Project Title: Synthesis of Remote Sensing and Field Observations to Model and Understand Disturbance and Climate Effects on the Carbon Balance of Oregon & Northern California

Project ID: 0010744

Program Manager: Roger C. Dahlman Phone: 301-903-4951 Division: SC-23.3

PI: Beverly E. Law

Institution: Oregon State University

Award Register#: ER63917 (DE-FG02-04ER63917)

Institution URL: www.oregonstate.edu

Project URL: http://terraweb.forestry.oregonstate.edu

KEYWORDS: regional carbon balance, NEP, biomass, eddy covariance fluxes, disturbance, climate, process modeling, remote sensing, AmeriFlux

GOAL: To develop and apply an approach to quantify and understand regional carbon balances for the North American Carbon Program.

OBJECTIVE: As an element of NACP research, the project methodology is a two pronged approach that derives and evaluates a regional carbon (C) budget for Oregon and N. California. The research compares "bottom -up" and "top-down" methods, and develops prototype analytical systems for regional analysis of the carbon balance that are potentially applicable to other continental regions, and that can be used to explore climate, disturbance and land-use effects on the carbon cycle. Objectives are: 1) Improve, test and apply a bottom up approach that synthesizes a spatially nested hierarchy of observations (multispectral remote sensing, inventories, flux and extensive sites), and the Biome-BGC model to quantify the C balance across the region; 2) Improve, test and apply a top down approach for regional and global C flux modeling that uses a model-data fusion scheme (MODIS products, AmeriFlux, atmospheric CO2 concentration network), and a boundary layer model to estimate net ecosystem production (NEP) across the region and partition it among GPP, R(a) and R(h). 3) Provide critical understanding of the controls on regional C balance (how NEP and carbon stocks are influenced by disturbance from fire and management, land use, and interannual climate variation). The key science questions are, "What are the magnitudes and distributions of C sources and sinks on seasonal to decadal time scales, and what processes are controlling their dynamics? What are regional spatial and temporal variations of C sources and sinks? What are the errors and uncertainties in the data products and results (i.e., in situ observations, remote sensing, models)?

APPROACH: In performing the regional analysis, the research plan for the bottom-up approach uses a nested hierarchy of observations that include AmeriFlux data (i.e., net ecosystem exchange (NEE) from eddy covariance and associated biometric data), intermediate intensity inventories from an extended plot array partially developed from the PI's previous research, Forest Service FIA and CVS inventory data, LAI, time since disturbance, disturbance type, and cover type from Landsat developed in this study, and productivity estimates from MODIS algorithms. The BIOME-BGC model was used to integrate information from these sources and quantify C balance across the region. The top-down approach uses NEE data from AmeriFlux sites along with high precision CO2 concentration data from AmeriFlux towers and four new calibrated CO2 sites along an east-west gradient from the coast, and regional NEE fluxes are estimated for a 10,000 sq km area using a boundary layer (BL) model.

RESULTS:

Field Results:

Regional Carbon Stocks.
The potential to store additional carbon in Pacific Northwest forests is among the highest in the world because much of the area has forests that are long-lived (e.g. Douglas-fir) and maintain relatively high productivity and biomass for decades to centuries. In Oregon and Northern California (4.4 x 107 ha), total live biomass of forests is estimated at 2.71 ± 0.28 Pg C (mean of 12 kg C ha-1) in the period 1991-1999. Total dead biomass (does not include fine woody debris or litter stocks) of forests in the region was 0.51 ± 0.19 Pg C, and total NPP was 0.109 ± 0.001 Pg C y-1. The majority of live and dead biomass (~65%) is on public lands (53% of forested land). If forests were managed for maximum carbon sequestration total carbon stocks could theoretically double in the Coast Range, West Cascades, Sierra Nevada, and East Cascades and triple in the Klamath Mountains. Our results indicate that Oregon and California forests are at 54% of theoretical maximum levels (3.2 ± 0.34 Pg C versus 5.9 ± 1.34 Pg C) given the absence of stand-replacing disturbance (i.e. catastrophic fire) (Hudiburg et al. 2008).

Age-related findings and modeling implications.
Trends in NPP with age vary among ecoregions, which suggests caution in generalizing that NPP declines in late succession. Contrary to commonly accepted patterns of biomass stabilization or decline, biomass was still increasing in stands over 300 years in the Coast Range, the Sierra Nevada and the West Cascades, and in stands over 600 years in the Klamath Mountains (Hudiburg et al. 2008).

Age dependence of necromass and biomass.
Our efforts to model carbon dynamics require dynamic parameterization of biomass accumulation and mortality as a function of forest age. Therefore, to model carbon fluxes across Oregon and California we require ecoregion-specific parameterization of these biological relationships. Our field measurements and federal inventory data show ecoregion differences in biomass accumulation and mortality.

Pyrogenic carbon emissions.
To properly model Net Biome Production across Oregon and Northern California it is necessary to quantify the pyrogenic carbon releases that result from wildfire. Biome-BGC requires prescription of emissions and carbon transformations into dead pools (e.g. litter, coarse woody debris), yet observations were not previously available for our region. Disturbance mapping can quantify area affected by wildfire, but combustion factors relating fire severity to the fraction of biomass combusted are also required. Quantification of combustion factors across many forest C pools showed that combustion

factors were highest for litter, humus, and foliage, lowest for live woody pools (Campbell et al. 2008, Campbell et al. 2007, Turner et al. 2007). Combustion factors increased with burn severity, but were not nearly as high for tree stemwood as previously assumed. We estimate the total pyrogenic carbon emissions from the Biscuit Fire to be between 3.0 and 3.9 Tg C (16 and 19 Mg C ha-1), close to our initial estimate of 3.0 Tg C (Law et al. 2004). We estimate that this flux is approximately 16 times the annual net ecosystem production of this landscape prior to the wildfire. We estimate that wildfires of 2002 may have reduced mean net biome production across the state of Oregon by nearly half (Campbell et al. 2007, Law et al. 2004).

Forest thinning effects on carbon fluxes.
The thinning of forests to reduce fire hazard is a wide spread type of forest disturbance not explicitly accounted for in our modeling, yet we recognize the need to do so. Aboveground Net Primary Production is reduced by thinning, as prescribed in the Forest Hill, CA study area of our intensive plots, and often returns to near pre-thinned levels by 16 years, more time than was previously assumed (5 yr). Thinning in this study appears to shift some production from above ground to belowground and from trees to understory. Thinning reduced soil CO_2 efflux only modestly and temporarily (Campbell et al. 2008, Campbell et al. 2007), contrary to expectations due to reduced live fine root mass for autotrophic respiration.

Remote Sensing Results:

The remote sensing component of the project created multiple layers from Landsat data for inputs to both bottom-up and top-down modeling. We produced a disturbance map (stand replacement change detection) for 1972 through 2005, LAI, and aggregated forest cover for the study region (reduced to a few land cover types). Similar concepts were applied at a coarser scale to produce a one-time disturbance map for the U.S. (Goward et al. 2008).

Stand replacement disturbance mapping. A no-cost extension was requested to finalize the results of stand replacement disturbance(SRD) mapping for Northern CA using a modification of methods described in Healey et al. (*in review*). In particular, manual cleanup of misclassified areas was performed using tasseled cap transformed imagery stacks to detect false change. Misclassified disturbance appeared to be due to both the use of multispectral scanner (MSS) imagery and the presence of more open canopy and xeric vegetation types. Final classification showed 52% of the 19M ha area was forest that had not experienced change due to stand replacing disturbance over the 30 year study period, 44% was non-forest, and while about 2% of the area had been clearcut less than 1% had been replaced due to wildfire, and 0.02% had experienced multiple stand-replacing disturbances. Results are below:

Class	hectares	% of total
Water	430,400	2.24%
Non-Forest	8,348,747	43.53%
Forest-no change	9,936,602	51.81%
Cut 72-77	19,555	0.10%

Cut 77-85	73,795	0.38%
Cut 85-90	80,969	0.42%
Cut 90-95	22,047	0.11%
Cut 95-00	48,764	0.25%
Cut 00-04	29,293	0.15%
Fire 72-77	6,342	0.03%
Fire 77-85	24,813	0.13%
Fire 85-90	39,732	0.21%
Fire 90-95	22,414	0.12%
Fire 95-00	18,175	0.09%
Fire 00-04	13,079	0.07%
Multiple Disturbances	2,953	0.02%
total area	19,117,680	

Once the final Stand Replacing Disturbance map was produced following the manual cleanup, formal accuracy assessment was recomputed. Overall accuracy of the Northern California disturbance map was 82% (kappa = 0.70). Our SRD map was compared to a similar map produced by the USFS Region 5 Remote Sensing Laboratory which found good overall agreement between products. An area that had poor agreement in the Lassen National Forest was manually modified using the same methodology mentioned above.

Frequency and size of disturbances varied greatly by ecoregion. This variation appeared to be due in part to ownership differences such as amounts of wilderness versus amounts of private industrial lands. Differences in vegetation type also appear to account for very disparate amounts of harvest. This is especially noticeable when comparing the northern coastal ecoregion (in which we observed a large amount of harvest), and the oak chaparral ecoregion which have almost no harvest and a much smaller presence of conifers.

Fire sizes, frequency and distribution also varied widely both temporally and by ecoregion. Reasons for this were not investigated but likely had to do with variations in climate, elevation, and vegetation type.

Continuous age mapping. Attempts to model stand age greater than 30 years using 2000 era Landsat imagery and ground data from FIA periodic and annual inventory plots (from the 1990's and 2000-2005 respectively) were unsuccessful. Efforts included attempts to model age as both continuous and thematic (2-3 age classes), to model each ecoregion individually (in order to improve relationships), as well as taking into account effects of aspect, vegetation type, and disturbance. This leads us to conclude that FIA stand age cannot be used to map age in all ecoregions across the ORCA study area. Relationships between stand age and spectral data exist in Western Oregon closed-canopy conifer forests characterized primarily by stand replacing disturbances. Relationships are not strong enough in areas of open and mixed conifer stands and those characterized primarily by partial disturbances, (namely the East Cascades, Blue Mountain, Klamath, and Sierra Nevada ecoregions) (Duane et al. in prep).

Continuous LAI mapping. LAI was successfully mapped as a continuous variable for all conifer and mixed forest regions of Oregon and Northern California. Maps were produced using a predictive modeling approach, relating Landsat ETM+ imagery from 2000 and LAI measured at all ORCA intermediate plots. Models were developed separately for each ecoregion (the Coast range, Klamath and West Cascades ecoregions were combined into one western ecoregion model.) n The LAI surface is used in the Biome-BGC modeling by serving as an independent check on the prognostic LAI estimates produced by the model. Preliminary comparisons of the Landsat-based LAI and the Biome-BGC LAI show close similarity in terms of capturing the general decrease in LAI over the east to west climatic gradient in Oregon and capturing the generally lower LAI in recently disturbed areas.

Top-down Modeling Results:

We have successfully accomplished to set up a top-down modeling approach that couples a simple and robust but detailed biosphere carbon flux model to a sophisticated atmospheric transport model. The method makes use of state-of-the-art input data sets (e.g. CarbonTracker, MODIS products, DayMet, PRISM meteorology, LandSat products, etc.), thus achieving to bring together the best information available to constrain regional carbon modeling methods.

The top-down modeling has three components: (1) A biosphere flux model (CFLUX; Turner et al. 2006) that provides the carbon exchange between surface and atmosphere. The model has to be applied in spatial mode (i.e., produce surface carbon flux maps for the entire ORCA modeling domain), high temporal resolution (hourly timesteps, or smaller), and must be able to capture the effect of spatial variability in climate, ecoregion, land cover type, disturbance type, and stand age. (2) Atmospheric transport modeling (WRF-STILT) that links the modeled surface carbon emissions to atmospheric measurements carried out at monitoring sites within the modeling domain. The applied modeling approach has to be capable of capturing local to regional atmospheric flow conditions as a function of mesoscale meteorological drivers and topography, as well as simulate atmospheric mixing as a function of turbulence conditions and boundary layer growth. (3) An atmospheric measurement component that provides high-accuracy time series of atmospheric CO_2 concentration. These data serve as a reference to evaluate and optimized the top-down modeling approach, which simulates atmospheric CO_2 concentrations by coupling the biosphere flux model with atmospheric transport modeling.

The top-down modeling approach has been set back due to delays in the establishment of a high-precision CO_2 concentration network and the provision of DayMet meteorological field which are required to operate the biosphere flux model in spatial mode. However, a network of high-precision CO_2 measurement devices was installed summer 2006, and DayMet data are available through 2005. Once we have DayMet for 2006 onward, we will be able to apply the top-down model across the region.

Bottom-up Modeling Results:

The annual carbon sink from Net Biome Production (i.e. the terrestrial carbon sink) for Oregon amounts to 40% of the annual fossil fuel carbon source for the state (Turner et al. 2007), similar to our estimates when we only considered forests of western Oregon (Law et al. 2004). In Law et al. 2004, the land-based sink decreased from 50% to 30% in 2002, the year of the 200,000 ha Biscuit Fire.

Most of the Net Biome Production in Oregon is occurring on public forest land. Harvest reductions on public forestland in the 1990s mandated by the Northwest Forest Plan have resulted in large areas of young to mature forests that are carbon sinks, large areas of old-growth forest that are near carbon equilibrium, relatively small areas of recently disturbed forest that are carbon sources, and relatively little carbon removed from the forest in the form of logs (Turner et al. 2007).

Direct carbon emissions from forest fires in Oregon were not a large offset to the terrestrial carbon sink from net ecosystem production in the 1980s and 1990s. However, in severe fire years such as 2002, the magnitude of the direct fire emissions can reach 50% of the average net biome production in previous years, and 20% of the fossil fuel carbon source for that year (Turner et al. 2007, Law et al. 2004).

There is a large interannual variation in state-wide net ecosystem production (NEP) for Oregon that is associated with interannual climate variation. The pattern of NEP response to interannual variation in climate, and the nature of projected changes in regional climate over the coming century, support the likelihood of a positive feedback to climate change in this heterogeneous region (Turner et al. 2007).

Comparison at the county level of forest carbon stocks from the ORCA Biome-BGC simulations with independent estimates derived from USDA Forest Service inventory data show good agreement, with bias in lower biomass forests. More rigorous comparisons within vegetation type in each ecoregion will be conducted to determine causes of model bias.

The ORCA bottom-up modeling approach is effective in simulating spatial and temporal patterns in forest harvest removals. Comparison of simulated removals to volumes removed as reported by the Oregon Department of forestry showed good agreement. Annual harvest removals amount to about 50% of annual net ecosystem production for all forest land in Oregon (Turner et al. 2007).

Carbon cycle modeling approaches that do not account for stand age in forests are effective in assessing the effects of interannual variation in climate on carbon flux, but largely miss the effects of disturbance on net ecosystem production. These effects have a significant influence on the absolute carbon exchange with the atmosphere, and on the kind of carbon accounting needed for carbon dioxide emissions inventories (Turner 2006).

Validation of estimates for regional carbon stocks derived from spatially-distributed ecosystem models is a significant challenge. In the ORCA project we investigated the application of lidar remote sensing for this purpose. A strong relationship of lidar-derived canopy height and measured forest biomass at the plot scale was found in conifer forests of western Oregon. Application of that relationship over a large area covered by air-borne lidar flights provided a strong basis for evaluating our carbon stock estimates for those areas from process model simulations (Lefsky et al. 2005).

Biogeochemical models offer an important means of understanding carbon dynamics, but the computational complexity of many models means that modeling all grid cells on a large region is computationally challenging. We have explored several alternative schemes for reducing computation demands. These include sampling the landscape and filling in by interpolations based on model inputs (Kennedy et al. 2006) and making models runs on a limited number of combinations of cover type and disturbance history within each 1 km grid cell rather than running the model on every 25 m grid cell (Turner et al.2007). The latter approach explicitly account for 97% of the study area over the state of Oregon and permitted region-wide simulations in a reasonable time frame.

The ORCA bottom-up modeling approach for determining regional carbon balance (Law et al. 2006, Law et al. 2004, Turner et al. 2004a, 2004b) has proved effective in capturing 1) effects of land management on carbon sequestration (e.g. public lands are a much larger carbon sink that private forest lands in Oregon), 2) the effects of climatic gradients on forest productivity (e.g. the strong west to east gradient in productivity in Oregon), and 3) the effects of interannual variation in climate on regional carbon flux (e.g. state wide net ecosystem production tends to decrease in relatively dry years).

In summary, the bottom-up modeling shows that interannual variation in climate introduces large interannual variation in the biologically driven regional carbon balance for the ORCA study region. The regional carbon sink decreases in relatively warm dry years such as 2003. The effect of a relatively dry growing season is manifest as a greater reduction in carbon uptake by plant growth than carbon release by decomposition. Implementation of the Northwest Forest Plan in 1994 led to a sharp decrease (84%) in the level of harvesting on federal forest land. In the late 1980s, both public and private forest land in the area of Oregon and Northern California was losing carbon, and the forest products pool was gaining a nearly equivalent amount. After the harvest reduction in the early 1990s, public forest land became a large carbon sink whereas private forestland was close to carbon neutral. Despite a recent trend towards more wild fire emissions, forest sector carbon sequestration in this region has increased.

Issues/notes:

DELIVERABLES:

PUBLICATIONS (pdf files on www.fsl.orst.edu/terra)

2008

Healey, S.P., W.B. Cohen, T.A. Spies, M. Moeur, D. Pflugmacher, M.G. Whitley, and M. Lefsky. Trends in the loss of older forests to harvest and fire in the Pacific Northwest, Ecosystems. In review.

Campbell, J.C., G. Alberti, J. Martin, B.E. Law. 2008. Carbon dynamics of a Ponderosa pine plantation following fuel reduction treatment in the northern Sierra Nevada. Forest Ecology and Management. In revision.

Hudiburg, T.M., B.E. Law, D. Turner, J. Campbell, D. Donato, M. Duane. 2008. Patterns of biomass accumulation, NPP, and mortality across Oregon and Northern California interpreted using federal inventory data and supplemental ground measurements. Ecological Applications. In press.

Donato, D.C. Forest Vegetation and Fuel Dynamics Following Stand-Replacing Wildfire, Re-Burn, and Postfire Management in the Siskiyou Mountains, Oregon. PhD Dissertation.

Goward, S.N., Masek, J.G., Cohen, W., Moisen, G., Collatz, G.J., Healey, S., Houghton, R.A., Huang, C., Kennedy, R., Law, B., Powell, S., Turner, D., Wulder, M.A. 2008. Forest disturbance and North American carbon flux. EOS 89:105-116.

Quaife, T., P. Lewis, M. De Kauwe, M. Williams, B.E. Law, M. Disney, P. Bowyer. 2008. Assimilating canopy reflectance data into an ecosystem model with an ensemble Kalman filter. Remote Sensing of Environment 112:1347-1364.

2007

Hudiburg, T.M. Climate, management, and forest type influences on carbon dynamics of West-Coast US Forests. MS thesis.

Campbell, J.C., D.C. Donato, D.A. Azuma, and B.E. Law. 2007. Pyrogenic carbon emission from a large wildfire in Oregon, USA. Journal of Geophysical Research-Atmospheres 112(G4), G04014, doi:10.1029/2007JG000451.

Turner, D.P., Ritts, W.D., Law, B.E., Cohen, W.B., Yang, Z., Hudiburg, T., Campbell, J.L., Duane, M. 2007. Scaling net ecosystem production and net biome production over a heterogeneous region in the western United States. Biogeosciences 4:597-612.

2006

Donato, D.C., J.B. Fontaine, J.L. Campbell, W.D. Robinson, B.J. Kauffman, B.E. Law. 2006. Post-wildfire logging hinders regeneration and increases fire risk. Science 311:352.

Law, B.E., D. Turner, M. Lefsky, J. Campbell, M. Guzy, O. Sun, S. Van Tuyl, W. Cohen. 2006. Carbon fluxes across regions: Observational constraints at multiple scales. In J. Wu, B. Jones, H. Li, O. Loucks, eds. Scaling and Uncertainty Analysis in Ecology: Methods and Applications. Columbia University Press, New York, USA.

Kennedy, R.E., Turner, D.P., Cohen, W.B., Guzy, M. 2006. A method to efficiently apply a biogeochemical model to a landscape. Landscape Ecology 21:213-224.

Turner, D.P. 2006b. On "Estimating carbon budgets for U.S. ecosystems". Eos 87:200.

Turner, D.P., W.D. Ritts, J.M. Styles, Z. Yang, W.B. Cohen, B.E. Law, and P. Thornton. 2006. A diagnostic carbon flux model to monitor the effects of disturbance and interannual variation in climate on regional NEP. Tellus 58B:476-490.

2005

Campbell, J.L., and B.E. Law. 2005. Forest soil respiration across three climatically-distinct chronoseqeunces. Biogeochemistry 73:109-125.

Lefsky, M.A., Turner, D.P., Guzy, M., Cohen, W.B. 2005. Combining lidar estimates of biomass and Landsat estimates of stand age for spatially extensive validation of modeled forest productivity. Remote Sensing of Environment 95:549-558.

Van Tuyl, S., B.E. Law, D. Turner, A. Gitelman. 2005. Variability in net primary production and carbon storage in biomass across Oregon forests - An assessment integrating data from forest inventories, intensive sites, and remote sensing. Forest Ecology and Management 209:273-291.

PRESENTATIONS

Campbell, J., J. Irvine, J. Martin, D. Donato, D.Vickers, K. Hibbard. 2006. Wildfire and carbon fluxes in Oregon II. Ameriflux Science Meeting. Boulder, CO.

Campbell, J., J. Irvine, B.E. Law. The ORCA West Coast Regional Project: Ground measurements made across key disturbance gradients for use in bottom-up scaling of carbon dynamics. Poster at the 2007 North American Carbon Program Meeting. Boulder, CO.

Duane, M., T. Hudiburg, W. Cohen, J. Campbell, D. Turner, D. Ritts, D. Weyermann, B.E. Law. 2006. Integration of FIA plot data and Landsat imagery to model stand age in Oregon. The 8th Annual Forest Inventory and Analysis Symposium, October 16-19, 2006 Monterey, California.

Hudiburg, Tara, Maureen Duane, Dave Turner, Yang Zhiqiang, John Campbell, Warren Cohen and Beverly Law. Parameterization and validation of Biome-BGC model estimates of carbon stores and fluxes across Oregon and Northern California using FIA plot data. Poster at the 2006 Ameriflux Science Meeting. Boulder, CO.

Law, B.E., D. Turner, W. Cohen, M. Goeckede, J. Campbell, M. Duane, T. Hudiburg, D. Ritts, Z. Yang. 2006. Bottom-up approaches to quantifying and explaining the carbon balance of North America. North American Carbon Program Science Meeting. Jan 22-26, 2007. Colorado Springs, CO. (*Plenary speech).

Law, B.E., D. Turner, W. Cohen, D. Ritts, Z. Yang, T. Hudiburg, J. Campbell, M. Duane. 2006. Scaling NEP and NBP over a heterogeneous region in the Western United States. International Greenhouse Gas Conference in the Northern Hemisphere. November 13 – 17, 2006. Sissi-Lassithi, Crete, Greece. (*keynote speech).

Law, B.E. Terrestrial Ecosystem Processes at Multiple Scales. September 27, 2006. Stanford University.

Law, B.E. AmeriFlux and Regional Programs – Remote sensing data uses and needs. NASA Global Vegetation Workshop. August 6-11, 2006. Missoula, Montana.

Law, B.E., D. Turner, J. Styles, W. Cohen. 2005. Regional Carbon Budget Approach and Progress in Support of the North American Carbon Program: ORCA. American Geophysical Union. December 5-9, 2005. San Francisco, CA.

Law, B.E. 2005. Regional analysis of the terrestrial carbon cycle. AmeriFlux annual meeting. Oct 17-20, 2005. Boulder, CO.

Goeckede, M., J. Styles, B. Law, D. Turner, W. Cohen. 2005. Use of Footprint Modeling in a Regional Carbon Budget Approach to Estimate Gross Carbon Fluxes for Oregon-California: Component of ORCA and NACP-W. American Geophysical Union. December 5-9, 2005. San Francisco, CA.

Styles, J., M. Goeckede, B. Law, D. Turner, W. Cohen. 2005. Oregon-California regional carbon budget approach using model-data fusion to estimate gross carbon fluxes – ORCA component. American Geophysical Union. December 5-9, 2005. San Francisco, CA.

Styles, J., B.E. Law, D. Turner, W. Cohen, G. Whitley. Climate and disturbance effects on gross ecosystem fluxes assessed by model-data fusion. 7th International Carbon Dioxide Conference. Boulder, CO. September 2005.

Turner, D.P. 2006. Modifications to Biome-BGC made at Oregon State University. Biome-BGC Workshop. University of Montana. Missoula MT. April 25-26.

Turner, D.P. 2006. Climatic effects on carbon flux in Oregon. Oregon State University. Department of Forest Science. February 24.

Turner, D.P. 2005. Monitoring terrestrial carbon fluxes at regional to global scales with remote sensing and modeling. Department of Geography. McGill University, Montreal Canada. December 16.

Turner, D. 2005. Integration of process modeling and remote sensing for analysis of the carbon cycle. Oregon State University. Department of Forest Science. Corvallis OR. February 22.

Turner, D.P., Styles, J., Cohen, W.B., Law, B.E., Ritts, W.D., Thornton, P. 2005. Monitoring effects of interannual variation in climate and fire regime on regional net ecosystem production with remote sensing and modeling. AmeriFlux Science meeting. Boulder CO. October 18-20.

Turner, D.P., Styles, J., Cohen, W.B., Law, B.E., Ritts, W.D., Thornton, P., Falk, M.. 2005. Monitoring effects of interannual variation in climate and fire regime on regional net ecosystem production with remote sensing and modeling. 7th International Carbon Dioxide Conference. Broomfield CO. September 26-30.

Education Contribution:

3 post-docs for modeling (Mathias Goeckede, Julie Styles, Zhiquan Yang)
1 post-doc for field data collection and analysis (John Campbell)
1 PhD student for field data collection (Dan Donato)
1 MS student for inventory data analysis (Tara Hudiburg)
1 MS student for laboratory analysis (Theresa Johnson)
1 visiting PhD student in support of the US-Italy bilateral agreement (Giorgio Alberti)