

ecologist and meteorologist
Yadvinder Malhi



YADVINDER MALHI has been a Royal Society University Research Fellow in the School of Geosciences, University of Edinburgh, since 1999. He read natural sciences at Cambridge, specialising in physics, and took a doctorate in meteorology at Reading. A brief stint on the science journal *Nature* was followed by his move to Edinburgh in 1995.

His research interests focus on how tropical ecosystems are responding to global climate change. Will trees grow larger and absorb some of the extra carbon dioxide humans are generating, for example? Investigating this takes him most often to South America – mainly Peru, Brazil, Bolivia and Ecuador. He is particularly interested in combining a range of observations – including micrometeorology, traditional forestry methodology, satellite remote sensing and global atmospheric measurements – to build up a detailed picture of the exchanges between the forests and the atmosphere.

His diary moves between two field trips and the pressures of life back home, not least those of getting married.

Sunday 6 January 2002, flying to California

The first big trip of the year and I am numbed by a long flight, lost baggage, a missed connection and an enforced overnight stay in Houston. I'm on my way to a workshop on climate change in tropical cloud forests. The other workshop participants are North and South American scientists from a variety of fields, with expertise encompassing botany, ecology, climate and weather modelling, prehistoric pollen analysis and satellite image analysis. Until now most of my work has been on the lowland tropical rainforests, particularly Amazonia. This meeting offers the exciting prospect of shifting attention to new types of ecosystem. The special feature of cloud forests, which grow at high altitudes in mountainous regions, is that the growing plants get their



water directly from condensation from the clouds. The flight provides a chance to read up on them.

Wednesday 9 January, Santa Barbara

We are planning research for the next few years and today all our ideas begin to come together. The most exciting moment is a presentation of satellite images of the southern Andes and people speak up, sharing their in-field experience of different areas. Suddenly our proposed study becomes real and as we scan images of vast, remote forests and spectacular mountains, our adrenalin levels rise. We finally select a study site: the 'Inca Wall' near Cuzco, Peru, where the Andes tower up from lowland Amazon rainforest. This is where we will tackle the question of what will happen to cloud forests. For the next hour I stand up and begin to flesh out for everyone the details of what we will measure and how and where. Nobody has any funding for this work yet, but we return to our offices with semi-crystallised plans, warm relations with new collaborators and the inspiration to apply for the money.

Sunday 13 January, Arizona

A short flight to Phoenix, Arizona, to visit a colleague who is spending six months working at Biosphere II (Biosphere I is the 'real' global biosphere, the Earth). This is an amazing place. Perched on a mountain in the Sonora desert,



it was developed ten years ago by a Texas billionaire to be a perfectly self-enclosed ecosystem. Within the giant greenhouse structure, there is a sealed-off rainforest area, an ocean with coral reefs and a beach, a mangrove swamp, a savanna and a desert. For a few years a team of ten 'bionauts' tried to live inside, totally cut off from the outside world. It wasn't viable; ecosystem science is still too complex and poorly understood, so five years ago it was redesignated as an ecosystem research station to examine the effects of climate change. Originally my visit was intended as an opportunistic peek but it turns out that the scientists here are keen to build research contacts with people working with real ecosystems. After a two-hour tour of the structure, we are ushered into a formal meeting. We describe our research interests and plans, and to my delight we negotiate a salary for my research student Emiliano for one year's work on an experiment on artificial drought in the rainforest.

Tuesday 15 January, Quito, Ecuador

Straight from red Arizona desert to green Ecuador. A blazing morning, with the equatorial sun shooting up towards the zenith. I sit on the hostel balcony, looking out over a ramshackle street, a mishmash of colonial-style houses and concrete blocks. To my left, the forest-clad slopes of a volcano tower above the city. Over recent years we have amassed evidence that even the remotest and most pristine forests are being altered by atmospheric change and we are looking for the clinching data. We locate plots in undisturbed forests that

were sampled 10–20 years ago and re-measure tree biomass, tree species composition and soil and leaf properties. This Ecuador expedition explores some of the wettest forests of Amazonia, nested up against the Andes where the humid trade winds slam into the wall of mountains and, like a squeezed sponge, shed their water as torrential rain.

The expedition will last for six weeks but I am here for only a week – to ensure that this expedition fits in with the wider pan-Amazonian design. And I also have the self-appointed task of ensuring that the right relationships develop with the right people in Ecuador in order to steer the initial planning decisions.

Wednesday 16 January

A bright blue Quito morning as we get ready for our flight into the Amazon Basin. The team packs at sunrise in a mood of sleepy-eyed excitement. The journey is stunning. First we plunge off the side of Quito into a deep valley, then climb up to the continental divide. The high pass, at a breathless altitude of 4,000 m, is ringed by snow-capped volcano-gods – Cotopaxi, Antisuyu, Cayembe – and covered in the bizarre grasslands of the paramo ecosystem. We descend through cloud forest into dry valleys partially deforested by settlement and up again into the clouds through the nearest range of mountains. This is the first barrier encountered by the rain-laden air of the Amazon and there is a noticeable change in humidity. The cloud forest stretches out over the apparently endless cloud-decked ridges of the Andes. In front, lowland Amazonia beckons, an almost unbroken expanse of wild forest continuing thousands of miles across the continent.

The field station at Jatun Sacha is basic but well-designed. It sits in a relatively small area of protected forest in a region that has been densely settled by Quechua highlanders. We are assigned our jungle cabins – there are ten of us, from Ecuador, Colombia, Brazil, Peru, Germany and the UK. We eat dinner, drink cachaça (Brazilian sugar cane rum), laugh, talk about plans for the morning and longer-term ideas. Now, while the others are asleep, I sit and write these notes amidst the flickering shadow-dance of the moths. The forest is full of insect song. Orion blazes overhead in the pitch-black sky.

Thursday 17 January

In the morning we mark out old forest plots in a floodplain and a dry-land forest, delighting in seeing armadillos, squirrel monkeys, giant millipedes, ground turkeys. In the afternoon I hike with Pedro, a likeable local Quechua

guide, up and down trails to find a remote plot. The forest gradually soaks into my skull and I feel healthier and more centred than I have during the whole British winter. It's hard to explain. Something to do with being part of a world ancient and mysterious and feeling it in your skin and senses, not just in your intellect. I wish that Rachel, my fiancée, were here to share this.

Sunday 20 January

I go home tomorrow but the expedition continues for another six weeks. Despite exhaustion, the field team drags itself out for a farewell drink at a nearby shack-bar. The bar turns out to be closed, but no one minds the effort. We laugh our way home beneath a crescent moon peeking out between the tall silhouettes of the forest trees, the air heavy with the fragrance of white ginger flowers.

Tuesday 22 January

After a week of forest isolation, I connect back into the global mind while changing planes in New York. The talk is of war: it rumbles on in Afghanistan and may move to Iraq; the Israel–Palestine tragedy continues and there is the threat of nuclear war over Kashmir. Much of my wider family lives a few miles from the India–Pakistan border. The big world and its tragedies confront me. Returning home means facing an enormous backlog of tasks. I have to submit a paper on 'Carbon in the Biosphere and Atmosphere in the 21st Century' to a special issue of *Philosophical Transactions of the Royal Society* by the end of next week. Then there are long-delayed revisions to another paper and two reviews to deal with, all of which should have been finalised months ago.

Wednesday 23 January, London

I stay with my parents overnight and download 300 emails. After the simplicity of the forest, life here just seems so complicated. I feel disoriented and daunted. Funny, after so many years of tropical fieldwork, I can still be hit by culture shock. Flying back to Edinburgh tomorrow.

Tuesday 29 January, Edinburgh

I'm trying to slip back into the rhythms of a normal working week. Lingering jet-lag leaves me groggy in the mornings and awake at midnight. The paper writing requires steady, continuous effort so I am trying to alternate between

one hour on this and one on other tasks. In the mornings I am too easily distracted but by mid-afternoon the mental juices are flowing and I am writing well. Still, I realise that I won't finish by the end of the month and so request another week's grace from the editor.

Wednesday 6 February

The carpet of anarchy that had crept across my office over the past month seems to be slowly retreating.

Friday 8 February

I stay in until 8 pm to nail and finally submit the paper. It is later than I planned but it is good to reach the weekend with the satisfaction of a completed task. Looking through it one last time I spot many errors but am quite surprised at how much I like the final manuscript.

Sunday 10 February, London

The days are lengthening and there are the first hints of spring. My wedding draws nearer. I feel very close to Rachel, as we struggle with some difficult decisions. Today is a very significant day. We go to Southall and meet up with my mum and sister to look for an Indian wedding suit. We're staying the night at my aunt and uncle's, the first time that Rachel has met anybody beyond my immediate family. They've taken warmly to her. I haven't been in Southall for ages and enjoy being back in Little Punjab. As I wander through the streets, I can't help wondering how much of Punjab I will be leaving behind, how much I have already left behind and how much ever belonged to me in the first place.

Friday 15 February, Edinburgh

I feel content with the world and bike in early to work. I spend half an hour browsing this week's new issue of *Science* on the web. There are some interesting articles on the effects of volcanoes on climate and why biodiversity is higher in the tropics but my eye is also caught by some articles on the emergence of art in Africa 70,000 years ago, much earlier than previously supposed, and another on ecosystems around deep-ocean volcanic vents. Reading across this breadth of subject matter invigorates me. It makes me feel part of a bigger, global enterprise: the human discovery of what this universe is all about.

Sunday 17 February

A fun weekend with Rachel. A mixture of theatre, parties, swimming and running in the bright sunshine, doing various household tasks and sending off wedding invitations. As the wedding approaches, I feel more prepared to enjoy it.

Saturday 23 February

It takes a few weeks after returning from fieldwork before people realise that I am back and the emails keep flooding in, with little tasks that need to be done and requests for help. I've reached that point now. When there are so many things to do, one of the main challenges is to maintain a common thread that gives me a sense of achievement and progress. Otherwise I just feel as if I'm treading water. What have been the major activities this week?

1. Revising a paper that describes the rationale and goals of our forest expeditions. I need to put in more on the uncertainties and the methodologies. I have invited my friend and colleague Jim to work up part of this analysis and it has been fun sharing my office with him for a couple of days.
 2. Preparing a contribution to a private US initiative to set up 50 long-term monitoring stations in tropical ecosystems worldwide. I really have no time to do this, but the potential is immense. We could be influential in deciding what gets measured in these tropical forests and then be involved in analysing the data coming in from them for years to come.
 3. Our students from Brazil are emailing me with problems that have arisen in the analysis of some data. Helping them make sense of it always requires careful thought.
 4. The Ecuador team has returned from the field. The expedition was largely a success (they managed to sample seven sites in one of the most fertile regions of the Amazon, an invaluable addition to our dataset) and I feel proud of them. Another post-doc, Simon, has sent in a brief report from his fieldwork in Nigeria. His trip sounds difficult, even epic. The challenge in Nigeria is finding forest plots that have not been logged over. So much of West Africa's forest has been trashed.
 5. On Wednesday I give a lecture on global change to final-year undergraduates. I don't do this often but enjoy their intelligent questions.
- I've also felt inclined to do a bit of wide-ranging exploratory reading this week, about life as information processing, about information theory, about whether plants show intelligent behaviour and about the bizarre life found on ocean

vents deep within the earth or at the bottom of Antarctic lakes. I'm not sure whether this will help me in any obvious way in my own work but I feel my subconscious is burrowing away at an idea. Can the theory of information help us understand biodiversity?

Thursday 28 February

So many things to do. I wonder if I upset people by not replying to all the emails I receive? Not replying regularly every day is the only strategy I can use in order to leave some space for creative thinking.

Sunday 3 March, Budapest

I'm at a conference for the European project that funds our work. After the conference dinner I work on preparing my presentation. Rather than recycling old Powerpoint slides, I decide to work up all the recent data from our expeditions to Peru, Bolivia and Ecuador. I reckon it will only take an hour but as the graphs begin to appear before my eyes, I become increasingly fascinated. At site after site, the same results emerge. In mature forests tree growth should be roughly balanced by tree death, with no net increase. Our data shows that almost every forest plot is increasing in biomass. This is what we've been looking for but I am amazed to see such a clear signal. It is a moment of discovery. Intrigued, I work until 4 am, which guarantees that I will be bleary-eyed for the morning sessions. But it's worth it.

Tuesday 2 April, Edinburgh

Tim sends the biomass results from the recent Ecuador expedition. Again, every plot we've measured shows an increase in biomass over the past five years. It is astonishing that we find the same pattern almost everywhere we go. I still can't quite believe it.

Wednesday 3 April

We have a paper published today in *Ecological Applications*. It analyses the uncertainties in measuring the sizes of tropical trees and how this affects our estimates about how much carbon is being absorbed by tropical forests. About seventeen months ago we made a heroic effort writing this paper. But by the time it is published I am so busy with other things there is hardly a moment to celebrate. The paper passes into the world unheralded. It is only over the years as people read it and respond to it – or not – that its significance will be judged.

Friday 5 April

At work until 10 pm. My student Barbara is writing up her PhD thesis while working in a new job in Rome. She is finding it a lonely struggle and in my busyness I have been negligent in sending comments back on her draft chapters. She has sent a blunt email this morning and I feel a pang of guilt.

Wednesday 10 April, London

The day of the legal wedding. Rachel and I are married and, after all the nerves, it feels beautiful. The ceremony itself is fantastic, warm, intimate. Once you accept that your life has changed, that you live as two not as one, you just soak in the intense new sensation.

Sunday 14 April, Cambridge

So much has happened over the wedding weekend that if I wrote down all the details they would fill a book. There has been music, chaos, dear old friends, relatives from far away, the elegance of Cambridge, memories from India, nervousness, last-minute crises, and love.

Sunday 21 April, Belize

A little honeymoon paradise. But today I need to dip back into work. I must find out if my latest research grant bid has been successful (submitted to the UK Natural Environment Research Council last December). The proposal is to set up a transect of study sites in Bolivia, from wet rainforest to dry forest to savanna, with the aim of understanding how tropical vegetation may respond to possible future drought. A lot hangs on this; the referees' comments have been positive and I am nervously excited.

Right: time to check the email.

Well, now I know. The grading was high enough but we just missed the limit of the money they had available. I feel disappointed, all the more so because it was so close. The saddest thing is that getting this core project would have triggered so much more auxiliary work: a Spanish post-doc working on tropical fires, security for our Brazilian PhD student, links with other groups. All this has to be put on hold and maybe cancelled. The Brazilian PhD may not survive the delay. So much work for no reward.

Wednesday 1 May, Edinburgh

The week is taken up with a three-week backlog of emails, while at the same

time preparing for the field trip to Brazil next week. My feet barely touch the ground.

Friday 3 May, en route to Brazil

Rachel's great-aunt, the former Labour minister Barbara Castle, died today, hours before I was scheduled to leave for Brazil. It has been a difficult decision to go. At the field sites in Brazil researchers have gathered and are relying on me to bring critical equipment and fix broken instrumentation. But my wife needs me to support her in this week of sadness. For once, I go to Brazil with an uneasy heart.

Sunday 5 May

So I am back in Brazil, my most regular research base, for three weeks. We have an ongoing project studying the carbon and water cycles of the rainforest and coastal mangroves, and observing the effects of drought by keeping the rain off a hectare of rainforest. In contrast to the pan-Amazon expeditions, this is hi-tech, equipment-intensive science. The first week will be spent at the rainforest in Caxiuanã, with subsequent weeks on an intensive research campaign in the mangroves. We arrive at the Caxiuanã field station and are met by a speedboat that glides us through the mirror-still waters. The evening sunlight splashes across sky and water. All seems complete. The world is disappearing, the forest and sky are slowly seducing me again. I chat with my colleague Patrick about the project, about grant money. Our funds are running out. So much is working beautifully here that to stop it now, just when the scientific returns are flooding in, would be madness. We are overspending our grant in the hope that future funding may bail us out. Not the wisest way to work, but our priority is getting the scientific results.

Tuesday 7 May

This is about my tenth trip to Caxiuanã. Why do I keep working here? Considering the amount of time I have put in, I have had very few scientific publications in my name associated with the site. I think one major factor is a sense of loyalty and commitment to the dear friends I work with. The other factor is probably just the special beauty of the place.

Friday 10 May, Belém

A day wandering about the city buying items for tomorrow's trip to the

mangrove research site. A lot of time is spent looking for someone to make frames for sensors to measure the precision growth of trees. We wander through the sweltering shanty towns of Belém from metalworker to metalworker, until finally we find a steely-eyed man who is able to do the work.

Sunday 12 May, Ajuruteua Beach

For the mangrove campaign all ten of us will be lodged in a shack on an Atlantic beach. This is a nice option in the right season, but today is a windy grey morning of continuous rain. Two of the party struggle in the gale to fill a tank with seawater to measure how much carbon is coming out of it. In the afternoon I potter around with some new sensors, with the aim of using them to measure the daily growth and shrinkage of the sea trees to an astonishing 0.001 mm precision. It is one of my happiest ways of spending a day: opening a box with new instruments, learning from scratch how they work, puzzling over manuals, then testing the equipment out on a tree. On each trip I like to try out something new to add a new strand to the fieldwork.

We paddle by canoe along a sea channel to reach our instrument tower, which is about to be flooded by the tide pulled by the new moon. The equipment is broken but not beyond repair. We work until dusk and then paddle back.

Monday 13 May

The last few days have been hard work but satisfying, with a fair dose of both comedy and frustration. Most of all there has been the magic of discovery – of measuring and seeing what we find. There is the chance of our getting to feel the ecosystem, of watching clouds come and go, the ocean rushing in and flooding the mangrove, the litter of the mangrove washing out and scattering on the beach. The scientific instruments are like extra eyes on the rhythms and processes of nature at work, so that you can see carbon dioxide gushing out of the roots, being sucked in by the leaves, see trees shrinking in the day as water is pulled up to the leaves, see them growing by minuscule fractions of a millimetre every day, see the water trickling up their stems.

Friday 17 May

The team is thinning out. We are all tired, but there is good humour and our spirits are still high. As the moon slips from new to first quarter, the tides are dying down and the mangroves are no longer flooded by the ocean.



I love this connection between the swing of the moon and the cycles of the mangrove – it combines my passions for astronomy and ecology.

There is disappointment when we arrive at our instrument tower. Despite my best attempts last night I did not react soon enough after one of a series of power cuts to stop the carbon dioxide flux equipment from keeling over. I feel frustrated and spend ten minutes in silence at the top of the tower, staring at the horizon, overcoming my disappointment and pondering what to do next.

Tuesday 21 May

Last day in the mangroves and everything is finally working perfectly, with the Zen of the perfect humming tower on a sunny afternoon. Numbers and knowledge flow silently from bark to wire to datalogger.

Saturday 15 June, Edinburgh

This week is taken up with a visit from Simon and Tim, post-docs on our tropical biomass change-project based in Leeds. They have collated vast amounts of data from the tropical forests and now is the time for synthesis. We have amassed so much evidence to show that undisturbed tropical forests are increasing in biomass and changing in composition. The most likely cause is the global increase in carbon dioxide levels. In addition, we are finding regional variations in the biomass and the structure of forests. All we need to



do now is work out ways of scaling up from our measurements at individual sites in order to understand how whole regions behave, and to see how well our study sites represent the range of climate and soils found in Amazonia. I am still astonished at our results. We concentrate on comparing the field expedition results with climate and soil data to understand how representative they are. We work hard, live off takeaways and beer, catch the World Cup over breakfast and generally exhaust ourselves.

Wednesday 7 August

That big story, the issue that will shape my work over the coming year, is evidence from our trans-Amazon and African expeditions, evidence that indicates with greater certainty that tropical forests are increasing in biomass and both growing and dying faster. There are still uncertainties to deal with but I now believe that we are seeing major alterations in apparently pristine ecosystems that are driven by atmospheric change. The long-term implications for these ecosystems are, as yet, unknown. Over the next six months I will collate papers on this topic from a variety of scientists into a special journal issue and possibly into a book.

What is more, this work has aroused the attention of the major Conservation International project to monitor tropical ecosystem change in 50 sites. We are giving them advice based on our field experience and will perhaps be helping them with the first few plots. It seems that tropical ecosystems will finally get the consistent long-term monitoring that they need in this time of global change.