REQUEST FOR A SPECIAL PROJECT 2013–2015

MEMBER STATE: NL

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Project Title:

Land use change in the 21st century

If this is a continuation of an existing project, please state the computer project account assigned previously.	**SP**NLGLAC	
Starting year: (Each project will have a well defined duration, up to a maximum of 3 years, agreed at the beginning of the project.)	2012	
Would you accept support for 1 year only, if necessary?	YES ☒	NO ☐

Computer resources required for 2012-2014: (The maximum project duration is 3 years, therefore a continuation project cannot request resources for 2014.)	**2013**	**2014**	**2015**
High Performance Computing Facility (units)	500000	500000	
Data storage capacity (total archive volume) (gigabytes)	1000	1000	

*An electronic copy of this form **must be sent** via e-mail to:* *special_projects@ecmwf.int*

Electronic copy of the form sent on (please specify date):

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Continue overleaf

[1] The Principal Investigator will act as contact person for this Special Project and, in particular, will be asked to register the project, provide an annual progress report of the project's activities, etc.

Principal Investigator: Bart van den Hurk

Project Title: Land use change in the 21st century

Project Progress: During the first half of 2012 the calculations for this project have been allocated to different computing resources. However new runs are anticipated, and continuation of this special project is requested.

Extended abstract

Objectives

Land use change has a detectable impact on many climate characteristics at local scale (temperature dynamics, hydrological cycle, radiation balance, carbon balance). There is scientific consensus that at the global mean scale historic (1850 – present) land use change has offset the greenhouse gas induced warming by ~0.1 – 0.15 K (IPCC, 2007). However, regional differences are large, and the uncertainty about future land use change and its biogeophysical and biogeochemical impacts is considerable. In many currently running climate change projections in the context of the 5th IPCC assessment report (due in 2013) land use change scenarios are associated with the sample of Representative Concentration Pathways (RCPs). The main emphasis of these experiments is to estimate the contribution of land use change on the evolution of greenhouse gas concentrations (via the carbon cycle) and the associated climate feedbacks. However, the many local and global geophysical and geochemical system feedbacks, the large variety in implementation strategies, and the rigid experimental design make a careful analysis of the local and remote impacts of land use change impossible. **Via this study, a new set of dedicated climate model integrations will be carried out in parallel to the IPCC historic and future scenario runs. The experiments will be carried out with the EC-Earth climate model, built on the ECMWF IFS.** The experimental set-up is designed to analyse (a) the specific contribution of land use change to global mean and regional climate change in the past and the future, (b) the amplification or damping feedback mechanisms that control these land use change impacts, and (c) the degree to which local land use change impacts affect climate variability in remote areas.

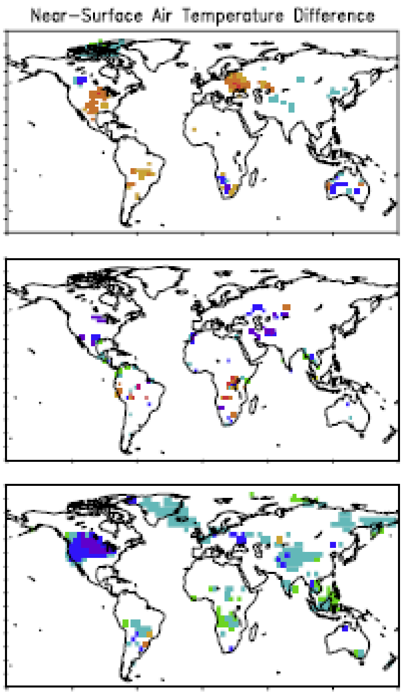

Fig 1: temperature response due to land use change from 3 models participating in LUCID (Pitman et al, 2009)

Scientific Approach

Large scale changes in land use can affect the regional climate systematically via a number of mechanisms (Bonan, 2008; Davin et al, 2010): by changing the surface albedo (also in presence of snow), by changing the partitioning between latent and sensible heat flux, by changing the surface roughness, and by storing/releasing carbon compounds. The biogeophysical effects (albedo, surface fluxes, roughness) may alter the atmospheric stratification and the ability to form rain (Ziegler et al, 1997), it may lead to asymmetric responses to anomalous conditions such as heatwaves (Teuling et al, 2010), change the atmospheric moisture budget (Adegoke et al, 2003), change aerosol emissions from deserts (Power, 2003), modify the spatial gradients of surface temperature affecting atmospheric circulation (Haarsma et al, 2008) or precipitation recycling (Goessling and Reick, 2011). The biogeochemical effects (carbon storage) may lead to multi-year persistence of droughts effects via vegetation (vdMolen et al, in press), or to long term perturbations in atmospheric greenhouse gas concentrations (Dekker et al, 2010). A rough estimate of the combination of these effects is that the land use changes since the pre-industrial period have cooled the Earth by about 0.1°C, offsetting the ~0.7° warming attributed to fossil fuel emissions (IPCC, 2007), with potentially large regional differences.

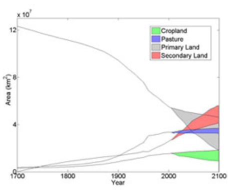

Fig 2: historic and future extent of crop-land, pasture and natural vegetation according to the CMIP5 land use scenarios (Hurtt et al, 2009).

A first attempt to explore these land use change effects systematically across an ensemble of climate models was presented by Pitman et al (2009), comparing model results from time slice experiments covering both pre-industrial and present day vegetation and CO_2-levels (in their so-called LUCID experiment). Their conclusions were somewhat obscured by the wide diversity in model responses to land use change forcings, due to a large variability in the implementation of land use changes in the models. Opposite boreal summer temperature signals in areas with strong land use change were found owing to different assumptions on the behaviour of the vegetation replacing the pristine land cover (fig 1). Inspired by this experiment, a protocol was designed (Taylor et al, 2011) to harmonize the land use change implementation in climate models participating in the 5th Coupled Model Intercomparison Project (CMIP5) currently underway to support the 5th IPCC assessment report in 2013. Historic and projected land use change data (Hurtt et al, 2009) were provided to modelling groups, where future land cover scenarios were derived from the Integrated Assessment Modelling (IAM) efforts used to construct the Representative Concentration Pathways (RCPs). The four land use change scenarios demonstrate a large uncertainty in the type and areal extent of future cropping and pasture area (Fig 2).

The simulation strategy

Thus, most models participating in CMIP5 now simulate the effects of land use change. However, a set of control simulations without land use change, necessary to attribute local and climate effects to this anthropogenic forcing, is not available. Also, the CMIP5 protocol does not provide a systematic exploration of the uncertainty induced by the underlying assumptions generating the land use change projections linked to a given RCP. Therefore, a second LUCID experiment is currently launched (Brovkin et al, 2011), referred to as LUCID-CMIP5. Simulations in this experiment parallel the CMIP5 projections, but keep land use fixed at the 2005 situation instead of following the prescribed land use change scenario. This study will join this LUCID-CMIP5 experiment and **execute a number of additional simulations (with different land use change evolutions) parallel to the current CMIP5 experiments**. We participate with the climate model EC-Earth (Hazeleger et al, 2010; also participating in the earlier mentioned LUCID experiment by Pitman et al (2009), and currently generating the CMIP5 projections for both RCP4.5 and RCP8.5 including land use change). The participation in LUCID-CMIP5 gives access to results from a number of modelling groups, allowing a multi-model analysis of local and remote effects and feedbacks (see below). Apart from this control simulation with land use frozen at 2005 conditions, **three additional transient simulations will be carried out per RCP, in which land use change scenarios are used that are associated with other RCP's** while retaining the RCP-specific greenhouse gas concentration pathway. This exchange of scenarios allows mapping the sensitivity of the *regional* climate system to the underlying (regional) land use change assumptions. In contrast to the previous LUCID experimental design coupled ocean-atmosphere simulations will be generated, to avoid damped or amplified land use change effects due to fixed sea surface temperatures.

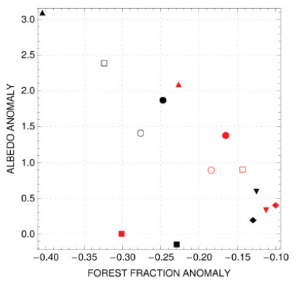

Fig 3: change of JJA albedo expressed as function of deforestation extent in North America for a sample of models (symbols) under different CO_2-concentration conditions (colours), deduced from LUCID (De Noblet et al, subm).

The analysis strategy

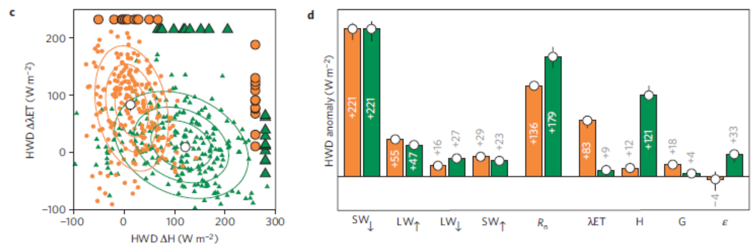

Fig 4: Observed anomalies in different surface energy balance terms during heatwave days for grasslands (orange) and forests (green). Observations are from European Fluxnet data collected in the summer seasons of 1997-2008 (Teuling et al, 2010).

The focus of the analysis is on the regional and global biogeophysical impacts of land use change: changes in surface albedo, water consumption, temperature change, cloud cover and precipitation. All analyses will be initially carried out using EC-Earth output, but will be repeated with other model projections participating in the CMIP5-LUCID experiment. The analysis focuses on three target subjects (but this can be extended if time and model output allows): (a) the magnitude of the regional land use change effects, (b) local feedbacks induced by land use change, in particular cloud formation and surface energy balance, and (c) remote impacts of land use change.

<u>Regional land use change effects</u>

Similar to the LUCID analysis strategy (Pitman et al, 2009; de Noblet et al, subm), a first order assessment of regional changes in temperature, surface radiation, evaporation and precipitation will be produced by comparing the CMIP5 simulations to the simulations with fixed 2005 land use. By expressing the changes in these variables as function of a major land use change indicator (e.g., fraction of deforestation) for a given region, an attribution of the degree to which the regional change is related to the land use change can be constructed (see Fig 3 for an example). 10yr averaged values from the transient simulations, as well as results from different land use change scenarios, can be combined into a single regression plot. Local changes in surface albedo associated with changes in the leaf area or vegetation cover are generally easily diagnosed and interpreted. However, the changed annual cycle of leaf area induces a change in the cumulative evaporation. In addition, the different response to anomalous heatwave conditions between forests and grassland (Teuling et al, 2010) is of interest here. It is unknown to what extent climate models reproduce the observed surface response to heatwaves (Fig 4). The analysis will focus on the impact of land use change on the annual water budget and the model response to anomalous weather conditions.

Local feedbacks

Van der Molen et al (2011) explored the sensitivity of local surface temperature to the imposed land use change. Over tropical areas the temperature response to the imposed change in surface albedo appeared to be much smaller than over the mid-latitude Northern Hemisphere land area (fig 5). By expressing the responses of temperature, cloud cover and radiative and turbulent fluxes as function of albedo and separating between tropical and mid-latitude areas, it was found that negative feedbacks via cloud formation and surface Bowen ratio damped the temperature response in the tropics. This analysis was applied to only one of the models participating in LUCID, and the results may be subject to model artefacts. In this study this analysis will be repeated for the entire available ensemble of participating models and projections.

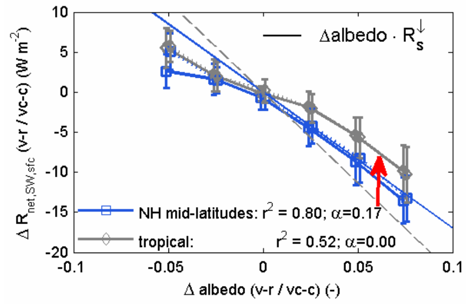

Fig 5: Change in net surface radiation in response to surface albedo changes. Thin solid lines indicate the response without feedbacks, blue refer to mid-latitude regions, grey to tropics (Van der Molen et al, 2011).

Another important feedback is the change of the local surface energy balance (de Noblet et al, subm). Van Heerwaarden et al (2010) developed a useful conceptual framework to separate forcings and feedbacks on the diurnal cycle of surface evaporation coupled to the atmospheric boundary layer. In our study forcings and feedbacks play a role at both the diurnal and the seasonal time scales. Changes in evaporation related to land use change can be separated in components related to changes in the radiation availablility (ΔE_{rad}), changes in the atmospheric moisture demand (ΔE_{atm}), and changes in the soil moisture supply due to antecedent evaporation, precipitation and runoff changes (ΔE_{sm}). ΔE_{rad} can be separated in a forcing term $\Delta E_{rad}{}^{f}$ (related to Δalbedo) and a feedback term $\Delta E_{rad}{}^{fb}$ (changes in cloud cover – see van der Molen et al, 2011). Changes in the atmospheric moisture demand ΔE_{atm} are dominated by a feedback due to altering the temperature and humidity of the atmosphere. ΔE_{sm} again consists of a combination of a forcing term (related to changes in the antecedent precipitation) and a feedback (the depletion of soil moisture). The total change equation $\Delta E = \Delta E_{rad}{}^{f} + \Delta E_{rad}{}^{fb} + \Delta E_{atm}{}^{f} + \Delta E_{atm}{}^{fb} + \Delta E_{sm}{}^{f} + \Delta E_{sm}{}^{fb}$ will be decomposed using statistical regression on time series in combination with theoretical considerations using the framework of van Heerwaarden et al (2010). The multi-model, multi-time slice and multi-scenario data set of our experiment leads to a robust quantification of the importance of the different feedback types.

Remote impacts of land use change

Pitman et al (2009) concluded that on average remote impacts of land use change on surface evaporation, temperature and precipitation were not significant. They did so by counting the number of remote grid cells with a systematic response to the land use change scenario (Fig 6). Remote impacts may have been strongly damped by the use of fixed SSTs in LUCID. However, findings by Goessling and Reick (2011) support the notion that – on a continental scale – suppression of evaporation leads to a local suppression of precipitation due to a strong local coupling. The analysis of Pitman et al (2009) will be repeated for the present simulations with the assumption of a strong local coupling in mind.

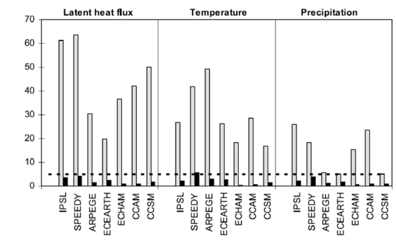

Fig 6: fraction of gridpoints with a significant change of latent heat flux, temperature and precipitation in response to land use change. Grey bars: grid points within areas of major land use change; black bars: all grid points. The horizontal line denotes the 5% chance level (Pitman et al, 2009).

Impact

The planned simulations and analyses will support the quantification of the large scale and local bio-geophysical impacts of land use change under present day and future conditions. It does not address the role of land use change in the global carbon cycle (which is analysed in great detail in the present CMIP5 protocol; Taylor et al, 2011). However, a systematic quantification of biogeophysical effects and feedbacks related to land use change has received far less attention, due to the complexity of the interacting processes (forcings and feedbacks), the dependence on model implementation, and the wide variety of possible impacts and responses. Here we focus on these biogeophysical effects and feedbacks by extending past simulations (LUCID) and analysis protocols (see examples above), applied to the family of future CMIP5 projections. Like analyses of the carbon-climate feedback strength (Friedlingstein et al, 2006) a clear analogy with observed feedbacks is difficult to find when focussing on future projections. However, the analysis framework is based on and strongly constrained by theoretical and observed relationships (Van Heerwaarden et al, 2010; Van der Molen et al, 2011; Teuling et al, 2010), allowing an assessment of the realism of the projected land use change effects. A multi-model and multi-scenario approach further helps to diagnose robust impacts, and compare the resulting land use change effects to the effects of elevated greenhouse gas concentration levels.

The LUCID-CMIP5 project is a component of an ongoing scientific assessment of land use change effects on regional climate. This coordination ensures a well defined experimental protocol, exchange of data and experience, and shared publications. The expected scientific impact of this project is therefore considered to be high.

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