BIOGEOCHEMISTRY

Managing land and climate

Management practices applied to existing types of land cover can influence the local climate as much as a conversion to a different type of plant cover.

Dennis Baldocchi

Approximately 83% of land on Earth has been appropriated for human use[1]. To prevent the further displacement of natural habitats, land-use will probably become more intensive over the coming years. Writing in *Nature Climate Change*, Sebastiaan Luyssaert *et al.*[2] report that land management choices can have as large an impact on the local temperature as the impact due to a change in the type of land cover. The team demonstrates the power of extracting information from modern flux networks to quantify energy-balance differences for diverse sites across North America and Europe; these paired sites differ in management and span a range of climates and plant functional types (grasslands, forests and crops). The authors augment their analysis by using satellite remote sensing to extend the time series back in time. They also apply a coupled-surface-layer/planetary-boundary-layer model to quantify the changes in surface temperature and attribute them to particular biophysical factors.

A broad understanding that human-induced changes in land cover, through deforestation and land management (for example, through grazing) can have an impact on the local climate has existed for centuries, and extends as far back as the Roman era and the time of the Greek philosophers. The mechanism for this land–climate interaction occurs through alterations to the surface energy balance and the carbon cycle[3,4]. Historically, a misunderstanding of the feedbacks between land management and climate has promulgated the idea that 'rain follows the plow'; a myth that helped to entice the westward migration of pioneers in North America, who converted the prairie, west of the Missouri River, to farms[5]. These farmers were surprised, years later, when periodic droughts returned, causing many to abandon their farms. Analyses of these historical events led modern scholars to recognize that the experiences of these pioneers were more in-line with an alternative theory: 'drought follows the plow' on marginal lands[6]. These historical misconceptions illustrate why we need a firm understanding of how changes in land cover and management interact with the climate system, if we are to make effective land policy and management decisions. The work of Luyssaert *et al.*[2] is a step in this direction.

The impacts of changing land cover and management on the surface-energy balance are very complex and are full of negative (stabilizing) and positive (reinforcing) feedbacks (Fig. 1). In principle, the impacts of land use and management on the local climate revolve around the perturbation of a suite of nonlinear functions that are dependent climate variables, like sunlight, temperature and humidity. These functions depend on a set of biological and physical parameters that can be viewed as 'knobs' that control aspects of the system and can be 'turned' by changes in management practice and land cover. Key parameters include the reflectance of incoming solar radiation (albedo), leaf pore capacity (stomatal resistance) and plant canopy structure (leaf area index). These parameters affect the way that energy is partitioned into sensible heat (which warms the air) and latent heat exchange (which may cool the land surface through evaporative cooling), and in turn affect the temperature of the ground surface. Of additional importance are positive and negative feedbacks associated with: (1) the growth of the planetary boundary layer, which may dampen the warming of the atmosphere, (2) changes in the surface temperature of the land, which will alter the amount of available energy and (3) changes in

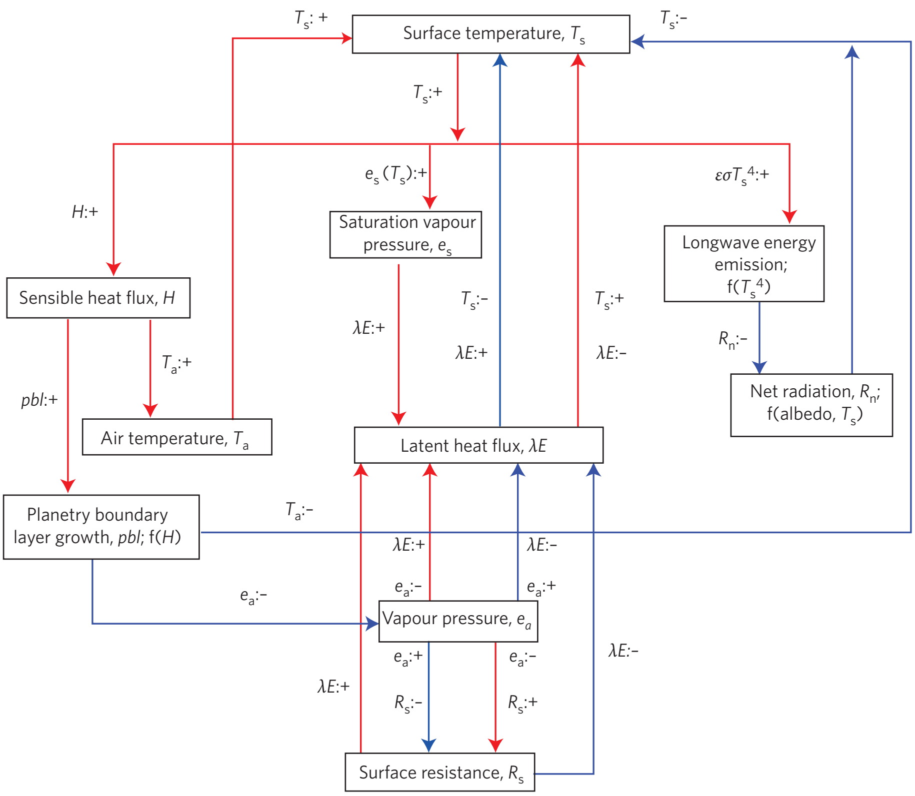

Figure 1 | Flow chart showing the main positive (red) and negative (blue) feedbacks between the surface energy budget and the surface temperature, which can be influenced by changes in land management and/or land cover. +/− indicates an increase or decrease in each quantity, respectively.

surface roughness, that regulate the transfer of heat to the atmosphere[7,8].

Management can impact the climate forcing of a piece of land in different ways and to different extents. For example, fertilization and irrigation of crops and pastures can increase the productivity of a land-cover type, thereby increasing its leaf area index, reducing surface reflectivity and increasing carbon uptake and water loss. Other management activities, such as the grazing of grasslands, the type of agricultural tillage, the timing of planting and forest thinning, can invoke a variety of positive and negative feedbacks, which can lead to warming or cooling. We also have to consider that changes in management and land cover alter greenhouse gas emissions. Practices that perturb carbon pools stored in vegetation and the soil promote carbon losses and increase the atmospheric CO_2 burden. Fertilization produces the emission of ultra-strong greenhouse gases like nitrous oxide, which has a radiative forcing about 300 times stronger than CO_2 (on a molecule per molecule basis over 100 years). Consequently, the assessment of how land management affects climate on short and long timescales requires full greenhouse gas accounting[9,10].

Alterations to biophysical processes are important at the local and regional scales as they may change the surface-energy balance by tens of Watts per square metre (W m^{-2}), compared with the low radiative forcing (3 W m^{-2}) that is induced by the current greenhouse gas burden in the atmosphere[11]. To compare the effects these forces have on the Earth's climate, however, it is necessary to consider the spatial scale at which they act. Greenhouse gas radiative forcing may be relatively small on an areal basis, but it is applied across the entire planet. Conversely, the radiative forcing attributed to land-cover change and management is concentrated in space and can change with time.

Naturally, a number of unresolved issues that warrant further investigation remain. How the enhancement or suppression of clouds will affect the albedo of the planetary boundary layer[12,13] is a particularly important question. More paired management studies that control the degree and type of management in a prescribed and incremental way would also strengthen future analysis. ❒

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CLIMATE CHANGE MITIGATION

Deposing global warming potentials

Accounting for time-dependent mechanisms in greenhouse gas radiative forcing and evaluating the performance of mitigation technologies in the context of climate stabilization targets can better inform technology choices today and in the future.

Alissa Kendall

The performance of technologies targeting greenhouse gas mitigation is nearly always measured using global warming potentials (GWPs). However, anecdotes, including my own unscientific survey, suggest that many researchers and practitioners working in fields related to climate change mitigation do not understand the actual meaning of GWPs, nor do they understand the application of GWPs in calculations of carbon dioxide equivalency (CO_2e) and carbon footprints — a peculiar state of affairs given that these metrics and indicators are important for assessing the performance of the very solutions those researchers are developing. Moreover, most stakeholders in the climate change mitigation discourse have unquestioningly adopted the Intergovernmental Panel on Climate Change's GWP as the method for characterizing and comparing greenhouse gases (GHGs). Only a relatively small (but growing) group of researchers have questioned, attempted to improve on and argued for change in the methods and metrics we use to track, trade and value different GHG emissions. Now, as they describe in *Nature Climate Change*, Morgan Edwards and Jessika Trancik offer new metrics that target technology assessment in relation to an explicit climate change mitigation goal[1].

Current GHG characterization practices apply GWPs to convert non-CO_2 GHGs to CO_2e, typically using a 100-year analytical time horizon. The conversion is made by taking the ratio of cumulative radiative forcing, over the selected analytical time horizon, for equal masses of CO_2 and the GHG being evaluated. GWP calculations include a few important simplifications: (1) both gases are evaluated over a particular analytical time horizon, regardless of when an emission or removal from the atmosphere occurs; and (2) the changing background concentrations of gases in the atmosphere are ignored, despite their effects on the radiative efficiency of a gas, and thus its radiative forcing. Starting around the year 2000, there have been calls for addressing some of these limitations, including the timing of emissions and sequestration[2,3] and the presumption that cumulative radiative forcing should be used as the indicator of the climate impact of a GHG[4]. Since then, researchers have continued to propose new metrics, many of which increase the level of complexity (of the metric's formulation and use) and which sometimes result in tailored metrics for particular technologies, sectors or applications. These include metrics tailored to biofuels[5], the transport sector[6], carbon mitigation projects[7] or carbon intensity calculations[8], to name only a few.

Edwards and Trancik[1] have entered the dialogue on alternatives to GWP with clear and well-defined intent — to contextualize technology performance within climate stabilization targets and to respond to