FINAL REPORT

Title: The effects of climate, forest age, and disturbance history on carbon and water processes at AmeriFlux sites across gradients in Pacific Northwest forests
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GOAL: Investigate the effects of disturbance and climate variables on processes controlling carbon and water processes at AmeriFlux cluster sites in semi-arid and mesic forests in Oregon. The observations were made at three existing and productive AmeriFlux research sites that represent climate and disturbance gradients as a natural experiment of the influence of climatic and hydrologic variability on carbon sequestration and resulting atmospheric CO_2 feedback that includes anomalies during the warm/ dry phase of the Pacific Decadal Oscillation.

OBJECTIVES: (1) Combine tower and biological observations at the semi-arid mature and young pine sites to investigate climatologic and hydrologic influences on NPP, NEP and component processes in different aged forests over multiple years that include anomalies in precipitation and temperature (disturbance history/age gradient); (2) Compare climatologic and hydrologic control on measured carbon and water fluxes in forests of the same functional type and similar age (mature pine and Douglas-fir sites), but in different ecoregions over multiple years that include variability in precipitation phase and timing (climate gradient).

APPROACH: (1) Produce micrometeorological estimates of the exchanges of CO_2, water and energy at these AmeriFlux sites to quantify seasonal and interannual variation in fluxes; (2) Produce biological estimates of NPP and carbon pools in live and dead biomass and soils at the sites. Conduct measurements of respiration from soil processes (heterotrophic and total soil CO_2 efflux) and vegetation to diagnose responses, and sapflux to determine the portion of LE that is tree transpiration; (3) Reduce uncertainty in NEE estimates through enhanced micrometeorological measurements with a roving network (two subcanopy flux systems, and spatially distributed temperature and wind measurements) to explain variability in subcanopy fluxes and flow; (4) Quantify the responses and carryover effects of e.g. chronic drought, early spring and extreme events on carbon and water processes including above- and belowground processes (photosynthesis, soil CO_2 efflux, transpiration) that can feed back to atmospheric CO_2 over the climatic and disturbance gradients.

RESULTS:

Science objective (1): *Disturbance history/age gradient*

2011

Five years of coincident eddy-covariance measurements at a mature ponderosa pine forest and a nearby young ponderosa pine plantation with warmer and dryer soil were used to contrast the carbon fluxes over several temporal scales and to examine the differing responses to water-stress associated with summer drought and water-year drought. The older forest with the cooler and wetter soil fixes carbon at a rate 3.3 times larger than the young plantation. In spring, gross photosynthesis (GEP) is larger in mature pine as expected based on the higher LAI, however, another important factor is the reduction in springtime respiration at the mature site due to lower soil temperatures associated with a later snowmelt and more shading of the ground by the canopy. Seasonal patterns of GEP, inherent water use efficiency and normalized transpiration indicate that the young pine responds to seasonal drought sooner and to a more severe degree. Less sensitivity to seasonal drought in mature pine, which is supported by the changes in the diel patterns of photosynthesis, is likely due to higher soil moisture reserves year round, a deeper root system that can access more water, and a larger storage capacity in the stems that provides a buffer against water-stress. The older site has likely reached maximum potential LAI for this climate zone and soil fertility, while the interannual variability of net carbon uptake at the young plantation includes the influence of increasing leaf area and related functional changes of the aggrading forest, and water-year precipitation. By contrast, the same moderate drought year was not associated with reduced net carbon uptake in the mature pine (Vickers et al. 2011).

Sources of uncertainty in process modeling of drought and age effects on forest carbon cycling. Semiarid forests are very sensitive to climatic change and among the most difficult ecosystems to accurately model. We tested the performance of the Biome-BGC model against eddy flux data taken from young (years 2004‑2008), mature (years 2002‑2008), and old-growth (year 2000) ponderosa pine stands at Metolius AmeriFlux sites, and subsequently examined several potential causes for model-data mismatch. We used the Generalized Likelihood Uncertainty Estimation methodology, which involved 500,000 model runs for each stand (1,500,000 total). Each simulation was run with randomly generated parameter values from a uniform distribution based on published parameter ranges for the Metolius area, resulting in modeled estimates of net ecosystem CO2 exchange (NEE) that were compared to measured eddy flux data. Simulations for the young stand exhibited the highest level of performance, though they overestimated NEE 99% of the time. Among the simulations for the mature and old-growth stands, 100% and 99% of the simulations underestimated ecosystem C accumulation. One obvious area of model-data mismatch is soil moisture, which was overestimated by the model in the young and old-growth stands yet underestimated in the mature stand. However, modeled estimates of soil water content and associated water deficits did not appear to be the primary cause of model-data mismatch. Difficulties in adequately modeling ecosystem respiration, mainly autotrophic respiration, appeared to be the fundamental cause of model-data mismatch (Mitchell et al. 2011).

Data assimilation to diagnose modeling of climate effects on carbon fluxes in young ponderosa pine. We examined the relative magnitude and contribution of parameter and driver uncertainty to the confidence intervals on estimates of net carbon fluxes. We used data from the Metolius young ponderosa pine forest and a simple daily model of coupled carbon and water fluxes (DALEC). Geostatistical simulations generated an ensemble of meteorological driving variables for the site, consistent with the spatio-temporal autocorrelations inherent in the observational data from 13 local weather stations. Simulated meteorological data were propagated through the model to derive the uncertainty on the CO_2 flux resulting from driver uncertainty typical of spatially extensive modeling studies. The model uncertainty was partitioned between temperature and precipitation. With at least one meteorological station within 25 km of the study site, driver uncertainty was relatively small (~10% of the total net flux), while parameterization uncertainty was larger at 50 % of NEE. The largest source of driver uncertainty was due to temperature (8% of NEE). When the nearest meteorological station was >100 km from the study site, uncertainty in NEE predictions introduced by meteorological drivers increased by 88%. Precipitation estimates were a larger source of bias in NEE estimates than were temperature estimates, although the biases partly compensated for each other. The time-scales on which precipitation errors occurred in the simulations were shorter than the temporal scales over which drought developed in the model, so drought events were reasonably simulated. The approach provides a means to assess the uncertainty and bias introduced by meteorological drivers in regional-scale ecological forecasting (Spadavecchia et al. 2011).

Modelers can reduce uncertainties in landscape to regional carbon budgets by leveraging moderate resolution imagery to account for both moderate and high severity wildfire effects on carbon emissions and NEP. Simulated total pyrogenic C emissions for the Metolius watershed (244,600 ha) was 0.73 Tg C, or *ca.* 2.4% of equivalent statewide anthropogenic carbon emissions from fossil fuel combustion and industrial processes for the same 2-year period. Simulated tree mortality was four-fold higher (3.02 Tg C) than pyrogenic C emissions, but dead wood decomposition will occur over decades. Immediately post-fire (2004), burned areas were a strong simulated C source (net C exchange: -0.076 Tg C y^{-1}; mean +/- SD: -142 +/- 121 g C m^{-2} y^{-1}). Although high-severity fire accounted for disproportionate C impacts, moderate-severity fire accounted for substantial effects on both per-unit-area and total pyrogenic C emissions, tree mortality, and reduced net ecosystem production. These results demonstrate the potential to reduce model uncertainties in landscape to regional carbon budgets by leveraging Landsat-based remote sensing fire products that account for both moderate and high severity wildfire effects on emissions and subsequent net carbon uptake (Meigs et al. 2011).

2012

In a synthesis that included the Metolius disturbance cluster of different aged pine forests, we conducted a global analysis of 49 forests that showed carbon allocation response to nutrient availability: forests with high-nutrient availability use 58 percent of their photosynthates for plant biomass production (BP), while forests with low-nutrient availability only convert 42 percent of annual photosynthates to biomass. This nutrient effect largely overshadows previously observed differences in carbon allocation patterns among climate zones, forest types and age classes. The carbon sink potential of forests largely depends on how carbon taken up during photosynthesis is partitioned. Biomass production and GPP were independently measured and showed that nutrient availability may be the unifying mechanism controlling the ratio of biomass production-to-GPP that encompasses climate, forest type, and stand age as influencing factors. The observed pattern of higher carbon partitioning to plant biomass with increasing nutrient availability adds to our understanding of the processes governing long-term carbon sequestration in forests and may have far-reaching consequences for carbon cycle management (Vicca et al. 2012).

Two-year watering experiment in young ponderosa pine: Changes in the hydrological cycle, as predicted and currently observed, are expected to significantly impact the water and carbon balance of water-limited forest ecosystems. However, differences in the water-sensitivity of component processes make carbon balance predictions challenging. To examine responses of ecosystem components to water limitations, we conducted a study of tree, soil and ecosystem-level processes in a young ponderosa pine stand under natural summer drought (control) and increased soil water conditions (watered). Weekly-averaged tree transpiration (Ttree), gross ecosystem photosynthesis (GPP) and soil CO_2 efflux (Rstree; nearby trees) were related with soil water content (SWC) and declined rapidly when relative extractable soil water (REW) was <50%. The sensitivity of daily variations in canopy conductance (Gs) to vapor pressure deficit was affected by SWC, decreasing at REW <50%. Watering maintained REW at about 70% in July and August but positively affected tree carbon and water dynamics only at the end of summer when fluxes in the control treatment were strongly water-limited. A tight coupling of above- and belowground fluxes became apparent. In the control treatment, root-rhizosphere respiration (Rr) decreased along with GPP and Ttree as drought progressed, while watering maintained Rr, Ttree and Gs at a significantly higher level than those of the unwatered trees in late summer. In contrast, microbial respiration responded instantaneously and strongly to the watering compared to the control treatment. The net effect was that increased soil water availability during the typical dry growing season has a negative effect on the short-term seasonal ecosystem carbon balance due to a larger increase in decomposition than photosynthesis. However, longer-term effects remain uncertain. In summary, our study highlights that understanding the dissimilar response of tree dynamics and soil decomposition to water availability is a key component in predicting future carbon sequestration in water-limited forest ecosystems. Key points of experimental results under natural drought and increased water availability: 1) Ecosystem, soil and tree flux dynamics are largely determined by water availability; 2) Above- and belowground tree flux dynamics are strongly coupled; 3) Watering increased soil decomposition more than photosynthesis, with the net effect of reduced carbon uptake during summer drought compared to unwatered trees (Rueher et al. 2012).

One of the largest sources of uncertainly in NEP measurements is below ground processes. Using high frequency records of soil CO_2 fluxes we found diel cycles of soil fluxes varied seasonally with peak flux rates occurring later in the day as soil water content decreased. Using a simple heat transport/diffusion model, we determined that the variation in diel soil CO_2 flux patterns could not be explained by changes in diffusion rates or production from deeper soil profiles, but rather from the variation of GEP (photosynthesis) with lags between ~12 and 22 days. The lags were related to combined path length (top of tree to ground at chamber center). During summer drought conditions, the lag could be represented by an integrated site level value of 15-20 days. For model applications, soil CO_2 fluxes are influenced by many biophysical factors, which may confound or obscure relationships with logical environmental drivers and act at multiple temporal and spatial scales. Therefore, caution is needed when attributing soil CO_2 fluxes to covariates like temperature and moisture (Martin et al. 2012).

Changes in temperature, vapor pressure deficit and radiation that are coherent on timescales of several days, corresponding to synoptic scale waves, were studied for their influence on the sequestration of atmospheric carbon by a young ponderosa pine ecosystem in semi-arid central Oregon. Air temperature was found to be the dominate factor driving changes in the net uptake of carbon at these timescales, where the net uptake declines in warm periods and increases in cool periods due to changes in ecosystem respiration, not photosynthesis. The lack of correlation between radiation and photosynthesis on these timescales is attributed to the increase in the fraction of diffuse radiation on cloudy days, and to light saturation of photosynthesis. The lack of correlation between vapor pressure deficit (or temperature) and photosynthesis in summer is because the trees are already water-stressed under the normal hot and dry conditions. An implication for modeling these ecosystems is that including realistic temperature variations is important to capture the large variability of the ecosystem respiration and net uptake on synoptic timescales, while changes in radiation (clouds) are less important (Vickers et al. 2012).

2013

Management strategies have been proposed to minimize the effects of climate change on forest resilience. We investigated the Pacific Northwest forest carbon balance under current practices, and changes that may result from management practices proposed for the region’s 34 million ha of forests to mitigate climate change effects. We examined the relationship between NPP and biomass using observations from our flux sites and ancillary plots. We used this information to simulate the effects of proposed clear-cut harvest of young mesic forests for wood products and bioenergy while preserving mesic mature/old forests for biodiversity (Sparing), thinning all forests (Sharing), and a combination of sparing mesic mature and old, clearing mesic young, and thinning dry forests (Sparing/Sharing). The forests of the region were found highly productive (NPP 163 Tg C $year^{-1}$) and a strong carbon sink with NEP of 45 Tg C $year^{-1}$. Observations indicated the relationship between NPP and biomass was not significantly different for thinned versus unthinned stands, after accounting for site quality and precipitation effects. After simulating proposed management to mitigate climate change, regional NPP was reduced by 35% (Sparing), 9% (Sharing), and 29% (Sparing/Sharing) compared with current practices. Applying management practices appropriate for current forest conditions to mitigate future climate change impacts can be accomplished, but at a cost of reducing NPP. Sparing all forests >50 years old resulted in the largest NPP reduction, but the impact could be reduced by clearing only a subset of young forests. The integration of in situ observations with remote sensing and modelling allowed us to test place-based scenarios (Law et al. 2013).

2014

The effects of soil and atmospheric drought on carbon and water dynamics were quantified based on a field irrigation experiment combined with model simulations. To assess future effects of intensifying drought on ecosystem processes, the SPA model was run using temperature and precipitation scenarios for 2040 and 2080. Experimentally increased summer water availability clearly affected tree hydraulics and enhanced C uptake in both the observations and the model. Simulation results showed that irrigation was sufficient to eliminate soil water limitation and maintain transpiration rates, but gross primary productivity (GPP) continued to decrease. Observations of stomatal conductance indicated a dominant role of vapor pressure deficit (VPD) in limiting C uptake. This was confirmed by running the simulation under reduced atmospheric drought (VPD of 1 kPa), which largely maintained GPP rates at pre-drought conditions. The importance of VPD as a dominant driver was underlined by simulations of extreme summer conditions. We found GPP to be affected more by summer temperatures and VPD as predicted for 2080 (−17%) than by reductions in summer precipitation (−9%). Because heterotrophic respiration responded less to heat (−1%), than to reductions in precipitation (−10%), net ecosystem C uptake declined strongest under hotter (−38%), compared to drier summer conditions (−8%). Considering warming trends across all seasons (September–May: +3 °C and June–August: +4.5 °C), the negative drought effects were largely compensated by an earlier initiation of favorable growing conditions and bud break, enhancing early season GPP and needle biomass. An adverse effect, triggered by changes in early season allocation patterns, was the decline of wood and root biomass. This imbalance may increase water stress over the long term to a threshold at which ponderosa pine may not survive, and highlights the need for an integrated process understanding of the combined effects of trends and extremes (Ruehr et al. 2014).

Accurate assessments of forest response to current and future climate and human actions are needed at regional scales. Predicting future impacts on forests will require improved analysis of species-level adaptation, resilience, and vulnerability to mortality. Land system models can be enhanced by creating trait-based groupings of species that better represent climate sensitivity, such as risk of hydraulic failure from drought. This emphasizes the need for more coordinated in situ and remote sensing observations to track changes in ecosystem function, and to improve model inputs, spatio-temporal diagnosis, and predictions of future conditions, including implications of actions to mitigate climate change (Law 2014).

2015

We published an overview and synthesis of research results on current and potential future effects of disturbances from drought, fire, and management on Pacific Northwest US forests, with an emphasis on forest carbon dynamics. In the Pacific Northwest region forests dominate the landscape and contain one of the highest biomass concentrations on earth. Biomass energy production has been proposed in order to make management activities, intended to mitigate disturbances, economically feasible. We demonstrate the need for comprehensive assessments to understand the impact of land use actions on the local and regional carbon balance. By accounting for more of the benefits and costs involved in reducing the risk of crown fires, modifying storage in long- and short-term products, and in substituting wood products for fossil fuel, we find that thinning existing forests to reduce crown-fire risk increases net carbon emissions to the atmosphere for many decades, but is likely to be less of an atmospheric impact in some dry forest regions that are highly vulnerable to fire. We propose the use of observation-driven land system models that integrate the extent that forests are vulnerable to climate change, management practices, and economic considerations. It also requires increased emphasis on in situ and remotely sensed observations and experiments to initialize and test the models, and to track trends in forest condition (Law et al. 2015).

Science objective (2): *Mature pine and Douglas-fir, climate gradient*

2012

A NACP study showed that models tend to overestimate NEP in autumn through spring and underestimate it in summer, and it overestimated GPP in dry conditions (Schaefer et al. 2012). The NACP study indicated that improvements to Vcmax and the calculation of light-use efficiency (LUE) will improve model performance. We are working on improving CLM4 algorithms for carbon allocation patterns, Vcmax, and light-use efficiency (LUE) for evergreen needleleaf forests across a climatic gradient. Using CLM4 at the Oregon flux sites and in Canada, we evaluated CLM4-simulated monthly and interannual variation in GPP. We found good model-data agreement from October to May at the mesic Douglas-fir site and from August to April at the drier Metolius mature pine site. Summer GPP was underestimated in June through August at the mesic site and May through July at the drier site (similar to Schaefer et al.). We used site specific foliage nitrogen content values and specific leaf area to parameterize the model and we conducted a sensitivity test with nitrogen availability at the mesic site. This did not improve simulated seasonality in GPP. Improvement to Vcmax seasonality in CLM4 will require adjustment to other factors such as response to temperature and soil water in order to improve simulated GPP in summer. When we modified mortality and carbon allocation (leaf/stem) with ecoregion-specific data, we found an overall improvement in NPP predictions (values in all ecoregions fell within the observed range of uncertainty), but stem biomass was further under-predicted. Changing the stem wood allocation algorithm improved the results, however wood density was still underestimated in the West Cascades and Klamath Mountains. Stem biomass is also influenced by harvest and fire removals, both of which are overestimated in these two ecoregions, and we will address that issue next. We will continue to work on ecoregion-specific parameterization, and evaluate CLM4 algorithms for carbon allocation patterns, Vcmax, and LUE for forest plant functional types in the Pacific Northwest region.

We improved net ecosystem exchange (NEE) estimates at the dense, tall Douglas-Fir site by accounting for missed sub-canopy respiration. An investigation of concurrent eddy covariance (EC) measurements of carbon dioxide and energy fluxes above the canopy and in the sub-canopy showed that sub-canopy respiration, which contributes an average of 60 % to total ecosystem respiration, is often missed by the above-canopy EC measurements due to systematic decoupling. Averaged over the entire observational period of 6 years (2006 through 2011), this decoupling occurs at night (88%) and during the day (65 %). Only the remainder represents a fully mixed canopy, i.e., periods when the above-canopy EC system represents integrates all forest carbon sinks and sources and the traditional single-height EC approach is valid. Based on previous work, we devised a practical scheme to diagnose vertical exchange regimes and computed the missing sub-canopy respiration. The 6-year averaged improved NEE is -502 gC m^{-2} yr^{-1} and thus on average 620 gC m^{-2} yr^{-1} lower compared to the traditional, single height above-canopy EC method (Thomas et al. 2012). This approach could be used at other tall canopy forests with canopy closure to reduce uncertainty in carbon fluxes from forests.

Changes in the hydrological cycle, as predicted and currently observed, will significantly impact the water and carbon balance of water-limited forest ecosystems. However, differences in the water-sensitivity of component processes make carbon balance predictions challenging. To examine responses of ecosystem components to water limitations, we conducted a study of tree, soil and ecosystem processes in a stand at our young ponderosa pine flux site under natural summer drought (control) and increased soil water conditions (watered). Weekly-averaged tree transpiration (Ttree), net ecosystem photosynthesis (Pneco) and soil CO2 efflux (Rstree; nearby trees) were related with soil water content (SWC) and declined rapidly when relative extractable soil water (REW) was less than 50 percent. The control of VPD over daily variations in canopy conductance (Gs) was less than SWC. Watering maintained REW at about 70% in July and August but positively affected tree carbon and water dynamics only at the end of summer when fluxes in the control treatment were strongly water-limited. A tight coupling of above- and belowground fluxes became apparent; while root-rhizosphere respiration (Rr) in the control treatment decreased along with Pneco and Ttree as drought progressed, watering maintained Rr, Ttree and Gs, which were significantly higher than those of the unwatered trees in late summer. In contrast, microbial respiration (Rm) responded instantaneously and strongly to the watering compared to the control treatment. The net effect was increased soil water availability negatively affected the net ecosystem C balance due to a larger increase in decomposition than photosynthesis. This clearly highlights that understanding the dissimilar response of tree dynamics and soil decomposition to water availability is key to reducing uncertainty in modeling future C sequestration in water-limited forest ecosystems (Ruhr et al. 2012).

Activity to reduce uncertainty in fluxes, necessary for meeting objectives (1) and (2).

2011

Two distinct nocturnal subcanopy flow regimes were observed beneath a tall open forest canopy (mature pine site). The first is characterized by weaker mixing above the canopy, downslope flow decoupled from the flow above the canopy and much smaller than expected ecosystem respiration from the eddy flux plus storage measurements (FS) compared to estimates based on chambers (ER). This is the often reported missing carbon dioxide problem, or nighttime flux problem. The second regime is characterized by stronger mixing above the canopy, subcanopy flow coupled to the flow above the canopy and agreement between FS and ER. That is, the inferred advection of carbon dioxide is negligible when the mixing strength above the canopy exceeds a critical value. The friction velocity, standard deviation of vertical velocity, bulk Richardson number, Monin-Obukhov length scale and the subcanopy 3-m wind direction are all shown to be good indicators of missing carbon dioxide (FS<ER) at this site. Because the subcanopy flow regime is largely determined by the turbulence above the canopy, this analysis supports a physical basis for the commonly used filtering approach to the nighttime flux problem based on the friction velocity above the canopy. In terms of maximizing the amount of data retained by the filter, the subcanopy wind direction was found to be the most effective filter variable, followed by z/L (Vickers et al. 2011).

2012

A study investigating the links between the sub-canopy respiration pulses and the transporting eddies (coherent structures) yielded systematic differences between the two mature sites (Pine and Douglas-Fir) and a CarboEurope deciduous site. The dense canopy of the mature fir site significantly dampens vertical motions leading to a severed communication of air between the sub-canopy and above-canopy turbulence measurements. In contrast, the open canopy architecture at the mature pine site allows for fast and efficient vertical communication of air. Here, coherent structures are mainly responsible for transporting the sub-canopy respiration pulses used to estimate daytime sub-canopy respiration. Similar investigations of the transport mechanisms in forests at other sites may help improve estimates of NEE and water loss, and may help account for missing CO_2 (Zeeman et al. 2012).

2013

In dense, tall forests, diagnosing vertical coupling and incorporating sub-canopy EC measurements into NEE estimates reduced carbon sink estimate by more than 50%. Estimates for annual net ecosystem exchange (NEE) for the tall, dense, mature Douglas-fir forest at the Mary’s River site for the period 2006-2011 were improved by developing and testing a novel conceptual framework (Thomas et al., 2013) that aimed at (i) reducing uncertainty by retaining more measurements for the computation of annual NEE sums and (ii) producing defendable and biologically meaningful estimates by accounting for the missing sub-canopy respiration. The framework assumes that (a) the scalar exchange between vertical layers can be categorized into discrete canopy coupling regimes and (b) advection leads to a systematic loss of scalar from the observational volume that can indirectly be estimated and accounted for as sub-canopy respiration flux when canopy layers are decoupled. Measuring NEE in dense, tall forests is challenging because of the systematic weak flows and wind directional shear, and limited turbulent mixing throughout the diurnal period. Periods with a decoupled sub-canopy layer dominated and occupied 65 and 88% of the day- and nighttime periods, respectively. Annual NEE derived from the new framework was estimated as 480 gC $m^{-2}yr^{-1}$, which was reduced by 620 gC m^{-2} yr^{-1} compared to traditional estimates from single-level EC data filtered using a critical friction velocity (standard AmeriFlux and Fluxnet approach). The reduced NEE was due to an enhanced ecosystem respiration (RE), while gross ecosystem productivity remained unchanged. Improved RE estimates agreed well with those from independent estimates based on soil, stem, and foliage respiration within 3%. We conclude that concurrent above- and sub-canopy EC observations are essential to measure a meaningful carbon balance in tall, dense forests since they do no lend themselves to traditional, standardized processing.

In an open canopy, sub-canopy CO_2 flux measurements show a large degree of spatial variability and systematic, site-specific differences in the mean diurnal pattern requiring the use of several stations to compute a meaningful and representative flux estimates to be included in carbon and water budgets.
In a study using observations from a small network of 3 sub-canopy EC stations deployed over a period of 81 days at the open-canopy Metolius Mature Pine site (US-Me2), we evaluate the spatial heterogeneity of the turbulence kinetic energy (TKE) and its terms, the CO_2 flux, moisture flux, heat flux, and the friction velocity (Vickers et al., 2013). Particularly for the sub-canopy CO_2 flux, spatial variability occurred on scales smaller than our network, where the distance between measurement sites is 87 m. In terms of state variables, large systematic differences also existed for the long-term average subcanopy CO_2 concentration and moisture between the three stations despite the lack of obvious differences in soils, exposure, vegetation, elevation or terrain slope. In addition, we also examined the average contributions to the TKE tendency for two vertical layers of the tall open pine forest: a lower layer in the subcanopy space in contact with the understory and the surface, and an upper layer extending from the top half of the open subcanopy trunk space upwards to about twice the canopy height. Findings suggest that a significant fraction of the subcanopy turbulence is driven by shear generation of turbulence above the canopy that is subsequently transported downward by turbulence into the subcanopy. Identifying the source for turbulent mixing in the sub-canopy helps to define biologically meaningful filters to reduce uncertainty in NEE by screening out flux estimates that do not reflect the ecosystem’s response, but depend primarily on the strength of the physical transport.

2014

A semi-parametric photosynthetically active diffuse radiation model was developed using commonly measured climatic variables from 108 site-years of data from 17 AmeriFlux sites including US-Fir, US-Me2 and US-Me6. The model has a logistic form and improves upon previous efforts using a larger data set and physically viable climate variables as predictors, including relative humidity, clearness index, surface albedo and solar elevation angle. Model performance was evaluated by comparison with a simple cubic polynomial model developed for the photosynthetically active spectral range. The logistic model outperformed the polynomial model with an improved coefficient of determination and slope relative to measured data (logistic: $R^2 = 0.76$; slope = 0.76;

cubic: R^2= 0.73; slope = 0.72), making this the most robust photosynthetically active-partitioning model for the United States currently available. This model provides an important tool to understand the contribution of diffuse light to net ecosystem exchange at AmeriFlux sites. (Kathelenkal et al. 2014).

2015

The reliable simulation of gross primary productivity (GPP) at various spatial and temporal scales is of significance to quantifying the net exchange of carbon between terrestrial ecosystems and the atmosphere. This study aimed to verify the ability of a nonlinear two-leaf model (TL-LUEn), a linear two-leaf model (TL-LUE), and a big-leaf light use efficiency model (MOD17) to simulate GPP at half-hourly, daily and 8-day scales using GPP derived from 58 eddy-covariance flux sites in Asia, Europe and North America as benchmarks. Model evaluation showed that the overall performance of TL-LUEn was slightly but not significantly better than TL-LUE at half-hourly and daily scale, while the overall performance of both TL-LUEn and TL-LUE were significantly better ($p < 0.0001$) than MOD17 at the two temporal scales. For different vegetation types, TL-LUEn and TL-LUE performed better than MOD17 for all vegetation types except crops at the half-hourly scale. At the daily and 8-day scales, both TL-LUEn and TL-LUE outperformed MOD17 for forests. The better performance of TL-LUEn and TL-LUE for forests was mainly achieved by the correction of the underestimation and overestimation of GPP simulated by MOD17 under low/high solar radiation and sky clearness conditions. TL-LUEn is more applicable at individual sites at the half-hourly scale while TL-LUE could be regionally used at half-hourly, daily and 8-day scales. MOD17 is also an applicable option regionally at the 8-day scale (Wu et al. 2015).

AWARDS (Impact of Research)

B.E. Law, AGU Fellow 2014

DELIVERABLES:
Publications (pdf files can be found on www.fsl.orst.edu/terra)

In press:

Law, B.E., L.T. Berner. In press. NACP TERRA-PNW: Forest Plant Traits, NPP, Biomass, and Soil Properties, 1999-2014. Nature Scientific Data.

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