Fluttering leaves in the Amazon rainforest, snowdrifts on the Arctic tundra, and moist soil in sub-Saharan subtly influence the global weather system. How? Land surface modeller **Eleanor Blyth** has the answers.

Small change

Go on to Google Earth, find a spot of land and slowly drill down. You find the most extraordinary things happen to the patterns on your computer screen. They start out very familiar: continents and large land masses such as the Sahara desert and the Amazon rainforest are clearly defined. Then the patterns become more abstract. In the Arctic regions, swirls of wetlands, dry areas and vegetation all interweave like some natural paisley pattern. If you could bore right down to the plant level you would see different patterns again: trees with leaves held out to the sky or mosses and lichens adapted to live in harsh environments where nothing else will grow.

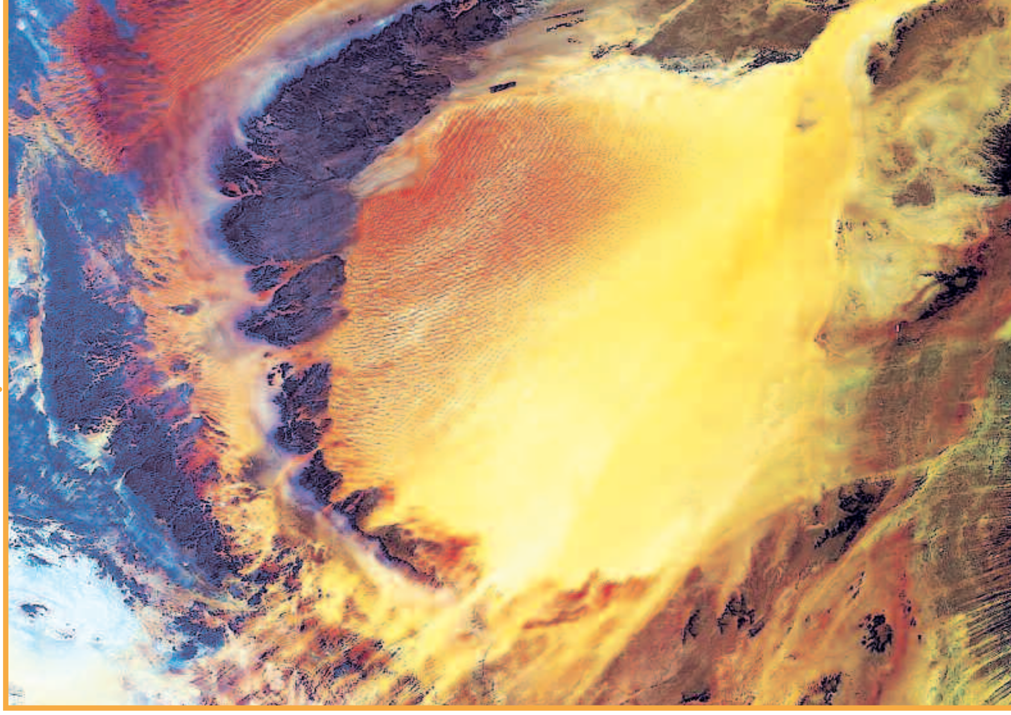
This order and beauty on such a range of levels suggests many connections at different scales with one scale subtly altering another. The processes and flows of water and vegetation across the landscape usually occur at scales of just a few tens of centimetres such as the flow of water through the soil, or the growth of a leaf. But there are physical, biological and chemical feedbacks on these processes at all scales. There is a physical feedback in the way sunlight increases evaporation, filling the air with moisture. As the air reaches saturation point evaporation is suppressed. In very dry regions of the world, there is a biological feedback where the plants protect themselves from drying out: to limit evaporation if the air gets to dry, they close their stomata.

This multi-scale, multi-process view informs the relatively new discipline of Earth system science. NERC and its research centres have an enviable worldwide reputation in this nascent field. Researchers at the Centre for Ecology & Hydrology (CEH) and the Climate and Land-Surface Systems Interaction Centre (CLASSIC), have discovered that unexpected, small processes at one level, say with the position of leaves on a tree, influence much larger changes on a global scale.

A meeting of minds

In the past it seemed that there were two types of environmental scientist: one who worked at the large scale, solving physics equations and predicting the climate and so on, and one who worked at the small scale, who went out and measured what happened to a leaf in the canopy of a tree, and, except in some notable cases, these two types of scientist largely ignored each other. Now both sides are learning to listen a bit harder. It turns out that they are both important, not only to the environment, but to each other. The more we look, the more we find how soils and plants at the small-scale are closely bound to weather and climate at the large-scale. Not just that soils and plants need rainfall, but also that rain clouds gather above moist soil.

At CEH in Wallingford, we work on



South-western Libya from space.

three key areas of the world: the Amazon, the Sahel in sub-Saharan Africa, and the Arctic. I am going to show how these regions all display this interdependency between small and large scale processes.

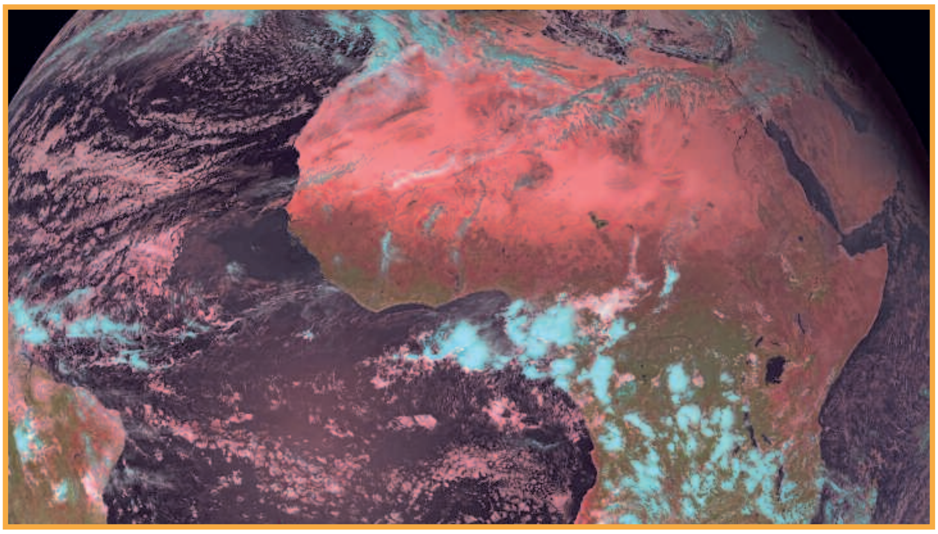
The lungs of the world

The Amazon rainforest has often been referred to as the lungs of the world. Actually, luckily, they work opposite to our lungs by taking in carbon dioxide and giving out oxygen, turning the carbon bit back into wood and leaves. Plants all over the globe do a great job of combating greenhouse gas increases in the atmosphere, removing half of our fossil fuel emissions. But the question is: can they keep up with the increase in carbon dioxide?

We use a computer model of the world to approach an answer to this question. In the UK we usually use the Met Office's General Circulation Model. We need to ensure that the plants in the computer model act like real plants. The computer plant model has leaves, roots and soil as well as water, energy and carbon. It photosynthesises. We knew for a long time that the model behaved a bit like real life, but something was not quite right. Then came the revelation: you can't get the computer model plant to work properly unless you include the shading of the leaves at the bottom of the tree by the leaves at the top. It turns out that the way the canopy absorbs sunlight, and the way this absorption changes throughout the day, penetrating deeper and deeper into the tree as the sun rises in the sky, is crucial – the tree doesn't just act like a flat plate. Once you put this detail into the model the global carbon balance falls into place. Well, it's a big improvement at least.

This revelation came about through diligent research in the rainforest, alongside detailed modelling studies. Our projects in the Amazon started in the 1980s and ran through to the 1990s with two big studies, the Amazonian Regional Micrometeorological Experiment, and the Anglo-Brazilian Regional Climate Observation Experiment. A third major project, the Large-scale Biosphere-

> "The more we look, the more we find how soils and plants are closely bound to weather and climate.



Atmosphere Experiment in Amazonia, is now running and the CLASSIC team are also looking at modelling this phenomena.

Of course, if you get the global carbon balance right, then you can run the model to try and predict the future climate. Unfortunately, some models predict that the Amazon will dry out and the rainforest may disappear. So the large-scale feeds back onto those trees in a direct way.

Climate engine

If the Amazon is the lung of the world, the Sahel is the engine of the world – or at least the engine of the weather systems. Much of the big weather systems develop here, like the hurricanes that sweep across the Atlantic. This is because a huge amount of energy from the sun hits the planet in the region. But unlike the Sahara, the Sahel is flush with water which can be pumped up into the atmosphere, driving weather systems.

In Wallingford we have spent decades studying the importance of the land surface to these weather systems, and how the energy and water cycle interact in this region. The spring issue of *Planet Earth* highlighted the latest research, the African Monsoon Multi-disciplinary Analysis, which will improve forecasting in the region. According to the small-affects-big theory I am proposing, very small processes affect these big weather systems. But how is that possible?

From work we completed in the 1990s in the Sahel it was clear that the soil properties in this region were exceptional. The soil drains much faster than we have found in other parts of the world. This is due to the structure of the soils. This speed of drainage means that water does not stay on the surface exposed to the atmosphere for very long. Within a day or so after rainfall the water has disappeared deep underground. The soils are exceptionally quick draining due to the underlying geology. Once we understood this process, and added the quick drainage to the model, the timing of subsequent rainfall changed: the rain occurred a month later than previous predictions. Crucially, this was more in line with observations. And downpours came in afternoons rather than at night, also in line with observations. So, once again, small scale soil moisture processes make a difference to the large scale processes, and needless to say the large scale process, the rainfall, changes soil moisture.

The cooling plate

For the final example of the small-to-large interaction, we're going to travel to the Arctic. We've had the lungs and an engine room. The Arctic acts more like a cooling plate.

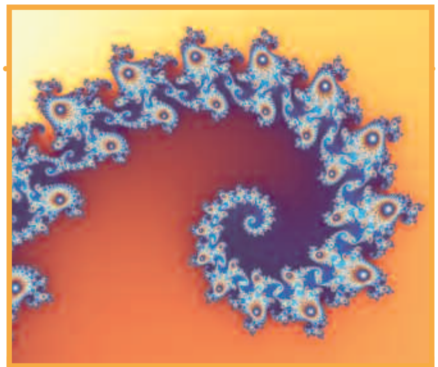
Snow completely covers the Arctic region every winter. Snow-covered land reflects nearly two thirds (70 percent) of the heat from the sun back out to space, helping keep the planet cool. At first glance, we can solve the effect of this cooling plate using our knowledge of physics alone: if we cover our model with a cooling white surface in the polar regions and program in the Earth's energy budget – how much heat comes in from the sun and how much leaves – we should get the observed heat balance. But the model based on general laws of physics on the large scale got it wrong until we included a small-scale detail about the structure of the trees. Snow falls down through the canopy on to the ground below. From space, the snow-covered landscape looks dark when you have trees so no longer cools the planet. This means that the existence or not of trees in the Arctic is important at the global scale.

In the Arctic there is a distinct line of latitude south of which trees dominate and north of which grasses and mosses dominate. It's like the tree line up a mountain side. Due to global warming that tree line is moving northwards because the trees can survive at higher latitudes. This means the area that cools the planet is shrinking.

The final part of the story, which is still a mystery, is another example of where small-scale ecology has a big influence. Although we know forests are migrating northwards, it seems to be happening more slowly than the theories predict. We are testing an intriguing possibility. It is very windy and dry in the Arctic winter and the snow rarely stays where it lands. Massive snowdrifts accumulate at forest edges. These snowdrifts take a long time to melt and effectively stop the spring from arriving by many months. It is possible that the snowdrifts are preventing saplings moving north away from the forest edge.

So where will our work take us next? An International Polar Year project called ABACUS (Arctic Biosphere Atmosphere Coupling at Multiple Scales) and the CLASSIC centre will see if this theory stands up to closer scrutiny. In the next few years both groups will try to quantify the interconnectedness across scales – the combination of complexity at the small scale and feedbacks with the large scale.

The importance of the small scale to the large scale is similar to two recent ideas given much airing in the press. In Chaos theory, small simple processes, repeated over and over, produce large scale structures of incredible complexity, for example, the famous Mandelbrot Set. Biologists have also found that complex structures like DNA are made from repeating simple units. James Lovelock's Gaia hypothesis, which describes how life on Earth depends on negative feedbacks in the system, such as the maintenance of stable global concentrations of oxygen and carbon dioxide by living organisms, sounds like the examples I have described. But what we are finding is subtly different from either of those theories. The combinations of the small scale to the large, with the feedback from the large to the small, makes the world interconnected. ❖



Eleanor Blyth is a land surface modeller at the Centre for Ecology & Hydrology, Wallingford, Oxfordshire. Tel: 01491 692463, email: emb@ceh.ac.uk

More information

www.abacus-ipy.org
www.ceh.org
http://classic.nerc.ac.uk
The Joint UK Land Environment Simulator represents the land surface in climate models (www.jchmr.org/jules).