satellite and airborne remote sensing, flux towers, automated sensors, GIS databases, which are linked in nested models. The California BCN will provide information on carbon stocks rates of carbon sequesteration in forests and agriculture. The BCN will also be used to detect and quantify areas of carbon liability, pushing the market beyond current carbon offset project to more sectors by allowing investors to identify potential assets through sponsorship of management changes (e.g. promoting soil conservation tillage practices in the agricultural sector). Lastly, the BCN will provide the carbon market with the information required for industries and customers to determine intrinsic values and market prices, moving California's carbon market toward greater efficiency.

California BCN Inputs

Measuring biospheric carbon stocks, both above ground stocks (i.e. forests) and below ground (i.e. soil carbon) is most comprehensive when a suite of methods, rather than any single method, is used. Such approaches include existing and up-and-coming remote sensing technologies on both satellites, piloted and un-piloted aircraft, and can be supplemented by data collected from weather stations, flux towers, field measurements, that are integrated in models which can produce spatially distributed carbon estimates. Our concept is that multiple lines of evidence will produce more confidence in carbon estimates than isolated single measurements. Furthermore, by archiving this data, it provide a historic record that can be reanalyzed if new methods prove superior, or to document quantitative changes in carbon stocks. The California BCN will integrate these approaches (informatics) using its state-of-the-art cyberinfrastructure to provide metrics of carbon stocks and fluxes that can be applied globally while providing site-specific information.

MODIS Satellite Feeds

The MODIS satellite sensor is flown on NASA's *Terra* and *Aqua* satellites and collects daylight reflected solar radiation over the entire surface of the earth, up to twice daily. Standard MODIS products, which are publically available over the internet, include global estimates of biospheric carbon uptake (Gross Primary Production). However, these measures are delivered at too coarse a scale to validate individual carbon assets. These data do however, provide a baseline to detect changes at the pixel level, which can be used to signal the need for higher spatial resolution data. We have, in another context, developed a method of MODIS time series analysis capable of detecting small, sub-pixel changes that is applicable to the BCN plan. This method of detecting temporal anomolies is being devloped by the US Forest Service for improving early wildfire detection (Koltunov et al., 2007) and has been demonstrated to detect selective logging in tropical forests (Koltunov et al., 2009). Such methods can be modified to provide automated detection of environmental changes at the global scale. These can be downscaled to determine the cause of change from the network of field sensors, from high spatial resolution satellites or aircraft or can be ingested into a modeling framework for analysis.

Land Cover Satellite Feeds

A number of moderate resolution satellites now exist that acquire systematic global data, with Landsat Thematic Mapper (TM) and the French Satellite Pour l'Observation de la Terre (SPOT) satellites having the longest history. The preferred satellite for our purpose is the Landsat TM because of its six spectral bands, data quality, and the free release of Landsat data through the USGS. The Landsat TM satellite provides data at 30m resolution pixels, which provides subgrid data disaggregation for MODIS and at the scale of field inventory data, flux tower footprints, and other field data. The data is available globally every 16 days although there is some uncertainty in whether the next Landsat (8) will be launched before one of the two current satellites (5 and 7) fails. Its six optical bands are in approximately the same bandpasses as the 500m MODIS data, thus these data can be used to downscale from MODIS to local sites, which can provide a basis for a sampling approach to global modeling. Data are available at no cost from USGS and can be downloaded directly from the local overpass with a standard x-band receiving station. MODIS and Landsat are complementary in trading off spatial and temporal resolution dynamics.

Aircraft Remote Sensing Data: Validation and Scaling

Airborne remote sensing missions provide detailed, site-specific information with higher spatial resolution, and the capacity for increased information about the reflected solar radiation or detailed elevation information. From high spatial resolution data, it is possible to map individual tree crowns, providing regional-scale assessments of aboveground standing carbon stocks. An alternative methodology is to use aircraft data as subsampling missions with data being used to "train" models of coarser satellite data. We have used these methods in other cases, such as mapping seasonal changes in canopy water content at the continental U.S. scale (Trombetti et al., 2008). Aircraft missions can be piloted or un-piloted, and are flown "on demand." While piloted missions may be more costly, the technology is also more mature and is not subject to current FAA restrictions. There are many private airborne data contractors available for hire in California and the western U.S. Routine, automated, systematic aircraft acquisitions would provide the information needed to assess and monitor existing stocks and provide validation of the assets at specific times. NASA has estimated the entire state could be flown at 20m resolution with hyperspectral imagery (also termed "imaging spectroscopy" meaning many adjacent narrow spectral bands that create a highly detailed spectrum for each pixel) in only five days, given limited acceptable flight hours during midday. Thus repeat frequencies, as often as sub-monthly, are possible.

Imaging spectrometers and multispectral imagers

Imaging spectrometers flown on aircraft collect remote sensing images with hundreds of spectral bands simultaneously, providing the quantitative information needed to directly identify materials and chemical properties by applying principles of spectroscopy at the pixel scale using specific diagnostic absorption features. Such data, with models and/or ancillary data could produce estimates of both above ground and below ground carbon stocks and fluxes.

Multiband thermal infrared images, from single band (10μm) and multiband TIR imagers

Thermal imager (TIR) technology has matured in recent years and has now become one of a suite of realistic airborne remote sensing instruments. Combining TIR data with optical data provides a direct measurement of plant stress and the state of carbon exchange through the plant stomata. This is because when stressed, the leaf stomata are fully or partially closed, resulting in lower evapotranspiration and hence lower latent heat exchange. This results in the foliage, and eventually the canopy becoming hotter, but up to several degrees celcius, than well watered or non-stressed canopies. Current instruments are capable of measuring differences at 0.1°C (or better), making changes in canopy functioning detectable. When combined with weather data, leaf area index, and vegetation type, the difference between canopy surface temperature and bulk air temperature can provide accurate instantaneous estimates of fluxes of water and carbon.

Airborne first/last return LiDAR sensors

LiDAR sensors can be flown on aircraft concurrently or independently from image spectrometers, providing highly accurate elevation data at very high spatial resolution. Data about canopy structure, height, presence of understory, etc. can be quantified. By using its own energy source, rather than solar radiation, LiDAR data acquisition can be conducted over a larger range of meteorological conditions, including cloud cover or even at night, and can provide scales from a few centimeters resolution for estimating ground surface microtopography and canopy surface and gap structure. These data provide information about the canopy surface including information about canopy height, canopy depth, gap size and frequency, and understory, which are used to estimate above ground carbon stocks. Figure 2 illustrates a LiDAR derived tree map (at $1m^2$ resolution) produced for the Sacramento-San Joaquin delta region (~$2500km^2$), which identified more than four million trees and tree clusters (i.e., possible multiple tree crowns that were closely spaced and could not be separated into individual trees). In addition to these data, we derived tree height and crown area for each tree/cluster from the liDAR data. These data are then used with allometric models to estimate spatially explicit biomass.

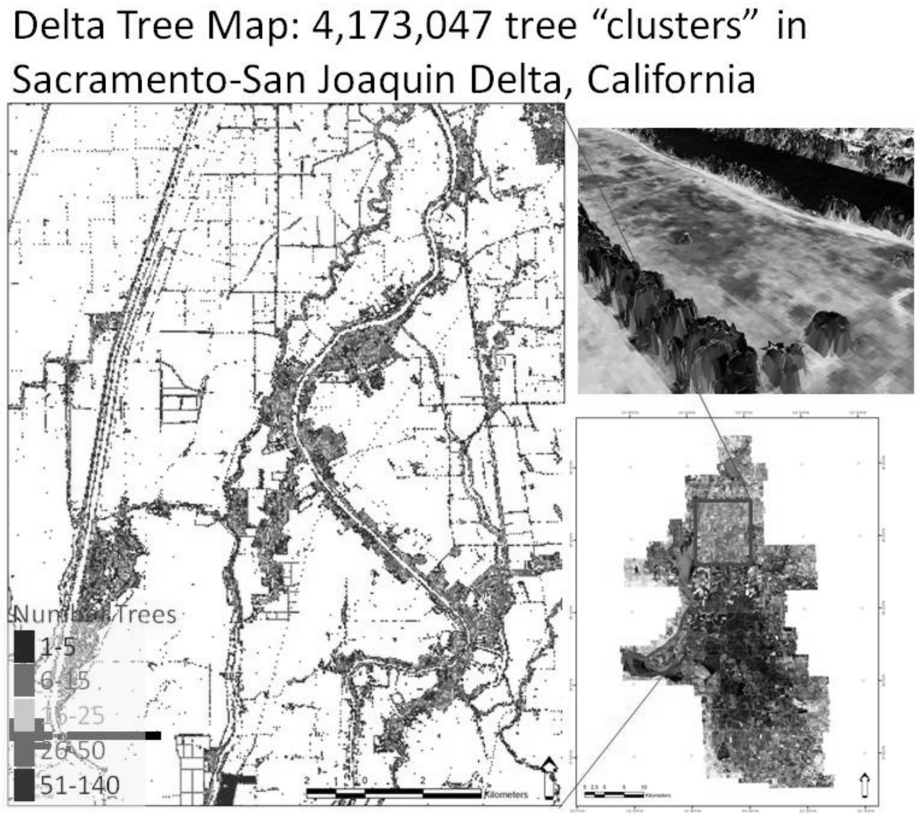

Figure 2. Example of airborne LiDAR-derived automated tree map for the Sacramento-San Joaquin delta of central California. The small map on the right shows the area of hyperspectral image coverage of the full delta and the box on the left shows an enlargement of the subarea shown in red. The numbers of trees are color coded as identified on the bottom left. The upper image on the right side shows liDAR data overlaying a "natural color" image of small section of the delta. Data were produced by Mr. Juei Wren Ho, a graduate student in the CSTARS lab.

Flux Towers

California has approximately 16 flux towers spanning the state from the Pacific Ocean to the deserts of eastern California, with one transect extending across the north-center of the state and one across the south, near the end of the Sierra Nevada Range. These provide direct measurements of carbon dioxide and water vapor exchange and air mass movements at the local scale. While local in scale (flux footprints vary with fetch, time of day, vegetation height, and other factors but are generally smaller than $1km^2$ for forests), flux towers can estimate the exchange of gases between the atmosphere and the biosphere, the information needed to quantify the rate of carbon sequestration of the forest or agricultural lands. This information can be used to help establish short term carbon sequestration to long-term estimates of future growth, and to identify and quantify carbon liabilities. These towers are primarily managed by carbon scientists at public universities, and are supported with public funds. Flux data is generally deposited at the Oak Ridge National Laboratory's FLUXNET website.

Knowing fluxes provides only part of the information required for robust carbon estimates, since scaling directly from these data presents numerous challenges. In the second phase of the BCN project, we propose that these data are best integrated and linked using a robust spatially explicit modeling framework that estimates synoptic carbon flux at a reasonably fine gridded resolution. The California team proposes to develop this integration by nesting existing models (CIMIS, WRF, ACASA) that are based on principles of physics and ecology, which can capture realistic flux estimates.

UC Davis Modeling Framework

The Canadian and California BCN as a whole, will examine a variety of modeling frameworks as described in the accompanying documents, the UCD modeling approach offers particular promise because it links a range of field and image data into physically based climate and ecosystem models. This linkage is important because it is a basis for scaling from field to region and ultimately to the globe. Because the models characterize actual physical phenomena and processes, this allows understanding of fluxes and other individual components and processes.

CIMIS – Linking Automated Field Sensors into an Automated Modeling Framework

The California Irrigation Management Information System (CIMIS) weather station network, run by the State of California Department of Water Resources for 30 years, consists of over 120 automated weather stations located across the state but concentrated in agricultural lands. They collected continuous information about meteorological conditions that is uploaded to a central database at 0.5 hr intervals. These data are compiled daily, which we have used in conjunction with remote sensing satellite data, to estimate spatially distributed (2 km grid) potential evapotranspiration rates (Spatial CIMIS), based on the Penman-Monteith equation, across the state. This data can be converted to estimates of primary productivity when used with the knowledge of current land-cover type. The "Spatial CIMIS" is available from the California CIMIS program as 2km gridded data (Hart et al., 2008), daily on their Spatial CIMIS website (CIMIS.dwr.ca.gov). The California Department of Water Resources released this new operational and fully automated product on their web site in 2009 after five years of testing by the CSTARS lab at UC Davis. Such information supplies the basic data needed to infer carbon fluxes at the regional scale, to quantify sequestered carbon. Both the original CIMIS and Spatial CIMIS models were developed at UC Davis Department of Land, Air, and Water Resources. We have run the National Center for Atmospheric Research's (NCAR) Weather Research Forecast (WRF) model for a year in a prognostic mode linked to Spatial CIMIS to predict potential evapotranspiration for 24, 48, and 72 hrs in advance. This methodology conceptually serves as a model for the integrating field, satellite, and models to predict carbon fluxes and stocks into the BCN. Our cyberinfrastructure modeling methodology also utilizes the scalable characteristics of Kepler scientific workflow systems that are designed for evolving data sources and information delivery capabilities.

Linking Data from Field to Satellite using a Mesoscale Weather Model to Predict Carbon Flux

The NCAR Weather Research Forecast (WRF) model is a next-generation mesoscale numerical weather prediction system designed to serve both operational forecasting and atmospheric research needs. Outputs include both carbon and water fluxes among others (http://www.mmm.ucar.edu/wrf/users/). It features multiple dynamical cores, a 3-dimensional variational (3DVAR) data assimilation system, and a software architecture allowing for computational parallelism and system extensibility. Figure 3 shows an example of a nested domain, with the largest domain, larger than California, which is operationally suitable for 4km resolution and with subdomains at high resolution (1-2km). The algorithm that computes the physical atmospheric processes in WRF is stable to better than 1km^2 resolution, which we have run, and likely to about 200m. WRF is suitable for a broad spectrum of applications across scales ranging from meters to thousands of kilometers. WRF allows researchers the ability to conduct simulations reflecting either real data or idealized configurations. WRF provides operational forecasting a model that is flexible and efficient computationally, while offering the advances in physics, numerics, and data assimilation contributed by the research community. Used in conjunction with CIMIS measurements and flux towers, it is possible to estimate today, statewide carbon sequestration rates of assets at 1-2km grids, and identify and quantify carbon liabilities. The outputs of the WRF model are available from the University of California, Davis Department of Land, Air, and Water Resources.

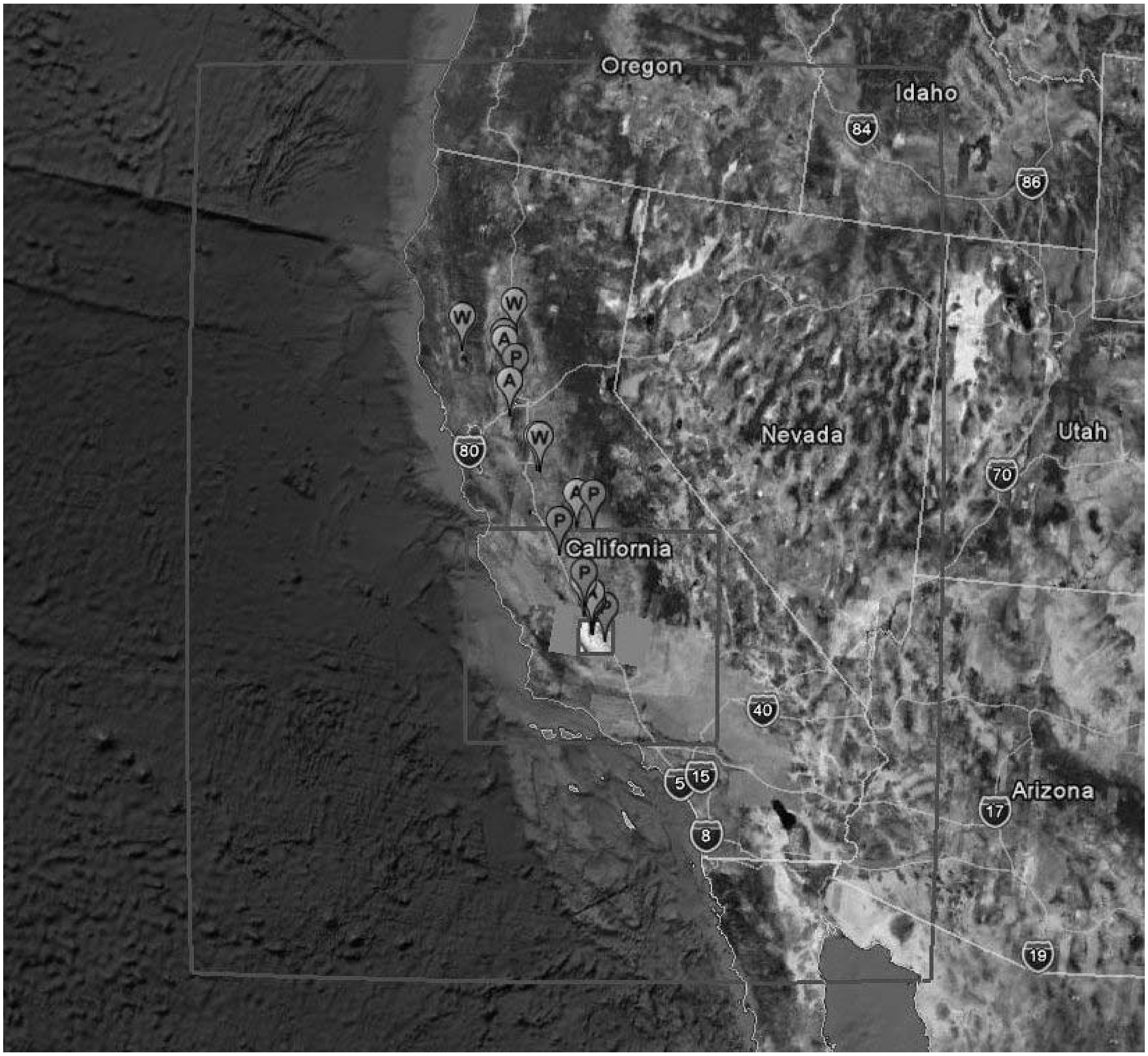

Figure 3: Map image showing a typical sequence of nested WRF-ACASA Domains with 16 km, 4 km, 1km horizontal resolution respectively over California and the Central Valley (red rectangles). Example shows potential carbon credit site locations, indicated by red markers. In this case alphabet letters stand for different crop sites (Pistachio, Almond, Wheat) which can be seen as surrogates for carbon project sites.

The UC Davis Advanced Carbon Atmosphere Soil Assimilation (ACASA) model (Pyles et al., 2000, 2003, Paw U et al., 2010) is one of the most sophisticated models for estimating energy and mass fluxes between the surface and the atmosphere. ACASA is a multi layer (soil and canopy) model that simulates microclimate and surface energy exchanges for each layer, including carbon fluxes and evapotranspiration using a high-order closure turbulence scheme (Fig. 4). ACASA is being configured and implemented as a fully integrated surface layer scheme within WRF (Fig. 5). With these two linked models, it is possible to have accurate estimates of fluxes to 100m grid cells. At this scale, we link flux tower and field data directly with model outputs.

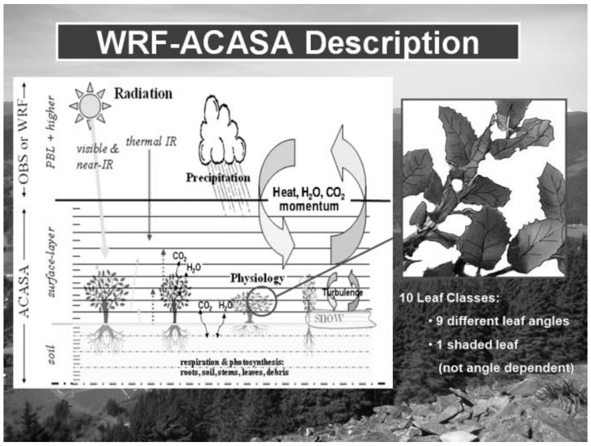

Figure 4: Schematic Overview of ACASA

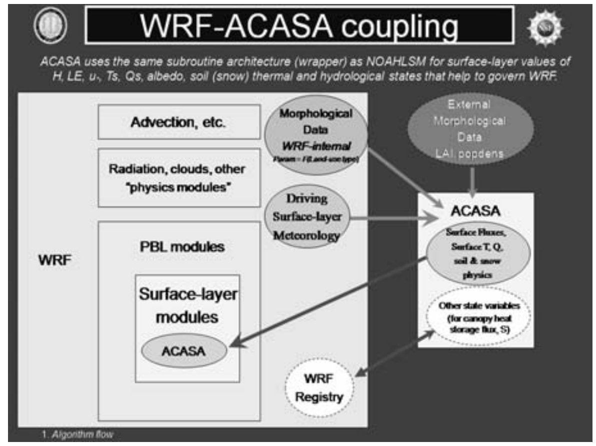

Fig 5: WRF with ACASA surface layer scheme

Simulation domains for both WRF and WRF-ACASA (Fig. 5) have been setup and tested for California at resolutions ranging from 16 km, 4 km, 1km, and down to 250 meters horizontal resolution (Falk et al., 2010, Paw U et al., 2010, Xu et al., 2010). Nested domains are used to effectively downscale coarser resolution input reanalysis and weather forecast data for the higher resolution domains over Regions Of Interest (ROI) while limiting computational expense. Initial simulations have been conducted with input data from the NCEP North American Regional Reanalysis Project (NARR) and from the NCEP/NCAR Reanalysis Project (NNRP). WRF forecast simulations can use input data from the NOAA/ NCEP Rapid Update Cycle (RUC) operational weather prediction system.

These models have been used together in two other limited case analyses at 100m and 200m resolution grids, and can be utilized to provide estimates of fluxes, once data improvements are complete. The linked WRF-ACASA model needs more detailed data inputs than WRF that describe the distribution and attributes of terrestrial ecosystems, including agro-ecosystems to provide accurate estimates of carbon and water fluxes. Parameters that need improvement in the general WRF initialization include land use type or ecosystem/crop type and actual seasonally varying leaf area index (LAI). Remotely sensed data are used to supplement and improve these data inputs. An automated airborne campaign, collecting liDAR and hyperspectral imagery at annual to sub-annual periods, when combined with weather station data and global weather satellites like MODIS make a feasible package to develop the California BCN concept.

A California BCN Business Plan

California is poised to rapidly begin to implement AB 32 (Global warming solutions act) and is preparing for the offset program. Thus the time is ready for the state to develop a monitoring and information distribution system for the carbon market. We have structured this report as an "action framework" as we do not have a full assessment of the financial demand and costing to prepare a business plan. This action framework is a companion to the white paper, "*The Case for a Biospheric Carbon Network*" (the "White Paper"), and to University of Alberta's "*Biospheric Carbon Centre, Canadian Action Plan*" that together provides a framework for the creation of a business plan to develop a monitoring and data analysis network for the carbon market. We are prepared to implement the next phase of the BCN organization in California and have identified potential advisory board members, start up expenses, and potential sources of funding. We recommend that the type of organization to produce BCN data, which will be trusted by the full range of stakeholders, will be a non-profit or Research Institute, possibly affiliated with a University. This concept is consistent with the CARB (2008) Scoping plan that identifies the need to "unleash the potential of California's universities" to address biosequestration and the need to do this with public-private partnerships. This type of organization would be intermediate between data sources (mostly government and universities), data distributors (mostly private like Google Earth, Amazon web services, Cisco Alerts), and third party investment advisors. We are open to collaboration and partnerships to develop a California BCN with relevant organizations.

Organizational Structure

Suggested Advisory Board

Susan Ustin , UC Davis
ShuHua Chen, UC Davis
Steve DeGryze, Terra Global Consulting
Diane Evans, Director, Earth Science and Technology Directorate, Jet Propulsion Laboratory
Guido Franco, California Climate Change Center Program Director
John Gamon, U. Alberta
Steve Hipskin, Chief, Earth Science Division, NASA Ames Research Center
Benjamin Houlton, UC Davis
Bertram Ludäscher, UC Davis
Kyaw Tha Paw U, UC Davis
Carlos Ramirez, USDA Forest Service, Head, Region 5 Remote Sensing Lab
Chris Uhlik, Google Earth

Potential Collaborators and Partners

University of Alberta
NASA
USGS
UC San Diego
University of Madison, Wisconsin
CA Climate Action Team
AmericaView
Sacramento Area Council of Governments
Google Earth Engine
Northrup-Grumman
Ball Aerospace
Autovision, Inc.
SpecTIR, Inc.

Target Market Overview

Regulated CA Carbon Market

AB32 is the "Global Warming Solutions Act" enacted in 2006 by the State of California that established a greenhouse gas reduction program for the State. One of the major components of the significant emission reduction program by 2020 is a cap and trade system for the greenhouse emissions market. Greenhouse gas emitters must submit a permit for every ton of emissions or offset them to fulfill their "compliance obligation" under this new legislation.
The government will reduce the amount of permits over time creating a high demand carbon offset market. Businesses will be required to reduce their emissions through operating practices to fulfill these regulations, creating either less carbon emissions or investing in carbon offset programs. Carbon surpluses can be sold from one business to another allowing company to contain their cost investments. For those sectors of the economy that will not fall under the regulatory compliance of the carbon offset market will provide them with the opportunity of increasing their business profits by selling carbon credits to the regulated economy sectors. This "cap and trade system" creates new incentives for businesses in all economy sectors to invest individually in the most profitable cost opportunity for their emissions reductions.

Offsets are carbon credits produced through the implementation of voluntary emission reduction by those sectors which fall under the no compliance obligation like forestry and agriculture businesses. These credits can then be sold to regulated businesses for carbon offset credits which then result in net zero emissions within the system. It is expected that these offset programs will be more effective in reducing emissions than changes in the operating practices that businesses will have to undertake to emit less greenhouse gas emissions. The California Air Resources Board (ARB) is responsible for developing this regulation, which requires a greenhouse gas emission reduction of roughly 273 million metric tons of carbon dioxide equivalent ($MtCO_2e$) through 2020 representing a 15% emissions reduction below the 2010 levels. California, the world's eighth largest economy, is expected to transform the international carbon market, which is expected to rely mostly on forest carbon offsets for the state itself.

The California cap and trade system proposes to allow regulated businesses to meet up to 8% of their compliance obligation with offsets. The state has currently approximately 8.3 $MtCO_2e$ of offset supply available. Private and public analyses of the cap and trade system predict the full usage of this system as it is expected to be the least expensive opportunity. Offset estimates range from approximately 214-232 $MtCO_2e$ through 2020. Among the four offset project types eligible in the state of California are domestic forestry, urban forestry, livestock (manure/methane) management and the destruction of ozone depleting substances (ODS).

By January 2012, California's Cap-and-Trade regulations go into effect (CARB, 2010). After 2015 all carbon offset programs must be developed according to the 2007 protocol guidelines adopted by ARB. Emission reductions must be real, verifiable, surplus/additional, permanent and enforceable (http://www.westernclimateinitiative.org/the-wci-cap-and-trade-program/faq#question11). Quantification for the WCI protocols must include field forest inventory and approved remote sensing methods (WCI 2010. Offset Protocol Review, http://www.westernclimateinitiative.org/component/remository/func-startdown/230/). The 2007 protocols that apply to some of the forested lands provides an initial approach for regulations.

The initial phase is proposed to cover only avoided deforestation and projects will be required to meet REDD readiness (CARB, 2010 Appendix D). Reduced Emissions from Deforestation and Degradation (REDD) considers carbon sequestered in existing forests as developed in the Bali Action Plan (Peskett et al. 2008). California is developing a pathway for the admissions of the offset credits, beginning with REDD from sector wide emissions reductions in foreign countries, like recent agreements with Acre in Western Brazil and Chiapas in south-eastern Mexico (announced at the Governor's Climate Summit-3, Davis, CA Nov. 17, 2010).
During AB32's first two compliance periods, sector based offsets, such as from REDD, can be used for up to 25% of the total allowed offset volume. In the third compliance period the limit increases to 50%.These maximums with the additional 8% limit apply to each regulated entity's annual compliance obligation. The aim is to maximize California's cap and trade market within the first period of the compliance carbon market accepting forest carbon offsets. Only domestic forestry, ODS and international REDD projects are projected to deliver the necessary carbon offset volume for the market. As of now, domestic forestry and ODS programs have provided 50% of the offset volume while representing 11% of all the registered offset projects. REDD likely supplies 25% of the carbon market and domestic forestry projects can supply high volumes of offsets per project. These two combined offset programs could capture a 50% share of the CA offset market through 2017 and increasing.

Nearly 80% of California's landscape is covered by woody vegetation (Figure 6) and includes both private and public lands. California conifer forests cover 21M Acres (Ac.), hardwoods and woodlands 10M Ac., rangeland 23.5M Ac., desert shrub 14.6M Ac., grasslands 10.9M Ac., and desert hardwoods 5.2M Ac. (Keithley and Bleier, 2008). The California ARB expects that a fully developed REDD market will be operable in California by 2015. The REDD market will involve the private sector investment as well as the government.

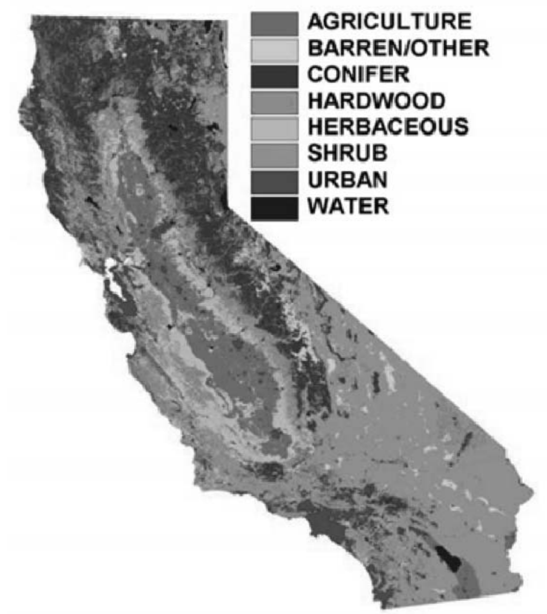

Figure 6. Distribution of California forests[1]. CDF-FRAP multi-source land-cover map classified into major land cover types (more than 77 Wildlife Habitat classes are actually present in the map). Brown et al. (2004) estimate 23.7M Ac. Forests and 56.5 M Ac. Of rangeland.

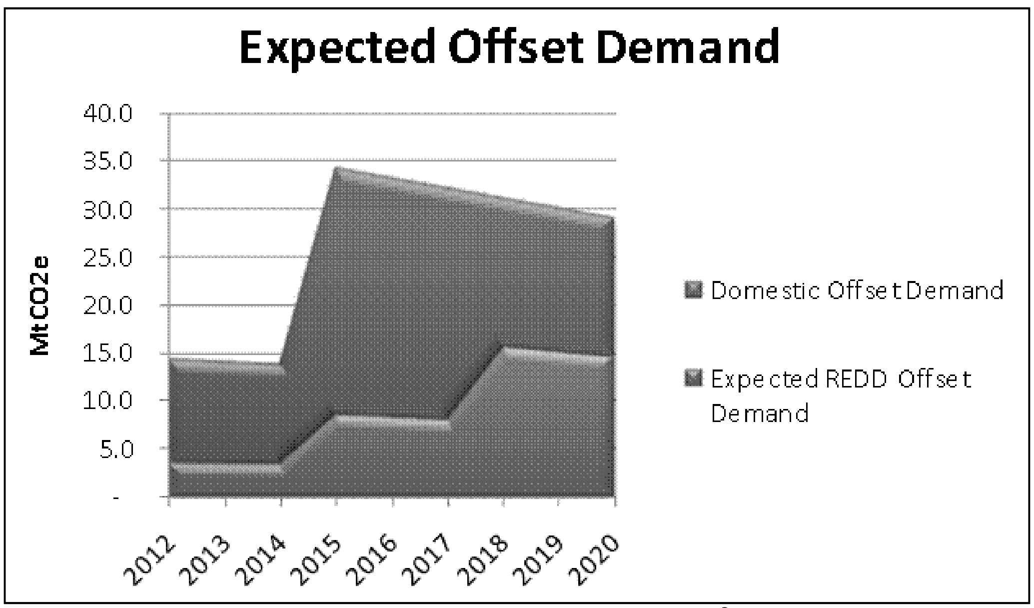

Figure 7. Expected carbon offset demand[2]

---

[1] Reproduced from Brown, S., A. Dushku, T. Pearson, D. Shoch, J. Winsten, S. Sweet, and J. Kadyszewski. 2004. *Carbon Supply from Changes in Management of Forest, Range, and Agricultural Lands of California.*Winrock International, for the California Energy Commission, PIER Energy-Related Environmental Research. 500-04-068F.

[2] Reproduced from Shillinglaw, B., M.K. Hanlon, and M. Meizlish. 2010. *The California carbon market: implications for forest carbon offset investment*. Market Outlook. New Forests, San Francisco, CA.

California predicts a doubling of the demand for carbon offsets and a five times increase in the demand for REDD offsets by 2020 (Figure 7). The California BCN has a significant opportunity to provide a flexible scientifically based platform and database for evaluating biologically based carbon offset programs. California's early market designs may serve as a model for the U.S. or other government-level programs.

Sector focus – Forestry and Agriculture sectors

Californian lands are classified into three main groups for the analyses presented here: forests, rangelands, and agricultural lands. Forests (about 23.7 million acres) include conifers, hardwoods, and mixed classes; rangelands (about 56.5 million acres) include a variety of non-woody (e.g., pasture, grasslands) and woody ecosystems (e.g., oak woodlands, chaparral); and agricultural lands (about 9.9 million acres) include a wide range of non-woody crops such as small grains, vegetables, berries and woody crops such as vineyards and orchards.

Current plans for developing a cap-and-trade system for forest lands depend on a cost of carbon that is realistic when meeting requirements for trade. If costs can be reduced so credits are feasible, the large extent of forest acreage of California presents significant opportunities for carbon sequestration (Figure 8). Previous research found that the cost of carbon sequestration from changing forest management practices is relatively high (Brown et al., 2004). No forest management project, regardless of length of project, can provide carbon sequestration at less than \$2.70/MT CO_2 (Brown et al., 2004). The largest potential source of carbon from forest management is for lengthening rotation by five years, which can potentially provide 2.16 to 3.91 MT CO_2 at a cost of less than \$13.60 per ton. For afforestation of rangelands, longer durations produce lower cost carbon. Afforestation of rangelands provides the most carbon at the least cost ($\leq$ \$2.70/MT CO_2)—about 33 MT CO_2 at 20 years to 4.57 billion MT CO_2 at 80 years (Brown et al., 2004). In agriculture, only about 1% of the agricultural soils in California are currently managed with conservation tillage (CT) (Brown et al., 2004). The rates of carbon sequestration from CT are assumed to be in the range of 0.35-0.61 t/ha/yr, this will produce a low value for credits. The CT must be no more than \$6.45/ha/yr unless it can be produced at no net cost to farming (Brown et al., 2004). With a focus on agricultural carbon sequestration from conservation tillage, which increases soil carbon up to a period of about 20 years maximum, seems to offer the greatest potential for producing carbon on agricultural land in California. It is estimated that California agricultural land could produce up to 3.9 $MTCO_2$ /year through CT.

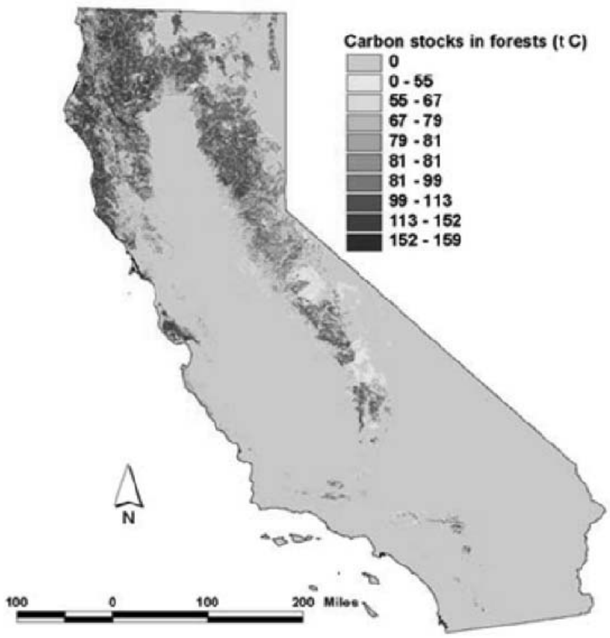

Figure 8. Map of carbon stocks for California forests[3]

California agriculture grows more than half of the nation's fruits, vegetables and nuts producing more than 350 crop varieties (http://www.agclassroom.org/kids/stats/california.pdf). Of those, the following are commercially-produced only in California: almonds, artichokes, dates, kiwifruit, figs, olives, persimmons, pomegranates, dried plums, raisins, clingstone peaches, pistachios, sweet rice, ladino clover seed, and walnuts.

Proposed Next Steps and Timeline for Starting a BCN Program

A number of factors have made planning for starting a BCN uncertain this year. First, the plan for implementing California's AB 32 has rapidly changed the timing and scope of a carbon market for carbon sequestration. Additional uncertainty about the state's role in implementing AB 32, has resulted from the severe recession and limited funding at the state level for the past three years, the fate of the California ballot initiative 23 [which would have mandated suspension of AB 32] that failed last November, along with uncertainty about the gubernatorial election outcome, which have together, inhibited development of a BCN business plan. Nonetheless, California is now poised to move rapidly into the cap-and-trade program and the need for developing a cost-effective monitoring and validation program for carbon credits is now at a critical stage and its development now rests on accurate estimates of carbon credits—the focus of this California action framework. The CCSIP budget was asymmetrically allocated to the Canadian plan at the expense of developing the California plan to the same depth. When we made this project decision, we anticipated that much of the Canadian plan could be implemented

---

[3] Reproduced from Brown, S., A. Dushku, T. Pearson, D. Shoch, J. Winsten, S. Sweet, and J. Kadyszewski. 2004. *Carbon Supply from Changes in Management of Forest, Range, and Agricultural Lands of California.*Winrock International, for the California Energy Commission, PIER Energy-Related Environmental Research. 500-04-068F.

in California and that the work did not need to be entirely duplicated. Nonetheless, the CCSIP investigation revealed that California's plans were more focused on measurement of stocks while the Canadian plan focused more on measuring and monitoring fluxes. Here, we propose that continued development of a formal California business plan is now appropriate. We propose two activities for the 2011-2012 period that will continue to move a California business plan into action.

2011/2012 CA External Development of a Focused Business Plan based on identifyin1 external stakeholders, donors and clients funding requires: $50,000 for 1 fundraising expert at 50% FTE.

2012/2013 BCN Regional Pilot Study is needed to test the proposed BCN CyberInfrastructure and demonstrate that a cost-effective regional model can be adopted that will supply accurate information about current carbon stocks at sufficiently high spatial resolution for the carbon market. Among the goals that must be accomplished is to demonstrate that this program can meet the requirements of the CARB implementation plan. Funding required: $1,500,000 for three years: FTE: 50% Director (science lead, outreach coordinator, fundraising), 25% financial staff, 3 post-doc level computer scientists, modelers, and analysts.

Potential funding sources

California Government

State of California Funding for Climate Change Research

Because California's climate impacts cover a broad spectrum of traditional disciplines, California has established the California Climate Change Center to address cross-cutting multidisciplinary problems that are outside the scope of traditional agencies. This program supports projects that are vital to the state but which do not naturally fit within the other environmental agencies programs.

California Energy Commission Public Interest Energy Research (PIER) Program's climate change research plan(s) provide topical guidance for the program. The University of California Office of the President administers the competitive research grants program for the state.

Air Quality Resource Board (ARB)

ARB has a lead role in implementing AB32. The California Air Resources Board (ARB) will work with stakeholders to design a California cap-and-trade program that is enforceable and meets the requirements of AB 32, including the need to consider any potential impacts on disproportionately impacted communities. Consistent with AB 32, ARB adopted the cap-and-trade regulation by January 1, 2011, and the program begins in 2012.

California Energy Commission (CEC)

Serving on the Climate Action Team (CAT) – the CEC leads the CAT Land Use and Local Government (LUSCAT) sector group and participates on 11 CAT subgroups responsible for developing action items that will result in quantifiable greenhouse gas emission reductions.

California Environmental Protection Agency (Cal EPA)

The Cal EPA develops, implements, and maintains the state's environmental protection laws, which include the protection of clean air designating carbon emissions as pollution.

Department of Water Resources (CA DWR)

Climate change is already affecting the state's water resources. In the past five years, the DWR has had a leadership role in mitigating greenhouse gas (GHG) emissions and in positioning California to adapt to changes in California climate and water resources.

Department of Food and Agriculture (CDFA)

Climate change will have a profound impact on CA agriculture. The CDFA leads efforts for compliance in reductions of GHG and develop programs for increasing sequestration of carbon.

Federal Government (US)

Funding from the US federal government is available both through small business grants and through research funding from federal agencies. Small business grant opportunities are available at www.Grants-Government.info. The full list of federally available grants is available at Grants.gov. Agencies, including the EPA and DOE, post their funding opportunities to the site. There are roughly $500 billion in annual awards through more than 1,000 programs. Some key agencies are listed below.

National Science Foundation (NSF)-Directorate for Geosciences

The directorate supports basic research in disciplinary aspects of the carbon cycle and hydrology. NSF Geosciences supports the National Center for Airborne Laser Mapping (NCALM), jointly managed by the Department of Earth and Planetary Science, University of California, Berkeley, which flys an airborne liDAR, available for university research.

National Science Foundation (NSF)-Directorate for Biological Sciences

A new NSF solicitation supports a new Environmental Synthesis Center supplementing UC Santa Barbara's National Center for Ecological Analysis and Synthesis program. The host campus for the new program has not yet been announced but this new program could play a role in evolving methods for quantifying carbon sequestration.

Department of Energy (DOE) –Office of Biological and Environmental Research (BER) and Climate and Environmental Sciences Division (CESD)

BER supports fundamental research and technology development toward developing complex systems understanding relative to advancing DOE missions in energy, climate, and environment. CESD supports fundamental research toward developing systems understanding of climate change, to advance DOE missions in energy, climate, and environment. DOE supports research in carbon sequestration technologies. DOE Laboratories in California with mandates in climate modeling and climate change research include Livermore National Laboratory and Lawrence Berkeley National Laboratory. These DOE laboratories, along with Los Alamos National Laboratory, are managed by the University of California and have numerous ongoing collaborations with UC faculty.

Environmental Protection Agency (EPA)- Black Carbon, Climate and Air Quality

The EPA funds research that investigates the emission sources, the global to local scale emissions inventory, and applies modeling tools to assess black carbon, co-pollutants and other short-lived climate forcers in a climate and air quality context.

United States Geological Survey (USGS)

The USGS provides impartial information on the health of U.S. ecosystems and environment, natural hazards, natural resources, the impacts of climate and land-use changes, and the core science systems that help us provide timely, relevant, and useable information. The USGS provides a national geospatial database for Landsat and other satellite data, global and continental digital elevation maps, digital national land use maps, digital high resolution orthophotos and other archived information.

United States Department of Agriculture (USDA)-Agriculture and Food Research Initiative

This program, offered in partnership with the Research Opportunities in Space and Earth Sciences (ROSES) 2010 program of the National Aeronautics and Space Administration (NASA) and the U.S. Forest Service, contributes toward the goals of the U.S. Global Change Research Program (USGCRP) and the U.S. Ocean Action Plan by providing critical scientific information about the movement of carbon in the environment and potential near- and long-term changes in the carbon cycle, including the role of and implications for societal actions.

The USDA contributes to carbon credit information through the U.S. Forest Service's Forest Inventory and Analysis National Program (FIA) program , the Natural Resources Conservation Service's soil database and soil conservation programs, among other carbon relevant programs.

Relevant Foundations

Sidney E. Frank Foundation

At this juncture, the foundation has two primary objectives: to think globally about what can be created in the world to improve the future including environmental projects and climate change research; and to respect those areas that enabled Sidney to live a full robust life. As the foundation solidifies its infrastructure, the family seeks ways to enable positive and life altering opportunities for others. To that end, projects to date have been in five topic areas: including one in the environment (climate change and clean energy),. While discretionary funds may occur elsewhere, the foundation's geographic focus includes California among other US states and international countries. The Sidney E. Frank foundation has assets of $400MM with a charge of giving away $20MM annually. Through lean operations and sound fiscal investments, the family's goal is to continue to grow assets to enable the capacity to even more substantially impact the world in which we live as a permanent legacy to the life lived by Sidney E. Frank.

The W.M. Keck Foundation

The Science and Engineering Research Program seeks to benefit humanity by supporting projects that are distinctive and novel in their approach, question the prevailing paradigm, or have potential to break open new territory in their field. They support pioneering science and engineering research and the development of promising new technologies and to facilitate the purchase of advanced instruments where such instruments would further specific research ventures. Historically, grants range from $500k to $2M. Funding is awarded to universities and institutions nationwide for projects in science and engineering research that: focus on important and emerging areas of research, potential to develop breakthrough technologies, instrumentation or methodologies, are innovative, distinctive and interdisciplinary, have high levels of risk due to challenging prevailing paradigm, and have potential to have transformative importance.

The David and Lucile Packard Foundation

The Foundation was created in 1964 by David Packard (1912–1996), the co-founder of the Hewlett-Packard Company, and Lucile Salter Packard (1914–1987). Throughout their lives in business and philanthropy, the Packards sought to use private funds for the public good, giving back to a society that enabled them to prosper. The foundation invests in innovative people and organizations to enable the creative pursuit of science, conserve and restore earth's natural systems, and its agriculture program goal is to achieve a 20 percent reduction by 2020 in projected net greenhouse gas emissions and nitrogen pollution caused by agriculture in the United States and biofuel production globally.

American Forest Foundation (AFF)

AFF is interested in funding projects encouraging the long-term sustainability of America's forests, restoring wildlife habitat, and developing quality environmental education programs, to assure that Americans today, and in the future, enjoy healthy, growing forests. Currently, AFF is working with a diverse group of partners to advance climate options that will allow for family forest owners to make meaningful contributions to carbon offset efforts. AFF initiated regional carbon offset aggregation pilot projects in 2008.

National Forest Foundation-Carbon Capital Fund

The Carbon Capital Fund provides financial support for carbon sequestration demonstration projects on National Forest lands, showing the value of trees and forests in a larger climate change strategy. These projects plant trees in naturally deforested areas, sequestering carbon and providing additional benefits to the forests.

Ag Biomass Foundation, Inc.

The Ag Biomass Foundation is an innovative, solution-oriented nonprofit dedicated to expanding the biomass industry by improving public policy through environmental mitigation and compliance at the grassroots level. The Gap Funding Initiative, a program in incubation, is designed to assist in the development and implementation of biomass projects. In addition, we are cultivating a regulatory processing assistance service for project fruition. The Ag Biomass

Foundation combines knowledge, experience and support from its Friends Of group, alliances and experts in sustainable agricultural and biomass energy system.

Pew Charitable Trust

Pew seeks the adoption of mandatory limits on greenhouse gas emissions in the United States in order to counter the serious threats posed by global warming. The Pew Center on Global Climate Change, launched in 1998, advances debate on climate change and reduction of greenhouse gases through research, public education, and cooperation with business.

References

Brown, S., A. Dushku, T. Pearson, D. Shoch, J. Winsten, S. Sweet, and J. Kadyszewski. 2004. Carbon Supply From Changes In Management of Forest, Range, and Agricultural Lands of California. Publication Number: 500-04-068F. Winrock International, for the California Energy Commission, PIER Energy-Related Environmental Research, March 2004.

CA Air Resources Board (CARB) 2010. Proposed regulation to implement the California cap-and-trade program. Vol. 2 Appendix D. 715p.

CA Air Resources Board (CARB) 2008. Climate Change Scoping Plan.

Falk, M., Pyles, R.D., Marras, S., Spano, D., Snyder, R.L., and Paw U, K.T. (2010), Coupling of the WRF and ACASA models for urban environments: two case studies, presented at the Ninth Symposium on the Urban Environment, Amer. Meteorol. Soc., Keystone, CO, 1-6 Aug.

Falk, M., (2010), Regional Fluxes of Energy and Carbon over Urban Areas from a Coupled WRF-ACASA Model, presented at the Atmospheric Seminar Series (AS3), Atmospheric, Earth, and Energy Division, Lawrence Livermore National Laboratory, CA, 3 Nov.

Falk, M., Pyles, R.D., Marras, S., Spano, D., Snyder, R.L., and Paw U, K.T. (2010), A Regional Study of Urban Fluxes from a Coupled WRF-ACASA Model, Abstract B21E-0372 presented at 2010 Fall Meeting, AGU, San Francisco, Calif., 13-17 Dec.

Governor's Climate Summit-3, Davis, CA Nov. 15-16, 2010.

Hart, Q.J., M. Brunagch, B. Temesgen, C. Rueda, S. Ustin, K. Frame. 2009. Daily reference evapotranspiration for California using satellite imagery and weather station measurement interpolation. Civil Engineering and Environmental Systems 26:19-33.

Jaeger E, Altintas I, Zhang J, Ludäscher B, Pennington D, Michener W. 2005. A Scientific Workflow Approach to Distributed Geospatial Data Processing using Web Services. *17th International Conference on Scientific and Statistical Database Management* (SSDBM'05), 27-29 June 2005, Santa Barbara, California.

Kleithley, C and C. Bleier. 2008. An adaptation plan for California's forest sector and rangelands.

http://www.fire.ca.gov/resource_mgt/resource_mgt_EPRP_Climate/Climate_change_Forestry_Adaptation_strategies_12-11-10.pdf

Koltunov, A.and S.L. Ustin 2007. Early fire detection using non-linear multitemporal prediction of thermal imagery. Remote Sensing of Environment 110: 18-28.

Koltunov A, Ustin SL, Asner GP, Fung I. 2009. Selective logging changes forest phenology in the Brazilian Amazon: Evidence from MODIS image time series analysis. Remote Sensing of Environment 113: 2431-2440.

Ludäscher, B., Altintas I, Berkley C, Higgins D, Jaeger E, Jones M, Lee EA, Tao J, Zhao Y. 2006. Scientific workflow management and the Kepler system. Concurrency and Computation-Practice & Experience 18: 1039-1065.

B. Ludäscher B, Altintas I, Bowers S, Cummings J, Critchlow T, Deelman E, Roure DD, Freire J, Goble C, Jones M, Klasky S, McPhillips T, Podhorszki N, Silva C, Taylor I, and Vouk M. 2009. Scientific Process Automation and Workflow Management, In A. Shoshani and D. Rotem, editors, *Scientific Data Management: Challenges, Existing Technology, and Deployment*, Computational Science Series, chapter 13. Chapman & Hall/CRC.

Paw U KT., Xu L, Pyles RD, and Falk M. (2010), A Comparison of Observations and Process-based Simulations (WRF-ACASA and WRF-NOAH) for Scaling Controls of Net Ecosystem Exchange (NEE) from the leaf to the regional and global scales (Invited), Abstract B41K-04 presented at 2010 Fall Meeting, AGU, San Francisco, Calif., 13-17 Dec.

Peskett L, Huberman D, Bowen-Jones E, Edwards G, Brown J. 2008. Making REDD work for the poor. Poverty Environment Partnership report. (www.povertyenvironment.net/pop)

Pyles RD, Weare BC, and KT Paw U. 2000. The UCD advanced canopy-atmosphere-soil algorithm: Comparisons with observations from different climate and vegetation regimes. Quarterly Journal of the Royal Meteorological Society 126: 2951-2980 Part A

Pyles RD, Weare BC, KT Paw U and W Gustafson. 2003. Coupling between the University of California, Davis, Advanced Canopy-Atmosphere-Soil Algorithm (ACASA) and MM5: Preliminary results for July 1998 for western North America. Journal of Applied Meteorology 42: 557-569.

Trombetti, M., D. Riaño, M.A. Rubio, Y.B.Cheng, and S.L. Ustin, 2008. Multi-temporal vegetation canopy water content retrieval and interpretation using artificial neural networks for the continental USA. Remote Sensing of Environment 12(1): 204-215.

Xu, L., Pyles, R.D., and Paw U, K.T. (2010), Coupling WRF and the land surface model ACASA for Future Carbon Dioxide Simulation, Abstract B31B-0295 presented at 2010 Fall Meeting, AGU, San Francisco, Calif., 13-17 Dec.

Xu, L., Pyles, R.D. and Paw U, K.T. (2010), Simulating Present and Future Water, Energy, and Carbon Dioxide Fluxes on a Regional Scale using the WRF/ACASA Coupled Model, presented at the 29th Conference on Agricultural and Forest Meteorology, Amer. Meteorol. Soc., Keystone, CO, 1-6 Aug.