A COLLISION OF WORLDS

Several communities that study the Earth's land do not yet speak the same language. A new paradigm in Earth-system modelling will emerge when these communities overcome language barriers, says **Eleanor Blyth**.

Imagine a world where the only requirement is that you can sing in tune. Then picture a world where the sole obligation is that you can write poetry. And finally, think of a world where your performance on stage trumps all else. Now imagine bringing these worlds together. A hierarchy in the World of Song would be based entirely on perfect pitch, eloquence triumphs in the World of Words and showmanship determines the winner in the World of Performance. Let's give them a problem to solve together: how to nurture the next generation of music stars. They may struggle to find a harmonious solution, either together or separately.

So we come to the third open science conference of iLEAPS (Integrated Land Ecosystems-Atmosphere Processes Study) held in Garmisch-Partenkirchen, Germany in 2011. Joe Berry from the Carnegie Institution for Science, Department of Global Ecology, Stanford, summarised the extraordinary place we find ourselves as we try to solve today's global environmental issues. He pointed to an essay published in *Physics Today* by John Harte who makes the point that Earth-system science falls between two traditional approaches to science that he refers to as "Newtonian" and "Darwinian".

"Newtonians" – the various types of modellers, for example – seek simplicity in universal laws exemplified by Einstein's theory of theories, "A scientific theory should be as simple as possible, but no simpler." In contrast "Darwinians" (ecologists, for example) revel in complex interdependencies. They make progress by observing complexity and develop overarching concepts like evolution.

I have been steeped in this world for 23 years.

Earth-system science is now witnessing the emergence of a new modelling paradigm that explicitly accounts for two types of effects on the climate system: a) human (for example, land-use change resulting from agriculture), and b) natural (for example, biodiversity and adaptations of natural ecosystems). The success of such models will depend on the collaboration among the different communities that study land-atmosphere interactions, and ultimately on the development of a common language (see Box for the many meanings of "reduction" in biology, chemistry, mathematics and plain English).

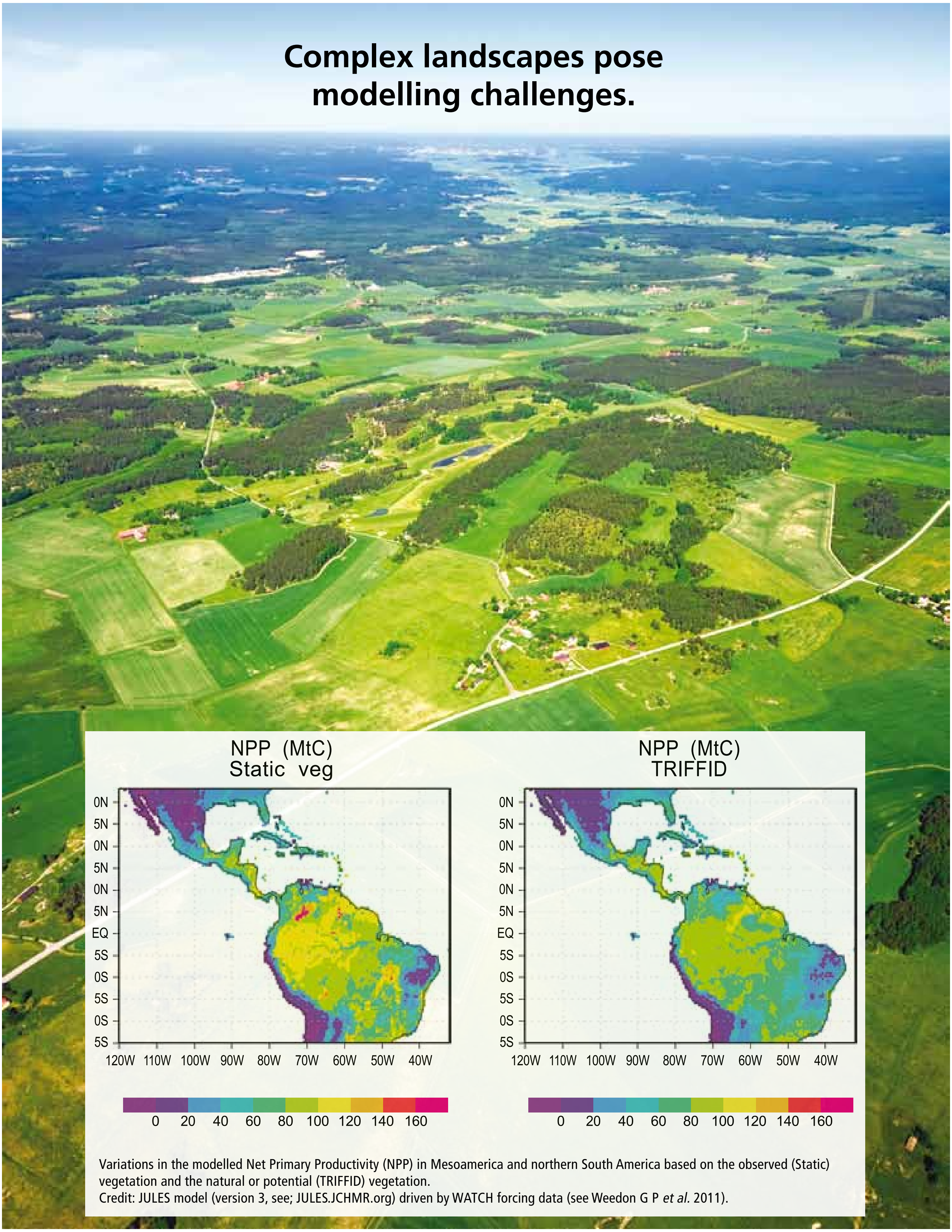
My world and theirs

I will have to declare my discipline: I am a land-surface modeller working on JULES (Joint UK Land Environment Simulator). JULES, which includes representations of the many land-atmosphere interactions, sits within the UK Hadley Centre climate model. In my "world" what matters is the correct calculation of all physical exchanges with the atmosphere: radiation, heat, water, momentum and carbon fluxes (carbon dioxide and methane). The skill is to understand the processes that determine those exchanges. For example, the effect of snow and vegetation on heat radiation and turbulent exchanges; the soil hydraulic and thermal processes that control the availability of water and heat.

In my community, we bury ourselves in equations and computer code, and in datasets that detail the vertical exchanges of matter and energy. We increasingly turn to large-scale satellite datasets that tell us how the land surface is responding to weather changes. When we use words like "region" we mean continent; when we talk about "fluxes" we mean vertical exchange of carbon dioxide, water or heat. I have been steeped in this world for 23 years.

The models are reasonably precise in their portrayal of the interface between the land and the atmosphere. However, they're somewhat blinkered. So far, they have not included detailed descriptions of the 37% of the Earth's surface outside of the ice sheets that is covered by the imprint of humanity: agriculture (11% crops and 26% pasture). This area is represented as natural grassland, but the models exclude land management (Figure 1a).

Meanwhile, a group of land-use



Variations in the modelled Net Primary Productivity (NPP) in Mesoamerica and northern South America based on the observed (Static) vegetation and the natural or potential (TRIFFID) vegetation.
Credit: JULES model (version 3, see; JULES.JCHMR.org) driven by WATCH forcing data (see Weedon G P *et al.* 2011).

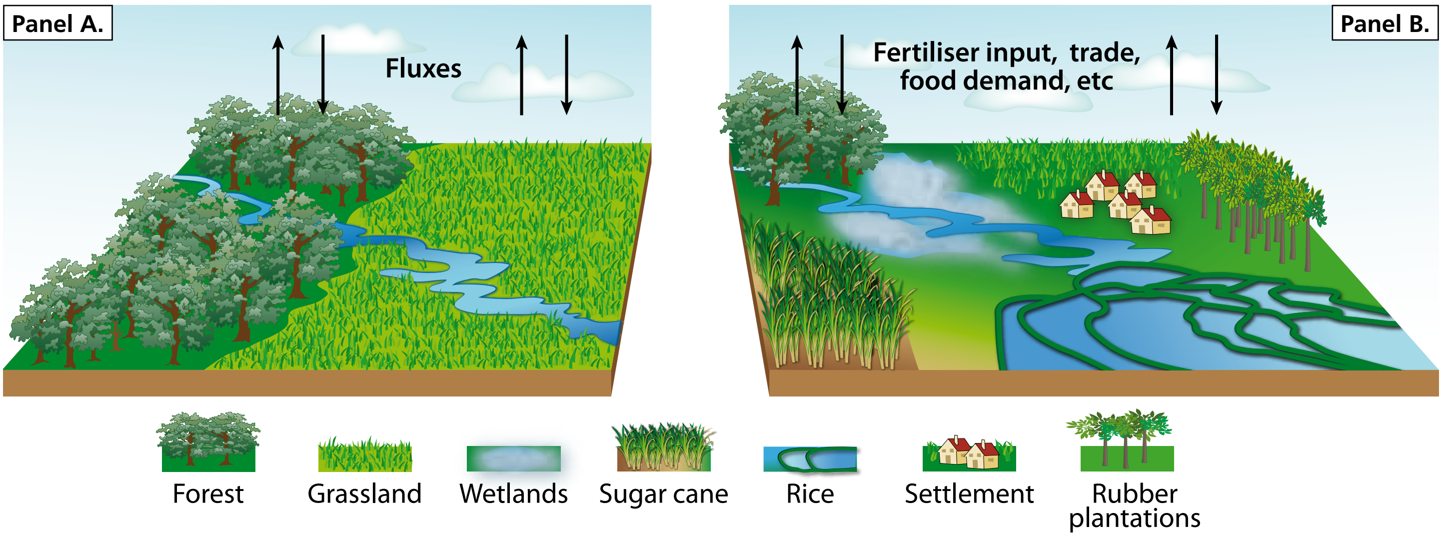


Figure 1. Simple or complex? Panel A shows a relatively simple, natural landscape as conceptualised by land-surface modellers. Panel B shows a more complex, human-dominated landscape as conceptualised by the land-use modellers. Exploring the interaction of the human food footprint with climate change will rely on combining these perspectives.

modellers study agricultural land in great detail. Their models include harvesting, sowing, tillage, fertiliser application, crop types and, most importantly, yield (Figure 1b). These models are run at the global scale and incorporate things like population demands for food and fuel and world trade of these commodities. With a 30% increase in population within 30 years looking likely, land-use change associated with food and fuel production will be a substantial player in global change. Clearly, Earth-system models must include current and future land-use.

And then there is the ecology and biodiversity community, which reminds us that the "forests" and "grasslands" of land-surface models are in fact complex admixtures of plants. This complexity may influence how vegetation affects and is affected by climate (see model outputs on page 25). It may also influence the services that ecosystems provide, for example food, carbon sequestration, etc. As recent modelling of the response of forests to climate change shows, the differences in how plant physiological processes are represented contributed most to the uncertainty in the model projections (Huntingford *et al.* 2013). No wonder, then, that this community spends considerable effort in characterising plant traits such as morphology, physiology and biochemistry in great detail.

The many meanings of "reduction"

Plain English: The amount by which something is lessened or diminished.

Biology: The first meiotic division.

Chemistry: A decrease in positive valence or an increase in negative valence by the gaining of electrons or reaction in which hydrogen is combined with a compound or a reaction in which oxygen is removed from a compound.

Mathematics: The cancelling of common factors in the numerator and denominator of a fraction or the converting of a fraction to its decimal equivalent or the converting of an expression or equation to its simplest form.

Learning to communicate

Facilitating the emergence of a new paradigm in modelling requires that we get these various groups talking, if not singing. We've started negotiating the languages, the scale of the modelling and the level of detail to insert into models. But many challenges remain.

For instance, land-surface models often include only five types of vegetation for the entire natural world. This includes only one "type" of broad-leaf tree to characterise the Amazon rainforest as well as temperate forests of trees such as oak, beech and aspen. In contrast, crop models include ten times as many crop types. This mismatch is cultural and scientific. The discrepancy between the two approaches lies in what the model is trying to achieve: predictions about which crop to grow or understanding how land-cover affects atmospheric circulations. The former requires more detail than the latter, but ultimately we want to bring the two together to explore the interaction of the human food footprint with the changes in the climate.

We're making progress. Recent projects (for example, LUCID; Pitman *et al.* 2009) brought together a suite of modellers to bridge the gap and identify issues when including agriculture into land-surface models. Meanwhile, it is likely that the new-generation land-surface models will include more ecologically realistic plant types, for example by using the Plant Trait Database that has been collated under the "TRY" project co-sponsored by IGBP (http://www.try-db.org/TryWeb/About.php). Then we will be able to better understand the footprint of humans on the climate system.

Understanding the role of

biodiversity on the climate system is the subject of a new European-South-American project, The Role of Biodiversity in Climate Change Mitigation, or ROBIN (http://robinproject.info). As part of the project, I am investigating how to incorporate more biodiversity into JULES so that the world is not modelled as a series of monocultures. Once that has been done, we will use the model to study whether including a variety of species within a region makes a difference to any of its ecosystem services.

For instance, ecosystems with high biodiversity may sequester more carbon. A number of mechanisms have been mooted to explain this process. Cardinale *et al.* (2011) reviewed around 15 years of experiments on temperate grasslands and concluded that high-diversity ecosystems have higher productivity than the average across individual monocultures. But – and here is the vital point – the productivity of the polyculture rarely exceeds the productivity of the most productive species in the mixture. If these results were to scale up to real ecosystems, it would be fair to conclude that monoculture involving the most productive species achieves the greatest productivity. In the Arctic, too, scientists on the international ABACUS project (Arctic Biosphere-Atmosphere Coupling across multiple Scales) showed that the carbon sequestration was reduced at the location where plants physically overlap (Fletcher *et al.* 2009).

Nevertheless, some other studies do point to a stabilising effect of biodiversity and find an increase in community biomass. The question therefore remains: do forests with greater biodiversity sequester more carbon than monoculture forests? What is the mechanism? And could it be that highly diverse forests are more resilient to climate change (for example, to droughts)?

These seem like reasonable scientific questions, which will benefit from greater collaboration between the concerned communities. Ecologists and biodiversity scientists often use language and concepts that are qualitative (e.g. habitat quality). Land modellers of various types tend to favour quantitative language and concepts. Negotiating a common language and vocabulary to make the emerging paradigm a reality is the need of the hour.

The age of the music star

We at the ROBIN project held lofty ambitions about creating music stars. Words and definitions came first. The project settled on three types of biodiversity: species diversity, functional diversity and structural diversity. The first is the traditional definition: how many species are there (and this can include animals as well as plants)? The second is a modeller's perspective: is there variation in how the plants affect climate? And a final one from the Earth Observation community: what kind of diversity can we see from space? The idea is to bring these three definitions into one analysis framework, working at different scales and with different communities. The project also aims to bring the land-use modellers into the arena – which brings us back to the issues discussed above.

In November 2012, ROBIN held its second annual general meeting in Santa Cruz, Bolivia. Half the attendants were from European countries and the other half were from Latin America (Mexico, Guyana, Bolivia and Brazil). They ranged from modellers and Earth observers to field workers and social scientists. The language was mainly English but half the participants were more comfortable in Spanish. The issues ranged from carbon budgets to tree species in the tropical forests and the farming practices of the different regions. Having discussed at length how we include key elements of biodiversity in the JULES model, such as incorporating more than one type of broadleaf tree (especially those that are drought resistant), we then went on a trip into the jungle. We walked through the trees, smelling leaves, looking at special plants whose seeds land in the arms of other trees and who then send tendrils down to the soil to start a rooting system.

I staggered out of that forest singing the praises of these Darwinians: how could we possibly describe this incredible variety with even a few tens of thousands of lines of computer code? Despite the challenges, I believe we will find harmony. Some processes can be described more simply than we do at present. The future will teach us that we are not all that different after all. I intend to enjoy every step of the way along this very diverse path. ▮

Despite the challenges, I believe we will find harmony.

ELEANOR BLYTH is a land-surface modeller at the Centre for Ecology and Hydrology, Oxfordshire, United Kingdom. E-mail: emb@ceh.ac.uk

REFERENCES

Cardinale B J *et al.* (2011) *American Journal of Botany* 98: 572-592.

Fletcher B J *et al.* (2009) *Oecologia*, doi: 10.1007/s00442-009-1532-5.

Harte J (2002) *Physics Today* 55: 29, doi: 10.1063/1.1522164.

Huntingford *et al.* (2013) *Nature Geoscience*, doi:10.1038/ngeo1741.

Pitman A J *et al.* (2009) *Geophysical Research Letters* 36: L14814, doi:10.1029/2009GL039076.

Weedon G P *et al.* (2011) *Journal of Hydrometeorology* 12: 823-848.