And then came the rain

Weather and climate models struggle to represent the climate of West Africa. **Doug Parker** believes that a massive international project, the African Monsoon Multidisciplinary Analysis, will address this, and much more.

As a meteorologist coordinating an investigation into the West African monsoon, I was given a lot of stick from my colleagues for forgetting to take a raincoat on our main field expedition. But luckily for me, I only got soaked on one occasion. In fact, 'monsoon' is the name for a wind, and the West African monsoon is the south-westerly wind which develops in the summer months, bringing moisture from the tropical Atlantic to feed the rainfall of a number of countries in sub-Saharan Africa.

I was in Africa to manage the UK contribution to the African Monsoon Multidisciplinary Analysis (AMMA). The philosophy behind AMMA is to connect the many scientific areas which are concerned with the West African monsoon, but are constrained by the absence of effective monitoring systems in the region. For instance, atmospheric experiments have in the past been hampered by a lack of measurements on the land and ocean, whereas experiments on the ground, concerning hydrology, agriculture and vegetation, and even disease dynamics, have always been restricted by poor atmospheric measurements. In Africa, all of these environmental and socio-economic systems are very closely connected. AMMA's goal is to measure and analyse them in a joined-up way. In the UK this is reflected in the partnership between two NERC centres – the Centre for Ecology & Hydrology (CEH) and the National Centre for Atmospheric Science (NCAS) – and the Met Office. Around the world, there are more than 1000 people in over 60 research institutes involved in some 28 countries, while during the summer of 2006 there were six research aircraft, three ships and an estimated 1000 ground-based sensors deployed in the field. It has been a big task.

West Africa is an exciting area scientifically for many reasons. It exhibits, in quite a small continental sub-region, many of the basic systems which control the tropical environment, over a range of surface types, from desert through savannah and forest to the Guinea coast and the Atlantic Ocean. Across this diverse tropical surface march some of the most intense weather systems on the planet. In winter, the harmattan winds from the desert bring dense dust storms; in the summer monsoon season, cumulonimbus storms regularly produce convective towers which punch 20 kilometres upwards into the atmosphere, and low-level winds in these storms can reach 100 knots. This exciting climate raises many difficulties if you plan to install monitoring equipment in the field – measurement systems have to withstand temperature ranges from about 15 to 60°C, the ravages of some of the most intense storms on Earth, and the attentions of a variety of hungry insects and larger creatures.

Weather and climate prediction models have systematic errors in representing the climate of West Africa, and really this is not surprising. It is probably the part of the world which is the hardest for models to deal with, due to the strong contrasts in the land surface, and the prevalence of very unpredictable thunderstorm systems and atmospheric dust from the Sahara. For this reason, scientists have described the area as a 'natural laboratory' for climate processes, and there is some feeling that if we can ever get it right for West Africa, other parts of the world will automatically benefit.

Setting up new networks

In basic terms, the tropics is a region where the surface heating of the atmosphere is very strong. For this reason measuring and predicting the rates of heating are critically important, but due to the many logistical and financial difficulties in Africa, nobody has made such comprehensive measurements before. AMMA-UK, through the team from CEH, has led the way in setting up a network of surface energy balance stations, from the forested coastal zone up to the margins of the Sahara. These systems tell us how the surface and atmosphere respond to rainfall over hours, days, and the whole season. They also show the influence of dust storms and upper level clouds on the surface heating. In order to measure the behaviour of weather systems, AMMA has rejuvenated the West African 'radiosonde' network, in which balloon-borne sensors float into the atmosphere and send measurements down to ground stations. A relatively small international investment has activated a much larger commitment of resources from the African meteorological services. We released about 7000 radiosondes from 23 stations in the region from the beginning of June to the end of September. At around £140 each, and involving a staff of more than 200 African observers and technicians, this has been one of the biggest sub-programmes of AMMA. During 2006, seven research aircraft including the NERC/Met Office BAe146 flew down to join the project. Flights with the aircraft have given us snapshots of the same parameters, but with very much more detail.

The team released about 7000 meteorological balloons across West Africa.

Willi Dolder / Still Pictures

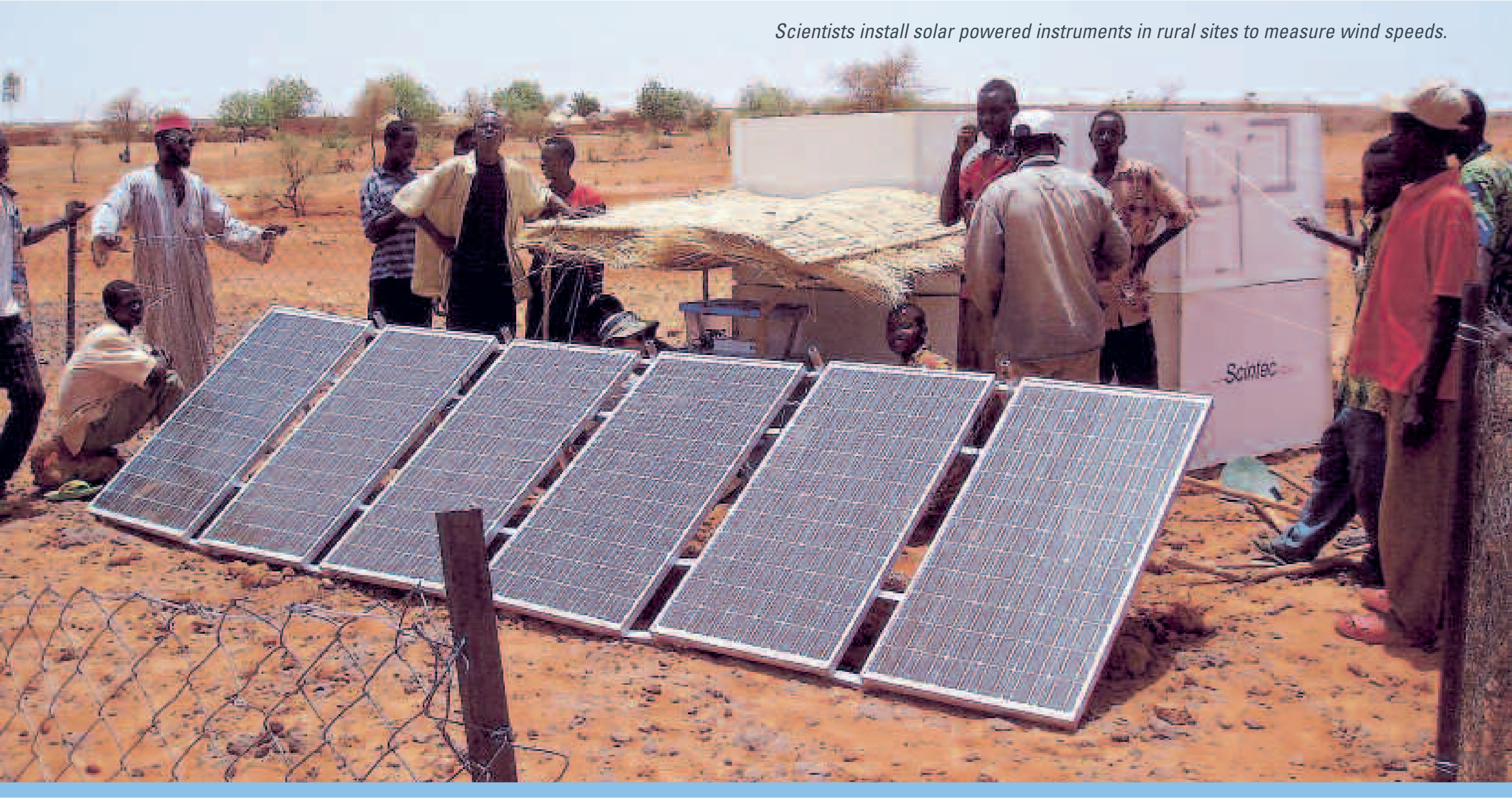
> "We have found that there are two monsoons – daytime and night.

Soil moisture and storms

Over the summer, the UK team spent five weeks working with the BAe146, based out of Niamey, Niger. Much of our work was devoted to systematic flying along pre-determined tracks, to build up statistics on how the atmosphere and land system change over a period of time. We had planned to observe the responses of the land and atmosphere to thunderstorm systems – for instance, flying for several days after a big storm to see how the land, vegetation and atmosphere recover and regenerate. However, thunderstorms are unpredictable and develop rapidly, so there were numerous occasions when we found ourselves taking evasive action.

It's common folklore in the meteorological community that whenever a research aircraft arrives, there will be very unseasonal weather conditions.

* In fact, there are good scientific reasons why this might be. It has been argued for some years, notably by Chris Taylor from CEH, that the kinds of soil moisture patterns we were seeking can also be preferred regions for generating new rain-bearing storms. The air over wet soils builds up considerable humidity with which to feed storms, while the air over dry soils gets hot and tends to rise. When wet and dry surfaces are close together, these ingredients can initiate a storm.



Scientists install solar powered instruments in rural sites to measure wind speeds.

During some of our flights, matters were rather more immediate and dramatic, and we began to suspect that cumulonimbus storms were choosing to fire off right underneath us*. We labelled one such example 'the Mummy' (after the movie of the same name). The BAe146 went out (without me) looking for soil moisture patterns to the north of our base but soon found itself flying through heavy dust. The aircraft emerged through an intense gust front into clear air. Almost immediately, active thunderstorms began building up all around. Out of the chaos, the scientists and pilots managed to improvise a rational flight plan, and came back with fantastic data from the birth of one of the biggest storms on the planet. The storm persisted the next day building into a massive system several hundred kilometres across, which was sampled by a number of ground stations. I was waiting in the operations room when the scientists and aircrew returned – the scientists had big grins on their faces, and the pilots a look of bemusement.

Three days later we found ourselves even closer to a storm – in fact a storm which we had taken pains to avoid in the first place. Seeing the system advancing towards Niamey from the east overnight, we took off the following day planning a circuit around the system, sampling the 'before and after' states of the atmosphere, with the advantage that our precious research aircraft was not left exposed on the runway when the gale-force storm winds arrived. We had recently put considerable effort into reconstructing two of our ground sites wiped out by previous storms. Leaving take-off to the last minute, we flew along and ahead of the advancing storm at low levels. As the cumulonimbus clouds drew up the air around us, it became rich in insects from the tropical forest, which in turn attracted flocks of swallows, speeding around the cockpit (such is their agility that none were hit, even at combined speeds of over 200 knots). Our track converged with the storm, and after many minutes we entered the 'gust front' – the plane bucked in the turbulence, the temperature dropped, ozone levels shot up. Every scientific instrument on the aircraft flipped from one extreme to the other.

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These have been among the most exciting flights imaginable for a meteorologist – not only for the visual and physical stimulation of being within such massive storm systems, but also for the unique data we collected. We used sophisticated chemical tracers to observe the air entering the storm, which is laden with characteristic chemicals emitted from vegetation, then we flew to the rear of the storm to find out where the air went. The air emerging from the top of the storms is too high for most research aircraft to sample, but we were able to measure the composition of air at these altitudes through a collaboration with a European Union programme. The collaboration, including a team from the University of Cambridge, launched a series of large stratospheric balloons carrying a sophisticated payload of chemical and aerosol sensors. The group launched each balloon in the late afternoon, and as it ascended towards the stratosphere it would catch the sun and be visible from all over Niamey as a bright star in the evening sky. The payload would descend to Earth over a period of several hours, and a team from the Nigerien Army returned it to the laboratories for analysis.

Epidemic forecasting

Tracking the air motion in thunderstorms, and over the dry convective plumes above the desert, is just one of the many specific goals of AMMA. Scientists in the UK consortium want to link the state of the atmosphere to the land beneath. On small scales, what is happening in the lowest few metres of the atmosphere determines the air in which mosquitoes live and breed. Rainfall can drench a 10km radius while the surrounding areas remain bone dry. Over a wet surface, mosquitoes find themselves in a humid atmosphere in which they can survive longer. If the mosquitoes live longer, then the malarial parasites have more chance of maturing and passing to humans. Will it ever be possible to predict mosquito development, and their influence on malaria, over a region as broad as the Sahel, by understanding the weather systems? In AMMA, scientists from CEH and the University of Liverpool are making measurements which should help, including observations in a typical local hut, specially constructed in collaboration with French and Nigerien scientists.

Chemical movements

A central part of AMMA, led by Claire Reeves from the University of East Anglia, studied the composition of air moving from the West African region into the global climate system. We have been particularly interested in chemical movements of isoprene and oxides of nitrogen in the lowermost atmosphere. Isoprene, although quite short-lived during the day, is the most important naturally-produced source of reactive carbon, and therefore an important gas in the climate system. Emissions from the forested zones of West Africa represent one of the biggest global sources of this highly reactive chemical. Through airborne measurements made by the Universities of East Anglia and York, we found that daytime isoprene patterns were tightly linked to the underlying vegetation. Day after day, certain areas of forest emitted high levels of isoprene, which was (with its reaction products) concentrated in the air immediately above the forest. A suite of other chemical measurements made by scientists from the Universities of Leeds, Leicester and Manchester will help us explain how such emissions from Africa can influence the global atmospheric composition.

We conducted our flights in pairs; a day and a night flight. During the day, the hot surface causes rapid convection in the atmosphere. The convection also acts like a kind of viscosity, and makes it hard for the winds to pick up strength and move the isoprene horizontally. In contrast, our nocturnal measurements showed how isoprene and its products moved northwards towards the desert. As the surface cools down and the convection stops, the air is free to move horizontally. In the summer, this generally means that winds draw isoprene northwards into the Saharan heat low. To chemists this is exciting, because the winds take isoprene into another climatic and chemical regime – to a meteorologist it is an excellent tracer of the routes taken by moisture, which ultimately brings rain to the marginal climatic zone of the Sahel.

In a sense we have found that there are two monsoons – a daytime monsoon of light winds and very efficient mixing of the air vertically, and a night-time monsoon where the low-level winds can carry chemicals (and moisture) north towards the Sahara. The correct representation of these separate daytime and night-time processes in models are essential if we are ever to develop useful forecasting in this region.

In such a large and diverse programme, it is sometimes easy to lose sight of the enormous scope of the international activities – indeed there are many more projects linked to AMMA than I have space to mention here. It is fair to say that AMMA aims to study every aspect of the environment and climate of West Africa, from the dynamics and chemistry of thunderstorms through to study of climatic control of diseases; from the analysis of subsistence agriculture to how hurricanes develop in the tropical Atlantic. The programme contributes both to advancing climate science and reinforcing monitoring systems for the future. We expect AMMA to have a long legacy.

A laboratory imitates conditions in a typical local hut to improve disease forecasting.

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NERC is one of the three 'founding agencies' of this French initiative. The European Community's Sixth Framework Programme has financed many of the large-scale, coordinated activities and has contributed to the participation of 22 African research agencies; www.amma-international.org