of an appropriate promoter (Fig. 1d).

Mascré and colleagues' work sheds light on the heterogeneity of the proliferative cell populations in mouse epidermis, and has increased our understanding of stem-cell biology. But does this knowledge apply to human tissues? Caution is required when inferring aspects of human tissue physiology from animal data. For instance, clonal analyses of several human squamous epithelia (tissues such as the epidermis, cornea and conjunctiva) have unambiguously shown the existence of self-renewing cells endowed with stem-cell properties, as well as non-self-renewing cells with differing capacities for multiplication, including canonical transient amplifying cells[8,9]. Both cell types participate in the regeneration of these epithelia in the clinic[10]. ■

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ENVIRONMENTAL SCIENCE

The rainforest's water pump

An investigation of naturally occurring water recycling in rainforests finally marries the results of global climate models with observations. Alarmingly, it also suggests that deforestation can greatly reduce tropical rainfall. SEE LETTER P.282

LUIZ E. O. C. ARAGÃO

The humid tropics contain more than 35% of global forests, covering an area of 11,564,000 square kilometres (ref. 1). Tropical trees can extract deep soil water and pump it back to the atmosphere through a process called evapotranspiration. As a result, 25–56% of the rainfall in these regions can be recycled within the ecosystem[2]. Large-scale climate models indicate that this mechanism — which maintains atmospheric moisture and so feeds far-inland regions with rainfall — may be weakened by the removal of existing tropical forests[3,4]. Yet, paradoxically, an increase in local rainfall over deforested areas has been observed[5].

On page 282 of this issue, Spracklen *et al.*[6] report an analysis of tropical rainfall that combines models of atmospheric transport with satellite observations of rainfall and vegetation cover*. The authors conclude that, for more than 60% of pan-tropical land (that is, the tropics across all continents), air masses that have travelled over extensive vegetated surfaces can generate at least twice as much rainfall as air masses that have flowed over deforested lands. On the basis of their findings, the authors predict a potentially widespread reduction of rainfall in the Amazon basin, if deforestation in the region were to continue at the rate[7] that occurred from 1997 to 2002.

Sustaining high rates of global human-population growth requires an increase in farmable land, energy and timber supplies. Without adequate planning, these needs tend to be met by cutting down rainforests. Because ecological processes and human activities (such as agriculture) depend on water provision, scientists have, for at least two decades, investigated the impact of tropical deforestation on the hydrological cycle, especially in Amazonia.

Pioneering studies[3,4] using global climate models (GCMs) found that vegetation removal can disrupt the water cycle. For example, models show that changes in land surface characteristics cause a reduction in evapotranspiration rates and so induce basin-wide decreases in Amazonian rainfall[3]. Another simulation shows that removing around 40% of the original forest cover could drive Amazonia into an irreversible, drier climate mode[8].

These findings, however, are at odds with observations. Studies indicate that rainfall over deforested areas is, in fact, higher than in adjacent forests[5]. This is because increased surface heating in deforested areas induces upward air motion, reducing air pressure and drawing moist air from neighbouring forests into the openings. The moist air rises, and so generates

*This article and the paper under discussion[6] were published online on 5 September 2012.

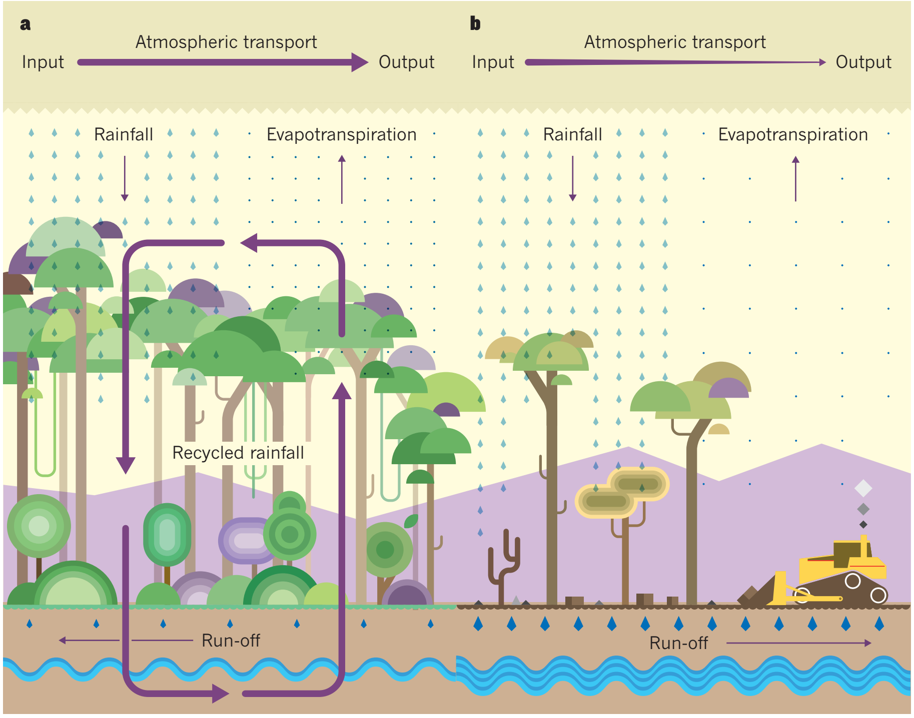

Figure 1 | Effect of deforestation on rainfall in the tropics. **a**, Much of the rainfall over tropical forests comes from water vapour that is carried by the atmosphere from elsewhere. But a large component is 'recycled' rain — water that is pumped by trees from soil into the atmosphere through a process called evapotranspiration[2]. Water exits from forests either as run-off into streams and rivers, or as evapotranspirated vapour that is carried away by the atmosphere. The atmospheric transport of water vapour into the forest is balanced by the exit of water in the form of vapour and run-off. **b**, Spracklen and colleagues' analysis[6] suggests that deforestation reduces evapotranspiration and so inhibits water recycling. This decreases the amount of moisture carried away by the atmosphere, reducing rainfall in regions to which the moisture is transported. Decreasing evapotranspiration may also increase localized run-off and raise river levels.

convective rainfall over the openings.

The problem for scientists is that models and observations capture processes at different scales, and so are not directly comparable. But with deforestation rates reaching 50,000 square kilometres per year (an area approximately the size of England) in the humid tropics[1], resolving this issue is crucial for strategically planning the conservation of tropical biomes and for maintaining the well-being of human populations.

Enter Spracklen *et al.*, who have beautifully reconciled the scale of observations with that of models. Specifically, for each 1° × 1° grid-cell across the pan-tropics, the authors have quantified the amount of rainfall generated by air masses that travelled over areas of varying leaf area index (LAI, the amount of leaf area per square metre of ground). The authors combined satellite observations of LAI and rainfall with the outputs of an atmospheric-transport model, which they used to estimate the trajectories of air masses in the 10 days before they arrived at each grid location. This analysis highlighted a clear connection between rainfall and the cumulative amount of LAI over which air masses travelled: for air masses exposed to low-to-medium vegetation cover, there is a nonlinear increase of 0.3 to 0.4 millimetres per day of rainfall for every additional LAI unit, with a subsequent saturation of rainfall over densely vegetated surfaces.

Contrary to previous observations, Spracklen and colleagues' results corroborate the large-scale rainfall-driving mechanisms described by GCMs. Simply put, densely vegetated surfaces recycle water efficiently through evapotranspiration (which averages around 3–4 millimetres per day in Amazonian forests[9]), maintaining the specific humidity of the air masses over these regions (Fig. 1a). Air travelling over sparsely vegetated surfaces, however, loses moisture during continental transport because of reduced water recycling (Fig. 1b). Using a scenario of Amazonian deforestation[7] for 2050 that assumes that the environmental policies of the early 2000s are continued into the future, the authors go on to demonstrate that forest loss is likely to reduce basin-wide rainfall by 12% during wet seasons, and by 21% during dry seasons.

The projected decline in rainfall caused by deforestation in eastern and southern Amazonia (see Fig. 4 of the paper[6]) overlaps regions that, according to GCMs, already have a high probability of increased drought frequency by the end of this century, assuming that global temperature rises by about 3 °C (ref. 10). The potential ecological and economic impacts of this overlap could be huge. Changes in regional climate could exacerbate drought-related tree mortality, which in turn would reduce carbon stocks, increase fire risk and lower biodiversity[11]. Such changes might also directly threaten agriculture, which generates US$15 billion per year in Amazonia[12], and the hydropower industry, which supplies 65% of Brazil's electricity[13]. Society should therefore take urgent action now, to curb tropical deforestation and avert future environmental problems.

That said, Brazil is committed by its National Plan on Climate Change to limit historical deforestation rates by 80% by the year 2020 (ref. 14), and so the scenario used by Spracklen *et al.* for their prediction is likely to overestimate the extent and magnitude of rainfall reduction in the mid-twenty-first century. An explicit consideration of temporal changes in atmospheric circulation and vegetation characteristics is also needed to refine projections of rainfall. And to provide an independent test of the patterns proposed by Spracklen *et al.*, current pan-tropical rainfall trends should be quantified.

Nevertheless, the authors have presented the first observational assessment of the influence of vegetation on tropical rainfall patterns at a spatial resolution and coverage compatible with the outputs of GCMs. Their cutting-edge methodology will allow observations to be used consistently to examine large-scale deforestation impacts on rainfall, and to refine and evaluate current models to support conservation planning in the tropics. ■

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