Chapter 5

Conclusions

The previous chapters illustrated the substantial impacts of land-cover on the overlying atmosphere. Given these impacts, we cannot assume the atmosphere as constant factor that only changes in response to climate changes. This fact affects a wide range of applications from responsible environmental decisions to climate-impact assessment on water availability, food production, and air quality. Policymakers must be made aware that land-cover changes (LCC) influence at least local weather, climate, and atmospheric conditions. Before taking any action or making any decision, the unintended consequences thereof have to be assessed. These consequences may be adverse to the environmental problem to be solved, even engrave the problem or lead to other – even more severe – problems (Verstraete et al. 2009).

Holding domestic industries responsible for their environmental changes caused during the part of the production process they control may be hard to establish, economically unfeasible, and/or disadvantageous. The difficulty of enforcing such measures even increases in the case of greenhouse gas (GHG) emissions related to LCC. The GHG emissions caused by LCC are difficult to assess as they depend strongly on land management practices (fertilization, irrigation, crops rotation, tillage, etc.), type of LCC and duration of land-use (Kim et al. 2009). In some cases, taxing for LCC-induced GHG emissions could even become unethical when it would hinder to convert suitable land for urgently needed food production.

Assessment of LCC impacts on future water and food resources is difficult due to the complexity of the interactions of responses to LCC

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among each other and climate change. In addition, the high spatial and temporal variability of precipitation and lack of accurate projections of LCC, GHG, and other emissions complicate the assessment.

The findings discussed in Chaps. 3 and 4 indicate LCC impacts on weather, climate, and the atmospheric composition at various scales and suggest feedback to further LCC. Atmospheric impacts of LCC can cause similar changes in regional temperature and precipitation like the changes in response to GHG. Thus, we have to conclude that LCC may have contributed to a certain degree to recent climate changes. This means that LCC are an important climate forcing that requires high research priority. Future modeling and observational studies should focus on quantifying the contribution of LCC to climate change.

5.1 Modeling and Observations

Modeling studies that assumed large, but realistic-size LCC indicate LCC-induced differences in 2 m air temperatures, surface temperatures, precipitation, and cloudiness larger than the accuracy of measurements. Thus, the impact of LCC could be detected if stations existed at the sites that experienced LCC. To obtain more observational evidence of LCC impacts on the atmosphere, existing long-term monitoring data in regions with extended LCC should be examined for changes related to documented LCC in the surroundings of sites. In regions of expected future LCC, installation of climate stations may help to quantify the impact of LCC on local weather and climate and to perform the overdue evaluation of LCC simulations. In LCC modeling, current common practice is to evaluate the model for current land-cover and atmospheric conditions and assume that the model performs similarly well with future land-cover conditions.

To document the actual role of the changing landscapes on weather, climate, and air composition, long-term monitoring sites should be established in areas of expected future LCC (e.g., deforestation) or land-use change (e.g., irrigation or expansion thereof). The monitoring efforts should focus on slow variables and their thresholds.

Any monitoring needs to cover the diversity of relevant land-cover. Since forest and grassland are still under-monitored, new sites have to be installed in these land-covers first. Both anthropogenic and natural LCC need to be recorded to permit associating them with climate changes (Verstraete et al. 2009). The latter helps to quantify the impact of LCC on weather and climate.

Such quantification also requires research on to which extent plants and/or ecosystems adapt their functional behavior to altered climate conditions and atmospheric composition and how biogeophysical and biogeochemical changes affect ecosystem functions (e.g., decomposition, nitrogen, and carbon cycling). These investigations require hierarchies of laboratory experiments that examine the ecosystem-function responses to various combinations of potential environmental changes. Improved ecosystem functions mean improved representation of future LCC, future emissions, energy and water needs in model studies, and reduction of uncertainty in the simulated resultant modified climate.

An important aspect of the value of LCC studies is the comparability of LCC impacts among studies performed for same LCC, but with different LCC extent and/or in different regions. To assess desertification and monitor dryland degradation, for instance, uniform criteria/standards of description and monitoring protocols have to be developed and adopted worldwide.

Since many LCC enhance the heterogeneity of the landscape, we need to develop new theories to interpret measurements with restricted or no fetch conditions or measurements in urban areas where surface characteristics vary too strongly as that a real "representative" site can be chosen. Such theories then may result in improved new parameterizations of the land-atmosphere interactions.

Earth observation from space is a cost-effective technology for monitoring LCC, and their impacts especially in remote, hard-to-reach regions. GOES-R, for instance, will have an increased resolution in many channels as compared to its predecessors; additional channels permit assessment of the chemical distribution of species. The integration of remote sensing data may improve our understanding of the significance of LCC-induced feedbacks. Better understanding of the feedbacks between climate and desertification, for instance, requires identifying the sources and sinks of trace gases and aerosols in drylands (Sivakumar 2007).

Satellite data could also help to assess and identify suitable areas for special field campaigns. Satellite-based passive microwave data may serve to detect changes in polynya, ice-shelves, and the extent and interannual variability of sea-ice. This data in combination with remotely sensed LCC can be used to analyze and evaluate ice-vegetation-atmosphere feedbacks.

Efforts have to be made to advance the development of (earth) system models that can describe the various interactions between biogeophysical and biogeochemical processes. Advances in LCC-impact and climate modeling require improved soil and vegetation parameters, root-depth specification, vegetation-distribution data and soil type profiles. We have to align monitoring and data collection with the modeling efforts to ensure that all of the needed soil and vegetation information is available for the models. Instead of classifying a region as covered by a certain soil type (e.g., clay loam), the data inventory should provide soil parameters (e.g., soil density, thermal and hydraulic conductivity, heat capacity, albedo, emissivity) as a 3D function in space. Similar applies for vegetation type.

Advances in earth-system modeling require to coupled models of different type. Prior to coupling models, it has to be evaluated at which scales which processes may interact and require the coupling. Such investigations will be the basis to decide whether to choose loosely coupled modeling techniques, one-way coupling or two-way-coupling. One-way coupling means that the driving model just provides the input for the other model without consideration of feedbacks. Two-way-coupling means that the results of the driven model feed back to the driving model and may cause changes in the state conditions and/or fluxes there. Besides the degree of coupling, one has to examine at which temporal intervals to induce the coupling. Thus, the time scales at which changes become important for other processes have to be determined. Any coupling requires developing routines to handle the required data exchange. Ideally, the system permits exchanging models addressing the same processes for sensitivity testing.

In any environmental decisions related to LCC, the feedbacks between the altered land surface and the atmosphere have to be considered on all spatial scales to assess their potential impacts on climate and air quality. Thus, future work has to focus on scaling issues (from local to regional to global scale) as the scale affects ecosystem functions. This research is especially urgent given the rapid growth of the number of megacities that are local LCC, but may be very sensitive to large-scale climate change.

Today, the knowledge on how spatially fine-scale LCC affect the large scale over longer time (e.g., seasonally) is very limited. The potentially far-reaching impacts of local LCC in a warmer climate (Li and Mölders 2008) require further investigations on the influence of land-cover on the climate system and the interaction between both.

The model grid increments determine which kind of land-atmosphere interactions can be resolved or must be parameterized and hence can provide atmospheric impacts. Mesoscale scale models can resolve processes that in large-scale models are of subgrid scale and have to be parameterized in large-scale models. Model-domain size, grid spacing, parameterizations (e.g., cloud microphysical schemes), and parameter choice affect significantly the distribution of simulated precipitation, chemical species, wet and dry deposition. Investigations must focus on consistency of responses at various scales and through the scales. Herein, the impacts of landscape pattern and heterogeneity on precipitation require systematic investigation. The effects of natural spatial variability and topography and climate variability have to be separated from changes due to anthropogenic LCC.

Despite the various LCC studies provide similar signals of LCC impacts, the LCC impacts on the atmosphere found vary largely among the various studies. This large variability requires uncertainty analysis on the influence of LCC. To increase the confidence in and assess the uncertainty of LCC simulations, simulations should be performed with different models that all assume the same LCC. Doing so requires guaranteeing comparable land-cover representations among participating models as differences due to land-cover representations may be of similar magnitude than those due to LCC (Pielke et al. 2007).

The knowledge on how concurrent LCC impacts interact with each other under different climate conditions is very limited. Future studies should focus on how the nonlinearity and significance of LCC found for current climate behaves on the long-term (e.g., vegetation season, decadal, or climate scale). If the LCC responses are climate-dependent, sophisticated biome models have to be developed that permit to include natural LCC in response to a changing climate. Social behavior models have to be run inline in the climate models to simulate economic responses (e.g., more land used for winter wheat) to a changing climate.

Coupling models inline ensures data consistency and facilitates to guarantee consistency of treatment. Offline simulations of LCC impact studies (e.g. impact on harvest, air quality, water management) have the advantage that more studies can be made, as the meteorology has not necessarily to be recalculated again for a new sensitivity study. However, meteorological data are not available for every time step. Interpolation and inconsistent treatment of processes by uncoupled models may lead to large errors (e.g., Mölders et al. 1994). For various aspects of the (earth) system, the strength of coupling must be examined. For systems that are only very loosely coupled, offline simulations may be a useful shortcut and tool for huge numbers of sensitivity studies.

Studies on LCC impacts also bear uncertainty from the unknown development of land management practices. New land management practices may change tillage, rotation of crops, fertilization, and irrigation or soil density with consequences for infiltration. Sensitivity studies have to be performed to assess land management-related uncertainty in LCC impacts on weather, climate, and atmospheric composition.

The efforts to reduce emission-related climate change or to improve air quality can themselves affect local and regional climate via direct and indirect aerosol effects. Thus, future climate projections must include LCC, aerosols, and trace gases to consider interactions between the altered energy, water, and trace gas cycles. This means studies assessing future or potential long-term changes on local and regional climate should consider LCC and GHG forcing concurrently.

Various processes are still underrepresented in GCMs, mesoscale, or air-quality models due to computer-time limitations. The anticipated growth and number of megacities requires assessing urbanization impacts, including urban heat island (UHI) and air-quality issues. Thus, urban canopy models should be run inline in climate models to assess future quality of life and to be able to use these models to find means to mitigate the UHI stress and air pollution. Running the urban canopy and climate models in a fully coupled mode permits to consider the feedbacks between the local scale and larger scales.

Studies show that CO_2-induced and climate-induced changes in vegetation structure can influence hydrological processes and climate at similar or higher magnitudes than the radiative and physiological effects (e.g., Alo and Wang 2010). Therefore, including vegetation feedbacks in future climate projections is an urgent need. Future scenarios should include relevant economic and environmental aspects that alter land-surface conditions, and land-cover should change accordingly during the simulation. Such aspects could be, for instance, reduced irrigation in regions that experience either an increase or strong stresses on water availability.

5.2 Future Assessment

Precipitation anomalies in response to urban effects (UHI, enhanced buoyancy, reduced evapotranspiration, altered cloud condensation, and ice nuclei distributions) can yield ecological and societal consequences of both signs. Plans for ameliorating negative consequences might include the development of improved water-management strategies, improved guidelines for home construction, and/or recommendations for optimal location of industrial or commercial areas. In such planning processes, results from atmospheric models in combination with statistical methods (e.g., analysis of variance) can help in identifying which of the different possible urban effects actually causes the precipitation variance. Such an identification process avoids arbitrary and possibly ineffectual changes and can help policymakers to make cost efficient decisions, and implement effective policies.

The changes in technology and energy supply bear great uncertainties for any future assessments. These changes namely may alter the atmospheric conditions via emissions, and land-cover for food and biofuel production. Some scientists warn that the assumptions of the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES) may not provide the full picture of future challenges (Pielke et al. 2008). According to them, the SRES-assumed rapid decline in energy intensity of greater than 1% per year over a century would require probably unachievable advances in energy efficiency; energy demands are more likely to increase than decrease given the increase in population and the economic transition in developing countries (Pielke et al. 2008). Maintaining a megacity, for instance, requires huge amounts of energy for pumping water into high buildings, cleaning wastewater, providing air conditioning or heating, and transportation of people and/or food supply.

Economic or social demands often conflict with environmental interests. A huge challenge for policymakers is to tackle these conflicts of interest. Typically, environmental policies related to biodiversity or water quality gain high public acceptance. However, policymakers usually neglect local climate impacts in urban and/or regional planning due to the lack of appropriate tools for assessing the impact of LCC on local climate (Fehrenbach et al. 2001).

In a changing world, big issues are that LCC and climate changes affect the welfare of states differently, and that the LCC, air pollution, and GHG impacts do not know international borders. This fact requires worldwide efforts and international collaboration to keep impacts as small as possible while at the same time addressing the energy, water, and food demands of an increasing world population.

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