

vegetation cover, where closed canopy forests have become fragmented, presumably as a result of increased browsing pressure from livestock. In this area the mean annual temperature is 21 degree Celsius and the mean annual precipitation is 250mm, most of which falls during the 3 month long wet season. We use meteorological and hydrological measurements in an intact forest patch to investigate the hydrology of the forest in situ. This investigation will help us study the potential consequences for the removal of vegetation to the hydrology of the region and the potential for re-growth of the removed vegetation cover. Measured through-fall and stem-flow are considerably higher than measured rainfall above the canopy during the wet season. This is a result of additional water gained through interaction between trees and clouds, called horizontal precipitation. At the same time potential evaporation and sap flow are suppressed during the wet season as the permanent cloud cover reduces incoming radiation. As a result, soil moisture increases during the wet season and decreases only when the clouds recede. After the end of the wet season the trees continue to be productive and transpire for another three months, using water stored in the lower soil horizons during the wet season. We conclude that the combination of horizontal precipitation and low net radiation during the cloudy season is a key condition for replenishing deep soil water storage, which promotes net primary productivity of deeper rooted plants beyond the end of the wet season. We speculate that the removal of trees may cause lower amounts of horizontal precipitation, resulting in lower deep soil water storage at the end of the wet season and a shorter period of positive net primary productivity. The shortening of this productive period in turn may inhibit re-vegetation of the degraded areas with perennial plants, such as trees.

B12A CC: 524 A Monday 1030h

Recent Advances in Coupled Terrestrial Carbon Cycle and Climate Modeling I (joint with A, GC)

Presiding: V Arora, Canadian Centre for Climate Modelling and Analysis; **S Cowling**, University of Toronto

B12A-01 1030h INVITED

Impact of Soil Carbon Decomposition Dynamics on Global Climate

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Enhanced release of CO₂ from soils due to increased temperatures may lead to a positive feedback between climate change and the carbon cycle, resulting in much higher CO₂ levels and accelerated global warming. However, the magnitude of this effect is uncertain and critically dependent on the response of soil respiration to changes in climate. Previous studies with the Hadley Centre's coupled climate-carbon cycle GCM (HadCM3LC) have used a simple, single-pool soil carbon model to simulate the response. Here we present results from experiments which use the more sophisticated "RothC" multi-pool soil carbon model driven with the same climate data. The results show strong similarities in the behaviour of the two models, although RothC tends to simulate slightly smaller changes to global soil carbon amounts for the same forcing. We conclude that the projection of a positive feedback between climate and carbon cycle is robust to using these very different representations of soil carbon dynamics but the magnitude of the feedback is dependent on the form of the soil carbon model.

B12A-02 1045h INVITED

The Terrestrial Carbon Cycle and the Role of Historical Land Cover Change in the UVic Earth System Climate Model

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The behaviour of the terrestrial carbon cycle under historical and future climate change is examined using the UVic Earth System Climate Model, which includes a dynamic terrestrial vegetation and global carbon cycle model. When the model is forced by historical emissions of anthropogenic carbon dioxide the UVic ESCM reproduces well the observed increase in atmospheric CO₂. When anthropogenic emissions are separated into those from fossil fuel combustion and those from land cover change, we find that historical land cover change emissions contribute an additional 26 ppmv of atmospheric CO₂ by the year 2000 and result in an increase in simulated twentieth century warming of 0.3 °C. This result is compared to a transient model simulation forced solely by the land-surface changes (such as surface albedo) that have resulted from historical land cover change. This transient simulation results in a global cooling of -0.15 °C from 1850 to 2000, and as a result, we conclude that the net effect of historical land cover change has been to contribute 0.15 °C to anthropogenic climate warming. Carbon cycle and climate simulations are extended into the future, forced by six projections of anthropogenic CO₂ emissions from 2000 to 2100, taken from the Special Report on Emission Scenarios (SRES). Under these future scenarios terrestrial and oceanic carbon sinks continue to take up anthropogenic carbon, though there is evidence that the terrestrial carbon sink weakens somewhat over the 21st century. When plotted as a fraction of anthropogenic emissions, fractional terrestrial uptake declines noticeably after the year 2000, leading to an increase in the fraction of emissions remaining in the atmosphere. Analysis of the feedbacks that operate between the terrestrial biosphere and climate reveals that the dominant effect is a negative feedback that results from increased plant photosynthesis under elevated atmospheric CO₂. A smaller positive feedback to climate results from increased soil respiration in response to climate warming.

B12A-03 1100h

Climate impacts of Australian land cover change

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Australian land cover has been dramatically altered since European settlement primarily for agricultural utilization, with native vegetation widely replaced or modified for cropping and intensive animal production. While there have been numerous investigations into the regional and near surface climate impacts of Australian land cover change, these investigations have not included the climate impacts of larger-scale changes in atmospheric circulation and their associated feedbacks, or the impacts of longer-term soil moisture feedbacks. In this research the CSIRO General Circulation Model (GCM) was used to investigate the climate impacts of Australian land cover change, with larger-scale and longer-term feedbacks. To avoid the common problem of overstating the magnitude and spatial extent of changes in land surface conditions prescribed in land cover change experiments, the current Australian land surface properties were described from finer-scale, satellite derived land cover datasets, with land surface conditions extrapolating from remnant native vegetation to pre-clearing extents to recreate the pre-clearing land surface properties. Aggregation rules were applied to the fine-scale data to generate the land surface parameters of the GCM, ensuring the equivalent sub-grid heterogeneity and land surface biogeophysics were captured in both the current and pre-clearing land surface parameters. The differences in climate simulated in the pre-clearing and current experiments were analyzed for changes in Australian continental and regional climate to assess the modeled climate impacts of Australian land cover change. The changes in modeled climate were compared to observed changes in Australian precipitation over the last 50 and 100 years to assess whether modeled results could be detected in the historical record. The differences in climate simulation also were analyzed at the global scale to assess the impacts of local changes on larger scale circulation and climate at distance from the land cover changes. The Australian continental and regional analyses demonstrated that Australian land cover change did have statistically significant impacts on air temperature and precipitation simulated in the CSIRO GCM. While none of the statistically significant trends in annual precipitation were found to be statistically significant in the climate modelling experiments, the modelled reductions in annual precipitation for south east Queensland and eastern New South Wales corresponded with the strong drying trends in those areas for 1950 - 1999. Larger scale analysis of differences in climate suggested the local changes in surface fluxes had strong impacts

on atmospheric circulation. The largest changes were in austral summer (DJF) circulation where monsoon flow into northern Australia was reduced, corresponding with increased monsoon flow into the South Pacific Convergence Zone and increased south easterly wind flow into eastern Queensland. These changes in circulation influenced DJF moisture flux into northern and eastern Australia, which intensified the direct warming and drying impact caused by the reduced transpiration from land cover change.

B12A-04 1115h

A Protocol for Identifying and Evaluating Key Feedbacks in Coupled Terrestrial Carbon Cycle-Climate Models

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Land and ocean carbon cycling are greatly influenced by climate and atmospheric CO₂. In turn, atmospheric CO₂ is influenced in the short-term and long-term by terrestrial and oceanic carbon cycle processes. Carbon cycle-climate feedbacks play a key role in how fast the Earth warms due to greenhouse gas release. The difficulty of including and evaluating feedback processes in global climate models stems from both climate science and computational science considerations. The scientific challenge for computational climate science is identification and suitable representation of significant carbon cycle feedbacks in the climate system, particularly ones that will change over the next several decades. We outline methods to identify terrestrial carbon cycle and hydrological feedbacks that are large enough to demand increased attention in the continuing development of climate system models. This is accomplished by employing local, site-scale terrestrial carbon and/or hydrologic cycle models that contains process representation of photosynthesis, respiration, decomposition, disturbance, hydrology and vegetation change. These simulations provide insight into mechanisms and complex interactions and secondary effects. A quantitative method involving "off-line" or decoupled global biosphere models is derived to compare the response of each of these processes, at a global scale, to global changes anticipated to occur over the next century. This method can expose unforeseen processes that are significant for carbon cycle-climate simulations. We provide a detailed example of the potential impact of temperature acclimation on heterotrophic respiration and positive climate-carbon feedback at high temperatures. Temperature acclimation itself does not significantly reduce the gain in carbon cycle-climate feedback. However, the response of the specific temperature function in the range of 15 to 35 °C and the readjustment of the relative magnitudes of the various soil carbon pools are significant. Accordingly these are the ecosystem processes that should receive priority consideration in evolving coupled climate-carbon models.

B12A-05 1130h

A Simple Approach to Estimating Temporal Changes in Global Vegetation for Use in a Coupled Terrestrial Ecosystem-Atmosphere Model

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Human-caused conversion of natural ecosystems to agricultural land is thought to have significant impacts on the global carbon cycle and climate. Hence, capturing such effects in global terrestrial ecosystem models is an important requirement when accounting for land-use change effects in coupled carbon-climate models. In this study, changes in area fractions of 10 Plant Functional Types (PFT) were estimated for the period 1850-2100, from changes in global cropland area obtained from the Ramankutty & Foley dataset (R&F).

The Seasonal Land Cover Regions (SLCR) version 2.0 dataset was used to identify present-day (1992) vegetation. Each SLCR class was split into estimated area fractions of the 10 PFTs according to knowledge of natural vegetation and cropland composition. Global land cover in 1850 was estimated from a potential natural vegetation map adjusted for cropland area from R&F, combined with natural vegetation observed in the SLCR. Two methods were used to estimate fractional coverage of PFTs. The Linear Interpolation model assumed that natural vegetation area varies in inverse proportion to cropland area. In contrast, the Rule-based model used simple transition rules to represent how natural PFTs are converted to agriculture (e.g., grassland before forest) and how abandoned cropland reverts to natural vegetation. Estimates of land use change for 1992-2100 were based on the IPCC SRES A2 and B2 development scenarios simulated by the IMAGE model for 1970-2100. Differences in the representation of 1992 vegetation cover between SLCR and IMAGE were resolved using a multiple regression approach. The adjusted data were then used to initialize the two models and forecast changes in distribution of natural vegetation and cropland cover. The simulated changes in PFTs for 1850-2100 will be used to represent land-use change effects in the Canadian Terrestrial Ecosystem Model (CTEM), currently being developed for the Canadian Centre for Climate Modelling and Analysis (CCCma) coupled carbon-climate model.

B12A-06 1145h

Importance of ice sheet retreat and vegetation dynamics on the Holocene climate during the past 8 kyr

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Various proxy data reveal that in many regions of the Northern Hemisphere, the middle Holocene (6 kyr BP) was warmer than the early Holocene (8 kyr BP) as well as the later Holocene, up to the end of the pre-industrial period (1800 AD). This warmth is somewhat counterintuitive because the Northern Hemisphere (NH) summer insolation was steadily decreasing since 10 kyr BP. Cooling in the second half of the Holocene (after 6 kyr BP) is hypothesized to be due mainly to the changes in the high-latitude solar insolation driven by slow changes in the orbital parameters. This cooling was also accompanied by significant changes in vegetation cover. The early-to-middle NH Holocene warming, on the other hand, is hypothesized to be due in part to ice-albedo feedback in Northern America, associated with decreases in the Laurentide ice sheet, which completely disappeared by 6 kyr BP. The vegetation-albedo feedback is also hypothesized to have played a role in this early warming event. To test the above hypotheses, the earlier geophysical McGill Paleoclimate Model (MPM) has been coupled to the dynamic global vegetation model known as VECODE (see Wang et al., in preparation), and a number of sensitivity experiments have been performed with the "green" MPM. The model results demonstrate the following: 1) the orbital forcing is most important for the gradually cooling of global SAT from about 6 kyr BP to the end of the pre-industrial period; 2) the disappearance of the Laurentide ice sheet over the period 8 to 6 kyr BP, associated with vegetation-albedo feedback, allows the global SAT to reach its maximum around 6 kyr BP; 3) the northern limit of the boreal forest first moves northward during the period 8-6.3 kyr BP due to the Laurentide ice sheet retreat; 4) during the period 6.3-0 kyr BP, the northern limit of the boreal forest moves southward about 120 km in response to the decreasing solar insolation in the NH; and 5) the desertification of northern African is mainly explained by the weakening of the summer monsoon circulation in tropical and subtropical regions.

B12A-07 1200h

A NEW, REGIONAL-SCALE COUPLED ATMOSPHERE-ECOSYSTEM MODEL: FORMULATION AND RESULTS

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The formulation of self-consistent and computationally efficient atmosphere-ecosystem models requires the bridging of a wide range of spatial and temporal scales. Disturbance events such wind-throw, fire and land-use change give rise to significant sub-grid scale heterogeneity in ecosystem structure and function at a variety of scales ranging down to the size of an individual canopy tree, far below the resolution of both climate and numerical weather prediction models. Moreover, over decadal timescales, the spatial distribution of this heterogeneity is dynamic due to the successional dynamics that follow disturbance events within ecosystems. To address this problem, we have developed the Ecosystem Demography Land Surface Model (ED-LSM), an integrated biosphere model that incorporates plant community dynamics, soil carbon and nitrogen biogeochemistry and land surface biophysics. The fast timescale fluxes of carbon, water and energy between the ecosystem and the atmosphere are captured using the leaf photosynthesis and soil decomposition modules of the Ecosystem Demography (ED) model coupled to a multi-leaf layer, multi-soil layer implementation of the LEAF-2 biophysical scheme. Long term changes in the biophysical, ecological and biogeochemical structure of the ecosystem are captured using the ED model's system of size- and age-structured partial differential equations that track the changes in the vertical and horizontal heterogeneity of above and below ground ecosystem structure that result from ecosystem responses to the atmosphere that play out over years, decades and centuries. The model can be run both offline and coupled to the Regional Atmospheric Modeling System (RAMS), which simulates both atmospheric dynamics and tracer transport of carbon dioxide. We have carried out coupled simulations of the model in temperate, tropical and boreal regions. Comparison of our results with observations from eddy-flux towers and meteorological stations highlights the model's ability to capture the influence of the heterogeneous land surface on the dynamics of the land-surface interaction in these different regions on time scales ranging from the synoptic to the decadal.

B13A CC: 524 A Monday 1330h

Measurement and Modeling of Carbon, Water, and Energy Exchange in Northern Ecosystems I

Presiding: H Margolis, Universit Laval; C Coursolle, Universit Laval

B13A-01 1330h

Modelling the Response of Energy, Water and CO₂ Fluxes Over Forests to Climate Variability

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Understanding the response of energy, water and CO₂ fluxes of terrestrial ecosystems to climate variability at various temporal scales is of interest to climate change research. To simulate carbon (C) and water dynamics and their interactions at the continental scale with high temporal and spatial resolutions, the remote sensing driven BEPS (Boreal Ecosystem Productivity Simulator) model was updated to couple with the soil model of CENTURY and a newly developed biophysical model. This coupled model separates the whole canopy into two layers. For the top layer, the leaf-level conductance is scaled up to canopy level using a sunlit and shaded leaf separation approach. Fluxes of water, and CO₂ are simulated as the sums of those from sunlit and shaded leaves separately. This new approach allows for close coupling in modeling these fluxes. The whole profile of soil under a seasonal snowpack is split

into four layers for estimating soil moisture and temperature. Long-term means of the vegetation productivity and climate are employed to initialize the carbon pools for the computation of heterotrophic respiration. Validated against tower data at four forested sites, this model is able to describe these fluxes and their response to climate variability. The model captures over 55% of year-round half/one hourly variances of these fluxes. The highest agreement of model results with tower data was achieved for CO₂ flux at Southern Old Aspen (SOA) (R²>0.85 and RMSE<2.37 μ mol C m⁻² s⁻¹, N=17520). However, the model slightly overestimates the diurnal amplitude of sensible heat flux in winter and sometimes underestimates that of CO₂ flux in the growing season. Model simulations suggest that C uptakes of forests are controlled by climate variability and the response of C cycle to climate depends on forest type. For SOA, the annual NPP (Net Primary Productivity) is more sensitive to temperature than to precipitation. This forest usually has higher NPP in warm years than in cool years. Interannual variability of heterotrophic respiration, however, is strongly related to precipitation. The soil releases more CO₂ in wet years than in dry years. Warm and relatively dry climate enhances the C uptake in this forest stand. Compared with SOA, a temperate deciduous forest in the southern part of the temperate deciduous forest biome in eastern United States responds to climate variability differently. High temperature and low precipitation in the growing season reduces NPP and consequently NEP (Net Ecosystem Productivity). In warm years, the Southern Old Jack Pine forest uptakes less C than in cool years. The modeled heterotrophic respiration and NEP are very sensitive to soil moisture and the empirical equation used to describe the effect of soil moisture on decomposition. This suggests that hydrological modelling is critical in C budget estimation. Next step, this model will be validated against more tower data and used for upscaling from site to region.

B13A-02 1345h

Contribution of Soil CO₂ Efflux to the Carbon Balance of Mature Deciduous and Coniferous Boreal Forests

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The Boreal Ecosystem Research and Monitoring Sites (BERMS) science team (now part of the Fluxnet Canada Research Network) is making long-term measurements of net CO₂ ecosystem exchange (NEE) between the atmosphere and several Canadian boreal forests using the eddy covariance (EC) technique. In order to better understand and constrain the annual carbon budgets obtained with EC, automated soil CO₂ efflux chamber systems were established in three of these stands. This study analyses continuous measurements of soil (R_s) and ecosystem (R_e) respiration (i.e., soil CO₂ efflux and nighttime NEE, respectively) made in 2003 in one deciduous (trembling aspen, SOA) and two coniferous (black spruce, SOBS and jack pine, SOJP) southern boreal forests. These forests are located 80 km apart in central Saskatchewan, Canada, and offer a unique opportunity to compare the response of different forest ecosystems to similar climate forcings. 2003 was characterized by an unprecedented drought in western Canada, which significantly reduced the sink strength of these forests. The values of NEE in 2003 were -97, -62 and -29 g C m⁻² y⁻¹ (minus sign means uptake by ecosystem) for the respective sites. Overall, the measurements of R_s and R_e using the two independent approaches agreed well. R_e was largely dominated by R_s at all three sites, the latter accounting for more than 80% of total R_e. Annual estimates of R_s were greater at SOA than at SOBS and SOJP, and likely reflect the higher productivity of the deciduous forest. The approximate values of R_s for the respective sites were 920, 600 and 540 g C m⁻² y⁻¹ in 2003. The spatial variability of R_s was greater at SOBS than at SOA and SOJP and was related to the heterogeneous nature of the moss-dominated forest-floor. The temporal variability of R_s at all sites was strongly controlled by soil temperature. The annual R₁₀ and Q₁₀ values computed from the relationships of R_s as a function of soil temperature at the 2-cm depth were 4.06, 2.43 and 1.50 (R₁₀), and 2.66, 3.01 and 3.05 (Q₁₀) for SOA, SOBS and SOJP, respectively. R_s was significantly reduced during late summer at SOA and SOBS, when soil volumetric water content was low. These results highlight the increasing evidence that water restriction is likely to have a significant impact on the carbon balance of forest ecosystems, and might counteract the effects of rising temperature in a changing climate.