makes one worry about trivial artifacts, such as contamination of PCR samples with DNA from more closely related species, but the authors took precautions that make this unlikely. Furthermore, most of the CNGs could be found in the dog genome, which they did not need to obtain by PCR because its sequence was determined at The Institute for Genomic Research (*4*). The degree and length of conservation of the CNGs is especially surprising because this was not observed in a recent multispecies comparison of the genomes of six yeast species (*5*). In that study, highly conserved sequences, most of which are probably transcription factor binding sites, are appropriately short and are embedded in less conserved sequences. The CNGs in mammalian genomes are much more extensive and more highly conserved than anything seen in yeast, even though the evolutionary time separating monotreme mammals from placental mammals is longer (by a factor of at least 3) than that separating the different yeast species. These findings imply that the CNGs are subject to a very strong and continual selective constraint, enabling them to remain largely unchanged for as long as 300 million years.

Dermitzakis *et al*. estimate that there are about 60,000 CNGs in the human genome, about twice the number of coding genes. This is satisfyingly similar to the conclusion of another multispecies comparison by Thomas and colleagues, who used a very different strategy (*6*). They chose a 1.8-megabase region of human chromosome 7 that includes 10 genes. They determined the sequences of the orthologous regions of 13 other vertebrate species: nine mammals, a bird (chicken), and three fish. Using somewhat different criteria, they identified "multispecies conserved sequences" (MCSs). Only about one-third of these conserved sequences overlap with protein-coding regions, again revealing the large amount of noncoding DNA that is under functional selection. Of course, the amount of conservation varies depending on the species: Nearly all of the coding MCSs are apparent in both the chicken and fish genomes, whereas only about 29% of the noncoding MCSs are found in the chicken genome with almost none in the fish genome.

What might the function of these CNGs be? The first thing that comes to mind is that they are regulatory regions controlling gene expression. However, many of them look too conserved to consist of protein binding sites (which are usually highly degenerate), and it is hard to imagine the sites being as densely packed as they would need to be to account for the length of the conserved sequences. Other possibilities for what they could do include acting as structural components of chromosomes, although it is equally difficult to imagine that these sequence elements require such a high degree of conservation. Uncovering the part that CNGs play in the cell will certainly require experimentation, and that activity is likely to occupy many people for quite some time.

Early in the Human Genome Project, people argued about what to sequence. Some advocated determining just the sequence of the protein-coding regions, because the vast majority of the genome is "junk" DNA. This would, they argued, be cost effective because most of the important information is in protein-coding DNA. Given what we've learned about the jewels in the genome's attic, aren't we glad they sequenced it all?

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ATMOSPHERIC SCIENCE

Drought in the Sahel

Ning Zeng

Since the late 1960s, the Sahel—a semiarid region in West Africa between the Sahara desert and the Guinea coast rainforest—has experienced a drought of unprecedented severity in recorded history. The drought has had a devastating impact on this ecologically vulnerable region and was a major impetus in the establishment of the United Nations Convention on Combating Desertification and Drought. Two reports in this issue shed light on the likely causes of the drought and its consequences for atmospheric dust transport.

Two main hypotheses have been proposed for the cause of the drought. The first focuses on anthropogenic factors such as overgrazing and conversion of woodland to agriculture. Both of these processes tend to increase surface albedo (less sunlight is absorbed) and reduce moisture supply to the atmosphere. They thus lead to less precipitation and even less favorable conditions for vegetation (*1–3*). The second invokes large-scale atmospheric circulation changes triggered by multidecadal variations in global sea surface temperature (*4–6*) (see the figure).

On page 1027 of this issue, Giannini *et al.* (*7*) report the most comprehensive modeling study to date of the ocean temperature scenario. The authors analyzed the results from a state-of-the-art atmospheric general circulation model (GCM) developed at NASA Goddard Space Flight Center. When forced by observed global sea surface temperatures from 1930 to 2000, the model reproduced much of the variability in the observed Sahel rainfall. The results provide strong evidence that global sea surface temperature is a major forcing in this region. Using a statistical tool called principal components analysis, Giannini *et al.* show that Sahel rainfall is most closely related to a largely tropical sea surface temperature anomaly pattern that spans the Pacific, Atlantic, and Indian oceans.

Another characteristic of the Sahel rainfall variability is the apparently different influence from different ocean basins on interannual and interdecadal time scales (*6, 8*). By decomposing the modeled Sahel rainfall into a high-frequency and a low-frequency component, Giannini *et al.* achieve high reproducibility compared to the observations on both interannual and interdecadal time scales. Furthermore, they identify the contributions from different ocean basins on different time scales.

The Sahel is one of the most climatically sensitive zones in the world because of the influence of a wide range of factors, such as its unique geographic location. The results reported by Giannini *et al.* are encouraging signs that GCMs have improved substantially in recent years, raising the hope for better climate prediction on seasonal to interannual time scales.

Compared to the ocean scenario, the role of land use change has been more difficult to quantify. Given a large change in land surface properties that could conceivably be caused by human activities, atmospheric models can simulate a substantial reduction in rainfall. However, the question more relevant to the recent Sahel drought is whether such large anthropogenic disturbance has actually taken place. A recent study of population dynamics and land use history suggests a modest land use change over the last

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35 to 40 years that is not nearly enough to explain the observed drought (*9*).

This is not to say that sea surface temperatures are the whole story. Similar to many earlier model studies, Giannini *et al.* were able to obtain only 25 to 35% of the observed rainfall change. What is missing may well be land-atmosphere feedbacks that positively enhance the drying tendency initiated by the changes in global sea surface temperature. One such feedback involves natural vegetation (*10*), which would be reduced in response to an initial decrease in rainfall. The subsequent feedbacks through increased albedo and reduced evaporation are similar to those proposed in the land use change mechanism.

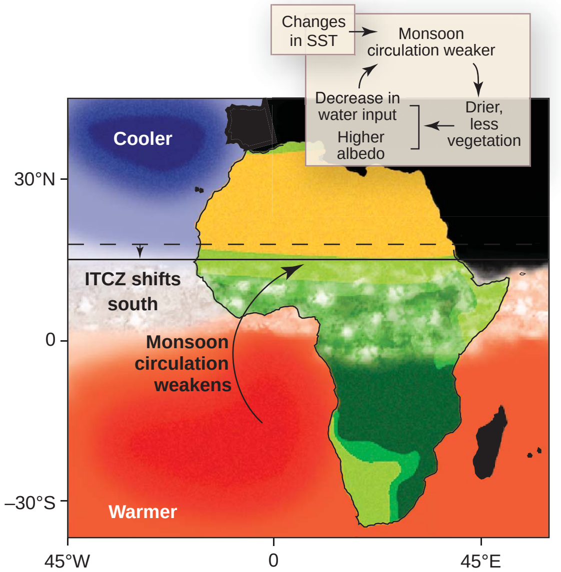
It is very likely that sea surface temperature change, natural vegetation processes, and land use change have acted synergistically to produce the unusual drought in the Sahel (see the figure). This speaks for the need to monitor the global oceans even for regional climate prediction. The importance of atmosphere, land, and ocean processes are emphasized in field experiments such as the upcoming African Monsoon Multidisciplinary Analysis (AMMA).

A much less studied consequence of drought in semiarid regions is atmospheric dust. On page 1024 of this issue, Prospero and Lamb (*11*) report observational evidence of dust transported across the Atlantic from Africa to the Caribbean island of Barbados. The dust concentrations at Barbados are anticorrelated with concurrent rainfall amount in the Sahel. The anticorrelation is even higher with rainfall from the previous year, indicating a delayed response. No data are available before the late 1960s, but extrapolation of the interannual correlation suggests that there was substantially less dust transport during the wet period before the drought. Because African dust sources account for about half of the global total today, the drought in recent decades may have increased the total global dust loading by one-third.

Dust in the air reflects sunshine and changes cloud properties, thus modifying the energy balance in the atmosphere and at the surface. The dust minerals also serve as a nutrient for marine phytoplankton in iron-limited regions. A substantial change in dust supply may modify the global carbon cycle and climate, as might have happened during the ice ages (*12*). Thus, regardless of the relative importance of natural versus anthropogenic causes, the drought in the Sahel may have an unexpected influence on global climate.

The quantification of natural and anthropogenic causes is important. If humans are mostly responsible for the drought, further land degradation may lead to a catastrophic reduction in the ecosystem's carrying capacity. If, instead, natural variability is the main player, we can take some comfort in knowing that we might be on the other side of the swing soon.

However, even in the latter case, the system may not be able to recover completely given that the Sahelian population is doubling every 20 years. Furthermore, if the trend in global sea surface temperature is related to anthropogenic global warming, as some studies suggest (*13*), we may again be on a one-way road. In this case, the Sahel may be a harbinger of global changes. A combination of improved climate prediction, sensible land use practice, and CO_2 emission reductions will be the key to the future of the Sahel.



Complex feedbacks. The recent Sahel drought was likely initiated by a change in worldwide ocean temperatures, which reduced the strength of the African monsoon, and was exacerbated by land-atmosphere feedbacks through natural vegetation and land cover change. Land use changes by humans may have also played an important role. SST, sea surface temperature; ITCZ, intertropical convergence zone.

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ATMOSPHERIC SCIENCE

How Particles Nucleate and Grow

Markku Kulmala

Aerosol particles are ubiquitous in Earth's atmosphere. They influence the quality of life in many ways: for example, through their climatic and health effects and by affecting visibility. Better understanding of these effects, especially their role in climate change, requires knowledge of the mechanism by which new particles nucleate and grow in the atmosphere.

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Particle nucleation in the atmosphere has exercised the minds of scientists since John Aitken built the first apparatus to measure the number of dust and fog particles in the late 19th century. Today, size distributions of nanometer-scale particles and concentrations of gases participating in particle nucleation can be measured directly in the atmosphere (*1*). However, although several mechanisms for particle nucleation have been proposed (*2–4*), it remains unclear which of them dominates in the atmosphere.

In recent years, the nucleation and growth of nanometer-scale atmospheric aerosol particles have been observed with state-of-the-art technology in many different atmospheric environments, including the lower stratosphere, the free troposphere, the continental boundary layer just above Earth's surface, and coastal environments (*5*). Some continental sampling sites can serve as natural laboratories. For example, at the SMEAR I station in Lapland, clean Arctic air is frequently replaced by polluted plumes from the Kola Peninsula, allowing different conditions for particle nucleation and growth to be studied in one location.

Particles typically form during the late morning and then grow throughout the day, reaching growth rates of 1 to 20 nm $hour^{-1}$. In the boundary layer, measured nucleation

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