6 Attributing causes of regional climate change

6.4 Land cover and resource management

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Number of pages: ca. 33 pages plain text (without figures and tables) Times New Roman, 12 pt, 1.5 line pitch, ca. 400 words per page

Introduction – (ca. 2 pages: can be extended: Marie-José Gaillard and Anna Wramneby)

State September 2011

This chapter seeks to review our current understanding of land cover changes, both in terms of land use and natural vegetation changes, and how these land surface dynamic processes influence regional climate change in the Baltic Sea Basin.

Understanding of land cover-climate feedbacks has increased over the last decade through sensitivity studies with global Earth System Models (ESMs) (IPCC, 2007). Since the mechanisms involved in, especially, biophysical feedbacks are governed by regional mechanisms, the use of regional climate and vegetation models could potentially identify feedbacks not captured at the course resolution of global models. For the Baltic Sea region such studies are few to non-existing, but within the scope of Europe some studies are available. These studies, however, address the role of potential natural vegetation changes but are important contributors to the understanding of the underlying terrestrial and atmospheric processes and are thus valuable in terms of exploring the climatic sensitivity to land cover changes. Natural ecosystem responses to climate are however comparably slow and the resulting feedbacks identified in available regional modelling experiments are often weaker than those feedbacks identified in global studies, many of which, however, are based on the assumption of extreme shifts in vegetation cover (e.g. Bala et al., 2007). A growing number of regional future land use scenarios (predominantly over Europe rather than purely focusing on the Baltic Sea region) enable a more realistic approach to explore the role of land cover changes in regional climate change.

Feedbacks between land surface and atmosphere (ca. 9 pages, can be extanded by Patrick Samuelsson and Thomas Kleinen)

Radiation and energy balance (Patrick Samuelsson): (to be extended up to ca. 3 pages?; NEW TEXT EXPECTED END of FEBRUARY)

Changes in land use and resource management are important contributors to regional climate change since they determine the land cover and thus influence the interaction between the land surface and the atmosphere both in terms of radiation and energy balance. In addition, climate induced natural vegetation changes may cause feedbacks to climate, especially in the boundary zones between the major biomes (e.g. the tundra-boreal forest ecotone). The physical properties of the land surface and the underlying terrestrial processes interact with the lower atmosphere according to the following principles:

Biophysical feedbacks (Anna Wramneby, Thomas Kleinen): (ca. 6 pages?)

keywords: albedo, hydrological cycle feedbacks

New text revised and completed by Thomas Kleinen- state February 6th

Feedbacks between vegetation and climate are categorized into two subgroups: 1) biogeophysical feedbacks related to changes in the physical exchange fluxes between atmosphere and land surface and 2) biogeochemical feedbacks related to terrestrial carbon sinks and sources (Findell et al., 2007). When attributing causes of regional climate changes, the biogeophysical feedbacks are of particular interest since these exert a direct measurable effect on regional climate. Biogeochemical feedbacks are more relevant for the global climate since the mixing timescale of CO_2 in the atmosphere is very short. Regional changes in the carbon balance therefore affect regional climate only indirectly. In this section we focus on the current understanding of the direct effects of biogeophysical feedbacks and future trends in these feedbacks associated with changes in land use and resource management, while the next section focuses on the biogeochemical feedbacks. However it is important to keep in mind that many of the socio-economic factors controlling future land use policies take the indirect biogeochemical processes into consideration while neglecting the direct biogeophysical ones (Jackson et al., 2008), presumably because the number of studies on CO_2

is substantially larger. In other words, our current understanding of land cover changes and their biogeophysical feedbacks in regional climate change is limited in comparison to the large scale carbon cycle feedbacks.

Albedo feedbacks

The albedo is the proportion of the incoming solar radiation reflected by a surface. The albedo therefore strongly influences the energy available for absorption by the land surface. The sharpest contrasts in albedo exist between open land and forested areas, especially in the presence of snow since snow would be completely exposed on open land but partly covered in a forested area, the so-called snow masking effect. Since the albedo feedback has been shown to be of significant magnitude under these circumstances (Bala et al., 2007), even the slightest change in species composition or land management in terms of forest thinning could give rise to substantial albedo feedbacks (Vesala et al., 2005).

Hydrological cycle feedbacks

Vegetation also influences the hydrological cycle. Structural changes in vegetation, such as changes in Leaf Area Index (LAI, the ratio of one-sided foliar area to the ground area covered), roughness length and rooting depth, modify the evapotranspiration of water from the land surface. Whereas the LAI influences the amount of intercepted water and the partitioning of energy fluxes into sensible and latent heat, the roughness length affects the turbulent mixing of heat into the atmosphere. The rooting depth determines the availability of water from deeper soil layers to the vegetation, i.e., a deeper and/or more extensive root system enhances the vegetation's ability to extract soil water. A comprehensive vegetation cover also reduces runoff. In environments where neither temperature nor water limit vegetation growth, the vegetation tends to flourish, which increases both the LAI and the roughness of the surface. Since the vegetation recycles or transpires water through the leaf stomata, an increasing LAI is associated with increasing evapotranspiration, which results in an increase of the fraction of the surface-atmosphere energy flux partitioned into latent heat at the expense of sensible heat. Sensible heat warms the atmosphere close to the vegetation surface, whereas latent heat is stored in the released water vapour and warms the atmosphere only when condensation occurs, typically some distance away and further up in the atmosphere. The hydrological cycle feedback therefore has a dampening effect on local to regional temperature changes since stronger evapotranspiration implies that more energy is required to vaporise water. An increased roughness length would then tend to emphasise the feedback through increased turbulent mixing in the atmosphere.

Biogeochemical feedbacks

keywords: carbon sources/sinks

Within the global carbon cycle, the land surface plays an important role. Vegetation takes up atmospheric Carbon Dioxide (CO_2) by photosynthesis, using the carbon to form biomass while the oxygen is released to the atmosphere. Dead biomass passes into the soil, where soil organic matter is decomposed while the resulting CO_2 is respired to the atmosphere. In addition disturbance processes like fire or harvests release carbon to the atmosphere. The land surface contains significant amounts of carbon in vegetation (350-550 PgC, Prentice et al., 2001) and in soils (1500-2400 PgC, Batjes 1996), with additional carbon stored in wetlands (200-450 PgC) and in loess permafrost soils (~200-400 PgC, McGuire et al., 2009).

Due to the general character of the Baltic Sea region with extensive forests and substantial wetland areas, the carbon storage in vegetation and soils of the region is significant, although we are not aware of specific regional estimates.

Both humans and climate potentially have a significant impact on these carbon storages. In climate-carbon-cycle models, such as those employed in the Coupled Climate Carbon Cycle Model Intercomparison Project (C4MIP, Friedlingstein et al., 2006), the carbon cycle sensitivity to climate change can be expressed as two parameters, β and γ. The parameter β describes the sensitivity to changes in the atmospheric CO_2 concentration, while the second parameter, γ, describes the sensitivity of the carbon cycle with respect to changes in climate, in particular temperature.

From vegetation experiments with elevated CO_2 concentrations, there is direct evidence of enhanced Net Primary Productivity (NPP) under rising atmospheric CO_2 (Norby et al., 2005), implying a positive β. While these experiments give direct evidence of this feedback between CO_2 uptake and CO_2 concentration, the so-called CO_2 fertilisation, there remains considerable uncertainty with respect to the universality of these results, especially since interactions with nutrient and water availability are likely but remain uncertain (Gedalof et al., 2010; Penuelas et al., 2010). Therefore it is very likely that elevated CO_2 concentrations enhance productivity, as long as other conditions for additional growth are met. The magnitude of this effect remains unclear, though. In earlier studies models showed an increase in carbon uptake under increased atmospheric CO_2 by 0.85-2.4 PgC/ppmv (Cramer et al., 2001), while later studies that consider the limitation of carbon uptake by Nitrogen (N) availability show a considerably decreased enhancement (Sokolov et al., 2008; Thornton et al., 2009; Zaehle et al., 2010). In the land surface model CLM4, for example, the estimated increase in NPP when considering N availability is only 30% of the increase without considering N dynamics (Bonan & Levis, 2010).

Through the temperature sensitivity of both photosynthesis and respiration, the terrestrial carbon balance is considerably influenced by changing temperatures. The precise response remains uncertain, though. Under warm and water limited conditions, an increase in temperature would lead to increased water stress due to the enhancement of evapotranspiration under warmer conditions. In cold regions, on the other hand, an increase in temperature would lead to a longer growing season, thereby enhancing vegetation growth. With respect to soil organic matter, an increase in temperature will lead to an increase in decomposition, i.e., enhanced C losses from the soil to the atmosphere (Davidson et al., 2006). Soil respiration measurements over the period 1989-2008 found increases in soil respiration by 0.1 PgC/yr, which implies a Q10 factor of 1.5 when compared to the warming over that timeframe (Bond-Lamberty et al., 2010), though the attribution to increased organic matter inputs into the soil or to increases in respiration remains unclear.

Modelling studies suggest that climate warming will accelerate C losses from the soil, implying a positive feedback between warming and the carbon cycle (Friedlingstein et al., 2006; Stich et al., 2008). The models in C4MIP showed a range -20 - -177 PgC/K for the γ factor (Friedlingstein et al., 2006), while Stich et al. (2008) found a range -60 - -198 PgC/K in five DGVMs. These values were derived from models that did not consider nutrient limitations, though, and could therefore be an overestimate, since warming may increase N mineralisation and availability in the soil, enhancing vegetation growth. Current climate-carbon cycle models that include a nitrogen cycle show this effect (Sokolov et al., 2008; thornton et al., 2009; Zaehle et al., 2010), but the uncertainties in γ remain very high.

Historical land cover changes and feedbacks (Marie-José Gaillard, Anne Birgitte Nielsen and Jed Kaplan) (ca 8 pages)

TO BE WRITTEN! One new co-author

Holocene land-cover changes – climate and/or human induced

For obvious reasons current and future trends in vegetation-climate feedbacks are to a large extent controlled by/a consequence of human induced land use changes (). Pre-historic climate changes may however to a significant effect also have been attributed to natural vegetation changes. Studies of historic and pre-historic vegetation related changes in regional climate also provide important evidence of the existence of a land cover-climate feedback system.

TO BE WRITTEN!! FIRST DRAFT BY MJ GAILLARD expected for March 15th

Examples of figures that will be used:

From Gaillard et al. 2010 in CP 6 Regional vegetation in southern Sweden (Skåne and Småland) modelled using pollen records and the REVEALS model (Sugita 2007a)

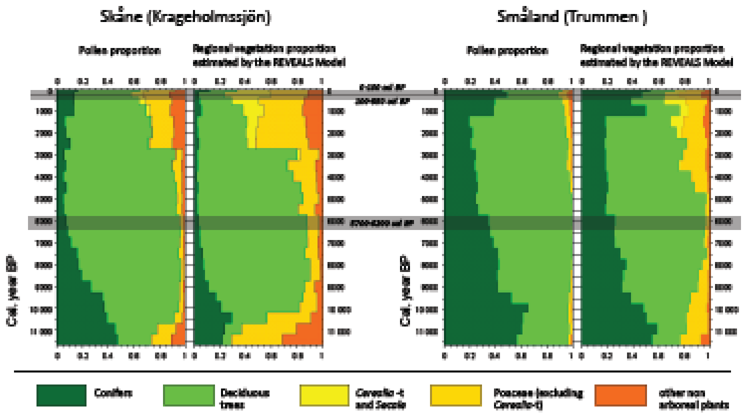
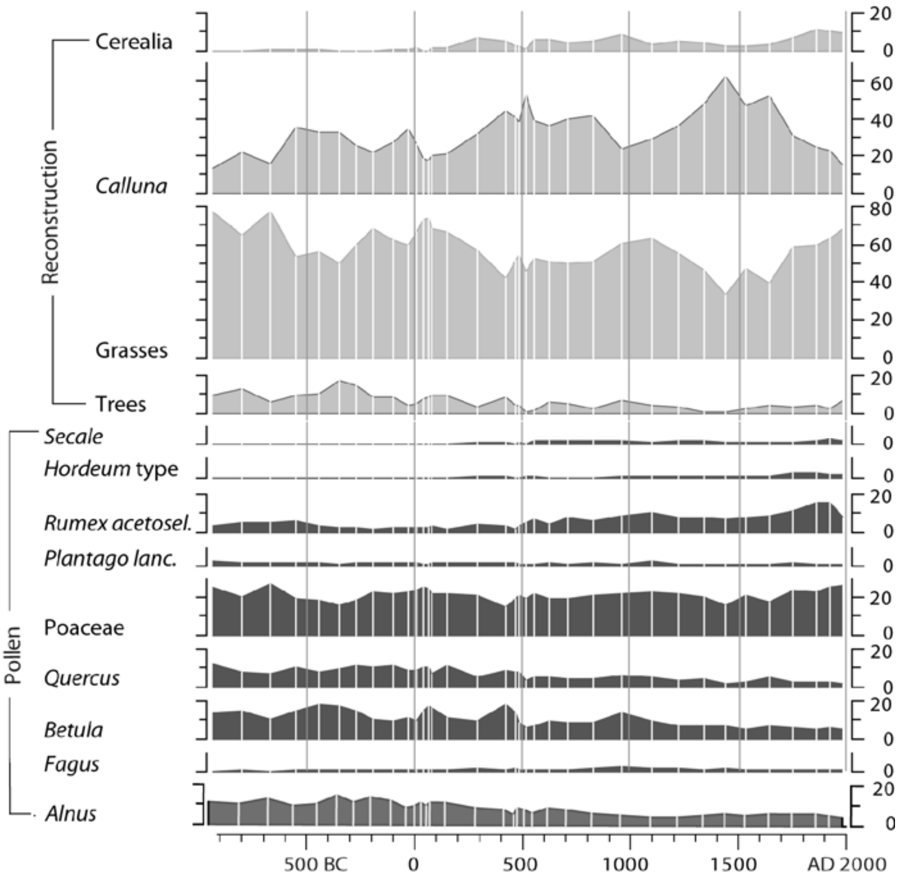
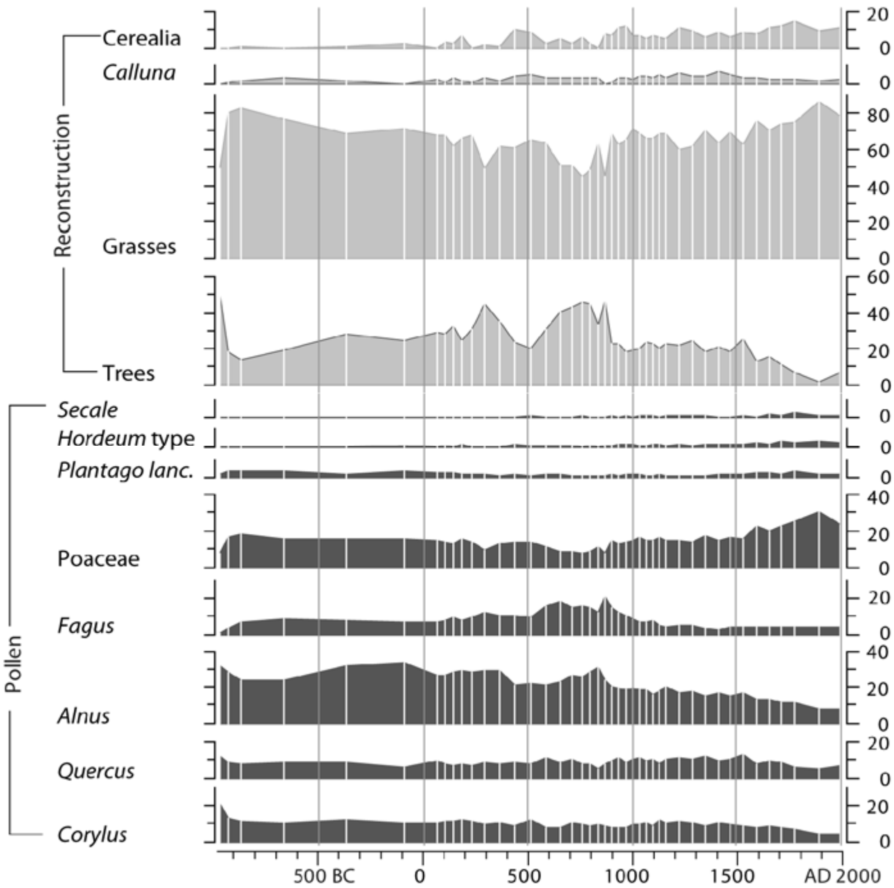


Fig. 7. REVEALS reconstructions of Holocene vegetation changes (right in each panel) in southern Sweden based on the pollen records (left in each panel) from Kragehomssjön (province of Skåne, left) and Lake Trummen (province of Småland, right) (from Sugita et al., 2008, modified). See Fig. 8 for the locations of Skåne and Småland. The selected three major time-windows studied in the LANDCLIM project are indicated. REVEALS was run with 24 pollen taxa with the pollen productivity estimates from southern Sweden (Broström et al., 2004). The taxa included in the groups "conifers", "deciduous trees", "Cerealia-t" (cereals, rye excluded) and "other non-arboreal plants" (herbs and shrubs) are the same as in Fig. 6. *Secale*=rye; Poaceae=grasses.

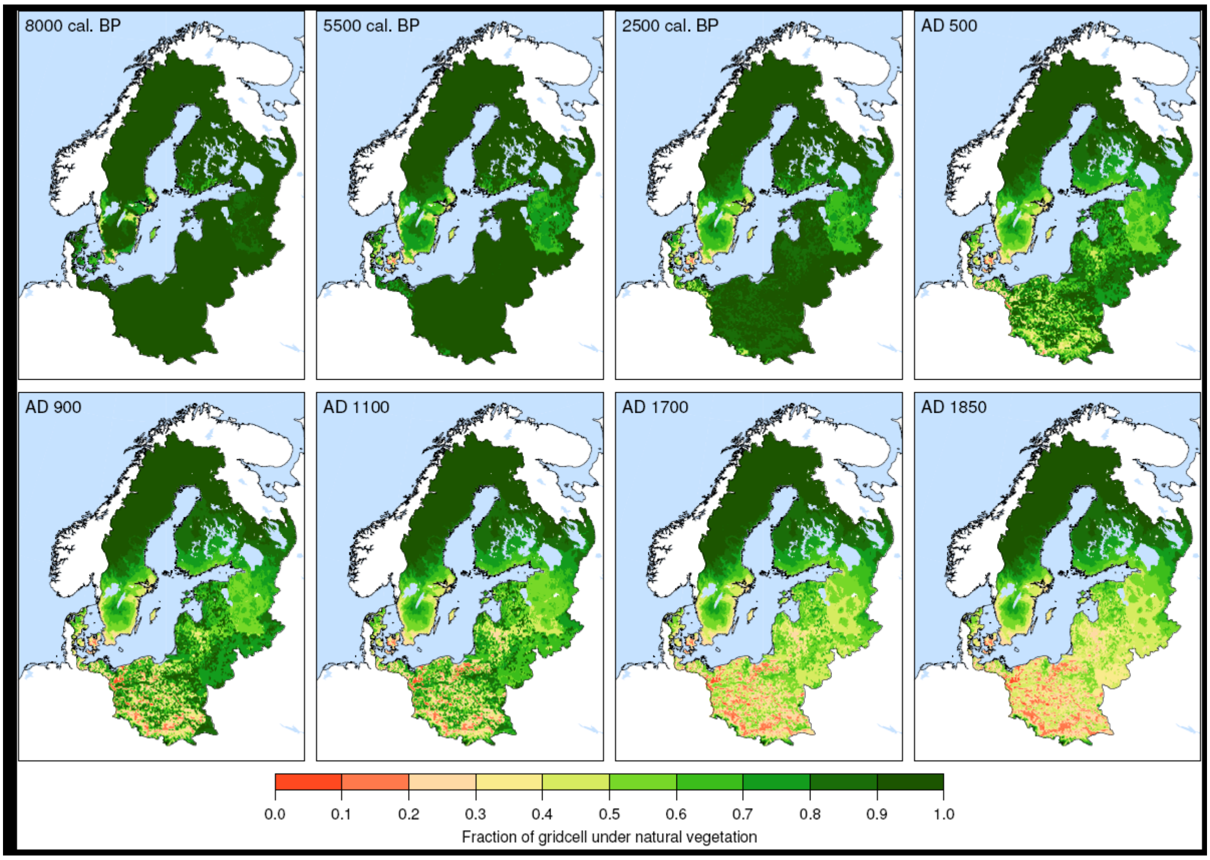


From Nielsen et al. 2010 in Veg. Hist and Archaeobot – landscape openness in Denmark, last 3000 years modelled by the Landscape Reconstruction Algorithm(Sugita 2007a and b) using pollen.



KK10 scenarios extracted for the Baltic area from what is published in Kaplan et al. 2009

Kaplan, J., Krumhardt, K., and Zimmermann, N.: The prehistoric and preindustrial deforestation of Europe, Quaternary Sci. Rev., 28, 3016–3034, 2009.



Potential future trends in land cover and associated feedbacks

Resource management (Camille Sandström, Hjalmar Laudon, Johan Bergh): ca 5 pages TO BE WRITTEN ! Two new co-authors TEXT expected for the end of February

Bindi and Olesen, 2011: The responses of agriculture in Europe to climate change

Anderson et al., 2011: Biophysical considerations in forestry for climate protection

Future land cover change scenarios and associated feedbacks (Anna Wramneby, Thomas Kleinen, and Marie-José Gaillard??): ca. 5 pages can be extended by Thomas Kleinen!! (MJG can complement/edit the text in terms of Anna's results/thesis, IF NECESSARY!)

Text revised and complemented by Thomas Kleinen-State February 6th 2012

Future land cover change scenarios and associated feedbacks (Anna Wramneby and Thomas Kleinen):

Globally, a number of future land use change scenarios have been explored and over the recent decades regional scenarios have emerged for different parts of the world (Alcamo et al., 2008). Regional studies pinpointing future changes in the Baltic Sea region are very limited, but over the European domain a growing number of future land use scenarios are becoming available. The difficulty in moving focus from global to regional future land use scenarios lies in the variety of possible outcomes since more details and locally specific questions need to be considered at the regional scale (Carter et al., 2007; Alcamo et al., 2008; Metzger et al., 2010).

As concluded in the 1st Assessment Report of Climate Change for the Baltic Sea Basin - BACC I (Smith et al., 2008), future land use trends in Europe are associated with comparatively rapid technological progress suggesting that the required food production will be sustained by a smaller agricultural land fraction. Abandoning agricultural land enables reforestation in large areas and this is also the current and future general trend according to available land use scenarios in Europe (e.g. Rounsevell et al., 2006). The general future land use trend in Europe could be assumed to be applicable also for the Baltic Sea region although a few studies conversely have indicated a sustained or even expanded agricultural fraction for some of the Baltic Sea countries (e.g. Denmark and Finland in Audsley et al., 2006). The feedbacks to climate from such regional land use changes are to a large extent unexplored. Biogeochemical feedbacks from regional land use changes have been discussed in the concept of global climate change in some studies (Carter et al., 2007; Rounsevell and Reay, 2009) but the direct biogeophysical feedbacks in relation to expected land use changes are yet to be addressed.

A wide range of global land cover-atmosphere modelling experiments have been performed over the last decades to infer the role of land surface dynamics both in terms of CO_2 exchange and biogeophysical factors. The majority of these studies have however either explored the role of extreme shifts in land cover (Bala et al., 2007) or investigated the role of potential natural vegetation changes (XXX Do we have citations for this? XXX). One exception is a study by Pongratz et al. (2009) who investigated the influence of historical land use changes on radiative forcing. For all of Europe, with the exception of Scandinavia, they found a decrease of radiative forcing by 0.3 W/m^2 between 800 and 1700. This study, as well as other global studies, suffers from the drawback that grid resolutions in global scale modeling necessarily are rather coarse, typically far coarser than the scale necessary to capture local to regional processes (Hibbard et al., 2007). Since the biogeophysical feedbacks are likely to play a more dominant role in regional rather than global climate change, our understanding of the underlying mechanisms and what to expect regionally in the future is only starting to emerge.

Biogeophysical feedbacks to the regional climate mean state

Studies of potential natural vegetation changes and their biogeophysical feedbacks to regional climate give some indication of what to expect in the future since the underlying mechanisms are likely to be similar for natural and anthropogenically modified vegetation. For the European domain such studies of future biogeophysical feedbacks from potential natural vegetation changes point towards a boreal tree line advance into the tundra regions in northerly regions (Barents Sea region: Göttel et al., 2008; Europe: Smith et al., 2010; Wramneby et al., 2010). The most significant feedback associated with the forest expansion at these northerly latitudes would be the well-known albedo feedback leading to an albedo reduction, which according to a number of global studies (Betts, 2000; Bala et al., 2007) likely is strong enough to offset the climate gains from the increased carbon sequestration in forests. Bathiany et al. (2010), for example, find that afforestation of all currently tree-less areas north of 45°N leads to a global mean warming of 0.26°C due to biogeophysical effects, while the reduction in atmospheric CO_2 would only be 6.5 ppm, leading to a net warming. The albedo effect would be most significant in winter and spring when forests mask snow causing an additional regional temperature rise. This feedback loop becomes strengthened as a warmer climate and more extensive snowmelt also lead to an earlier and longer growing season, which in turn promotes further forest expansion.

While the albedo feedback and its amplifying effect on climate warming is expected to be the most important biogeophysical feedback in boreal regions such as northern Europe (Strengers et al., 2010), an increase in forest cover also implies a contrasting biogeophysical feedback mechanism due to enhanced evapotranspiration. This feedback may, however, be of minor importance for the boreal forests dominated by needleleaved evergreens since these forests have a comparatively low evapotranspiration rate (Bonan et al., 2008). For the part of the Baltic Sea region enjoying a more temperate climate, the role of evapotranspiration might however be of greater importance due to the dominance of more strongly transpiring broadleaved deciduous forests although some disagreement prevails about the role of temperate forests in climate change (South et al., 2011). Significant feedbacks from such changes in the hydrological cycle were for example identified in Wramneby et al. (2010), who applied the regional climate-vegetation model RCA-GUESS (Smith et al., 2010) over Europe to investigate the role of long-term vegetation-climate feedbacks from future greenhouse forcing to changes in mean climate. In central Europe CO_2 fertilization and increased water use efficiency caused vegetation to respond positively, with increased leaf area enhancing evapotranspiration and mitigating regional climate warming. The hydrological cycle feedback in central Europe sharply contrasted with the response in southern Europe, where significant future warming and reduced precipitation restricted plant growth and survival.

Given that the majority of available future land use scenarios at the European scale assume increasing fractions of forested areas in parallel with a reduction in agricultural land, the resulting feedbacks could be similar to those identified above. This would imply a positive (warmer climate) albedo mediated feedback in winter when previously snow covered agricultural land becomes replaced by snow masking forested areas and at least potentially a negative (colder climate) feedback from an enhanced hydrological cycle in summer due to higher LAIs. The biogeophysical feedback effects on precipitation and cloudiness over Europe are less clear. Wramneby et al. (2010), for example, were not able to find any evidence that variations in cloudiness and precipitation over Europe could be attributed to vegetation dynamics. The lack of an established relationship between increased/reduced evapotranspiration, precipitation, and cloud formation over Europe could be attributed to the fact these are strongly determined by the advection of moisture from the Atlantic. This likely overwhelms any feedback signal from vegetation-mediated changes in evapotranspiration. In addition the ratio between sensible and latent heat exerts a strong local control on temperature, but effects on cloud formation and precipitation will take place at the site of condensation, further away and higher up in the atmosphere, diffusing the signal (Wramneby et al., 2010). Incorporating likely land use scenarios might however strengthen the feedbacks identified so far and potentially also show feedbacks in precipitation and cloudiness.

Biogeophysical feedbacks to regional climate variability

The long-term effects of biogeophysical feedbacks on regional climate change may very well go in line with the features suggested above. Future land cover changes are, however, not only relevant with respect to feedbacks to the regional mean climate state. Recent studies have emphasized the role of feedbacks in climate variability and have shown that land cover-climate feedbacks might behave very differently from those feedbacks expected in the long-term. Although changes in land use are often considered as non-climatic causes of increased climate variability (XXX citation? XXX), a number of studies has shown that processes at the land surface may contribute to increased climate variability through direct land surface feedbacks. Such direct biogeophysical feedbacks to climate were, for example, demonstrated by Seneviratne et al. (2006), who performed a suite of climate model sensitivity simulations with and without soil moisture responses to infer the role of the land surface, attributing a substantial fraction of the future temperature variability in Europe to land surface processes mediated by soil moisture feedbacks. In one respect climate variability gives us a better understanding of climate change, since the concrete consequences have already been observed in recent extreme climate events such as floods and droughts. For the European domain, and certainly relevant for the Baltic Sea countries, such events have already had severe consequences (Della-Marta et al. 2007). A subsequent study about the role of land cover-atmosphere feedbacks as explanatory factors behind recent European climate variability has recently shown that the cooling effects from forests maintaining a reasonable evapotranspiration rate, as compared to open land, could be reversed at least during the initial stages of a heat wave (Teuling et al., 2011). By comparing eddy flux tower measurements from the European FLUXNET sites, Teuling et al. (2011) could show that the evapotranspiration from water conservative forests is significantly reduced in comparison to open land during the initial stage of a heat wave. Conversely, as the heat wave continues, soil moisture depletion prevents further cooling over open land while forests can continue to cool the atmosphere.

Biogeochemical feedbacks

Scenarios on the future development of European land use generally rest on two assumptions (Alcamo et al., 2007): An increase in agricultural productivity and a decrease in European population. According to United Nations projections, a population decline by 8% is expected by 2030 (UN, 2004), with a further decline likely for later years. At the same time, agricultural productivity is expected to increase by between 25% and 163% (Ewert et al., 2005), depending on technological developments. The net result of these trends is a decrease in the agricultural area required for food production.

While these trends have not been broken down towards smaller areas like the Baltic countries in the literature, it seems safe to assume that these general trends will also apply here.

For Europe as a whole, the scenarios therefore show a decline in cropland by 28 to 47% in 2080 and a decline in grassland by 6 to 58% (Rounsevell et al., 2005), with the areas freed taken up by either urban expansion or forest expansion, though some of the area may be used for cultivating bioenergy crops.

For northern Europe, it can be expected that climate change will lead to a northward expansion of the forest area into former tundra areas (xxxxxx NOT FINISHED!!

Summary (Anna Wramneby and Marie-José Gaillard) ca. 1-2 pages)

TO BE COMPLETED by Marie-José

This chapter sought to review our current understanding of land cover changes as a cause to regional climate change in the Baltic Sea Basin. The main findings are as follows:

Biophysical land cover-atmosphere feedbacks have been important contributors to regional climate changes in the past.

Studies of feedbacks to climate in response to potential natural vegetation changes and large-scale land use changes explore the sensitivity of climate to vegetation changes and have during the recent decades increased our understanding of the underlying mechanisms.

Studies of biophysical feedbacks in response to available future land use scenarios do not exist at the regional scale such as the Baltic Sea Region.

Regional future land use scenarios are emerging. The general future land use trend in Europe according to the majority of available scenarios points in the direction of a conversion of agricultural land into forests.

Feedbacks associated with forest expansion in temperate, boreal and arctic regions are related to albedo reductions (warming) in winter and early spring. The role of hydrological cycle feedbacks in these climate zones are less understood but could be relevant in spring and summer at least in temperate climate zones.

It is expected that the outcomes from additional regional to local future land use scenarios will widely diverge as more detailed information becomes incorporated into the models. This would in turn yield multiple possible outcomes related to the resulting biophysical feedbacks.

Climate policies of today barely reflect the consequences of biophysical land-atmosphere feedbacks.

Biophysical land cover feedbacks in a short-term perspective could contrast those feedbacks relevant in the long run.

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