Hart

The clouds aren't far up. Not at this altitude, at this location. I stand outside the Organization for Tropical Studies' Las Alturas Biological Station, at the foot of Cerro Chai, a rounded-pyramidal peak on the western flank of the Cordillera Talamanca. The lowest clouds slide downhill fast, frayed and fragile fabrics merging and diverging, sinuous and complex. Directly above them, a more resolute, steadfast stratum of thick grayish-white puffs slides quickly but steadily upslope, flouncing the supposedly prevalent northeasterly tradewinds. And then far up, an even deck of bright white pleasant clouds, a soft mosaic delineated by the blue backdrop of the sky, as though lifted from distant prairies most serene and superimposed on the atmospheric chaos of these mountains.

It's nearing 2:00 p.m., the hesitant end of my post-fieldwork siesta. I should get back inside, back to work. I've got a fresh crop of plants that need sorting, measuring, tissue collection, and processing. They're not the species I came here hoping to study (everything always changes once the boots hit the soil...), but they're the ones that I have managed to collect. And I've got to get the rest of my work done before the sun sets – without electricity here, my day's activity is orchestrated by the arc of the sun.

I was sent down here to painstakingly measure the minutiae of plant leaves, not to watch the clouds. But field time, and the observations and experience I gain from it, are precious. And watching the formation and movement of these clouds is essential to understanding the life of the plants in the forest that so intimately depends on them. Indeed, the forest is named for them. Tropical montane cloud forest, which spends so much of its time in the cool, moist embrace of the clouds, could exist nowhere else. And as the global environment changes and the atmosphere warms, forced by the frenzied humdrum and stuffy exhaust of humanity, it becomes increasingly uncertain if can even continue to exist here.

By this hour, the second deck of clouds is thickening downward as it slides up and over the mountain, engulfing Cerro Chai's picture-perfect peak. Chai frequently has its head in the clouds. A hike along the trail that threads up its western face brings one to what seems like clear evidence of this: a sudden transition from a tall, dark montane rainforest to a shorter, gnarly, epiphyte-laden oak forest, laid upon its peak like a mossy doily. A hike down the road instead provides confirmation: A stunning view of Chai, rising over the pastures and their lonely cows, its top shrouded in a gray mushroom cap of cloud that casts an ominous shadow upon its slopes.

Chai is by no means unique in its complicated dealings with the atmosphere. In fact, forest like that found on Chai's upper slopes, so often bathed in thick cloud, is a characteristic occurrence in tropical mountains worldwide. In the tropics, where everything seems perpetually wet, the air is no exception. Solar radiation is intense; proximity to the equator means that the midday sun is never far from overhead, and its rays strike the ground head-on, imparting maximal energy. Temperatures are consistently high, and in all but the driest tropical regions the growing-season party never ends. So day in, day out, warm seas lose surface water as vapor, and plants suck up water but inevitably lose some of it to the sky when they open their leaf pores (stomata) to gather carbon dioxide for their photosynthetic alchemy. All this water, continually released into the balmy air, is borne hither and tither on the prevalent winds. In most cases, these are the easterly tradewinds that incessantly caress the tropical belt. But in places like Cerro Chai, downwind of a barrier so tall that even the persistent trades fail to traverse them beneath the imposing ceiling of the so-called tradewind inversion (a warm, worldwide blanket of air sinking and sliding slowly equatorward from the high atmospheric reaches of the middle latitudes), local prevalent winds can differ dramatically in direction, or can even be replaced by the chaotic cross-section of eddies I'm watching overhead.

Blow whence and where it may, a wayfaring “parcel” of warm, moist tropical air will continue to live its life unimpeded – bubbling into the quiescent cumulus clouds of landscape paintings, occasionally burgeoning into the awesome, leaden cumulonimbus that are the cells of the thunderstorms for which the tropics are famous. That is, unless topography intervenes. Where tropical hills and mountains get in the way, a parcel flowing across the land has nowhere else to go but up. As it rises over the earth's contours, our parcel is increasingly released from the oppressive burden of so much more of its kind being constantly pulled down onto it from above by the eternal brute force of gravity – the atmospheric pressure drops. In accord with this drop in external pressure, the moist parcel expands, and its internal energy, the combined frenetic motion of its billions of billions of air molecules, is spread over a wider and wider space. If the mountains are tall enough, the parcel will continue to slide upslope and thus further into the atmosphere. Its molecules become less and less crowded, relax, and slow down. This cools the parcel to such a point where, if the mountain's slope continues to climb, further upward motion will bring it across the dew point, the temperature rubicon beyond which the water-vapor molecules (the selfsame that escaped from the sea or from the leaves far, far below) will begin to coalesce and condense onto the surface of even the slightest motes of cloud dust. The vapor becomes liquid water, and suddenly, as through a microscopic atmospheric metamorphosis, the parcel is a cloud.

Clouds formed by this process, which results from the interaction between the lower atmosphere and the mountains, are thus called *orographic* – a term used as a general descriptor for anything mountain-related, but offering the pleasant etymological image of “mountain-written clouds”. Orographic clouds form worldwide, and in a variety of environments, but it is in the tropics, with its heat and moisture aplenty, where they are most widespread. And it is here also where their effects on the life below are most pronounced. For wherever they form in the tropics, orographic clouds drift up slopes and up and over isolated peaks, immersing the forests they encounter along the way. The water that clouds are made of is not raindrops, but rather drop*lets*, which are so light that even the slightest updraft can keep them aloft. But when they blow through a forest, swirling erratically through the dense matrix of vegetation, many droplets collide with the surfaces of leaves and stems and bark, and adhere. Droplet by droplet, this cloud mist contributes to the water budget of the forest in the form of what is often called “occult precipitation” – it is effectively hidden from traditional rain gauges, designed as they are to catch water whose major vector of movement is vertical, because it is falling under the influence of gravity).

Cloud forests receive a considerable additional fraction of their annual budget of precipitation in the form of such occult precipitation. This water can be critical for the survival of the plants that live here, especially in seasonal cloud forests, which can experience prolonged periods in which occult precipitation is the only kind they'll see. Over the long reach of evolutionary time, many plants have adapted to take advantage of this distinct and dependable source of water. Thus far, nearly all cloud-forest species studied have some ability to take up water across the surfaces of their wetted leaves, in direct contradiction of the received wisdom that water flows from soil to roots to stem to leaves. And a great number of plants have abandoned the ground entirely, taking up residence in the crooks or on the surfaces of tree branches, where they capture fleeting pulses of cloud water when available, then hunker down and wait out the dry spells in between. These plants, called epiphytes, form the "hanging gardens" for which cloud forests are so famous, and in the wettest sites they can be so ubiquitous that one can hardly differentiate the leaves of the trees themselves from everything else growing on them.

Orographic cloud immersion is not only the defining characteristic of cloud forests, but it is essential for the survival of the astoundingly diverse nature living there. For this reason it is quite worrisome that we believe that human activity may be altering this process. Both deforestation upwind and global climate change can alter the average heat and moisture content of air parcels that blow into cloud forest, tweaking important variables in the calculus of cloud microphysics, yielding an increase in the average height at which a parcel becomes a cloud. The net result is the continual uplift of the base height of the clouds, and thus of the special forest climate they provide. So as the clouds recede upward, the cloud forests are expected to follow them, into ever higher and smaller land areas. From a conservation standpoint, this is a red flag, because many cloud forests are home to a startling number of plants and critters that are endemic – found only in one small part of the world – and many probably depend on the unique climate of the cloud forest for their survival. In fact, tropical mountains are believed to be the engines of evolution behind the staggering biodiversity of the tropics, serving as highly complex and climatically diverse landscapes that easily isolate populations, driving their genetic divergence and speciation. Additionally, given that cloud forest is only found in mountains, its distribution (its geometrical arrangement on the earth's surface) is archipelagic – it occurs in strands and scatters of habitat islands that demarcate the cloud-shrouded tropical altitudes of the world. Thus cloud forests are climatically unique, extremely biodiverse, and spatially limited and isolated – a sure recipe for conservation concern. Indeed, they are often considered among the most sensitive ecosystems to climate change, and the likely response of cloud-forest species to this threat is a question on many folks' minds.

As an initial step in pursuit of this question, I am studying how certain species of cloud forest epiphytes are adapted to local climates. My focal species are all in the plant family Bromeliaceae, subfamily Tillandsioideae. In other words, they are relatives of the pineapple (indeed, they look like clumps of warped pineapple tops stuck onto the trees), and within the pineapple family they are part of a long lineage of predominantly epiphytic species. There are many species of bromeliad epiphytes, and this is thought to be due to their historic adaptations to other challenging habitats – waterlogged, nutrient-poor soils lent strong advantage to the ancient bromeliad ancestors that could trap water and detritus amongst their overlapped leaves and then absorb their nutrients directly from that homebrew compost tea directly through the leaf surfaces. Such adaptations made bromeliads quite well preadapted to an epiphytic lifestyle, easing the stress of their evolutionary departure from the ground.

Current-day bromeliad epiphytes continue to absorb their water and nutrients directly into their leaves, through the tiny leaf-hairs, or *trichomes*, that have evolved into one-way valves, hoarding water when it's plentiful, conserving it when it's scarce. Indeed, their roots are no more than anchors, holding them fast to their perches. Some bromeliad epiphyte species still trap water amongst their overlapped leaves, and thus are frequently referred to as “tank” species. Others, commonly called “atmospherics”, have taken another strategy entirely, featuring denser and larger trichomes to maximize the amount of water taken up when available, and an extreme ability to tolerate dryness in the interim.

In my research, I am collecting individuals of my species at different sites across a range of elevations and local climates, and then comparing across these sites the sizes and densities of the trichomes and stomata, the two microscopic leaf structures that together determine the water balance of these plants. On the basis of previous ecophysiological studies comparing between various bromeliad species, I have constructed a series of hypotheses about how these measures will relate to climate and elevation within a given species. The results of my tests will suggest the means by which a single species might adapt to a variety of climatic conditions, and thus how that same species might be expected to respond to climate change.

[NO RESULTS YET, BUT WILL CUT DOWN UPPER SECTION AND DISCUSS RESULTS HERE]

This study is but a small drop in a very large bucket, a focused and particular assessment. But it is just the first of many steps to come. My time and experiences this summer have convinced me that an understanding of the climatic and biological diversity of tropical mountains is essential to the study of tropical species' evolution (how species have arisen in the past), distribution (where they live now and why), and conservation (their likely responses to future climate).

The natural world, like the swirling cloud above me, is chaotic yet deeply ordered. Science is the most powerful tool we have for piercing the chaos, revealing the order. But it can of course only work one question at a time. A frustrating fact given the wealth of questions that swirl and slide through my mind, turbulent but orderly, mirroring the above. The curiosity is tantalizing. The tedium of its pursuit, banal. The world is the grandest of dramas, yet the living it often the most menial of affairs.

But live we must. I turn and walk into the house, to spend my afternoon and evening painstakingly shaving leaves with an penknife and then painting them with nail polish. It occurs to me to ask how exactly I wound up here... But then immediately after it occurs to me: Scientists must always simultaneously attend the hyper-particular and the most general. So perhaps I am doing just fine by keeping my feet on the ground and my head in the clouds.