



Abstracts - Posters

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Effects of the 2003 European heatwave on the terrestrial carbon and water cycle: a joint flux-tower, remote sensing and modeling analysis

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Climate-carbon-cycle feedbacks have most often been discussed in the context of gradual changes of temperature ('global warming'). Recent flux tower, remote sensing and modeled data over Europe from the past years have however stressed the potential role of extreme events and of interactions with the hydrological cycle for the terrestrial carbon cycle. Here we present a comprehensive analysis of the terrestrial carbon cycle's reaction to such climate anomalies over Europe in 2003, taking advantage of the European CARBOEUROPE/FLUXNET monitoring sites, spatial remote sensing observations via the EOS-MODIS sensor and ecosystem modeling, that provide independent and complementary views on the effect of the 2003 heatwave on the European biosphere's productivity and carbon balance. In our analysis these data streams consistently demonstrate a strong negative anomaly of the primary productivity during the summer of 2003. FLUXNET eddy-covariance data indicate that the drop in productivity was not primarily caused by high temperatures ('heat stress') but rather by limitation of water (drought stress) and that, contrary to the classical expectation about a heat wave, not only gross primary productivity but also ecosystem respiration declined by up to more than to $80 \text{ gC m}^{-2} \text{ month}^{-1}$. Anomalies of carbon and water fluxes were strongly correlated. While there are large between-site differences in water-use efficiency ($1\text{-}6 \text{ kgC/kgH}_2\text{O}$) here defined as gross carbon uptake divided by evapotranspiration ($\text{WUE}=\text{GPP}/\text{ET}$), the year-to-year changes in WUE were small ($<1\text{g/kg}$) and quite similar for most sites, i.e. WUE decreased during the year of the heatwave. Remote sensing data from MODIS and AVHRR both indicate a strong negative anomaly of the fraction of absorbed photosynthetically active radiation (fAPAR) in summer 2003, at more than 5 standard deviations of the previous years. The spatial differentiation of this anomaly follows climatic and land-use patterns: Largest anomalies occur in the centre of the meteorological anomaly (centralWestern Europe) and in areas dominated by crops or grassland. In conjunction with diagnostic and prognostic ecosystem modeling we come to the conclusion that terrestrial European ecosystems acted as a net anomalous source of $0.1\text{-}0.5 \text{ PgC CO}_2\text{-C}$ in 2003 thus exhibiting a positive feedback in the carbon cycle climate system. Preliminary analysis of the terrestrial biosphere's response to the 2005 climate anomaly indicates a similar reaction but quite complementary spatial patterns, where in particular the Iberian Peninsula and Eastern Europe is heavily affected.

Effects of an increase in summer precipitation on net ecosystem CO₂ and H₂O fluxes in a sotol-grassland in Big Bend National Park, Texas.

Loik ME, LD Patrick, H Alpert, AB Griffith and DT Tissue

Global climate models predict that in the next century precipitation in desert regions of the U.S. will increase, which is anticipated to affect biosphere / atmosphere exchanges of both CO₂ and H₂O. In a sotol grassland ecosystem in the Chihuahuan Desert at Big Bend National Park, we measured the response of leaf-level fluxes of CO₂ and H₂O one day before and up to seven days after three supplemental precipitation pulses in the summer (June, July, and August 2004). In addition, the responses of leaf, soil, and ecosystem fluxes of CO₂ and H₂O to these precipitation pulses were also evaluated in September, one month after the final seasonal supplemental watering event. Both shrubs and grasses in watered plots had increased rates of photosynthesis following pulses in June and July. In September, only grasses in watered plots had higher rates of photosynthesis than plants in the control plots. While rates of leaf gas exchange remained greater in watered plots in September, soil CO₂ effluxes were lower in watered plots than control plots. As shown by stable isotopes, C₄ plants contributed more to soil respiration in control plots, while C₃ and CAM plants contributed the most in watered plots. Due to these increased rates of photosynthesis in grasses and decreased rates of daytime soil respiration in September, watered ecosystems were a sink for carbon, assimilating on average 31 mmol CO₂ m⁻² ground area day⁻¹. In fact, as a result of a 25% increase in summer precipitation, watered plots fixed eight times more CO₂ during a 24-hr period than control plots. In June and July, there were greater rates of transpiration for both grasses and shrubs in the watered plots. During the early summer, there was a strong relationship observed between photosynthesis and stomatal conductance. In September, however, rates of transpiration were similar across plots, with grasses transpiring significantly more than shrubs. Similar rates of transpiration and soil water evaporation led to no treatment differences observed in evapotranspiration, which averaged 42 mmol H₂O m⁻² ground area day⁻¹ for all plots. In the future, with an increase in precipitation in arid areas, the sotol grassland ecosystem in the Chihuahuan Desert may remain a sink of carbon for a longer time at the end of the growing season.

Calibrating INCA-C For Climate Change Prediction

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INCA-C, the Integrated Catchments model for Carbon, is a generic catchment-scale model for predicting the retention and transport of dissolved organic carbon (DOC) in rivers. While the model has been used to simulate current conditions, its primary purpose is to forecast future riverine biogeochemistry under changing climate, land use and deposition scenarios. Initial results from tests at four sites in Canada, Norway and Finland are promising. The model simulates seasonal variability in DOC and captures some of the inter-annual pattern in stream DOC concentrations. Results from the Canadian applications have shown that INCA-C is able to simulate DOC flux using only climate parameters as drivers. The Norwegian application demonstrated the importance of including both climate and deposition parameters in the suite of predictor variables. The Finnish application has raised some questions about the applicability of the model to lake-dominated catchments.

Most of the variability in long-term stream water DOC time series is seasonal as opposed to long-term. Naïve model calibration may result in to adequate simulation of seasonal fluctuations but poor representation of long-term patterns. Calibrating to time series with a stronger trend signal, such as those from experimental climate manipulation studies, should lead to improved model parameterizations for climate change prediction. Calibrating the INCA-C to the results of climate change experiments would provide a stronger test of the model ability to simulate climate change effects than calibrating to monitoring time series where the effects of different climatic drivers may be confounded. Future work will explore alternate calibration strategies so as to make INCA-C a more useful tool for predicting the effects of changing climate on surface water DOC.

Presentation of PhD project: Ecosystem-atmosphere exchange of carbon in a heath land under future climatic conditions

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To assess how future climatic conditions will influence the ecosystem fluxes of CO₂, two approaches will be used: Direct measurement of the carbon exchanges, and a survey of ¹³C-pulse labeling to differentiate the respiratory losses of carbon from heterotrophic and autotrophic activity.

In order to obtain knowledge on seasonal variation of the carbon exchange, measurements of CO₂ fluxes of the ecosystems will be made. Three main parameters will be measured: Net ecosystem exchange of CO₂ (NEE), ecosystem respiration (ER) and soil respiration. From these parameters plant photosynthesis and respiration can be calculated. On basis of the measurements, multiple regression models will be described developed for prediction of carbon fluxes as a function of PAR, temperature, air humidity, and soil water content on a seasonal basis. It is the aim to explain the seasonal variability in carbon fluxes and to set up a mass balance to conclude: 1) If the system during the measuring year overall is a drain or a source of CO₂ to the atmosphere. 2) Determine to which extent climatic manipulations (elevated [CO₂]_{atm}, higher temperature, and summer drought) affect the carbon balance of the system.

¹³C-pulse labeling will be carried out by exposing the plants to an atmosphere enriched with ¹³CO₂. During an incubation period air samples will be taken to test with IRMS; how much of the assimilated ¹³C which is released by respiration. The plants and soil will afterwards be prepared for the following analysis:

- Plant and soil analysis of content of ¹³C by IRMS
- Chloroform fumigation to quantify the ¹³C in the DOC and microbial biomass
- Extraction of specific lipids in soil, for analysis of ¹³C by GC-C-IRMS to differentiate the respiratory losses to species level.

Effect of Soil Temperature and Water Content on Soil Respiration in a through-fall manipulated Mediterranean evergreen woodland: a DayCent application

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In modeling terrestrial ecosystem carbon uptake and releases, large uncertainty exists in estimates of soil respiration feedbacks, in particular in Mediterranean terrestrial ecosystems because of lack of data. New datasets are needed to validate ecosystems models. The modeling of soil respiration at a daily time step follows the logic that the main abiotic drivers that determine soil respiration are soil temperature and soil water availability. Yet, most existing C models still lack to fully capture the interaction of these two parameters and its effect on soil respiration.

Objectives of this study is to verify the performance of the DayCent ecosystem model to capture trends of soil climatic drivers, in a Mediterranean woodland under different precipitation regimes, and to validate estimates of the carbon fluxes, with experimental data.

DayCent is an ecosystem model that estimates microbial respiration as a result of litter and soil C decomposition, in function of a combined effect of soil T and soil water content. It calculates a multiplier of decomposition rates, *defac*; where *defac* is $f(\text{soil T}) * g(\text{rain/PET})$. We applied DayCent model in an *Arbutus Unedo* coppiced woodland and validated it with a continuous monitoring dataset of soil water, temperature and respiration fluxes, in a through fall manipulation experiment. We also present modeled standing litter pool, to assess the model performance in simulating C pool dynamics at the site scale and the effect on heterotrophic respiration in dry conditions. The model is illustrated and the simulation data verified with a year of continuous monitoring experimental data.

Water addition effects on carbon fluxes in a high arctic semi desert and a sub arctic heath ecosystem

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Climate change is believed to cause different future precipitation amounts and patterns compared to present. As a consequence carbon balance may change dramatically in the Arctic, which contains 14% of the global soil C stores. In order to investigate the influence of soil moisture on arctic carbon fluxes, two experiments were carried out. The first experiment was performed in a high arctic semi desert close to the Zackenberg field station in NE Greenland. Here, summer precipitation was experimentally increased by weekly watering and soil plus root respiration (ER) was measured throughout the third growing season. It turned out that ER was enhanced by up to 47% in watered plots, and also the microbial biomass was raised by up to 24%. Moreover, low CO₂ emission at low light intensities regardless of watering suggested that the major part of the below-ground respiration originated from turnover of recently fixed C. In the second experiment monoliths containing soil and plants were transported from a dwarf shrub heath near Abisko in the subarctic part of Sweden to the laboratory in Lund. Here they were adjusted to three different moisture levels and subjected to four different temperature levels between 7°C and 20°C. Ecosystem CO₂ exchange was monitored continuously day and night during the experiment. The results revealed that the three different moisture levels caused distinctly different CO₂ fluxes. Also, fluxes increased with increasing temperatures, and the temperature sensitivity of the ecosystem, calculated as Q₁₀ values, differed between soil moisture levels. In conclusion, both carbon balance of high arctic and subarctic ecosystems are sensitive to changes of precipitation predicted in global change scenarios.

Forest FACE Synthesis Project: *Net Primary Productivity*

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Climate change predictions from models are highly dependent on assumptions about feedbacks between the biosphere and atmosphere. One critical feedback occurs if C uptake by the biosphere, or its net primary productivity (NPP), increases in response to the fossil-fuel driven increase in atmospheric [CO₂] (“CO₂ fertilization”), thereby slowing the rate of increase in atmospheric [CO₂]. With the objective of better informing ecosystem and global models that include a feedback between terrestrial biosphere metabolism and atmospheric [CO₂], we analyzed the response of NPP to elevated CO₂ (~550 ppm) in four free-air CO₂ enrichment (FACE) experiments in forest stands. The forest stands represent a broad range of productivity, climatic and soil conditions, stand developmental history, and life history characteristics of the dominant species, although all four are young stands in the temperate zone. We show that the response of forest NPP to elevated [CO₂] is highly conserved across a broad range of productivity, with a stimulation at the median of 23 ±2%. The surprising consistency of response across diverse sites provides a benchmark to evaluate predictions of ecosystem and global models and allows us now to focus on unresolved questions about carbon partitioning and retention, and spatial variation in NPP response caused by availability of other growth limiting resources.

The synthesis activity was supported by U. S. Department of Energy, Office of Science, Biological & Environmental Research and by the National Science Foundation Research Coordination Network on Terrestrial Ecosystem Response to Atmospheric and Climatic Change (TERACC).

Reference:

Norby RJ *et al.* 2005. Forest response to elevated CO₂ is conserved across a broad range of productivity. *Proceedings of the National Academy of Sciences* 102: 18052-18056.

Effects of Experimental Drought on Soil Respiration and Radiocarbon Efflux from a temperate Forest Soil

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Soil moisture affects microbial decay of SOM and rhizosphere respiration in temperate forest soils, but isolating the response of soil respiration to summer drought and subsequent wetting is difficult because moisture changes are often confounded with temperature variation. We distinguished between temperature and moisture effects by simulation of prolonged soil droughts in a mixed deciduous forest at the Harvard Forest, Massachusetts, USA. Roofs constructed over triplicate 5 x 5 m plots excluded throughfall water during the summers of 2001 (168 mm) and 2002 (344 mm), while adjacent control plots received ambient throughfall and the same natural temperature regime. In 2003, throughfall was not excluded to assess the response of soil respiration under natural weather conditions after two prolonged summer droughts. Throughfall exclusion significantly decreased mean soil respiration rate by 53 mg C m⁻² h⁻¹ over 84 days in 2001 and by 68 mg C m⁻² h⁻¹ over 126 days in 2002, representing 10-30% of annual soil respiration in this forest and 35-75% of annual net ecosystem exchange of C. The differences in soil respiration were best explained by differences in gravimetric water content in the Oi horizon ($r^2=0.69$) and the Oe/Oa horizon ($r^2=0.60$). Volumetric water content of the A horizon was not significantly affected by throughfall exclusion. The radiocarbon signature of soil CO₂ efflux and of CO₂ respired during incubations of O horizon, A horizon and living roots allowed partitioning of soil respiration into contributions from young C substrate (including rhizosphere respiration) and from decomposition of older SOM. Rhizosphere respiration (root respiration and microbial respiration of young substrates in the rhizosphere) made up 43-71% of the total C respired in the control plots and 41-80% in the exclusion plots, and tended to increase with drought. An exception to this trend was an interesting increase in CO₂ efflux of radiocarbon-rich substrates during a period of abundant growth of mushrooms. Our results suggest that prolonged summer droughts decrease primarily heterotrophic respiration in the O horizon, which could cause increases in the storage of soil organic carbon in this forest. However, the C stored in two summers of simulated drought was only partly released as increased respiration during the following summer of natural throughfall. We do not know if this soil C sinks during drought is transient or long-lasting. In any case, differential decomposition of the O horizon caused by interannual variation of precipitation probably contributes significantly to observed interannual variation of net ecosystem exchange in temperate forests.

Water savings in mature deciduous forest trees under elevated CO₂

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Plants are known to reduce their leaves' stomatal conductance when exposed to elevated CO₂. Whether this leads to water savings in tall forest-trees under future CO₂ concentrations is largely unknown but could have significant implications for climate and hydrology. Tall forest-trees in NW Switzerland exposed to elevated CO₂ concentration (540 ppm during daylight hours) using free air CO₂ enrichment (FACE) and the Swiss Canopy Crane (SCC) indicate water savings, but signals are highly variable between species (*Quercus petraea*, *Fagus sylvatica* and *Carpinus betulus*). Across species, sap flow was reduced by 14% in trees subjected to elevated CO₂. In order to exclude effects of sapwood thickness, canopy position etc. on flux readings, we also analyzed relative transpiration rates by standardizing the flux of each tree with its own maximum during the period in consideration. This analysis arrived at water savings of ca. 18 %. The CO₂-effect is greatest at low vapour pressure deficit (vpd). Surprisingly, the water saving effect is also seen in night-time fluxes and increases with night-time vpd. The effect was largely produced by *Carpinus* and *Fagus*, with *Quercus* contributing little. In line with these findings, during rainless periods, soil moisture at 10 cm depth decreased at a slower rate under high-CO₂ trees than under control trees. High resolution thermal images taken at different heights above the forest-canopy did not consistently detect reduced water loss through altered energy balance (warmer leaves, signal <0.2 K). Short discontinuations of CO₂ supply had no measurable canopy temperature effects either, most likely reflecting strong aerodynamic coupling of canopies. The combined results from this study suggest a ca. 16 % reduction of forest transpiration at current atmospheric moisture across a wide range of weather conditions, but this signal is likely to diminish as atmospheric feedback comes into play at landscape scale.

Effects of increased soil water availability on ecosystem carbon dioxide fluxes in spatio-temporally heterogeneous temperate grassland.

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There is considerable interest in how ecosystems will respond to changes in climate. Alterations in precipitation are expected to influence the spatio-temporal patterns of plant and soil processes that are controlled by soil moisture, and potentially, the amount of carbon (C) exchanged from ecosystems. These effects of altered climate on C dynamics will likely be greatest in water-limited ecosystems, such as grasslands. In this study we examined how irrigation affects carbon dioxide (CO₂) fluxes in five widely variable grasslands of Yellowstone National Park. We irrigated plots every two weeks with 25% of the average monthly 30-year average of precipitation. Ecosystem CO₂ fluxes were measured with a closed chamber-system once a month from May-September.

Soil moisture was closely associated with CO₂ fluxes and shoot-biomass, and increased by 1.6-11.5% among the different sites as a result of irrigation. Highest increases were found for the driest sites, where several ecosystem CO₂ fluxes of the irrigated plots were significantly different from those on the unirrigated plots. At the wet sites no irrigation effects were observed until September. This indicates that only the dry sites were water-limited throughout the 2005 growing season, which was characterized by above-average precipitation. The late-season irrigation responses at the wet sites likely can be explained by delayed plant senescence.

Our results suggest large spatio-temporal differences in the response of grassland CO₂ fluxes to changes in precipitation. Such information is important to accurately predict how changes in precipitation/soil moisture will affect CO₂ dynamics and how they may feed back to the global C cycle.

Regional Expression of the 1988 U.S. Midwest Drought in Seasonal $\delta^{13}\text{C}$ of Tree Rings

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A massive drought in 1988 strongly impacted the U.S. Midwest, but instrumental-based measurements (precipitation and Palmer Drought Severity Index [PDSI]) revealed regional variations in moisture as the drought evolved in 1988 and diminished in 1989. Plant stable-carbon isotope composition ($\delta^{13}\text{C}$) may be a useful proxy for such local climate conditions because moisture affects leaf stomatal conductance, which in turn influences the plant's ability to discriminate against $^{13}\text{CO}_2$ relative to $^{12}\text{CO}_2$. Tree rings from 3 conifer species across a network of 9 sites over 4 states around the Great Lakes were sampled to determine the effectiveness of stable-carbon isotope composition in discerning drought strength, temporal evolution, and spatial character. $\delta^{13}\text{C}$ of cellulose from 4 subdivisions of the 1988 and 1989 growth rings was analyzed and compared to moisture parameters. The range of $\delta^{13}\text{C}$ variation within each ring was typically 1-2‰ for both years, and the co-occurrence of all 3 species at a single site revealed coherent patterns for the pines (red pine and white pine) but no correlation of the white spruce with the pines. Various averaged combinations of monthly PDSI and precipitation assigned to each subdivision versus both $\delta^{13}\text{C}$ and discrimination ($\Delta \approx \delta^{13}\text{C}_{\text{air}} - \delta^{13}\text{C}_{\text{plant}}$) yielded significant correlations (generally higher with PDSI), which were even stronger when the spruce data was removed. Fraction of average monthly cumulative precipitation (relative to 1900-2001 climate data) was more strongly related to $\delta^{13}\text{C}$ than either monthly precipitation or monthly fraction of average precipitation, but was not as strongly related to $\delta^{13}\text{C}$ as PDSI. Furthermore, the pattern of increasing $\delta^{13}\text{C}$ in 1988 observed at several sites is an indicator of the increasing moisture stress of that year, and the difference in average isotopic composition of the 3rd and 4th subdivisions between 1988 and 1989 matched the regional moisture shift well. These results support the use of stable-carbon isotopes in tree rings as an environmental moisture proxy for exploring the characteristics of modern and ancient droughts, even at these relatively mesic sites.

Water Change and Ecosystem Effects

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Precipitation, water availability, and ecosystem functions in a sand forest steppe

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The Hungarian VULCAN site represents the continental Pannonian sand forest-steppe. MAT = 10,4 °C and MAP = 505 mm with uneven spatial and temporal distribution. The vegetation is a mosaic of dry grasslands and juniper-poplar groves (*Juniperus communis* L., *Populus alba* L.). The shrub is formed by the root suckers of the clonal white poplar. The soil is coarse sand (Calcaric Arenosol, FAO).

The extreme drought in 2003, apart from a single major rain event in July, lasted six months. Due to the high water permeability of the soil deep soil layers may benefit from big rain events while the uppermost 10-20 cm can dry out up to the wilting point.

The shallow-rooting fescue grass showed higher sensitivity to drought than the clonal white poplar. Within the poplar clone functional differentiation is supposed: P acquisition takes place by shallow roots of the root suckers while water is supplied mostly by deep roots of the nurturing tree.

For the relationship between temperature and soil respiration under non water limited conditions the bell shaped curve gave the best fit.

Data-model synthesis approaches for understanding the effects of precipitation on arid and semiarid plants and ecosystems

Kiona Ogle, University of Wyoming, Department of Botany

SUMMARY: This work is motivated by the potential for altered precipitation regimes to greatly impact water-limited ecosystems of the southwestern United States. Several research groups are exploring the effects of changes in precipitation on ecosystems of the Southwest. Such studies have produced enormous quantities of data representing different spatial, temporal, and biological scales. But, no modeling or synthesis effort has been made with respect to these data. Yet, such syntheses could help build a better understanding of how water-limited ecosystems may be affected by altered precipitation. This poster presents a conceptual framework for synthesizing such large, disparate datasets within the context of mechanistic models using Bayesian hierarchical methods.

Drought experiments within the Solling Roof Project

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Between 1991 and 1994 we applied 4 prolonged summer droughts in a today 72-year-old roofed Norway spruce forest at Solling, central Germany. Droughts lasted from 42 to 172 days and wettings with collected throughfall water were applied during 10 to 33 days. It was hypothesized that in forests with high accumulation of organic nitrogen, summer droughts and subsequent wettings will intensify mineralization and nitrification processes. During wettings there will be a surplus production of nitrate, the soil solution will temporarily become acidified (i.e. decrease of pH), and the molar Ca/Al ratio will decrease to critical values for fine root growth (i.e. <1.0) due to the strong acidification of our soils. In fact, we observed such mechanism but just in a single sampling spot in 20 cm soil depth and only during the wetting period in 1992. For all other periods and locations we found the opposite: Soil nitrate concentrations and fluxes decreased and we concluded that severe summer droughts and subsequent wettings do not induce distinct nitrification pulses but apparently inhibited the nitrification process. We also observed i) significantly increased needle losses, even three years after the last artificial summer drought, ii) reduced height growth but with a relatively quick recovery, and iii) that fine root growth just stopped during droughts (i.e. no dieback symptoms were visible) but restarted growth right after the wettings (data not shown). From these findings we concluded that future forest growth with respect to global warming and pollution will be determined by a combination of both, water and nutrient availability in soils.

Impacts of Land Water Balance Changes on Terrestrial Ecosystems of the U.S.A.

Faith Ann Heinsch and Steven W. Running

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Both temperature and precipitation have been changing over the last century resulting in changes in the water balance of the U.S. However, **temperature** and **precipitation** alone do **NOT** provide an integrated land water balance. We suggest calculating an integrated Penman-Monteith land water balance to produce an accurate assessment of the impacts of temperature and precipitation changes on ecosystems. While most of the data required for calculating a large-scale Penman-Monteith water balance are readily available, they are not consistently available at continental scales, particularly specific humidity and shortwave radiation. Results from the Penman-Monteith analysis suggest that the effects of changes in the U.S. water balance will be regionally-dependent, resulting in positive (e.g., increased NPP) and negative (e.g., increased wildfire) effects on ecosystems. Thus, the Penman-Monteith equation allows us to ascertain the true water limitations on ecosystems, and demonstrates that while the eastern U.S. appears to be getting wetter, there has been little change in the western U.S.

A number of studies have demonstrated the ecosystem effects of current changes in water balance. Multiple analyses using remote sensing data have ascertained that the growing season of the U.S. increased by approximately ten days between 1982-1999. However, subsequent decreases in the water balance have led to tree mortality in the southwestern U.S. In Alaska, spruce forests are experiencing extended warm periods, which **may** lead first to increased insect infestation, followed by tree die-off, accumulation of fuels, and large fires, all of which could result in species conversion. For Alaskan yellow cedar, the extended warm period results in insect infestation, stress, and/or death. In Canada, forest fires are increasing as temperatures increase, and there appears to be a similar trend for forests in the western U.S.

Another method for determining limitations on ecosystems is calculated using a Growing Season Index (GSI; Jolly et al., 2005). The GSI is a simple, effective measure of growing season constraints, calculated using standard meteorological data that determines the effects of water availability on growing season length and vegetation productivity. The GSI can be used to assess both current vegetation and trends in vegetation growth over time, and it may also provide insight into future constraints on individual ecosystems.

Summer rainfall removal in upland and floodplain boreal ecosystems within Interior Alaska

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Abstract

The objective of this study was to determine the influence of summer rainfall on the growth of trees in both upland and floodplain locations in interior Alaska. In order to control summer precipitation at the ground level corrugated plastic covers were installed under the forest canopy of floodplain balsam poplar/white spruce stands and upland hardwood/white spruce stands. The covers were installed in 1989 and yearly measurements of tree basal area growth were conducted through 2005. Average tree growth in the control plots was about 60% higher on the floodplain sites compared to the upland sites for similar species. Summer rainfall exclusion from the upland sites significantly decreased growth for birch in 1992 and 1993 and balsam poplar in 1992. Birch, balsam poplar, and white spruce displayed a nonsignificant decrease in growth in almost all other years. Aspen showed no treatment effect. On floodplain sites, basal area growth of balsam poplar in 1992 and white spruce from 1990 through 2005 was significantly decreased due to summer rainfall exclusion. In upland sites soil moisture recharge from melting snow pack is a major moisture supply for tree growth although it is not clear if a significant moisture stress occurs during the summer even in the control plots. However in the floodplain stands tree growth was highly dependent on seasonal rainfall even though the ground water table was within the rooting zone and the soils were supplied with a spring recharge due to snowmelt. A number of factors are probably causing the strong relationship. These include rooting distribution, soil texture, and the electrical conductivity of the ground water which is sufficiently high to limit moisture uptake.

Impact of night-time warming and increasing drought period in a Mediterranean shrubland

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Summary

Climatic changes could have strong effects on vulnerable ecosystems as Mediterranean shrublands/garrigue/maquis, where the growth and survival of the plants are strictly dependent on the drought and to the high summer temperature. In order to assess the impacts of the temperature increase and precipitation reduction on Mediterranean shrublands, an experimental area was established on 2001 in Sardinia, at the Porto Conte forest Alghero (SS). A system of automatic roofs covers 6 experimental plots (20 m²), in order to simulate an increase of temperature during the night (3 plots) or to intercept the precipitations during a 2-3 months period (3 plots). Three additional plots are used as control. All the observations were conducted in other five European shrubland ecosystems, according to common protocols developed in the context of the European project VULCAN (www.vulcanproject.com).

The studies of the different ecological and physiological processes are organized in working packages (Plant, Soil, Fauna, Water) and integrated in a risk assessments evaluation. The aim of the poster is to summarize the impact of the treatments on the plant community and on ecosystem functionality, after four years of experimentation.

Inter-annual variability of plant regeneration after fire of a Mediterranean shrubland of Central Spain in relation to season of burning

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Rainfall patterns in Mediterranean climates vary largely from year to year. Once a fire occurs, vegetation must recover either from resprouting or germination. Water availability might determine plant sensitivity to heat and control time and vigor of resprouting. Similarly, rainfall patterns might control the soil-seed pool and time of germination and seedling survival. Few experiments have been carried out looking at changes in resprouting or seeding in relation to variability in climatology from year to year.

The information presented is based on results of an experiment that consisted in burning during three consecutive years a shrubland in Central Spain that was dominated by two resprouters (*Phillyrea angustifolia* and *Erica arborea*) and three seeders (*Cistus ladanifer*, *Rosmarinus officinalis* and *Erica umbellata*). Fires were lit shortly before the onset of the summer (spring fires) or at the end of it (autumn fires). Three plots were burned at each season, for a total of 18 plots burned during the three years. After fires, resprouting plants (which had been tagged before the fire) or seedlings (which were tag to be monitored) were followed during several years. Rainfall of the first four years studied was rather variable, with one of the years being very dry.

Resprouting: Time of resprouting was very variable between years and between seasons of burning for the two species studied. Time of resprouting was size-related, with smaller plants resprouting later (in some cases, up to months) than larger plants. Survival of *Phillyrea* was unrelated to plant size (nearly all survived), fire season or fire year. Survival *Erica* was size-dependent, and highly variable between seasons and years.

Seeding: Results available for one species (*Cistus*) indicate that total germination varies between years and season of fire. Germination patterns are closely related to precipitation ones. In wet years, all germination occur the first-year-after fire. In dry years, germination can happen up to three-years-after fire. Mortality is high during the first months after emergence. Contrary to what is assumed, by the time summer sets in, the main attritions have taken place. Survival during the first year is high, and was much unrelated to the dryness of the year. Survival of second-year-after fire germinates is much smaller (down to a quarter of the first year). Hence, the next generation is determined by the cohort of the first-year-after fire. Preliminary analysis of the other two species confirm this and earlier findings whereby some species do not recruit in first-year-after fire when these are dry. In this case, even if second-year-after fire is wet, and high germination can take place, their reestablishment will be in danger. For some species, missing the first-year-after fire window implies that the species might loose its opportunity for re-establishing after fire.

Overall, precipitation patterns affect plant regeneration after fire either by resprouting or seeding. Not all species are equally sensitive to changes in precipitation patterns. Understanding how Mediterranean shrublands will be affected by future changes in climate requires a better understanding of the sensitivity of the species involved.

Ecosystem response to climate change: sensitivity of grassland ecosystems across the Great Plains, USA to variability in precipitation

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Water availability is a key driver of aboveground net primary productivity (ANPP) in grassland ecosystems and increasing evidence suggests that many aspects of ecosystem structure and function are quite sensitive to intra-annual variability in precipitation, even in cases where precipitation remains within normal bounds. Projected changes in climate include warming of the atmosphere and increasingly variable precipitation regimes (Houghton et al. 2001), both of which may affect soil, plant, and ecosystem properties. Given that models predict somewhat disparate scenarios of future climatic regimes, experimental studies should emphasize fundamental precipitation-productivity relationships and their mechanistic underpinnings, rather than be tied to a particular model.

Precipitation variability arises through 1) changes in the frequency of rainfall events and 2) differences in the quantity of rainfall per event. Through the use of rainout shelters, we will experimentally manipulate these 2 aspects of precipitation variability across the Great Plains of the United States in sites that span a broad precipitation, soil nutrient, and species composition (short to mixed to tallgrass) gradient. The main objective of this study is to identify common and unique responses of these grassland types to precipitation variability. For this reason, we plan to apply a uniform experimental treatment protocol in three distinct ecosystems – the shortgrass steppe, the mixed grass prairie, and the tallgrass prairie – as an initial step in evaluating not only ecosystem change that might be produced as a consequence to climate change, but also to further understand characteristic responses of vegetation to alterations in precipitation regimes.

The Effects of Altered Precipitation on Water and Nutrients in a Northern Hardwood Forest Ecosystem: Results From a Model Experiment

Lindsey Rustad (US Forest Service), Scott Ollinger (University of New Hampshire), and Robert Smith (USDA Forest Service)

Current predictions indicate that, unless greenhouse gas emissions are significantly curtailed, atmospheric CO₂ concentrations will double in the next century, global mean annual temperature will increase by 1.4 to 5.8°C, and the amount, timing, and intensity of regional and global patterns of precipitation will change (IPCC 2001). Although considerable research has been conducted on the effects of elevated CO₂ and temperature on ecosystem processes, less is known about precipitation effects. Although new ecosystem-scale experiments are needed on this topic, results from ecosystem process models can provide powerful tools to integrate existing knowledge, identify gaps in our understanding of complex relationships, and predict outcomes for alternate scenarios for which data are not available.

The goals of this model experiment were to explore the effects of changes in the timing and magnitude of precipitation on ecosystem processes in a northern hardwood forest ecosystem. We hypothesize that (1) changes in the magnitude of precipitation will alter soil moisture which, in turn, will have profound direct and indirect effects on C, N, and base cation cycles, and (2) the timing of precipitation change will be critical in moderating the amplitude of the response due to the superimposition of the precipitation change on seasonal cycles of temperature, evapotranspiration, snow pack depth, soil water availability, and plant phenology.

For this model experiment, we used the the BROOK90 hydrology model (Federer et al. 2003) and the PnET and PnET-BGC forest ecosystem/soil chemistry models (Aber et al. 1995, 1996; Aber and Driscoll 1997; Gbondo-Tugbawa 2001, Ollinger et al. 2002), calibrated for a northern hardwood forest at Hubbard Brook, NH. Four climate scenarios were simulated: spring drought (90% reduction May and June), spring addition (90% increase May and June), late summer drought (90% removal August and September), and late summer addition (90% increase August and September). For soil water potential, we simulated effects of the 4 scenarios on total soil water potential (kPa) for an upper (Bhs, ~ 21 cm depth) and lower (Bs3, ~ 72 cm depth) soil horizon for a dry year (2001; 1043 mm), a normal year (1994; 1420 mm), and a wet year (1990; 1818 mm). For C, N and base cations, we superimposed the 4 scenarios on measured climate at Hubbard Brook for the years 1980-1997.

Soil Water - Minimum control plot soil water potentials for the upper Bhs for dry, normal, and wet years were estimated to be -1676, -427, and -389 kPa, respectively. The imposed spring drought decreased these to -1696, -1688, and -1623 kPa, respectively, and the imposed late summer drought decreased these to -1809, -1721, and -1758 kPa, respectively. These values are well below the values of -500 to -1000 kPa which are considered to correspond to critical plant water potentials and reductions in root growth (Federer 1980; Joslin et al 2001). Spring and late summer water additions appeared to relieve water stress during a dry year, but had

limited effect on total soil water potential during normal to wet years where water appears not to be physiologically limiting.

Dissolved Inorganic Nitrogen (DIN) Export - Simulated spring and late summer droughts each reduced N input by $0.5 \text{ kg N ha}^{-1} \text{ yr}^{-1}$ compared to the control. Model results showed a reduction in DIN export of $2 \text{ kg N ha}^{-1} \text{ yr}^{-1}$, suggesting a greater effect of drought on mineralization rates than immobilization processes. Simulated spring additions increased N input by $\sim 0.5 \text{ kg N ha}^{-1} \text{ yr}^{-1}$. Model results showed increased export of $\sim 1 \text{ kg N ha}^{-1} \text{ yr}^{-1}$, suggesting an increase in mineralization relative to immobilization. Late summer additions had no effect on DIN losses, indicating that the timing of the addition is important.

Wood Production - After 10 years, simulated spring and late summer droughts resulted in 22% and 17% declines in wood production, respectively, whereas spring additions resulted in a modest 7% increase in wood production, and late summer additions had no effect on wood production.

Soil Base Saturation - The simulated droughts and additions result in decreases and increases in weathering of $16 \text{ mol Ca}^{2+}/\text{ha}/\text{yr}$, throughfall inputs of $11 \text{ mol Ca}^{2+}/\text{ha}/\text{yr}$, and leaching losses (associated with throughfall input of SO_4^{2-}) of $36 \text{ mol Ca}^{2+}/\text{ha}/\text{yr}$ for a net increase of $9 \text{ mol Ca}^{2+}/\text{ha}/\text{yr}$ for the drought treatments and a net decrease of $9 \text{ mol Ca}^{2+}/\text{ha}/\text{yr}$ for the additions. These changes are small compared to the exchangeable soil Ca pool on the order of $7000 \text{ mol}/\text{ha}$.

Conclusions - Although the New England region in the USA typically experiences relatively high rates of precipitation (average $> 100 \text{ cm}/\text{yr}$) evenly distributed throughout the year, mild drought stress is common in mid-summer during most years and multi-year droughts have occurred at least once a decade during the last century. Projected future changes in both the magnitude and, perhaps more importantly, the timing of precipitation will directly affect soil moisture, which in turn can initiate a cascade of alterations in above and belowground plant physiology, soil microbial dynamics, and solid and solution phase soil chemistry. Observations in space and time on ecosystem responses to intra- and inter-annual changes in precipitation as well as large-scale ecosystem manipulation studies are needed to better understand forest ecosystem response to altered precipitation.

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- Ollinger, S.V., J.D. Aber, P.B. Reich and R. Freuder. 2002. Interactive effects of tropospheric ozone, nitrogen deposition, elevated CO₂ and land use history on the carbon dynamics of northern hardwood forests. *Global Change Biology* 8:545-562. and model future ecosystem responses to these anticipated changes.

Precipitation and sea-salt addition at Gårdsjön, Sweden.

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A 6300 m² forested experimental catchment Gårdsjön G1 at Swedish west coast was in 1991 fitted with a 7000 m² plastic roof and treated with an artificial clean precipitation sprinkled underneath the roof between 1991 and 2001 in a large de-acidification experiment. The plastic sheeting was removed in summer 2001. The basic monitoring was maintained and the catchment became one of the experimental sites within EU project EUROLIMPACS (www.eurolimpacs.ucl.ac.uk) designed to assess the effects of future global change on Europe's freshwater ecosystems. Two aspects of potential impact were studied experimentally – an increased sea-salt input due to increased storminess and increased precipitation.

In 2004, a short steady state (precipitation rate equal to discharge rate) watering experiment with variable sea-salt input was performed. This provided opportunity to observe chemical response of runoff due to changed sea-salt input alone, i.e. while maintaining “constant” hydrology for a period of 11 days. In 2005 a different strategy was employed. An effect of “wet summer” was studied by adding 600 mm of water over 5 summer months. The focus has been on changes of runoff chemistry including major anions and cations, DOC and Hg. Both experiments brought about clear changes which either ceased when the water (and/or sea-salt) addition stopped or e.g. in case of Hg persisted for a several months after the campaign was finished.

Drought-tolerance of an eastern Amazon forest: studies of xylem physiology in the context of a large-scale rainfall exclusion experiment

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The capacity of xylem to transport water from the soil to the leaves is itself at risk during periods of drought due to the increased potential for cavitation. Our research focuses on the effects of drought on the water transport capacity of Amazonian rainforest trees. Our goal is to understand the extent to which cavitation results in a loss of hydraulic conductivity, potentially leading to stomatal closure, leaf shedding, and tree death. Our research was carried out within the context of the world's largest rainfall exclusion experiment. This experiment, the first conducted in a rainforest (eastern Amazonia; Para State/Brazil) consists of two 1-ha plots, of which one is a control and one in which rainfall reaching the forest floor has been reduced by 50% since 2000. We measured xylem hydraulic conductivity using a field pressure-drop flow meter to test the hypothesis that cavitation limits water uptake from deep soil layer. We chose four species which are common in this area. Our preliminary results indicate that the specific conductivity (Ks) of branches did not differ significantly between plots for all studied species. Vulnerability curves in branches showed a high tolerance to cavitation (50% loss of hydraulic conductivity at values smaller than -3.5MPa), consistent with the lack of an impact of imposed drought on xylem hydraulic conductivity. The possibility that water uptake by leaves (instead of through the soil) could play an important role in the water balance of these trees might be responsible for these findings. Drought tolerance exhibited by Amazon tropical rainforest trees allows them to maintain physiological function and xylem continuity despite the marked seasonality in rainfall in the eastern Amazon.

Water Change and Soil and Plant Effects

Melany Fisk *et al.*: Snow depth, soil frost, and nutrient loss in a northern hardwood forest

Olevi Kull *et al.*: Reflection of experimental drought and warming at European shrublands

Kristian Albert *et al.*: How does prolonged drought affect plant physiological processes? - Focus on the interactions with increased temperature and elevated [CO₂] within the CLIMAITE project?

Jake Weltzin *et al.*: Responses of canopy greenness, green-up, and senescence to elevated [CO₂], warming, and soil moisture availability

Holly Alpert & Michael Loik: Effects of Snow Depth and Microhabitat on *Pinus jeffreyi* Establishment in the Great Basin Desert, USA

Inger Kappel Schmidt & Claus Beier: CLIMAITE – Climate change effects on biological processes In Terrestrial Ecosystems

Inger Kappel Schmidt & Claus Beier: Impacts of climate change on vulnerable European shrubland ecosystem.

Werner Borken *et al.*: Do we overestimate the effect of wetting on C and N mineralization of soil organic matter?

Lindsey Rustad: Terrestrial Ecosystem Responses to Atmospheric and Climatic Change (TERACC)

Snow depth, soil frost, and nutrient loss in a northern hardwood forest

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Soil freezing events related to lack of snowcover have resulted in high NO_3^- losses in forests of the northeastern United States. Increased frequency of these freezing events may occur with climate change in the region, raising concerns about the mechanisms underlying nutrient loss and the consequent long-term ecosystem effects. Our experimental work at the Hubbard Brook Experimental Forest, New Hampshire, has linked elevated NO_3^- loss to root mortality induced by soil freezing, and has raised important questions about the mechanisms by which freezing affects soil biogeochemistry. We hypothesized that physical disruption of soil by frost heaving and the formation of ice lenses represents an important disturbance to the ecosystem N cycle. We tested four possible mechanisms by which soil freezing increases N loss: 1) reduced root uptake because of root mortality and/or injury, 2) rapid mineralization of dead roots killed by physical disruption, 3) physical disruption of soil aggregates and consequent release and mineralization of particulate organic matter (POM) and 4) physical effects of freezing on mineralization of fresh litter.

We tested our hypotheses in a plot-based field study in which soil freezing was induced by snow removal through January of two successive winters. Snow removal reduced soil temperatures and increased the depth and rate of frost penetration in soil. Effects of snow removal on soil solution NO_3^- depended upon tree species composition, with increased NO_3^- observed in stands dominated by sugar maple but not those dominated by yellow birch. Soil freezing-induced fine root mortality was localized to first and second order roots in the organic horizon and was most severe in plots dominated by sugar maple. There was no effect of snow manipulation on mycorrhizal colonization of mature sugar maple roots. Two years of soil freezing increased POM as well as organic matter concentrations in soil particles $< 2000 \mu\text{m}$. Freezing also increased the release of NH_4^+ from ^{15}N -labelled litter. Our results suggest that impaired fine root uptake of N is an important mechanism contributing to elevated NO_3^- loss following soil freezing events. Fine root turnover probably contributed to increased POM, but this did not coincide with elevated NO_3^- observed in the first year of the study. Physical fragmentation of litter more likely contributes to NO_3^- losses. Ecosystem responses to soil freezing will depend on tree species composition, with stands dominated by sugar maple most susceptible to root death and NO_3^- loss.

Reflection of experimental drought and warming at European shrublands

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We examined plant response to warming and drought at shrubland ecosystems of six European sites (UK, Denmark, Netherlands, Hungary, Spain, Italy). We used ground based canopy reflectance measurements in visible/near-infra-red wavebands for evaluation of the method to use in early detection in canopy composition and structure with possible implication in remote sensing technology. Reflectance index NDVI revealed expected relationship with green biomass data (obtained from point quadrat measurements) with strong tendency to saturate at high biomass conditions. Differences in reflectance indices between treatments were considerably smaller than differences between sites. Cross-sites comparison showed that in general effect of warming treatment was positive on NDVI, whereas drought treatment had negative effect. Green biomass data showed similar trends. Reflectance index PRI had no tendency to saturate at high biomass values suggesting that this parameter works better than NDVI in high biomass conditions. PRI showed a good agreement with leaf-level photochemical efficiency measurements. Plot level PRI measurements suggested that photochemical efficiency of plants was mainly influenced by the warming treatment. Reflectance proves to be a useful means for detecting changes in vegetation while reflectance is easier to measure and has better averaging ability than direct measurements of biomass or physiological status of vegetation.

How does prolonged drought affect plant physiological processes? - Focus on the interactions with increased temperature and elevated [CO₂] within the CLIMAITE project?

By Kristian Albert, Helge Ro-Poulsen and Teis N. Mikkelsen

Within the CLIMAITE project following manipulations are made according to a realistic Danish climatic scenario anno 2075: 1) Elevated CO₂ to 510 ppm by means of FACE technology 2) Passive night time warming by approximately 2°C air temp by means of heat reflective curtains 3) Extended summer drought from about June until end of July until soil water content are close to 4-5% by means of automatized curtains.

The investigated plant species are the grass *Deschampsia flexuosa* and the evergreen heather *Calluna vulgaris* in a semi-natural heathland on sandy soil. The site has both a low water holding capacity and nutrient limitation is indicated of Phosphorus to a higher degree than Nitrogen. Focus is on plant photosynthetic performance and initially a large effort is primarily to detect effect of treatments and secondly investigate their mechanisms. This is being done by conducting measurements on the leaf scale throughout field season by 1) traditional CO₂ and H₂O gas-exchange 2) Plant stress detection by PAM fluorimetry and Chlorophyll-a fluorescence induction curves 3) Leaf content of Chlorophyll-a, C, N 4) Carbon isotopes 5) Water potential. The allocated techniques and protocols aims at answering the following intriguing questions: What are the potentially plant responses? And what do they actually do? - Close collaboration with other Ph.d projects aims at linking the plant performance to plant biomass build-up both above and below ground, net ecosystem gas exchange by chamber measurements and spectral analysis of canopy reflectance. At bottom line the plant photosynthetic studies goes in as input to the ecosystem responses. More about the plant responses: In general, the application of pulse-induced treatments, the short-term effects (5 years) will be different from the longer-term effects (>5 years) due to differences in response-time in different ecosystem components and processes. Initially, the pre-treatment function will change strongly and in a directed manner, but the rate of change will decrease over time as the system approaches a new "dynamic equilibrium". The seasonal variation in climate e.g. temperature and precipitation patterns will lead to large yearly and seasonal differences. Balancing the responses to the drivers also very much depends on whether the plants are mostly water limited versus nutrient limited. Specifically the plant response to Increased CO₂ will lead to higher carbon sequestering and better water use efficiency and will be negatively affected by a prolonged summer drought and night time warming. Although the mechanisms may differ as 1) Drought may affect stomata conductance, increase the plant stress (direct and indirect effects on PSII), respiration processes, leaf content of carbon isotopes and water potential whereas 2) Night time warming may affect respiration processes primarily and accelerate drying of soil adding 'drought effects'. Net result of manipulation combinations on photosynthesis will depend on the realized plant response capacity. We argue that plant responses are mediated by the strength of each manipulated driver which in nature differs through season. This may lead to different impact through season and adds to complexity, in particular when separation of the underlying mechanisms is to be made.

Responses of canopy greenness, green-up, and senescence to elevated [CO₂], warming, and soil moisture availability

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We used NDVI to assess community responses and phenological shifts to interacting factors of elevated CO₂, warming, and soil moisture availability in constructed old-field communities. There were no effects of CO₂, but soil moisture availability and warming were most influential to NDVI, and warming extended the growing season interactively with CO₂ and soil moisture.

Effects of Snow Depth and Microhabitat on *Pinus jeffreyi* Establishment in the Great Basin Desert, USA

Holly Alpert and Michael E. Loik, University of California, Santa Cruz, USA

Climate change will impact plant species ranges, and precipitation may be a driving factor of such change in semi-arid regions. Ecotones provide opportune spatial settings in which to study distribution shifts. This work will investigate the influence of precipitation and microhabitat on *Pinus jeffreyi* establishment at the ecotone of the Sierra Nevada conifer forest and the Great Basin sagebrush steppe in eastern California, USA. *Pinus jeffreyi* is a dominant species of the conifer forest, and models have projected certain low-elevation treelines to move downslope with increases in precipitation, contrary to conventional thinking. This research will involve outplanting of *Pinus jeffreyi* seedlings into snow depth (increased, decreased, and ambient) and microhabitat (two nurse shrubs and intershrub spaces) treatments. We will monitor seedling survival and growth through the growing season. Results from this study will be helpful for land and water managers, as this area is both a popular recreation area and provides freshwater for the city of Los Angeles.

CLIMAITE – Climate change effects on biological processes In Terrestrial Ecosystems

Inger Kappel Schmidt, Forest & Landscape, KVL, Denmark and Claus Beier, RISØ, Denmark and the CLIMAITE network.

Human activity lead to increased atmospheric CO₂ concentrations that again will affect the global climate causing global warming and changes in precipitation patterns. CLIMAITE is a multidisciplinary national Danish research initiative studying the biological effects of such climatic changes in terrestrial ecosystems. The aim of CLIMAITE is to develop a conceptual understanding of how climatic and environmental changes in concert will affect biological processes in terrestrial ecosystems. This will improve our understanding of interactions between external stress factors and biological processes and provide a stronger scientific background for societal and political actions to counteract negative consequences of climatic changes. CLIMAITE will particularly focus on two issues related to biological processes and climate change, which are believed to play a key role for the biological effects of climate change:

Multiple environmental changes involving simultaneous changes in three factors: atmospheric CO₂ concentrations, temperature and water availability. Each of these factors directly affect biological processes and there is increasing evidence that the combined effects of these changes will be very complex and include strong interactions between factors, and that the combined effects will be difficult to predict from the effect of the individual factors.

Temporal variation patterns including extension of the growing season, increased frequency of freeze/thaw cycles, number of frost free days, and frequency of extreme weather events etc. are believed to play significant roles for the biological effects as compared to just average changes in the affecting factors.

CLIMAITE will advance time by 70 years and artificially create the climate anno 2075 in the field according to climate predictions for Denmark. The research is based on a large scale field experiment with climate manipulations alone and in combination:

CO₂ – a Free Air Carbon Enrichment (face) increases CO₂ concentration to 510 ppm

Temperature – night time warming with reflective curtains increases the air and soil temperature

Prolonged drought – precipitation will be removed for 4-8 weeks in early summer by automatic rain covers.

The experiment is situated in a grass rich heathland 50 km NW of Copenhagen. The effects of the treatments on individual species, ecosystem structure and ecosystem functioning will be investigated through targeted studies on the soil, plants, meso- and micro fauna and microorganisms. The studies will include changes in carbon and nutrient balances and circulation, stress tolerance and adaptation, species competition and composition and plant

tissue chemistry and herbivory. The research will take advantage of novel research tools including field scale ecosystem manipulations, stable isotope techniques, controlled herbivory and DNA techniques.

CLIMAITE involves a consortium of 6 research groups from Risø National Laboratory, University of Copenhagen, Royal Veterinary and Agricultural University and the National Environmental Research Institute.

Impacts of climate change on vulnerable European shrubland ecosystem.

Inger Kappel Schmidt, Forest and Landscape, Denmark and Claus Beier, Risø, Denmark and VULCAN partners.

VULCAN -Vulnerability assessment of shrubland ecosystems in Europe under climatic changes - is an EU project investigating the effects of changes in climate on the functioning of shrublands.

VULCAN combines 2 different approaches to study these effects. The first approach is known as "space for time" substitution, where the long term effect of a pressure on the ecosystem, e.g. temperature, at any particular site is studied by moving to another site, which is already exposed to the change in focus. In Vulcan, this was done by carrying out the same studies in comparable ecosystems in UK, Denmark, the Netherlands, Hungary, Spain and Italy – 6 sites, which are naturally exposed to large differences in the climatic conditions we wanted to study. The other approach applied in VULCAN was "ecosystem manipulations", which means that the ecosystem is exposed to the changes in the field by realistic manipulations of climate.

The experimental manipulations were initiated in 1999 in DK, NL, UK and ES and in HU and IT in 2001.

- Experimental *warming* was done by covering the study plots by a curtain reflecting the infrared radiation during night thereby increasing the temperature by c. 1 degree.
- Experimental *drought* was done by covering the study plots with a transparent polyethylene (PE) plastic curtain during rain events for 1-2 months to remove all incoming water
- Untreated *control* plots placed next to the warming and drought treatments were used for reference.

The poster will primarily show data from the Danish field experiment at a heath/grassland. We observed effects of both warming and drought on a number of key processes, e.g. species composition, growing season length, carbon storage patterns and soil water chemistry. The experimental warming tended to increase and drought decreased aboveground biomass. Warming also increased the growing season by ca. 14 days. Species showed different responses, e.g. the most dominant grass *Deschampsia flexuosa* decreased its abundance in the drought treatment where more rhizomatous grass species increased their abundance. Warming affected both C and N cycling in the soil. The results indicate carbon loss from the soil in response to both warming and drought.

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Do we overestimate the effect of wetting on C and N mineralization of soil organic matter? *Werner Borken, Kerstin Hentschel, Jan Muhr and Egbert Matzner*

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Many field and laboratory studies suggest that wetting of dry soil may cause an exceptional strong increase in the mineralization of soil organic matter resulting from accumulation or exposition of labile organic compounds during dry periods. Here we report the results of a laboratory study on the effects of wetting intensity on carbon and nitrogen mineralization rates of a Norway spruce soil. After mild drying undisturbed soil columns were exhibited to (i) 8 mm, (ii) 20 mm and (iii) 50 mm of artificial throughfall per day and subsequently to 4 mm throughfall per day at a temperature of 15°C. The control columns (not dried) received 4 mm throughfall per day during the wetting periods. The same amount of throughfall (156 mm) was added to all treatments throughout the three repeated drying/wetting cycles. In all three cycles, CO₂ production recovered within 2-4 days close to the level of the control columns following wetting of dry soil and remained afterwards below the level of the control columns. CO₂ production decreased in all treatments during the three cycles. Inorganic N fluxes were higher in the control than in the treatments and increased gradually from the first to the third cycles. The intensity of wetting had no effect on both CO₂ production and inorganic N fluxes. We conclude that no significant amounts of labile soil organic compounds were accumulated during the drying periods. The microbial community could have been affected by drying because the C and N mineralization rates of the control columns were higher than those of the treatments. Overall, our results suggest that (1) soil organic matter including litter may accumulate during extended drying periods and that (2) wetting of dry soil cause no surplus release of CO₂ and inorganic N due to mineralization of 'accumulated' soil organic matter. The sink strength of spruce forest soils might increase with increasing intensity and length of summer droughts.

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Terrestrial Ecosystem Responses to Atmospheric and Climatic Change (TERACC)

TERACC is an international research coordination network of global change scientists from over 100 individual research sites. The central goals of TERACC are to:

1. integrate and synthesize existing whole ecosystem research on ecosystem responses to individual global change drivers.
2. foster new research on whole-ecosystem responses to the *combined* effects of elevated atmospheric CO₂, warming, and other aspects of global change.
3. promote better communication and integration between experimentalists and modelers.

TERACC originally consisted of a liaison between two existing Global Change in Terrestrial Ecosystems (GCTE) networks: the Network of Ecosystem Warming Studies and the Elevated CO₂ Network. It has since expanded to include PrecipNET (a network of precipitation manipulation experiments), the NERC Nitrogen Network (a network of N addition experiments), and a core group of ecosystem- to global-scale modelers.

TERACC activities include workshops, education, and outreach.

To date, TERACC has sponsored or co-sponsored the following workshops:

1. Ecosystem Functioning in a Warmer and CO₂-rich World, July 10, 2001, Amsterdam, Netherlands (33 participants from 8 countries).
2. From Transient to Steady State Response of Ecosystems to CO₂-Enrichment and Global Warming, April 28 - May 1, 2002, Durham, New Hampshire. (36 participants from 8 countries).
3. Interactions Between Increasing CO₂ and Temperature in Terrestrial Ecosystems, April 27 - 30, 2003, Lake Tahoe, California (71 participants from 8 countries).
4. Modeling Ecosystem Responses to Global Change: Techniques and Recent Advances, January 9 - 13, 2005, Fort Myers, Florida (48 participants from 7 countries).
5. Global Environmental Change and Biodiversity, May 1 - 4, 2005, Dourdan, France (52 participants from 14 countries). *Co-sponsored by DIVERSITAS and the Tyndall Center.*
6. Forest FACE Synthesis Project, May 22 - 25, 2004, Townsend, Tennessee (10 participants from the U.S.).
7. Forest FACE N Synthesis, Belgium.
8. Effects of PREcipitation Change On Terrestrial Ecosystems (EPRECOT), May 22-25, 2006, Helsingør, Denmark (70 participants from 14 countries). *Co-sponsored by the European Commission's Sixth Framework Programme.*

All workshops have a common theme of integrating experimental and modeling approaches and all workshops provide significant time for small group and/or informal discussion.

TERACC is committed to helping educate the next generation of global change scientists. The primary mechanism to achieve this has been the inclusion of graduate students at annual meetings. To date, 33 graduate students have attended TERACC meetings. By example, TERACC is also encouraging international partners to do the same. TERACC has also provided funds for two graduate students to attend an international training seminar, for one post-doctoral student to complete a meta-analysis of Forest FACE data, resulting in a peer-reviewed manuscript, and for four minority undergraduate students to participate in summer research experiences.

TERACC strives to increase the participation of under-represented groups in global change science. To this end, TERACC members have (a) obtained outside funding for four minority undergraduate students to engage in summer research experiences, (b) partnered with faculty from two HBCU's in proposal writing activities, and (c) identified and invited individuals from under-represented groups to participate in TERACC workshops.

TERACC members communicate through a list server (currently with over 150 members from 14 countries) and TERACC maintains a website. Results have been disseminated in 20 peer-reviewed papers, 2 peer-reviewed book chapters, 1 book (in preparation), on the TERACC web-site, and at numerous scientific conferences and meetings. Through the recognition of the needs to (a) evaluate the effects of multiple, simultaneous, interacting vectors of global change, and (b) better integrate experimental and modeling approaches, TERACC is making a significant and unique contribution to global change science and to the global change community.

Multifactor Experiments

Dominique Bachelet: Precipitation, CO₂ and fire effects on North American ecosystems.

Shiqiang Wan *et al.*: Duolun Global Change Multi-factor Experiment (DGCME)
A multidisciplinary project of global change impact on the temperate steppe in China

David Briske *et al.*: Texas Warming and Rainfall Manipulation (T-WaRM) Project:
Infrastructure, Design, and Data Highlights

Jesse E. Bell: Precipitation and Temperature Change of an Oklahoma Transect over a Hundred Year Period

Ronald P. Neilson *et al.*: Laptop presentation: Continental Vegetation Responses to Climate Change

Scott V. Ollinger *et al.*: Effects of Future Changes in Climate and Atmospheric Composition on a Northeastern U.S. Forest Ecosystem

Orla Dermody *et al.*: Elevated [CO₂], warming, and precipitation interact to alter the spatial and temporal availability of soil moisture in an old field ecosystem

Rebecca Sherry *et al.*: Inter-annual Climate Variability: Field Results from a Pulse Heating and Water Addition Experiment

Sune Linder *et al.*: Spring Phenology of Norway spruce (*Picea abies* (L.) Karst.) at Ambient and Elevated [CO₂] and Temperature

Ross McMurtrie *et al.*: The Hawkesbury Forest Experiment: Impacts of Precipitation and CO₂ on Trees

Vidya Appukkuttan-Suseela & Jeffrey S. Dukes: The Boston-Area Climate Experiment: A gradient-based approach for characterizing ecosystem responses to warming and precipitation change

Ståle Haaland *et al.*: CLUE-project. Testing some hypothesis *in situ*

Jake F. Weltzin *et al.*: Moisture drives species diversity in a multi-factor global change experiment

Precipitation, CO₂ and fire effects on North American ecosystems.

Dominique Bachelet, Oregon State University and the MAPSS Team, USFS PNW station, Corvallis, OR. USA

The VINCERA (“**V**ulnerability and **I**mpacts of **N**orth American Forests to **C**limate Change: **E**cosystem **R**esponses and **A**daptation”) project involved several DGVMs including MC1 from the MAPSS team in Corvallis, Oregon. The models were run with a consistent data set for historical climate and six climate change scenarios that were developed by the Canadian Forest Service (Price and McKenney) with two emission scenarios. I chose one climate change scenario (CGCM2) and one Inter-governmental Panel on Climate Change (IPCC) emission scenario (SRES A2) to show the relationship between simulated NPP and precipitation for North American ecosystems under projected changes in climate and with a variable CO₂ effect. I compare a low CO₂ effect where the potential productivity of all life forms is enhanced by 25% and transpiration is decreased by 25% at 700ppm, to a high CO₂ effect where the potential productivity of all life forms is enhanced by 65% and transpiration is decreased by 65% at 700ppm. I also show the impacts of fire suppression (simple reduction of area burned after 1950) on the response of NPP. All vegetation types show greater NPP levels under future climate with the high CO₂ effect. Fire suppression mostly affects temperate forests increasing the NPP range under future climate with the high CO₂ effect and decreasing NPP with the low CO₂ effect.

Duolun Global Change Multi-factor Experiment (DGCME)

A multidisciplinary project of global change impact on the temperate steppe in China

*Shiqiang Wan, Xingguo Han, Guanghui Lin, Linghao Li,
Jianxin Sun, Gaoming Jiang, Shuli Nu, Zhiyou Yuan, Zhengwen Wang
Institute of Botany, the Chinese Academy of Sciences, Beijing, China*

The temperate steppe in northern China represents the typical vegetation across the vast area in the Eurasian continent. Located in arid and semiarid regions, the temperate steppe is predicted to be sensitive to climatic change and grazing disturbance. Duolun Global Change Multi-factor Experiment (DGCME) was designed to examine the potential impacts on the temperate steppe of global warming, changing precipitation regime, fertilization, grazing, and their possible interactions.

The preliminary results showed that: (1) changes in plant phenology under warming and changing precipitation regimes were species-specific; (2) both N and N+P fertilization stimulated ecosystem C fluxes whereas P fertilization alone had little effect; (3) there were transient responses of ecosystem C fluxes to increasing precipitation in different seasons; (4) warming facilities could cause substantial differences in the responses of microclimate and ecosystem C fluxes.

**Texas Warming and Rainfall Manipulation (T-WaRM) Project:
Infrastructure, Design, and Data Highlights**

*David D. Briske, Mark G. Tjoelker and Astrid Volder
Texas A&M University, College Station, Texas USA*

Project infrastructure is organized around eight permanent rainfall exclusion shelters (9 x 18 m) located in remnant oak savanna of east-central Texas, USA. *Quercus stellata* (post oak) is the dominant deciduous tree, *Schizachyrium scoparium* (little bluestem) is the dominant C₄ grass, and *Juniperus virginiana* (juniper) is an invasive evergreen tree. Two simulated rainfall patterns vary seasonally in event size, but not in total annual rainfall or distribution of events. Rainfall redistribution withholds 40% of the summer rainfall (May – September) and redistributes it over the two preceding spring and two subsequent autumn months. Three monocultures and two grass-tree combinations were planted in each shelter in plots warmed with infrared lamps and paired controls. This design allows for investigation of plant responses to altered rainfall patterns and warming both independently and in combination. Rainfall redistribution significantly decreased soil water by 31 % during the dry summer phase, but increased it only by 3 % in the spring and autumn wet phases. Warming increased soil temperature (3 cm depth) by 0.5 °C and consistently reduced soil water content by approximately 1%. Warming had little effect on plant growth and grass-tree interactions, although there was an overall positive effect of warming on juniper growth. Grass tiller density responded positively to rainfall redistribution whereas growth of both tree species was negatively affected over the entire year. Rainfall redistribution intensified grass-tree competition in the dry summer phase and reduced grass-tree facilitation in the wet autumn phase. These data demonstrate that rainfall redistribution can modify competition-facilitation dynamics in oak savanna ecosystems.

Precipitation and Temperature Change of an Oklahoma Transect over a Hundred Year Period

Jesse E. Bell

Predictions of the future effects of climate change have been shown to increase temperature and alter regional precipitation. In this assessment of regional climate we evaluated the long-term change in precipitation and temperature across an environmental gradient (Oklahoma, USA) to view the past change of an area. Oklahoma is around 960km from east to west and along that gradient there is a gradual precipitation decrease from around 1422mm in the eastern part to 508mm in the western panhandle. Associated with this decrease in precipitation, there is a change in vegetation type according to each region. Throughout Oklahoma there has been extensive documentation of climate data across the state for nearly the last 100 years. This gives the unique opportunity of evaluating how precipitation and temperature have changed in regional areas over the recent century. In our analysis of the datasets we were able to see a general trend in an increase in precipitation through the environmental gradient, with the exception of the Woodward site. There was also a decreasing trend in the amount of annual rain events in each region with the exception of the Boise City site, which saw an increasing trend.

Continental Vegetation Responses to Climate Change

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Under the VINCERA (Vulnerability and Impacts of North American forests to Climate: Ecosystem Responses and Adaptation) project, the DGVM MC1 simulated the impacts of potential climate change through the 21st century under 6 future climate scenarios (CGCM2, HADCM3, CSIRO Mk2) and 2 CO₂ emission scenarios (SRES A2 and B2). We documented changes in vegetation distribution, carbon balance and fire impacts. All major forested regions of North America (Boreal, Western temperate and Eastern temperate) experience the potential for increased fire, but for very different reasons and with very different carbon balance results. A change in the magnitude of the CO₂ growth enhancement effect in the model can dramatically alter the results. Fire suppression also has the potential to significantly change these outcomes.

Effects of Future Changes in Climate and Atmospheric Composition on a Northeastern U.S. Forest Ecosystem

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Across the northeastern region of the United States, mean temperatures have increased 0.6 °C over the past 30 years and are expected to rise another 2-8 °C over the next century. Expected concurrent changes in multiple environmental factors (temperature, precipitation, CO₂ and N deposition) can interact in ways that either accentuate or offset one another. Multi-factor manipulation experiments provide valuable tests of certain combinations of these changes, but ecosystem models are needed to predict interactive effects across the range of conditions likely experienced by northeastern U.S. forests.

In this study, we used the PnET-CN ecosystem model to evaluate the effects of historical and predicted future changes in climate and atmospheric CO₂ on net primary production (NPP), net ecosystem C exchange (NEE), water runoff and nitrogen retention at the Hubbard Brook Experimental Forest in New Hampshire, USA. We used four sets of climate predictions generated using two general circulation models and two scenarios of future CO₂ concentrations. A series of model experiments were conducted to examine the individual and combined effects of future climate, CO₂ and disturbance. Effects of CO₂ were examined through individual and combined responses of photosynthesis and stomatal conductance.

Results indicate a wide range of future increases in NPP. Both climate and CO₂ contributed to predicted growth increases, but interestingly, their relative importance shifted from CO₂ to climate from the first to second half of the 21st century. The response of predicted runoff varied from no change to a > 10% decrease, depending on a combination of future precipitation and whether stomatal conductance was allowed to respond to rising CO₂. NEE and N retention responded more strongly than other predicted variables to assumptions regarding future management and disturbance. Future work will focus on additional scenarios of environmental change and spatial extension over the greater northeastern U.S. region.

Elevated [CO₂], warming, and precipitation interact to alter the spatial and temporal availability of soil moisture in an old field ecosystem

*Dermody, Orla^{*1}, Weltzin, Jake¹, Engel, E¹ and Norby, Richard².*

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It is generally unknown how the response of natural ecosystems to elevated [CO₂] will be modified by changing temperature and precipitation. Reduced stomatal conductance in elevated [CO₂] may increase the availability of soil moisture. However, the positive effects of [CO₂] on soil moisture may diminish with warming and decreased precipitation. Additionally, an increase in leaf area index (LAI) in elevated [CO₂] could negate the effects of reduced stomatal conductance on soil moisture. Using open-top chambers (4-m diameter), the interactive effects of elevated [CO₂], warming, and precipitation on soil moisture availability were examined in the OCCAM (Old-Field Community Climate and Atmospheric Manipulation) experiment at Oak Ridge National Laboratory in eastern Tennessee. Soil moisture was measured with time-domain reflectometry (TDR) probes positioned vertically from 0-15cm and horizontally at 30 cm and 55 cm below ground. LAI was measured using an AccuPAR ceptometer. Although not always significant, elevated [CO₂] increased soil moisture at all depths, particularly during peak growing season. The effects of elevated [CO₂] were maintained with warming. Increases in soil moisture in elevated [CO₂] occurred concomitantly with declines in stomatal conductance. Growth in elevated [CO₂] increased LAI of the old-field community. However, despite higher LAI the positive effects of [CO₂] on soil moisture were maintained. At least in this ecosystem elevated [CO₂] increased soil moisture even with altered temperature and precipitation regimes. It remains to be seen how the balance between evaporation and transpiration will be altered by elevated [CO₂] and changing temperature and precipitation regimes.

Inter-annual Climate Variability: Field Results from a Pulse Heating and Water Addition Experiment

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Climate change is predicted to increase frequency of extreme weather events and anomalously warm, wet, or dry years. This study was designed to examine the effects of an anomalously warm and wet year on all aspects of the tallgrass prairie ecosystem during and after treatments. Some of the results are reported here. Radiant infrared heaters warmed plots an average of 4.1°C, with greater warming during summer. A 2x natural precipitation treatment increased soil moisture by an average of 10.1%. Warming and 2x precipitation increased soil CO₂ efflux additively. Spring and early summer flowering phenology was advanced with warming compared to control. Flowering was delayed with warming in late summer. 2x precip had little effect on phenology in this extremely dry year. Above-ground biomass nearly doubled in warmed plots during spring of the treatment year. As summer drought set in, biomass in 2x precipitation plots overtook that in warmed plots, and warmed plots had the least biomass in fall of that year. Warmed plots also had less biomass into summer of the next year due to a soil moisture deficit that lasted approximately 2 months after the end of treatments in the top most layer of soil, and over 10 months in the lowest soil level. C₄ grasses increased in warmed plots during the treatment year as well as in the following fall, a 9 month carry-over effect.

Spring Phenology of Norway spruce (*Picea abies* (L.) Karst.) at Ambient and Elevated [CO₂] and Temperature

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During 2001, twelve whole-tree chambers (WTC) were constructed around individual trees and used to examine the long-term physiological responses of field-grown Norway spruce to the predicted climate scenario for the year 2100 (i.e. 700 ppm CO₂ and 3°C warmer in summer/5°C warmer in winter). The spring phenology of the WTC and non-chambered reference trees was followed for three consecutive years.

In addition to climatic variables, beginning in April bud development was followed and once bud burst occurred, shoot length, stem diameter, soil moisture and soil temperature were measured from 2002 to 2004. During each year, compared to ambient air temperature, bud swelling began earlier, new shoots emerged two to three weeks sooner and ceased to grow earlier in response to elevated air temperature. Elevated [CO₂] had a slight effect on bud development and growth rate of shoots. Although total shoot length increased during the first 2 years of treatment, there was a significant decrease after the third year and trees growing in elevated [CO₂] had the shortest shoots every year.

Stem diameter increased when shoot elongation terminated in elevated temperature chambers and increased before shoot elongation (i.e. bud burst) began in ambient temperature chambers. This reflects the timing of resource allocation under these treatments. The greatest increase in stem diameter occurred in trees grown in elevated [CO₂] and ambient temperature.

The Hawkesbury Forest Experiment: Impacts of Precipitation and CO₂ on Trees *McMurtrie R.E.¹, Medlyn B.E.¹, Barton C.V.M.², Conroy J.P.³, Eamus D.⁴, Fuentes S.⁴, Linder S.⁵ and Parsby J.⁵*

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Improvements in water-use efficiency at high CO₂ are of huge potential importance to Australia, the driest inhabited continent. Our ability to predict how Australian forests will respond to rising CO₂ is hampered by a lack of experimental information on responses under water-limited conditions. The Hawkesbury Forest Experiment, funded by the Australian Greenhouse Office, has been established near Sydney to investigate how rising CO₂ will affect Australian forests. The project is an integrated program of experimental and modeling approaches. The centre-piece is a field facility with twelve 10m tall CO₂- and temperature-controlled whole-tree chambers (WTCs), which have been in use for the last 8 years in a Norway spruce forest in northern Sweden. We are growing *Corymbia maculata* trees under contrasting watering and CO₂ treatments, which will allow us to test the effect of high CO₂ on growth of large woody plants under water-limitation. Long-term predictions of forest responses to climate change must rely on ecosystem models incorporating our best understanding of plant eco-physiological responses. Our overall modeling strategy involves developing both detailed models of experimental trees in the WTCs, and simpler stand-scale models for predicting longer-term responses.

The Boston-Area Climate Experiment: A gradient-based approach for characterizing ecosystem responses to warming and precipitation change

Vidya Suseela and Jeffrey S. Dukes

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Anthropogenic emissions of greenhouse gases are expected to change the global mean temperature as well as precipitation patterns of the biosphere. This will have complex and varied impacts on ecosystem processes. The goal of Boston-Area Climate Change Experiment (BACE) is to combine both scientific research and public education about climate change. Unlike most previous experiments, the BACE uses a gradient-based approach for characterizing ecosystem responses to warming and precipitation change simultaneously. The BACE will test hypotheses such as: ecosystem-level responses to warming are nonlinear and dependent on precipitation, species respond individualistically to warming and precipitation, and increased precipitation can in turn enhance the CO₂ emission by facilitating the breakdown of recalcitrant organic matter. The BACE is located at the Waltham Educational Center in Waltham, Massachusetts. The experiment will warm plots of a New England old-field ecosystem by five different amounts, while subjecting the plots to three different precipitation regimes (wet, ambient, and dry). The responses of variables like net primary production, soil respiration, decomposition, microbial composition, phenology and community composition will be measured. The BACE will also have an education component, which will increase public awareness of the possible consequences of climate change.

CLUE-project. Testing some hypothesis *in situ*

Haaland et al., 2006

Introduction

Climate manipulation experiments are conducted in 11 natural plot-scale catchments (30 m² - 300 m²) located adjacent to the Storgama catchment (8°32' E, 59°01' N, altitude 450m - 600m), in Telemark County, southernmost Norway. Storgama is one of the calibrated catchments in the Norwegian Pollution Control Authority monitoring program for Long-Range Transported Air Pollutants and has been studied since 1973, initially as part of the Norwegian SNSF-project (Overrein *et al.*, 1980). The bedrock is nutrient poor crystalline granite of acid igneous origin, exposed (about 30%) or covered by shallow soils rich in organic matter. The soil is classified as either Follic Histosols or Dystric or Lithic Leptosols, according to FAO-Unesco (1990) (Strand *et al.*, 2005). In general, the soil has low pH and base saturation (BS), relatively high effective cation exchange capacity (CEC), and a high content of soil organic matter (SOM) (Strand *et al.*, 2005). The vegetation is mainly Calluna heathland with unproductive and scattered Scots pine, birch and junipers. Moorgrass (*Molina coerulea* L) and sphagnum mosses are predominant in depressions. Heather (*Calluna vulgaris* L) dominates otherwise. This type of catchments characteristics is typical for large areas of the southern and south-western parts of Norway.

In situ manipulations

Due to future climate change predictions simulated by REGCLIM (regclim.met.no), we simulate the effect of an increased summer and autumn precipitation by experimentally adding artificial precipitation to the plot-scale catchments. Artificial precipitation, taken from an oligotrophic pond and filtered through an active carbon filter, is applied on to 2 plots; 5 mm two times a week and, to avoid elevated evapotranspiration loss, added during nighttime. The water quality is then similar to the average precipitation quality in the area. The quantity increase is approximately 50 % compared to the regular precipitation regime in the area. The hypothesis is that fluxes of N and C will increase. In addition, the quality of TOC might change, for instance alter the colour to TOC ratio, size fraction distribution and fluorescence properties. Both hypotheses are so far inconsistent with our findings. The precipitation system is automatically controlled using magnetic valves and a Motorola controller. Defined fiberglass ribbons has been constructed at the outlet to each catchment and runoff is collected through ø 40mm PVC tubing, leading to either closed volume proportional sipping equipment or non-transparent containers. Runoff quantity is logged digitally and water is sampled for further analysis using build in volume proportional collecting systems. Soil temperature in 2 depths (5cm and 10cm) at 3 different places in each catchment is logged every 15 minutes using soil termistors. Soil moisture is measured weekly using gypsum blocks. For all the experiments, we use 5 untreated catchments as references.

We also manipulate the soil freezing/thawing regime to examine the effect of changed winter soil temperature in an upland, semi-natural area currently characterized by stable sub-zero snow-rich winters. The hypothesis to be tested is that increased frequency and intensity of soil freezing in winter will increase the leaching of N and C from soils to water. We remove all of the snow from 2 of the plot-catchments. We also insulate the ground by means of plastic covered mats placed on the ground in late autumn onto 2 other catchments.

CLUE-project has a total funding of € 1.7 million from the Research Council of Norway, and will run from 2003 until end of 2007.

Several papers, using the results from these manipulation experiments, are in preparation.

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Project website: www.climatechange.no/clue

Moisture drives species diversity in a multi-factor global change experiment

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Global change experiments have traditionally focused on how changes in [CO₂] alter a single species. But ecosystems, such as old-fields, are diverse, and global change encompasses factors such as rising temperature and altered precipitation in addition to increasing atmospheric concentrations of carbon dioxide. We constructed an ecosystem with plant species typical of old-field systems, including C₃ and C₄ grasses, forbs, and legumes to investigate the interactive effects of elevated CO₂, temperature, and water on plant diversity, richness, and evenness. Throughout the growing season, we observed greater richness and diversity in dry plots than in wet plots ($P = 0.06$). Temperature, through its effect on soil moisture availability, reduced species richness ($P = 0.01$). There were no direct effects of [CO₂] on any diversity measurements. Interestingly, over three years *Lespedeza cuneata* became the dominant species in our communities, having the greatest foliar cover in most of our plots. At the community level, it had a negative impact on species diversity and evenness. These differences were often driven by the presence or absence of *Trifolium* which declined as *Lespedeza* began to dominate the plant community. In this global change experiment, soil moisture, not [CO₂], had the greatest impact on plant diversity and richness.