CLIMATE CHANGE

Terrestrial ecosystem inertia

Some components of the climate system continue to adjust long after atmospheric greenhouse-gas levels have stopped changing. A coupled climate–vegetation model shows that forests can be committed to die-back or expansion before change is observed.

Gian-Kasper Plattner

Climate change affects all components of the Earth system. Yet individual components of the system react with a broad range of response times to increasing atmospheric greenhouse-gas concentrations. Whereas radiative forcing changes almost instantaneously as atmospheric carbon dioxide levels rise, warming of surface air temperatures, melting of ice sheets and sea-level rise are expected to continue long after atmospheric carbon dioxide levels have been stabilized — in the case of sea-level rise for many centuries to millennia[1–5]. These long-term changes are referred to as the 'climate change commitment', which describes future changes that we have already committed to because of earlier actions[1] (Fig. 1). The concept has so far mostly been studied for physical properties of the climate system. On page 484 of this issue, Jones and colleagues extend the idea of climate change commitments to terrestrial ecosystems, and use a coupled climate–vegetation model to simulate the substantial inertia in terrestrial ecosystems, in particular in forests[6].

Terrestrial ecosystems have been shown to react sensitively to climate change as projected in scenarios for the twenty-first century[7]. Changes in radiation, temperature, the water cycle or other environmental variables affect the future growth of plants and also affect the future composition of land ecosystems. These, in turn, can affect the climate system through feedback processes. Unfortunately, climate change simulations with the most complex available models that simulate climate and ecosystem changes in a fully coupled mode are usually computationally too costly to be run much beyond a few decades to centuries. Climate change commitments beyond these timescales are therefore generally not taken into account, for example, in assessments of dangerous climate change.

Jones and colleagues[6] ran the coupled Hadley Centre climate carbon cycle model, including a dynamic global vegetation model, with an efficient numerical spin-up technique to overcome computational restrictions and accelerate their model. In this way, they were able to investigate the long-term response to climate stabilization. All runs started with a baseline twenty-first-century emission scenario (Special Report on Emissions scenario A2, SRES A2), and then kept atmospheric carbon dioxide concentrations constant at various points in the climate evolution. The difference between the state of the ecosystem at the point when carbon dioxide concentrations were held constant, and the state of the system when it eventually reaches equilibrium under the same greenhouse-gas levels is the climate change commitment for these ecosystems (Fig. 1).

Jones and colleagues focused on two specific types of terrestrial ecosystems, the tropical rainforest and the boreal forest. They found that the climate change commitment for both these ecosystems is considerable and could become inevitable and irreversible on human timescales, if climate change crosses critical thresholds. The results indicate that an ecosystem could even be committed to substantial ecosystem changes before the first signs of the changes are detectable. Importantly, though, the projected changes in the Hadley Centre model are opposite in direction for the two focus regions: the ecosystem response could therefore be either loss (tropical rainforest) or expansion (boreal forest), highlighting the regional nature of the committed changes. Exactly how a certain ecosystem will respond to increasing carbon dioxide concentrations depends on regional climate change, the ecosystem's sensitivities to these changes and feedback processes, as well as to other processes such as carbon dioxide fertilization. Jones and colleagues have demonstrated that committed ecosystem changes can be large and will need to be taken into account, for example, when projecting regional climate change, assessing dangerous levels of climate change or discussing future mitigation policies.

Given that the results rely on a single model, there are obvious limits to the robustness of the derived magnitude of

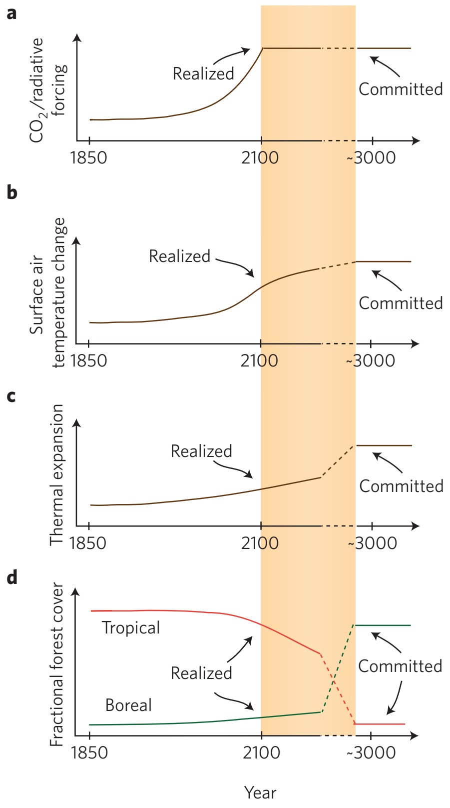

Figure 1 | Climate and ecosystem change commitments. Even if atmospheric carbon dioxide concentrations and carbon-dioxide-induced radiative forcing are held constant from 2100 (**a**), global mean surface air temperature change (**b**) and global mean sea-level rise due to thermal expansion (**c**) will continue to rise for centuries to come. Jones and colleagues[6] report that fractional forest cover in tropical and boreal forest areas will also change long after atmospheric greenhouse-gas levels have been stabilized, but in qualitatively different ways (**d**). The climate impacts that are realized at the point of stabilization are substantially weaker than the committed climate or ecosystem changes in the future. The time window of adjustment is highlighted by the orange bar. Note that the timescale over which the adjustment takes place will be different for each of these variables and the common year-3000 equilibrium indicated here is for illustrative purposes only.

committed ecosystem change. Climate models differ quite a bit in terms of their future temperature or precipitation projections in response to changes in atmospheric carbon dioxide[5], as do the ecosystem responses to these projected changes in carbon dioxide and climate[7–8]. Each climate model has its own characteristic peculiarities, weaknesses and strengths. The Hadley Centre climate model used by Jones *et al.* is known to simulate a more severe loss of tropical rainforests in response to the simulated regional climate change than most other models, which affects one of the two regions specifically highlighted in the research. In the boreal areas, the second region that Jones and colleagues focus on, climate models tend to agree much better in terms of projected climate change and boreal ecosystem response to these changes, owing to the dominance of the temperature response that climate models tend to simulate more robustly than the precipitation response[5]. The concept of ecosystem commitments should therefore be robust across ecosystems as well as across climate models, but the sign and magnitude of the commitments clearly bears a strong regional component.

In the light of these issues, the exact quantification of ecosystem commitments remains a subject for further research. Numbers will depend not only on each model's sensitivity to increasing carbon dioxide levels in the atmosphere, but also on the interplay of carbon dioxide fertilization and regional climate change in different models. It will be crucial to complement the results from the Hadley Centre climate model with simulations by a series of other models, and to investigate in more detail which processes lie behind the shifts in individual ecosystems. Another important extension of the concept of committed ecosystem change lies with oceanic ecosystems, which are affected by both climate warming and ocean acidification under increasing levels of atmospheric carbon dioxide. These perturbations threaten particularly vulnerable marine systems such as the Arctic Ocean[9] or the eastern boundary upwelling systems — regions of disproportionately high biological productivity and considerable economic value[10].

Jones and colleagues[6] have provided a proof-of-principle for the concept of ecosystem commitment to climate change and a first step towards its quantification. We now need a more comprehensive understanding of the potential magnitude of ecosystem commitments across a range of models and scenarios, and for a number of different ecosystem types. The challenge of fully understanding this important concept still lies ahead. ❐

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PALAEOCLIMATE

Lessons from the past millennium

Understanding millennial-scale climate variability provides context for present and future climate change. It now emerges that temperatures were spatially and seasonally more heterogeneous over the past 1,000 years than previously thought.

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Knowledge of past climate evolution is essential for understanding natural climate variability. The debate about the 'hockey-stick' curve — a reconstruction of Northern Hemisphere temperatures over the past millennium[1] — revolved around the extent to which recent climate warming is unprecedented in a longer-term context. The controversy calmed down after several reassessments[2,3] that confirmed the unique magnitude of warming since the late twentieth century, but the amplitude of multi-centennial temperature changes over the past millennium is still not well understood. Although these remaining uncertainties were acknowledged, the discussion moved to the next level in the European Geophysical Union (EGU) session 'Climate of the Last Millennium: Reconstructions, Analyses and Explanations of Regional and Seasonal Changes' at the 2009 General Assembly in Vienna[4]. Presentations focused largely on climate changes at regional and seasonal scales during the transition from the Medieval Climate Anomaly to the Little Ice Age.

Climate reconstructions based on different temperature proxies deviate substantially, but they broadly agree on two periods with distinct climatic conditions (Fig. 1). Temperatures were relatively warm, although not as warm as today, during the Medieval Climate Anomaly spanning AD 800–1300, and a slow transition then led into the anomalously cool Little Ice Age that lasted from AD 1500 to about AD 1850. Questions remain, however, regarding the spatial extent of these climatic anomalies and the mechanisms behind these climatic shifts. As European and North American proxy sites dominate the reconstructions, it is difficult to distinguish whether the Medieval Climate Anomaly and the Little Ice Age were global phenomena caused by external drivers — such as slow variations in solar irradiance — or if the climate anomalies were only regional. If temperatures rose across the globe during the Medieval Climate Anomaly, the analogy to present-day greenhouse warming — which is almost uniform globally — would be much stronger.

Palaeoclimatologists no longer study temperature alone. Increasingly, proxies for other climatic variables, such as precipitation, are being considered. A combination of different proxies can then be used to deduce more comprehensive measures for the state of past climate,