Climate and Africa: Why the Land Goes Dry

Scientists are poring over the dry facts in hopes of comprehending Africa's drought and why it is so persistent

By STEFI WEISBURD and JANET RALOFF

First of two articles

Africa is a continent in trouble. While most news accounts have focused on the disease and starvation afflicting Ethiopia and Chad, these outbreaks of famine are merely regional symptoms of an extreme environmental duress that has been building for 20 years and that now ravages an area twice the size of the United States. Of the many environmental pressures plaguing some 45 sub-Saharan nations — including war, deforestation, farming on marginal lands, soil erosion and unsustainable rates of population growth — most experts consider a coast-to-coast drought along the Sahara Desert's southern border the most serious and intractable.

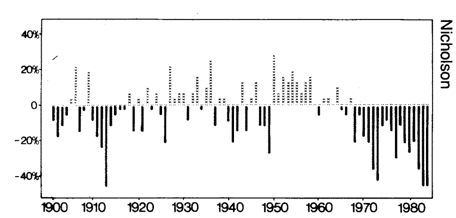
Overgrazing: Once they've eaten all the grass, goats take to the trees.

The drought began in 1968, after 10 years of remarkably and consistently high rainfall. It took more than a decade for both the affected populations and world meteorological community to recognize that this drought was not just a brief anomaly. Some scientists today believe a climate change has occurred that will last decades or longer.

Though there are regions in southeast Africa that are also experiencing drier times, the regions affected most are those normally semiarid states along the southern Sahara. This "trans-Sahelian" region spans not just the Sahel — a band of states running east from Mauritania, Gambia and Senegal to Chad — but also an eastward continuation of the band across the continent to Ethiopia and Somalia.

Droughts in this region are natural; the current episode is just one of three in this century. What makes it unusual, however, is its magnitude, its duration and the human suffering it has wrought. "The prevailing view, the orthodox view of meteorologists, is that this [drought] is a natural fluctuation which will right itself in due course," says meteorologist F. Kenneth Hare, provost of Trinity College at the University of Toronto. But a growing number of researchers suspect that changes in the land may also be contributing to regional changes in climate (SN: 2/23/85, p. 118). The big concern, Hare says, is that "we might therefore be looking at a permanent decrease in the rainfall, induced by human activity" — such as deforestation and overgrazing of farmland.

The exact causes of drought in the Sahel and the factors that make it persist are still open scientific questions. It will be some time before climate, as well as the extent to which humans influence it, is understood well enough to predict or plan for droughts. In the last 40 years, meteorologists have come to understand how weather behaves over about 10 days; only recently have they understood the physical processes that drive changes over months and seasons. According to Jagadish Shukla, director of the Center for Ocean-Atmosphere-Land Interactions at the University of Maryland in College Park, "We are much farther behind in understanding changes that take place over a period of a decade or longer."



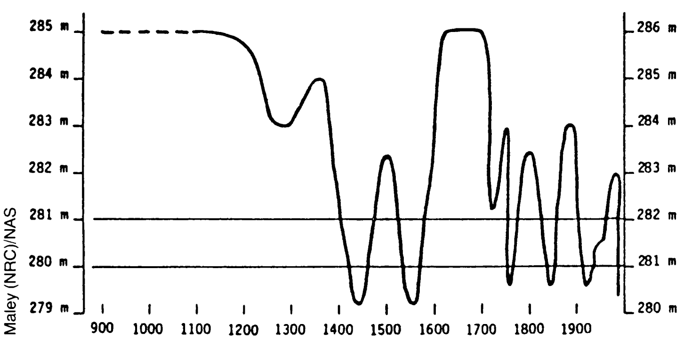
Annual rainfall in the Sahel has frequently departed from the mean over the last century. The present drought is one of many dry spells that have plagued the region.

The most predictable aspect of rainfall in Africa — especially in semiarid regions like the Sahel — is that it can vary widely in both space and time. Moving south from the top of the Sahel, toward the equator, rainfall stations only 100 kilometers apart can record precipitation differences of 100 millimeters in a single year; annual rainfall near the equator is 16 times that in the Sahel. And from year to year, rainfall at a single station may stray from mean values by 30 percent in the Sudan region (south of the Sahel), by 50 percent in the Sahel and by up to 100 percent in the lands along the southern Sahara border, says geographer Sharon Nicholson of Florida State University in Tallahassee.

Nicholson notes, for example, that Dakar, in the western Sudan, received 797 mm of rain yearly during a wet spell in the 1950s. In 1972 and 1983, annual precipitation there plummeted to 130 mm. That's like dropping from rainfall typical of the farm areas in Ohio and Indiana to that of deserts in the American Southwest, she says.

Unlike other parts of Africa, the Sahelian zone suffers from long — sometimes decades long — episodes of dry or wet conditions. (When the Sahel is dry, southern Africa tends to follow suit, although droughts in the Kalahari and southern Africa are not as intense or long lasting.) Though the present drought has lasted much longer than those of 1910 or 1940, historical and geological records suggest that there have been dry spells of similar duration and magnitude before — most recently between 1820 and 1840, Nicholson says. And though the last two centuries appear to have been drier overall than the two preceding them, geologic evidence, such as the record of Lake Chad's water levels, indicates that the climate of the region has swung between dry and wet conditions many times over the continent's history.

Annual rainfall measurements do not tell the whole story, however; the *timing* of the rain is also important. The Sahelian rainy season usually lasts four months, beginning in June. But according to



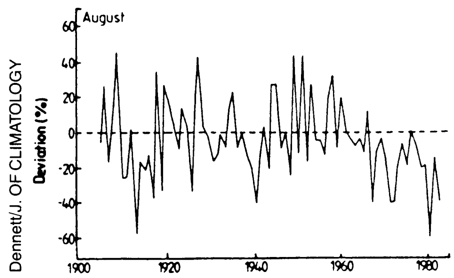
Over the last millennium, the water level of Lake Chad in the Sahel fluctuated dramatically, reflecting change in climate. Nicholson notes that the lake, which was almost filled in 1972, is now almost dry.

meteorologist Mike Dennett at the University of Reading in England, the amount of rainfall during August — the rainiest month — has been dropping, and has remained consistently below normal, for 17 years. In an upcoming paper in the Royal Meteorological Society's JOURNAL OF CLIMATOLOGY, Dennett and his colleagues will report that "the present dryness [in the Sahel] is due mainly to reduced rainfall in August, at the peak of the rainy season, rather than to differences in rainfall at the beginning or end of the rainy season." Moreover, Dennett says, "the situation isn't getting any better" — 1984 proved to be the driest year since 1941, when reliable records became available for his recording stations.

For agriculture, when it rains can be almost as important as how much it rains. And this explains in part why famine has occurred only intermittently during the last 17 years, despite consistently dry Augusts. Unless sufficient rain occurs in the early part of the crop cycle, seeds won't germinate early enough to allow plants the time to mature before the growing season is over. Dennett says it's when rainfall is below normal both at the beginning of the growing season and again in August that the harvests have been devastating enough to contribute to serious, widespread famine. That suggests early-season rain may be a predictor of the famine potential in any given drought year.

In looking for the cause of droughts, researchers focus on large, global-scale effects rather than local ones because the patterns of rainfall and dryness in Africa extend over vast regions. Most scientists believe the annual variation in Sahelian rainfall, for example, is rooted in natural quirks of complex and highly variable interactions between the atmosphere and oceans. But specific mechanisms — how winds, temperatures and barometric pressures combine to drive climate changes and rainfall patterns in Africa — are not well understood. Moreover, what *triggers* a drought may be a different beast from what *maintains* the drought for decades.

Researchers trying to understand what initiates drought must figure out the dynamics of complicated atmospheric systems that link climates on opposite sides of the globe. For example, winds carrying heat from the equator toward the poles will alter the air's temperature profile, which in turn will change wind patterns, and so forth. Even if conditions on land and in the oceans remained constant, there would be substantial and largely unpredictable natural fluctuations from year to year. Add in changing oceans and land, and the problem of unraveling a sequence of events leading to a drought gets to be very sticky.



August rainfall (shown as deviations from 1931-60 mean) recorded at 5 southern Sahelian stations. Post-1968 decline understates rain deficit farther north.

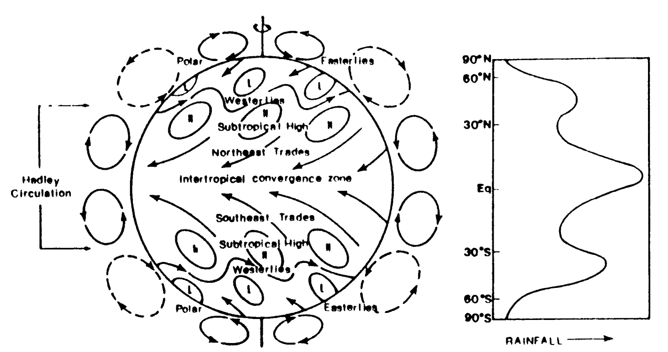
Among the indicators of change in oceanic and atmospheric circulation patterns are sea surface temperatures, sea level pressure patterns and changes in the winds that carry moisture-laden or dry air to the continent. Eugene Rasmusson, chief of diagnostics at the National Meteorological Center in Camp Springs, Md., says he and many other researchers are focusing on sea surface temperatures because there are better data available on the ocean than on the atmosphere, and because changes in the ocean tend to last longer than fluctuations in the atmosphere.

Rasmusson has found a statistical link between droughts in southeast Africa and El Niños, episodes of major warming of sea surface temperatures (SSTs) in the central equatorial Pacific, half a world away. Of 28 such warming episodes during the past 110 years, he says, 22 have accompanied below-normal rainfall in southern Africa. And of the 20 driest years before 1978, 12 coincided with El Niños. Since SST anomalies usually last several seasons and debut several months prior to the rainy season in southeast Africa, Rasmusson believes they hold promise for predicting droughts there. Although it has not yet been demonstrated, he also thinks that the rainfall patterns tend to reverse when Pacific sea surface temperatures are *below* normal.

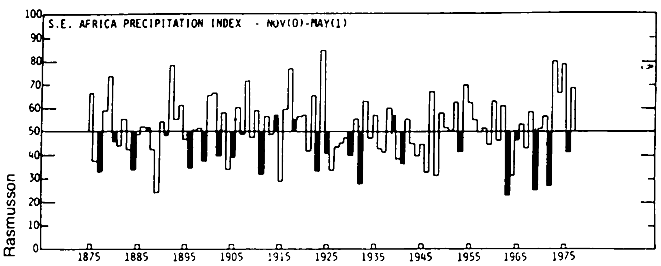
As for the western Sahel, Peter Lamb of the Illinois State Water Survey in Champaign and Janice Lough at the University of Arizona in Tucson believe there is a connection between drought conditions there and sea surface temperatures in the tropical Atlantic. Both noticed an unusual pattern appearing in 1949, 1968 and 1972 — especially dry years in the western Sahel. It consisted of colder-than-normal waters extending southwest in a belt from the west African coast to South America and the Caribbean, accompanied by warmer-than-normal waters to the south of this band.

This pattern, adds Rasmusson, was present and especially strong in 1984, changing temperatures in low latitudes of the Atlantic by as much as 2° C. Lough believes the pattern also occurred in the dry years of 1913 and 1921, although data from that period are not as reliable. Lamb and Lough's respective studies also showed that wet years were more likely when SST patterns were very different — almost the opposite of drought-year patterns.

Lamb suspects that the drought/SST pattern, which shifts the region of highest sea surface temperatures 300 km to the south, similarly shifts the so-called inter-



Winds and pressure systems over Africa. The intertropical convergence zone (ITCZ) near the equator marks the transition between the dry harmattan winds blowing over the Sahara and the moist southwesterly monsoon winds coming from the tropical Atlantic. During the northern hemisphere summer, the ITCZ moves north, bringing a short season of rainfall to the Sahel region. Later in the year it moves southward as a high-pressure cell ushers in the Sahelian dry season. Since the ITCZ is composed of many rapidly moving, intense small storms that are sensitive to slight disturbances in the atmospheric pressure field, rainfall can be highly variable.



Rasmusson

Rainfall data, shown as percentile rankings, from 16 stations in southeast Africa. Black bars indicate El Niño years, when the eastern equatorial Pacific surface waters were warmer than normal. Rasmusson, who found a link between El Niños and below-normal rainfall, notes that the 1982-83 El Niño was also accompanied by subnormal rainfall.

tropical convergence zone (ITCZ), where wind fields from the two hemispheres meet. This would then inhibit the northward movement of moisture-bearing monsoon winds into western Africa. Lough differs only in that she thinks the drought pattern and ITCZ movement are by-products of the same (much larger scale) atmospheric change, rather than one influencing the other.

Some researchers say the link between SSTs and droughts in the western Sahel is more tenuous than that for southern Africa. But even if the links for both regions were firmed up, they would still represent only one step in a complex chain of events and would reveal little about the physical processes that cause drought. Moreover, there remains the question of what drives droughts in *eastern* Africa, which includes Ethiopia. "It may be that the Ethiopian side is associated with some different configurations and processes," says Rasmusson. "But we really don't understand this at all."

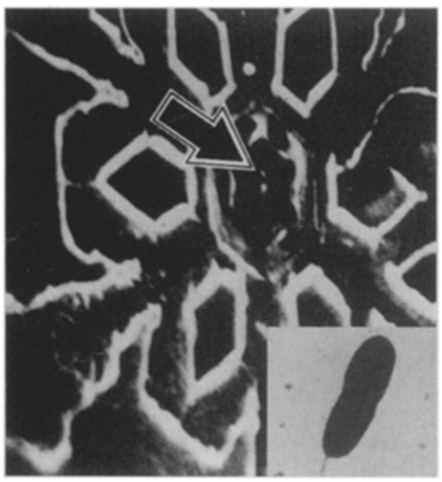
Though most research suggests it's unlikely that human-mediated land changes—such as deforestation and overgrazing of farmland — will initiate a drought, there is growing suspicion that they might be capable of prolonging one. In fact, the persistence of the current African rainfall deficit is fueling speculation that if such a drought-feedback system is at work there, drought may come to present the long-term climatic norm, at least for trans-Sahelian Africa.

Three basic mechanisms have been posited as factors that could create such a feedback: a reduction in the soil's water-holding capacity; changes in land surface reflectance; and removal of biogenic materials that permit ice formation in rain clouds. Though any of these mechanisms could occur in the absence of human activity, it is well established that endemic poverty and population pressures in the trans-Sahel are already fostering the type of land abuse that could initiate all three conditions.

At Britain's Meteorological Office in Bracknell, England, Peter Rowntree is studying the possible role soil moisture might have. Less soil moisture results in less evaporation, he explains, which means that more solar energy goes into heating the environment than into evaporating moisture. This contributes to a warming of air near the dry ground. Since warm air holds more moisture, its dew point, or the temperature at which water condenses, is therefore increased.

With less moisture returning to the air and a higher dew point, there will be less chance of rain. Dennett adds that the near-surface heating of air also tends to reduce the air's upward movement, itself a factor in reducing rainfall, since the water removed from the soil doesn't get a chance to climb high enough into the atmosphere to reach the cool temperatures where rain clouds form. And recent experiments run on the Meteorological Office's 11-layer general circulation (computer) model tend to confirm all this.

In a control experiment using the general circulation model, Rowntree looked at the rainfall that would be associated with soil moisture levels characteristic of well-vegetated land. To simulate Sahel conditions, the experiment was then rerun with only 6.6 percent as much soil moisture—a value Rowntree says "implies that essentially you have bare soil, or you only have vegetation with shallow roots." An experimental run calculated how rainfall would change over a nine-month period beginning in March.


Schnell

Ice-nucleating Pseudomonas syringae *bacterium (1 μm long) in ice crystal (arrow), and photomicrograph silhouette (inset).*

"We observed a rainfall decrease during northern summer — that's June, July and August — of about 1 mm a day," Rowntree says. "That's something like the observed decreases in rainfall that occurred over the last few years." While this doesn't *prove* that rainfall has been reduced in the Sahel because widespread overgrazing and devegetation have denuded the ground, and have thereby reduced the soil's ability to retain water, "I do think that is the suggestion," Rowntree told SCIENCE NEWS. Some type of feedback mechanism must be prolonging the dry period, he says, because the probability that this drought could sustain itself for 17 years purely by chance is roughly 1 chance in 130,000.

In addition to reducing a soil's ability to retain moisture, devegetation would be expected to increase the soil's reflectance of spectral energy, since a dry soil is not as black as a wet one. This energy reflectance, or albedo, would contribute to near-surface air heating and the further baking out of soil moisture. In experiments by a number of different researchers 10 years ago, computer models suggested rainfall would decrease over areas where albedo increased.

Robert Chervin, with the National Center for Atmospheric Research in Boulder, Colo., says his experiments showed that such albedo increases resulted in statistically significant reductions in rainfall for the affected region, and corresponding increases in rainfall in adjacent areas. The affected regions were thousands of kilometers in size, he says, "so we're not talking about city-block-size changes."

Though the Atlantic Ocean is the ultimate source of much of Africa's rain, Chervin points out that even in western Africa, local soil evaporation also contributes substantially to precipitation. And it is this evaporative component that could be affected by human activity.

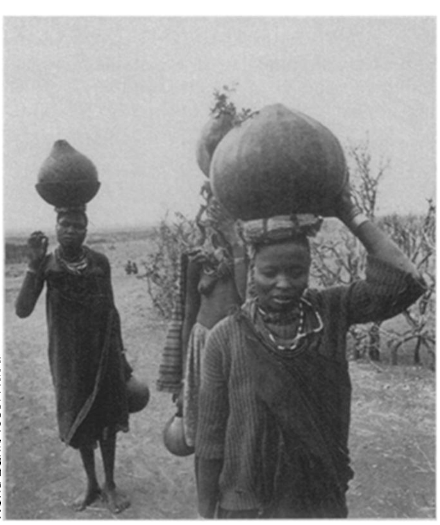
Rain—even in the driest desert—starts as ice crystals. But water will not freeze unless it contains the proper type of foreign particles to act as ice nuclei. For years people had assumed ice nuclei could be just about anything, such as dust. But research has shown "that 'clean' dust, without biological materials from plants or bacteria, was useless," explains Russell Schnell, an atmospheric scientist with the National Oceanic and Atmospheric Administration in Boulder.

Schnell discovered that nature produces the nuclei, in the form of lipoproteins contained in the coats of several species of bacteria that live on plants. They allow frost to form on unprotected crops. But more important, some of these bacteria also help plant matter to decay, and in doing so can shed the lipoproteins onto vegetative litter on the soil surface, making the organic litter itself into ideal ice nuclei. Schnell believes that by devegetating the Sahel — for firewood, crops and animal fodder — humans have eliminated the required food source for the particular bacteria needed to initiate the precipitation process in clouds above them. One result might be for the rains to start falling a little farther south, he says, "providing a self-feeding desert situation."

In field studies in the Sahel several years ago, Schnell found that as he got closer and closer to overgrazed areas, there were fewer and fewer ice nuclei in soil and vegetation. Moreover, he says, not only have experiments shown that these nuclei can be carried up from the ground and into clouds in a span of time as short as 20 minutes, "but we have also been able to put these things into clouds and make them rain." The rub, Schnell says, is that no one can yet conceive of a definitive experiment to prove that the removal of these biogenic ice nuclei are implicated in Africa's precipitation deficit by more than just coincidence.

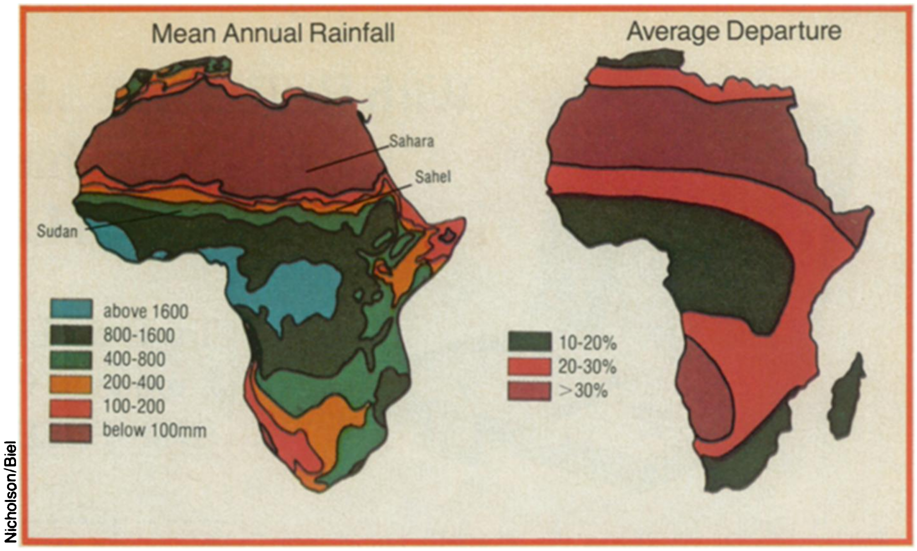
Plant pathologists David Sands and Al Scharen at Montana State University in Bozeman are among those currently investigating the bacteria-rainfall connection in Africa. Focusing on the needs of farmers in north Africa—Morocco, Tunisia and Egypt—they're trying to characterize which plants serve as the best hosts to these bacteria. Their goal is to identify "bioprecipitation support crops" that drought-afflicted farmers could use as a sort of ground-based cloud-seeding program.

One means of weighing the relative impact on the African climate of these land changes or any other factors, like sea surface temperatures, is to run computer experiments using general circulation models, such as the one used by Rowntree. These models, of which there are about a dozen in the world, consist of a series of equations relating changes in wind patterns, barometric pressure and temperature of the atmosphere. The dynamics of the atmosphere and climate can be explored by altering various boundary conditions such as SSTs, surface properties like albedo and roughness, the chemical composition of the atmosphere, and even astronomical parameters such as distance to the sun. By letting the computer keep track of all the details as it integrates the equations, scientists can test their ideas on the physical mechanisms that brought drought to Africa and then allowed it to stay.



World Bank/Yosef Hadar

During droughts, women travel long distances daily for their families' water.



Nicholson/Biel

Rainfall on the African continent varies widely in both space and time. Regions in the north, like the Sahel, and south suffer not only from relatively low annual rainfall but also from large changes in rainfall totals from year to year.

But, according to the University of Maryland's Shukla, no really comprehensive numerical experiments have been carried out for Africa, and results from studies done for other regions cannot simply be applied to the Sahel. Until global circulation modelers begin focusing on Africa, he says, any scenarios on what causes its droughts will be total conjecture.

Chervin adds that the cost of running such experiments is very high — about $2,000 per hour on a Cray-1 computer—so one had better first be very sure of the model. The weakest point of models today, Shukla and others agree, is their treatment of interactions between the atmosphere and land. But Piers Sellers, at NASA's Goddard Space Flight Center in Greenbelt, Md., believes that within two years models should be able to start providing some answers.

Models are of little use, however, without good observational data to put into them. That's why researchers at a recent State Department seminar focusing on the African drought stressed a need for better data collection and communication. "There is an inadequate reporting network over Africa, and in particular over the sub-Sahara," Rasmusson said. "This network has actually been deteriorating over the last quarter century."

Nicholson feels that the biggest problem for rainfall data is not collection but transmission. Many of her rainfall measurements have to be hand copied, requiring periodic travel to Africa. Also severely lacking from many countries is up-to-date archiving of data. It's been particularly difficult to obtain information from areas like Chad and Ethiopia because of political problems such as war. Lack of data from these areas is considered especially serious because the climate there is thought to be driven by forces quite different from those in the west Sahel.

There is also a dire need for upper-air data on temperature, wind flow and pressure—information crucial to understanding the dynamics of the atmosphere. Very few countries have balloons to take these measurements, Nicholson says.

Remote sensing surveys from satellites are beginning to provide important information, from cloud cover to temperatures of atmosphere and ocean. Satellite observations may also aid studies of land and climate by measuring soil surface temperatures and by mapping vegetation. In providing a big picture of how land conditions change between ground stations, remote sensing helps researchers obtain global data quickly without relying on information networks between countries. But Sellers cautions that there are some types of data that satellites will never be able to measure directly, like moisture below the soil surface. So remote sensing is not a replacement for good ground and balloon measurements.

Because of the large-scale nature of droughts and the atmospheric and oceanic systems that may bring them on, it's doubtful that people will ever be able to control these phenomena. At best, "solutions" to the problems lie with predictions and preparations for dry periods. But drought predictions are a long way off. As for the present drought, says Nicholson, "We have no way of forecasting how long it is going to persist. It could end; it could continue. We just don't know." □

NEXT: The Human Dimension